Arbiter: Bridging the Static and Dynamic Divide in Vulnerability Discovery on Binary Programs

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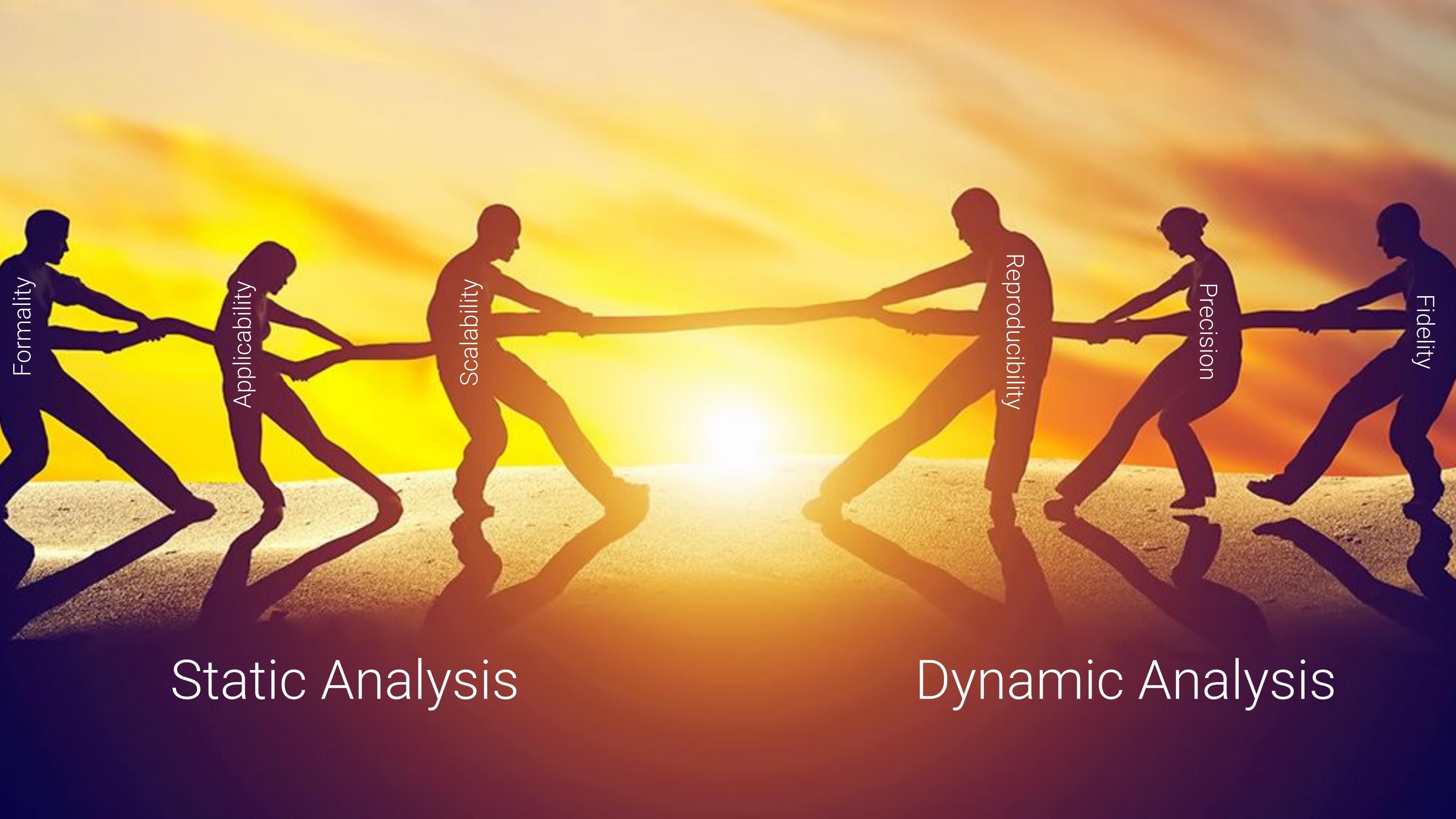

Formality
Applicability
Scalability
Reproducibility
Precision
Fidelity
Static Analysis
Dynamic Analysis


Fuzzing
Memory
corruption
Sanitizer

Intuition

The properties of a vulnerability convey requirements on analysis techniques.

Vulnerability detection is a *vulnerability-driven process*.

Pros and Cons

Static	Dynamic
• High scalability	• Limited scalability
• High coverage	• Limited coverage
• More False Positives	• Fewer False Positives

Vulnerability Properties

We identified three properties that enable the composited use of analyses to achieve scalability and precision.

P1: Data-flow Sensitive Vulnerabilities. DFSV

P2: Easily Identifiable Sources or Sinks. EISS

P3: Control-flow-determined Aliasing. CFDA

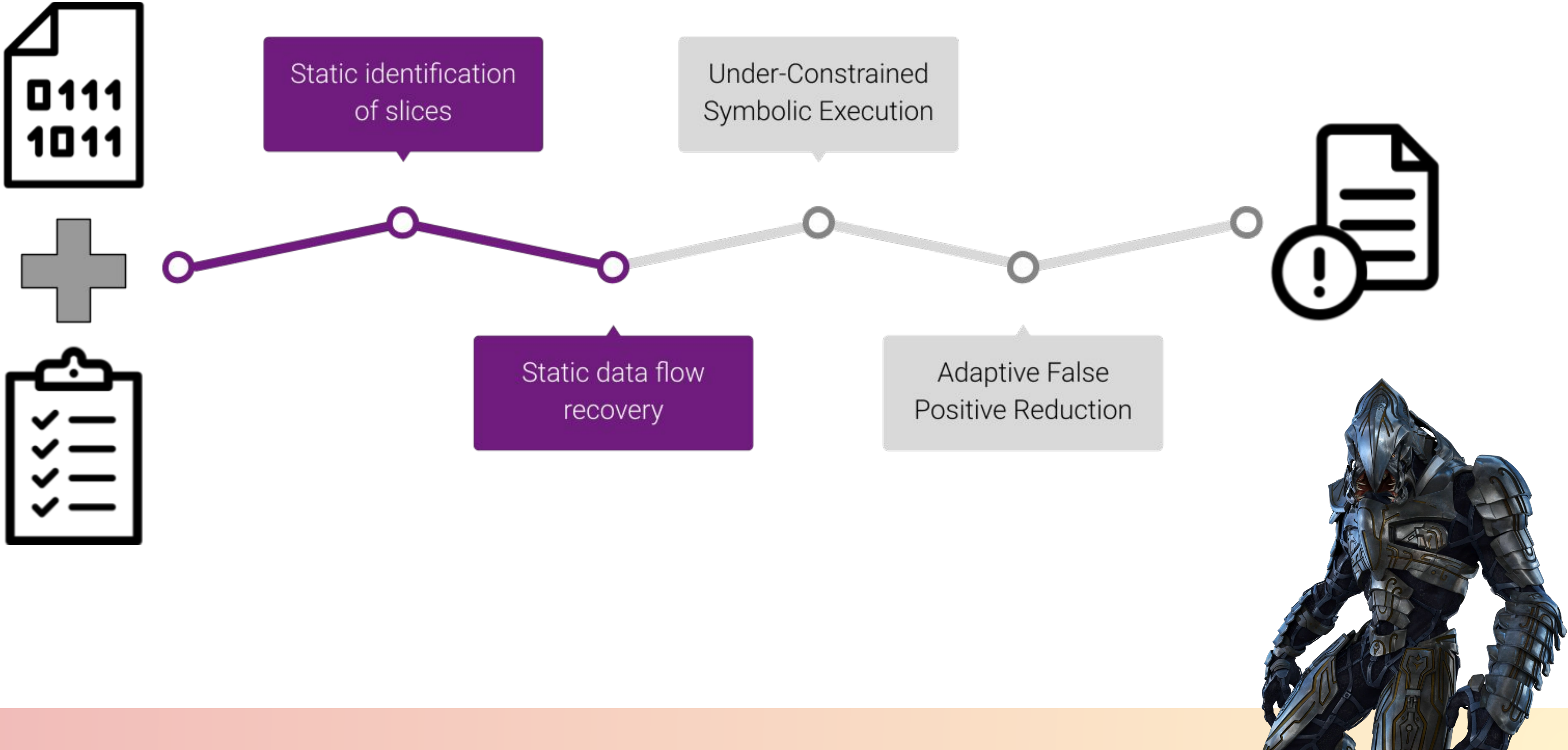
The Analyses

EISS Allows us to use the high scalability and high coverage of static analysis to identify candidate paths.

DFSV Provides high precision by enabling the use of Under-Constrained Symbolic Execution (UCSE) to filter out false-positives.

CFDA Supports an adaptive augmentation of context sensitivity in UCSE, providing a configurable trade-off between precision and soundness.

Arbiter


0111
1011
Static identification of slices
Static data flow recovery
Under-Constrained Symbolic Execution
Adaptive False Positive Reduction

Property-Compliant Vulnerabilities

CWE ID	Description	CVE Example
CWE-131	Incorrect Calculation of Buffer Size	CVE-2018-18311
CWE-134	Use of Externally-Controlled Format String	CVE-2012-0809
CWE-252	Unchecked Return Value	CVE-2013-4559
CWE-337	Predictable Seed in Pseudo-Random Number Generator	CVE-2020-13784

Evaluation

- Evaluated on 76k binaries, generated a total of 1130 alerts.
- 661 True Positives, 410 False Positives.

Class	Alerts	True Positives	False Positives	Untriage-able
CWE-131	436	194	195	47
CWE-134	158	12	142	4
CWE-252	159	83	71	5
CWE-337	377	372	2	3

Validation of Static Analysis

Evaluation vs AFL

We triggered 25 bugs discovered by Arbiter. Of those:

- Only 7 were in standalone binaries.
- AFL could fuzz 5 (2 binaries were too complex).
- AFL only found 3 bugs in 24 hours.

Case Study: OCaml

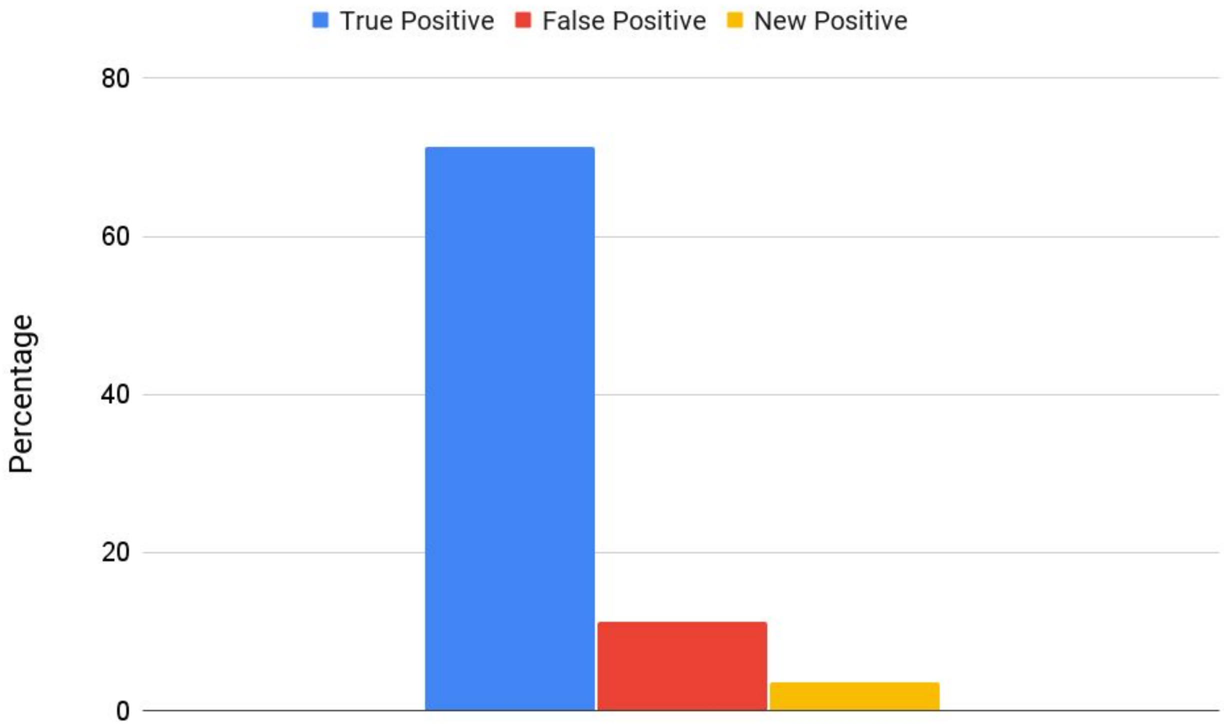
In triaging Arbiter's CWE-131 reports, we kept finding identical cases of buggy heap management code.

Looking into the corresponding source code, *there were no bugs*.

All of the programs were OCaml...

The bug was introduced **at compile time** by the OCaml compiler, affected all 32-bit OCaml programs.

Evaluation on The Juliet Dataset



Case Study: The Juliet Dataset

New Bugs!
Arbiter found 190 previously-unknown bugs in Juliet, missed by all existing work!

The Cause?
Source code analyzer modeling of the abs() C function is (apparently) wrong.

0xFFFFFFFF

0xFFFFFFFF

```
int goodB2GSink(unsigned int data) {
  ...
  if (abs((long)data) < (long)sqrt((double)UINT_MAX)) {
    unsigned int result = data * data;
    printUnsignedLine(result);
  }
  ...
}
```

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Summary

- Vulnerability detection is a vulnerability-driven process.
- Three vulnerability properties enable hybrid analysis, which improves scalability and precision.
- Evaluation on 76k binaries shows ~60% true positive rate.

Thank you!

Questions?

https://github.com/jkrshnmenon/arbiter

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Backup slides

Digging In

	Static Detections	Context-Insensitive UCSE	Context-Sensitive UCSE #1	Context-Sensitive UCSE #2	Context-Sensitive UCSE #3	Final Alerts*
CWE-131	692,501	31,436	3,310	1,037	351	436
CWE-134	429,711	39,305	4,894	489	222	158
CWE-252	55,388	4,413	942	126	107	159
CWE-337	4,641	2,741	633	92	45	377

The pattern: Arbiter casts an initial wide net, followed by alert reductions up to 10x per step.

* Final alerts can be higher than prior steps due to paths that are traced to program entry point during earlier false positive reduction steps.