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CISPA

SoK: Prudent Evaluation Practices for Fuzzing

Moritz Schloegel, Nils Bars, Nico Schiller, Lukas Bernhard, Tobias Scharnowski, Addison Crump, Arash Ale Ebrahim, Nicolai Bissantz, Marius Muench, and Thorsten Holz

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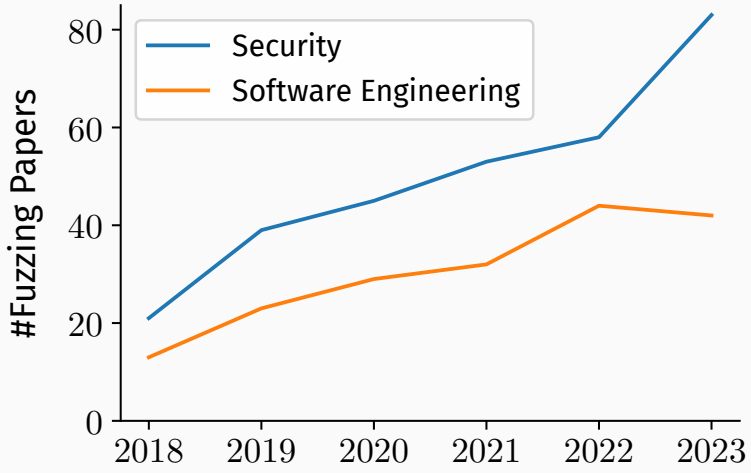
Ruhr University Bochum
University of Birmingham

Fuzzing Papers are Still Popular



Are we evaluating fuzzers right?

SoK: Prudent Evaluation Practices for Fuzzing

Moritz Schloegel[1], Nils Bars[1], Nico Schiller[1], Lukas Bernhard[1], Tobias Scharnowski[1]
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[3]*University of Birmingham, m.muench@bham.ac.uk*

***Abstract*—Fuzzing has proven to be a highly effective approach to uncover software bugs over the past decade. After AFL popularized the groundbreaking concept of lightweight coverage**

1. Introduction

Fuzzing, a portmanteau of "fuzz testing", has gained

Study reproducibility

Goals

Study reproducibility

... and other evaluation pitfalls

Approach

1. Find all fuzzing papers on 7 top-tier venues between 2018 and 2023

Approach

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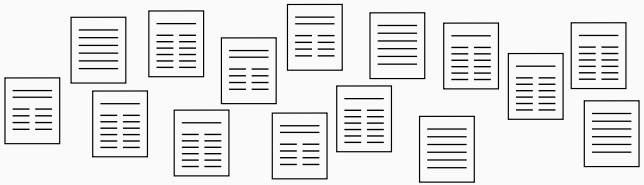

Approach

1. Find all fuzzing papers on 7 top-tier venues between 2018 and 2023
2. Literature analysis of 150 of these papers

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2. Literature analysis of 150 of these papers
3. Case studies: Reproducing experiments of 8 papers

Approach

1. Find all fuzzing papers on 7 top-tier venues between 2018 and 2023
2. Literature analysis of 150 of these papers
3. Case studies: Reproducing experiments of 8 papers
4. Update recommendations (where needed)

How to make sure fuzzing is reproducible?

Klees et al. – “Evaluating Fuzz Testing”, ACM CCS, 2018

Metzmann et al. – “FuzzBench: An Open Fuzzer Benchmarking Platform and Service”, ESEC/FSE, 2021

Böhme et al. – On the Reliability of Coverage Testing, ICSE, 2022

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Disclaimer

No intention of finger pointing!

Recommendations

1. Document setup and parameters
2. Sample relevant targets
3. Pick a good baseline
4. Choose suitable evaluation metrics
   - Code coverage
   - Bugs
5. Conduct a statistical evaluation

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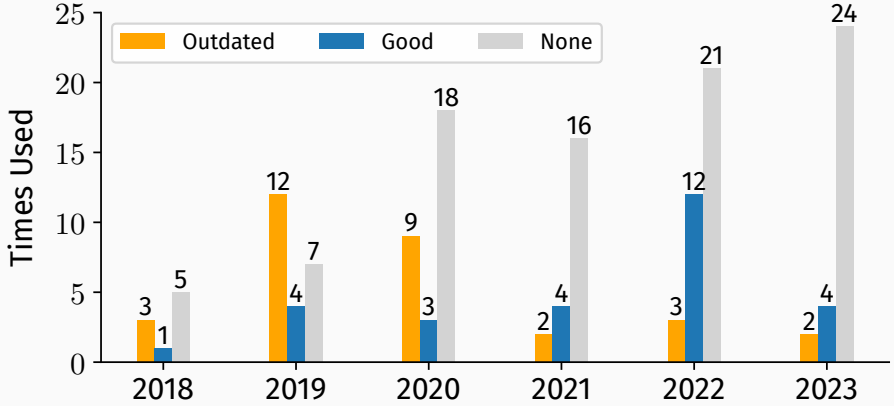
Benchmarks


Outdated
Good
None
Times Used
25
20
15
10
5
0
3
1
5
12
4
7
9
3
18
2
4
16
3
12
21
2
4
24
2018
2019
2020
2021
2022
2023

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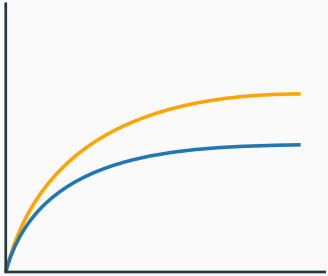
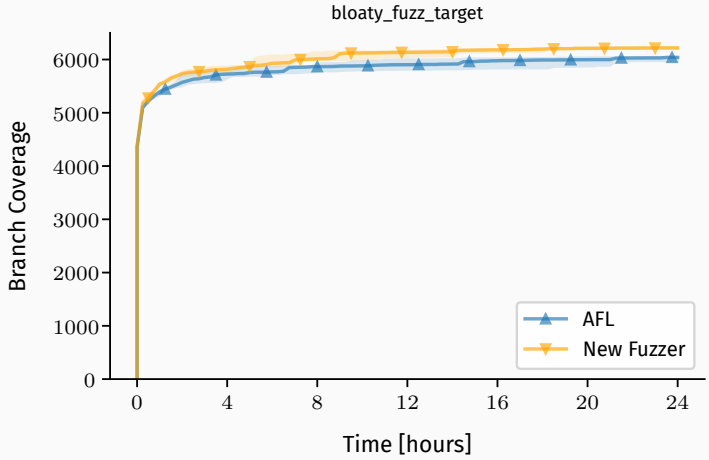


❸ Pick a Good Baseline

A new fuzzer that proposes to:

1. *Dynamically* adapt probabilities with which mutations are chosen
2. Use an *evolutionary strategy* to optimize these probabilities

❸ Pick a Good Baseline



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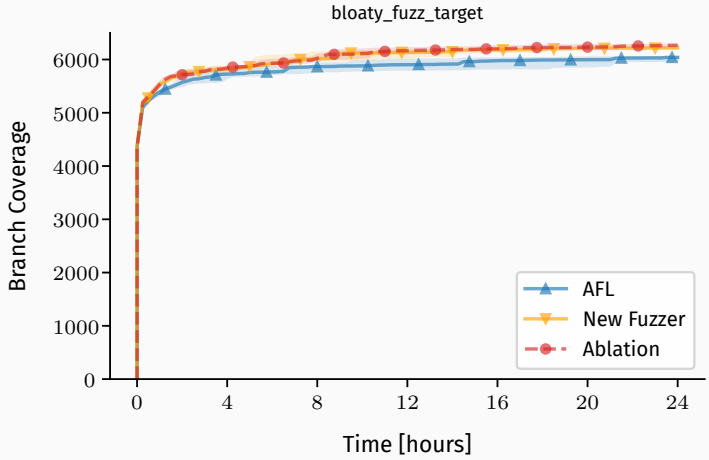

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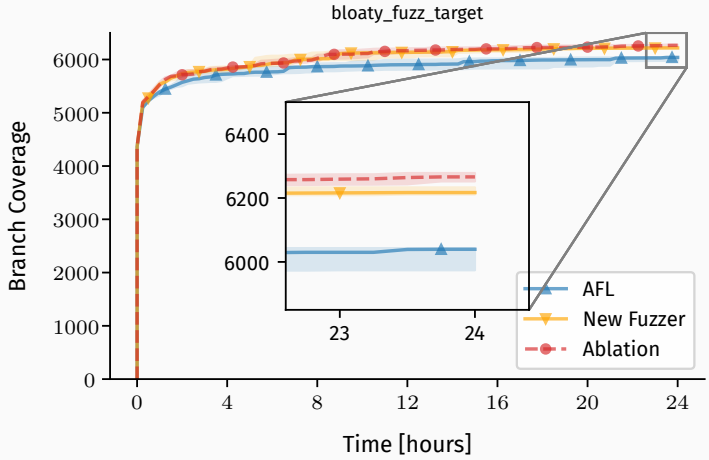

❸ Pick a Good Baseline

Lesson learned: ablation studies are important

Recommendations

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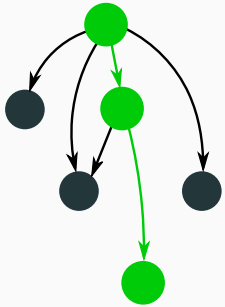
2. Sample relevant targets
3. Pick a good baseline
4. Choose suitable evaluation metrics
   - Code coverage
   - Bugs
5. Conduct a statistical evaluation

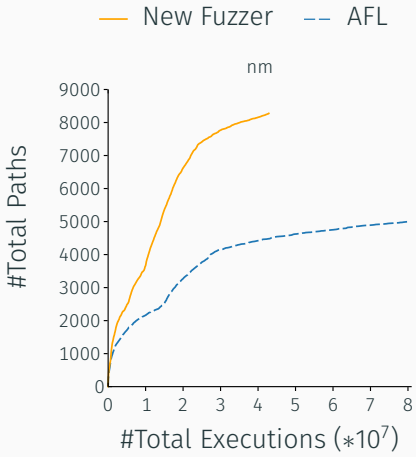


❹ Suitable Metrics: Code Coverage

New fuzzer:

- Improves input scheduling
- Aims to covers more *paths* with fewer inputs

❹ Suitable Metrics: Code Coverage



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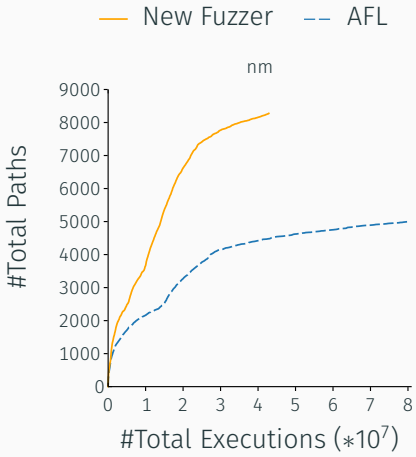
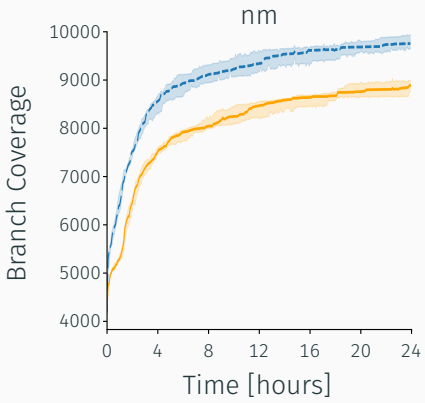




❹ Suitable Metrics: Code Coverage

Lesson learned: new metrics may mislead readers

$\Rightarrow$ include known metrics!

Recommendations

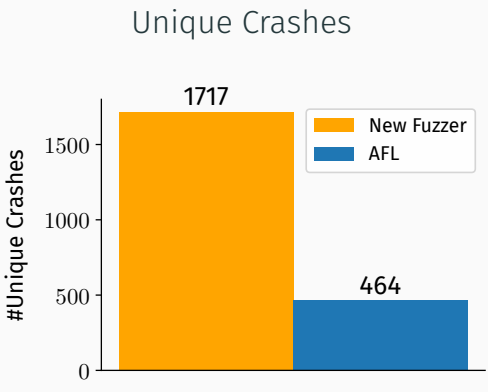
1. Document setup and parameters
2. Sample relevant targets
3. Pick a good baseline
4. **Choose suitable evaluation metrics**
   - Code coverage
   - **Bugs**
5. Conduct a statistical evaluation

❹ Suitable Metrics: Unique Crashes

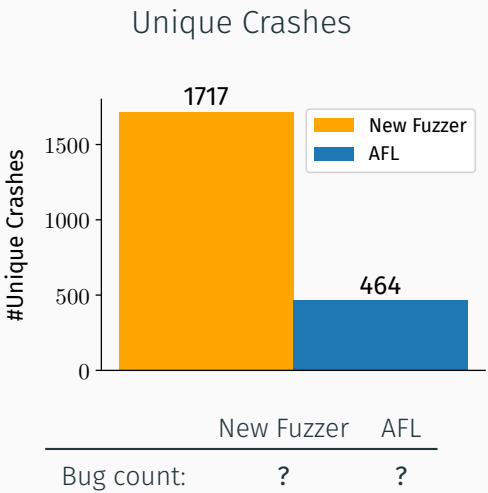
A new fuzzer that:

- Proposes memory usage as additional feedback
- Uses *unique crashes* as a metric

❹ Suitable Metrics: Unique Crashes

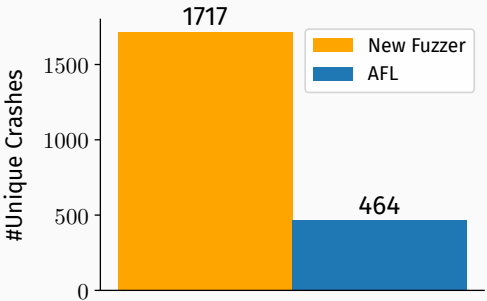


❹ Suitable Metrics: Unique Crashes

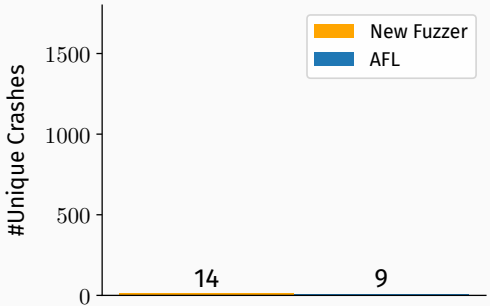


❹ Suitable Metrics: Unique Crashes

Unique Crashes

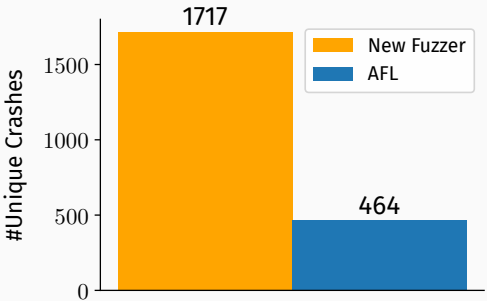


… after one patch

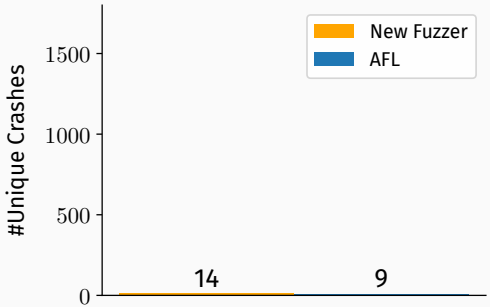


❹ Suitable Metrics: Unique Crashes

Unique Crashes



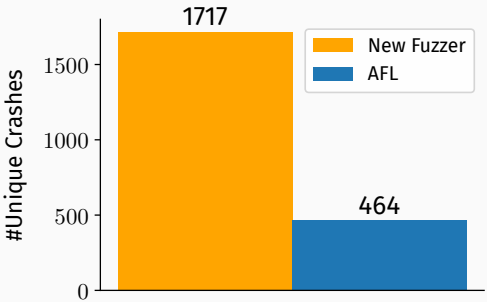
… after one patch



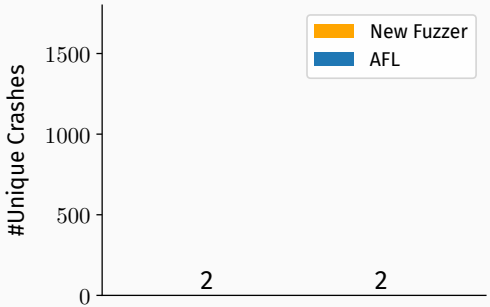
	New Fuzzer	AFL
Bug count:	1+?	1+?

❹ Suitable Metrics: Unique Crashes

Unique Crashes

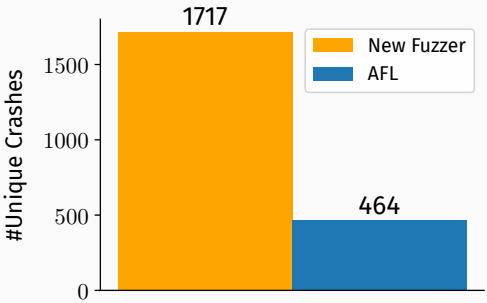


...after manual deduplication

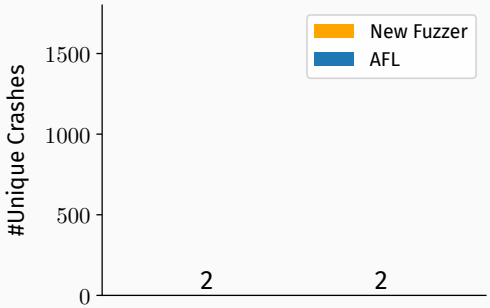


❹ Suitable Metrics: Unique Crashes

Unique Crashes



...after manual deduplication



	New Fuzzer	AFL
Bug count:	2	2

❹ Suitable Metrics: Unique Crashes

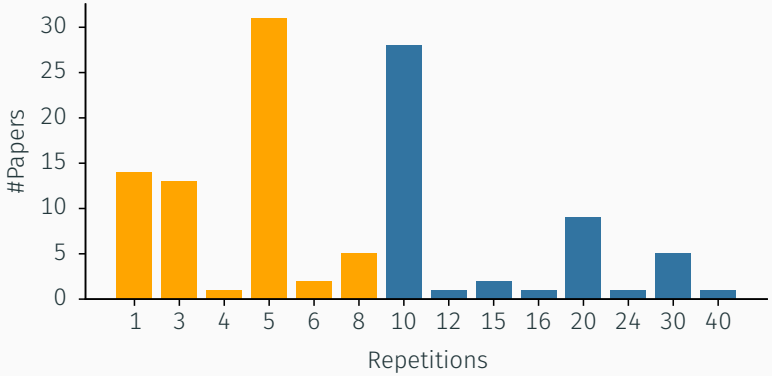
Lesson learned: “unique” crashes $\neq$ actual bugs

$\Rightarrow$ need deduplication or should use actual bugs

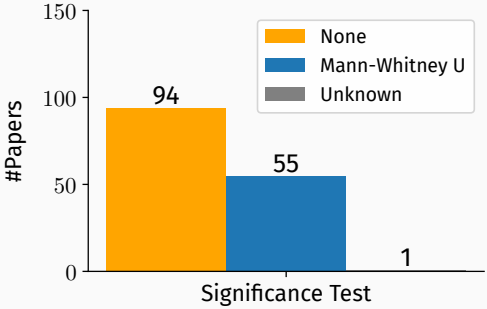
Recommendations

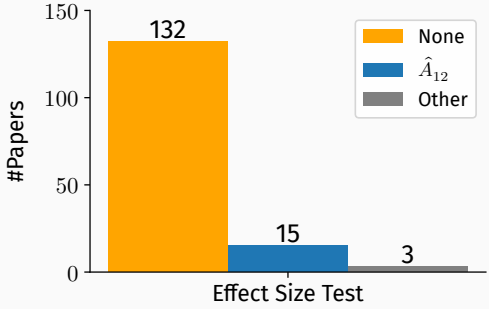
1. Document setup and parameters
2. Sample relevant targets
3. Pick a good baseline
4. Choose suitable evaluation metrics
   - Code coverage
   - Bugs
5. **Conduct a statistical evaluation**

❺ Statistically evaluate results



❺ Statistically evaluate results





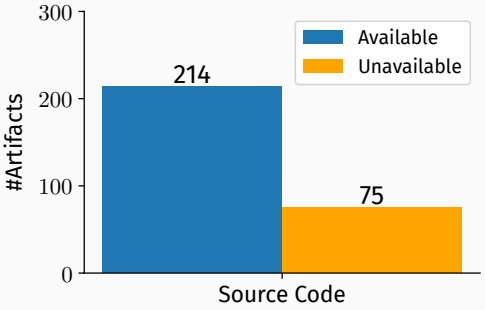
Recommendations

There's more beyond the evaluation itself:

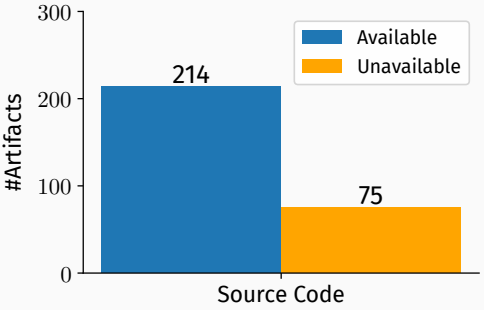
- What about the fuzzer source code?
- What about new bugs found during the evaluation?

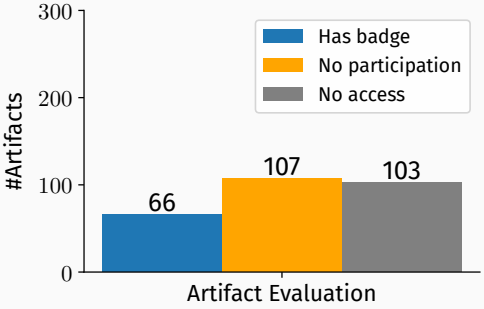
Beyond the paper: artifact availability

Artifact Availability



Artifact Availability





Artifact Availability

Good: much code is openly available!

BUT: low artifact evaluation participation

Recommendations

There's more beyond the evaluation itself:

- What about the fuzzer source code?
- **What about new bugs found during the evaluation?**

What happens to found bugs?

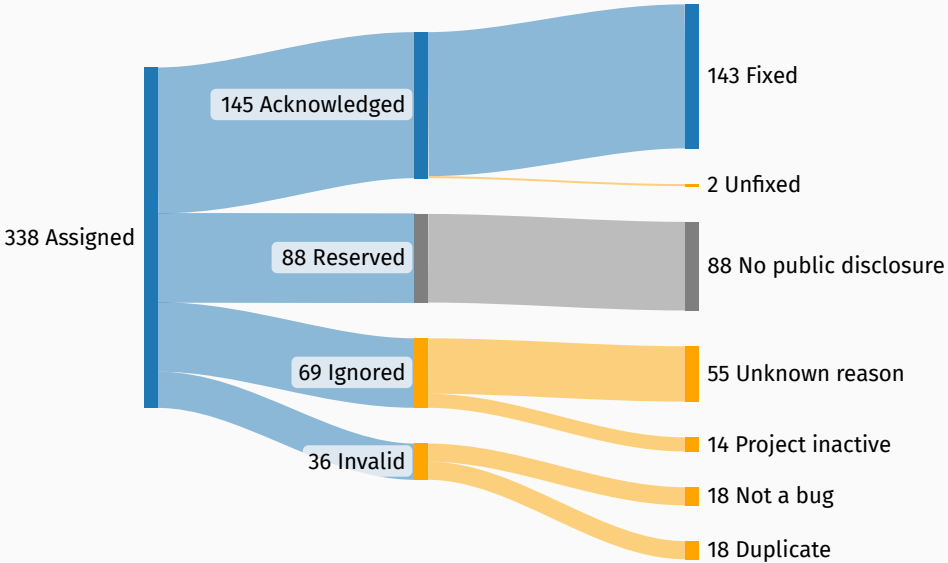
What happens to found bugs?

$\Rightarrow$ Responsible disclosure?

Approach

❶ Look for CVEs in fuzzing papers

❷ Check their outcome


338 Assigned
145 Acknowledged
88 Reserved
69 Ignored
36 Invalid
143 Fixed
2 Unfixed
88 No public disclosure
55 Unknown reason
14 Project inactive
18 Not a bug
18 Duplicate

Misaligned incentives

Misaligned incentives & no verification

Misaligned incentives & no verification

$\Rightarrow$ Easy to game the system

Recommendations

❶ Document setup and parameters

❷ Sample relevant targets

❸ Pick a good baseline

❹ Choose suitable evaluation metrics
- Code coverage
- Bugs

❺ Conduct a statistical evaluation

\+ Artifact availability

\+ CVE misuse

$\Rightarrow$ guidelines

Guidelines on GitHub

README

Fuzzing Evaluation Guidelines

Current version: 1.0.3

Proposals for changes welcome (please open an issue for discussion or a pull request for changes).

DISCLAIMER: These items represent are a best-effort attempt at capturing action items to follow during the evaluation of a scientific paper that focuses on fuzzing. **They do not apply universally to all fuzzing methods - in certain scenarios, techniques may wish to deviate for good reason from these guidelines. In any case, a case-by-case judgment is necessary.** The guidelines do not discuss many malicious choices that immediately negate any chance of a fair evaluation, such as giving your fuzzer an unfair advantage (e.g., by fine-tuning the fuzzer or its targets) or putting other fuzzers at a disadvantage.

A. Preparation for Evaluation

1. Find relevant tools and baselines to compare against
    - 1.1 Include state-of-the-art techniques from both academia and industry
    - 1.2 If your fuzzer is based on an existing fuzzer, include the baseline (to measure the delta of your changes, which allows attributing improvements to your technique)
    - 1.3 Use recent versions of fuzzers
    - 1.4 If applicable, derive a baseline variant of your technique that replaces core contributions by alternatives. For example, consider using a variant that replaces an informed algorithm with randomness.

Summary

1. Fuzzing evaluations are hard to get right
2. Join artifact evaluation
3. Help us shape the guidelines

Paper

Guidelines