gcc-python-plugin Documentation

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CHAPTER 1

Requirements

The plugin has the following requirements:

- GCC: 4.6 or later (it uses APIs that weren't exposed to plugins in 4.5)
- Python: tested with 2.7 and 3.2; it may work with earlier versions
- "six": The libcpychecker code uses the "six" Python compatibility library to smooth over Python 2 vs Python 3 differences, both at build-time and run-time:

  http://pypi.python.org/pypi/six/

- "pygments": The libcpychecker code uses the "pygments" Python syntax-highlighting library when writing out error reports:

  http://pygments.org/

- "lxml": The libcpychecker code uses the "lxml" internally when writing out error reports.
- graphviz: many of the interesting examples use "dot" to draw diagrams (e.g. control-flow graphs), so it's worth having graphviz installed.

CHAPTER 2

Prebuilt-packages

Various distributions ship with pre-built copies of the plugin. If you're using Fedora, you can install the plugin via RPM on Fedora 16 onwards using:

```
yum install gcc-python2-plugin
```

as root for the Python 2 build of the plugin, or:

```
yum install gcc-python3-plugin
```

for the Python 3 build of the plugin.

On Gentoo, use *layman* to add the *dMaggot* overlay and *emerge* the *gcc-python-plugin* package. This will build the plugin for Python 2 and Python 3 should you have both of them installed in your system. A live ebuild is also provided to install the plugin from git sources.

CHAPTER 3

Building the plugin from source

3.1 Build-time dependencies

If you plan to build the plugin from scratch, you'll need the build-time dependencies.

On a Fedora box you can install them by running the following as root:

```
yum install gcc-plugin-devel python-devel python-six python-pygments graphviz
```

for building against Python 2, or:

```
yum install gcc-plugin-devel python3-devel python3-six python3-pygments graphviz
```

when building for Python 3.

3.2 Building the code

You can obtain the source code from git by using:

```
$ git clone git@github.com:davidmalcolm/gcc-python-plugin.git
```

To build the plugin, run:

```
make plugin
```

To build the plugin and run the selftests, run:

```
make
```

You can also use:

```
make demo
```

to demonstrate the new compiler errors.

By default, the *Makefile* builds the plugin using the first `python-config` tool found in *$PATH* (e.g. */usr/bin/python-config*), which is typically the system copy of Python 2. You can override this (e.g. to build against Python 3) by overriding the *PYTHON* and *PYTHON_CONFIG* Makefile variables with:

```
make PYTHON=python3 PYTHON_CONFIG=python3-config
```

There isn't a well-defined process yet for installing the plugin (though the rpm specfile in the source tree contains some work-in-progress towards this).

Some notes on GCC plugins can be seen at http://gcc.gnu.org/wiki/plugins and http://gcc.gnu.org/onlinedocs/gccint/Plugins.html

---

Note: Unfortunately, the layout of the header files for GCC plugin development has changed somewhat between different GCC releases. In particular, older builds of GCC flattened the "c-family" directory in the installed plugin headers.

This was fixed in this GCC commit:

http://gcc.gnu.org/viewcvs?view=revision&revision=176741

So if you're using an earlier build of GCC using the old layout you'll need to apply the following patch (reversed with "-R") to the plugin's source tree to get it to compile:

```
$ git show 215730cbec40a6fe482fabb7f1ecc3d747f1b5d2 | patch -p1 -R
```

If you have a way to make the plugin's source work with either layout, please email the plugin's mailing list

---

CHAPTER 4

Basic usage of the plugin

Once you've built the plugin, you can invoke a Python script like this:

```
gcc -fplugin=./python.so -fplugin-arg-python-script=PATH_TO_SCRIPT.py OTHER_ARGS
```

and have it run your script as the plugin starts up.

Alternatively, you can run a one-shot Python command like this:

```
gcc -fplugin=./python.so -fplugin-arg-python-command="python code" OTHER_ARGS
```

such as:

```
gcc -fplugin=./python.so -fplugin-arg-python-command="import sys; print(sys.path)" OTHER_ARGS
```

The plugin automatically adds the absolute path to its own directory to the end of its *sys.path*, so that it can find support modules, such as gccutils.py and *libcpychecker*.

There is also a helper script, *gcc-with-python*, which expects a python script as its first argument, then regular gcc arguments:

```
./gcc-with-python PATH_TO_SCRIPT.py other args follow
```

For example, this command will use graphviz to draw how GCC "sees" the internals of each function in *test.c* (within its SSA representation):

```
./gcc-with-python examples/show-ssa.py test.c
```

Most of the rest of this document describes the Python API visible for scripting.

The plugin GCC's various types as Python objects, within a "gcc" module. You can see the API by running the following within a script:

```
import gcc
help(gcc)
```

To make this easier, there's a script to do this for you:

```
./gcc-python-docs
```

from where you can review the built-in documentation strings (this document may be easier to follow though).

The exact API is still in flux: and may well change (this is an early version of the code; we may have to change things as GCC changes in future releases also).

4.1 Debugging your script

You can place a forced breakpoint in your script using this standard Python one-liner:

```
import pdb; pdb.set_trace()
```

If Python reaches this location it will interrupt the compile and put you within the *pdb* interactive debugger, from where you can investigate.

See http://docs.python.org/library/pdb.html#debugger-commands for more information.

If an exception occurs during Python code, and isn't handled by a try/except before returning into the plugin, the plugin prints the traceback to stderr and treats it as an error:

```
/home/david/test.c: In function 'main':
/home/david/test.c:28:1: error: Unhandled Python exception raised within callback
Traceback (most recent call last):
  File "test.py", line 38, in my_pass_execution_callback
    dot = gccutils.tree_to_dot(fun)
NameError: global name 'gccutils' is not defined
```

(In this case, it was a missing *import* statement in the script)

GCC reports errors at a particular location within the source code. For an unhandled exception such as the one above, by default, the plugin reports the error as occurring as the top of the current source function (or the last location within the current source file for passes and callbacks that aren't associated with a function).

You can override this using gcc.set_location:

gcc.**set_location**(*loc*)
: Temporarily overrides the error-reporting location, so that if an exception occurs, it will use this *gcc.Location*, rather than the default. This may be of use when debugging tracebacks from scripts. The location is reset each time after returning from Python back to the plugin, after printing any traceback.

4.2 Accessing parameters

gcc.**argument_dict**
: Exposes the arguments passed to the plugin as a dictionary.

  For example, running:

```
gcc -fplugin=python.so \
    -fplugin-arg-python-script=test.py \
    -fplugin-arg-python-foo=bar
```

  with *test.py* containing:

```
import gcc
print(gcc.argument_dict)
```

  has output:

```
{'script': 'test.py', 'foo': 'bar'}
```

gcc.**argument_tuple**
: Exposes the arguments passed to the plugin as a tuple of (key, value) pairs, so you have ordering. (Probably worth removing, and replacing `argument_dict` with an OrderedDict instead; what about duplicate args though?)

4.3 Adding new passes to the compiler

You can create new compiler passes by subclassing the appropriate *gcc.Pass* subclasss. For example, here's how to wire up a new pass that displays the control flow graph of each function:

```
# Show the GIMPLE form of each function, using GraphViz
import gcc
from gccutils import get_src_for_loc, cfg_to_dot, invoke_dot

# We'll implement this as a custom pass, to be called directly after the
# builtin "cfg" pass, which generates the CFG:

class ShowGimple(gcc.GimplePass):
    def execute(self, fun):
        # (the CFG should be set up by this point, and the GIMPLE is not yet
        # in SSA form)
        if fun and fun.cfg:
            dot = cfg_to_dot(fun.cfg, fun.decl.name)
            # print dot
            invoke_dot(dot, name=fun.decl.name)

ps = ShowGimple(name='show-gimple')
ps.register_after('cfg')
```

For more information, see *Creating new optimization passes*

4.4 Wiring up callbacks

The other way to write scripts is to register callback functions to be called when various events happen during compilation, such as using *gcc.PLUGIN_PASS_EXECUTION* to piggyback off of an existing GCC pass.

```
# Show all the passes that get executed
import gcc

def my_pass_execution_callback(*args, **kwargs):
    (optpass, fun) = args
    print(args)

gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                      my_pass_execution_callback)
```

For more information, see *Working with callbacks*

CHAPTER 5

Global data access

gcc.**get_variables**()
Get all variables in this compilation unit as a list of *gcc.Variable*

class gcc.**Variable**
Wrapper around GCC's *struct varpool_node*, representing a variable in the code being compiled.

decl
The declaration of this variable, as a *gcc.Tree*

gccutils.**get_variables_as_dict**()
Get a dictionary of all variables, where the keys are the variable names (as strings), and the values are instances of *gcc.Variable*

gcc.**maybe_get_identifier**(*str*)
Get the gcc.IdentifierNode with this name, if it exists, otherwise None. (However, after the front-end has run, the identifier node may no longer point at anything useful to you; see *gccutils.get_global_typedef()* for an example of working around this)

gcc.**get_translation_units**()
Get a list of all *gcc.TranslationUnitDecl* for the compilation units within this invocation of GCC (that's "source code files" for the layperson).

class gcc.**TranslationUnitDecl**
Subclass of *gcc.Tree* representing a compilation unit

block
The *gcc.Block* representing global scope within this source file.

language
The source language of this translation unit, as a string (e.g. "GNU C")

gcc.**get_global_namespace**()
C++ only: locate the *gcc.NamespaceDecl* for the global namespace (a.k.a. "::")

gccutils.**get_global_typedef**(*name*)
Given a string *name*, look for a C/C++ *typedef* in global scope with that name, returning it as a gcc.TypeDecl, or None if it wasn't found

gccutils.**get_global_vardecl_by_name**(*name*)
Given a string *name*, look for a C/C++ variable in global scope with that name, returning it as a *gcc.VarDecl*, or None if it wasn't found

gccutils.**get_field_by_name**(*decl*, *name*)
Given one of a *gcc.RecordType*, gcc.UnionType, or gcc.QualUnionType, along with a string

name, look for a field with that name within the given struct or union, returning it as a *gcc.FieldDecl*, or None if it wasn't found

CHAPTER 6

Overview of GCC's internals

To add a new compiler warning to GCC, it's helpful to have a high-level understanding of how GCC works, so here's the 10,000 foot view of how GCC turns source code into machine code.

The short version is that GCC applies a series of optimization passes to your code, gradually converting it from a high-level representation into machine code, via several different internal representations.

Each programming language supported by GCC has a "frontend", which parses the source files.

For the case of C and C++, the preprocessor manipulates the code first before the frontend sees it. You can see the preprocessor output with the *-E* option.

Exactly what happens in each frontend varies by language: some language frontends emit language-specific trees, and some convert to a language-independent tree representation known as *GENERIC*. In any case, we eventually we reach a representation known as *GIMPLE*. The GIMPLE representation contains simplified operations, with temporary variables added as necessary to avoid nested sub-expressions.

For example, given this C code:

```
int
main(int argc, char **argv)
{
    int i;

    printf("argc: %i\n", argc);

    for (i = 0; i < argc; i++) {
        printf("argv[%i]: %s\n", argv[i]);
    }

    helper_function();

    return 0;
}
```

we can see a dump of a C-like representation of the GIMPLE form by passing *-fdump-tree-gimple* to the command-line:

```
$ gcc -fdump-tree-gimple test.c
$ cat test.c.004t.gimple
```

giving something like this:

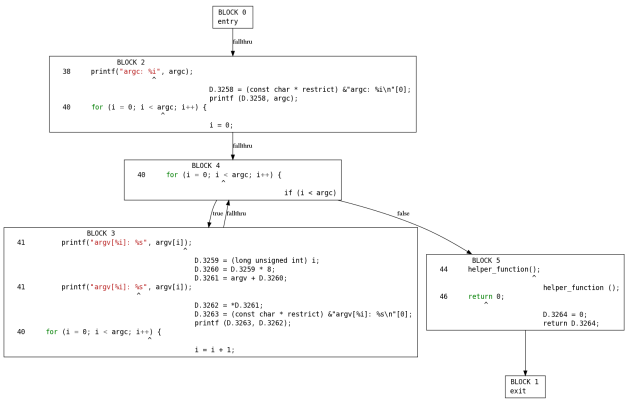
```
main (int argc, char * * argv)
{
```

```
  const char * restrict D.3258;
  long unsigned int D.3259;
  long unsigned int D.3260;
  char * * D.3261;
  char * D.3262;
  const char * restrict D.3263;
  int D.3264;
  int i;

  D.3258 = (const char * restrict) &"argc: %i\n"[0];
  printf (D.3258, argc);
  i = 0;
  goto <D.2050>;
  <D.2049>:
  D.3259 = (long unsigned int) i;
  D.3260 = D.3259 * 8;
  D.3261 = argv + D.3260;
  D.3262 = *D.3261;
  D.3263 = (const char * restrict) &"argv[%i]: %s\n"[0];
  printf (D.3263, D.3262);
  i = i + 1;
  <D.2050>:
  if (i < argc) goto <D.2049>; else goto <D.2051>;
  <D.2051>:
  helper_function ();
  D.3264 = 0;
  return D.3264;
}
```

It's far easier to see the GIMPLE using:

```
./gcc-with-python examples/show-gimple.py test.c
```

which generates bitmaps showing the "control flow graph" of the functions in the file, with source on the left-hand side, and GIMPLE on the right-hand side:



Each function is divided into "basic blocks". Each basic block consists of a straight-line sequence of code with a single entrypoint and exit: all branching happens between basic blocks, not within them. The basic blocks form a "control flow graph" of basic blocks, linked together by edges. Each block can contain a list of *gcc.Gimple* statements.

You can work with this representation from Python using *gcc.Cfg*

Once the code is in GIMPLE form, GCC then attempts a series of optimizations on it.

Some of these optimizations are listed here: http://gcc.gnu.org/onlinedocs/gccint/Tree-SSA-passes.html

If you're looking to add new compiler warnings, it's probably best to hook your code into these early passes.

The GIMPLE representation actually has several forms:

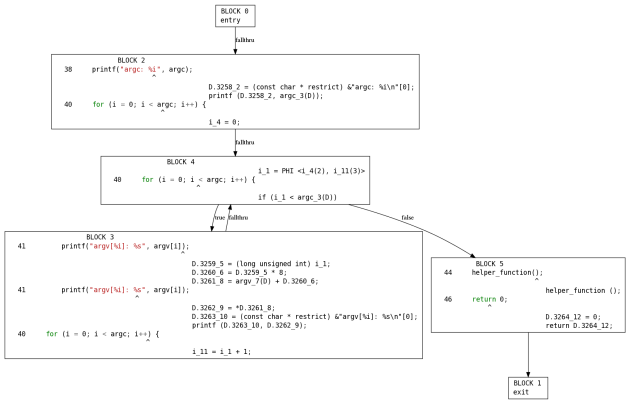
- an initial "high gimple" form, potentially containing certain high-level operations (e.g. control flow, exception handling)
- the lower level gimple forms, as each of these operations are rewritten in lower-level terms (turning control flow from jumps into a CFG etc)
- the SSA form of GIMPLE. In Static Single Assignment form, every variable is assigned to at most once, with additional versions of variables added to help track the impact of assignments on the data flowing through a function. See http://gcc.gnu.org/onlinedocs/gccint/SSA.html

You can tell what form a function is in by looking at the flags of the current pass. For example:

```
if ps.properties_provided & gcc.PROP_cfg:
    # ...then this gcc.Function ought to have a gcc.Cfg:
    do_something_with_cfg(fn.cfg)

if ps.properties_provided & gcc.PROP_ssa:
    # ...then we have SSA data
    do_something_with_ssa(fn)
```

Here's our example function, after conversion to GIMPLE SSA:

```
./gcc-with-python examples/show-ssa.py test.c
```



You can see that the local variable *i* has been split into three versions:

- *i_4*, assigned to in block 2
- *i_11*, assigned to at the end of block 3
- *i_1*, assigned to at the top of block 4.

As is normal with SSA, GCC inserts fake functions known as "PHI" at the start of basic blocks where needed in order to merge the multiple possible values of a variable. You can see one in our example at the top of the loop in block 4:

```
i_1 = PHI <i_4(2), i_11(3)>
```

where i_1 either gets the value of i_4, or of i_11, depending on whether we reach here via block 2 (at the start of the iteration) or block 3 (continuing the "for" loop).

After these optimizations passes are done, GCC converts the GIMPLE SSA representation into a lower-level representation known as Register Transfer Language (RTL). This is probably too low-level to be of interest to those seeking to

add new compiler warnings: at this point it's attempting to work with the available opcodes and registers on the target CPU with the aim of generating efficient machine code.

See http://gcc.gnu.org/onlinedocs/gccint/RTL.html

The RTL form uses the same Control Flow Graph machinery as the GIMPLE representation, but with RTL expressions within the basic blocks.

Once in RTL, GCC applies a series of further optimizations, before finally generating assembly language (which it submits to *as*, the GNU assembler): http://gcc.gnu.org/onlinedocs/gccint/RTL-passes.html You can see the assembly language using the *-S* command line option.

```
$ ./gcc -S test.c
$ cat test.s
```

CHAPTER 7

Example scripts

There are various sample scripts located in the *examples* subdirectory.

Once you've built the plugin (with *make*), you can run them via:

```
$ ./gcc-with-python examples/NAME-OF-SCRIPT.py test.c
```

7.1 *show-docs.py*

A trivial script to make it easy to read the builtin documentation for the gcc API:

```
$ ./gcc-with-python examples/show-docs.py test.c
```

with this source:

```
import gcc
help(gcc)
```

giving output:

```
Help on built-in module gcc:

NAME
    gcc

FILE
    (built-in)

CLASSES
    __builtin__.object
        BasicBlock
        Cfg
        Edge
        Function
        Gimple
(truncated)
```

7.2 *show-passes.py*

You can see the passes being executed via:

```
$ ./gcc-with-python examples/show-passes.py test.c
```

This is a simple script that registers a trivial callback:

```
# Sample python script, to be run by our gcc plugin
# Show all the passes that get executed
import gcc

def my_pass_execution_callback(*args, **kwargs):
    (optpass, fun) = args
    print(args)

gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                      my_pass_execution_callback)
```

Sample output, showing passes being called on two different functions (*main* and *helper_function*):

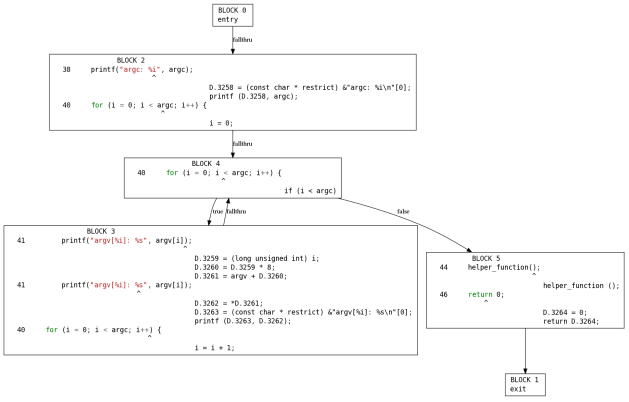
```
(gcc.GimplePass(name='*warn_unused_result'), gcc.Function('main'))
(gcc.GimplePass(name='omplower'), gcc.Function('main'))
(gcc.GimplePass(name='lower'), gcc.Function('main'))
(gcc.GimplePass(name='eh'), gcc.Function('main'))
(gcc.GimplePass(name='cfg'), gcc.Function('main'))
(gcc.GimplePass(name='*warn_function_return'), gcc.Function('main'))
(gcc.GimplePass(name='*build_cgraph_edges'), gcc.Function('main'))
(gcc.GimplePass(name='*warn_unused_result'), gcc.Function('helper_function'))
(gcc.GimplePass(name='omplower'), gcc.Function('helper_function'))
(gcc.GimplePass(name='lower'), gcc.Function('helper_function'))
(gcc.GimplePass(name='eh'), gcc.Function('helper_function'))
(gcc.GimplePass(name='cfg'), gcc.Function('helper_function'))
[...truncated...]
```

7.3 *show-gimple.py*

A simple script for viewing each function in the source file after it's been converted to "GIMPLE" form, using GraphViz to visualize the control flow graph:

```
$ ./gcc-with-python examples/show-gimple.py test.c
```

It will generate a file *test.png* for each function, and opens it in an image viewer.



The Python code for this is:

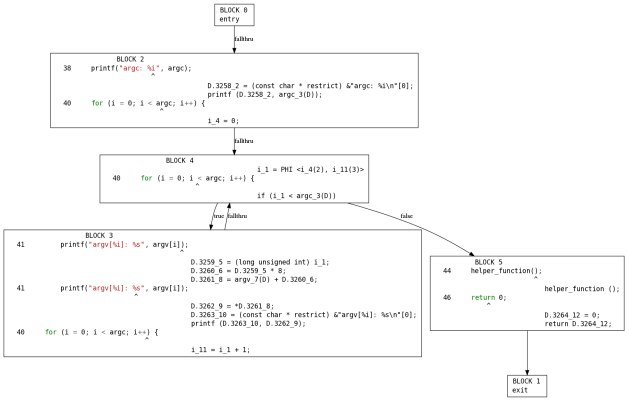
```
# Show the GIMPLE form of each function, using GraphViz
import gcc
from gccutils import get_src_for_loc, cfg_to_dot, invoke_dot

# We'll implement this as a custom pass, to be called directly after the
# builtin "cfg" pass, which generates the CFG:

class ShowGimple(gcc.GimplePass):
    def execute(self, fun):
        # (the CFG should be set up by this point, and the GIMPLE is not yet
        # in SSA form)
        if fun and fun.cfg:
            dot = cfg_to_dot(fun.cfg, fun.decl.name)
            # print dot
            invoke_dot(dot, name=fun.decl.name)

ps = ShowGimple(name='show-gimple')
ps.register_after('cfg')
```

7.4 *show-ssa.py*

This is similar to *show-gimple.py*, but shows each function after the GIMPLE has been converted to Static Single Assignment form ("SSA"):

```
$ ./gcc-with-python examples/show-ssa.py test.c
```

As before, it generates an image file for each function and opens it in a viewer.



The Python code for this is:

```
# Sample python script, to be run by our gcc plugin
# Show the SSA form of each function, using GraphViz
import gcc
from gccutils import get_src_for_loc, cfg_to_dot, invoke_dot

# A custom GCC pass, to be called directly after the builtin "ssa" pass, which
# generates the Static Single Assignment form of the GIMPLE within the CFG:
class ShowSsa(gcc.GimplePass):
    def execute(self, fun):
```

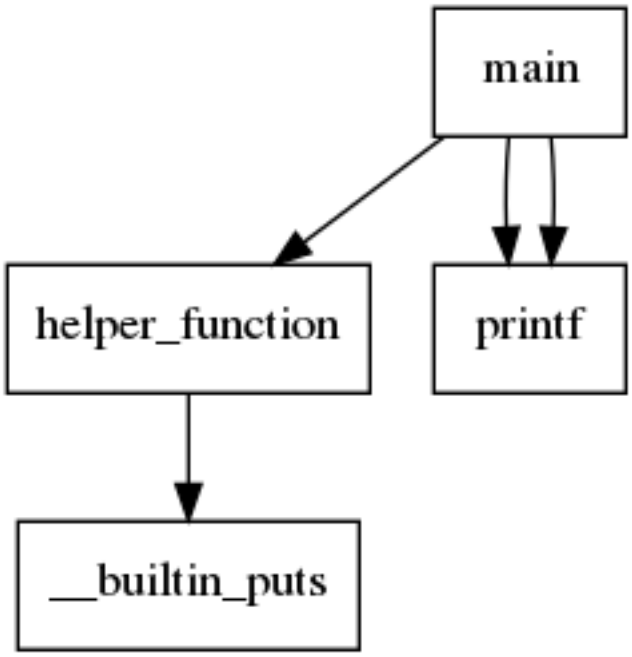
```
            # (the SSA form of each function should have just been set up)
            if fun and fun.cfg:
                dot = cfg_to_dot(fun.cfg, fun.decl.name)
                # print(dot)
                invoke_dot(dot, name=fun.decl.name)

    ps = ShowSsa(name='show-ssa')
    ps.register_after('ssa')
```

7.5 show-callgraph.py

This simple script sends GCC's interprocedural analysis data through GraphViz.

```
    $ ./gcc-with-python examples/show-callgraph.py test.c
```

It generates an image file showing which functions call which other functions, and opens it in a viewer.



The Python code for this is:

```
    # Sample python script, to be run by our gcc plugin
    # Show the call graph (interprocedural analysis), using GraphViz
    import gcc
    from gccutils import callgraph_to_dot, invoke_dot

    # In theory we could have done this with a custom gcc.Pass registered
    # directly after "*build_cgraph_edges".  However, we can only register
    # relative to passes of the same kind, and that pass is a
    # gcc.GimplePass, which is called per-function, and we want a one-time
    # pass instead.
    #
```

```
    # So we instead register a callback on the one-time pass that follows it

    def on_pass_execution(p, fn):
        if p.name == '*free_lang_data':
            # The '*free_lang_data' pass is called once, rather than per-function,
            # and occurs immediately after "*build_cgraph_edges", which is the
            # pass that initially builds the callgraph
            #
            # So at this point we're likely to get a good view of the callgraph
            # before further optimization passes manipulate it
            dot = callgraph_to_dot()
            invoke_dot(dot)

    gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                          on_pass_execution)
```

CHAPTER 8

Working with C code

8.1 “Hello world”

Here’s a simple “hello world” C program:

```
#include <stdio.h>

int main(int argc, char *argv[])
{
    printf("Hello, python\n");
}
```

Here’s a Python script that locates the function at one pass within the compile and prints various interesting things about it:

```
import gcc

# Here's a callback.  We will wire it up below:
def on_pass_execution(p, fn):
    # This pass is called fairly early on, per-function, after the
    # CFG has been built:
    if p.name == '*warn_function_return':
        # For this pass, "fn" will be an instance of gcc.Function:
        print('fn: %r' % fn)
        print('fn.decl.name: %r' % fn.decl.name)

        # fn.decl is an instance of gcc.FunctionDecl:
        print('return type: %r' % str(fn.decl.type.type))
        print('argument types: %r' % [str(t) for t in fn.decl.type.argument_types])

        assert isinstance(fn.cfg, gcc.Cfg) # None for some early passes
        assert len(fn.cfg.basic_blocks) == 3
        assert fn.cfg.basic_blocks[0] == fn.cfg.entry
        assert fn.cfg.basic_blocks[1] == fn.cfg.exit
        bb = fn.cfg.basic_blocks[2]
        for i,stmt in enumerate(bb.gimple):
            print('gimple[%i]:' % i)
            print('  str(stmt): %r' % str(stmt))
            print('  repr(stmt): %r' % repr(stmt))
            if isinstance(stmt, gcc.GimpleCall):
                from gccutils import pprint
                print('  type(stmt.fn): %r' % type(stmt.fn))
```

```
                    print('  str(stmt.fn): %r' % str(stmt.fn))
                    for i, arg in enumerate(stmt.args):
                        print('  str(stmt.args[%i]): %r' % (i, str(stmt.args[i])))
                    print('  str(stmt.lhs): %s' % str(stmt.lhs))

    # Wire up our callback:
    gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                          on_pass_execution)
```

We can run the script during the compile like this:

```
    ./gcc-with-python script.py test.c
```

Here's the expected output:

```
    fn: gcc.Function('main')
    fn.decl.name: 'main'
    return type: 'int'
    argument types: ['int', 'char * *']
    gimple[0]:
      str(stmt): '__builtin_puts (&"Hello, python"[0]);'
      repr(stmt): 'gcc.GimpleCall()'
      type(stmt.fn): <type 'gcc.AddrExpr'>
      str(stmt.fn): '__builtin_puts'
      str(stmt.args[0]): '&"Hello, python"[0]'
      str(stmt.lhs): None
    gimple[1]:
      str(stmt): 'return;'
      repr(stmt): 'gcc.GimpleReturn()'
```

Notice how the call to *printf* has already been optimized into a call to *__builtin_puts*.

8.2 Spell-checking string constants within source code

This example add a spell-checker pass to GCC: all string constants are run through the "enchant" spelling-checker:

```
    $ ./gcc-with-python tests/examples/spelling-checker/script.py input.c
```

The Python code for this is:

```
    import gcc

    # Use the Python bindings to the "enchant" spellchecker:
    import enchant
    spellingdict = enchant.Dict("en_US")

    class SpellcheckingPass(gcc.GimplePass):
        def execute(self, fun):
            # This is called per-function during compilation:
            for bb in fun.cfg.basic_blocks:
                if bb.gimple:
                    for stmt in bb.gimple:
                        stmt.walk_tree(self.spellcheck_node, stmt.loc)

        def spellcheck_node(self, node, loc):
            # Spellcheck any textual constants found within the node:
```

```
            if isinstance(node, gcc.StringCst):
                words = node.constant.split()
                for word in words:
                    if not spellingdict.check(word):
                        # Warn about the spelling error (controlling the warning
                        # with the -Wall command-line option):
                        if gcc.warning(loc,
                                       'Possibly misspelt word in string constant: %r' % word,
                                       gcc.Option('-Wall')):
                            # and, if the warning was not suppressed at the command line, emit
                            # suggested respellings:
                            suggestions = spellingdict.suggest(word)
                            if suggestions:
                                gcc.inform(loc, 'Suggested respellings: %r' % ', '.join(suggestions))

    ps = SpellcheckingPass(name='spellchecker')
    ps.register_after('cfg')
```

Given this sample C source file:

```
    #include <stdio.h>

    int main(int argc, char *argv[])
    {
        const char *p = argc ? "correctly spelled" : "not so korectly speled";

        printf("The quick brown fox jumps over the lazy dog\n");

        printf("Ths s n xmple f spllng mstke\n");
    }
```

these warnings are emitted on stderr:

```
    tests/examples/spelling-checker/input.c: In function 'main':
    tests/examples/spelling-checker/input.c:24:48: warning: Possibly misspelt word in string constan
    tests/examples/spelling-checker/input.c:24:48: note: Suggested respellings: 'correctly'
    tests/examples/spelling-checker/input.c:24:48: warning: Possibly misspelt word in string constan
    tests/examples/spelling-checker/input.c:24:48: note: Suggested respellings: 'speed, spieled, spe
    tests/examples/spelling-checker/input.c:28:11: warning: Possibly misspelt word in string constan
    tests/examples/spelling-checker/input.c:28:11: note: Suggested respellings: "Th, Th's, Ohs, Thu,
    tests/examples/spelling-checker/input.c:28:11: warning: Possibly misspelt word in string constan
    tests/examples/spelling-checker/input.c:28:11: note: Suggested respellings: 'ample'
    tests/examples/spelling-checker/input.c:28:11: warning: Possibly misspelt word in string constan
    tests/examples/spelling-checker/input.c:28:11: note: Suggested respellings: 'spelling'
    tests/examples/spelling-checker/input.c:28:11: warning: Possibly misspelt word in string constan
    tests/examples/spelling-checker/input.c:28:11: note: Suggested respellings: 'mistake'
```

8.3 Finding global variables

This example adds a pass that warns about uses of global variables:

```
    $ ./gcc-with-python \
        tests/examples/find-global-state/script.py \
        -c \
        tests/examples/find-global-state/input.c
```

The Python code for this is:

```
    import gcc
    from gccutils import get_src_for_loc

    DEBUG=0

    def is_const(type_):
        if DEBUG:
            type_.debug()

        if hasattr(type_, 'const'):
            if type_.const:
                return True

        # Don't bother warning about an array of const e.g.
        # const char []
        if isinstance(type_, gcc.ArrayType):
            item_type = type_.dereference
            if is_const(item_type):
                return True


    class StateFinder:
        def __init__(self):
            # Locate all declarations of variables holding "global" state:
            self.global_decls = set()

            for var in gcc.get_variables():
                type_ = var.decl.type

                if DEBUG:
                    print('var.decl: %r' % var.decl)
                    print(type_)

                # Don't bother warning about const data:
                if is_const(type_):
                    continue

                self.global_decls.add(var.decl)
            if DEBUG:
                print('self.global_decls: %r' % self.global_decls)

            self.state_users = set()

        def find_state_users(self, node, loc):
            if isinstance(node, gcc.VarDecl):
                if node in self.global_decls:
                    # store the state users for later replay, so that
                    # we can eliminate duplicates
                    #   e.g. two references to "q" in "q += p"
                    # and replay in source-location order:
                    self.state_users.add( (loc, node) )

        def flush(self):
            # Emit warnings, sorted by source location:
            for loc, node in sorted(self.state_users,
                                    key=lambda pair:pair[0]):
                gcc.inform(loc,
```

```
                        'use of global state "%s %s" here'
                        % (node.type, node))

def on_pass_execution(p, fn):
    if p.name == '*free_lang_data':
        sf = StateFinder()

        # Locate uses of such variables:
        for node in gcc.get_callgraph_nodes():
            fun = node.decl.function
            if fun:
                cfg = fun.cfg
                if cfg:
                    for bb in cfg.basic_blocks:
                        stmts = bb.gimple
                        if stmts:
                            for stmt in stmts:
                                stmt.walk_tree(sf.find_state_users,
                                               stmt.loc)

        # Flush the data that was found:
        sf.flush()

gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                      on_pass_execution)
```

Given this sample C source file:

```
#include <stdio.h>

static int a_global;

struct {
  int f;
} bar;

extern int foo;

int test(int j)
{
  /* A local variable, which should *not* be reported: */
  int i;
  i = j * 4;
  return i + 1;
}

int test2(int p)
{
  static int q = 0;
  q += p;
  return p * q;
}

int test3(int k)
{
  /* We should *not* report about __FUNCTION__ here: */
  printf("%s:%i:%s\n", __FILE__, __LINE__, __FUNCTION__);
}
```

```
int test4()
{
  return foo;
}

int test6()
{
  return bar.f;
}

struct banana {
  int f;
};

const struct banana a_banana;

int test7()
{
  return a_banana.f;
}
```

these warnings are emitted on stderr:

```
tests/examples/find-global-state/input.c:41:nn: note: use of global state "int q" here
tests/examples/find-global-state/input.c:41:nn: note: use of global state "int q" here
tests/examples/find-global-state/input.c:42:nn: note: use of global state "int q" here
tests/examples/find-global-state/input.c:53:nn: note: use of global state "int foo" here
tests/examples/find-global-state/input.c:58:nn: note: use of global state "struct
{
  int f;
} bar" here
```

CHAPTER 9

Locations

gccutils.**get_src_for_loc**(*loc*)

Given a *gcc.Location*, get the source line as a string (without trailing whitespace or newlines)

class gcc.**Location**

Wrapper around GCC's *location_t*, representing a location within the source code. Use *gccutils.get_src_for_loc()* to get at the line of actual source code.

The output from __repr__ looks like this:

```
gcc.Location(file='./src/test.c', line=42)
```

The output from__str__ looks like this:

```
./src/test.c:42
```

file

(string) Name of the source file (or header file)

line

(int) Line number within source file (starting at 1, not 0)

column

(int) Column number within source file (starting at 1, not 0)

in_system_header

(bool) This attribute flags locations that are within a system header file. It may be of use when writing custom warnings, so that you can filter out issues in system headers, leaving just those within the user's code:

```
# Don't report on issues found in system headers:
if decl.location.in_system_header:
    return
```

offset_column(*self*, *offset*)

Generate a new *gcc.Location* based on the caret location of this location, offsetting the column by the given amount.

From GCC 6 onwards, these values can represent both a caret and a range, e.g.:

```
a = (foo && bar)
    ~~~~~^~~~~~
```

__init__(*self*, *caret*, *start*, *finish*)

Construct a location, using the caret location of caret as the caret, and the start/finish of start and finish respectively:

```
        compound_loc = gcc.Location(caret, start, finish)
```

caret
(*gcc.Location*) The caret location within this location. In the above example, the caret is on the first '&' character.

start
(*gcc.Location*) The start location of this range. In the above example, the start is on the opening parenthesis.

start
(*gcc.Location*) The finish location of this range. In the above example, the finish is on the closing parenthesis.

class gcc.**RichLocation**
Wrapper around GCC's *rich_location*, representing one or more locations within the source code, and zero or more fix-it hints.

add_fixit_replace(*self*, *new_content*)
Add a fix-it hint, suggesting replacement of the content covered by range 0 of the rich location with new_content.

CHAPTER 10

Generating custom errors and warnings

gcc.**warning**(*location*, *message*, *option=None*)

Emits a compiler warning at the given *gcc.Location*, potentially controlled by a *gcc.Option*.

If no option is supplied (or *None* is supplied), then the warning is an unconditional one, always issued:

```
gcc.warning(func.start, 'this is an unconditional warning')
```

```
$ ./gcc-with-python script.py input.c
input.c:25:1: warning: this is an unconditional warning [enabled by default]
```

and will be an error if *-Werror* is supplied as a command-line argument to GCC:

```
$ ./gcc-with-python script.py -Werror input.c
input.c:25:1: error: this is an unconditional warning [-Werror]
```

It's possible to associate the warning with a command-line option, so that it is controlled by that option.

For example, given this Python code:

```
gcc.warning(func.start, 'Incorrect formatting', gcc.Option('-Wformat'))
```

if the given warning is enabled, a warning will be printed to stderr:

```
$ ./gcc-with-python script.py input.c
input.c:25:1: warning: incorrect formatting [-Wformat]
```

If the given warning is being treated as an error (through the usage of *-Werror*), then an error will be printed:

```
$ ./gcc-with-python script.py -Werror input.c
input.c:25:1: error: incorrect formatting [-Werror=format]
cc1: all warnings being treated as errors
```

```
$ ./gcc-with-python script.py -Werror=format input.c
input.c:25:1: error: incorrect formatting [-Werror=format]
cc1: some warnings being treated as errors
```

If the given warning is disabled, the warning will not be printed:

```
$ ./gcc-with-python script.py -Wno-format input.c
```

Note: Due to the way GCC implements some options, it's not always possible for the plugin to fully disable some warnings. See *gcc.Option.is_enabled* for more information.

The function returns a boolean, indicating whether or not anything was actually printed.

gcc.**error**(*location*, *message*)
Emits a compiler error at the given *gcc.Location*.

For example:

```
gcc.error(func.start, 'something bad was detected')
```

would lead to this error being printed to stderr:

```
$ ./gcc-with-python script.py input.c
input.c:25:1: error: something bad was detected
```

gcc.**permerror**(*loc*, *str*)
This is a wrapper around GCC's *permerror* function.

Expects an instance of *gcc.Location* (not None) and a string

Emit a "permissive" error at that location, intended for things that really ought to be errors, but might be present in legacy code.

In theory it's suppressable using "-fpermissive" at the GCC command line (which turns it into a warning), but this only seems to be legal for C++ source files.

Returns True if the warning was actually printed, False otherwise

gcc.**inform**(*location*, *message*)
This is a wrapper around GCC's *inform* function.

Expects an instance of *gcc.Location* or *gcc.RichLocation*, (not None) and a string

Emit an informational message at that location.

For example:

```
gcc.inform(stmt.loc, 'this is where X was defined')
```

would lead to this informational message being printed to stderr:

```
$ ./gcc-with-python script.py input.c
input.c:23:3: note: this is where X was defined
```

CHAPTER 11

Working with functions and control flow graphs

Many of the plugin events are called for each function within the source code being compiled. Each time, the plugin passes a *gcc.Function* instance as a parameter to your callback, so that you can work on it.

You can get at the control flow graph of a *gcc.Function* via its `cfg` attribute. This is an instance of *gcc.Cfg*.

class `gcc.`**Function**
Wrapper around one of GCC's `struct function *`

cfg
An instance of *gcc.Cfg* for this function (or None during early passes)

decl
The declaration of this function, as a *gcc.FunctionDecl*

local_decls
List of *gcc.VarDecl* for the function's local variables. It does not contain arguments; for those see the *arguments* property of the function's *decl*.

Note that for locals with initializers, *initial* only seems to get set on those *local_decls* that are static variables. For other locals, it appears that you have to go into the gimple representation to locate assignments.

start
The *gcc.Location* of the beginning of the function

end
The *gcc.Location* of the end of the function

funcdef_no
Integer: a sequence number for profiling, debugging, etc.

class `gcc.`**Cfg**
A `gcc.Cfg` is a wrapper around GCC's *struct control_flow_graph*.

basic_blocks
List of *gcc.BasicBlock*, giving all of the basic blocks within this CFG

entry
Instance of *gcc.BasicBlock*: the entrypoint for this CFG

exit
Instance of *gcc.BasicBlock*: the final one within this CFG

get_block_for_label(*labeldecl*)
Given a `gcc.LabelDecl`, get the corresponding *gcc.BasicBlock*

You can use `gccutils.cfg_to_dot` to render a gcc.Cfg as a graphviz diagram. It will render the diagram, showing each basic block, with source code on the left-hand side, interleaved with the "gimple" representation on the right-hand side. Each block is labelled with its index, and edges are labelled with appropriate flags.

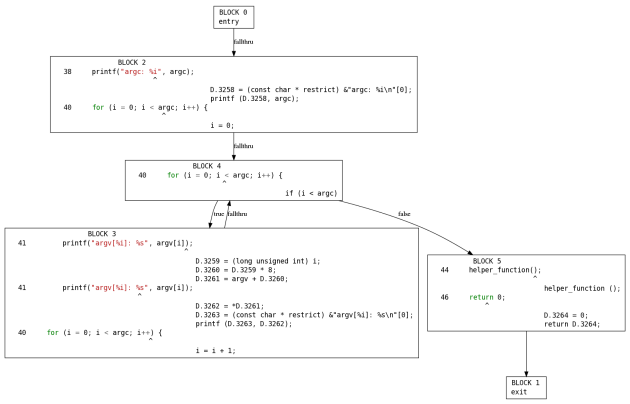
For example, given this sample C code:

```
int
main(int argc, char **argv)
{
    int i;

    printf("argc: %i\n", argc);

    for (i = 0; i < argc; i++) {
        printf("argv[%i]: %s\n", argv[i]);
    }

    helper_function();

    return 0;
}
```

then the following Python code:

```
dot = gccutils.cfg_to_dot(fun.cfg)
gccutils.invoke_dot(dot)
```

will render a CFG bitmap like this:



class `gcc.`**`BasicBlock`**

A `gcc.BasicBlock` is a wrapper around GCC's *basic_block* type.

`index`

The index of the block (an int), as seen in the cfg_to_dot rendering.

`preds`

The list of predecessor *`gcc.Edge`* instances leading into this block

`succs`

The list of successor *`gcc.Edge`* instances leading out of this block

`phi_nodes`

The list of *`gcc.GimplePhi`* phoney functions at the top of this block, if appropriate for this pass, or None

gimple
The list of *gcc.Gimple* instructions, if appropriate for this pass, or None

rtl
The list of *gcc.Rtl* expressions, if appropriate for this pass, or None

class gcc.**Edge**
A wrapper around GCC's *edge* type.

src
The source *gcc.BasicBlock* of this edge

dest
The destination *gcc.BasicBlock* of this edge

true_value
Boolean: *True* if this edge is taken when a *gcc.GimpleCond* conditional is true, *False* otherwise

false_value
Boolean: *True* if this edge is taken when a *gcc.GimpleCond* conditional is false, *False* otherwise

complex
Boolean: *True* if this edge is "special" e.g. due to exception-handling, or some other kind of "strange" control flow transfer, *False* otherwise

CHAPTER 12

gcc.Tree and its subclasses

The various language front-ends for GCC emit "tree" structures (which I believe are actually graphs), used throughout the rest of the internal representation of the code passing through GCC.

class gcc.**Tree**

A gcc.Tree is a wrapper around GCC's *tree* type

debug()

Dump the tree to stderr, using GCC's own diagnostic routines

type

Instance of *gcc.Tree* giving the type of the node

addr

(long) The address of the underlying GCC object in memory

The __str__ method is implemented using GCC's own pretty-printer for trees, so e.g.:

```
str(t)
```

might return:

```
'int <T531> (int, char * *)'
```

for a *gcc.FunctionDecl*

str_no_uid

A string representation of this object, like str(), but without including any internal UIDs.

This is intended for use in selftests that compare output against some expected value, to avoid embedding values that change into the expected output.

For example, given the type declaration above, where *str(t)* might return:

```
'int <T531> (int, char * *)'
```

where the UID "531" is liable to change from compile to compile, whereas *t.str_no_uid* has value:

```
'int <Txxx> (int, char * *)'
```

which won't arbitrarily change each time.

There are numerous subclasses of *gcc.Tree*, some with numerous subclasses of their own. Some important parts of the class hierarchy include:

Subclass	Meaning
gcc.Binary	A binary arithmetic expression, with numerous subclasses
gcc.Block	A symbol-binding block
gcc.Comparison	A relational operators (with various subclasses)
gcc.Constant	Subclasses for constants
gcc.Constructor	An aggregate value (e.g. in C, a structure or array initializer)
gcc.Declaration	Subclasses relating to declarations (variables, functions, etc)
gcc.Expression	Subclasses relating to expressions
gcc.IdentifierNode	A name
gcc.Reference	Subclasses for relating to reference to storage (e.g. pointer values)
gcc.SsaName	A variable reference for SSA analysis
gcc.Statement	Subclasses for statement expressions, which have side-effects
gcc.Type	Subclasses for describing the types of variables
gcc.Unary	Subclasses for unary arithmetic expressions

Note: Each subclass of *gcc.Tree* is typically named after either one of the *enum tree_code_class* or *enum tree_code* values, with the names converted to Camel Case:

For example a *gcc.Binary* is a wrapper around a *tree* of type *tcc_binary*, and a gcc.PlusExpr is a wrapper around a *tree* of type *PLUS_EXPR*.

As of this writing, only a small subset of the various fields of the different subclasses have been wrapped yet, but it's generally easy to add new ones. To add new fields, I've found it easiest to look at *gcc/tree.h* and *gcc/print-tree.c* within the GCC source tree and use the *print_node* function to figure out what the valid fields are. With that information, you should then look at *generate-tree-c.py*, which is the code that generates the Python wrapper classes (it's used when building the plugin to create *autogenerated-tree.c*). Ideally when exposing a field to Python you should also add it to the API documentation, and add a test case.

gccutils.**pformat**(*tree*)

This function attempts to generate a debug dump of a *gcc.Tree* and all of its "interesting" attributes, recursively. It's loosely modelled on Python's *pprint* module and GCC's own *debug_tree* diagnostic routine using indentation to try to show the structure.

It returns a string.

It differs from *gcc.Tree.debug()* in that it shows the Python wrapper objects, rather than the underlying GCC data structures themselves. For example, it can't show attributes that haven't been wrapped yet.

Objects that have already been reported within this call are abbreviated to "..." to try to keep the output readable.

Example output:

```
    <FunctionDecl
      repr() = gcc.FunctionDecl('main')
      superclasses = (<type 'gcc.Declaration'>, <type 'gcc.Tree'>)
      .function = gcc.Function('main')
      .location = /home/david/coding/gcc-python/test.c:15
      .name = 'main'
      .type = <FunctionType
                repr() = <gcc.FunctionType object at 0x2f62a60>
                str() = 'int <T531> (int, char * *)'
                superclasses = (<type 'gcc.Type'>, <type 'gcc.Tree'>)
                .name = None
                .type = <IntegerType
                          repr() = <gcc.IntegerType object at 0x2f629d0>
                          str() = 'int'
                          superclasses = (<type 'gcc.Type'>, <type 'gcc.Tree'>)
                          .const = False
```

```
                            .name = <TypeDecl
                                      repr() = gcc.TypeDecl('int')
                                      superclasses = (<type 'gcc.Declaration'>, <type 'gcc.Tree'>)
                                      .location = None
                                      .name = 'int'
                                      .pointer = <PointerType
                                                   repr() = <gcc.PointerType object at 0x2f62b80>
                                                   str() = ' *'
                                                   superclasses = (<type 'gcc.Type'>, <type 'gcc.Tree'
                                                   .dereference = ... ("gcc.TypeDecl('int')")
                                                   .name = None
                                                   .type = ... ("gcc.TypeDecl('int')")
                                                 >
                                      .type = ... ('<gcc.IntegerType object at 0x2f629d0>')
                                    >
                            .precision = 32
                            .restrict = False
                            .type = None
                            .unsigned = False
                            .volatile = False
                          >
              >
    >
```

gccutils.**pprint**(*tree*)

Similar to *gccutils.pformat()*, but prints the output to stdout.

(should this be stderr instead? probably should take a stream as an arg, but what should the default be?)

12.1 Blocks

class gcc.**Block**

A symbol binding block, such as the global symbols within a compilation unit.

vars

The list of *gcc.Tree* for the declarations and labels in this block

12.2 Declarations

class gcc.**Declaration**

A subclass of *gcc.Tree* indicating a declaration

Corresponds to the *tcc_declaration* value of *enum tree_code_class* within GCC's own C sources.

name

(string) the name of this declaration

location

The *gcc.Location* for this declaration

is_artificial

(bool) Is this declaration a compiler-generated entity, rather than one provided by the user?

An example of such an "artificial" declaration occurs within the arguments of C++ methods: the initial *this* argument is a compiler-generated *gcc.ParmDecl*.

is_builtin
(bool) Is this declaration a compiler-builtin?

class gcc.**FieldDecl**
A subclass of *gcc.Declaration* indicating the declaration of a field within a structure.

name
(string) The name of this field

class gcc.**FunctionDecl**
A subclass of *gcc.Declaration* indicating the declaration of a function. Internally, this wraps a *(struct tree_function_decl *)*

function
The *gcc.Function* for this declaration

arguments
List of *gcc.ParmDecl* representing the arguments of this function

result
The *gcc.ResultDecl* representing the return value of this function

fullname

Note: This attribute is only usable with C++ code. Attempting to use it from another language will lead to a *RuntimeError* exception.

(string) The "full name" of this function, including the scope, return type and default arguments.

For example, given this code:

```
namespace Example {
    struct Coord {
        int x;
        int y;
    };

    class Widget {
    public:
        void set_location(const struct Coord& coord);
    };
};
```

set_location's fullname is:

```
'void Example::Widget::set_location(const Example::Coord&)'
```

callgraph_node
The *gcc.CallgraphNode* for this function declaration, or *None*

is_public
(bool) For C++: is this declaration "public"

is_private
(bool) For C++: is this declaration "private"

is_protected
(bool) For C++: is this declaration "protected"

is_static
(bool) For C++: is this declaration "static"

class gcc.**ParmDecl**
A subclass of *gcc.Declaration* indicating the declaration of a parameter to a function or method.

class gcc.**ResultDecl**
A subclass of *gcc.Declaration* declararing a dummy variable that will hold the return value from a function.

class gcc.**VarDecl**
A subclass of *gcc.Declaration* indicating the declaration of a variable (e.g. a global or a local).

initial
The initial value for this variable as a gcc.Constructor, or None

static
(boolean) Is this variable to be allocated with static storage?

class gcc.**NamespaceDecl**

A subclass of *gcc.Declaration* representing a C++ namespace

alias_of
The *gcc.NamespaceDecl* which this namespace is an alias of or None if this namespace is not an alias.

declarations

Note: This attribute is only usable with non-alias namespaces. Accessing it on an alias will lead to a RuntimeError exception.

List of *gcc.Declaration* objects in this namespace. This attribute is only valid for non-aliases

namespaces

Note: This attribute is only usable with non-alias namespaces. Accessing it on an alias will lead to a RuntimeError exception.

List of *gcc.NamespaceDecl* objects nested in this namespace. This attribute is only valid for non-aliases

lookup(*name*)
Locate the given name within the namespace, returning a *gcc.Tree* or *None*

unalias()
Always returns a *gcc.NamespaceDecl* object which is not an alias. Returns self if this namespace is not an alias.

12.3 Types

class gcc.**Type**
A subclass of *gcc.Tree* indicating a type

Corresponds to the *tcc_type* value of *enum tree_code_class* within GCC's own C sources.

name
The `gcc.IdentifierNode` for the name of the type, or *None*.

pointer
The *gcc.PointerType* representing the *(this_type *)* type

attributes
The user-defined attributes on this type (using GCC's *__attribute* syntax), as a dictionary (mapping from attribute names to list of values). Typically this will be the empty dictionary.

sizeof
sizeof() this type, as an *int*, or raising *TypeError* for those types which don't have a well-defined size

---

Note: This attribute is not usable from within *lto1*; attempting to use it there will lead to a *RuntimeError* exception.

Additional attributes for various *gcc.Type* subclasses:

const
(Boolean) Does this type have the *const* modifier?

const_equivalent
The *gcc.Type* for the *const* version of this type

volatile
(Boolean) Does this type have the *volatile* modifier?

volatile_equivalent
The *gcc.Type* for the *volatile* version of this type

restrict
(Boolean) Does this type have the *restrict* modifier?

restrict_equivalent
The *gcc.Type* for the *restrict* version of this type

unqualified_equivalent
The *gcc.Type* for the version of this type that does not have any qualifiers.

The standard C types are accessible via class methods of *gcc.Type*. They are only created by GCC after plugins are loaded, and so they're only visible during callbacks, not during the initial run of the code. (yes, having them as class methods is slightly clumsy).

Each of the following returns a *gcc.Type* instance representing the given type (or None at startup before any passes, when the types don't yet exist)

Class method	C Type
gcc.Type.void()	*void*
gcc.Type.size_t()	*size_t*
gcc.Type.char()	*char*
gcc.Type.signed_char()	*signed char*
gcc.Type.unsigned_char()	*unsigned char*
gcc.Type.double()	*double*
gcc.Type.float()	*float*
gcc.Type.short()	*short*
gcc.Type.unsigned_short()	*unsigned short*
gcc.Type.int()	*int*
gcc.Type.unsigned_int()	*unsigned int*
gcc.Type.long()	*long*
gcc.Type.unsigned_long()	*unsigned long*
gcc.Type.long_double()	*long double*
gcc.Type.long_long()	*long long*
gcc.Type.unsigned_long_long()	*unsigned long long*
gcc.Type.int128()	*int128*
gcc.Type.unsigned_int128()	*unsigned int128*
gcc.Type.uint32()	*uint32*
gcc.Type.uint64()	*uint64*

class gcc.**IntegerType**

Subclass of *gcc.Type*, adding a few properties:

unsigned

(Boolean) True for 'unsigned', False for 'signed'

precision

(int) The precision of this type in bits, as an int (e.g. 32)

signed_equivalent

The gcc.IntegerType for the signed version of this type

Note: This attribute is not usable from within *lto1*; attempting to use it there will lead to a *RuntimeError* exception.

---

unsigned_equivalent

The gcc.IntegerType for the unsigned version of this type

Note: This attribute is not usable from within *lto1*; attempting to use it there will lead to a *RuntimeError* exception.

---

max_value

The maximum possible value for this type, as a `gcc.IntegerCst`

min_value

The minimum possible value for this type, as a `gcc.IntegerCst`

class gcc.**FloatType**

Subclass of *gcc.Type* representing C's *float* and *double* types

precision

(int) The precision of this type in bits (32 for *float*; 64 for *double*)

class gcc.**PointerType**
Subclass of *gcc.Type* representing a pointer type, such as an *int **

dereference
The *gcc.Type* that this type points to. In the above example (*int **), this would be the *int* type.

class gcc.**EnumeralType**
Subclass of *gcc.Type* representing an enumeral type.

values
A list of tuple representing the constants defined in this enumeration. Each tuple consists of two elements; the first being the name of the constant, a `gcc.IdentifierNode`; and the second being the value, a *gcc.Constant*.

class gcc.**ArrayType**
Subclass of *gcc.Type* representing an array type. For example, in a C declaration such as:

```
char buf[16]
```

we have a *gcc.VarDecl* for *buf*, and its type is an instance of *gcc.ArrayType*, representing *char [16]*.

dereference
The *gcc.Type* that this type points to. In the above example, this would be the *char* type.

range
The *gcc.Type* that represents the range of the array's indices. If the array has a known range, then this will ordinarily be an *gcc.IntegerType* whose *min_value* and *max_value* are the (inclusive) bounds of the array. If the array does not have a known range, then this attribute will be *None*.

That is, in the example above, *range.min_val* is *0*, and *range.max_val* is *15*.

But, for a C declaration like:

```
extern char array[];
```

the type's *range* would be *None*.

class gcc.**VectorType**

dereference
The *gcc.Type* that this type points to

class gcc.**FunctionType**
Subclass of *gcc.Type* representing the type of a given function (or or a typedef to a function type, e.g. for callbacks).

See also *gcc.FunctionType*

The *type* attribute holds the return type.

is_variadic
True if this type represents a variadic function. Note that for a variadic function, the final ... argument is not explicitly represented in *argument_types*.

argument_types
A tuple of *gcc.Type* instances, representing the function's argument types

`gccutils.`**get_nonnull_arguments**(*funtype*)
This is a utility function for working with the *"nonnull"* custom attribute on function types:

http://gcc.gnu.org/onlinedocs/gcc/Function-Attributes.html

Return a *frozenset* of 0-based integers, giving the arguments for which we can assume "nonnull-ness", handling the various cases of:

- the attribute isn't present (returning the empty frozenset)
- the attribute is present, without args (all pointer args are non-NULL)
- the attribute is present, with a list of 1-based argument indices (Note that the result is still 0-based)

class gcc.**MethodType**

Subclass of *gcc.Type* representing the type of a given method. Similar to *gcc.FunctionType*

The *type* attribute holds the return type.

argument_types

A tuple of *gcc.Type* instances, representing the function's argument types

class gcc.**RecordType**

A compound type, such as a C *struct*

fields

The fields of this type, as a list of *gcc.FieldDecl* instances

methods

The methods of this type, as a list of *gcc.MethodType* instances

You can look up C structures by looking within the top-level *gcc.Block* within the current translation unit. For example, given this sample C code:

```
/* Example of a struct: */
struct test_struct {
    int a;
    char b;
    float c;
};

void foo()
{
}
```

then the following Python code:

```
import gcc

class TestPass(gcc.GimplePass):
    def execute(self, fn):
        print('fn: %r' % fn)
        for u in gcc.get_translation_units():
            for decl in u.block.vars:
                if isinstance(decl, gcc.TypeDecl):
                    # "decl" is a gcc.TypeDecl
                    # "decl.type" is a gcc.RecordType:
                    print('  type(decl): %s' % type(decl))
                    print('  type(decl.type): %s' % type(decl.type))
                    print('  decl.type.name: %r' % decl.type.name)
                    for f in decl.type.fields:
                        print('    type(f): %s' % type(f))
                        print('      f.name: %r' % f.name)
                        print('      f.type: %s' % f.type)
                        print('      type(f.type): %s' % type(f.type))
```

```
test_pass = TestPass(name='test-pass')
```

will generate this output:

```
fn: gcc.Function('foo')
  type(decl): <type 'gcc.TypeDecl'>
  type(decl.type): <type 'gcc.RecordType'>
  decl.type.name: gcc.IdentifierNode(name='test_struct')
    type(f): <type 'gcc.FieldDecl'>
      f.name: 'a'
      f.type: int
      type(f.type): <type 'gcc.IntegerType'>
    type(f): <type 'gcc.FieldDecl'>
      f.name: 'b'
      f.type: char
      type(f.type): <type 'gcc.IntegerType'>
    type(f): <type 'gcc.FieldDecl'>
      f.name: 'c'
      f.type: float
      type(f.type): <type 'gcc.RealType'>
```

12.4 Constants

class gcc.**Constant**

Subclass of *gcc.Tree* indicating a constant value.

Corresponds to the *tcc_constant* value of *enum tree_code_class* within GCC's own C sources.

constant

The actual value of this constant, as the appropriate Python type:

Subclass	Python type
class ComplexCst	
class FixedCst	
class IntegerCst	*int* or *long*
class PtrmemCst	
class RealCst	*float*
class StringCst	*str*
class VectorCst	

12.5 Binary Expressions

class gcc.**Binary**

Subclass of *gcc.Tree* indicating a binary expression.

Corresponds to the *tcc_binary* value of *enum tree_code_class* within GCC's own C sources.

location
The *gcc.Location* for this binary expression

classmethod get_symbol()
Get the symbol used in debug dumps for this *gcc.Binary* subclass, if any, as a *str*. A table showing these strings can be seen *here*.

Has subclasses for the various kinds of binary expression. These include:

Simple arithmetic:

Subclass	C/C++ operators	enum tree_code
class gcc.**PlusExpr**	+	PLUS_EXPR
class gcc.**MinusExpr**	-	MINUS_EXPR
class gcc.**MultExpr**	*	MULT_EXPR

Pointer addition:

Subclass	C/C++ operators	enum tree_code
class gcc.**PointerPlusExpr**		POINTER_PLUS_EXPR

Various division operations:

Subclass	C/C++ operators
class gcc.**TruncDivExr**	
class gcc.**CeilDivExpr**	
class gcc.**FloorDivExpr**	
class gcc.**RoundDivExpr**	

The remainder counterparts of the above division operators:

Subclass	C/C++ operators
class gcc.**TruncModExpr**	
class gcc.**CeilModExpr**	
class gcc.**FloorModExpr**	
class gcc.**RoundModExpr**	

Division for reals:

Subclass	C/C++ operators
class gcc.**RdivExpr**	

Division that does not need rounding (e.g. for pointer subtraction in C):

Subclass	C/C++ operators
class gcc.**ExactDivExpr**	

Max and min:

Subclass	C/C++ operators
class gcc.**MaxExpr**	
class gcc.**MinExpr**	

Shift and rotate operations:

Subclass	C/C++ operators
class gcc.**LrotateExpr**	
class gcc.**LshiftExpr**	<<, <<=
class gcc.**RrotateExpr**	
class gcc.**RshiftExpr**	>>, >>=

Bitwise binary expressions:

Subclass	C/C++ operators
class gcc.**BitAndExpr**	&, &= (bitwise “and”)
class gcc.**BitIorExpr**	|, |= (bitwise “or”)
class gcc.**BitXorExpr**	^, ^= (bitwise “xor”)

Other gcc.Binary subclasses:

Subclass	Usage
class gcc.**CompareExpr**	
class gcc.**CompareGExpr**	
class gcc.**CompareLExpr**	
class gcc.**ComplexExpr**	
class gcc.**MinusNomodExpr**	
class gcc.**PlusNomodExpr**	
class gcc.**RangeExpr**	
class gcc.**UrshiftExpr**	
class gcc.**VecExtractevenExpr**	
class gcc.**VecExtractoddExpr**	
class gcc.**VecInterleavehighExpr**	
class gcc.**VecInterleavelowExpr**	
class gcc.**VecLshiftExpr**	
class gcc.**VecPackFixTruncExpr**	
class gcc.**VecPackSatExpr**	
class gcc.**VecPackTruncExpr**	
class gcc.**VecRshiftExpr**	
class gcc.**WidenMultExpr**	
class gcc.**WidenMultHiExpr**	
class gcc.**WidenMultLoExpr**	
class gcc.**WidenSumExpr**	

12.6 Unary Expressions

class gcc.**Unary**

Subclass of *gcc.Tree* indicating a unary expression (i.e. taking a single argument).

Corresponds to the *tcc_unary* value of *enum tree_code_class* within GCC's own C sources.

operand

The operand of this operator, as a *gcc.Tree*.

location

The *gcc.Location* for this unary expression

classmethod get_symbol()

Get the symbol used in debug dumps for this *gcc.Unary* subclass, if any, as a *str*. A table showing these strings can be seen *here*.

Subclasses include:

Subclass	Meaning; C/C++ operators
class gcc.**AbsExpr**	Absolute value
class gcc.**AddrSpaceConvertExpr**	Conversion of pointers between address spaces
class gcc.**BitNotExpr**	~ (bitwise “not”)
class gcc.**CastExpr**	
class gcc.**ConjExpr**	For complex types: complex conjugate
class gcc.**ConstCastExpr**	
class gcc.**ConvertExpr**	
class gcc.**DynamicCastExpr**	
class gcc.**FixTruncExpr**	Convert real to fixed-point, via truncation
class gcc.**FixedConvertExpr**	
class gcc.**FloatExpr**	Convert integer to real
class gcc.**NegateExpr**	Unary negation
class gcc.**NoexceptExpr**	
class gcc.**NonLvalueExpr**	
class gcc.**NopExpr**	
class gcc.**ParenExpr**	
class gcc.**ReducMaxExpr**	
class gcc.**ReducMinExpr**	
class gcc.**ReducPlusExpr**	
class gcc.**ReinterpretCastExpr**	
class gcc.**StaticCastExpr**	
class gcc.**UnaryPlusExpr**	

12.7 Comparisons

class gcc.**Comparison**

Subclass of *gcc.Tree* for comparison expressions

Corresponds to the *tcc_comparison* value of *enum tree_code_class* within GCC's own C sources.

location

The *gcc.Location* for this comparison

classmethod get_symbol()

Get the symbol used in debug dumps for this *gcc.Comparison* subclass, if any, as a *str*. A table showing these strings can be seen *here*.

Subclasses include:

Subclass	C/C++ operators
class EqExpr	==
class GeExpr	>=
class GtExpr	>
class LeExpr	<=
class LtExpr	<
class LtgtExpr	
class NeExpr	!=
class OrderedExpr	
class UneqExpr	
class UngeExpr	
class UngtExpr	
class UnleExpr	
class UnltExpr	
class UnorderedExpr	

12.8 References to storage

class gcc.**Reference**
Subclass of *gcc.Tree* for expressions involving a reference to storage.

Corresponds to the *tcc_reference* value of *enum tree_code_class* within GCC's own C sources.

location
The *gcc.Location* for this storage reference

classmethod get_symbol()
Get the symbol used in debug dumps for this *gcc.Reference* subclass, if any, as a *str*. A table showing these strings can be seen *here*.

class gcc.**ArrayRef**
A subclass of *gcc.Reference* for expressions involving an array reference:

```
unsigned char buffer[4096];
...
/* The left-hand side of this gcc.GimpleAssign is a gcc.ArrayRef: */
buffer[42] = 0xff;
```

array
The *gcc.Tree* for the array within the reference (*gcc.VarDecl('buffer')* in the example above)

index
The *gcc.Tree* for the index within the reference (*gcc.IntegerCst(42)* in the example above)

class gcc.**ComponentRef**
A subclass of *gcc.Reference* for expressions involving a field lookup.

This can mean either a direct field lookup, as in:

```
struct mystruct s;
...
s.idx = 42;
```

or dereferenced field lookup:

```
struct mystruct *p;
...
p->idx = 42;
```

target
The *gcc.Tree* for the container of the field (either *s* or **p* in the examples above)

field
The *gcc.FieldDecl* for the field within the target.

class gcc.**MemRef**
A subclass of *gcc.Reference* for expressions involving dereferencing a pointer:

```
int p, *q;
...
p = *q;
```

operand
The *gcc.Tree* for the expression describing the target of the pointer

Other subclasses of *gcc.Reference* include:

Subclass	C/C++ operators
class **ArrayRangeRef**	
class **AttrAddrExpr**	
class **BitFieldRef**	
class **ImagpartExpr**	
class **IndirectRef**	
class **MemberRef**	
class **OffsetRef**	
class **RealpartExpr**	
class **ScopeRef**	
class **TargetMemRef**	
class **UnconstrainedArrayRef**	
class **ViewConvertExpr**	

12.9 Other expression subclasses

class gcc.**Expression**

Subclass of *gcc.Tree* indicating an expression that doesn't fit into the other categories.

Corresponds to the *tcc_expression* value of *enum tree_code_class* within GCC's own C sources.

location

The *gcc.Location* for this expression

classmethod **get_symbol**()

Get the symbol used in debug dumps for this *gcc.Expression* subclass, if any, as a *str*. A table showing these strings can be seen *here*.

Subclasses include:

Subclass	C/C++ operators
class gcc.**AddrExpr**	

Continued on next page

Table 12.1 – continued from previous page

Subclass	C/C++ operators
class gcc.**AlignofExpr**	
class gcc.**ArrowExpr**	
class gcc.**AssertExpr**	
class gcc.**AtEncodeExpr**	
class gcc.**BindExpr**	
class gcc.**CMaybeConstExpr**	
class gcc.**ClassReferenceExpr**	
class gcc.**CleanupPointExpr**	
class gcc.**CompoundExpr**	
class gcc.**CompoundLiteralExpr**	
class gcc.**CondExpr**	
class gcc.**CtorInitializer**	
class gcc.**DlExpr**	
class gcc.**DotProdExpr**	
class gcc.**DotstarExpr**	
class gcc.**EmptyClassExpr**	

Continued on next page

Table 12.1 – continued from previous page

Subclass	C/C++ operators
class gcc.**ExcessPrecisionExpr**	
class gcc.**ExprPackExpansion**	
class gcc.**ExprStmt**	
class gcc.**FdescExpr**	
class gcc.**FmaExpr**	
class gcc.**InitExpr**	
class gcc.**MessageSendExpr**	
class gcc.**ModifyExpr**	
class gcc.**ModopExpr**	
class gcc.**MustNotThrowExpr**	
class gcc.**NonDependentExpr**	
class gcc.**NontypeArgumentPack**	
class gcc.**NullExpr**	
class gcc.**NwExpr**	
class gcc.**ObjTypeRef**	
class gcc.**OffsetofExpr**	

Continued on next page

Table 12.1 – continued from previous page

Subclass	C/C++ operators
class gcc.**PolynomialChrec**	
class gcc.**PostdecrementExpr**	
class gcc.**PostincrementExpr**	
class gcc.**PredecrementExpr**	
class gcc.**PredictExpr**	
class gcc.**PreincrementExpr**	
class gcc.**PropertyRef**	
class gcc.**PseudoDtorExpr**	
class gcc.**RealignLoad**	
class gcc.**SaveExpr**	
class gcc.**ScevKnown**	
class gcc.**ScevNotKnown**	
class gcc.**SizeofExpr**	
class gcc.**StmtExpr**	
class gcc.**TagDefn**	
class gcc.**TargetExpr**	

Continued on next page

Table 12.1 – continued from previous page

Subclass	C/C++ operators
class gcc.**TemplateIdExpr**	
class gcc.**ThrowExpr**	
class gcc.**TruthAndExpr**	
class gcc.**TruthAndifExpr**	
class gcc.**TruthNotExpr**	
class gcc.**TruthOrExpr**	
class gcc.**TruthOrifExpr**	
class gcc.**TruthXorExpr**	
class gcc.**TypeExpr**	
class gcc.**TypeidExpr**	
class gcc.**VaArgExpr**	
class gcc.**VecCondExpr**	
class gcc.**VecDlExpr**	
class gcc.**VecInitExpr**	
class gcc.**VecNwExpr**	
class gcc.**WidenMultMinusExpr**	

Continued on next page

Table 12.1 – continued from previous page

Subclass	C/C++ operators
class gcc.**WidenMultPlusExpr**	
class gcc.**WithCleanupExpr**	
class gcc.**WithSizeExpr**	

TODO

12.10 Statements

class gcc.**Statement**

A subclass of *gcc.Tree* for statements

Corresponds to the *tcc_statement* value of *enum tree_code_class* within GCC's own C sources.

class gcc.**CaseLabelExpr**

A subclass of *gcc.Statement* for the *case* and *default* labels within a *switch* statement.

low

- for single-valued case labels, the value, as a *gcc.Tree*
- for range-valued case labels, the lower bound, as a *gcc.Tree*
- *None* for the default label

high

For range-valued case labels, the upper bound, as a *gcc.Tree*.

None for single-valued case labels, and for the default label

target

The target of the case label, as a gcc.LabelDecl

12.11 SSA Names

class gcc.**SsaName**

A subclass of *gcc.Tree* representing a variable references during SSA analysis. New SSA names are created every time a variable is assigned a new value.

var

The variable being referenced, as a *gcc.VarDecl* or *gcc.ParmDecl*

def_stmt

The *gcc.Gimple* statement which defines this SSA name

version

An *int* value giving the version number of this SSA name

CHAPTER 13

Gimple statements

class gcc.**Gimple**

A statement, in GCC's Gimple representation.

The __str__ method is implemented using GCC's own pretty-printer for gimple, so e.g.:

```
str(stmt)
```

might return:

```
'D.3259 = (long unsigned int) i;'
```

loc

Source code location of this statement, as a *gcc.Location* (or None)

block

The lexical block holding this statement, as a *gcc.Tree*

exprtype

The type of the main expression computed by this statement, as a *gcc.Tree* (which might be gcc.VoidType)

str_no_uid

A string representation of this statement, like str(), but without including any internal UIDs.

This is intended for use in selftests that compare output against some expected value, to avoid embedding values that change into the expected output.

For example, given an assignment to a temporary, the *str(stmt)* for the gcc.GimpleAssign might be:

```
'D.3259 = (long unsigned int) i;'
```

where the UID "3259" is liable to change from compile to compile, whereas the *stmt.str_no_uid* has value:

```
'D.xxxx = (long unsigned int) i;'
```

which won't arbitrarily change each time.

walk_tree(*callback*, **args*, ***kwargs*)

Visit all *gcc.Tree* nodes associated with this statement, potentially more than once each. This will visit both the left-hand-side and right-hand-side operands of the statement (if any), and recursively visit any of their child nodes.

For each node, the callback is invoked, supplying the node, and any extra positional and keyword arguments passed to *walk_tree*:

```
        callback(node, *args, **kwargs)
```

If the callback returns a true value, the traversal stops, and that *gcc.Tree* is the result of the call to *walk_tree*. Otherwise, the traversal continues, and *walk_tree* eventually returns *None*.

gcc.Gimple has various subclasses, each corresponding to the one of the kinds of statement within GCC's internal representation.

The following subclasses have been wrapped for use from Python scripts:

Subclass	Meaning
gcc.GimpleAsm	One or more inline assembly statements
gcc.GimpleAssign	An assignment of an expression to an l-value: `LHS = RHS1 EXPRCODE RHS2;`
gcc.GimpleCall	A function call: `[ LHS = ] FN(ARG1, ..., ARGN);`
gcc.GimpleCond	A conditional jump, of the form: `if (LHS EXPRCODE RHS) goto TRUE_LABEL else goto FA`
gcc.GimpleLabel	A label statement (jump target): `LABEL:`
gcc.GimpleNop	The "do nothing" statement
gcc.GimplePhi	Used in the SSA passes: `LHS = PHI <ARG1, ..., ARGN>;`
gcc.GimpleReturn	A "return" statement: `RETURN [RETVAL];`

gcc.GimpleSwitch	A switch statement:
	`switch (INDEXVAR)`
	`{`
	`  case LAB1: ...; break;`
	`  ...`
	`  case LABN: ...; break;`
	`  default: ...`
	`}`

There are some additional subclasses that have not yet been fully wrapped by the Python plugin (email the gcc-python-plugin's mailing list if you're interested in working with these):

Subclass	Meaning
gcc.GimpleBind	A lexical scope
gcc.GimpleCatch	An exception handler
gcc.GimpleDebug	A debug statement
gcc.GimpleEhDispatch	Used in exception-handling
gcc.GimpleEhFilter	Used in exception-handling
gcc.GimpleEhMustNotThrow	Used in exception-handling
gcc.GimpleErrorMark	A dummy statement used for handling internal errors
gcc.GimpleGoto	An unconditional jump
gcc.GimpleOmpAtomicLoad	Used for implementing OpenMP
gcc.GimpleOmpAtomicStore	(ditto)
gcc.GimpleOmpContinue	(ditto)
gcc.GimpleOmpCritical	(ditto)
gcc.GimpleOmpFor	(ditto)
gcc.GimpleOmpMaster	(ditto)
gcc.GimpleOmpOrdered	(ditto)
gcc.GimpleOmpParallel	(ditto)
gcc.GimpleOmpReturn	(ditto)
gcc.GimpleOmpSection	(ditto)
gcc.GimpleOmpSections	(ditto)
gcc.GimpleOmpSectionsSwitch	(ditto)
gcc.GimpleOmpSingle	(ditto)
gcc.GimpleOmpTask	(ditto)
gcc.GimplePredict	A hint for branch prediction
gcc.GimpleResx	Resumes execution after an exception
gcc.GimpleTry	A try/catch or try/finally statement
gcc.GimpleWithCleanupExpr	Internally used when generating GIMPLE

class gcc.**GimpleAsm**

Subclass of *gcc.Gimple*: a fragment of inline assembler code.

string

The inline assembler code, as a *str*.

class gcc.**GimpleAssign**

Subclass of *gcc.Gimple*: an assignment of an expression to an l-value:

```
LHS = RHS1 EXPRCODE RHS2;
```

lhs

Left-hand-side of the assignment, as a *gcc.Tree*

rhs

The operands on the right-hand-side of the expression, as a list of *gcc.Tree* instances (either of length 1 or length 2, depending on the expression).

exprcode

The kind of the expression, as an *gcc.Tree* subclass (the type itself, not an instance)

class gcc.**GimpleCall**

Subclass of *gcc.Gimple*: an invocation of a function, potentially assigning the result to an l-value:

```
[ LHS = ] FN(ARG1, ..., ARGN);
```

lhs

Left-hand-side of the assignment, as a *gcc.Tree*, or *None*

rhs
The operands on the right-hand-side of the expression, as a list of *gcc.Tree* instances

fn
The function being called, as a *gcc.Tree*

fndecl
The declaration of the function being called (if any), as a *gcc.Tree*

args
The arguments for the call, as a list of *gcc.Tree*

noreturn
(boolean) Has this call been marked as not returning? (e.g. a call to *exit*)

class gcc.**GimpleReturn**
Subclass of *gcc.Gimple*: a "return" statement, signifying the end of a *gcc.BasicBlock*:

```
RETURN [RETVAL];
```

retval

The return value, as a *gcc.Tree*, or *None*.

class gcc.**GimpleCond**
Subclass of *gcc.Gimple*: a conditional jump, of the form:

```
if (LHS EXPRCODE RHS) goto TRUE_LABEL else goto FALSE_LABEL
```

lhs
Left-hand-side of the comparison, as a *gcc.Tree*

exprcode
The comparison predicate, as a *gcc.Comparison* subclass (the type itself, not an instance). For example, the gcc.GimpleCond statement for this fragment of C code:

```
if (a == b)
```

would have stmt.exprcode == gcc.EqExpr

rhs
The right-hand-side of the comparison, as a *gcc.Tree*

true_label
The `gcc.LabelDecl` node used as the jump target for when the comparison is true

false_label
The `gcc.LabelDecl` node used as the jump target for when the comparison is false

Note that a C conditional of the form:

```
if (some_int) {suiteA} else {suiteB}
```

is implicitly expanded to:

```
if (some_int != 0) {suiteA} else {suiteB}
```

and this becomes a gcc.GimpleCond with *lhs* as the integer, *exprcode* as *<type 'gcc.NeExpr'>*, and *rhs* as *gcc.IntegerCst(0)*.

class gcc.**GimplePhi**
Subclass of *gcc.Gimple* used in the SSA passes: a "PHI" or "phoney" function, for merging the various possible values a variable can have based on the edge that we entered this *gcc.BasicBlock* on:

```
LHS = PHI <ARG1, ..., ARGN>;
```

lhs
Left-hand-side of the assignment, as a *gcc.SsaName*

args
A list of (*gcc.Tree*, *gcc.Edge*) pairs representing the possible (expr, edge) inputs. Each *expr* is either a *gcc.SsaName* or a *gcc.Constant*

class gcc.**GimpleSwitch**
Subclass of *gcc.Gimple*: a switch statement, signifying the end of a *gcc.BasicBlock*:

```
switch (INDEXVAR)
{
  case LAB1: ...; break;
  ...
  case LABN: ...; break;
  default: ...
}
```

indexvar
The index variable used by the switch statement, as a *gcc.Tree*

labels
The labels of the switch statement, as a list of *gcc.CaseLabelExpr*.

The initial label in the list is always the default.

class gcc.**GimpleLabel**
Subclass of *gcc.Gimple*, representing a "label" statement:

```
.. py:attribute:: labels
```

The underlying `gcc.LabelDecl` node representing this jump target

class gcc.**GimpleAssign**
Subclass of *gcc.Gimple*: an assignment of an expression to an l-value:

```
LHS = RHS1 EXPRCODE RHS2;
```

lhs
Left-hand-side of the assignment, as a *gcc.Tree*

rhs
The operands on the right-hand-side of the expression, as a list of *gcc.Tree* instances (either of length 1 or length 2, depending on the expression).

exprcode
The kind of the expression, as an *gcc.Tree* subclass (the type itself, not an instance)

class gcc.**GimpleNop**

Subclass of *gcc.Gimple*, representing a "do-nothing" statement (a.k.a. "no operation").

CHAPTER 14

Optimization passes

14.1 Working with existing passes

GCC organizes the optimization work it does as "passes", and these form trees: passes can have both successors and child passes.

There are actually five "roots" to this tree:

- The *gcc.Pass* holding *all "lowering" passes*, invoked per function within the callgraph, to turn high-level GIMPLE into lower-level forms (this wraps *all_lowering_passes* within gcc/passes.c).
- The *gcc.Pass* holding *all "small IPA" passes*, working on the whole callgraph (IPA is "Interprocedural Analysis"; *all_small_ipa_passes* within gcc/passes.c)
- The *gcc.Pass* holding *all regular IPA passes* (*all_regular_ipa_passes* within gcc/passes.c)
- The *gcc.Pass* holding those *passes relating to link-time-optimization* (*all_lto_gen_passes* within gcc/passes.c)
- The *"all other passes" gcc.Pass catchall*, holding the majority of the passes. These are called on each function within the call graph (*all_passes* within gcc/passes.c)

classmethod gcc.Pass.**get_roots**()
Returns a 5-tuple of *gcc.Pass* instances, giving the 5 top-level passes within GCC's tree of passes, in the order described above.

classmethod gcc.Pass.**get_by_name**(*name*)
Get the *gcc.Pass* instance for the pass with the given name, raising ValueError if it isn't found

class gcc.**Pass**
This wraps one of GCC's *struct opt_pass* * instances.

Beware: "pass" is a reserved word in Python, so use e.g. *ps* as a variable name for an instance of *gcc.Pass*

name
The name of the pass, as a string

sub
The first child pass of this pass (if any)

next
The next sibling pass of this pass (if any)

properties_required

properties_provided

properties_destroyed

Currently these are int bitfields, expressing the flow of data betweeen the various passes.

They can be accessed using bitwise arithmetic:

```
if ps.properties_provided & gcc.PROP_cfg:
    print(fn.cfg)
```

Here are the bitfield flags:

Mask	Meaning	Which pass sets this up?	Which pass clears this?
gcc.PROP_gimple_any	Is the full GIMPLE grammar allowed?	(the frontend)	*"expand"*
gcc.PROP_gimple_lcf	Has control flow been lowered?	*"lower"*	*"expand"*
gcc.PROP_gimple_leh	Has exception-handling been lowered?	*"eh"*	*"expand"*
gcc.PROP_cfg	Does the gcc.Function have a non-None "cfg"?	*"cfg"*	*"*free_cfg"*
gcc.PROP_referenced_vars	Do we have data on which functions reference which variables? (Dataflow analysis, aka DFA). This flag was removed in GCC 4.8	*"*referenced_vars"*	(none)
gcc.PROP_ssa	Is the GIMPLE in SSA form?	*"ssa"*	*"expand"*
gcc.PROP_no_crit_edges	Have all critical edges within the CFG been split?	*"crited"*	(none)
gcc.PROP_rtl	Is the function now in RTL form? (rather than GIMPLE-SSA)	*"expand"*	*"*clean_state"*
gcc.PROP_gimple_lomp	Have OpenMP directives been lowered into explicit calls to the runtime library (libgomp)	*"ompplower"*	*"expand"*
gcc.PROP_cfglayout	Are we reorganizing the CFG into a more efficient order?	*"into_cfglayout"*	*"outof_cfglayout"*
gcc.PROP_gimple_lcx	Have operations on complex numbers been lowered to scalar operations?	*"cplxlower"*	*"cplxlower0"*

static_pass_number

(int) The number of this pass, used as a fragment of the dump file name. This is assigned automatically for custom passes.

dump_enabled

(boolean) Is dumping enabled for this pass? Set this attribute to *True* to enable dumping. Not available from GCC 4.8 onwards

There are four subclasses of *gcc.Pass*:

class gcc.**GimplePass**

Subclass of *gcc.Pass*, signifying a pass called per-function on the GIMPLE representation of that function.

class gcc.**RtlPass**

Subclass of *gcc.Pass*, signifying a pass called per-function on the RTL representation of that function.

class gcc.**SimpleIpaPass**

Subclass of *gcc.Pass*, signifying a pass called once (not per-function)

class gcc.**IpaPass**

Subclass of *gcc.Pass*, signifying a pass called once (not per-function)

14.2 Creating new optimization passes

You can create new optimization passes. This involves three steps:

- subclassing the appropriate *gcc.Pass* subclass (e.g. *gcc.GimplePass*)
- creating an instance of your subclass
- registering the instance within the pass tree, relative to another pass

Here's an example:

```
# Here's the (trivial) implementation of our new pass:
class MyPass(gcc.GimplePass):
    # This is optional.
    # If present, it should return a bool, specifying whether or not
    # to execute this pass (and any child passes)
    def gate(self, fun):
        print('gate() called for %r' % fun)
        return True

    def execute(self, fun):
        print('execute() called for %r' % fun)

# We now create an instance of the class:
my_pass = MyPass(name='my-pass')

# ...and wire it up, after the "cfg" pass:
my_pass.register_after('cfg')
```

For *gcc.GimplePass* and *gcc.RtlPass*, the signatures of *gate* and *execute* are:

gate(*self*, *fun*)

execute(*self*, *fun*)

where fun is a *gcc.Function*.

For *gcc.SimpleIpaPass* and *gcc.IpaPass*, the signature of *gate* and *execute* are:

gate(*self*)

execute(*self*)

Warning: Unfortunately it doesn't appear to be possible to implement *gate()* for *gcc.IpaPass* yet; for now, the *gate()* method on such passes will not be called. See http://gcc.gnu.org/bugzilla/show_bug.cgi?id=54959

If an unhandled exception is raised within *gate* or *execute*, it will lead to a GCC error:

```
/home/david/test.c:36:1: error: Unhandled Python exception raised calling 'execute' method
Traceback (most recent call last):
  File "script.py", line 79, in execute
    dot = gccutils.tree_to_dot(fun)
NameError: global name 'gccutils' is not defined
```

gcc.Pass.**register_after**(*name*[, *instance_number=0*])

Given the name of another pass, register this *gcc.Pass* to occur immediately after that other pass.

If the other pass occurs multiple times, the pass will be inserted at the specified instance number, or at every instance, if supplied 0.

Note: The other pass must be of the same kind as this pass. For example, if it is a subclass of *gcc.GimplePass*, then this pass must also be a subclass of *gcc.GimplePass*.

If they don't match, GCC won't be able to find the other pass, giving an error like this:

```
cc1: fatal error: pass 'ssa' not found but is referenced by new pass 'my-ipa-pass'
```

where we attempted to register a *gcc.IpaPass* subclass relative to 'ssa', which is a *gcc.GimplePass*

gcc.Pass.**register_before**(*name*[, *instance_number=0*])
As above, but this pass is registered immediately before the referenced pass.

gcc.Pass.**replace**(*name*[, *instance_number=0*])
As above, but replace the given pass. This method is included for completeness; the result is unlikely to work well.

14.3 Dumping per-pass information

GCC has a logging framework which supports per-pass logging ("dump files").

By default, no logging is done; dumping must be explicitly enabled.

Dumping of passes can be enabled from the command-line in groups:

- *-fdump-tree-all* enables dumping for all *gcc.GimplePass* (both builtin, and custom ones from plugins)
- *-fdump-rtl-all* is similar, but for all *gcc.RtlPass*
- *-fdump-ipa-all* as above, but for all *gcc.IpaPass* and *gcc.SimpleIpaPass*

For more information, see http://gcc.gnu.org/onlinedocs/gcc/Debugging-Options.html

It's not possible to directly enable dumping for a custom pass from the command-line (it would require adding new GCC command-line options). However, your script *can* directly enable dumping for a custom pass by writing to the *dump_enabled* attribute (perhaps in response to the arguments passed to plugin, or a driver script).

If enabled for a pass, then a file is written to the same directory as the output file, with a name based on the input file and the pass number.

For example, given a custom *gcc.Pass* with name *'test-pass'*, then when *input.c* is compiled to *build/output.o*:

```
$ gcc -fdump-tree-all -o build/output.o src/input.c
```

then a dump file *input.c.225t.test-pass* will be written to the directory *build*. In this case, *225* is the *static_pass_number* field, *"t"* signifies a tree pass, with the pass name appearing as the suffix.

gcc.**dump**(*obj*)
Write str() of the argument to the current dump file. No newlines or other whitespace are added.

Note that dumping is disabled by default; in this case, the call will do nothing.

gcc.**get_dump_file_name**()
Get the name of the current dump file.

If called from within a pass for which dumping is enabled, it will return the filename in string form.

If dumping is disabled for this pass, it will return *None*.

The typical output of a dump file will contain:

```
;; Function bar (bar)

(dumped information when handling function bar goes here)

;; Function foo (foo)

(dumped information when handling function foo goes here)
```

For example:

```
class TestPass(gcc.GimplePass):
    def execute(self, fun):
        # Dumping of strings:
        gcc.dump('hello world')

        # Dumping of other objects:
        gcc.dump(42)

ps = TestPass(name='test-pass')
ps.register_after('cfg')
ps.dump_enabled = True
```

would have a dump file like this:

```
;; Function bar (bar)

hello world42
;; Function foo (foo)

hello world42
```

Alternatively, it can be simpler to create your own logging system, given that one can simply open a file and write to it.

gcc.**get_dump_base_name**()

Get the base file path and name prefix for GCC's dump files.

You can use this when creating non-standard logfiles and other output.

For example, the libcpychecker code can write HTML reports on reference-counting errors within a function, writing the output to a file named:

```
    filename = '%s.%s-refcount-errors.html' % (gcc.get_dump_base_name(),
                                               fun.decl.name)
```

given *fun*, a *gcc.Function*.

By default, this is the name of the input file, but within the output file's directory. (It can be overridden using the *-dumpbase* command-line option).

CHAPTER 15

Working with callbacks

One way to work with GCC from the Python plugin is via callbacks. It's possible to register callback functions, which will be called when various events happen during compilation.

For example, it's possible to piggyback off of an existing GCC pass by using *gcc.PLUGIN_PASS_EXECUTION* to piggyback off of an existing GCC pass.

gcc.**register_callback**(*event_id*, *function*[, *extraargs*], ***kwargs*)

Wire up a python function as a callback. It will be called when the given event occurs during compilation. For some events, the callback will be called just once; for other events, the callback is called once per function within the source code being compiled. In the latter case, the plugin passes a *gcc.Function* instance as a parameter to your callback, so that you can work on it:

```
import gcc

def my_pass_execution_callback(*args, **kwargs):
     print('my_pass_execution_callback was called: args=%r  kwargs=%r'
           % (args, kwargs))

gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                      my_pass_execution_callback)
```

The exact arguments passed to your callback vary: consult the documentation for the particular event you are wiring up to (see below).

You can pass additional arguments when registering the callback - they will be passed to the callback after any normal arguments. This is denoted in the descriptions of events below by **extraargs*.

You can also supply keyword arguments: they will be passed on as keyword arguments to the callback. This is denoted in the description of events below by ***kwargs*.

The various events are exposed as constants within the *gcc* module and directly wrap GCC's plugin mechanism.

The following GCC events are currently usable from the Python plugin via *gcc.register_callback()*:

ID	Meaning
gcc.PLUGIN_ATTRIBUTES	For creating custom GCC attributes
gcc.PLUGIN_PRE_GENERICIZE	For working with the AST in the C and C++ frontends
gcc.PLUGIN_PASS_EXECUTION	Called before each pass is executed
gcc.PLUGIN_FINISH_UNIT	At the end of working with a translation unit (aka source file)
gcc.PLUGIN_FINISH_TYPE	After a type has been parsed
gcc.PLUGIN_FINISH_DECL	After a declaration has been parsed (GCC 4.7 or later)
gcc.PLUGIN_FINISH	Called before GCC exits

gcc.**PLUGIN_ATTRIBUTES**
Called when GCC is creating attributes for use with its non-standard __attribute__(()) syntax.

If you want to create custom GCC attributes, you should register a callback on this event and call *gcc.register_attribute()* from within that callback, so that they are created at the same time as the GCC's built-in attributes.

No arguments are passed to your callback other than those that you supply yourself when registering it:

(**extraargs*, ***kwargs*)

See creating custom GCC attributes for examples and more information.

gcc.**PLUGIN_PASS_EXECUTION**
Called when GCC is about to run one of its passes.

Arguments passed to the callback are:

(*ps*, *fun*, **extraargs*, ***kwargs*)

where *ps* is a *gcc.Pass* and *fun* is a *gcc.Function*. Your callback will typically be called many times: there are many passes, and each can be invoked zero or more times per function (in the code being compiled)

More precisely, some passes have a "gate check": the pass first checks a condition, and only executes if the condition is true.

Any callback registered with *gcc.PLUGIN_PASS_EXECUTION* will get called if this condition succeeds.

The actual work of the pass is done after the callbacks return.

In pseudocode:

```
if pass.has_gate_condition:
    if !pass.test_gate_condition():
       return
invoke_all_callbacks()
actually_do_the_pass()
```

For passes working on individual functions, all of the above is done per-function.

To connect to a specific pass, you can simply add a conditional based on the name of the pass:

```
import gcc

def my_callback(ps, fun):
    if ps.name != '*warn_function_return':
        # Not the pass we want
        return
    # Do something here
    print(fun.decl.name)

gcc.register_callback(gcc.PLUGIN_PASS_EXECUTION,
                      my_callback)
```

gcc.**PLUGIN_PRE_GENERICIZE**
Arguments passed to the callback are:

(*fndecl*, **extraargs*, ***kwargs*)

where *fndecl* is a *gcc.Tree* representing a function declaration within the source code being compiled.

gcc.**PLUGIN_FINISH_UNIT**
Called when GCC has finished compiling a particular translation unit.

Arguments passed to the callback are:

(**extraargs*, ***kwargs*)

gcc.**PLUGIN_FINISH_DECL**

Note: Only available in GCC 4.7 onwards.

Called when GCC has finished compiling a declaration (variables, functions, parameters to functions, types, etc)

Arguments passed to the callback are:

(*decl*, **extraargs*, ***kwargs*)

where *decl* is a *gcc.Declaration*.

gcc.**PLUGIN_FINISH_TYPE**

Called when GCC has finished parsing a type. Arguments to the callback are:

(*type*, **extraargs*, ***kwargs*)

where *type* is a *gcc.Type*.

gcc.**PLUGIN_FINISH**

Called before GCC exits.

Arguments passed to the callback are:

(**extraargs*, ***kwargs*)

The remaining GCC events aren't yet usable from the plugin; an attempt to register a callback on them will lead to an exception being raised. Email the gcc-python-plugin's mailing list if you're interested in working with these):

ID	Meaning
gcc.PLUGIN_PASS_MANAGER_SETUP	To hook into pass manager
gcc.PLUGIN_INFO	Information about the plugin
gcc.PLUGIN_GGC_START	For interacting with GCC's garbage collector
gcc.PLUGIN_GGC_MARKING	(ditto)
gcc.PLUGIN_GGC_END	(ditto)
gcc.PLUGIN_REGISTER_GGC_ROOTS	(ditto)
gcc.PLUGIN_REGISTER_GGC_CACHES	(ditto)
gcc.PLUGIN_START_UNIT	Called before processing a translation unit (aka source file)
gcc.PLUGIN_PRAGMAS	For registering pragmas
gcc.PLUGIN_ALL_PASSES_START	Called before the first pass of the *"all other passes" gcc.Pass catchall*
gcc.PLUGIN_ALL_PASSES_END	Called after last pass of the *"all other passes" gcc.Pass catchall*
gcc.PLUGIN_ALL_IPA_PASSES_START	Called before the first IPA pass
gcc.PLUGIN_ALL_IPA_PASSES_END	Called after last IPA pass
gcc.PLUGIN_OVERRIDE_GATE	Provides a way to disable a built-in pass
gcc.PLUGIN_EARLY_GIMPLE_PASSES_START	
gcc.PLUGIN_EARLY_GIMPLE_PASSES_END	
gcc.PLUGIN_NEW_PASS	

CHAPTER 16

Creating custom GCC attributes

GNU C supports a non-standard __attribute__(()) syntax for marking declarations with additional information that may be of interest to the optimizer, and for checking the correctness of the code.

The GCC Python plugin allows you to create custom attributes, which may be of use to your scripts: you can use this to annotate C code with additional information. For example, you could create a custom attribute for functions describing the interaction of a function on mutex objects:

```
extern void some_function(void)
  __attribute__((claims_mutex("io")));

extern void some_other_function(void)
  __attribute__((releases_mutex("io")));
```

and use this in a custom code-checker.

Custom attributes can take string and integer parameters. For example, the above custom attributes take a single string parameter. A custom attribute can take more than one parameter, or none at all.

To create custom attributes from Python, you need to wire up a callback response to the *gcc.PLUGIN_ATTRIBUTES* event:

```
    gcc.register_callback(gcc.PLUGIN_ATTRIBUTES,
                          register_our_attributes)
```

This callback should then call *gcc.register_attribute()* to associate the name of the attribute with a Python callback to be called when the attribute is encountered in C code.

gcc.**register_attribute**(*name*, *min_length*, *max_length*, *decl_required*, *type_required*, *function_type_required*, *callable*)

Registers a new GCC attribute with the given *name* , usable in C source code via __attribute__(()).

Parameters

- **name** (*str*) – the name of the new attribute
- **min_length** (*int*) – the minimum number of arguments expected when the attribute is used
- **max_length** (*int*) – the maximum number of arguments expected when the attribute is used (-1 for no maximum)
- **decl_required** –
- **type_required** –
- **function_type_required** –

- **callable** (*a callable object, such as a function*) – the callback to be invoked when the attribute is seen

In this example, we can simply print when the attribute is seen, to verify that the callback mechanism is working:

```
    def attribute_callback_for_claims_mutex(*args):
        print('attribute_callback_for_claims_mutex called: args: %s' % (args, ))

    def attribute_callback_for_releases_mutex(*args):
        print('attribute_callback_for_releases_mutex called: args: %s' % (args, ))

    def register_our_attributes():
        gcc.register_attribute('claims_mutex',
                               1, 1,
                               False, False, False,
                               attribute_callback_for_claims_mutex)
        gcc.register_attribute('releases_mutex',
                               1, 1,
                               False, False, False,
                               attribute_callback_for_releases_mutex)
```

Putting it all together, here is an example Python script for the plugin:

```
    import gcc

    # Verify that we can register custom attributes:

    def attribute_callback_for_claims_mutex(*args):
        print('attribute_callback_for_claims_mutex called: args: %s' % (args, ))

    def attribute_callback_for_releases_mutex(*args):
        print('attribute_callback_for_releases_mutex called: args: %s' % (args, ))

    def register_our_attributes():
        gcc.register_attribute('claims_mutex',
                               1, 1,
                               False, False, False,
                               attribute_callback_for_claims_mutex)
        gcc.register_attribute('releases_mutex',
                               1, 1,
                               False, False, False,
                               attribute_callback_for_releases_mutex)

    # Wire up our callback:
    gcc.register_callback(gcc.PLUGIN_ATTRIBUTES,
                          register_our_attributes)
```

Compiling this test C source file:

```
    /* Function declarations with custom attributes: */
    extern some_function(void) __attribute__((claims_mutex("io")));

    extern some_other_function(void) __attribute__((releases_mutex("io")));

    extern yet_another_function(void) __attribute__((claims_mutex("db"),
                                                     claims_mutex("io"),
                                                     releases_mutex("io")));
```

leads to this output from the script:

```
attribute_callback_for_claims_mutex called: args: (gcc.FunctionDecl('some_function'), gcc.String
attribute_callback_for_releases_mutex called: args: (gcc.FunctionDecl('some_other_function'), gc
attribute_callback_for_claims_mutex called: args: (gcc.FunctionDecl('yet_another_function'), gcc
attribute_callback_for_claims_mutex called: args: (gcc.FunctionDecl('yet_another_function'), gcc
attribute_callback_for_releases_mutex called: args: (gcc.FunctionDecl('yet_another_function'), g
```

16.1 Using the preprocessor to guard attribute usage

Unfortunately, the above C code will only work when it is compiled with the Python script that adds the custom attributes.

You can avoid this by using *gcc.define_macro()* to pre-define a preprocessor name (e.g. "WITH_ATTRIBUTE_CLAIMS_MUTEX") at the same time as when you define the attribute:

```
import gcc

def attribute_callback_for_claims_mutex(*args):
    print('attribute_callback_for_claims_mutex called: args: %s' % (args, ))

def attribute_callback_for_releases_mutex(*args):
    print('attribute_callback_for_releases_mutex called: args: %s' % (args, ))

def register_our_attributes():
    gcc.register_attribute('claims_mutex',
                           1, 1,
                           False, False, False,
                           attribute_callback_for_claims_mutex)
    gcc.define_macro('WITH_ATTRIBUTE_CLAIMS_MUTEX')

    gcc.register_attribute('releases_mutex',
                           1, 1,
                           False, False, False,
                           attribute_callback_for_releases_mutex)
    gcc.define_macro('WITH_ATTRIBUTE_RELEASES_MUTEX')

# Wire up our callback:
gcc.register_callback(gcc.PLUGIN_ATTRIBUTES,
                      register_our_attributes)
```

This way the user can write this C code instead, and have it work both with and without the Python script:

```
#if defined(WITH_ATTRIBUTE_CLAIMS_MUTEX)
 #define CLAIMS_MUTEX(x) __attribute__((claims_mutex(x)))
#else
 #define CLAIMS_MUTEX(x)
#endif

#if defined(WITH_ATTRIBUTE_RELEASES_MUTEX)
 #define RELEASES_MUTEX(x) __attribute__((releases_mutex(x)))
#else
 #define RELEASES_MUTEX(x)
#endif


/* Function declarations with custom attributes: */
extern void some_function(void)
```

```
        CLAIMS_MUTEX("io");

    extern void some_other_function(void)
        RELEASES_MUTEX("io");

    extern void yet_another_function(void)
        CLAIMS_MUTEX("db")
        CLAIMS_MUTEX("io")
        RELEASES_MUTEX("io");
```

giving this output from the script:

```
    attribute_callback_for_claims_mutex called: args: (gcc.FunctionDecl('some_function'), gcc.String
    attribute_callback_for_releases_mutex called: args: (gcc.FunctionDecl('some_other_function'), gc
    attribute_callback_for_claims_mutex called: args: (gcc.FunctionDecl('yet_another_function'), gcc
    attribute_callback_for_claims_mutex called: args: (gcc.FunctionDecl('yet_another_function'), gcc
    attribute_callback_for_releases_mutex called: args: (gcc.FunctionDecl('yet_another_function'), g
```

CHAPTER 17

Usage example: a static analysis tool for CPython extension code

Note: This code is under heavy development, and still contains bugs. It is not unusual to see Python tracebacks when running the checker. You should verify what the checker reports before acting on it: it could be wrong.

An example of using the plugin is a static analysis tool I'm working on which checks the C source of CPython extension modules for common coding errors.

This was one of my main motivations for writing the GCC plugin, and I often need to extend the plugin to support this use case.

For this reason, the checker is embedded within the gcc-python source tree itself for now:

- *gcc-with-cpychecker* is a harness script, which invokes GCC, adding the arguments necessary to use the Python plugin, using the *libcpychecker* Python code
- the *libcpychecker* subdirectory contains the code that does the actual work
- various test cases (in the source tree, below *tests/cpychecker*)

17.1 gcc-with-cpychecker

gcc-with-cpychecker is a harness script, which invokes GCC, adding the arguments necessary to use the Python plugin, using the *libcpychecker* Python code

You should be able to use the checker on arbitrary CPython extension code by replacing "gcc" with "gcc-with-cpychecker" in your build with something like:

```
make CC=/path/to/built/plugin/gcc-with-cpychecker
```

to override the Makefile variable *CC*.

You may need to supply an absolute path, especially if the "make" recursively invokes "make" within subdirectories (thus having a different working directory).

Similarly, for projects that use distutils, the code is typically built with an invocation like this:

```
python setup.py build
```

This respects the environment variable *CC*, so typically you can replace the above with something like this in order to add the additional checks:

```
CC=/path/to/built/plugin/gcc-with-cpychecker python setup.py build
```

17.1.1 Additional arguments for *gcc-with-cpychecker*

--maxtrans <int>
Set the maximum number of transitions to consider within each function before pruning the analysis tree. You may need to increase this limit for complicated functions.

--dump-json
Dump a JSON representation of any problems. For example, given a function *foo.c*, if any warnings or errors are found in function *bar*, a file *foo.c.bar.json* will be written out in JSON form.

17.2 Reference-count checking

The checker attempts to analyze all possible paths through each function, tracking the various `PyObject*` objects encountered.

For each path through the function and `PyObject*`, it determines what the reference count ought to be at the end of the function, issuing warnings for any that are incorrect.

The warnings are in two forms: the classic textual output to GCC's standard error stream, together with an HTML report indicating the flow through the function, in graphical form.

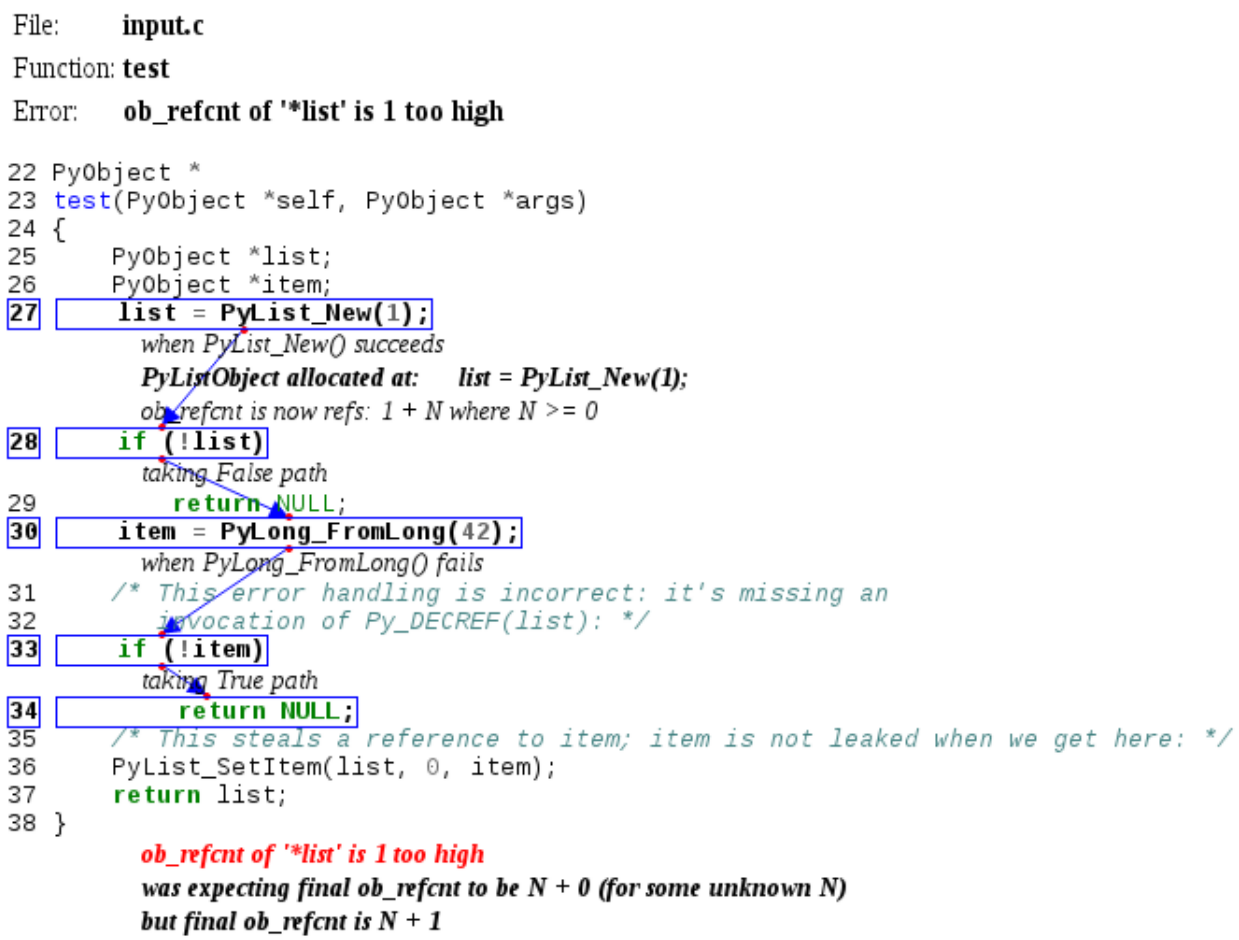
For example, given this buggy C code:

```
PyObject *
test(PyObject *self, PyObject *args)
{
    PyObject *list;
    PyObject *item;
    list = PyList_New(1);
    if (!list)
        return NULL;
    item = PyLong_FromLong(42);
    /* This error handling is incorrect: it's missing an
       invocation of Py_DECREF(list): */
    if (!item)
        return NULL;
    /* This steals a reference to item; item is not leaked when we get here: */
    PyList_SetItem(list, 0, item);
    return list;
}
```

the checker emits these messages to stderr:

```
input.c: In function 'test':
input.c:38:1: warning: ob_refcnt of '*list' is 1 too high [enabled by default]
input.c:38:1: note: was expecting final ob_refcnt to be N + 0 (for some unknown N)
input.c:38:1: note: but final ob_refcnt is N + 1
input.c:27:10: note: PyListObject allocated at:     list = PyList_New(1);
input.c:27:10: note: when PyList_New() succeeds at:     list = PyList_New(1);
input.c:27:10: note: ob_refcnt is now refs: 1 + N where N >= 0
input.c:28:8: note: taking False path at:     if (!list)
input.c:30:10: note: reaching:     item = PyLong_FromLong(42);
input.c:30:10: note: when PyLong_FromLong() fails at:     item = PyLong_FromLong(42);
input.c:33:8: note: taking True path at:     if (!item)
input.c:34:9: note: reaching:         return NULL;
input.c:38:1: note: returning
input.c:24:1: note: graphical error report for function 'test' written out to 'input.c.test-refcount-
```

along with this HTML report (as referred to by the final line on stderr):



The HTML report is intended to be relatively self-contained, and thus easy to attach to bug tracking systems (it embeds its own CSS inline, and references the JavaScript it uses via URLs to the web).

Note: The arrow graphics in the HTML form of the report are added by using the JSPlumb JavaScript library to generate HTML 5 <canvas> elements. You may need a relatively modern browser to see them.

Note: The checker tracks reference counts in an abstract way, in two parts: a part of the reference count that it knows about within the context of the function, along with a second part: all of the other references held by the rest of the program.

For example, in a call to PyInt_FromLong(0), it is assumed that if the call succeeds, the object has a reference count of 1 + N, where N is some unknown amount of other references held by the rest of the program. The checker knows that N >= 0.

If the object is then stored in an opaque container which is known to increment the reference count, the checker can say that the reference count is then 1 + (N+1).

If the function then decrements the reference count (to finish transferring the reference to the opaque container), the checker now treats the object as having a reference count of 0 + (N+1): it no longer owns any references on the object,

but the reference count is actually unchanged relative to the original 1 + N amount. It also knows, given that N >= 0 that the actual reference count is >= 1, and thus the object won't (yet) be deallocated.

17.2.1 Assumptions and configuration

For any function returning a `PyObject*`, it assumes that the `PyObject*` should be either a new reference to an object, or NULL (with an exception set) - the function's caller should "own" a reference to that object. For all other `PyObject*`, it assumes that there should be no references owned by the function when the function terminates.

It will assume this behavior for any function (or call through a function pointer) that returns a `PyObject*`.

It is possible to override this behavior using custom compiler attributes as follows:

Marking functions that return borrowed references

The checker provides a custom GCC attribute:

```
__attribute__((cpychecker_returns_borrowed_ref))
```

which can be used to mark function declarations:

```
/* The checker automatically defines this preprocessor name when creating
   the custom attribute: */
#if defined(WITH_CPYCHECKER_RETURNS_BORROWED_REF_ATTRIBUTE)
  #define CPYCHECKER_RETURNS_BORROWED_REF \
    __attribute__((cpychecker_returns_borrowed_ref))
#else
  #define CPYCHECKER_RETURNS_BORROWED_REF
#endif

PyObject *foo(void)
  CPYCHECKER_RETURNS_BORROWED_REF;
```

Given the above, the checker will assume that invocations of `foo()` are returning a borrowed reference (or NULL), rather than a new reference. It will also check that this is that case when verifying the implementation of `foo()` itself.

Marking functions that steal references to their arguments

The checker provides a custom GCC attribute:

```
__attribute__((cpychecker_steals_reference_to_arg(n)))
```

which can be used to mark function declarations:

```
/* The checker automatically defines this preprocessor name when creating
   the custom attribute: */
#if defined(WITH_CPYCHECKER_STEALS_REFERENCE_TO_ARG_ATTRIBUTE)
  #define CPYCHECKER_STEALS_REFERENCE_TO_ARG(n) \
   __attribute__((cpychecker_steals_reference_to_arg(n)))
#else
 #define CPYCHECKER_STEALS_REFERENCE_TO_ARG(n)
#endif

extern void foo(PyObject *obj)
  CPYCHECKER_STEALS_REFERENCE_TO_ARG(1);
```

Given the above, the checker will assume that invocations of `foo()` steal a reference to the first argument (`obj`). It will also verify that this is the case when analyzing the implementation of `foo()` itself.

More then one argument can be marked:

```
extern void bar(int i, PyObject *obj, int j, PyObject *other)
  CPYCHECKER_STEALS_REFERENCE_TO_ARG(2)
  CPYCHECKER_STEALS_REFERENCE_TO_ARG(4);
```

The argument indices are 1-based (the above example is thus referring to `obj` and to `other`).

All such arguments to the attribute should be `PyObject*` (or a pointer to a derived structure type).

It is assumed that such references are stolen for all possible outcomes of the function - if a function can either succeed or fail, the reference is stolen in both possible worlds.

17.3 Error-handling checking

The checker has knowledge of much of the CPython C API, and will generate a trace tree containing many of the possible error paths. It will issue warnings for code that appears to not gracefully handle an error.

(TODO: show example)

As noted above, it assumes that any function that returns a `PyObject*` can return can either NULL (setting an exception), or a new reference. It knows about much of the other parts of the CPython C API, including many other functions that can fail.

The checker will emit warnings for various events:

- if it detects a dereferencing of a `NULL` value
- if a `NULL` value is erroneously passed to various CPython API entrypoints which are known to implicitly dereference those arguments (which would lead to a segmentation fault if that code path were executed):

```
input.c: In function 'test':
input.c:38:33: warning: calling PyString_AsString with NULL (gcc.VarDecl('repr_args')) as argume
input.c:31:15: note: when PyObject_Repr() fails at:     repr_args = PyObject_Repr(args);
input.c:38:33: note: PyString_AsString() invokes Py_TYPE() on the pointer via the PyString_Check
input.c:27:1: note: graphical error report for function 'test' written out to 'input.c.test-refc
```

- if it detects that an uninitialized local variable has been used
- if it detects access to an object that has been deallocated, or such an object being returned:

```
input.c: In function 'test':
input.c:43:1: warning: returning pointer to deallocated memory
input.c:29:15: note: when PyLong_FromLong() succeeds at:     PyObject *tmp = PyLong_FromLong(0x1
input.c:31:8: note: taking False path at:     if (!tmp) {
input.c:39:5: note: reaching:     Py_DECREF(tmp);
input.c:39:5: note: when taking False path at:     Py_DECREF(tmp);
input.c:39:5: note: reaching:     Py_DECREF(tmp);
input.c:39:5: note: calling tp_dealloc on PyLongObject allocated at input.c:29 at:     Py_DECREF
input.c:42:5: note: reaching:     return tmp;
input.c:43:1: note: returning
input.c:39:5: note: memory deallocated here
input.c:27:1: note: graphical error report for function 'returning_dead_object' written out to '
```

17.4 Errors in exception-handling

The checker keeps track of the per-thread exception state. It will issue a warning about any paths through functions returning a `PyObject*` that return NULL for which the per-thread exception state has not been set:

```
input.c: In function 'test':
input.c:32:5: warning: returning (PyObject*)NULL without setting an exception
```

The checker does not emit the warning for cases where it is known that such behavior is acceptable. Currently this covers functions used as tp_iternext callbacks of a `PyTypeObject`.

If you have a helper function that always sets an exception, you can mark this property using a custom GCC attribute:

```
__attribute__((cpychecker_sets_exception))
```

which can be used to mark function declarations.

```
/* The checker automatically defines this preprocessor name when creating
   the custom attribute: */
 #if defined(WITH_CPYCHECKER_SETS_EXCEPTION_ATTRIBUTE)
   #define CPYCHECKER_SETS_EXCEPTION \
      __attribute__((cpychecker_sets_exception))
 #else
   #define CPYCHECKER_SETS_EXCEPTION
 #endif

 extern void raise_error(const char *msg)
   CPYCHECKER_SETS_EXCEPTION;
```

Given the above, the checker will know that an exception is set whenever a call to *raise_error()* occurs. It will also verify that *raise_error()* actually behaves this way when compiling the implementation of *raise_error*.

There is an analogous attribute for the case where a function returns a negative value to signify an error, where the exception state is set whenever a **negative** value is returned:

```
__attribute__((cpychecker_negative_result_sets_exception))
```

which can be used to mark function declarations.

```
/* The checker automatically defines this preprocessor name when creating
   the custom attribute: */
 #if defined(WITH_CPYCHECKER_NEGATIVE_RESULT_SETS_EXCEPTION_ATTRIBUTE)
   #define CPYCHECKER_NEGATIVE_RESULT_SETS_EXCEPTION \
      __attribute__((cpychecker_negative_result_sets_exception))
 #else
   #define CPYCHECKER_NEGATIVE_RESULT_SETS_EXCEPTION
 #endif

 extern int foo(void)
   CPYCHECKER_NEGATIVE_RESULT_SETS_EXCEPTION;
```

Given the above, the checker will know that an exception is raised whenever a call to *foo* returns a negative value. It will also verify that *foo* actually behaves this way when compiling the implementation of *foo*.

The checker already knows about many of the functions within the CPython API which behave this way.

17.5 Format string checking

The checker will analyze some Python APIs that take format strings and detect mismatches between the number and types of arguments that are passed in, as compared with those described by the format string.

It currently verifies the arguments to the following API entrypoints:

- PyArg_ParseTuple
- PyArg_ParseTupleAndKeywords
- PyArg_Parse
- Py_BuildValue
- PyObject_CallFunction
- PyObject_CallMethod

along with the variants that occur if you define *PY_SSIZE_T_CLEAN* before *#include <Python.h>*.

For example, type mismatches between `int` vs `long` can lead to flaws when the code is compiled on big-endian 64-bit architectures, where `sizeof(int) != sizeof(long)` and the in-memory layout of those types differs from what you might expect.

The checker will also issue a warning if the list of keyword arguments in a call to PyArg_ParseTupleAndKeywords is not NULL-terminated.

Note: All of the various "#" codes in these format strings are affected by the presence of the macro *PY_SSIZE_T_CLEAN*. If the macro was defined before including Python.h, the various lengths for these format codes are of C type *Py_ssize_t* rather than *int*.

This behavior was clarified in the Python 3 version of the C API documentation, though the Python 2 version of the API docs leave the matter of which codes are affected somewhat ambiguous.

Nevertheless, the API *does* work this way in Python 2: all format codes with a "#" do work this way.

Internally, the C preprocessor converts such function calls into invocations of:

- *_PyArg_ParseTuple_SizeT*
- *_PyArg_ParseTupleAndKeywords_SizeT*

The checker handles this behavior correctly, by checking "#" codes in the regular functions against *int* and those in the modified functions against *Py_ssize_t*.

17.5.1 Associating PyTypeObject instances with compile-time types

The "O!" format code to `PyArg_ParseTuple` takes a `PyTypeObject` followed by the address of an object. This second argument can point to a `PyObject*`, but it can also point to a pointer to a derived class.

For example, CPython's own implementation contains code like this:

```
static PyObject *
unicodedata_decomposition(PyObject *self, PyObject *args)
{
    PyUnicodeObject *v;

    /* ...snip... */
```

```
    if (!PyArg_ParseTuple(args, "O!:decomposition",
                          &PyUnicode_Type, &v))

    /* ...etc... */
```

in which the input argument is written out into the `PyUnicodeObject*`, provided that it is indeed a unicode instance.

When the cpychecker verifies the types in this format string it verifies that the run-time type of the `PyTypeObject` matches the compile-time type (`PyUnicodeObject *`). It is able to do this since it contains hard-coded associations between these worlds for all of Python's built-in types: for the above case, it "knows" that `PyUnicode_Type` is associated with `PyUnicodeObject`.

If you need to provide a similar association for an extension type, the checker provides a custom GCC attribute:

```
__attribute__((cpychecker_type_object_for_typedef(typename)))
```

which can be used to mark PyTypeObject instance, giving the name of the typedef that PyObject instances of that type can be safely cast to.

```
/* The checker automatically defines this preprocessor name when creating
   the custom attribute: */
#if defined(WITH_CPYCHECKER_TYPE_OBJECT_FOR_TYPEDEF_ATTRIBUTE)
  #define CPYCHECKER_TYPE_OBJECT_FOR_TYPEDEF(typename) \
     __attribute__((cpychecker_type_object_for_typedef(typename)))
#else
  /* This handles the case where we're compiling with a "vanilla"
     compiler that doesn't supply this attribute: */
  #define CPYCHECKER_TYPE_OBJECT_FOR_TYPEDEF(typename)
#endif

/* Define some PyObject subclass, as both a struct and a typedef */
struct OurObjectStruct {
    PyObject_HEAD
    /* other fields */
};
typedef struct OurObjectStruct OurExtensionObject;

/*
  Declare the PyTypeObject, using the custom attribute to associate it with
  the typedef above:
*/
extern PyTypeObject UserDefinedExtension_Type
  CPYCHECKER_TYPE_OBJECT_FOR_TYPEDEF("OurExtensionObject");
```

Given the above, the checker will associate the given `PyTypeObject` with the given typedef.

17.6 Verification of PyMethodDef tables

The checker will verify the types within tables of PyMethodDef initializers: the callbacks are typically cast to `PyCFunction`, but the exact type needs to correspond to the flags given. For example `(METH_VARARGS | METH_KEYWORDS)` implies a different function signature to the default, which the vanilla C compiler has no way of verifying.

```
/*
  BUG: there's a mismatch between the signature of the callback and
  that implied by ml_flags below.
```

```
 */
static PyObject *widget_display(PyObject *self, PyObject *args);

static PyMethodDef widget_methods[] = {
    {"display",
     (PyCFunction)widget_display,
     (METH_VARARGS | METH_KEYWORDS), /* ml_flags */
     NULL},

    {NULL, NULL, 0, NULL} /* terminator */
};
```

Given the above, the checker will emit an error like this:

```
input.c:59:6: warning: flags do not match callback signature for 'widget_display' within PyMethodDef
input.c:59:6: note: expected ml_meth callback of type "PyObject (fn)(someobject *, PyObject *args, Py
input.c:59:6: note: actual type of underlying callback: struct PyObject * <Tc53> (struct PyObject *,
input.c:59:6: note: see http://docs.python.org/c-api/structures.html#PyMethodDef
```

It will also warn about tables of `PyMethodDef` initializers that are lacking a `NULL` sentinel value to terminate the iteration:

```
static PyMethodDef widget_methods[] = {
    {"display",
     (PyCFunction)widget_display,
     0, /* ml_flags */
     NULL},

    /* BUG: this array is missing a NULL value to terminate
       the list of methods, leading to a possible segfault
       at run-time */
};
```

Given the above, the checker will emit this warning:

```
input.c:39:6: warning: missing NULL sentinel value at end of PyMethodDef table
```

17.7 Additional tests

- the checker will verify the argument lists of invocations of PyObject_CallFunctionObjArgs and PyObject_CallMethodObjArgs, checking that all of the arguments are of the correct type (PyObject* or subclasses), and that the list is NULL-terminated:

```
    input.c: In function 'test':
    input.c:33:5: warning: argument 2 had type char[12] * but was expecting a PyObject* (or subclass
    input.c:33:5: warning: arguments to PyObject_CallFunctionObjArgs were not NULL-terminated
```

17.8 Limitations and caveats

Compiling with the checker is significantly slower than with "vanilla" gcc. I have been focussing on correctness and features, rather than optimization. I hope that it will be possible to greatly speed up the checker via ahead-of-time compilation of the Python code (e.g. using Cython).

The checker does not yet fully implement all of C: expect to see Python tracebacks when it encounters less common parts of the language. (We'll fix those bugs as we come to them)

The checker has a rather simplistic way of tracking the flow through a function: it builds a tree of all possible traces of execution through a function. This brings with it some shortcomings:

- In order to guarantee that the analysis terminates, the checker will only track the first time through any loop, and stop analysing that trace for subsequent iterations. This appears to be good enough for detecting many kinds of reference leaks, especially in simple wrapper code, but is clearly suboptimal.
- In order to avoid combinatorial explosion, the checker will stop analyzing a function once the trace tree gets sufficiently large. When it reaches this cutoff, a warning is issued:

```
input.c: In function 'add_module_objects':
input.c:31:1: note: this function is too complicated for the reference-count checker to analyze
```

  To increase this limit, see the `--maxtrans` option.

- The checker doesn't yet match up similar traces, and so a single bug that affects multiple traces in the trace tree can lead to duplicate error reports.

Only a subset of the CPython API has been modelled so far. The functions known to the checker are:

PyArg_Parse and _PyArg_Parse_SizeT, PyArg_ParseTuple and _PyArg_ParseTuple_SizeT, PyArg_ParseTupleAndKeywords and _PyArg_ParseTupleAndKeywords_SizeT, PyArg_UnpackTuple, Py_AtExit, PyBool_FromLong, Py_BuildValue and _Py_BuildValue_SizeT, PyCallable_Check, PyCapsule_GetPointer, PyCObject_AsVoidPtr, PyCObject_FromVoidPtr, PyCObject_FromVoidPtrAndDesc, PyCode_New, PyDict_GetItem, PyDict_GetItemString, PyDict_New, PyDict_SetItem, PyDict_SetItemString, PyDict_Size, PyErr_Format, PyErr_NewException, PyErr_NoMemory, PyErr_Occurred, PyErr_Print, PyErr_PrintEx, PyErr_SetFromErrno, PyErr_SetFromErrnoWithFilename, PyErr_SetNone, PyErr_SetObject, PyErr_SetString, PyErr_WarnEx, *PyEval_CallMethod*, *PyEval_CallObjectWithKeywords*, PyEval_InitThreads, PyEval_RestoreThread, PyEval_SaveThread, Py_FatalError, PyFile_SoftSpace, PyFile_WriteObject, PyFile_WriteString, Py_Finalize, *PyFrame_New*, Py_GetVersion, PyGILState_Ensure, PyGILState_Release, PyImport_AddModule, PyImport_AppendInittab, PyImport_ImportModule, Py_Initialize, *Py_InitModule4_64*, PyInt_AsLong, PyInt_FromLong, PyList_Append, PyList_GetItem, PyList_New, PyList_SetItem, PyList_Size, PyLong_FromLong, PyLong_FromLongLong, PyLong_FromString, PyLong_FromVoidPtr, PyMapping_Size, PyMem_Free, PyMem_Malloc, PyModule_AddIntConstant, PyModule_AddObject, PyModule_AddStringConstant,_, PyModule_GetDict, PyNumber_Int, PyNumber_Remainer, PyObject_AsFileDescriptor, PyObject_Call, PyObject_CallFunction and _PyObject_CallFunction_SizeT, PyObject_CallFunctionObjArgs, PyObject_CallMethod and _PyObject_CallMethod_SizeT, PyObject_CallMethodObjArgs, PyObject_CallObject, PyObject_GetAttr, PyObject_GetAttrString, PyObject_GetItem, PyObject_GenericGetAttr, PyObject_GenericSetAttr, PyObject_HasAttrString, PyObject_IsTrue, *_PyObject_New*, PyObject_Repr, PyObject_SetAttr, PyObject_SetAttrString, PyObject_Str, PyOS_snprintf, PyRun_SimpleFileExFlags, PyRun_SimpleStringFlags, PySequence_Concat, PySequence_DelItem, PySequence_GetItem, PySequence_GetSlice, PySequence_SetItem, PySequence_Size, PyString_AsString, PyString_Concat, PyString_ConcatAndDel, PyString_FromFormat, PyString_FromString, PyString_FromStringAndSize, PyString_InternFromString, PyString_Size, *PyStructSequence_InitType*, *PyStructSequence_New*, PySys_GetObject, PySys_SetObject, *PyTraceBack_Here*, PyTuple_GetItem, PyTuple_New, PyTuple_Pack, PyTuple_SetItem, PyTuple_Size, PyType_IsSubtype, PyType_Ready, PyUnicodeUCS4_AsUTF8String, PyUnicodeUCS4_DecodeUTF8, PyWeakref_GetObject

The checker also has some knowledge about these SWIG-generated functions: *SWIG_Python_ErrorType*, *SWIG_Python_SetErrorMsg*

and of this Cython-generated function: *__Pyx_GetStdout*

17.9 Ideas for future tests

Here's a list of some other C coding bugs I intend for the tool to detect:

- tp_traverse errors (which can mess up the garbage collector); missing it altogether, or omitting fields

- errors in GIL-handling
  - lock/release mismatches
  - missed opportunities to release the GIL (e.g. compute-intensive functions; functions that wait on IO/syscalls)

Ideas for other tests are most welcome (patches even more so!)

We will probably need various fallbacks and suppression modes for turning off individual tests (perhaps pragmas, perhaps compile-line flags, etc)

17.10 Reusing this code for other projects

It may be possible to reuse the analysis engine from cpychecker for other kinds of analysis - hopefully the python-specific parts are relatively self-contained. Email the gcc-python-plugin's mailing list if you're interested in adding verifiers for other kinds of code.

17.11 Common mistakes

Here are some common mistakes made using the CPython extension API, along with the fixes.

17.11.1 Missing *Py_INCREF()* on *Py_None*

The following is typically incorrect: a method implementation is required to return a new reference, but this code isn't incrementing the reference count on Py_None.

```
PyObject*
some_method(PyObject *self, PyObject *args)
{
    [...snip...]

    /* BUG: loses a reference to Py_None */
    return Py_None;
}
```

If called enough, this could cause Py_None to be deallocated, crashing the interpreter:

```
Fatal error: deallocating None
```

The Py_RETURN_NONE macro takes care of incrementing the reference count for you:

```
PyObject*
some_method(PyObject *self, PyObject *args)
{
    [...snip...]

    /* Fixed version of the above: */
    Py_RETURN_NONE;
}
```

17.11.2 Reference leak in Py_BuildValue

Py_BuildValue with "O" adds a new reference on the object for use by the new tuple, hence the following code leaks the reference already owned on the object:

```
/* BUG: reference leak: */
return Py_BuildValue("O", some_object_we_own_a_ref_on);
```

Py_BuildValue with "N" steals the reference (and copes with it being NULL by propagating the exception):

```
/* Fixed version of the above: */
return Py_BuildValue("N", some_object_we_own_a_ref_on);
```

CHAPTER 18

Success Stories

If you use the gcc python plugin to improve your code, we'd love to hear about it.

If you want to share a success story here, please email the plugin's mailing list.

18.1 The GNU Debugger

Bugs found in gdb by compiling it with the plugin's *gcc-with-cpychecker* script:

- http://sourceware.org/bugzilla/show_bug.cgi?id=13308
- http://sourceware.org/bugzilla/show_bug.cgi?id=13309
- http://sourceware.org/bugzilla/show_bug.cgi?id=13310
- http://sourceware.org/bugzilla/show_bug.cgi?id=13316
- http://sourceware.org/ml/gdb-patches/2011-06/msg00376.html
- http://sourceware.org/ml/gdb-patches/2011-10/msg00391.html
- http://sourceware.org/bugzilla/show_bug.cgi?id=13331

Tom Tromey also wrote specialized Python scripts to use the GCC plugin to locate bugs within GDB.

One of his scripts analyzes gdb's resource-management code, which found some resource leaks and a possible crasher:

- http://sourceware.org/ml/gdb-patches/2011-06/msg00408.html

The other generates a whole-program call-graph, annotated with information on gdb's own exception-handling mechanism. A script then finds places where these exceptions were not properly integrated with gdb's embedded Python support:

- http://sourceware.org/ml/gdb/2011-11/msg00002.html
- http://sourceware.org/bugzilla/show_bug.cgi?id=13369

18.2 LibreOffice

Stephan Bergmann wrote a script to analyze LibreOffice's source code, detecting a particular usage pattern of C++ method calls:

- https://fedorahosted.org/pipermail/gcc-python-plugin/2011-December/000136.html
- https://bugs.freedesktop.org/show_bug.cgi?id=43460

18.3 psycopg

Daniele Varrazzo used the plugin's *gcc-with-cpychecker* script on psycopg, the popular Python interface to PostgreSQL, and was able to find and fix numerous subtle errors:

- https://fedorahosted.org/pipermail/gcc-python-plugin/2012-March/000229.html
- http://initd.org/psycopg/articles/2012/03/29/psycopg-245-released/

18.4 pycups

Bugs found in the Python bindings for the CUPS API by compiling it with the plugin's *gcc-with-cpychecker* script:

- https://fedorahosted.org/pycups/ticket/17

18.5 python-krbV

Bug found in the Python bindings for the Kerberos 5 API by compiling it with the plugin's *gcc-with-cpychecker* script:

- https://fedorahosted.org/python-krbV/ticket/1

18.6 Bugs found in itself

Bugs found and fixed in the gcc Python plugin itself, by running the the plugin's *gcc-with-cpychecker* script when compiling another copy:

- various reference counting errors:
  - http://git.fedorahosted.org/git/?p=gcc-python-plugin.git;a=commitdiff;h=a9f48fac24a66c77007d99bf23f2eab188eb909e
  - http://git.fedorahosted.org/git/?p=gcc-python-plugin.git;a=commitdiff;h=2922ad81c8e0ea954d462433ecc83d86d9ebab68
  - http://git.fedorahosted.org/git/?p=gcc-python-plugin.git;a=commitdiff;h=4642a564e03c9e2c8114bca206205ad9c8fbc308>
- bad format string: https://fedorahosted.org/pipermail/gcc-python-plugin/2011-August/000065.html
- minor const-correctness error: http://git.fedorahosted.org/git/?p=gcc-python-plugin.git;a=commitdiff;h=4fe4a83288e04be35a96d0bfec332197fb32c358

CHAPTER 19

Getting Involved

The plugin's web site is this GitHub repository:

https://github.com/davidmalcolm/gcc-python-plugin

The primary place for discussion of the plugin is the mailing list: https://fedorahosted.org/mailman/listinfo/gcc-python-plugin

A pre-built version of the HTML documentation can be seen at:

http://readthedocs.org/docs/gcc-python-plugin/en/latest/index.html

The project's mailing list is here: https://fedorahosted.org/mailman/listinfo/gcc-python-plugin

19.1 Ideas for using the plugin

Here are some ideas for possible uses of the plugin. Please email the plugin's mailing list if you get any of these working (or if you have other ideas!). Some guesses as to the usefulness and difficulty level are given in parentheses after some of the ideas. Some of them might require new attributes, methods and/or classes to be added to the plugin (to expose more of GCC internals), but you can always ask on the mailing list if you need help.

- extend the libcpychecker code to add checking for the standard C library. For example, given this buggy C code:

```
int foo() {
     FILE *src, *dst;
     src = fopen("source.txt", "r");
     if (!src) return -1;

     dst = fopen("dest.txt", "w");
     if (!dst) return -1;  /* <<<< BUG: this error-handling leaks "src" */

     /* etc, copy src to dst (or whatever) */
}
```

  it would be great if the checker could emit a compile-time warning about the buggy error-handling path above (or indeed any paths through functions that leak *FILE**, file descriptors, or other resources). The way to do this (I think) is to add a new *Facet* subclass to libcpychecker, analogous to the *CPython* facet subclass that already exists (though the facet handling is probably rather messy right now). (useful but difficult, and a lot of work)

- extend the libcpychecker code to add checking for other libraries. For example:
  - reference-count checking within glib and gobject

  (useful for commonly-used C libraries but difficult, and a lot of work)

- detection of C++ variables with non-trivial constructors that will need to be run before *main* - globals and static locals (useful, ought to be fairly easy)
- finding unused parameters in definitions of non-virtual functions, so that they can be removed - possibly removing further dead code. Some care would be needed for function pointers. (useful, ought to be fairly easy)
- detection of bad format strings (see e.g. https://lwn.net/Articles/478139/)
- compile gcc's own test suite with the cpychecker code, to reuse their coverage of C and thus shake out more bugs in the checker (useful and easy)
- a new PyPy gc root finder, running inside GCC (useful for PyPy, but difficult)
- reimplement GCC-XML in Python (probably fairly easy, but does anyone still use GCC-XML now that GCC supports plugins?)
- .gir generation for GObject Introspection (unknown if the GNOME developers are actually interested in this though)
- create an interface that lets you view the changing internal representation of each function as it's modified by the various optimization pases: lets you see which passes change a given function, and what the changes are (might be useful as a teaching tool, and for understanding GCC)
- add array bounds checking to C (to what extent can GCC already do this?)
- taint mode for GCC! e.g. detect usage of data from network/from disk/etc; identify certain data as untrusted, and track how it gets used; issue a warning (very useful, but very difficult: how does untainting work? what about pointers and memory regions? is it just too low-level?)
- implement something akin to PyPy's pygame-based viewer, for viewing control flow graphs and tree structures: an OpenGL-based GUI giving a fast, responsive UI for navigating the data - zooming, panning, search, etc. (very useful, and fairly easy)
- generation of pxd files for Cython (useful for Cython, ought to be fairly easy)
- reverse-engineering a .py or .pyx file from a .c file: turning legacy C Python extension modules back into Python or Cython sources (useful but difficult)

19.2 Tour of the C code

The plugin's C code heavily uses Python's extension API, and so it's worth knowing this API if you're going to hack on this part of the project. A good tutorial for this can be seen here:

http://docs.python.org/extending/index.html

and detailed notes on it are here:

http://docs.python.org/c-api/index.html

Most of the C "glue" for creating classes and registering their methods and attributes is autogenerated. Simple C one-liners tend to appear in the autogenerated C files, whereas longer implementations are broken out into a hand-written C file.

Adding new methods and attributes to the classes requires editing the appropriate generate-*.py script to wire up the new entrypoint. For very simple attributes you can embed the C code directly there, but anything that's more than a one-liner should have its implementation in the relevant C file.

For example, to add new methods to a `gcc.Cfg` you'd edit:

- *generate-cfg-c.py* to add the new methods and attributes to the relevant tables of callbacks
- *gcc-python-wrappers.h* to add declarations of the new C functions

- *gcc-python-cfg.c* to add the implementations of the new C functions

Please try to make the API "Pythonic".

My preference with getters is that if the implementation is a simple field lookup, it should be an attribute (the "getter" is only implicit, existing at the C level):

```
print(bb.loopcount)
```

whereas if getting the result involves some work, it should be an explicit method of the class (where the "getter" is explicit at the Python level):

```
print(bb.get_loop_count())
```

19.3 Using the plugin to check itself

Given that the *cpychecker* code implements new error-checking for Python C code, and that the underlying plugin is itself an example of such code, it's possible to build the plugin once, then compile it with itself (using CC=gcc-with-cpychecker as a Makefile variable:

```
$ make CC=/path/to/a/clean/build/of/the/plugin/gcc-with-cpychecker
```

Unfortunately it doesn't quite compile itself cleanly right now.

19.4 Test suite

There are three test suites:

- *testcpybuilder.py*: a minimal test suite which is used before the plugin itself is built. This verifies that the *cpybuilder* code works.
- *make test-suite* (aka *run-test-suite.py*): a test harness and suite which was written for this project. See the notes below on patches.
- *make testcpychecker* and *testcpychecker.py*: a suite based on Python's *unittest* module

19.5 Debugging the plugin's C code

The *gcc* binary is a harness that launches subprocesses, so it can be fiddly to debug. Exactly what it launches depend on the inputs and options. Typically, the subprocesses it launches are (in order):

- *cc1* or *cc1plus*: The C or C++ compiler, generating a .s assember file.
- *as*: The assembler, converting a .s assembler file to a .o object file.
- *collect2*: The linker, turning one or more .o files into an executable (if you're going all the way to building an *a.out*-style executable).

The easiest way to debug the plugin is to add these parameters to the gcc command line (e.g. to the end):

```
-wrapper gdb,--args
```

Note the lack of space between the comma and the *–args*.

e.g.:

```
./gcc-with-python examples/show-docs.py test.c -wrapper gdb,--args
```

This will invoke each of the subprocesses in turn under gdb: e.g. *cc1*, *as* and *collect2*; the plugin runs with *cc1* (*cc1plus* for C++ code).

For example:

```
$ ./gcc-with-cpychecker -c -I/usr/include/python2.7 demo.c -wrapper gdb,--args

GNU gdb (GDB) Fedora 7.6.50.20130731-19.fc20
[...snip...]
Reading symbols from /usr/libexec/gcc/x86_64-redhat-linux/4.8.2/cc1...Reading symbols from /usr/lib/c
done.
(gdb) run
[...etc...]
```

Another way to do it is to add "-v" to the gcc command line (verbose), so that it outputs the commands that it's running. You can then use this to launch:

```
$ gdb --args ACTUAL PROGRAM WITH ACTUAL ARGS
```

to debug the subprocess that actually loads the Python plugin.

For example:

```
$ gcc -v -fplugin=$(pwd)/python.so -fplugin-arg-python-script=test.py test.c
```

on my machine emits this:

```
Using built-in specs.
COLLECT_GCC=gcc
COLLECT_LTO_WRAPPER=/usr/libexec/gcc/x86_64-redhat-linux/4.6.1/lto-wrapper
Target: x86_64-redhat-linux
Configured with: ../configure --prefix=/usr --mandir=/usr/share/man --infodir=/usr/share/info --with-
Thread model: posix
gcc version 4.6.1 20110908 (Red Hat 4.6.1-9) (GCC)
COLLECT_GCC_OPTIONS='-v' '-fplugin=/home/david/coding/gcc-python/gcc-python/contributing/python.so'
 /usr/libexec/gcc/x86_64-redhat-linux/4.6.1/cc1 -quiet -v -iplugindir=/usr/lib/gcc/x86_64-redhat-linu
(output of the script follows)
```

This allows us to see the line in which *cc1* is invoked: in the above example, it's the final line before the output from the script:

```
/usr/libexec/gcc/x86_64-redhat-linux/4.6.1/cc1 -quiet -v -iplugindir=/usr/lib/gcc/x86_64-redhat-linux
```

We can then take this line and rerun this subprocess under gdb by adding *gdb –args* to the front like this:

```
$ gdb --args /usr/libexec/gcc/x86_64-redhat-linux/4.6.1/cc1 -quiet -v -iplugindir=/usr/lib/gcc/x86_64
```

This approach to obtaining a debuggable process doesn't seem to work in the presence of *ccache*, in that it writes to a temporary directory with a name that embeds the process ID each time, which then gets deleted. I've worked around this by uninstalling ccache, but apparently setting:

```
CCACHE_DISABLE=1
```

before invoking *gcc -v* ought to also work around this.

I've also been running into this error from gdb:

```
[Thread debugging using libthread_db enabled]
Cannot find new threads: generic error
```

Apparently this happens when debugging a process that uses dlopen to load a library that pulls in libpthread (as does gcc when loading in my plugin), and a workaround is to link cc1 with -lpthread

The workaround I've been using (to avoid the need to build my own gcc) is to use LD_PRELOAD, either like this:

```
LD_PRELOAD=libpthread.so.0 gdb --args ARGS GO HERE...
```

or this:

```
(gdb) set environment LD_PRELOAD libpthread.so.0
```

19.5.1 Handy tricks

Given a (PyGccTree*) named "self":

```
(gdb) call debug_tree(self->t)
```

will use GCC's prettyprinter to dump the embedded (tree*) and its descendants to stderr; it can help to put a breakpoint on that function too, to explore the insides of that type.

19.6 Patches

The project doesn't have any copyright assignment requirement: you get to keep copyright in any contributions you make, though AIUI there's an implicit licensing of such contributions under the GPLv3 or later, given that any contribution is a derived work of the plugin, which is itself licensed under the GPLv3 or later. I'm not a lawyer, though.

The Python code within the project is intended to be usable with both Python 2 and Python 3 without running 2to3: please stick to the common subset of the two languages. For example, please write print statements using parentheses:

```
print(42)
```

Under Python 2 this is a *print* statement with a parenthesized number: (42) whereas under Python 3 this is an invocation of the *print* function.

Please try to stick PEP-8 for Python code, and to PEP-7 for C code (rather than the GNU coding conventions).

In C code, I strongly prefer to use multiline blocks throughout, even where single statements are allowed (e.g. in an "if" statement):

```
if (foo()) {
    bar();
}
```

as opposed to:

```
if (foo())
    bar();
```

since this practice prevents introducing bugs when modifying such code, and the resulting "diff" is much cleaner.

A good patch ought to add test cases for the new code that you write, and documentation.

The test cases should be grouped in appropriate subdirectories of "tests". Each new test case is a directory with an:

- *input.c* (or *input.cc* for C++)
- *script.py* exercising the relevant Python code
- *stdout.txt* containing the expected output from the script.

For more realistic examples of test code, put them below *tests/examples*; these can be included by reference from the docs, so that we have documentation that's automatically verified by *run-test-suite.py*, and users can use this to see the relationship between source-code constructs and the corresponding Python objects.

More information can be seen in *run-test-suite.py*

By default, *run-test-suite.py* will invoke all the tests. You can pass it a list of paths and it run all tests found in those paths and below.

You can generate the "gold" stdout.txt by hacking up this line in run-test-suite.py:

```
out.check_for_diff(out.actual, err.actual, p, args, 'stdout', 0)
```

so that the final 0 is a 1 (the "writeback" argument to *check_for_diff*). There may need to be a non-empty stdout.txt file in the directory for this to take effect though.

Unfortunately, this approach over-specifies the selftests, making them rather "brittle". Improvements to this approach would be welcome.

To directly see the GCC command line being invoked for each test, and to see the resulting stdout and stderr, add *–show* to the arguments of *run-test-suite.py*.

For example:

```
$ python run-test-suite.py tests/plugin/diagnostics --show
tests/plugin/diagnostics: gcc -c -o tests/plugin/diagnostics/output.o -fplugin=/home/david/coding/gcc
tests/plugin/diagnostics/input.c: In function 'main':
tests/plugin/diagnostics/input.c:23:1: error: this is an error (with positional args)
tests/plugin/diagnostics/input.c:23:1: error: this is an error (with keyword args)
tests/plugin/diagnostics/input.c:25:1: warning: this is a warning (with positional args) [-Wdiv-by-ze
tests/plugin/diagnostics/input.c:25:1: warning: this is a warning (with keyword args) [-Wdiv-by-zero]
tests/plugin/diagnostics/input.c:23:1: error: a warning with some embedded format strings %s and %i
tests/plugin/diagnostics/input.c:25:1: warning: this is an unconditional warning [enabled by default]
tests/plugin/diagnostics/input.c:25:1: warning: this is another unconditional warning [enabled by def
expected error was found: option must be either None, or of type gcc.Option
tests/plugin/diagnostics/input.c:23:1: note: This is the start of the function
tests/plugin/diagnostics/input.c:25:1: note: This is the end of the function
OK
1 success; 0 failures; 0 skipped
```

CHAPTER 20

Documentation

We use Sphinx for documentation, which makes it easy to keep the documentation up-to-date. For notes on how to document Python in the .rst form accepted by Sphinx, see e.g.:

http://sphinx.pocoo.org/domains.html#the-python-domain

CHAPTER 21

Miscellanea

The following odds and ends cover the more esoteric aspects of GCC, and are documented here for completeness. They may or may not be useful when writing scripts.

21.1 Interprocedural analysis (IPA)

GCC builds a "call graph", recording which functions call which other functions, and it uses this for various optimizations.

It is constructed by the *"*build_cgraph_edges"* pass.

In case it's of interest, it is available via the following Python API:

gcc.**get_callgraph_nodes**()
Get a list of all *gcc.CallgraphNode* instances

gccutils.**callgraph_to_dot**()
Return the GraphViz source for a rendering of the current callgraph, as a string.

Here's an example of such a rendering:

class gcc.**CallgraphNode**

decl
The *gcc.FunctionDecl* for this node within the callgraph

callees
The function calls made by this function, as a list of *gcc.CallgraphEdge* instances

callers
The places that call this function, as a list of *gcc.CallgraphEdge* instances

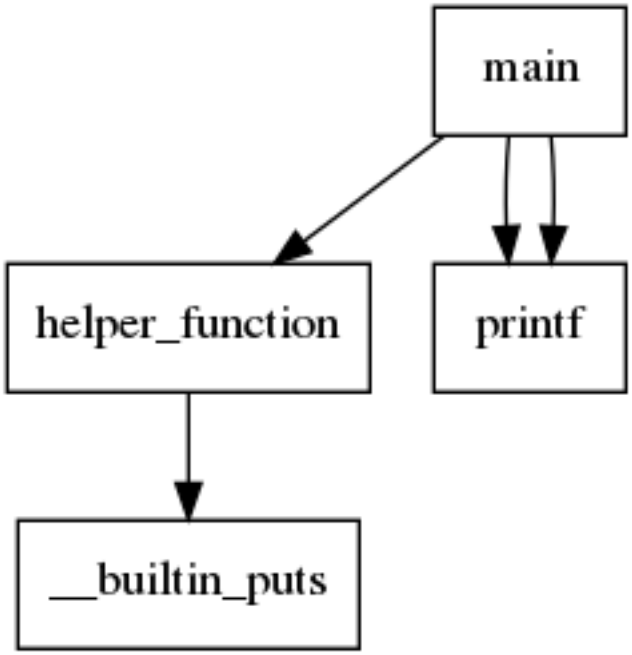
Internally, this wraps a *struct cgraph_node **

class gcc.**CallgraphEdge**

caller
The function that makes this call, as a *gcc.CallgraphNode*

callee
The function that is called here, as a *gcc.CallgraphNode*

call_stmt
The *gcc.GimpleCall* statememt for the function call



Internally, this wraps a *struct cgraph_edge **

21.2 Whole-program Analysis via Link-Time Optimization (LTO)

You can enable GCC's "link time optimization" feature by passing *-flto*.

When this is enabled, gcc adds extra sections to the compiled .o file containing the SSA-Gimple internal representation of every function, so that this SSA representation is available at link-time. This allows gcc to inline functions defined in one source file into functions defined in another source file at link time.

Although the feature is intended for optimization, we can also use it for code analysis, and it's possible to run the Python plugin at link time.

This means we can do interprocedural analysis across multiple source files.

Warning: Running a gcc plugin from inside link-time optimization is rather novel, and you're more likely to run into bugs. See e.g. http://gcc.gnu.org/bugzilla/show_bug.cgi?id=54962

An invocation might look like this:

```
gcc \
   -flto \
   -flto-partition=none \
   -v \
   -fplugin=PATH/TO/python.so \
   -fplugin-arg-python-script=PATH/TO/YOUR/SCRIPT.py \
   INPUT-1.c \
   INPUT-2.c \
   ...
   INPUT-n.c
```

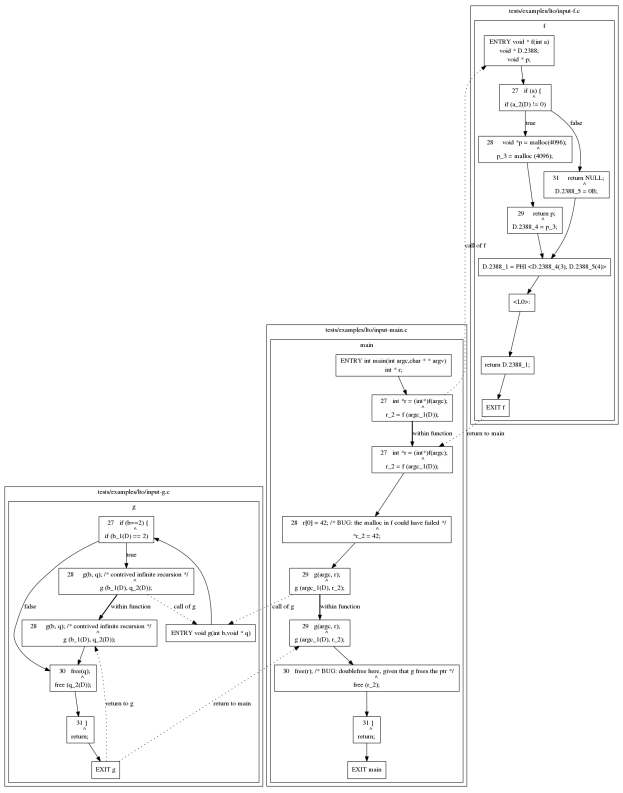
Looking at the above options in turn:

- *-flto* enables link-time optimization
- *-flto-partition=none* : by default, gcc with LTO partitions the code and generates summary information for each partition, then combines the results of the summaries (known as "WPA" and "LTRANS" respectively). This appears to be of use for optimization, but to get at the function bodies, for static analysis, you should pass this option, which instead gathers all the code into one process.
- *-v* means "verbose" and is useful for seeing all of the subprograms that gcc invokes, along with their command line options. Given the above options, you should see invocations of *cc1* (the C compiler), *collect2* (the linker) and *lto1* (the link-time optimizer).

For example,

```
$ ./gcc-with-python \
  examples/show-lto-supergraph.py \
  -flto \
  -flto-partition=none \
  tests/examples/lto/input-*.c
```

will render a bitmap of the supergraph like this:



gcc.**is_lto**()

Return type bool

Determine whether or not we're being invoked during link-time optimization (i.e. from within the *lto1* program)

Warning: The underlying boolean is not set up until passes are being invoked: it is always *False* during the initial invocation of the Python script.

21.3 Inspecting GCC's command-line options

GCC's command-line options are visible from Python scripts as instances of *gcc.Option*.

class gcc.**Option**
Wrapper around one of GCC's command-line options.

You can locate a specific option using its *text* attribute:

```
option = gcc.Option('-Wdiv-by-zero')
```

The plugin will raise a *ValueError* if the option is not recognized.

It does not appear to be possible to create new options from the plugin.

text
(string) The text used at the command-line to affect this option e.g. *-Werror*.

help
(string) The help text for this option (e.g. "Warn about uninitialized automatic variables")

is_enabled
(bool) Is this option enabled?

Note: Unfortunately, for many options, the internal implementation makes it difficult to extract this. The plugin will raise a *NotImplementedError* exception when querying this attribute for such an option.

Calling *gcc.warning()* with such an option will lead to GCC's warning machinery treating the option as enabled and emitting a warning, regardless of whether or not the option was actually enabled.

It appears that this must be fixed on an option-by-option basis within the plugin.

---

is_driver
(bool) Is this a driver option?

is_optimization
(bool) Does this option control an optimization?

is_target
(bool) Is this a target-specific option?

is_warning
(bool) Does this option control a warning message?

Internally, the class wraps GCC's *enum opt_code* (and thus a *struct cl_option*)

gcc.**get_option_list**()
Returns a list of all *gcc.Option* instances.

gcc.**get_option_dict**()
Returns a dictionary, mapping from the option names to *gcc.Option* instances

21.4 Working with GCC's tunable parameters

GCC has numerous tunable parameters, which are integer values, tweakable at the command-line by:

```
--param <name>=<value>
```

A detailed description of the current parameters (in GCC 4.6.0) can be seen at http://gcc.gnu.org/onlinedocs/gcc-4.6.0/gcc/Optimize-Options.html#Optimize-Options (search for "–param" on that page; there doesn't seem to be an anchor to the list)

The parameters are visible from Python scripts using the following API:

gcc.**get_parameters**()
Returns a dictionary, mapping from the option names to *gcc.Parameter* instances

class gcc.**Parameter**

option
(string) The name used with the command-line –param switch to set this value

current_value
(int/long)

default_value
(int/long)

min_value
(int/long) The minimum acceptable value

max_value
(int/long) The maximum acceptable value, if greater than min_value

help
(string) A short description of the option.

21.5 Working with the preprocessor

For languages that support a preprocessor, it's possible to inject new "built-in" macros into the compilation from a Python script.

The motivation for this is to better support the creation of custom attributes, by creating preprocessor names that can be tested against.

gcc.**define_macro**(*argument*)
Defines a preprocessor macro with the given argument, which may be of use for code that needs to test for the presence of your script. The argument can either be a simple name, or a name with a definition:

```
gcc.define_macro("SOMETHING")  # define as the empty string
gcc.define_macro("SOMETHING=72")
```

This function can only be called from within specific event callbacks, since it manipulates the state of the preprocessor for a given source file.

For now, only call it in a handler for the event *gcc.PLUGIN_ATTRIBUTES*:

```
import gcc

def attribute_callback_for_claims_mutex(*args):
    print('attribute_callback_for_claims_mutex called: args: %s' % (args, ))

def attribute_callback_for_releases_mutex(*args):
    print('attribute_callback_for_releases_mutex called: args: %s' % (args, ))

def register_our_attributes():
    gcc.register_attribute('claims_mutex',
```

```
                                1, 1,
                                False, False, False,
                                attribute_callback_for_claims_mutex)
        gcc.define_macro('WITH_ATTRIBUTE_CLAIMS_MUTEX')

        gcc.register_attribute('releases_mutex',
                                1, 1,
                                False, False, False,
                                attribute_callback_for_releases_mutex)
        gcc.define_macro('WITH_ATTRIBUTE_RELEASES_MUTEX')

    # Wire up our callback:
    gcc.register_callback(gcc.PLUGIN_ATTRIBUTES,
                          register_our_attributes)
```

21.6 Version handling

gcc.**get_gcc_version**()
Get the gcc.Version for this version of GCC

gcc.**get_plugin_gcc_version**()
Get the gcc.Version that this plugin was compiled with

Typically the above will be equal (the plugin-loading mechanism currently checks for this, and won't load the plugin otherwise).

On my machine, running this currently gives:

```
gcc.Version(basever='4.6.0', datestamp='20110321', devphase='Red Hat 4.6.0-0.15', revision='', ...)
```

class gcc.**Version**
Information on the version of GCC being run. The various fields are accessible by name and by index.

basever
(string) On my machine, this has value:

```
'4.6.0'
```

datestamp
(string) On my machine, this has value:

```
'20110321'
```

devphase
(string) On my machine, this has value:

```
'Red Hat 4.6.0-0.15'
```

revision
(string) On my machine, this is the empty string

configuration_arguments
(string) On my machine, this has value:

```
'../configure --prefix=/usr --mandir=/usr/share/man --infodir=/usr/share/info --with-bugurl=
```

Internally, this is a wrapper around a *struct plugin_gcc_version*

gcc.**GCC_VERSION**
(int) This corresponds to the value of GCC_VERSION within GCC's internal code: (MAJOR * 1000) + MINOR:

GCC version	Value of gcc.GCC_VERSION
4.6	4006
4.7	4007
4.8	4008
4.9	4009

21.7 Register Transfer Language (RTL)

class gcc.**Rtl**
A wrapper around GCC's *struct rtx_def* type: an expression within GCC's Register Transfer Language

loc
The *gcc.Location* of this expression, or None

operands
The operands of this expression, as a tuple. The precise type of the operands will vary by subclass.

There are numerous subclasses. However, this part of the API is much less polished than the rest of the plugin.

CHAPTER 22

Release Notes

22.1 0.15

This releases adds support for gcc 6 (along with continued support for gcc 4.6, 4.7, 4.8, 4.9 and 5).

Additionally, this release contains the following improvements (contributed by Tom Tromey; thanks Tom):

- document *gcc.PLUGIN_FINISH_TYPE*
- document *gcc.EnumeralType*; add 'values' attribute
- add unqualified_equivalent to gcc.Type subclasses
- preserve qualifiers when adding more qualifiers
- fix include for gcc 4.9.2
- handle variadic function types

22.2 0.14

This releases adds support for gcc 5 (along with continued support for gcc 4.6, 4.7, 4.8 and 4.9).

22.3 0.13

The major features in this release are:

- gcc 4.9 compatibility
- a major revamping to the HTML output from gcc-with-cpychecker

New dependency: `lxml`. The new HTML output format uses lxml internally.

22.3.1 Changes to the GCC Python Plugin

GCC 4.9 compatibility

This release of the plugin adds support for gcc 4.9 (along with continued support for gcc 4.6, 4.7 and gcc 4.8).

Building against 4.9 requires a GCC 4.9 with the fix for GCC bug 63410 applied.

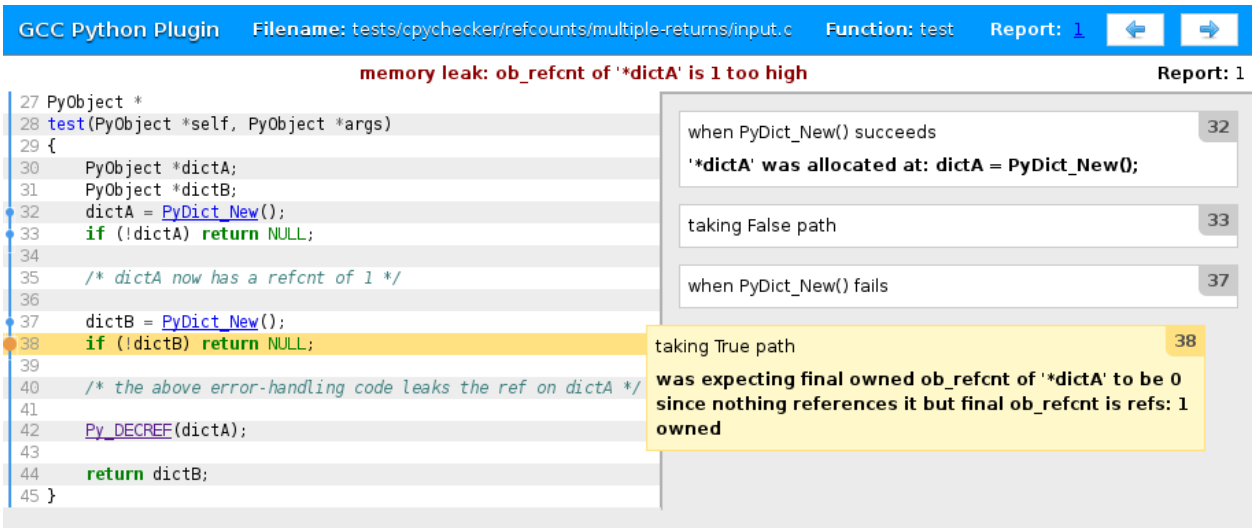
Other fixes

- fixed a build-time incompatibility with Python 3.3.0
- various internal bug fixes:
  - bug in garbage-collector integration (https://bugzilla.redhat.com/show_bug.cgi?id=864314)
  - the test suite is now parallelized (using multiprocessing)
- improvements to Makefile
- improvements to documentation
- add gcc.Location.in_system_header attribute

22.3.2 Improvements to *gcc-with-cpychecker*

The major improvement to gcc-with-cpychecker is a big revamp of the output.

A new "v2" HTML report is available, written to `SOURCE_NAME.v2.html` e.g. `demo.c.v2.html`:



The new HTML report is easier to read in the presence of complicated control flow. It also include links to the API documentation for calls made to the CPython API.

For both old-style and new-style reports, the wording of the messages has been clarified:

- Reference-count tracking messages now largely eliminate the `0 + N where N >=` gobbledegook, since this was confusing to everyone (including me). Instead, error reports talk about references as owned vs borrowed references e.g.
  - "refs: 1 owned"
  - "refs: 0 owned 1 borrowed"

  resorting to ranges:

```
refs: 0 owned + B borrowed where 1 <= B <= 0x80000000
```

  only where necessary.
- Reports now add `memory leak:` and `future use-after-free:` prefixes where appropriate, to better indicate the issue.

- Objects are referred to more in terms the user is likely to understand e.g. `*dictA` rather than `PyDictObject`.

The checker also reports better source locations in its messages e.g. in the presence of multiple `return` statements (https://fedorahosted.org/gcc-python-plugin/ticket/58).

Other improvements

- Add a new test script: *tests/examples/find-global-state*, showing examples of finding global state in the code being compiled.
- handle `PySequence_DelItem()`
- fix bug in handling of `PyRun_SimpleStringFlags()`
- fix issue with handling of `PyArg_ParseTuple()` (https://fedorahosted.org/gcc-python-plugin/ticket/50)
- although we don't model the internals of C++ exceptions, fix things so we don't crash with a traceback in the absense of `-fno-exceptions` (https://fedorahosted.org/gcc-python-plugin/ticket/51)

22.3.3 Contributors

Thanks to Buck Golemon, Denis Efremov, Philip Herron, and Tom Tromey for their contributions to this release.

22.4 0.12

22.4.1 Changes to the GCC Python Plugin

GCC 4.8 compatibility

This release of the plugin adds support for gcc 4.8 (along with continued support for gcc 4.7 and gcc 4.6).

gcc-c-api

The source tree contains a new component: gcc-c-api. This provides a wrapper library *libgcc-c-api.so* that hides much of the details of GCC's internals (such as the binary layout of structures, and the differences between GCC 4.6 through 4.8).

I plan for this to eventually be its own project, aiming at providing a stable API and ABI for working with GCC, once it has proven itself in the context of the python plugin.

The API provides an XML description of itself, which should greatly simplify the job of generating bindings for accessing GCC internals from other languages.

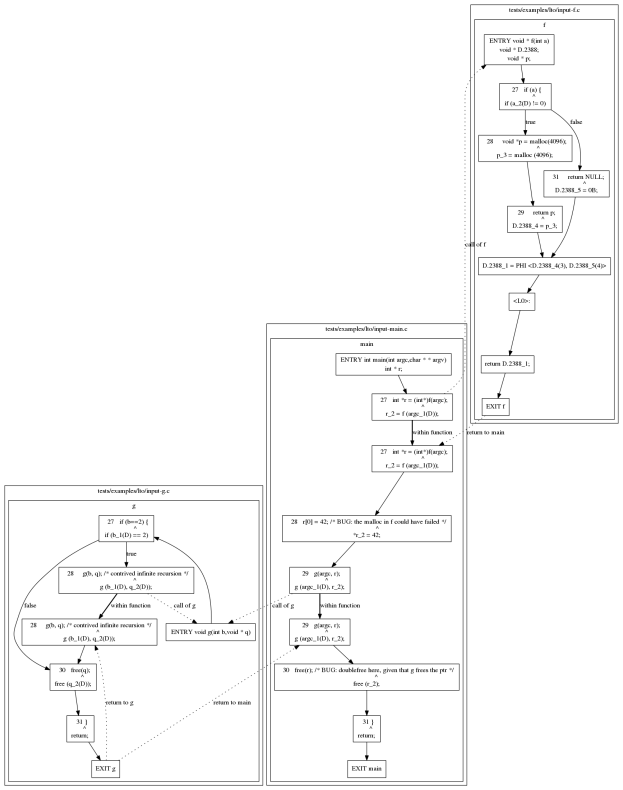
Link-Time Optimization support

The plugin can now be used with GCC's Link-Time Optimization feature (LTO), allowing whole-program visualizations and analysis.

For example, you can rendering a whole-program "supergraph" of control flow graphs using this invocation:

```
$ ./gcc-with-python \
  examples/show-lto-supergraph.py \
  -flto \
  -flto-partition=none \
  tests/examples/lto/input-*.c
```

which will render a bitmap of the supergraph like this:



API improvements

Sane repr() implementations have been added to the following classes: *gcc.CaseLabelExpr* *gcc.GimpleLabel* *gcc.BasicBlock* *gcc.SsaName* *gcc.ArrayRef* *gcc.ComponentRef* *gcc.PointerType* *gcc.IntegerType* *gcc.Location*

gcc.Location instances can now be compared and sorted. They are ordered alphabetically by file, then by line number, then by column)

Other fixes

- the Makefile has a "make install" target (at last)
- prevent forkbomb when running with CC=gcc-with-cpychecker
- fixed memory leak within *gcc.Gimple.walk_tree()*
- ensure that the result of *gcc.Cfg.basic_blocks* can't contain any *None* items (which used to sometimes happen when certain optimizations had occurred).

- run-test-suite.py now has a –show option, giving more verbose information on what the test suite is doing
- fix hashing and equality for *gcc.Function* and *gcc.Gimple*
- fix `gcc.IntegerCst.__hash__()` and ensure it compares sanely against *int*
- ensure that equivalent *gcc.ComponentRef* objects have the same hash and are equal
- ensure there is a unique gcc.CallgraphEdge for each underlying edge, and a unique gcc.Cfg for each underlying control flow graph
- add a "label" attribute to gcc.GimpleLabel
- add *gcc.GCC_VERSION*

22.4.2 Internal improvements to *gcc-with-cpychecker*

- fix exception on pointer comparisons
- fix exception on int-to-float casts
- fix traceback when analyzing a callsite that discards the LHS when an Outcome.returns() a value
- fix two different exceptions when casting an integer value to a pointer
- add example of refcounting bugs to "make demo"
- fix a traceback seen on bogus uses of Py_XDECREF()

22.5 0.11

22.5.1 Changes to the GCC Python Plugin

The main change in this release is support for compiling the plugin with a C++ compiler. Recent versions of GCC 4.7 are now built with C++ rather than C, meaning that plugins must also be built with C++ (since all of GCC's internal symbols are name-mangled). This release fixes the plugin's Makefile so that it autodetects whether the plugin needs to be built with a C or C++ compiler and (I hope) does the right thing automatically. I've also made the necessary changes to the C source code of the plugin so that it is compilable as either language.

This should enable the plugin to now be usable with recent builds of gcc 4.7.* (along with gcc 4.6).

The plugin doesn't yet support gcc 4.8 prereleases.

Other fixes:

- there is now a unique *gcc.Edge* wrapper for each underlying edge in GCC's control flow graphs, rather than the old erroneous behavior of having multiple identical duplicate wrappers.
- fixed missing documentation for *gcc.SsaName*, and *gcc.Edge*'s *true_value* and *false_value* flags

22.5.2 Internal improvements to *gcc-with-cpychecker*

The CPython static analysis code shipped with the plugin contains a detailed description of the behavior of the CPython API (e.g. which arguments will lead to a segfault if NULL, and why; the possible outcomes of a call and their impact on reference-counts; etc).

However, these descriptions were tightly bound to implementation details of the checker.

This release introduces a new internal API to the analyzer for describing the possible behaviors of CPython API entrypoints, in an attempt to decouple these descriptions from the checker, and ports many of the descriptions to using it.

These changes shouldn't be visible to users of the checker, but should make future maintenance much easier.

22.6 0.10

Thanks to Buck Golemon, Daniele Varrazzo, David Narvaez, Eevee, Jason Mueller, Kevin Pyle, Matt Rice and Tom Tromey for their contributions to this release.

22.6.1 Changes to the GCC Python Plugin

- The plugin can now be used with Python 3.3 (fixing Unicode issues and dict-ordering assumptions).
- The plugin now exposes inline assembler to Python scripts via *gcc.GimpleAsm*.
- There is a new *gccutils.sorted_callgraph()* function to get the callgraph in topologically-sorted order.
- The test suite has been reworked to fix issues with checkouts on OS X case-insensitive filesystems.
- C++ support: support for locating the global namespace (aka "::"), for locating declarations and child namespaces within a namespace, and aliases.
- *gcc.Declaration* now has an is_builtin attribute
- Numerous improvements to the plugin's Makefile

22.6.2 Improvements to *gcc-with-cpychecker*

- By default, the refcount checker is now only run on code that includes <Python.h> (implemented by checking if the "PyObject" typedef exists).

  This greatly speeds up compilation of large projects for which the Python extension modules are only a small subset of the source tree.

- Added some custom attributes for marking functions that set an exception, either always, or when returning a negative value:

```
__attribute__((cpychecker_negative_result_sets_exception))
__attribute__((cpychecker_sets_exception))
```

- Improve descriptions of ranges: rather than emitting descriptions with the rather vague "value", such as:

```
when considering range: 1 <= value <= 0x7fffffff
```

  instead try to embed a descriptive name for the value, such as:

```
when considering range: 1 <= n <= 0x7fffffff
```

Mass recompile of Fedora 17's Python extension code

I ran the reference-count checker on all of the C/C++ Python extension modules in Fedora 17 and reported hundreds of genuine problems, many of which have been fixed.

In the process of doing this I found and fixed many problems in the checker itself. For example:

- the checker now understand's GCC's *__builtin_expect*, fixing various false reports about dereferencing NULL pointers when running the checker on Cython-generated code in python-lxml-2.3
- added descriptions of part of SWIG and Cython's internal APIs to suppress some false positives seen with SWIG and Cython-generated code.
- tweak the refcount rules to fix some false positives where the checker erroneously considered the case of a deallocation by:

```
Py_DECREF(obj);
```

  where "obj" provably had other references not owned by the function being analyzed, and thus for the case where obj->ob_refcnt > 1 the deallocation could not happen.

The plugin also now has a triaging script which can examine all of the errors within a build and provide a report, showing all of them in prioritized categories.

The source tree now contains helper scripts for conducting such a mass recompile.

Pyscopg support

Daniele Varrazzo used the checker extensively on psycopg, the popular Python interface to PostgreSQL, and was able to find and fix numerous subtle errors:

- https://fedorahosted.org/pipermail/gcc-python-plugin/2012-March/000229.html
- http://initd.org/psycopg/articles/2012/03/29/psycopg-245-released/

Experimental new error visualization

The checker can now dump its internal representation in JSON form, via a new *–dump-json* option, and an experimental new renderer can generate HTML from this. An example can be seen here:

http://fedorapeople.org/~dmalcolm/gcc-python-plugin/2012-03-19/example/example.html

This is still a work-in-progress

C++ support

The checker is now able to run on C++ code: support has been added for methods, references, "this", destructors, the `gcc.GimpleNop` operation.

Coverage of the CPython API

The format code handling for Py_BuildValue was missing support for the following codes:

- 'u' and 'u#'
- 'f' and 'd'
- 'D'
- 'c'

In addition, the handling for 's#' and 'z#' had a bug in which it erroneously expected an int* or Py_ssize_t*, rather than just a int or Py_ssize_t.

This release fixes these issues, and gives full coverage of all valid format codes for Py_BuildValue in Python 2.

This release adds heuristics for the behavior of the following CPython API entrypoints:

- PyCode_New
- PyCObject_FromVoidPtrAndDesc
- PyDict_Size
- PyErr_Clear
- PyEval_CallMethod
- Py_FatalError
- PyFile_SoftSpace, PyFile_WriteObject, and PyFile_WriteString
- PyFloat_AsDouble and PyFloat_FromDouble
- PyFrame_New
- Py_GetVersion
- PyImport_AddModule
- PyIter_Next
- PyNumber_Int, PyNumber_Remainder
- PyObject_CallObject, PyObject_GetAttr, PyObject_GetAttrString, PyObject_GetItem, PyObject_SetAttr, and PyObject_SetAttrString
- PyOS_snprintf
- PyString_InternFromString
- PySequence_Concat, PySequence_GetSlice, PySequence_SetItem, PySequence_Size
- PySys_GetObject
- PyTraceBack_Here
- PyTuple_GetItem
- PyUnicodeUCS4_DecodeUTF8
- PyWeakref_GetObject

along with various other bugfixes.

22.7 0.9

22.7.1 Changes to the GCC Python Plugin

The plugin now works with GCC 4.7 prereleases (ticket #21).

The plugin is now integrated with GCC's garbage collector: Python wrapper objects keep their underlying GCC objects alive when GCC's garbage collector runs, preventing segfaults that could occur if the underlying objects were swept away from under us (ticket #1).

It's now possible to attach Python callbacks to more GCC events: *gcc.PLUGIN_FINISH*, gcc.PLUGIN_GGC_START, gcc.PLUGIN_GGC_MARKING, gcc.PLUGIN_GGC_FINISH, *gcc.PLUGIN_FINISH_DECL* (gcc 4.7)

gcc.ArrayType has gained a "range" attribute, allowing scripts to detect out-of-bounds conditions in array-handling.

A number of memory leaks were fixed: these were found by running the plugin on itself.

Various documentation improvements (ticket #6, ticket #31).

22.7.2 Improvements to *gcc-with-cpychecker*

The gcc-with-cpychecker tool has received some deep internal improvements in this release.

The logic for analyzing the outcome of comparisons has been rewritten for this release, fixing some significant bugs that could lead to the analyzer incorrectly deciding whether or not a block of code was reachable.

Similarly, the logic for detecting loops has been rewritten, elimininating a bug in which the checker would prematurely stop analyzing loops with complicated termination conditions, and not analyze the body of the loop.

Doing so extended the reach of the checker, and enabled it to find the memory leaks referred to above.

In addition, the checker now emits more detailed information on the ranges of possible values it's considering when a comparison occurs against an unknown value:

```
input.c: In function 'test':
input.c:41:5: warning: comparison against uninitialized data (item) at    input.c:41 [enabled by defa
input.c:34:12: note: when PyList_New() succeeds at:     result = PyList_New(len);
input.c:35:8: note: taking False path at:     if (!result) {
input.c:39:12: note: reaching:     for (i = 0; i < len; i++) {
input.c:39:5: note: when considering range: 1 <= value <= 0x7fffffff at:     for (i = 0; i < len; i+
input.c:39:5: note: taking True path at:     for (i = 0; i < len; i++) {
input.c:41:5: note: reaching:        if (!item) {
```

The checker should do a better job of identifying PyObject subclasses. Previously it was treating any struct beginning with "ob_refcnt" and "ob_type" as a Python object (with some tweaks for python 3 and debug builds). It now also covers structs that begin with a field that's a PyObject (or subclass), since these are likely to also be PyObject subclasses.

Usage of deallocated memory

Previously, the checker would warn about paths through a function that could return a pointer to deallocated memory, or which tried to read through such a pointer. With this release, the checker will now also warn about paths through a function in which a pointer to deallocated memory is passed to a function.

For example, given this buggy code:

```
extern void some_function(PyObject *);

void
test(PyObject *self, PyObject *args)
{
    /* Create an object: */
    PyObject *tmp = PyLong_FromLong(0x1000);

    if (!tmp) {
        return;
    }

    /*
      Now decref the object.  Depending on what other references are owned
      on the object, it can reach a refcount of zero, and thus be deallocated:
    */
    Py_DECREF(tmp);
```

```
    /* BUG: the object being returned may have been deallocated */
    some_function(tmp);
}
```

the checker will emit this warning:

```
input.c: In function 'test':
input.c:45: warning: passing pointer to deallocated memory as argument 1 of function at input.c:45: r
input.c:32: note: when PyLong_FromLong() succeeds at:     PyObject *tmp = PyLong_FromLong(0x1000);
input.c:34: note: taking False path at:     if (!tmp) {
input.c:42: note: reaching:     Py_DECREF(tmp);
input.c:42: note: when taking False path at:     Py_DECREF(tmp);
input.c:42: note: reaching:     Py_DECREF(tmp);
input.c:42: note: calling tp_dealloc on PyLongObject allocated at input.c:32 at:     Py_DECREF(tmp);
input.c:45: note: reaching:     foo(tmp);
input.c:30: note: graphical error report for function 'passing_dead_object_to_function' written out t
```

Coverage of the CPython API

This release adds heuristics for the behavior of the following CPython API entrypoints:

- PyString_Concat
- PyString_ConcatAndDel

along with various other bugfixes and documentation improvements.

22.8 0.8

Thanks to David Narvaez and Tom Tromey for their code contributions to this release.

22.8.1 Changes to the GCC Python Plugin

Initial C++ support

This release adds the beginnings of C++ support: *gcc.FunctionDecl* instances now have a "fullname" attribute, along with "is_public", "is_private", "is_protected", "is_static" booleans.

For example, given this code:

```
    namespace Example {
        struct Coord {
            int x;
            int y;
        };

        class Widget {
        public:
            void set_location(const struct Coord& coord);
        };
    };
```

set_location's fullname is:

```
'void Example::Widget::set_location(const Example::Coord&)'
```

This is only present when the plugin is invoked from the C++ frontend (*cc1plus*), gracefully handling the case when we're invoked from other language frontends.

Similarly, *gcc.MethodType* has gained an "argument_types" attribute.

Unconditional warnings

The *gcc.warning()* function in previous versions of the plugin required an "option" argument, such as `gcc.Option('-Wformat')`

It's now possible to emit an unconditional warning, by supplying *None* for this argument, which is now the default value:

```
gcc.warning(func.start, 'this is an unconditional warning')
```

```
$ ./gcc-with-python script.py input.c
input.c:25:1: warning: this is an unconditional warning [enabled by default]
```

which will be an error if *-Werror* is supplied as a command-line argument to gcc:

```
$ ./gcc-with-python script.py -Werror input.c
input.c:25:1: error: this is an unconditional warning [-Werror]
```

22.8.2 Improvements to *gcc-with-cpychecker*

The "libcpychecker" Python code is a large example of using the plugin: it extends GCC with code that tries to detect various bugs in CPython extension modules.

As of this release, all of the errors emitted by the tool have been converted to warnings. This should make *gcc-with-cpychecker* more usable as a drop-in replacement for *gcc*: the first source file with a refcounting error should no longer terminate the build (unless the program uses `-Werror`, of course).

Verification of PyMethodDef tables

This release adds checking of tables of PyMethodDef initialization values, used by Python extension modules for binding C functions to Python methods.

The checker will verify that the signatures of the callbacks match the flags, and that the such tables are NULL terminated:

```
input.c:48:22: warning: flags do not match callback signature for 'test' within PyMethodDef table
input.c:48:22: note: expected ml_meth callback of type "PyObject (fn)(someobject *, PyObject *)" (2 a
input.c:48:22: note: actual type of underlying callback: struct PyObject * <Tc58> (struct PyObject *,
input.c:48:22: note: see http://docs.python.org/c-api/structures.html#PyMethodDef
```

Coverage of the CPython API

When the checker warns about code that can erroneously pass `NULL` to various CPython API entrypoints which are known to implicitly dereference those arguments, the checker will now add an explanatory note about why it is complaining.

For example:

```
input.c: In function 'test':
input.c:38:33: warning: calling PyString_AsString with NULL (gcc.VarDecl('repr_args')) as argument 1
input.c:31:15: note: when PyObject_Repr() fails at:     repr_args = PyObject_Repr(args);
input.c:38:33: note: PyString_AsString() invokes Py_TYPE() on the pointer via the PyString_Check() ma
input.c:27:1: note: graphical error report for function 'test' written out to 'input.c.test-refcount-
```

The checker will now verify the argument lists of invocations of PyObject_CallFunctionObjArgs and PyObject_CallMethodObjArgs, checking that all of the arguments are of the correct type (PyObject* or subclasses), and that the list is NULL-terminated:

```
input.c: In function 'test':
input.c:33:5: warning: argument 2 had type char[12] * but was expecting a PyObject* (or subclass)
input.c:33:5: warning: arguments to PyObject_CallFunctionObjArgs were not NULL-terminated
```

This release also adds heuristics for the behavior of the following CPython API entrypoints:

- PyArg_Parse
- PyCObject_{As,From}VoidPtr
- PyCallable_Check
- PyCapsule_GetPointer
- PyErr_{NewException,SetNone,WarnEx}
- PyEval_CallObjectWithKeywords
- PyEval_{Save,Restore}Thread (and thus the Py_{BEGIN,END}_ALLOW_THREADS macros)
- PyList_{GetItem,Size}
- PyLong_FromLongLong
- PyMapping_Size
- PyModule_GetDict
- PyObject_AsFileDescriptor
- PyObject_Call{Function,FunctionObjArgs,MethodObjArgs}
- PyObject_Generic{Get,Set}Attr
- PyString_Size
- PyTuple_Pack
- PyUnicode_AsUTF8String
- Py_AtExit

Bug fixes

- gcc-with-cpychecker will now try harder on functions that are too complicated to fully handle. Previously, when a function was too complicated for the reference-count tracker to fully analyze, it would give up, performing no analysis. The checker will now try to obtain at least some subset of the list of all traces through the function, and analyze those. It will still note that the function was too complicated to fully analyze.

  Given that we do a depth-first traversal of the tree, and that "success" transitions are typically visited before "failure" transitions, this means that it should at least analyze the trace in which all functions calls succeed, together with traces in which some of the later calls fail.

- the reference-count checker now correctly handles "static" *PyObject** local variables: a *static PyObject ** local preserves its value from call to call, and can thus permanently own a reference.

  Fixes a false-positive seen in psycopg2-2.4.2 (*psycopg/psycopgmodule.c:psyco_GetDecimalType*) where the refcount checker erroneously reported that a reference was leaked.

- the checker for Py_BuildValue("O") (and "S" and "N") was being too strict, requiring a (PyObject*). Although it's not explicitly documented, it's clear that these can also accept pointers to any PyObject subclass.

  Fixes a false positive seen when running gcc-with-cpychecker on coverage-3.5.1b1.tar.gz, in which *coverage/tracer.c:Tracer_trace* passes a PyFrameObject* as an argument to such a call.

- the reference-count checker now correctly suppresses reports about "leaks" for traces that call a function that never return (such as *abort()*).

  Fixes a false positive seen in rpm-4.9.1.2 in a handler for fatal errors: (in python/rpmts-py.c:die) where the checker erroneously reported that a reference was leaked.

- *tp_iternext* callbacks are allowed to return NULL without setting an exception. The reference-count checker will now notice if a function is used in such a role, and suppress warnings about such behavior.

- fixed various Python tracebacks (tickets #14, #19, #20, #22, #23, #24, #25)

- various other fixes

22.9 0.7

This is a major update to the GCC Python plugin.

The main example script, cpychecker, has seen numerous improvements, and has now detected many reference-counting bugs in real-world CPython extension code. The usability and signal:noise ratio is greatly improved over previous releases.

22.9.1 Changes to the GCC Python Plugin

It's now possible to create custom GCC attributes from Python, allowing you to add custom high-level annotation to a C API, and to write scripts that will verify these properties. It's also possible to inject preprocessor macros from Python. Taken together, this allows code like this:

```
#if defined(WITH_ATTRIBUTE_CLAIMS_MUTEX)
 #define CLAIMS_MUTEX(x) __attribute__((claims_mutex(x)))
#else
 #define CLAIMS_MUTEX(x)
#endif

#if defined(WITH_ATTRIBUTE_RELEASES_MUTEX)
 #define RELEASES_MUTEX(x) __attribute__((releases_mutex(x)))
#else
 #define RELEASES_MUTEX(x)
#endif


/* Function declarations with custom attributes: */
extern void some_function(void)
    CLAIMS_MUTEX("io");

extern void some_other_function(void)
    RELEASES_MUTEX("io");
```

```
    extern void yet_another_function(void)
        CLAIMS_MUTEX("db")
        CLAIMS_MUTEX("io")
        RELEASES_MUTEX("io");
```

Other improvements:

- gcc's debug dump facilities are now exposed via a Python API
- it's now possible to run Python commands in GCC (rather than scripts) using -fplugin-arg-python-command
- improvements to the "source location" when reporting on an unhandled Python exception. Amongst other tweaks, it's now possible for a script to override this, which the cpychecker uses, so that if it can't handle a particular line of C code, the GCC error report gives that location before reporting the Python traceback (making debugging much easier).
- "switch" statements are now properly wrapped at the Python level (gcc.GimpleSwitch)
- C bitfields are now wrapped at the Python level
- gcc.Type instances now have a "sizeof" attribute, and an "attributes" attribute.
- added a gcc.Gimple.walk_tree method, to make it easy to visit all nodes relating to a statement
- added a new example: spell-checking all string literals in code

22.9.2 Improvements to "cpychecker"

The "libcpychecker" Python code is a large example of using the plugin: it extends GCC with code that tries to detect various bugs in CPython extension modules.

The cpychecker analyzes the paths that can be followed through a C function, and verifies various properties, including reference-count handling.

As of this release, the pass has found many reference-counting bugs in real-world code. You can see a list of the bugs that it has detected at:

http://gcc-python-plugin.readthedocs.org/en/latest/success.html

The checker is now *almost* capable of fully handling the C code within the gcc python plugin itself.

The checker has also been reorganized to (I hope) make it easy to add checking for other libraries and APIs.

Major rewrite of reference-count tracking

I've rewritten the internals of how reference counts are tracked: the code now makes a distinction betweeen all of the reference that can be analysed within a single function, versus all of the other references that may exist in the rest of the program.

This allows us to know for an object e.g. that the function doesn't directly own any references, but that the reference count is still > 0 (a "borrowed reference"), as compared to the case where the function owns a reference, but we don't know of any in the rest of the program (this is typical when receiving a "new reference" e.g. from a function call to a constructor).

Within the reference-count checker, we now look for memory locations that store references to objects. If those locations not on the stack, then the references they store are now assumed to legally count towards the ob_refcnt that the function "owns". This is needed in order to correctly handle e.g. the PyList_SET_ITEM() macro, which directly writes to the list's ob_item field, "stealing" a reference: we can detect these references, and count them towards the ob_refcnt value.

The checker can now detect types that look like PyObject subclasses at the C level (by looking at the top-most fields), and uses this information in various places.

The checker now exposes custom GCC attributes allowing you to mark APIs that have non-standard reference-handling behavior:

```
PyObject *foo(void)
  CPYCHECKER_RETURNS_BORROWED_REF;

extern void bar(int i, PyObject *obj, int j, PyObject *other)
  CPYCHECKER_STEALS_REFERENCE_TO_ARG(2)
  CPYCHECKER_STEALS_REFERENCE_TO_ARG(4);
```

It also exposes an attribute allowing you to the run-time and compile-time type information for a Python extension class:

```
/* Define some PyObject subclass, as both a struct and a typedef */
struct OurObjectStruct {
    PyObject_HEAD
    /* other fields */
};
typedef struct OurObjectStruct OurExtensionObject;

/*
  Declare the PyTypeObject, using the custom attribute to associate it with
  the typedef above:
*/
extern PyTypeObject UserDefinedExtension_Type
  CPYCHECKER_TYPE_OBJECT_FOR_TYPEDEF("OurExtensionObject");
```

Function calls with NULL-pointer arguments

The checker knows about various CPython API hooks that will crash on NULL pointer arguments, and will emit warnings when it can determine a path through the code that will lead to a definite call with a NULL value.

Dereferences of uninitialized pointers

The checker will now complain about paths through a function for which it can prove that an uninitialized pointer will be dereferenced.

Error-reporting improvements

The error-reporting machinery can generate HTML reports: see e.g.: http://readthedocs.org/docs/gcc-python-plugin/en/latest/cpychecker.html#reference-count-checking and http://dmalcolm.livejournal.com/6560.html

The checker can now annotate its HTML (and textual) reports with information showing how some pertinent aspect of the program's state changes during a particular path through a function.

For example, when reporting on reference-counting errors, the HTML report showing the flow through the function will now display all changes to an object's ob_refcnt, together with all changes to what the value ought to be (e.g. due to pointers being stored to persistent memory locations):

Similarly, when reporting on exception-handling errors, it now displays the "history" of changes to the thread-local exception state.

File: **input.c**

Function: **test**

Error: **ob_refcnt of '*list' is 1 too high**

```
22 PyObject *
23 test(PyObject *self, PyObject *args)
24 {
25     PyObject *list;
26     PyObject *item;
27     list = PyList_New(1);
         when PyList_New() succeeds
         PyListObject allocated at:    list = PyList_New(1);
         ob_refcnt is now refs: 1 + N where N >= 0
28     if (!list)
         taking False path
29         return NULL;
30     item = PyLong_FromLong(42);
         when PyLong_FromLong() fails
31     /* This error handling is incorrect: it's missing an
32        invocation of Py_DECREF(list): */
33     if (!item)
         taking True path
34         return NULL;
35     /* This steals a reference to item; item is not leaked when we get here: */
36     PyList_SetItem(list, 0, item);
37     return list;
38 }
```

ob_refcnt of '*list' is 1 too high

was expecting final ob_refcnt to be N + 0 (for some unknown N)

but final ob_refcnt is N + 1

There's also a debug mode which dumps _everything_ that changes within the report, which is helpful for debugging the checker itself.

The error report will attempt to use the most representative name for a leaked object, using a variable name or a C expression fragment as appropriate.

The checker will attempt to combine duplicate error reports, so that it will only emit one error for all of the various traces of execution that exhibit a particular reference-counting bug.

Finally, when writing out an HTML report, the path to the HTML is now noted within gcc's regular stderr messages.

Signal:noise ratio improvements

To suppress various false-positives that I commonly ran into on real code, the checker now makes certain assumptions:

- When encountering an unknown function that returns a PyObject*, the checker assumes that it will either return a new reference to a sane object (with a sane ob_type), or return NULL and set the thread-local exception state.
- The checker assumes that a PyObject* argument to a function is non-NULL and has a >0 refcount, and has a sane ob_type (e.g. with a sane refcount and tp_dealloc)
- When dereferencing a pointer that it has no knowledge about (e.g. a pointer field in a structure), the checker now assumes that it's non-NULL, unless it knows that NULL is a definite possibility i.e. it optimistically assumes that you know what you're doing (this could be turned into a command-line option). Note that for the cases where we know that the pointer can _definitely_ be NULL, an error will still be reported (e.g. when considering the various possible return values for a function known to be able to return NULL).

Coverage of the CPython API

I've gone through much of the CPython API, "teaching" the checker about the reference-count semantics of each API call (and which calls will crash if fed a NULL pointer). This involves writing a simple fragment of Python code for each function, which describes the various different affects that the call can have on the internal state within the callee.

This release adds support for calls to the following:

- _PyObject_New
- Py_{Initialize|Finalize}
- Py_InitModule4
- PyArg_ParseTuple[AndKeywords], and the PY_SSIZE_T_CLEAN variants (only partial coverage so far: "O", "O!" should work though)
- PyArg_UnpackTuple
- PyBool_FromLong
- Py_BuildValue and the PY_SSIZE_T_CLEAN variant (only partial coverage so far)
- PyDict_{GetItem,GetItemString,New,SetItem,SetItemString}
- PyErr_{Format,NoMemory,Occurred,Print,PrintEx,SetFromErrno[WithFilename], SetObject,SetString}
- PyEval_InitThreads
- PyGILState_{Ensure,Release}
- PyImport_{AppendInittab,ImportModule}
- PyInt_{AsLong,FromLong}
- PyList_Append

- PyLong_{FromString,FromVoidPtr}
- PyMem_{Malloc,Free}
- PyModule_Add{IntConstant,Object,StringConstant}
- PyObject_{Call,CallMethod,HasAttrString,IsTrue,Repr,Str}
- PyRun_{SimpleFileExFlags,SimpleStringFlags}
- PySequence_GetItem
- PyString_{AsString,FromFormat,FromString,FromStringAndSize}
- PyStructSequence_{InitType,New}
- PySys_SetObject
- PyTuple_{New,SetItem,Size}
- PyType_{IsSubtype,Ready}

I've been targetting those API entrypoints that I use myself in the plugin; this is one area which is particularly amenable to patching, for anyone who wants to get involved. I've also added a (disabled) hook that complains about Python API entrypoints that weren't explicitly handled, to make it easy to find gaps in our coverage of the CPython API.

Other user-visible improvments

- There's now a "gcc-with-cpychecker" harness, to make it easier to invoke GCC with the cpychecker code from e.g. Makefiles
- The checker now respects *__attribute((nonnull))* on function arguments when detecting NULL pointers
- Handle functions that don't return (e.g. "exit")
- Number the unknown heap regions, to clarify things when there's more than one

Internal improvements

- The cpychecker now has some protection against combinatorial explosion for functions that have very large numbers of possible routes through them. For such functions, the checker will emit a note on stderr and not attempt to find reference-counting bugs in the function.
- The cpychecker is now done as a custom pass (rather than by wiring up a callback associated with every pass)
- I've tuned the logging within the checker, eliminating some CPU/memory consumption issues seen when analysing complicated C code. In particular, the log message arguments are now only expanded when logging is enabled (previously this was happening all the time).
- Lots of other internal improvements and bug fixes (e.g. handling of arrays vs pointers, static vs auto local variables, add missing handlers for various kinds of C expression, lots of work on improving the readability of error messages)

CHAPTER 23

Appendices

The following contain tables of reference material that may be useful when writing scripts.

23.1 All of GCC's passes

This diagram shows the various GCC optimization passes, arranged vertically, showing child passes via indentation.

The lifetime of the various properties that they maintain is shown, giving the pass that initially creates the data (if any), the pass that destroys it (if any), and each pass that requires a particular property (based on the PROP_* flags).

These tables contain the same information. The diagram and tables were autogenerated, using GCC 4.6.0

23.1.1 The lowering passes

Pass Name	Required properties	Provided properties	Destroyed properties
*warn_unused_result	gimple_any		
*diagnose_omp_blocks	gimple_any		
mudflap1	gimple_any		
omplower	gimple_any	gimple_lomp	
lower	gimple_any	gimple_lcf	
ehopt	gimple_lcf		
eh	gimple_lcf	gimple_leh	
cfg	gimple_leh	cfg	
*warn_function_return	cfg		
*build_cgraph_edges	cfg		

23.1.2 The "small IPA" passes

Pass Name	Required properties	Provided properties	Destroyed properties
*free_lang_data	gimple_any, gimple_lcf, gimple_leh, cfg		
visibility			
early_local_cleanups			
> *free_cfg_annotations	cfg		
> *init_datastructures	cfg		

Continued on next page

Table 23.1 – continued from previous page

Pass Name	Required properties	Provided properties	Destroyed properties
> ompexp	gimple_any		
> *referenced_vars	gimple_leh, cfg	referenced_vars	
> ssa	cfg, referenced_vars	ssa	
> veclower	cfg		
> *early_warn_uninitialized	ssa		
> *rebuild_cgraph_edges	cfg		
> inline_param			
> einline			
> early_optimizations			
> > *remove_cgraph_callee_edges			
> > copyrename	cfg, ssa		
> > ccp	cfg, ssa		
> > forwprop	cfg, ssa		
> > ealias	cfg, ssa		
> > esra	cfg, ssa		
> > copyprop	cfg, ssa		
> > mergephi	cfg, ssa		
> > cddce	cfg, ssa		
> > eipa_sra			
> > tailr	cfg, ssa		
> > switchconv	cfg, ssa		
> > ehcleanup	gimple_lcf		
> > profile	cfg		
> > local-pure-const			
> > fnsplit	cfg		
> release_ssa	ssa		
> *rebuild_cgraph_edges	cfg		
> inline_param			
tree_profile_ipa			
> feedback_fnsplit	cfg		
increase_alignment			
matrix-reorg			
emutls	cfg, ssa		

23.1.3 The "regular IPA" passes

Pass Name	Required properties	Provided properties	Destroyed properties
whole-program	gimple_any, gimple_lcf, gimple_leh, cfg		
ipa-profile			
cp			
cdtor			
inline			
pure-const			
static-var			
type-escape-var			
pta			
ipa_struct_reorg			

23.1.4 Passes generating Link-Time Optimization data

Pass Name	Required properties	Provided properties	Destroyed properties
lto_gimple_out	gimple_any, gimple_lcf, gimple_leh, cfg		
lto_decls_out			

23.1.5 The "all other passes" catch-all

Pass Name	Required properties	Provided properties	Destroyed properties
ehdisp	gimple_any, gimple_lcf, gimple_leh, cfg		
*all_optimizations			
> *remove_cgraph_callee_edges			
> *strip_predict_hints	cfg		
> copyrename	cfg, ssa		
> cunrolli	cfg, ssa		
> ccp	cfg, ssa		
> forwprop	cfg, ssa		
> cdce	cfg, ssa		
> alias	cfg, ssa		
> retslot	ssa		
> phiprop	cfg, ssa		
> fre	cfg, ssa		
> copyprop	cfg, ssa		
> mergephi	cfg, ssa		
> vrp	ssa		
> dce	cfg, ssa		
> cselim	cfg, ssa		
> ifcombine	cfg, ssa		
> phiopt	cfg, ssa		
> tailr	cfg, ssa		

Table 23.2 – continued from previous page

Pass Name	Required properties	Provided properties	Destroyed properties
> ch	cfg, ssa		
> stdarg	cfg, ssa		
> cplxlower	ssa	gimple_lcx	
> sra	cfg, ssa		
> copyrename	cfg, ssa		
> dom	cfg, ssa		
> phicprop	cfg, ssa		
> dse	cfg, ssa		
> reassoc	cfg, ssa		
> dce	cfg, ssa		
> forwprop	cfg, ssa		
> phiopt	cfg, ssa		
> objsz	cfg, ssa		
> ccp	cfg, ssa		
> copyprop	cfg, ssa		
> sincos	ssa		
> bswap	ssa		
> crited	cfg	no_crit_edges	
> pre	cfg, ssa, no_crit_edges		
> sink	cfg, ssa, no_crit_edges		
> loop	cfg		
> > loopinit	cfg		
> > lim	cfg		
> > copyprop	cfg, ssa		
> > dceloop	cfg, ssa		
> > unswitch	cfg		
> > sccp	cfg, ssa		
> > *record_bounds	cfg, ssa		
> > ckdd	cfg, ssa		
> > ldist	cfg, ssa		
> > copyprop	cfg, ssa		
> > graphite0	cfg, ssa		
> > > graphite	cfg, ssa		
> > > lim	cfg		
> > > copyprop	cfg, ssa		
> > > dceloop	cfg, ssa		
> > ivcanon	cfg, ssa		
> > ifcvt	cfg, ssa		
> > vect	cfg, ssa		
> > > veclower2	cfg		
> > > dceloop	cfg, ssa		
> > pcom	cfg		
> > cunroll	cfg, ssa		
> > slp	cfg, ssa		
> > parloops	cfg, ssa		
> > aprefetch	cfg, ssa		
> > ivopts	cfg, ssa		
> > loopdone	cfg		
> recip	ssa		

Table 23.2 – continued from previous page

Pass Name	Required properties	Provided properties	Destroyed properties
> reassoc	cfg, ssa		
> vrp	ssa		
> dom	cfg, ssa		
> phicprop	cfg, ssa		
> cddce	cfg, ssa		
> tracer			
> uninit	ssa		
> dse	cfg, ssa		
> forwprop	cfg, ssa		
> phiopt	cfg, ssa		
> fab	cfg, ssa		
> widening_mul	ssa		
> tailc	cfg, ssa		
> copyrename	cfg, ssa		
> uncprop	cfg, ssa		
> local-pure-const			
cplxlower0	cfg	gimple_lcx	
ehcleanup	gimple_lcf		
resx	gimple_lcf		
nrv	cfg, ssa		
mudflap2	gimple_leh, cfg, ssa		
optimized	cfg		
*warn_function_noreturn	cfg		
expand	gimple_leh, cfg, ssa, gimple_lcx	rtl	gimple_any, gimple_lcf, gim
*rest_of_compilation	rtl		
> *init_function			
> sibling			
> rtl eh			
> initvals			
> unshare			
> vregs			
> into_cfglayout		cfglayout	
> jump			
> subreg1			
> dfinit			
> cse1			
> fwprop1			
> cprop	cfglayout		
> rtl pre	cfglayout		
> hoist	cfglayout		
> cprop	cfglayout		
> store_motion	cfglayout		
> cse_local			
> ce1			
> reginfo			
> loop2			
> > loop2_init			
> > loop2_invariant			
> > loop2_unswitch			

Table 23.2 – continued from previous page

Pass Name	Required properties	Provided properties	Destroyed properties
> > loop2_unroll			
> > loop2_doloop			
> > loop2_done			
> web			
> cprop	cfglayout		
> cse2			
> dse1			
> fwprop2			
> auto_inc_dec			
> init-regs			
> ud dce			
> combine	cfglayout		
> ce2			
> bbpart	cfglayout		
> regmove			
> outof_cfglayout			cfglayout
> split1			
> subreg2			
> no-opt dfinit			
> *stack_ptr_mod			
> mode_sw			
> asmcons			
> sms			
> sched1			
> ira			
> *all-postreload	rtl		
> > postreload			
> > gcse2			
> > split2			
> > zee			
> > cmpelim			
> > btl1			
> > pro_and_epilogue			
> > dse2			
> > csa			
> > peephole2			
> > ce3			
> > rnreg			
> > cprop_hardreg			
> > rtl dce			
> > bbro			
> > btl2			
> > *leaf_regs			
> > split4			
> > sched2			
> > *stack_regs			
> > > split3			
> > > stack			
> > alignments			

Table 23.2 – continued from previous page

Pass Name	Required properties	Provided properties	Destroyed properties
> > compgotos			
> > vartrack			
> > *free_cfg			cfg
> > mach			
> > barriers			
> > dbr			
> > split5			
> > eh_ranges			
> > shorten			
> > nothrow			
> > final			
> dfinish			
*clean_state			rtl

23.2 `gcc.Tree` operators by symbol

The following shows the symbol used for each expression subclass in debug dumps, as returned by the various *get_symbol()* class methods.

There are some duplicates (e.g. - is used for both *gcc.MinusExpr* as an infix binary operator, and by *gcc.NegateExpr* as a prefixed unary operator).

Class	get_symbol()
gcc.AddrExpr	&
gcc.BitAndExpr	&
gcc.BitIorExpr	|
gcc.BitNotExpr	~
gcc.BitXorExpr	^
gcc.CeilDivExpr	*/[cl]*
gcc.CeilModExpr	*%[cl]*
gcc.EqExpr	==
gcc.ExactDivExpr	*/[ex]*
gcc.FloorDivExpr	*/[fl]*
gcc.FloorModExpr	*%[fl]*
gcc.GeExpr	>=
gcc.GtExpr	>
gcc.IndirectRef	*
gcc.LeExpr	<=
gcc.LrotateExpr	*r<<*
gcc.LshiftExpr	<<
gcc.LtExpr	<
gcc.LtgtExpr	<>
gcc.MaxExpr	*max*
gcc.MinExpr	*min*
gcc.MinusExpr	-
gcc.ModifyExpr	=

Continued on next page

Table 23.3 – continued from previous page

Class	get_symbol()
gcc.MultExpr	*
gcc.NeExpr	!=
gcc.NegateExpr	-
gcc.OrderedExpr	ord
gcc.PlusExpr	+
gcc.PointerPlusExpr	+
gcc.PostdecrementExpr	–
gcc.PostincrementExpr	++
gcc.PredecrementExpr	–
gcc.PreincrementExpr	++
gcc.RdivExpr	/
gcc.ReducPlusExpr	r+
gcc.RoundDivExpr	/[rd]
gcc.RoundModExpr	%[rd]
gcc.RrotateExpr	r>>
gcc.RshiftExpr	>>
gcc.TruncDivExpr	/
gcc.TruncModExpr	%
gcc.TruthAndExpr	&&
gcc.TruthAndifExpr	&&
gcc.TruthNotExpr	!
gcc.TruthOrExpr	||
gcc.TruthOrifExpr	||
gcc.TruthXorExpr	^
gcc.UneqExpr	u==
gcc.UngeExpr	u>=
gcc.UngtExpr	u>
gcc.UnleExpr	u<=
gcc.UnltExpr	u<
gcc.UnorderedExpr	unord
gcc.VecLshiftExpr	v<<
gcc.VecRshiftExpr	v>>
gcc.WidenMultExpr	w*
gcc.WidenSumExpr	w+

This document describes the Python plugin I've written for GCC. In theory the plugin allows you to write Python scripts that can run inside GCC as it compiles code, exposing GCC's internal data structures as a collection of Python classes and functions. The bulk of the document describes the Python API it exposes.

Hopefully this will be of use for writing domain-specific warnings, static analysers, and the like, and for rapid prototyping of new GCC features.

I've tried to stay close to GCC's internal representation, but using classes. I hope that the resulting API is pleasant to work with.

The plugin is a work-in-progress; the API may well change.

Bear in mind that writing this plugin has been the first time I have worked with the insides of GCC. I have only wrapped the types I have needed, and within them, I've only wrapped properties that seemed useful to me. There may well be plenty of interesting class and properties for instances that can be added (patches most welcome!). I may also have misunderstood how things work.

Most of my development has been against Python 2 (2.7, actually), but I've tried to make the source code of the plugin buildable against both Python 2 and Python 3 (3.2), giving separate python2.so and python3.so plugins. (I suspect that it's only possible to use one or the other within a particular invocation of "gcc", due to awkward dynamic-linker symbol collisions between the two versions of Python).

The plugin is Free Software, licensed under the GPLv3 (or later).

CHAPTER 24

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