code intelligence

Fuzzing Java with Jazzer

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code intelligence

Background

- Mathematician by education
- OSS contributor (Bazel, Chromium, Android Password Store)

Responsibilities at Code Intelligence

- Fuzzing Technologies
- OSS Initiatives & Cooperations

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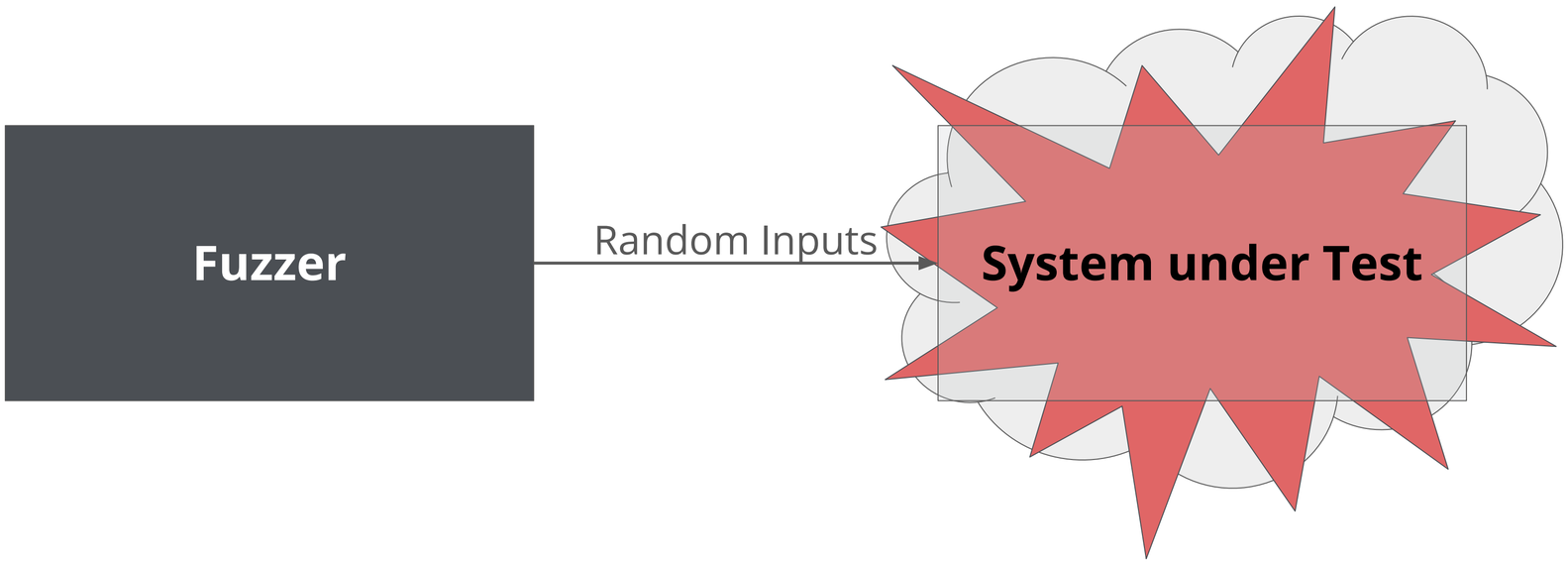
What is Fuzzing?

fuzz | verb.

/ˈfəz/

1. to make or become blurred



Blackbox Fuzzing

Whitebox Fuzzing

covered branches, magic bytes, compared values

```
private static final int[] MAGIC_NUMBERS_GIF = { 0x47, 0x49, };
private static final int[] MAGIC_NUMBERS_JPEG = { 0xff, 0xd8, };

//...
if (compareBytePair(MAGIC_NUMBERS_GIF, input)) {
    return ImageFormats.GIF;
} else if (compareBytePair(MAGIC_NUMBERS_JPEG, bytePair)) {
    return ImageFormats.JPEG;
}
return ImageFormats.UNKNOWN
//...
```

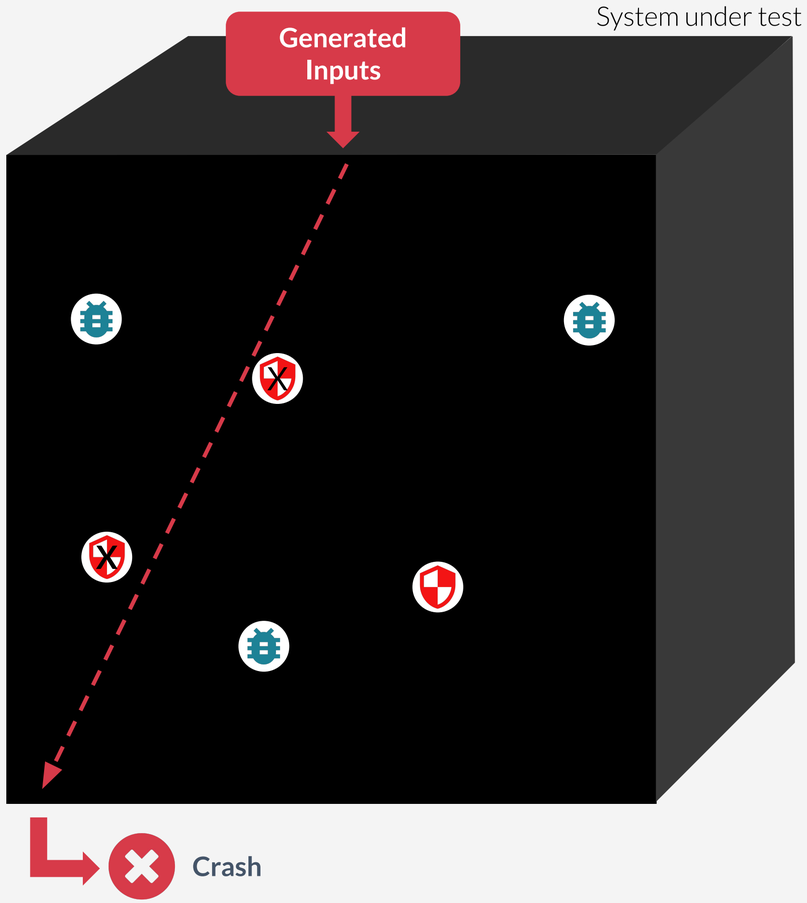
Black-box vs Coverage-guided Fuzzing

Vulnerabilities

Bugs

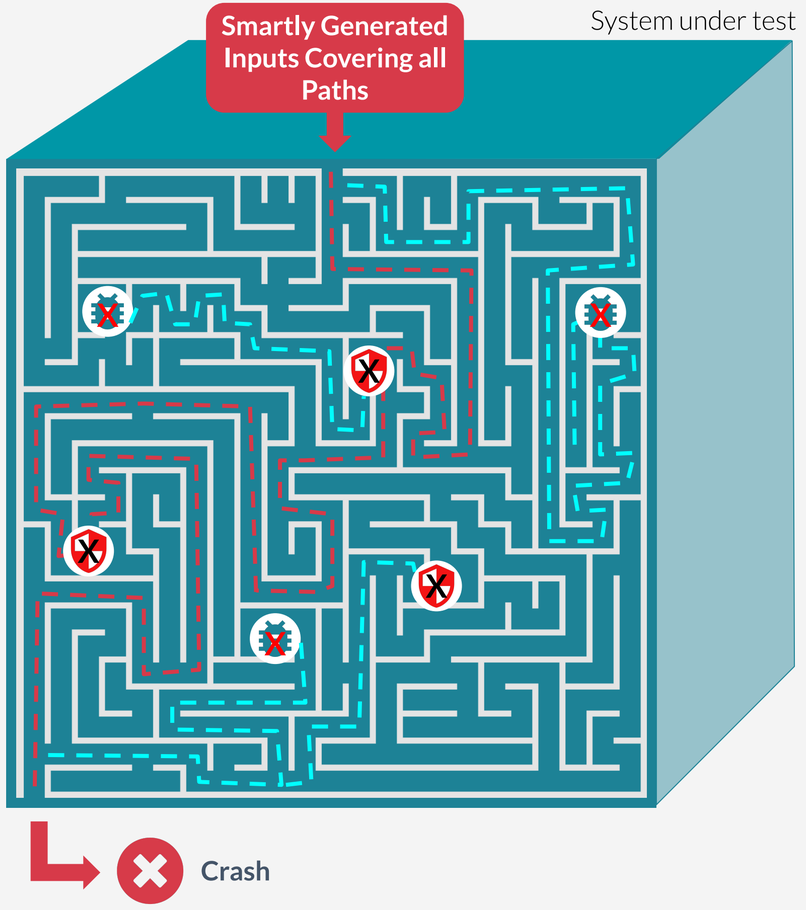
Black-box Fuzzing

- No knowledge of which code is reached
- Misses critical bugs

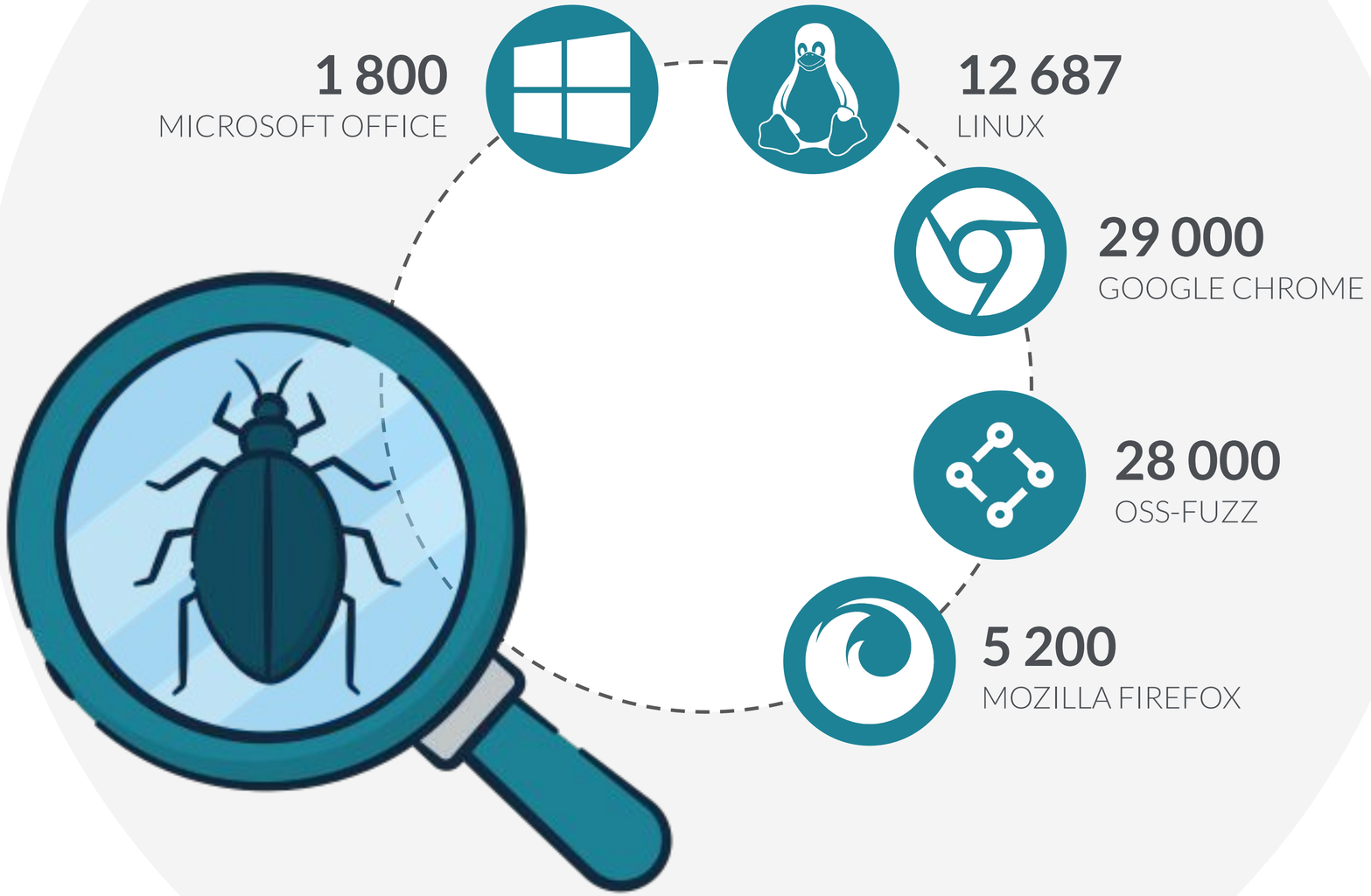


Coverage-guided Fuzzing

- Intelligent & feedback-driven mutations
- Maximizes code coverage



What's all the Fuzz About?



Finding Heartbleed

This tutorial will show you how to find Heartbleed using libFuzzer and ClusterFuzz.

50 CVEs in 50 Days: Fuzzing Adobe Reader

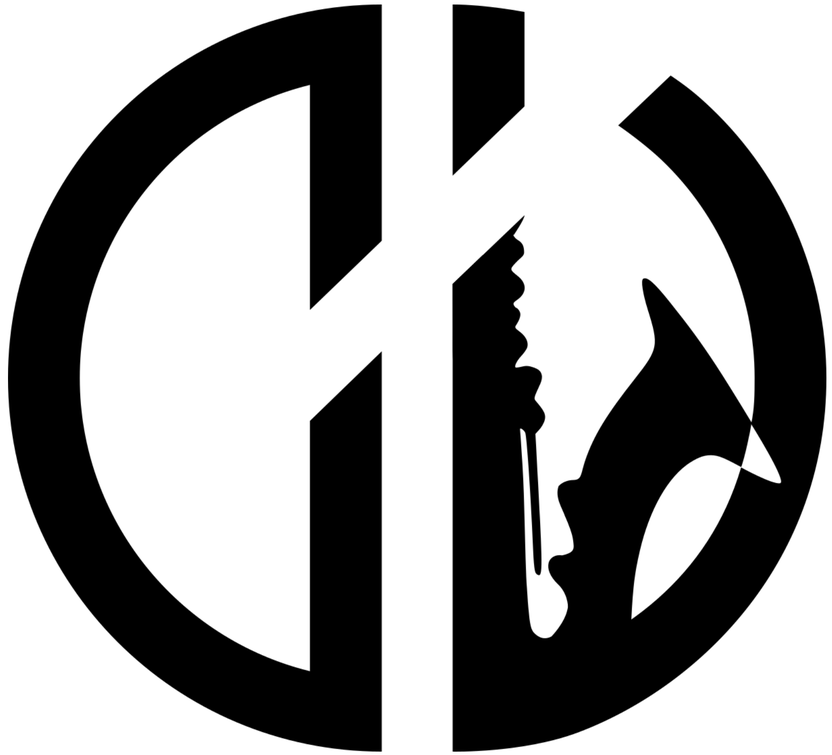
December 12, 2018

Research By: Yoav Alon, Netanel Ben-Simon

Jazzer — Modern Fuzzing for the JVM

- Coverage-guided: based on libFuzzer & JaCoCo
- No sources required: agent-based instrumentation
- Collects dynamic data from comparisons & common functions
- Open-source since Feb 2021

github.com/CodeIntelligenceTesting/jazzer



Jazzer — Modern Fuzzing for the JVM

Jazzer is available on/with:

- Linux (x64)
- macOS (x64 + aarch64)
- Windows (x64)
- Docker Hub (cifuzz/jazzer & cifuzz/jazzer-autofuzz)
- Bazel (rules_fuzzing)

Why Fuzz Memory-Safe Languages?

Usually functional bugs:

- Uncaught exceptions
- Assertions
- Inconsistent implementations (*differential fuzzing*)

Usually security issues:

- Infinite loops
- OutOfMemoryError
- Remote Code Execution
- Injections into Domain Specific Languages (SQL, EL, Scripts, …)
- …

Getting Started with Autofuzz

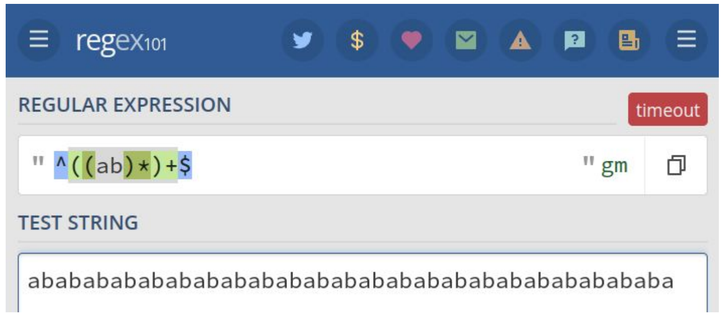
```
docker run \
    -v $(pwd):/fuzzing \
    -it cifuzz/jazzer-autofuzz \
    org.jsoup:jsoup:1.14.1 \
    "org.jsoup.Jsoup::parse(java.lang.String)"
```

Optional arguments:

```
    --keep_going=N          # Stop after N findings
    --autofuzz_ignore=some.Exception,some.other.Exception
```

Evil Regular Expressions

Even short regular expressions can consume exponential resources during *matching*:



Q: Are there regular expressions that consume exponential resources during *compilation*?

Fuzzing the Java Standard Library

```
docker run \
    -v $(pwd):/fuzzing \
    -it cifuzz/jazzer \
    --autofuzz=java.util.regex.Pattern::compile \
    --autofuzz_ignore=java.lang.Exception \
    --instrumentation_includes=java.util.regex.**
```

Writing Fuzz Targets with Jazzer

1. Add a dependency on com.code-intelligence:jazzer-api.
2. Create a class with a `public static void fuzzerTestOneInput(...)` method
   a. receiving a `byte[]` with raw fuzzer input or
   b. receiving a `FuzzedDataProvider` instance
3. Compile and package as a (deploy) jar.

java.lang.String	**consumeRemainingAsString**()	Consumes the remaining fuzzer input as a String.
short	**consumeShort**()	Consumes a short from the fuzzer input.
short	**consumeShort**(short min, short max)	Consumes a short between min and max from the fuzzer input.
short[]	**consumeShorts**(int maxLength)	Consumes a short array from the fuzzer input.
java.lang.String	**consumeString**(int maxLength)	Consumes a String from the fuzzer input.
default boolean	**pickValue**(boolean[] array)	Picks an element from array based on the fuzzer input.
default byte	**pickValue**(byte[] array)	Picks an element from array based on the fuzzer input.

Running Fuzz Targets with Jazzer

```
docker run \
    -v $(pwd):/fuzzing \ # Should contain the jars.
    -it cifuzz/jazzer \
    --cp=project.jar:fuzzers.jar \
    --target_class=com.example.ExampleFuzzTarget
```

(or download/build release binaries and run them directly)

Property-Based Fuzzing

json-sanitizer build passing

Given JSON-like content, The JSON Sanitizer converts it to valid JSON.

Output

The output is well-formed JSON as defined by RFC 4627. The output satisfies these additional properties:

- The output will not contain the substrings (case-insensitively) `"<script"`, `"</script"` or `"<!--"` and can thus be embedded inside an HTML script element without further encoding.

```
<script>
  const config = {"foo": true, "bar": [1, 2]};
  doThings(config);
</script>
```

Property-Based Fuzzing

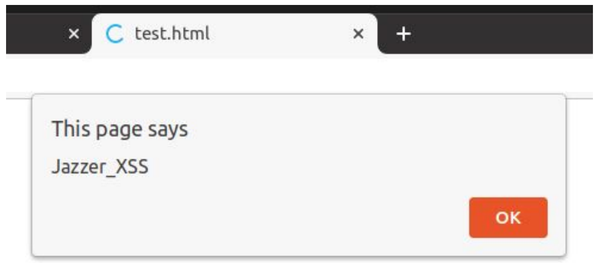
```
public static void fuzzerTestOneInput(FuzzedDataProvider data) {

    String input = data.consumeRemainingAsString();
    String output = JsonSanitizer.sanitize(input);

    assert !output.contains("</script>");
}
```

Property-Based Fuzzing

```
b</\script><\script>alert(`Jazzer_XSS`);//
```

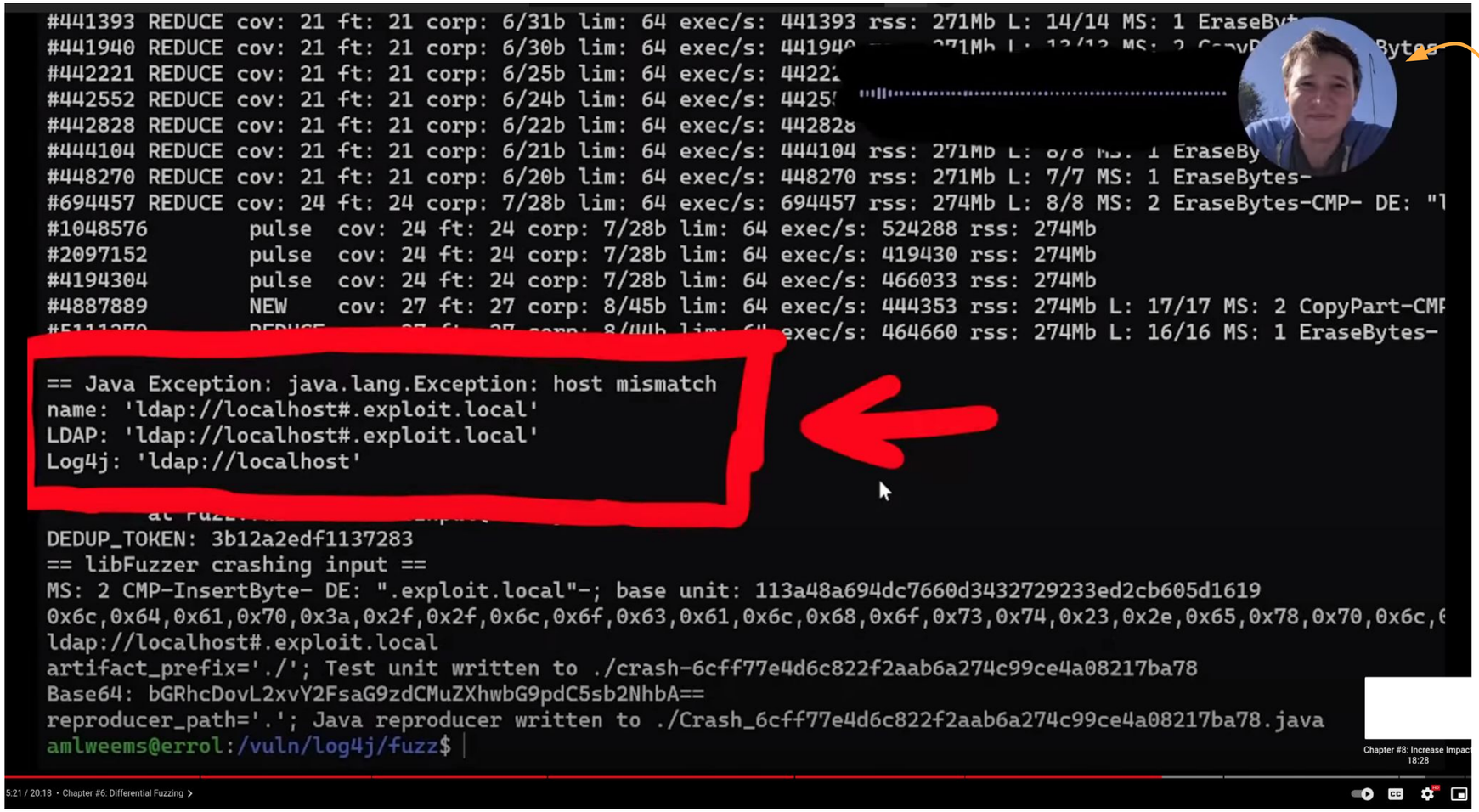
JsonSanitizer

```
<script>
  const config = "b</script><script>alert(`Jazzer_XSS`);//";
  doThings(config);
</script>
```



CVE-2021-23899: XSS in OWASP JsonSanitizer (+ multiple crashes)

Property-Based Fuzzing



Anthony Weems (@amlweems)

Fuzzing Java to Find Log4j Vulnerability - CVE-2021-45046

46,449 views • Feb 1, 2022

LiveOverflow

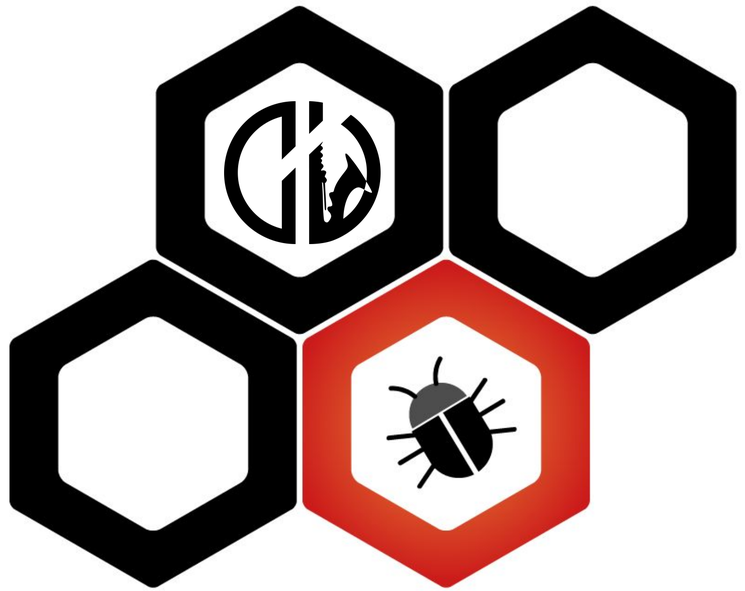
717K subscribers

youtube.com/watch?v=kvREvOvSWt4

OSS-Fuzz – Large-Scale (Java) Fuzzing

OSS-Fuzz is Google's fuzzing initiative for open-source software (est. 2016).

Jazzer has been available on OSS-Fuzz since March 2021.



Current stats:

- **23** Java projects
  - including: jsoup, Jackson, zxing, protobuf-java, …
- **>500** bugs found
- **>50** issues with security impact
- **13** CVEs for released security-critical bugs

"Long-tail" findings

A potential Denial of Service issue in protobuf-java

High **perezd** published **GHSA-wrvw-hg22-4m67** on Jan 6 (~6 months after OSS-Fuzz started fuzzing the project)

Package	Affected versions	Patched versions
com.google.protobuf:protobuf-java (Maven)	**< 3.19.2**	**3.16.1, 3.18.2, 3.19.2**
com.google.protobuf:protobuf-kotlin (Maven)	**< 3.19.2**	**3.18.2, 3.19.2**
google-protobuf (RubyGems)	**< 3.19.2**	**3.19.2**

Description

Summary

A potential Denial of Service issue in protobuf-java was discovered in the parsing procedure for binary data.

Reporter: OSS-Fuzz

Affected versions: All versions of Java Protobufs (including Kotlin and JRuby) prior to the versions listed below. Protobuf "javalite" users (typically Android) are not affected.

Severity

CVE-2021-22569 **High** - CVSS Score: 7.5, An implementation weakness in how unknown fields are parsed in Java. A small (~800 KB) malicious payload can occupy the parser for several minutes by creating large numbers of short-lived objects that cause frequent, repeated GC pauses.

Bug Detectors – Fuzzing Beyond DoS

Concept:

- Fuzzing is already good at dynamically exploring code and program state.
- Thus, all it takes to find vulnerabilities is to *detect them when they happen*.

Precedent:

- AddressSanitizer (ASan)
  - Detects memory correctness issues in native code (e.g., out-of-bounds array reads/writes).
- ThreadSanitizer (TSan)
  - Detects data races in multi-threaded code (used by Go, experimental JVM support).

Q: Can we build similar bug detectors for common classes of Java vulnerabilities?

Bug Detectors – Fuzzing Beyond DoS

Implemented:

- reflective calls
- insecure deserialization
- Expression Language (EL) injection
- LDAP injection
- OS command injection (arguments aren't considered yet)
- regex injection
- JNDI source injection

Extending this list is an ongoing project with Google's OSS-Fuzz team.

Reproducing "Log4Shell" with Jazzer

Disclaimer:

- Hindsight is 20/20.
- Required improvements to `Map.get()` instrumentation and a bug detector for JNDI lookups.
- Only finds the vulnerability when fuzzing log4j itself.

```
public class Log4jFuzzer {
  private static final Logger log = LogManager.getLogger(Log4jFuzzer.class.getName());
  public static void fuzzerTestOneInput(FuzzedDataProvider data) {
    log.error(data.consumeRemainingAsString());
  }
  // + boilerplate to speed up log.error calls
}
```

Reproducing "Log4Shell" with Jazzer

```
#9801    REDUCE cov: 3372 ft: 4958 corp: 362/16Kb lim: 65 exec/s: 2450 rss: 1090Mb L: 55/65 MS: 2 ChangeByte-EraseBytes-

== Java Exception: com.code_intelligence.jazzer.api.FuzzerSecurityIssueCritical: Remote JNDI Lookup
JNDI lookups with attacker-controlled remote URLs can, depending on the JDK
version, lead to remote code execution or the exfiltration of information.
    at com.code_intelligence.jazzer.sanitizers.NamingContextLookup.lookupHook(NamingContextLookup.kt:55)
    at org.apache.logging.log4j.core.net.JndiManager.lookup(JndiManager.java:172)
    at org.apache.logging.log4j.core.lookup.JndiLookup.lookup(JndiLookup.java:56)
    at org.apache.logging.log4j.core.lookup.Interpolator.lookup(Interpolator.java:221)
    at org.apache.logging.log4j.core.lookup.StrSubstitutor.resolveVariable(StrSubstitutor.java:1110)
    at org.apache.logging.log4j.core.lookup.StrSubstitutor.substitute(StrSubstitutor.java:1033)
    at org.apache.logging.log4j.core.lookup.StrSubstitutor.substitute(StrSubstitutor.java:912)
    at org.apache.logging.log4j.core.lookup.StrSubstitutor.substitute(StrSubstitutor.java:978)
    at org.apache.logging.log4j.core.lookup.StrSubstitutor.substitute(StrSubstitutor.java:912)
    at org.apache.logging.log4j.core.lookup.StrSubstitutor.replace(StrSubstitutor.java:467)
    at org.apache.logging.log4j.core.pattern.MessagePatternConverter.format(MessagePatternConverter.java:132)
    ...
    at org.apache.logging.log4j.spi.AbstractLogger.error(AbstractLogger.java:740)
    at com.example.Log4jFuzzer.fuzzerTestOneInput(Log4jFuzzer.java:40)
DEDUP_TOKEN: 39967e271d3922c3
== libFuzzer crashing input ==
MS: 4 ChangeByte-InsertByte-EraseBytes-PersAutoDict- DE: "ldap://g.co/"-; base unit: c80f693736a2e246623e558e1f483edd3b6308c4
0x2a,0x0,0x24,0x7b,0x24,0x6a,0x27,0x29,0x76,0xff,0x61,0x2a,0x64,0x24,0x29,0x76,0x61,0x2a,0x64,0x24,0x7b,0x6a,0x6e,0x64,0x69,0x3a,
0x6c,0x64,0x61,0x70,0x3a,0x2f,0x2f,0x67,0x2e,0x63,0x6f,0x2f,0xf,0xe9,0x2a,0x29,0xd6,0x61,0x64,0xa5,0x24,0xa,0x0,0x69,0x3a,0xf,0xe9
0x2a,0x29,0x76,0x61,0x0,0x5f,0x5c,0x7d,0x7d,0x0,0x24,0x7b,
*\x00${$j')v\xffa*d$)va*d${jndi:ldap://g.co/\x0f\xe9*)\xd6ad\xa5$\x0a\x00i:\x0f\xe9*)va\x00_\\}}\x00${
INFO: exiting: 77 time: 284s
```

Advanced Functionality

- Track partial progress on difficult compares
  - Enable via `-use_value_profile=1`
  - Slows down fuzzing, but can uncover otherwise unreachable code paths
- Seamlessly fuzz native libraries
  - Compile and link with `-fsanitize=fuzzer-no-link,address`
- Use the Jazzer API to provide additional feedback or write custom bug detectors

```
static void    exploreState(byte state, int id)

static void    guideTowardsContainment
               (java.lang.String haystack,
               java.lang.String needle, int id)

static void    guideTowardsEquality(byte[] current,
               byte[] target, int id)

static void    guideTowardsEquality(java.lang.String current,
               java.lang.String target, int id)
```


@fhenneke fmeum

Next Steps for Jazzer

- Make Jazzer available as a Maven dependency
  - UX goal: **Fuzzing should be as accessible as Unit Testing.**

```
7
8   class ParserTest {
9
10      @Test
11      void parse() {
12          assertEquals( expected: "Hello", new Parser().parse(new byte[]{5, 0x48, 0x65, 0x6c, 0x6c, 0x6f}));
13      }
14
15      @FuzzTest
16      void parseFuzzer(byte[] data) {
17          new Parser().parse(data);
18      }
19
```

- Extend and add bug detectors
  - Ideas (even rough ones) are very welcome!
- Improve Autofuzz' reliability and performance

github.com/CodeIntelligenceTesting/jazzer

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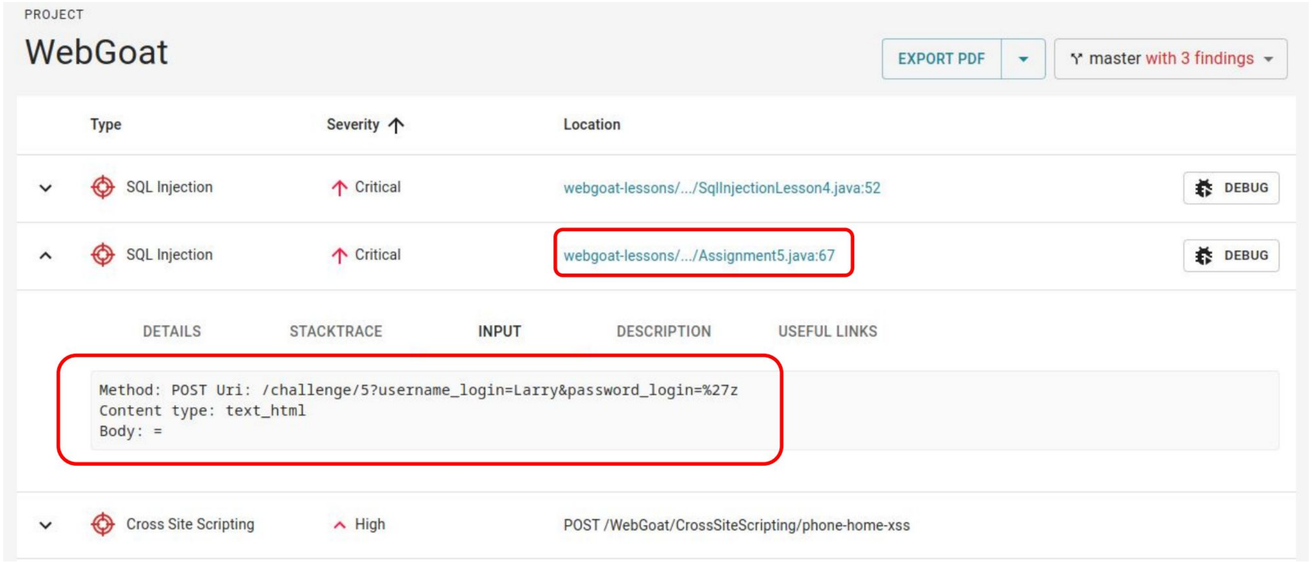
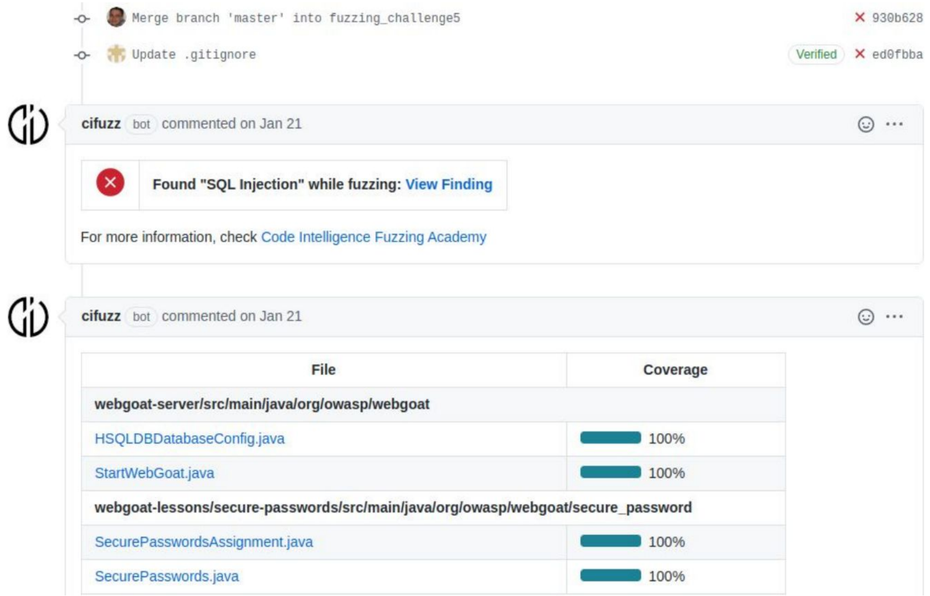
CI Fuzz — Web Apps, CI/CD & more

- Fuzzes multi-service deployments (REST/gRPC)
- Integrates with your CI/CD pipeline





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