Secure Software Development

Finding Bugs II

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PREVIOUSLY ON

SSD

Finding Bugs

- Human experts can find bugs by looking at source code

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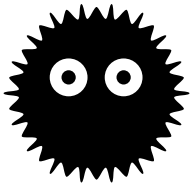
- Explaining source code helps in finding bugs
- Adding print statements to source code can assist in finding bugs
- Stepping through source code with a debugger often reveals bugs

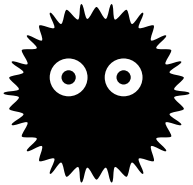

FUZZER

Fuzzing



- Fuzzing is an automated software testing method

Fuzzing



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- Provide invalid, unexpected, or random data as input

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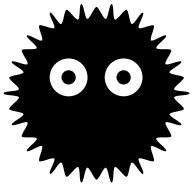

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- Monitor program behavior (e.g., crash, assertion, ...)

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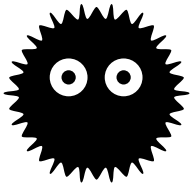
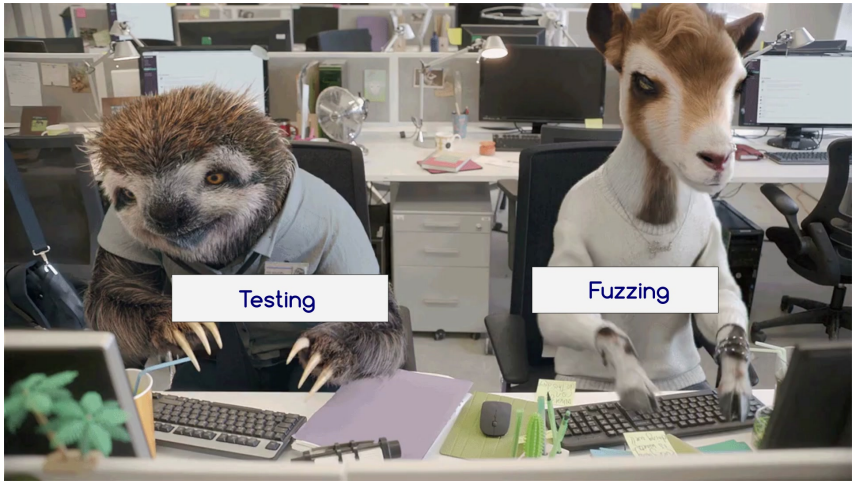


- Fuzzing is an automated software testing method
- Provide invalid, unexpected, or random data as input
- Monitor program behavior (e.g., crash, assertion, ...)
- Typically used for file formats or protocols

Fuzzing



Fuzzing vs. Testing

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- Invalid, unexpected, or random data as input

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- Normal, valid, well-formed data as input

Fuzzing vs. Testing

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- Invalid, unexpected, or random data as input
- Automatically generated testcases

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- Normal, valid, well-formed data as input
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Fuzzing vs. Testing

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- Invalid, unexpected, or random data as input
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- Fun ☺

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- Normal, valid, well-formed data as input
- Manually generated testcases
- Boring ☹

Fuzzing vs. Testing

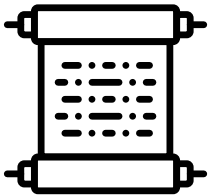
Fuzzing

- Invalid, unexpected, or random data as input
- Automatically generated testcases
- Fun ☺
- Goal: Find exploitable errors

Testing

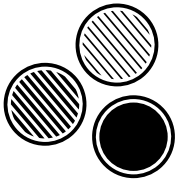
- Normal, valid, well-formed data as input
- Manually generated testcases
- Boring ☹
- Goal: Normal users don't get errors

Fuzzing History



- Fuzzing dates back to 1981, was considered worst means of testing
- Term was coined 1988: testing noise over fuzzy network connections
- Google runs ClusterFuzz since 2012 to fuzz Chrome
- Most teams used fuzzing to automatically detect bugs in the DARPA Cyber Grand Challenge 2016
- american fuzzy lop (AFL) regularly finds bugs in open source programs

Types of Fuzzing



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- The smarter the fuzzing, the harder the setup

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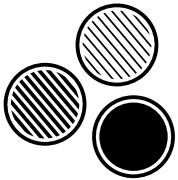
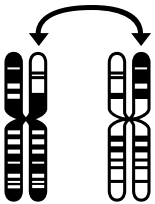


- Fuzzing can be somewhere between dumb and smart
- The smarter the fuzzing, the harder the setup
- However, smarter fuzzing finds more bugs

Mutation Based (“Dumb Fuzzing”)



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- Mutation might be completely random or follow some pattern

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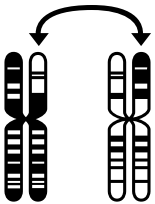

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✚ Easy to set up

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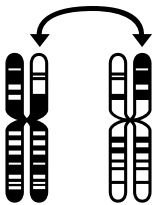

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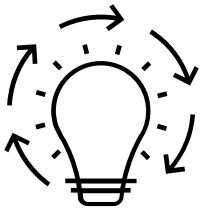
\+ No knowledge of the input structure is required

\+ Easy to set up

− Might fail for complicated protocols (e.g., challenge response)

− Fails for complex file formats (e.g., checksum)

Generation Based ("Smart Fuzzing")



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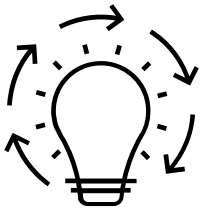

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✚ More targeted, *i.e.*, does not fuzz "uninteresting" data

✚ Handles complex dependencies, e.g., checksums

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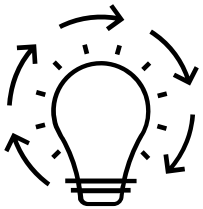

- Testcases are generated from a format description (e.g., RFC)
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\+ Knowledge of protocol gives better results

\+ More targeted, *i.e.*, does not fuzz "uninteresting" data

\+ Handles complex dependencies, e.g., checksums

\- Requires specification of protocol

\- Writing testcase generator is a lot of work

Evolutionary Fuzzing

- Generate inputs/mutations based on program response
- Different metrics: code coverage, reaching potentially dangerous functions, ...

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✚ Dynamically learns protocols, no configuration needed

✚ Finds many bugs

✚ Robust and fast

Evolutionary Fuzzing

- Generate inputs/mutations based on program response
- Different metrics: code coverage, reaching potentially dangerous functions, ...

\+ Dynamically learns protocols, no configuration needed

\+ Finds many bugs

\+ Robust and fast

− Does not handle large input files well

− Often requires binary instrumentation

Practical Example: Fuzzing

Fuzzing

```c
typedef void (*function)(char*);

typedef struct {
  char* name;
  function func;
} functions;

int is_valid(functions* list, char* name) {
  int i = -1;
  while(list[++i].name) {
    if(!strncmp(list[i].name, name, strlen(list[i].name))) return 1;
  }
  return 0;
}

void execute(functions* list, char* name, char* cmd) {
  int i = 0;
  function func;
  while(list[++i].name) {
    if(!strncmp(list[i].name, name, strlen(name))) {
      func = list[i].func;
      break;
    }
  }
  func(cmd);
}

void ping(char* cmd) {
  printf("Pong\n");
}

void pong(char* cmd) {
  printf("Ping\n");
}
void echo(char* cmd) {
  printf("%s", cmd);
}

int main(int argc, char **argv) {
  char buffer[64];
  functions list[] = {
    {"pong", pong},
    {"ping", ping},
    {"echo", echo},
    {NULL, NULL}
  };

  FILE* f = fopen(argv[1], "r");
  if(!f) return 1;
  while(fgets(buffer, 64, f)) {
    char* cmd = strtok(buffer, " \n");
    if(cmd) {
      if(is_valid(list, cmd)) {
        execute(list, cmd, strtok(NULL, ""));
      } else {
        printf("Unknown command!\n");
      }
    }
  }
  fclose(f);
  return 0;
```

```
% AFL_USE_ASAN=1 afl-gcc fuzz.c
afl-cc 2.51b by <lcamtuf@google.com>
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[+] Instrumented 14 locations (64-bit, ASAN/MSAN mode, ratio 33%).
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[...]
[+] All set and ready to roll!
```

```
                american fuzzy lop 2.51b (a.out)

┌─ process timing ────────────────────┬─ overall results ─┐
│        run time : 0 days, 0 hrs, 0 min, 2 sec │  cycles done : 0  │
│   last new path : 0 days, 0 hrs, 0 min, 1 sec │  total paths : 7  │
│ last uniq crash : 0 days, 0 hrs, 0 min, 2 sec │ uniq crashes : 2  │
│  last uniq hang : none seen yet               │   uniq hangs : 0  │
├─ cycle progress ────┬─ map coverage ──────────┴───────────────────┘
│  now processing : 0 (0.00%)  │    map density : 0.02% / 0.04%
│ paths timed out : 0 (0.00%)  │ count coverage : 1.17 bits/tuple
├─ stage progress ────┼─ findings in depth ─────────────────────────┐
│  now trying : interest 32/8  │ favored paths : 1 (14.29%)          │
│ stage execs : 250/431 (58.00%)│  new edges on : 7 (100.00%)        │
│ total execs : 1720           │ total crashes : 247 (2 unique)      │
│  exec speed : 541.6/sec      │  total tmouts : 0 (0 unique)        │
├─ fuzzing strategy yields ──┴──────────────────────┬─ path geometry ┐
│   bit flips : 4/96, 0/95, 0/93                    │    levels : 2  │
│  byte flips : 0/12, 0/11, 0/9                     │   pending : 7  │
│ arithmetics : 2/669, 0/55, 0/0                    │  pend fav : 1  │
│  known ints : 2/64, 0/306, 0/0                    │  own finds : 6 │
│  dictionary : 0/0, 0/0, 0/0                       │  imported : n/a│
│       havoc : 0/0, 0/0                            │ stability : 100.00% │
│        trim : 7.69%/3, 0.00%                      └────────────────┘
^C                                                          [cpu000: 81%]

+++ Testing aborted by user +++
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% cat afl-out/crashes/id*
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% gdb --args ./fuzzing afl-out/crashes/id:000000
(gdb) r
Starting program: fuzzing afl-out/crashes/id:000000

Program received signal SIGSEGV, Segmentation fault.
0x0000000000000000 in ?? ()
(gdb) bt
#0  0x0000000000000000 in ?? ()
#1  0x00000000004008ba in execute (list=0x7fffffffdb60,
  name=0x7fffffffdba0 "pingJecho", cmd=0x7fffffffdbaa "Hi") at fuzzing.c:30
#2  0x0000000000400a25 in main (argc=2, argv=0x7fffffffdcd8) at fuzzing.c:60
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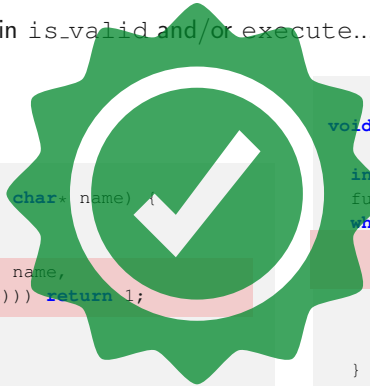

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┌─ process timing ────────────────────┐┌─ overall results ─┐
│        run time : 0 days, 0 hrs, 0 min, 2 sec ││  cycles done : 0  │
│   last new path : 0 days, 0 hrs, 0 min, 0 sec ││  total paths : 5  │
│ last uniq crash : 0 days, 0 hrs, 0 min, 1 sec ││ uniq crashes : 1  │
│  last uniq hang : none seen yet               ││   uniq hangs : 0  │
├─ cycle progress ────────────────────┐┌─ map coverage ──────────────┤
│  now processing : 0 (0.00%)         ││    map density : 0.02% / 0.03%
│ paths timed out : 0 (0.00%)         ││ count coverage : 1.37 bits/tuple
├─ stage progress ────────────────────┐├─ findings in depth ─────────┤
│  now trying : arith 8/8             ││ favored paths : 1 (20.00%)  │
│ stage execs : 456/718 (63.51%)      ││  new edges on : 4 (80.00%)  │
│ total execs : 816                   ││ total crashes : 1 (1 unique)
│  exec speed : 311.4/sec             ││  total tmouts : 0 (0 unique)
├─ fuzzing strategy yields ───────────┴┴─ path geometry ─────────────┤
│   bit flips : 3/96, 1/95, 0/93              │    levels : 2        │
│  byte flips : 0/12, 0/11, 0/9               │   pending : 5        │
│ arithmetics : 0/0, 0/0, 0/0                 │  pend fav : 1        │
│  known ints : 0/0, 0/0, 0/0                 │  own finds : 4       │
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│        trim : 7.69%/3, 0.00%                ├──────────────────────┘
^C                                            │          [cpu000: 51%]

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int is_valid(functions* list, char* name) {
  int i = -1;
  while(list[++i].name) {
    if(!strncmp(list[i].name, name,
          strlen(list[i].name))) return 1;
  }
  return 0;
}
```

```
void execute(functions* list, char*
     name, char* cmd) {
  int i = -1;
  function func;
  while(list[++i].name) {
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      func = list[i].func;
      break;
    }
  }
  func(cmd);
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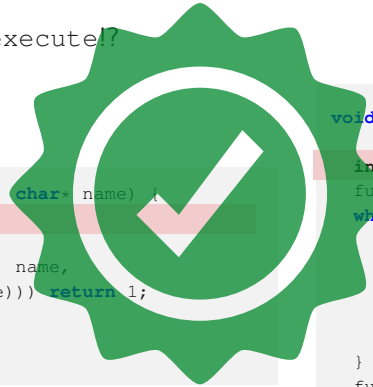

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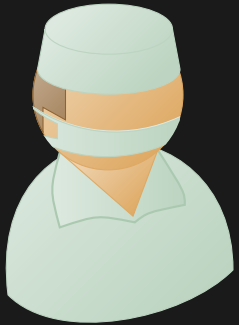
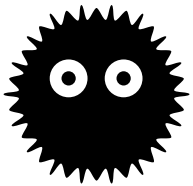
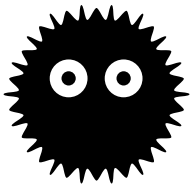


Practical Example Analysis: Fuzzing



- ✚ Fuzzing can be fast and efficient $\rightarrow \approx 4\,\text{s}$ for 2 bugs
- ✚ Setting up a (rather dumb) fuzzer is easy
- ✚ Finds bugs that are often overlooked when manually testing



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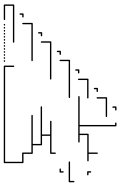
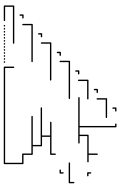
- ✚ Setting up a (rather dumb) fuzzer is easy
- ✚ Finds bugs that are often overlooked when manually testing
- ━ Understanding the input leading to a crash can be complicated
- ━ Never sure if all bugs were found

Practical Example Impact: Fuzzing

- In this case, only a NULL pointer





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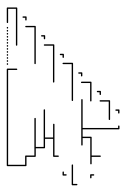
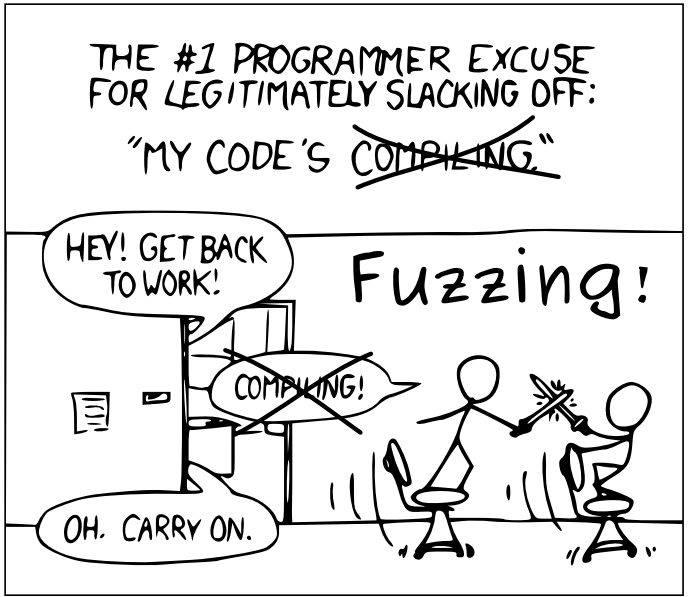


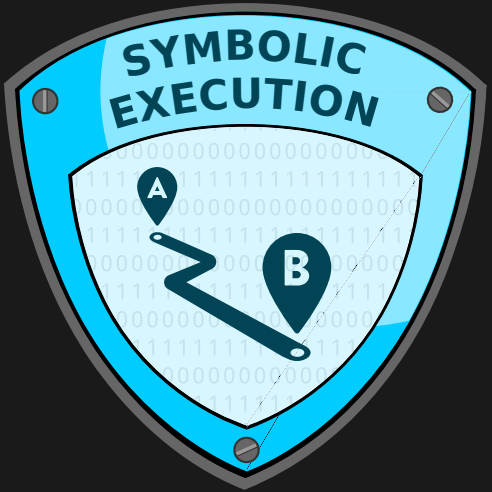
- In this case, only a NULL pointer
- No code execution, but attacker can crash the program
- Potentially dangerous if attacker can manipulate the uninitialized memory

```
typedef void (*function)(char*);
function func;
[...]
func(cmd);
```

libFuzzer

- libFuzzer fuzzes single functions
- Useful for libraries
- Easier to get code coverage
- Used in Chromium


THE #1 PROGRAMMER EXCUSE FOR LEGITIMATELY SLACKING OFF:
"MY CODE'S COMPILING."
HEY! GET BACK TO WORK!
COMPILING!
OH. CARRY ON.
Fuzzing!


SYMBOLIC
EXECUTION
A
B

Symbolic Execution

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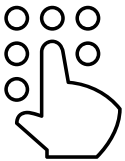

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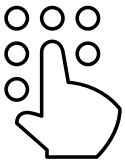

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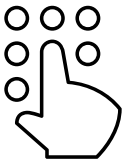

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- Programs are interpreted, input is modelled using symbolic values
- Variables can be expressed using the symbolic values
- Conditional jumps are constraint by the symbolic values
- Expressions consisting of symbolic values are solved using SAT solvers to get concrete input

Symbolic Execution

Illustration of how symbolic execution works

```
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y = x * 2;
z = y + 4
if (z == 12) {
  bug();
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$12 = 2 \cdot \lambda + 4 \Rightarrow \lambda = 4$

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- Possible solution: Concolic (concrete + symbolic) execution
- Run symbolic execution in parallel with real execution, take real values if symbolic expressions get too complicated

Practical Example: Serial Number (Symbolic Execution)

Serial Number (Symbolic Execution)

```
bool checkSerial(const char *in) {
  int sum = 0;
  int digits = strlen(in);
  int parity = (digits - 1) % 2;
  for (int i = digits; i > 0; i--) {
    char current = in[i - 1];
    if (current < '0' || current > '9')
      return 0;
    int digit = current - '0';

    if (parity == i % 2)
      digit *= 2;

    sum += (digit / 10) + (digit % 10);
  }
  return 0 == sum % 10;
}
```

```
char input[256];

int main() {
  int i;
  puts("Enter verification number");
  fgets(input, 256, stdin);
  if (strlen(input) != 13)
    return 1;

  input[strlen(input) - 1] = 0;
  if (checkSerial(input)) {
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Go here

Avoid this

Serial Number (Symbolic Execution)

```python
import angr

good = 0x8048630
avoid = ( 0x8048642 )
length = 12

project = angr.Project('main.elf')
state = project.factory.full_init_state()
simgr = project.factory.simgr()
simgr.explore(find=good, avoid=avoid)

s = simgr.found[0]
for i in range(length):
    b = s.memory.load( 0x0804a060 + i, 1)
    s.add_constraints(b >= ord('0'), b <= ord('9'))

s.se.eval_upto(s.memory.load( 0x0804a060 , length), length, cast_to=str)
print("Valid number: %s" % simgr.found[0].state.posix.dumps(0)[0:length])
```

Practical Example Analysis: Serial Number

Serial Number (Symbolic Execution)

```
% gcc -std=gnu99 -m32 -no-pie main.c -o main.elf
```

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Valid number: 430009016964
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```
% ./main.elf
Enter verification number
430009016964
Number validated!
```

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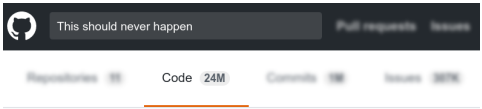

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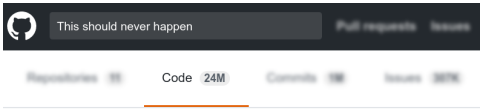


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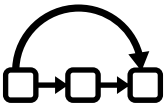

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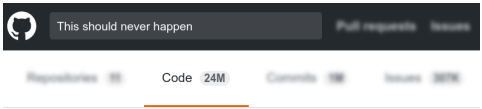


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- Find flawed authentication (can it be bypassed?)

Challenge #5 - Hearty-Starty

You are given a large binary that is hard to reverse-engineer

- You can find the challenge binary in the SSD CTF system
- It will ask you for an input and check its correctness
- If you enter the correct input you get the flag
- Use a disassembler like `radare2` and symbolic execution with `angr`
- **Hint**: Look out for endless loops, and terminate such states
- This is a semi-automated process, use `IPython` to interact with `angr`

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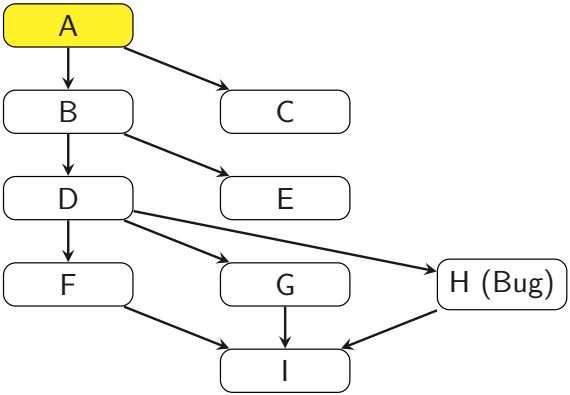
- Open-source implementation Driller: uses AFL + angr



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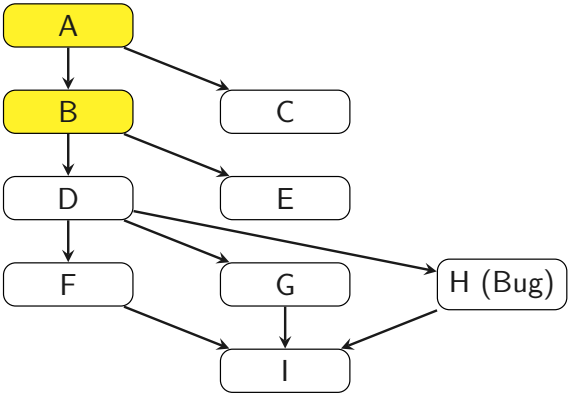

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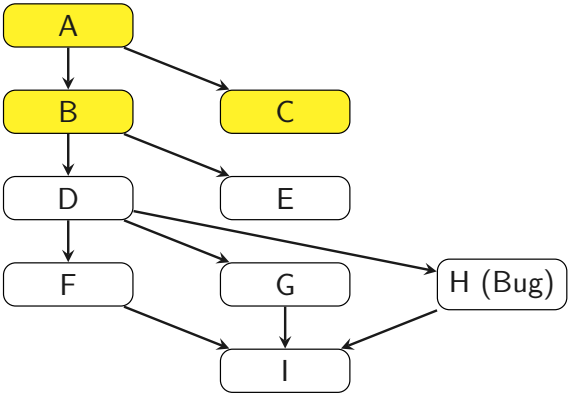

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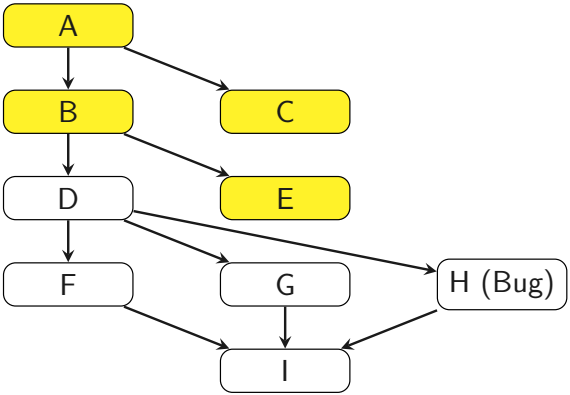

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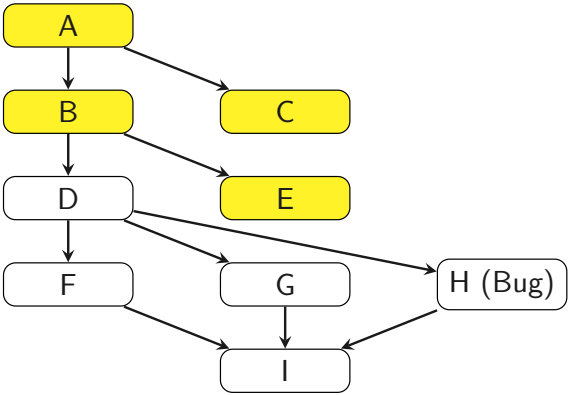

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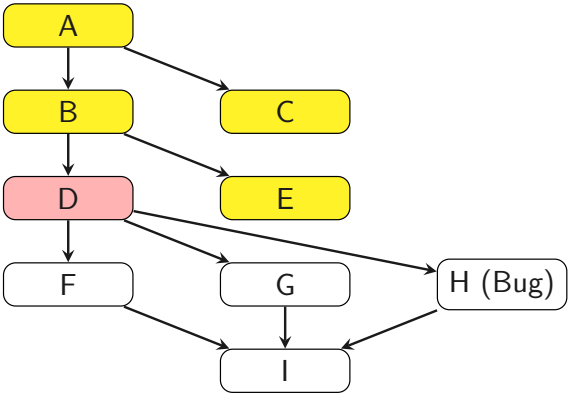

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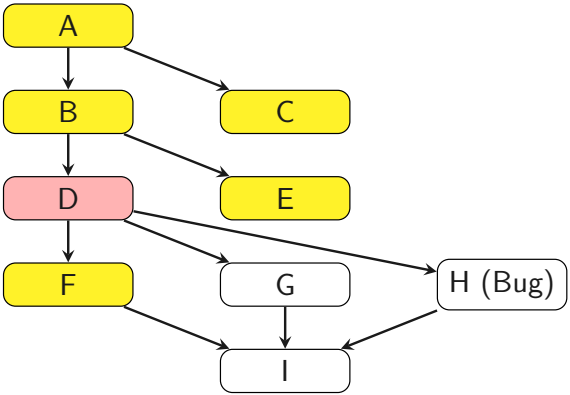

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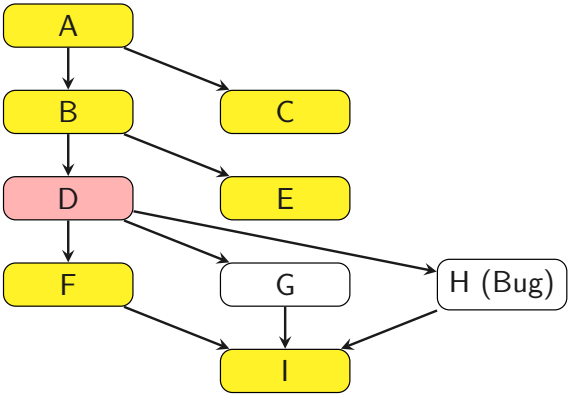

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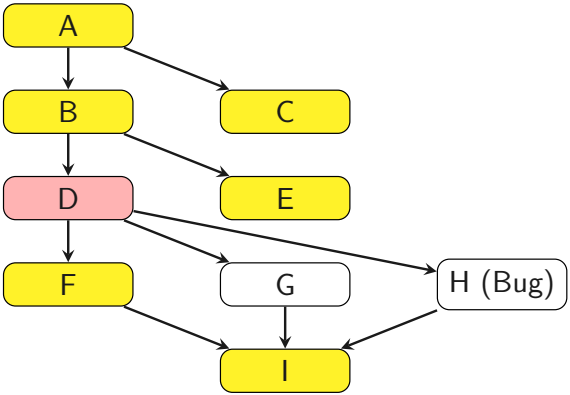

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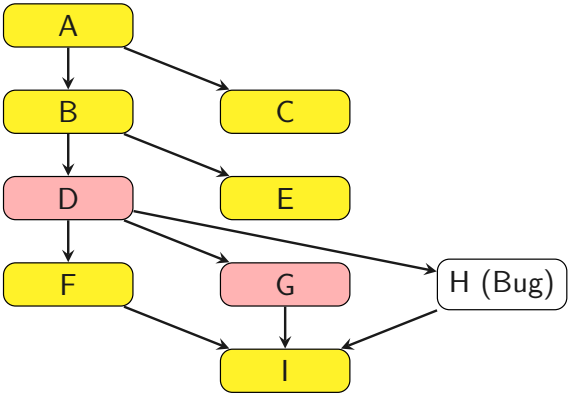

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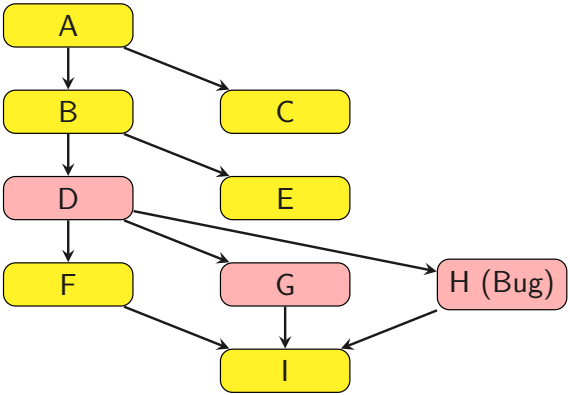

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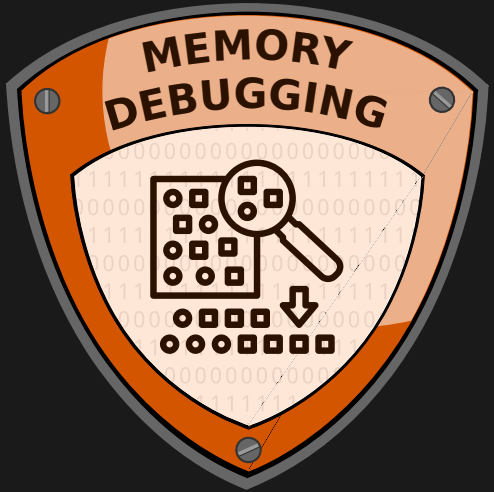
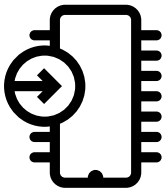

MEMORY
DEBUGGING

Memory Debugging



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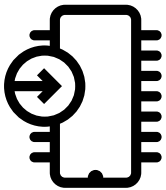
- Monitor memory accesses, allocations and deallocations

Memory Debugging



- Memory Debugging or Runtime Debugging finds memory problems
- Monitor memory accesses, allocations and deallocations
- Finds bug caused by wrong memory allocation and deallocation
- Can work with source code or binaries only

Memory Debugging - Types of Bugs

- Out-of-bounds reads/writes, e.g., buffer overflows

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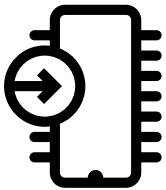
How Memory Debugging Works



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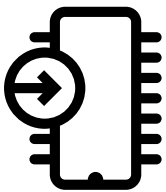

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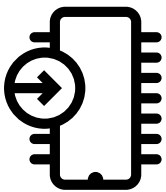

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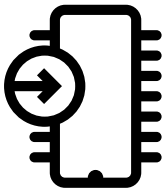

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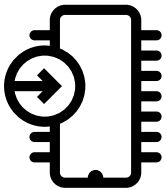

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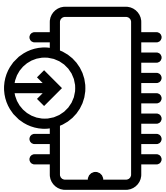
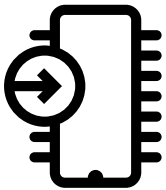


- Used in e.g., clang's address sanitizer, added directly by the compiler
- ✚ Can find nearly all memory errors
- ✚ Can provide detailed information, as faulty code is known
- ━ Requires recompilation, *i.e.*, access to the source code
- ━ Non-negligible memory and runtime overhead

How Memory Debugging Works - Dynamic Linking



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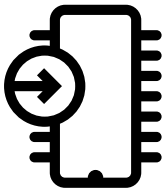

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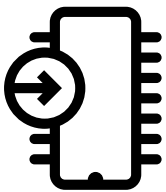

- Used in e.g., Electric Fence, can be added at runtime through `LD_PRELOAD`
- \+ No change to program required
- \+ No source code required
- − Types of detectable errors are limited
- − High memory overhead

How Memory Debugging Works - Dynamic Linking

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- How can dynamic-linking-based techniques detect such errors?

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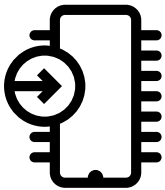
- Out-of-bounds read/write crashes the program (segfault)

How Memory Debugging Works - Binary Instrumentation



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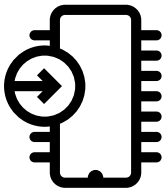

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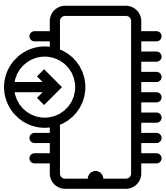

- Used by e.g., Valgrind's memcheck
- \+ Does not require source code
- \+ Can find many types of errors
- − Slow
- − Highly architecture dependent

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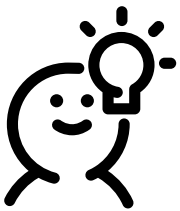

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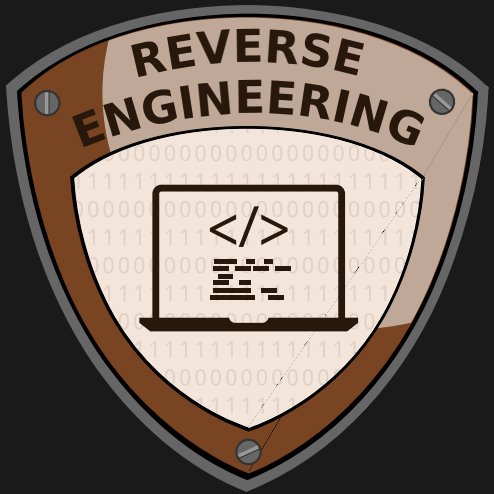
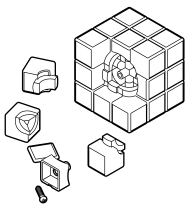
- Valgrind framework supports plugins to write arbitrary instrumentation tools


REVERSE
ENGINEERING
</>

Reverse Engineering



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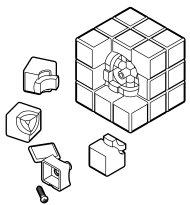

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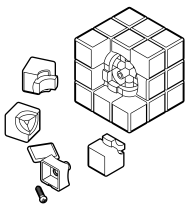

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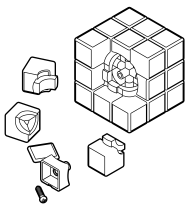

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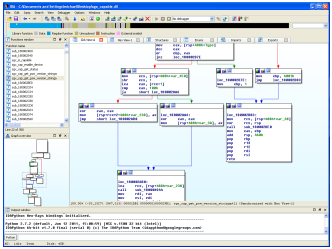
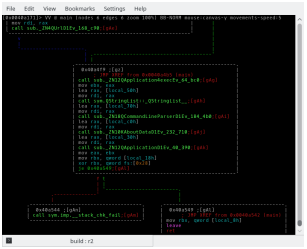
- Re-engineering allows to build a new binary from the reverse engineered binary

Reverse Engineering

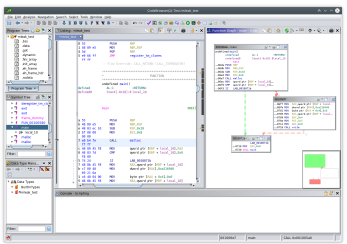
IDA Pro ($\geq$ 1200 €)



radare2 (open source)



Ghidra (open source)



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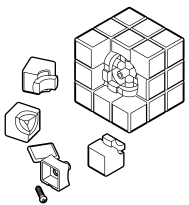

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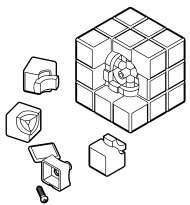

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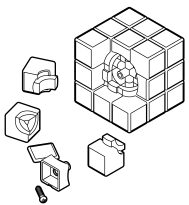

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- Decompilers further convert code to high-level language (C or pseudo code)
- Good decompilers cost a lot of money ☹ (IDA Pro - HexRays)

Practical Example: Disassembly vs. Decompilation

Disassembly vs. Decompilation

```c
#include <stdio.h>
#include <string.h>

int main() {
    char buffer[64];
    printf("Enter password:\n");
    fgets(buffer, 64, stdin);
    if(!strncmp(buffer, "secret1234", 10)) {
        printf("Correct!\n");
    } else {
        printf("Wrong\n");
    }
    return 0;
}
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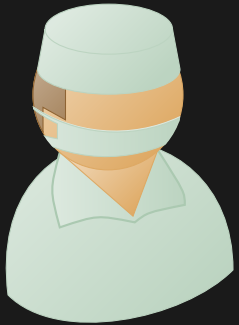
```
% gcc re.c -o re
```

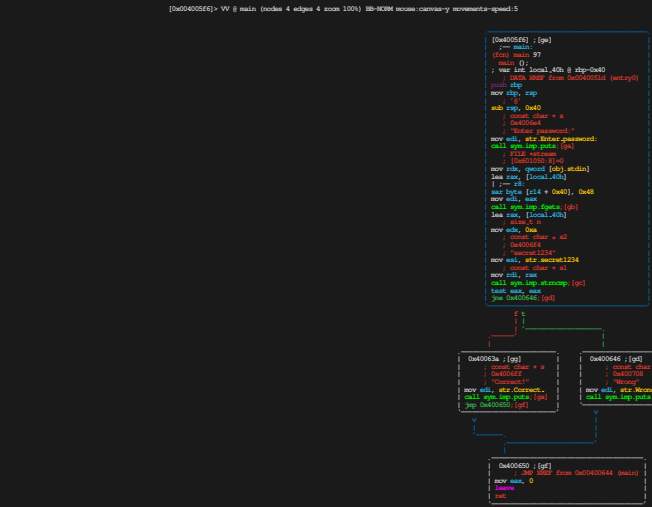


Practical Example Analysis: Disassembly vs. Decompilation

Disassembly vs. Decompilation

```
% r2 re
[0x00400500]> aaaa
[x] Analyze all flags starting with sym. and entry0 (aa)
[x] Analyze len bytes of instructions for references (aar)
[x] Analyze function calls (aac)
[x] Emulate code to find computed references (aae)
[x] Analyze consecutive function (aat)
[x] Constructing a function name for fcn.* and
    sym.func.* functions (aan)
[x] Type matching analysis for all functions (afta)
[0x00400500]> VV @ main
```

Disassembly vs. Decompilation



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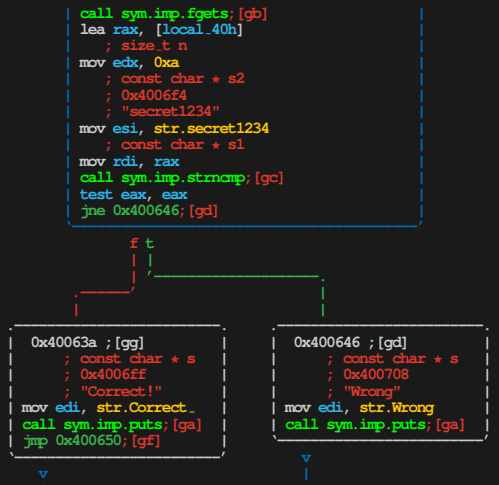

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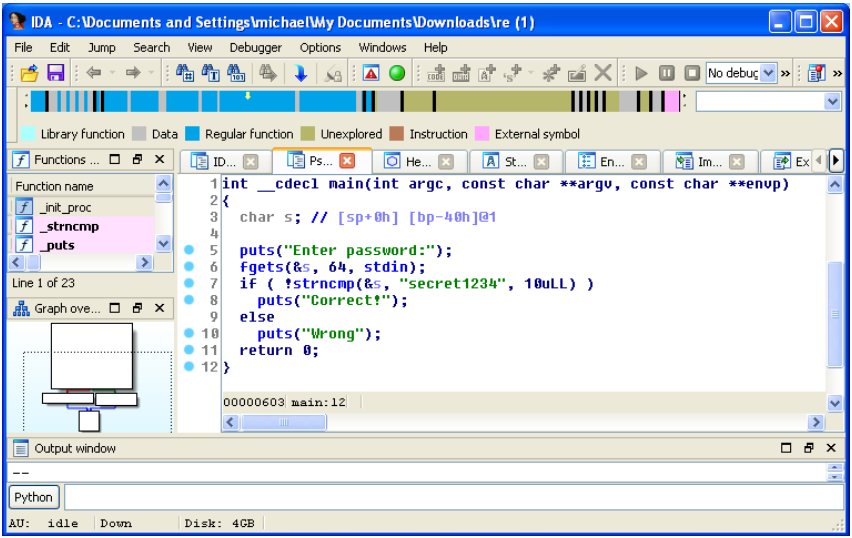

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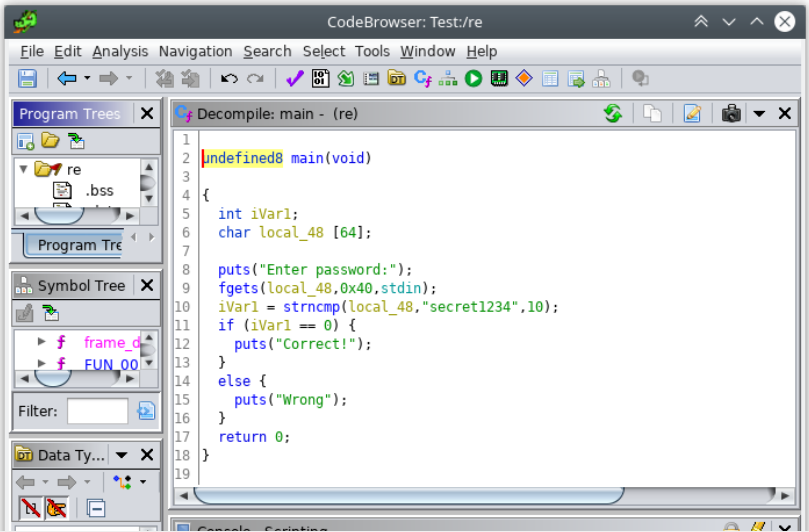
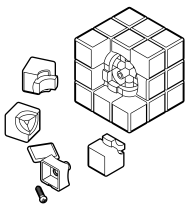


Practical Example Impact: Disassembly vs. Decompilation

Disassembly vs. Decompilation

- Disassembler only returns often hard-to-understand assembly code



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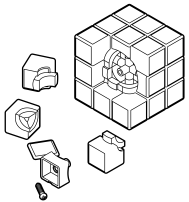

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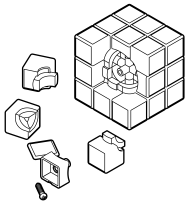
- Decompilation output is often a lot easier to read

Disassembly vs. Decompilation



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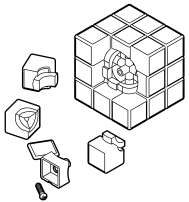

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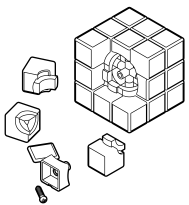

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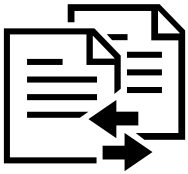
- Highly dependent on
  - architecture
  - used compiler
  - optimization level
  - obfuscation
- If it works, it gives a quick overview for further investigations

Challenge #6 - Mysterious Binary

Figure out how to run the binary and get the flag

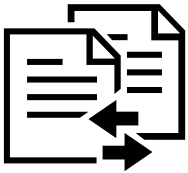
- Hint: It is neither a Linux nor a Windows binary
- If you manage to run it, it will ask for a PIN
- Entering the correct PIN reveals the flag
- Use a disassembler (e.g., radare2)
- Hint: Don't look directly for the flag, look for the PIN


BINARY
DIFFING



- Security patches for closed-source products often have no (real) description of the bug

Binary Diffing



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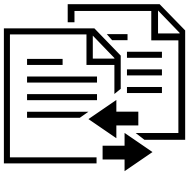

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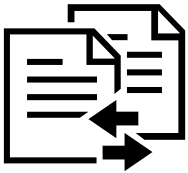

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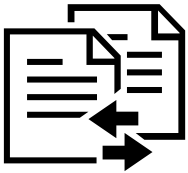
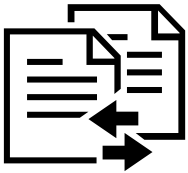


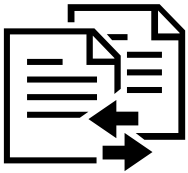
- Security patches for closed-source products often have no (real) description of the bug
- The patch is usually available for download
- Binary diffing is like normal diffing, except for binaries
- Reveals differences in two binaries, *i.e.*, the bug fix
- Can also be used to find vulnerable functions by comparing binary with known vulnerable functions

Binary Diffing

- Diffing tools use different methods to find matching and unmatching blocks

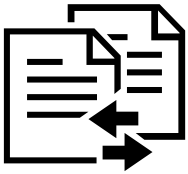


Binary Diffing



- Diffing tools use different methods to find matching and unmatching blocks
  - Same function name
  - Same assembly, same decompiled code
  - Equal number of calls to and from function
  - Same referenced strings
  - ...

Binary Diffing



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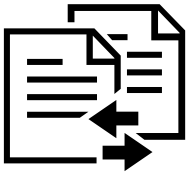
Binary Diffing



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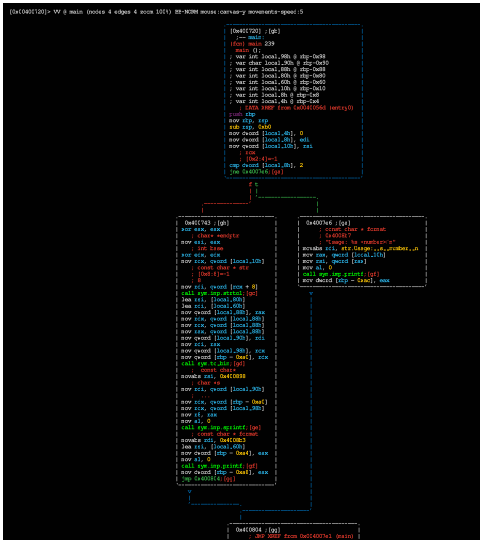
  - Same function name
  - Same assembly, same decompiled code
  - Equal number of calls to and from function
  - Same referenced strings
  - ...
- Most diff tools rely on the control-flow graph from a disassembler
- The basic blocks are then matched using some heuristic

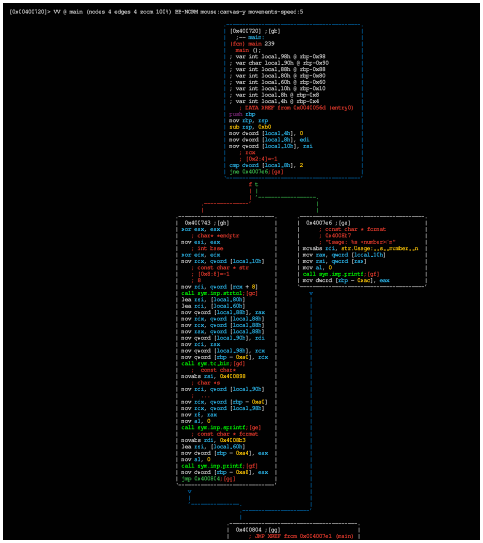
Practical Example: 1-day (Binary Diffing)

1-day (Binary Diffing)



- Given a binary with an unknown bug

1-day (Binary Diffing)



- Given a binary with an unknown bug
- The vendor released a patch, fixing the vulnerability

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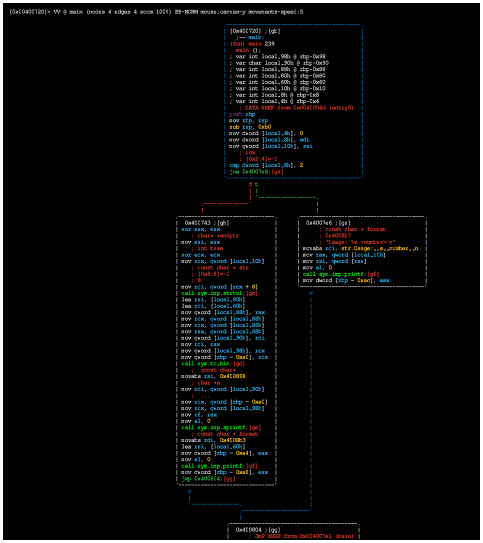

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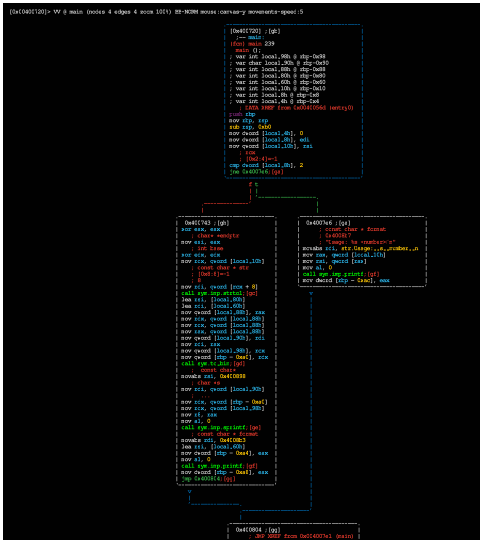

- Given a binary with an unknown bug
- The vendor released a patch, fixing the vulnerability
- Fixed bug has no documentation...
- ...but we have both the patched (`patched`) and original (`vuln`) binary

1-day (Binary Diffing)

```
% ./vuln
Usage: ./vuln <number>
```

```
% ./vuln
Usage: ./vuln <number>
```

```
% ./vuln 123
Dec: 123
Hex: 0x7b
Bin: 0b1111011
```

1-day (Binary Diffing)

```
% radiff2 -AAAAC vuln patched
```

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% radiff2 -AAAAC vuln patched
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```
                sym._init  26 0x4004a8 | UNMATCH  (0.923077) | 0x4004e0   26 sym._init
            sym.imp.strcpy  32 0x4004e0 | UNMATCH  (0.906250) | 0x400510   32 sym.imp.strcpy
            sym.imp.printf  48 0x4004f0 | UNMATCH  (0.854167) | 0x400530   48 sym.imp.printf
sym.imp.__libc_start_main  48 0x400500 | UNMATCH  (0.854167) | 0x400550   48 sym.imp.__libc_start_main
            sym.imp.strtol  48 0x400510 | UNMATCH  (0.854167) | 0x400560   48 sym.imp.strtol
            sym.imp.strcat  48 0x400520 | UNMATCH  (0.854167) | 0x400520   48 sym.imp.strlen
           sym.imp.sprintf  48 0x400530 | UNMATCH  (0.854167) | 0x400570   48 sym.imp.sprintf
              fcn.00400540  57 0x400540 |   MATCH  (0.192982) | 0x400580   57 fcn.00400580
 sym.deregister_tm_clones  35 0x400580 | UNMATCH  (0.914286) | 0x4005c0   35 sym.deregister_tm_clones
               sym.to_bin 236 0x400630 |   MATCH  (0.723776) | 0x400670  286 sym.to_bin
          sym.imp.strncat  48 0x400540 |      NEW  (0.000000)
```

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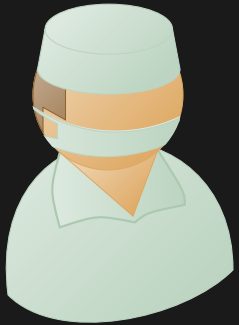

Practical Example Analysis: 1-day (Binary Diffing)

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```
% radiff2 -g sym.to_bin vuln patched | xdot -
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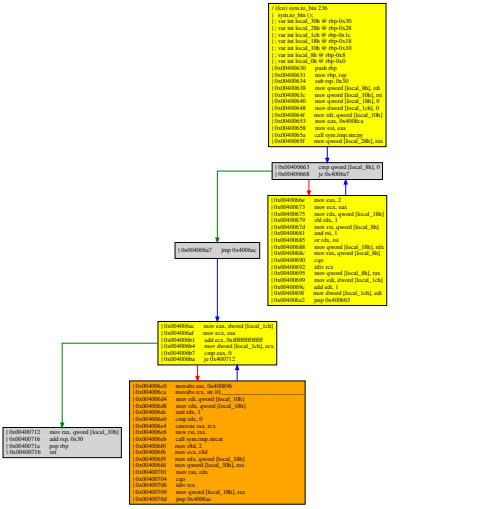

```
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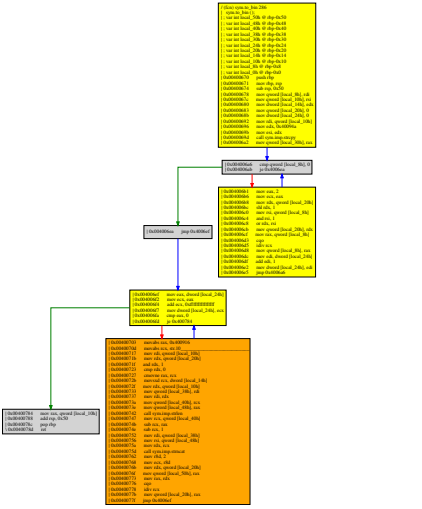
```



1-day (Binary Diffing)

```
| 0x004006c0     movabs rax, 0x400896
| 0x004006ca     movabs rcx, str.10_____________________________
| 0x004006d4     mov rdi, qword [local_10h]
| 0x004006d8     mov rdx, qword [local_18h]
| 0x004006dc     and rdx, 1
| 0x004006e0     cmp rdx, 0
| 0x004006e4     cmovne rax, rcx
| 0x004006e8     mov rsi, rax
| 0x004006eb     call sym.imp.strcat
| 0x004006f0     mov r8d, 2
| 0x004006f6     mov ecx, r8d
| 0x004006f9     mov rdx, qword [local_18h]
| 0x004006fd     mov qword [local_30h], rax
| 0x00400701     mov rax, rdx
| 0x00400704     cqo
| 0x00400706     idiv rcx
| 0x00400709     mov qword [local_18h], rax
| 0x0040070d     jmp 0x4006ac
```

Original (`vuln`)

```
| 0x00400703     movabs rax, 0x400916
| 0x0040070d     movabs rcx, str.10_____________________________
| 0x00400717     mov rdi, qword [local_10h]
| 0x0040071b     mov rdx, qword [local_20h]
| 0x0040071f     and rdx, 1
| 0x00400723     cmp rdx, 0
| 0x00400727     cmovne rax, rcx
| 0x0040072b     movsxd rcx, dword [local_14h]
| 0x0040072f     mov rdx, qword [local_10h]
| 0x00400733     mov qword [local_38h], rdi
| 0x00400737     mov rdi, rdx
| 0x0040073a     mov qword [local_40h], rcx
| 0x0040073e     mov qword [local_48h], rax
| 0x00400742     call sym.imp.strlen
| 0x00400747     mov rcx, qword [local_40h]
| 0x0040074b     sub rcx, rax
| 0x0040074e     sub rcx, 1
| 0x00400752     mov rdi, qword [local_38h]
| 0x00400756     mov rsi, qword [local_48h]
| 0x0040075a     mov rdx, rcx
| 0x0040075d     call sym.imp.strncat
| 0x00400762     mov r8d, 2
| 0x00400768     mov ecx, r8d
| 0x0040076b     mov rdx, qword [local_20h]
| 0x0040076f     mov qword [local_50h], rax
| 0x00400773     mov rax, rdx
| 0x00400776     cqo
| 0x00400778     idiv rcx
| 0x0040077b     mov qword [local_20h], rax
| 0x0040077f     jmp 0x4006ef
```

Patched (`patched`)

1-day (Binary Diffing)

```
| 0x004006c0    movabs rax, 0x400896
| 0x004006ca    movabs rcx, str.10
| 0x004006d4    mov rdi, qword [local_10h]
| 0x004006d8    mov rdx, qword [local_18h]
| 0x004006dc    and rdx, 1
| 0x004006e0    cmp rdx, 0
| 0x004006e4    cmovne rax, rcx
| 0x004006e8    mov rsi, rax
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```

Good: `strncat`

Patched (`patched`)

1-day (Binary Diffing)

```
% ./vuln 9999999999
Dec: 9999999999
Hex: 0x2540be3ff
Bin: 0b1001010100000010111110001111111Dec: 9999999999
Hex: 0x2540be3ff
Bin: 0b100

[1]    27986 segmentation fault (core dumped)  ./vuln 9999999999
```

1-day (Binary Diffing)

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Dec: 9999999999
Hex: 0x2540be3ff
Bin: 0b1001010100000010111110001111111Dec: 9999999999
Hex: 0x2540be3ff
Bin: 0b100

[1]    27986 segmentation fault (core dumped)  ./vuln 9999999999
```

```
% ./patched 9999999999
Dec: 9999999999
Hex: 0x2540be3ff
Bin: 0b1001010100000010111110001111111
```

Practical Example Impact: 1-day (Binary Diffing)

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- Binary diffing is a way to reverse engineer patches

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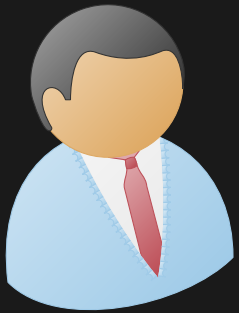
1-day (Binary Diffing)

- Binary diffing is a way to reverse engineer patches
- If there are not many changes, vulnerability can be quickly spotted
- Knowledge of the vulnerability allows attackers to craft exploits
- As long as patches are not applied, such 1-days are effective
- Also a starting point for same/similar bugs in the program



Real-world Example: Apple's Password Hint Bug

Apple's Password Hint Bug

- macOS Sierra had a bug in the file-system encryption

Apple's Password Hint Bug

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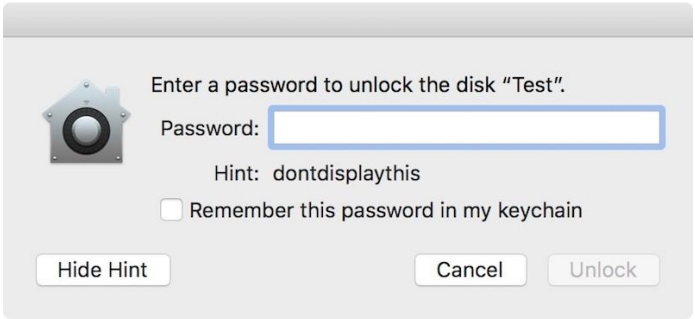
- macOS Sierra had a bug in the file-system encryption
- User can set a password hint which can be displayed
- However, the password hint was never shown, but...
- ...the password was shown instead



Apple's Password Hint Bug

Security experts used binary diffing on the patch...

```
1  if ( v50 )
2      objc_msgSend(v19, "setObject:forKey:", v50, CFSTR("kSKAPFSDiskPasswordOption"));
3    if ( a9 )
4      objc_msgSend(v19, "setObject:forKey:", v50, CFSTR("kSKAPFSDiskPasswordHintOption"));
U:---  OldStorageKit.txt   All (5,0)       [i] (ObjC/l FlyC- Projectile[-] SP/s)
```

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1 if ( v50 )
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```

...to discover that it was a copy&paste fail

```
1 if ( v51 )
2     objc_msgSend(v19, "setObject:forKey:", v51, CFSTR("kSKAPFSDiskPasswordOption"));
3   if ( v49 )
4     objc_msgSend(v19, "setObject:forKey:", v49, CFSTR("kSKAPFSDiskPasswordHintOption"));
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Finding Bugs Summary

- Finding bugs is like catching fish - you don't know how long it takes

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- Hard part is to figure out where the fish (bug) is, and when it will bite (occur)

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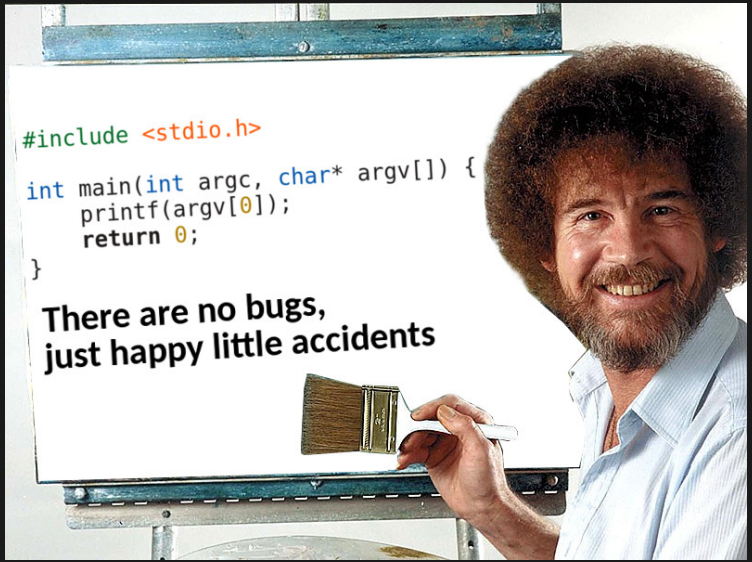
- ...but it eliminates many bugs (for free)

Questions?


#include <stdio.h>
int main(int argc, char* argv[]) {
printf(argv[0]);
return 0;
}
There are no bugs,
just happy little accidents

Further Reading i


Nicholas Nethercote and Julian Seward.
Valgrind: a framework for heavyweight dynamic binary instrumentation.
In ACM Sigplan notices, 2007.


Jeongwook Oh.
Fight against 1-day exploits: Diffing binaries vs anti-diffing binaries.
Black Hat, 2009.


Yan Shoshitaishvili, Ruoyu Wang, Christopher Salls, Nick Stephens, Mario Polino, Audrey Dutcher, John Grosen, Siji Feng, Christophe Hauser, Christopher Kruegel, and Giovanni Vigna.
SoK: (State of) The Art of War: Offensive Techniques in Binary Analysis.
In IEEE Symposium on Security and Privacy, 2016.

Further Reading ii


Nick Stephens, John Grosen, Christopher Salls, Andrew Dutcher, Ruoyu Wang, Jacopo Corbetta, Yan Shoshitaishvili, Christopher Kruegel, and Giovanni Vigna.
Driller: Augmenting fuzzing through selective symbolic execution.
In NDSS, 2016.