Finding security vulnerabilities with modern fuzzing techniques

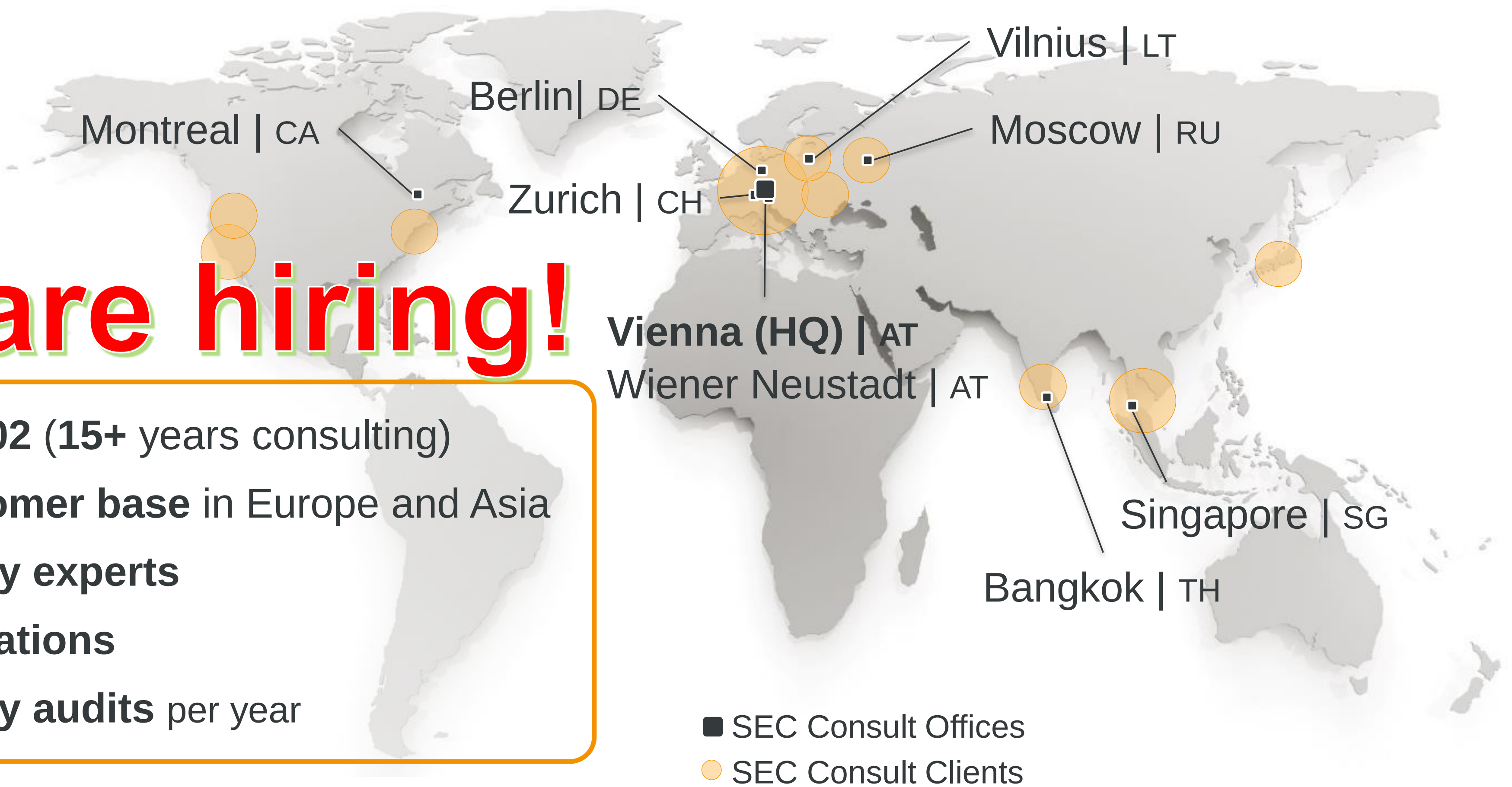
Title: Finding security vulnerabilities with Fuzzing | Responsible: R. Freingruber | Version / Date: V1.0/2018-05 | Confidentiality Class: public

Introduction

- **René Freingruber (r.freingruber@sec-consult.com)**
  - Twitter: @ReneFreingruber
  - BSc @ TU Vienna, Currently MSc @ Technikum Vienna
  - Senior Security Consultant at SEC Consult
    - Red Team, Reverse Engineering, Exploit development, Fuzzing
    - Trainer: Secure C/C++, Reverse Engineering and Red Teaming
  - Previous talks:
    - 2014: Bypassing EMET
      - 31C3, DeepSec, ZeroNights, RuxCon, ToorCon and NorthSec
    - 2015: Bypassing Application Whitelisting
      - CanSecWest, DeepSec, Hacktivity, NorthSec, IT-SeCX, BSides Vienna and QuBit
    - 2016: Hacking companies via firewalls
      - DeepSec, BSides Vienna, DSS ITSEC and IT-SeCX (lightning talks at recon.eu and hack.lu)
    - Since 2017 fuzzing talks
      - DefCamp, Heise devSec, IT-SeCX, BSides Vienna, RuhrSec

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

ADVISOR FOR YOUR INFORMATION SECURITY



We are hiring!

Founded 2002 (**15+** years consulting)

Strong customer base in Europe and Asia

100+ Security experts

120+ certifications

500+ Security audits per year

Some rules

- Ask anything anytime!
  - My english is not the best – please use simple words ☺

- Tell me if I‘m too fast!

- Tell me if there is anything you don‘t understand!

- Tell me if it‘s too easy / too hard!

- Contact me:
  - E-Mail: r.freingruber@sec-consult.com
  - Twitter: @ReneFreingruber

… Tell me if you want to have a break ☺

Demos

- **Some demos building on great stuff from others!**
  - LibFuzzer Tutorial (From Google and Workshop from Dor1s, @Dor3s)
  - Seccon 2016 CTF chat binary
  - FuzzGoat (from fuzzstati0n)
  - Of course all the great fuzzers like AFL, LibFuzzer, WinAFL, honggfuzz, …

- **Many demos just require to type in commands…**
  - It‘s the nature of the topic (we don‘t want to implement everything our self)
  - I want to use the full time to learn you as much as possible (the basics!)
  - If you want “open examples” just try the learned stuff at home with some applications! (if you have questions drop me a mail or write on twitter)

Fuzzing

Fuzzing

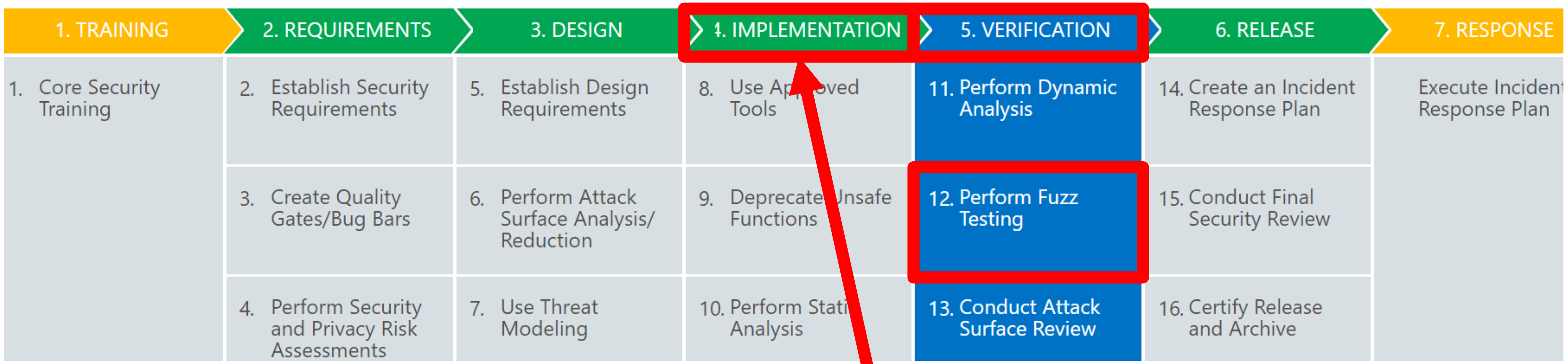
Definition of fuzzing (source Wikipedia):

Fuzzing or fuzz testing is an **automated software testing technique** that involves providing **invalid, unexpected, or random data as inputs** to a computer program. **The program** is then **monitored for exceptions such as crashes**, or failing built-in code assertions or for finding potential memory leaks.

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Why do we need Fuzzing?

Microsoft Security Development Lifecycle (SDL) Process



1. TRAINING	2. REQUIREMENTS	3. DESIGN	4. IMPLEMENTATION	5. VERIFICATION	6. RELEASE	7. RESPONSE
1. Core Security Training	2. Establish Security Requirements	5. Establish Design Requirements	8. Use Approved Tools	11. Perform Dynamic Analysis	14. Create an Incident Response Plan	Execute Incident Response Plan
	3. Create Quality Gates/Bug Bars	6. Perform Attack Surface Analysis/ Reduction	9. Deprecate Unsafe Functions	12. Perform Fuzz Testing	15. Conduct Final Security Review	
	4. Perform Security and Privacy Risk Assessments	7. Use Threat Modeling	10. Perform Static Analysis	13. Conduct Attack Surface Review	16. Certify Release and Archive	

Source: https://www.microsoft.com/en-us/SDL/process/verification.aspx

I also recommend fuzzing during implementation

Example: You finished a complex task and you are not sure if it behaves correctly and is secure

➔ Start a fuzzer over night / the weekend ➔ Check corpus

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Why do we need Fuzzing?

SDL Phase 4 *Security Requirements*

Where input to file parsing code could have crossed a trust boundary, **file fuzzing must be performed on that code**. […]

- **An Optimized set of templates must be used.** Template optimization is based on the maximum amount of **code coverage** of the parser with the minimum number of templates. Optimized templates have been shown to double fuzzing effectiveness in studies. **A minimum of 500,000 iterations, and have fuzzed at least 250,000 iterations since the last bug found/fixed that meets the SDL Bug Bar.**

Source: https://msdn.microsoft.com/en-us/library/windows/desktop/cc307418.aspx

Fuzzing

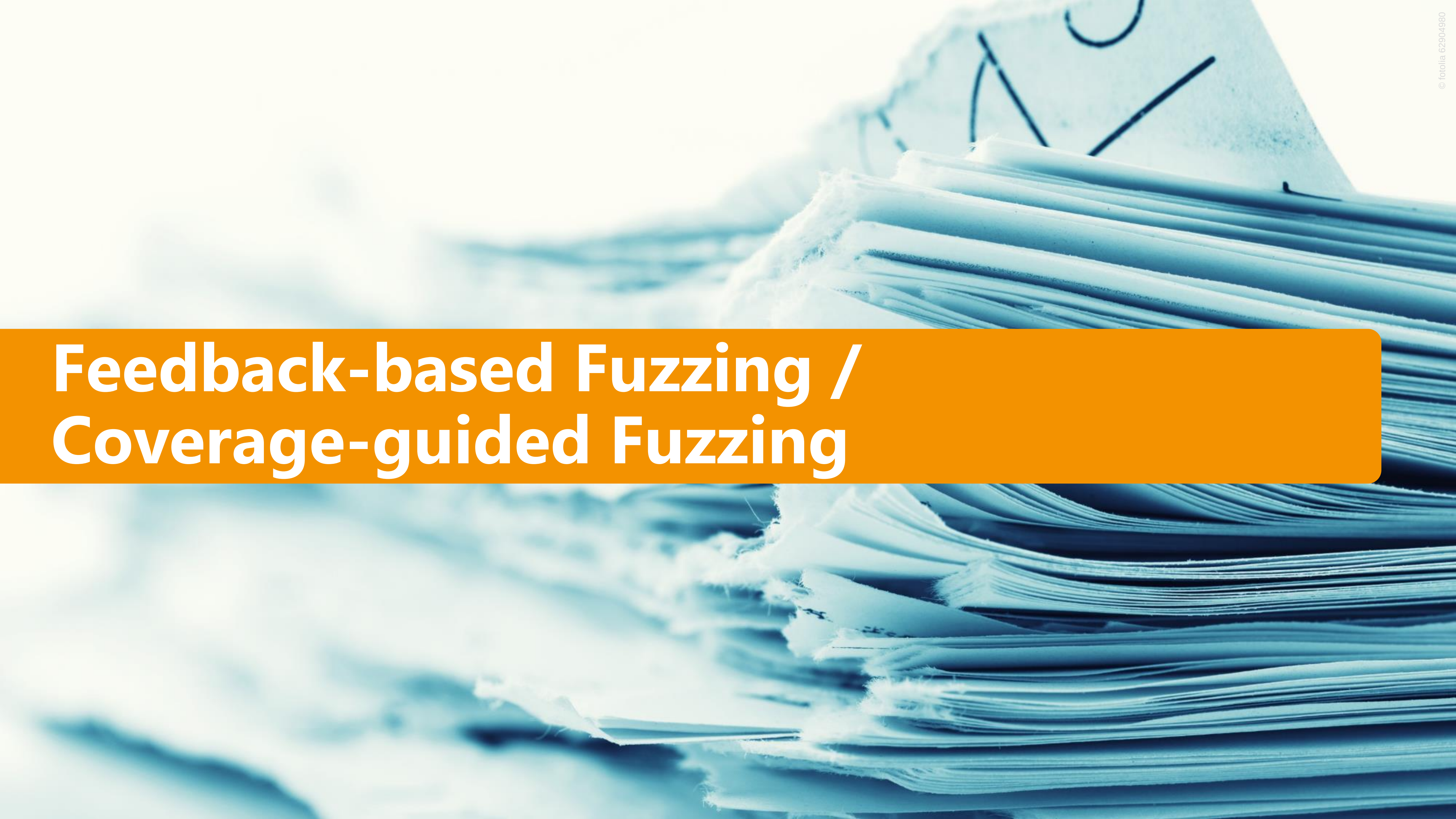
- **Advantages:**
  - Very fast (in most cases much faster than manual source code review)
  - You don’t have to pay a human, only the power consumption of a computer
  - It runs 24 hours / 7 days, a human works only 8 hours / 5 days
  - Scalable (want to find more bugs? ➔ Start 100 fuzzing machines instead of 1)

- **Disadvantages:**
  - Deep bugs (lots of pre-conditions) are hard to find
  - Typically you can’t find business logic bugs

Types of Fuzzing

- **Grammar-based Fuzzing :**
  - Idea: Implement the file format / protocol inside your fuzzer
  - Example: "at offset 4 is an unsigned dword, at offset 10 is a checksum, at offset 14 is a null-terminated string, at offset 20 a type field, …"
  - Covers everything which you defined (but maybe forgets corner cases which you didn't think of)
  - After the (long) initial work, the fuzzer covers lots of corner cases very fast
  - Examples: Peach, Domato, Boofuzz, Sulley, Spike, …

- **Feedback-based Fuzzing:**
  - Let the fuzzer learn the file format itself ➔ No initial work required (fast results)
  - However, learning the format can take a long time and maybe some checks could not be learned by the fuzzer
  - ➔ If we build better feedback-based fuzzers it has no (or just small) drawbacks
  - Examples: AFL, WinAFL, LibFuzzer, Honggfuzz, …
  - Side note: Use this technique for binary inputs. For "interactive" inputs (e.g.: JavaScript / DOM in browser or shell-like software which listens on a port) this technique is only partially useful.



Feedback-based Fuzzing / Coverage-guided Fuzzing

Feedback based fuzzing

➔ **Consider this code:**

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 01 00 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 02 00 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** FF 00 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Feedback based fuzzing

➔ **Fuzz input 1:** 00 01 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 02 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 FF 00 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 01 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 54 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 55 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

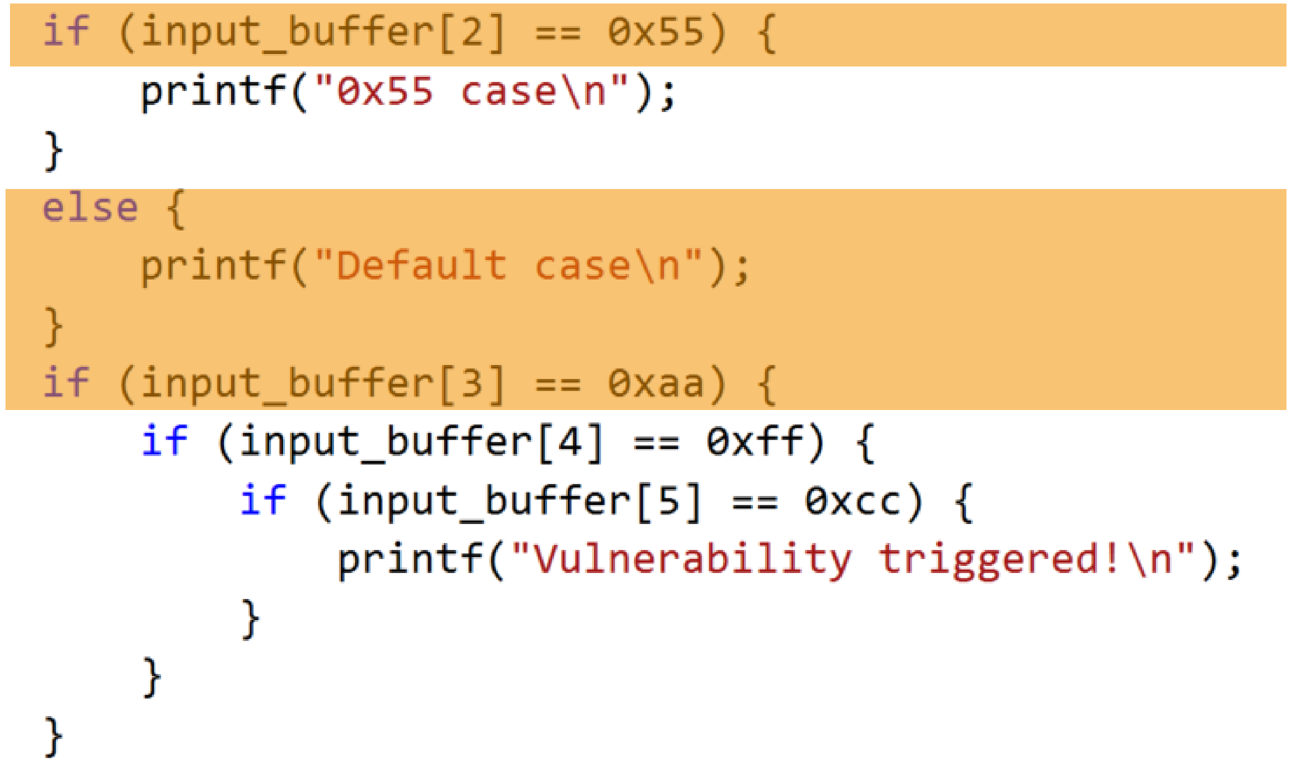
Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 56 00 00 00



```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 FF 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 00 A9 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 00 AA 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 00 AB 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

Feedback based fuzzing

➔ **Fuzz input 1:** 00 00 00 00 00 FF

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

Input 1: 00 00 00 00 00 00

Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

Feedback based fuzzing

➔ **Fuzz input 2:** 01 00 55 00 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

Feedback based fuzzing

➔ **Fuzz input 2:** 02 00 55 00 00 00

```c
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

Feedback based fuzzing

➔ **Fuzz input 2:** 00 00 55 AA 00 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

<no new entry because we already saw that coveage>

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Feedback based fuzzing

➔ **Fuzz input 2:** 00 00 55 00 00 FF

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

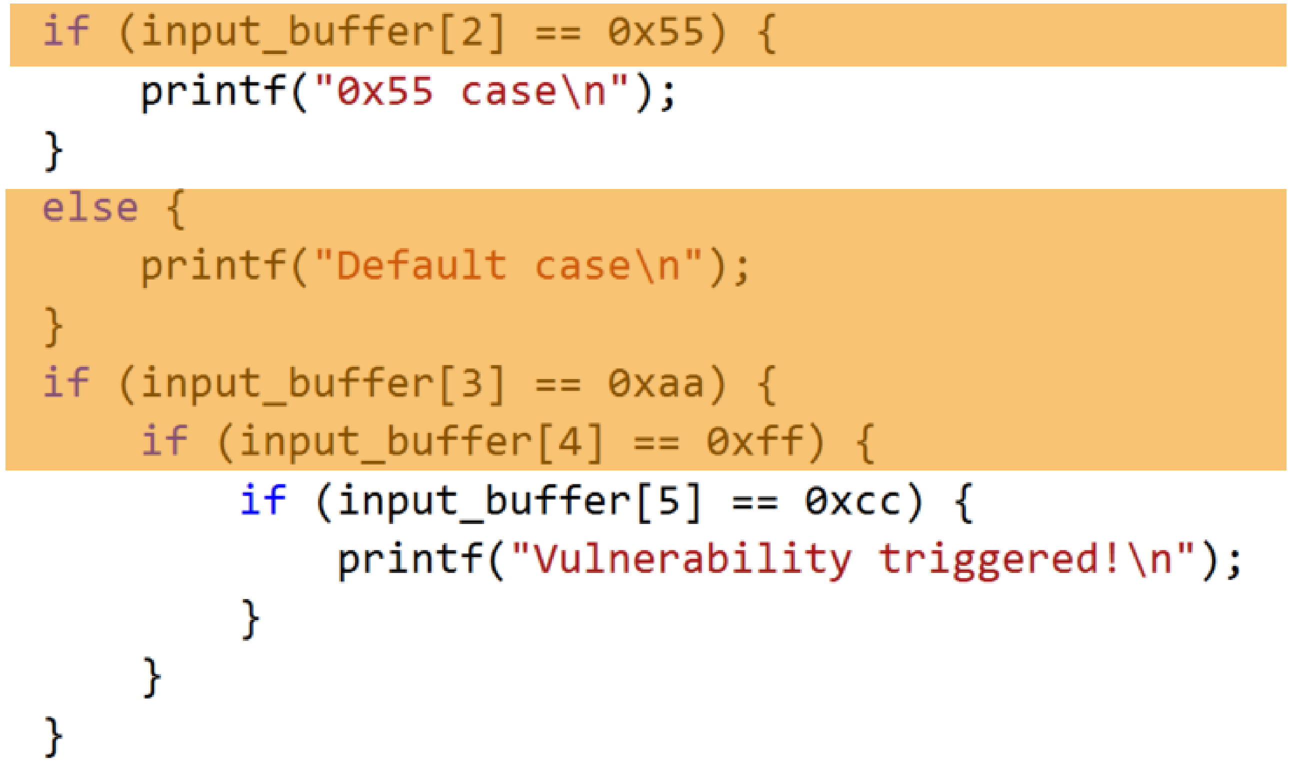
Input 2: 00 00 55 00 00 00

Input 3: 00 00 00 AA 00 00

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Feedback based fuzzing

➔ **Fuzz input 3:** 01 00 00 AA 00 00



```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

~~Input 2: 00 00 55 00 00 00~~

Input 3: 00 00 00 AA 00 00

Feedback based fuzzing

➔ **Fuzz input 3:** 00 00 00 AA FF 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

~~Input 2: 00 00 55 00 00 00~~

Input 3: 00 00 00 AA 00 00

Input 4: 00 00 00 AA FF 00

Feedback based fuzzing

➔ **Fuzz input 3:** 00 00 00 AA 00 FF

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

~~Input 2: 00 00 55 00 00 00~~

Input 3: 00 00 00 AA 00 00

Input 4: 00 00 00 AA FF 00

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Feedback based fuzzing

➔ **Fuzz input 4:** 01 00 00 AA FF 00

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

~~Input 2: 00 00 55 00 00 00~~

~~Input 3: 00 00 00 AA 00 00~~

Input 4: 00 00 00 AA FF 00

Feedback based fuzzing

➔ **Fuzz input 4:** 00 00 00 AA FF CC

```
if (input_buffer[2] == 0x55) {
    printf("0x55 case\n");
}
else {
    printf("Default case\n");
}
if (input_buffer[3] == 0xaa) {
    if (input_buffer[4] == 0xff) {
        if (input_buffer[5] == 0xcc) {
            printf("Vulnerability triggered!\n");
        }
    }
}
```

Fuzzer queue:

~~Input 1: 00 00 00 00 00 00~~

~~Input 2: 00 00 55 00 00 00~~

~~Input 3: 00 00 00 AA 00 00~~

Input 4: 00 00 00 AA FF 00

➔ **Vulnerability found!**

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Popular Fuzzers

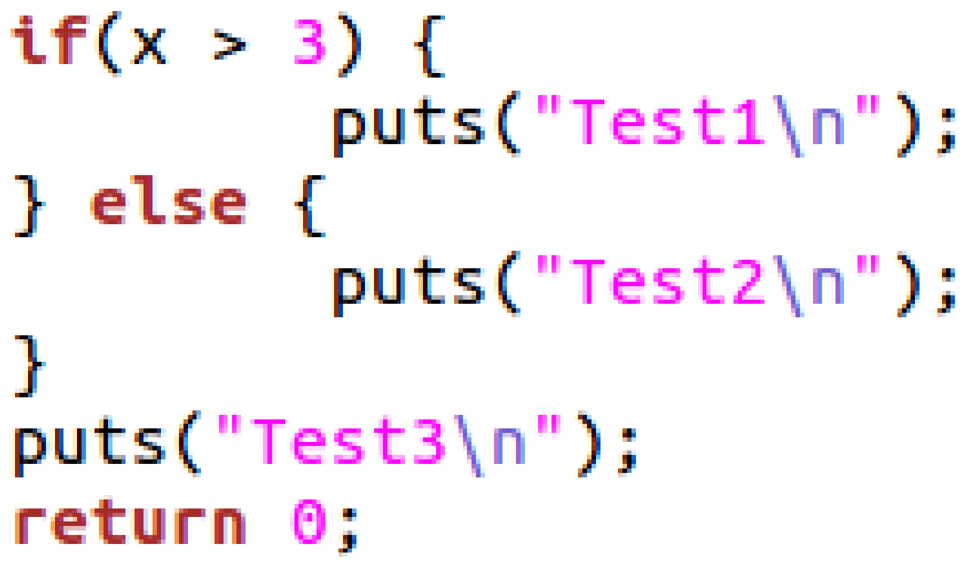
American Fuzzy Lop - AFL

- **One of the most famous file-format fuzzers**
  - Developed by **Michal Zalewski**

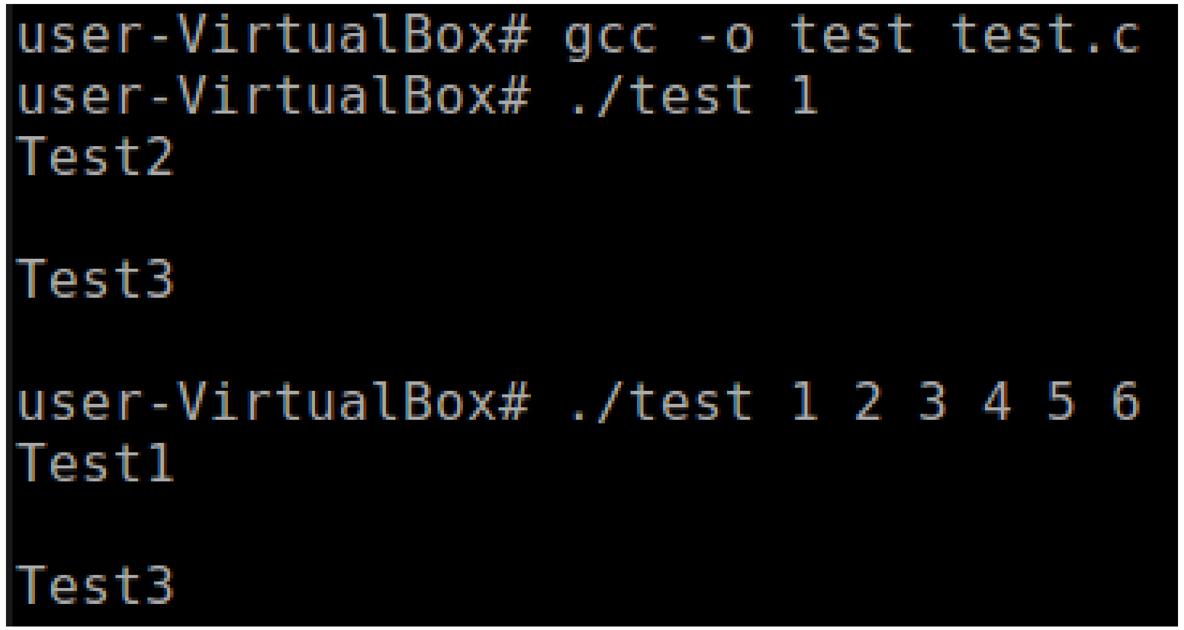
- Instruments application during compile time (GCC or LLVM)
  - Binary-only targets can be emulated / instrumented with qemu
  - Forks exist for PIN, DynamoRio, DynInst, syzygy, IntelPT, … (more on this later!)
  - **Simple to use!** (start fuzzing in under 1 minute!)
  - **Good designed!** (very fast & good heuristics)

Feedback based fuzzing

- **Consider this code (x = argc):**



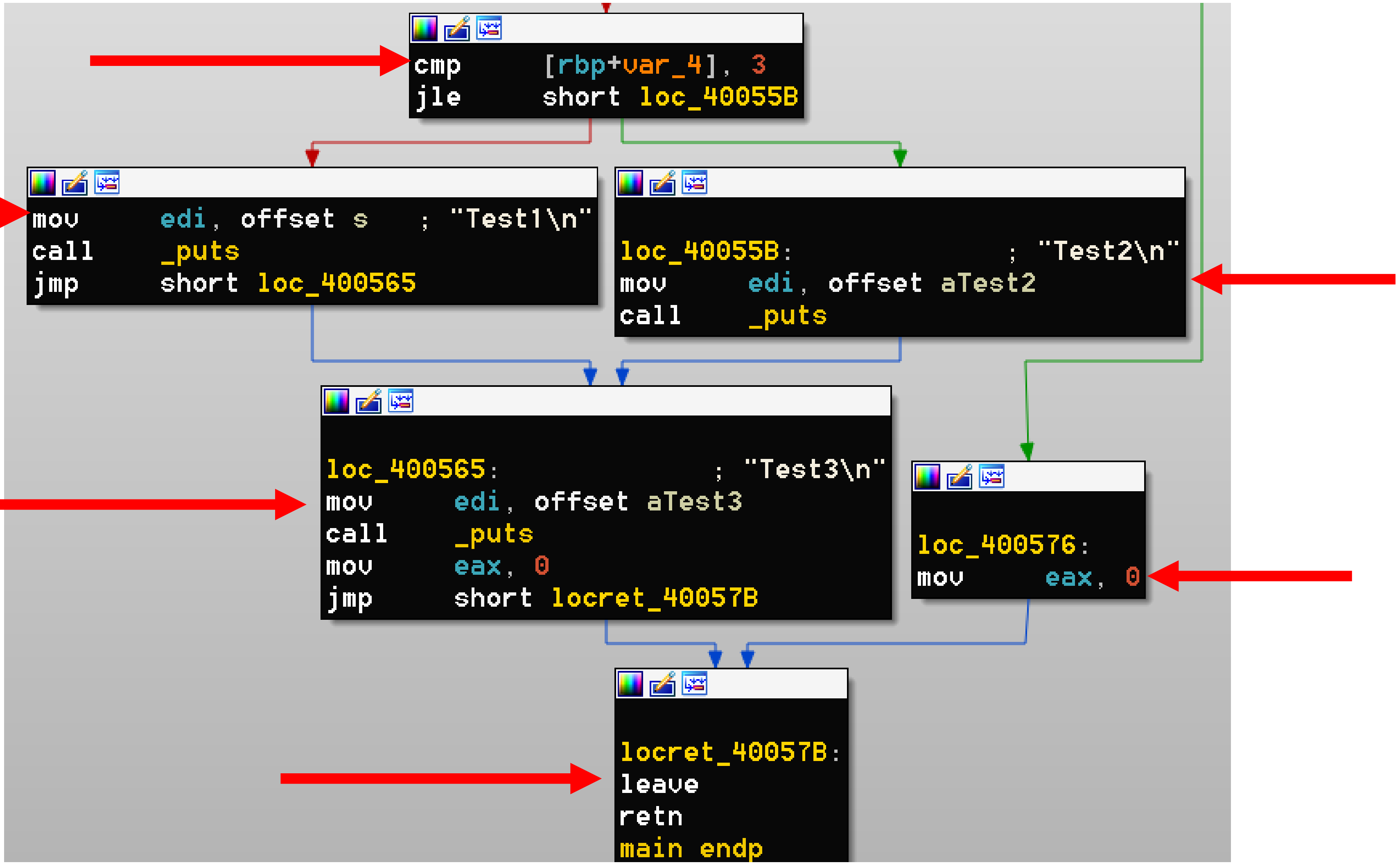
```
if(x > 3) {
        puts("Test1\n");
} else {
        puts("Test2\n");
}
puts("Test3\n");
return 0;
```



```
user-VirtualBox# gcc -o test test.c
user-VirtualBox# ./test 1
Test2

Test3

user-VirtualBox# ./test 1 2 3 4 5 6
Test1

Test3
```

Feedback based fuzzing

- **Basic Blocks:**



```
cmp     [rbp+var_4], 3
jle     short loc_40055B
```

```
mov     edi, offset s    ; "Test1\n"
call    _puts
jmp     short loc_400565
```

```
loc_40055B:                ; "Test2\n"
mov     edi, offset aTest2
call    _puts
```

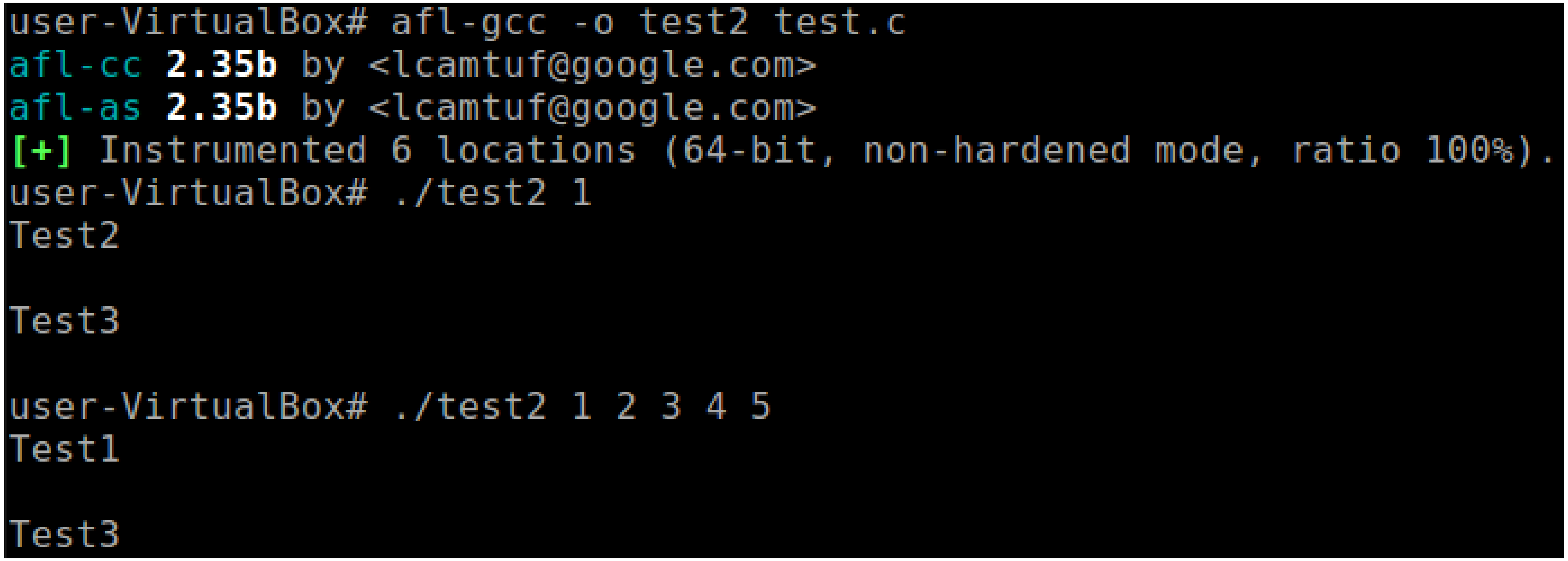
```
loc_400565:                ; "Test3\n"
mov     edi, offset aTest3
call    _puts
mov     eax, 0
jmp     short locret_40057B
```

```
loc_400576:
mov     eax, 0
```

```
locret_40057B:
leave
retn
main endp
```

Feedback based fuzzing

- **Just use afl-gcc instead of gcc…**



```
user-VirtualBox# afl-gcc -o test2 test.c
afl-cc 2.35b by <lcamtuf@google.com>
afl-as 2.35b by <lcamtuf@google.com>
[+] Instrumented 6 locations (64-bit, non-hardened mode, ratio 100%).
user-VirtualBox# ./test2 1
Test2

Test3

user-VirtualBox# ./test2 1 2 3 4 5
Test1

Test3
```

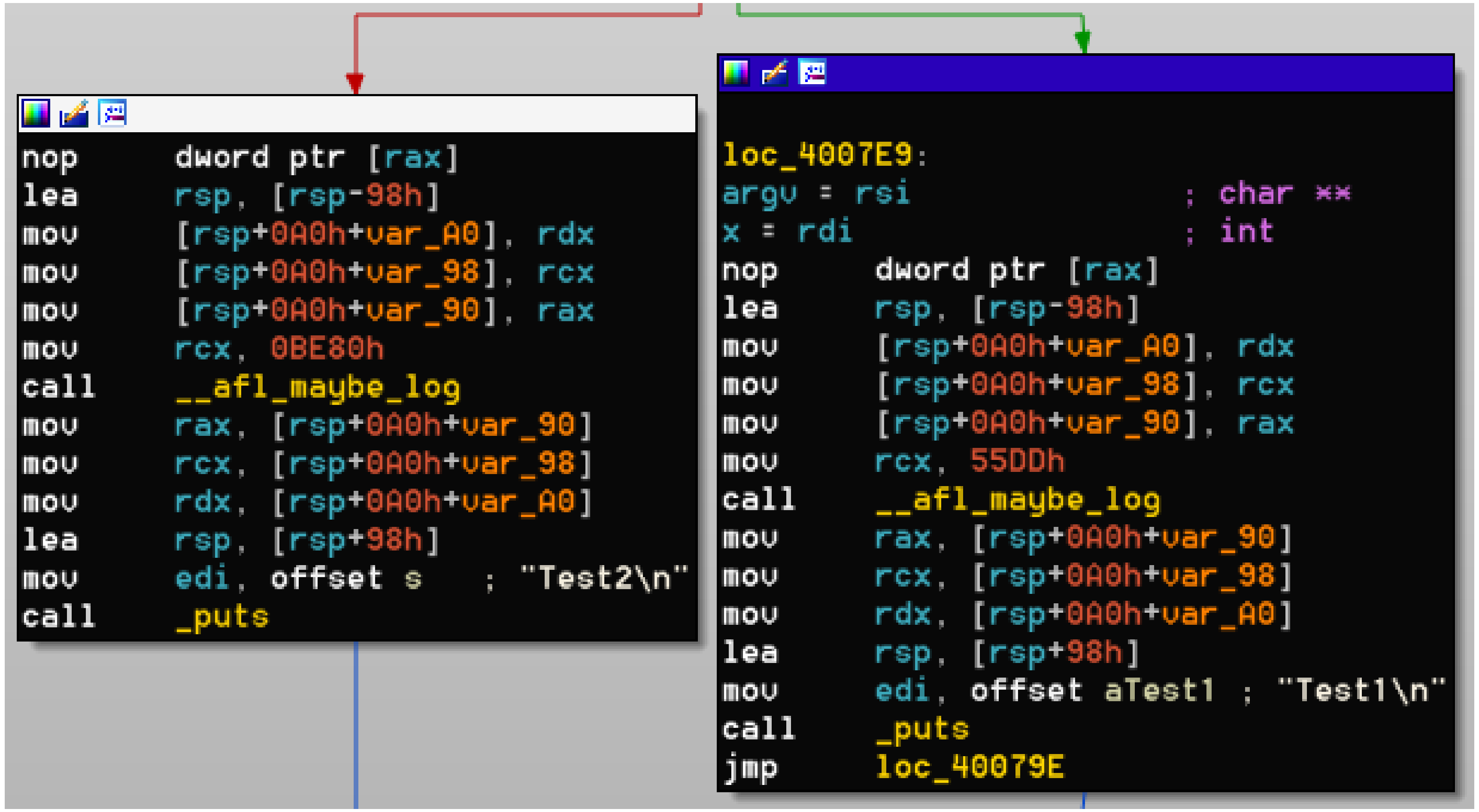
Feedback based fuzzing

- **Result:**

Store old register values

Instrumentation

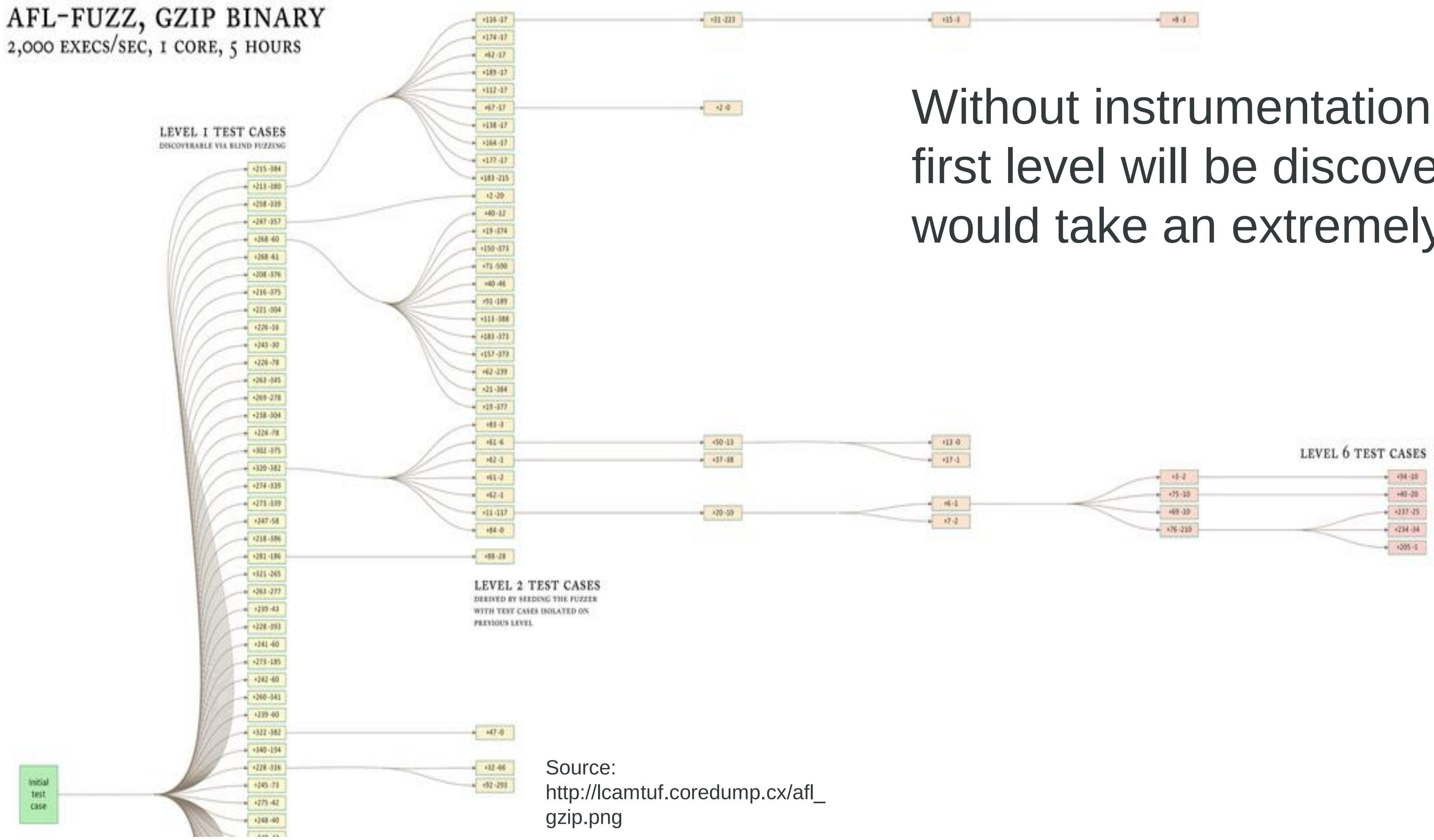
Restore old register values



```
nop     dword ptr [rax]
lea     rsp, [rsp-98h]
mov     [rsp+0A0h+var_A0], rdx
mov     [rsp+0A0h+var_98], rcx
mov     [rsp+0A0h+var_90], rax
mov     rcx, 0BE80h
call    __afl_maybe_log
mov     rax, [rsp+0A0h+var_90]
mov     rcx, [rsp+0A0h+var_98]
mov     rdx, [rsp+0A0h+var_A0]
lea     rsp, [rsp+98h]
mov     edi, offset s   ; "Test2\n"
call    _puts
```

```
loc_4007E9:
argv = rsi                  ; char **
x = rdi                     ; int
nop     dword ptr [rax]
lea     rsp, [rsp-98h]
mov     [rsp+0A0h+var_A0], rdx
mov     [rsp+0A0h+var_98], rcx
mov     [rsp+0A0h+var_90], rax
mov     rcx, 55DDh
call    __afl_maybe_log
mov     rax, [rsp+0A0h+var_90]
mov     rcx, [rsp+0A0h+var_98]
mov     rdx, [rsp+0A0h+var_A0]
lea     rsp, [rsp+98h]
mov     edi, offset aTest1 ; "Test1\n"
call    _puts
jmp     loc_40079E
```

American Fuzzy Lop - AFL


AFL-FUZZ, GZIP BINARY
2,000 EXECS/SEC, 1 CORE, 5 HOURS
LEVEL 1 TEST CASES
DISCOVERABLE VIA BLIND FUZZING
LEVEL 2 TEST CASES
DERIVED BY SEEDING THE FUZZER WITH TEST CASES ISOLATED ON PREVIOUS LEVEL
LEVEL 6 TEST CASES
Initial test case

Without instrumentation just the first level will be discovered (or it would take an extremely long time)

Source: http://lcamtuf.coredump.cx/afl_gzip.png

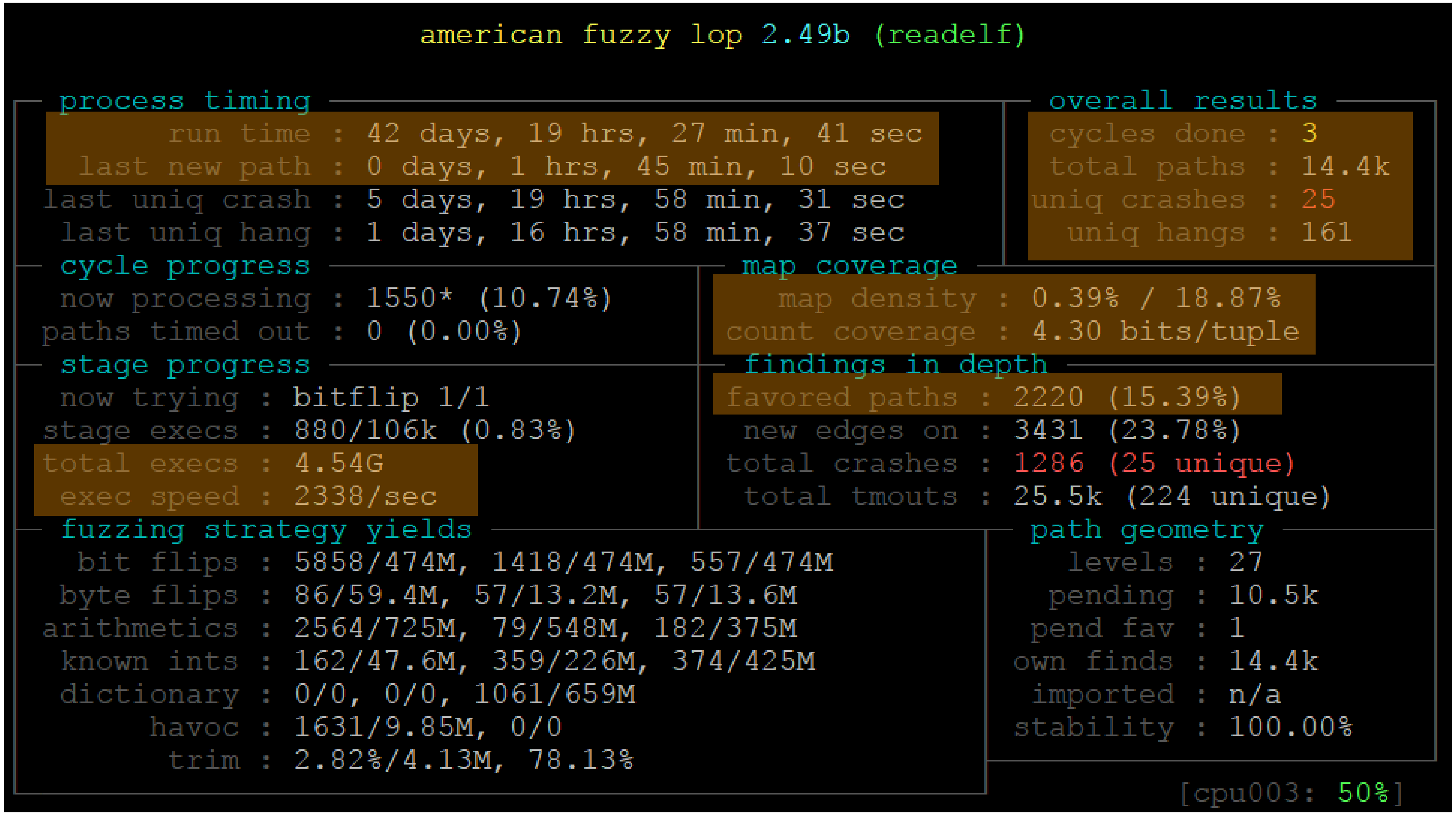
Practice: Lection 1

Topic: Lection 1 – Simple AFL fuzzing

Duration: 5 – 10 min

Description: Try AFL in action with a simple and small target.

AFL Status Screen



```
                 american fuzzy lop 2.49b (readelf)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 42 days, 19 hrs, 27 min, 41 sec    │  cycles done : 3      │
│   last new path : 0 days, 1 hrs, 45 min, 10 sec      │  total paths : 14.4k  │
│ last uniq crash : 5 days, 19 hrs, 58 min, 31 sec     │ uniq crashes : 25     │
│  last uniq hang : 1 days, 16 hrs, 58 min, 37 sec     │   uniq hangs : 161    │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 1550* (10.74%)    │    map density : 0.39% / 18.87%        │
│ paths timed out : 0 (0.00%)         │ count coverage : 4.30 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : bitflip 1/1           │ favored paths : 2220 (15.39%)          │
│ stage execs : 880/106k (0.83%)      │  new edges on : 3431 (23.78%)          │
│ total execs : 4.54G                 │ total crashes : 1286 (25 unique)       │
│  exec speed : 2338/sec              │  total tmouts : 25.5k (224 unique)     │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 5858/474M, 1418/474M, 557/474M        │    levels : 27         │
│  byte flips : 86/59.4M, 57/13.2M, 57/13.6M          │   pending : 10.5k      │
│ arithmetics : 2564/725M, 79/548M, 182/375M          │  pend fav : 1          │
│  known ints : 162/47.6M, 359/226M, 374/425M         │ own finds : 14.4k      │
│  dictionary : 0/0, 0/0, 1061/659M                   │  imported : n/a        │
│       havoc : 1631/9.85M, 0/0                       │ stability : 100.00%    │
│        trim : 2.82%/4.13M, 78.13%                   ├────────────────────────┘
└─────────────────────────────────────────────────────┘          [cpu003: 50%]
```

Input Corpus

- We can either start fuzzing with an empty input folder or with downloaded / generated input files

- **Empty file:**
    - Let AFL identify the complete format (unknown target binaries)
    - Downside: Can be very slow

- **Downloaded sample files:**
    - Much faster because AFL doesn‘t have to find the file format structure itself
    - Bing API to crawl the web (Hint: Don‘t use DNS of your provider …)
    - Other good sources: Unit-tests, bug report pages, …
    - Problem: Many sample files execute the same code ➔ **Corpus Distillation**

Example

- **Example:** Let's say we want to fuzz LIEF (Library to Instrument Executable Formats from Quarkslab) with PE files
  - Our real goal: Generate a good PE-corpus which we can use for fuzzing AntiVirus engines (therefore we first fuzz different open source PE libraries)
  - Side note: LIEF is a very powerful PE library and my first choice in PE libraries! That's why I have chosen it as target here!

- **Step 1: Get possible input files:**
  - Write a python script to grab all small .exe / .dll / .sys / … files from a workstation (execute it on Windows XP, Vista, Win7, Win8.1, Win10, …)
  - Add public available corpus files: I found additional 2149 files on the internet
  - Result: Many thousand files

Example

- **Step 2: Recompile application with afl-gcc**
  - I modified the c++ “pe_reader” example to catch all exceptions (otherwise AFL would incorrectly identify thrown exceptions as crashes)
  - Export CC & CXX and call cmake / configure

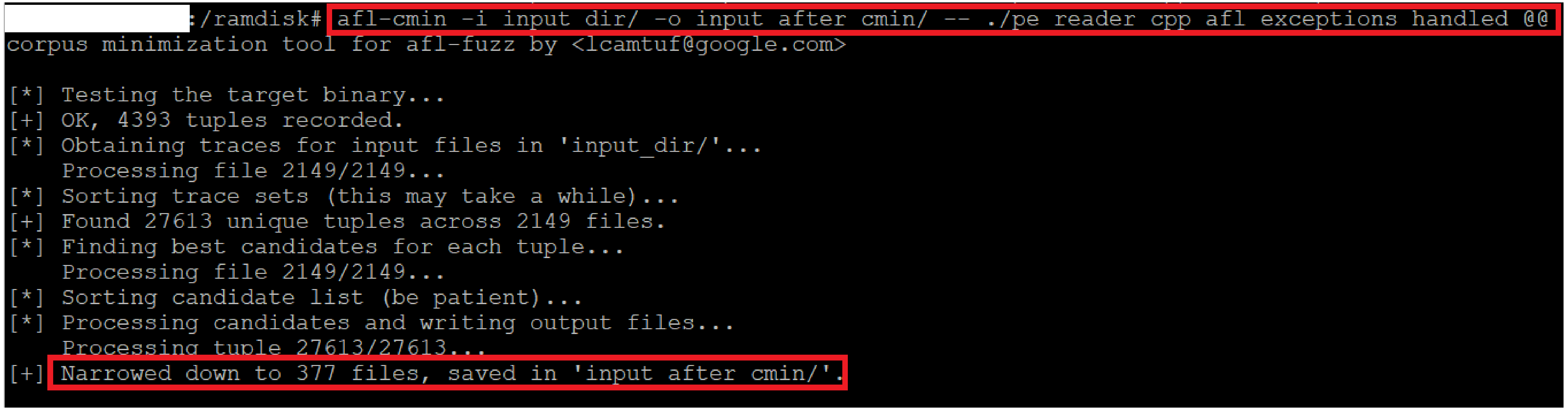
```
git clone https://github.com/lief-project/LIEF.git
cd LIEF
mkdir build;cd build
export CC=afl-gcc
export CXX=afl-g++
cmake -DPYTHON_VERSION=2.7 ..
make
```

Example

- **Step 3: Minimize the files to a small corpus (Corpus Distillation)**
  - Optional: Do everything on a RAM disk (e.g.: /dev/shm):

    ```
    mkdir /ramdisk
    mount -t tmpfs -o size=4G tmpfs /ramdisk
    ```

  - Example: The 2149 public files can be reduced to 377 files



```
[redacted]:/ramdisk# afl-cmin -i input_dir/ -o input_after_cmin/ -- ./pe_reader_cpp_afl_exceptions_handled @@
corpus minimization tool for afl-fuzz by <lcamtuf@google.com>

[*] Testing the target binary...
[+] OK, 4393 tuples recorded.
[*] Obtaining traces for input files in 'input_dir/'...
    Processing file 2149/2149...
[*] Sorting trace sets (this may take a while)...
[+] Found 27613 unique tuples across 2149 files.
[*] Finding best candidates for each tuple...
    Processing file 2149/2149...
[*] Sorting candidate list (be patient)...
[*] Processing candidates and writing output files...
    Processing tuple 27613/27613...
[+] Narrowed down to 377 files, saved in 'input_after_cmin/'.
```

Example

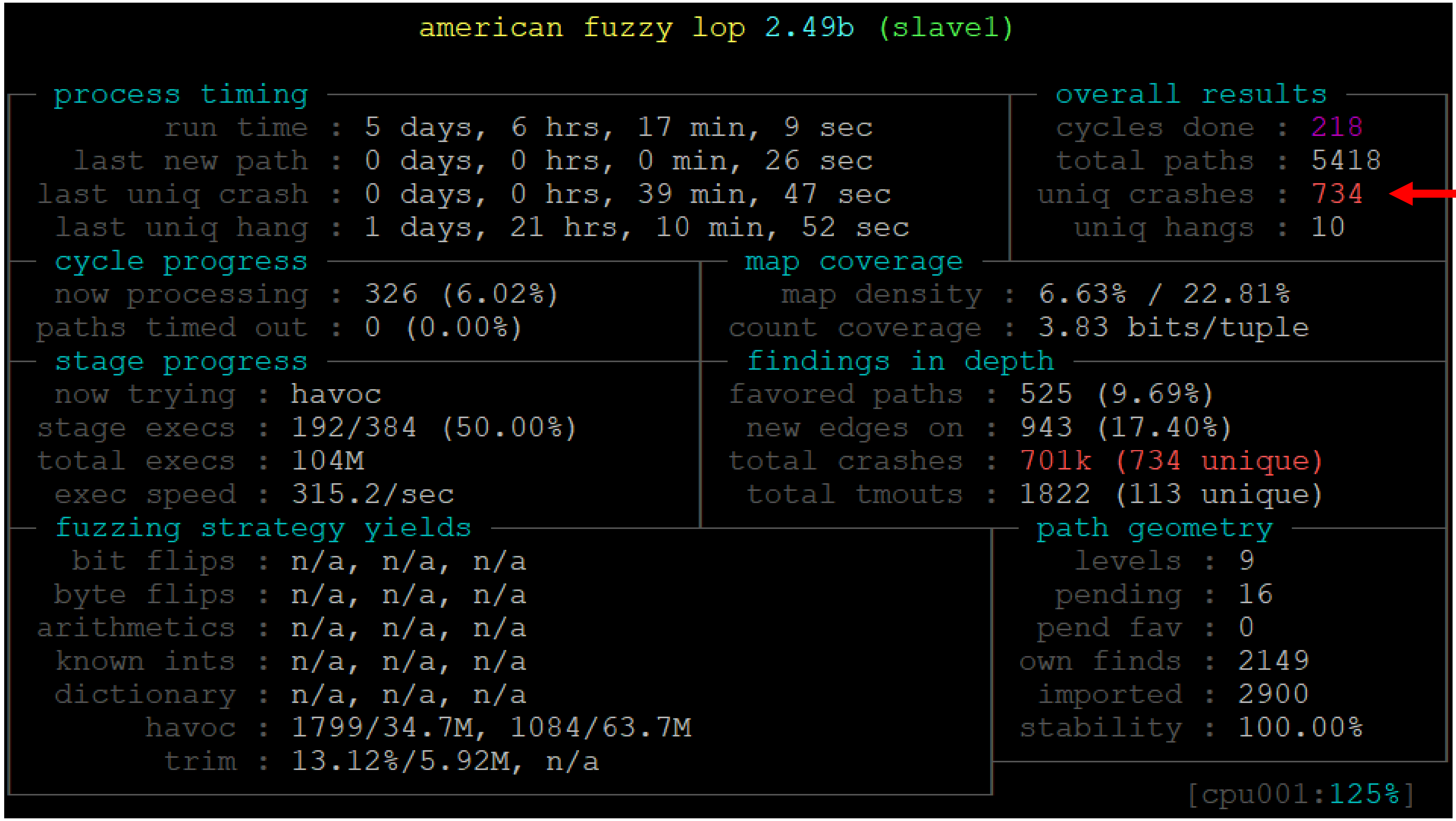
- **Step 4: Minimize file size of the files in the corpus**
  - Not very efficient in the case of PE files (byte removal / modification lead to invalid checksum ➔ different executed code ➔ AFL-tmin can’t reduce it)
  - For example: In total the filesize of all 377 files together was just reduced by 400 KB

```
./afl-tmin -i testcase_file -o testcase_out_file
-- /path/to/tested/program [...program's cmdline...] @@
```

- **Step 5: Start fuzzing**

```
afl-fuzz -i input_after_tmin -o output/ -M master -- ./pe_reader @@
afl-fuzz -i input_after_tmin -o output/ -S slave1 -- ./pe_reader @@
```

Example



```
                     american fuzzy lop 2.49b (slave1)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 5 days, 6 hrs, 17 min, 9 sec       │  cycles done : 218    │
│   last new path : 0 days, 0 hrs, 0 min, 26 sec       │  total paths : 5418   │
│ last uniq crash : 0 days, 0 hrs, 39 min, 47 sec      │ uniq crashes : 734    │
│  last uniq hang : 1 days, 21 hrs, 10 min, 52 sec     │   uniq hangs : 10     │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 326 (6.02%)       │    map density : 6.63% / 22.81%       │
│ paths timed out : 0 (0.00%)         │ count coverage : 3.83 bits/tuple      │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc                 │ favored paths : 525 (9.69%)           │
│ stage execs : 192/384 (50.00%)      │  new edges on : 943 (17.40%)          │
│ total execs : 104M                  │ total crashes : 701k (734 unique)     │
│  exec speed : 315.2/sec             │  total tmouts : 1822 (113 unique)     │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : n/a, n/a, n/a                         │    levels : 9          │
│  byte flips : n/a, n/a, n/a                         │   pending : 16         │
│ arithmetics : n/a, n/a, n/a                         │  pend fav : 0          │
│  known ints : n/a, n/a, n/a                         │ own finds : 2149       │
│  dictionary : n/a, n/a, n/a                         │  imported : 2900       │
│       havoc : 1799/34.7M, 1084/63.7M                │ stability : 100.00%    │
│        trim : 13.12%/5.92M, n/a                     ├────────────────────────┘
└─────────────────────────────────────────────────────┘          [cpu001:125%]
```

Side note: This are in reality only 2 (not exploita.) bugs in the code. (LIEF ships with LibFuzzer scripts!)

American Fuzzy Lop - AFL

Steps for fuzzing with AFL:

1. Remove input files with same functinality:
   Hint: Call it after tmin again (cmin is a heuristic)
   ```
   ./afl-cmin -i testcase_dir -o testcase_out_dir
   -- /path/to/tested/program [...program's cmdline...]
   ```

2. Reduce file size of input files:
   ```
   ./afl-tmin -i testcase_file -o testcase_out_file
   -- /path/to/tested/program [...program's cmdline...]
   ```

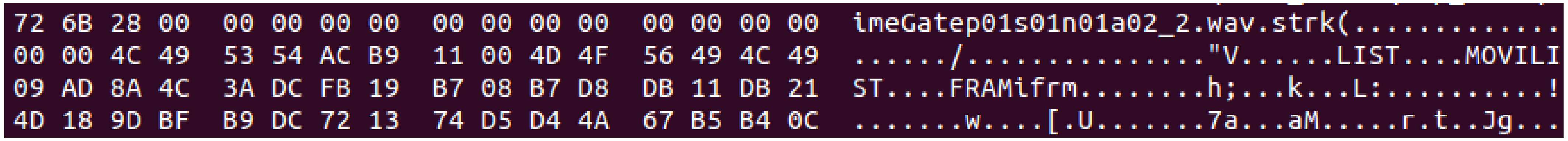
3. Start fuzzing:
   ```
   ./afl-fuzz -i testcase_dir -o findings_dir
   -- /path/to/tested/program [...program's cmdline...] @@
   ```

Real World example: CVE-2009-0385

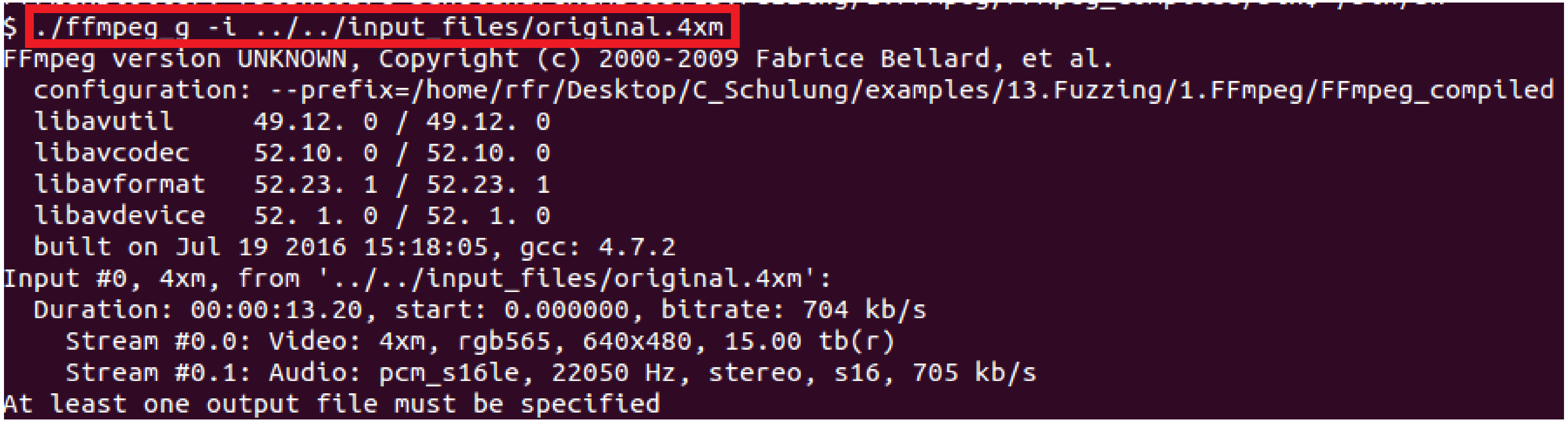
- Real world example
- CVE-2009-0385
- Vulnerability from 2009 in FFMPEG
  - Vulnerability in parsing .4xm files
- More information (on exploit development) can be found in “A bug hunter’s diary” chapter 5

Real World example: CVE-2009-0385

- Input .4xm file (with video & audio stream):



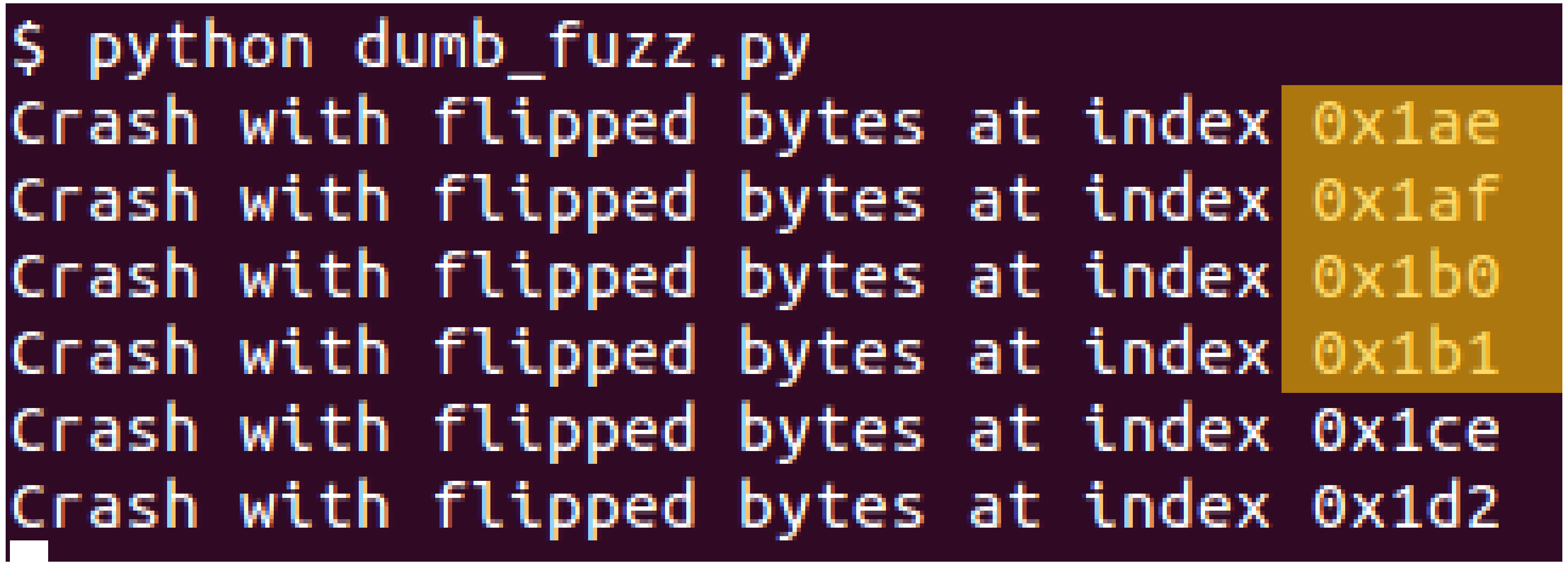
```
72 6B 28 00  00 00 00 00  00 00 00 00  00 00 00 00  imeGatep01s01n01a02_2.wav.strk(............
00 00 4C 49  53 54 AC B9  11 00 4D 4F  56 49 4C 49  ....../..............."V......LIST....MOVILI
09 AD 8A 4C  3A DC FB 19  B7 08 B7 D8  DB 11 DB 21  ST....FRAMifrm........h;...k...L:..........!
4D 18 9D BF  B9 DC 72 13  74 D5 D4 4A  67 B5 B4 0C  .......w....[.U.......7a...aM.....r.t..Jg...
```



```
$ ./ffmpeg_g -i ../../input_files/original.4xm
FFmpeg version UNKNOWN, Copyright (c) 2000-2009 Fabrice Bellard, et al.
  configuration: --prefix=/home/rfr/Desktop/C_Schulung/examples/13.Fuzzing/1.FFmpeg/FFmpeg_compiled
  libavutil     49.12. 0 / 49.12. 0
  libavcodec    52.10. 0 / 52.10. 0
  libavformat   52.23. 1 / 52.23. 1
  libavdevice   52. 1. 0 / 52. 1. 0
  built on Jul 19 2016 15:18:05, gcc: 4.7.2
Input #0, 4xm, from '../../input_files/original.4xm':
  Duration: 00:00:13.20, start: 0.000000, bitrate: 704 kb/s
    Stream #0.0: Video: 4xm, rgb565, 640x480, 15.00 tb(r)
    Stream #0.1: Audio: pcm_s16le, 22050 Hz, stereo, s16, 705 kb/s
At least one output file must be specified
```

Real World example: CVE-2009-0385

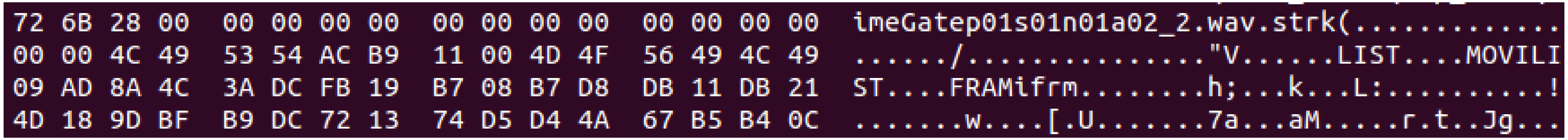
- Dumb fuzzer:



```
$ python dumb_fuzz.py
Crash with flipped bytes at index 0x1ae
Crash with flipped bytes at index 0x1af
Crash with flipped bytes at index 0x1b0
Crash with flipped bytes at index 0x1b1
Crash with flipped bytes at index 0x1ce
Crash with flipped bytes at index 0x1d2
```

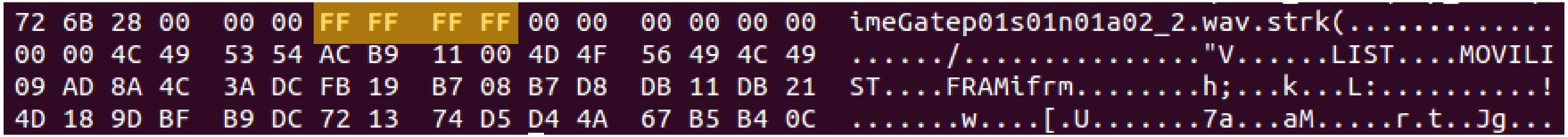
Real World example: CVE-2009-0385

- Original:



```
72 6B 28 00  00 00 00 00  00 00 00 00  00 00 00 00  imeGatep01s01n01a02_2.wav.strk(............
00 00 4C 49  53 54 AC B9  11 00 4D 4F  56 49 4C 49  ....../..............."V......LIST....MOVILI
09 AD 8A 4C  3A DC FB 19  B7 08 B7 D8  DB 11 DB 21  ST....FRAMifrm........h;...k...L:..........!
4D 18 9D BF  B9 DC 72 13  74 D5 D4 4A  67 B5 B4 0C  .......w....[.U.......7a...aM.....r.t..Jg...
```

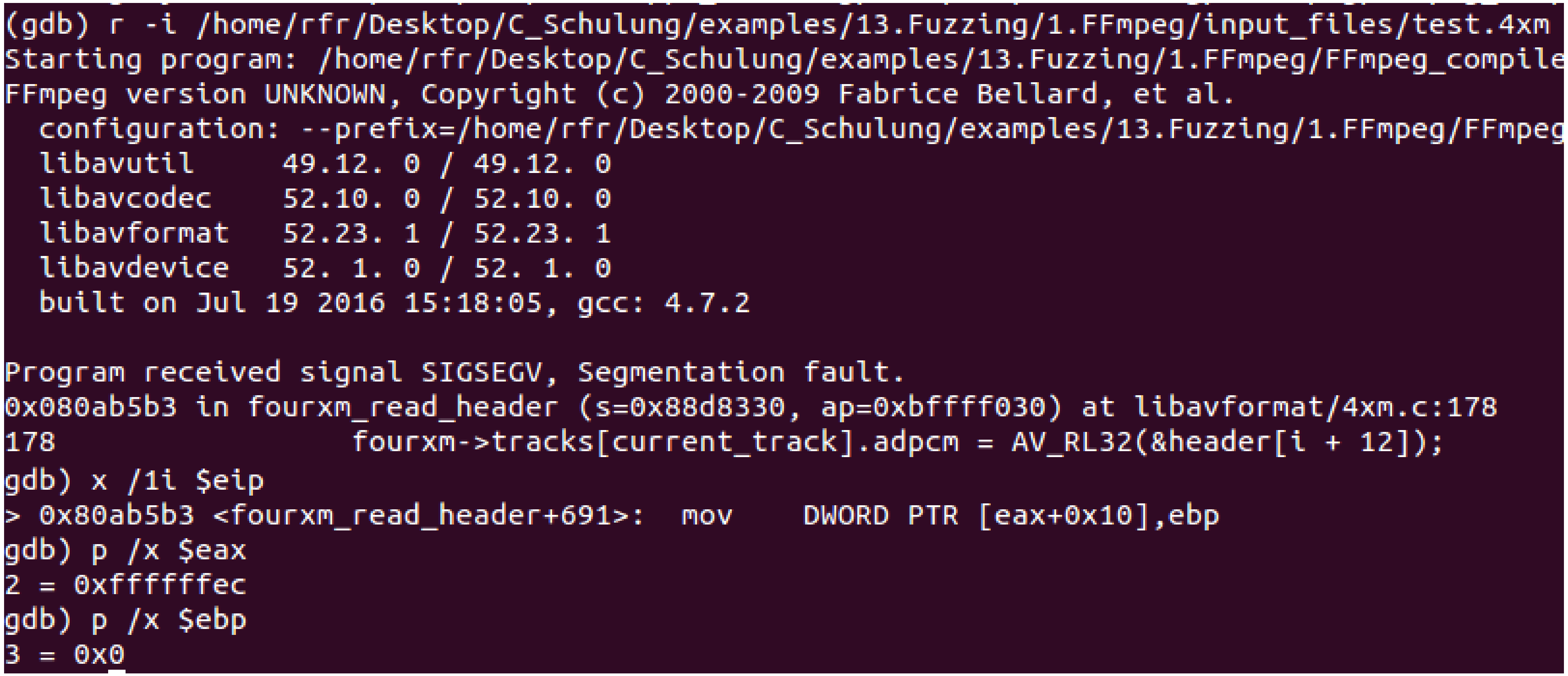
- Fuzzer found crash:



```
72 6B 28 00  00 00 FF FF  FF FF 00 00  00 00 00 00  imeGatep01s01n01a02_2.wav.strk(............
00 00 4C 49  53 54 AC B9  11 00 4D 4F  56 49 4C 49  ....../..............."V......LIST....MOVILI
09 AD 8A 4C  3A DC FB 19  B7 08 B7 D8  DB 11 DB 21  ST....FRAMifrm........h;...k...L:..........!
4D 18 9D BF  B9 DC 72 13  74 D5 D4 4A  67 B5 B4 0C  .......w....[.U.......7a...aM.....r.t..Jg...
```

Real World example: CVE-2009-0385

- Verify the crash in the debugger:

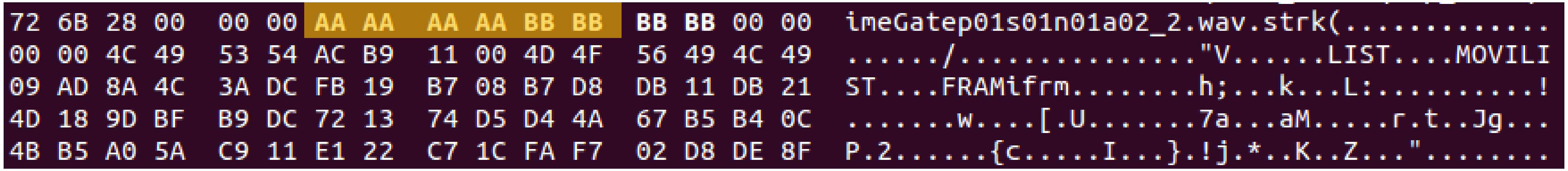


```
(gdb) r -i /home/rfr/Desktop/C_Schulung/examples/13.Fuzzing/1.FFmpeg/input_files/test.4xm
Starting program: /home/rfr/Desktop/C_Schulung/examples/13.Fuzzing/1.FFmpeg/FFmpeg_compile
FFmpeg version UNKNOWN, Copyright (c) 2000-2009 Fabrice Bellard, et al.
  configuration: --prefix=/home/rfr/Desktop/C_Schulung/examples/13.Fuzzing/1.FFmpeg/FFmpeg
  libavutil     49.12. 0 / 49.12. 0
  libavcodec    52.10. 0 / 52.10. 0
  libavformat   52.23. 1 / 52.23. 1
  libavdevice   52. 1. 0 / 52. 1. 0
  built on Jul 19 2016 15:18:05, gcc: 4.7.2

Program received signal SIGSEGV, Segmentation fault.
0x080ab5b3 in fourxm_read_header (s=0x88d8330, ap=0xbffff030) at libavformat/4xm.c:178
178                 fourxm->tracks[current_track].adpcm = AV_RL32(&header[i + 12]);
gdb) x /1i $eip
> 0x80ab5b3 <fourxm_read_header+691>:  mov    DWORD PTR [eax+0x10],ebp
gdb) p /x $eax
2 = 0xffffffec
gdb) p /x $ebp
3 = 0x0
```

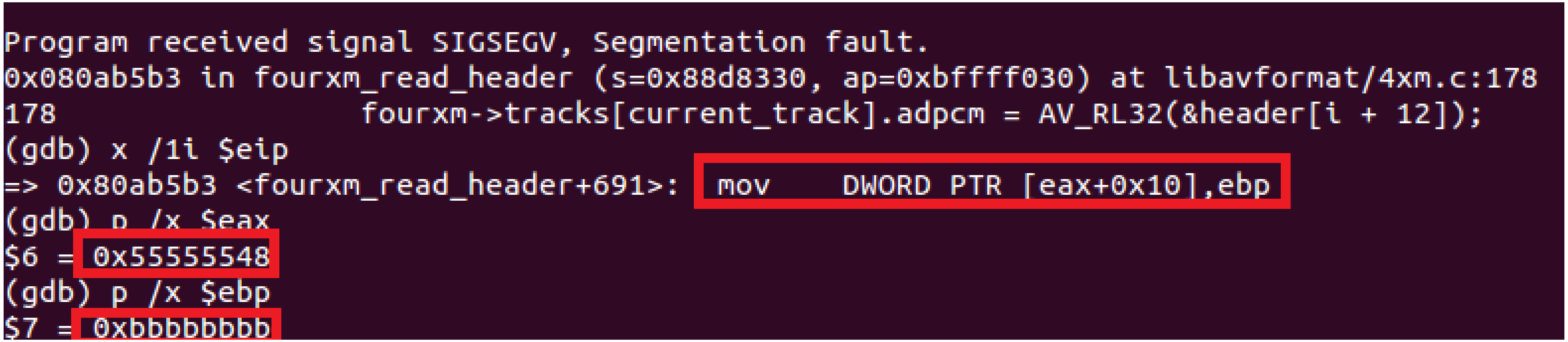
SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Real World example: CVE-2009-0385

- Attacker has a write-4 vulnerability (destination and value controlled):



```
72 6B 28 00  00 00 AA AA  AA AA BB BB  BB BB 00 00  imeGatep01s01n01a02_2.wav.strk(............
00 00 4C 49  53 54 AC B9  11 00 4D 4F  56 49 4C 49  ....../..............."V......LIST....MOVILI
09 AD 8A 4C  3A DC FB 19  B7 08 B7 D8  DB 11 DB 21  ST....FRAMifrm........h;...k...L:..........!
4D 18 9D BF  B9 DC 72 13  74 D5 D4 4A  67 B5 B4 0C  .......w....[.U........7a...aM.....r.t..Jg...
4B B5 A0 5A  C9 11 E1 22  C7 1C FA F7  02 D8 DE 8F  P.2......{c.....I...}.!j.*..K..Z..."........
```

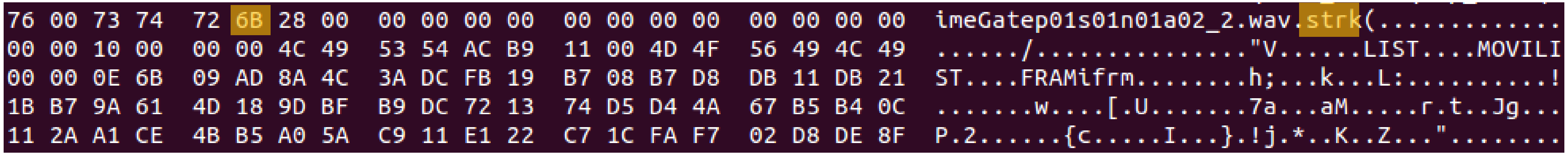


```
Program received signal SIGSEGV, Segmentation fault.
0x080ab5b3 in fourxm_read_header (s=0x88d8330, ap=0xbffff030) at libavformat/4xm.c:178
178                     fourxm->tracks[current_track].adpcm = AV_RL32(&header[i + 12]);
(gdb) x /1i $eip
=> 0x80ab5b3 <fourxm_read_header+691>:  mov    DWORD PTR [eax+0x10],ebp
(gdb) p /x $eax
$6 = 0x55555548
(gdb) p /x $ebp
$7 = 0xbbbbbbbb
```

Real World example: CVE-2009-0385

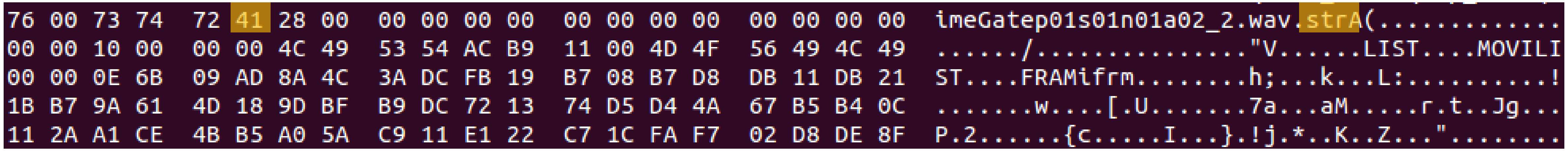
- Now assume we don’t have a valid 4xm file:

- Before modification:



```
76 00 73 74  72 6B 28 00  00 00 00 00  00 00 00 00  00 00 00 00  imeGatep01s01n01a02_2.wav.strk(............
00 00 10 00  00 00 4C 49  53 54 AC B9  11 00 4D 4F  56 49 4C 49  ....../................"V......LIST....MOVILI
00 00 0E 6B  09 AD 8A 4C  3A DC FB 19  B7 08 B7 D8  DB 11 DB 21  ST....FRAMifrm........h;...k...L:..........!
1B B7 9A 61  4D 18 9D BF  B9 DC 72 13  74 D5 D4 4A  67 B5 B4 0C  .......w....[.U.......7a...aM.....r.t..Jg...
11 2A A1 CE  4B B5 A0 5A  C9 11 E1 22  C7 1C FA F7  02 D8 DE 8F  P.2......{c.....I...}.!j.*..K..Z..."........
```

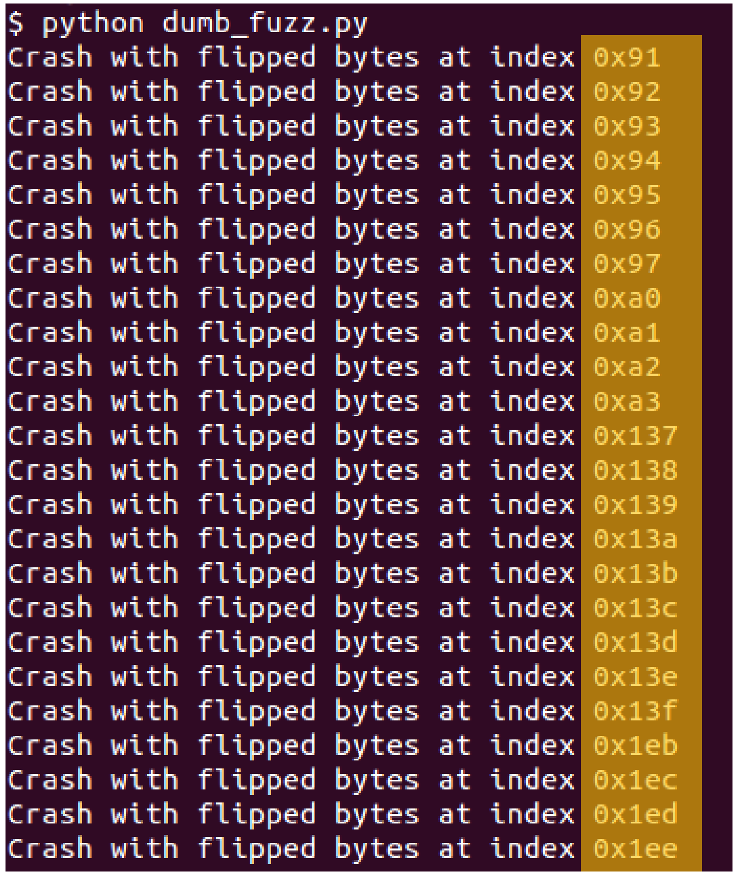
- After modification:



```
76 00 73 74  72 41 28 00  00 00 00 00  00 00 00 00  00 00 00 00  imeGatep01s01n01a02_2.wav.strA(............
00 00 10 00  00 00 4C 49  53 54 AC B9  11 00 4D 4F  56 49 4C 49  ....../................"V......LIST....MOVILI
00 00 0E 6B  09 AD 8A 4C  3A DC FB 19  B7 08 B7 D8  DB 11 DB 21  ST....FRAMifrm........h;...k...L:..........!
1B B7 9A 61  4D 18 9D BF  B9 DC 72 13  74 D5 D4 4A  67 B5 B4 0C  .......w....[.U.......7a...aM.....r.t..Jg...
11 2A A1 CE  4B B5 A0 5A  C9 11 E1 22  C7 1C FA F7  02 D8 DE 8F  P.2......{c.....I...}.!j.*..K..Z..."........
```

Real World example: CVE-2009-0385

- ➔ The dumb fuzzer can't find the vulnerability anymore!



```
$ python dumb_fuzz.py
Crash with flipped bytes at index 0x91
Crash with flipped bytes at index 0x92
Crash with flipped bytes at index 0x93
Crash with flipped bytes at index 0x94
Crash with flipped bytes at index 0x95
Crash with flipped bytes at index 0x96
Crash with flipped bytes at index 0x97
Crash with flipped bytes at index 0xa0
Crash with flipped bytes at index 0xa1
Crash with flipped bytes at index 0xa2
Crash with flipped bytes at index 0xa3
Crash with flipped bytes at index 0x137
Crash with flipped bytes at index 0x138
Crash with flipped bytes at index 0x139
Crash with flipped bytes at index 0x13a
Crash with flipped bytes at index 0x13b
Crash with flipped bytes at index 0x13c
Crash with flipped bytes at index 0x13d
Crash with flipped bytes at index 0x13e
Crash with flipped bytes at index 0x13f
Crash with flipped bytes at index 0x1eb
Crash with flipped bytes at index 0x1ec
Crash with flipped bytes at index 0x1ed
Crash with flipped bytes at index 0x1ee
```

Many other crashes…
But not the real vulnerability at offset 0x1ae

Reason: In error case the code dereferences the pointer to the „strk“ chunk which is in this case NULL

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

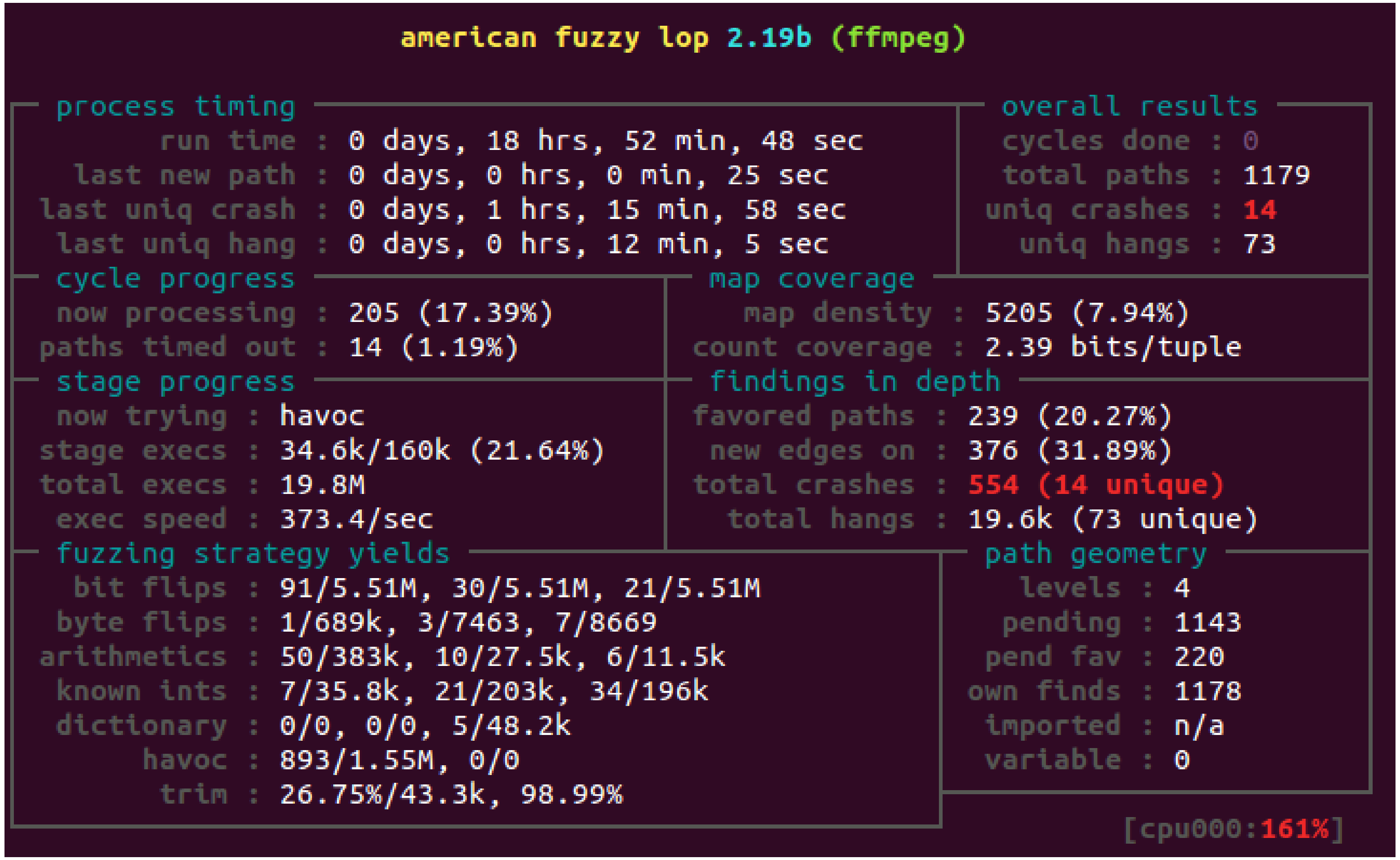
Practice: Lection 2

Topic: Lection 2 – Real World Fuzzing FFMPEG with AFL

Duration: 10 – 15 min

Description: Try to fuzz FFMPEG with AFL

AFL with CVE-2009-0385 (FFMPEG)

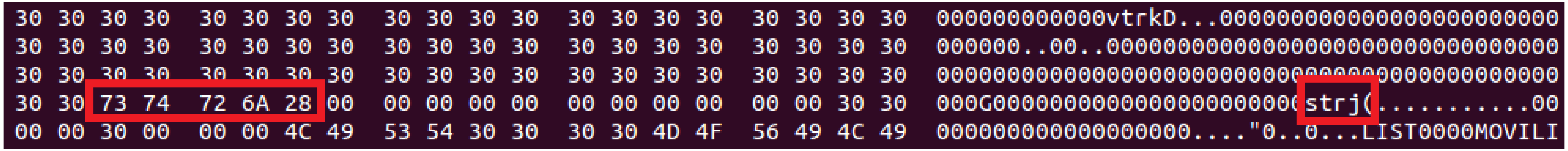


```
                    american fuzzy lop 2.19b (ffmpeg)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 18 hrs, 52 min, 48 sec      │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 0 min, 25 sec        │  total paths : 1179   │
│ last uniq crash : 0 days, 1 hrs, 15 min, 58 sec       │ uniq crashes : 14     │
│  last uniq hang : 0 days, 0 hrs, 12 min, 5 sec        │   uniq hangs : 73     │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 205 (17.39%)      │    map density : 5205 (7.94%)          │
│ paths timed out : 14 (1.19%)        │ count coverage : 2.39 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc                 │ favored paths : 239 (20.27%)           │
│ stage execs : 34.6k/160k (21.64%)   │  new edges on : 376 (31.89%)           │
│ total execs : 19.8M                 │ total crashes : 554 (14 unique)        │
│  exec speed : 373.4/sec             │   total hangs : 19.6k (73 unique)      │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 91/5.51M, 30/5.51M, 21/5.51M          │    levels : 4          │
│  byte flips : 1/689k, 3/7463, 7/8669                │   pending : 1143       │
│ arithmetics : 50/383k, 10/27.5k, 6/11.5k            │  pend fav : 220        │
│  known ints : 7/35.8k, 21/203k, 34/196k             │ own finds : 1178       │
│  dictionary : 0/0, 0/0, 5/48.2k                     │  imported : n/a        │
│       havoc : 893/1.55M, 0/0                        │  variable : 0          │
│        trim : 26.75%/43.3k, 98.99%                  ├────────────────────────┘
└─────────────────────────────────────────────────────┘          [cpu000:161%]
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

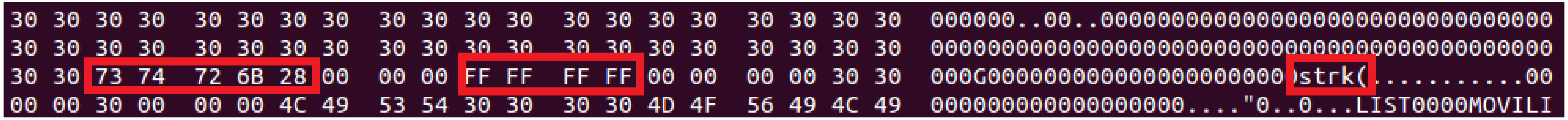
AFL with CVE-2009-0385 (FFMPEG)

- AFL input with invalid 4xm file (strk chunk changed to strj)



```
30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  000000000000vtrkD...000000000000000000000000
30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  000000..00..0000000000000000000000000000000
30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  00000000000000000000000000000000000000000000
30 30 73 74  72 6A 28 00  00 00 00 00  00 00 00 00  00 00 30 30  000G0000000000000000000000strj(..........00
00 00 30 00  00 00 4C 49  53 54 30 30  30 30 4D 4F  56 49 4C 49  000000000000000000...."0..0...LIST0000MOVILI
```

- AFL still finds the vulnerability!
    - Level 1 identifies correct “strk” chunk
    - Level 2 based on level 1 output AFL finds the vulnerability (triggered by 0xffffffff)



```
30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  000000..00..0000000000000000000000000000000
30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  30 30 30 30  00000000000000000000000000000000000000000000
30 30 73 74  72 6B 28 00  00 00 FF FF  FF FF 00 00  00 00 30 30  000G000000000000000000000000strk(..........00
00 00 30 00  00 00 4C 49  53 54 30 30  30 30 4D 4F  56 49 4C 49  000000000000000000...."0..0...LIST0000MOVILI
```

Crash Triage

- **Some hints on analyzing exploitability / root cause:**

- First command to execute when the application crashes is:
    - x /2i $rip
        - X… examine ➔ print something at the given location ($rip in our case)
        - $rip … instruction pointer ➔ the current instruction
        - /2i … print 2 times data interpreted as instruction

    - Now we see which instruction resulted in a crash and the next step is to understand why it crashed

Crash Triage

- **Examples:**
  - `Mov dword ptr [rcx+0x20], eax`
  - `Mov rbx, qword ptr [rax]`
    - Every time you see [and] it means that we read/write from RAM memory ➔ In most cases the address inside the brackets is therefore wrong and resulted in a crash. So we would analyze rcx and rax in the above outputs: p /x $rcx ; p /x $rax
    - In many cases you can control rcx or rax (e.g: it contains 0x414141..) then you maybe have an arbitrary read or write. In other cases you may have a relative read/write and in other cases it contains a fixed address which can't be accessed (which can indicate a use-after-free bug)
    - In many other cases rcx or rax is just zero which resulted in a null pointer exception (because our input didn't initialized it); This is in most cases not exploitable

Crash Triage

- Examples:
    - `=> 0x4141414141414141: Cannot access memory at address 0x4141414141414141`
        - This means $rip points to 0x4141… and therefore we had most likely a stack based buffer overflow and overwrote the return address on the stack
    - `ret`
        - Sometimes you directly crash at the “ret” instruction (which is basically a “pop rip”) if the return address is invalid. This for example is the case in ARM gdb.
    - `inc eax`
        - No obvious reason how this instruction could crash. This often occurs if $rip points to a memory region which is not marked as executable (DEP/NX protection). Therefore “inc eax” is stored in such a region. To verify you can type “shell”, then “pidof <applicationName” and then check: cat /proc/<PID>maps if the memory range is executable or not.

Crash Triage

- Examples:
  - `leave`
    - A little bit more tricky: leave is the same as “mov esp, ebp ; pop ebp”. The move instruction cannot crash (if it’s in an executable memory range), therefore “pop ebp” must crash. Pop ebp reads from the stack (where ESP points to)
  - `<vfprintf> mov dword ptr [rax], r9d`
    - Since the crash occurred in a standard function (vfprintf) it often helps to check the stack backtrace with “backtrace”. Check the last function call in the application ➔ Arguments to the library function are very likely incorrect.

Crash Triage

- We use **CrashWalk from Ben Nagy for Crash Triage (crash analysis)**
  - https://github.com/bnagy/crashwalk
  - Cwtriage --root afl_output –afl
  - Cwdump ./crashwalk.db
  - Cwfind <crash hash>

- GDB / WinDbg Plugin !exploitable

- Another great possibility on Windows is the BugId tool by SkyLined
  - https://github.com/SkyLined/BugId

- Symbolic execution can also help in triage
  - For example: SymGDB, Triton, PONCE, Moflow tools

Practice: Lection 3

Topic: Lection 3 – FuzzGoat and Crash Triage

Duration: 5-10 min

Description: Learn to perform crash triage.

Edge vs. BasicBlock Coverage

- Instrumentation tracks **edge coverage**, injected code at every basic block:

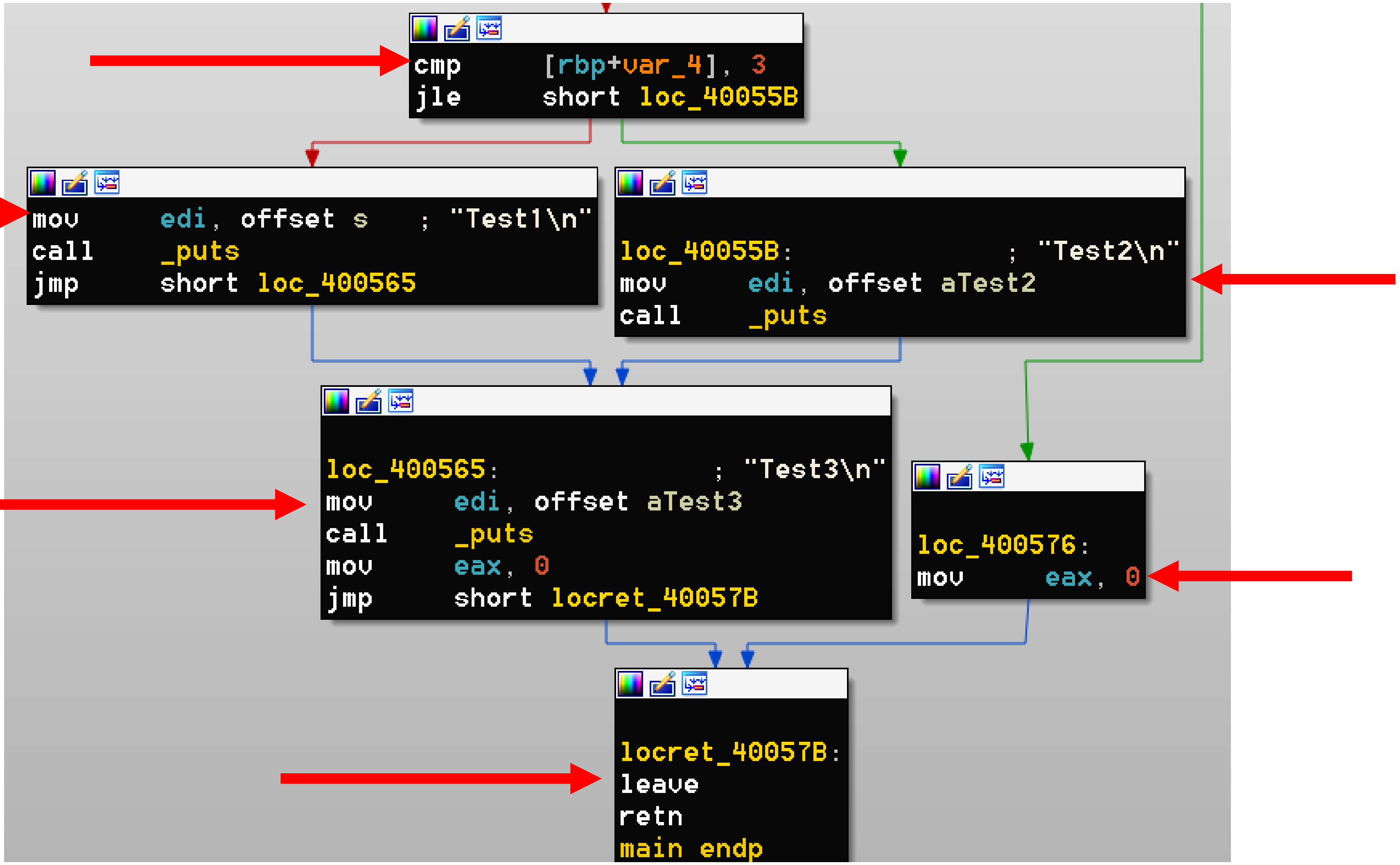
```
cur_location = <compile_time_random_value>;
bitmap[(cur_location ^ prev_location) % BITMAP_SIZE]++;
prev_location = cur_location >> 1;
```

➔ AFL can distinguish between

  - A->B->C->D->E (tuples: AB, BC, CD, DE)
  - A->B->D->C->E (tuples: AB, BD, DC, CE)

Feedback based fuzzing

- **Basic Blocks:**



```
cmp     [rbp+var_4], 3
jle     short loc_40055B
```

```
mov     edi, offset s    ; "Test1\n"
call    _puts
jmp     short loc_400565
```

```
loc_40055B:                 ; "Test2\n"
mov     edi, offset aTest2
call    _puts
```

```
loc_400565:                 ; "Test3\n"
mov     edi, offset aTest3
call    _puts
mov     eax, 0
jmp     short locret_40057B
```

```
loc_400576:
mov     eax, 0
```

```
locret_40057B:
leave
retn
main endp
```

Edge vs. BasicBlock Coverage

- Instrumentation tracks **edge coverage**, injected code at every basic block:

```
cur_location = <compile_time_random_value>;
bitmap[(cur_location ^ prev_location) % BITMAP_SIZE]++;
prev_location = cur_location >> 1;
```

➔ AFL can distinguish between

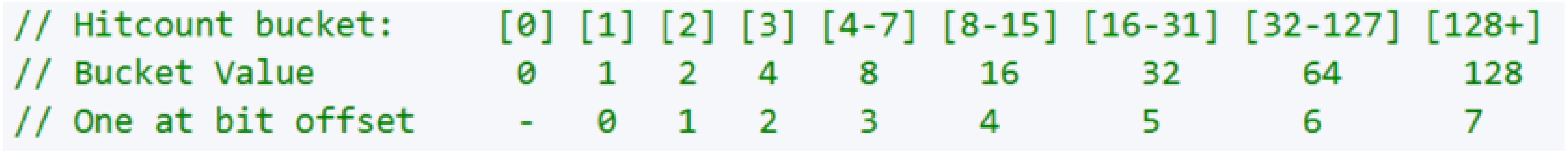
- A->B->C->D->E (tuples: AB, BC, CD, DE)
- A->B->D->C->E (tuples: AB, BD, DC, CE)

➔ Without shifting A->B and B->A are indistinguishable

Edge vs. BasicBlock Coverage

- AFL receives after every iteration a “coverage_map”.
    - Every byte in the map represents a hitcount for an edge (or basic block)

- Hitcounts are translated to bucket indexes to mark a unique edge + hitcount combination with one bit!

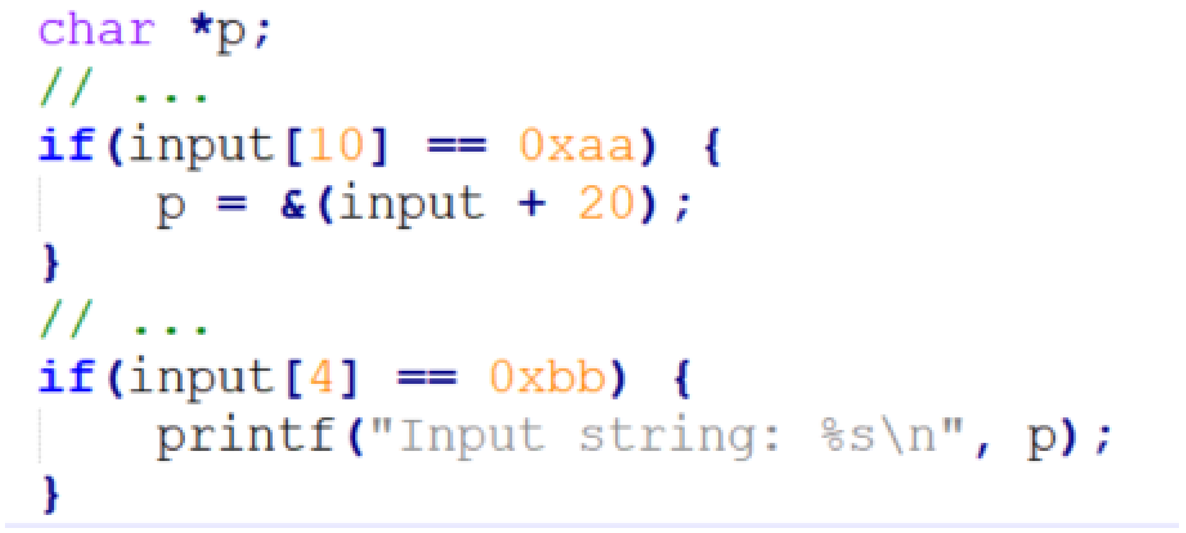


```
// Hitcount bucket:     [0] [1] [2] [3] [4-7] [8-15] [16-31] [32-127] [128+]
// Bucket Value          0   1   2   4    8     16      32       64      128
// One at bit offset     -   0   1   2    3     4       5        6       7
```

- ➔ A global coverage map stores information about the already seen coverage by doing an AND after every iteration. If one iteration has at one bit a 1 where the global coverage map stores a 0 new behavior is detected ➔ Very fast check for new behavior!

Edge vs. BasicBlock Coverage

- Consider the following code; Our input file has 0xaa at offset 10, 0x00 at all other positions



```
char *p;
// ...
if(input[10] == 0xaa) {
    p = &(input + 20);
}
// ...
if(input[4] == 0xbb) {
    printf("Input string: %s\n", p);
}
```

- BasicBlock Coverage: Vulnerability (uninitialized variable) will not be found (or very late)
- Edge Coverage: Vulnerability will be found because input will be mutated to not contain 0xaa at offset 10 (This input will be added to the queue)

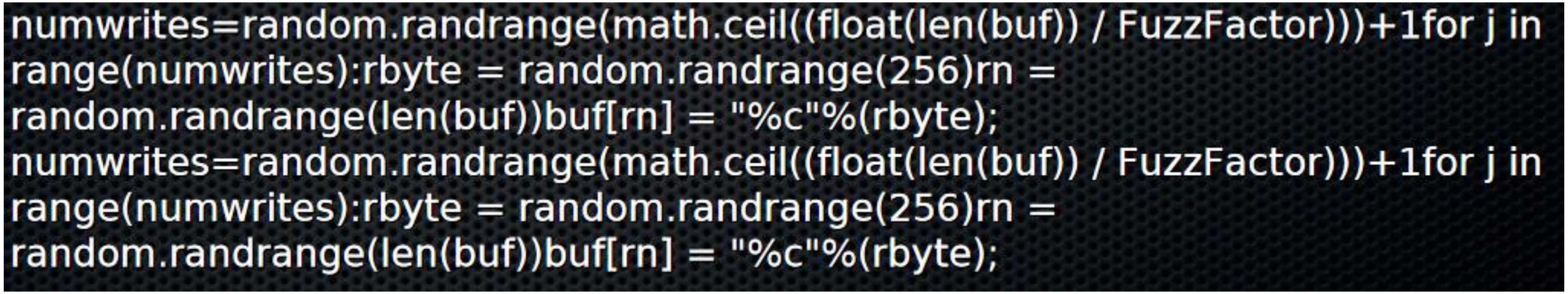
Some public fuzzing numbers

Some public fuzzing numbers

- **Example:** Talk by Charlie Miller from 2010 „Babysitting an Army of Monkeys“
- Fuzzed Adobe Reader, PPT, OpenOffice, Preview
- Strategy: Dumb fuzzing
  - **Download** many input files (**PDF 80 000 files**)
  - **Minimal corpus** of input files with valgrind (**PDF 1515 files**)
  - Measure CPU to know when file parsing ended
  - Only change bytes (no adding / removing)
  - Simple fuzzer in 5 LoC

Some public fuzzing numbers

Fuzzer:



```
numwrites=random.randrange(math.ceil((float(len(buf)) / FuzzFactor)))+1for j in
range(numwrites):rbyte = random.randrange(256)rn =
random.randrange(len(buf))buf[rn] = "%c"%(rbyte);
numwrites=random.randrange(math.ceil((float(len(buf)) / FuzzFactor)))+1for j in
range(numwrites):rbyte = random.randrange(256)rn =
random.randrange(len(buf))buf[rn] = "%c"%(rbyte);
```

Source: Charlie Miller „Babysitting an Army of Monkeys“

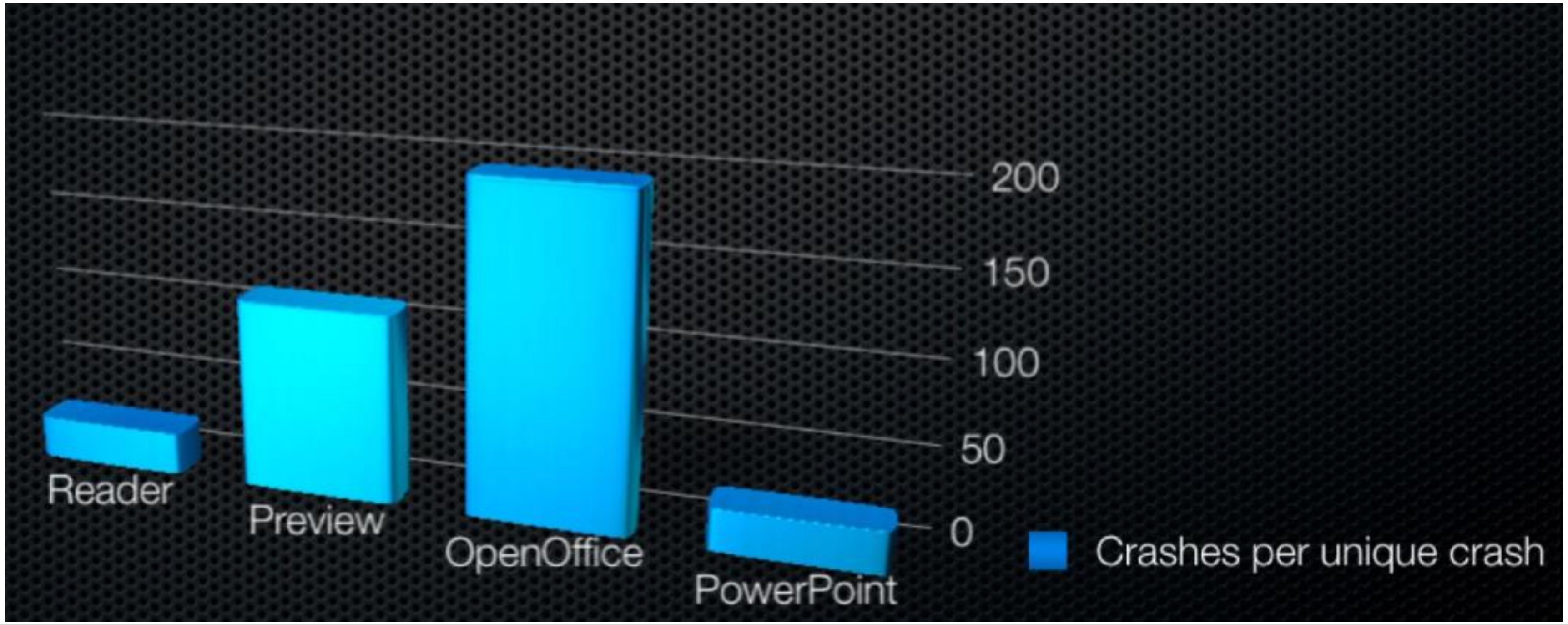
Some public fuzzing numbers

Results:

- 3 months fuzzing
- 7 Million Iterations

Crashes with unique EIP:

Source: Charlie Miller „Babysitting an Army of Monkeys“



Some public fuzzing numbers

Other numbers from Jaanus Kääp:

- https://nordictestingdays.eu/files/files/jaanus_kaap_fuzzing.pdf
- Code coverage for minset calculation (no edge coverage because of speed)
- PDF → initial set 400 000 files → Corpus 1217 files
- DOC → initial set 400 000 files → Corpus 1319 files
- DOCX → initial set 400 000 files → Corpus 2222 files

Some public fuzzing numbers

Google fuzzed Adobe Flash in 2011:

„What does **corpus distillation look like at Google scale?** Turns out we have a large index of the web, so we cranked through **20 terabytes of SWF file downloads** followed by **1 week of run time on 2,000 CPU cores** to calculate the **minimal set of about 20,000 files**. Finally, those same **2,000 cores plus 3 more weeks** of runtime were put to good work **mutating the files** in the minimal set (bitflipping, etc.) and generating crash cases. "

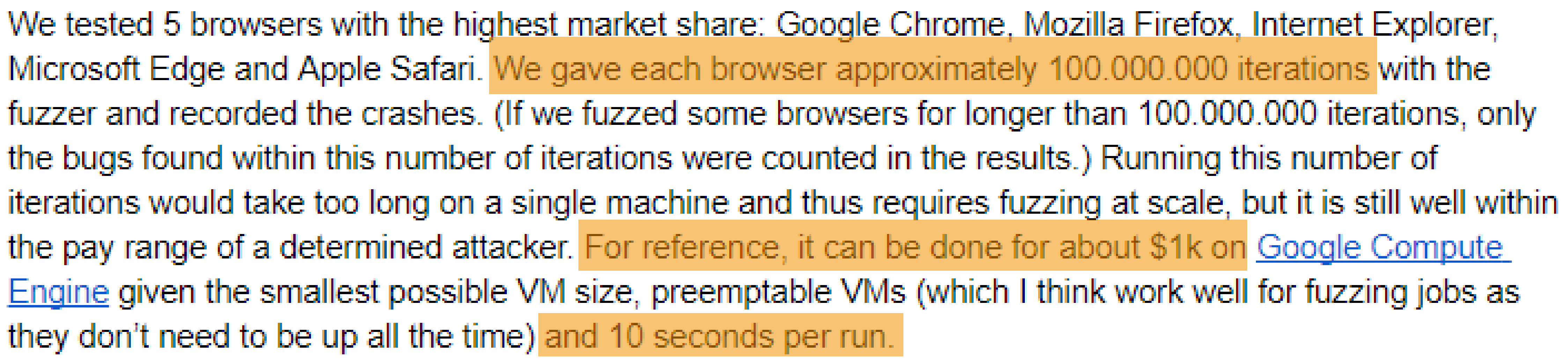
The initial run of the ongoing effort resulted in about **400 unique crash signatures**, which were logged as 106 individual security bugs following Adobe's initial triage.

- Source: https://security.googleblog.com/2011/08/fuzzing-at-scale.html

Some public fuzzing numbers

Google fuzzed the DOM of major browsers in 2017:

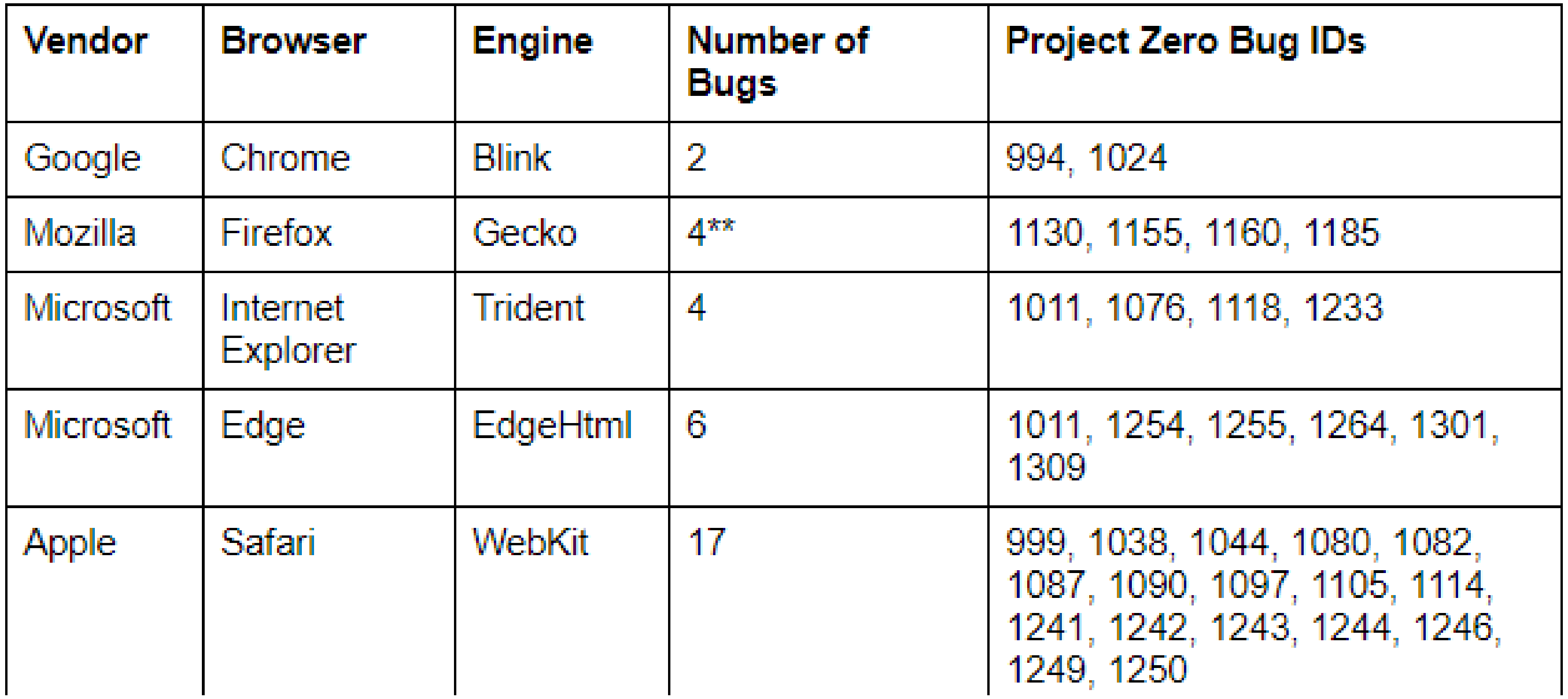
https://googleprojectzero.blogspot.co.at/2017/09/the-great-dom-fuzz-off-of-2017.html



We tested 5 browsers with the highest market share: Google Chrome, Mozilla Firefox, Internet Explorer, Microsoft Edge and Apple Safari. We gave each browser approximately 100.000.000 iterations with the fuzzer and recorded the crashes. (If we fuzzed some browsers for longer than 100.000.000 iterations, only the bugs found within this number of iterations were counted in the results.) Running this number of iterations would take too long on a single machine and thus requires fuzzing at scale, but it is still well within the pay range of a determined attacker. For reference, it can be done for about $1k on Google Compute Engine given the smallest possible VM size, preemptable VMs (which I think work well for fuzzing jobs as they don't need to be up all the time) and 10 seconds per run.

Some public fuzzing numbers

Google fuzzed the DOM of major browsers in 2017:



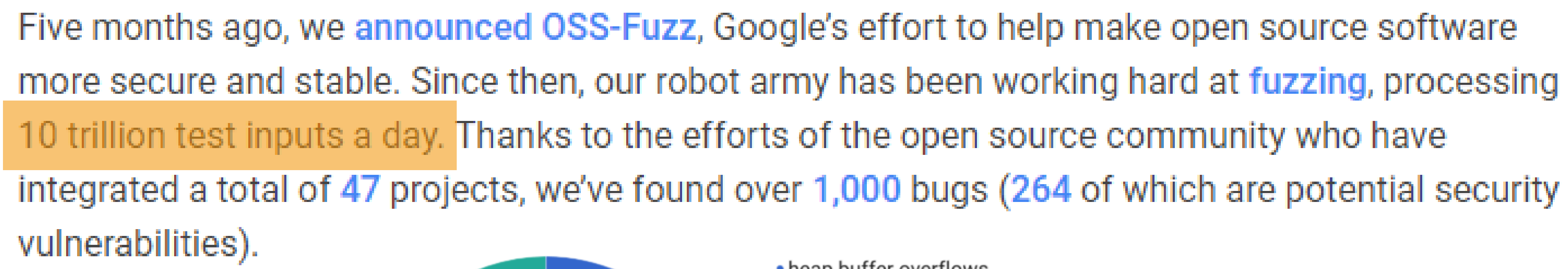
Vendor	Browser	Engine	Number of Bugs	Project Zero Bug IDs
Google	Chrome	Blink	2	994, 1024
Mozilla	Firefox	Gecko	4**	1130, 1155, 1160, 1185
Microsoft	Internet Explorer	Trident	4	1011, 1076, 1118, 1233
Microsoft	Edge	EdgeHtml	6	1011, 1254, 1255, 1264, 1301, 1309
Apple	Safari	WebKit	17	999, 1038, 1044, 1080, 1082, 1087, 1090, 1097, 1105, 1114, 1241, 1242, 1243, 1244, 1246, 1249, 1250

Source: https://googleprojectzero.blogspot.co.at/2017/09/the-great-dom-fuzz-off-of-2017.html

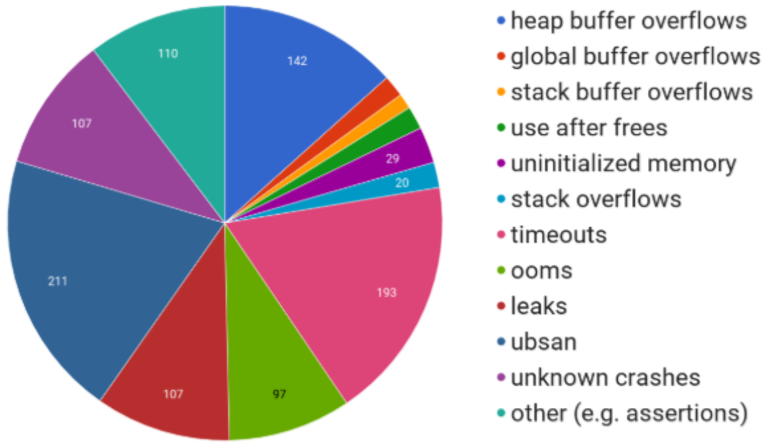
Some public fuzzing numbers

Google created OSS-Fuzz – Continuous Fuzzing for Open Source Software

https://opensource.googleblog.com/2017/05/oss-fuzz-five-months-later-and.html



Five months ago, we announced OSS-Fuzz, Google's effort to help make open source software more secure and stable. Since then, our robot army has been working hard at fuzzing, processing 10 trillion test inputs a day. Thanks to the efforts of the open source community who have integrated a total of 47 projects, we've found over 1,000 bugs (264 of which are potential security vulnerabilities).



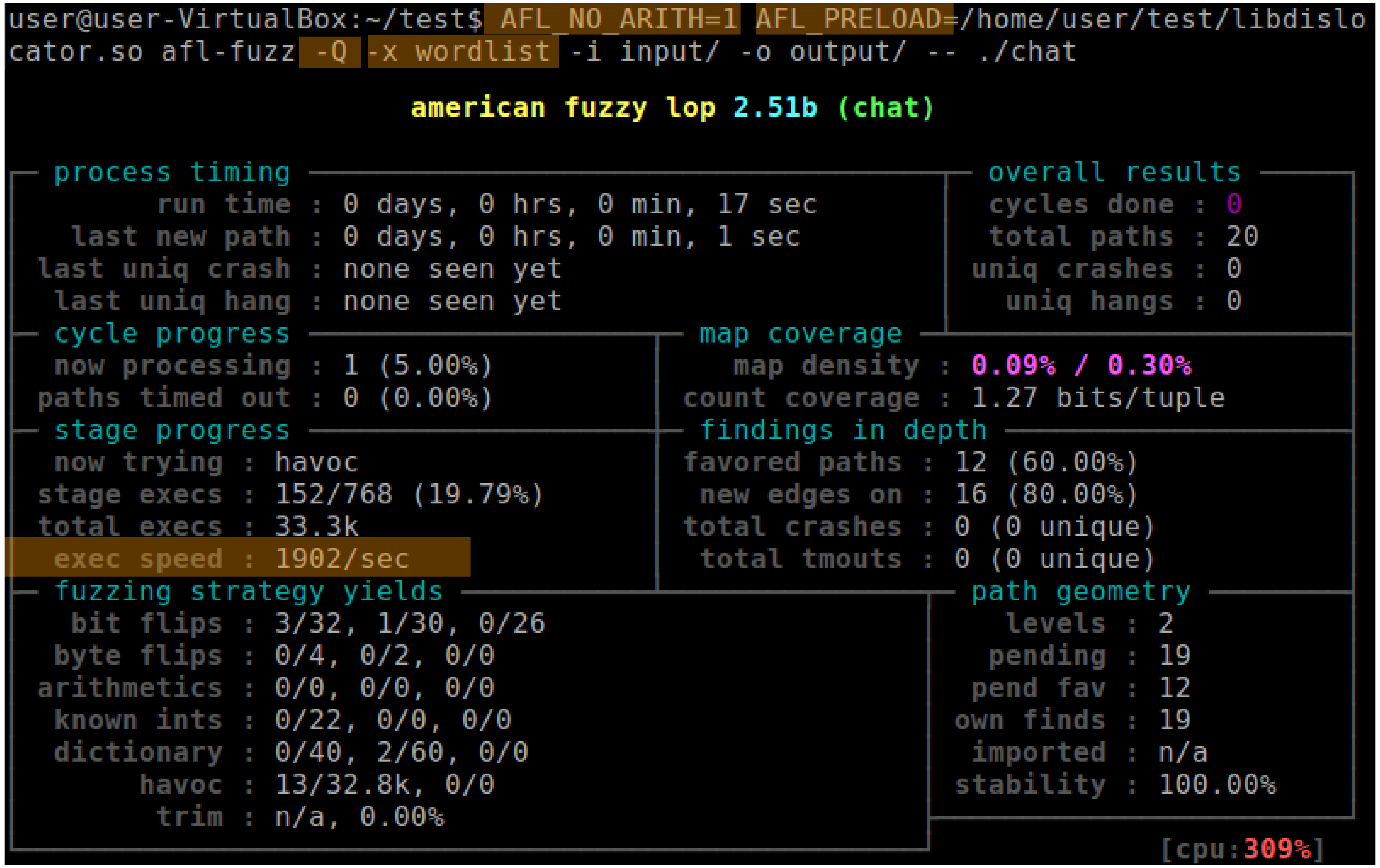
SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Methods to extract coverage feedback

Methods to measure code-coverage

1. Instrumentation during compilation (source code available; gcc or llvm → AFL)
2. Emulation of binary (e.g. with qemu)

AFL qemu mode



```
user@user-VirtualBox:~/test$ AFL_NO_ARITH=1 AFL_PRELOAD=/home/user/test/libdislo
cator.so afl-fuzz -Q -x wordlist -i input/ -o output/ -- ./chat

                    american fuzzy lop 2.51b (chat)

┌─ process timing ─────────────────────────────────────┬─ overall results ────┐
│        run time : 0 days, 0 hrs, 0 min, 17 sec       │  cycles done : 0     │
│   last new path : 0 days, 0 hrs, 0 min, 1 sec        │  total paths : 20    │
│ last uniq crash : none seen yet                      │ uniq crashes : 0     │
│  last uniq hang : none seen yet                      │   uniq hangs : 0     │
├─ cycle progress ────────────────────┬─ map coverage ─┴──────────────────────┤
│  now processing : 1 (5.00%)         │    map density : 0.09% / 0.30%        │
│ paths timed out : 0 (0.00%)         │ count coverage : 1.27 bits/tuple      │
├─ stage progress ────────────────────┼─ findings in depth ───────────────────┤
│  now trying : havoc                 │ favored paths : 12 (60.00%)           │
│ stage execs : 152/768 (19.79%)      │  new edges on : 16 (80.00%)           │
│ total execs : 33.3k                 │ total crashes : 0 (0 unique)          │
│  exec speed : 1902/sec              │  total tmouts : 0 (0 unique)          │
├─ fuzzing strategy yields ───────────┴───────────┬─ path geometry ───────────┤
│   bit flips : 3/32, 1/30, 0/26                  │    levels : 2             │
│  byte flips : 0/4, 0/2, 0/0                     │   pending : 19            │
│ arithmetics : 0/0, 0/0, 0/0                     │  pend fav : 12            │
│  known ints : 0/22, 0/0, 0/0                    │ own finds : 19            │
│  dictionary : 0/40, 2/60, 0/0                   │  imported : n/a           │
│       havoc : 13/32.8k, 0/0                     │ stability : 100.00%       │
│        trim : n/a, 0.00%                        ├───────────────────────────┘
└─────────────────────────────────────────────────┘          [cpu:309%]
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Practice: Lection 5

Topic: Lection 5 – AFL Qemu mode

Duration: 2-5 min

Description: Use Qemu mode to fuzz closed source binaries. Compare execution speed.

AFL Qemu mode

- Blogpost from 21-09-2018: **Improving AFL's qemu mode performance**
  - **From Andrea**, a BSc student at University of Padova!
  - https://abiondo.me/2018/09/21/improving-afl-qemu-mode/
  - His AFL fork: https://github.com/abiondo/afl
  - **Performance increase of 3x-4x times!**

- Basic idea: AFL disables "block chaining" in QEMU to also trace direct jumps (with chaining it would not make the callback to log the block).

- Block chaining is important for performance, the patch from Andrea modifies the code in a way that "block chaining" can again be enabled and code gets inserted (without callbacks) ➔ Better performance

- Moreover he added code to "cache block chains" between forked childs!

Methods to measure code-coverage

1. Instrumentation during compilation (source code available; gcc or llvm ➔ AFL)
2. Emulation of binary (e.g. with qemu)
3. Writing own debugger and set breakpoints on every basicblock (slow, but useful in some situations)

Code-Coverage via Breakpoints

- **Disadvantage:**
  - It’s very slow
    - Statically setting breakpoints can speedup the process, but it’s still slow because of the debugger process switches
    - Only applicable if we remove a breakpoint after the first hit ➔ We only measure code-coverage (without a hit-count), edge-coverage not possible or extremely slow
  - On-disk files are modified (statically), which can be detected with checksums (e.g. Adobe Reader .api files)

Code-Coverage via Breakpoints

- **Advantage:**
  - Minset calculation
    - Detection if a new file has new code-coverage is very fast (native runtime) because we statically set breakpoints for unexplored code and run the application without a debugger
    - If it crashes we know it hit one of our breakpoints and therefore contains unexplored code

Methods to measure code-coverage

1. Instrumentation during compilation (source code available; gcc or llvm ➔ AFL)
2. Emulation of binary (e.g. with qemu)
3. Writing own debugger and set breakpoints on every basicblock (slow, but useful in some situations)
4. Dynamic instrumentation of compiled application (no source code required; tools: DynamoRio, PIN, Valgrind, Frida, …)

Methods to measure code-coverage

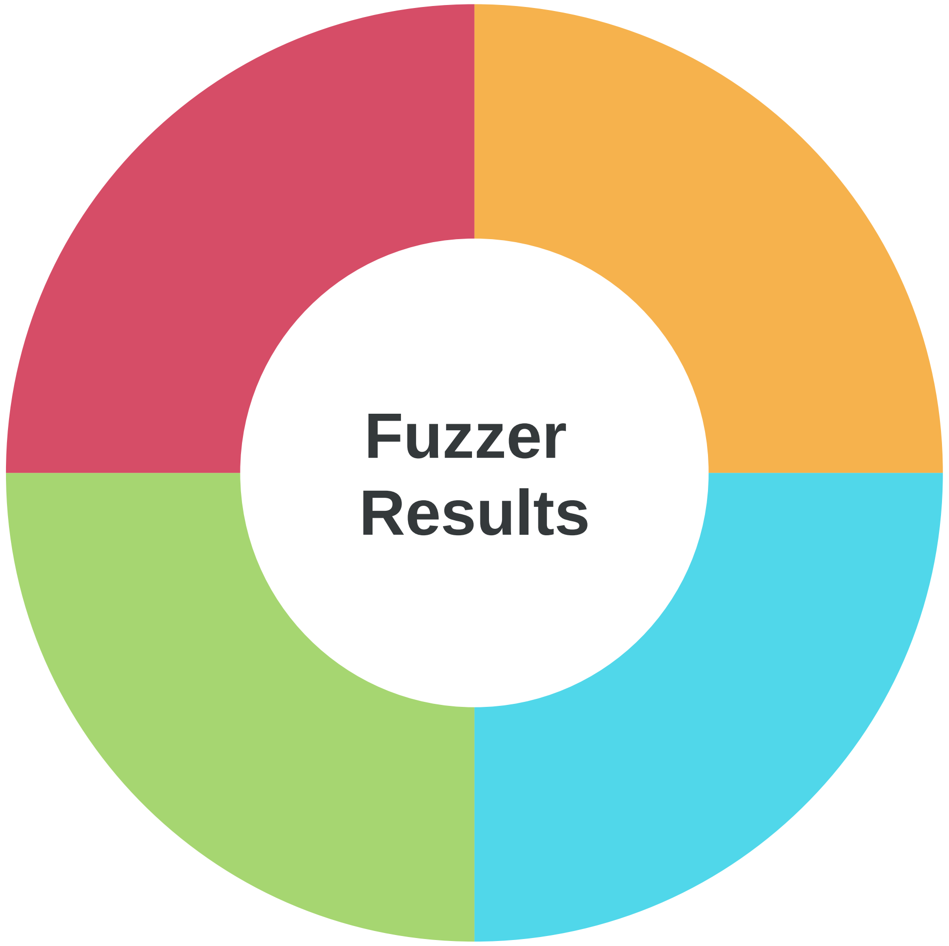
1. Instrumentation during compilation (source code available; gcc or llvm ➔ AFL)
2. Emulation of binary (e.g. with qemu)
3. Writing own debugger and set breakpoints on every basicblock (slow, but useful in some situations)
4. Dynamic instrumentation of compiled application (no source code required; tools: DynamoRio, PIN, Valgrind, Frida, …)
5. Static instrumentation via static binary rewriting (Talos fork of AFL which uses DynInst framework – AFL-dyninst, should be fastest possibility if source code is not available but it's not 100% reliable and currently Linux only); **WinAFL in syzygy mode is very useful on Windows if source-code is available!**

Methods to measure code-coverage

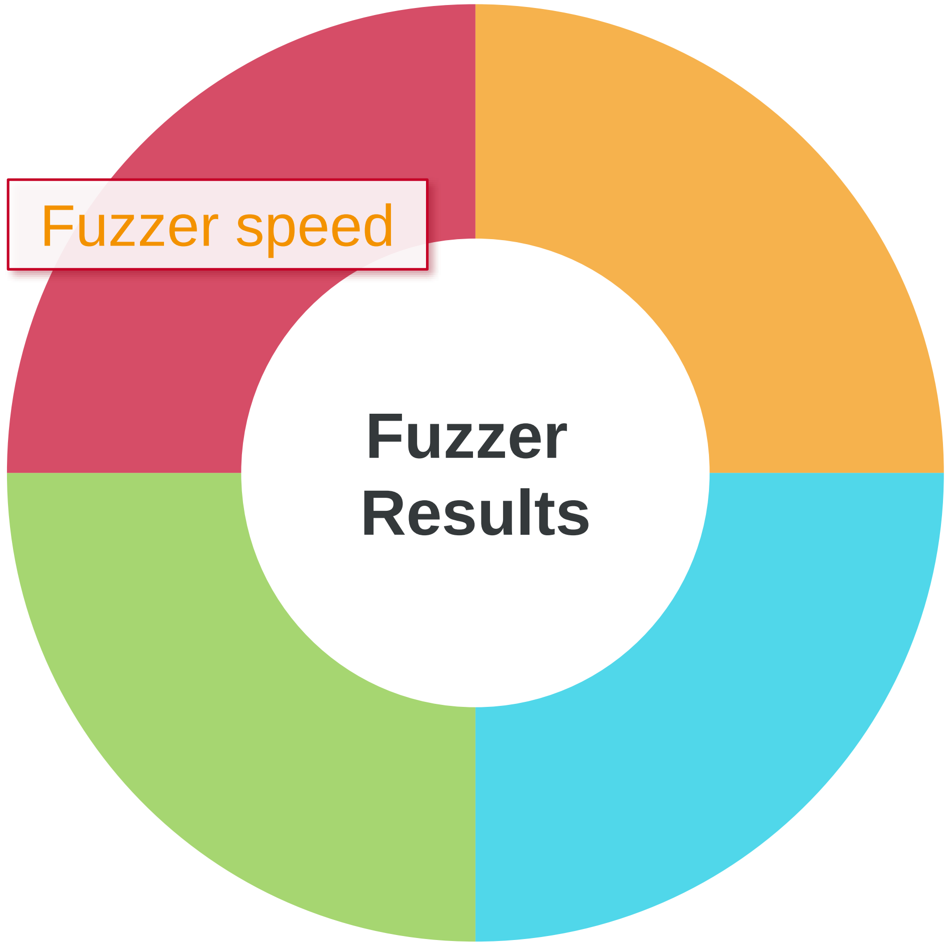
1. Instrumentation during compilation (source code available; gcc or llvm ➔ AFL)
2. Emulation of binary (e.g. with qemu)
3. Writing own debugger and set breakpoints on every basicblock (slow, but useful in some situations)
4. Dynamic instrumentation of compiled application (no source code required; tools: DynamoRio, PIN, Valgrind, Frida, …)
5. Static instrumentation via static binary rewriting (Talos fork of AFL which uses DynInst framework – AFL-dyninst, should be fastest possibility if source code is not available but it's not 100% reliable and currently Linux only); WinAFL in syzygy mode is very useful on Windows if source-code is available!
6. Use of hardware features
   - IntelPT (Processor Tracing); available since 6th Intel-Core generation (~2015)
   - WindowsIntelPT (from Talos) or kAFL

Areas which influent fuzzer results

Areas which influence fuzzing results



Areas which influence fuzzing results

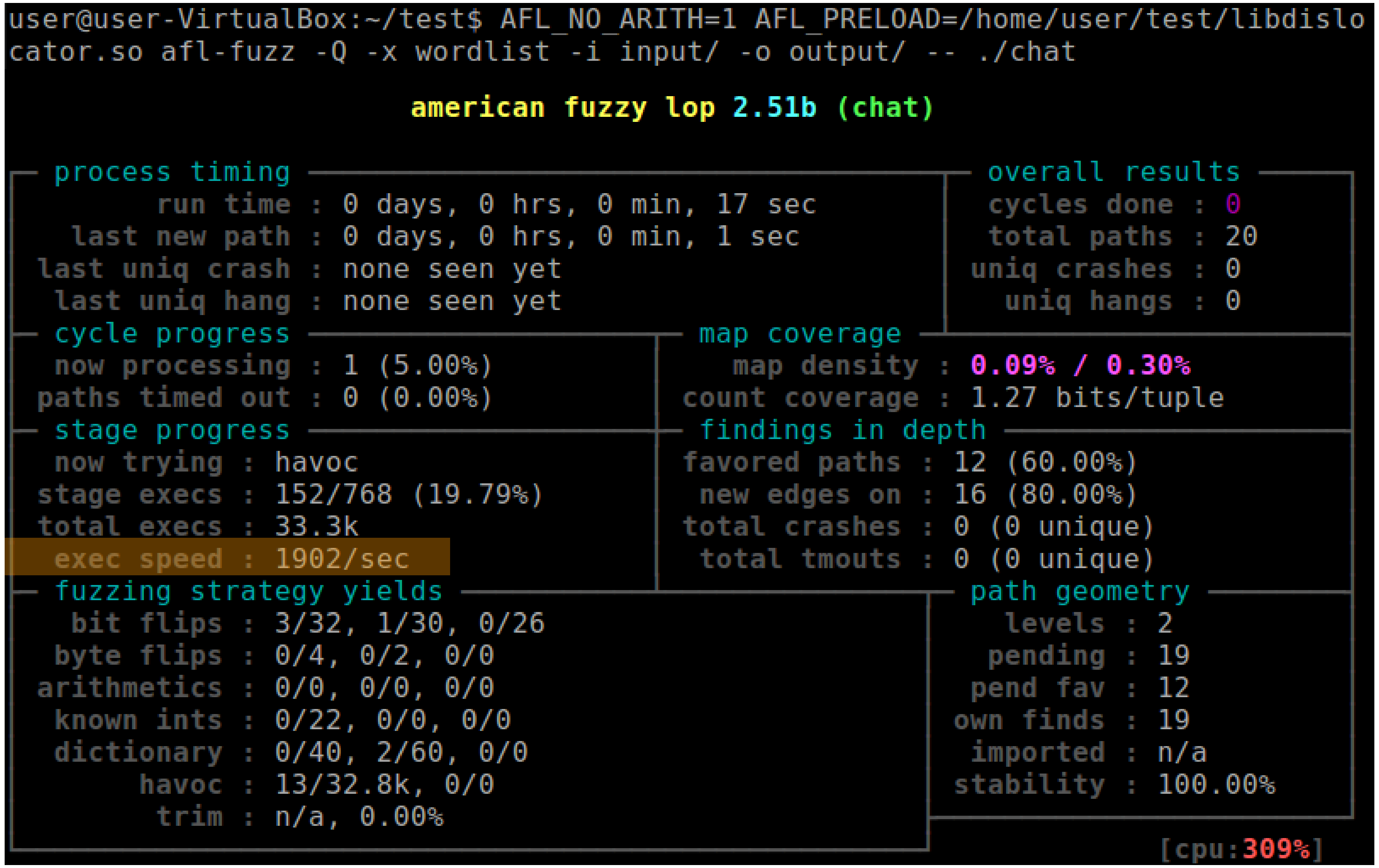


Fuzzer Speed

1. Use a RAM Disk
2. Remove slow API calls
3. Fork Server (AFL's Fork Server was designed by Jann Horn)
4. Deferred Fork Server
5. Persistent Mode (in-memory fuzzing)
6. Prevent process switches (between target application and the Fuzzer) by injecting the Fuzzer code into the target process
7. Modify the input in-memory instead of on-disk

Example to the Fork Server:

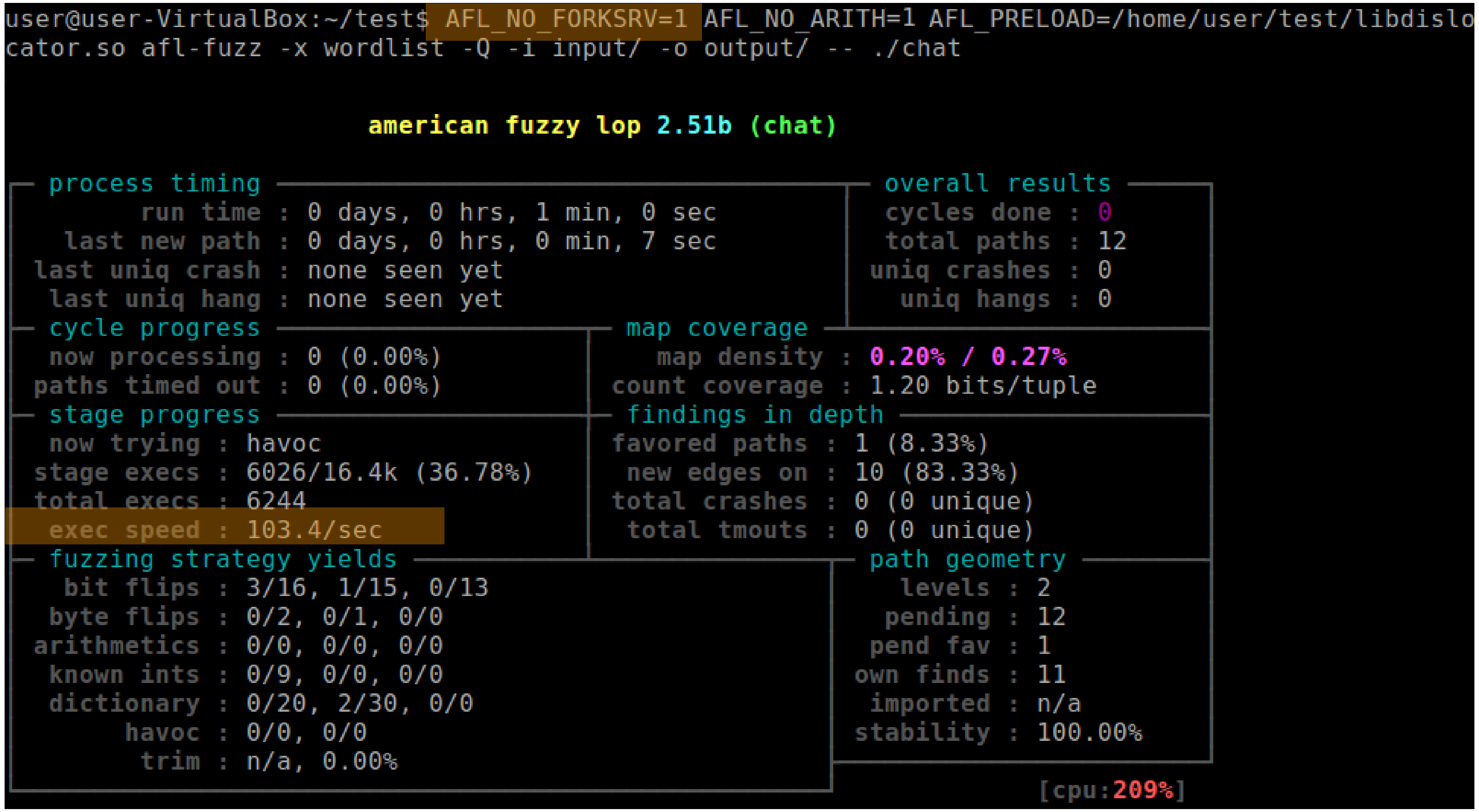
With Fork Server:



```
user@user-VirtualBox:~/test$ AFL_NO_ARITH=1 AFL_PRELOAD=/home/user/test/libdislo
cator.so afl-fuzz -Q -x wordlist -i input/ -o output/ -- ./chat

                      american fuzzy lop 2.51b (chat)

┌─ process timing ─────────────────────────────────────┬─ overall results ────┐
│        run time : 0 days, 0 hrs, 0 min, 17 sec        │  cycles done : 0     │
│   last new path : 0 days, 0 hrs, 0 min, 1 sec         │  total paths : 20    │
│ last uniq crash : none seen yet                       │ uniq crashes : 0     │
│  last uniq hang : none seen yet                       │   uniq hangs : 0     │
├─ cycle progress ────────────────┬─ map coverage ─┴──────────────────────┤
│  now processing : 1 (5.00%)      │    map density : 0.09% / 0.30%        │
│ paths timed out : 0 (0.00%)      │ count coverage : 1.27 bits/tuple      │
├─ stage progress ────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc              │ favored paths : 12 (60.00%)           │
│ stage execs : 152/768 (19.79%)   │  new edges on : 16 (80.00%)           │
│ total execs : 33.3k              │ total crashes : 0 (0 unique)          │
│  exec speed : 1902/sec           │  total tmouts : 0 (0 unique)          │
├─ fuzzing strategy yields ───────┴───────────────┬─ path geometry ────────┤
│   bit flips : 3/32, 1/30, 0/26                  │    levels : 2           │
│  byte flips : 0/4, 0/2, 0/0                     │   pending : 19          │
│ arithmetics : 0/0, 0/0, 0/0                     │  pend fav : 12          │
│  known ints : 0/22, 0/0, 0/0                    │ own finds : 19          │
│  dictionary : 0/40, 2/60, 0/0                   │  imported : n/a         │
│       havoc : 13/32.8k, 0/0                     │ stability : 100.00%     │
│        trim : n/a, 0.00%                        ├─────────────────────────┘
└─────────────────────────────────────────────────┘          [cpu:309%]
```

Example to the Fork Server:

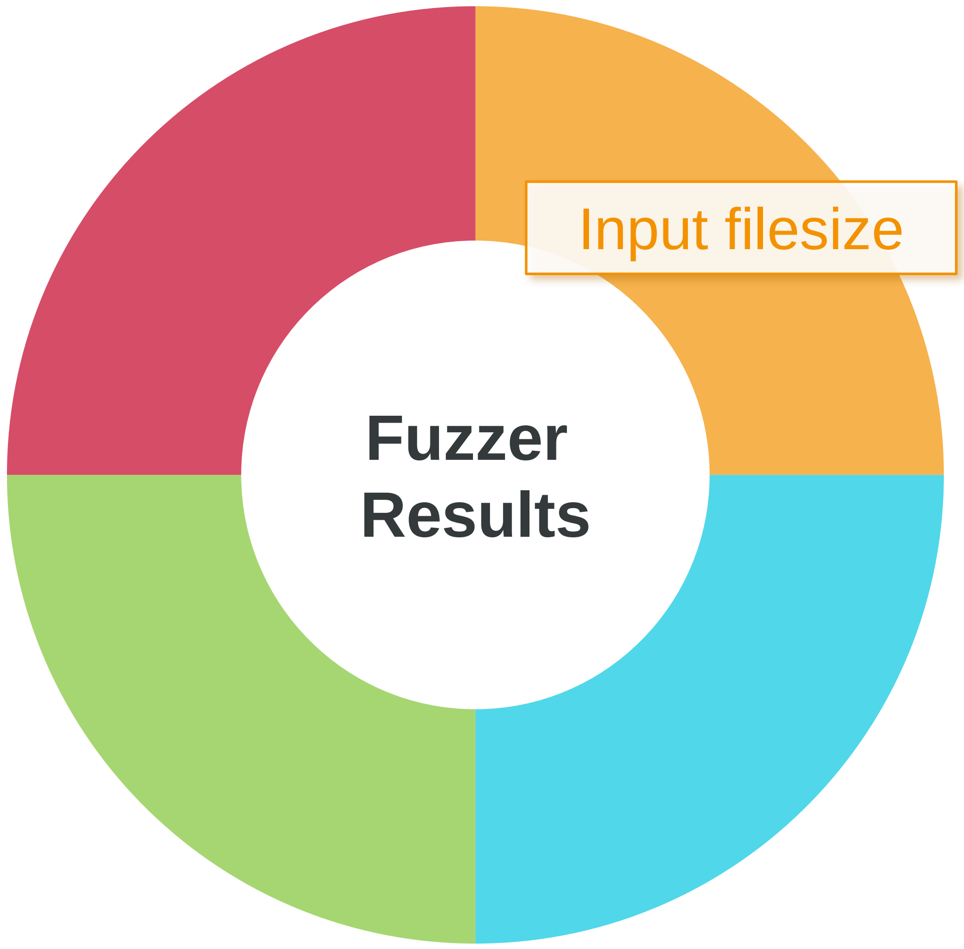
Without Fork Server:



```
user@user-VirtualBox:~/test$ AFL_NO_FORKSRV=1 AFL_NO_ARITH=1 AFL_PRELOAD=/home/user/test/libdislo
cator.so afl-fuzz -x wordlist -Q -i input/ -o output/ -- ./chat


                       american fuzzy lop 2.51b (chat)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 0 hrs, 1 min, 0 sec        │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 0 min, 7 sec        │  total paths : 12     │
│ last uniq crash : none seen yet                      │ uniq crashes : 0      │
│  last uniq hang : none seen yet                      │   uniq hangs : 0      │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 0 (0.00%)         │    map density : 0.20% / 0.27%        │
│ paths timed out : 0 (0.00%)         │ count coverage : 1.20 bits/tuple      │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc                 │ favored paths : 1 (8.33%)             │
│ stage execs : 6026/16.4k (36.78%)   │  new edges on : 10 (83.33%)           │
│ total execs : 6244                  │ total crashes : 0 (0 unique)          │
│  exec speed : 103.4/sec             │  total tmouts : 0 (0 unique)          │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 3/16, 1/15, 0/13                      │    levels : 2          │
│  byte flips : 0/2, 0/1, 0/0                         │   pending : 12         │
│ arithmetics : 0/0, 0/0, 0/0                         │  pend fav : 1          │
│  known ints : 0/9, 0/0, 0/0                         │ own finds : 11         │
│  dictionary : 0/20, 2/30, 0/0                       │  imported : n/a        │
│       havoc : 0/0, 0/0                              │ stability : 100.00%    │
│        trim : n/a, 0.00%                            ├────────────────────────┘
└─────────────────────────────────────────────────────┘          [cpu:209%]
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Areas which influence fuzzing results



Input file size

- **The input file size is extremely important!**

- Smaller files
  - Have a higher likelihood to change the correct bit / byte during fuzzing
  - Are faster processed by deterministic fuzzing
  - Are faster loaded by the target application

- AFL ships with two utilities
  - AFL-cmin: Reduce number of files with same functionality
  - AFL-tmin: Reduce file size of an input file
    - Uses a “fuzzer” approach and heuristics
    - Runtime depends on file size
    - Problems with file offsets

Input file size

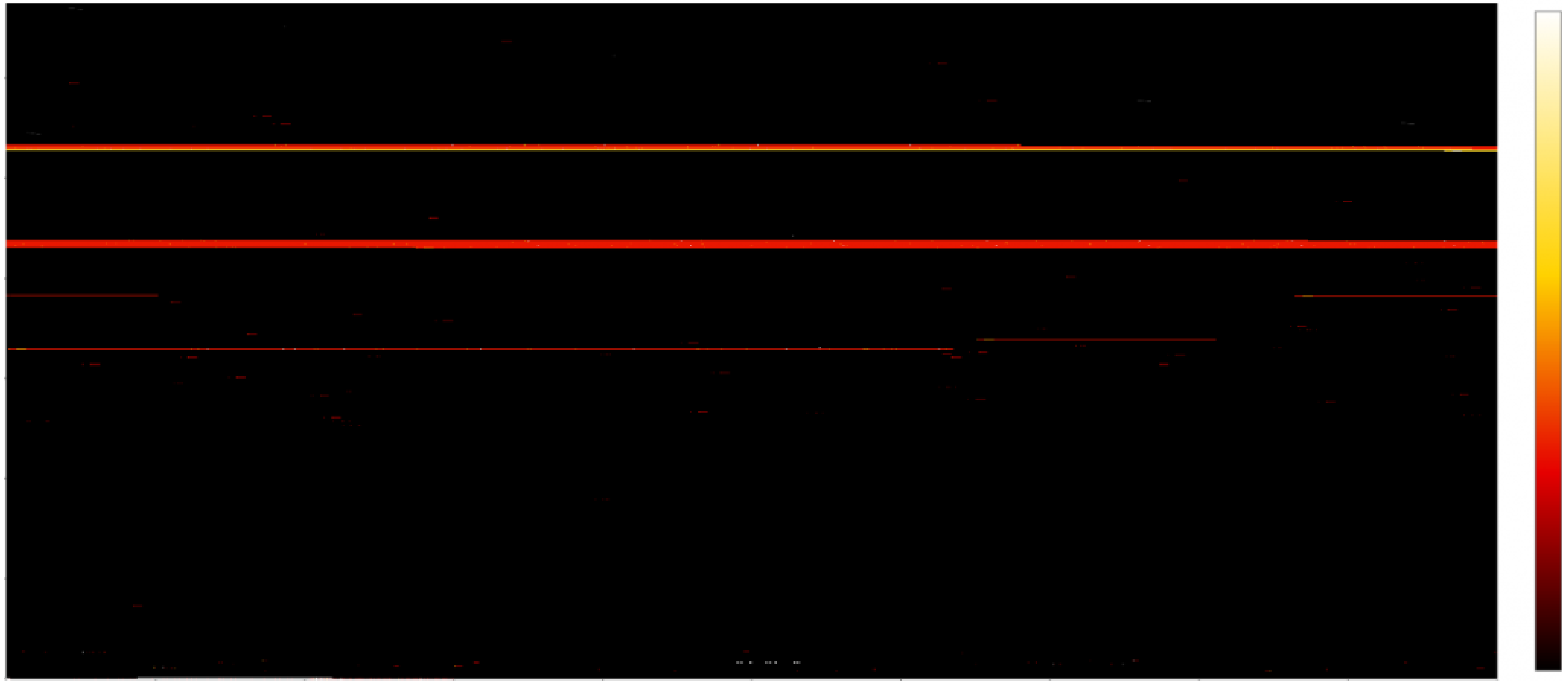
- **Example: Fuzzing mimikatz**

Initial memory dump:	**27 004 528 Byte**
Memory dump which I fuzzed:	**2 234 Byte**

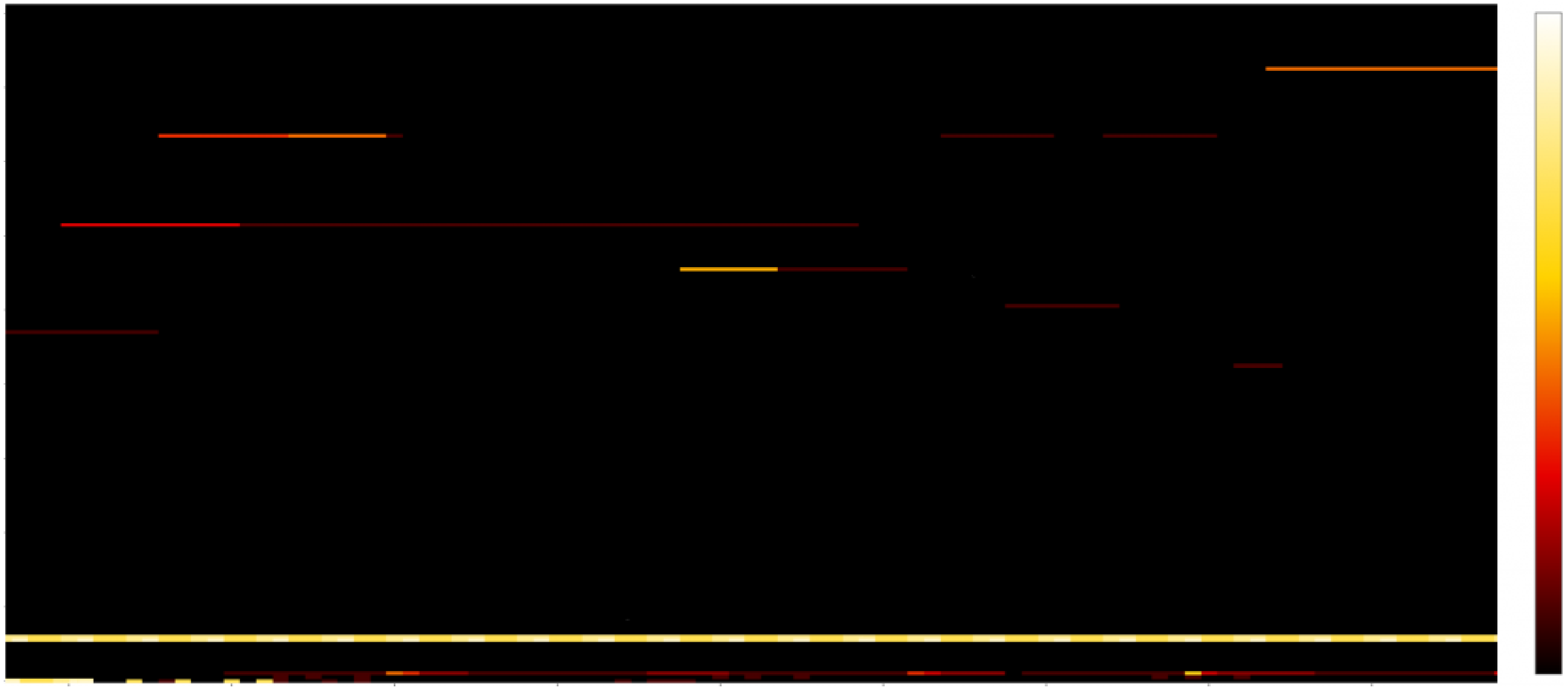
➔ **I'm approximately 12 000 times faster with this setup…**

- You would need 12 000 CPU cores to get the same result in the same time as my fuzzing setup with one CPU core
- Or with the same number of CPU cores you need 12 000 days (~33 years) to get the same result as I within one day

Heat map of the memory dump (mimikatz access)

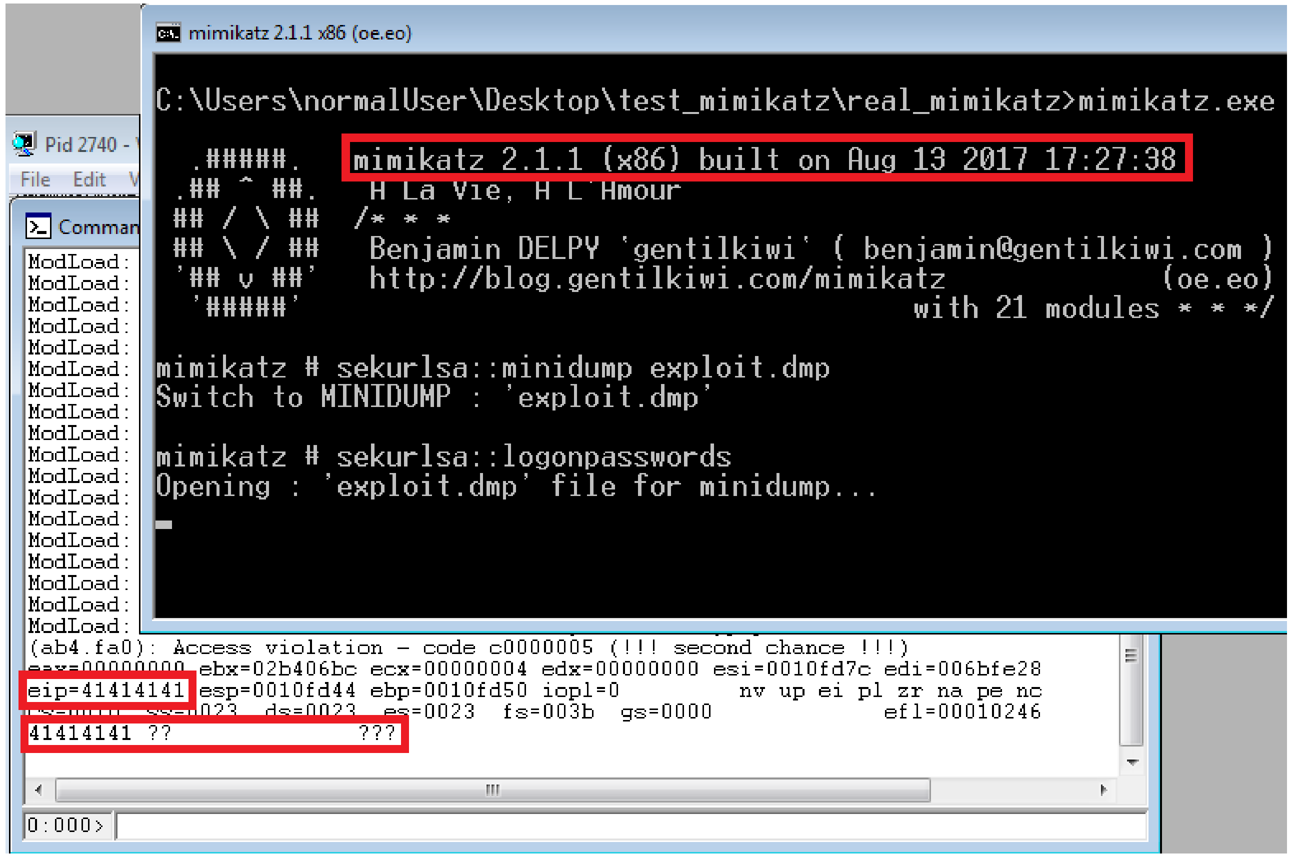


Heat map of the memory dump (mimikatz access) - Zoomed



Fuzzing and exploiting mimikatz

See below link for in-depth discussion how I fuzzed mimikatz with WinAFL:
https://www.sec-consult.com/en/blog/2017/09/hack-the-hacker-fuzzing-mimikatz-on-windows-with-winafl-heatmaps-0day/index.html



```
C:\Users\normalUser\Desktop\test_mimikatz\real_mimikatz>mimikatz.exe

  .#####.   mimikatz 2.1.1 (x86) built on Aug 13 2017 17:27:38
 .## ^ ##.   "A La Vie, A L'Amour"
 ## / \ ##  /* * *
 ## \ / ##   Benjamin DELPY `gentilkiwi` ( benjamin@gentilkiwi.com )
 '## v ##'   http://blog.gentilkiwi.com/mimikatz             (oe.eo)
  '#####'                                   with 21 modules * * */

mimikatz # sekurlsa::minidump exploit.dmp
Switch to MINIDUMP : 'exploit.dmp'

mimikatz # sekurlsa::logonpasswords
Opening : 'exploit.dmp' file for minidump...
```

```
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
(ab4.fa0): Access violation - code c0000005 (!!! second chance !!!)
eax=00000000 ebx=02b406bc ecx=00000004 edx=00000000 esi=0010fd7c edi=006bfe28
eip=41414141 esp=0010fd44 ebp=0010fd50 iopl=0         nv up ei pl zr na pe nc
cs=0000  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010246
41414141 ??              ???
0:000>
```

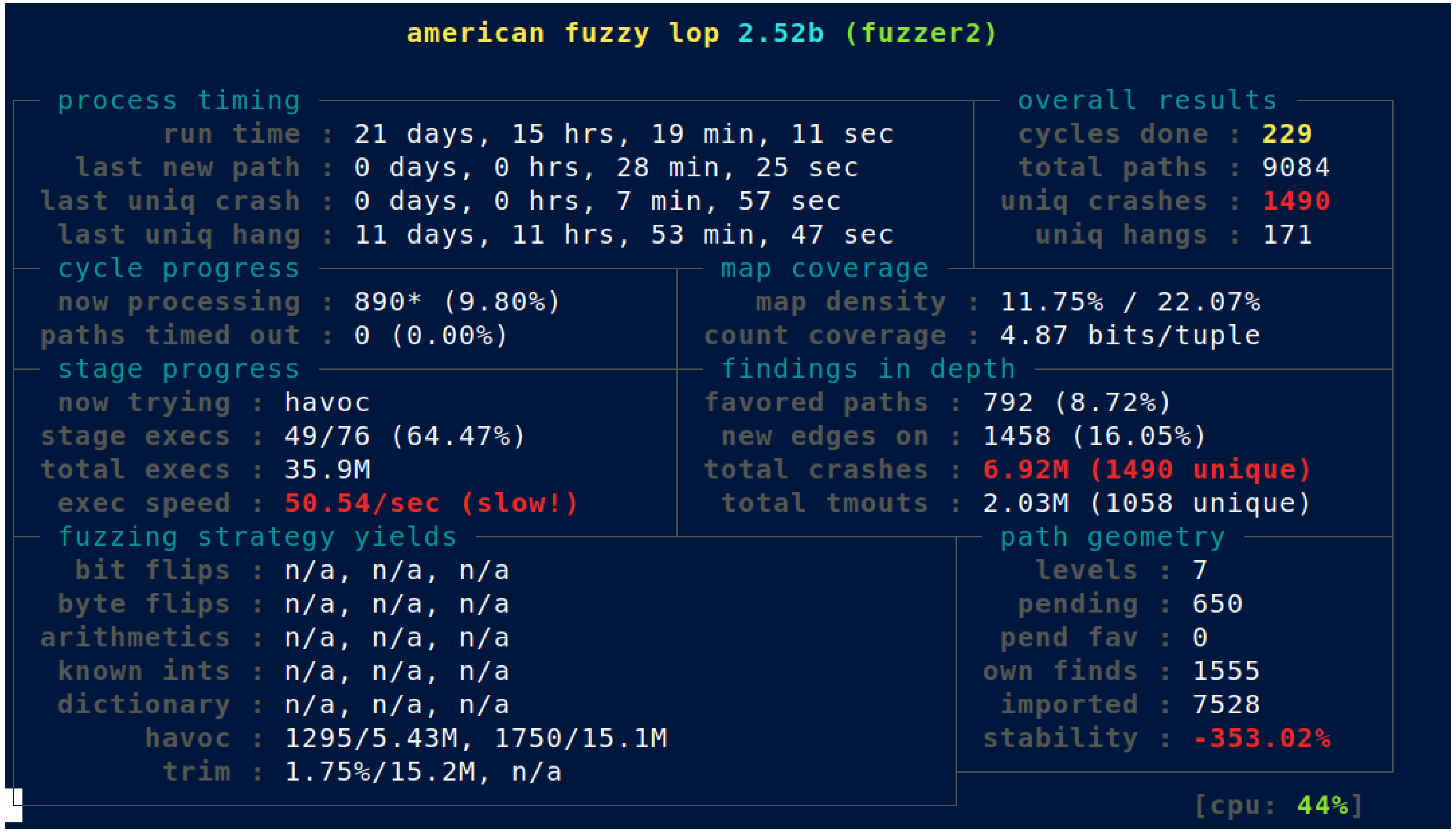
SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

AFL Qemu mode

- **Example: Niklas B** (@_niklasb) fuzzed map files in **Counter-Strike Global Offensive** and found lots of bugs/vulns with AFL Qemu mode!
    - https://phoenhex.re/2018-08-26/csgo-fuzzing-bsp
    - You should definitely read the blog post!

- **Important decisions to mention**
    - He fuzzed the Linux binaries (with Qemu mode)
    - He fuzzed the server (command line) and not the 3D game client
    - He wrote a script to reduce input file size from 300 KB to 16 KB
        - Cite from the blog post: "Input file size matters a *lot*. By going down from 300KB to 16KB I gained at least a factor of 5 in performance. Probably even smaller would be even better."
    - Initial runtime per iteration was 15+ seconds ➔ He wrote a custom wrapper which just calls the required functions ➔ ~50 exec / sec per thread

AFL Qemu mode

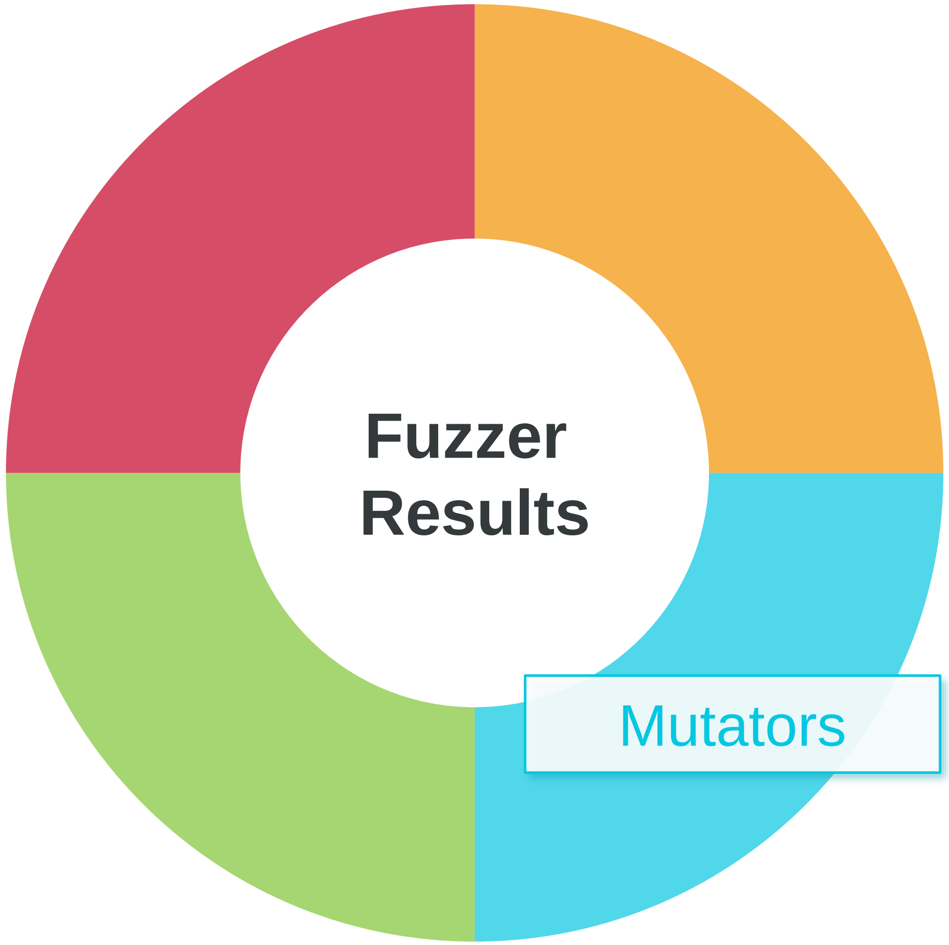


```
                    american fuzzy lop 2.52b (fuzzer2)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 21 days, 15 hrs, 19 min, 11 sec     │  cycles done : 229    │
│   last new path : 0 days, 0 hrs, 28 min, 25 sec       │  total paths : 9084   │
│ last uniq crash : 0 days, 0 hrs, 7 min, 57 sec        │ uniq crashes : 1490   │
│  last uniq hang : 11 days, 11 hrs, 53 min, 47 sec     │   uniq hangs : 171    │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 890* (9.80%)      │    map density : 11.75% / 22.07%       │
│ paths timed out : 0 (0.00%)         │ count coverage : 4.87 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc                 │ favored paths : 792 (8.72%)            │
│ stage execs : 49/76 (64.47%)        │  new edges on : 1458 (16.05%)          │
│ total execs : 35.9M                 │ total crashes : 6.92M (1490 unique)    │
│  exec speed : 50.54/sec (slow!)     │  total tmouts : 2.03M (1058 unique)    │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : n/a, n/a, n/a                         │    levels : 7          │
│  byte flips : n/a, n/a, n/a                         │   pending : 650        │
│ arithmetics : n/a, n/a, n/a                         │  pend fav : 0          │
│  known ints : n/a, n/a, n/a                         │ own finds : 1555       │
│  dictionary : n/a, n/a, n/a                         │  imported : 7528       │
│       havoc : 1295/5.43M, 1750/15.1M                │ stability : -353.02%   │
│        trim : 1.75%/15.2M, n/a                      ├────────────────────────┘
└─────────────────────────────────────────────────────┘          [cpu: 44%]
```

https://phoenhex.re/2018-08-26/csgo-fuzzing-bsp

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Areas which influence fuzzing results



AFL Mutation

- **AFL performs deterministic, random, and dictionary** based mutations
  - AFL has a very good deterministic mutation algorithms

- **Deterministic mutation strategies**:
  - Bit flips
    - single, two, or four bits in a row
  - Byte flips
    - single, two, or four bytes in a row
  - Simple arithmetics
    - single, two, or four bytes
    - additions/subtractions in both endians performed
  - Known integers
    - overwrite values with interesting integers (-1, 256, 1024, etc.)

AFL Mutation

- **Random mutation strategies** performed for an input file after deterministic mutations are exhausted.

- Random mutation strategies:
  - Stacked tweaks
    - performs randomly multiple deterministic mutations
    - clone/remove part of file
  - Test case splicing
    - splices two distinct input files at random locations and joins them

Magic Values

- **Consider Lection 6 with the following code:**

```
magicValue = *(uint64_t *)data;
if(magicValue == 0xdeadbeef13371337) {
        printf("Found magic value\n");
        *crash_ptr = 0xdeafbeef;                  // Crash here
} else {
        printf("No magic value\n");
}
```

- **Question: Can AFL identify this bug?**

Practice: Lection 6

Topic: Lection 6 – Magic Values

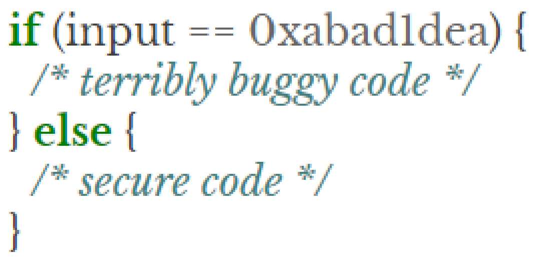
Duration: 5-10 min

Description: See the impact of magic values in fuzzing.

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

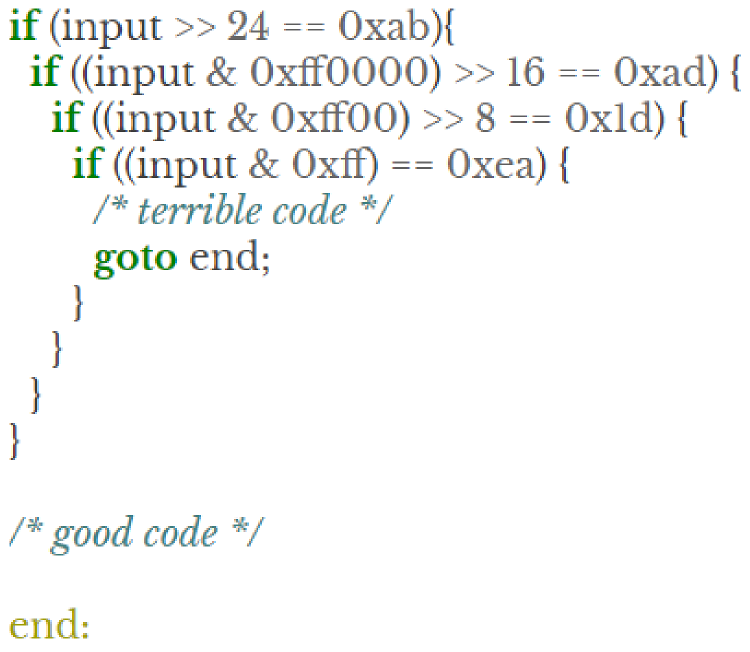
Magic Values

- **Circumventing Fuzzing Roadblocks with Compiler Transformation.**
  - Enforce “Compiler **Deoptimization**” with LLVM compiler passes.
  - https://lafintel.wordpress.com/2016/08/15/circumventing-fuzzing-roadblocks-with-compiler-transformations/



```
if (input == 0xabad1dea) {
  /* terribly buggy code */
} else {
  /* secure code */
}
```

vs.



```
if (input >> 24 == 0xab){
 if ((input & 0xff0000) >> 16 == 0xad) {
  if ((input & 0xff00) >> 8 == 0x1d) {
   if ((input & 0xff) == 0xea) {
    /* terrible code */
    goto end;
   }
  }
 }
}

/* good code */

end:
```

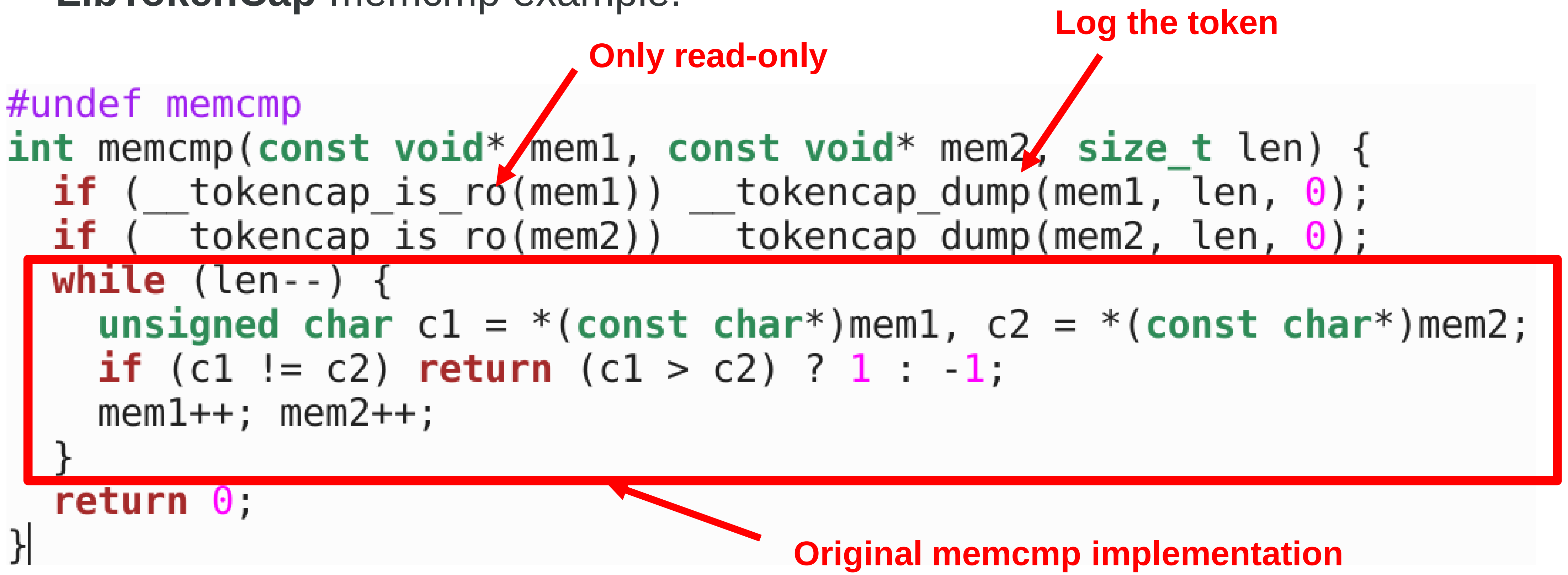
LibTokenCap

- With **LD_PRELOAD** function implementations can be replaced for dynamically loaded libraries
  - Just compile a library containing a function with the name of the target function which behavior you want to change
  - LD_PRELOAD=/path/to/your/library.so ./target_application
  - With AFL you can use AFL_PRELOAD=… afl-fuzz … -- ./target_application

- Preeny contains other useful examples (especially for CTFs)
  - https://github.com/zardus/preeny
  - Defork: Remove fork()
  - Desleep / Dealarm / Deptrace / Desrand: Often useful for CTFs
  - Hint: Replace network function to read from files instead ➔ Fuzz it with AFL

LibTokenCap

- **LibTokenCap** memcmp example:



```
#undef memcmp
int memcmp(const void* mem1, const void* mem2, size_t len) {
  if (__tokencap_is_ro(mem1)) __tokencap_dump(mem1, len, 0);
  if (__tokencap_is_ro(mem2)) __tokencap_dump(mem2, len, 0);
  while (len--) {
    unsigned char c1 = *(const char*)mem1, c2 = *(const char*)mem2;
    if (c1 != c2) return (c1 > c2) ? 1 : -1;
    mem1++; mem2++;
  }
  return 0;
}
```

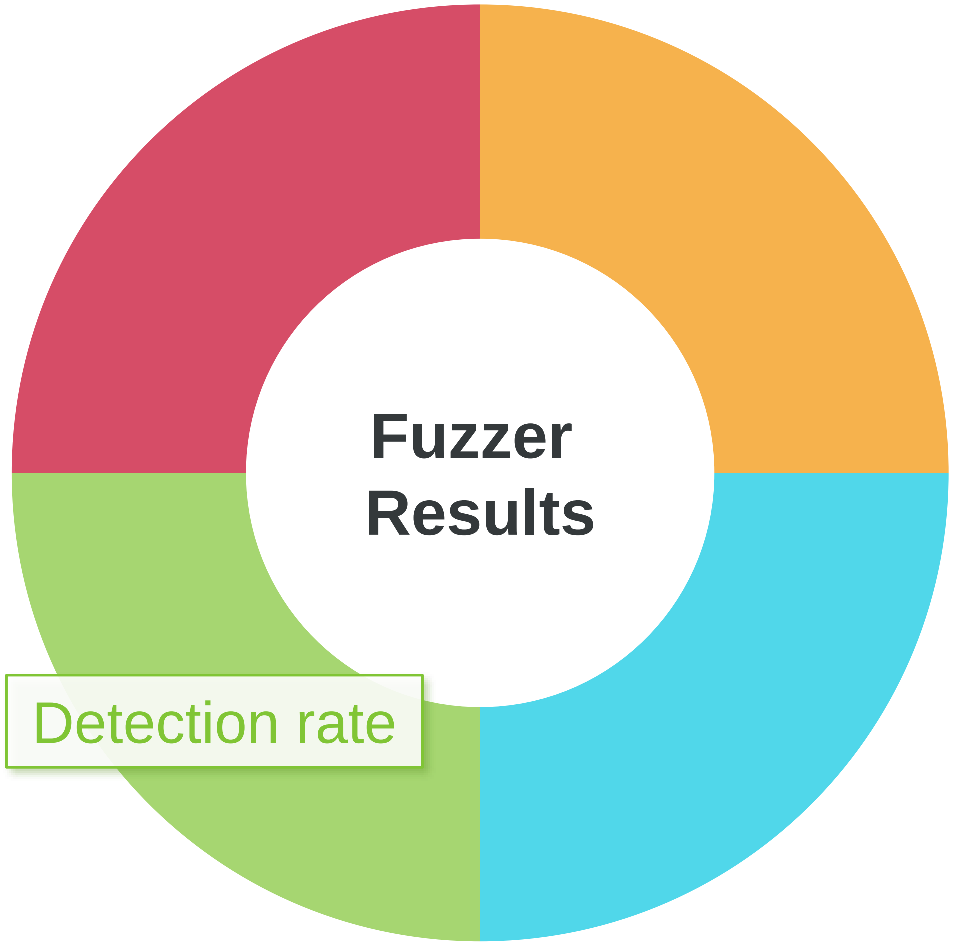
Practice: Lection 7

Topic: Lection 7 – LibTokenCap

Duration: 5-10 min

Description: See LibTokenCap in action.

Areas which influence fuzzing results



SECCON Chat CTF Binary

Task:

Go to lection 9 (skip lection 8 for the moment), copy the „chat“ binary and try to identify security vulnerabilities by playing with the binary.

Can you spot the vulnerability?

Please don‘t read the solution file yet!

Detecting not crashing vulnerabilities

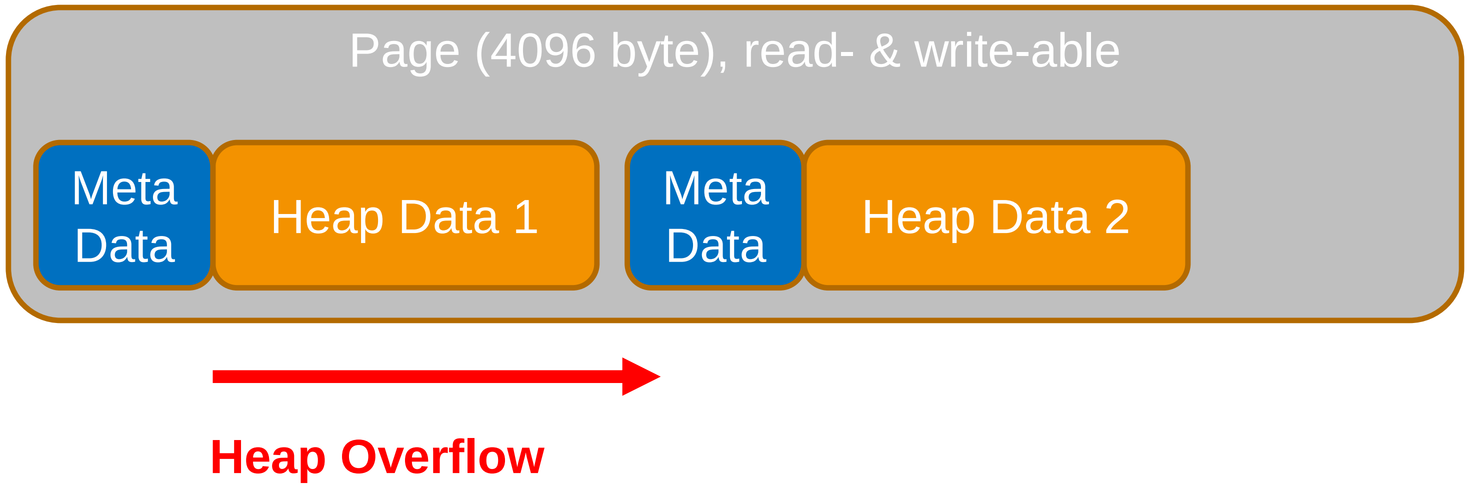
➔ Did someone detect a crash in the binary?

➔ What do you think: how many vulnerabilities are in this binary?

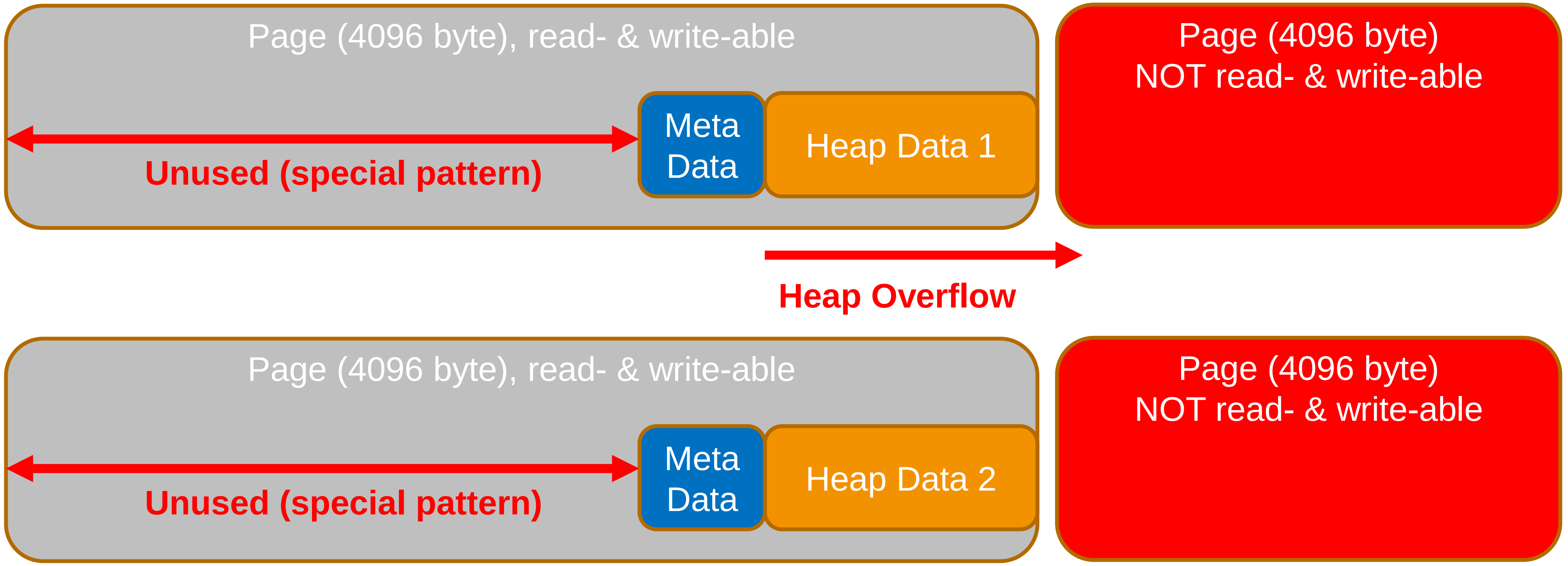
➔ Other real world example: Heartbleed is a read buffer overflow and does not lead to a crash…

➔ **We (the Fuzzer) need a way to detect such flaws / vulnerabilities!**

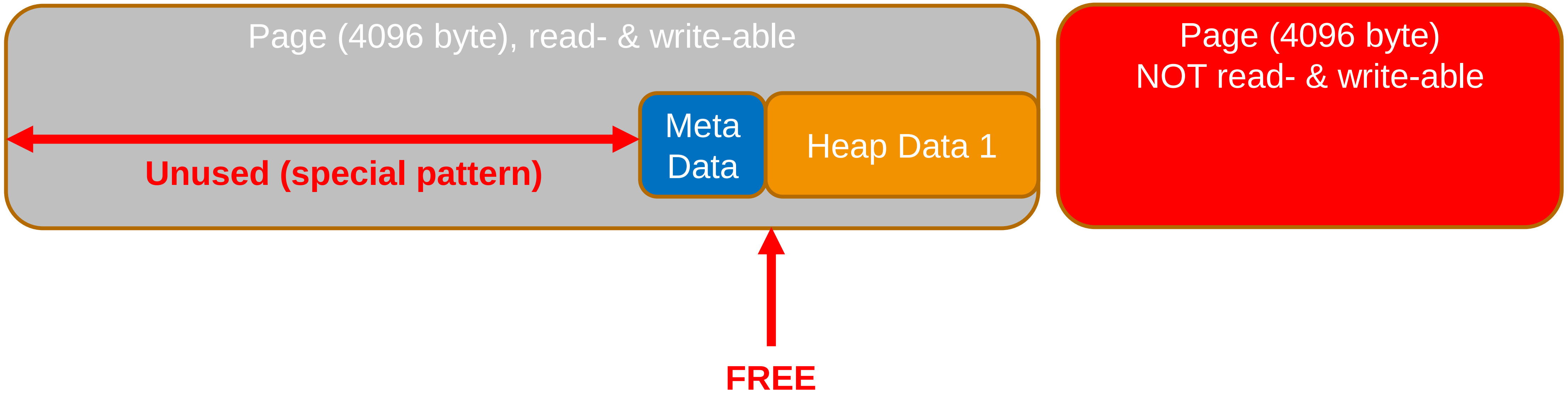
Heap Overflow Detection



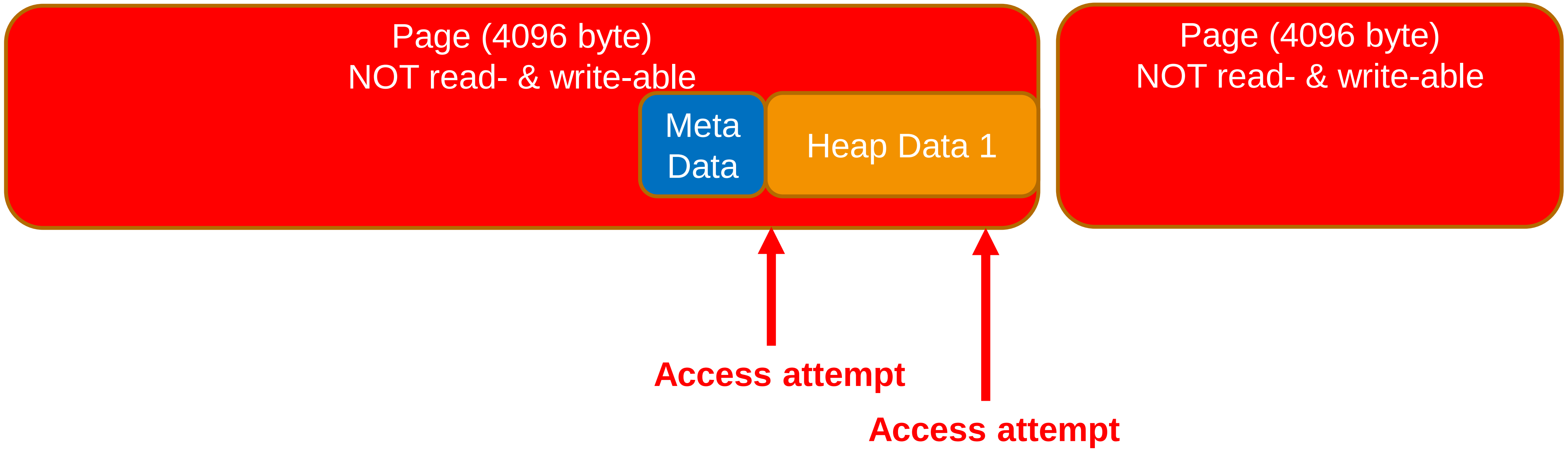
Heap Overflow Detection



Use-After-Free Detection


Page (4096 byte), read- & write-able
Meta Data
Heap Data 1
Unused (special pattern)
Page (4096 byte) NOT read- & write-able
FREE

Use-After-Free Detection



Heap Library

- On Linux: **LibDislocator** (shipped with AFL)
    - Replaces the heap allocator to detect heap corruptions
    - Works also against closed source applications

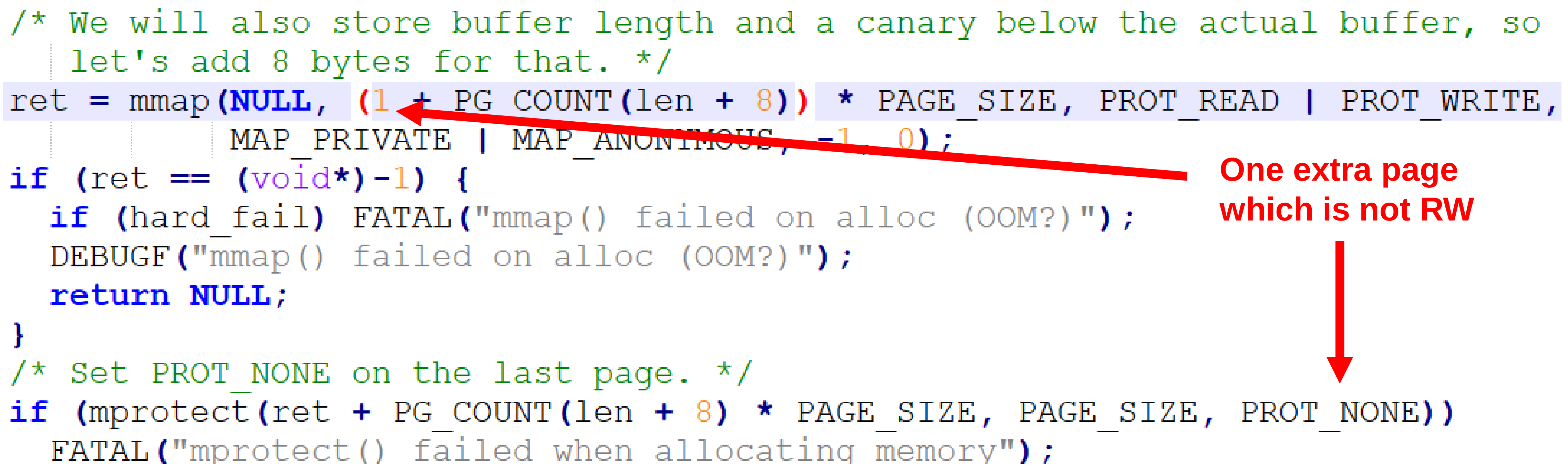
- On Windows: **Page heap with Application Verifier**

- **Own heap allocator** which checks after free() all memory locations for a dangling pointer!
    - Detect Use-After-Free at free and not at use step
    - Concept similar to MemGC protection from Edge

- AFL_HARDEN=1 make (Fortify Source & Stack Cookies)

Heap Library

- **Libdislocator**



```
/* We will also store buffer length and a canary below the actual buffer, so
   let's add 8 bytes for that. */
ret = mmap(NULL, (1 + PG_COUNT(len + 8)) * PAGE_SIZE, PROT_READ | PROT_WRITE,
           MAP_PRIVATE | MAP_ANONYMOUS, -1, 0);
if (ret == (void*)-1) {
  if (hard_fail) FATAL("mmap() failed on alloc (OOM?)");
  DEBUGF("mmap() failed on alloc (OOM?)");
  return NULL;
}
/* Set PROT_NONE on the last page. */
if (mprotect(ret + PG_COUNT(len + 8) * PAGE_SIZE, PAGE_SIZE, PROT_NONE))
  FATAL("mprotect() failed when allocating memory");
```

One extra page which is not RW

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

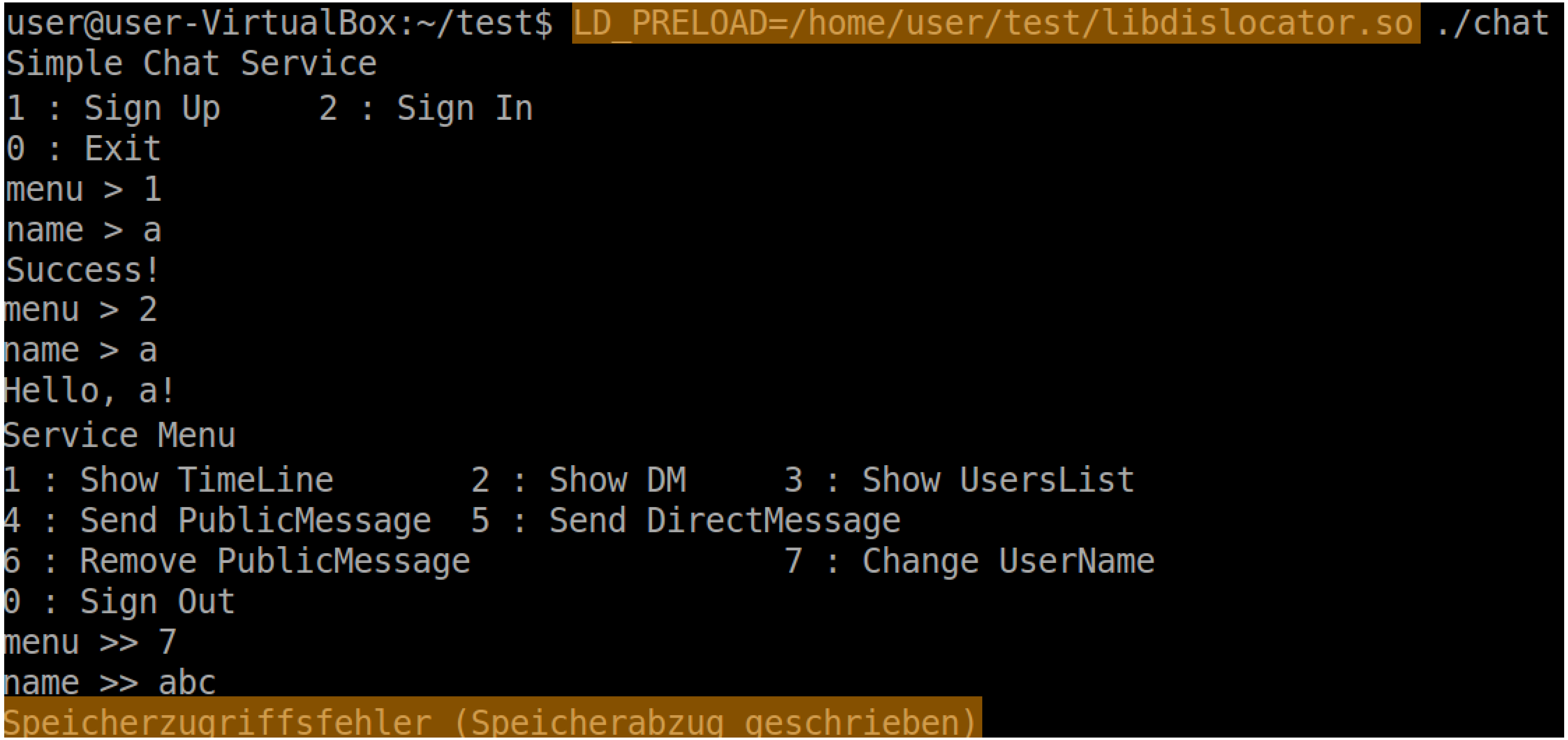
Practice: Lection 8

Topic: Lection 8 – LibDislocator

Duration: 20 min

Description: See LibDislocator in action.

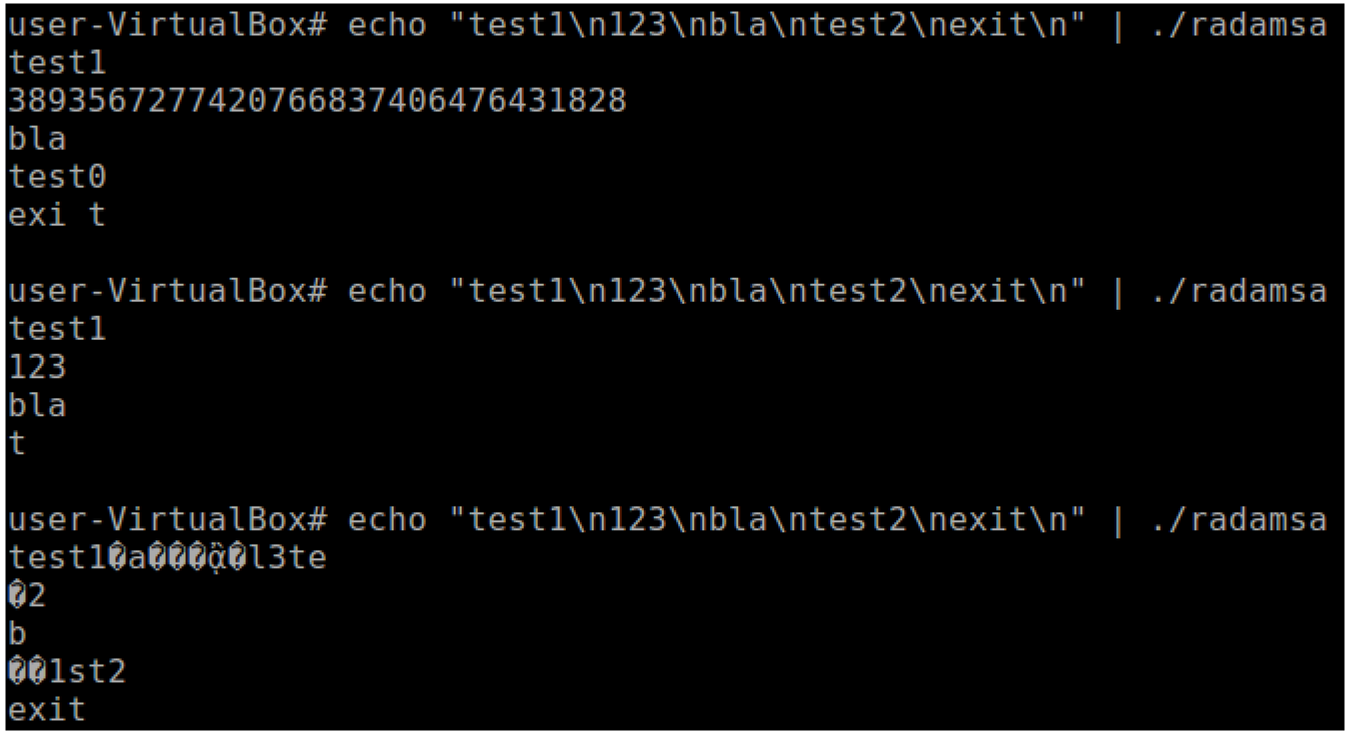
Libdislocator catches heap overflow



```
user@user-VirtualBox:~/test$ LD_PRELOAD=/home/user/test/libdislocator.so ./chat
Simple Chat Service
1 : Sign Up     2 : Sign In
0 : Exit
menu > 1
name > a
Success!
menu > 2
name > a
Hello, a!
Service Menu
1 : Show TimeLine        2 : Show DM       3 : Show UsersList
4 : Send PublicMessage   5 : Send DirectMessage
6 : Remove PublicMessage                   7 : Change UserName
0 : Sign Out
menu >> 7
name >> abc
Speicherzugriffsfehler (Speicherabzug geschrieben)
```

Radamsa

- **Radamsa** is a very powerful input mutator
  - If you don‘t want to write a mutator yourself, just use radamsa!
  - https://github.com/aoh/radamsa



```
user-VirtualBox# echo "test1\n123\nbla\ntest2\nexit\n" | ./radamsa
test1
3893567277420766837406476431828
bla
test0
exi t

user-VirtualBox# echo "test1\n123\nbla\ntest2\nexit\n" | ./radamsa
test1
123
bla
t

user-VirtualBox# echo "test1\n123\nbla\ntest2\nexit\n" | ./radamsa
test1�a���ą�l3te
�2
b
��1st2
exit
```

Radamsa

- **Problem of radamsa:** External program execution is slow (no library support)
  - Already submitted by others as issue: https://github.com/aoh/radamsa/issues/28

- **Example:** SECCON CTF fuzzer for the chat binary

- **Test 1:** Before every execution we mutate the input with a call to radamsa
  - **Result:** Execution speed is **~17 executions per second**

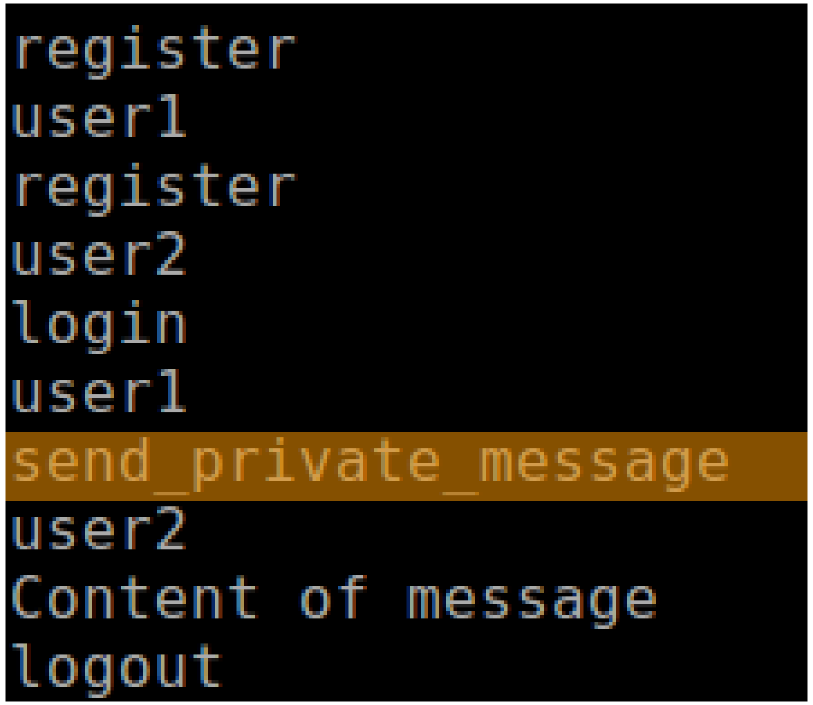
- **Test 2:** Mutate input with python (no radamsa at all)
  - **Result:** Execution speed is **~740 executions per second**

- **➔ Always create multiple output files (e.g.: 100 or 1000) or use IP:Port output**

Radamsa

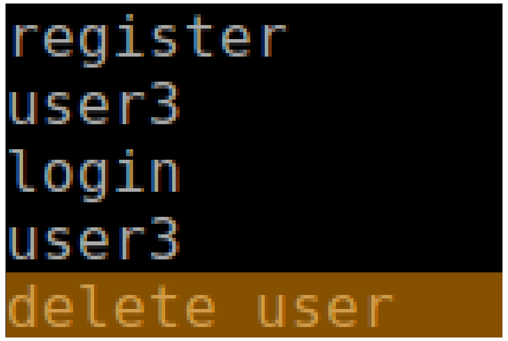
- **Testcases as input:**

test1.txt



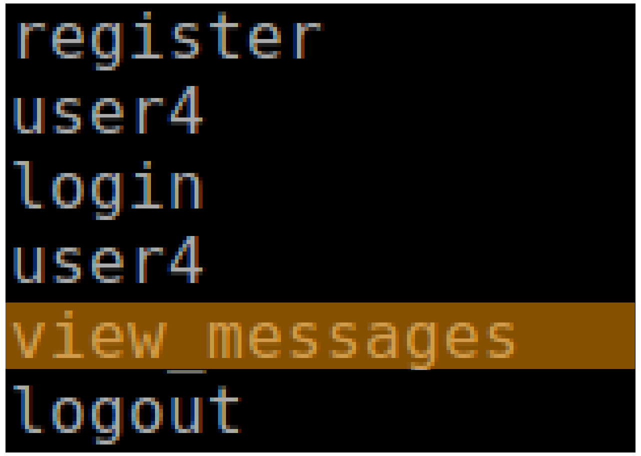
```
register
user1
register
user2
login
user1
send_private_message
user2
Content of message
logout
```

test2.txt



```
register
user3
login
user3
delete user
```

test3.txt

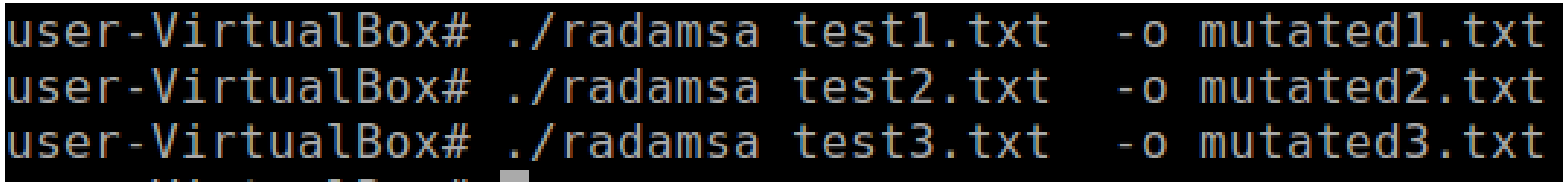


```
register
user4
login
user4
view_messages
logout
```

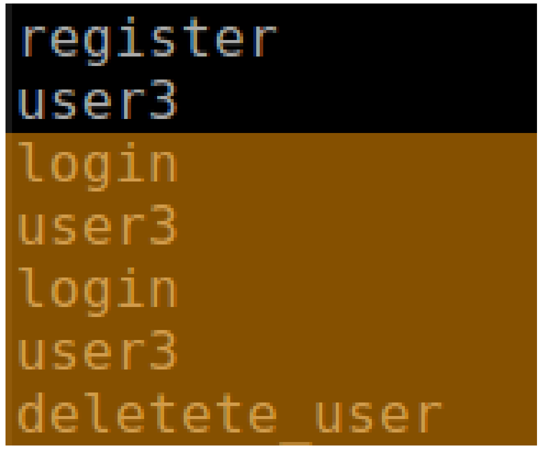
Radamsa

- **Often seen wrong use of radamsa:**

Possible output



```
user-VirtualBox# ./radamsa test1.txt  -o mutated1.txt
user-VirtualBox# ./radamsa test2.txt  -o mutated2.txt
user-VirtualBox# ./radamsa test3.txt  -o mutated3.txt
```



```
register
user3
login
user3
login
user3
deletete_user
```

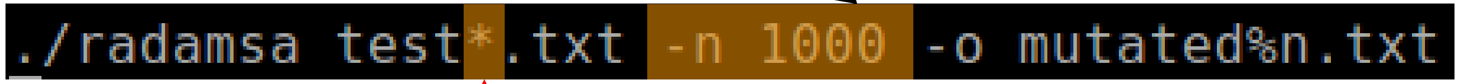
Only variations of the current input file

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Radamsa

- **Correct invocation:**

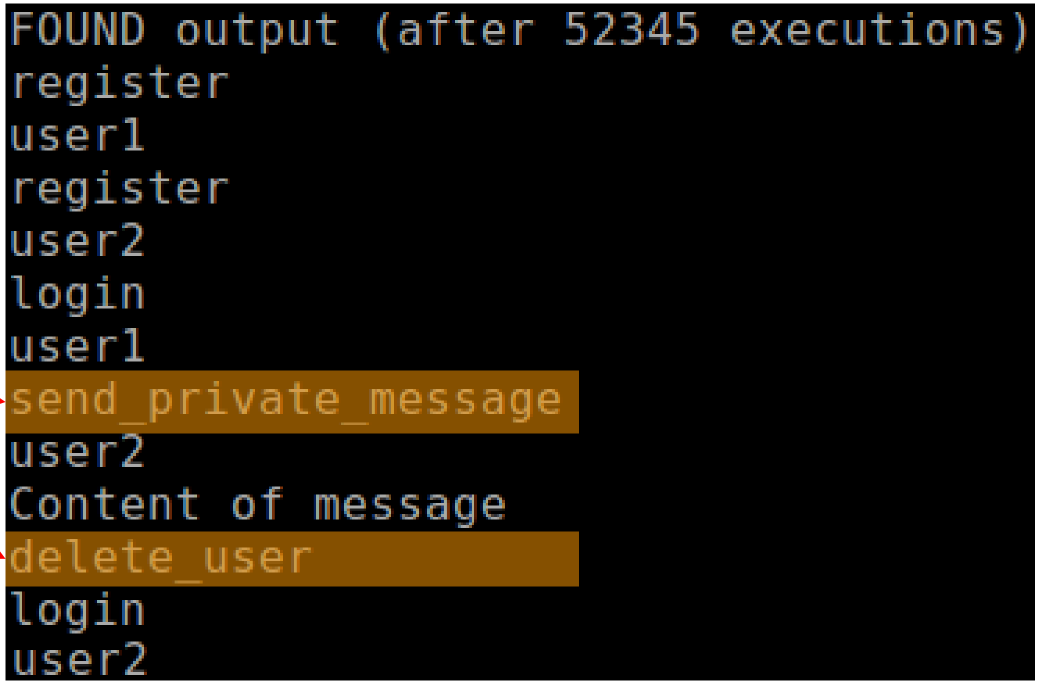
Always generate multiple outputs (100 or 1000; 100 is recommended by radamsa)



```
./radamsa test*.txt -n 1000 -o mutated%n.txt
```

Combination of multiple input files!

Possible output



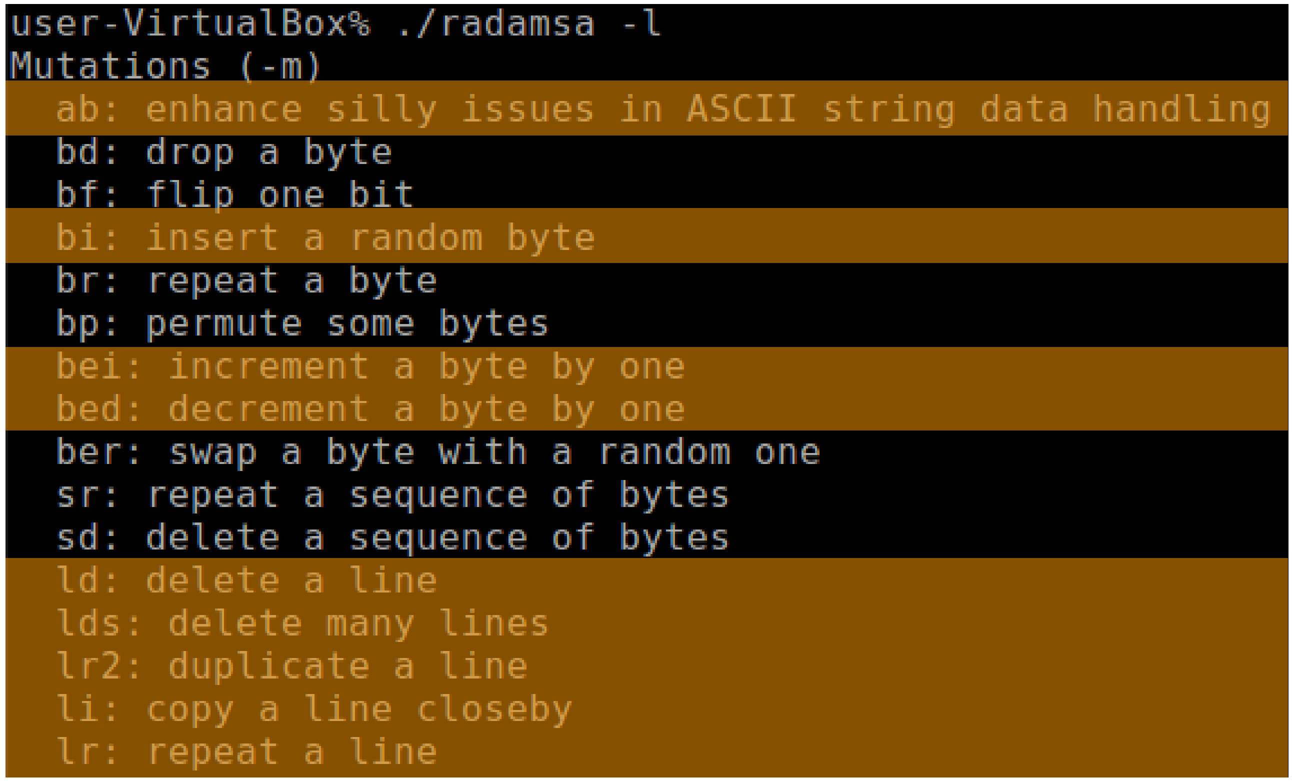
```
FOUND output (after 52345 executions)
register
user1
register
user2
login
user1
send_private_message
user2
Content of message
delete_user
login
user2
```

However, merging of multiple input files is very unlikely ("send msg + delete user + view msg" will not be found within 2 hours)

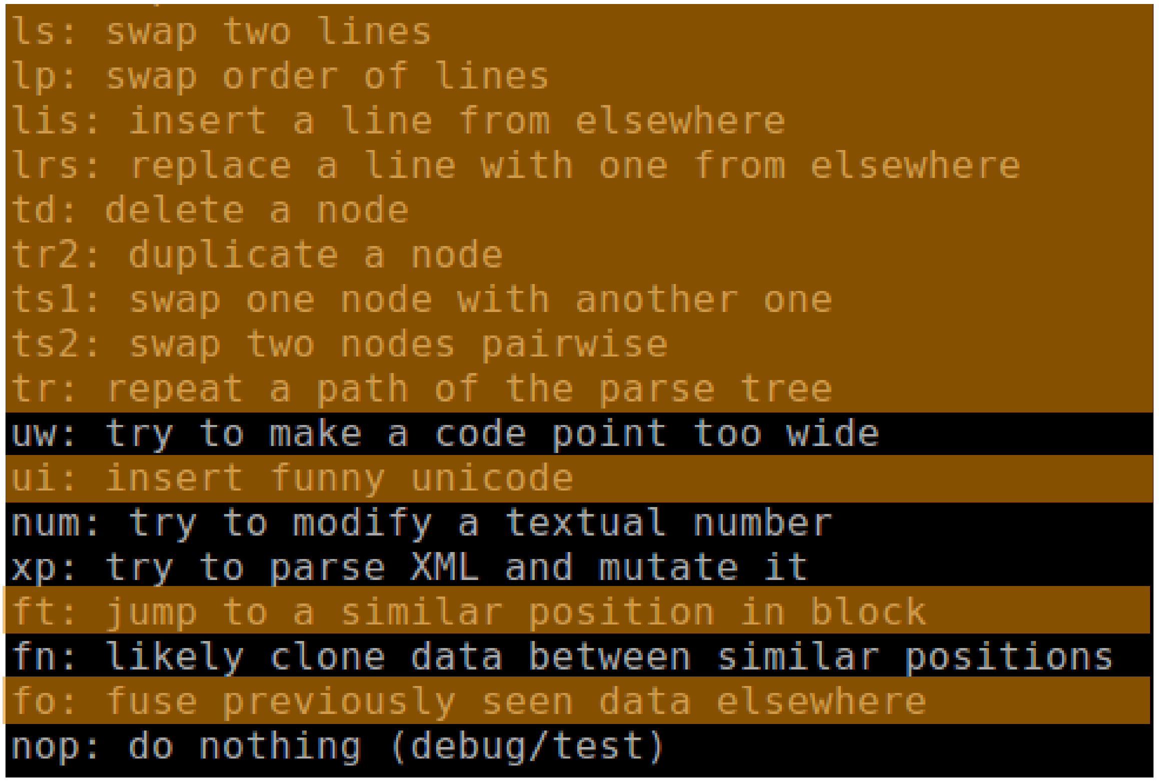
SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Radamsa

- **Correct selection of mutators (Example of the “chat” target):**



```
user-VirtualBox% ./radamsa -l
Mutations (-m)
  ab: enhance silly issues in ASCII string data handling
  bd: drop a byte
  bf: flip one bit
  bi: insert a random byte
  br: repeat a byte
  bp: permute some bytes
  bei: increment a byte by one
  bed: decrement a byte by one
  ber: swap a byte with a random one
  sr: repeat a sequence of bytes
  sd: delete a sequence of bytes
  ld: delete a line
  lds: delete many lines
  lr2: duplicate a line
  li: copy a line closeby
  lr: repeat a line
```



```
ls: swap two lines
lp: swap order of lines
lis: insert a line from elsewhere
lrs: replace a line with one from elsewhere
td: delete a node
tr2: duplicate a node
ts1: swap one node with another one
ts2: swap two nodes pairwise
tr: repeat a path of the parse tree
uw: try to make a code point too wide
ui: insert funny unicode
num: try to modify a textual number
xp: try to parse XML and mutate it
ft: jump to a similar position in block
fn: likely clone data between similar positions
fo: fuse previously seen data elsewhere
nop: do nothing (debug/test)
```

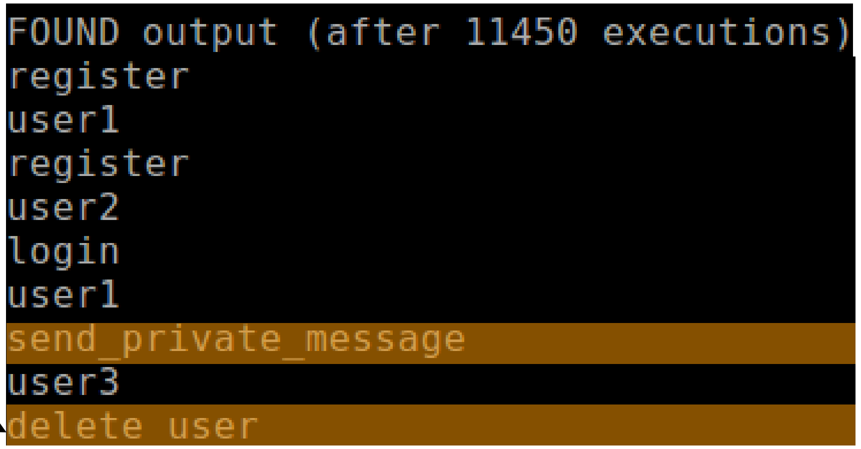
Radamsa vs. Ni

- **Radamsa is written in Owl Lisp** (a functional dialect of Scheme)
  - Modifying the code is hard (at least for me because I don't know Owl Lisp)
  - Currently no library support ☹ (➔ Slower than in-memory mutation)
  - Good mutation and gramma detection (~ 3500 lines)
  - Maintained
- **Ni is written in C**
  - Simple to modify, add to own project or compile as library (and it's fast)
  - https://github.com/aoh/ni (from the same guys)
  - Not as advanced as radamsa ☹ (~800 lines)
  - Not maintained: Last commit 2014

Ni can also merging multiple inputs

➔ **Other inputs are only used during "random_block()" function**

➔ **Merging / Gramma detection not so advanced as with radamsa**



```
FOUND output (after 11450 executions)
register
user1
register
user2
login
user1
send_private_message
user3
delete user
```

Speed comparision

- The following table gives a **speed comparison** between different test setups for mutating data
  - **Numbers in the table are generated testcases per second**
  - Table does not contain fuzzing or file read/write times (only generation of fuzz data)
  - TC stands for number of test cases
  - RD stands for RAM disk for files & programs
  - Test program was a Python script
  - Radamsa fast mode uses the following mutators:
    - -m bf,bd,bi,br,bp,bei,bed,ber,sr,sd
    - Taken from FAQ from https://github.com/aoh/radamsa

Speed comparision – input small text files

Type of test	Radamsa ext.	Radamsa fast ext.	Ni ext.	Ni library (ctypes)
Input stdin (1 tc), output stdout (1 tc)	~ 265	~ 345	(no stdin support)	-
Input files (3 tc), output stdout (1 tc)	~ 255	~300	~775	-
Input files (3 tc), output via files (100 tc)	~1100	~1930	~7300	-
Input via files (3 tc), output via files (1000 tc)	~1100	~2150	~8350	-
Input files (3 tc), output via files (100 tc); RD	~1220	~2740	~7300	-
Input files (3 tc), output via files (1000 tc); RD	**~1230**	**~3100**	**~8400**	-
Input 3 samples, output one (all in-memory)	-	-	-	~4000

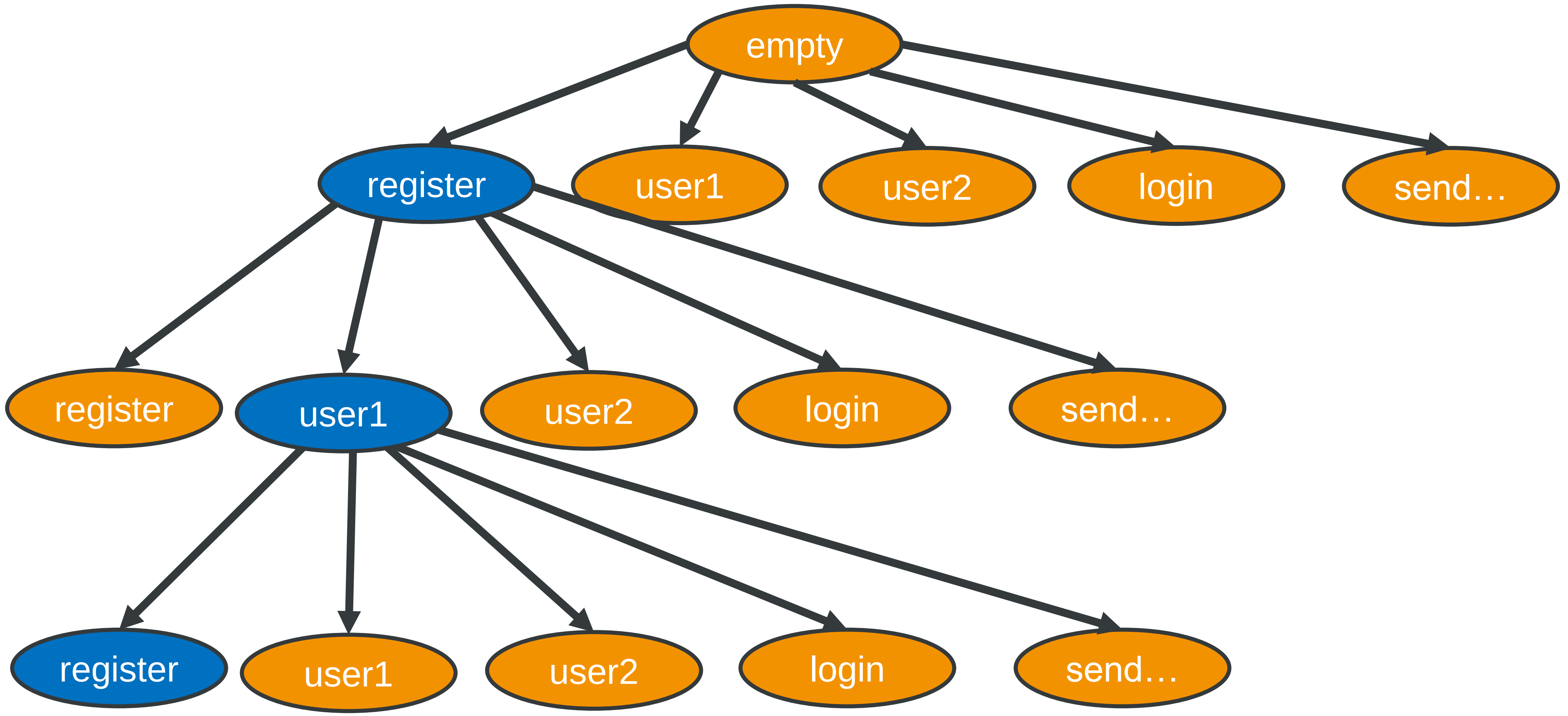
The problem of the search space

The following input triggers the second Use-After-Free flaw in the chat binary:

```
Depth 1 → register
          user1
          register
          user2
          login
Depth 6 → user1
```

```
           send_private_message
           user2
           content
Depth 10 → delete_user
           login
           user2
Depth 13 → view_messages
```

The problem of the search space



<empty>

register

register
user1

register
user1
register

The problem of the search space

- **We need at least 7 distinct input-tokens to find the flaw** (register, user1, user2, login, send_private_message, delete_user, view_message)
    - During real fuzzing we have way more inputs (all possible commands, special chars, long strings, special numbers, ….)
- After every input line we can again select one from the 7 possible input-tokens
- We have to find 13 input lines in the correct order to trigger the bug!
- **For 13 input lines we have 7^13 = 96 889 010 407 possibilities**

➔ **Runtime of the fuzzer to find this flaw?**

➔ This is also a huge difference to file format fuzzing! File format fuzzing does not produce such huge search spaces, because “commands” can’t be sent at every node in the tree! (nodes have less children)

➔ AFL is not the best choice to fuzz such problems

The problem of the search space

➔ **We must reduce the search space!**

- Initial Start-Sequence (Create Users) (This can be seen as our “input corpus”)
- Initial End-Sequence (Check public and private messages of all users)
- Encode the format into the fuzzer
  - Example: send_message(username, random_string_msg))
  - ➔ Peach Fuzzer
  - But that was basically what we wanted to avoid (Fuzzer should work without modification)
- Instead of adding one command per iteration, add many commands (inputs)
  - Same when fuzzing web browsers ➔ Add thousands of html, svg, JavaScript, CSS, … lines to one test case and check for a crash
  - Important: Too many commands can create invalid inputs (e.g. invalid command ➔ Exit application)
- Additional feedback to “choose” promising entries (E.g.: prefer text output which was not seen yet, prefer fuzzer queue entries which often produce new output, …)

The problem of the search space

The following input triggers the second Use-After-Free flaw in the chat binary:

~~register~~
~~user1~~
~~register~~
~~user2~~
~~login~~
~~user1~~

Depth 4 →

send_private_message
user2
content
delete_user
~~login~~
~~user2~~
~~view_messages~~

Practice: Lection 9

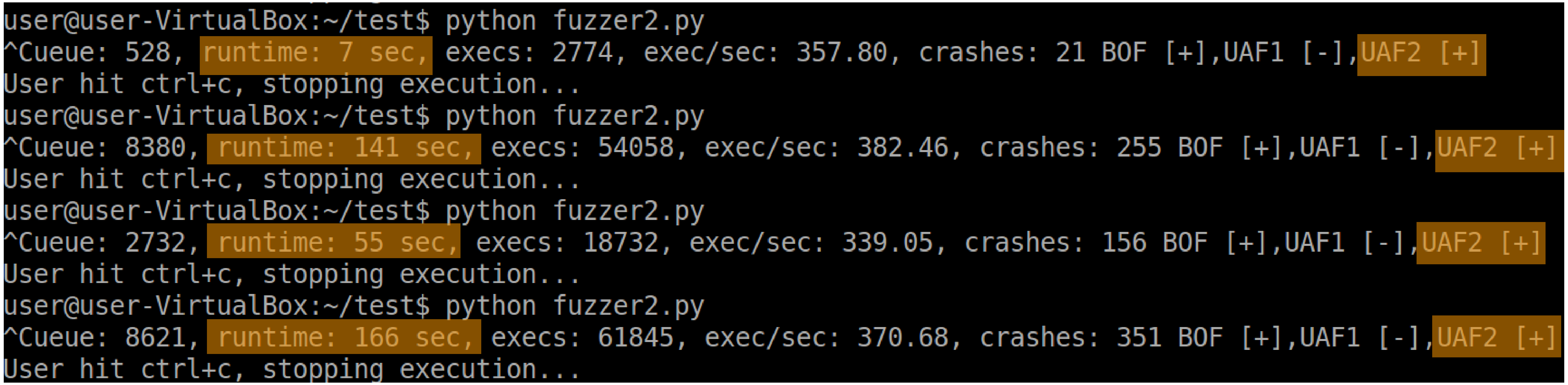
Topic: Lection 9 – CTF Chat binary fuzzing

Duration: 5-10 min

Description: See how to fuzz a CTF binary.

Chat CTF Fuzzer

- Runtime to find the deep second UAF (Use-After-Free) vulnerabiltiy…



```
user@user-VirtualBox:~/test$ python fuzzer2.py
^Cueue: 528, runtime: 7 sec, execs: 2774, exec/sec: 357.80, crashes: 21 BOF [+],UAF1 [-],UAF2 [+]
User hit ctrl+c, stopping execution...
user@user-VirtualBox:~/test$ python fuzzer2.py
^Cueue: 8380, runtime: 141 sec, execs: 54058, exec/sec: 382.46, crashes: 255 BOF [+],UAF1 [-],UAF2 [+]
User hit ctrl+c, stopping execution...
user@user-VirtualBox:~/test$ python fuzzer2.py
^Cueue: 2732, runtime: 55 sec, execs: 18732, exec/sec: 339.05, crashes: 156 BOF [+],UAF1 [-],UAF2 [+]
User hit ctrl+c, stopping execution...
user@user-VirtualBox:~/test$ python fuzzer2.py
^Cueue: 8621, runtime: 166 sec, execs: 61845, exec/sec: 370.68, crashes: 351 BOF [+],UAF1 [-],UAF2 [+]
User hit ctrl+c, stopping execution...
```

- UAF1 was removed from patched binary because UAF1 would trigger before UAF2
- This fuzzer also works for any other CTF binary!!

Demo Time!

Topic: Mimikatz vs. GFlags & Application Verifier with PageHeap on Windows

Runtime: 3 min 15 sec

Description: See how to find bugs by just using the application and enabling the correct verifier settings.

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Detecting not crashing vulnerabilities

- **LLVM has many useful sanitizers!**
  - Address-Sanitizer (ASAN): -fsanitize=address
    - Out-of-bounds access (Heap, stack, globals), Use-After-Free, …
  - Memory-Sanitizer (MSAN): -fsanitize=memory
    - Uninitialized memory use
  - UndefinedBehaviorSanitizer (UBSAN): -fsanitize=undefined
    - Catch undefined behavior (Misaligned pointer, signed integer overflow, …)

- If you don‘t have source code: **DrMemory** (based on DynamoRio)

- **Use sanitizers during development**
  - You can also grab ASAN (address sanitizer) builds of firefox or chrome!

- **I personally prefer heap libraries for fuzzing because they are faster but many people also use sanitizers for fuzzing.**

Practice: Lection 10

Topic: Lection 10 – Sanitizers

Duration: 5-10 min

Description: See different sanitizers in action.

ASAN / MSAN

- **Use ASAN / MSAN with AFL:**
    - Cite from „notes_for_asan.txt“ from docs of AFL

„To compile with ASAN, set **AFL_USE_ASAN=1** before calling 'make clean all'. The afl-gcc / afl-clang wrappers will pick that up and add the appropriate flags.

Note that ASAN is incompatible with -static, so be mindful of that.

(You can also use AFL_USE_MSAN=1 to enable MSAN instead.)”

Practice: Lection 11

Topic: Lection 11 – DrMemory

Duration: 5 min

Description: See DrMemory in action.

Detecting not crashing vulnerabilities

- **Change the heap implementation to check for dangling pointers AFTER a free() operation! (similar to MemGC)**
    - Check all pointers in data section, heap and stack if they point into memory
    - Check must only be performed **one time for new queue entries**

```
send_private_message
user2
content
```

Free()
Detection here! →

```
delete_user
login
user2
```

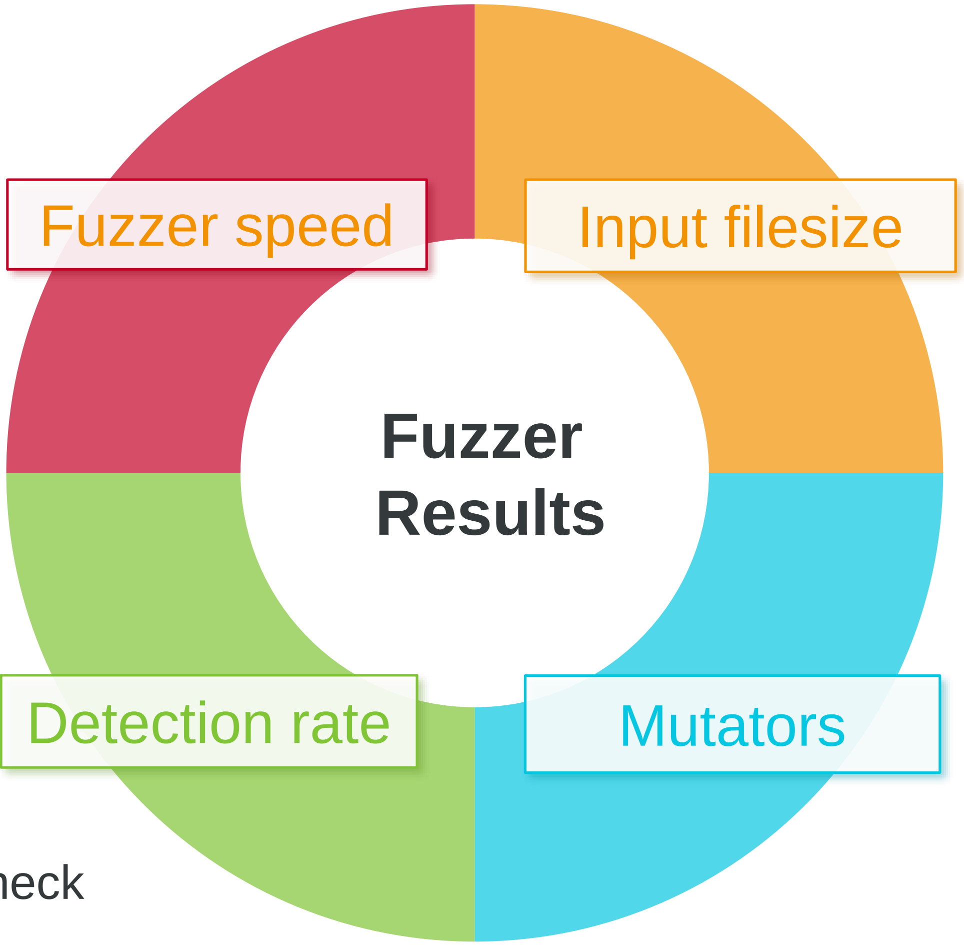
Use after free →

```
view_messages
```

Overview: Areas which influence fuzzing results

Fork-server
Faster instrumentation code
Static vs. Dynamic Instrumentation
In-memory fuzzing
No process switches
…

AFL-tmin & AFL-cmin
Heat maps via Taint Analysis and Shadow Memory
…



Page heap / Heap libs
Sanitizers (ASAN, MSAN, SyzyASan, DrMemory, ..)
Dangling Pointer Check
Writeable Format Strings Check
…

Application aware mutators
Generated dictionaries
Append vs. Modify mode
Grammar-based mutators
Use of feedback from application
…

Practice: Lection 12

Topic: Lection 12 – AFL-cov

Duration: 5 min

Description: See how to visualize AFL coverage.

LibFuzzer

LibFuzzer

- **LibFuzzer – Similar concept to AFL but in-memory fuzzing**
  - Requires LLVM SanitizerCoverage + writing small fuzzer-functions
  - LibFuzzer is more “**a fuzzer for developers**”
  - AFL fuzzes the execution path of a binary (no modification required)
  - LibFuzzer fuzzes the execution path of a specific function (minimal code modifications required)
    - Fuzz function1 which processes data format 1 ➔ Corpus 1
    - Fuzz function2 which processes data format 2 ➔ Corpus 2
    - AFL can also do in-memory fuzzing (persistent mode)
- **I highly recommend this tutorial:** http://tutorial.libfuzzer.info
- **And this workshop:** https://github.com/Dor1s/libfuzzer-workshop
  - Our next labs are from this workshop!

Practice: Lection 13

Topic: Lection 13 – LibFuzzer simple example

Duration: 5 min

Description: Use LibFuzzer in an simple example.

Can you spot the vulnerability?

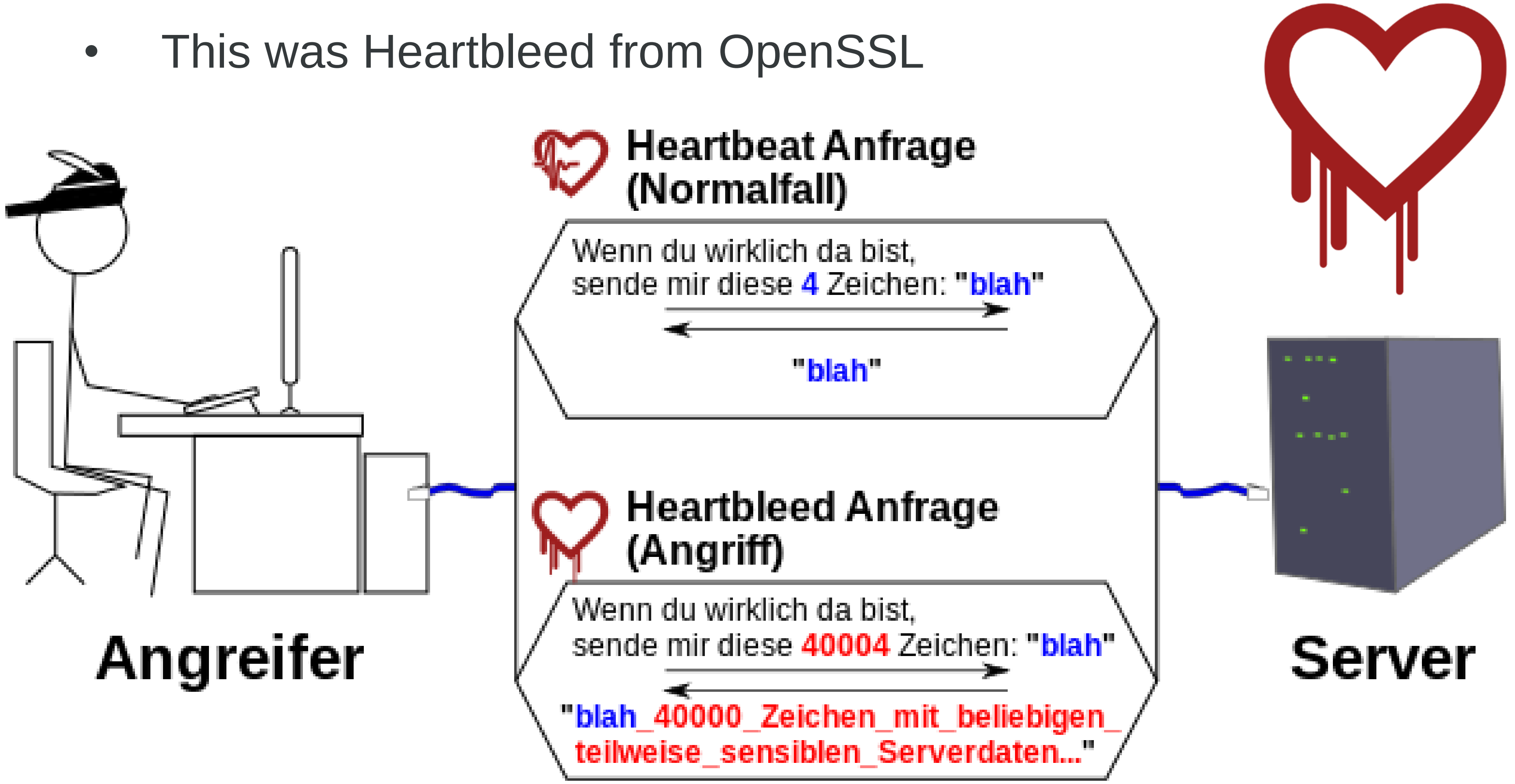
```
int dtls1_process_heartbeat(SSL *s) {
        unsigned char *p = &s->s3->rrec.data[0], *pl;
        unsigned short hbtype;
        unsigned int payload, padding = 16; /* Use minimum padding */

        /* Read type and payload length first */
        hbtype = *p++;
        n2s(p, payload);
        pl = p;
       /* snipped removed */
        if (hbtype == TLS1_HB_REQUEST) {
                unsigned char *buffer, *bp;
                int r;
                /* Allocate memory for the response, size is 1 byte
                 * message type, plus 2 bytes payload length, plus
                 * payload, plus padding
                 */
                buffer = OPENSSL_malloc(1 + 2 + payload + padding);
                bp = buffer;

                /* Enter response type, length and copy payload */
                *bp++ = TLS1_HB_RESPONSE;
                s2n(payload, bp);
                memcpy(bp, pl, payload);
                bp += payload;
                /* Random padding */
                RAND_pseudo_bytes(bp, padding);

                r = dtls1_write_bytes(s, TLS1_RT_HEARTBEAT, buffer, 3 + payload + padding);

                if (r >= 0 && s->msg_callback)
                        s->msg_callback(1, s->version, TLS1_RT_HEARTBEAT,
                                buffer, 3 + payload + padding,
                                s, s->msg_callback_arg);
```

Attacker controlled ➔ „p" points to an attacker controlled buffer

This macro reads 2 bytes from p and stores them in payload

Can you spot the vulnerability?

- This was Heartbleed from OpenSSL



Heartbeat Anfrage (Normalfall)
Wenn du wirklich da bist, sende mir diese 4 Zeichen: "blah"
"blah"
Heartbleed Anfrage (Angriff)
Wenn du wirklich da bist, sende mir diese 40004 Zeichen: "blah"
"blah_40000_Zeichen_mit_beliebigen_teilweise_sensiblen_Serverdaten..."
Angreifer
Server

Source: https://de.wikipedia.org/wiki/Heartbleed

Can you spot the vulnerability?

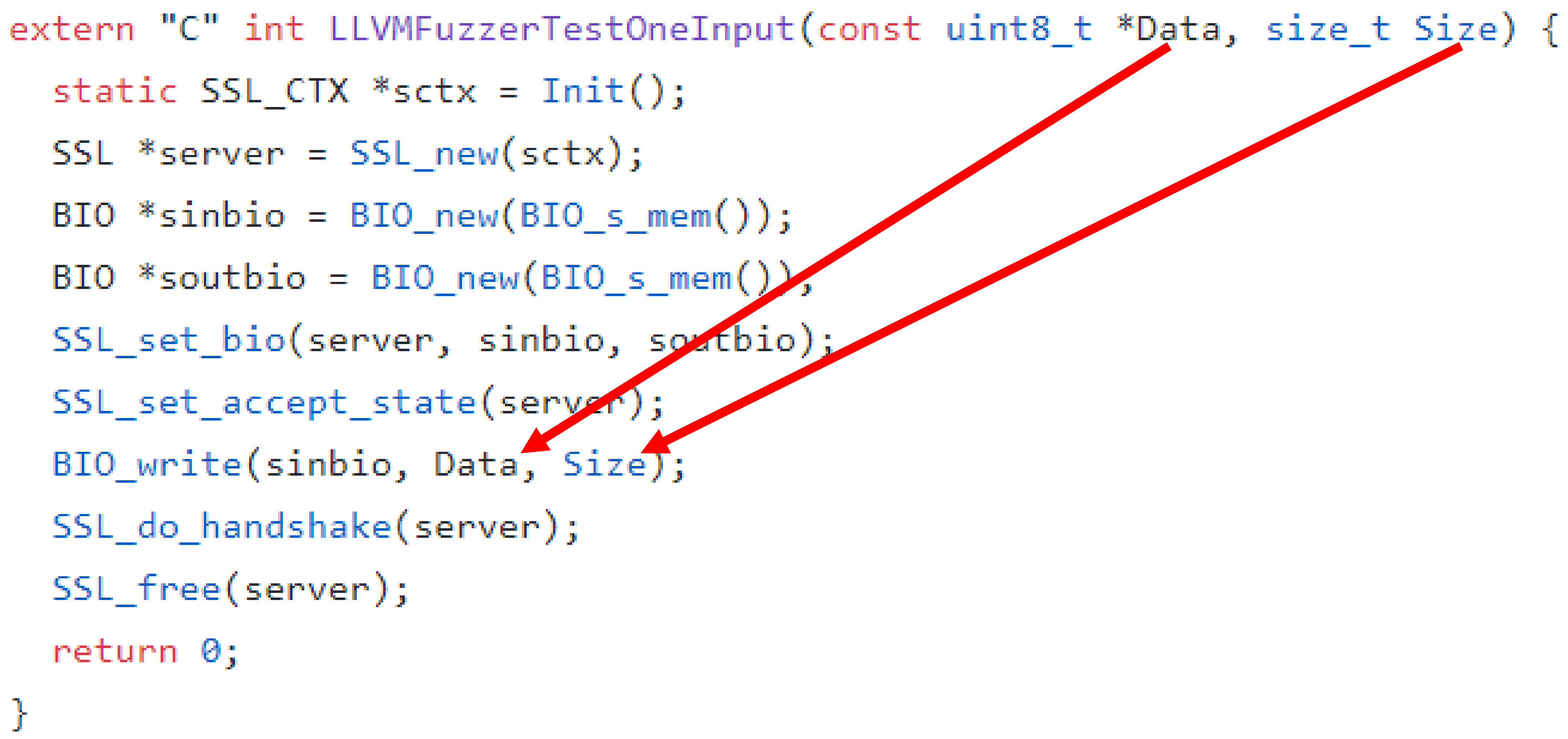
```
int dtls1_process_heartbeat(SSL *s) {
         unsigned char *p = &s->s3->rrec.data[0], *pl;
         unsigned short hbtype;
         unsigned int payload, padding = 16; /* Use minimum padding */

         /* Read type and payload length first */
         hbtype = *p++;
         n2s(p, payload);
         pl = p;
        /* snipped removed */
         if (hbtype == TLS1_HB_REQUEST) {
                 unsigned char *buffer, *bp;
                 int r;
                 /* Allocate memory for the response, size is 1 byte
                  * message type, plus 2 bytes payload length, plus
                  * payload, plus padding
                  */
                 buffer = OPENSSL_malloc(1 + 2 + payload + padding);
                 bp = buffer;

                 /* Enter response type, length and copy payload */
                 *bp++ = TLS1_HB_RESPONSE;
                 s2n(payload, bp);
                 memcpy(bp, pl, payload);
                 bp += payload;
                 /* Random padding */
                 RAND_pseudo_bytes(bp, padding);

                 r = dtls1_write_bytes(s, TLS1_RT_HEARTBEAT, buffer, 3 + payload + padding);

                 if (r >= 0 && s->msg_callback)
                         s->msg_callback(1, s->version, TLS1_RT_HEARTBEAT,
                                 buffer, 3 + payload + padding,
                                 s, s->msg_callback_arg);
```

Attacker controlled

Copies „payload“ (user supplied) bytes from pl (= p = ssl input data) to „bp“ (output buffer)
Size of „pl“ is never checked!

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

LibFuzzer



```
extern "C" int LLVMFuzzerTestOneInput(const uint8_t *Data, size_t Size) {
  static SSL_CTX *sctx = Init();
  SSL *server = SSL_new(sctx);
  BIO *sinbio = BIO_new(BIO_s_mem());
  BIO *soutbio = BIO_new(BIO_s_mem());
  SSL_set_bio(server, sinbio, soutbio);
  SSL_set_accept_state(server);
  BIO_write(sinbio, Data, Size);
  SSL_do_handshake(server);
  SSL_free(server);
  return 0;
}
```

Source: http://tutorial.libfuzzer.info

Practice: Lection 14

Topic: Lection 14 – LibFuzzer Heartbleed.

Duration: 5 min

Description: Use LibFuzzer to find HeartBleed.

Practice: Lection 15

Topic: Lection 15 – LibFuzzer C-ares

Duration: 5 min

Description: Use LibFuzzer to find a bug in C-ares.

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Practice: Lection 16

Topic: Lection 16 – LibFuzzer Woff

Duration: 5 min

Description: Use LibFuzzer to find a bug in Woff.

DynamoRio

Dynamic Instrumentation Frameworks

- **Dynamic runtime manipulation** of instructions of a running application!

- Many default tools are shipped with these frameworks
  - drrun.exe –t drcov -- calc.exe
  - drrun.exe –t my_tool.dll -- calc.exe
  - pin -t inscount.so -- /bin/ls

- Register callbacks, which are trigger at specific events (new basic block / instruction which is moved into code cache, load of module, exit of process, …)

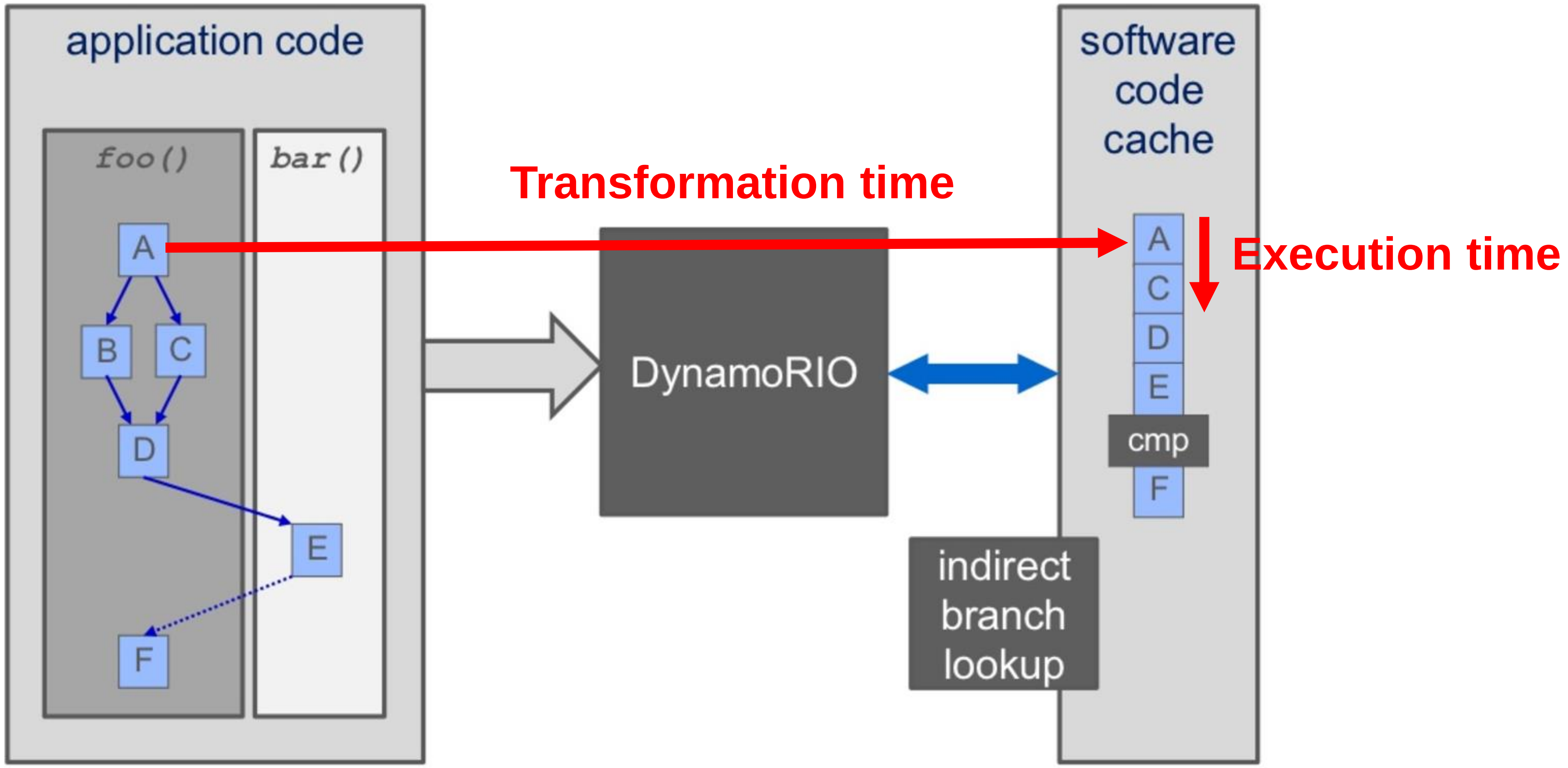
Dynamic Instrumentation Frameworks

- **For transformation time callbacks can be registered**
  - Called only once if new code gets executed
  - drmgr_register_bb_instrumentation_event()

- **For execution time we have two possibilities**
  - Called every time the code is executed
  - Clean calls: save full context (registers) and call a C function (slow)
  - Inject assembler instructions (fast)
    - Context not saved, tool writer must take care himself
    - Registers can be “spilled” (can be used by own instructions without losing old state)
    - DynamoRio takes care of selecting good registers & saving and restoring them

- **Nudges can be send to the process & callbacks can react on them**
  - Example: Turn logging on after the application started

DynamoRIO



Source: The DynamoRIO Dynamic Tool Platform, Derek Bruening, Google

DynamoRIO

- **Example:** Start Adobe Reader, load PDF file, exit Adobe Reader, extract coverage data (Processing 25 PDFs with one single CPU core)
- Runtime without DynamoRio: ~30-40 seconds
- BasicBlock coverage (no hit count): 105 seconds
  - Instrumentation only during transformation into code cache (transformation time)
- BasicBlock coverage (hit count): 165 seconds
  - Instrumentation on basic block level (execution time)
- Edge coverage (hit count): 246 seconds
  - Instrumentation on basic block level (many instructions required to save and restore required registers for instrumentation code) (execution time)

DynamoRio vs PIN

- **PIN** is another dynamic instrumentation framework (older)
- Currently more people use PIN (➔ more examples are available)
- DynamoRio is noticeable faster than PIN
- But PIN is more reliable
  - DynamoRio can’t start Encase Imager, PIN can
  - DynamoRio can’t start CS GO, PIN can
  - During client writing I noticed several strange behaviors of DynamoRio

Demo Time!

Topic: Instrumentation of Adobe Reader with DynamoRio

Runtime: 2 min 31 sec

Description: Use DynamoRio to extract code-coverage of a closed-source application using only a simple command.

Demo Time!

Topic: Determine Adobe Reader “PDF loaded” breakpoint with coverage analysis.

Runtime: 1 min 08 sec

Description: Log coverage of “PDF open” action to get a breakpoint address to detect end of PDF loading.

Practice: Lection 17

Topic: Lection 17 – DrCov

Duration: 1 min

Description: Use DrCov to extract coverage information.

Practice: Lection 18

Topic: Lection 18 – Log function calls.

Duration: 5 min

Description: Read a sample DynamoRio client code and execute it.

Practice: Lection 19

Topic: Lection 19 – Write a DynamoRio client to log all cmp values.

Duration: 15 min

Description: Log cmp values and use them for fuzzing.

Windows Fuzzing

WinAFL

- **WinAFL - AFL for Windows** developed by **Ivan Fratric**
  - Download: https://github.com/ivanfratric/winafl

- Two modes:
  - DynamoRio: Source code not required
    - Can be used to modify closed-source applications at runtime ➔ Our focus today!
  - Syzygy: Source code required
    - Fuzzing Mimikatz ➔ Demo 4 from https://sec-consult.com/en/blog/2017/11/the-art-of-fuzzing-slides-and-demos/index.html

- ➔ WinAFL uses in-memory fuzzing and we therefore **must specify a target function** which should be fuzzed

```
afl-fuzz.exe -i in -o out -D C:\work\winafl\DynamoRIO\bin64 -t 20000 --
-coverage_module gdiplus.dll -coverage_module WindowsCodecs.dll
-fuzz_iterations 5000 -target_module test_gdiplus.exe
-target_offset 0x1270 -nargs 2 -- test_gdiplus.exe @@
```

Demo Time!

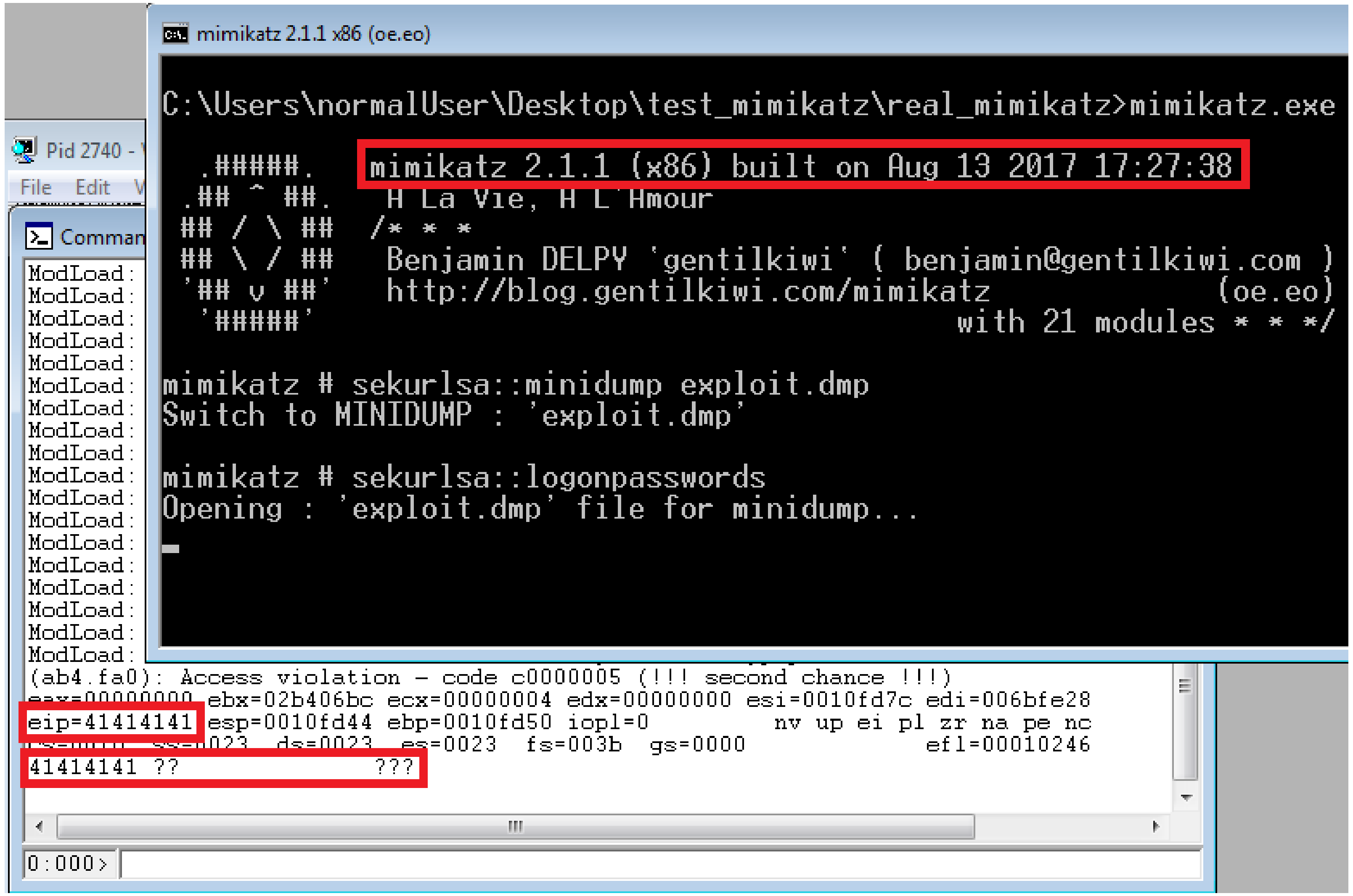
Topic: Fuzzing mimikatz on Windows with WinAFL

Runtime: 10 min 39 sec

Description: See the WinAFL fuzzing process on Windows of binaries with source-code available in action.

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Fuzzing and exploiting mimikatz



```
C:\Users\normalUser\Desktop\test_mimikatz\real_mimikatz>mimikatz.exe

  .#####.   mimikatz 2.1.1 (x86) built on Aug 13 2017 17:27:38
 .## ^ ##.   "A La Vie, A L'Amour"
 ## / \ ##  /* * *
 ## \ / ##   Benjamin DELPY `gentilkiwi` ( benjamin@gentilkiwi.com )
 '## v ##'   http://blog.gentilkiwi.com/mimikatz             (oe.eo)
  '#####'                                     with 21 modules * * */

mimikatz # sekurlsa::minidump exploit.dmp
Switch to MINIDUMP : 'exploit.dmp'

mimikatz # sekurlsa::logonpasswords
Opening : 'exploit.dmp' file for minidump...
```

```
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
ModLoad:
(ab4.fa0): Access violation - code c0000005 (!!! second chance !!!)
eax=00000000 ebx=02b406bc ecx=00000004 edx=00000000 esi=0010fd7c edi=006bfe28
eip=41414141 esp=0010fd44 ebp=0010fd50 iopl=0         nv up ei pl zr na pe nc
cs=001b  ss=0023  ds=0023  es=0023  fs=003b  gs=0000             efl=00010246
41414141 ??              ???
0:000>
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

AutoIt

- **AutoIt definition** (https://www.autoitscript.com):

AutoIt v3 is a freeware BASIC-like **scripting language** designed for **automating the Windows GUI** and general scripting. It uses a **combination of simulated keystrokes, mouse movement and window/control** manipulation in order to automate tasks …

AutoIt Demo Source Code

```
#include <AutoItConstants.au3>

Run("notepad.exe")
Local $hWand = WinWait("[CLASS:Notepad]", "", 10)
ControlSend($hWand, "", "Edit1", "Hello World")
WinClose($hWand)
ControlClick("[CLASS:#32770]", "", "Button3")
WinSetState("[CLASS:Notepad]", "", @SW_MAXIMIZE)
MouseMove(14,31)
MouseClick($MOUSE_CLICK_LEFT)
MouseMove(85,209)
MouseClick($MOUSE_CLICK_LEFT)
ControlClick("[CLASS:#32770]", "", "Button2")
```

Practice: Lection 20

Topic: Lection 20 - AutoIt

Runtime: 5 min

Description: Use AutoIt to automate some GUI.

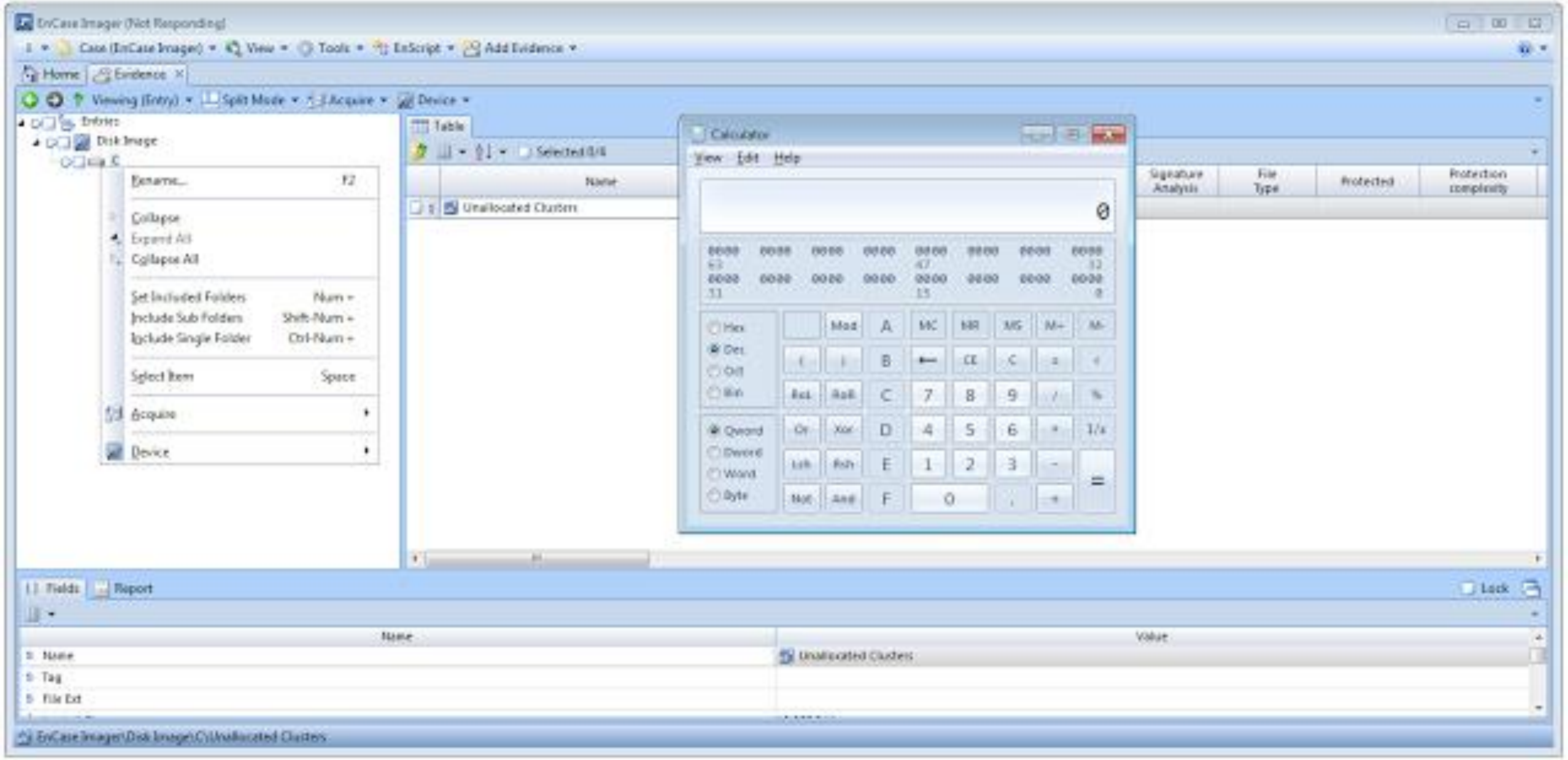
Demo Time!

Topic: Real-world EnCase Imager Fuzzing (Vulnerability found by SEC Consult employee Wolfgang Ettlinger)

Runtime: 29 sec

Description: See real-world fuzzing in action.

Exploitability of the vulnerability

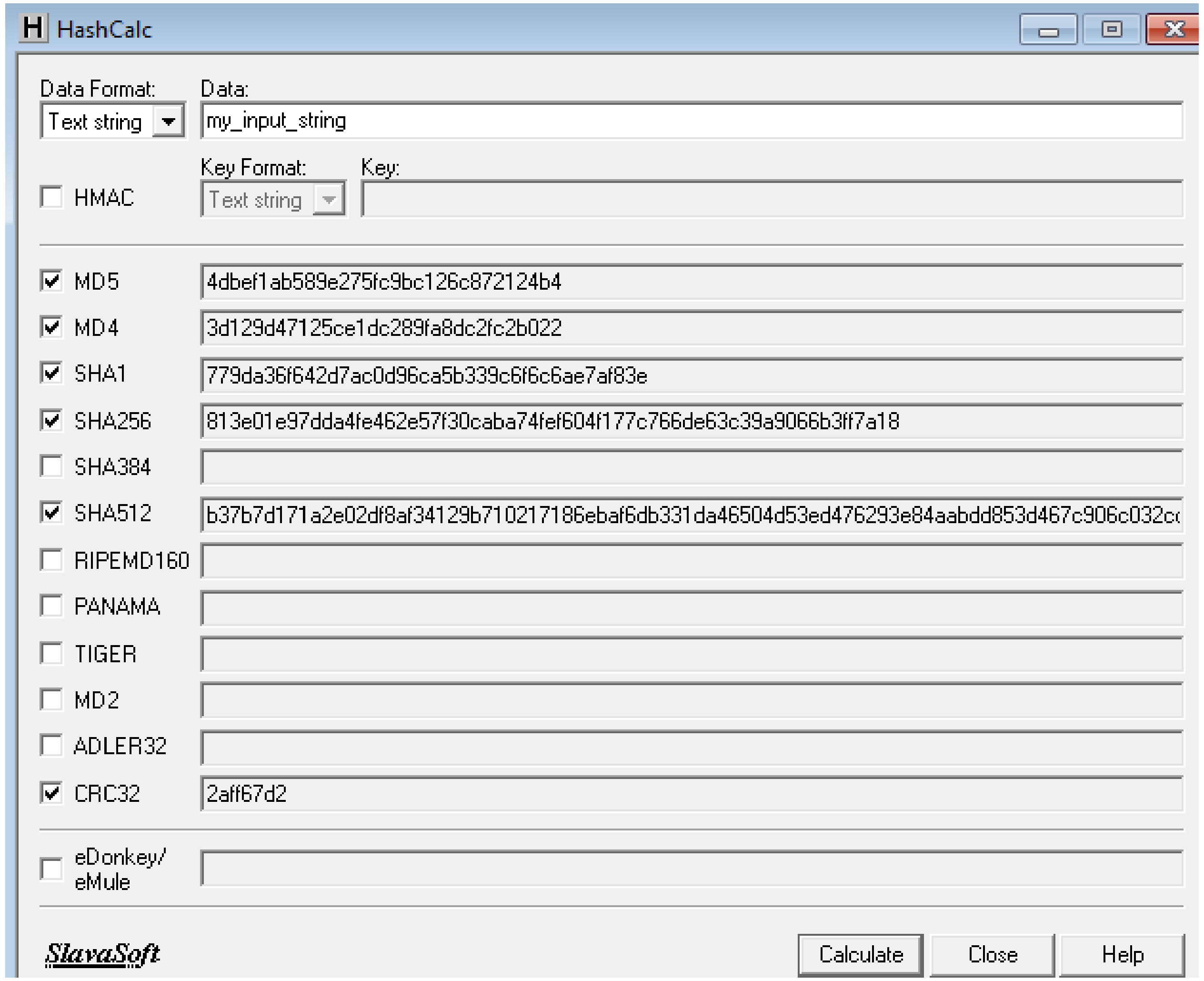


AutoIt

- **Another use case: Popup Killer**
  - During fuzzing applications often spawn error message ➔ popup killer closes them
  - Another implementation can be found in CERT Basic Fuzzing Framework (BFF) Windows Setup files (C++ code to monitor for message box events)

```
#include <MsgBoxConstants.au3>
While 1
  Local $aList = WinList()
  ; $aList[0][0] number elements
  ; $aList[x][0] => title ; $aList[x][1] => handle
  For $i = 1 To $aList[0][0]
    If StringCompare($aList[$i][0], "Engine Error") == 0 Then
      ControlClick($aList[$i][1], "", "Button2", "left", 2)
    EndIf
  Next
  sleep(500) ; 500 ms
WEnd
```

GUI automation – Example HashCalc



HashCalc

Data Format: Text string	Data: my_input_string
☐ HMAC	Key Format: Text string · Key:
☑ MD5	4dbef1ab589e275fc9bc126c872124b4
☑ MD4	3d129d47125ce1dc289fa8dc2fc2b022
☑ SHA1	779da36f642d7ac0d96ca5b339c6f6c6ae7af83e
☑ SHA256	813e01e97dda4fe462e57f30caba74fef604f177c766de63c39a9066b3ff7a18
☐ SHA384	
☑ SHA512	b37b7d171a2e02df8af34129b710217186ebaf6db331da46504d53ed476293e84aabdd853d467c906c032c
☐ RIPEMD160	
☐ PANAMA	
☐ TIGER	
☐ MD2	
☐ ADLER32	
☑ CRC32	2aff67d2
☐ eDonkey/ eMule	

Question 1:
What is the maximum MD5 fuzzing speed with GUI automation?

Question 2:
How many MD5 hashes can you calculate on a CPU per second?

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

GUI automation

- **HashCalc.exe MD5 fuzzing**
- GUI automation with AutoIt: ~**3 exec / sec**
- In-Memory with debugger: **~750 exec / sec**
- In-Memory with DynamoRio (no instr.): **~170 000 exec / sec**

Reverse Engineering Tricks for Fuzzing

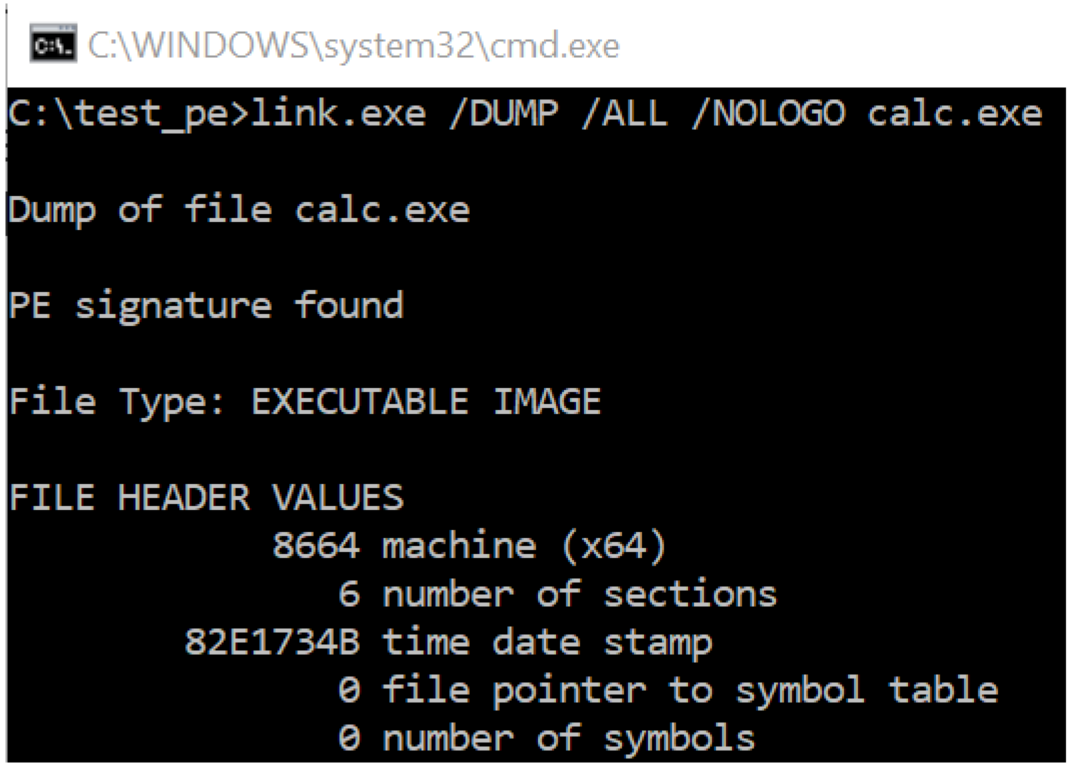
How to find the target function

- **Important task when fuzzing with WinAFL ➔ Find a potential target function to fuzz!**
    - How can we do this (as fast as possible) if source code is not available?
    - This function must open, process and close the input file!

- **Technique 1: Log CreateFile() and CloseFile()**
    - Simple solution: On 32-bit we can use Process Monitor and it's stack traces
    - API Monitor is another option
    - DynamoRio / PIN script

How to find the target function

- **Example:** We now use our PE corpus to fuzz dumpbin from Visual Studio
  - Dumpbin is internally just a wrapper to link.exe

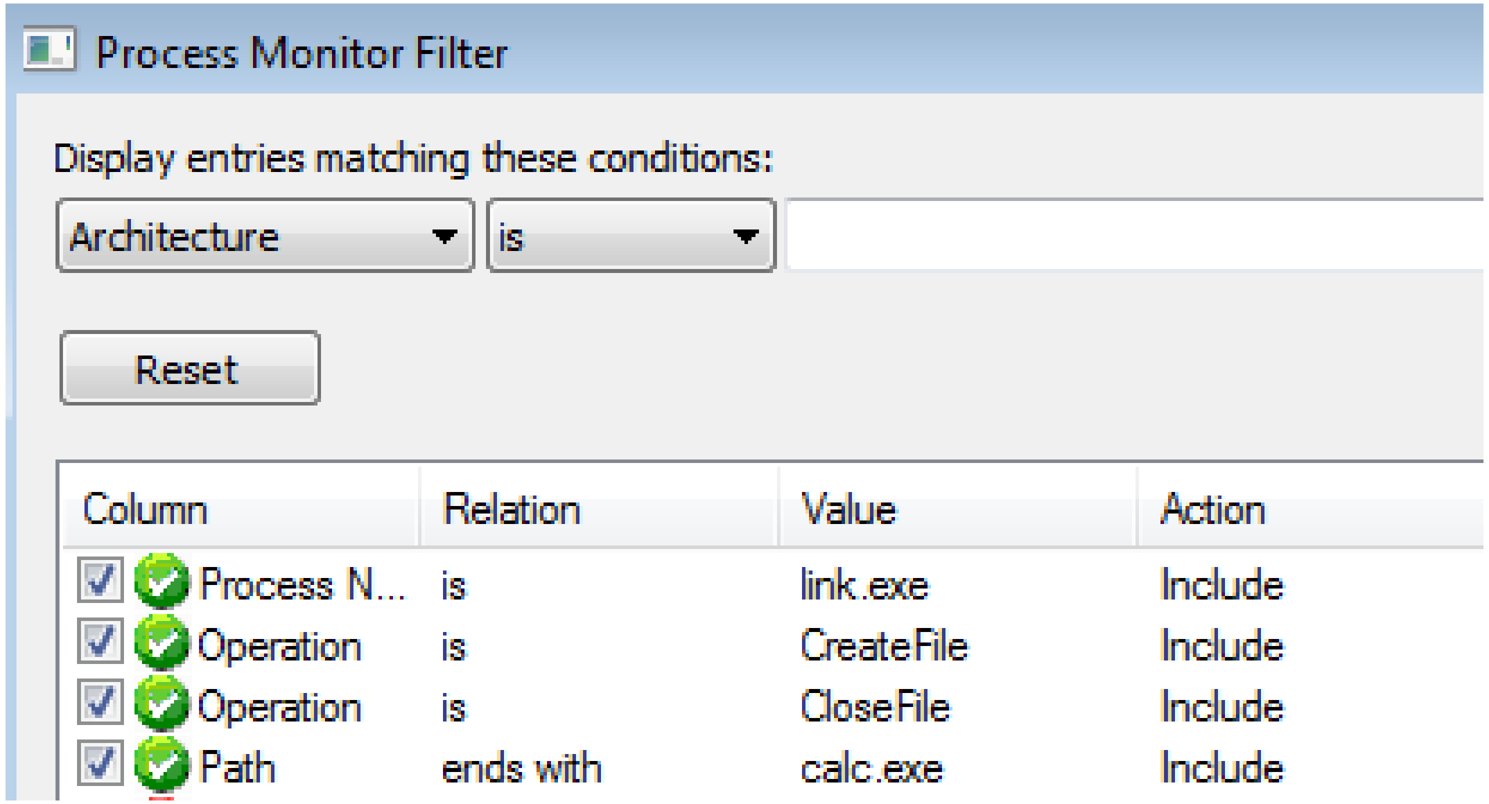


C:\WINDOWS\system32\cmd.exe

```
C:\test_pe>link.exe /DUMP /ALL /NOLOGO calc.exe

Dump of file calc.exe

PE signature found

File Type: EXECUTABLE IMAGE

FILE HEADER VALUES
            8664 machine (x64)
               6 number of sections
        82E1734B time date stamp
               0 file pointer to symbol table
               0 number of symbols
```

How to find the target function

- **Process Monitor** to find CreateFile and CloseFile



Process Monitor Filter

Display entries matching these conditions:

Architecture ▾ is ▾

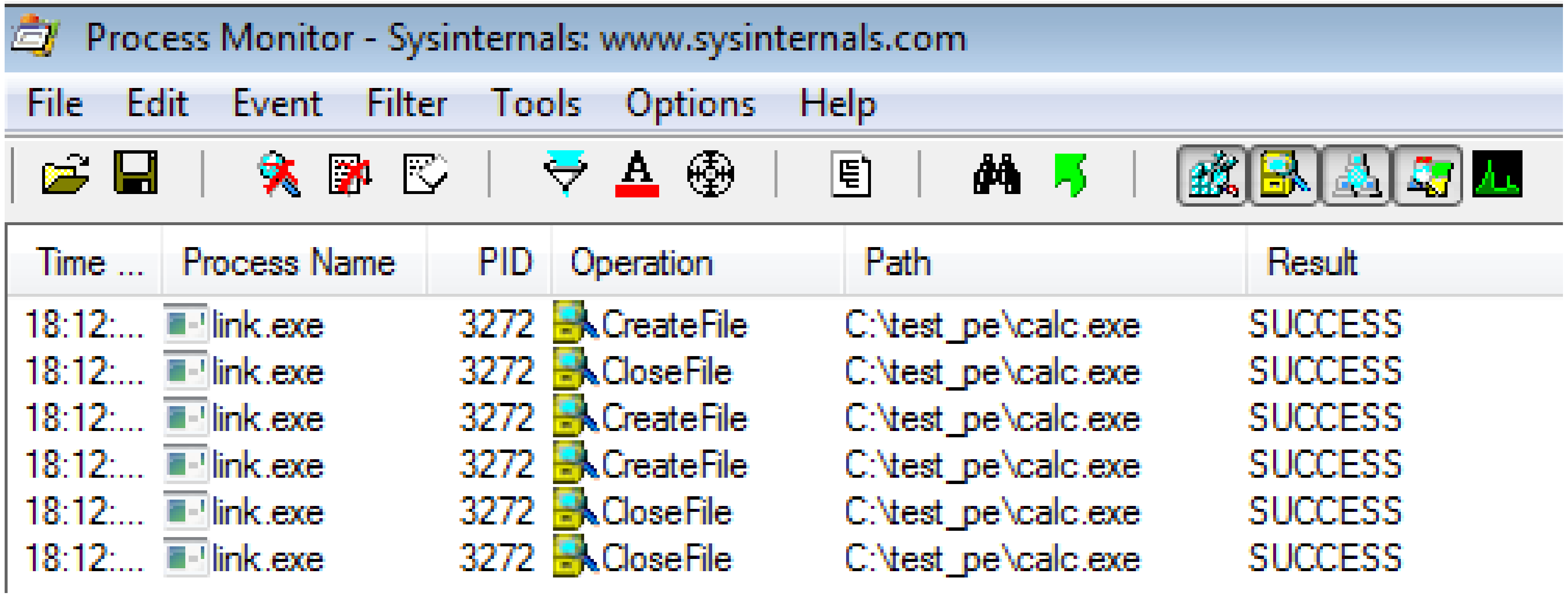
Reset

	Column	Relation	Value	Action
✓	Process N...	is	link.exe	Include
✓	Operation	is	CreateFile	Include
✓	Operation	is	CloseFile	Include
✓	Path	ends with	calc.exe	Include

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

How to find the target function

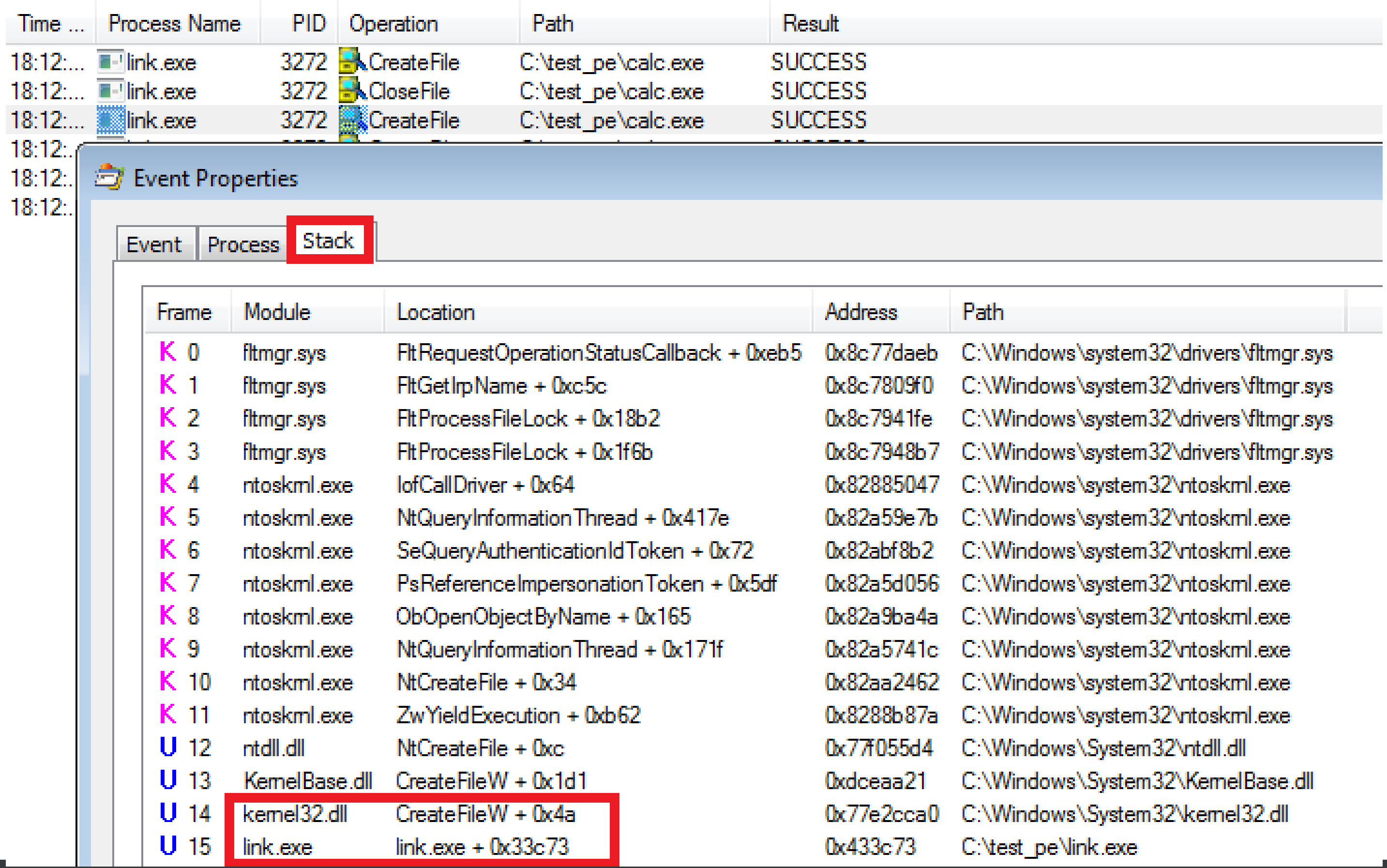
- **Result:**


Process Monitor - Sysinternals: www.sysinternals.com

Time ...	Process Name	PID	Operation	Path	Result
18:12:...	link.exe	3272	CreateFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CloseFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CreateFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CreateFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CloseFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CloseFile	C:\test_pe\calc.exe	SUCCESS

How to find the target function

- **Second CreateFile looks good ➔ CreateFileW**



Time ...	Process Name	PID	Operation	Path	Result
18:12:...	link.exe	3272	CreateFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CloseFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CreateFile	C:\test_pe\calc.exe	SUCCESS

Event Properties

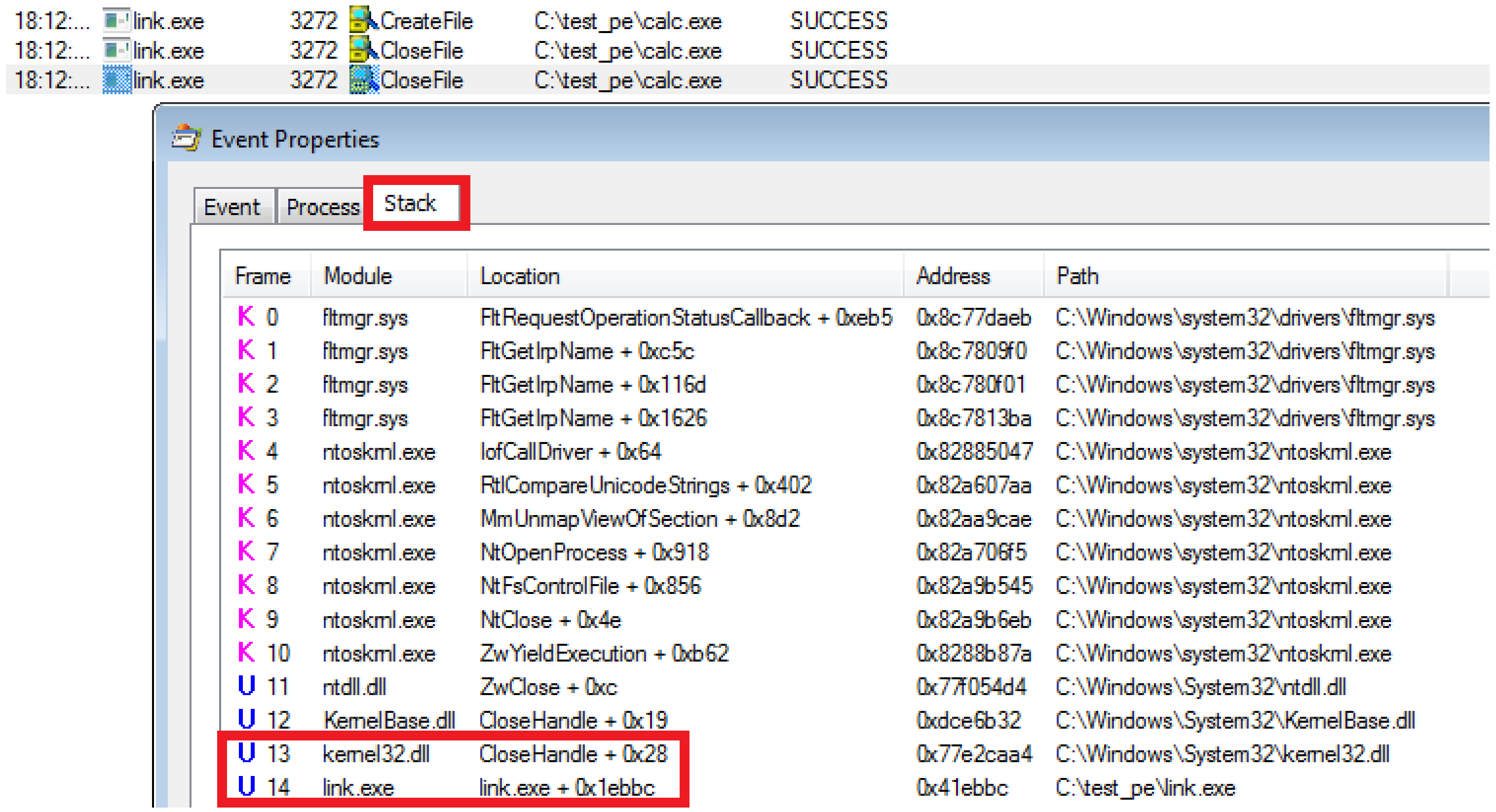
Event | Process | Stack

Frame		Module	Location	Address	Path
K	0	fltmgr.sys	FltRequestOperationStatusCallback + 0xeb5	0x8c77daeb	C:\Windows\system32\drivers\fltmgr.sys
K	1	fltmgr.sys	FltGetIrpName + 0xc5c	0x8c7809f0	C:\Windows\system32\drivers\fltmgr.sys
K	2	fltmgr.sys	FltProcessFileLock + 0x18b2	0x8c7941fe	C:\Windows\system32\drivers\fltmgr.sys
K	3	fltmgr.sys	FltProcessFileLock + 0x1f6b	0x8c7948b7	C:\Windows\system32\drivers\fltmgr.sys
K	4	ntoskrnl.exe	IofCallDriver + 0x64	0x82885047	C:\Windows\system32\ntoskrnl.exe
K	5	ntoskrnl.exe	NtQueryInformationThread + 0x417e	0x82a59e7b	C:\Windows\system32\ntoskrnl.exe
K	6	ntoskrnl.exe	SeQueryAuthenticationIdToken + 0x72	0x82abf8b2	C:\Windows\system32\ntoskrnl.exe
K	7	ntoskrnl.exe	PsReferenceImpersonationToken + 0x5df	0x82a5d056	C:\Windows\system32\ntoskrnl.exe
K	8	ntoskrnl.exe	ObOpenObjectByName + 0x165	0x82a9ba4a	C:\Windows\system32\ntoskrnl.exe
K	9	ntoskrnl.exe	NtQueryInformationThread + 0x171f	0x82a5741c	C:\Windows\system32\ntoskrnl.exe
K	10	ntoskrnl.exe	NtCreateFile + 0x34	0x82aa2462	C:\Windows\system32\ntoskrnl.exe
K	11	ntoskrnl.exe	ZwYieldExecution + 0xb62	0x8288b87a	C:\Windows\system32\ntoskrnl.exe
U	12	ntdll.dll	NtCreateFile + 0xc	0x77f055d4	C:\Windows\System32\ntdll.dll
U	13	KernelBase.dll	CreateFileW + 0x1d1	0xdceaa21	C:\Windows\System32\KernelBase.dll
U	14	kernel32.dll	CreateFileW + 0x4a	0x77e2cca0	C:\Windows\System32\kernel32.dll
U	15	link.exe	link.exe + 0x33c73	0x433c73	C:\test_pe\link.exe

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

How to find the target function

- **And the call stack of the CloseFile():**



18:12:...	link.exe	3272	CreateFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CloseFile	C:\test_pe\calc.exe	SUCCESS
18:12:...	link.exe	3272	CloseFile	C:\test_pe\calc.exe	SUCCESS

Event Properties

Event | Process | Stack

Frame	Module	Location	Address	Path
K 0	fltmgr.sys	FltRequestOperationStatusCallback + 0xeb5	0x8c77daeb	C:\Windows\system32\drivers\fltmgr.sys
K 1	fltmgr.sys	FltGetIrpName + 0xc5c	0x8c7809f0	C:\Windows\system32\drivers\fltmgr.sys
K 2	fltmgr.sys	FltGetIrpName + 0x116d	0x8c780f01	C:\Windows\system32\drivers\fltmgr.sys
K 3	fltmgr.sys	FltGetIrpName + 0x1626	0x8c7813ba	C:\Windows\system32\drivers\fltmgr.sys
K 4	ntoskrnl.exe	IofCallDriver + 0x64	0x82885047	C:\Windows\system32\ntoskrnl.exe
K 5	ntoskrnl.exe	RtlCompareUnicodeStrings + 0x402	0x82a607aa	C:\Windows\system32\ntoskrnl.exe
K 6	ntoskrnl.exe	MmUnmapViewOfSection + 0x8d2	0x82aa9cae	C:\Windows\system32\ntoskrnl.exe
K 7	ntoskrnl.exe	NtOpenProcess + 0x918	0x82a706f5	C:\Windows\system32\ntoskrnl.exe
K 8	ntoskrnl.exe	NtFsControlFile + 0x856	0x82a9b545	C:\Windows\system32\ntoskrnl.exe
K 9	ntoskrnl.exe	NtClose + 0x4e	0x82a9b6eb	C:\Windows\system32\ntoskrnl.exe
K 10	ntoskrnl.exe	ZwYieldExecution + 0xb62	0x8288b87a	C:\Windows\system32\ntoskrnl.exe
U 11	ntdll.dll	ZwClose + 0xc	0x77f054d4	C:\Windows\System32\ntdll.dll
U 12	KernelBase.dll	CloseHandle + 0x19	0xdce6b32	C:\Windows\System32\KernelBase.dll
U 13	kernel32.dll	CloseHandle + 0x28	0x77e2caa4	C:\Windows\System32\kernel32.dll
U 14	link.exe	link.exe + 0x1ebbc	0x41ebbc	C:\test_pe\link.exe

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

How to find the target function

- **Technique 2: Memory breakpoints on input data**
  - E.g.: fuzzing network packets or from stdin
  - Set the breakpoint at recv() and when it triggers we are in the code which works with the data

- **Technique 3: Log every (internal) function call together with arguments**
  - After that search the log file for your input
  - Can be implemented with DynamoRio / PIN (funcap is a debugger implementation for this but it’s extremely slow)
  - Hint: Log only cross-module calls to find easy-to-target exported library functions

How to find the target function

- **Technique 4: Measure code coverage and subtract them**
  - Execute program twice, one time trigger the target behavior, one time not
  - Extract both times code coverage (drrun –t drcov -- C:\applications.exe arg1 arg2)
  - Use IDA Pro plugin lighting house to subtract the coverage ➔ Result is code responsible for the target behavior
  - Side note: You can also extract coverage from your input corpus and use lighting house to detect code which you currently don’t reach!
  - Demo 8 from https://sec-consult.com/en/blog/2017/11/the-art-of-fuzzing-slides-and-demos/index.html

- **Technique 5: Use a taint engine to follow inputs**
  - More on this later!

Demo Time!

Topic: Identification of target function address of a closed-source application (HashCalc).

Runtime: 10 min 15 sec

Description: Using reverse engineering (breakpoints on function level via funcap and DynamoRio with LightHouse) to identify the target function address.

Demo Time!

Topic: In-memory fuzzing of HashCalc using a debugger.

Runtime: 4 min 21 sec

Description: Using the identified addresses and WinAppDbg we can write an in-memory fuzzer to increase the fuzzing speed to 750 exec / sec!

Demo Time!

Topic: In-memory fuzzing of HashCalc using DynamoRio.

Runtime: 2 min 58 sec

Description: Using the identified addresses and DynamoRio we can write an in-memory fuzzer to increase the fuzzing speed to 170 000 exec / sec!

Practice: Lection 21

Topic: Lection 21 - WinAFL GDI Fuzzing

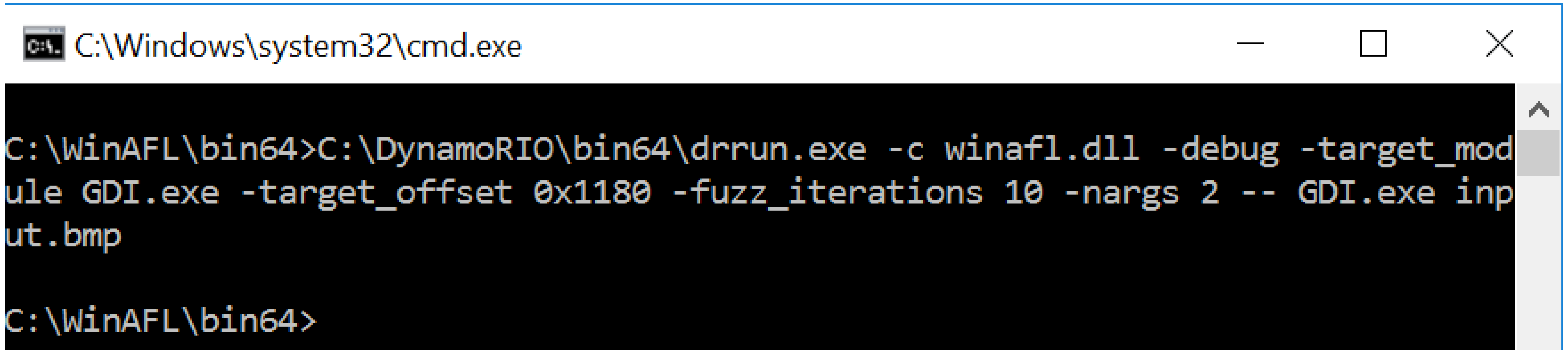
Runtime: 10 min

Description: Using WinAFL to fuzz GDI.

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

GDI Fuzzing with WinAFL

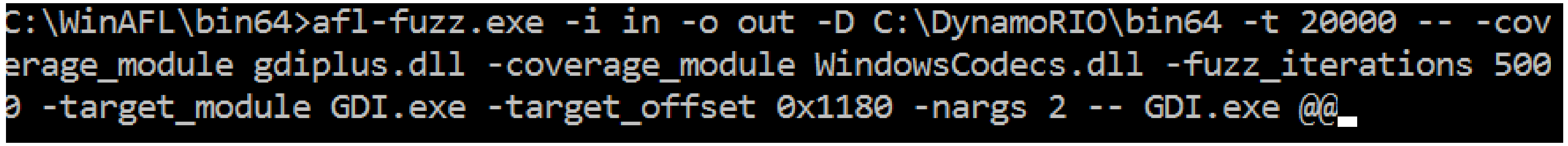
- Use the recompiled GDI.exe binary (with /MT) / Install VC Redist 2010
- Debug:



C:\Windows\system32\cmd.exe

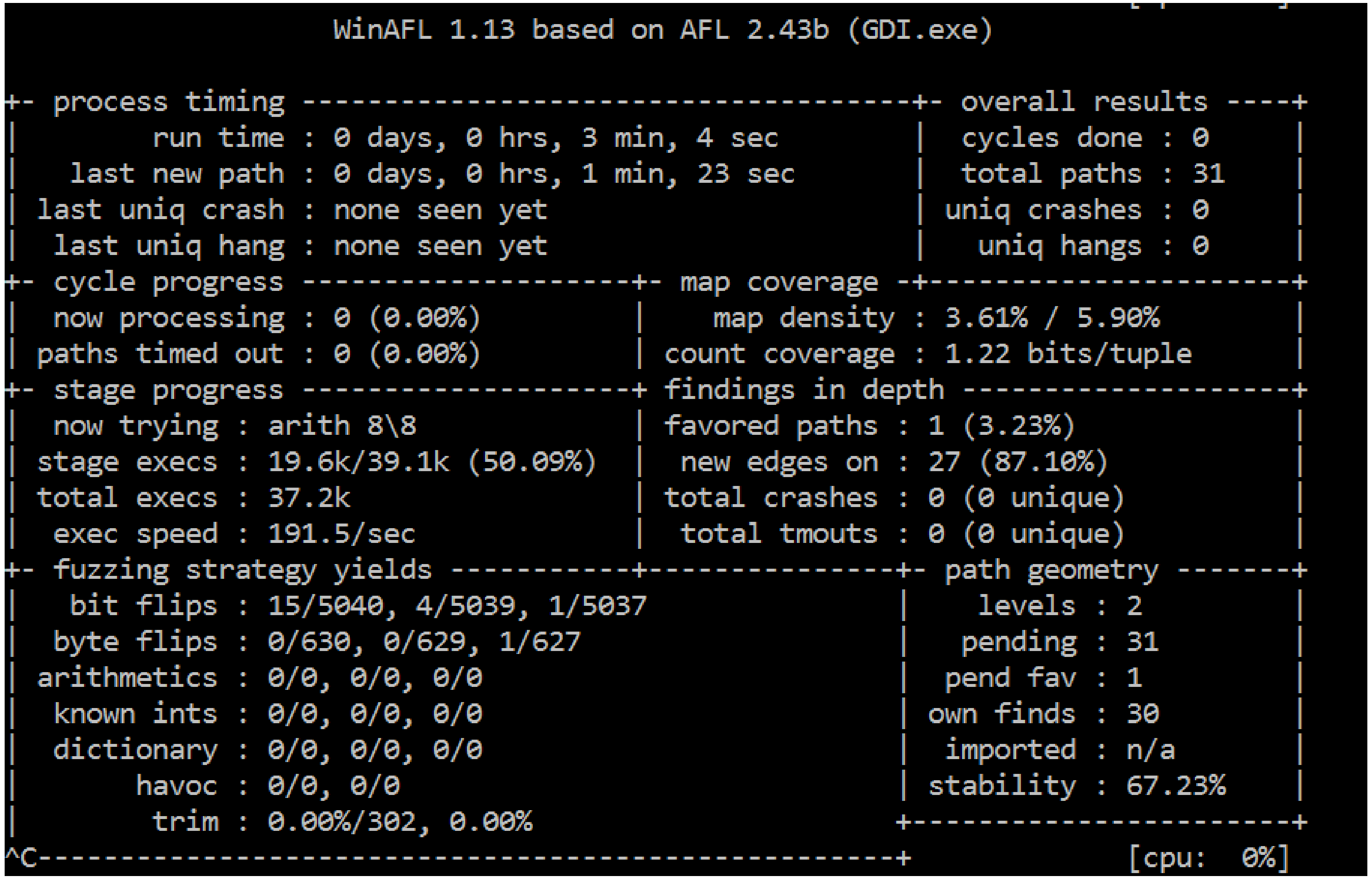
```
C:\WinAFL\bin64>C:\DynamoRIO\bin64\drrun.exe -c winafl.dll -debug -target_mod
ule GDI.exe -target_offset 0x1180 -fuzz_iterations 10 -nargs 2 -- GDI.exe inp
ut.bmp

C:\WinAFL\bin64>
```

- Fuzzing:



```
C:\WinAFL\bin64>afl-fuzz.exe -i in -o out -D C:\DynamoRIO\bin64 -t 20000 -- -cov
erage_module gdiplus.dll -coverage_module WindowsCodecs.dll -fuzz_iterations 500
0 -target_module GDI.exe -target_offset 0x1180 -nargs 2 -- GDI.exe @@
```

GDI Fuzzing with WinAFL



```
                  WinAFL 1.13 based on AFL 2.43b (GDI.exe)

+- process timing -------------------------------------+- overall results ----+
|        run time : 0 days, 0 hrs, 3 min, 4 sec        |  cycles done : 0     |
|   last new path : 0 days, 0 hrs, 1 min, 23 sec       |  total paths : 31    |
| last uniq crash : none seen yet                      | uniq crashes : 0     |
|  last uniq hang : none seen yet                      |   uniq hangs : 0     |
+- cycle progress --------------------+- map coverage -+----------------------+
|  now processing : 0 (0.00%)         |    map density : 3.61% / 5.90%        |
| paths timed out : 0 (0.00%)         | count coverage : 1.22 bits/tuple      |
+- stage progress --------------------+ findings in depth --------------------+
|  now trying : arith 8\8             | favored paths : 1 (3.23%)             |
| stage execs : 19.6k/39.1k (50.09%)  |  new edges on : 27 (87.10%)           |
| total execs : 37.2k                 | total crashes : 0 (0 unique)          |
|  exec speed : 191.5/sec             |  total tmouts : 0 (0 unique)          |
+- fuzzing strategy yields -----------+---------------+- path geometry -------+
|   bit flips : 15/5040, 4/5039, 1/5037               |    levels : 2         |
|  byte flips : 0/630, 0/629, 1/627                   |   pending : 31        |
| arithmetics : 0/0, 0/0, 0/0                         |  pend fav : 1         |
|  known ints : 0/0, 0/0, 0/0                         | own finds : 30        |
|  dictionary : 0/0, 0/0, 0/0                         |  imported : n/a       |
|       havoc : 0/0, 0/0                              | stability : 67.23%    |
|        trim : 0.00%/302, 0.00%                      +-----------------------+
^C----------------------------------------------------+             [cpu:  0%]
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Browser fuzzing

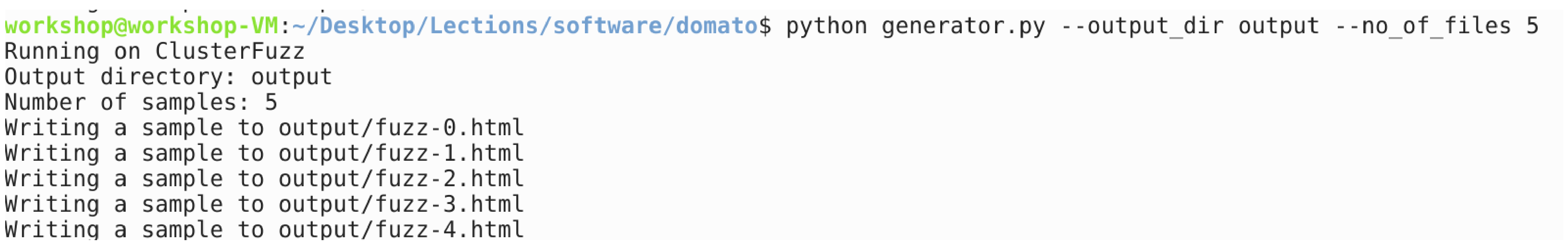
Browser Fuzzing

- The discussed techniques should **NOT** be used to fuzz browsers (DOM, JS, CSS, SVG, …)

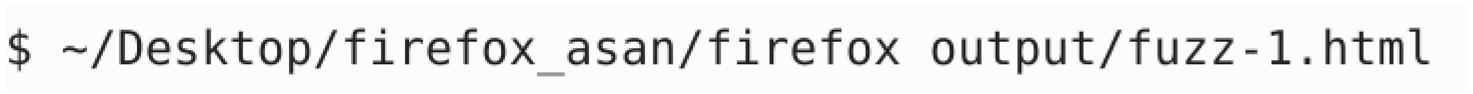
- Reason: When fuzzing a browser you want to find a combination of JS / HTML / … code which leads to a vulnerability. This is not a binary file format and therefore the discussed techniques are inefficient
    - However: If the browser parses an image, icon, audio, font, … file you can use the techniques!
    - It's similar to the "chat" binary where AFL-style fuzzing was also inefficient

Browser Fuzzing

- For browsers you generate HTML / JS files with a grammar-based fuzzer.
- **Example:** Domato from Ivan Fratric (Google Project Zero)



```
workshop@workshop-VM:~/Desktop/Lections/software/domato$ python generator.py --output_dir output --no_of_files 5
Running on ClusterFuzz
Output directory: output
Number of samples: 5
Writing a sample to output/fuzz-0.html
Writing a sample to output/fuzz-1.html
Writing a sample to output/fuzz-2.html
Writing a sample to output/fuzz-3.html
Writing a sample to output/fuzz-4.html
```



```
$ ~/Desktop/firefox_asan/firefox output/fuzz-1.html
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Practice: Lection 22

Topic: Lection 22 - Domato

Runtime: 5 min

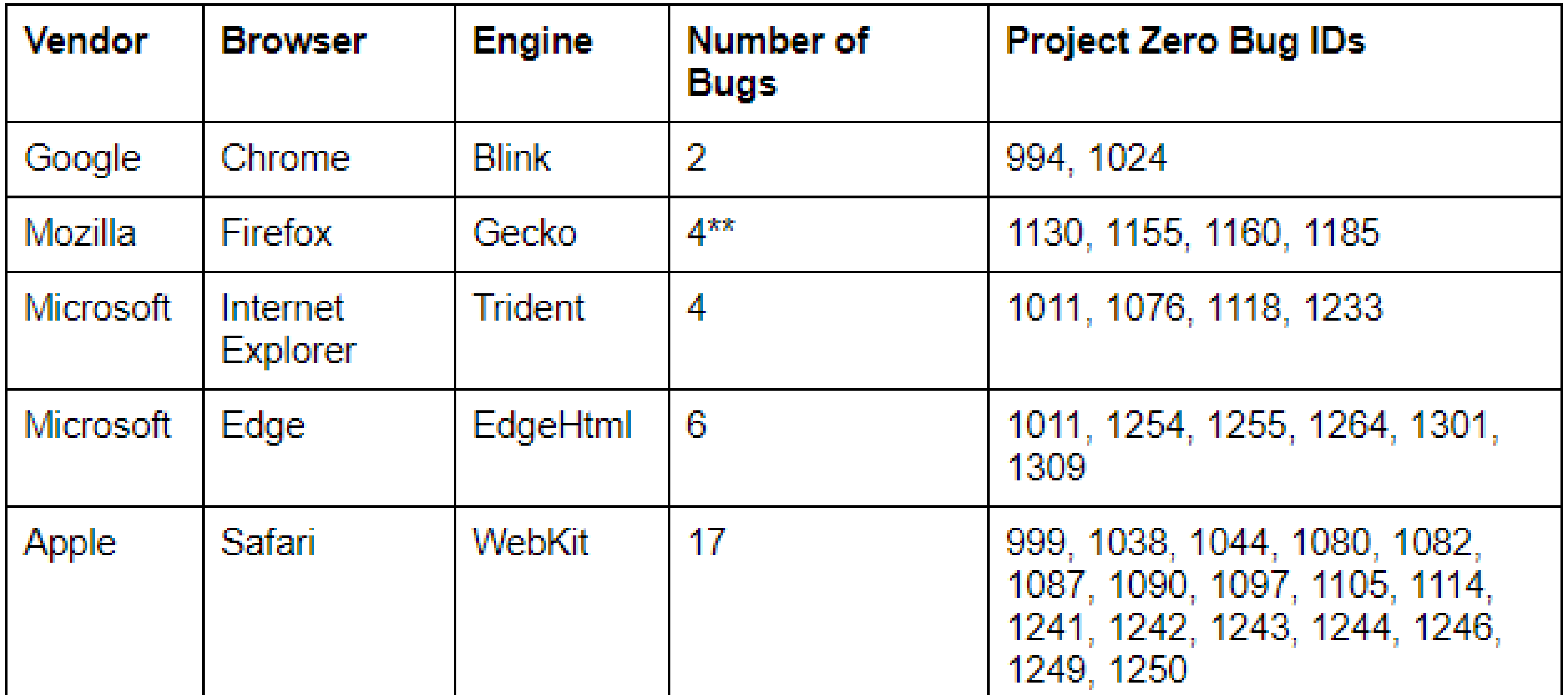
Description: Use Domato to generate fuzzed HTML files.

Browser Fuzzing

- Google P0 fuzzed major browsers in 2017
  - https://googleprojectzero.blogspot.com/2017/09/the-great-dom-fuzz-off-of-2017.html
  - 100 000 000 iterations per browser with 10 seconds per run
  - Chrome, Firefox and Safari with ASAN builds
  - IE and Edge with Page Heap
  - Cost: Approximately 1000 $

Browser Fuzzing

- Results:



Vendor	Browser	Engine	Number of Bugs	Project Zero Bug IDs
Google	Chrome	Blink	2	994, 1024
Mozilla	Firefox	Gecko	4**	1130, 1155, 1160, 1185
Microsoft	Internet Explorer	Trident	4	1011, 1076, 1118, 1233
Microsoft	Edge	EdgeHtml	6	1011, 1254, 1255, 1264, 1301, 1309
Apple	Safari	WebKit	17	999, 1038, 1044, 1080, 1082, 1087, 1090, 1097, 1105, 1114, 1241, 1242, 1243, 1244, 1246, 1249, 1250

Browser Fuzzing

- On the Windows VM you can find the exploit for CVE-2011-2371 (Firefox Integer Overflow – Array.reduceRight)
- A very good exploit to get started with browser exploitation
- Simple compared to other exploits, works very reliable on all Windows operating systems
- Bypasses ASLR & DEP
- Does not crash the browser

My research

On the shoulders of giants

- **My research builds on-top of the hard work other researchers shared with the public. Without their awesome work all of my stuff would definitely not work!**

- **AFL** by **Michal Zalewski**
  - Simplest fuzzer to start on Linux and very efficient in finding bugs

- **LibFuzzer** from **LLVM**
  - Use it when you have C/C++ code and can compile with clang (faster than AFL)

- **Honggfuzz** by **Robert Swiecki**
  - Simpler to modify than AFL, useful when fuzzing network apps

- **WinAFL** by **Ivan Fratric**
  - Use it if you want to fuzz Windows software with feedback (alternative: If you don't want to use coverage feedback you can try **CERT Fuzzer**, but I definitely recommend feedback-based fuzzing)
  - Based on **DynamoRio** by **Derek Bruening**

Problems of WinAFL

I encountered some problems when fuzzing with WinAFL:

- **Lack of a snapshot mechanism** ➔ Just jump at the end of the function back to the start without resetting the old memory state
  - Heap, Stack, global variables, TEB and PEB may change… some data (e.g.: network packets) may only be available in first iteration, access permission can change, file positions can change or be closed, locks, semaphores, critical sections, multi-threaded applications, ….
  - Lots of stuff can go wrong here

Problems of WinAFL

Example:

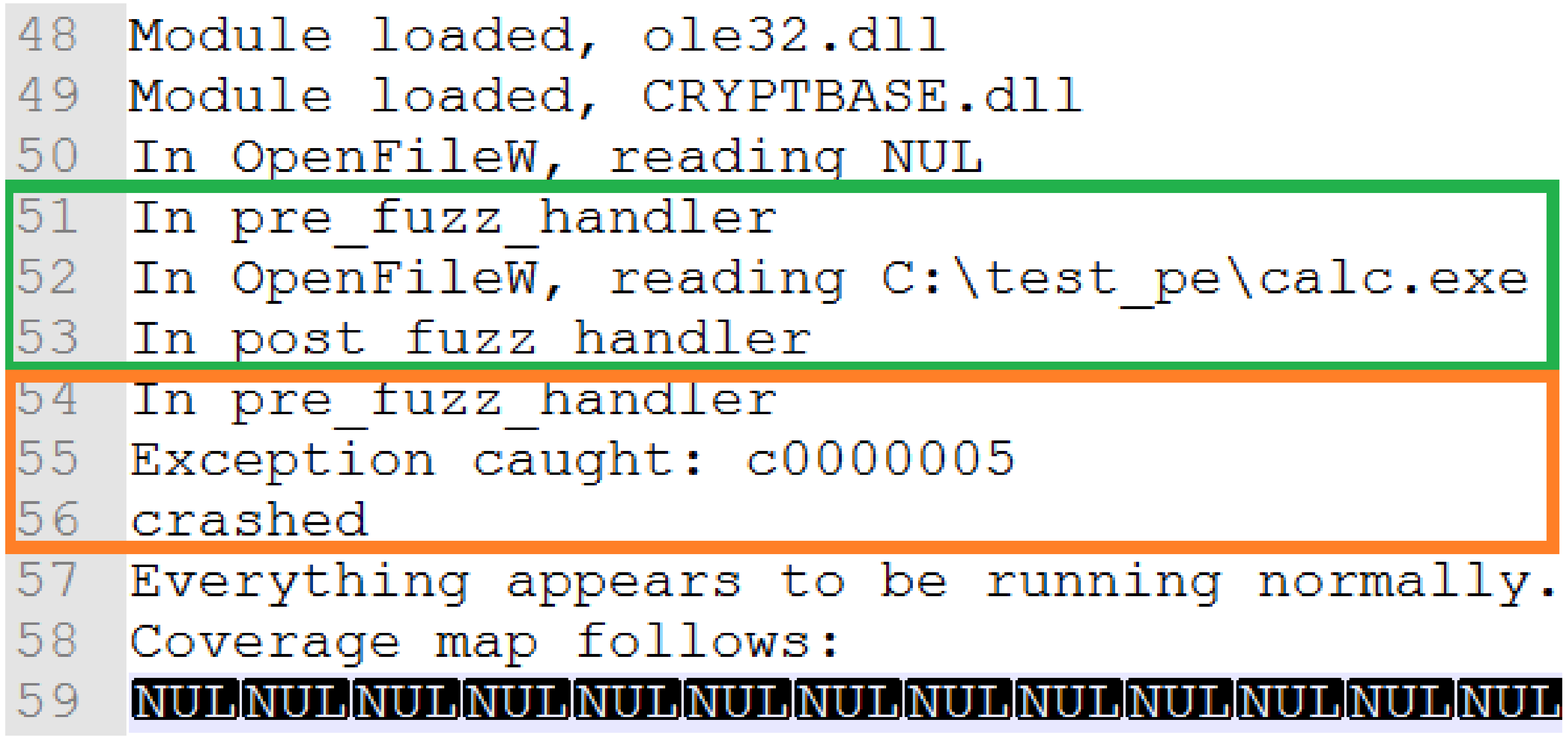
```
void target_fuzz_function(char *input, size_t len) {
      crypto_func(input, len);    // works with g_var1 & g_var2
      free(g_var1);
      g_var2->field123 = 567;
}
```

➔ **Second iteration works with the freed variable g_var1** (and modified g_var2 content)

➔ We could tell the fuzzer to fuzz only "crypto_func". But what if this function was inlined? What if crypto_func also works with g_var3? If we assume closed source applications and the target function is very big, it's hard / time consuming to manually find these dependencies! What if the compiler changed the order ?

Problems of WinAFL

Example: If we start to fuzz link.exe with WinAFL with the identified address we see in the log file:



```
Module loaded, ole32.dll
Module loaded, CRYPTBASE.dll
In OpenFileW, reading NUL
In pre_fuzz_handler
In OpenFileW, reading C:\test_pe\calc.exe
In post_fuzz_handler
In pre_fuzz_handler
Exception caught: c0000005
crashed
Everything appears to be running normally.
Coverage map follows:
NULNULNULNULNULNULNULNULNULNULNULNULNUL
```

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Problems of WinAFL

I encountered some problems when fuzzing with WinAFL:

- **Not 100% compatible with Page Heap because of in-memory fuzzing**
  - If data is not freed during the iteration, some checks are never performed!
  - If a global variable is freed during the iteration, we introduce a double-free!
  - If memory is allocated in the iteration, but not freed, we spray the heap which means we have to restart the application after some thousand iterations

PageHeap

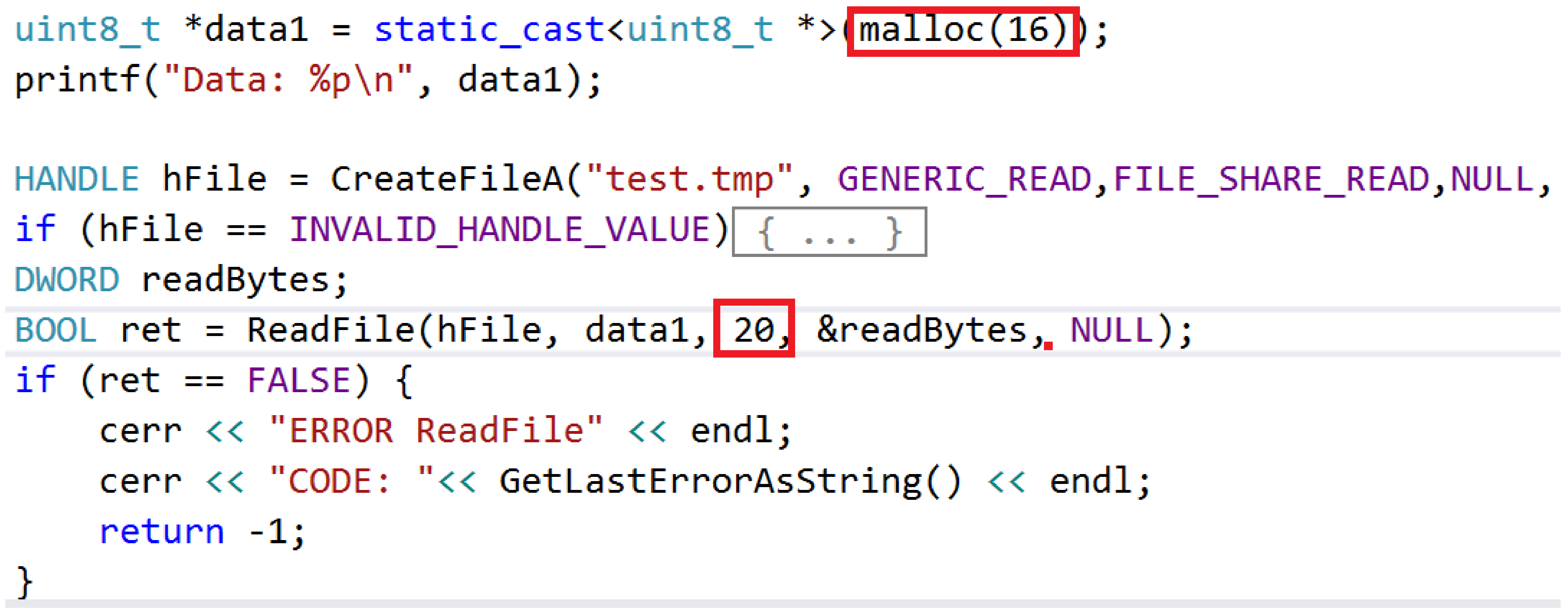
- **Undetected by page heap:**

```
Uint8_t *data = static_cast<uint8_t *>(Malloc(17));
data[-1] = 0x11;  // no crash
data[17] = 0x11;  // no crash
data[30] = 0x11;  // no crash
// No free(data1)
```

- Windows requires 16-byte aligned heap pointers (on x64), therefore it can only use fill patterns to detect 1 to 15 byte overflows (or negative ones); Fill patterns are just checked at free()
    - In-memory fuzzing often doesn’t reach the free because we go to the next iteration…
    - Same applies for other heap allocation routines (new, RtlAllocateHeap, …)

PageHeap

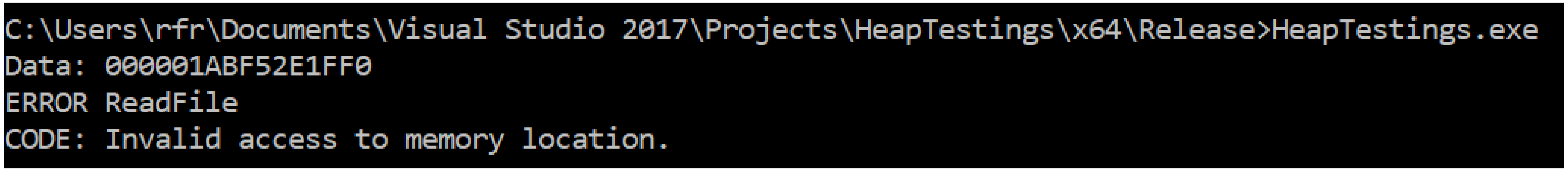
- **Undetected by page heap:**



```
uint8_t *data1 = static_cast<uint8_t *>(malloc(16));
printf("Data: %p\n", data1);

HANDLE hFile = CreateFileA("test.tmp", GENERIC_READ,FILE_SHARE_READ,NULL,
if (hFile == INVALID_HANDLE_VALUE) { ... }
DWORD readBytes;
BOOL ret = ReadFile(hFile, data1, 20, &readBytes, NULL);
if (ret == FALSE) {
    cerr << "ERROR ReadFile" << endl;
    cerr << "CODE: "<< GetLastErrorAsString() << endl;
    return -1;
}
```

PageHeap

- Execution with page heap enabled:



```
C:\Users\rfr\Documents\Visual Studio 2017\Projects\HeapTestings\x64\Release>HeapTestings.exe
Data: 000001ABF52E1FF0
ERROR ReadFile
CODE: Invalid access to memory location.
```

- Inside WinDbg:

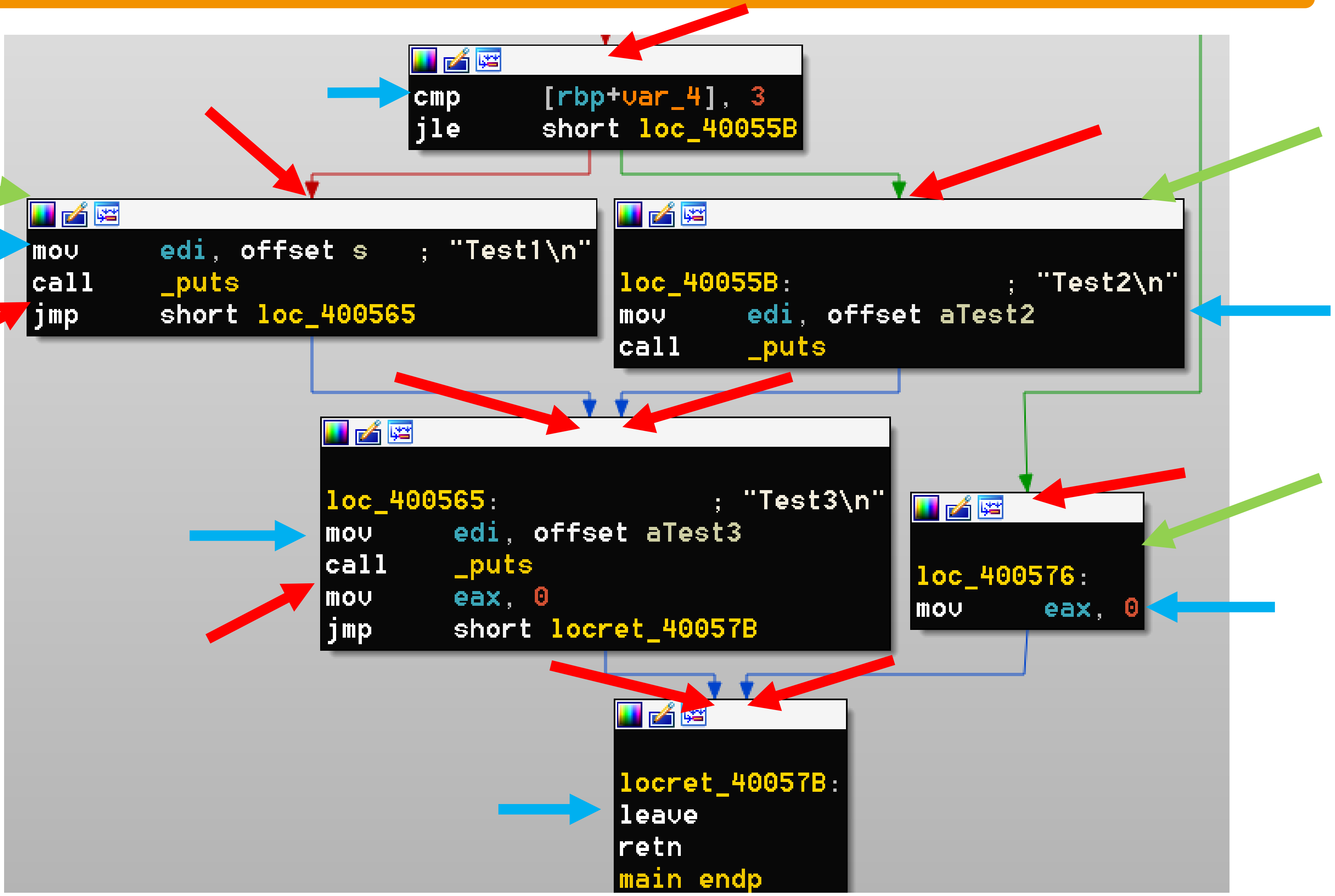
```
0:000> g
ModLoad: 00007ffa`5aa70000 00007ffa`5aa81000   C:\WINDOWS\System32\kernel.appcore.dll
ModLoad: 00007ffa`5c760000 00007ffa`5c7fd000   C:\WINDOWS\System32\msvcrt.dll
ModLoad: 00007ffa`5c640000 00007ffa`5c75f000   C:\WINDOWS\System32\RPCRT4.dll
ntdll!NtTerminateProcess+0x14:
00007ffa`5e7303f4 c3              ret
```

➔ **We don‘t see an exception** although page heap is enabled!

➔ Our fuzzer would also miss it!

Feedback based fuzzing

- **AFL injects here**
- **WinAFL injects here**
- **Where it makes sense**



```
cmp     [rbp+var_4], 3
jle     short loc_40055B
```

```
mov     edi, offset s    ; "Test1\n"
call    _puts
jmp     short loc_400565
```

```
loc_40055B:                  ; "Test2\n"
mov     edi, offset aTest2
call    _puts
```

```
loc_400565:                  ; "Test3\n"
mov     edi, offset aTest3
call    _puts
mov     eax, 0
jmp     short locret_40057B
```

```
loc_400576:
mov     eax, 0
```

```
locret_40057B:
leave
retn
main endp
```

SEC Consult Fuzzer

So I started to develop my own fuzzer to solve the problems

1. **Full logic is injected into the target application** ➔ No inter-process communication required, mutations are performed in-memory, file-reads are cached, full multi-core support

2. **Snapshot mechanism** which creates process snapshots and can quickly (!) restore the snapshot (this works with my **own heap implementation** which doesn't have the problems of page heap)

3. **Taint Engine** to reduce number of bytes which must be fuzzed

4. **Playing around with new ideas from academic papers** ➔ I try to implement and test all of them

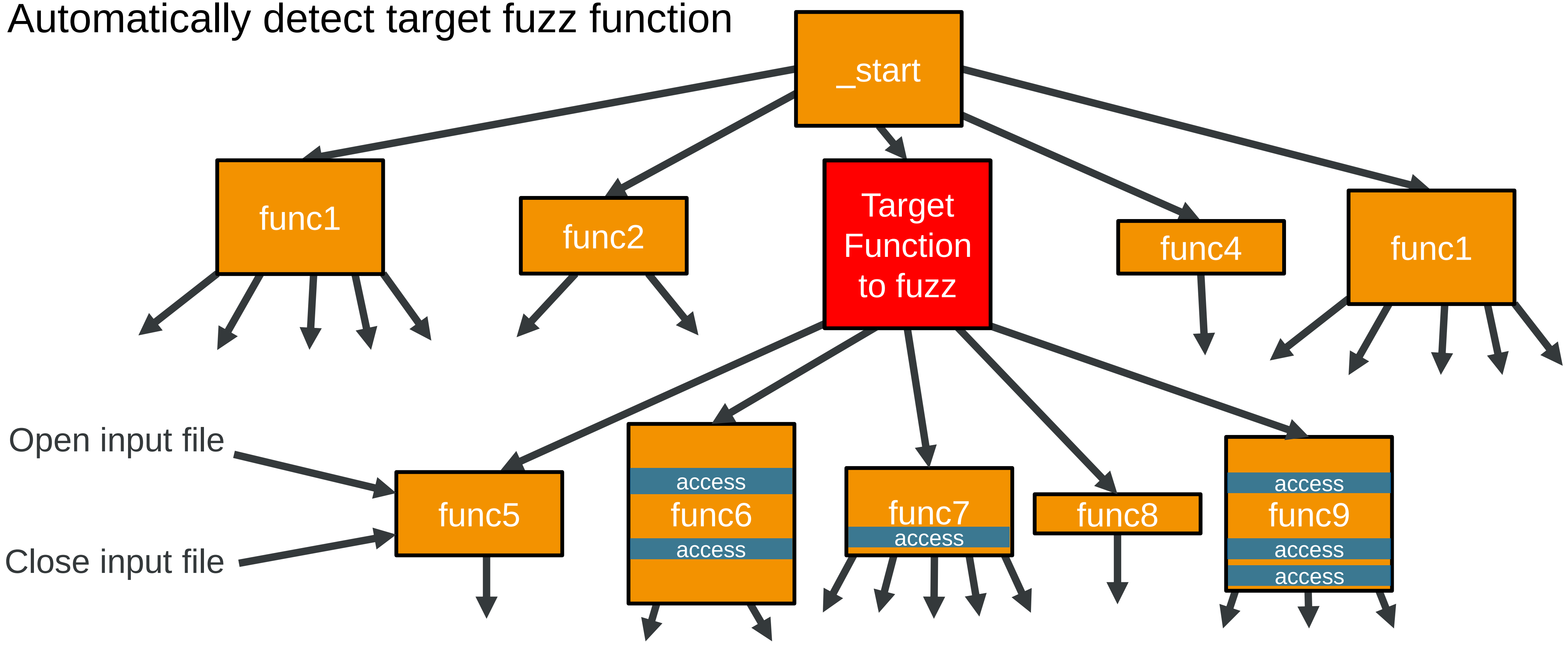
Taint Analysis

- **Taint Analysis:**
  - With a PIN / DynamoRio tool follow data-flow by tainting memory
    - Assign one bit to every byte in RAM, 0… not tainted, 1 … tainted
    - Store per tainted byte extra information (e.g. on which input bytes it depends)
    - Move taint status around with every instruction (e.g. mov rax, [memory] ➔ If [memory] is tainted rax will also be tainted; xor rax, rax ➔ Rax will be untainted) by injecting code with DynamoRio

  - Taint Analysis Tools:
    - Libdft, Triton, bap, panda, manticore, Own DynamoRio client, …

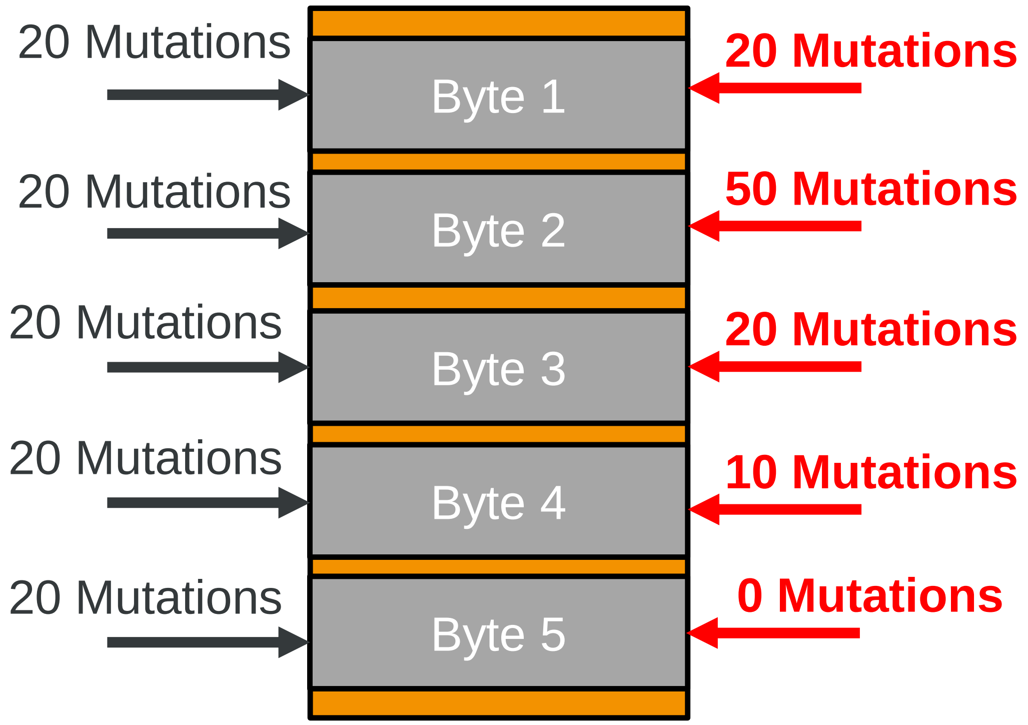
Combine Call-Graph with Taint-Analysis

- ➔ We can write a DynamoRio/PIN tool which tracks calls and taint status
- ➔ Automatically detect target fuzz function



Fuzzing with taint analysis

1. Typically byte-modifications are uniform distributed over the input file
2. With taint analysis we can distribute it uniform over the tainted instructions!



Maybe don‘t fuzz this at all

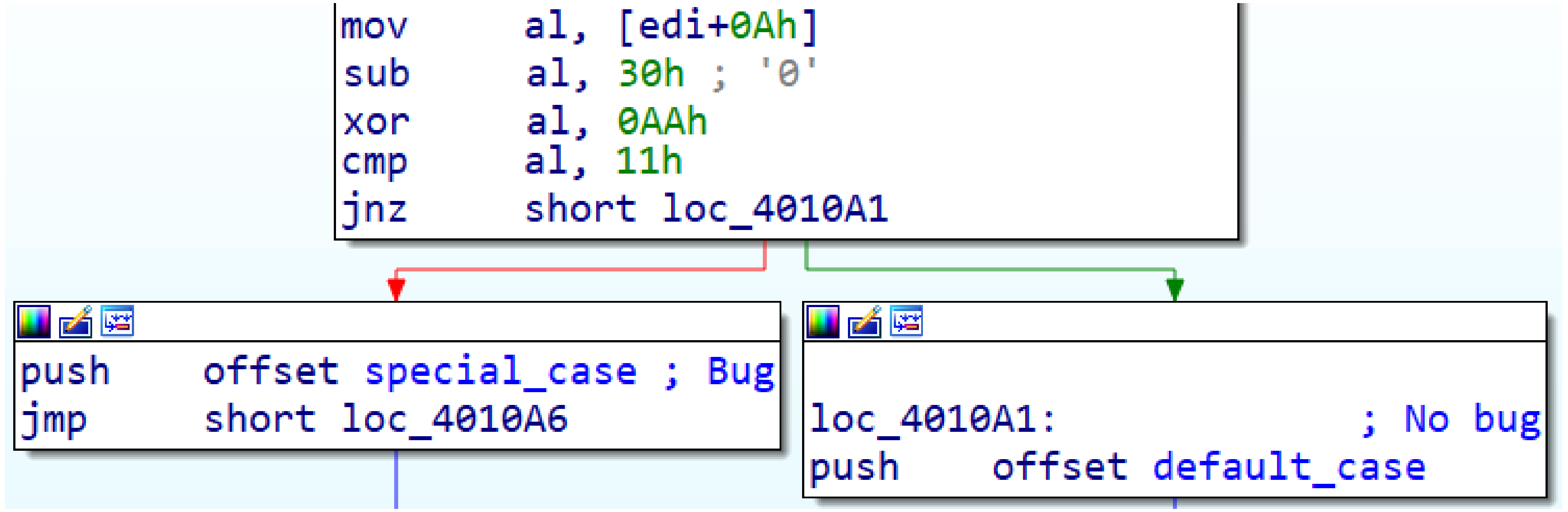
X2 is maybe a copy / search function

Instruction X1: Read byte 2
Instruction X2: Read byte 1,2,3,4
Instruction X3: Read byte 2
Instruction X4: Read byte 1,2
Instruction X5: Read byte 2,3

Byte 1 read by 2 instructions	2/10 = 20%
Byte 2 read by 5 instructions	5/10 = 50%
Byte 3 read by 2 instructions	2/10 = 20%
Byte 4 read by 1 instruction	1/10 = 10%
Byte 5 read by 0 instructions	0/10 = 0%

Fuzzing vs. Symbolic execution

➔ Fuzzing all bytes:



```
mov     al, [edi+0Ah]
sub     al, 30h ; '0'
xor     al, 0AAh
cmp     al, 11h
jnz     short loc_4010A1
```

```
push    offset special_case ; Bug
jmp     short loc_4010A6
```

```
loc_4010A1:              ; No bug
push    offset default_case
```

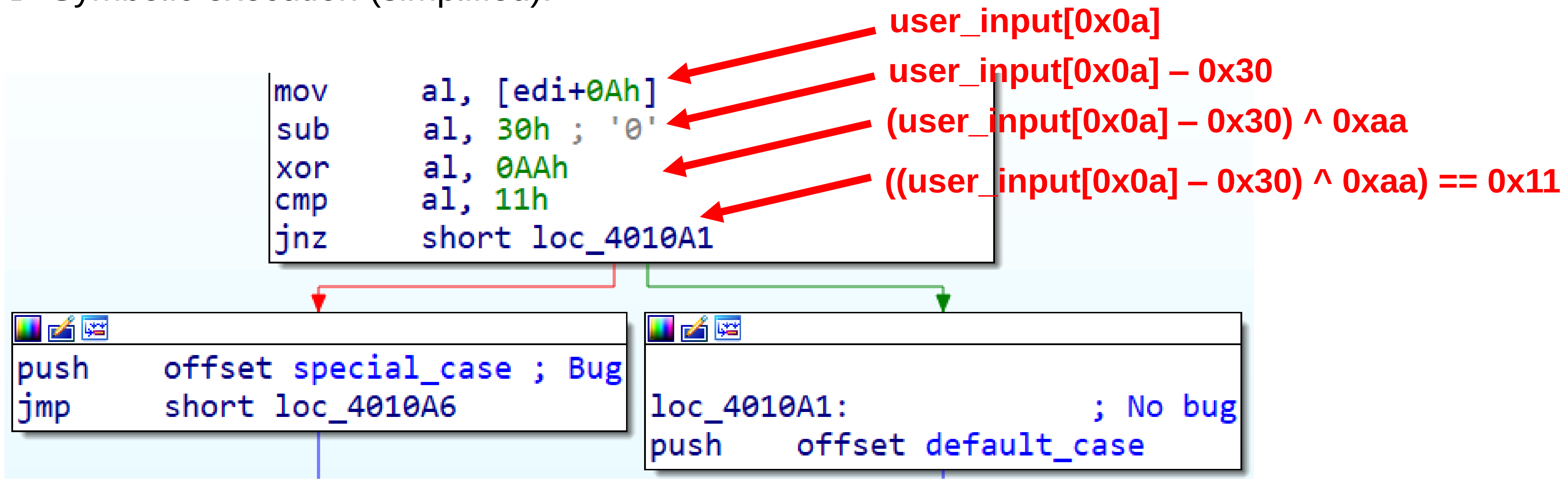
➔ Input file is for example 1000 Byte (1 KB)

➔ 256 possible Byte values for 1000 Byte ➔ 256 000 potential executions (in our case ~2600)

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

Fuzzing vs. Symbolic execution

➔ Symbolic execution (simplified):



```
mov     al, [edi+0Ah]
sub     al, 30h ; '0'
xor     al, 0AAh
cmp     al, 11h
jnz     short loc_4010A1
```

```
push    offset special_case ; Bug
jmp     short loc_4010A6
```

```
loc_4010A1:                  ; No bug
push    offset default_case
```

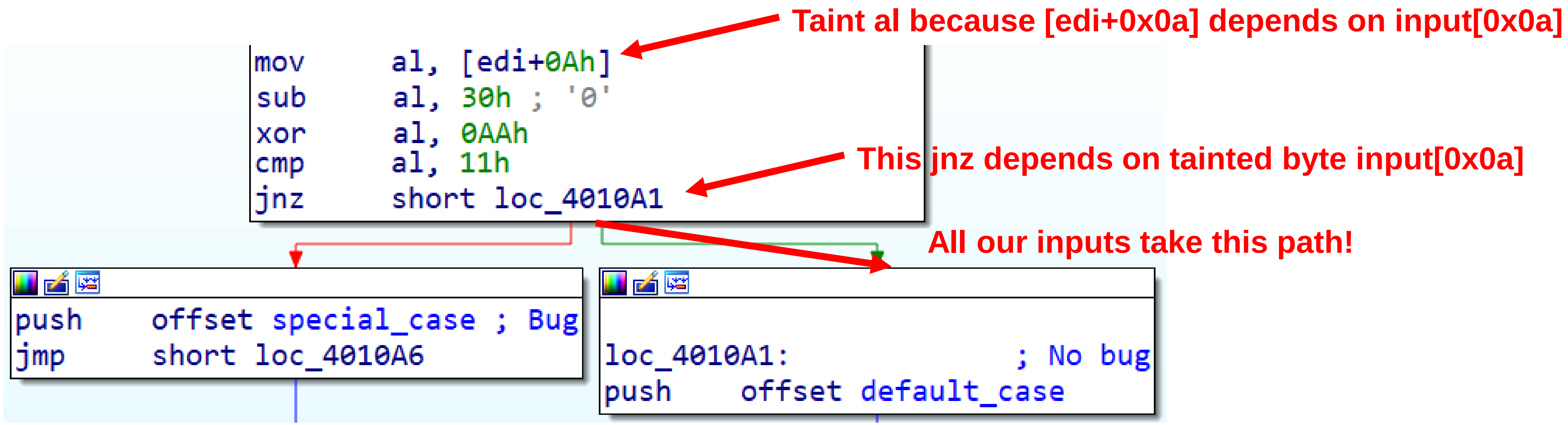
user_input[0x0a]
user_input[0x0a] – 0x30
(user_input[0x0a] – 0x30) ^ 0xaa
((user_input[0x0a] – 0x30) ^ 0xaa) == 0x11

➔ Two branches, one with value == 0x11 and one with value != 0x11

➔ **Solution for == 0x11: user_input[0x0a] := (0x11 ^ 0xaa) + 0x30 = 0xeb**

Fuzzing vs. Symbolic execution

➔ Taint Analysis in Fuzzing



Taint al because [edi+0x0a] depends on input[0x0a]

This jnz depends on tainted byte input[0x0a]

All our inputs take this path!

```
mov     al, [edi+0Ah]
sub     al, 30h ; '0'
xor     al, 0AAh
cmp     al, 11h
jnz     short loc_4010A1
```

```
push    offset special_case ; Bug
jmp     short loc_4010A6
```

```
loc_4010A1:                 ; No bug
push    offset default_case
```

➔ Query for conditional jumps (dep. On our input), where all inputs take the same path

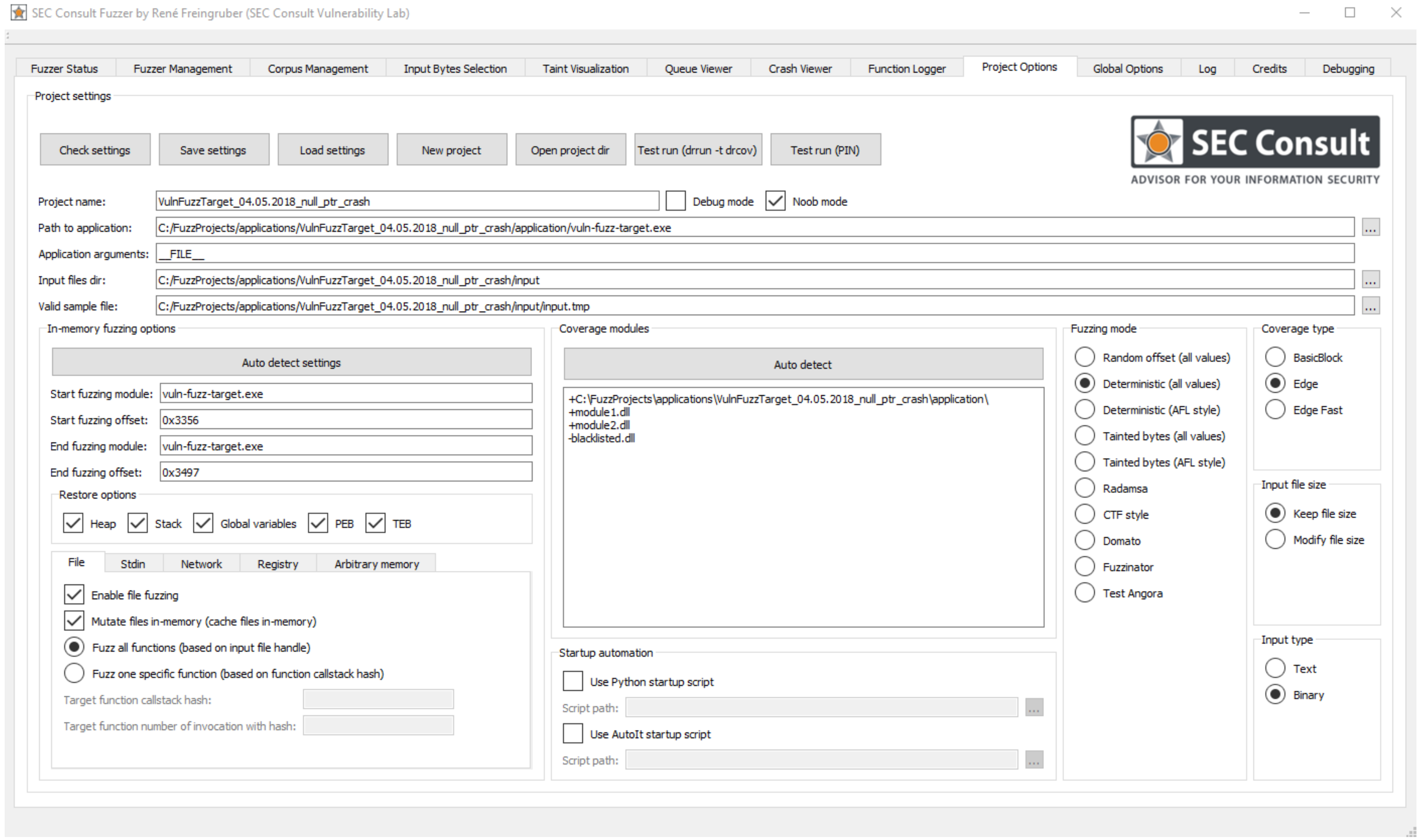
➔ **Taint Engine returns input byte 0x0a ➔ Just fuzz this byte!**

➔ Check the cmp operand size ➔ If it’s 1 or 2 bytes use fuzzing, if it’s 4 or 8 b. use symbolic execution

Demo Time!

- **Demo: SEC Consult Fuzzer**

- **Fuzzer is still early alpha!**
  - Release: In some months



Project settings

Project name: VulnFuzzTarget_04.05.2018_null_ptr_crash [ ] Debug mode [✓] Noob mode

Path to application: C:/FuzzProjects/applications/VulnFuzzTarget_04.05.2018_null_ptr_crash/application/vuln-fuzz-target.exe

Application arguments: __FILE__

Input files dir: C:/FuzzProjects/applications/VulnFuzzTarget_04.05.2018_null_ptr_crash/input

Valid sample file: C:/FuzzProjects/applications/VulnFuzzTarget_04.05.2018_null_ptr_crash/input/input.tmp

In-memory fuzzing options

Start fuzzing module: vuln-fuzz-target.exe
Start fuzzing offset: 0x3356
End fuzzing module: vuln-fuzz-target.exe
End fuzzing offset: 0x3497

Restore options: [✓] Heap [✓] Stack [✓] Global variables [✓] PEB [✓] TEB

File | Stdin | Network | Registry | Arbitrary memory

[✓] Enable file fuzzing
[✓] Mutate files in-memory (cache files in-memory)
[● Fuzz all functions (based on input file handle)]
Fuzz one specific function (based on function callstack hash)
Target function callstack hash:
Target function number of invocation with hash:

Coverage modules

```
+C:\FuzzProjects\applications\VulnFuzzTarget_04.05.2018_null_ptr_crash\application\
+module1.dll
+module2.dll
-blacklisted.dll
```

Startup automation

[ ] Use Python startup script
Script path:
[ ] Use AutoIt startup script
Script path:

Fuzzing mode: Random offset (all values) [● Deterministic (all values)] Deterministic (AFL style) Tainted bytes (all values) Tainted bytes (AFL style) Radamsa CTF style Domato Fuzzinator Test Angora

Coverage type: BasicBlock [● Edge] Edge Fast

Input file size: [● Keep file size] Modify file size

Input type: Text [● Binary]

Rules for fuzzing

Fuzzing rules

1. Start fuzzing!
2. Start with simple fuzzing, during fuzzing add more logic to the next fuzzer version
3. Use Code/Edge Coverage Feedback
4. Create a good input corpus (via download, feedback or grammar)
5. Minimize the number of sample files and the file size
6. Use sanitizers / heap libraries during fuzzing (not for corpus generation)
7. Modify the mutation engine to fit your input data
8. Skip the “initialization code” during fuzzing (fork-server, persistent mode, …)
9. Use wordlists to get a better code coverage
10. Instrument only the code which should be tested
11. Don’t fix checksums inside your Fuzzer, remove them from the target application (faster)
12. Start fuzzing!

Where to get more information

- Reddit:
  - https://www.reddit.com/r/fuzzing/
  - Most fuzzing related blog posts are published here
- Rode0day:
  - https://rode0day.mit.edu/
  - A continuous bug finding competition
- DARPA Challenge set for Linux/Windows/MacOS
  - https://github.com/trailofbits/cb-multios

Thank you for your attention!

For any further questions contact me

René Freingruber
@ReneFreingruber
r.freingruber@sec-consult.com
+43 676 840 301 749

SEC Consult Unternehmensberatung GmbH
Mooslackengasse 17
1190 Vienna, AUSTRIA

www.sec-consult.com

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY

SEC Consult in your Region.

AUSTRIA (HQ)

SEC Consult Unternehmensberatung GmbH
Mooslackengasse 17
1190 Vienna

Tel +43 1 890 30 43 0
Fax +43 1 890 30 43 15
Email office@sec-consult.com

GERMANY

SEC Consult Deutschland Unternehmensberatung GmbH
Ullsteinstraße 118, Turm B/8 Stock
12109 Berlin

Tel +49 30 30807283
Email office-berlin@sec-consult.com

SWITZERLAND

SEC Consult (Schweiz) AG
Turbinenstrasse 28
8005 Zürich

Tel +41 44 271 777 0
Fax +43 1 890 30 43 15
Email office-zurich@sec-consult.com

LITHUANIA

UAB Critical Security, a SEC Consult company
Sauletekio al. 15-311
10224 Vilnius

Tel +370 5 2195535
Email office-vilnius@sec-consult.com

SINGAPORE

SEC Consult Singapore PTE. LTD
4 Battery Road
#25-01 Bank of China Building
Singapore (049908)

Email office-singapore@sec-consult.com

CANADA

i-SEC Consult Inc.
100 René-Lévesque West, Suite 2500
Montréal (Quebec) H3B 5C9

Email office-montreal@sec-consult.com

RUSSIA

CJCS Security Monitor
5th Donskoy proyezd, 15, Bldg. 6
119334, Moscow

Tel +7 495 662 1414
Email info@securitymonitor.ru

THAILAND

SEC Consult (Thailand) Co.,Ltd.
29/1 Piyaplace Langsuan Building 16th Floor, 16B
Soi Langsuan, Ploen Chit Road
Lumpini, Patumwan | Bangkok 10330

Email office-vilnius@sec-consult.com

SEC Consult
ADVISOR FOR YOUR INFORMATION SECURITY