Precise and Accurate Patch Presence Test for Binaries

Usenix Security'18

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University of California, Riverside

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What’s the problem?

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Short Answer: Given an Android image (or other binary), how do we decide whether a CVE has been patched?

A real-world example

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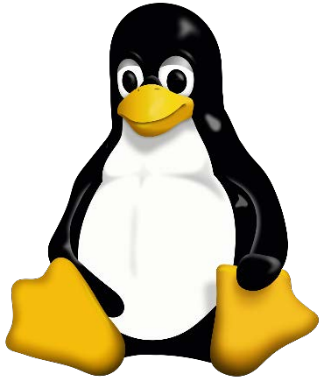

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Open Source

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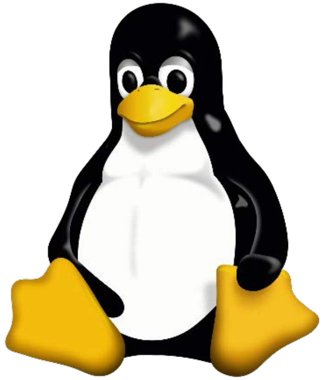

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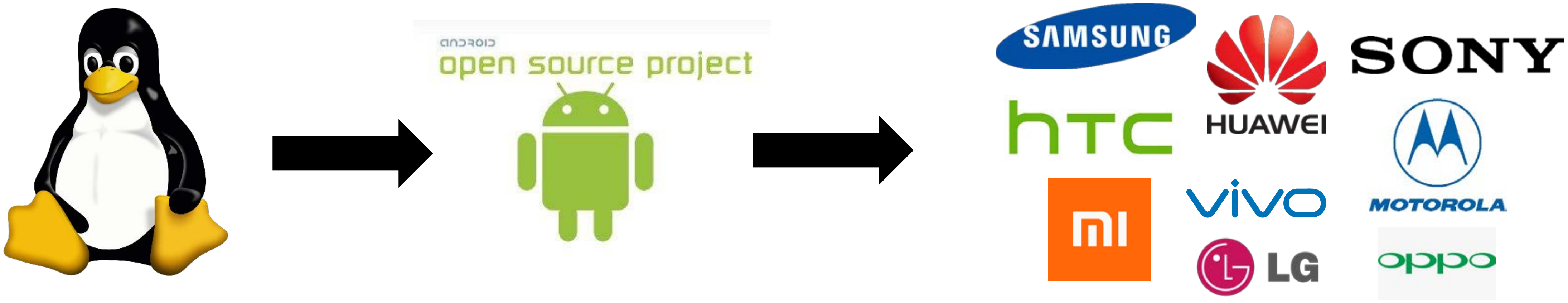

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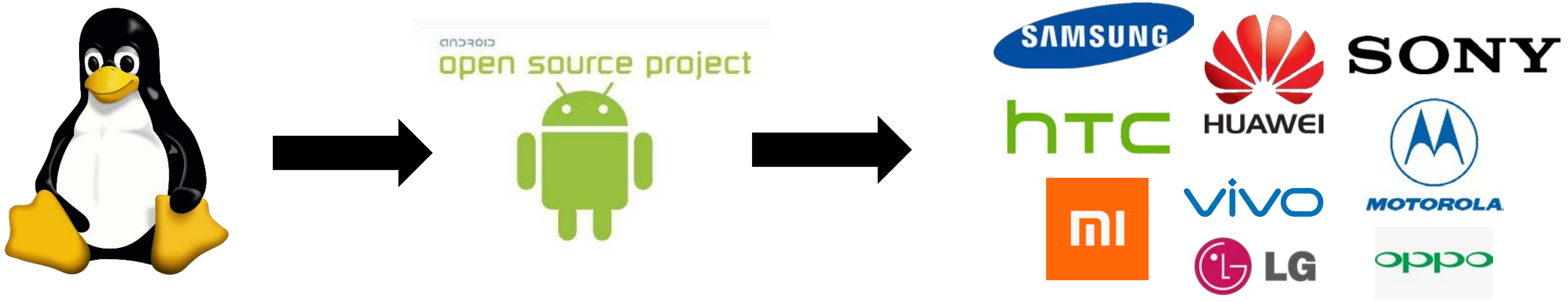

Few source “snapshots” w/o commit history.

- Are the mainstream linux/AOSP patches propagated?

Open vs. Closed

- Open-source is the trend.

- Code reuse in closed-source software.

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- Open-source is the trend.

- Code reuse in closed-source software.

- Is the open-source security patch applied in the binary?

Why challenging?

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Func():
.......
AAAAAA
+ the line
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......
BBBBBB
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......
```

backport

```
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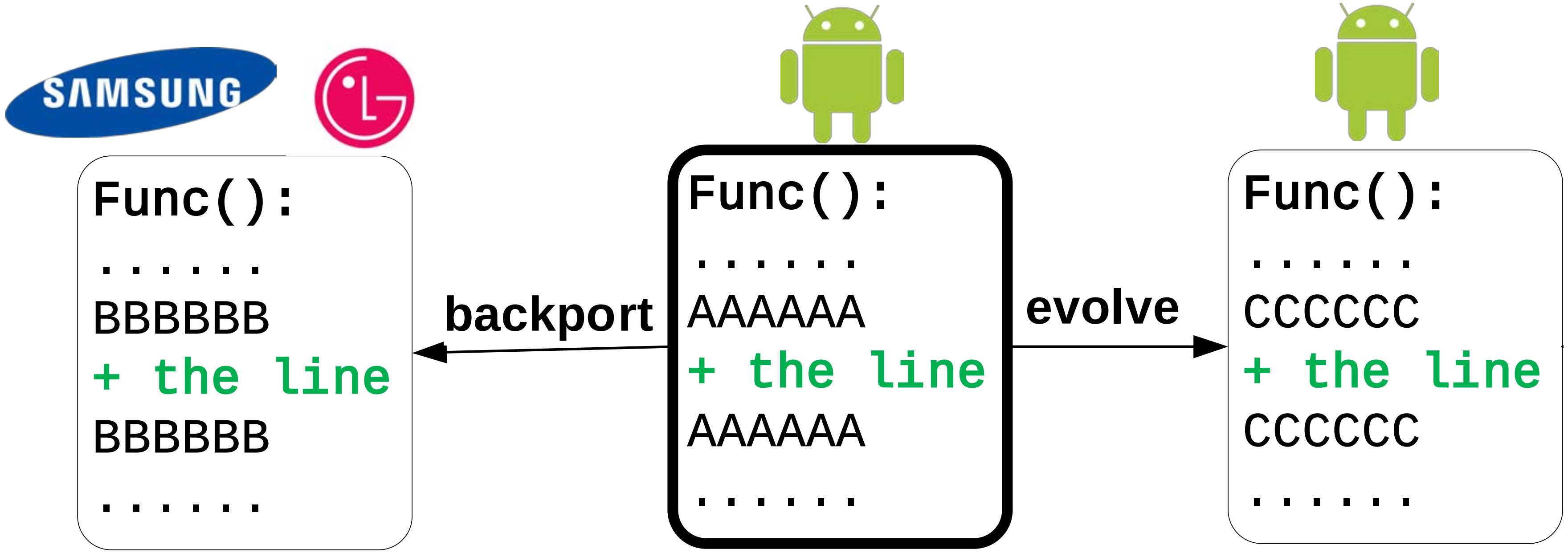

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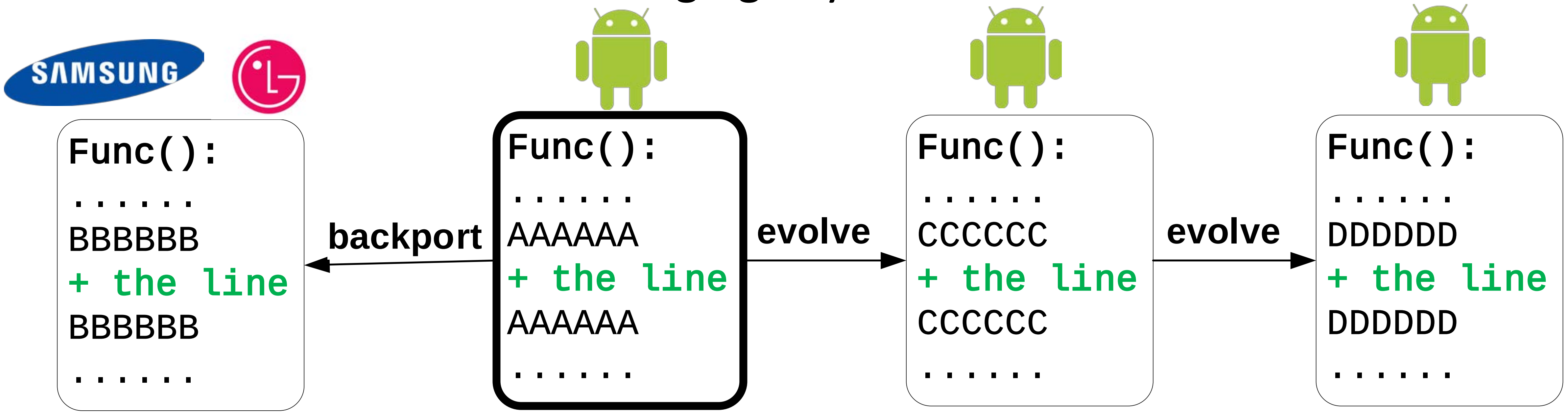
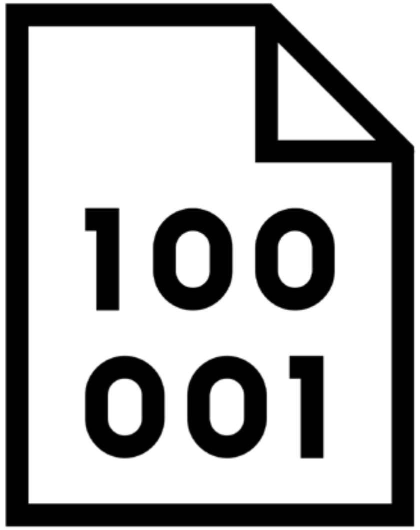


#2: Haystack is a binary…

- Find the needle in a binary.



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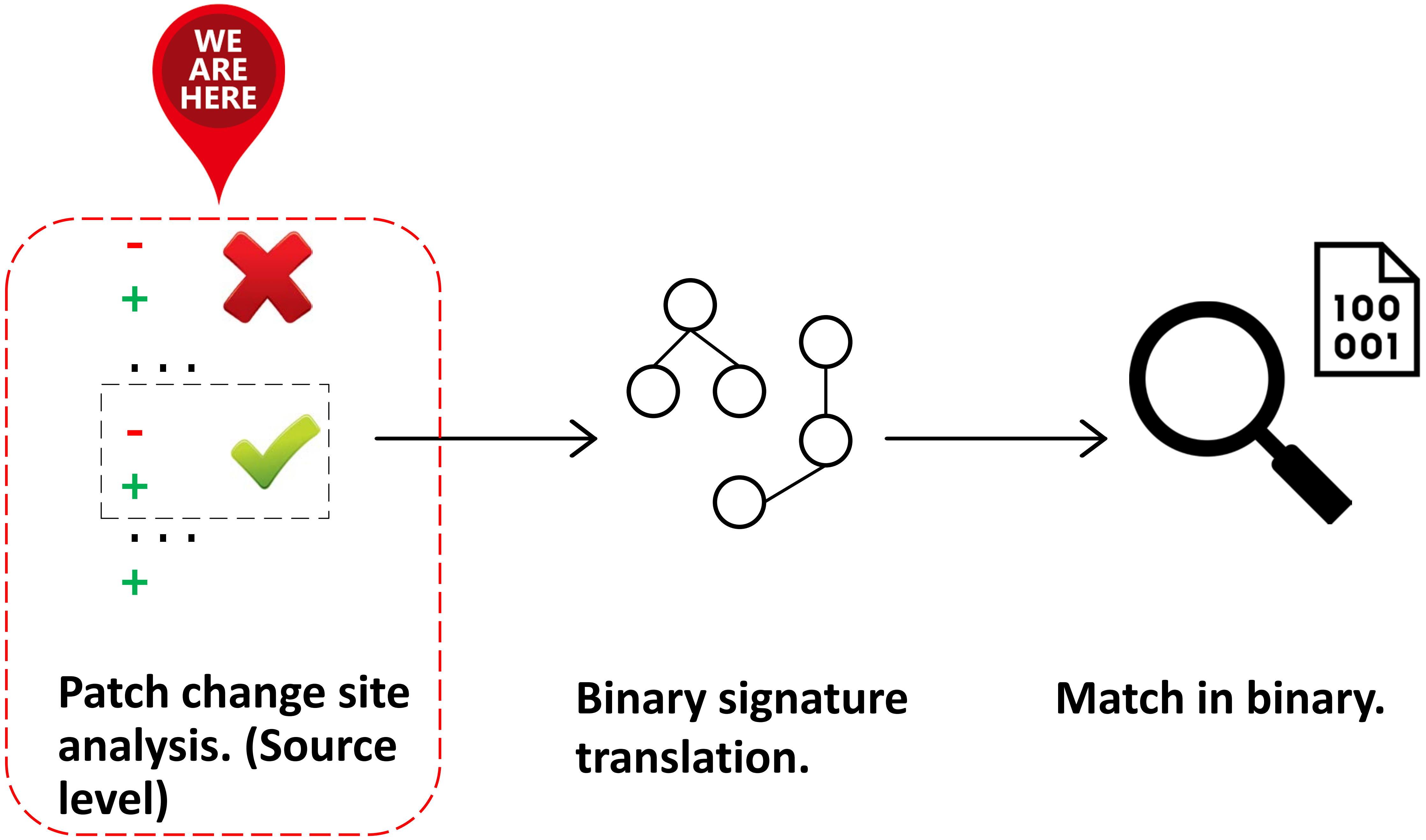
Lack of knowledge about the needle (i.e. the patch).

How does FIBER work?

How does a human expert work?


WE ARE HERE
Patch change site analysis. (Source level)
Binary signature translation.
Match in binary.
100
001

Change Site Analysis: What will human do?

- Given an open-source security patch, you need to locate it in a binary.
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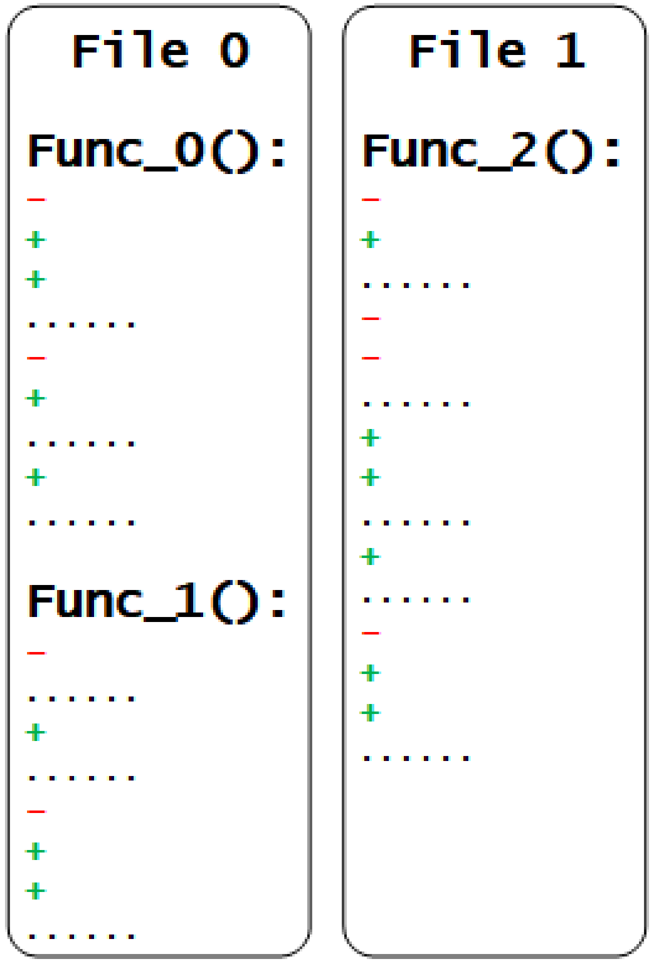

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- Given an open-source security patch, you need to locate it in a binary.
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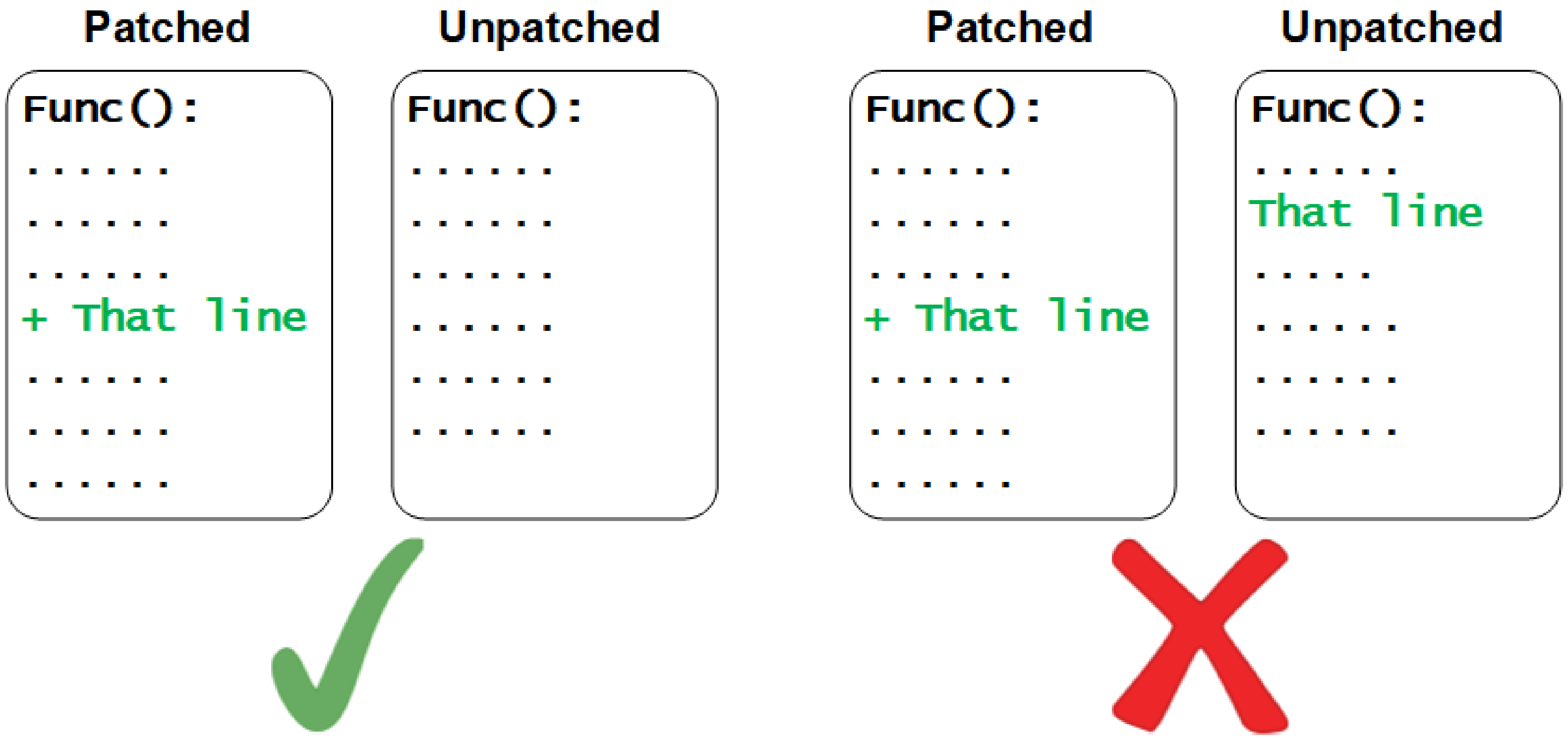
Pick those most obvious, unique and representative change sites.

```
File 0

Func_0():
-
+
+
......
-
+
......
+
......

Func_1():
-
......
+
......
-
+
+
......
```

```
File 1

Func_2():
-
+
......
-
-
......
+
+
......
+
......
-
+
+
......
```

Change Site Analysis

- **Unique** – Exists only in the patched version.



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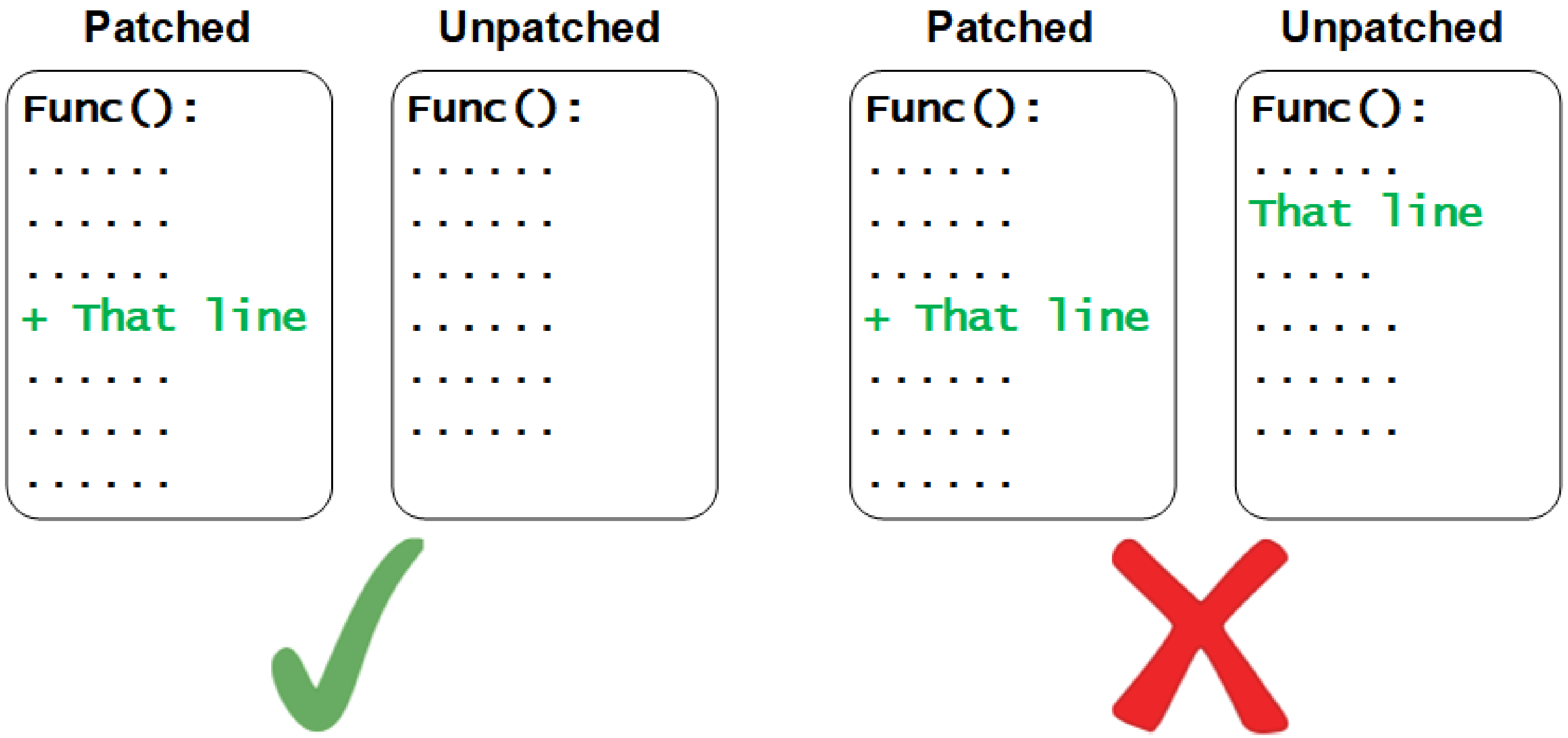

Solution: token-based string search to test uniqueness, add contexts if not unique.

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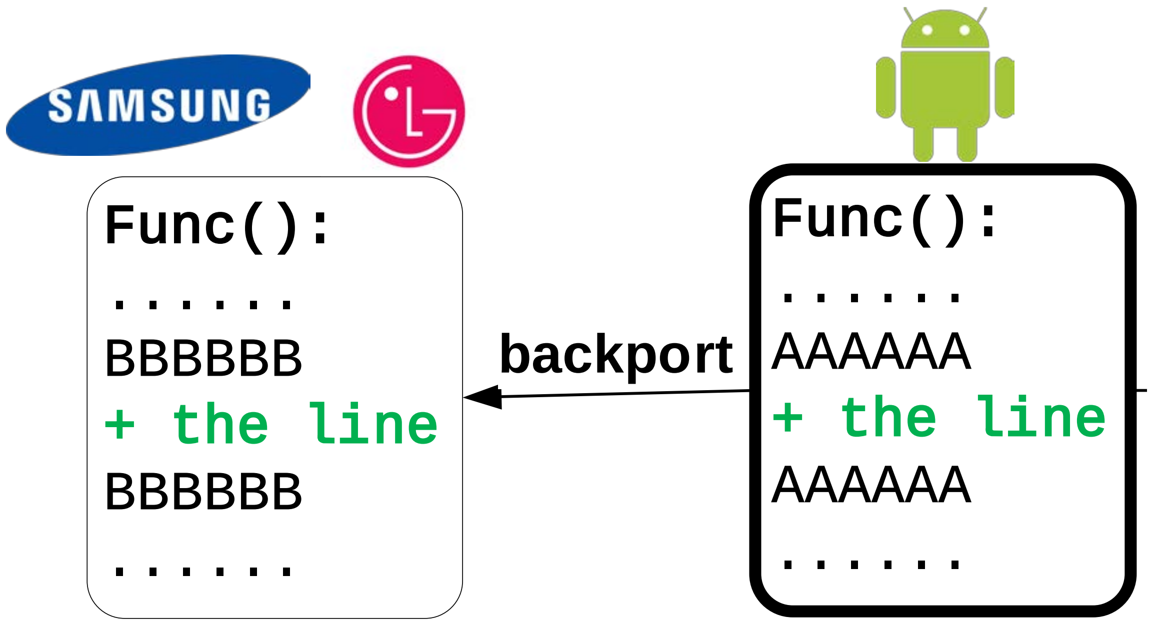

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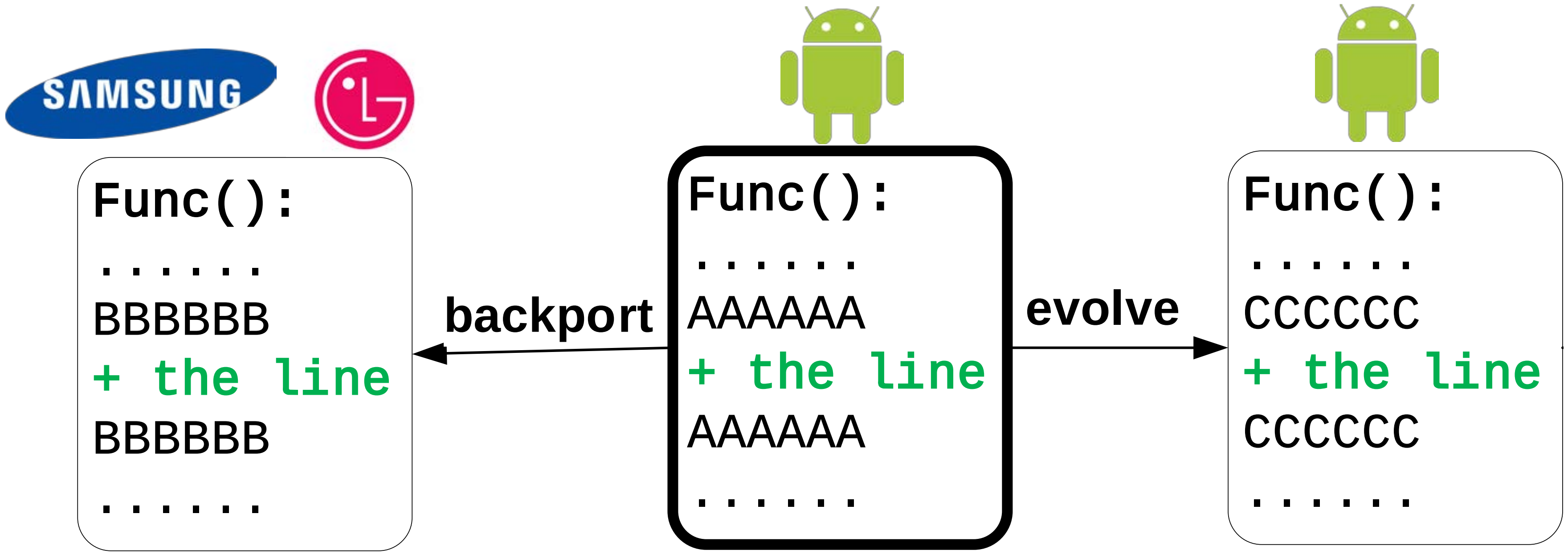

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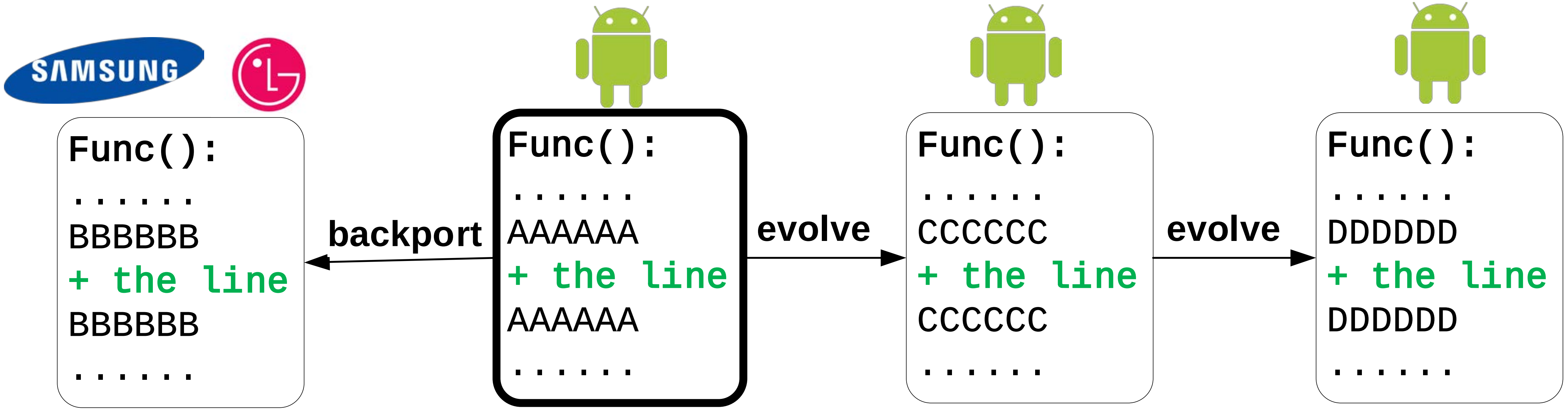

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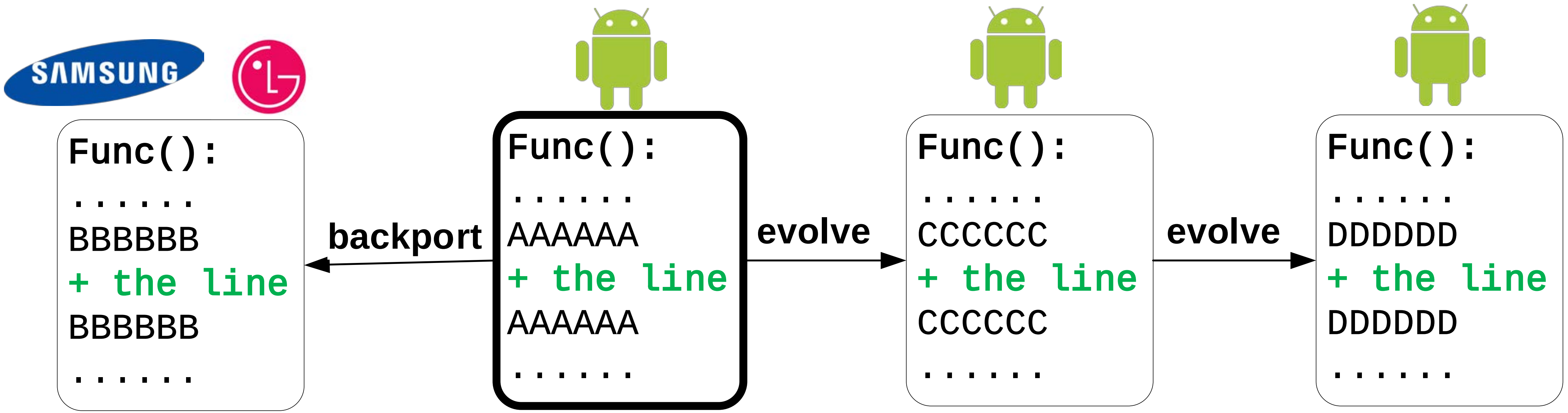

Solution: keep the change site as small as possible (always start from a single line), add contexts only when necessary.

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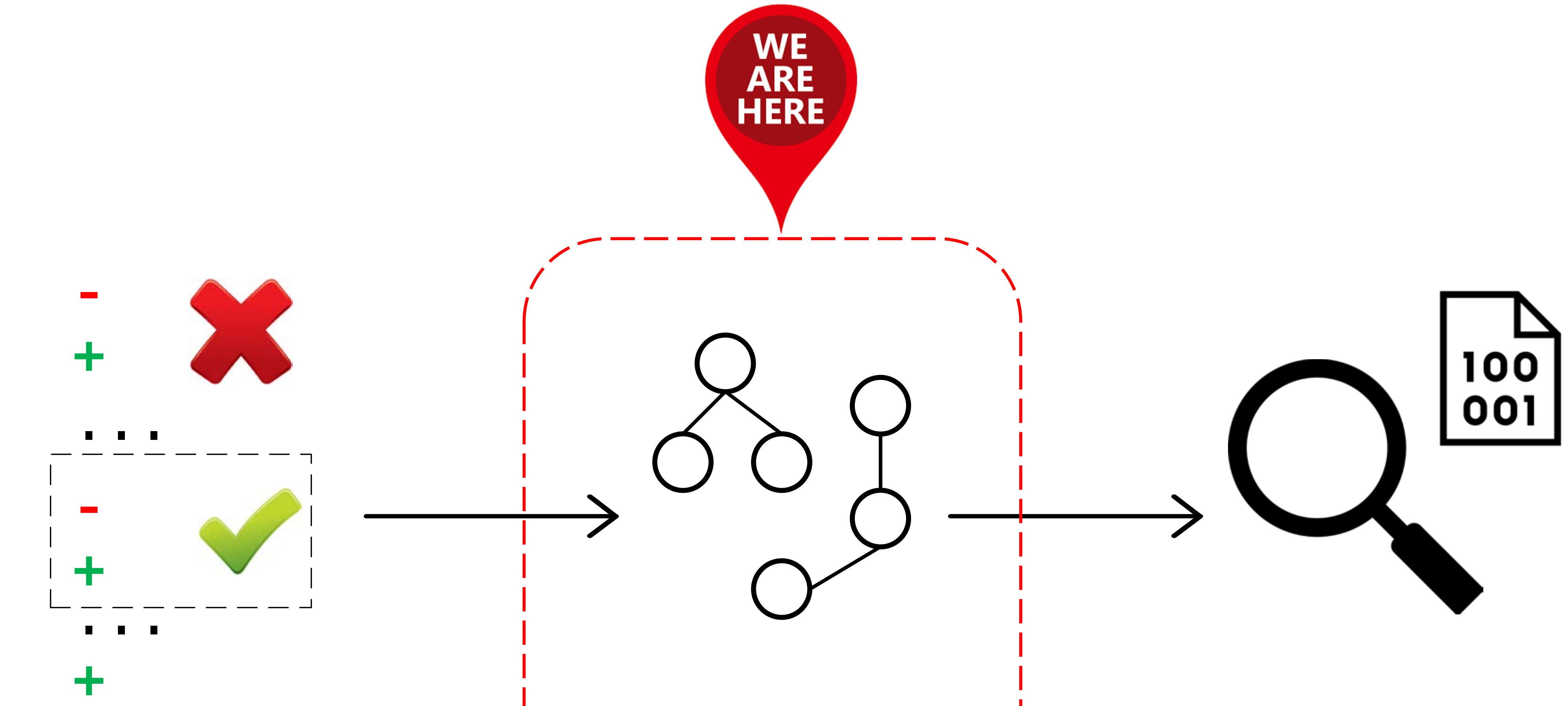
Solution: we rank the change sites based on statement types involved, according to our domain knowledge.



Patch change site analysis. (Source level)

Binary signature translation.

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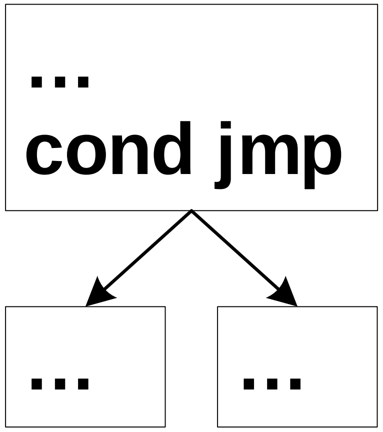

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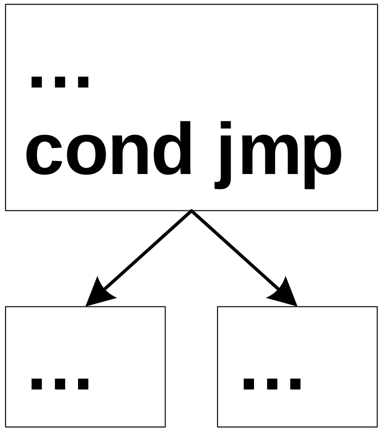
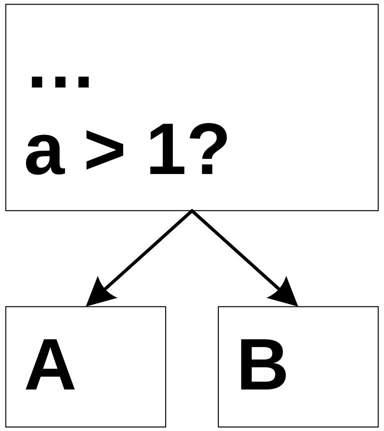


Semantics



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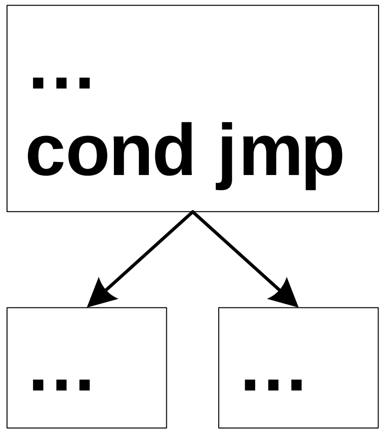

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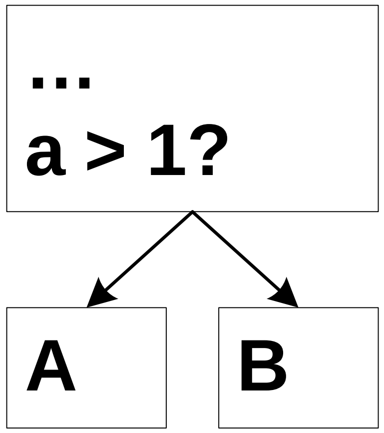

Correlate both its syntax and semantics to the binary code.

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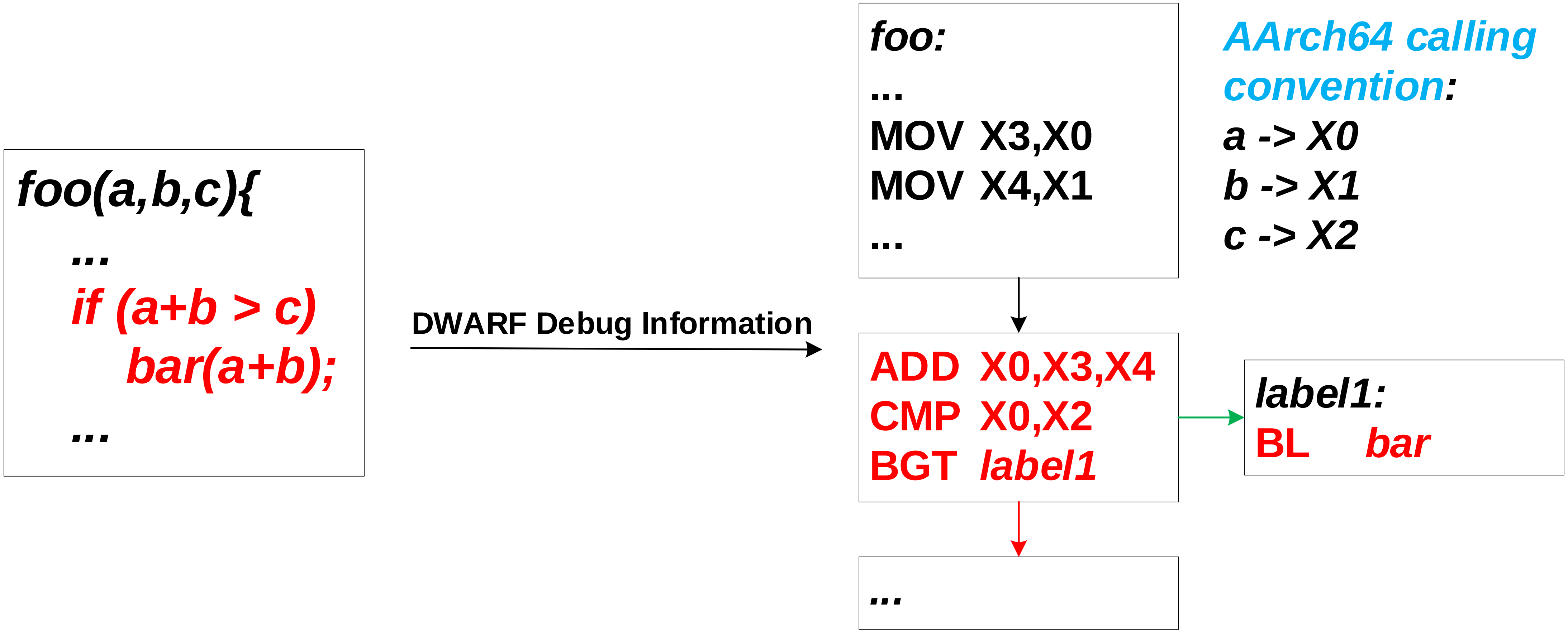

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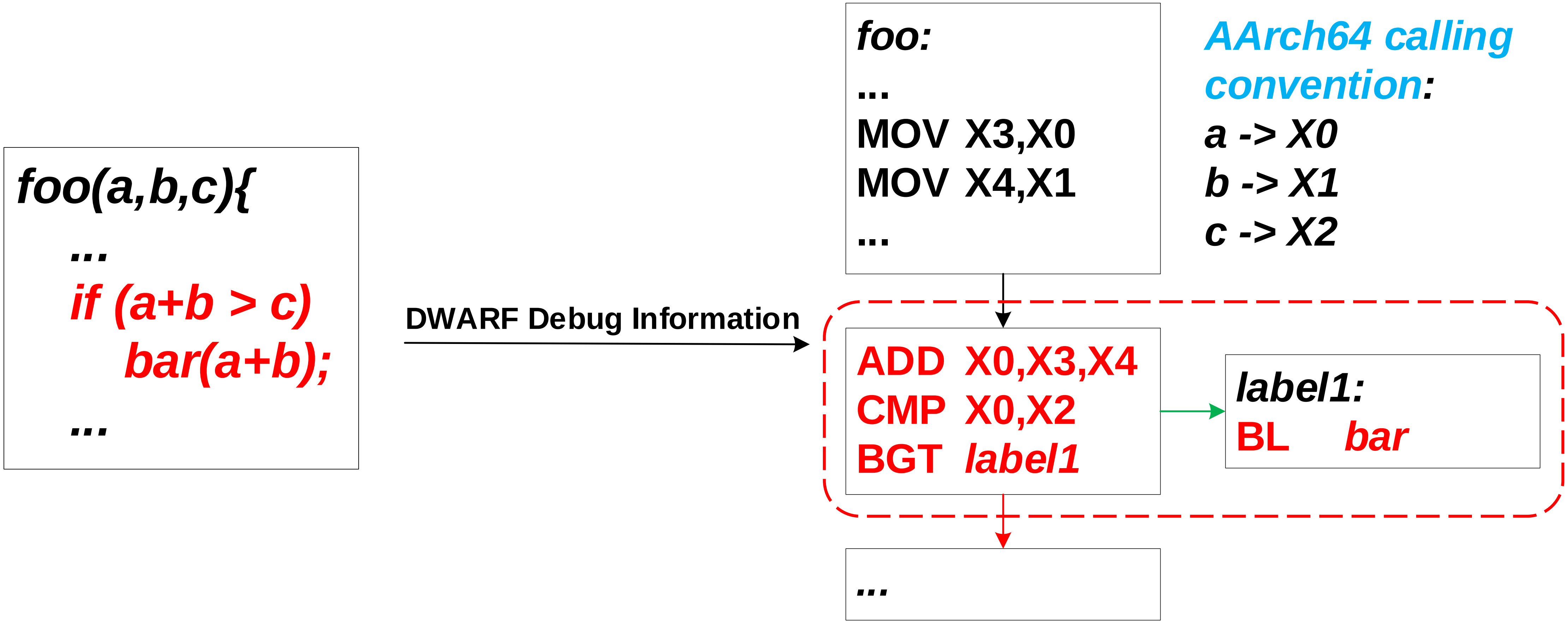

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Solution: we perform a basic-block level data-flow analysis to identify root instructions.

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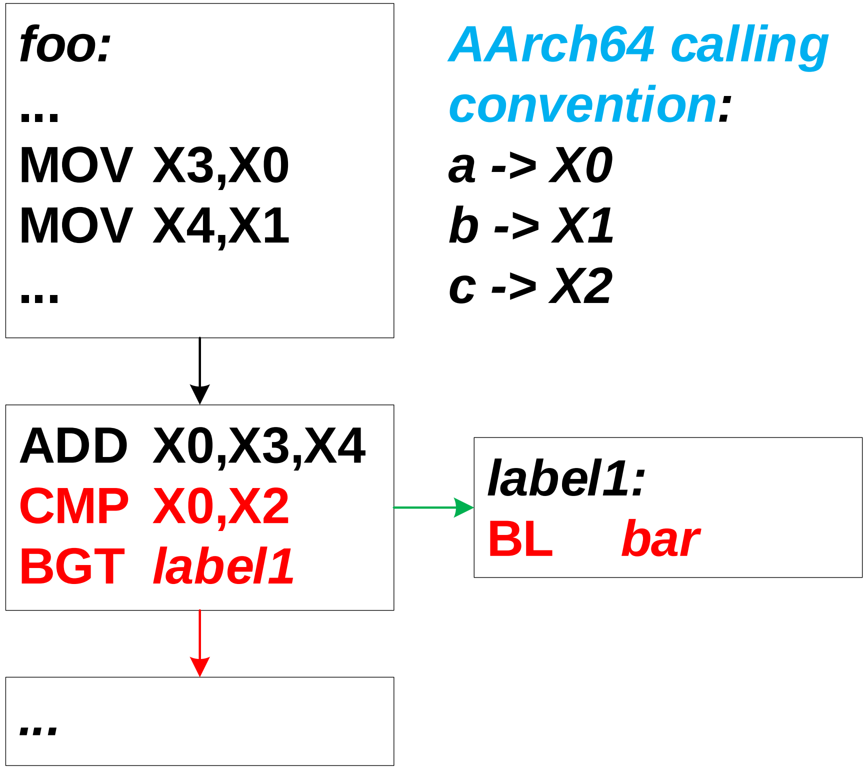

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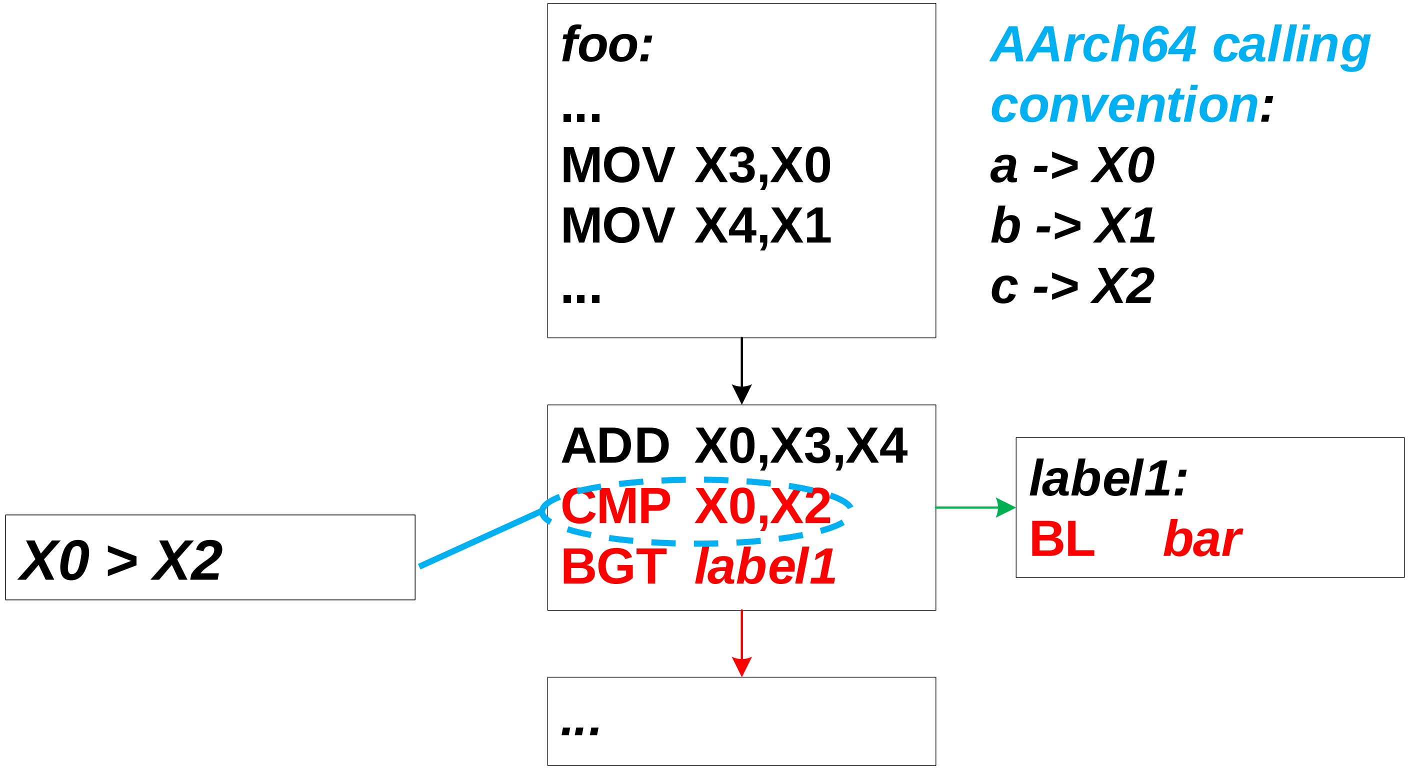

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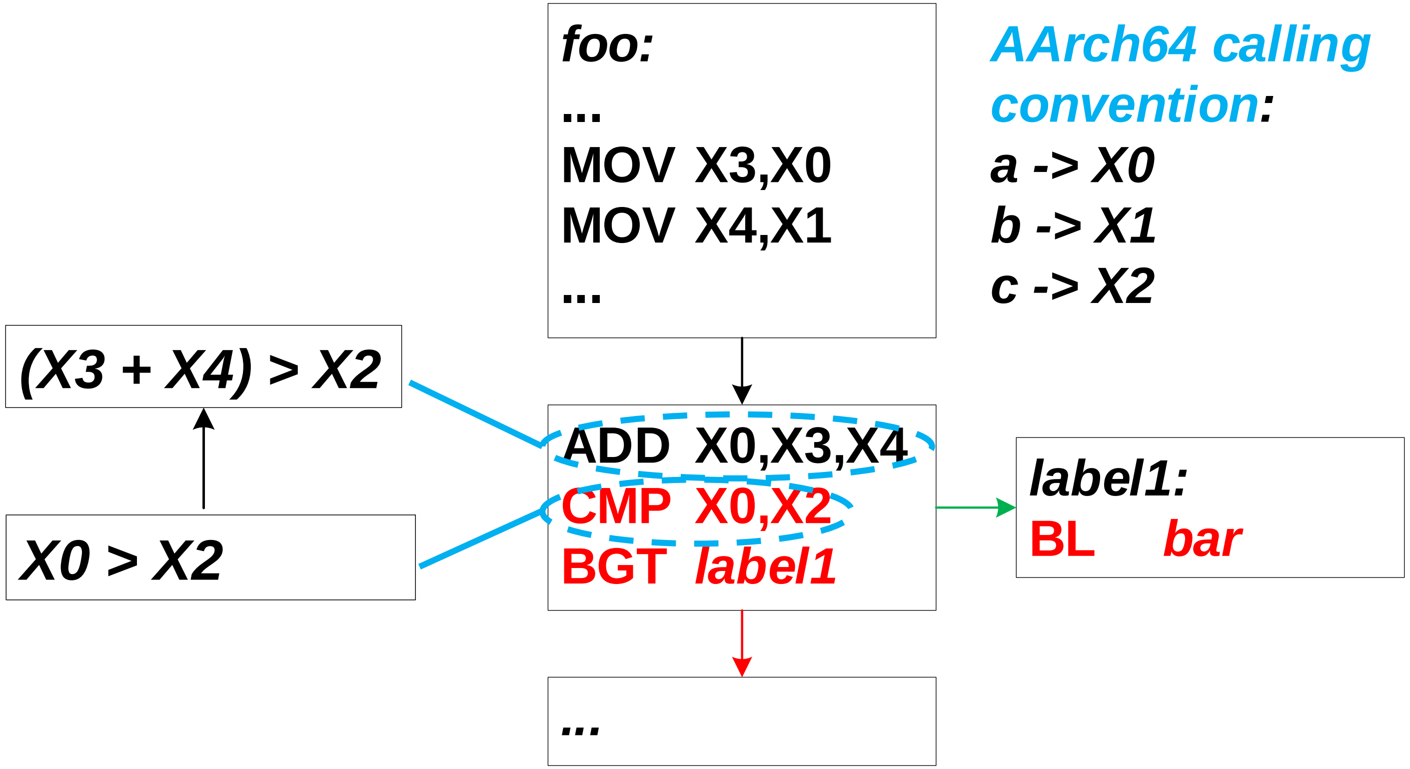

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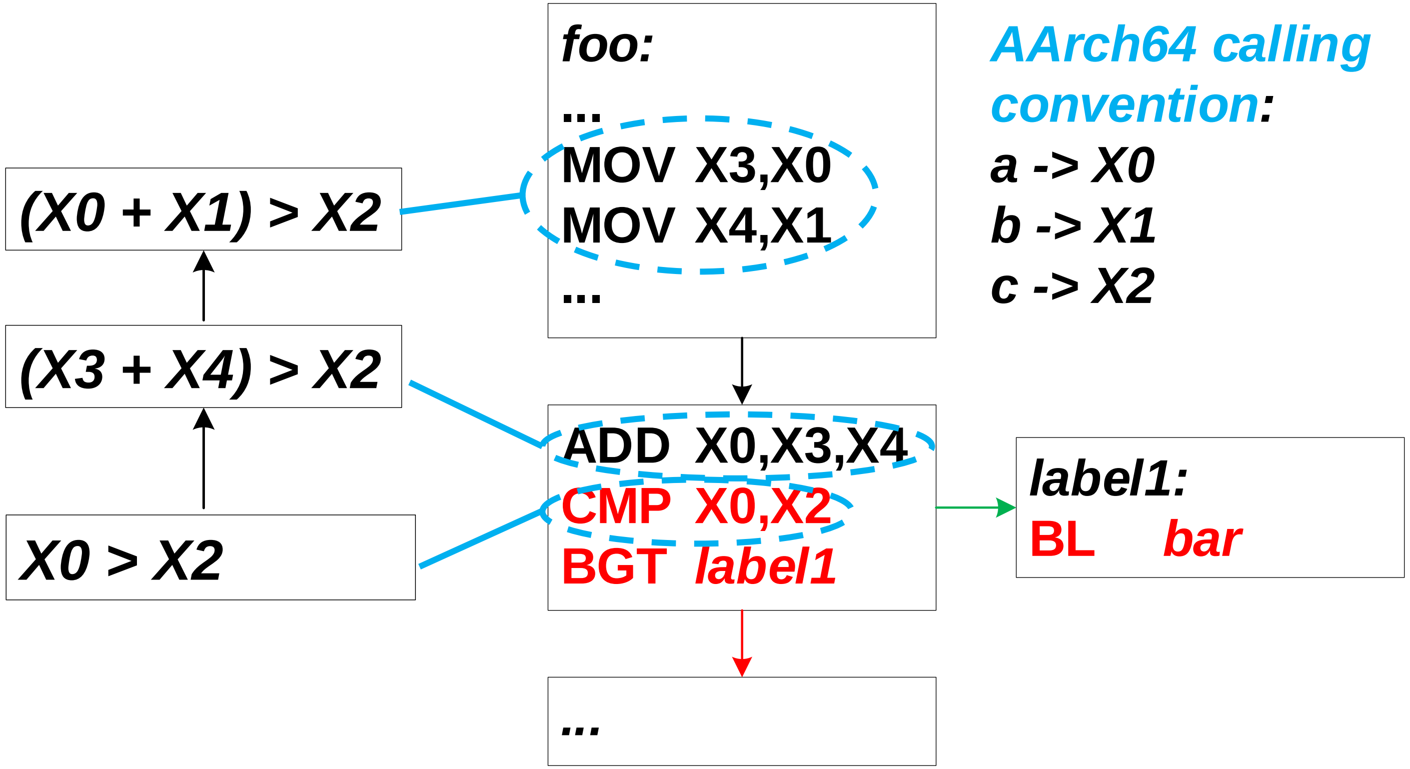

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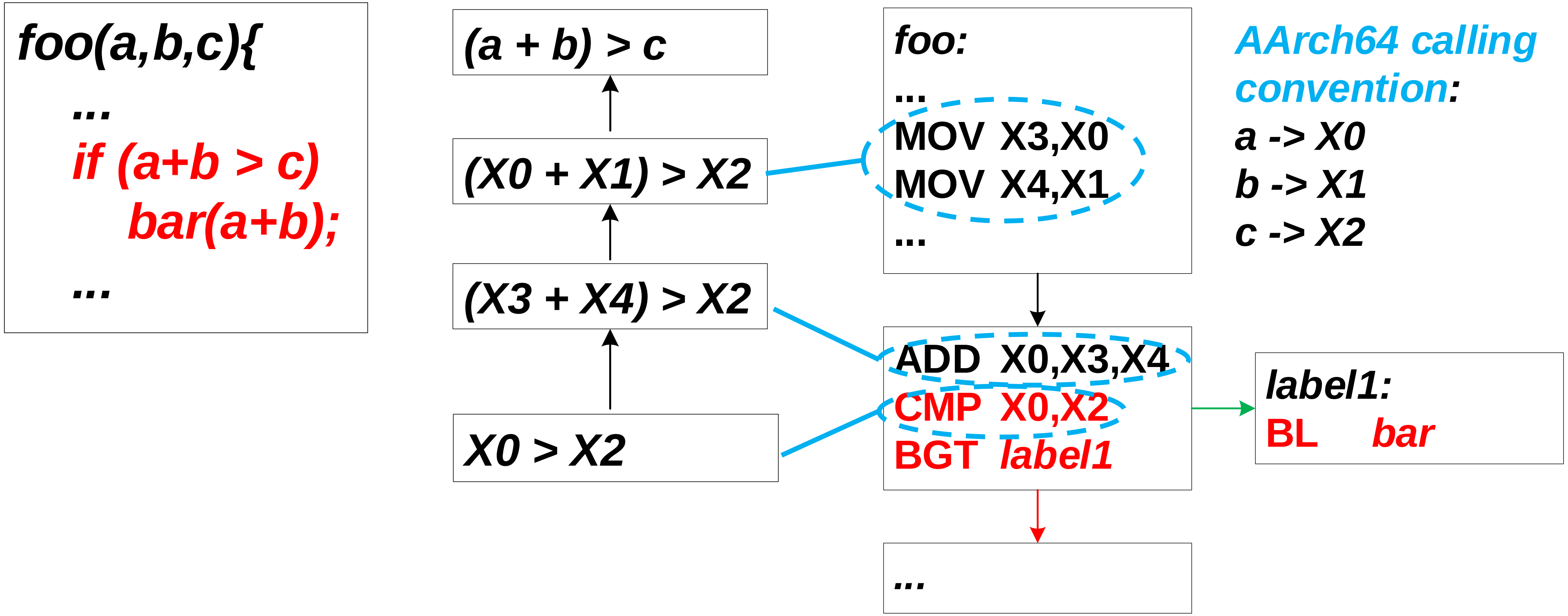

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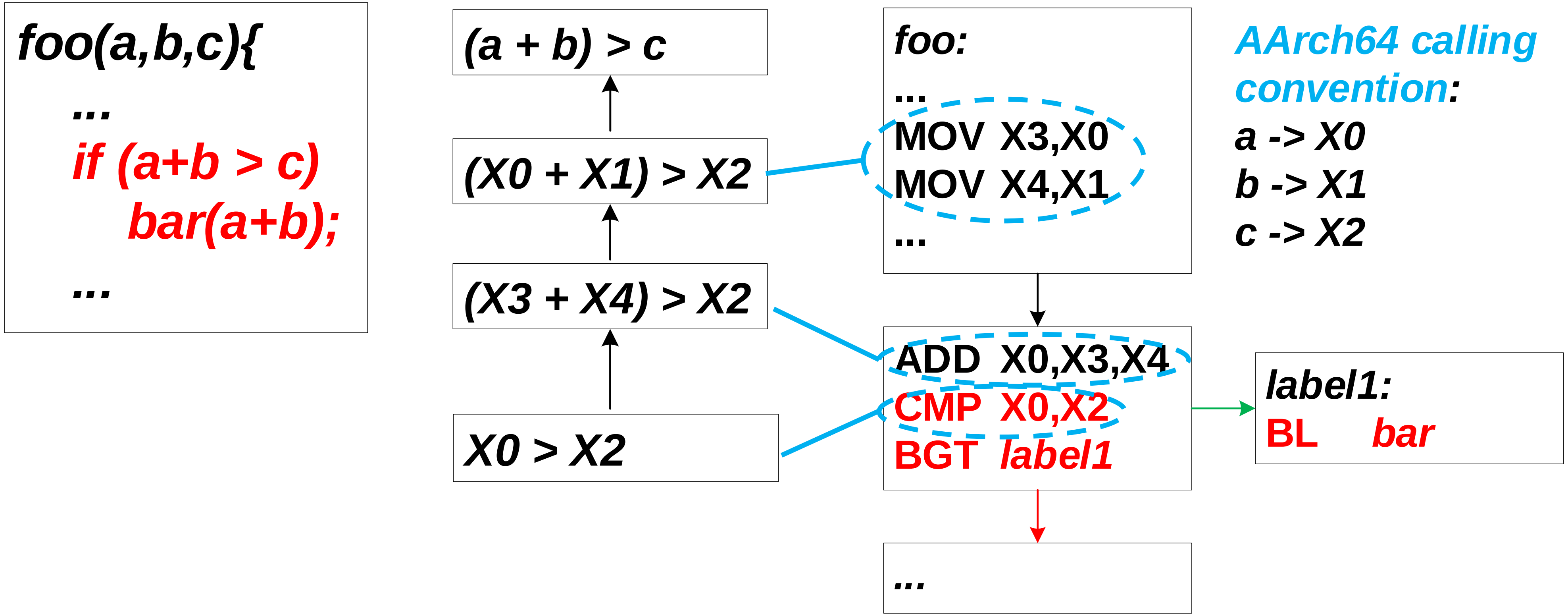
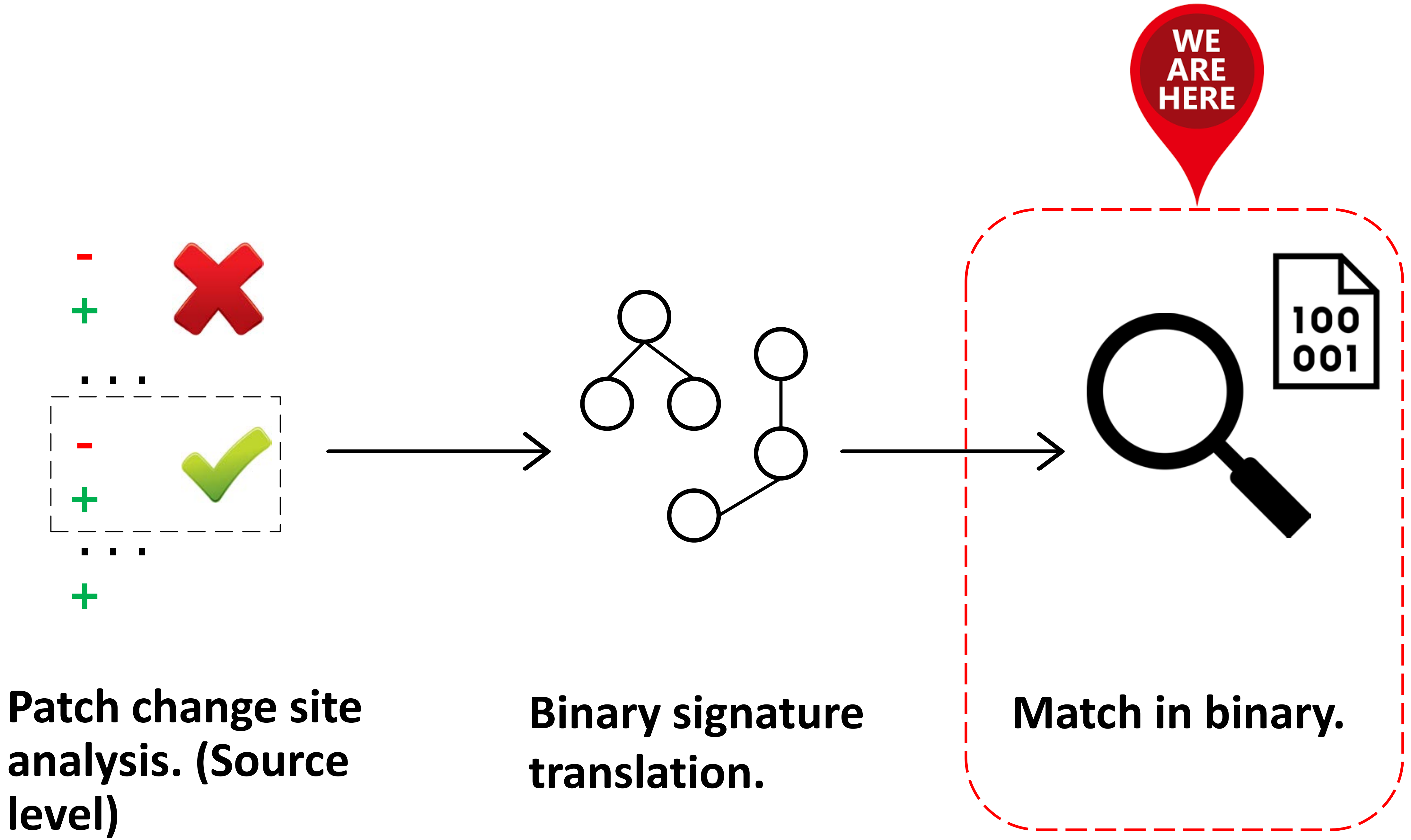


Solution: we use function-level, intra-procedure and under-constrained symbolic execution to obtain formulas.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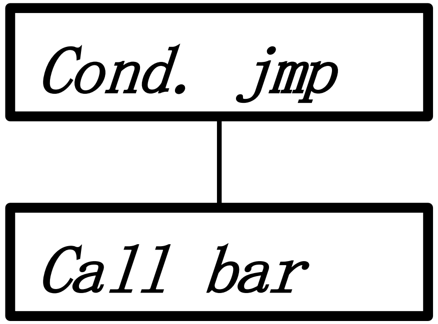

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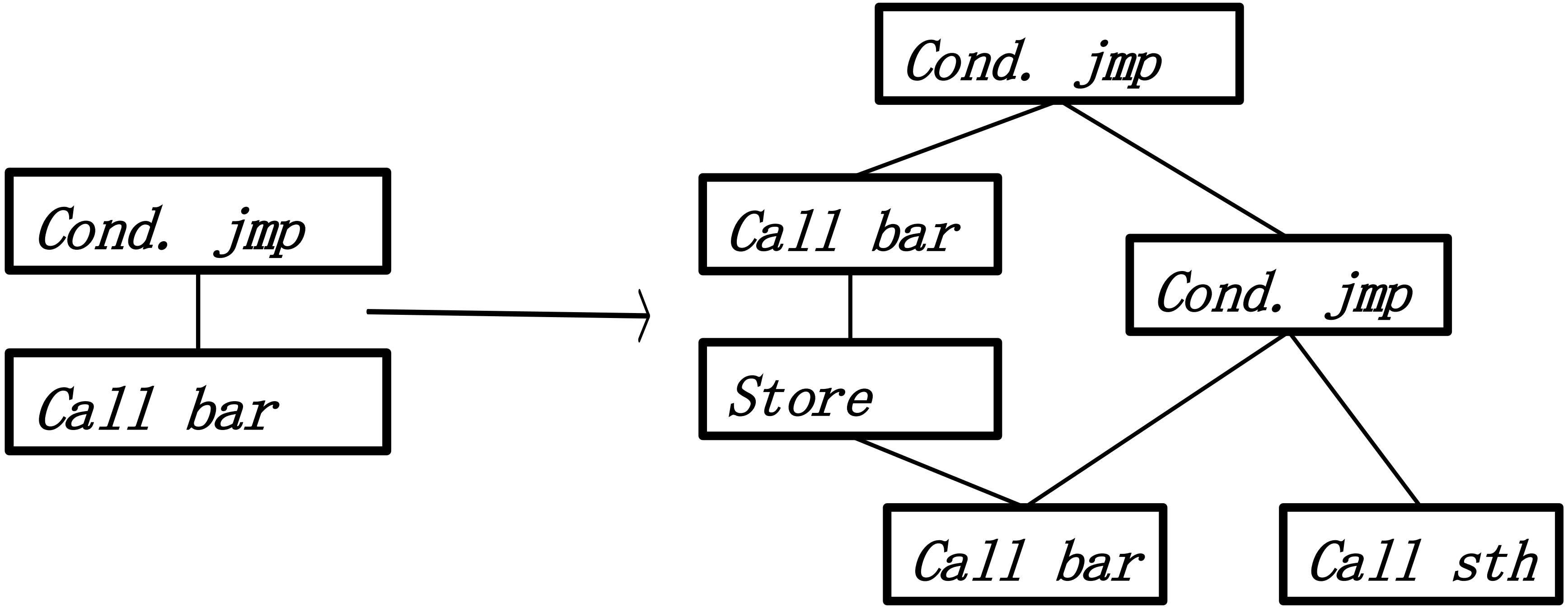

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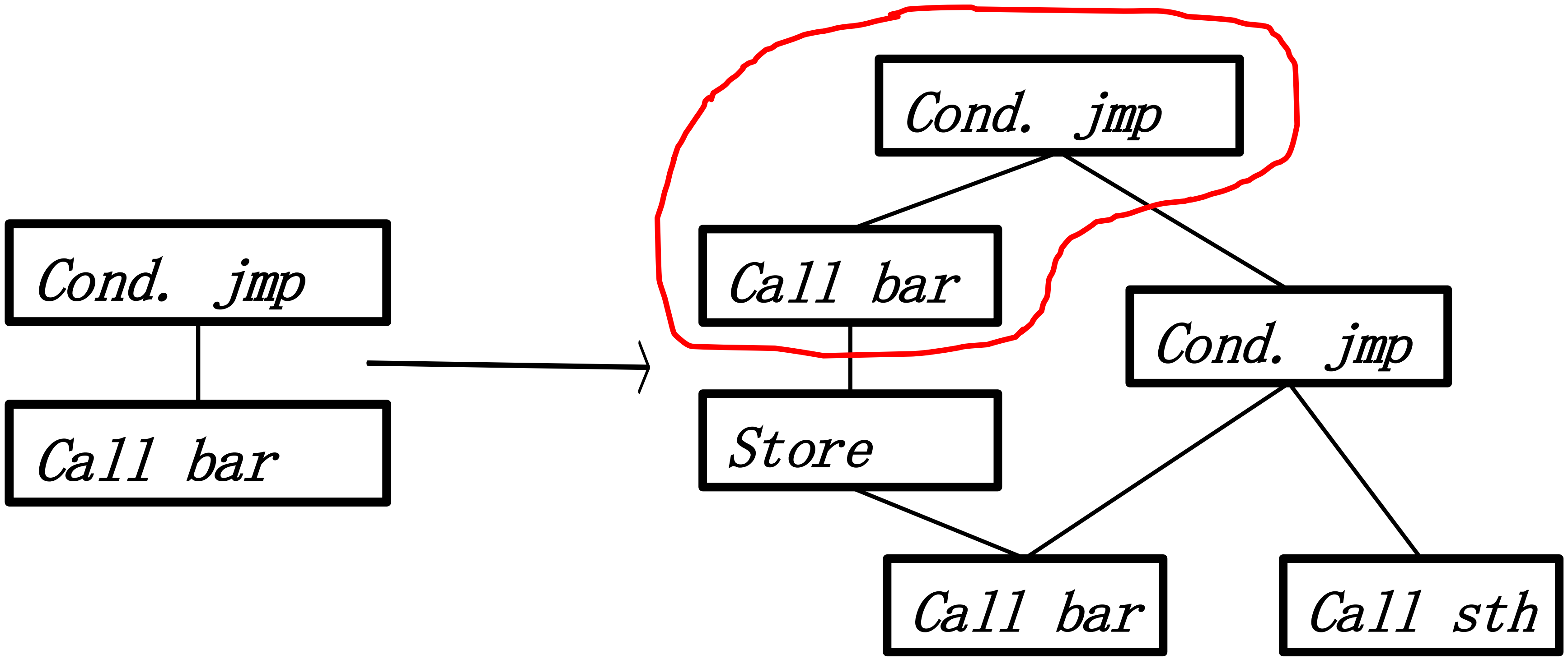

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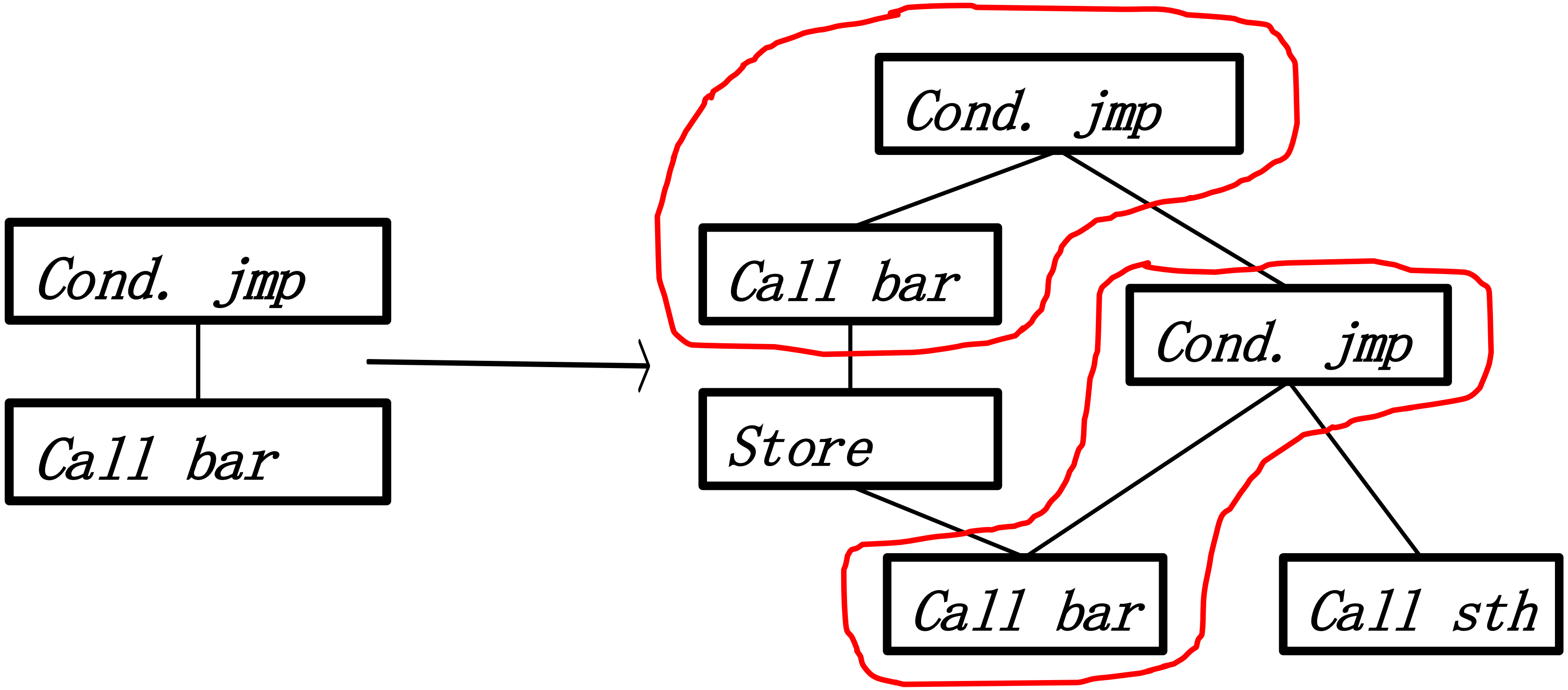

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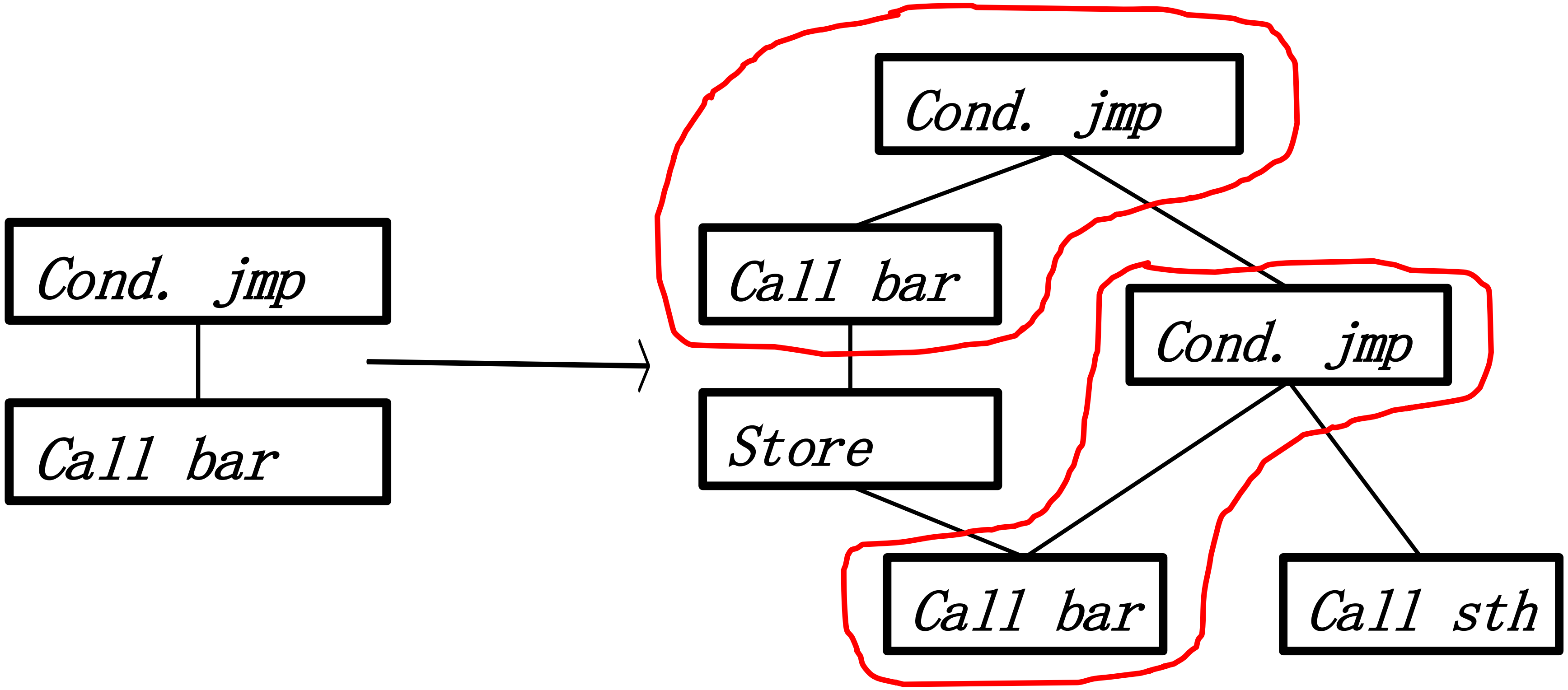

Solution: look at easy-to-match attributes, e.g. topology, root instruction type, etc.

Matching

- Slow Pass.

```
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```

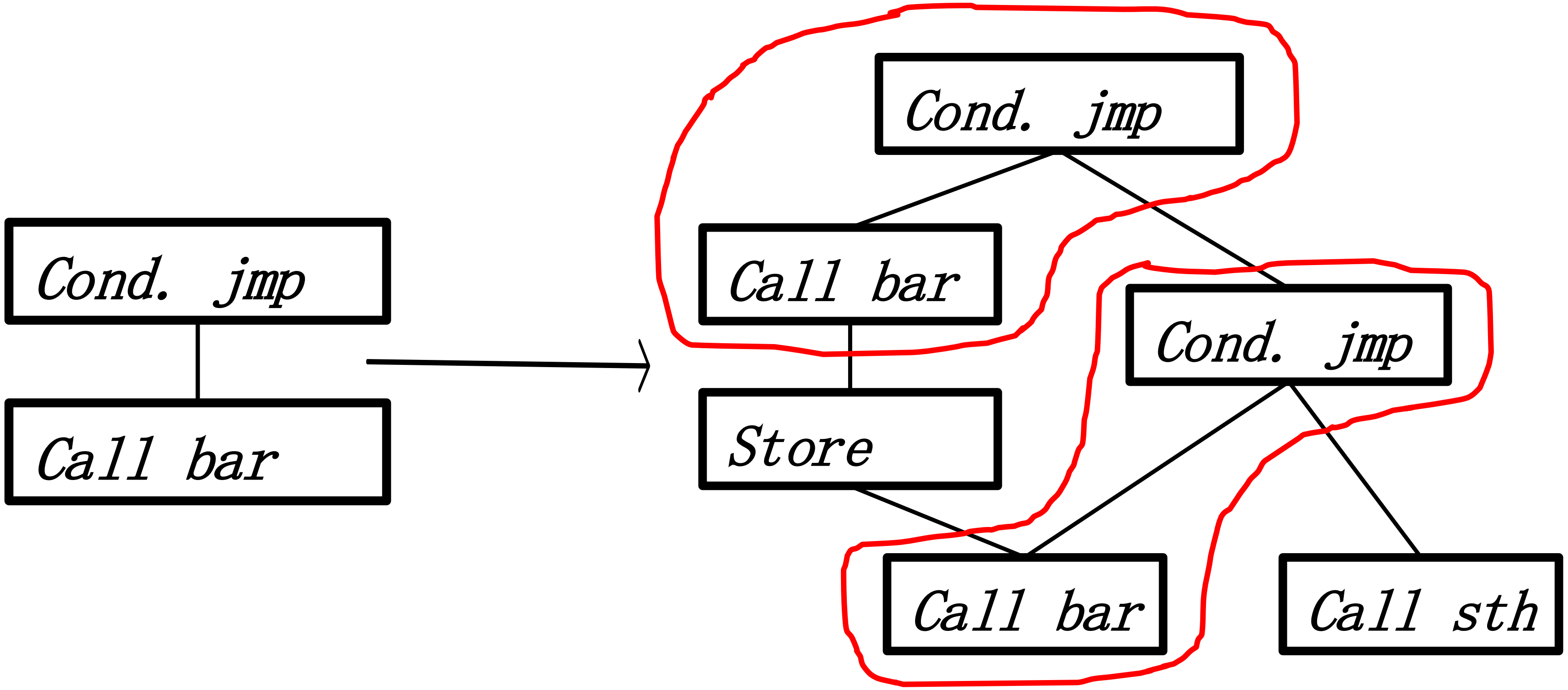

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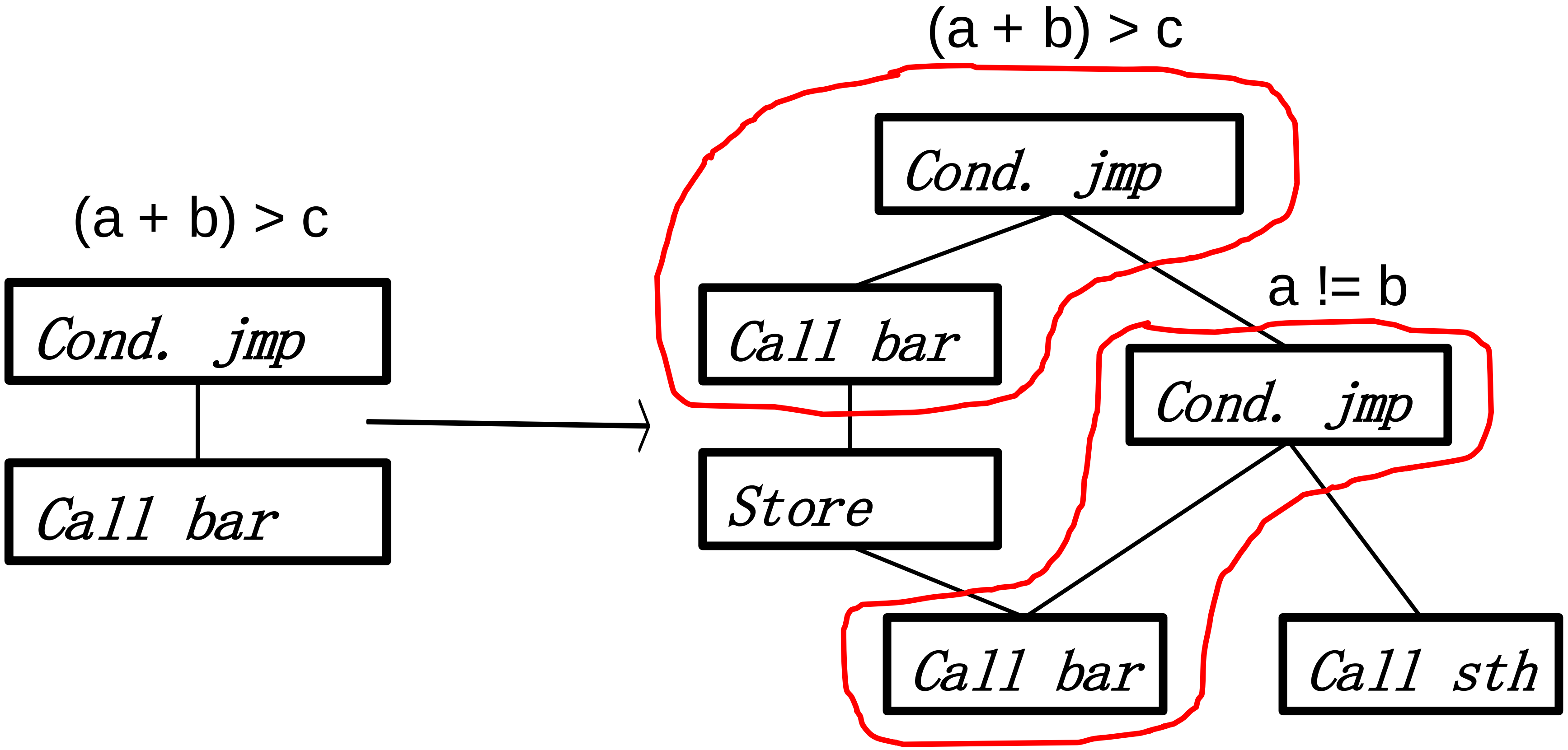

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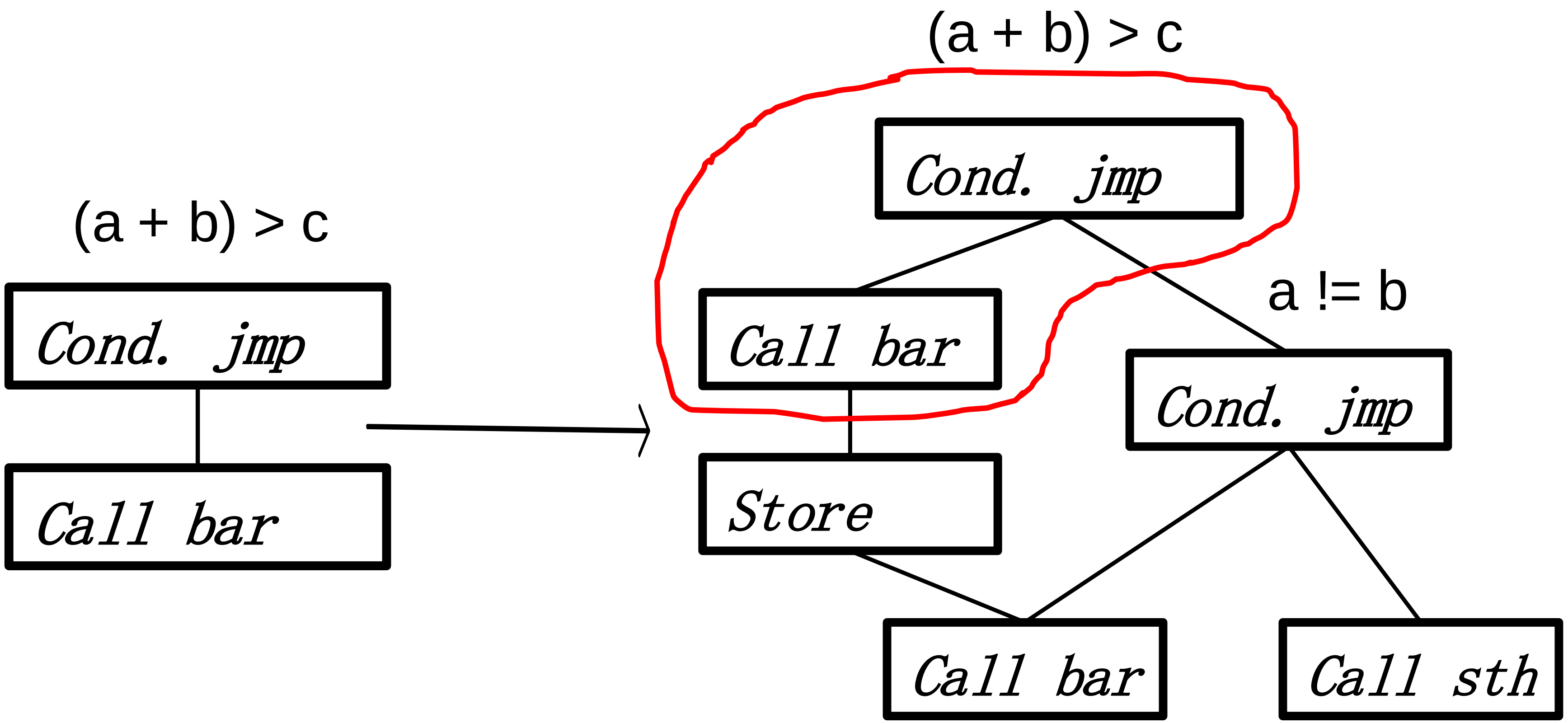

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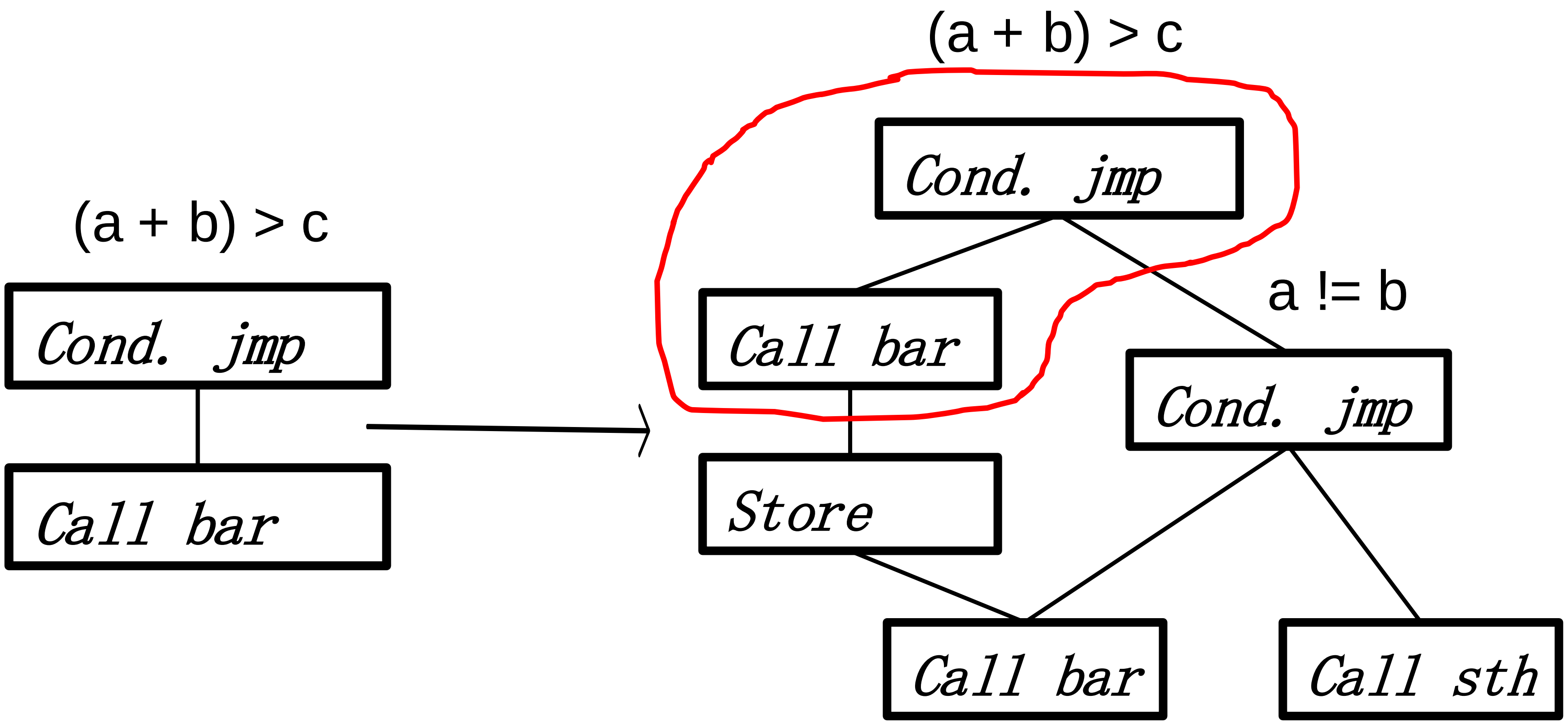

Solution: basically we strictly compare two formulas simplified by Z3 solver , with necessary relaxations. (e.g. commutative operators)

Special (and Interesting) Cases

```
Func():
.......
.......
+ uniq_func_noinline()
.......
.......
```

```
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.......
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.......
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Simply test the function call presence, no semantic formulas needed.

```
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.......
.......
- f(a,b)
+ f(a,c)
.......
.......
```

```
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......
......
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......
```

That ***line*** matters? No, that ***parameter*** matters!

How well does FIBER work?

In evaluation:

107 security patches crawled from Android Bulletin (*Jun 2016 – May 2017*)

8 Android kernel images from **3** mainstream vendors.

Accuracy

Device	No.	Patch Cnt*	Build Date (mm/dd/yy)	Kernel Version	Accuracy				Online Matching Time (s)			
					TP	TN	FP	FN	Total	Avg	~70%	Max.
Samsung S7	0	102	06/24/16	3.18.20	42	56	0	4(3.92%)	1690.43	16.57	8.47	306.47
	1	102	09/09/16	3.18.20	43	55	0	4(3.92%)	1888.06	18.51	8.24	438.76
	2	102	01/03/17	3.18.31	85	11	0	6(5.88%)	2421.44	23.74	5.49	1047.10
	3	102	05/18/17	3.18.31	92	4	0	6(5.88%)	1770.66	17.36	5.33	386.94
LG G5	4	103	05/27/16	3.18.20	32	65	0	6(5.88%)	2122.37	20.61	8.90	648.93
	5	103	10/26/17	3.18.31	95	0	0	8(7.77%)	1384.47	13.44	4.76	229.46
Huawei P9	6	31	02/22/16	3.10.90	10	20	0	1(3.23%)	390.35	12.59	8.47	89.35
	7	30	05/22/17	4.1.18	25	2	0	3(10.00%)	515.64	17.19	7.4	279.49

* Some patches we collected are not applicable for certain test subject kernels.

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Accuracy: excellent, on average 94% accuracy w/o FP.

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FP: we wrongly believe the patch is present. *Dangerous!*

FN: we wrongly believe the patch is not there. *Extra time to confirm.*

Accuracy: excellent, on average 94% accuracy w/o FP.

Why FN?

- Function inline.
- Function prototype change.
- Code customization.
- Patch adaptation.
- Other engineering issues.

Refer to section 6.2 in the paper for more details.

Why FN?

Function inline:

Added new callee function in the change site is inlined in different ways across reference and target binaries.

Why FN?

Patch adaptation:

The change site itself has been customized during patch porting.

Performance

Device	No.	Patch Cnt*	Build Date (mm/dd/yy)	Kernel Version	Accuracy				Online Matching Time (s)			
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Performance: acceptable, some cases may take long time to match, overall still much more efficient than manual work. Parallelization is also easily possible.

Un-ported patches

CVE	Type**	Severity*
CVE-2014-9781	P	High
CVE-2016-2502	P	High
CVE-2016-3813	I	Moderate
CVE-2016-4578	I	Moderate
CVE-2016-2184	P	Critical
CVE-2016-7910	P	Critical
CVE-2016-8413	I	Moderate
CVE-2016-10200	P	Critical
CVE-2016-10229	E	Critical

* Obtained from Android security bulletin.

** **P:** Privilege Elevation **E:** Remote Code Execution

** **I:** Information Disclosure

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Lag (month)	Cnt.
1	2
2	5
6	2

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** **P:** Privilege Elevation **E:** Remote Code Execution

** **I:** Information Disclosure

Lag (month)	Cnt.
1	2
2	5
6	2

Some critical patches were not propagated even after 6 months (confirmed)!

CVE-2016-7910


```
diff --git a/block/genhd.c b/block/genhd.c
index 3c9dede..0ad8796 100644
--- a/block/genhd.c
+++ b/block/genhd.c
@@ -856,6 +856,7 @@ static void disk_seqf_stop(                    , void
*v)                                    struct seq_file *seqf
   if (iter) {
       class_dev_iter_exit(iter);
       kfree(iter);
+       seqf->private = NULL;
   }
 }
```

0x0 → [X0+ offset]

CVE-2016-7910


```
diff --git a/block/genhd.c b/block/genhd.c
index 3c9dede..0ad8796 100644
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0x0 → [X0 + offset]

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We use Angr as our symbolic execution engine. (w/ modifications)

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Still under improvement.

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We use Angr as our symbolic execution engine. (w/ modifications)

#code of Fiber: 5,097 LOC Python.

Still under improvement.

Now fully open-sourced on Github!

https://fiberx.github.io

Thanks!

Q & A

https://fiberx.github.io

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UC RIVERSIDE