SMT-Based Refutation of Spurious Bug Reports in the Clang Static Analyzer

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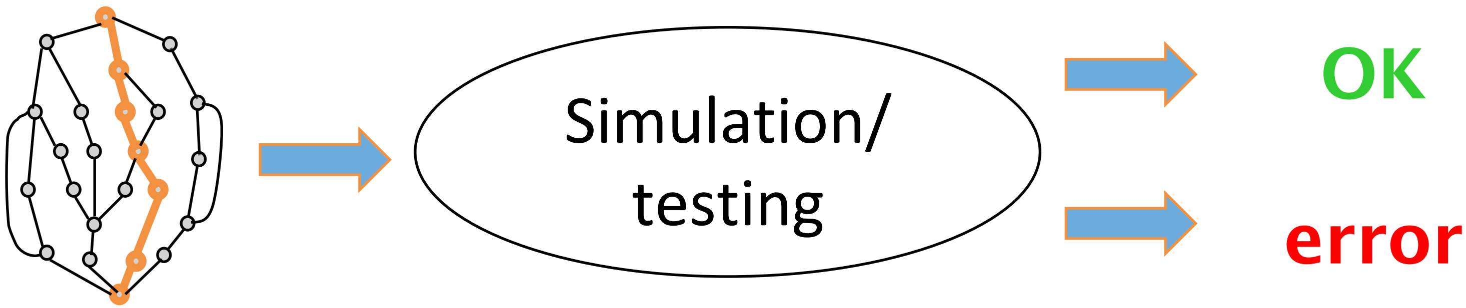
Static Analysis vs Testing



- Usually checks one path in the program.
- May miss errors.
- It’s fast.

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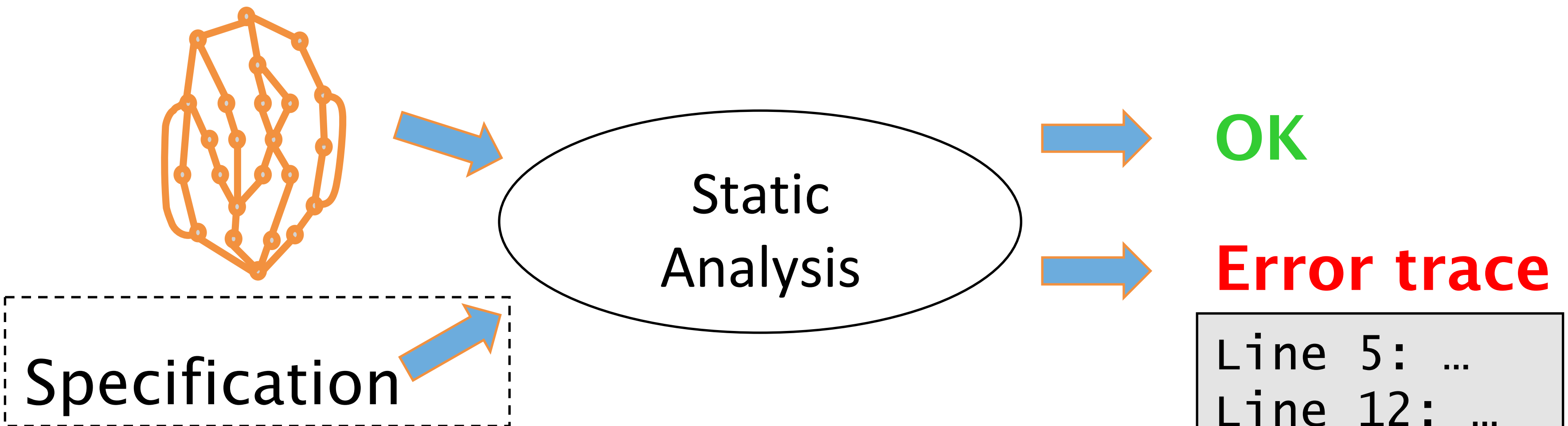


```
Line 5: …
Line 12: …
…
Line 41:…
```

- Report errors as traces.
- Explores all executions, might over-approximate paths.
- Might present false positives due to over-approximations.
- Does not scale well (state/path explosion).

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- Sacrifices precision for speed.

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```
unsigned int func(unsigned int a) {
  unsigned int *z = 0;
  if ((a & 1) && ((a & 1) ^ 1))
    return *z;
  return 0;
}
```

Is this program safe?

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- This program is safe, i.e., the null pointer dereference is unreachable.

Running the CSA

DEMO

Refuting False Bugs using SMT Solvers

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- Why don't we replace the imprecise solver?
- First SMT backend implemented (Z3) in late 2017 by Dominic Chan. It was aimed to replace the built-in constraint solver in the CSA.
- It was up to 20 times slower than the built-in constraint solver :/

Refuting False Bugs using SMT Solvers

We developed an alternative solution: to use the more precise SMT solvers to reason about bug reachability only as a **post processing** step.

Refuting False Bugs using SMT Solvers

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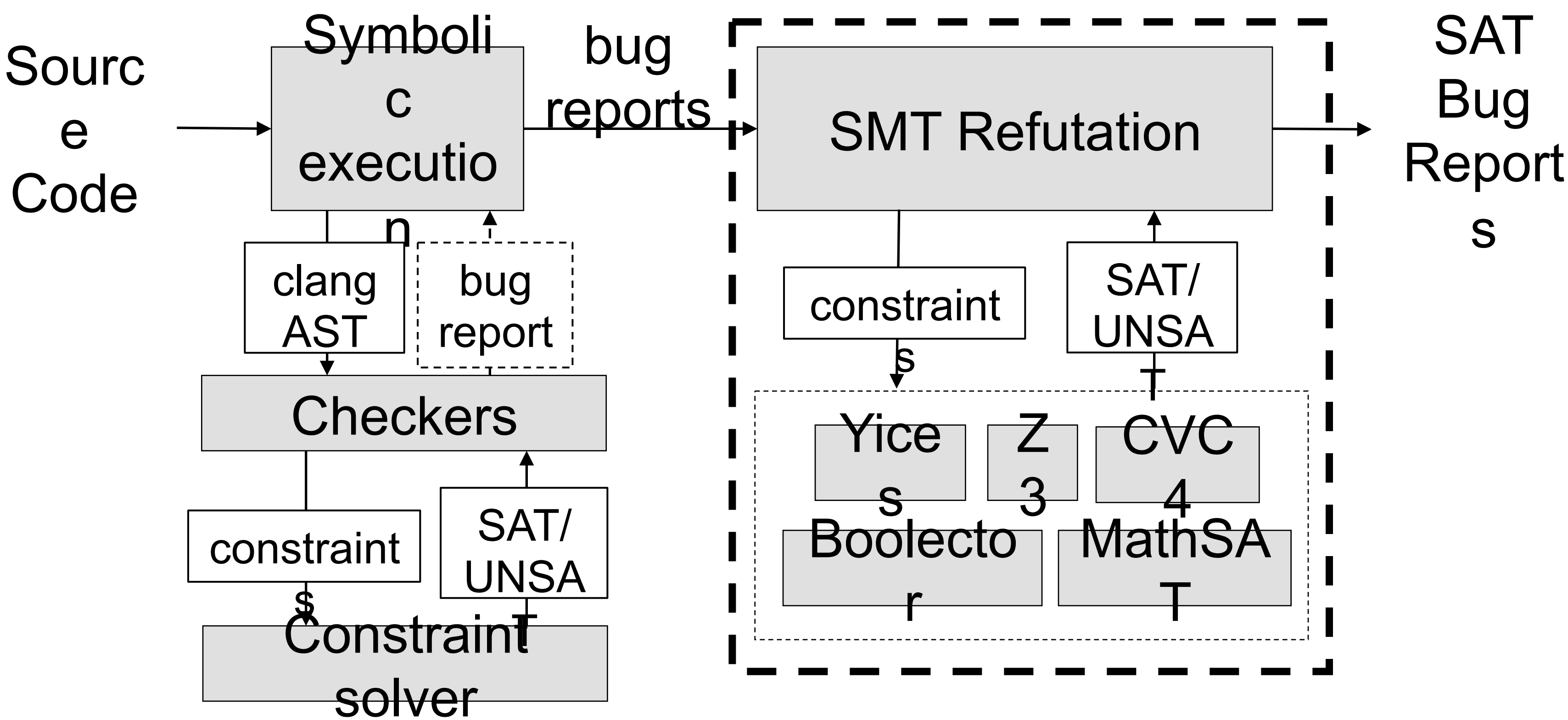
- We implemented support for five different state-of-the-art SMT solvers in the CSA: Z3, Boolector, MathSAT, Yices and CVC4.

Running the CSA with SMT refutation

DEMO

Clang Static Analyzer with SMT Refutation



Experimental Evaluation

- We evaluated twelve open-source projects:
  - tmux, Redis, openSSL, twin, git, postgreSQL, sqlite3, curl, libWebM, Memcached, Xerces-c, and XNU.
- Using five different SMT solvers:
  - Z3, Boolector, MathSAT, CVC4 and Yices
- Instructions to reproduce the experiments in: https://github.com/mikhailramalho/analyzer-projects

Experimental Evaluation

Projects	time (s) (no refutation)	time (s) (refutation)*	reported bugs (no refutation)	refuted bugs
redis	347.8	338.3	93	1
openSSL	138	128	38	2
twin	225.6	216.7	63	1
git	488.7	405.9	70	11
postgreSQL	1167.2	1112.4	196	6
SQLite3	1078.6	1058.4	83	15
xerces-c++	489.8	433.2	81	2
XNU	3441.7	3405.1	557	51
tmux	86.5	89.9	19	0
curl	79.8	79.9	39	0
libWebM	43.9	44.2	6	0
memcached	96	96.2	25	0

* average time of Z3, Boolector, MathSAT, Yices and CVC4.

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Experimental Evaluation

Average 10% bugs removed

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Average 6% speedup

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Average 1% slowdown

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- In total, 89 bugs were refuted and an in-depth analysis of them show that all of them were false positives.

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- The average time to analyse the projects with refuted bugs was 35.0 seconds faster, a 6.25% speed up.

- Out of the four projects where no bug was refuted the analysis was 1.0 second slower on average: a 1.24% slowdown.

How do I run CSA on my project?

DEMO

Conclusions

- The technique removes from 0% to 20% bugs in real-world projects:
  - Empirical evidences shows that, on average, 50% of the bugs reported are spurious.
- The technique only incurs in a small overhead, and can actually make the analysis faster in a number of real-world projects.
- Further improvements can only be achieved through cross translation-unit support in the CSA.

The future?

- D54978: Move the SMT API to LLVM:
  - Part of the clang 9.0.
- Validation of optimizations using SMT:
  - Already done in the ScalarEvolution pass.
- Maybe an SMT backend in LLVM:
  - Memory handling?
  - Loops?

Acknowledgments

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  - Artem Dergachev
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  - Anna Zaks
  - Réka Kovács
  - Dominic Chen
  - Gábor Horváth

Thank you!

- Me: mikhail.ramalho@gmail.com
- Experiments: https://github.com/mikhailramalho/analyzer-projects
- Clang static analyzer: https://clang-analyzer.llvm.org/
- 5 min video: https://www.youtube.com/watch?v=ylW5iRYNsGA