RUB CASA Securing the Digital Society

Chair for Software Security

PogoFuzz: Profile-Guided Optimization for Fuzzing

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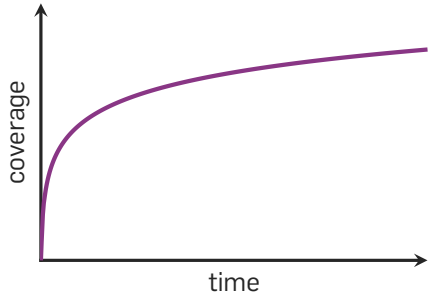
Fuzzing at Scale

- Fuzzing campaigns benefit from scale (more compute generally means more bugs).
- OSS-Fuzz continuously fuzzes over 1300 projects at on average over 80 cores each.
- We can only guess at large companies' internal fuzzing setups.

Even small improvements matter, as long as they scale.

Improving Fuzzers



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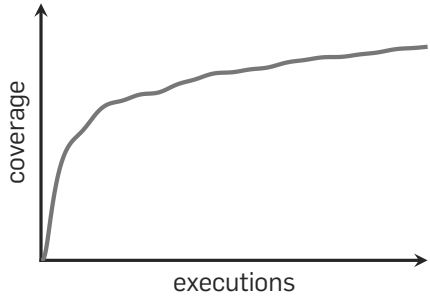

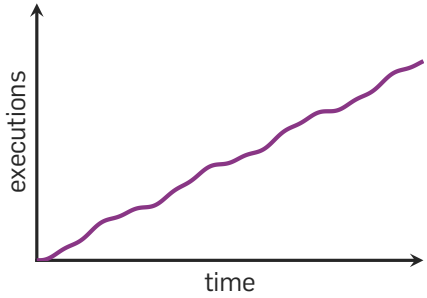

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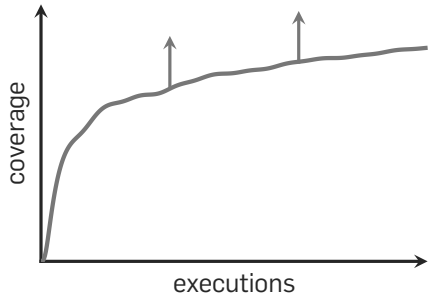

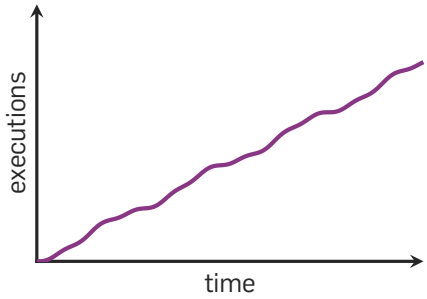

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(this is what most people try to do)

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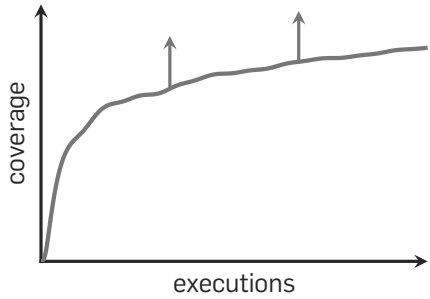

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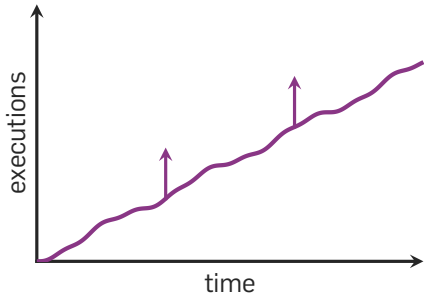

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(this is what we do)

The Fuzzing Loop

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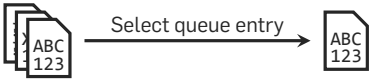

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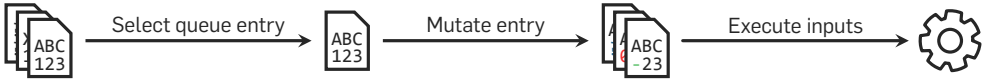

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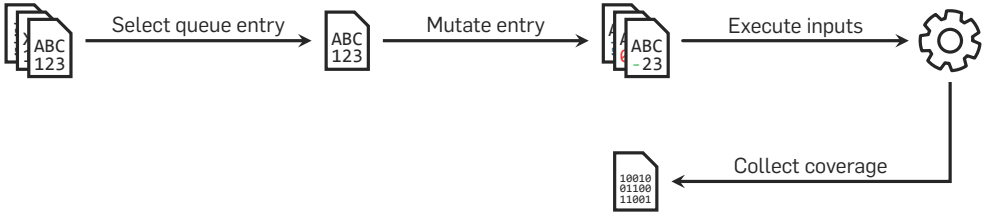

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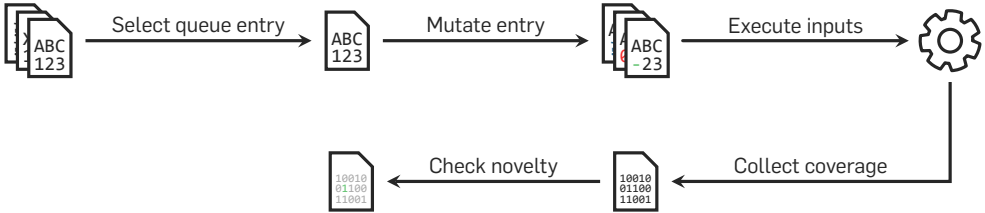

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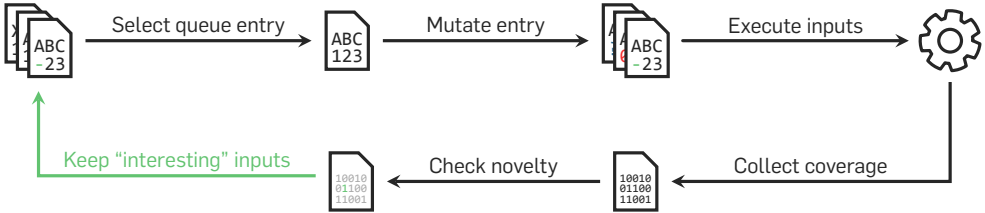

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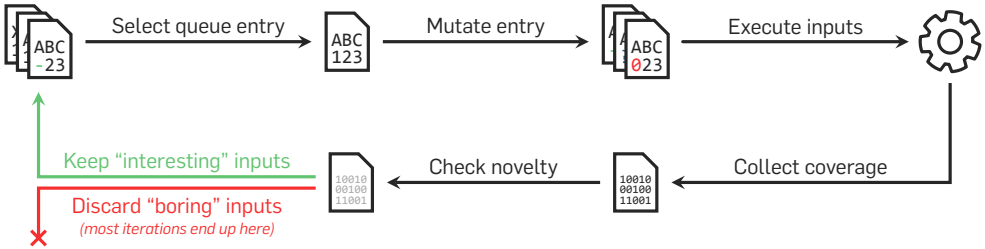

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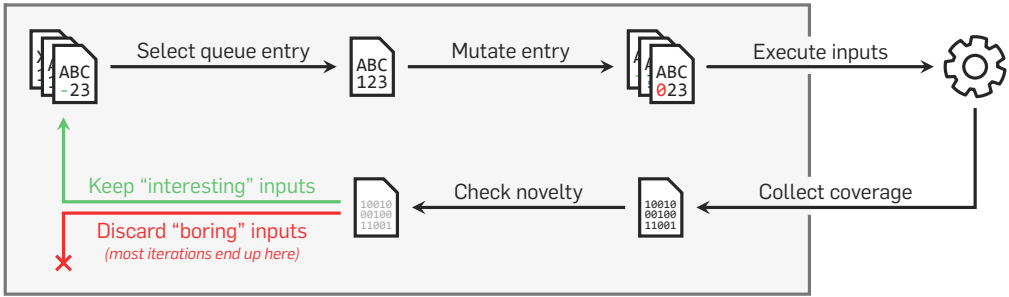

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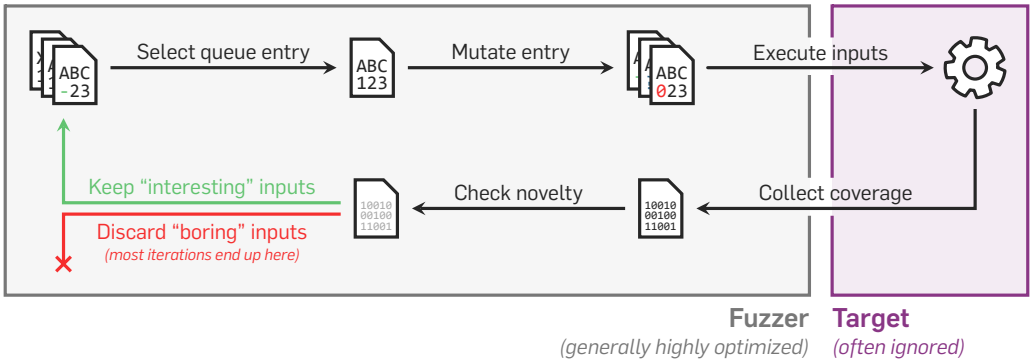
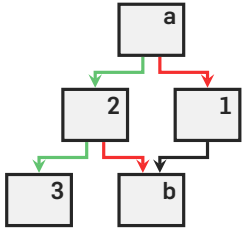


Profile-Guided Optimization



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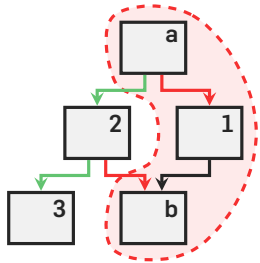

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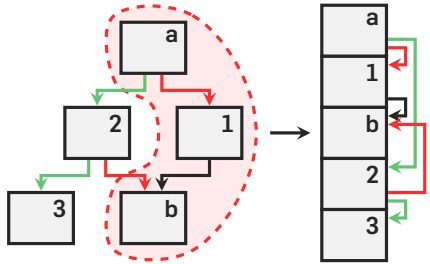

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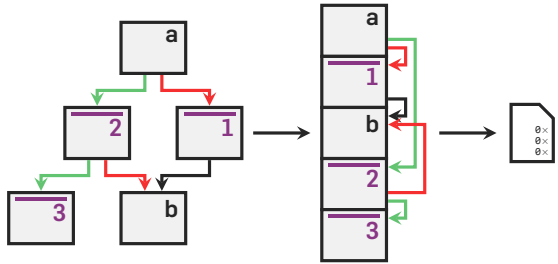

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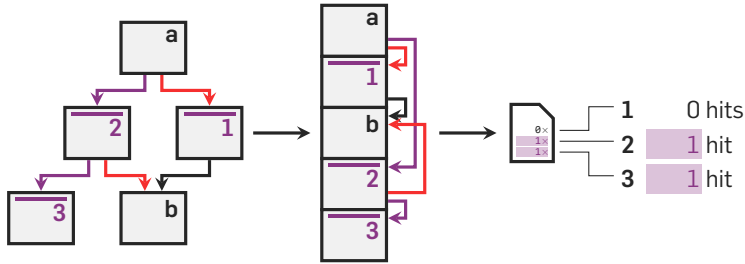

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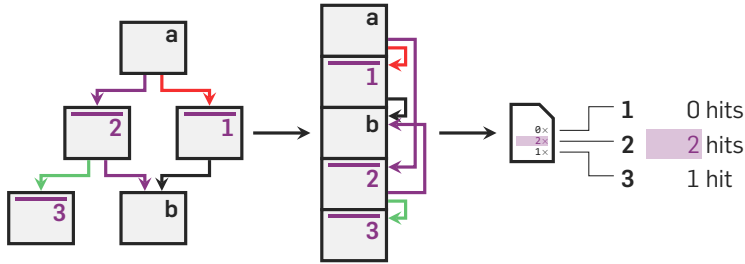

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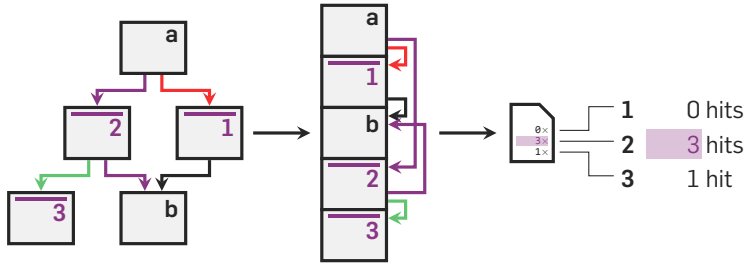

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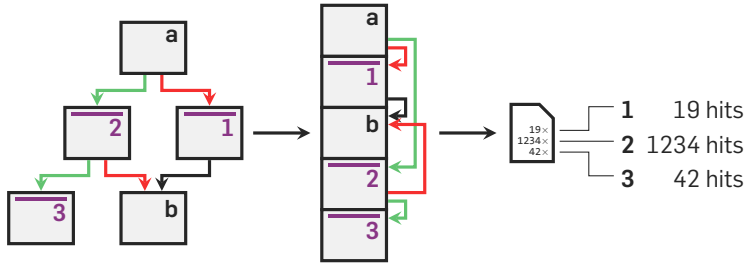

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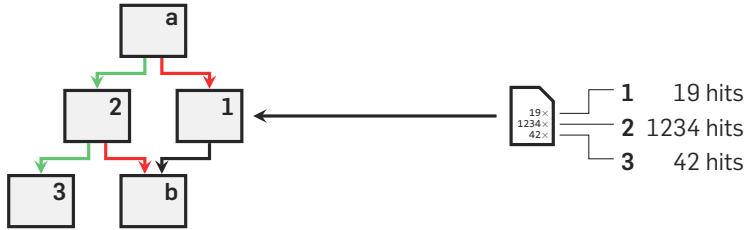

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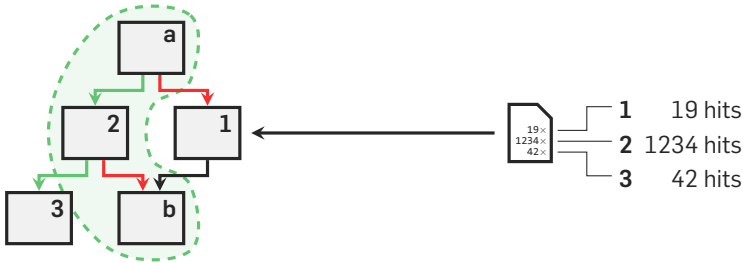

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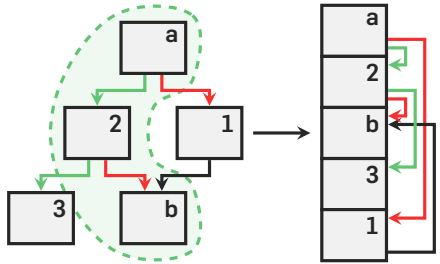

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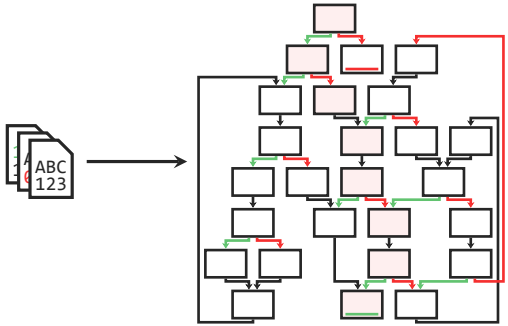
PogoFuzz
Core Idea



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Instead, the target has to run the same code **over and over again**.

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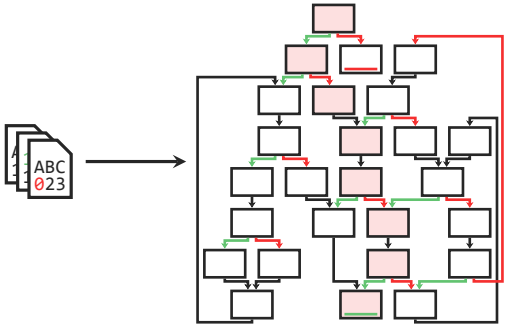

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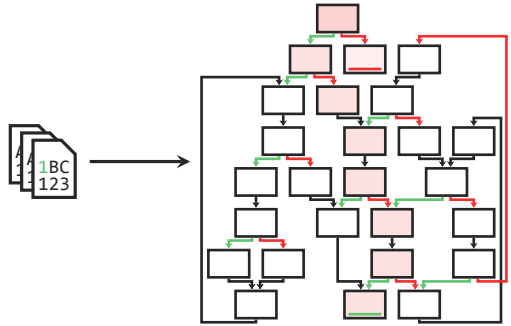

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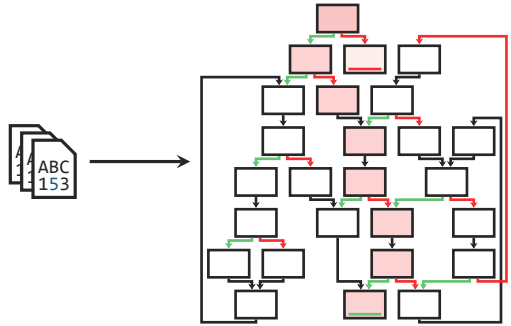

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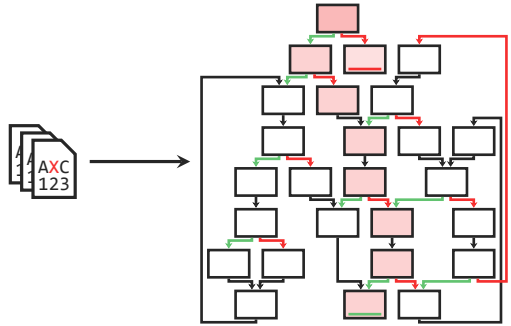

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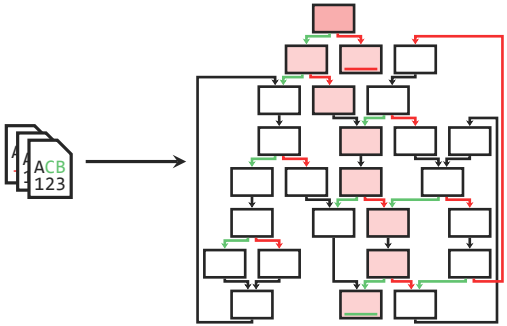

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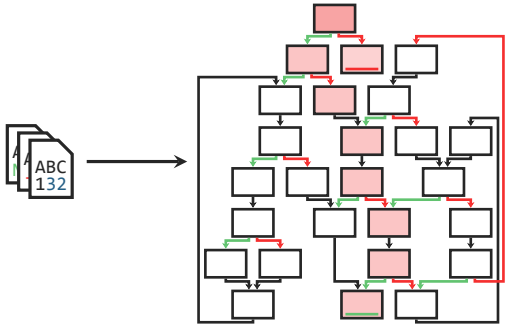

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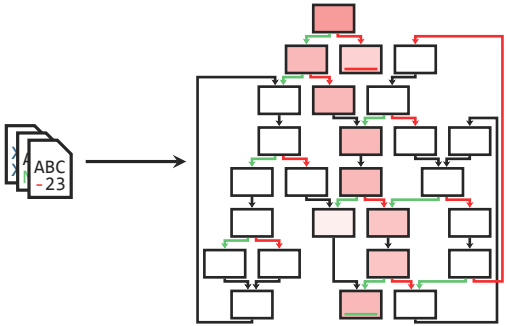

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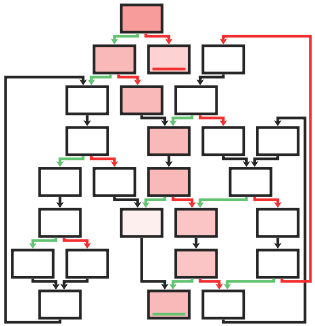
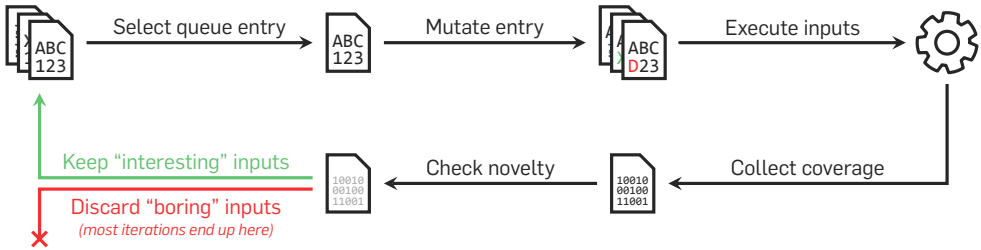


If we **(re)optimize the target** for this common case, the fuzzing loop should run faster.

PogoFuzz
Approach



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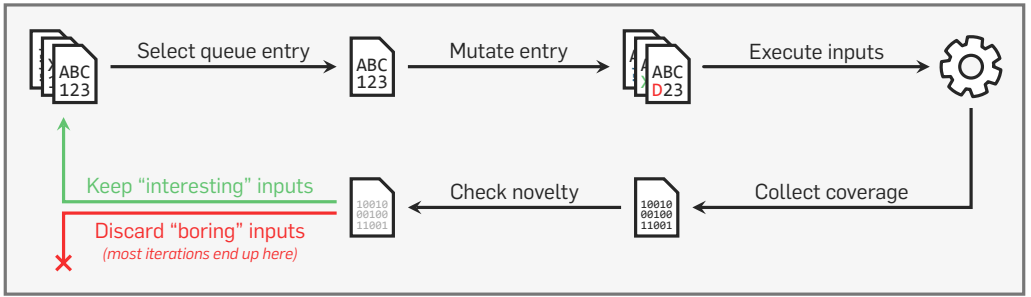

e.g., **AFL++**

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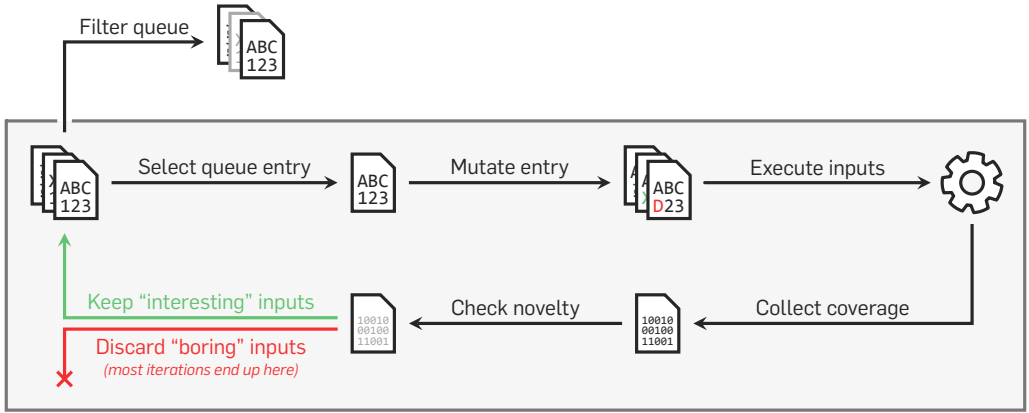

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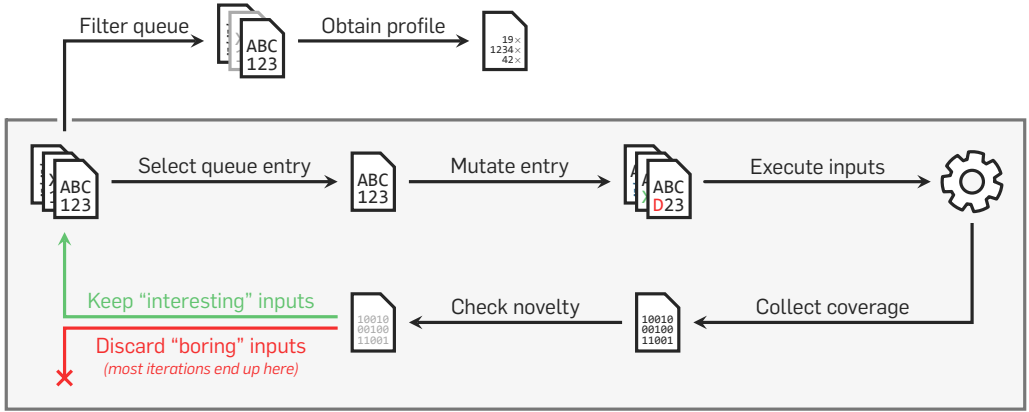

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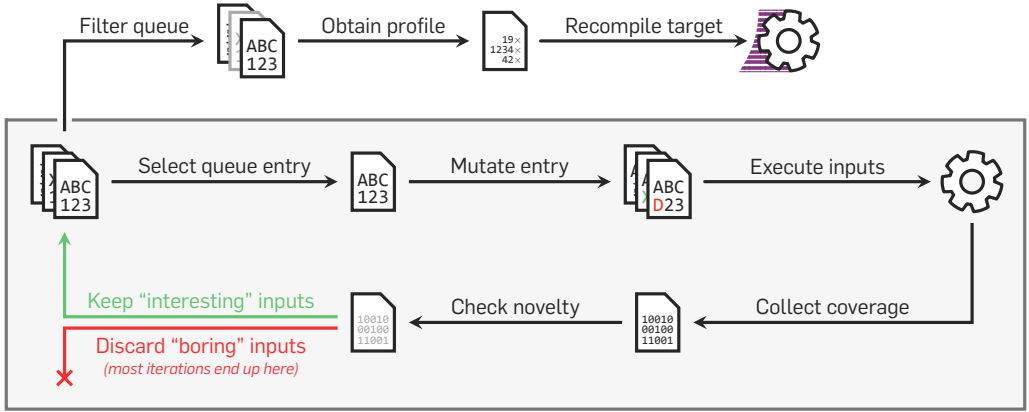

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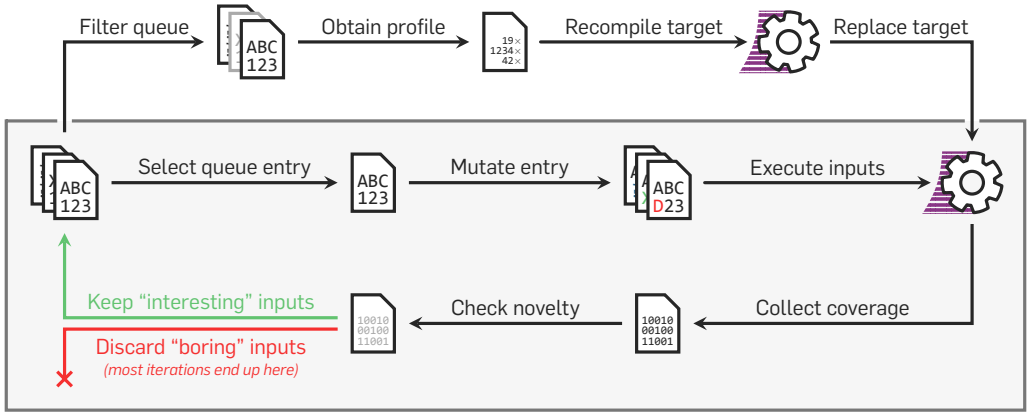

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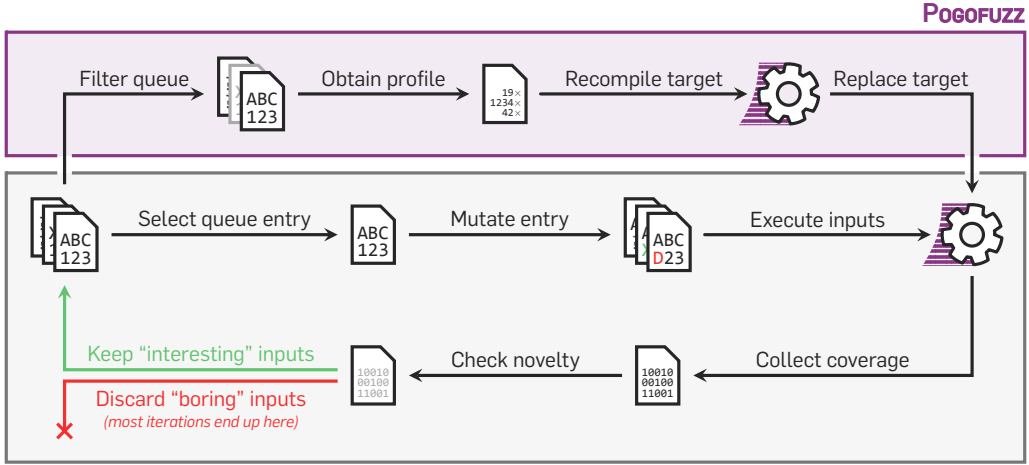

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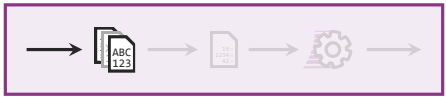
PogoFuzz
Queue Filtering



- Obtaining a PGO-compatible profile for a test case requires running it through an instrumented target binary.
- This is not much different from a binary instrumented for fuzzing.
- Doing this on the entire queue is still wasteful: some low-energy test cases are very unlikely to be reexamined by the fuzzer.

We apply a threshold to the fuzzer's internal energy metric to only pick relevant inputs.

PogoFuzz
Profiling

- We obtain a PGO profile using a binary with LLVM's IR PGO instrumentation.
- Queue entries with higher energy are more likely to be picked by the fuzzer, so they should have higher weight in the profile.
- We want to avoid slow post-processing of partial profiles.

We use a custom LLVM pass to directly scale the profile counts of each instrumentation point by the energy of the current test case.

PoGoFuzz
Recompilation

- One of the cores suspends fuzzing to perform the profiling and recompilation.
- Meanwhile, other cores can continue fuzzing on the old binary.
- Once recompilation completes, the target binary is replaced *in situ* through the normal fork server restart mechanism.

The cost of recompilation should amortize as more cores are added.

Preliminary Experiments
Target Selection

- PogoFuzz's impact is likely to vary depending on the target.
- The baseline **execution speed** of the target program plays a key role in this.
- The value of reoptimization depends on **how diverse** the input set is.

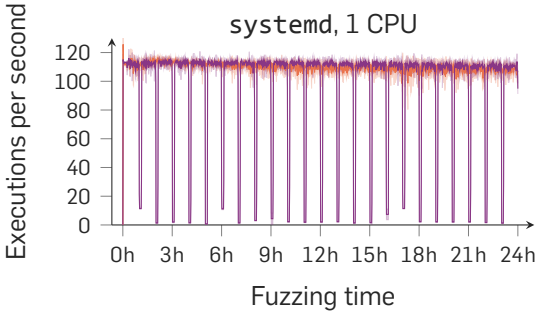
We picked **four FuzzBench targets** for diversity on these factors, based on execution speed and queue size at the end of a vanilla 24h FuzzBench run.

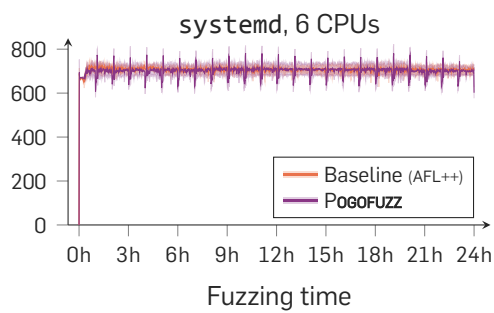
- `libxml2` (slow, large queue)
- `libxslt` (fast, large queue)
- `systemd` (slow, small queue)
- `zlib` (fast, small queue)

Preliminary Experiments
Configurations

- We compare against an unmodified baseline AFL++ (same version).
- For every target, we run an experiment with 1, 2, 3, 4, and 6 cores assigned to fuzzing.
- For `libxslt` and `zlib`, we later extended this to 8 cores.
- Each configuration was evaluated in five trials of 24 hours each.

Results
Impact of Reoptimization





Even the worst-case throughput loss (over 10% for single-core runs of `systemd`) amortizes quickly with more cores.

Results
Overall Performance

Target	Cores	Baseline (AFL++) Median	Baseline (AFL++) σ	PoGoFuzz Median	PoGoFuzz σ	Δ
libxml2	1	100.7	29.9	**104.0**	28.2	+3.3%
	2	192.8	59.6	**214.4**	78.6	+11.2%
	3	304.5	88.3	**382.9**	62.9	**+25.7%**
	4	403.1	80.4	**413.0**	95.1	**+2.5%**
	6	762.2	213.0	**793.2**	124.7	**+4.1%**
libxslt	1	360.6	10.2	**362.3**	9.5	+0.5%
	2	**731.6**	17.0	707.4	45.6	−3.3%
	3	1121.9	13.9	**1149.6**	19.1	**+2.5%**
	4	1476.8	19.9	**1520.1**	23.9	**+2.9%**
	6	2260.7	33.3	**2290.0**	37.3	**+1.3%**
	8	2985.1	37.3	**3096.8**	14.9	**+3.7%**

Target	Cores	Baseline (AFL++) Median	Baseline (AFL++) σ	PoGoFuzz Median	PoGoFuzz σ	Δ
systemd	1	**9.5**	0.1	8.5	0.1	−10.6%
	2	**19.9**	0.6	19.1	0.6	−4.0%
	3	29.8	0.8	**29.9**	0.7	+0.3%
	4	**40.8**	2.0	38.8	0.7	−4.9%
	6	**61.4**	1.4	60.9	2.4	−0.8%
zlib	1	631.8	129.3	**670.7**	21.8	+6.2%
	2	**1540.9**	25.9	1495.9	20.1	−2.9%
	3	2312.8	46.0	**2330.2**	109.3	+0.8%
	4	**3160.1**	16.9	3137.8	8.6	−0.7%
	6	**4758.3**	67.7	4694.2	51.8	−1.3%
	8	6337.6	62.3	**6407.2**	135.7	+1.1%

PoGoFuzz achieves **consistent gains** at 3+ cores for `libxml2` and `libxslt`.

Open Questions

- Can the reoptimization process confuse the the fuzzer instrumentation (e.g., regarding the ordering in the feedback map)?
  - We think this is unlikely (and did not see it in our experiments).
  - PGO-informed optimizations generally occur **after** the instrumentation is inserted.
- Is LLVM's IR-based PGO really the tool of choice here? LLVM offers alternatives:
  - Context-sensitive IR
  - Clang front-end PGO
  - Sampling-based approaches (e.g., CSSPGO)
- How can we determine optimal recompilation points?

Proposed Experiments
Scaling

- The relative cost of recompilation drops as the number of cores increases.
- Does this trend continue with more cores?

We will extend our experiments with additional configurations up to at least **24 cores**.

Proposed Experiments
Generalizability: Targets

- We know that the value of PGO is target-dependent.
- How does PogoFuzz perform on other fuzzing targets?

We will extend our experiments to cover **all FuzzBench targets**.

Proposed Experiments

Generalizability: Fuzzers

- Different fuzzers explore the input space differently.
- How does the choice of fuzzer affect the performance gain?

We will port POGOFUZZ to **other fuzzers** (e.g., Honggfuzz or LibAFL) for evaluation.

Proposed Experiments
Recompilation Interval

- Is recompiling every hour necessary, or is it sufficient to do this less frequently?
- Can we skip recompilation if the queue has not changed significantly?

We will evaluate the impact of **different recompilation intervals** (e.g., 2, 4, or 8 hours), and explore **heuristics** to extend (or shorten) that interval.

Takeaways

PogoFuzz augments existing fuzzers, speeding up fuzzing by **regularly (re)optimizing** the target for the current queue.

Paper and slides are available at
`softsec.link/fz26.pogofuzz`

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