UNIFUZZ: A Holistic and Pragmatic Metrics-Driven Platform for Evaluating Fuzzers

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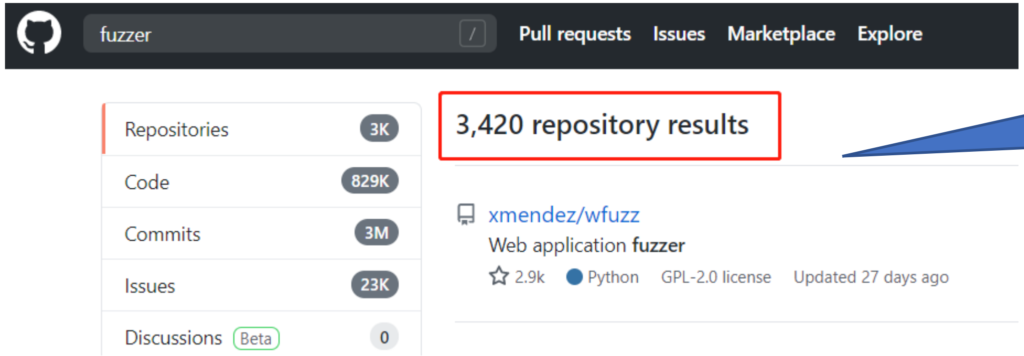
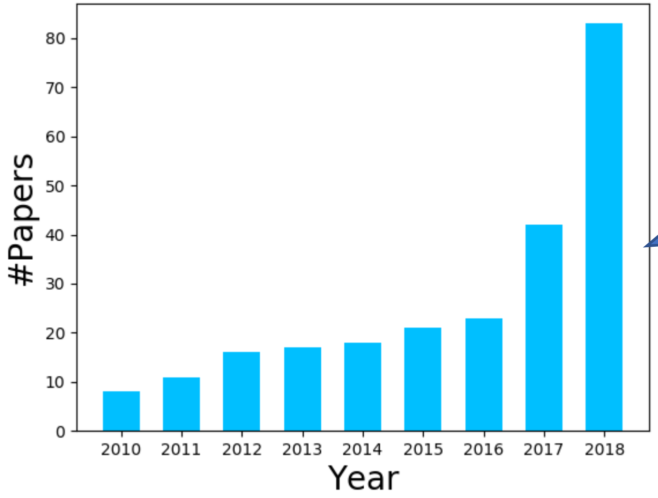
Fuzzing： a vulnerability detection technique

➢ **A plethora of fuzzing works have emerged in both industry and academia.**



GitHub has over 3,000 fuzzing related repos.



Dblp, a famous computer science bibliography website, contains more than 200 fuzzing related papers since 2010.

Open questions about fuzzing technique

- **How do these fuzzers perform in practice?**
- **How to compare different fuzzers under a fair and comprehensive set of performance metrics?**
- **Which fuzzing primitives or techniques are promising and should be promoted?**

The previous works cannot answer these questions

- **Many existing works do not conduct appropriate and sufficient experiments to provide trustworthy results.**
  - Insufficient repetitions, not using statistical test
  - Inconsistency of environments

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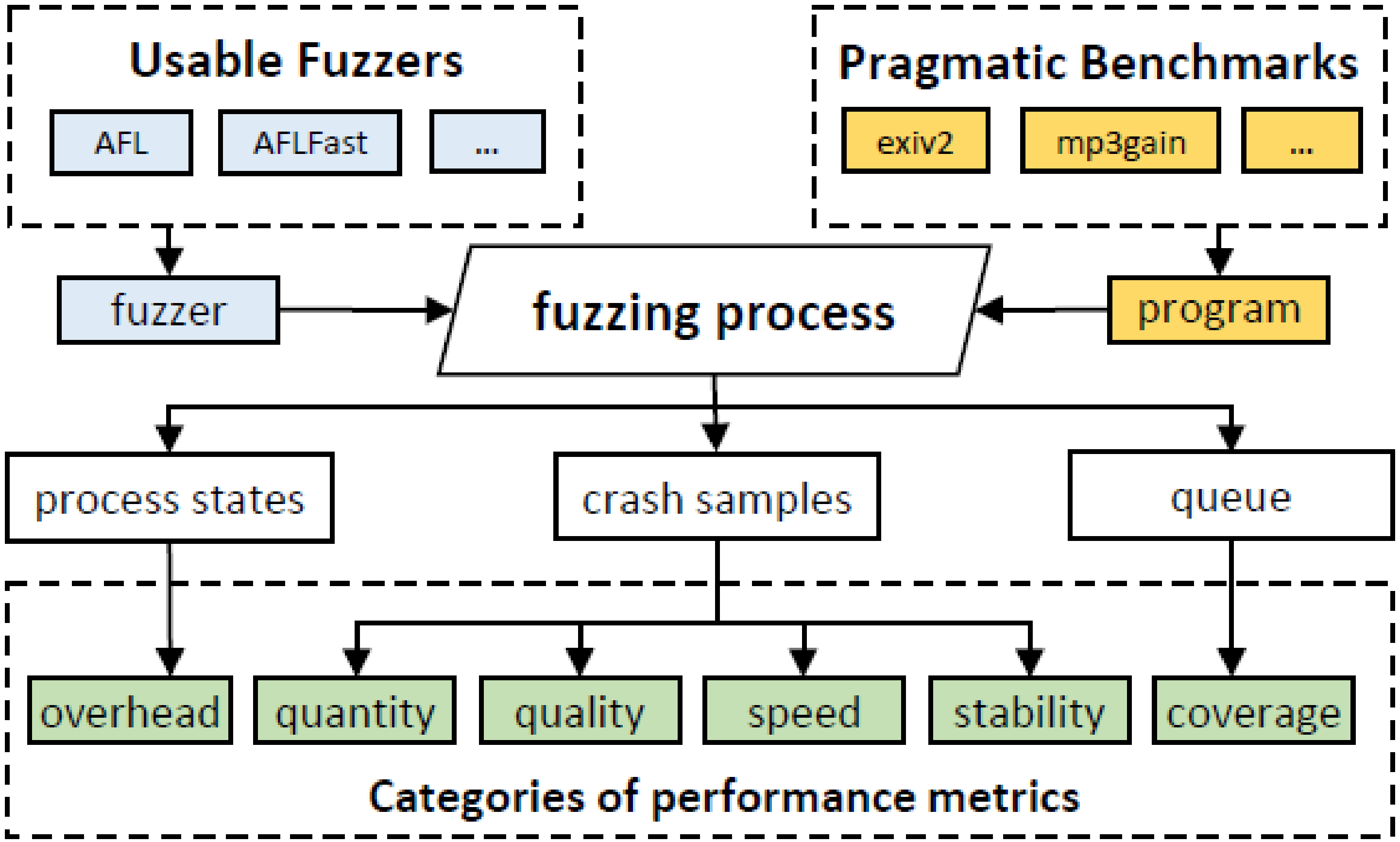
- **Many existing works do not conduct appropriate and sufficient experiments to provide trustworthy results.**
  - Insufficient repetitions, not using statistical test
  - Inconsistency of environments
- **The evaluations of the existing fuzzers are often biased due to the lack of uniform benchmarks.**
  - The choice varies widely.
- **The existing metrics may not be suitable nor comprehensive for evaluating fuzzers.**
  - Never consider “overhead”

Challenges for conducting comprehensive evaluations

- **Challenge1: usability issues of the existing fuzzers**
- **Challenge2: lack of pragmatic real-world benchmarks**
- **Challenge3: lack of proper and comprehensive performance metrics**

Our Solution

UNIFUZZ: a holistic and pragmatic metrics-driven platform for evaluating fuzzers



Overview of UNIFUZZ

Usable fuzzers

Table 7: The fuzzers incorporated in UNIFUZZ.

Fuzzer	Mutation/Generation	Directed/Coverage	Target
AFL [70]	M	C	S/B [1]
AFLFast [29]	M	C	S/B
AFLGo [28]	M	D	S
AFLPIN [7]	M	C	B
AFLSmart [59]	M	C	S/B
Angora [30]	M	C	S/B
CodeAlchemist [39]	G	n.a.	B
Driller [64]	M	C	B
Domato [34]	G	n.a.	B
Dharma [11]	G	n.a.	B
Eclipser [32]	M	C	S
FairFuzz [45]	M	C	S
Fuzzilli [19]	M	C	S
Grammarinator [41]	G	n.a.	B
Honggfuzz [36]	M	C	S
Jsfuzz [23]	M	C	S
jsfunfuzz [22]	G	n.a.	B
LearnAFL [68]	M	C	S
MoonLight [40]	n.a.	n.a.	n.a.
MOPT [48]	M	C	S/B
NAUTILUS [27]	G+M	C	S
NEUZZ [62]	M	C	S
NEZHA [57]	M	C	L [2]
Orthrus [61]	n.a.	n.a.	n.a.
Peach [12]	G	n.a.	B
PTfuzz [71]	M	C	S
QSYM [69]	M	C	B
QuickFuzz [38]	G+M	n.a.	B
radamsa [13]	M	C	B
slowfuzz [58]	M	n.a.	L
Superion [66]	G+M	C	S
T-Fuzz [56]	M	C	S
VUzzer [60]	M	C	B
VUzzer64 [60]	M	C	B
zzuf [43]	M	n.a.	B

[1] S: source code, B: binary.
[2] L: user needs to write libFuzzer code.

- **We conducted large-scale tests on the usability of the existing fuzzers.**
  - **15+ serious flaws**
  - **35+ usable fuzzers**
    - **Dockerfile**
    - **Detailed documents**

Pragmatic benchmark suite

Type	Program	Version	Arguments
Image	exiv2	0.26	@@
	gdk-pixbuf-pixdata (gdk)	gdk-pixbuf 2.31.1	@@ /dev/null
	imginfo	jasper 2.0.12	-f @@
	jhead	3.00	@@
	tiffsplit	libtiff 3.9.7	@@
Audio	lame	lame 3.99.5	@@ /dev/null
	mp3gain	1.5.2-r2	@@
	wav2swf	swftools 0.9.2	-o /dev/null @@
Video	ffmpeg	4.0.1	(-y -i @@ -c:v \ mpeg4 -c:a copy -f \ mp4 /dev/null)
	flvmeta	1.2.1	@@
	mp42aac	Bento4 1.5.1-628	@@ /dev/null
Text	cflow	1.6	@@
	infotocap	ncurses 6.1	-o /dev/null @@
	jq	1.5	. @@
	mujs	1.0.2	@@
	pdftotext	xpdf 4.00	@@ /dev/null
	sqlite3	3.8.9	(stdin)
Binary	nm	binutils 5279478	(-A -a -l -S -s \ --special-syms \ --synthetic \ --with-symbol-versions \ -D @@)
	objdump	binutils 2.28	-S @@
Network	tcpdump	4.8.1 + libpcap 1.8.1	-e -vv -nr @@

- **20 real-world benchmark programs**
  - 6 functionality types
  - 12+ vulnerability types
- **convenient offline results analysis**
  - bug triage
  - severity analysis
  - CVE matching

Comprehensive performance metrics

Six categories of performance metrics

- Quantity of unique bugs
  - Statistical test
- Quality of the bugs
  - Severity of the bugs, rareness of the bugs
- Speed of finding the bugs
- Stability of finding the bugs
- Coverage
- Overhead

Evaluations

Large-scale evaluations of the state-of-the-art fuzzers

- We conducted large-scale evaluations on the state-of-the-art fuzzers.
  - 8 state-of-the-art fuzzers: AFL, AFLFast, Angora, Honggfuzz, MOPT, QSYM, T-Fuzz, VUzzer64.
  - large-scale: 200,000+ CPU hours
  - 6 categories of performance metrics

Summary of interesting findings

- **No fuzzer outperformed the others among all the benchmark programs.**
  - Fuzzers may have preference over some specific programs.
- **The synthetic benchmark programs may not be able to reflect a fuzzer's performance on the real-world programs.**
- **A single metric may lead to unilateral conclusions.**
- **More factors can affect the fuzzing evaluation results than what we thought.**

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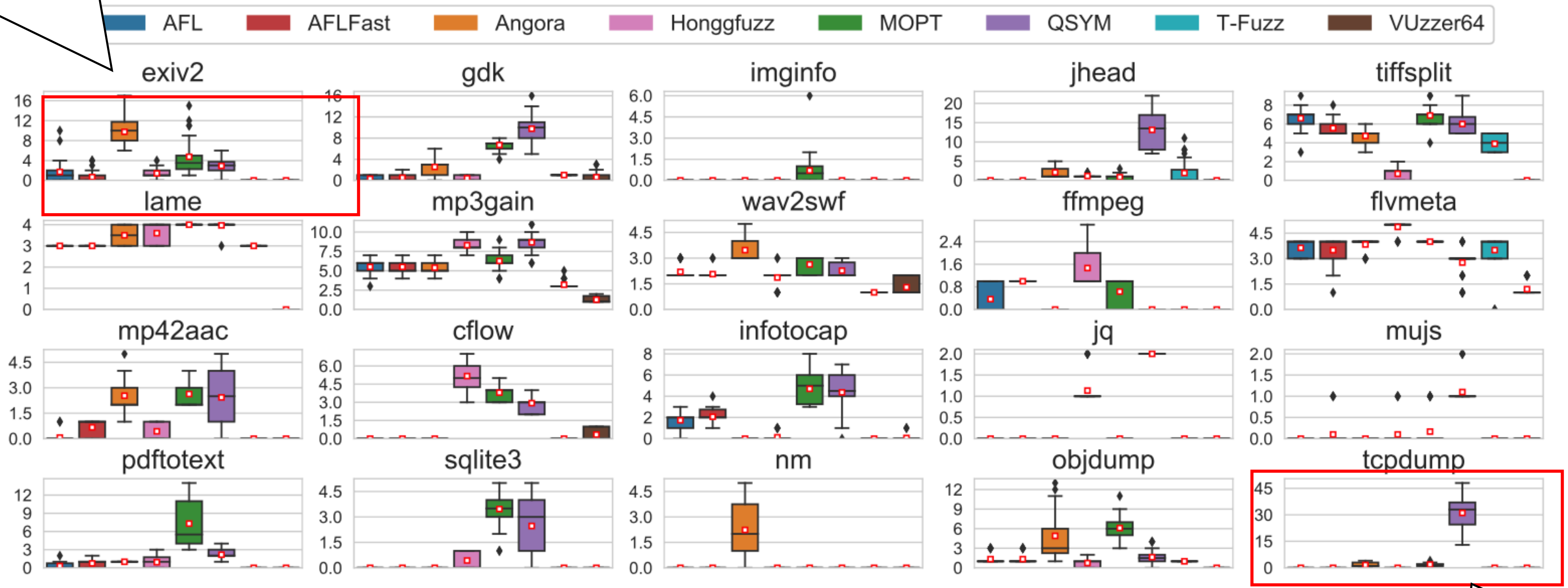
Angora performed the best on *exiv2*.



QSYM performed the best on *tcpdump*.

The number of unique bugs found by each fuzzers.

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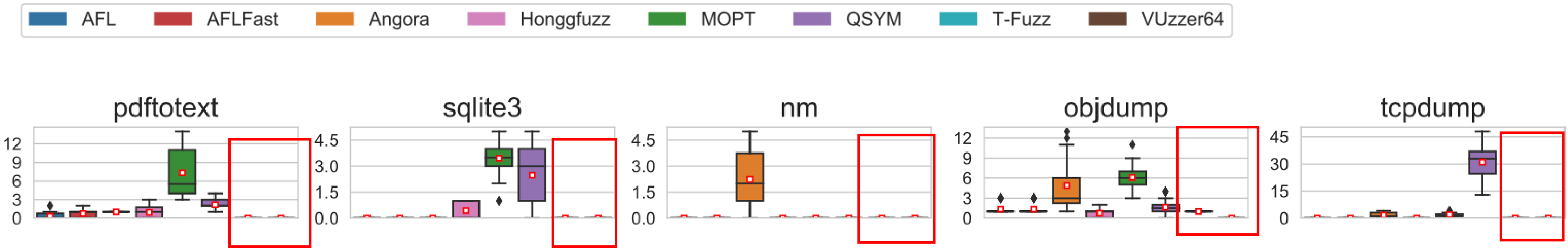
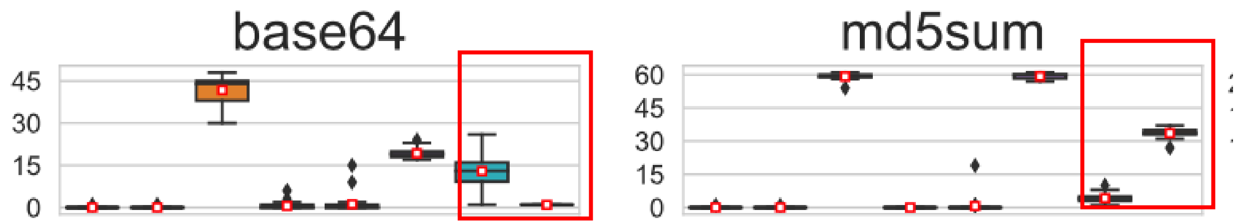
Synthetic benchmark VS. Real-world benchmark



The #unique bugs on the real-world programs.



The #unique bugs on the synthetic programs (LAVA-M).

T-Fuzz and VUzzer64 had better performance on the synthetic benchmark programs than on the real-world benchmark programs.

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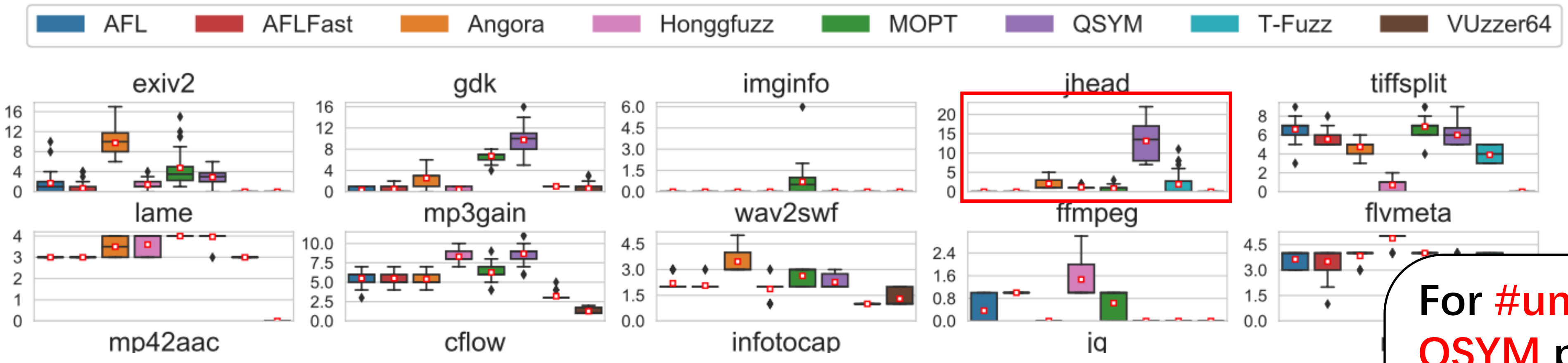
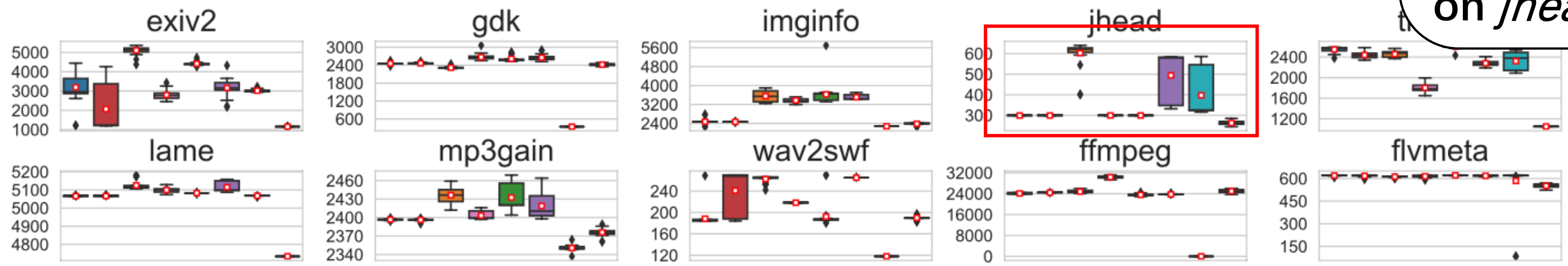


The #unique bugs

For #unique bugs metric, QSYM performed the best on *jhead*.
For #line coverage metric, Angora performed the best on *jhead*.



The #line coverage

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Factor1: instrumentation methods

- **Fuzzers usually have different instrumentation methods.**
  - Compile-time instrumentation, e.g., AFL, Angora.
  - Dynamic binary instrumentation., e.g., VUzzer.
- **Thus, the same tested benchmark program are compiled into different binaries!**
- **We found that Angora cannot find some bugs on the program *infotocap* due to its instrumentation method, not its capability in finding bugs.**

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Using *cross validation* when analyzing the crash samples, e.g., re-executing the crash samples with different complied binaries to check whether these crash samples can be reproduced on all the binaries.

Factor2: crash analysis tools

➢ **Different crash analysis tools are used in validating the bugs triggered by the crash samples.**

Using different analysis tools may lead to different evaluation results, e.g., #unique bugs.

Table 13: Validated crash samples by different tools.

Bug Type	Number	Rate
Neither ASAN or GDB can validate	40,122	12.2%
Only GDB can validate	47,910	14.5%
Only ASAN can validate	40,267	12.2%
Both ASAN and GDB can validate	201,558	61.1%
Total	329,857	100%

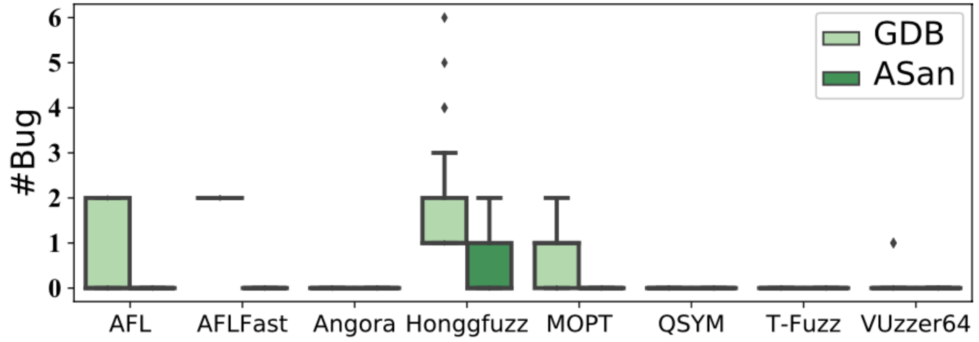

Figure 11: The number of unique bugs discovered on `ffmpeg` with GDB and ASan.

When using ASAN to validate the crashes, the result is that only Honggfuzz can discover bugs.

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Using multiple analysis tools may mitigate these biases!

Table 13:

Bug Type		
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Conclusion

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- We proposed and implemented UNIFUZZ, a holistic, and pragmatic metrics-driven platform for evaluating fuzzers in a comprehensive and fair manner.
- UNIFUZZ has incorporated 35 usable fuzzers, 20 real-world benchmark programs and 6 categories of performance metrics.
- We conducted extensive evaluations on the 8 state-of-the-art fuzzers and got many interesting findings.
- We have open sourced UNIFUZZ to facilitate the future fuzzing research and welcome the community contributions.

Q&A

https://github.com/unifuzz/overview