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PIANO NAZIONALE DI RIPRESA E RESILIENZA

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Predictive Context-sensitive Fuzzing

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Feb 29, 2024. **NDSS'24 Symposium**

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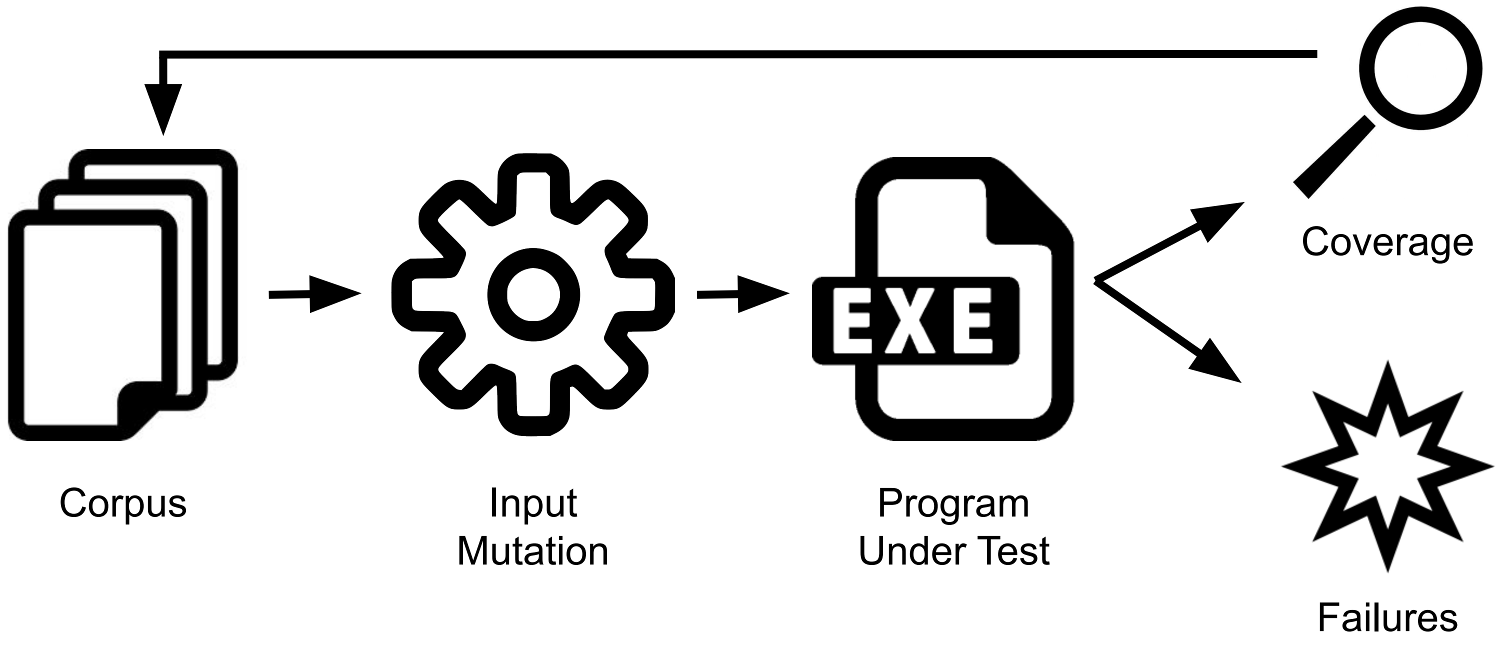
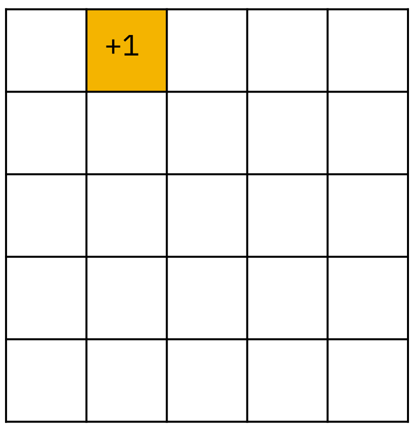
Coverage-guided fuzzing

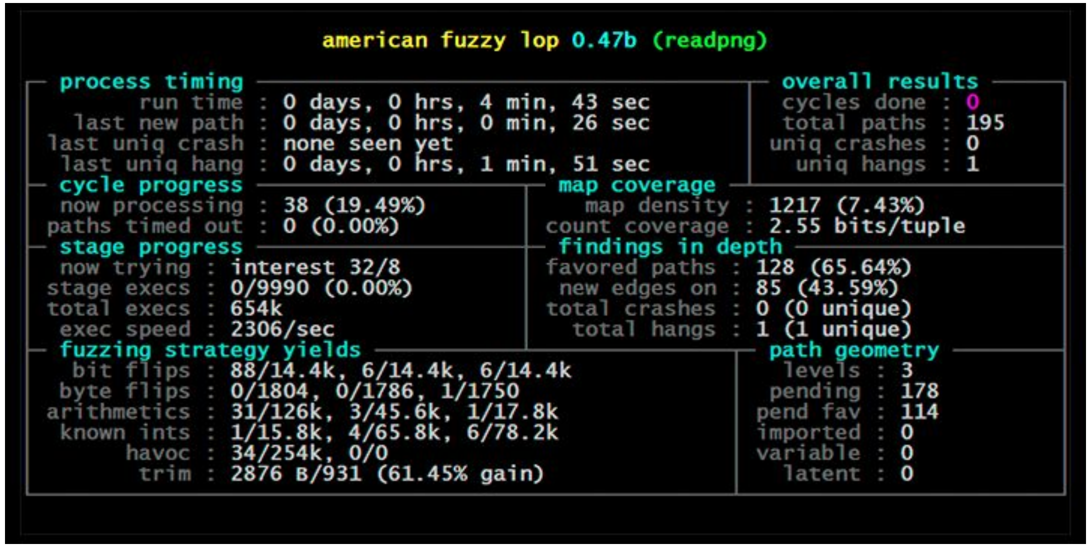


Edge-coverage guided fuzzing

```
hash_edge(0x41414141, 0x42424242)

0x41414141: jmp 0x42424242
```





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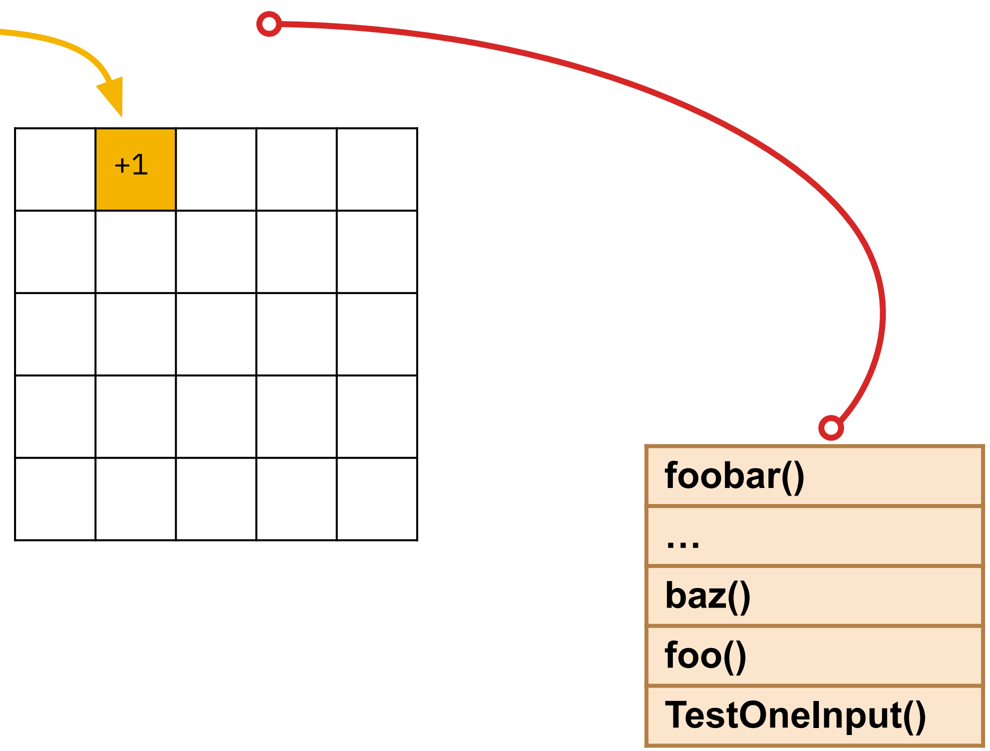
Context-sensitive, edge-coverage guided fuzzing

```
hash_edge(0x41414141, 0x42424242, ctx)
```

```
foobar:
<ctx = ctx ^ foobar>
...

0x41414141: jmp 0x42424242

...
<ctx = ctx ^ foobar)>
ret
```



Why helpful?

```
void cmd_handler_foo(int a, size_t b) { memset(buf, a, b); }
void cmd_handler_bar(int a, size_t b) { cmd_handler_foo(...
void cmd_handler_baz(int a, size_t b) { cmd_handler_bar(...

typedef void (* dispatch_t)(int, size_t);

dispatch_t handlers[UCHAR_MAX] = {
    cmd_handler_foo,
    cmd_handler_bar,
    cmd_handler_baz,
};

int main(int argc, char **argv)
{
    int cmd;

    while ((cmd = getchar()) != EOF) {
        if (handlers[cmd]) {
            handlers[cmd](getchar(), getchar());
```

Project Zero

News and updates from the Project Zero team at Google

Wednesday, December 1, 2021

This shouldn't have happened: A vulnerability postmortem

Posted by Tavis Ormandy, Project Zero

Introduction

This is an unusual blog post. I normally write posts to highlight some hidden attack surface or interesting complex vulnerability class. This time, I want to talk about a vulnerability that is neither of those things. The striking thing about this vulnerability is just how simple it is. This should have been caught earlier, and I want to explore why that didn't happen.

In 2021, all good bugs need a catchy name, so I'm calling this one "BigSig".

First, let's take a look at the bug, I'll explain how I found it and then try to understand why we missed it for so long.

🚨 coverage of cmd **bar** is a superset of cmd **foo**

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Challenges to efficiency

1. coverage map explosion
2. queue explosion

Fuzzer	Queue size	Exec/sec	Collisions (map use)
classic edge (2^16 map)	9 911	609	9.8% (19.86%)
pcguard edge (coll.-free)	11 093	572	-
ctx-sensitive (2^16 map)	(2) **33 675**	530	(1) **50.7%** (79.54%)
ctx-sensitive (2^20 map)	(2) **21 157**	(1) **84**	1.2% (7.21%)
predictive ctx-sensitive	15 455	490	-

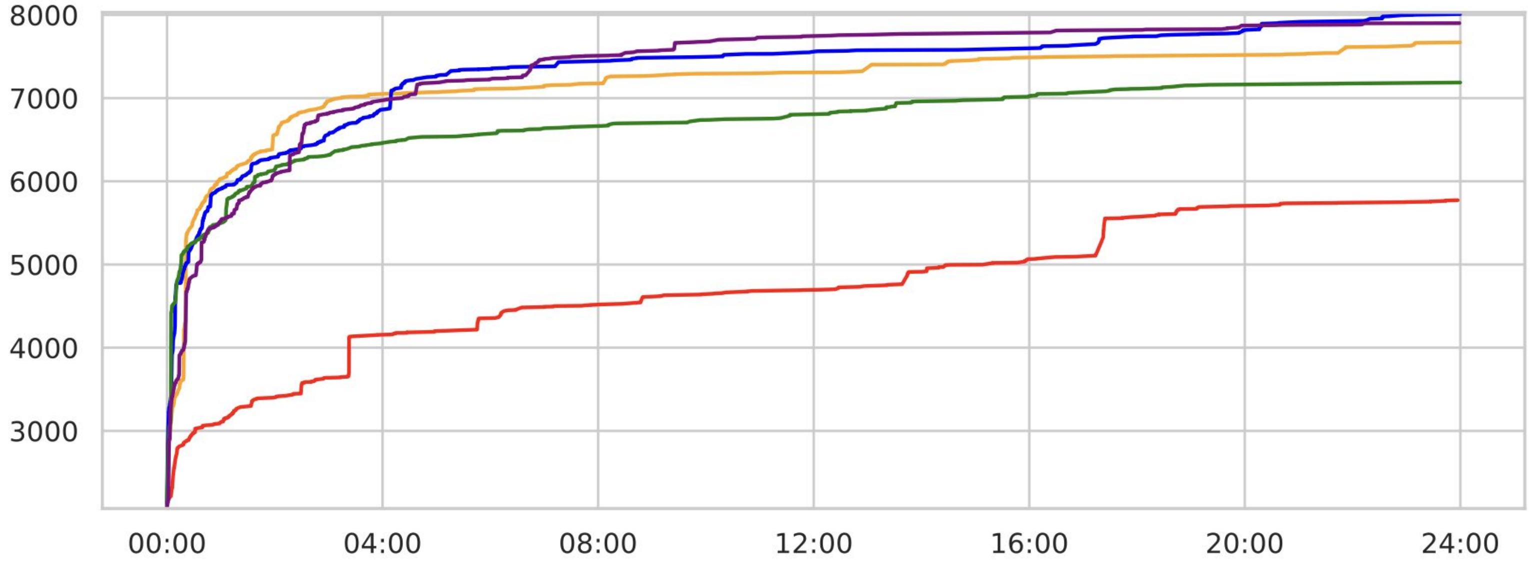
24h on **libxml2** - AFL++ 3.15a
Drivers & seeds: FuzzBench

Challenges to efficiency

1. coverage map explosion
2. queue explosion

Fuzzer
classic edge (2^16 map)
pcguard edge (coll.-free)
ctx-sensitive (2^16 map)
ctx-sensitive (2^20 map)
predictive ctx-sensitive

Impact on edge coverage



Making it efficient…

Key ideas

1. encode context without collisions
2. track context only at selected regions
3. predict profitable regions

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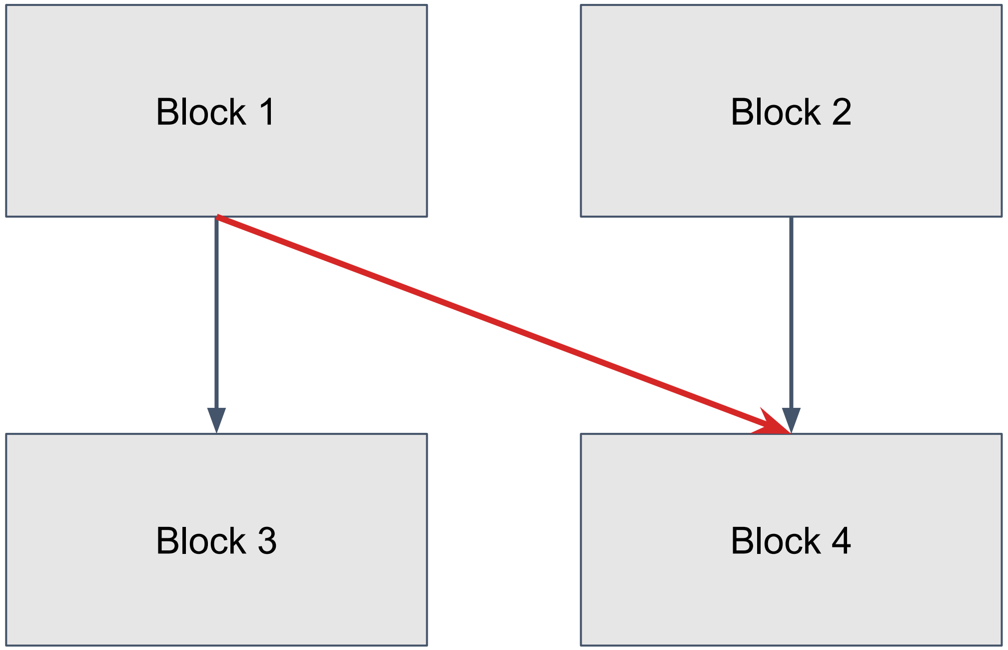
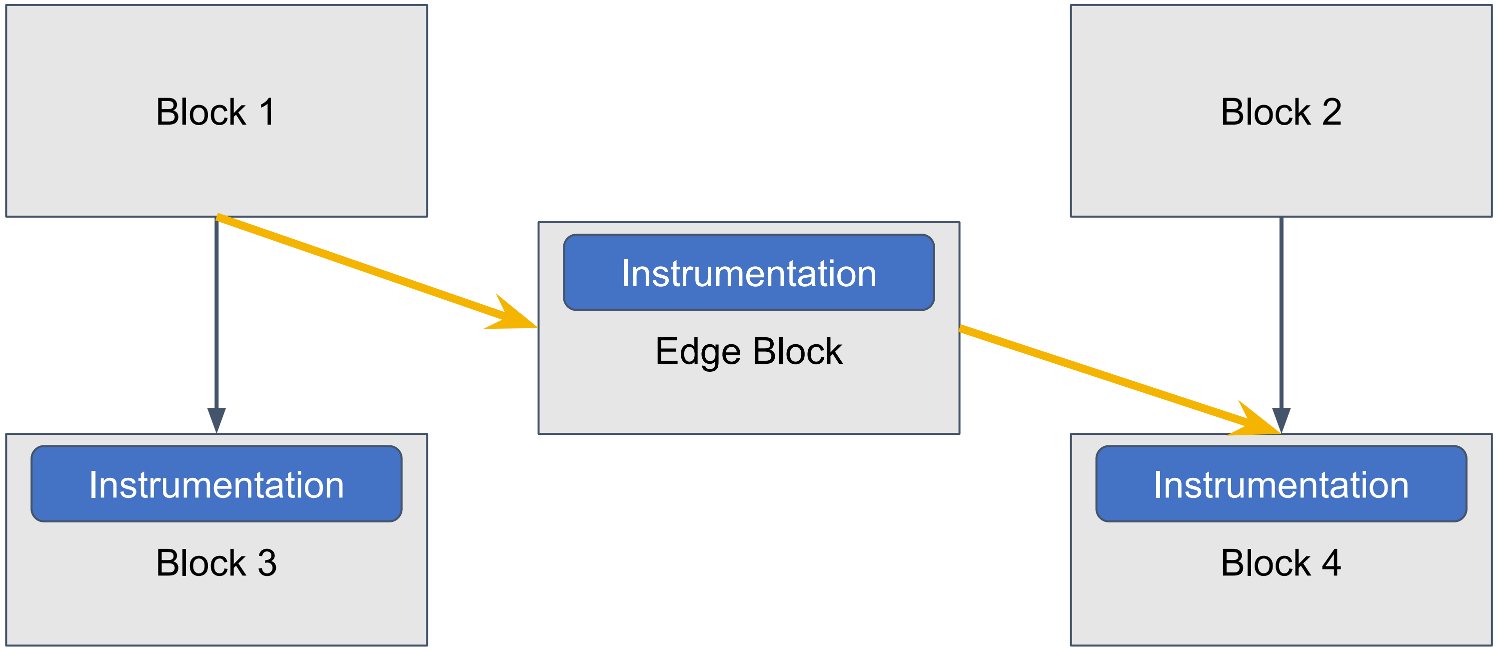
Collision-free edge coverage



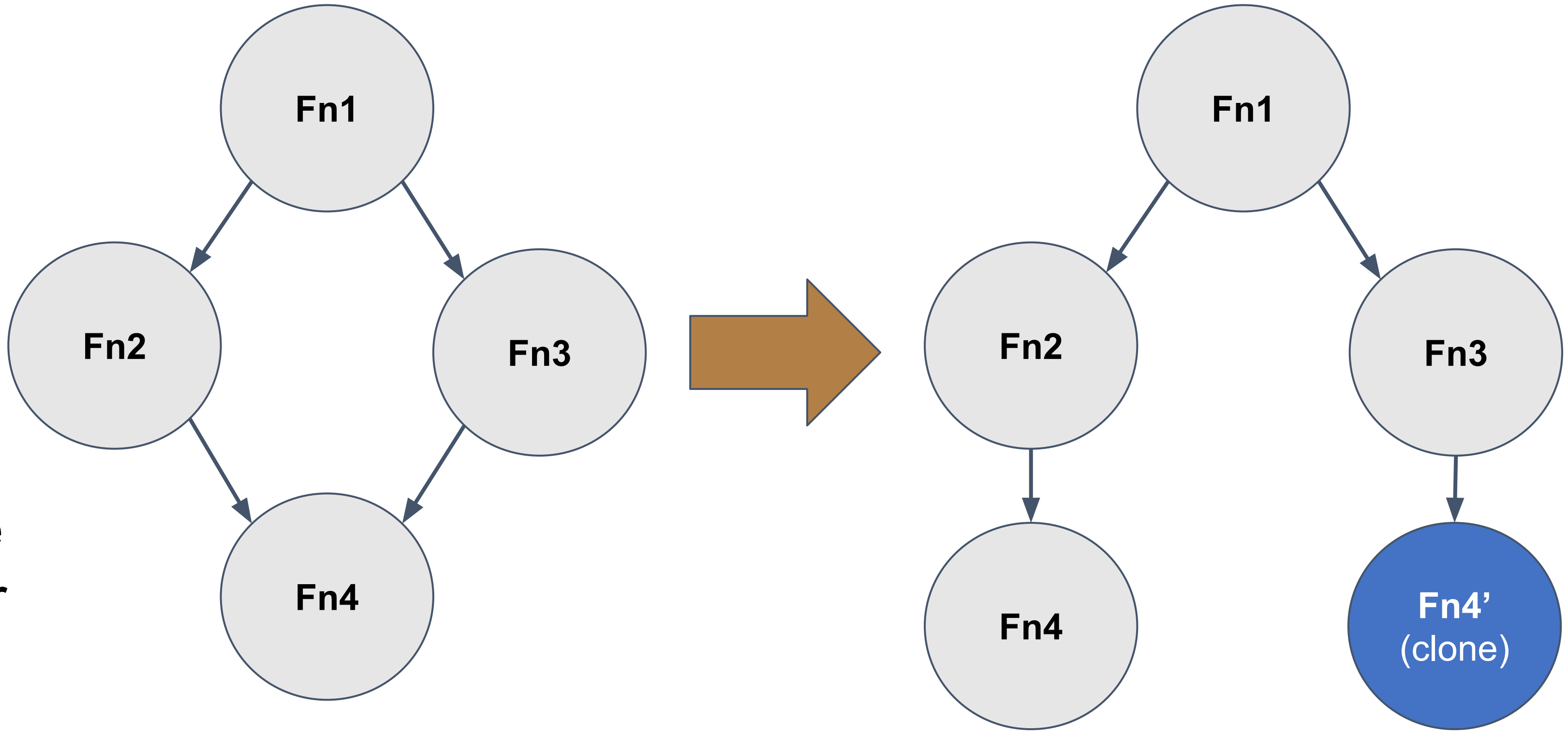
Splitting CFG critical edges removes collisions in edge-coverage tracking

Collision-free edge coverage



As basic-block IDs now suffice to uniquely identify edges

Collision-free context-sensitivity?



By **cloning** a function, we get unique CFG edges for a (caller, callee) pair

Selective sensitivity

Cloning is fuzzer-friendly, but the path explosion problem stays!

Benchmark (FuzzBench)	Edges	Functions	Call sites	Calling contexts
ffmpeg	716 K	5 K	44 K	8 M
libarchive	67 K	<1 K	4 K	27 M
libhevc	120 K	2k	< 1K	125 M
libxml2	104 K	1k	7 K	44 B
njs	57 K	490	4 K	13 M

Initial strategies

Prioritize within cloning **budget**

- favor call sites from nodes closer to call-graph root (harness)
- favor call sites closer to leaves
- treat every call site with the same priority

vs. random selection

📣 No explosion, but none > pcguard 👎

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Data flow-based prediction

Prioritize call sites with distinctive incoming data

- clone one if it passes data "seen less often" at other callers
- **diversity** as a proxy for interesting
- needs only call-site sensitivity (i.e., no full contexts)
- focus on pointer-type arguments

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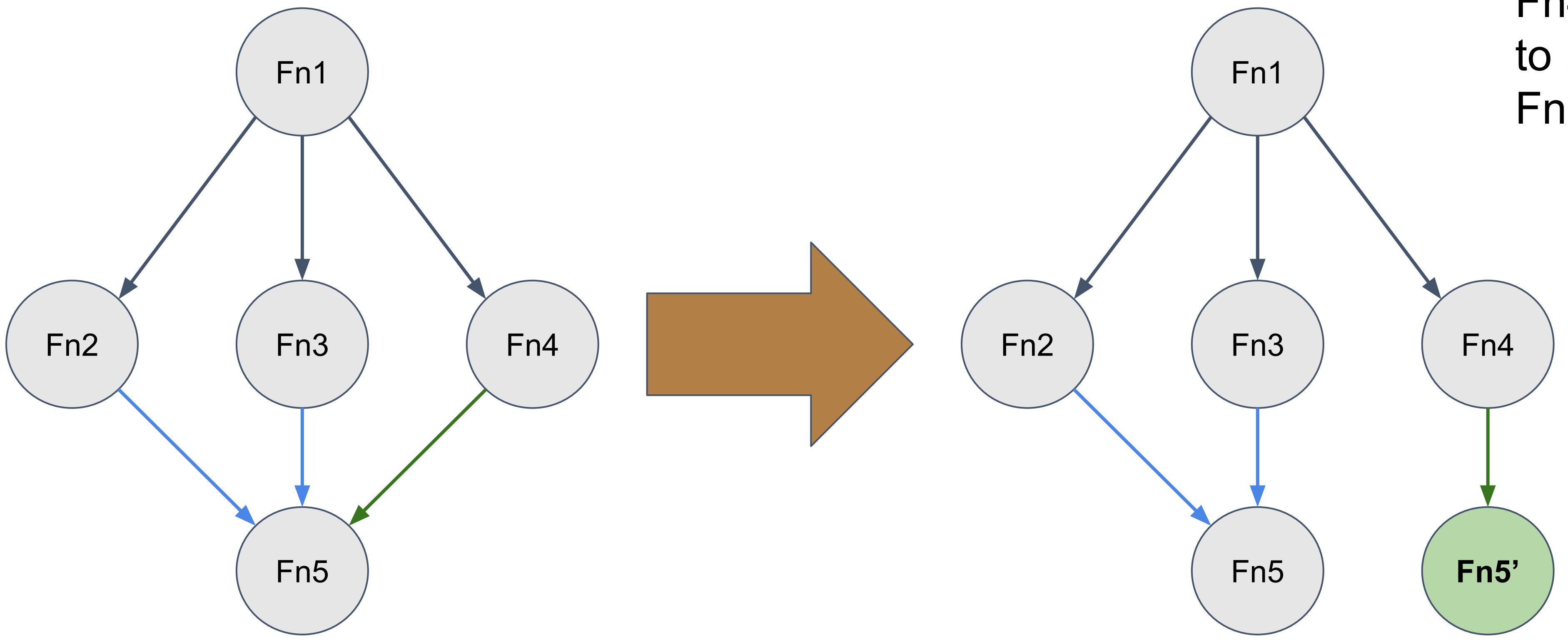
Data flow-based prediction



Fn4 passes objects to Fn5 not seen at Fn2 or Fn3? Clone it

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Implementation

- gllvm
- AFL++ 3.15a
- LLVM 10
- SVF framework

https://github.com/eurecom-s3/predictive-cs-fuzzing

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Evaluation

RQ: Can we find bugs that existing approaches overlook?

RQ: How is fuzzing performance affected?

Who: pcguard LTO, Angora-style CS fuzzing, Predictive CS fuzzing

How: 16 programs from FuzzBench bug benchmarks
budget of 2^18 entries (L2 size)

Bug counts

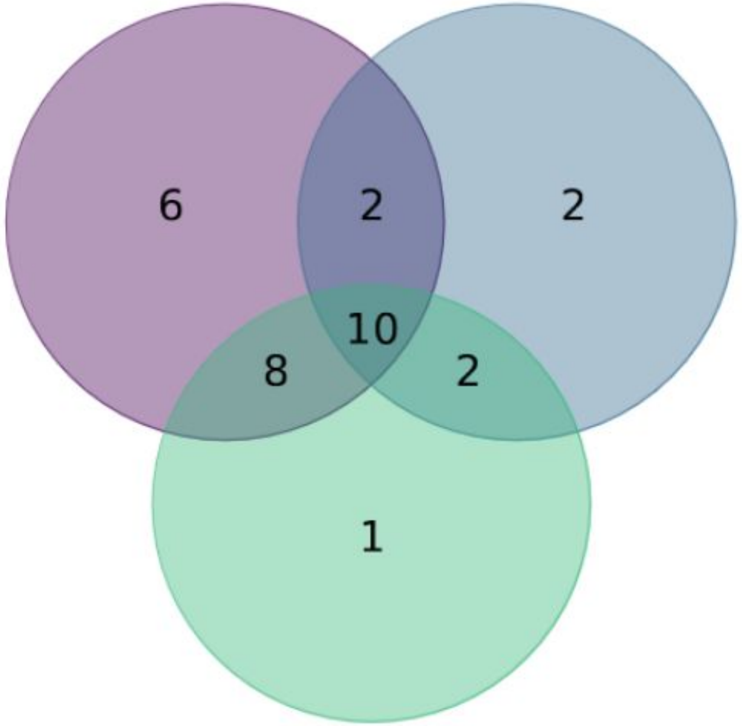
- predictive (125)
- lto (112)
- context (102)

Highlights

- +11.6% than lto, +22.5% than context
- 23 of our bugs (19.2%) were **missed** by lto (7 from new coverage, 16 from exploitation)

And new bugs!

■	predictive	(26)
■	lto	(16)
■	context	(21)



Highlights

- 26 out of 31 were exposed by predictive
- 8 security issues (1 each in ffmpeg, njs, libhevc, and matio; 4 in stb) - 6 CVEs assigned

Fuzzing performance

Trends

- **queue size:** +26.4% vs lto (context: +81.7%)
- **throughput:** 6.5% slower than lto (context: 20.3%)
- **coverage:** close to lto on 12/16 subjects, better on 8
- tenable compilation costs, 3.6x binary size increase

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Final remarks

Existing approaches face an **impossible trade-off** between collisions and trashing from queue/map explosion. We show a profitable avenue as we proactively select the most promising contexts based on data-flow diversity

Future opportunities: non-pointer arguments, cloning for indirect calls