Coccinelle, Prequel, and Spinfer: Automating Summarization and Application of Code Evolutions in the Linux Kernel

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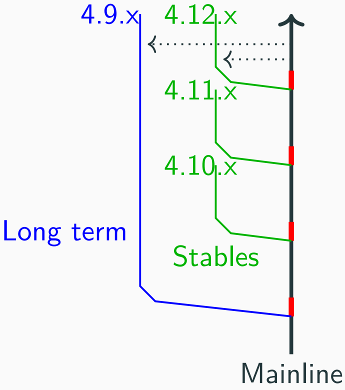
Properties of the Linux kernel

- Code size is 18 MLOC
- Around 4000 contributers per year
- Need for frequent, rapid, large-scale changes
  - Security
  - Performance
  - New hardware features

Properties of the Linux kernel

Changes need to be propagated across multiple versions:



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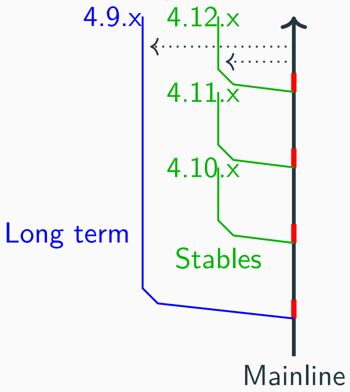

Seems like an impossible challenge?

Mitigating factor: Lots of similar code

Linux 4.0, drivers/usb/atm:

	cxacru.c	speedtch.c	ueagle-atm.c	usbatm.c	xusbatm.c
usbatm_usb_probe	x	x	x	-	x
interface_to_usbdev	x	x	x	x	x
usb_submit_urb	x	x	x	x	-
usb_set_intfdata	-	x	-	x	x
request_firmware	x	x	x	-	-
wait_for_completion	x	-	-	x	-
mutex_lock	x	-	x	x	-
init_timer	x	x	-	x	-
kzalloc	x	x	x	x	-

Opportunities

- Possibility to script repetitive changes

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1. Scripting repetitive changes

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Example:

- `init_timer` replaced by `setup_timer`
- Over 400 occurrences in various Linux kernel versions.

Examples

drivers/infiniband/hw/nes/nes_hw.c:

```
- init_timer(&nesadapter->mh_timer);
- nesadapter->mh_timer.function = nes_mh_fix;
+ setup_timer(&nesadapter->mh_timer, nes_mh_fix, (unsigned long)nesdev);
  nesadapter->mh_timer.expires = jiffies + (HZ/5);
- nesadapter->mh_timer.data = (unsigned long)nesdev;
```

drivers/usb/atm/speedtch.c:

```
- init_timer(&instance->status_check_timer);
- instance->status_check_timer.function = speedtch_status_poll;
- instance->status_check_timer.data = (unsigned long)instance;
+ setup_timer(&instance->status_check_timer, speedtch_status_poll, (unsigned long)instance);
  instance->last_status = 0xff;
  instance->poll_delay = MIN_POLL_DELAY;
- init_timer(&instance->resubmit_timer);
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Coccinelle

- Allows recurring changes to C code to be expressed using patch-like code patterns (semantic patches) using the language SmPL.
- Applies SmPL semantic patches to an entire code base, updating all relevant code sites at once.
- Under development since 2005. Open source since 2008.
- Goal: fit with the existing habits of the Linux developer.

Creating a semantic patch

Start with a typical example:

```
- init_timer(&nesadapter->mh_timer);
- nesadapter->mh_timer.function = nes_mh_fix;
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  nesadapter->mh_timer.expires = jiffies + (HZ/5);
- nesadapter->mh_timer.data = (unsigned long)nesdev;
```

Creating a semantic patch

Drop irrelevant code:

```
- init_timer(&nesadapter->mh_timer);
- nesadapter->mh_timer.function = nes_mh_fix;
+ setup_timer(&nesadapter->mh_timer, nes_mh_fix, (unsigned long)nesdev);
  ...
- nesadapter->mh_timer.data = (unsigned long)nesdev;
```

Creating a semantic patch

Abstract over common subterms:

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

Results

Updates 163 instances: 248 remaining.

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Another option: initialize `data` before `function`

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- timer.data = d;
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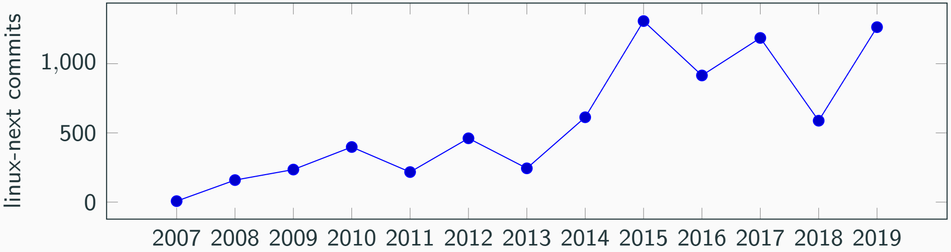
```

Updates 100 more instances: 148 still remaining.

Impact: Patches using Coccinelle in the Linux kernel



Almost 8000 patches overall (linux-next).

Assessment

- + Helps the developer express his knowledge of how a change should be done.
- + Also useful for metrics, bug finding, etc.
- + Supports C, some C++, and Java (prototype).

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+ Also useful for metrics, bug finding, etc.
+ Supports C, some C++, and Java (prototype).
– Doesn't help if one doesn't know what to do.
– Doesn't help understand what others have done.

2. Finding examples of repetitive changes

Problem:

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- "Don't use `init_timer`, use `setup_timer` instead."

Prequel

Analogy between:

- Performing changes (semantic patch):
  - Describe code to match and remove
  - Describe code to add
- Matching changes (patch query):
  - Describe removed code
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Query language for patches in a git history

Goal: fit with the existing habits of the Linux developer.

init_timer ⟶ setup_timer **patch query**

```
@@
@@
- init_timer(...);
+ setup_timer(...);
```

init_timer ⟶ setup_timer **patch query**

```
@@
@@
- init_timer(...);
+ setup_timer(...);
```

Results:

```
fcb58a033271: 100% (157/301)
acc6539fe629: 100% (205/301)
e9c43a75cda0: 100% (163/301)
2443c6cc92ed: 100% (114/301)
...
aff55a3638a2: 88% (137/301)
03f23fc51dc9: 83% (222/301)
b9eaf1872222: 80% (1/301)
96ff2c11c5e8: 75% (116/301)
01e77e13fc5a: 75% (291/301)
...
```

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- Gives examples of how to make a change.
- Also useful for metrics.
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- \+ Gives examples of how to make a change.
- \+ Also useful for metrics.
- \+ Supports C, some C++, and Java (prototype).
- – Human intervention required to understand and perform the illustrated changes.

3. Inferring semantic patches from examples

Problem:

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From patch examples, infer a semantic patch that generalizes the changes.

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Main challenges:

- Identify change instance boundaries
- Identify constraints between fragments in a change instance
  - Control-flow constraints.
  - Data-flow constraints.
- Recognize multiple change variants
- Recognize noise

Principally the work of Lucas Serrano

Methodology

- Collection of common code fragments (clustering).
- Identification of common control-flow graph structures (...).
- Generalization of common code fragments into patterns.
  - Metavariables connecting common terms within matched code fragments.
  - Metavariables connecting terms from the matched code to the constructed code.

To avoid high complexity, address these one by one.

Examples

```
- init_timer(&nesadapter->mh_timer);
- nesadapter->mh_timer.function = nes_mh_fix;
+ setup_timer(&nesadapter->mh_timer, nes_mh_fix, (unsigned long)nesdev);
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- init_timer(&instance->status_check_timer);
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+ setup_timer(&instance->resubmit_timer, speedtch_resubmit_int, (unsigned long)instance);
```

```
- init_timer(&dev->tx_watchdog);
- dev->tx_watchdog.data = (unsigned long)ndev;
- dev->tx_watchdog.function = ns83820_tx_watch;
+ setup_timer(&dev->tx_watchdog, ns83820_tx_watch, (unsigned long)ndev);
```

Clustering

A	B
`init_timer(&nesadapter->mh_timer);`	`nesadapter->mh_timer.function = ...;`
`init_timer(&instance->status_check_timer);`	`instance->status_check_timer.function = ...;`
`init_timer(&instance->resubmit_timer);`	`instance->resubmit_timer.function = ...;`
`init_timer(&dev->tx_watchdog);`	`dev->tx_watchdog.function = ...;`

C	D
`nesadapter->mh_timer.data = ...;`	`setup_timer(&nesadapter->mh_timer, ...);`
`instance->status_check_timer.data = ...;`	`setup_timer(&instance->status_check_timer, ...);`
`instance->resubmit_timer.data = ...;`	`setup_timer(&instance->resubmit_timer, ...);`
`dev->tx_watchdog.data = ...;`	`setup_timer(&dev->tx_watchdog, ...);`

Abstraction of clustered examples

init_timer(&X0);	X0.function = X1;
`init_timer(&nesadapter->mh_timer);`	`nesadapter->mh_timer.function = ...;`
`init_timer(&instance->status_check_timer);`	`instance->status_check_timer.function = ...;`
`init_timer(&instance->resubmit_timer);`	`instance->resubmit_timer.function = ...;`
`init_timer(&dev->tx_watchdog);`	`dev->tx_watchdog.function = ...;`

X0.data = X1;	setup_timer(&X0,X1,X2);
`nesadapter->mh_timer.data = ...;`	`setup_timer(&nesadapter->mh_timer, ...);`
`instance->status_check_timer.data = ...;`	`setup_timer(&instance->status_check_timer, ...);`
`instance->resubmit_timer.data = ...;`	`setup_timer(&instance->resubmit_timer, ...);`
`dev->tx_watchdog.data = ...;`	`setup_timer(&dev->tx_watchdog, ...);`

Semantic-patch-rule graph construction

Ingredients:

```
- init_timer(&X0);
- X0.function = X1;
- X0.data = X1;
+ setup_timer(&X0,X1,X2);
```

Current rule:

Semantic-patch-rule graph construction

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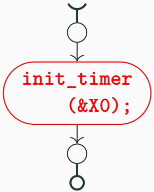
Current rule:



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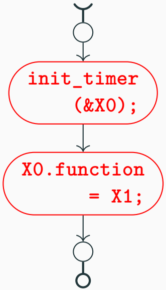


Dominance and post-dominance required

Semantic-patch-rule graph construction (splitting)

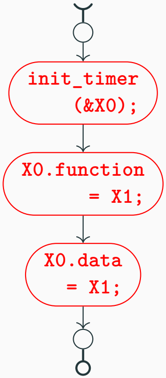
Ingredients:

```
+ setup_timer(&X0,X1,X2);
```

Pending ingredients:

```
- X0'.data = X1';
+ setup_timer(&X0',X1',X2');
```

Current rule:



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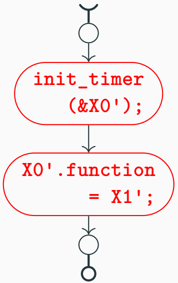

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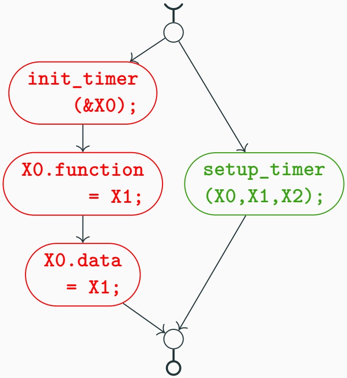

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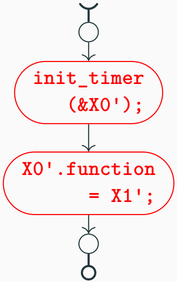
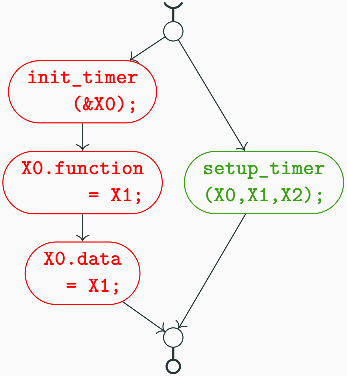


Generation of semantic patch code and assignment of metavariables

In completed rule graphs introduce metavariables according to some constraints:

- Metavariables used in removed or context code should reflect relationships common to all instances.
- Metavariables used in added code must be instantiated by removed or context code.
- Respecting the constraints on added code may entail more splitting.

Generation of semantic patch code and assignment of metavariables




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

Complete result

```
@@expression T,F,D;@@
- init_timer(&T);
+ setup_timer(&T, F, D);
  ...
- T.data = D;
- T.function = F;
```

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- T.function = F;
- T.data = D;
  ...
- init_timer(&T);
+ setup_timer(&T, F, D);
```

```
@@expression T,F;@@
- init_timer(&T);
+ setup_timer(&T, F, 0UL);
  ...
- T.function = F;
```

How did we address the challenges?

Identify change instance boundaries:

- Generate and test: smaller rules may cover all instances.

Control-flow constraints:

- Dominance/postdominance requirement

Data-flow constraints:

- Metavariable constraints

How did we address the challenges?

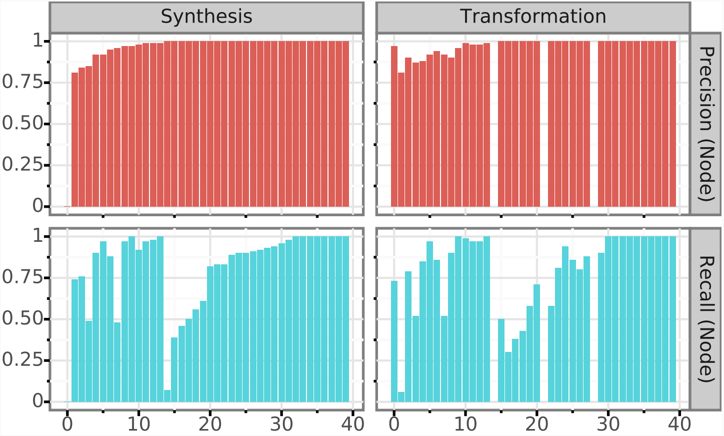
Recognize multiple change variants:

- Iterative rule construction. Splitting.

Noise:

- Distance metric used in clustering - distant terms are dropped.

Evaluation results



Completes in at most a few minutes for most examples.

Conclusion

Pipeline for fully automating summarizing and performing of evolutions:

- Prequel to find examples.
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Potential uses:

- Backporting of complete services to older kernel releases (e.g., device drivers)
- Backporting of patches over API changes.
- Upstreaming of out-of-tree code.
- Make Coccinelle more accessible to new or infrequent users.

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http://coccinelle.lip6.fr, http://prequel-pql.gforge.inria.fr/