INTRODUCTION TO COCCINELLE AND SMPL

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Prerequisites

- Source code of the Linux kernel version 4.6
- Latest version of the Coccinelle
    - Either installl it from the package manager [Coccinelle is available with around 10 linux distros including Fedora, Ubuntu, Debian, ArchLinux etc.].
    - Or build it from the source. (https://github.com/coccinelle/coccinelle)

Code Maintenance Issues

- **Software evolution:**
  - Refactoring code to use newer APIs

```
- init_timer(&cf->timer);
- cf->timer.function = omap_cf_timer;
- cf->timer.data = (unsigned long) cf;
+ setup_timer(&cf->timer, omap_cf_timer, (unsigned long)cf);
```

  - Need to find all parts of the code that need updating
  - Process should be fast, reliable and systematic
  - However, things are never straightforward

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  - Are the programmers following the standards?
  - Is the code accounting for all errors that can take place?
  - Is the written code overly defensive?

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  - Is the code accounting for all errors that can take place?
  - Is the written code overly defensive?

- **The Human Factor:**
  - Mistakes can always happen

Coccinelle

- Program matching and transformation tool
- Independent of the compilation process
- Very intuitive patch like style
- Used by several communities:
  - Linux Kernel: 5K+ patches
  - QEMU: 200+ patches
  - systemd: 80+ patches

Semantic Patch Language (SmPL)

- Abstract C-like grammar
- Independent of the compilation process
- Metavariables are used to abstract over sub-terms in code
  - If an expression matches within a pattern, it can be tracked throughout its presence in the code e.g. variable names, typedefs
- "..." is used to abstract over code sequences
  - Used as don't care
  - Variants are used as syntactic sugar for + and ? in regular expressions
- Lines can be annotated with {-,+,*}
  - Transformations are described using patch-like style (-/+)
  - Matching employs *

Example: Using BIT macro

- Bit masking is preferrably done using the BIT macro

```diff
-        BUILD_BUG_ON(max >= (1 << 16));
+        BUILD_BUG_ON(max >= (BIT(16)));
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```

- Code we should focus on for building a semantic patch:

```
- 1 << 16
+ BIT(16)
```

- Is 16 important here?

Example: Using BIT macro (Contd.)

- Do we care about number of shifts?

```
-         if (opts & (1 << REISERFS_LARGETAIL))
+         if (opts & (BIT(REISERFS_LARGETAIL)))
```

Example: Using BIT macro (Contd.)

- Do we care about number of shifts?

```diff
- if (opts & (1 << REISERFS_LARGETAIL))
+ if (opts & (BIT(REISERFS_LARGETAIL)))
```

- Use metavariables

```
@@
constant c;
@@

-1 << c
+BIT(c)
```

Example: Using BIT macro (Contd.)

- Constant will capture numbers and defined constants
- What if we had something like

```
1 << (31 - inode->i_sb->s_blocksize_bits)
```

Example: Using BIT macro (Contd.)

- Constant will capture numbers and defined constants

- What if we had something like

```
1 << (31 - inode->i_sb->s_blocksize_bits)
```

- expression to the rescue

```
@@
expression E;
@@

-1 << E
+BIT(E)
```

Metavariables

`Example: x->y = m->n + 1;`

- **Constant:** match patterns on values and constants
  e.g. `numbers like 2,3 and defined constants in a code`

Metavariables

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- **Expression:** match patterns on constants and complex subterms
  e.g. `struct->elem, x-y, func(arg) etc`

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- **Expression:** match patterns on constants and complex subterms
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- **Identifier:** a structure field, a macro, a function, or a variable

- **Statement:** match patterns which do not return a value
  e.g. `if, while, break etc`

Metavariables

- **Constant:** match patterns on values and constants
  e.g. `numbers like 2,3 and defined constants in a code`
- **Expression:** match patterns on constants and complex subterms
  e.g. `struct->elem, x-y, func(arg)`
- **Identifier:** a structure field, a macro, a function, or a variable
- **Statement:** match patterns which do not return a value
  e.g. `if, while, break etc`
- **Type:** match patterns for the type of variables/functions
  e.g `int, boolean, float etc`

Transformation specification

- - in the leftmost column for something to remove
- + in the leftmost column for something to add
- * in the leftmost column for something of interest
    - Cannot be used with + and -.
- Spaces, newlines that are irrelevant.

Spatch

- Coccinelle’s command-line tool
- To check that your semantic patch is valid:

```
spatch --parse-cocci mysp.cocci
```

- To run your semantic patch:

```
spatch --sp-file mysp.cocci file.c
```

```
spatch --sp-file mysp.cocci --dir directory
```

Exercise 1

- Save the semantic patch to bitmask.cocci. [slide 12 and 14]
- Run it using spatch on any particular directory or on whole kernel.
  spatch --sp-file bitmask.cocci --dir directory
- Redirect results to an output file for an inspection.
- Is it ok to use BIT macro in every case? Should we want to restrict it for the files which are already using it?

Exercise 2

- Parentheses are not needed around the bitwise left shift operations like in `u32 val = (1 << 31);`.
- Write a semantic patch to remove these parentheses.
- Run the semantic patch over the directory drivers/net/wireless/ .
- Some other cases to think about:
  - Extra parentheses around the function arguments
  - Using the same identifier on the left and right side of the assignment

Using BIT macro (Revisited)

Example:

```
diff -u -p a/arch/mips/pci/pci-mt7620.c b/arch/mips/pci/pci-mt7620.c
--- a/arch/mips/pci/pci-mt7620.c
+++ b/arch/mips/pci/pci-mt7620.c
@@ -37,11 +37,11 @@
 #define PDRV_SW_SET                            BIT(23)

 #define PPLL_DRV                               0xa0
-#define PDRV_SW_SET                            (1<<31)
-#define LC_CKDRVPD                             (1<<19)
-#define LC_CKDRVOHZ                            (1<<18)
-#define LC_CKDRVHZ                             (1<<17)
-#define LC_CKTEST                              (1<<16)
+#define PDRV_SW_SET                            (BIT(31))
+#define LC_CKDRVPD                             (BIT(19))
+#define LC_CKDRVOHZ                            (BIT(18))
+#define LC_CKDRVHZ                             (BIT(17))
+#define LC_CKTEST                              (BIT(16))
```

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@@ -37,11 +37,11 @@
 #define PDRV_SW_SET                        BIT(23)

 #define PPLL_DRV                           0xa0
-#define PDRV_SW_SET                        (1<<31)
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+#define PDRV_SW_SET                        (BIT(31))
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+#define LC_CKDRVHZ                         (BIT(17))
+#define LC_CKTEST                          (BIT(16))
```

- Would like to restrict the bitmask semantic patch to files that are already using the BIT macro?

Using BIT macro (Revisited)

Example:

```
-#define LC_CKDRVPD    (1<<19)
-#define LC_CKDRVOHZ   (1<<18)
+#define LC_CKDRVPD    (BIT(19))
+#define LC_CKDRVOHZ   (BIT(18))
```

Semantic patch:

```
@usesbit@
@@
BIT(...)

@depends on usesbit@
expression E;
@@

- 1 << E
+ BIT(E)
```

Isomorphism

- Coccinelle captures code as defined in your rule
- Valid variants of your defined pattern can exist
- Cumbersome to list them all in your rule/s
- Examples:
  - `x == NULL` and `!x`
  - `sizeof(struct i) * e` and `e * sizeof(struct i)`
- Isomorphisms can handle such variations
- Rules defining isomorphisms exist in standard.iso

Isomorphism Examples

Example 1:

```
Expression

@ is_null @
expression X;
@@

X == NULL <=> NULL == X => !X
```

Example 2:

```
Expression

@ drop_cast @
expression E;
pure type T;
@@

 (T)E => E
```

Exercise 3

- To avoid code duplication or error prone code, the kernel provides macros such as DIV_ROUND_UP.

- The definition of the DIV_ROUND_UP goes like this:
  `DIV_ROUND_UP(n,d) (((n) + (d) - 1) / (d))`

- Write the semantic patch for replacing the pattern **(((n) + (d) - 1) / (d))** with **DIV_ROUND_UP.**

- Redirect results to an output file for an inspection.

Exercise 4

- Consider the example of DIV_ROUND_UP.
- The macro is defined in linux/kernel.h. So, it depends on this header file.
- Expand the semantic patch you wrote in exercise 3 using **'depends on'.**
- Review the output given by updated semantic patch.

Example: setup_timer

- The function setup_timer combines the initialization of a timer with the initialization of the timer's function and data fields.

```
-       init_timer(&cf->timer);
-       cf->timer.function = omap_cf_timer;
-       cf->timer.data = (unsigned long) cf;
+       setup_timer(&cf->timer, omap_cf_timer, (unsigned long)cf);
```

- Why setup_timer?

- How Coccinelle can help here?

setup_timer: case one

Example:

```
@@

@@
- init_timer(&cf->timer);
- cf->timer.function = omap_cf_timer;
- cf->timer.data = (unsigned long) cf;
+ setup_timer(&cf->timer, omap_cf_timer, (unsigned long)cf);
```

Semantic patch

```
@case_one@
expression e,func,da;
@@

- init_timer (&e);
+ setup_timer (&e, func, da);
- e.function = func;
- e.data = da;
```

setup_timer: case one

Semantic patch:

```
@case_one@
expression e,func,da;
@@

- init_timer (&e);
+ setup_timer (&e, func, da);
- e.function = func;
- e.data = da;
```

- Is this the only case where we can use setup_timer?
- Is it necessary that the call to init_and the initialization of the function and data fields always occur in the order shown in the example?

setup_timer: case two

Example:

```
- init_timer(&hose->err_timer);
- hose->err_timer.data = (unsigned long)hose;
- hose->err_timer.function = pcibios_enable_err;
+ setup_timer(&hose->err_timer, pcibios_enable_err, (unsigned long)hose);
```

Semantic patch:

```
@case_two@
expression e,func,da;
@@

- init_timer (&e);
+ setup_timer (&e, func, da);
- e.data = da;
- e.function = func;
```

setup_timer: comparing both cases

Case one:

```
@case_one@
expression e,func,da;
@@

- init_timer (&e);
+ setup_timer (&e, func, da);
- e.function = func;
- e.data = da;
```

Case two:

```
@case_two@
expression e,func,da;
@@

-init_timer (&e);
+setup_timer (&e, func, da);
-e.data = da;
-e.function = func;
```

Disjunctions

- A sequence of patterns between (... | ...).
- Patterns checked in order and the first that matches is chosen.
- Combining case one and case two in our example:

```
@case_one_and_two@
expression e, func, da;
@@

-init_timer (&e);
+setup_timer (&e, func, da);

(
-e.function = func;
-e.data = da;
|
-e.data = da;
-e.function = func;
)
```

Exercise 5

- Implement the semantic patches for both cases of the setup_timer. Compare the results.
- Implement the rule combining case one and case two using disjunction.
- Think about why do we need to use disjunctions? Can we use multiple rules?
- Check the results. Does it cover all the cases that were matched by the separate rules?
- Grep for the init_timer and check if the rule with disjunction covers everything?

setup_timer(Contd.)

Example:

```
init_timer (&np->timer);
np->timer.expires = jiffies + 1*HZ;
np->timer.data = (unsigned long) dev;
np->timer.function = rio_timer;
add_timer (&np->timer);
```

- Does previous rule covered all cases?
- Is it necessary that the call to init_timer and the initialization of the function & the data field always occurs in a contiguous manner?

Dots

Problem:

- Sometimes it is necessary to search for multiple related code fragments.

Solution:

- Specify patterns consisting of the fragments of code separated by arbitrary execution paths.
- Specify constraints on the contents of those execution paths.

setup_timer: case three

Semantic patch:

```
@case_three@
expression e,func,da;
@@

- init_timer (&e);

+ setup_timer (&e, func, da);
    ...

- e.data = da;
- e.function = func;
```

Example:

```
-        init_timer (&np->timer);
+        setup_timer(&np->timer, rio_timer, (unsigned long)dev);
         np->timer.expires = jiffies + 1*HZ;
-        np->timer.data = (unsigned long) dev;
-        np->timer.function = rio_timer;
         add_timer (&np->timer);
```

Using dots

Semantic patch:

```
@case_three@
expression e,func,da;
@@

- init_timer (&e);

+ setup_timer (&e, func, da);
    ...

- e.data = da;
- e.function = func;
```

- '...' matches all possible execution paths from the pattern before to the pattern after
- The patterns before and after cannot appear in the region matched by “. . . ” (shortest path principle).

Example: Compressing lines for immediate return

- In the following code last two lines could be compressed into one:

```
int bytes_written;
u16 link_speed;

link_speed = rtw_get_cur_max_rate(padapter) / 10;
bytes_written = snprintf(command, total_len, "LinkSpeed %d", link_speed);
return bytes_written;
```

Compressing lines for immediate return

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```
int bytes_written;
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```

```
int bytes_written;
u16 link_speed;

link_speed = rtw_get_cur_max_rate(padapter) / 10;
return snprintf(command, total_len, "LinkSpeed %d", link_speed);
```

Dots: Compressing lines for immediate return

Example:

```
-        bytes_written = snprintf(command, total_len, "LinkSpeed %d",
+        return snprintf(command, total_len, "LinkSpeed %d",
                                            link_speed);
-        return bytes_written;
```

Semantic patch:

```
@@
expression r;
identifier f;
@@

-r = f(...)
+return
     f(...);
-return r;
```

Exercise 6

- Implement the rule for case three of setup_timer using dots. [Slide 40]
- Run the patch over the kernel code and investigate the result.
- Think about the case three like pattern for the case two.
- Implement the rule for those kind of patterns.
- Try to limit the number of rules.

Exercise 6(Contd.)

Example:

```
init_timer(&sharpsl_pm.ac_timer);
sharpsl_pm.ac_timer.function = sharpsl_ac_timer;

init_timer(&sharpsl_pm.chrg_full_timer);
sharpsl_pm.chrg_full_timer.function = sharpsl_chrg_full_timer;
```

- Is it even necessary that the initialization of the data field always occurs?

- Expand the semantic patch to include such cases.

Exercise 7

Example:

```
int bytes_written;
u16 link_speed;

link_speed = rtw_get_cur_max_rate(padapter) / 10;
return snprintf(command, total_len, "LinkSpeed %d", link_speed);
```

- Do we really need the variable bytes_written after compressing the lines?
- Expand the semantic patch[slide 44] to remove the variable along with compressing lines.

Hint: Ensure that the variable is not used anywhere else.

Using dots(Contd.)

Semantic patch:

```
@case_three@
expression e,func,da;
@@

- init_timer (&e);

+ setup_timer (&e, func, da);
    ...

- e.data = da;
- e.function = func;
```

- Check the properties of the matched statement sequence
- Does the rule look correct? Or do we need to ensure something?

Using dots with when

- Dots can be modified with a when clause, indicating a pattern that should not occur

```
@case_three@
expression e1, e2, e3, e4, func, da;
@@

-init_timer(&e1);
+setup_timer(&e1, func, da);

... when != func = e2
    when != da = e3

-e1.data = da;
-e1.function = func;
```

when

- Keyword used to indicate conditions on execution path
- As seen before, controls the behavior of "..."
- Can be coupled with:
    - **strict:** force condition on every execution path (including failures)
    - **forall:** force condition on every execution path (excluding failures)
    - **exists:** is there an execution path that matches the pattern?
    - **any:** allow the patterns specified...
    - conditions specified by the user

More use of dots

- Two possible modifiers to the control flow for ellipses:

  1. <...P...> indicates that matching the pattern in between the ellipses is optional

  2. <+...P...+> indicates that the pattern in between the ellipses must be matched at least once, on some control-flow path.

     - The + is intended to be reminiscent of the + used in regular expressions.

More use of dots(Contd.)

Example:

```
@r@
@@
-if (...) {
<+...
  return ...;
 ...+>
}
```

Meaning:

- To remove all ifs that contain at least one return.

More use of dots(Contd.)

Example:

```
@r@
@@
-if (...) {
<...
  return ...;
 ...>
}
```

Meaning:

- To remove all ifs

Exercise 8

1. Implement the example of 'compression of lines for the immediate return problem'.

2. The semantic patch for removing unused variables only matches a variable declaration when the declaration does not initialize the variable.

3. Extend the complete semantic patch so that it also removes unused variables that are initialized to a constant.

Exercise 9

In the following code, when `x` has any pointer type, the cast to `u8 *`, or to any other pointer type is not needed.

```
kfree((u8 *)x);
```

- Write a semantic patch to remove such casts.
- Consider generalizing your semantic patch to functions other than kfree.
- Are there any patterns that can benefit from using disjunctions?

Coccicheck

- A Coccinelle-specific target which is defined in the top level Makefile.

- Four basic modes
  - Patch mode
  - Context mode
  - Org mode
  - Report mode

- Default output: Report mode

- Command that can be used for specifying particular mode:
  make coccicheck MODE=patch

Modes for the Coccinelle script

- Four basic modes

  - Patch mode: proposes a fix when possible.

```
@@ -582,8 +580,7 @@ static int iss_net_configure(int index,
        return 1;
}

-       init_timer(&lp->tl);
-       lp->tl.function = iss_net_user_timer_expire;
+       setup_timer(&lp->tl, iss_net_user_timer_expire, 0UL);

    return 0;
```

Modes for the Coccinelle script

- Four basic modes

  - Context mode:
    1. highlights lines of interest and their context in a diff-like style.
    2. Lines of interest are indicated with '-'.

```
@@ -582,8 +580,7 @@ static int iss_net_configure(int index,
return 1;
}

-        init_timer(&lp->tl);
-        lp->tl.function = iss_net_user_timer_expire;
-        setup_timer(&lp->tl, iss_net_user_timer_expire, 0UL);

    return 0;
```

Modes for the Coccinelle script

- Four basic modes
  - Org mode: Generates a report in the Org mode format of Emacs.

```
* TODO [[view:/home/linux-next/linux/arch/sh/drivers/pci/common.c::face=ovl-fa
::cole=12] [Use setup_timer function.]]
[[view:/home/linux-next/linux/arch/sh/drivers/pci/common.c::face=ovl-face1::l
[/home/linux-next/linux/arch/sh/drivers/pci/common.c::109]]

* TODO [[view:/home/linux-next/linux/arch/sh/drivers/pci/common.c::face=ovl-fa
::cole=12] [Use setup_timer function.]]
[[view:/home/linux-next/linux/arch/sh/drivers/pci/common.c::face=ovl-face1::l
[/home/linux-next/linux/arch/sh/drivers/pci/common.c::115]]
```

Modes for the Coccinelle script

- Four basic modes
  - Report mode: Generates a list in the following format
    file:line:column-column: message

```
/home/linux-next/linux/arch/sh/drivers/pci/common.c:108:2-12: Use setup_timer
/home/linux-next/linux/arch/sh/drivers/pci/common.c:114:2-12: Use setup_timer
/home/linux-next/linux/arch/sh/drivers/push-switch.c:81:1-11: Use setup_timer
/home/linux-next/linux/arch/x86/kernel/pci-calgary_64.c:1010:1-11: Use setup_t
line 1011.
/home/linux-next/linux/arch/powerpc/oprofile/op_model_cell.c:682:1-11: Use set
line 683.
```

setup_timer again

Problem:

- What if `init_timer` is called in one function and data field is initialized in another function?
- Will it be safe to use `setup_timer` in that case?

Solution:

- How about giving warning in such cases?

setup_timer again

- We need two rules to match both parts

Semantic patch:

```
@r1@
identifier f;
@@

f(...) { ...
  init_timer(...)
  ...
}
@r2@
identifier g;
struct timer_list t;
expression e;
@@

g(...) { ...
t.data = e
 ...
}
```

setup_timer again

- We want to match 2 different functions. So, let's avoid function name overriding.

Semantic patch:

```
@r1 exists@
identifier f;
@@

f(...) { ...
  init_timer(...)
  ...
}
@r2 exists@
identifier g != r1.f;
struct timer_list t;
expression e;
@@

g(...) { ...
t.data = e
 ...
}
```

Position variables

- Position metavariables can be used to store the position of any token, for later matching or printing.

- In the case of `setup_timer` we want to use the position of `init_timer` so that Coccinelle can give warning at such code.

Position variables

Example:

```
@r1 exists@
identifier f;
position p;
@@

f(...) { ...
  init_timer@p(...)
  ...
}

@r2 exists@
identifier g != r1.f;
struct timer_list t;
expression e8;
@@

g(...) { ...
  t.data = e8
  ...
}
```

Embedding python script

- 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.

Python script with the warning

Example:

```
@r1 exists@
identifier f;
position p;
@@
f(...) { ...
  init_timer@p(...)
  ...
}

@r2 exists@
identifier g != r1.f;
struct timer_list t;
expression e;
@@
g(...) { ...
  t.data = e
  ...
}
@script:python depends on r2@
p << r1.p;
@@
print "Data field initialized in another function. Dangerous to use
setup_timer %s:%s" % (p[0].file,p[0].line)
```

Python script without printing warning

Example:

```
@r1 exists@
identifier f;
position p;
@@
f(...) { ...
  init_timer@p(...)
  ...
}

@r2 exists@
identifier g != r1.f;
struct timer_list t;
expression e;
@@
g(...) { ...
  t.data = e
  ...
}
@script:python depends on r2@
p << r1.p;
@@
cocci.include_match(False)
```

Exercise 10

- When searching for things, rather than transforming them, it may be useful to generate the output in a variety of formats. This can be done using the interface to python (ocaml is also available).

- Position variables are useful in this context, because they provide the file name and line number of various program elements.

Exercise 10 (Contd.)

- Consider the following patch discussed earlier:

```
@@
expression r;
identifier f;
@@
-r = f(...)
+return
     f(...);
-return r;
```

- Following python code is intended to print the file name and line numbers of the assignment and erroneous test, respectively:

```
@script:python@
p1 << r.p1; // inherit a metavariable p1 from rule r
p2 << r.p2; // inherit a metavariable p2 from rule r
@@
print p1[0].file, p1[0].line, p2[0].line
```

Exercise 10 (Contd.)

Do this:

- Create a semantic patch consisting of the original patch rule shown on the previous page followed by the python code specified in the last slide.
- Give name r to the rule and remove the transfromation.
- Add position variables p1 and p2.
- Attach position variables to the relevant code.
- Test the semantic patch and investigate the results.

Exercise 11

- We have seen that * can be used to highlight items of interest.
- Repeat the previous exercise, this time without using python, but instead annotate the original code pattern with * rather than performing transformations.
- How is the result different than the result produced when using python?

Exercise 12

- Implement the setup_timer case with the python code.

- Combine all rules in a single script and then try to run it. Observe how output changes.

- Try to reorder the rules in a semantic patch and then observe the changes.

- Do we also need a rule for the immediate call of init_timer, intialization of data and function fields? If yes, then why? If no, then why?

  Hint: Consider performance and speed of the semantic patch.

Feature summary

- Metavariables and Isomorphisams
- Different uses of ...
- When
- Named rules and metavariable inheritance
- Position variables
- Scripting through Python/Ocaml
- Different modes for the Coccinelle script

Useful links

- Source code of the Coccinelle: "https://github.com/coccinelle/coccinelle"
- Grammar and features: "http://coccinelle.lip6.fr/docs/options.pdf"
- Documentation: "Documentation/coccinelle.txt"
- Project: "http://coccinelle.lip6.fr/"
- Spgen: "https://github.com/coccinelle/coccinelle/tree/master/tools/spgen"

THANK YOU!

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