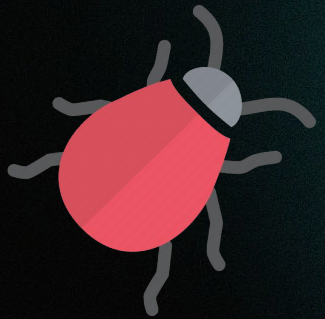
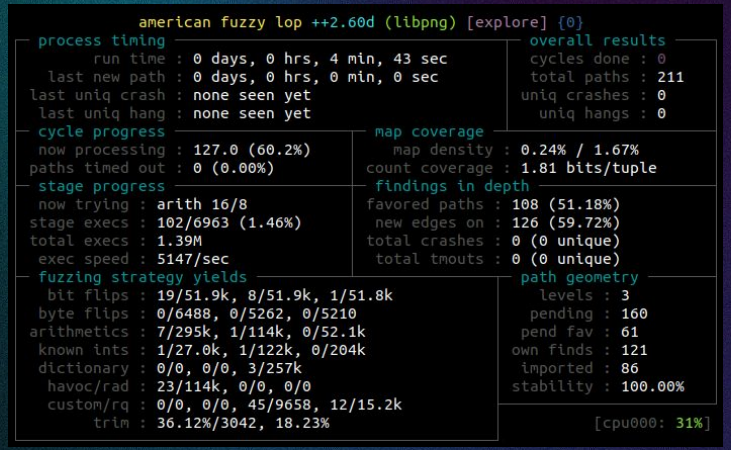
Introduction To Fuzzing



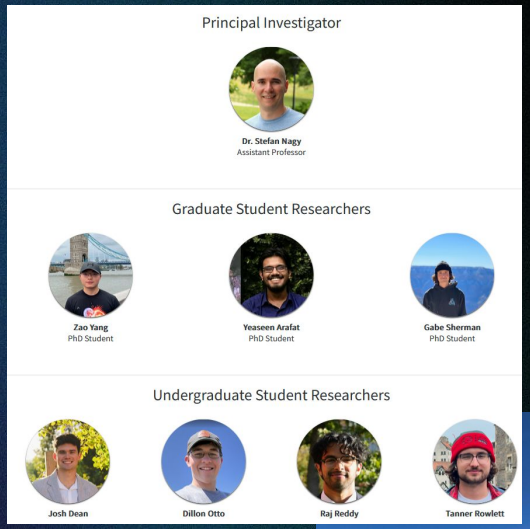


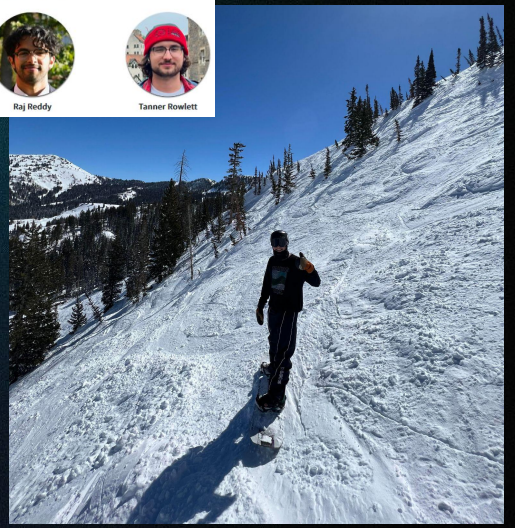
3/17/2025
Gabriel Sherman

Slides adapted from Stefan Nagy

About Me

- What I do:
  - Ph.D. student at the University of Utah
  - Performing research in cybersecurity
  - Uncovered over 50 bugs in software
  - Talk to me about the program!





- Other things about me:
  - Love being outside
  - Have a weiner dog

Check out our lab: https://futures.cs.utah.edu/

Software Is Buggy!

This can have disastrous effects ...

Ballista Botnet Exploits Unpatched TP-Link Vulnerability, Infects Over 6,000 Devices

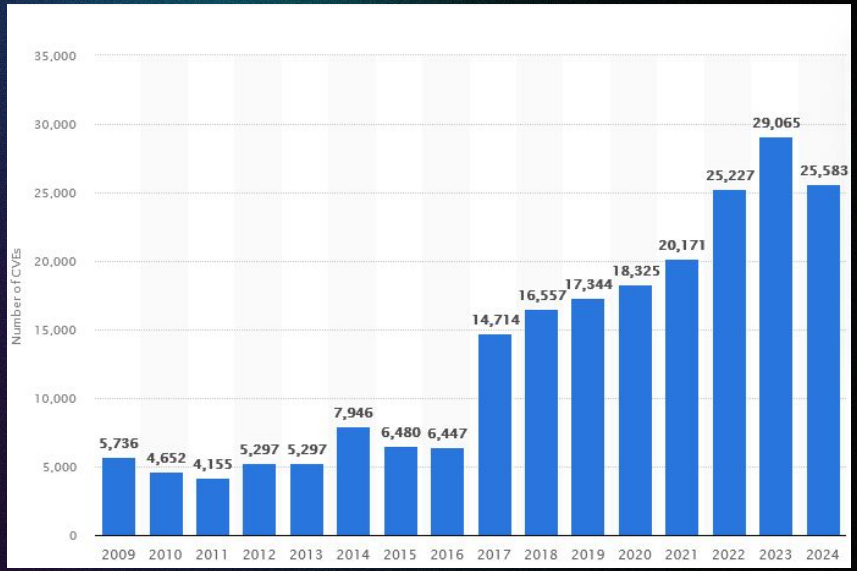
Mar 11, 2025 Ravie Lakshmanan

The 'most serious' security breach ever is unfolding right now. Here's what you need to know.

Dec. 20, 2021 at 10:00 pm | *Updated Dec. 20, 2021 at 10:25 pm*

Heartbleed Bug: Tech firms urge password reset

9 April 2014

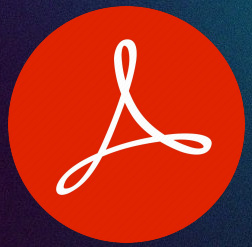


https://www.statista.com/statistics/500755/worldwide-common-vulnerabilities-and-exposures/

Software Uses Inputs

Audio Video Photos And more...






When these inputs are not properly handled, bugs occur!

How do we find bugs?

Manual Analysis

- Codebases are huge! (Millions of lines of code)
- Massive amounts of effort
- Still might miss something

Static Analysis

- Analyze program without running it
- Quickly becomes computationally infeasible
- False positives and false negatives

Dynamic Analysis

- Analyze program by running it!
- What you see is what you get
- Minimal overhead

Fuzzing

A dynamic analysis technique that aims to execute a program as many times as possible with random inputs.

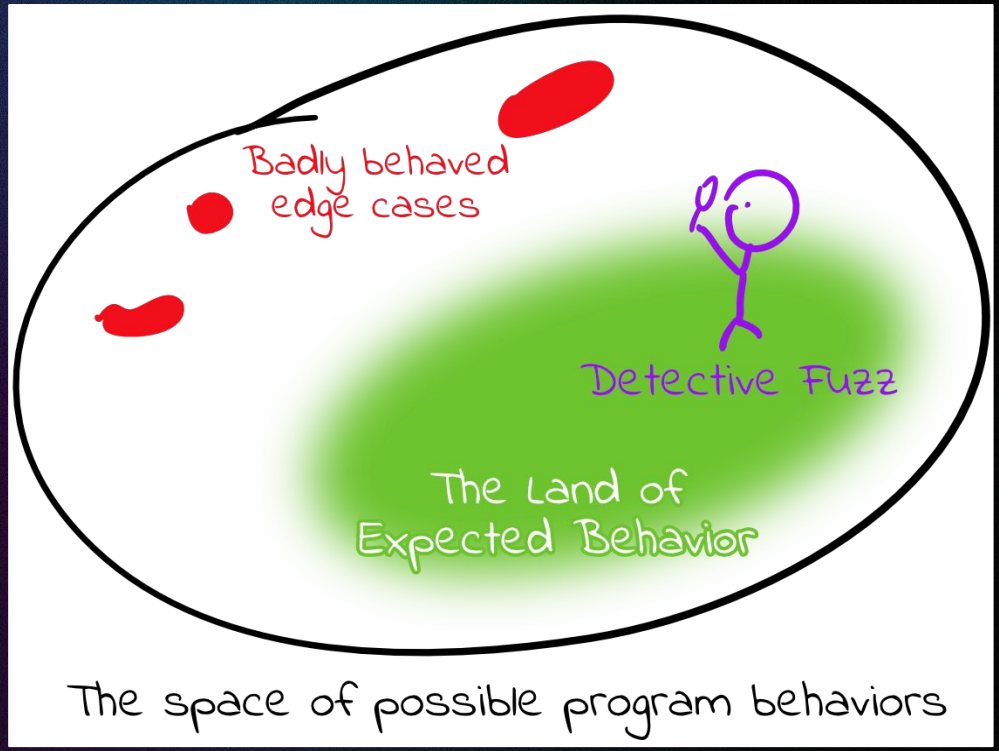
- Widely used in today's software ecosystem

- Google's OSS-Fuzz project has found over 10,000 vulnerabilities and 36,000 bugs through fuzzing

Fuzzing

The General Idea:

- Quickly generate a ton of random inputs
- Execute the program on each input. Does the program:
  - Crash?
  - Hang?
  - Do Nothing?



What can you fuzz?

Everything

What can you fuzz?

JANUS: Detecting Rendering Bugs in Web Browsers via Visual Delta Consistency

Chijin Zhou†, Quan Zhang†, Bingzhou Qian‡, and Yu Jiang†✉
†BNRist, Tsinghua University, Beijing, China
‡National University of Defense Technology, Changsha, China

FUZZILLI: Fuzzing for JavaScript JIT Compiler Vulnerabilities

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What can you fuzz?

WhiteFox: White-Box Compiler Fuzzing Empowered by Large Language Models

CHENYUAN YANG, University of Illinois at Urbana-Champaign, USA
YINLIN DENG, University of Illinois at Urbana-Champaign, USA
RUNYU LU, Huazhong University of Science and Technology, China
JIAYI YAO, Chinese University of Hong Kong, China
JIAWEI LIU, University of Illinois at Urbana-Champaign, USA
REYHANEH JABBARVAND, University of Illinois at Urbana-Champaign, USA
LINGMING ZHANG, University of Illinois at Urbana-Champaign, USA

Finding and Understanding Bugs in C Compilers

Xuejun Yang Yang Chen Eric Eide John Regehr
University of Utah, School of Computing
{jxyang, chenyang, eeide, regehr}@cs.utah.edu

What can you fuzz?

Fuzzware: Using Precise MMIO Modeling for Effective Firmware Fuzzing

Tobias Scharnowski[1], Nils Bars[1], Moritz Schloegel[1], Eric Gustafson[2], Marius Muench[3], Giovanni Vigna[2,4], Christopher Kruegel[2], Thorsten Holz[1] and Ali Abbasi[1]

[1]*Ruhr-Universität Bochum,* [2]*UC Santa Barbara,* [3]*Vrije Universiteit Amsterdam,* [4]*VMware*

SNIPUZZ: Black-box Fuzzing of IoT Firmware via Message Snippet Inference

Xiaotao Feng
Swinburne University of Technology
Australia

Ruoxi Sun
The University of Adelaide
Australia

Xiaogang Zhu*
Swinburne University of Technology
Australia

Minhui Xue
The University of Adelaide
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Sheng Wen*
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Australia

Dongxi Liu
CSIRO Data61
Australia

Surya Nepal
CSIRO Data61
Australia

Yang Xiang
Swinburne University of Technology
Australia

What can you fuzz?

OpenSSL

AFLplusplus

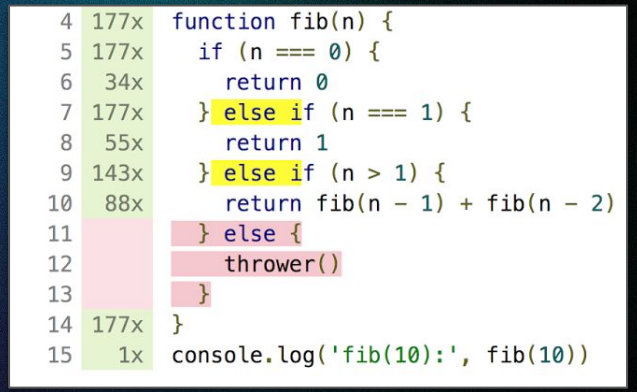
- *Coverage guided*, *grey-box* fuzzer
- Most widely used fuzzing engine out there (5.5k github stars)
- High portability and adaptability
- Learn how to use this when learning fuzzing!
- Some useful links:
  - https://github.com/AFLplusplus/AFLplusplus
  - https://aflplus.plus/

Coverage-guided fuzzing

Fuzzers generate tons of inputs. How we determine if an input is interesting or meaningful?

- Keep and further mutate inputs that gain new coverage in the program under test

- No new coverage means we didn't trigger new functionality!



A Simple Example

bgatradf

New coverage! –
Mutate this input

Program

```
if(input[0] == ‘a’){
        if(input[1] == ‘b’){
                return 2;
        }
        if(input[1] == ‘c’){
                Crash!
        }
}
```

A Simple Example

bagtfd

No new coverage

Program

```
if(input[0] == ‘a’){
        if(input[1] == ‘b’){
                return 2;
        }
        if(input[1] == ‘c’){
                Crash!
        }
}
```

A Simple Example

aertstbwr

New coverage! –
Mutate this input

Program

```
if(input[0] == ‘a’){
        if(input[1] == ‘b’){
                return 2;
        }
        if(input[1] == ‘c’){
                Crash!
        }
}
```

A Simple Example

abwrertst

New coverage! –
Mutate this input

Program

```
if(input[0] == ‘a’){
        if(input[1] == ‘b’){
                return 2;
        }
        if(input[1] == ‘c’){
                Crash!
        }
}
```

A Simple Example

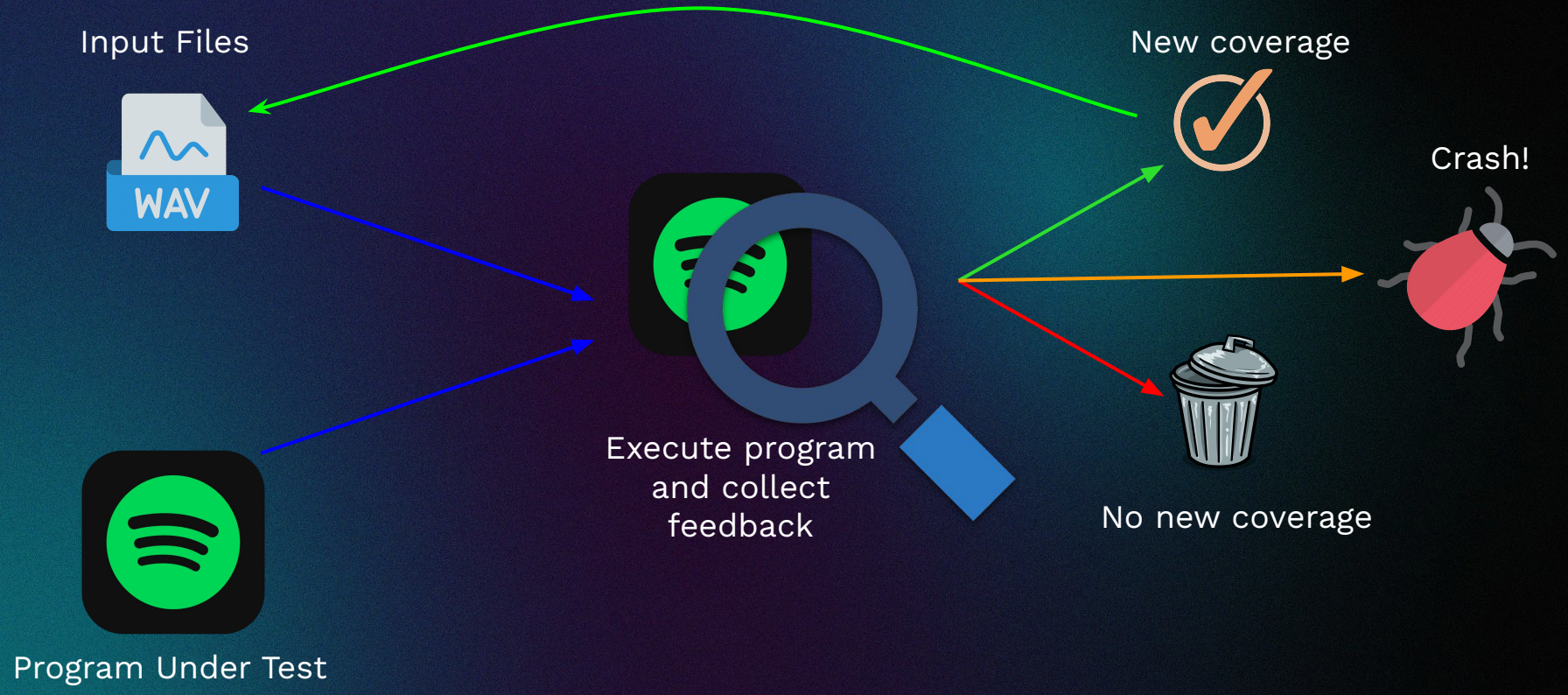
acwrertst

Crash!

Program

```
if(input[0] == ‘a’){
        if(input[1] == ‘b’){
                return 2;
        }
        if(input[1] == ‘c’){
                Crash!
        }
}
```

The Overall Process



More On Coverage

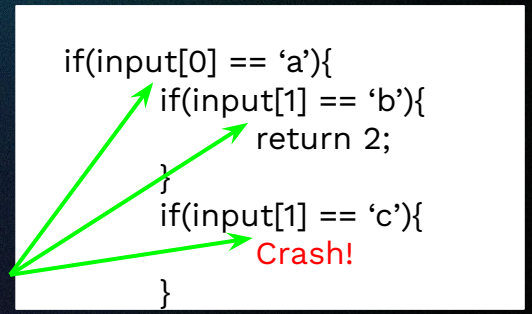
How do programs report their coverage?

- *Instrument* the program to report when regions of code are reached.
- Open Source?
  - Instrument at compilation time – afl-clang-fast and afl-clang-fast++ are good in most cases
- Closed Source?
  - Instrument on the fly using afl-qemu

Uninstrumented Program

```
if(input[0] == ‘a’){
        if(input[1] == ‘b’){
                return 2;
        }
        if(input[1] == ‘c’){
                Crash!
        }
```

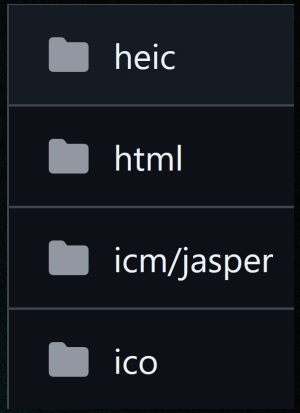
Instrumented Program

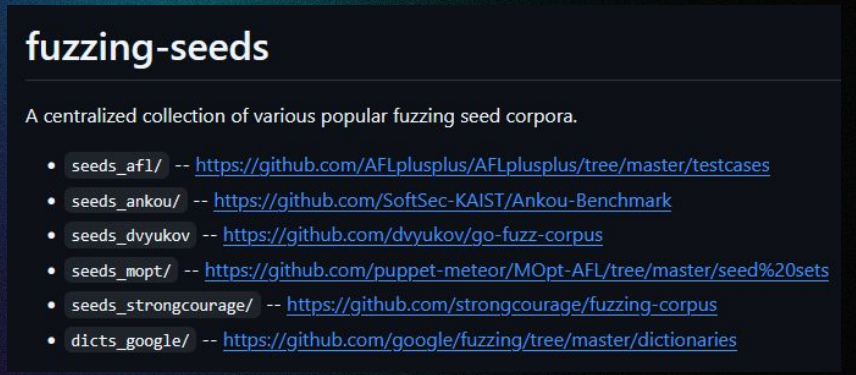


Hey AFL, I’m being executed!

Get a headstart

- Fuzzers generate inputs and mutate them. Give it a headstart by providing *seeds*.
- Fuzzing seeds are *examples* of inputs the program may expect. This lets the fuzzer operate on and mutate these rather than starting from scratch.
- Seeds are *program dependent*.
- Some examples
  - Adobe acrobat: Different PDF files
  - Spotify: Different audio files
  - Imessage: .db files





https://github.com/FuturesLab/fuzzing-seeds/

Library Fuzzing

Libraries are used *everywhere* in software. Bugs and vulnerabilities that affect them not only affect the library itself, but software that depends on it!

For example...

XZ-Utils Backdoor: Adversary placed a backdoor in the liblzma library. Granted them remote access to linux systems.

Linux could have been brought down by backdoor found in widely used utility

The malicious code modifies functions within a data compression library that is a foundational part of several Linux distributions

OpenSSL Heartbleed Vulnerability: Improper input validation allowed attackers to leak sensitive information (secret keys, passwords, etc). 500,000 servers were immediately vulnerable.

How to Fuzz a Library

In order to fuzz a library, we employ the use of fuzzing drivers, or *harnesses*. While some programs can simply be executed, libraries depend on other programs to invoke their functionality. Think of libraries as a toolbox, but someone still needs to actually pick up the tools and use them.

Fuzzing harnesses invoke functions of the library and pass fuzzer-generated inputs to the library in a meaningful way

Fuzzing Harness Example

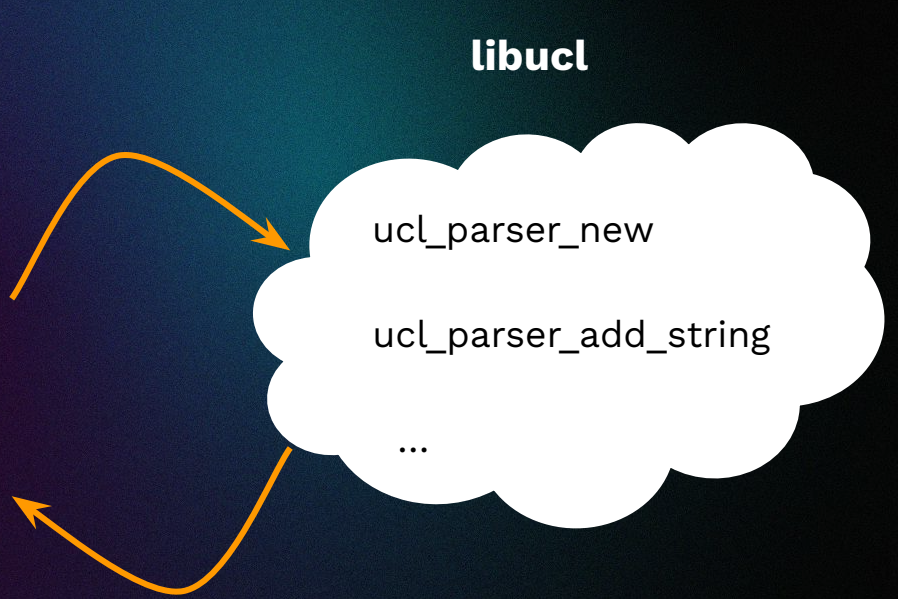
```c
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include "ucl.h"

int LLVMFuzzerTestOneInput(const uint8_t *data, size_t size) {
        // If size is 0 we need a null-terminated string.
        // We dont null-terminate the string and by the design
        // of the API passing 0 as size with non null-terminated string
        // gives undefined behavior.
        if(size==0){
                return 0;
        }
        struct ucl_parser *parser;
        parser = ucl_parser_new(0);

        ucl_parser_add_string(parser, (char *)data, size);

        if (ucl_parser_get_error(parser) != NULL) {
                return 0;
        }

        ucl_parser_free (parser);
        return 0;
}
```



Library Fuzzing Overview

```c
#include <stdlib.h>
#include <stdint.h>
#include <string.h>

#include <libical/ical.h>

extern "C" int LLVMFuzzerTestOneInput(const uint8_t *data, size_t size)
{
    char *ical_string = (char*)malloc(size + 1);
    memcpy(ical_string, data, size);
    ical_string[size] = '\0';

    icalcomponent *component = icalparser_parse_string(ical_string);
    icalcomponent_free(component);

    free(ical_string);

    return 0;
}
```

Inputs

Feed inputs to the library in a *meaningful way*

Coverage Information

Let’s Get Technical

These next slides describe how to build, instrument, and fuzz a library. Familiarity with build systems(CMake, autoconf, etc.), program compilation(clang), and the linux environment is recommended.

If not, don’t worry! I’ve provided a demo of this build process here.

Google’s OSS-Fuzz project is a great resource for library harnessing. Harnesses, library build scripts, and compilation scripts can all be found there.

https://github.com/google/oss-fuzz/tree/master/projects

Step 1: Build the Library

Goal: Build the library with AFLplusplus instrumentation

Depending on the build system, set the compiler to be AFL's own compiler:

- CMake: -DCMAKE_C_COMPILER=afl-clang-fast -DCMAKE_CXX_COMPILER=afl-clang-fast++
- Autoconf: CC=afl-clang-fast CXX=afl-clang-fast++

Step 2: Compilation

Goal: Compile the harness of interest and link it with the *instrumented* library

This varies between libraries and harnesses. Pretty much will need to use the -I, -L, and -l flags. For example, here's how you compile the harness in the c-ares demo.

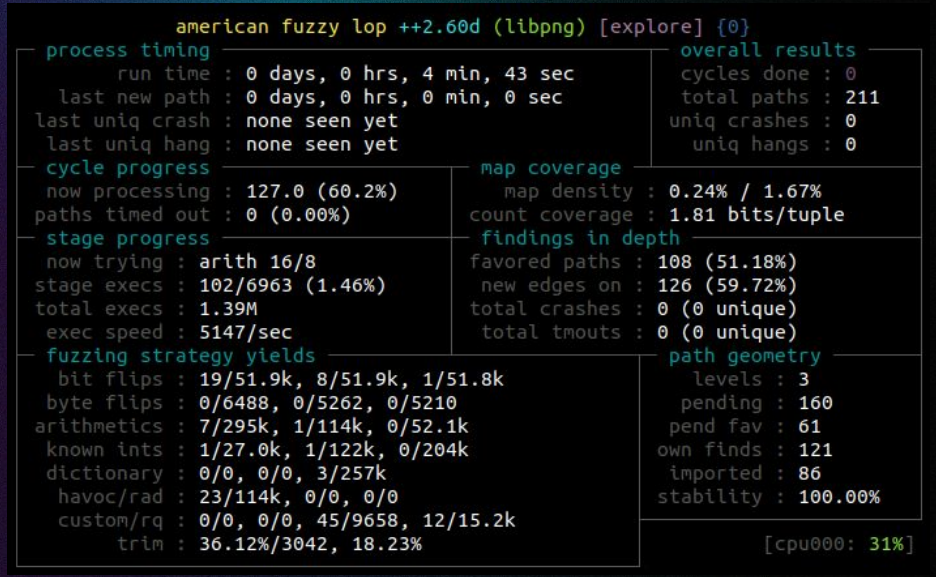
```
afl-clang-fast -o harness.out harness.c
-I lib_fuzz/include -I lib_fuzz/ -L lib_fuzz/.libs/ -lcares -fsanitize=address
```

Step 3: Start Fuzzing!

Goal: Run the fuzzing engine on your harness and fuzz the library!

Typical command to begin fuzzing:
afl-fuzz -i <seeds directory> -o <output directory> ./<binary name> @@

- *new edges on* section should increase. If not, something's wrong.
- If *total crashes* is nonzero, you may have found a bug!



Common Mistakes

new edges on* section is not increasing*:

- If your harness was not compiled with the *-static* flag, you need to set the LD_LIBRARY_PATH environment variable to point to the instrumented *.so* file.
  - Run ldd ./<binary_name>. This will give you the path of each library the harness is talking to. If the instrumented library is not in this path, set the LD_LIBRARY_PATH.
- Make sure you are linking your harness against the correct library.
- Your library is not actually instrumented with AFL.
  - To make sure the library is instrumented, find the .so file(the shared library). Run objdump -D <path to .so file> | grep afl. If nothing comes up the library is not instrumented!

Immediately getting a ton of crashes:

- You either found a bug really quick or your harness is incorrect.

afl-clang-fast not found:

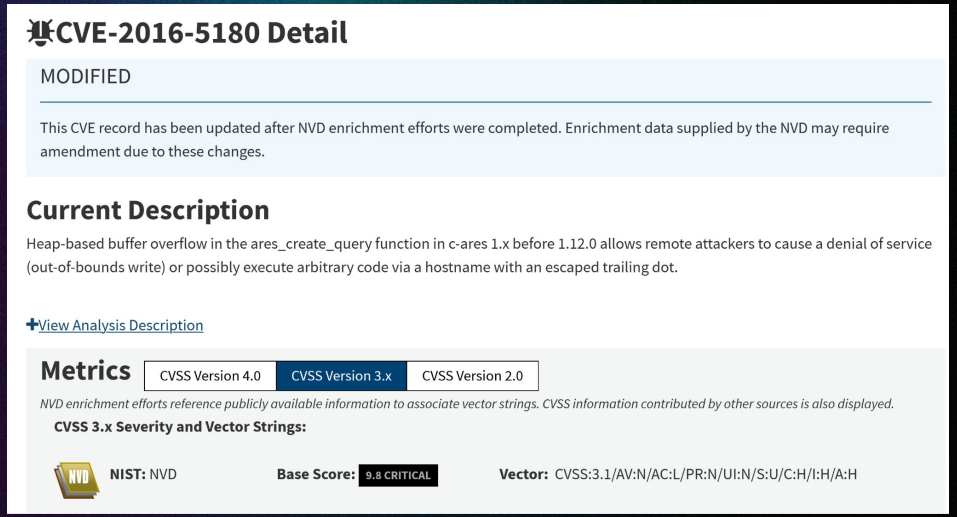
- AFL isn't in your $PATH. Either add it to the path or provide the absolute path to the binary

DEMO(~10 mins)

https://github.com/gabe-sherman/cybersec_fuzzing_demo

You need a Linux environment, or use WSL(Windows subsystem for linux)

- Fuzz a basic library and observe what a good fuzzing trial looks like
- Find a vulnerability in c-ares that allowed arbitrary code execution in < 5 seconds



CVE-2016-5180 Detail

MODIFIED

This CVE record has been updated after NVD enrichment efforts were completed. Enrichment data supplied by the NVD may require amendment due to these changes.

Current Description

Heap-based buffer overflow in the ares_create_query function in c-ares 1.x before 1.12.0 allows remote attackers to cause a denial of service (out-of-bounds write) or possibly execute arbitrary code via a hostname with an escaped trailing dot.

View Analysis Description

Metrics CVSS Version 4.0 | CVSS Version 3.x | CVSS Version 2.0

NVD enrichment efforts reference publicly available information to associate vector strings. CVSS information contributed by other sources is also displayed.

CVSS 3.x Severity and Vector Strings:

NIST: NVD **Base Score:** 9.8 CRITICAL **Vector:** CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:U/C:H/I:H/A:H

Use the Internet!

There are a ton of blog posts out there describing the different aspects of fuzzing and harnessing. These are some of the best resources for learning.

https://bushido-sec.com/index.php/2025/01/03/fuzzing-harness-guide/

https://google.github.io/clusterfuzz/setting-up-fuzzing/heartbleed-example/

https://www.mayhem.security/blog/firmware-fuzzing-101

https://www.fuzzingbook.org/

https://trustfoundry.net/2020/01/22/introduction-to-triaging-fuzzer-generated-crashes/

Join Research!

Network Security

Cryptography

Mobile Security

Fuzzing

And more ... (AI security, systems security, exploits, cyber-physical systems, etc.)

Questions?