Coccinelle: A Program Matching and Transformation Tool for Systems Code

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http://coccinelle.lip6.fr

The problem: Dealing with Systems Code

- It's huge
- It's configuration polymorph
- It's (unfortunately) buggy
- It's often written in C
- It evolves continuously

Two Examples

- Bug finding (and fixing)
  - Search for patterns of wrong code
  - Systematically fix found wrong code
- Collateral evolutions
  - Evolution in a library interface entails lots of Collateral Evolutions in clients
    - Search for patterns of interaction with the library
    - Systematically transform the interaction code

The Coccinelle tool

- Program matching and transformation for unpreprocessed C code.
- Fits with the existing habits of Systems (Linux) programmers.

- Semantic Patch Language (SmPL):
  - Based on the syntax of patches,
  - Declarative approach to transformation
  - High level search that abstracts away from irrelevant details
  - A single small semantic patch can modify hundreds of files, at thousands of code sites

Using SmPL to abstract away from irrelevant details

- Differences in spacing, indentation, and comments
- Choice of the names given to variables (metavariables)
- Irrelevant code ('. . .', control flow oriented)
- Other variations in coding style (isomorphisms)

  e.g. `if(!y)` ≡ `if(y==NULL)` ≡ `if(NULL==y)`

Bug finding and fixing

- The "!&" bug

C allows mixing booleans and bit constants

```
if (!state->card->
    ac97_status & CENTER_LFE_ON)
        val &= ~DSP_BIND_CENTER_LFE;
```

In sound/oss/ali5455.c until Linux 2.6.18

(problem is over two lines)

A Simple SmPL Sample

```
@@
expression E;
constant C;
@@

- !E & C                    // !C is not a constant
+ !(E & C)
```

96 instances in Linux from 2.6.13 (August 2005) to v2.6.28 (December 2008)

58 in 2.6.20 (February 2007),

2 in Linux-next (26th May 2009)

Collateral Evolutions

Evolution

lib.c

becomes

```
int foo(int x){
int bar(int x, int y){
```

Legend: before / after

Collateral Evolutions (CE) in clients

client1.c

```
foo(1);
bar(1,?);

foo(2);
bar(2,?);
```

client2.c

```
foo(foo(2));
bar(bar(2,?),?);

if(foo(3)) {
if(bar(3,?)) {
```

clientn.c

CE in Linux device drivers

- Many libraries and many clients:
  - Lots of driver support libraries: one per device type, one per bus (pci library, sound library, …)
  - Lots of device specific code: Drivers make up more than 50% of Linux
- Many evolutions and collateral evolutions

  1200 evolutions in 2.6, some affecting 400 files, at over 1000 sites [EuroSys 2006] (summer 2005)

- Taxonomy of evolutions :

  Add argument, split data structure, getter and setter introduction, protocol change, change return type, add error checking, …

Example from Linux 2.5.71

- Evolution: scsi_get()/scsi_put() dropped from SCSI library
- Collateral evolutions: SCSI resource now passed directly to *proc_info* callback functions via a new parameter

```
int a_proc_info(int x
                ,scsi *y
                ) {
   scsi *y;
   ...
   y = scsi_get();
   if(!y) { ... return -1; }
   ...
   scsi_put(y);
   ...
   }
```

From local var to parameter

Delete calls to library

Delete error checking code

Legend: before / after

Semantic Patches

```
@@
function a_proc_info;
identifier x,y;
@@
   int a_proc_info(int x
+                  ,scsi *y
                           ) {
-    scsi *y;
     ... 
-    y = scsi_get();
-    if(!y) { ... return -1; }
     ...
-    scsi_put(y);
     ...
   }
```

Control-flow '...' operator

Affected Linux driver code

drivers/scsi/53c700.c

```
int s53c700_info(int limit)
{
  char *buf;
  scsi *sc;
  sc = scsi_get();
  if(!sc) {
     printk(“error”);
     return -1;
  }
  wd7000_setup(sc);
  PRINTP(“val=%d”,
          sc->field+limit);
  scsi_put(sc);
  return 0;
}
```

drivers/scsi/pcmcia/nsp_cs.c

```
int nsp_proc_info(int lim)
{
  scsi *host;
  host = scsi_get();
  if(!host) {
     printk(“nsp_error”);
     return -1;
  }
  SPRINTF(“NINJASCSI=%d”,
          host->base);
  scsi_put(host);
  return 0;
}
```

Similar, but not identical

Applying the semantic patch

```
int s53c700_info(int limit)
{
  char *buf;
  scsi *sc;
  sc = scsi_get();
  if(!sc) {
     printk("error");
     return -1;
  }
  wd7000_setup(sc);
  PRINTP("val=%d",
          sc->field+limit);
  scsi_put(sc);
  return 0;
}
```

```
int nsp_proc_info(int lim)
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  scsi *host;
  host = scsi_get();
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     printk("nsp_error");
     return -1;
  }
  SPRINTF("NINJASCSI=%d",
           host->base);
  scsi_put(host);
  return 0;
}
```

proc_info.sp

```
@@
function a_proc_info;
identifier x,y;
@@
 int a_proc_info(int x
+                ,scsi *y
                    ) {
-   scsi *y;
    ...
-   y = scsi_get();
-   if(!y) { ... return -1; }
    ...
-   scsi_put(y);
      ...
  }
```

```
$ spatch –sp_file proc_info.sp
  –dir linux-next
```

Applying the semantic patch

```
int s53c700_info(int limit, scsi *sc)
{
  char *buf;




  wd7000_setup(sc);
  PRINTP("val=%d",
         sc->field+limit);

  return 0;
}
```

```
int nsp_proc_info(int lim, scsi *host)
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-   scsi_put(y);
      ...
  }
```
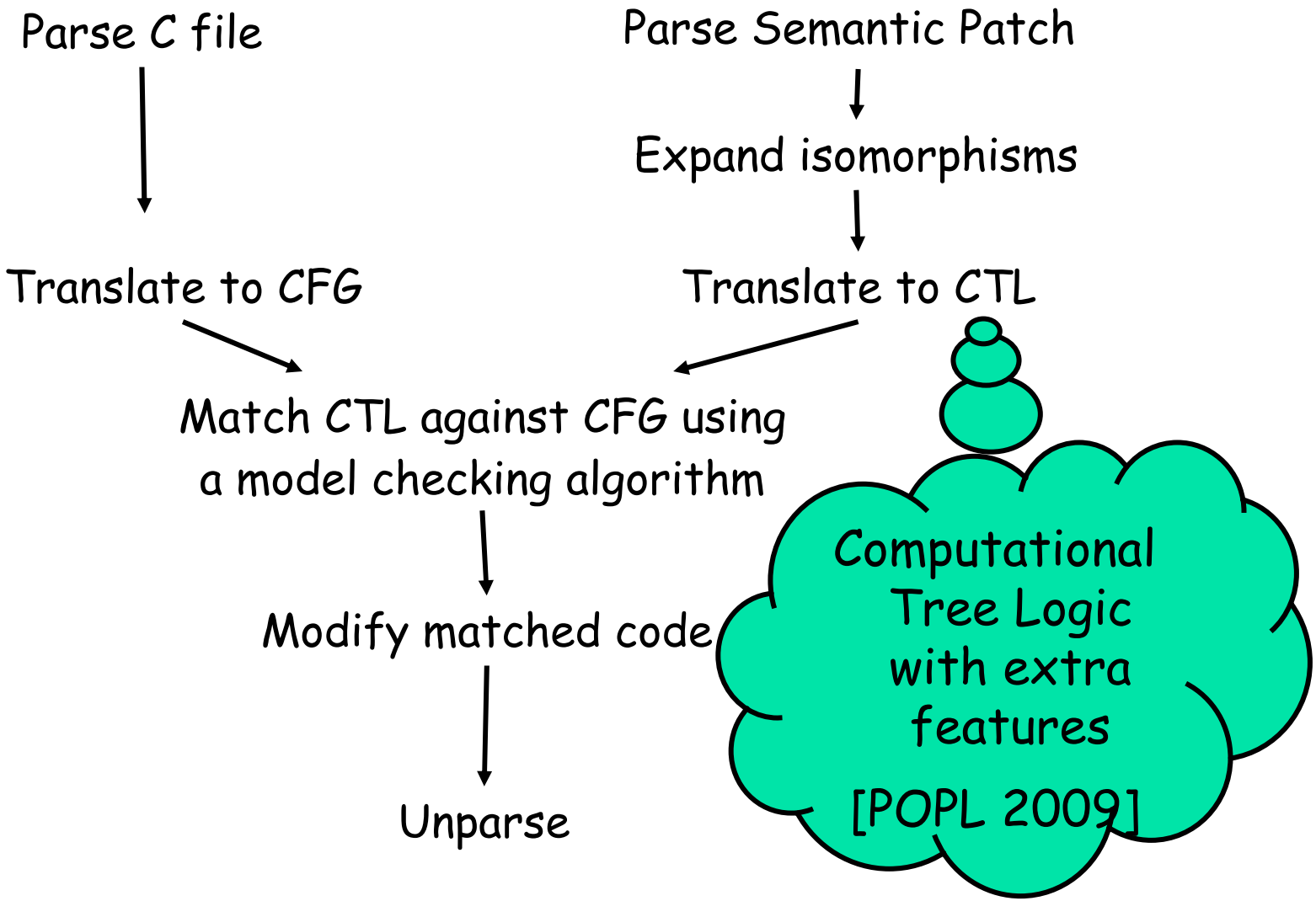

```
$ spatch –sp_file proc_info.sp
  –dir linux-next
```

How does the Coccinelle tool work?

Transformation engine



Other issues

- Need to produce readable code
  - Keep space, indentation, comments
  - Keep CPP instructions as-is. Also programmer may want to transform some #define,*iterator* macros (e.g. list_for_each)

Very different from most other C tools

- Interactive engine, partial match
- Implementation of isomorphisms
  - Rewriting the Semantic patch (not the C code),
  - Generate disjunctions

60 000 lines of OCaml code

Evaluation on Collateral Evolutions [Eurosys 2008]

Experiments

- Methodology
  - Detect past collateral evolutions in Linux 2.5 and 2.6 using the `patchparse` tool [Eurosys'06]
  - Select representative ones
    - Test suite of over 60 CEs
  - Study them and write corresponding semantic patches
    - Note: we are not kernel developers
- Going "back to the future". Compare:
  - what Linux programers did manually
  - What Coccinelle, given our SPs, does automatically

Test suite

- 20 Complex CEs : bugs introduced by the programmers
  - In each case 1-16 errors + misses
- 23 Mega CEs : affect over 100 sites on Linux between 2.6.12 and 2.6.20
  - 22-1124 files affected
  - Up to 39 human errors
  - Up to 40 people for up to two years
- 26 CEs for the bluetooth directory update from 2.6.12 to 2.6.20
  - Median case

More than 5800 driver files

Results

- SP are on average 106 lines long (6-369)
- SPs often 100 times smaller than "human-made" patches. A measure of time saved:
  - Not doing manually the CE on all the drivers
  - Not reading and reviewing big patches, for people with drivers outside source tree
- Correct and complete automated evolutions for 93% of the files
  - Problems on the remaining 7%: We miss code sites
    - CPP issues, lack of isomorphisms (data-flow and inter-procedural)
    - We are not kernel developers … don't know how to specify
- Average processing time of 0.7s per file

Sometimes the tool was right and the human wrong

Impact on the Linux kernel

- **Collateral evolution related SPs**
  - Over 11 semantic patches
  - Over 52 patches
- **SPs for bug-fixing and bad programming practices**
  - Over 57 semantic patches
  - Over 148+20 patches

Future/Current Work
Coccinelle *in the large*

- Management of conflicts between Linux kernel and services (detection, solving)
- Version consistency

- Protocol-based bug detection in Linux [DSN2009]

- Collaborative design of rules
  - Rule ranking
  - Collaborative refinements

Conclusion

- SmPL: a declarative language for program matching and transformation
- Looks like a patch; fits with Systems (Linux) programmers' habits
- Quite "easy" to learn; already accepted by the Linux community

- A transformation engine based on model checking technology

Questions?

http://coccinelle.lip6.fr

Why Coccinelle ?

A Coccinelle (ladybug) is a bug that eats smaller bugs

Kill bugs before they hatch!!!

COCCINELLE