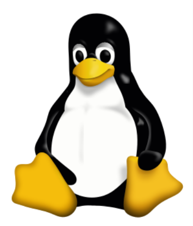
Coccinelle:
10 Years of Automated Evolution in the Linux Kernel

Julia Lawall (Inria-Whisper team, Julia.Lawall@inria.fr)

March 2, 2020

Our focus: The Linux kernel

- Open source OS kernel, developed by Linus Torvalds
- First released in 1991
- Version 1.0.0 released in 1994
- Today used in the top 500 supercomputers, billions of smartphones (Android), battleships, stock exchanges, …

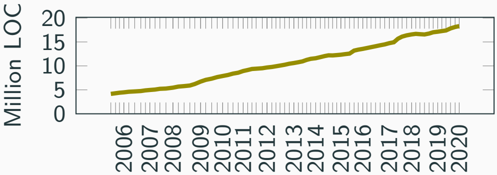


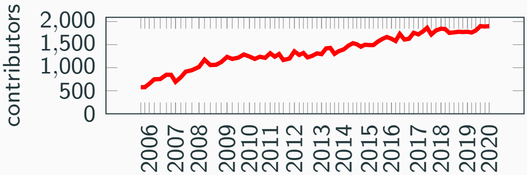
Some history

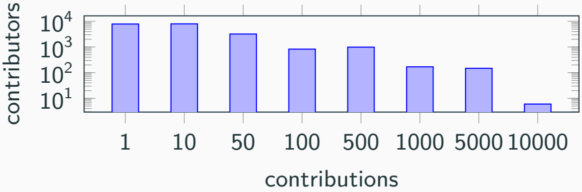
First release in 1991.

- v1.0 in 1994: 121 KLOC, v2.0 in 1996: 500 KLOC

Recent evolution:







Key challenge

As software grows, how to ensure its continued maintenance?

- Updating interfaces is easy.
  Make functions and data structures:
  - More efficient
  - Easier to use correctly
  - Better adapted to their usage context

Key challenge

As software grows, how to ensure its continued maintenance?

- Updating interfaces is easy.
  Make functions and data structures:
  - More efficient
  - Easier to use correctly
  - Better adapted to their usage context

- Updating the uses of interfaces gets harder as the software grows.
  - More time consuming
  - More error prone
  - Need to communicate new coding strategies to all developers

Key challenge

As software grows, how to ensure its continued maintenance?

- Updating interfaces is easy.
  Make functions and data structures:
  - More efficient
  - Easier to use correctly
  - Better adapted to their usage context
- Updating the uses of interfaces gets harder as the software grows.
  - More time consuming
  - More error prone
  - Need to communicate new coding strategies to all developers

Developers may hesitate to make needed changes.

Example change: `init_timer` → `setup_timer`

Initializing a timer requires:

- The callback function to run when the timer expires
- The data that should be passed to that callback function

Example change: `init_timer` → `setup_timer`

Initializing a timer requires:

- The callback function to run when the timer expires
- The data that should be passed to that callback function

Original initialization strategy (present in Linux v1.2.0):

```
init_timer(&ns_timer);
ns_timer.data = 0UL;
ns_timer.function = ns_poll;
```

Example change: `init_timer` → `setup_timer`

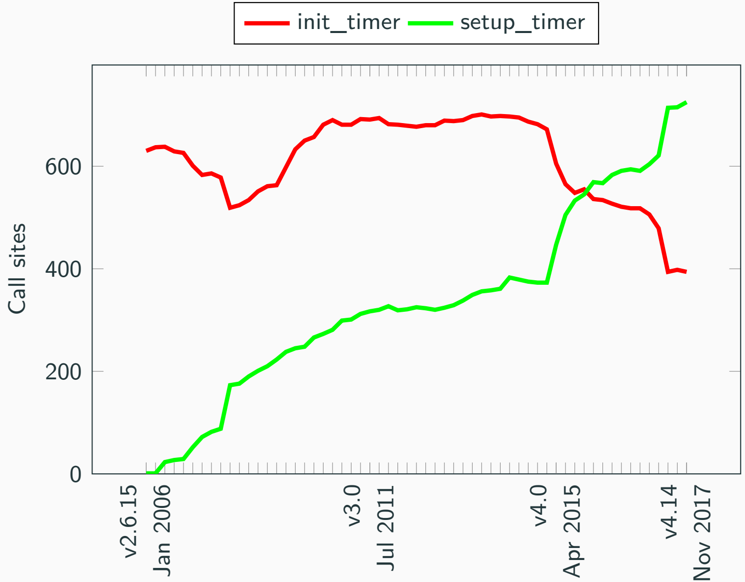
Replacement initialization strategy (introduced in Linux v2.6.15, Jan. 2006):

```
setup_timer(&ns_timer, ns_poll, 0UL);
```

Advantages:

- More concise
- More uniform
- More secure

Example change: `init_timer` → `setup_timer`



Example bug: missing of_node_puts

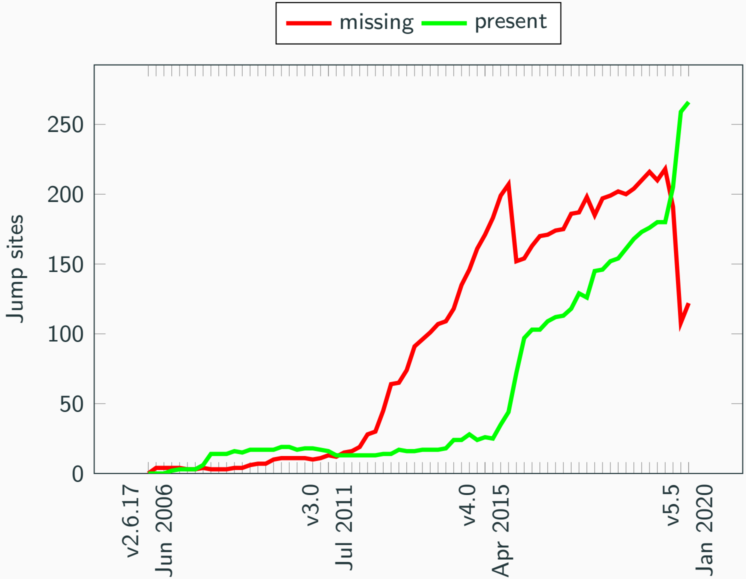
Device node structures are reference counted:

- of_node_get to access the structure.
- of_node_put to let go of the structure.

Iterators, e.g., `for_each_child_of_node`, `put` one value and `get` another.

- Explicit `put` needed on `break`, `return`, `goto` out of the loop.
- Often forgotten.

Example bug: missing `of_node_puts`



Assessment

- Changes may involve scattered code fragments and data and control flow relationships between them.
    - Grep insufficient to find the problem.

Assessment

- Changes may involve scattered code fragments and data and control flow relationships between them.
  - Grep insufficient to find the problem.
- Changes may be widely scattered across the code base.
  - Tedious and time-consuming to find all occurrences.

Assessment

- Changes may involve scattered code fragments and data and control flow relationships between them.
  - Grep insufficient to find the problem.
- Changes may be widely scattered across the code base.
  - Tedious and time-consuming to find all occurrences.
- Changes may come in many variants.
  - Hard to anticipate; some variants may be overlooked.

Assessment

- Changes may involve scattered code fragments and data and control flow relationships between them.
  - Grep insufficient to find the problem.
- Changes may be widely scattered across the code base.
  - Tedious and time-consuming to find all occurrences.
- Changes may come in many variants.
  - Hard to anticipate; some variants may be overlooked.
- Developers are unaware of changes that affect their code.
  - New code can be introduced using the old coding strategy.

Coccinelle to the rescue!

What is Coccinelle?

- Pattern-based tool for matching and transforming C code
- Under development since 2005. Open source since 2008.
- Allows code changes to be expressed using patch-like code patterns (semantic patches).
- Goal: Automate large-scale changes in a way that fits with the habits of the Linux kernel developer.

Starting point: a patch

```
--- a/drivers/atm/nicstar.c
+++ b/drivers/atm/nicstar.c
@@ -287,4 +287,2 @@
-               init_timer(&ns_timer);
+               setup_timer(&ns_timer, ns_poll, 0UL);
                ns_timer.expires = jiffies + NS_POLL_PERIOD;
-               ns_timer.data = 0UL;
-               ns_timer.function = ns_poll;
```

Semantic patches

- Like patches, but independent of irrelevant details (line numbers, spacing, variable names, etc.)
- Derived from code, with abstraction.

Example: Creating an `init_timer` → `setup_timer` semantic patch

A patch: derived from drivers/atm/nicstar.c

```
-               init_timer(&ns_timer);
+               setup_timer(&ns_timer, ns_poll, 0UL);
                ns_timer.expires = jiffies + NS_POLL_PERIOD;
-               ns_timer.data = 0UL;
-               ns_timer.function = ns_poll;
```

Example: Creating an `init_timer` → `setup_timer` semantic patch

Remove irrelevant code:

```
-               init_timer(&ns_timer);
+               setup_timer(&ns_timer, ns_poll, 0UL);
                ...
-               ns_timer.data = 0UL;
-               ns_timer.function = ns_poll;
```

Example: Creating an `init_timer` → `setup_timer` semantic patch

Abstract over subterms:

```
@@
expression timer, fn_arg, data_arg;
@@
-               init_timer(&timer);
+               setup_timer(&timer, fn_arg, data_arg);
                ...
-               timer.data = data_arg;
-               timer.function = fn_arg;
```

Example: Creating an `init_timer` → `setup_timer` semantic patch

Generalize a little more:

```
@@
expression timer, fn_arg, data_arg;
@@
-                init_timer(&timer);
+                setup_timer(&timer, fn_arg, data_arg);
                 ...
-                timer.data = data_arg;
                 ...
-                timer.function = fn_arg;
```

Results

Dataset: 598 Linux kernel `init_timer` files from different versions.

- 828 calls.
- Our semantic patch updates 308 of them.

Results

Dataset: 598 Linux kernel `init_timer` files from different versions.

- 828 calls.
- Our semantic patch updates 308 of them.

Untreated example: drivers/tty/n_gsm.c:

```
init_timer(&dlci->t1);
dlci->t1.function = gsm_dlci_t1;
dlci->t1.data = (unsigned long)dlci;
```

Example: Creating an `init_timer` → `setup_timer` semantic patch

Extended semantic patch:

```
@@ expression timer, fn_arg, data_arg; @@
-                init_timer(&timer);
+                setup_timer(&timer, fn_arg, data_arg);
                 ...
-                timer.data = data_arg;
                 ...
-                timer.function = fn_arg;
```

Example: Creating an `init_timer` → `setup_timer` semantic patch

Extended semantic patch:

```
@@ expression timer, fn_arg, data_arg; @@
-                init_timer(&timer);
+                setup_timer(&timer, fn_arg, data_arg);
                 ...
-                timer.data = data_arg;
                 ...
-                timer.function = fn_arg;

@@ expression timer, fn_arg, data_arg; @@
-                init_timer(&timer);
+                setup_timer(&timer, fn_arg, data_arg);
                 ...
-                timer.function = fn_arg;
                 ...
-                timer.data = data_arg;
```

Covers 656/828 calls.

Example: Creating an `init_timer` → `setup_timer` semantic patch

Remaining issues

- Some code initializes the function and data before calling `init_timer`.
- Some timers have no data initialization, default to 0.
- Coccinelle sometimes times out.

Complete semantic patch

- 6 rules, 68 lines of code.
- Covers 808/828 calls.
- TODO: Some timers have no local `function` or `data` initialization.

Semantic patch example

```
@@
expression root,e;
local idexpression child;
iterator name for_each_child_of_node;
@@

 for_each_child_of_node(root, child) {
   ... when != of_node_put(child)
       when != e = child
+  of_node_put(child);
?  break;
   ...
}
... when != child
```

Used in the big v5.4 cleanup.

Assessment

- Changes may involve scattered code fragments and data and control flow relationships between them.
  - . . . connects related fragments over control-flow paths.

Assessment

- Changes may involve scattered code fragments and data and control flow relationships between them.
  - . . . connects related fragments over control-flow paths.
- Changes may be widely scattered across the code base.
  - Coccinelle finds an updates all relevant code automatically.

Assessment

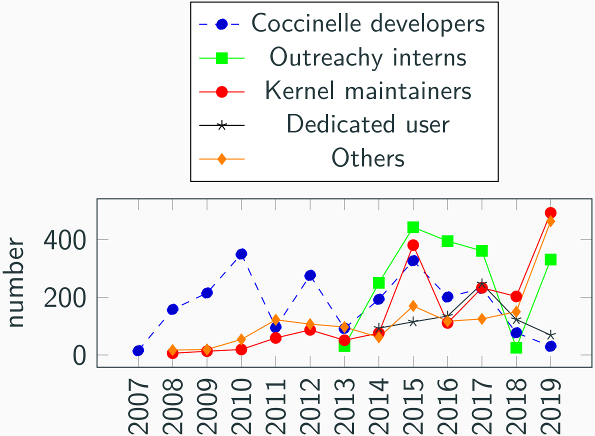
- Changes may involve scattered code fragments and data and control flow relationships between them.
  - . . . connects related fragments over control-flow paths.
- Changes may be widely scattered across the code base.
  - Coccinelle finds an updates all relevant code automatically.
- Changes may come in many variants.
  - Semantic patches are easily adapted to new variants.

Assessment

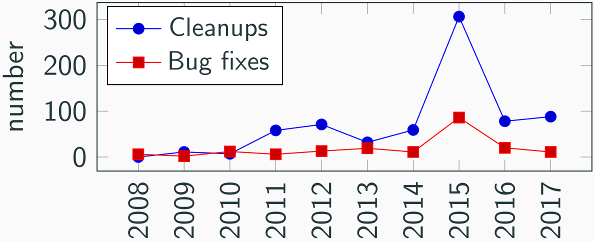
- Changes may involve scattered code fragments and data and control flow relationships between them.
  - . . . connects related fragments over control-flow paths.
- Changes may be widely scattered across the code base.
  - Coccinelle finds an updates all relevant code automatically.
- Changes may come in many variants.
  - Semantic patches are easily adapted to new variants.
- Developers are unaware of changes that affect their code.
  - Semantic patches in commit logs document changes.
  - Semantic patches can be collected in a library and checked during continuous integration.

Impact: Patches in the Linux kernel

Over 7700 Linux kernel commits up to Linux v5.5 (Jan 2020).



Impact: Cleanup vs. bug fix changes among maintainer patches using Coccinelle



Impact: Maintainer use examples

TTY. Remove an unused function argument.

- 11 affected files.

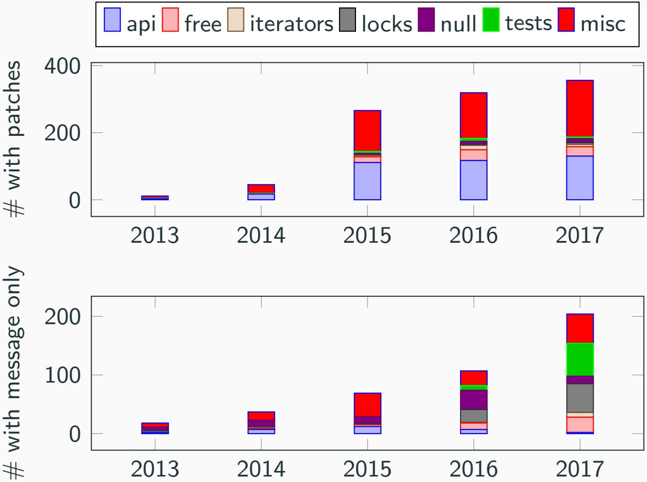
DRM. Eliminate a redundant field in a data structure.

- 54 affected files.

Interrupts. Prepare to remove the irq argument from interrupt handlers, and then remove that argument.

- 188 affected files.

Impact: 0-day reports mentioning Coccinelle per year



Conclusion

- Coccinelle: brings automatic matching and transformation to the systems software developer.
  - Enables needed evolution, independent of the amount of affected code.

Conclusion

- Coccinelle: brings automatic matching and transformation to the systems software developer.
  - Enables needed evolution, independent of the amount of affected code.
- Success: Almost 8000 commits in the Linux kernel based on Coccinelle.

Conclusion

- Coccinelle: brings automatic matching and transformation to the systems software developer.
  - Enables needed evolution, independent of the amount of affected code.
- Success: Almost 8000 commits in the Linux kernel based on Coccinelle.
- Future work: Automatic generation of semantic patches from examples.

Conclusion

- Coccinelle: brings automatic matching and transformation to the systems software developer.
  - Enables needed evolution, independent of the amount of affected code.
- Success: Almost 8000 commits in the Linux kernel based on Coccinelle.
- Future work: Automatic generation of semantic patches from examples.
- Beyond C: Some support for C++, a variant for Java (Coccinelle4J)

Conclusion

- Coccinelle: brings automatic matching and transformation to the systems software developer.
  - Enables needed evolution, independent of the amount of affected code.
- Success: Almost 8000 commits in the Linux kernel based on Coccinelle.
- Future work: Automatic generation of semantic patches from examples.
- Beyond C: Some support for C++, a variant for Java (Coccinelle4J)
- Probably, everyone in this room uses some Coccinelle modified code!

Conclusion

- Coccinelle: brings automatic matching and transformation to the systems software developer.
  - Enables needed evolution, independent of the amount of affected code.
- Success: Almost 8000 commits in the Linux kernel based on Coccinelle.
- Future work: Automatic generation of semantic patches from examples.
- Beyond C: Some support for C++, a variant for Java (Coccinelle4J)
- Probably, everyone in this room uses some Coccinelle modified code!

http://coccinelle.lip6.fr/
https://github.com/coccinelle/coccinelle
https://github.com/kanghj/coccinelle/tree/java