30TH USENIX
SECURITY SYMPOSIUM

The Use of Likely Invariants as Feedback for Fuzzers

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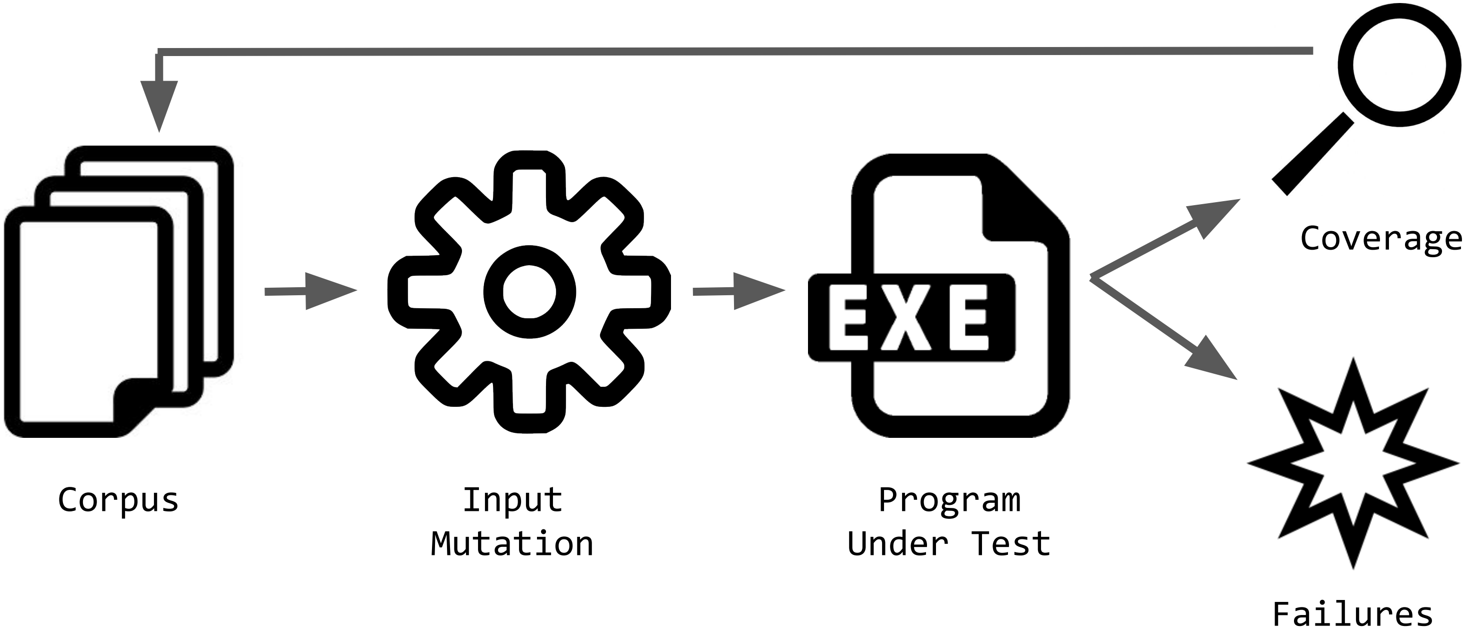
Coverage-guided Fuzzing



Coverage-guided Fuzzing

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char buf[BUF_SIZE];

char foo(int x) {
  if (x < sizeof(buf))
    return buf[x];
  return 0;
}
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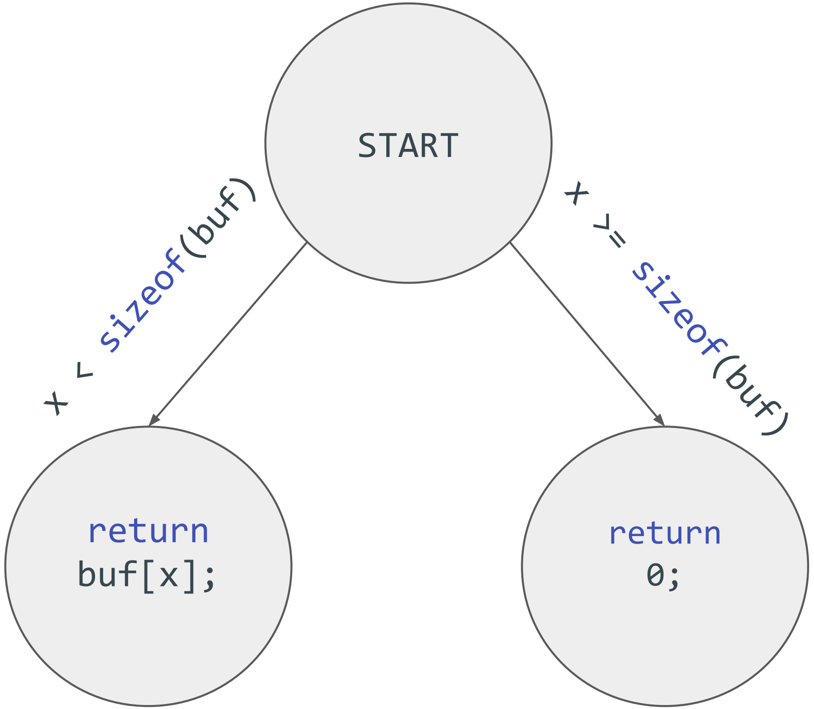

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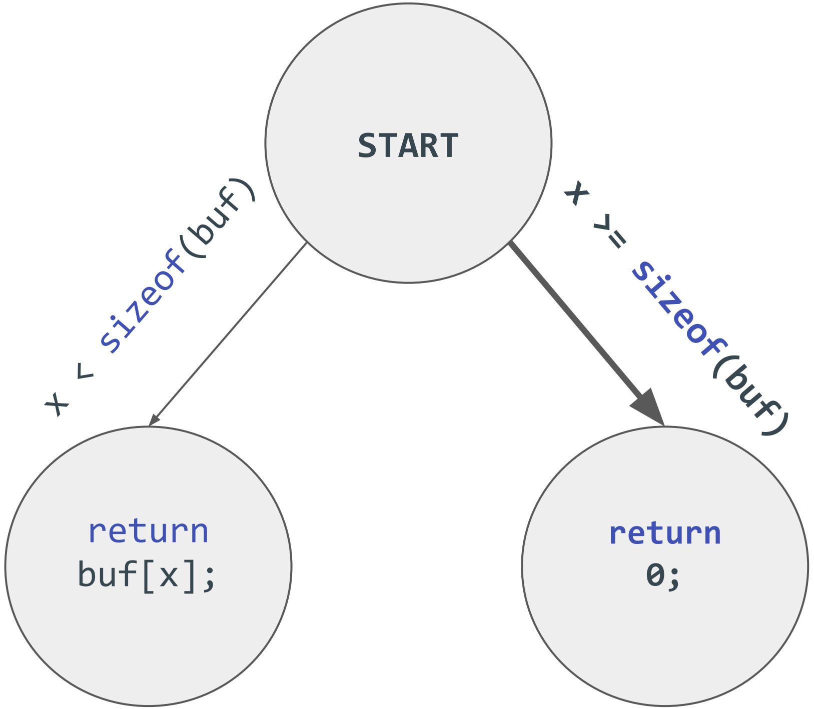

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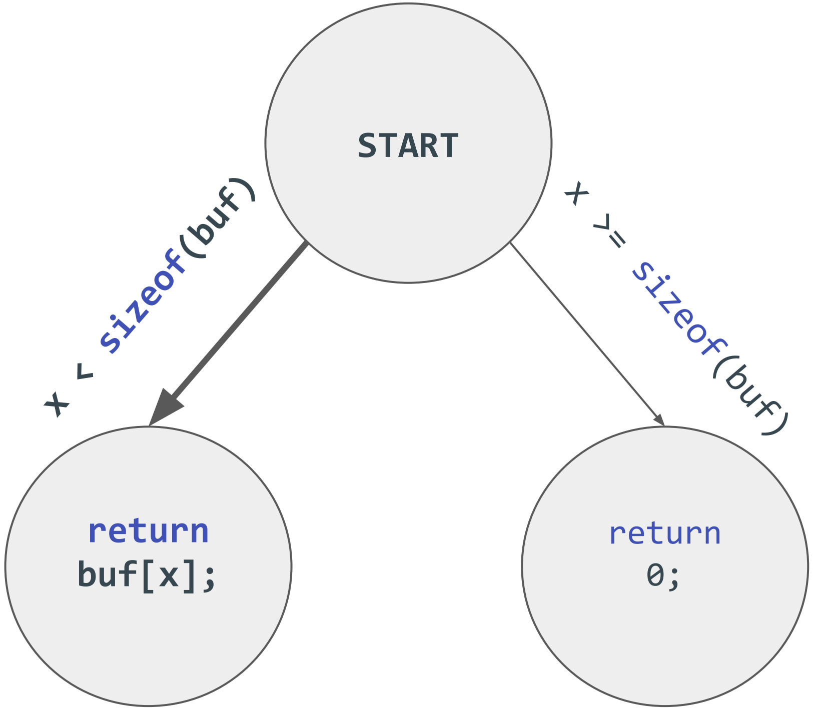

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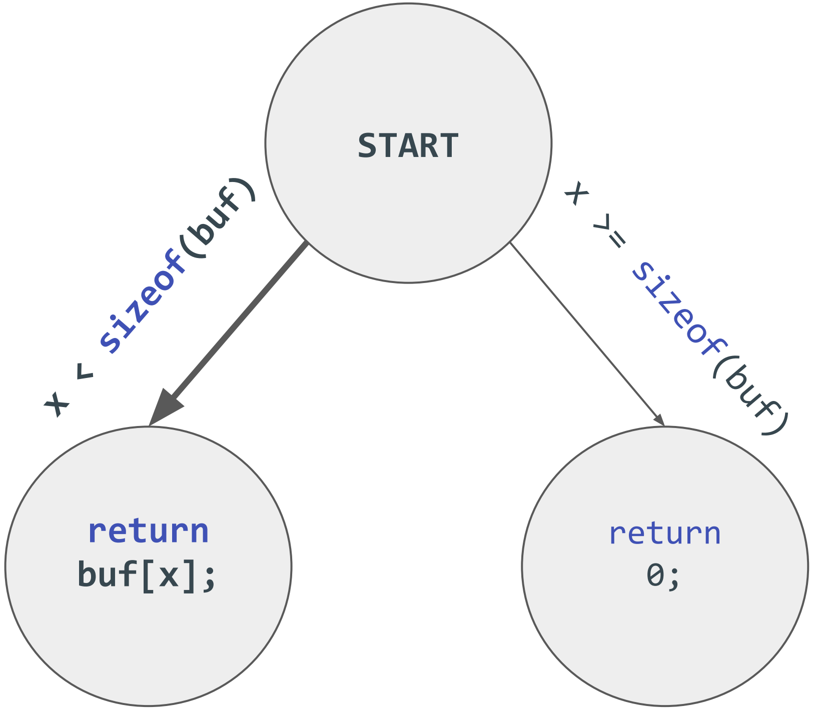


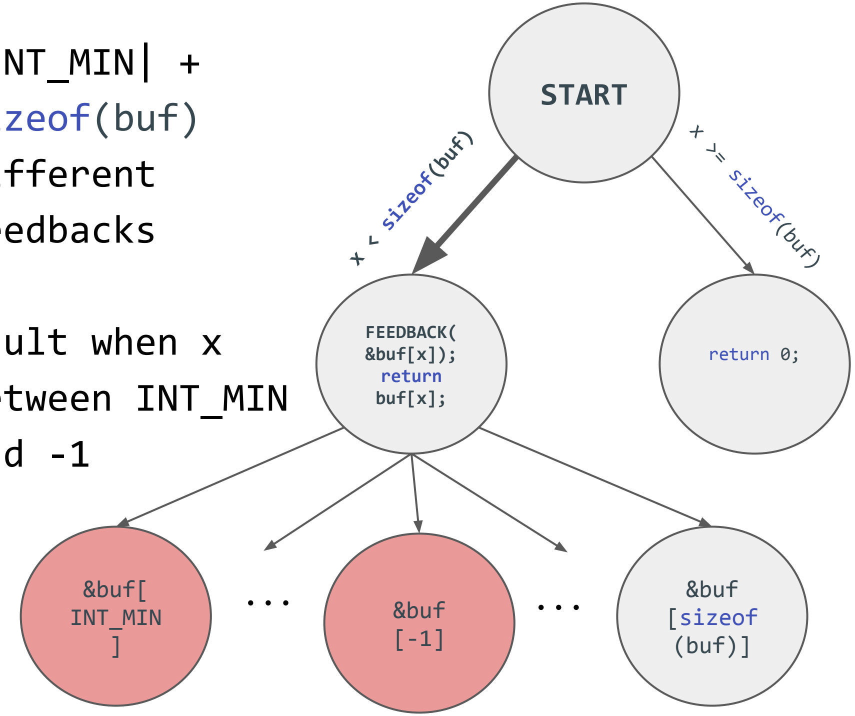
Now the fuzzer cannot find any new coverage.

Feedback-driven Fuzzing

```c
char buf[BUF_SIZE];

char foo(int x) {
  if (x < sizeof(buf)) {
    FEEDBACK(&buf[x]);
    return buf[x];
  }
  return 0;
}
```

- |INT_MIN| + sizeof(buf) different feedbacks
- Fault when x between INT_MIN and -1

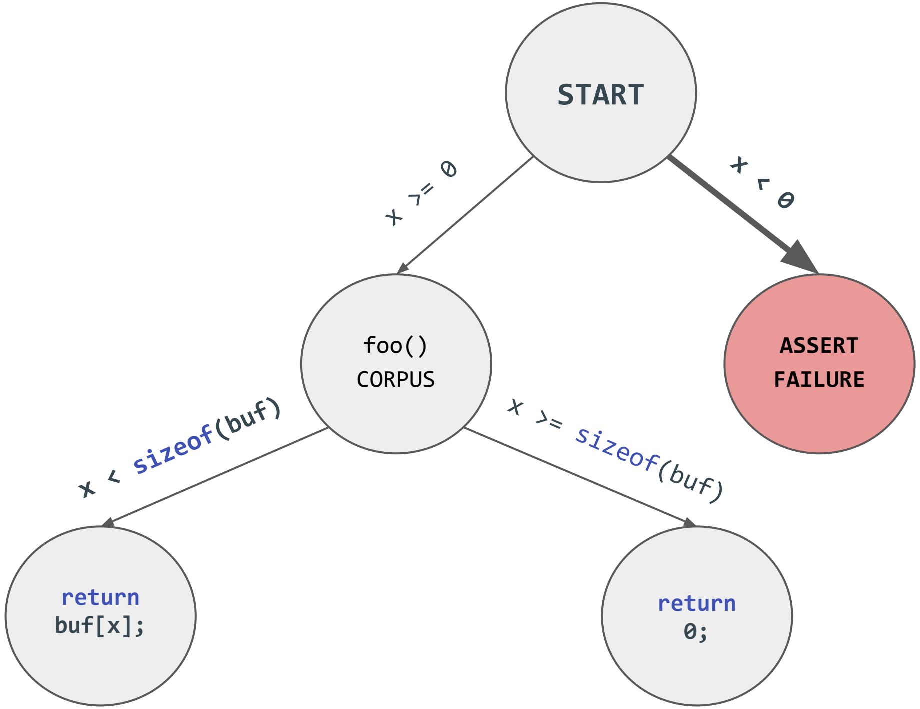


Note: x does not come directly from the input, otherwise it is easy for a fuzzer to trigger the bug thanks to the random generation

Property-based Testing

```c
char buf[BUF_SIZE];

char foo(int x) {
  assert (x >= 0);
  if (x < sizeof(buf))
    return buf[x];
  return 0;
}
```



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Mining Invariants

- Learn invariants from static analysis
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- Learn ***likely*** invariants from dynamic analysis
  - Needs a corpus of testcases
  - Suffers from the "*Coverage Problem*", likely invariants are in worst case only local properties related to the observed executions
  - So many false positives

Idea: Likely Invariants as Feedback

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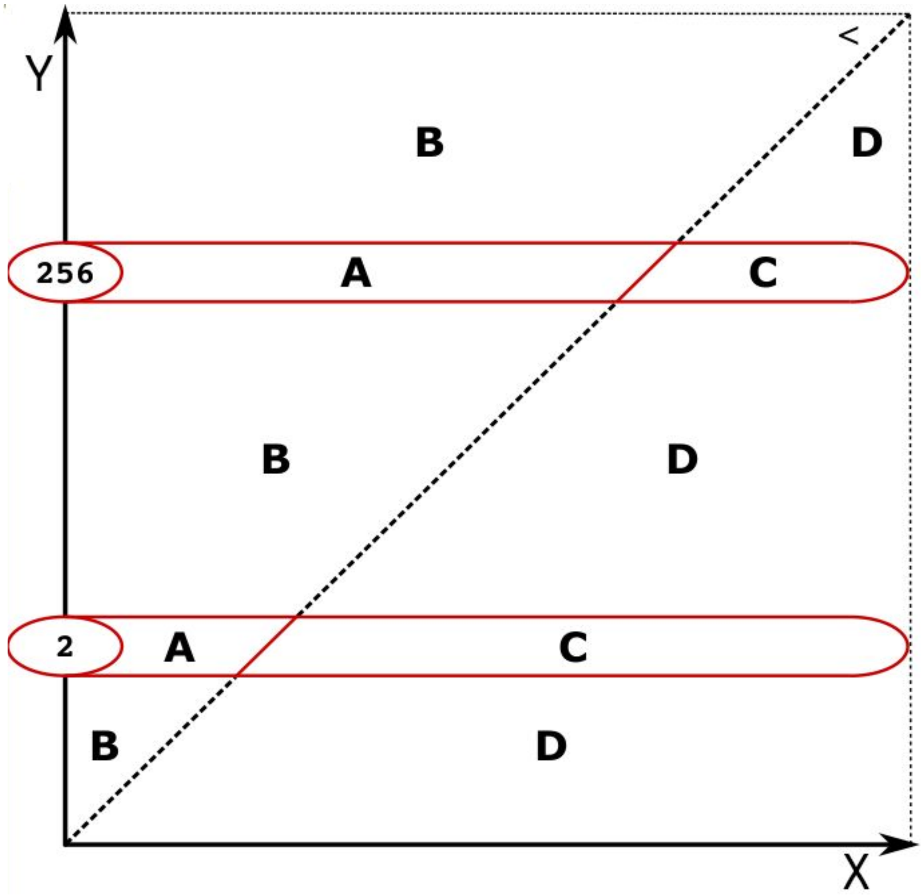
Idea: Likely Invariants as Feedback

- In Fuzzing, we are interested in storing testcases that trigger new program states. Likely invariants violations can distinguish “unusual” states of the variables.
- Coverage Problem? Not a problem, local properties are interesting constraints to separate the space of the possible values.
- Basic block, not function, level (ok for memory unsafe languages)



- $Y \in \{0,2,256\}$
- $Y < X$

The space is divided in 4 subspaces, A B C D

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- Compute set of related variables and do not generate invariants between unrelated variables (*Comparability calculation algorithm*)
- Compute basic invariants using intra-procedural *Range Analysis* and instruct the learner to not output inviolable checks
- Traverse the *Dominator Tree* in order to not emit the same check over the same variables different times in different basic blocks

Prototype: InvsCov

Based on the AFL++ Fuzzing Framework and LLVM. We provide two LLVM passes and Clang wrappers.

Likely invariants mined using the Daikon dynamic invariants detector.

Instrumentation

We extend the classic AFL-style instrumentation to keep track of the combination of violated invariants.

```
// Original AFL edge-coverage code
__afl_area_ptr[cur_loc ^ prev_loc]++;
prev_loc = cur_loc >> 1;

// Extended to capture violations of invariants
__afl_area_ptr[cur_loc ^ prev_loc]++;
prev_loc = cur_loc >> 1;
prev_loc ^= __daikon_constr_1(var0);
prev_loc ^= __daikon_constr_2(var2, var3);

...
```

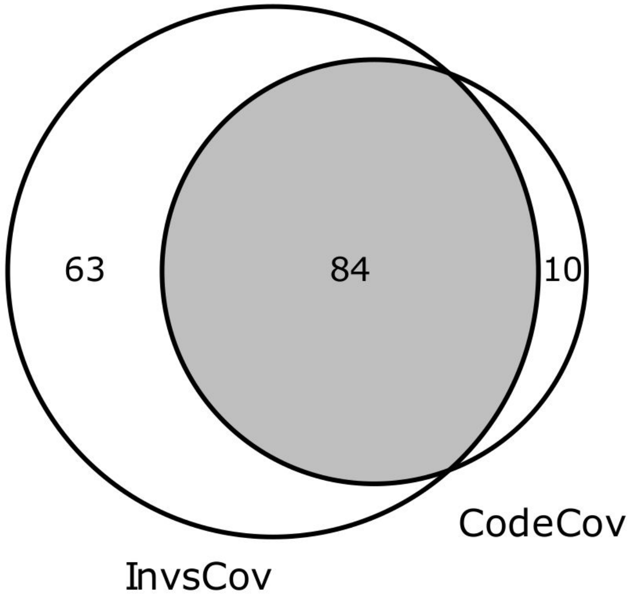
Evaluation

We evaluated our prototype using old versions of 8 real-world subjects used in previous works. The initial corpus is the result of a previous 24h fuzzing campaign, then we run the fuzzers for 48h.

- 62% growth on the fuzzer’s queue size (no state explosion)
- 8% slowdown on the average testcase execution speed
- 1% growth on total edge coverage

Evaluation

- 56% growth on bugs found vs. code coverage
- 41% growth on bugs found vs. context-sensitive coverage
- 67% of the bugs that only InvsCov could find were reached but not triggered by CodeCov



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- On-demand learning of invariants during fuzzer. Reimplement a fast version of Daikon that is also adaptive.
- Track implicit memory values not used in a block but still interesting (e.g. the size of buffers).
- Identify other ways to remove impossible-to-violate likely invariants at compile time.
- What happens when we guide the fuzzer towards “rare” invariants violations?

Thank you!

Questions?