

Coccinelle

User's manual

release 1.0.4

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Contents

I	User Manual	3
1	Introduction	4
2	Installing Coccinelle	5
2.1	Requirements	5
2.2	Getting Coccinelle	5
2.3	Compiling Coccinelle	5
2.4	Running Coccinelle	5
3	Tutorial	6
4	Examples	7
4.1	Examples	7
4.1.1	Function renaming	7
4.1.2	Removing a function argument	8
4.1.3	Introduction of a macro	9
4.1.4	Look for NULL dereference	11
4.1.5	Reference counter: the of_xxx API	12
4.1.6	Filtering identifiers, declarers or iterators with regular expressions	14
4.2	Tips and Tricks	14
4.2.1	How to remove useless parentheses?	14
5	Isomorphisms and <code>standard.iso</code>	16
6	Parsing C, <code>cpp</code>, and <code>standard.h</code>	17
7	Developing a Semantic Patch	18
8	Advanced Features	19
II	Reference Manual	20
9	SmPL grammar	21
9.1	Program	21
9.2	Metavariables for transformations	21
9.3	Metavariables for scripts	26
9.4	Transformation	27
9.5	Types	29
9.6	Function declarations	30
9.7	Declarations	31

9.8	Statements	31
9.9	Expressions	32
9.10	Constants, Identifiers and Types for Transformations	34
9.11	Comments and preprocessor directives	34
9.12	Command-line semantic match	34
9.13	Iteration	35
10	spatch command line options	36
10.1	Introduction	36
10.2	Selecting and parsing the semantic patch	37
10.2.1	Standalone options	37
10.2.2	The semantic patch	37
10.2.3	Isomorphisms	37
10.2.4	Display options	37
10.3	Selecting and parsing the C files	38
10.3.1	Standalone options	38
10.3.2	Selecting C files	38
10.3.3	Parsing C files	40
10.4	Application of the semantic patch to the C code	42
10.4.1	Feedback at the rule level during the application of the semantic patch	42
10.4.2	Feedback at the CTL level during the application of the semantic patch	42
10.4.3	Actions during the application of the semantic patch	43
10.5	Generation of the result	44
10.6	Other options	45
10.6.1	Version information	45
10.6.2	Help	45
10.6.3	Controlling the execution of Coccinelle	45
10.6.4	Parallelism	45
10.6.5	External analyses	46
10.6.6	Miscellaneous	46
III	Appendix	47

Foreword

This manual documents the release 1.0.4 of Coccinelle. It is organized as follows:

- Part I is an introduction to Coccinelle
- Part II is the reference description of Coccinelle, its language and command line tool.

Conventions

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Availability

Coccinelle can be freely downloaded from <http://coccinelle.lip6.fr>.

This website contains also additional information and a wiki website.

Part I

User Manual

Chapter 1

Introduction

Coccinelle is a tool to help automate repetitive source-to-source style-preserving program transformations on C source code, like for instance to perform some refactorings. Coccinelle is presented as a command line tool called `spatch` that takes as input the name of a file containing the specification of a program transformation, called a *semantic patch*, and a set of C files, and then performs the transformation on all those C files.

To make it easy to express those transformations, Coccinelle proposes a WYSISWYG approach where the C programmer can leverage the things he already knows: the C syntax and the patch syntax. Indeed, with Coccinelle transformations are written in a specific language called SmPL, for Semantic Patch Language, which as its name suggests is very close to the syntax of a patch, but does not work at a line level, as traditional patches do, but rather at higher, semantic level.

Here is an example of a simple program transformation. To replace every call to `foo` of any expression x by a call to `bar`, create a semantic patch file `ex1.cocci` (semantic patches usually end with the `.cocci` filename extension) containing:

```
@@ expression x; @@  
  
- foo(x)  
+ bar(x)
```

Then to “apply” the specified program transformation to a set of C files, simply do:

```
$ spatch -sp_file ex1.cocci *.c
```

Coccinelle primarily targets ANSI C, and supports some GCC extensions. It has only partial support for K&R C. K&R function declarations are only recognized if the parameter declarations are indented. Furthermore, the parameter names are subsequently considered to be type names, due to confusion with function prototypes, in which a name by itself is indeed the name of a type.

Chapter 2

Installing Coccinelle

2.1 Requirements

2.2 Getting Coccinelle

2.3 Compiling Coccinelle

2.4 Running Coccinelle

Chapter 3

Tutorial

Chapter 4

Examples

4.1 Examples

This section presents a range of examples. Each example is presented along with some C code to which it is applied. The description explains the rules and the matching process.

4.1.1 Function renaming

One of the primary goals of Coccinelle is to perform software evolution. For instance, Coccinelle could be used to perform function renaming. In the following example, every occurrence of a call to the function `foo` is replaced by a call to the function `bar`.

Before	Semantic patch	After
<pre>1 #DEFINE TEST "foo" 2 3 printf("foo"); 4 5 int main(int i) { 6 //Test 7 int k = foo(); 8 9 if(1) { 10 foo(); 11 } else { 12 foo(); 13 } 14 15 foo(); 16 }</pre>	<pre>1 @@ 2 3 @@ 4 5 6 - foo() 7 + bar()</pre>	<pre>1 #DEFINE TEST "foo" 2 3 printf("foo"); 4 5 int main(int i) { 6 //Test 7 int k = bar(); 8 9 if(1) { 10 bar(); 11 } else { 12 bar(); 13 } 14 15 bar(); 16 }</pre>

4.1.2 Removing a function argument

Another important kind of evolution is the introduction or deletion of a function argument. In the following example, the rule `rule1` looks for definitions of functions having return type `irqreturn_t` and two parameters. A second *anonymous* rule then looks for calls to the previously matched functions that have three arguments. The third argument is then removed to correspond to the new function prototype.

```
1 @ rule1 @
2 identifier fn;
3 identifier irq, dev_id;
4 typedef irqreturn_t;
5 @@
6
7 static irqreturn_t fn (int irq, void *dev_id)
8 {
9     ...
10 }
11
12 @@
13 identifier rule1.fn;
14 expression E1, E2, E3;
15 @@
16
17 fn(E1, E2
18 - ,E3
19 )
```

drivers/atm/firestream.c at line 1653 before transformation

```
1 static void fs_poll (unsigned long data)
2 {
3     struct fs_dev *dev = (struct fs_dev *) data;
4
5     fs_irq (0, dev, NULL);
6     dev->timer.expires = jiffies + FS_POLL_FREQ;
7     add_timer (&dev->timer);
8 }
```

drivers/atm/firestream.c at line 1653 after transformation

```
1 static void fs_poll (unsigned long data)
2 {
3     struct fs_dev *dev = (struct fs_dev *) data;
4
5     fs_irq (0, dev);
6     dev->timer.expires = jiffies + FS_POLL_FREQ;
7     add_timer (&dev->timer);
8 }
```

4.1.3 Introduction of a macro

To avoid code duplication or error prone code, the kernel provides macros such as `BUG_ON`, `DIV_ROUND_UP` and `FIELD_SIZE`. In these cases, the semantic patches look for the old code pattern and replace it by the new code.

A semantic patch to introduce uses of the `DIV_ROUND_UP` macro looks for the corresponding expression, *i.e.*, $(n + d - 1)/d$. When some code is matched, the metavariables `n` and `d` are bound to their corresponding expressions. Finally, Coccinelle rewrites the code with the `DIV_ROUND_UP` macro using the values bound to `n` and `d`, as illustrated in the patch that follows.

Semantic patch to introduce uses of the `DIV_ROUND_UP` macro

```
1 @ haskernel @
2 @@
3
4 #include <linux/kernel.h>
5
6 @ depends on haskernel @
7 expression n,d;
8 @@
9
10 (
11 - ((n) + (d)) - 1) / (d))
12 + DIV_ROUND_UP(n,d)
13 |
14 - ((n) + ((d) - 1)) / (d))
15 + DIV_ROUND_UP(n,d)
16 )
```

Example of a generated patch hunk

```
1 --- a/drivers/atm/horizon.c
2 +++ b/drivers/atm/horizon.c
3 @@ -698,7 +698,7 @@ got_it:
4         if (bits)
5             *bits = (div<<CLOCK_SELECT_SHIFT) | (pre-1);
6         if (actual) {
7 -             *actual = (br + (pre<<div) - 1) / (pre<<div);
8 +             *actual = DIV_ROUND_UP(br, pre<<div);
9             PRINTD (DBG_QOS, "actual_rate:_%u", *actual);
10        }
11        return 0;
```

The `BUG_ON` macro makes an assertion about the value of an expression. However, because some parts of the kernel define `BUG_ON` to be the empty statement when debugging is not wanted, care must be taken when the asserted expression may have some side-effects, as is the case of a function call. Thus, we create a rule introducing `BUG_ON` only in the case when the asserted expression does not perform a function call.

One particular piece of code that has the form of a function call is a use of `unlikely`, which informs the compiler that a particular expression is unlikely to be true. In this case, because `unlikely` does not perform any side effect, it is safe to use `BUG_ON`. The second rule takes care of this case. It furthermore disables the isomorphism that allows a call to `unlikely` to be replaced with its argument, as then the second rule would be the same as the first one.

```

1 @@
2 expression E,f;
3 @@
4
5 (
6   if (<+... f(...) ...+>) { BUG(); }
7 |
8 - if (E) { BUG(); }
9 + BUG_ON(E);
10 )
11
12 @ disable unlikely @
13 expression E,f;
14 @@
15
16 (
17   if (<+... f(...) ...+>) { BUG(); }
18 |
19 - if (unlikely(E)) { BUG(); }
20 + BUG_ON(E);
21 )

```

For instance, using the semantic patch above, Coccinelle generates patches like the following one.

```

1 --- a/fs/ext3/balloc.c
2 +++ b/fs/ext3/balloc.c
3 @@ -232,8 +232,7 @@ restart:
4         prev = rsv;
5     }
6     printk("Window_map_complete.\n");
7 -     if (bad)
8 -         BUG();
9 +     BUG_ON(bad);
10 }
11 #define rsv_window_dump(root, verbose) \
12     __rsv_window_dump((root), (verbose), __FUNCTION__)

```

4.1.4 Look for NULL dereference

This SmPL match looks for NULL dereferences. Once an expression has been compared to NULL, a dereference to this expression is prohibited unless the pointer variable is reassigned.

Original

```
1 foo = kmalloc(1024);
2 if (!foo) {
3     printk ("Error_%s", foo->here);
4     return;
5 }
6 foo->ok = 1;
7 return;
```

Semantic match

```
1 @@
2 expression E, E1;
3 identifier f;
4 statement S1,S2,S3;
5 @@
6
7 * if (E == NULL)
8 {
9     ... when != if (E == NULL) S1 else S2
10    when != E = E1
11 * E->f
12    ... when any
13    return ...;
14 }
15 else S3
```

Matched lines

```
1 foo = kmalloc(1024);
2 if (!foo) {
3     printk ("Error %s", foo->here);
4     return;
5 }
6 foo->ok = 1;
7 return;
```

4.1.5 Reference counter: the of_xxx API

Coccinelle can embed Python code. Python code is used inside special SmPL rule annotated with `script:python`. Python rules inherit metavariables, such as identifier or token positions, from other SmPL rules. The inherited metavariables can then be manipulated by Python code.

The following semantic match looks for a call to the `of_find_node_by_name` function. This call increments a counter which must be decremented to release the resource. Then, when there is no call to `of_node_put`, no new assignment to the `device_node` variable `n` and a `return` statement is reached, a bug is detected and the position `p1` and `p2` are initialized. As the Python only depends on the positions `p1` and `p2`, it is evaluated. In the following case, some emacs Org mode data are produced. This example illustrates the various fields that can be accessed in the Python code from a position variable.

```
1 @ r exists @
2 local idexpression struct device_node *n;
3 position p1, p2;
4 statement S1,S2;
5 expression E,E1;
6 @@
7
8 (
9 if (!(n@p1 = of_find_node_by_name(...))) S1
10 |
11 n@p1 = of_find_node_by_name(...)
12 )
13 <... when != of_node_put(n)
14     when != if (...) { <+... of_node_put(n) ...+> }
15     when != true !n || ...
16     when != n = E
17     when != E = n
18 if (!n || ...) S2
19 ...>
20 (
21     return <+...n...+>;
22 |
23 return@p2 ...;
24 |
25 n = E1
26 |
27 E1 = n
28 )
29
30 @ script:python @
31 p1 << r.p1;
32 p2 << r.p2;
33 @@
34
35 print "* TODO [[view:%s::face=ovl-face1::linb=%s::colb=%s::cole=%s][inc.
    counter:%s::%s]]" % (p1[0].file,p1[0].line,p1[0].column,p1[0].column_end,
    p1[0].file,p1[0].line)
36 print "[[view:%s::face=ovl-face2::linb=%s::colb=%s::cole=%s][return]]" % (p2
    [0].file,p2[0].line,p2[0].column,p2[0].column_end)
```

Lines 13 to 17 list a variety of constructs that should not appear between a call to `of_find_node_by_name` and a buggy return site. Examples are a call to `of_node_put` (line 13) and a transition into the then branch of a conditional testing whether `n` is `NULL` (line 15). Any number of conditionals testing whether `n` is `NULL` are allowed as indicated by the use of a nest `<...>` to describe the path between the call to `of_find_node_by_name`, the return and the conditional in the pattern on line 18.

The previous semantic match has been used to generate the following lines. They may be edited using the emacs Org mode to navigate in the code from a site to another.

```

1 * TODO [[view:/linux-next/arch/powerpc/platforms/pseries/setup.c::face=ovl-
    facel::linb=236::colb=18::cole=20][inc. counter:/linux-next/arch/powerpc/
    platforms/pseries/setup.c::236]]
2 [[view:/linux-next/arch/powerpc/platforms/pseries/setup.c::face=ovl-face2::
    linb=250::colb=3::cole=9][return]]
3 * TODO [[view:/linux-next/arch/powerpc/platforms/pseries/setup.c::face=ovl-
    facel::linb=236::colb=18::cole=20][inc. counter:/linux-next/arch/powerpc/
    platforms/pseries/setup.c::236]]
4 [[view:/linux-next/arch/powerpc/platforms/pseries/setup.c::face=ovl-face2::
    linb=245::colb=3::cole=9][return]]

```

Note : Coccinelle provides some predefined Python functions, *i.e.*, `cocci.print_main`, `cocci.print_sec` and `cocci.print_secs`. One could alternatively write the following SmPL rule instead of the previously presented one.

```

1 @ script:python @
2 p1 << r.p1;
3 p2 << r.p2;
4 @@
5
6 cocci.print_main(p1)
7 cocci.print_sec(p2, "return")

```

The function `cocci.print_secs` is used when several positions are matched by a single position variable and every matched position should be printed.

Any metavariable could be inherited in the Python code. However, accessible fields are not currently equally supported among them.

4.1.6 Filtering identifiers, declarers or iterators with regular expressions

If you consider the following SmPL file which uses the regexp functionality to filter the identifiers that contain, begin or end by foo,

```
1 @anyid@
2 type t;
3 identifier id;
4 @@
5 t id () {...}
6
7 @script:python@
8 x << anyid.id;
9 @@
10 print "Identifier: %s" % x
11
12 @contains@
13 type t;
14 identifier foo =~ ".*foo";
15 @@
16 t foo () {...}
17
18 @script:python@
19 x << contains.foo;
20 @@
21 print "Contains foo: %s" % x
```

```
23 @endsby@
24 type t;
25 identifier foo =~ ".*foo$";
26 @@
27
28 t foo () {...}
29
30 @script:python@
31 x << endsby.foo;
32 @@
33 print "Ends by foo: %s" % x
34
35 @beginsby@
36 type t;
37 identifier foo =~ "^foo";
38 @@
39 t foo () {...}
40
41 @script:python@
42 x << beginsby.foo;
43 @@
44 print "Begins by foo: %s" % x
```

and the following C program, on the left, which defines the functions foo, bar, foobar, barfoobar and barfoo, you will get the result on the right.

```
1 int foo () { return 0; }
2 int bar () { return 0; }
3 int foobar () { return 0; }
4 int barfoobar () { return 0; }
5 int barfoo () { return 0; }
```

```
1 Identifier: foo
2 Identifier: bar
3 Identifier: foobar
4 Identifier: barfoobar
5 Identifier: barfoo
6 Contains foo: foo
7 Contains foo: foobar
8 Contains foo: barfoobar
9 Contains foo: barfoo
10 Ends by foo: foo
11 Ends by foo: barfoo
12 Begins by foo: foo
13 Begins by foo: foobar
```

4.2 Tips and Tricks

This section presents some tips and tricks for using Coccinelle.

4.2.1 How to remove useless parentheses?

If you want to rewrite any access to a pointer value by a function call, you may use the following semantic patch.

```
1 - a = *b
```



```
2 + a = readb(b)
```

However, if for some reason your code looks like `bar = *(foo)`, you will end up with `bar = readb((foo))` as the extra parentheses around `foo` are captured by the metavariable `b`.

In order to generate better output code, you can use the following semantic patch instead.

```
1 - a = *(b)
2 + a = readb(b)
```

And rely on your `standard.iso` isomorphism file which should contain:

```
1 Expression
2 @ paren @
3 expression E;
4 @@
5
6 (E) => E
```

Coccinelle will then consider `bar = *(foo)` as equivalent to `bar = *foo` (but not the other way around) and capture both. Finally, it will generate `bar = readb(foo)` as expected.

Chapter 5

Isomorphisms and `standard.iso`

Chapter 6

Parsing C, cpp, and standard.h

Chapter 7

Developing a Semantic Patch

Chapter 8

Advanced Features

Part II

Reference Manual

Chapter 9

SmPL grammar

This document presents the grammar of the SmPL language used by the Coccinelle tool. For the most part, the grammar is written using standard notation. In some rules, however, the left-hand side is in all uppercase letters. These are macros, which take one or more grammar rule right-hand-sides as arguments. The grammar also uses some unspecified nonterminals, such as `id`, `const`, etc. These refer to the sets suggested by the name, *i.e.*, `id` refers to the set of possible C-language identifiers, while `const` refers to the set of possible C-language constants.

A square bracket that is surrounded by spaces in the description of a term should appear explicitly in the term, as in an array reference. On the other hand, square brackets that surround some other term indicate that the presence of that term is optional.

A HTML version of this documentation is available online at http://coccinelle.lip6.fr/docs/main_grammar.html.

9.1 Program

```
program      ::= include_cocci* changeset+
include_cocci ::= include string
               | using string
               | using pathToIsoFile
               | virtual id (, id)*
changeset    ::= metavariables transformation
               | script_metavariables script_code
```

`script_code` is any code in the chosen scripting language. Parsing of the semantic patch does not check the validity of this code; any errors are first detected when the code is executed. Furthermore, `@` should not be used in this code. Spatch scans the script code for the next `@` and considers that to be the beginning of the next rule, even if `@` occurs within e.g., a comment.

`virtual` keyword is used to declare virtual rules. Virtual rules may be subsequently used as a dependency for the rules in the SmPL file. Whether a virtual rule is defined or not is controlled by the `-D` option on the command line.

9.2 Metavariables for transformations

The *rulename* portion of the metavariable declaration can specify properties of a rule such as its name, the names of the rules that it depends on, the isomorphisms to be used in processing the rule, and whether quantification over paths should be universal or existential. The optional annotation *expression* indicates that the pattern is to be considered as matching an expression, and thus can be used to avoid some parsing problems.

The *metadecl* portion of the metavariable declaration defines various types of metavariables that will be used for matching in the transformation section.

```

metavariables      ::= @@ metadect* @@
                    | @ rulename @ metadect* @@
rulename           ::= id [extends id] [depends on dep] [iso] [disable-iso] [exists] [expression]
dep                ::= id
                    | !id
                    | ! (dep)
                    | ever id
                    | never id
                    | dep && dep
                    | dep || dep
                    | (dep)
iso                ::= using string (, string)*
disable-iso        ::= disable COMMA_LIST(id)
exists             ::= exists
                    | forall
COMMA_LIST(elem)   ::= elem (, elem)*

```

The keyword `disable` is normally used with the names of isomorphisms defined in `standard.iso` or whatever isomorphism file has been included. There are, however, some other isomorphisms that are built into the implementation of Coccinelle and that can be disabled as well. Their names are given below. In each case, the text describes the standard behavior. Using *disable-iso* with the given name disables this behavior.

- `optional_storage`: A SmPL function definition that does not specify any visibility (i.e., static or extern), or a SmPL variable declaration that does not specify any storage (i.e., auto, static, register, or extern), matches a function declaration or variable declaration with any visibility or storage, respectively.
- `optional_qualifier`: This is similar to `optional_storage`, except that here it is the qualifier (i.e., const or volatile) that does not have to be specified in the SmPL code, but may be present in the C code.
- `optional_attributes`: This is similar to `optional_attributes`, except that here it is an attribute (e.g., `__init`) that does not have to be specified in the SmPL code, but may be present in the C code. **Note that this isomorphism is currently useless, because matching of attributes is not supported, due to the difficulty of parsing attributes in C code.**
- `value_format`: Integers in various formats, e.g., 1 and 0x1, are considered to be equivalent in the matching process.
- `optional_declarer_semicolon`: Some declarers (top-level terms that look like function calls but serve to declare some variable) don't require a semicolon. This isomorphism allows a SmPL declarer with a semicolon to match such a C declarer, if no transformation is specified on the SmPL semicolon.
- `comm_assoc`: An expression of the form *exp bin_op . . .*, where *bin_op* is commutative and associative, is considered to match any top-level sequence of *bin_op* operators containing *exp* as the top-level argument.
- `prototypes`: A rule for transforming a function prototype is generated when a function header changes.

The possible types of metavariable declarations are defined by the grammar rule below. Metavariables should occur at least once in the transformation code immediately following their declaration. Fresh identifier metavariables must only be used in + code. These properties are not expressed in the grammar, but are checked by a subsequent analysis. The metavariables are designated according to the kind of terms they can match, such as a statement, an identifier, or an expression. An expression metavariable can be further constrained by its type. A declaration metavariable matches the declaration of one or more variables, all sharing the same type specification (e.g., `int a,b,c=3;`). A field metavariable does the same, but for structure fields. In the minus code, a statement list metavariable can only appear as a complete function body or as the complete body of a sequence statement. In the plus code, a statement list metavariable can occur anywhere a statement list is allowed, i.e., including as an element of another statement list.


```

metadecl ::= metavariable ids ;
          | fresh identifier ids ;
          | identifier COMMA_LIST(pmid_with_regexp) ;
          | identifier COMMA_LIST(pmid_with_virt_or_not_eq) ;
          | parameter [list] ids ;
          | parameter list [ id ] ids ;
          | parameter list [ const ] ids ;
          | type ids ;
          | statement [list] ids ;
          | declaration ids ;
          | field [list] ids ;
          | typedef ids ;
          | attribute ids ;
          | declarer name ids ;
          | declarer COMMA_LIST(pmid_with_regexp) ;
          | declarer COMMA_LIST(pmid_with_not_eq) ;
          | iterator name ids ;
          | iterator COMMA_LIST(pmid_with_regexp) ;
          | iterator COMMA_LIST(pmid_with_not_eq) ;
          | [local | global] idexpression [ctype] COMMA_LIST(pmid_with_not_eq) ;
          | [local | global] idexpression [{ctypes} *] COMMA_LIST(pmid_with_not_eq) ;
          | [local | global] idexpression *+ COMMA_LIST(pmid_with_not_eq) ;
          | expression list ids ;
          | expression *+ COMMA_LIST(pmid_with_not_eq) ;
          | expression enum * COMMA_LIST(pmid_with_not_eq) ;
          | expression struct * COMMA_LIST(pmid_with_not_eq) ;
          | expression union * COMMA_LIST(pmid_with_not_eq) ;
          | expression COMMA_LIST(pmid_with_not_ceq) ;
          | expression list [ id ] ids ;
          | expression list [ const ] ids ;
          | ctype [ ] COMMA_LIST(pmid_with_not_eq) ;
          | ctype COMMA_LIST(pmid_with_not_ceq) ;
          | {ctypes} * COMMA_LIST(pmid_with_not_ceq) ;
          | {ctypes} * [ ] COMMA_LIST(pmid_with_not_eq) ;
          | constant [ctype] COMMA_LIST(pmid_with_not_eq) ;
          | constant [{ctypes} *] COMMA_LIST(pmid_with_not_eq) ;
          | position [any] COMMA_LIST(pmid_with_not_eq_mid) ;
          | symbol ids;
          | format ids;
          | format list [ id ] ids ;
          | format list [ const ] ids ;
          | assignment operator COMMA_LIST(assignopdecl) ;
          | binary operator COMMA_LIST(binopdecl) ;
assignopdecl ::= id [ = assignop_constraint]
assignop_constraint ::= {COMMA_LIST(assign_op)}
                  | assign_op
binopdecl ::= id [ = binop_constraint]
binop_constraint ::= {COMMA_LIST(bin_op)}
                  | bin_op

```

A metavariable declaration local idexpression *v* means that *v* is restricted to be a local variable. If it should just be

a variable, but not necessarily a local one, then drop local. A more complex description of a location, such as `a->b` is considered to be an expression, not an idexpression.

Constant is for constants, such as 27. But it also considers an identifier that is all capital letters (possibly containing numbers) as a constant as well, because the names given to macros in Linux usually have this form.

An identifier is the name of a structure field, a macro, a function, or a variable. Is is the name of something rather than an expression that has a value. But an identifier can be used in the position of an expression as well, where it represents a variable.

It is possible to specify that an expression list or a parameter list metavariable should match a specific number of expressions or parameters.

It is possible to specify some information about the definition of a fresh identifier. See the wiki.

A symbol declaration specifies that the provided identifiers should be considered C identifiers when encountered in the body of the rule. Identifiers in the body of the rule that are not declared explicitly are by default considered symbols, thus symbol declarations are optional.

An attribute declaration indicates a name that should be considered to be an attribute. It is not possible to match or remove an attribute, only to add one.

A position metavariable is used by attaching it using `@` to any token, including another metavariable. Its value is the position (file, line number, etc.) of the code matched by the token. It is also possible to attach expression, declaration, type, initialiser, and statement metavariables in this manner. In that case, the metavariable is bound to the closest enclosing expression, declaration, etc. If such a metavariable is itself followed by a position metavariable, the position metavariable applies to the metavariable that it follows, and not to the attached token. This makes it possible to get eg the starting and ending position of `f (. . .)`, by writing `f (. . .) @E@p`, for expression metavariable `E` and position metavariable `p`.

When used, a format or format list metavariable must be enclosed by a pair of `@s`. A format metavariable matches the format descriptor part, i.e., `2x` in `%2x`. A format list metavariable matches a sequence of format descriptors as well as the text between them. Any text around them is matched as well, if it is not matched by the surrounding text in the semantic patch. Such text is not partially matched. If the length of the format list is specified, that indicates the number of matched format descriptors. It is also possible to use `. . .` in a format string, to match a sequence of text fragments and format descriptors. This only takes effect if the format string contains format descriptors. Note that this makes it impossible to require `. . .` to match exactly in a string, if the semantic patch string contains format descriptors. If that is needed, some processing with a scripting language would be required. An example for the use of string format metavariables is found in `demos/format.cocci`.

Assignment (resp. binary) operator metavariables match any assignment (resp. binary) operator. The list of operators that can be matched can be restricted by adding an operator constraint, i.e. a list of accepted operators.

Other kinds of metavariables can also be attached using `@` to any token. In this case, the metavariable floats up to the enclosing appropriate expression. For example, `3 +@E 4`, where `E` is an expression metavariable binds `E` to `3 + 4`. A particular case is `Ps@Es`, where `Ps` is a parameter list and `Es` is an expression list. This pattern matches a parameter list, and then matches `Es` to the list of expressions, ie a possible argument list, represented by the names of the parameters. Another particular case is `E@S`, where `E` is any expression and `S` is a statement metavariable. `S` matches the closest enclosing statement, which may be more than what is matched by the semantic match pattern itself.

Matching of various kinds of format strings within strings is supported. With the `-ibm` option, matching of decimal format declarations is supported, but the length and precision arguments are not interpreted. Thus it is not possible to match metavariables in these fields. Instead, the entire format is matched as a single string.

```

ids          ::= COMMA_LIST(pmid)
pmid         ::= id
              | mid
mid          ::= rulename_id.id
pmid_with_regexp ::= pmid =~ regexp
              | pmid !~ regexp
pmid_with_not_eq ::= pmid [!= id_or_meta]
              | pmid [!= { COMMA_LIST(id_or_meta) }]
pmid_with_virt_or_not_eq ::= virtual.id
              | pmid_with_not_eq
pmid_with_not_ceq ::= pmid [!= id_or_cst]
              | pmid [!= { COMMA_LIST(id_or_cst) }]
id_or_cst    ::= id
              | integer
id_or_meta   ::= id
              | rulename_id.id
pmid_with_not_eq_mid ::= pmid [!= mid]
              | pmid [!= { COMMA_LIST(mid) }]

```

Subsequently, we refer to arbitrary metavariables as metaid^{ty} , where ty indicates the *metakind* used in the declaration of the variable. For example, $\text{metaid}^{\text{Type}}$ refers to a metavariable that was declared using `type` and stands for any type.

`metavariable` declares a metavariable for which the parser tried to figure out the metavariable type based on the usage context. Such a metavariable must be used consistently. These metavariables cannot be used in all contexts; specifically, they cannot be used in context that would make the parsing ambiguous. Some examples are the leftmost term of an expression, such as the left-hand side of an assignment, or the type in a variable declaration. These restrictions may seem somewhat arbitrary from the user's point of view. Thus, it is better to use metavariables with metavariable types. If Coccinelle is given the argument `-parse_cocci`, it will print information about the type that is inferred for each metavariable.

The *c_type* and *ctypes* nonterminals are used by both the grammar of metavariable declarations and the grammar of transformations, and are defined on page 29.

An identifier metavariable with `virtual` as its “rule name” is given a value on the command line. For example, if a semantic patch contains a rule that declares an identifier metavariable with the name `virtual.alloc`, then the command line could contain `-D alloc=kmalloc`. There should not be space around the `=`. An example is in `demos/vm.cocci` and `demos/vm.c`.

It is possible to give an identifier metavariable a list of constraints that it should or should not be equal to. If the constraint is a list of (unquoted) strings, then the value of the metavariable should be the same as one of the strings, in the case of an equality constraint, or different from all of the strings, in the case of an inequality constraint. It is also possible to include inherited identifier metavariables among the constraints. In the case of a positive constraint, things work in the same way, but not with respect to the inherited value of the metavariable. On the other hand, an inequality constraint does not work so well, because the only value available is the one available in the current environment. If the proposed value is different from the one in the current environment, but perhaps the same as the one in some other environment, the match will still succeed.

Warning: Each metavariable declaration causes the declared metavariables to be immediately usable, without any inheritance indication. Thus the following are correct:

```

@@
type r.T;
T x;
@@

```

```

[...] // some semantic patch code

@@
r.T x;
type r.T;
@@

[...] // some semantic patch code

```

But the following is not correct:

```

@@
type r.T;
r.T x;
@@

[...] // some semantic patch code

```

This applies to position variables, type metavariables, identifier metavariables that may be used in specifying a structure type, and metavariables used in the initialization of a fresh identifier. In the case of a structure type, any identifier metavariable indeed has to be declared as an identifier metavariable in advance. The syntax does not permit `r.n` as the name of a structure or union type in such a declaration.

9.3 Metavariables for scripts

Metavariables for scripts can only be inherited from transformation rules. In the spirit of scripting languages such as Python that use dynamic typing, metavariables for scripts do not include type declarations.

```

script_metavariables ::= @ script:language [rulename] [depends on dep] @ script_metaddecl* @@
                        | @ initialize:language [depends on dep] @ script_virt_metaddecl* @@
                        | @ finalize:language [depends on dep] @ script_virt_metaddecl* @@
language              ::= python
                        | ocaml
script_metaddecl      ::= id << rulename_id.id ;
                        | id << rulename_id.id = "... " ;
                        | id << rulename_id.id = [ ] ;
                        | id ;
script_virt_metaddecl ::= id << virtual.id ;

```

Currently, the only scripting languages that are supported are Python and OCaml, indicated using `python` and `ocaml`, respectively. The set of available scripting languages may be extended at some point.

Script rules declared with `initialize` are run before the treatment of any file. Script rules declared with `finalize` are run when the treatment of all of the files has completed. There can be at most one of each per scripting language (thus currently at most one of each). Initialize and finalize script rules do not have access to SmPL metavariables. Nevertheless, a finalize script rule can access any variables initialized by the other script rules, allowing information to be transmitted from the matching process to the finalize rule.

Initialize and finalize rules do have access to virtual metavariables, using the usual syntax. As for other scripting language rules, the rule is not run (and essentially does not exist) if some of the required virtual metavariables are not bound. In ocaml, a warning is printed in this case. An example is found in `demos/initvirt.cocci`.

A script metavariable that does not specify an origin, using `<<`, is newly declared by the script. This metavariable should be assigned to a string and can be inherited by subsequent rules as an identifier. In Python, the assignment of such a metavariable `x` should refer to the metavariable as `coccinelle.x`. Examples are in the files `demos/pythontococci.cocci` and `demos/camltococci.cocci`.

In an OCaml script, the following extended form of *script_metaddecl* may be used:

```

script_metadecl' ::= (id,id) << rulename_id.id ;
                  | id << rulename_id.id ;
                  | id ;

```

In a declaration of the form `(id,id) << rulename_id.id ;`, the left component of `(id,id)` receives a string representation of the value of the inherited metavariable while the right component receives its abstract syntax tree. The file `parsing_c/ast_c.ml` in the Coccinelle implementation gives some information about the structure of the abstract syntax tree. Either the left or right component may be replaced by `_`, indicating that the string representation or abstract syntax trees representation is not wanted, respectively.

The abstract syntax tree of a metavariable declared using `metavariable` is not available.

Script metavariables can have default values. This is only allowed if the abstract syntax tree of the metavariable is not requested. The default value of a position metavariable is written as `[]`. The default value of any other kind of metavariable is a string. There is no control that the string actually represents the kind of term represented by the metavariable. Normally, a script rule is only applied if all of the metavariables have values. If default values are provided, then the script rule is only applied if all of the metavariables for which there are no default values have values. See `demos/defaultscript.cocci` for examples of the use of this feature.

9.4 Transformation

The transformation specification essentially has the form of C code, except that lines to remove are annotated with `-` in the first column, and lines to add are annotated with `+`. A transformation specification can also use *dots*, “`...`”, describing an arbitrary sequence of function arguments or instructions within a control-flow path. Implicitly, “`...`” matches the shortest path between something that matches the pattern before the dots (or the beginning of the function, if there is nothing before the dots) and something that matches the pattern after the dots (or the end of the function, if there is nothing after the dots). Dots may be modified with a `when` clause, indicating a pattern that should not occur anywhere within the matched sequence. `when any` removes the aforementioned constraint that “`...`” matches the shortest path. Finally, a transformation can specify a disjunction of patterns, of the form `(pat1 | ... | patn)` where each `(, | or)` is in column 0 or preceded by `\`.

The grammar that we present for the transformation is not actually the grammar of the SmPL code that can be written by the programmer, but is instead the grammar of the slice of this consisting of the `-` annotated and the unannotated code (the context of the transformed lines), or the `+` annotated code and the unannotated code. For example, for parsing purposes, the following transformation is split into the two variants shown below and each is parsed separately.

```

1  proc_info_func(...) {
2      <...
3  -   hostno
4  +   hostptr->host_no
5      ...>
6  }

```

```

1  proc_info_func(...) {
2      <...
3  -   hostno
4      ...>
5  }

```

```

1  proc_info_func(...) {
2      <...
3  +   hostptr->host_no
4      ...>
5  }

```

Requiring that both slices parse correctly ensures that the rule matches syntactically valid C code and that it produces syntactically valid C code. The generated parse trees are then merged for use in the subsequent matching and transformation process.

The grammar for the minus or plus slice of a transformation is as follows:

```

transformation ::= include+
                | OPTDOTSEQ(top, when)
include        ::= #include include_string
top            ::= expr
                | decl_stmt+
                | fundecl
when           ::= when != when_code
                | when = rule_elem_stmt
                | when COMMA_LIST(any_strict)
                | when true != expr
                | when false != expr
when_code      ::= OPTDOTSEQ(decl_stmt+, when)
                | OPTDOTSEQ(expr, when)
rule_elem_stmt ::= one_decl
                | expr;
                | return [expr];
                | break;
                | continue;
                | \ (rule_elem_stmt (\ | rule_elem_stmt)+ \)
any_strict     ::= any
                | strict
                | forall
                | exists

```

$OPTDOTSEQ(grammar_ds, when_ds) ::= [\dots (when_ds)^*] grammar_ds (\dots (when_ds)^* grammar_ds)^* [\dots (when_ds)^*]$

Lines may be annotated with an element of the set $\{-, +, *\}$ or the singleton $?$, or one of each set. $?$ represents at most one match of the given pattern, i.e. a match of the pattern is optional. $*$ is used for semantic match, i.e., a pattern that highlights the fragments annotated with $*$, but does not perform any modification of the matched code. $*$ cannot be mixed with $-$ and $+$. There are some constraints on the use of these annotations:

- Dots, i.e. \dots , cannot occur on a line marked $+$.
- Nested dots, i.e., dots enclosed in $<$ and $>$, cannot occur on a line marked $+$.

Each element of a disjunction must be a proper term like an expression, a statement, an identifier or a declaration. Thus, the rule on the left below is not a syntactically correct SmPL rule. One may use the rule on the right instead.

<pre> 1 @@ 2 type T; 3 T b; 4 @@ 5 6 (7 writeb(..., 8 9 readb(..., 10) 11 - (T) 12 b) </pre>	<pre> 1 @@ 2 type T; 3 T b; 4 @@ 5 6 (7 read 8 9 write 10) 11 (... , 12 - (T) 13 b) </pre>
---	---

Some kinds of terms can only appear in $+$ code. These include comments, ifdefs, and attributes (`__attribute__((...))`).

9.5 Types

<i>ctypes</i>	::= <i>COMMA_LIST</i> (<i>ctype</i>)
<i>ctype</i>	::= [<i>const_vol</i>] <i>generic_ctype</i> * [*] [<i>const_vol</i>] void * ⁺ (<i>ctype</i> (<i>ctype</i>) [*])
<i>const_vol</i>	::= const volatile
<i>generic_ctype</i>	::= <i>ctype_qualif</i> [<i>ctype_qualif</i>] char [<i>ctype_qualif</i>] short [<i>ctype_qualif</i>] short int [<i>ctype_qualif</i>] int [<i>ctype_qualif</i>] long [<i>ctype_qualif</i>] long int [<i>ctype_qualif</i>] long long [<i>ctype_qualif</i>] long long int double long double float size_t ssize_t ptrdiff_t enum <i>id</i> { <i>PARAMSEQ</i> (<i>dot_expr</i> , <i>exp_whencode</i>) [,] } [struct union] <i>id</i> [{ <i>struct_decl_list</i> * }]
<i>ctype_qualif</i>	::= unsigned signed
<i>struct_decl_list</i>	::= <i>struct_decl_list_start</i>
<i>struct_decl_list_start</i>	::= <i>struct_decl</i> <i>struct_decl struct_decl_list_start</i> ... [when != <i>struct_decl</i>] [†] [<i>continue_struct_decl_list</i>]
<i>continue_struct_decl_list</i>	::= <i>struct_decl struct_decl_list_start</i> <i>struct_decl</i>
<i>struct_decl</i>	::= <i>ctype d_ident</i> ; <i>fn_ctype</i> (* <i>d_ident</i>) (<i>PARAMSEQ</i> (<i>name_opt_decl</i> , <i>ε</i>)); [<i>const_vol</i>] <i>id d_ident</i> ;
<i>d_ident</i>	::= <i>id</i> [[<i>expr</i>]] [*]
<i>fn_ctype</i>	::= <i>generic_ctype</i> * [*] void * [*]
<i>name_opt_decl</i>	::= <i>decl</i> <i>ctype</i> <i>fn_ctype</i>

[†] The optional when construct ends at the end of the line.

9.6 Function declarations

```

fundecl ::= [fn_ctype] funinfo* funid ([PARAMSEQ(param,  $\varepsilon$ )] { [stmt_seq] }
funproto ::= [fn_ctype] funinfo* funid ([PARAMSEQ(param,  $\varepsilon$ )] );
funinfo ::= inline
           | storage
storage ::= static
           | auto
           | register
           | extern
funid ::= id
          | metaidld
          | OR(stmt)
param ::= type id
          | metaidParam
          | metaidParamList
          | .....
decl ::= ctype id
         | fn_ctype (* id) (PARAMSEQ(name_opt_decl,  $\varepsilon$ ))
         | void
         | metaidParam

PARAMSEQ(gram_p, when_p) ::= COMMA_LIST(gram_p | ... [when_p])

```

To match a function it is not necessary to provide all of the annotations that appear before the function name. For example, the following semantic patch:

```

1 @@
2 @@
3
4 foo() { ... }

```

matches a function declared as follows:

```

1 static int foo() { return 12; }

```

This behavior can be turned off by disabling the `optional_storage` isomorphism. If one adds code before a function declaration, then the effect depends on the kind of code that is added. If the added code is a function definition or CPP code, then the new code is placed before all information associated with the function definition, including any comments preceding the function definition. On the other hand, if the new code is associated with the function, such as the addition of the keyword `static`, the new code is placed exactly where it appears with respect to the rest of the function definition in the semantic patch. For example,

```

1 @@
2 @@
3
4 + static
5 foo() { ... }

```

causes `static` to be placed just before the function name. The following causes it to be placed just before the type

```

1 @@
2 type T;
3 @@
4
5 + static
6 T foo() { ... }

```


It may be necessary to consider several cases to ensure that the added ode is placed in the right position. For example, one may need one pattern that considers that the function is declared `inline` and another that considers that it is not.

Varargs are written in C using `...`. Unfortunately, this notation is already used in the semantic patch language. A pattern for a varargs parameter is written as a sequence of 6 dots.

The C parser allows functions that have no return type, and assumes that the return type is `int`. The support for parsing such functions is limited. In particular, the parameter list must contain a type for each parameter, and may not contain varargs.

9.7 Declarations

```

decl_var      ::= common_decl
                | [storage] ctype COMMA_LIST(d_ident) ;
                | [storage] [const_vol] id COMMA_LIST(d_ident) ;
                | [storage] fn_ctype ( * d_ident ) ( PARAMSEQ(name_opt_decl, ε) ) = initialize ;
                | typedef ctype typedef_ident ;
one_decl      ::= common_decl
                | [storage] ctype id;
                | [storage] [const_vol] id d_ident ;
common_decl   ::= ctype;
                | funproto
                | [storage] ctype d_ident = initialize ;
                | [storage] [const_vol] id d_ident = initialize ;
                | [storage] fn_ctype ( * d_ident ) ( PARAMSEQ(name_opt_decl, ε) ) ;
                | decl_ident ( [COMMA_LIST(expr)] ) ;
initialize    ::= dot_expr
                | metaidInitialiser
                | { [COMMA_LIST(init_list_elem)] }
init_list_elem ::= dot_expr
                | designator = initialize
                | metaidInitialiser
                | metaidInitialiserList
                | id : dot_expr
designator      ::= . id
                | [ dot_expr ]
                | [ dot_expr ... dot_expr ]
decl_ident     ::= DeclarerId
                | metaidDeclarer

```

An initializer for a structure can be ordered or unordered. It is considered to be unordered if there is at least one key-value pair initializer, e.g., `.x = e`.

A declaration can have e.g. the form `register x;`. In this case, the variable implicitly has type `int`, and SmPL code that declares an `int` variable will match such a declaration. On the other hand, the implicit `int` type has no position. If the SmPL code tries to record the position of the type, the match will fail.

9.8 Statements

The first rule *statement* describes the various forms of a statement. The remaining rules implement the constraints that are sensitive to the context in which the statement occurs: *single_statement* for a context in which only one statement is allowed, and *decl_statement* for a context in which a declaration, statement, or sequence thereof is allowed.

```

stmt ::= directive
      | metaidStmt
      | expr;
      | if (dot_expr) single_stmt [else single_stmt]
      | for ([dot_expr]; [dot_expr]; [dot_expr]) single_stmt
      | while (dot_expr) single_stmt
      | do single_stmt while (dot_expr) ;
      | iter_ident (dot_expr*) single_stmt
      | switch ([dot_expr] {case_line* }
      | return [dot_expr];
      | { [stmt_seq] }
      | NEST(decl_stmt+, when)
      | NEST(expr, when)
      | break;
      | continue;
      | id:
      | goto id;
      | {stmt_seq }

directive ::= include
      | #define id [top]
      | #define id (PARAMSEQ(id,  $\varepsilon$ )) [top]
      | #undef id
      | #pragma id id+
      | #pragma id (PARAMSEQ(expr,  $\varepsilon$ ))
      | #pragma id ...

single_stmt ::= stmt
      | OR(stmt)

decl_stmt ::= metaidStmtList
      | decl_var
      | stmt
      | OR(stmt_seq)

stmt_seq ::= decl_stmt* [DOTSEQ(decl_stmt+, when) decl_stmt*]
      | decl_stmt* [DOTSEQ(expr, when) decl_stmt*]

case_line ::= default : stmt_seq
      | case dot_expr : stmt_seq

iter_ident ::= iteratorId
      | metaidIterator

OR(gram_o) ::= ( gram_o (| gram_o)*)
DOTSEQ(gram_d, when_d) ::= ... [when_d] (gram_d ... [when_d])*
NEST(gram_n, when_n) ::= <... [when_n] gram_n (... [when_n] gram_n)* ...>
      | <+... [when_n] gram_n (... [when_n] gram_n)* ...+>

```

OR is a macro that generates a disjunction of patterns. The three tokens (, |, and) must appear in the leftmost column, to differentiate them from the parentheses and bit-or tokens that can appear within expressions (and cannot appear in the leftmost column). These token may also be preceded by \ when they are used in an other column. These tokens are furthermore different from (, |, and), which are part of the grammar metalanguage.

9.9 Expressions

A nest or a single ellipsis is allowed in some expression contexts, and causes ambiguity in others. For example, in a sequence ...*expr* ..., the nonterminal *expr* must be instantiated as an explicit C-language expression, while

in an array reference, $expr_1 [expr_2]$, the nonterminal $expr_2$, because it is delimited by brackets, can be also instantiated as \dots , representing an arbitrary expression. To distinguish between the various possibilities, we define three nonterminals for expressions: $expr$ does not allow either top-level nests or ellipses, $nest_expr$ allows a nest but not an ellipsis, and dot_expr allows both. The `EXPR` macro is used to express these variants in a concise way.

```

expr      ::= EXPR(expr)
nest_expr ::= EXPR(nest_expr)
           | NEST(nest_expr, exp_whencode)
dot_expr  ::= EXPR(dot_expr)
           | NEST(dot_expr, exp_whencode)
           | ... [exp_whencode]
EXPR(exp) ::= exp assign_op exp
           | exp metaidAssignOp exp
           | exp++
           | exp--
           | unary_op exp
           | exp bin_op exp
           | exp metaidBinOp exp
           | exp ? dot_expr : exp
           | (type) exp
           | exp [dot_expr]
           | exp . id
           | exp -> id
           | exp ([PARAMSEQ(arg, exp_whencode)])
           | id
           | (type) { COMMA_LIST(init_list_elem) }
           | metaidExp
           | metaidConst
           | const
           | (dot_expr)
           | OR(exp)
arg        ::= nest_expr
           | metaidExpList
exp_whencode ::= when != expr
assign_op  ::= = | -= | += | *= | /= | %=
           | &= | |= | ^= | <=<= | >=>=
bin_op     ::= * | / | % | + | -
           | << | >> | ^ | & | |
           | < | > | <= | >= | == | != | && | ||
unary_op   ::= ++ | -- | & | * | + | - | !

```

9.10 Constants, Identifiers and Types for Transformations

```
const      ::= string
            | [0-9]+
            | ...
string     ::= "[^"]*"
id         ::= id | metaidld | OR(stmt)
typedef_ident ::= id | metaidType
type       ::= ctype | metaidType
pathToIsoFile ::= <.*>
regex      ::= "[^"]*"

```

9.11 Comments and preprocessor directives

A `//` or `/* */` comment that is annotated with `+` in the leftmost column is considered to be added code. A `//` or `/* */` comment without such an annotation is considered to be a comment about the SmPL code, and thus is not matched in the C code.

The following preprocessor directives can likewise be added. They cannot be matched against. The entire line is added, but it is not parsed.

- `if`
- `ifdef`
- `ifndef`
- `else`
- `elif`
- `endif`
- `error`
- `line`

9.12 Command-line semantic match

It is possible to specify a semantic match on the `spatch` command line, using the argument `-sp`. In such a semantic match, any token beginning with a capital letter is assumed to be a metavariable of type `metavariable`. In this case, the parser must be able to figure out what kind of metavariable it is. It is also possible to specify the type of a metavariable by enclosing the type in `:`'s, concatenated directly to the metavariable name.

Some examples of semantic matches that can be given as an argument to `-sp` are as follows:

- `f(e)`: This only matches the expression `f(e)`.
- `f(E)`: This matches a call to `f` with any argument.
- `F(E)`: This gives a parse error; the semantic patch parser cannot figure out what kind of metavariable `F` is.
- `F:identifier:(E)`: This matches any one argument function call.
- `f:identifier:(e:struct foo *):` This matches any one argument function call where the argument has type `struct foo *`. Since the types of the metavariables are specified, it is not necessary for the metavariable names to begin with a capital letter.

- `F:identifier:(F):` This matches any one argument function call where the argument is the name of the function itself. This example shows that it is not necessary to repeat the metavariable type name.
- `F:identifier:(F:identifier:):` This matches any one argument function call where the argument is the name of the function itself. This example shows that it is possible to repeat the metavariable type name.

When constraints, *e.g.* `when != e`, are allowed but the expression `e` must be represented as a single token. The generated semantic match behaves as though there were a `*` in front of every token.

9.13 Iteration

It is possible to iterate Coccinelle, giving the subsequent iterations a different set of virtual rules or virtual identifier bindings. An example is found in `demos/iteration.cocci`. The example shown there is as follows:

```
virtual after_start

@initialize:ocaml@

let tbl = Hashtbl.create(100)

let add_if_not_present from f file =
try let _ = Hashtbl.find tbl (f,file) in ()
with Not_found ->
  Hashtbl.add tbl (f,file) file;
  let it = new iteration() in
  (match file with
   Some fl -> it#set_files [fl]
  | None -> ());
  it#add_virtual_rule After_start;
  it#add_virtual_identifier Err_ptr_function f;
  it#register()
```

The virtual rule `after_start` is used to distinguish between the first iteration (in which it is not considered to have matched) and all others. This is done by not mentioning `after_start` in the command line, but adding it on each iteration.

The main code for performing the iteration is found in the function `add_if_not_present`, between the lines calling `new iteration` and `register`. `new iteration` creates a structure representing the new iteration. `set_files` sets the list of files to be considered on the new iteration. If this function is not called, the new iteration treats the same files as the current iteration. `add_virtual_rule A` has the same effect as putting `-D a` on the command line. Note that the first letter of the rule name is capitalized, although this is not done elsewhere. `add_virtual_identifier X v` has the same effect as putting `-D x=v` on the command line. Note again the case change. `extend_virtual_identifiers()` (not shown) preserves all virtual identifiers of the current iteration that are not overridden by calls to `add_virtual_identifier`. Finally, the call to `register` queues the collected information to trigger a new iteration at some time in the future.

Modification is not allowed when using iteration. Thus, it is required to use the `-no-show-diff`, unless the semantic patch contains `*s` (a semantic match rather than a semantic patch).

The remainder of the code above uses a hash table to ensure that the same information is not enqueued more than once. Coccinelle itself provides no support for this.

Chapter 10

spatch command line options

10.1 Introduction

This document describes the options provided by Coccinelle. The options have an impact on various phases of the semantic patch application process. These are:

1. Selecting and parsing the semantic patch.
2. Selecting and parsing the C code.
3. Application of the semantic patch to the C code.
4. Transformation.
5. Generation of the result.

One can either initiate the complete process from step 1, or to perform step 1 or step 2 individually.

Coccinelle has quite a lot of options. The most common usages are as follows, for a semantic match `foo.cocci`, a C file `foo.c`, and a directory `foodir`:

- `spatch --parse-cocci foo.cocci`: Check that the semantic patch is syntactically correct.
- `spatch --parse-c foo.c`: Check that the C file is syntactically correct. The Coccinelle C parser tries to recover during the parsing process, so if one function does not parse, it will start up again with the next one. Thus, a parse error is often not a cause for concern, unless it occurs in a function that is relevant to the semantic patch.
- `spatch --sp-file foo.cocci foo.c`: Apply the semantic patch `foo.cocci` to the file `foo.c` and print out any transformations as the changes between the original and transformed code, using the program `diff`. `--sp-file` is optional in this and the following cases.
- `spatch --sp-file foo.cocci foo.c --debug`: The same as the previous case, but print out some information about the matching process.
- `spatch --sp-file foo.cocci --dir foodir`: Apply the semantic patch `foo.cocci` to all of the C files in the directory `foodir`.
- `spatch --sp-file foo.cocci --dir foodir --include-headers`: Apply the semantic patch `foo.cocci` to all of the C files and header files in the directory `foodir`.

In the rest of this document, the options are annotated as follows:

- ◆: a basic option, that is most likely of interest to all users.
- ◇: an option that is frequently used, often for better understanding the effect of a semantic patch.
- ◇: an option that is likely to be rarely used, but whose effect is still comprehensible to a user.
- An option with no annotation is likely of interest only to developers.

10.2 Selecting and parsing the semantic patch

10.2.1 Standalone options

- ◆ **--parse-cocci** *<file>* Parse a semantic patch file and print out some information about it.
- ◆ **--debug-parse-cocci** Print some information about the definition of virtual rules and the bindings of virtual identifiers. This is particularly useful when using iteration, as it prints out this information for each iteration.

10.2.2 The semantic patch

- ◆ **--sp-file** *<file>*, **-c** *<file>*, **--cocci-file** *<file>* Specify the name of the file containing the semantic patch. The file name should end in `.cocci`. All three options do the same thing. These options are optional. If they are not used, the single file whose name ends in `.cocci` is assumed to be the name of the file containing the semantic patch.
- ◇ **--sp** “semantic patch string” Specify a semantic match as a command-line argument. See the section “Command-line semantic match” in the manual.

10.2.3 Isomorphisms

- ◇ **--iso**, **--iso-file** Specify a file containing isomorphisms to be used in place of the standard one. Normally one should use the `using` construct within a semantic patch to specify isomorphisms to be used *in addition to* the standard ones.
- ◇ **--iso-limit** *<int>* Limit the depth of application of isomorphisms to the specified integer.
- ◇ **--no-iso-limit** Put no limit on the number of times that isomorphisms can be applied. This is the default.
- ◇ **--disable-iso** Disable a specific isomorphism from the command line. This option can be specified multiple times.
- track-iso** Gather information about isomorphism usage.
- profile-iso** Gather information about the time required for isomorphism expansion.

10.2.4 Display options

- ◇ **--show-cocci** Show the semantic patch that is being processed before expanding isomorphisms.
- ◇ **--show-SP** Show the semantic patch that is being processed after expanding isomorphisms.
- ◇ **--show-ctl-text** Show the representation of the semantic patch in CTL.

- ◆ **--ctl-inline-let** Sometimes `let` is used to name intermediate terms CTL representation. This option causes the let-bound terms to be inlined at the point of their reference. This option implicitly sets **--show-ctl-text**.
- ◆ **--ctl-show-mcodekind** Show transformation information within the CTL representation of the semantic patch. This option implicitly sets **--show-ctl-text**.
- ◆ **--show-ctl-tex** Create a LaTeX files showing the representation of the semantic patch in CTL.

10.3 Selecting and parsing the C files

10.3.1 Standalone options

- ◆ **--parse-c** *<file/dir>* Parse a `.c` file or all of the `.c` files in a directory. This generates information about any parse errors encountered.
 - ◆ **--parse-h** *<file/dir>* Parse a `.h` file or all of the `.h` files in a directory. This generates information about any parse errors encountered.
 - ◆ **--parse-ch** *<file/dir>* Parse a `.c` or `.h` file or all of the `.c` or `.h` files in a directory. This generates information about any parse errors encountered.
 - ◆ **--control-flow** *<file>*, **--control-flow** *<file>:<function>* Print a control-flow graph for all of the functions in a file or for a specific function in a file. This requires `dot` (<http://www.graphviz.org/>) and `gv`.
 - ◆ **--control-flow-to-file** *<file>*, **--control-flow-to-file** *<file>:<function>* Like **--control-flow** but just puts the dot output in a file in the *current* directory. For `PATH/file.c`, this produces `file:xxx.dot` for each (selected) function `xxx` in `PATH/file.c`.
 - ◆ **--type-c** *<file>* Parse a C file and pretty-print a version including type information.
- tokens-c** *<file>* Prints the tokens in a C file.
- parse-unparse** *<file>* Parse and then reconstruct a C file.
- compare-c** *<file>* *<file>*, **--compare-c-hardcoded** Compares one C file to another, or compare the file `tests/compare1.c` to the file `tests/compare2.c`.
- test-cfg-ifdef** *<file>* Do some special processing of `#ifdef` and display the resulting control-flow graph. This requires `dot` and `gv`.
- test-attributes** *<file>*, **--test-cpp** *<file>* Test the parsing of cpp code and attributes, respectively.

10.3.2 Selecting C files

An argument that ends in `.c` is assumed to be a C file to process. Normally, only one C file or one directory is specified. If multiple C files are specified, they are treated in parallel, *i.e.*, the first semantic patch rule is applied to all functions in all files, then the second semantic patch rule is applied to all functions in all files, etc. If a directory is specified then no files may be specified and only the rightmost directory specified is used.

- ◆ **--include-headers** This option causes header files to be processed independently. This option only makes sense if a directory is specified using **--dir**.

- ◆ **--use-glimpse** Use a glimpse index to select the files to which a semantic patch may be relevant. This option requires that a directory is specified. The index may be created using the script `coccinelle/scripts/glimpseindex-cocci.sh`. Glimpse is available at <http://webglimpse.net/>. In conjunction with the option **--patch-cocci** this option prints the regular expression that will be passed to glimpse.

- ◆ **--use-idutils** [*<file>*] Use an id-utils index created using lid to select the files to which a semantic patch may be relevant. This option requires that a directory is specified. The index may be created using the script `coccinelle/scripts/idindex-cocci.sh`. In conjunction with the option **--patch-cocci** this option prints the regular expression that will be passed to glimpse.
 The optional file name option is the name of the file in which to find the index. It has been reported that the viewer seascope can be used to generate an appropriate index. If no file name is specified, the default is `.id-utils.index`.

- ◆ **--use-coccigrep** Use a version of grep implemented in Coccinelle to check that selected files are relevant to the semantic patch. This option is only relevant to the case of working on a complete directory, when parallelism is requested (max and index options). Otherwise it is the default, except when multiple files are requested to be treated as a single unit. In that case grep is used.
 Note that coccigrep or grep is used even if glimpse or id-utils is selected, to account for imprecision in the index (glimpse at least does not distinguish between underline and space, leading to false positives).

- ◆ **--selected-only** Just show what files will be selected for processing.

- ◆ **--dir** Specify a directory containing C files to process. A trailing `/` is permitted on the directory name and has no impact on the result. By default, the include path will be set to the “include” subdirectory of this directory. A different include path can be specified using the option **-I**. **--dir** only considers the rightmost directory in the argument list. This behavior is convenient for creating a script that always works on a single directory, but allows the user of the script to override the provided directory with another one. Spatch collects the files in the directory using `find` and does not follow symbolic links.

- kbuild-info** *<file>* The specified file contains information about which sets of files should be considered in parallel.

- disable-worth-trying-opt** Normally, a C file is only processed if it contains some keywords that have been determined to be essential for the semantic patch to match somewhere in the file. This option disables this optimization and tries the semantic patch on all files.

- test** *<file>* A shortcut for running Coccinelle on the semantic patch “`file.cocci`” and the C file “`file.c`”. The result is put in the file `/tmp/file.res`. If writing a file in `/tmp` with a non-fresh name is a concern, then do not use this option.

- testall** A shortcut for running Coccinelle on all files in a subdirectory `tests` such that there are all of a `.cocci` file, a `.c` file, and a `.res` file, where the `.res` contains the expected result. If the argument `-()`-expected-score-file is provided, then that file is used for the result. Otherwise, the result goes in “`tests/SCORE_expected.sexp`”. **Warning:** It is intended that not all of the test cases provided with Coccinelle actually pass.

- ◆ **--test-spacing** Like **--testall**, but ensures that the spacing is the same as in the `.res` file. If the argument `-()`-expected-spacing-score-file is provided, then that file is used for the result. Otherwise, the result goes in “`tests/SCORE_spacing_expected.sexp`”.

--test-okfailed, --test-regression-okfailed Other options for keeping track of tests that have succeeded and failed.

--compare-with-expected Compare the result of applying Coccinelle to file `.c` to the file `file.res` representing the expected result.

--expected-score-file `<file>` which score file to compare with in the testall run

10.3.3 Parsing C files

- ◇ **--show-c** Show the C code that is being processed.
 - ◇ **--parse-error-msg** Show parsing errors in the C file.
 - ◇ **--verbose-parsing** Show parsing errors in the C file, as well as information about attempts to accomodate such errors. This implicitly sets **--parse-error-msg**.
 - ◇ **--parse-handler** `<file>` Loads the file containing the OCaml code in charge of parse error reporting. This function should have arguments 1) the line number containing the error, 2) the sequence of tokens, the starting and ending line of the function containing the error, and array containing the lines of the file containing the error, and the pass of the parser on which the error occurs. This function should then be passed to the function `Parse_c.set_parse_error_function`.
 - ◇ **--type-error-msg** Show information about where the C type checker was not able to determine the type of an expression.
 - ◇ **--int-bits** `<n>`, **--long-bits** `<n>` Provide integer size information. `n` is the number of bits in an unsigned integer or unsigned long, respectively. If only the option **--int-bits** is used, unsigned longs will be assumed to have twice as many bits as unsigned integers. If only the option **--long-bits** is used, unsigned ints will be assumed to have half as many bits as unsigned integers. This information is only used in determining the types of integer constants, according to the ANSI C standard (C89). If neither is provided, the type of an integer constant is determined by the sequence of “u” and “l” annotations following the constant. If there is none, the constant is assumed to be a signed integer. If there is only “u”, the constant is assumed to be an unsigned integer, etc.
 - ◇ **--no-loops** Drop back edges for loops. This may make a semantic patch/match run faster, at the cost of not finding matches that wrap around loops.
- use-cache** Use preparsed versions of the C files that are stored in a cache.
- cache-prefix** Specify the directory in which to store preparsed versions of the C files. This sets **--use-cache**
- cache-limit** Specify the maximum number of preparsed C files to store. The cache is cleared of all files with names ending in `.ast-raw` and `.depend-raw` on reaching this limit. Only effective if **--cache-prefix** is used as well. This is most useful when iteration is used to process a file multiple times within a single run of Coccinelle.
- debug-cpp, --debug-lexer, --debug-etdt, --debug-typedef** Various options for debugging the C parser.
- filter-msg, --filter-define-error, --filter-passed-level** Various options for debugging the C parser.

--only-return-is-error-exit In matching “...” in a semantic patch or when forall is specified, a rule must match all control-flow paths starting from a node matching the beginning of the rule. This is relaxed, however, for error handling code. Normally, error handling code is considered to be a conditional with only a then branch that ends in goto, break, continue, or return. If this option is set, then only a then branch ending in a return is considered to be error handling code. Usually a better strategy is to use when strict in the semantic patch, and then match explicitly the case where there is a conditional whose then branch ends in a return.

Macros and other preprocessor code

- ◆ **--macro-file** *<file>* Extra macro definitions to be taken into account when parsing the C files. This uses the provided macro definitions in addition to those in the default macro file.
- ◆ **--macro-file-builtins** *<file>* Builtin macro definitions to be taken into account when parsing the C files. This causes the macro definitions provided in the default macro file to be ignored and the ones in the specified file to be used instead.
- ◆ **--ifdef-to-if, no-ifdef-to-if** The option **--ifdef-to-if** represents an `#ifdef` in the source code as a conditional in the control-flow graph when doing so represents valid code. **--no-ifdef-to-if** disables this feature. **--ifdef-to-if** is the default.
- ◆ **--noif0-passing** Normally code under `#if 0` is ignored. If this option is set then the code is considered, just like the code under any other `#ifdef`.
- ◆ **--defined** *s* The string *s* is a comma-separated list of constants that should be considered to be defined, with respect to uses of `#ifdef` and `#ifndef` in C code. No spaces should appear in *s*. Multiple **--defined** arguments can be provided and the list of strings accumulates. For the provided strings any `#elses` of `#ifdefs` are ignored and any `#ifndefs` are ignored, unless the argument **--noif0-passing** is also given, in which case **--defined** has no effect. Note that occurrences of `#define` in the C code have no effect on the list of defined constants.
- ◆ **--undefined** *s* Analogous to **--defined** except that the strings represent constants that should be considered to be undefined.

--noadd-typedef-root This seems to reduce the scope of a typedef declaration found in the C code.

Include files

- ◆ **--recursive-includes, --all-includes, --local-includes, --no-includes** These options control which include files mentioned in a C file are taken into account. **--recursive-includes** indicates that all included files mentioned in the .c file(s) or any included files will be processed. **--all-includes** indicates that all included files mentioned in the .c file(s) will be processed. **--local-includes** indicates that only included files in the current directory will be processed. **--no-includes** indicates that no included files will be processed. If the semantic patch contains type specifications on expression metavariables, then the default is **--local-includes**. Otherwise the default is **--no-includes**. At most one of these options can be specified.
- ◆ **-I** *<path>* This option specifies a directory in which to find non-local include files. This option can be used several times to specify multiple include paths.
- ◆ **--include-headers-for-types** Header files are parsed to collect type information, but are not involved in the subsequent matching and transformation process.

- ◆ **--include** *<file>* This option give the name of a file to consider as being included in each processed file. The file is added to the end of the file's list of included files. The complete path name should be given; the **-I** options are not taken into account to find the file. This option can be used several times to include multiple files.
- ◆ **--relax-include-path** This option when combined with **--all-includes** causes the search for local include files to consider the current directory, even if the include patch specifies a subdirectory. This is really only useful for testing, eg with the option **--testall**
- ◆ **--c++** Make an extremely minimal effort to parse C++ code. Currently, this is limited to allowing identifiers to contain “::”, tilde, and template invocations. Consider testing your code first with **spatch --type-c** to see if there are any type annotations in the code you are interested in processing. If not, then it was probably not parsed.
- ◆ **--ibm** Make a effort to parse IBM C code. Currently decimal declarations are supported.

10.4 Application of the semantic patch to the C code

10.4.1 Feedback at the rule level during the application of the semantic patch

- ◆ **--show-bindings** Show the environments with respect to which each rule is applied and the bindings that result from each such application.
- ◆ **--show-dependencies** Show the status (matched or unmatched) of the rules on which a given rule depends. **--show-dependencies** implicitly sets **--show-bindings**, as the values of the dependencies are environment-specific.
- ◆ **--show-trying** Show the name of each program element to which each rule is applied.
- ◆ **--show-transinfo** Show information about each transformation that is performed. The node numbers that are referenced are the number of the nodes in the control-flow graph, which can be seen using the option **--control-flow** (the initial control-flow graph only) or the option **--show-flow** (the control-flow graph before and after each rule application).
- ◆ **--show-misc** Show some miscellaneous information.
- ◆ **--show-flow** *<file>*, **--show-flow** *<file>:<function>* Show the control-flow graph before and after the application of each rule.

--show-before-fixed-flow This is similar to **--show-flow**, but shows a preliminary version of the control-flow graph.

10.4.2 Feedback at the CTL level during the application of the semantic patch

- ◆ **--verbose-engine** Show a trace of the matching of atomic terms to C code.
- ◆ **--verbose-ctl-engine** Show a trace of the CTL matching process. This is unfortunately rather voluminous and not so helpful for someone who is not familiar with CTL in general and the translation of SmPL into CTL specifically. This option implicitly sets the option **--show-ctl-text**.

- ◆ **--graphical-trace** Create a pdf file containing the control flow graph annotated with the various nodes matched during the CTL matching process. Unfortunately, except for the most simple examples, the output is voluminous, and so the option is not really practical for most examples. This requires `dot` (<http://www.graphviz.org/>) and `pdftk`.
- ◆ **--gt-without-label** The same as **--graphical-trace**, but the PDF file does not contain the CTL code.
- ◆ **--partial-match** Report partial matches of the semantic patch on the C file. This can be substantially slower than normal matching.
- ◆ **--verbose-match** Report on when CTL matching is not applied to a function or other program unit because it does not contain some required atomic pattern. This can be viewed as a simpler, more efficient, but less informative version of **--partial-match**.

10.4.3 Actions during the application of the semantic patch

- ◆ **-D rulename** Run the patch considering that the virtual rule “rulename” is satisfied. Virtual rules should be declared at the beginning of the semantic patch in a comma separated list following the keyword `virtual`. Other rules can depend on the satisfaction or non satisfaction of these rules using the keyword `depends on` in the usual way.
 - ◆ **-D variable=value** Run the patch considering that the virtual identifier metavariable “variable” is bound to “value”. Any identifier metavariable can be designated as being virtual by giving it the rule name `virtual`. An example is in `demos/vm.coci`
 - ◆ **--allow-inconsistent-paths** Normally, a term that is transformed should only be accessible from other terms that are matched by the semantic patch. This option removes this constraint. Doing so, is unsafe, however, because the properties that hold along the matched path might not hold at all along the unmatched path.
 - ◆ **--disallow-nested-exps** In an expression that contains repeated nested subterms, *e.g.* of the form $f(f(x))$, a pattern can match a single expression in multiple ways, some nested inside others. This option causes the matching process to stop immediately at the outermost match. Thus, in the example $f(f(x))$, the possibility that the pattern $f(E)$, with metavariable E , matches with E as x will not be considered.
 - ◆ **--no-safe-expressions** normally, we check that an expression does not match something earlier in the disjunction. But for large disjunctions, this can result in a very big CTL formula. So this option give the user the option to say he doesn't want this feature, if that is the case.
 - ◆ **--pyoutput coccilib.output.Gtk, --pyoutput coccilib.output.Console** This controls whether Python output is sent to Gtk or to the console. **--pyoutput coccilib.output.Console** is the default. The Gtk option is currently not well supported.
- loop** When there is “...” in the semantic patch, the CTL operator **AU** is used if the current function does not contain a loop, and **AW** may be used if it does. This option causes **AW** always to be used.
- ◆ **--ocaml-regexps** Use the regular expressions provided by the OCaml `Str` library. This is the default if the PCRE library is not available. Otherwise PCRE regular expressions are used by default.
- steps <int>** This limits the number of steps performed by the CTL engine to the specified number. This option is unsafe as it might cause a rule to fail due to running out of steps rather than due to not matching.

--bench *(int)* This collects various information about the operations performed during the CTL matching process.

- ◆ **--reverse** Inverts the semantic patch before applying it. A potential use case is backporting changes to previous versions. If a semantic patch represents an API change, then the reverse undoes the API change. Note that inverting a semantic patch is not always possible. In particular, the composition of a semantic patch with its inverse is not guaranteed to be an empty patch.

10.5 Generation of the result

Normally, the only output is the differences between the original code and the transformed code obtained using the program `diff` with the unified format option. If stars are used in column 0 rather than `-` and `+`, then the `-` lines in the output are the lines that matched the stars.

- ◆ **--keep-comments** Don't remove comments adjacent to removed code.
- ◆ **--linux-spacing, --smpl-spacing** Control the spacing within the code added by the semantic patch. The option **--linux-spacing** causes `spatch` to follow the conventions of Linux, regardless of the spacing in the semantic patch. This is the default. The option **--smpl-spacing** causes `spatch` to follow the spacing given in the semantic patch, within individual lines.
- ◆ **--indent** *n* The number of spaces to indent, if no other information is available. If this information is not provided, then the default indentation is a tab. This option is thus particularly relevant to projects that don't use tabs.
- ◆ **-o** *(file)* This causes the transformed code to be placed in the file *file*. The difference between the original code and the transformed code is still printed to the standard output using `diff` with the unified format option. This option only makes sense when `-` and `+` are used.
- ◆ **--in-place** Modify the input file to contain the transformed code. The difference between the original code and the transformed code is still printed to the standard output using `diff` with the unified format option. By default, the input file is overwritten when using this option, with no backup. This option only makes sense when `-` and `+` are used.
- ◆ **--backup-suffix** *s* The suffix *s* of the file to use in making a backup of the original file(s). This suffix should include the leading `"."`, if one is desired. This option only has an effect when the option **--in-place** is also used.
- ◆ **--out-place** Store the result of modifying the code in a `.cocci-res` file. The difference between the original code and the transformed code is still printed to the standard output using `diff` with the unified format option. This option only makes sense when `-` and `+` are used.
- ◆ **--no-show-diff** Normally, the difference between the original and transformed code is printed on the standard output. This option causes this not to be done.
- ◆ **-U** Set number of context lines to be provided by `diff`.
- ◆ **--patch** *(path)* The prefix of the pathname of the directory or file name that should be dropped from the `diff` line in the generated patch. This is useful if you want to apply a patch only to a subdirectory of a source code tree but want to create a patch that can be applied at the root of the source code tree. An example could be `spatch --sp-file foo.cocci --dir /var/linuxes/linux-next/drivers --patch /var/linuxes/linux-next`. A trailing `/` is permitted on the directory name and has no impact on the result.

- ◆ **--save-tmp-files** Coccinelle creates some temporary files in `/tmp` that it deletes after use. This option causes these files to be saved.

--debug-unparsing Show some debugging information about the generation of the transformed code. This has the side-effect of deleting the transformed code.

10.6 Other options

10.6.1 Version information

- ◆ **--version** The version of Coccinelle is printed on the standard output. No other options are allowed.
- ◆ **--date** The date of the current version of Coccinelle are printed on the standard output. No other options are allowed.

10.6.2 Help

- ◆ **--h, --shorthelp** The most useful commands.
- ◆ **--help, --help, --longhelp** A complete listing of the available commands.

10.6.3 Controlling the execution of Coccinelle

- ◆ **--timeout** `<int>` The maximum time in seconds for processing a single file. A timeout of 0 is no timeout.
- ◆ **--max** `<int>` This option informs Coccinelle of the number of instances of Coccinelle that will be run concurrently. This option requires **--index**. It is usually used with **--dir**.
- ◆ **--index** `<int>` This option informs Coccinelle of which of the concurrent instances is the current one. This option requires **--max**.
- ◆ **--mod-distrib** When multiple instances of Coccinelle are run in parallel, normally the first instance processes the first n files, the second instance the second n files, etc. With this option, the files are distributed among the instances in a round-robin fashion.

--debugger Option for running Coccinelle from within the OCaml debugger.

--profile Gather timing information about the main Coccinelle functions.

--disable-once Print various warning messages every time some condition occurs, rather than only once.

10.6.4 Parallelism

- ◆ **--jobs** `<int>` Run the specified number of jobs in parallel. Can be abbreviated as **-j**. This option is not compatible with the use of an `initialize` or `finalize` rule in the semantic patch. This option furthermore creates a temporary directory in the directory from which `spatch` is executed that has the name of the semantic patch (without its extension) and that contains `stdout` and `stderr` files generated by the various processes. When the semantic patch completes, the contents of these files are printed to standard output and standard error, respectively, and the directory is removed.

--chunksize *<int>* The specified number of files are dispatched as a single unit of parallelism. This option is only interesting with the options **--all-includes** or **--recursive-includes**, when combined with the option **--include-headers-for-types**. In this case, parsed header files are cached. It is only the files that are treated within a single chunk that can benefit from this cache, due to the lack of shared memory in ocaml.

10.6.5 External analyses

--external-analysis-file Loads in the contents of a database produced by some external analysis tool. Each entry contains the analysis result of a particular source location. Currently, such a database is a .csv file providing integer bounds or an integer set for some subset of the source locations that references an integer memory location. This database can be inspected with `cocclib` functions, e.g. to control the pattern match process.

10.6.6 Miscellaneous

◇ **--quiet** Suppress most output. This is the default.

--pad, --xxx, --l1

Part III

Appendix

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