Coccinelle: A Program Matching and Transformation Tool for Linux

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joint work with

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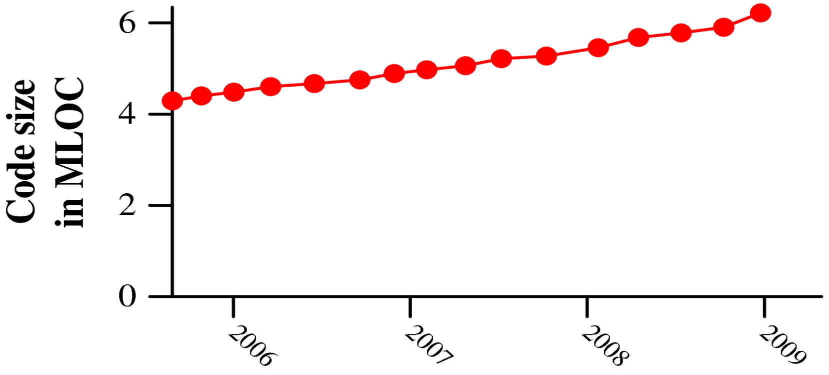
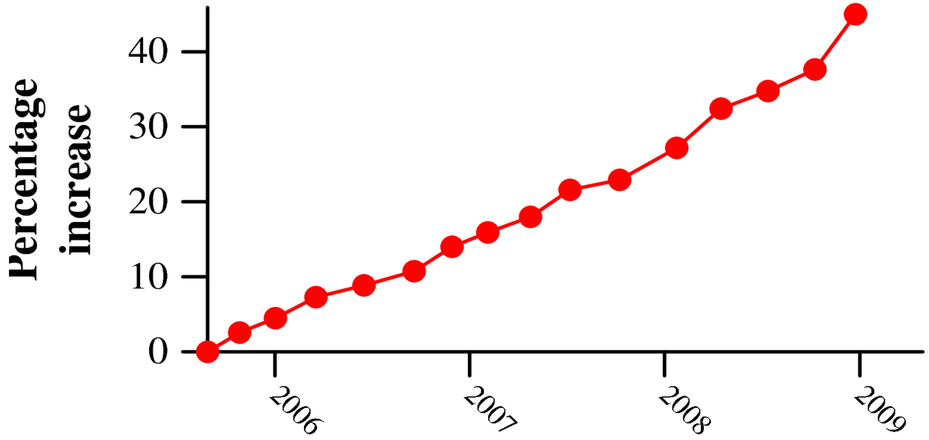
http://coccinelle.lip6.fr/

The problem: Dealing with Linux Code

- It's huge
  - 6 MLOC
  - Increased by almost 50% in 3 years
  - Over 50% dedicated to drivers





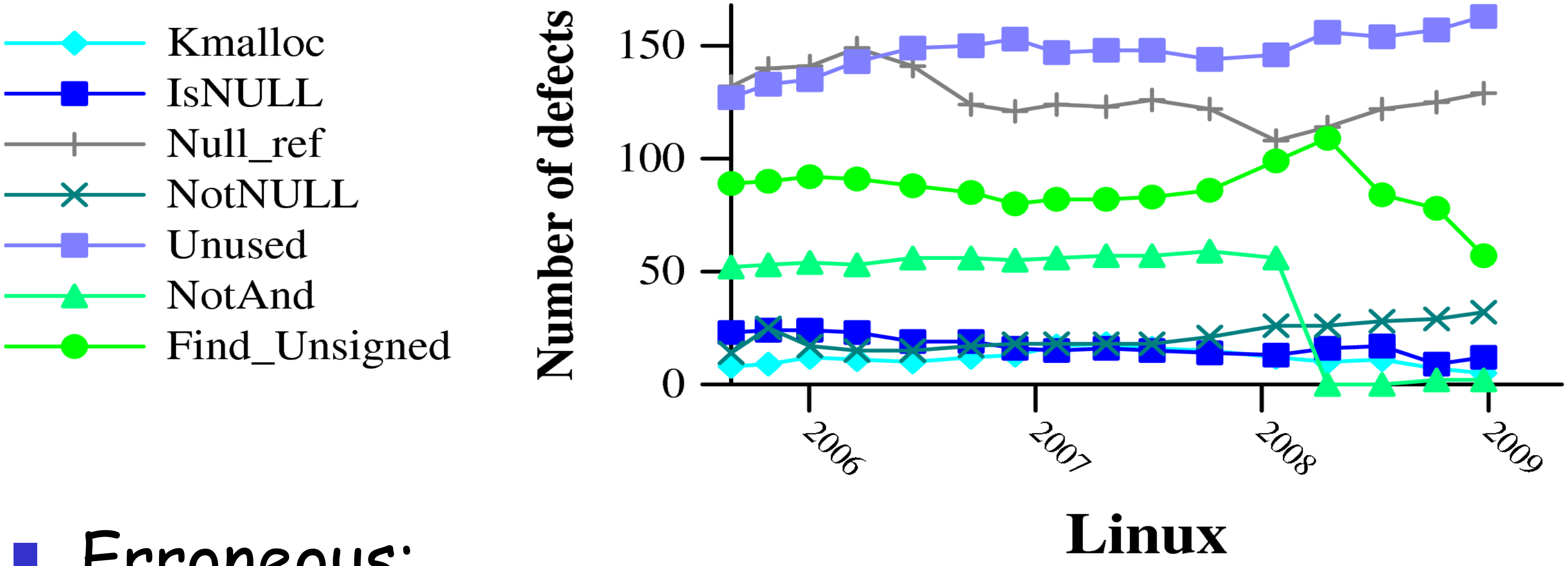
The problem: Dealing with Linux Code

- It’s huge
- It’s configuration polymorphic
  - Several platforms
  - Many combinations of devices.

The problem: Dealing with Linux Code

- It's huge
- It's configuration polymorphic
- It's (unfortunately) buggy

Bugs´ lives



- Erroneous:
  - Kmalloc, IsNULL, NotAnd, Find_Unsigned
- Suspicious: NULL_ref, NotNULL
- Bad practices: Unused

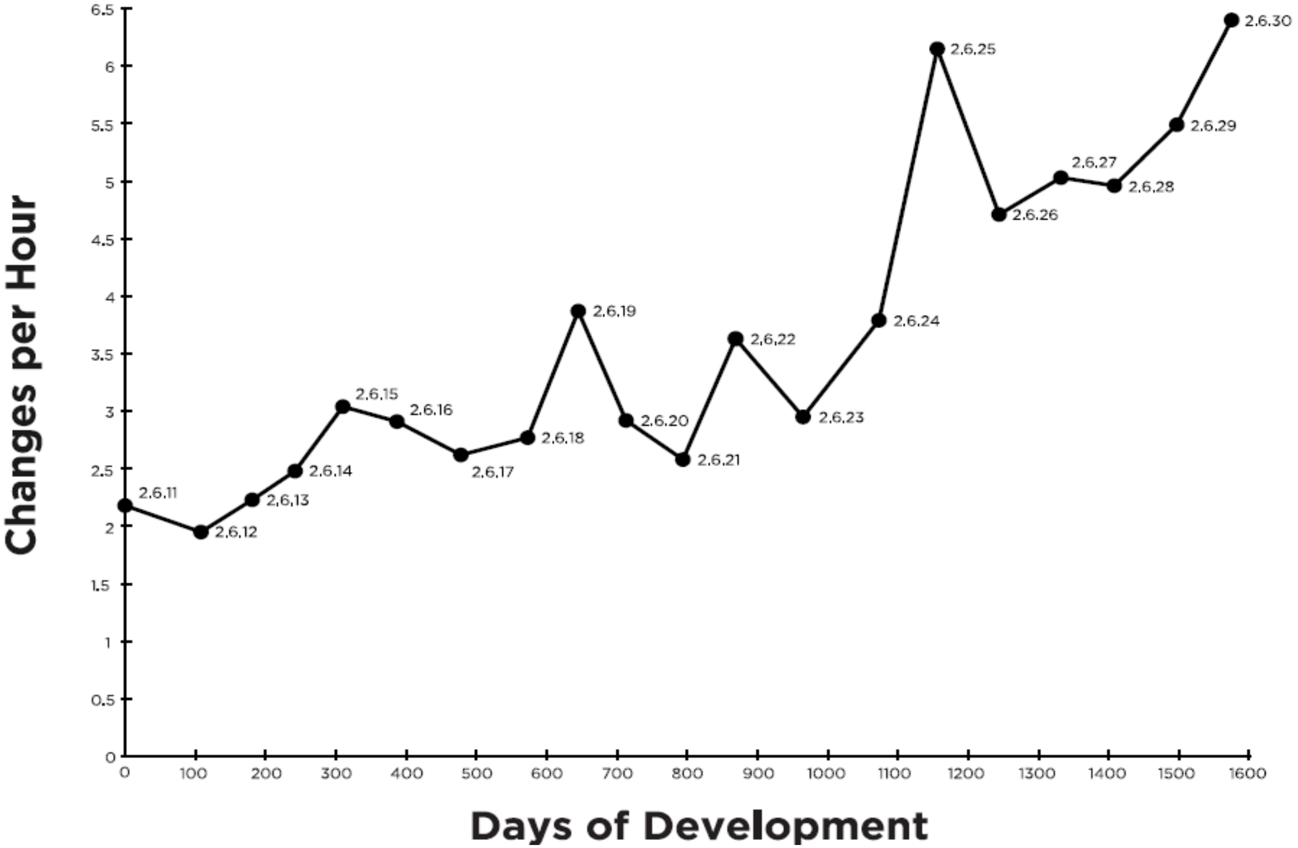
The problem: Dealing with Linux Code

- It's huge
- It's configuration polymorphic
- It's (unfortunately) buggy
- It's written in C
  - Error prone language

The problem: Dealing with Linux Code

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

Can you still follow?



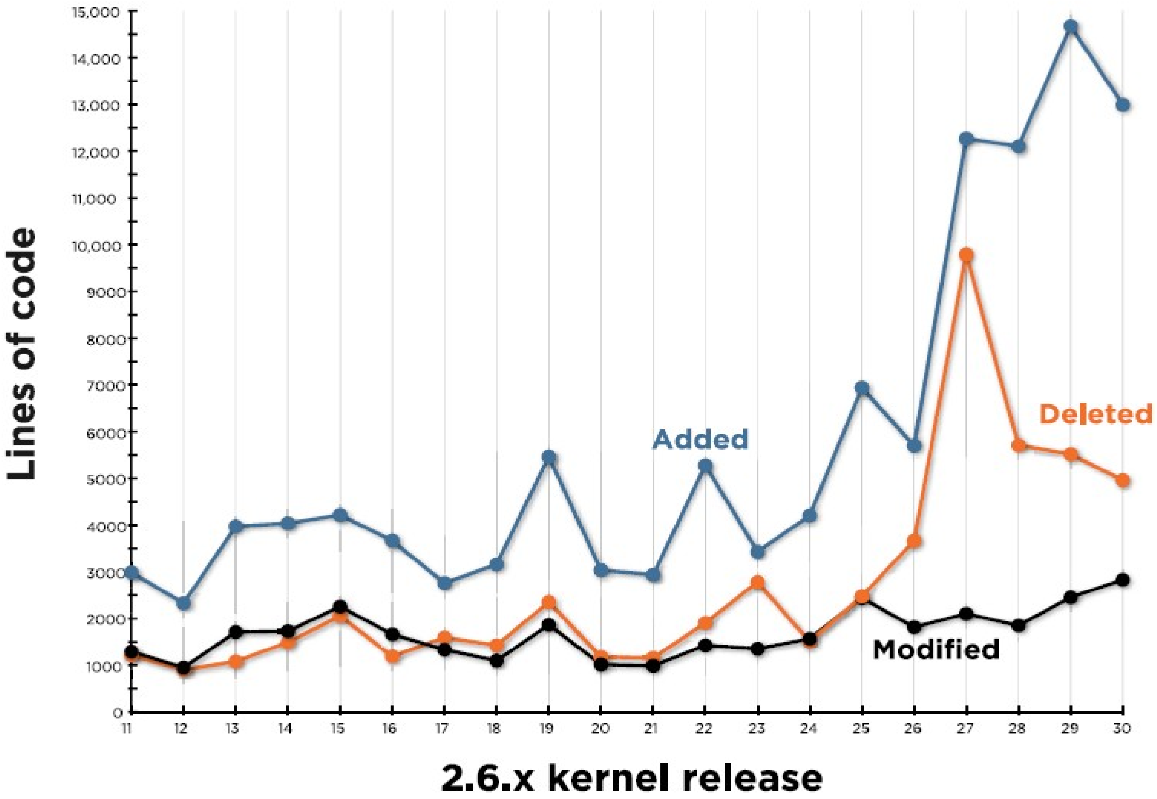
Linux Kernel Development

Greg Kroah-Hartman, SuSE Labs /Novell Inc.

Jonathan Corbet, LWN.net

Amanda McPherson, The Linux Foundation

Changes in detail



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Two problems

- 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 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 and last Saturday)

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

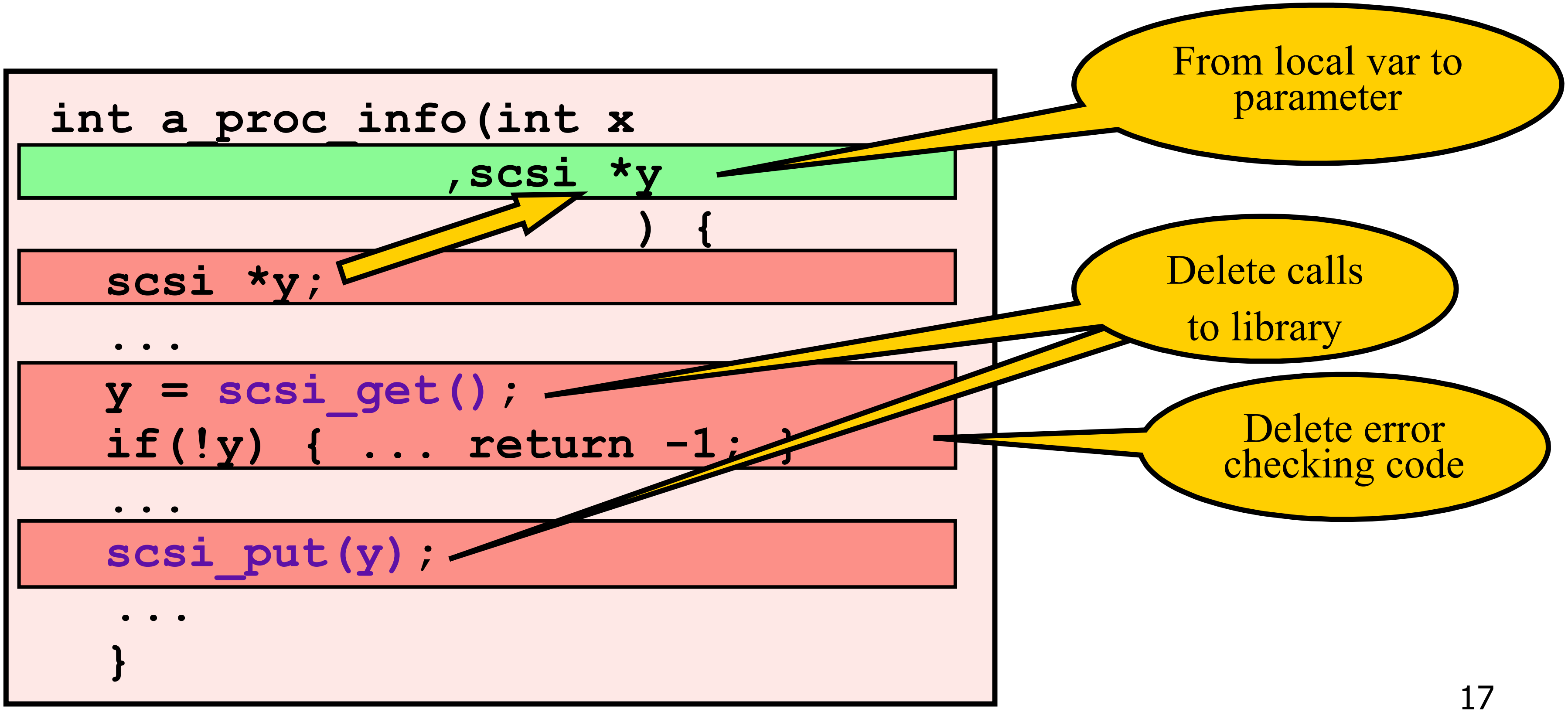
  1200 evolutions in 2.6, some affecting 400 files, at over 1000 sites [EuroSys 2006] (summer 2005)
- Taxonomy of evolutions :

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

Example from Linux 2.5.71

Legend: 🟥 before 🟩 after

- 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

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)
{
  scsi *host;
  host = scsi_get();
  if(!host) {
     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)
{






  SPRINTF("NINJASCSI=%d",
           host->base);

  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
```

Advance examples

Evolution: kmalloc/memset ⇒ kzalloc

```
fh = kmalloc(sizeof(struct zoran_fh), GFP_KERNEL);
if (!fh) {
  dprintk(1,
    KERN_ERR
    "%s: zoran_open(): allocation of zoran_fh failed\n",
    ZR_DEVNAME(zr));
  return -ENOMEM;
}
memset(fh, 0, sizeof(struct zoran_fh));
```

Evolution: kmalloc/memset ⇒ kzalloc

```
fh = kmalloc(sizeof(struct zoran_fh), GFP_KERNEL);
if (!fh) {
  dprintk(1,
    KERN_ERR
    "%s: zoran_oper
    ZR_DEVNAME(zr))
  return -ENOMEM;
}
memset(fh, 0, sizec
```

```
fh = kzalloc(sizeof(struct zoran_fh), GFP_KERNEL);
if (!fh) {
  dprintk(1,
    KERN_ERR
    "%s: zoran_open(): allocation of zoran_fh failed\n",
    ZR_DEVNAME(zr));
  return -ENOMEM;
}
```

Evolution: kmalloc/memset ⇒ kzalloc

1) Eliminate irrelevant code

```
fh = kmalloc(sizeof(struct zoran_fh), GFP_KERNEL);
...
memset(fh, 0, sizeof(struct zoran_fh));
```

Evolution: kmalloc/memset ⇒ kzalloc

2) Describe the transformation

```
-fh = kmalloc(sizeof(struct zoran_fh), GFP_KERNEL);
+fh = kzalloc(sizeof(struct zoran_fh), GFP_KERNEL);
...
-memset(fh, 0, sizeof(struct zoran_fh));
```

Evolution: kmalloc/memset ⇒ kzalloc

3) Abstract over subterms

```
@@
expression x;
expression E1,E2;




@@
-x = kmalloc(E1, E2);
+x = kzalloc(E1, E2);
...

-memset(x, 0, E1);
```

Evolution: kmalloc/memset ⇒ kzalloc

4) Refinement

```
@@
expression x;
expression E1,E2, E3;
statement S;
identifier f;

@@
-x = kmalloc(E1, E2);
+x = kzalloc(E1, E2);
... when != ( f(...,x,...) | <+...x...+> = E3 )
    when != ( while (...) S | for (...;...;...) S )
-memset(x, 0, E1);
```

Evolution: kmalloc/memset ⇒ kzalloc

5) Generalization

```
@@
expression x;
expression E1,E2, E3;
statement S;
identifier f;
type T1, T2;
@@
-x = (T1)kmalloc(E1, E2);
+x = kzalloc(E1, E2);
... when != ( f(...,x,...) | <+...x...+> = E3 )
    when != ( while (...) S | for (...;...;...) S )
-memset((T2)x, 0, E1);
```

Updates 355/564 files

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

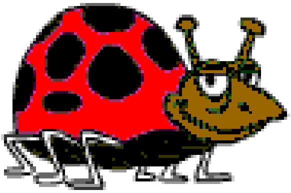
- SP are on average 106 lines long (6-369)
- SPs often 100 times smaller than "human-made" patches. A measure of time saved:
  - Not doing manually the CE on all the drivers
  - Not reading and reviewing big patches, for people with drivers outside source tree
- Correct and complete automated evolutions 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

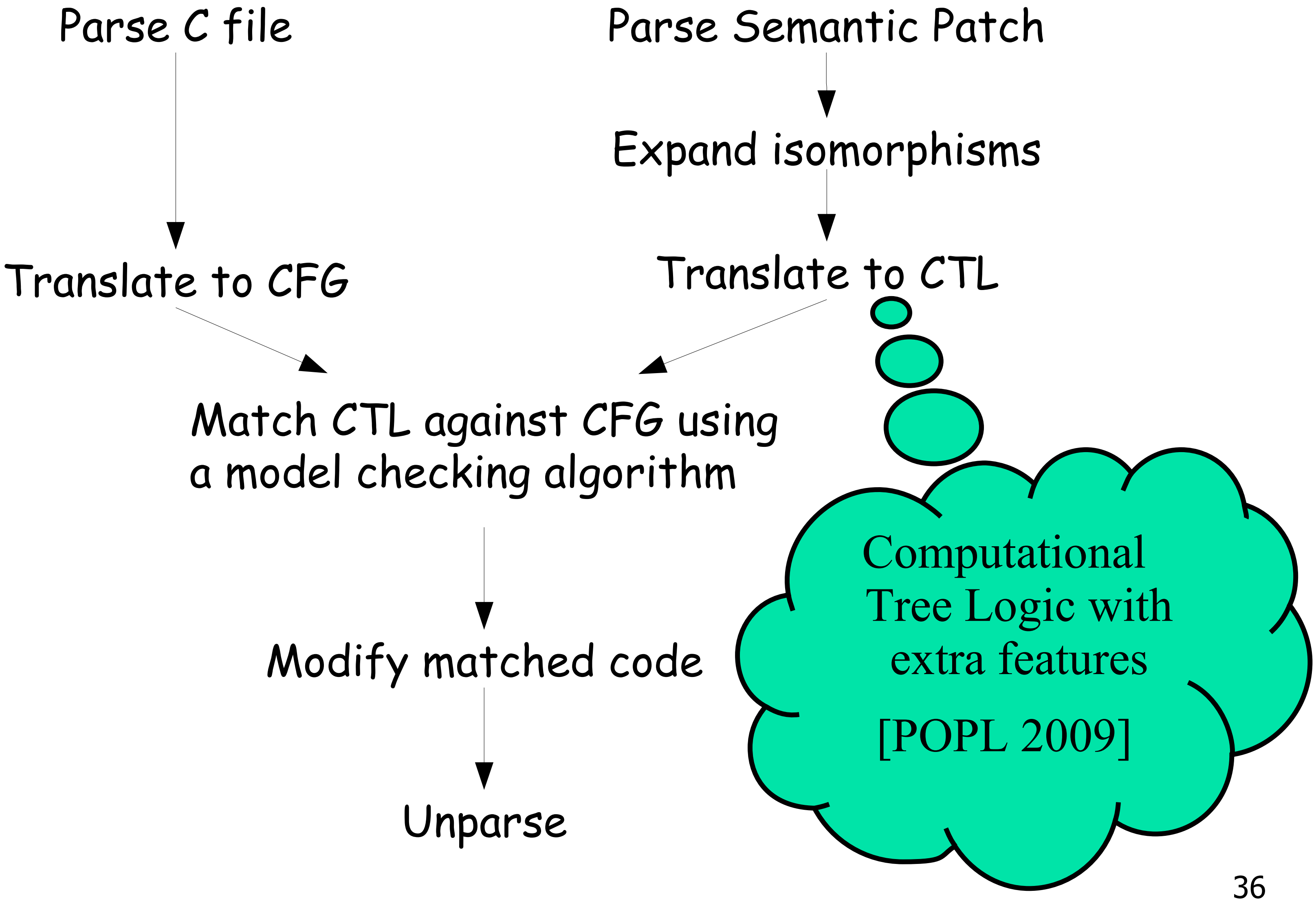
Impact on the Linux kernel

- **Collateral evolution related SPs**
  - Over 60 semantic patches
- **SPs for bug-fixing and bad programming practices**
  - **Over 57 semantic patches**
- **Generated patches**
  - Over 230 patches accepted

How does the Coccinelle tool work?



Transformation engine



Parse C file

Translate to CFG

Parse Semantic Patch

Expand isomorphisms

Translate to CTL

Match CTL against CFG using a model checking algorithm

Modify matched code

Unparse

Computational Tree Logic with extra features

[POPL 2009]

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),

68 000 lines of O'Caml code

Current/Future Work
Coccinelle *in the large*

- Semantic patch inference (spdiff) [ASE2008]
- Protocol-based bug detection in Linux [DSN2009]
- Enforcing API usage [ACP4IS2009]
- Herodotos: To study bugs´ lives [INRIA RR6984, CFSE2009]
- Collaborative design of rules
- Version consistency

Conclusion

- SmPL: a declarative language for program matching and transformation
- Quite “easy” to learn; already accepted by the Linux community
- SPs looks like a patch; fits with Linux programmers’ habits
- SPs documents evolutions
- A transformation engine based on model checking technology

More information…

http://coccinelle.lip6.fr/

Coccinelle Users Day

November 25, 2009

Paris, LiP6-Passy-Kennedy

Contact: Nadia.MESRAR@inria.fr

Why Coccinelle ?

A ladybug (Coccinelle)

eats aphids (bugs).

http://www.flickr.com/photos/misskei/137166247/

Kill bugs before they hatch!!!

http://coccinelle.lip6.fr/