Semantic Patches
for specifying and automating
Collateral Evolutions

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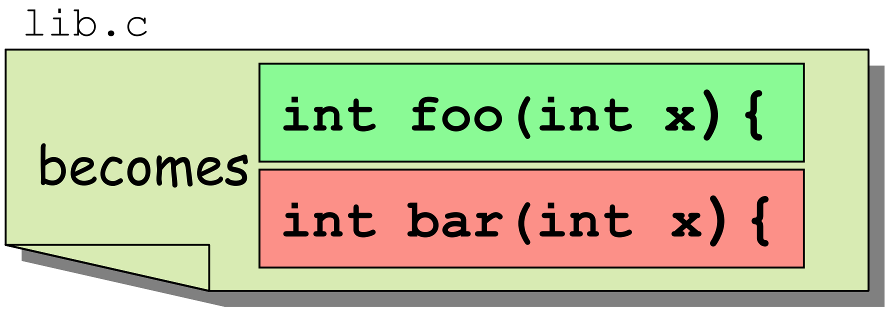
The problem: Collateral Evolutions

- Evolution

  in a library



lib.c

```
int foo(int x){
```

becomes

```
int bar(int x){
```

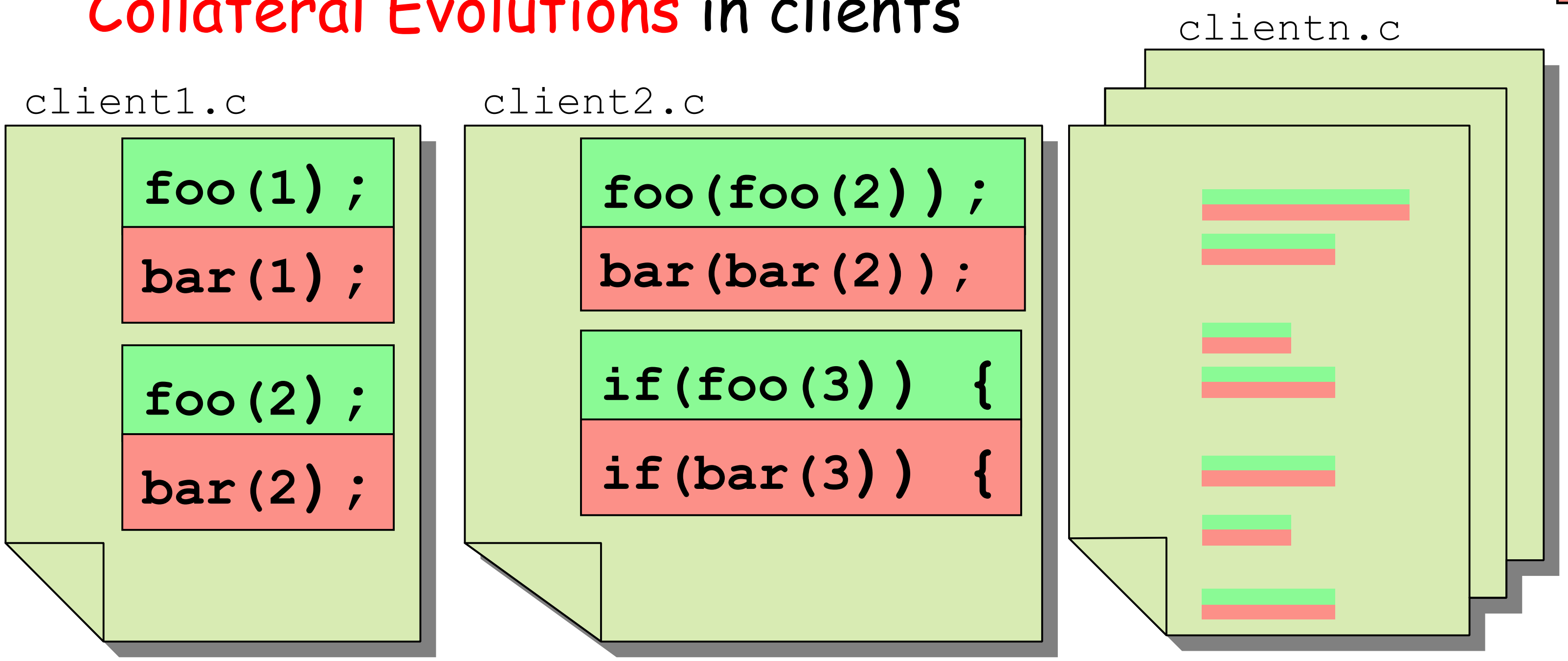
Legend:

🟩 before

🟥 after

- Can entail lots of

  Collateral Evolutions 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

Our target: Linux device drivers

- Many libraries: driver support libraries

  One per device type, per bus (pci library, sound, …)
- Many clients: device specific code

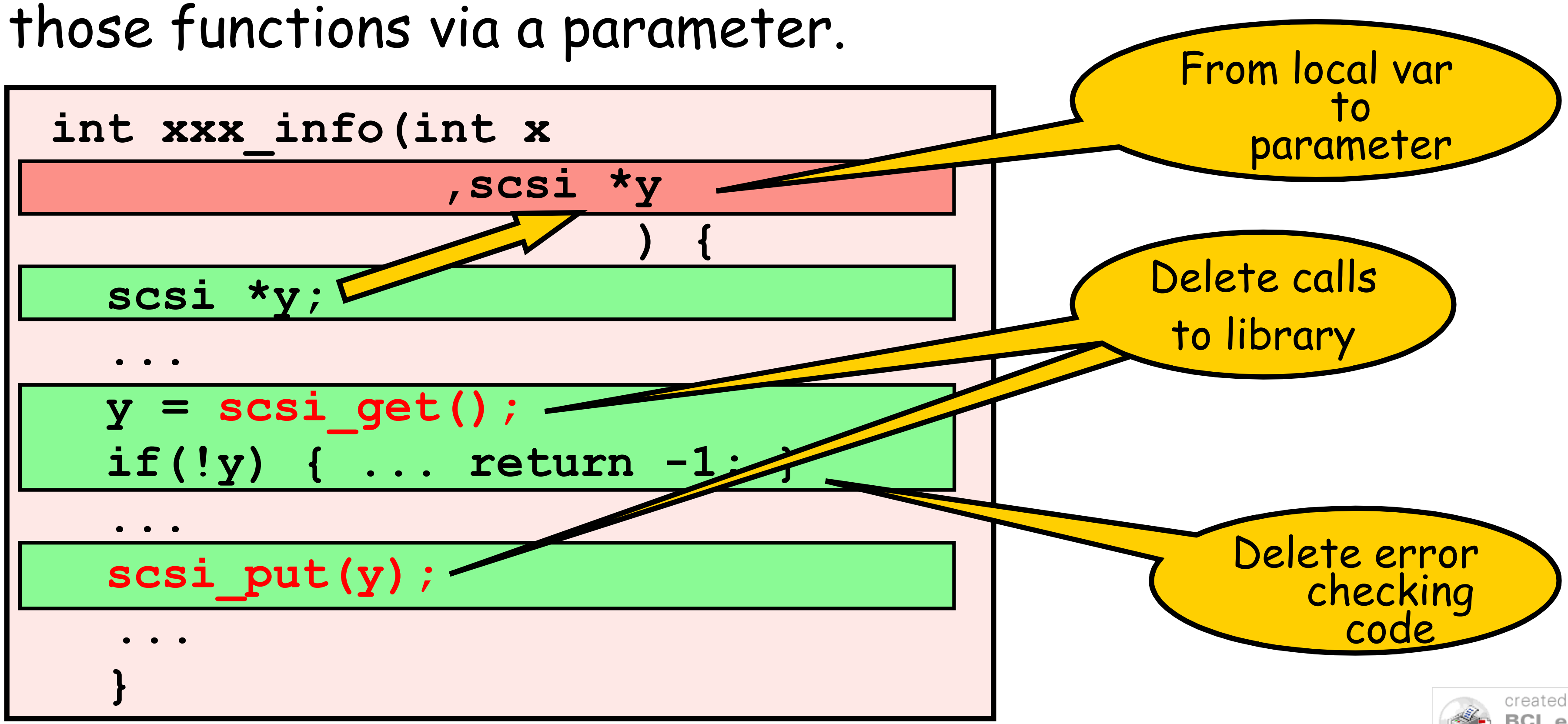
  Drivers make up > 50% of the Linux source code
- Many evolutions and collateral evolutions

  1200 evolutions in 2.6, some affecting 400 files, at over 1000 sites
- Taxonomy of evolutions :

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

Complex Collateral Evolutions

The *xxx_info* functions should not call the `scsi_get` and `scsi_put` library functions to compute a `scsi` resource. This resource will now be passed directly to those functions via a parameter.



```
 int xxx_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

Our idea

The example

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

- How to specify the required program transformation ?
- In what programming language ?

A patch-like syntax ?

Our idea: Semantic Patches

```
@@
function xxx_info;

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

metavariables

Declarative language

the '...' operator

modifiers

SmPL: Semantic Patch Language

- A single small semantic patch can modify hundreds of files, at thousands of code sites

- This is because the features of SmPL make a semantic patch generic by abstracting away the specific details at each code site:
  - Differences in spacing, indentation, and comments
  - Choice of the names given to variables (use of metavariables)
  - Different ways to sequence instructions in C (control-flow oriented rather than AST oriented)
  - Other variations in coding style (use of isomorphisms)

Sequences and the '…' operator

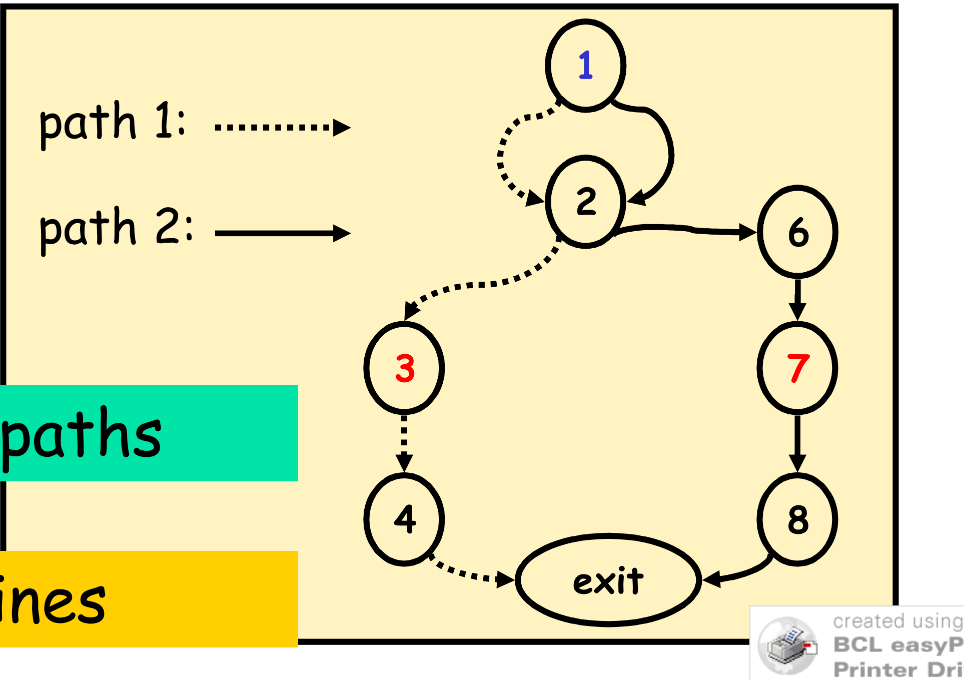
C file

```
1 y = scsi_get();
2 if(exp) {
3  scsi_put(y);
4  return -1;
5 }
6 printf("%d",y->f);
7 scsi_put(y);
8 return 0;
```

Semantic patch

```
- y = scsi_get();
  ...
- scsi_put(y);
```

Control-flow graph of C file



"…" means for all subsequent paths

One '-' line can erase multiple lines

Isomorphisms

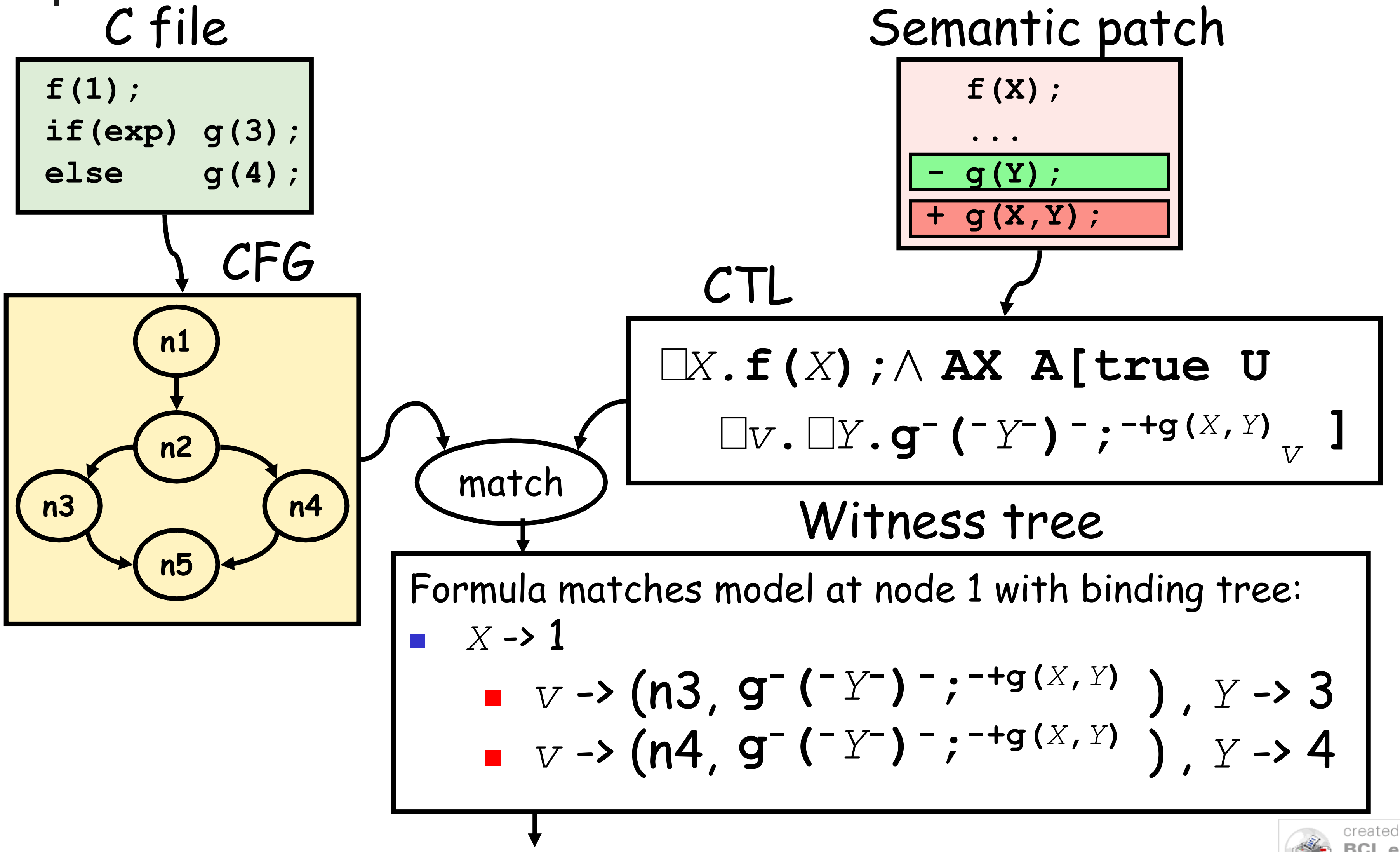
- Examples:
  - Boolean : X == NULL ⇔ !X ⇔ NULL == X
  - Control : if(E) S1 else S2 ⇔ if(!E) S2 else S1
  - Pointer : E->field ⇔ *E.field
  - etc.
- How to specify isomorphisms ?

```
@@ expression *X; @@

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

We have reused SmPL syntax

Example



C file

```
f(1);
if(exp) g(3);
else    g(4);
```

CFG

Semantic patch

```
  f(X);
  ...
- g(Y);
+ g(X,Y);
```

CTL

$\Box X.\mathbf{f}(X);\wedge\ \mathbf{AX}\ \mathbf{A[true\ U}$

$\Box v.\Box Y.\mathbf{g}^{-}(^{-}Y^{-})^{-};^{-+\mathbf{g}(X,Y)}{}_{v}\ \mathbf{]}$

match

Witness tree

Formula matches model at node 1 with binding tree:

- X -> 1
  - v -> (n3, $\mathbf{g}^{-}(^{-}Y^{-})^{-};^{-+\mathbf{g}(X,Y)}$), Y -> 3
  - v -> (n4, $\mathbf{g}^{-}(^{-}Y^{-})^{-};^{-+\mathbf{g}(X,Y)}$), Y -> 4

Conclusion

- Collateral Evolution is an important problem, especially in Linux device drivers
- SmPL: a declarative language to specify collateral evolutions
- Looks like a patch; fits with Linux programmers' habits
- But takes into account the semantics of C (CFG-oriented, isomorphisms), hence the name Semantic Patches
- A transformation engine to automate collateral evolutions based on model checking technology