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 ← rubber duck

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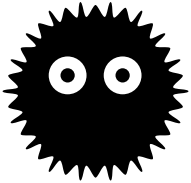
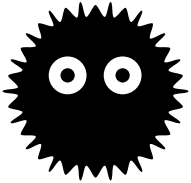
- Explaining source code helps in finding bugs
- Adding print statements to source code can assist in finding bugs
- Stepping through source code with a debugger often reveals bugs


FUZZER



- Fuzzing is an automated software testing method



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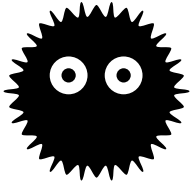
- Provide invalid, unexpected, or random data as input

Fuzzing



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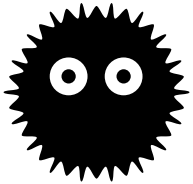
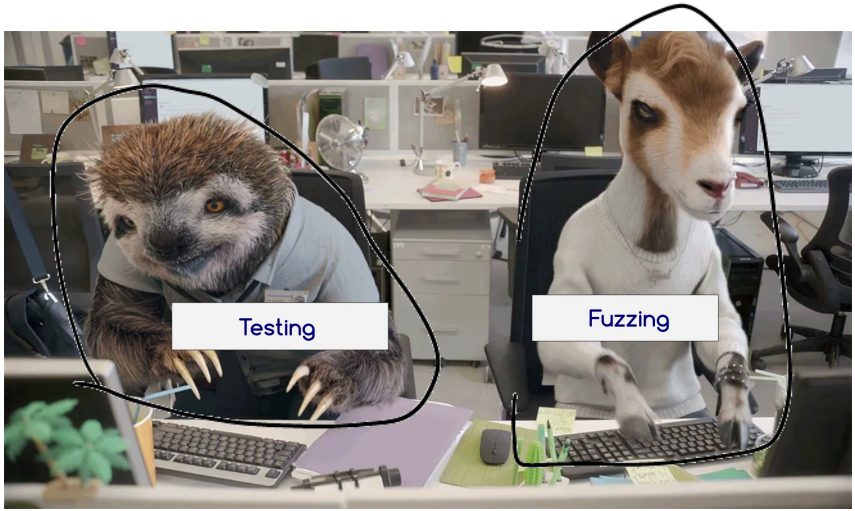
- Monitor program behavior (e.g., crash, assertion, ...)



- 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


Testing
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

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Fuzzing

- 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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- Automatically generated testcases
- Fun ☺

Testing

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

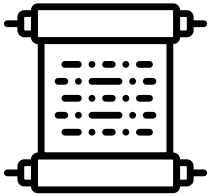
Fuzzing vs. Testing

Fuzzing

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

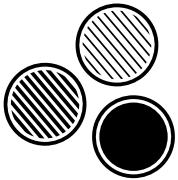
Testing

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



- Fuzzing 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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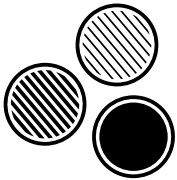
- The smarter the fuzzing, the harder the setup

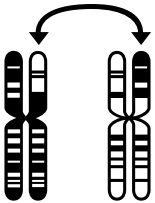
Types of Fuzzing



- 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")

bit-flips
swap bytes
truncate



- Mutate existing data sets to generate new testcases
- Mutation might be completely random or follow some pattern

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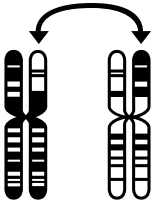

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\+ No knowledge of the input structure is required

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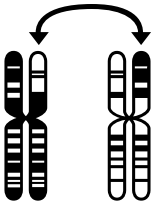

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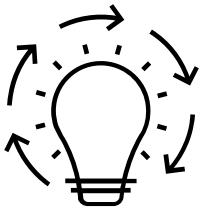
− Might fail for complicated protocols (e.g., challenge response)

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

Generation Based ("Smart Fuzzing")



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- Anomalies are added to each field of the input

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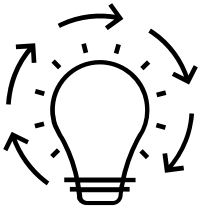

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\+ Knowledge of protocol gives better results

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

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

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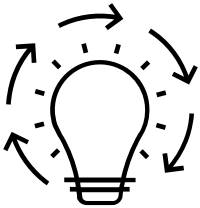

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\+ Knowledge of protocol gives better results

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\- Requires specification of protocol

\- Writing testcase generator is a lot of work

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- Different metrics: code coverage, reaching potentially dangerous functions, ...

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- 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


```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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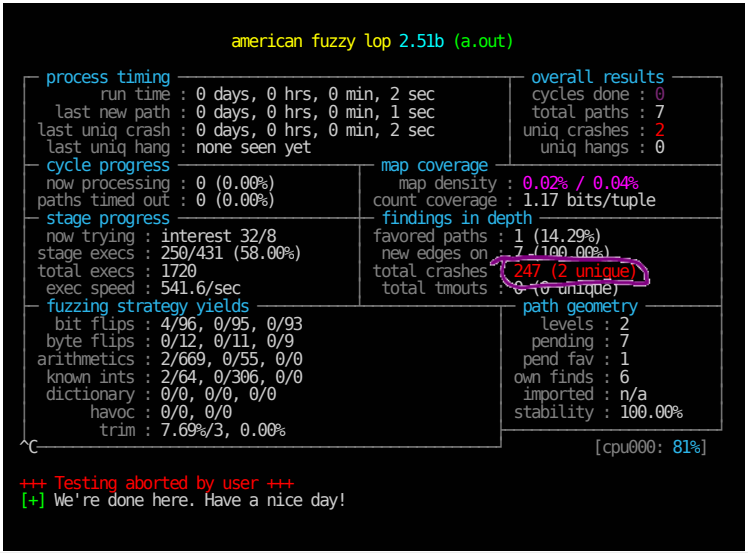
[+] You have 4 CPU cores and 1 runnable tasks (utilization: 25%).
[...]
[+] All set and ready to roll!
```


american fuzzy lop 2.51b (a.out)
process timing
run time : 0 days, 0 hrs, 0 min, 2 sec
last new path : 0 days, 0 hrs, 0 min, 1 sec
last uniq crash : 0 days, 0 hrs, 0 min, 2 sec
last uniq hang : none seen yet
overall results
cycles done : 0
total paths : 7
uniq crashes : 2
uniq hangs : 0
cycle progress
now processing : 0 (0.00%)
paths timed out : 0 (0.00%)
map coverage
map density : 0.02% / 0.04%
count coverage : 1.17 bits/tuple
stage progress
now trying : interest 32/8
stage execs : 250/431 (58.00%)
total execs : 1720
exec speed : 541.6/sec
findings in depth
favored paths : 1 (14.29%)
new edges on : 7 (100.00%)
total crashes : 247 (2 unique)
total tmouts : 0 (0 unique)
fuzzing strategy yields
bit flips : 4/96, 0/95, 0/93
byte flips : 0/12, 0/11, 0/9
arithmetics : 2/669, 0/55, 0/0
known ints : 2/64, 0/306, 0/0
dictionary : 0/0, 0/0, 0/0
havoc : 0/0, 0/0
trim : 7.69%/3, 0.00%
path geometry
levels : 2
pending : 7
pend fav : 1
own finds : 6
imported : n/a
stability : 100.00%
^C
[cpu000: 81%]
+++ Testing aborted by user +++
[+] We're done here. Have a nice day!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% cat afl-out/crashes/id*
pingJecho Hi
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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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The bug must be somewhere in `is_valid` and/or `execute`...

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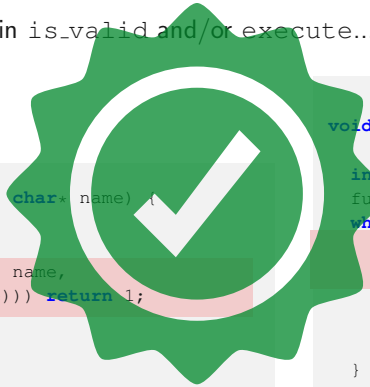

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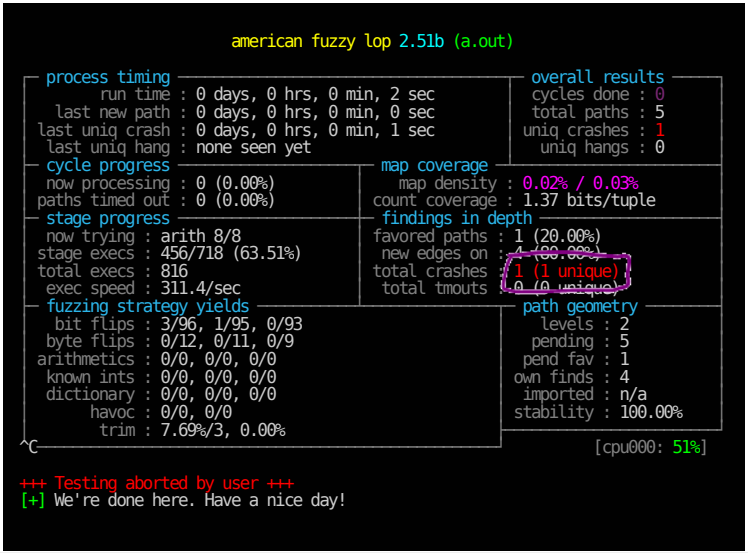
american fuzzy lop 2.51b (a.out)
process timing
run time : 0 days, 0 hrs, 0 min, 2 sec
last new path : 0 days, 0 hrs, 0 min, 0 sec
last uniq crash : 0 days, 0 hrs, 0 min, 1 sec
last uniq hang : none seen yet
overall results
cycles done : 0
total paths : 5
uniq crashes : 1
uniq hangs : 0
cycle progress
now processing : 0 (0.00%)
paths timed out : 0 (0.00%)
map coverage
map density : 0.02% / 0.03%
count coverage : 1.37 bits/tuple
stage progress
now trying : arith 8/8
stage execs : 456/718 (63.51%)
total execs : 816
exec speed : 311.4/sec
findings in depth
favored paths : 1 (20.00%)
new edges on : 4 (80.00%)
total crashes : 1 (1 unique)
total tmouts : 0 (0 unique)
fuzzing strategy yields
bit flips : 3/96, 1/95, 0/93
byte flips : 0/12, 0/11, 0/9
arithmetics : 0/0, 0/0, 0/0
known ints : 0/0, 0/0, 0/0
dictionary : 0/0, 0/0, 0/0
havoc : 0/0, 0/0
trim : 7.69%/3, 0.00%
path geometry
levels : 2
pending : 5
pend fav : 1
own finds : 4
imported : n/a
stability : 100.00%
^C
[cpu000: 51%]
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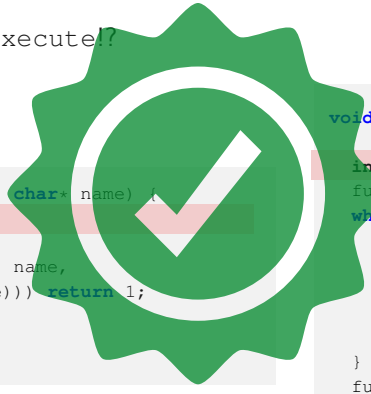
      break;
    }
  }
  func(cmd);
}
```

Again in `is_valid` and/or `execute`!?



```
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) {
    if(!strncmp(list[i].name, name,
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      func = list[i].func;
      break;
    }
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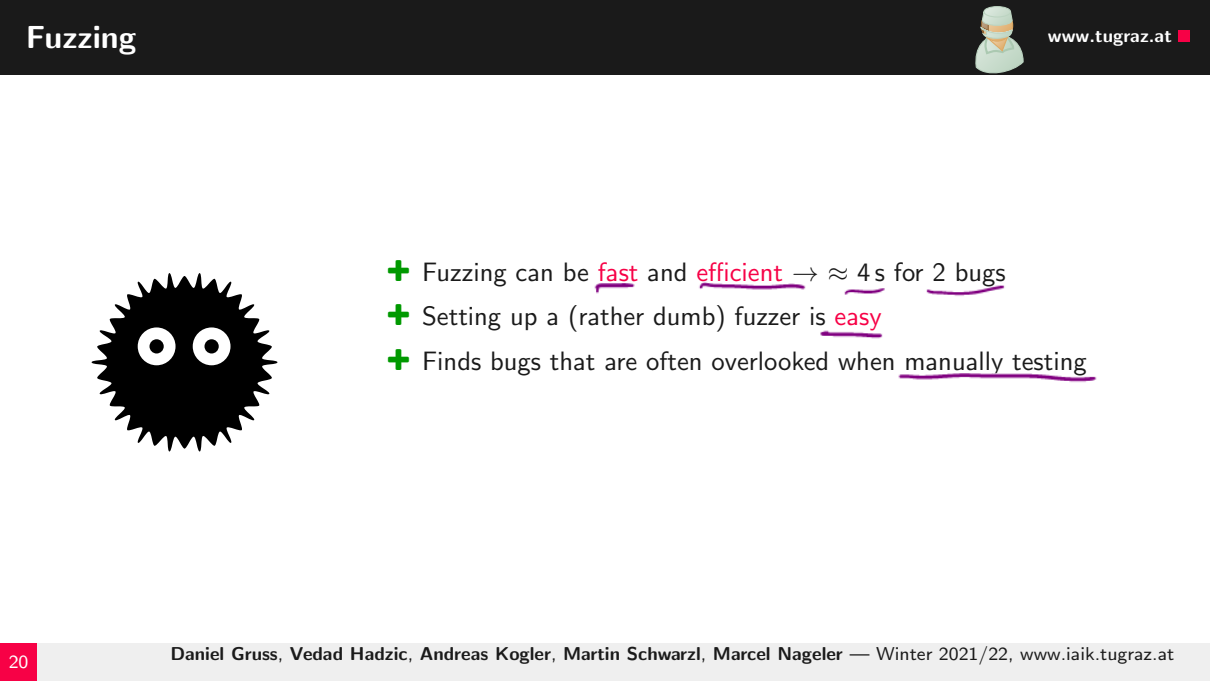
}
```

Practical Example Analysis: Fuzzing



- ✚ Fuzzing can be fast and efficient → ≈ 4 s for 2 bugs
- ✚ Setting up a (rather dumb) fuzzer is easy
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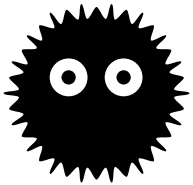
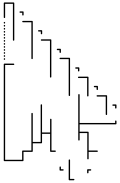
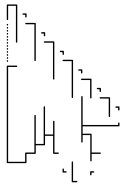


- ✚ Fuzzing can be fast and efficient → ≈ 4 s for 2 bugs
- ✚ Setting up a (rather dumb) fuzzer is easy
- ✚ Finds bugs that are often overlooked when manually testing
- ━ Understanding the input leading to a crash can be complicated
- ━ Never sure if all bugs were found

Practical Example Impact: Fuzzing

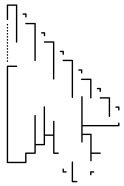
- In this case, only a NULL pointer





- In this case, only a NULL pointer
- No code execution, but attacker can crash the program

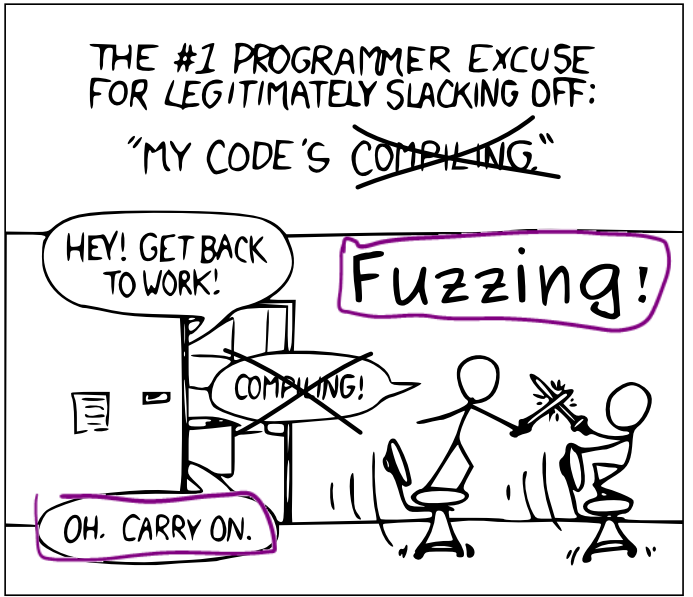
DoS

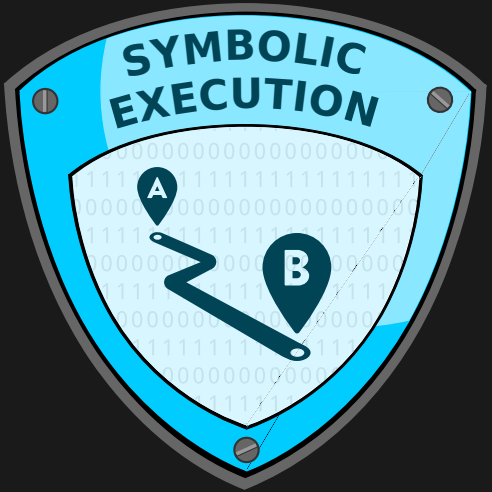


- In this case, only a NULL pointer
- No code execution, but attacker can crash the program
- Potentially dangerous if attacker can manipulate the uninitialized memory

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

- libFuzzer 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!
Fuzzing!
OH. CARRY ON.


SYMBOLIC
EXECUTION
A
B

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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

Illustration of how symbolic execution works

```
x = read();
y = x * 2;
z = y + 4
if (z == 12) {
  bug();
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Symbolic Execution - Limitations

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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)) {
    printf("Number validated!\n");
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```

input[13] = 0

Go here

Avoid this


```
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


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

Serial Number (Symbolic Execution)


```
% gcc -std=gnu99 -m32 -no-pie main.c -o main.elf
% python solve.py
Valid number: 430009016964
python solve.py  25.58s user 0.88s system 100% cpu 26.204 total
```


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

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$$\frac{700 \cdot 10^{12}}{2.2 \cdot 10^9} \approx 318181s \approx 88 \text{ hours}$$

Practical Example Impact: Serial Number (Symbolic Execution)

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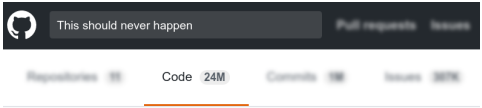

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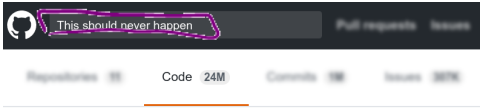


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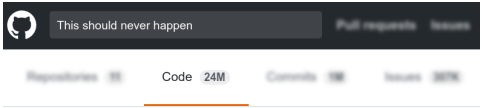


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- Find flawed authentication (can it be bypassed?)

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`

Open code with firefox

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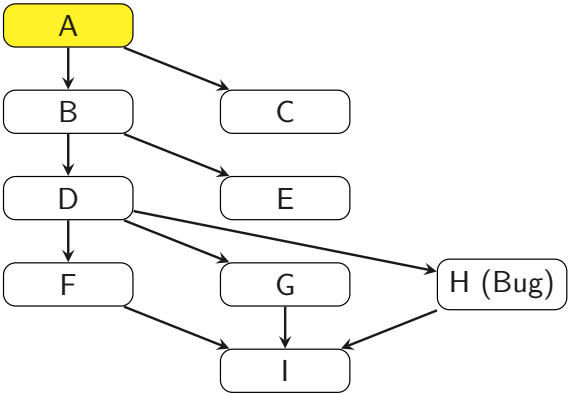
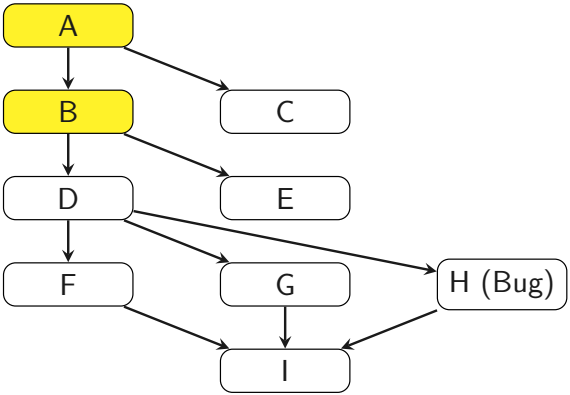
- Open-source implementation Driller: uses AFL + angr



Start fuzzing



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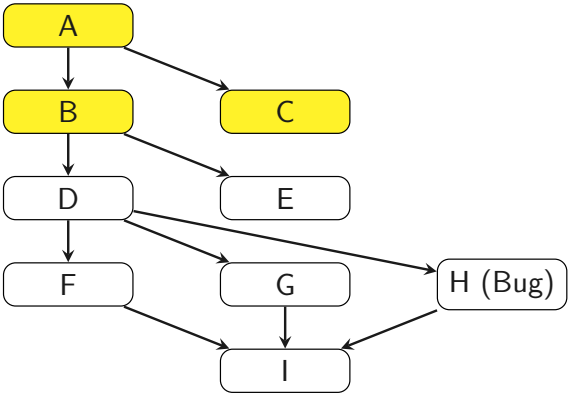

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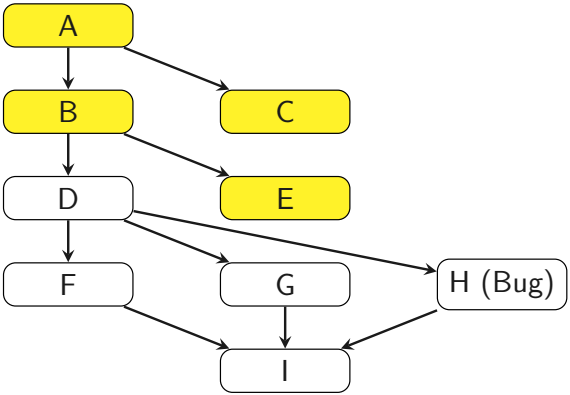

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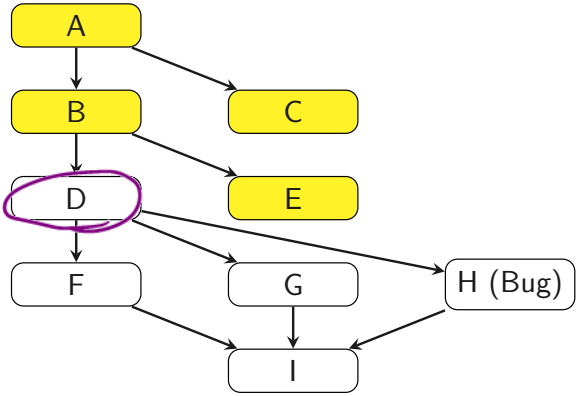
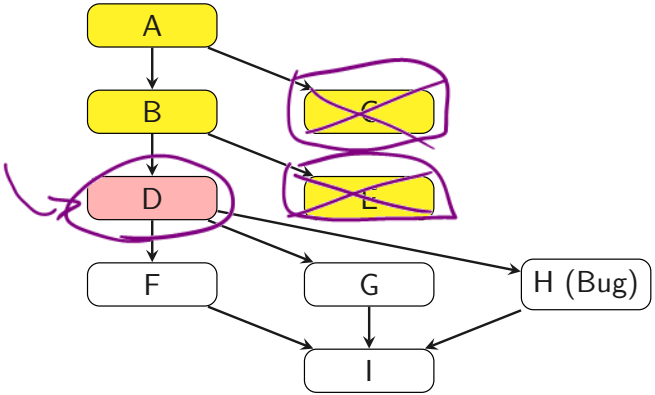


Fuzzing stuck → symbolic execution



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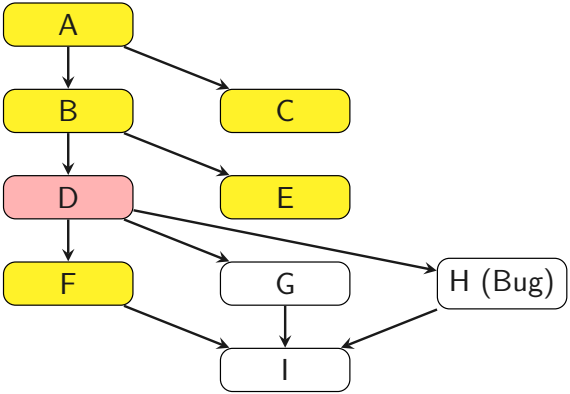
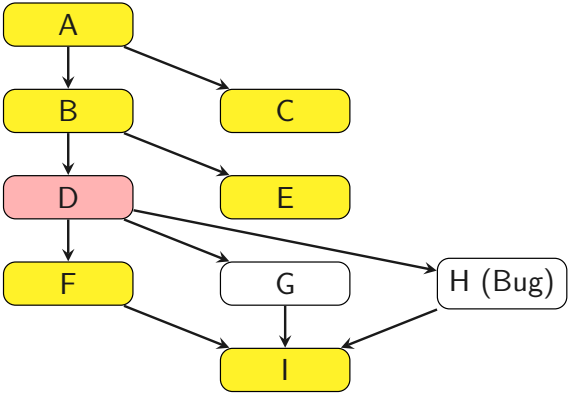


Start fuzzing (again)



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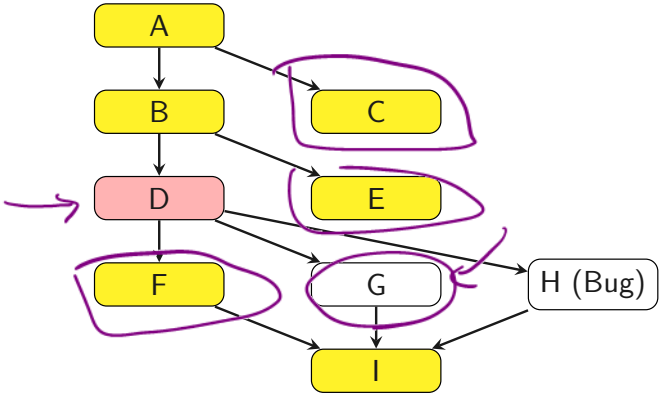

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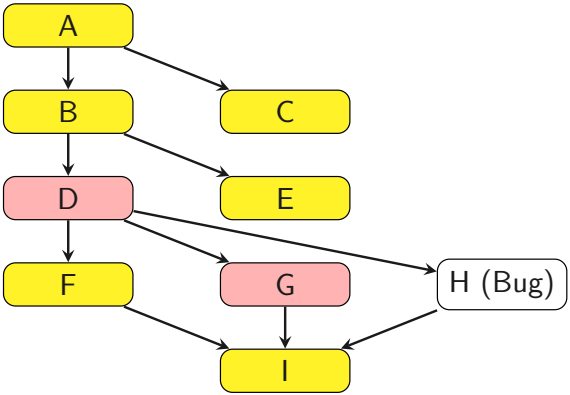

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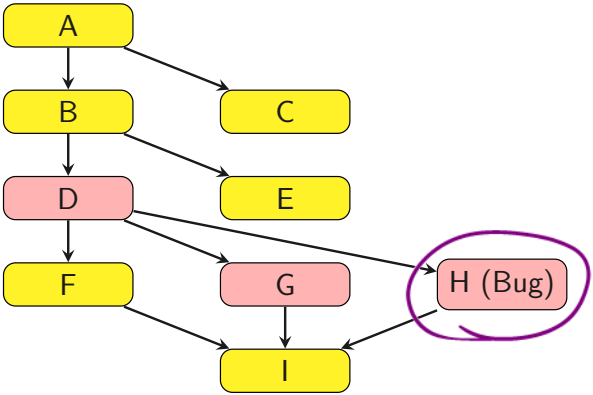

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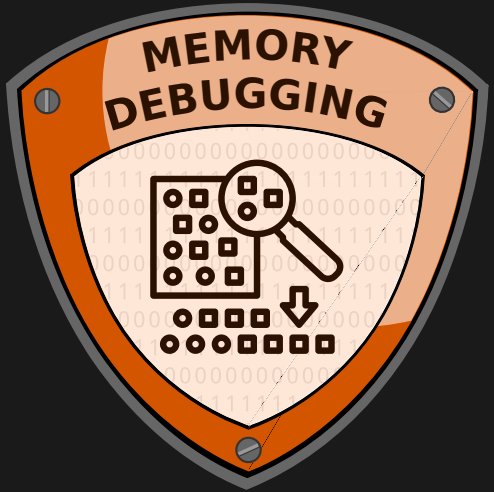
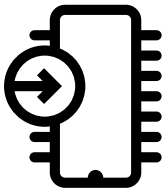

MEMORY
DEBUGGING



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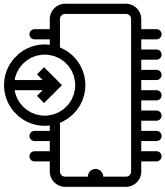
- Monitor memory accesses, allocations and deallocations



- 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

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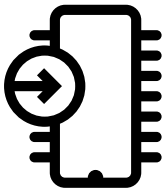
- Memory leaks



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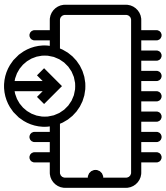

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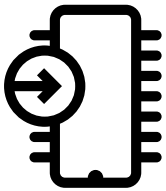

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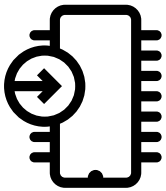

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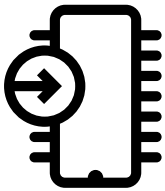

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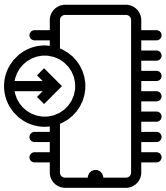
- ✚ Can find nearly all memory errors
- ✚ Can provide detailed information, as faulty code is known



- Used in e.g., clang's address sanitizer, added directly by the compiler
- \+ Can find nearly all memory errors
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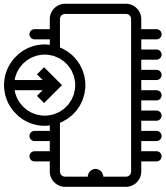
- − Requires recompilation, *i.e.*, access to the source code
- − Non-negligible memory and runtime overhead



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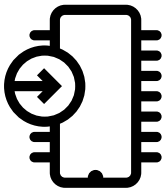

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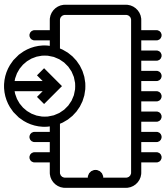

- Used in e.g., Electric Fence, can be added at runtime through `LD_PRELOAD`
- \+ No change to program required
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- − Types of detectable errors are limited
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- How can dynamic-linking-based techniques detect such errors?

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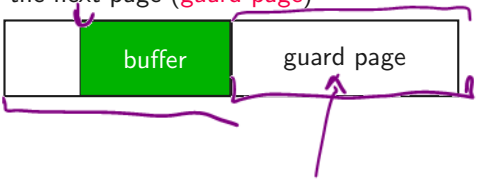

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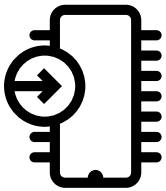
- Out-of-bounds read/write crashes the program (segfault)



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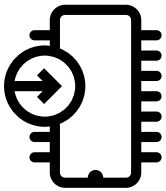

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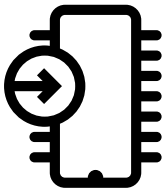

- Used by e.g., Valgrind's memcheck
- \+ Does not require source code
- \+ Can find many types of errors
- − Slow
- − Highly architecture dependent

- Dynamic Binary Instrumentation frameworks...

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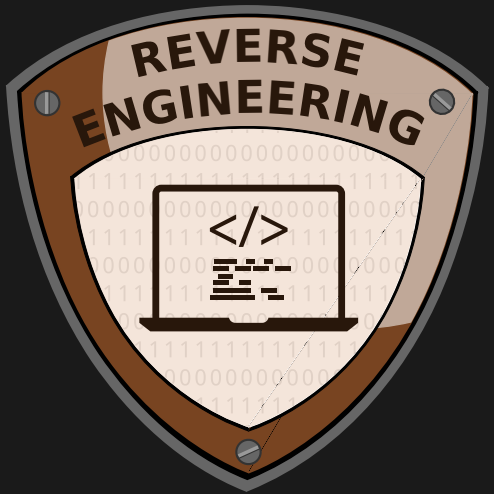
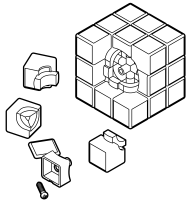

REVERSE
ENGINEERING
</>



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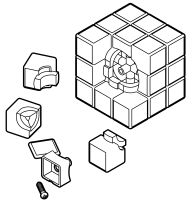

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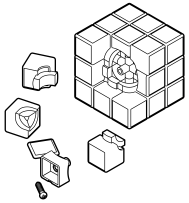

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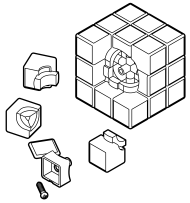

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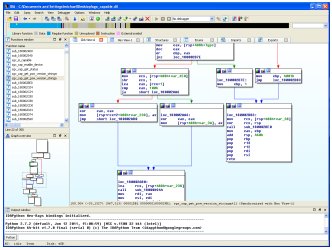
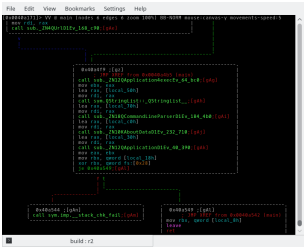
- Re-engineering allows to build a new binary from the reverse engineered binary

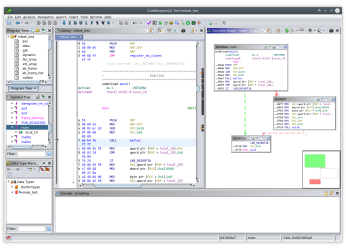
IDA Pro ($\geq$ 1200 €)

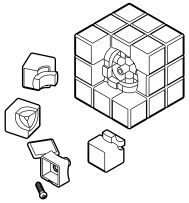


radare2 (open source)



Ghidra (open source)





- Disassembler allows to
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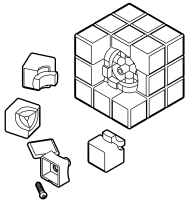

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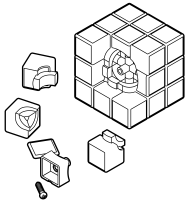

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- Decompilers further convert code to high-level language (C or pseudo code)
- Good decompilers cost a lot of money ☹ (IDA Pro - HexRays)

Practical Example: Disassembly vs. Decompilation


```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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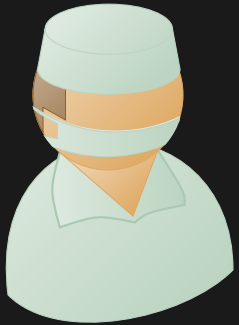
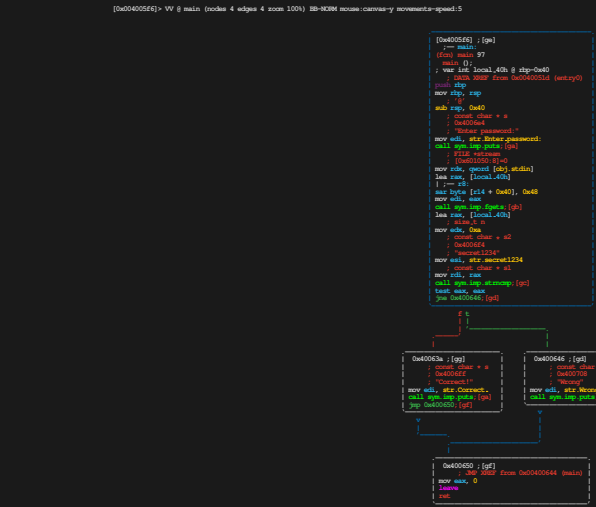
```
% gcc re.c -o re
```



Practical Example Analysis: Disassembly vs. Decompilation


```
% 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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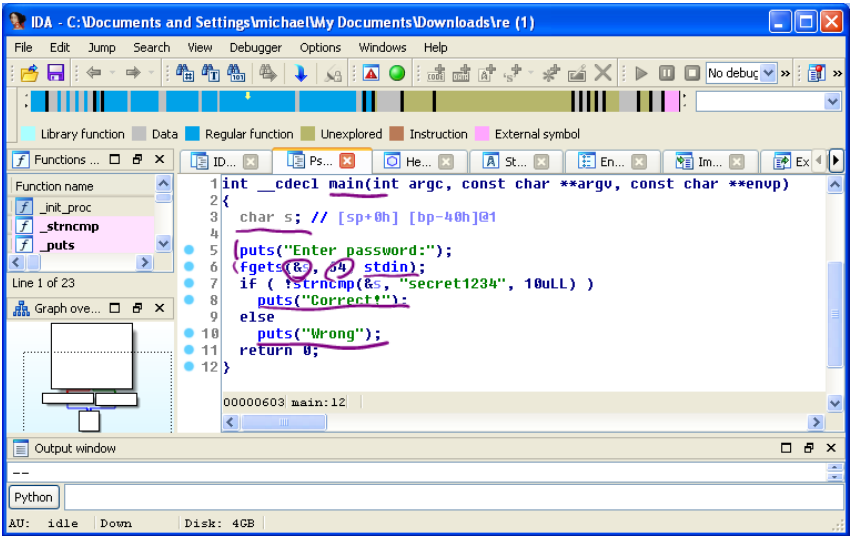

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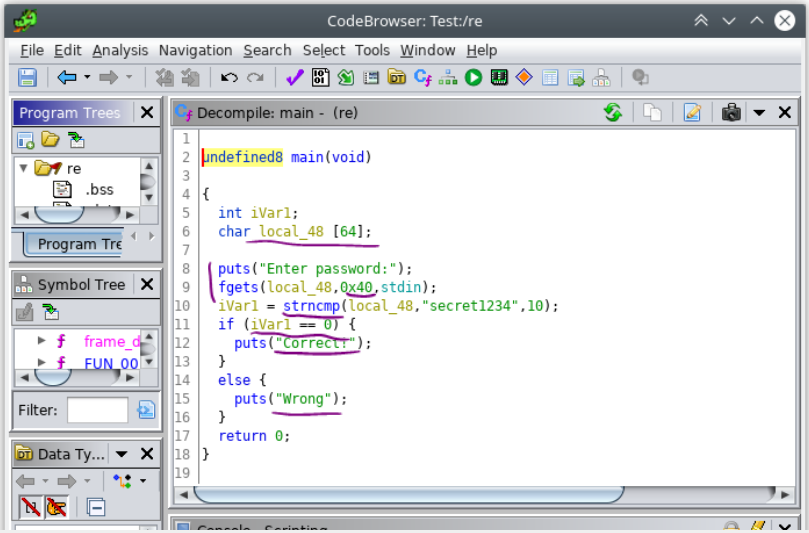
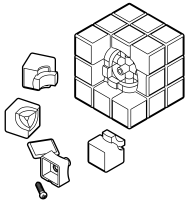
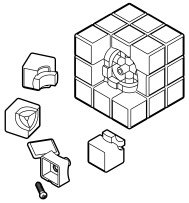


Practical Example Impact: Disassembly vs. Decompilation

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





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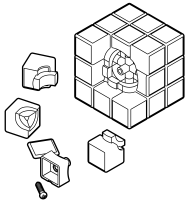

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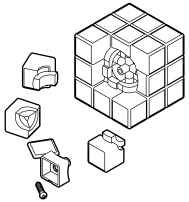

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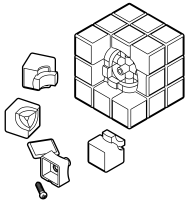

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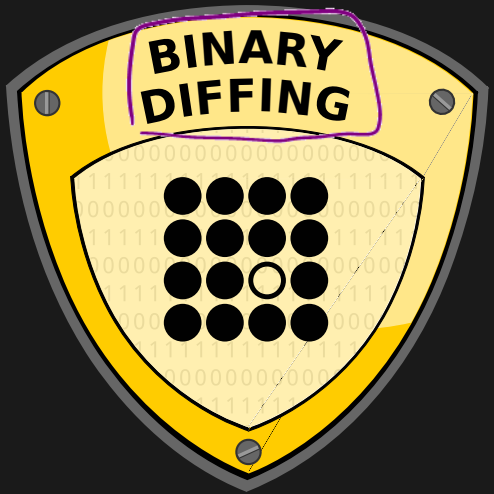
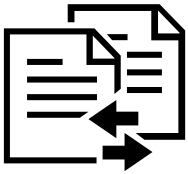
- If it works, it gives a quick overview for further investigations


BINARY
DIFFING



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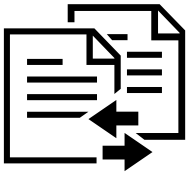

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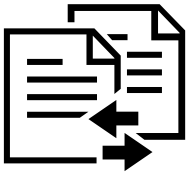

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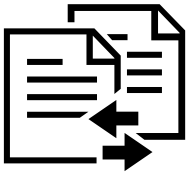

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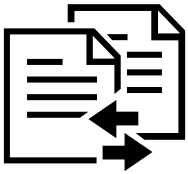

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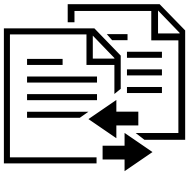
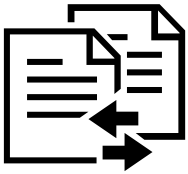
- Can also be used to find vulnerable functions by comparing binary with known vulnerable functions

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





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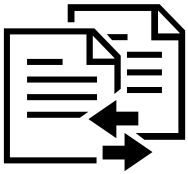

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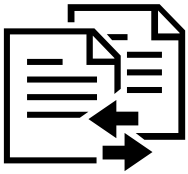

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- Most diff tools rely on the control-flow graph from a disassembler
- The basic blocks are then matched using some heuristic

Practical Example: 1-day (Binary Diffing)

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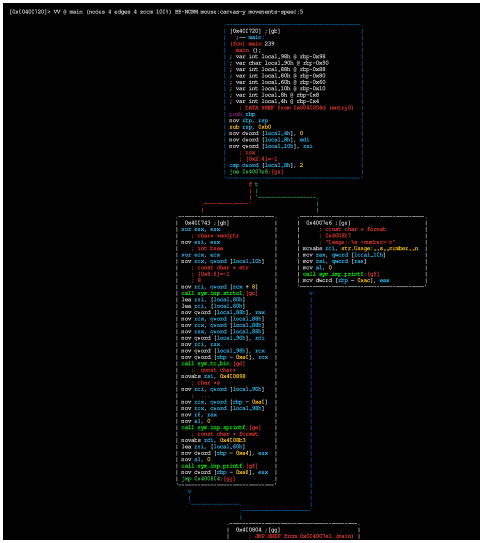

- Given a binary with an unknown bug

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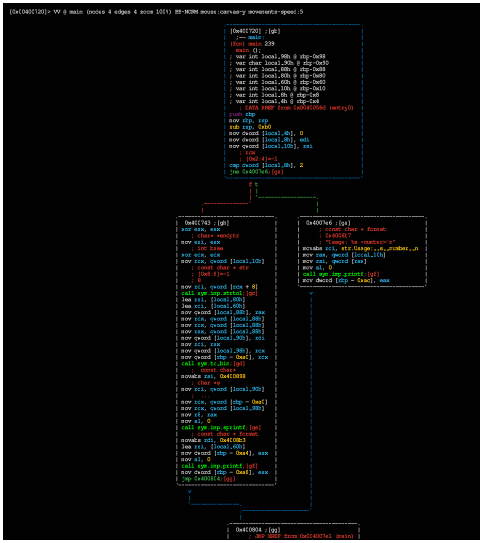

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- The vendor released a patch, fixing the vulnerability

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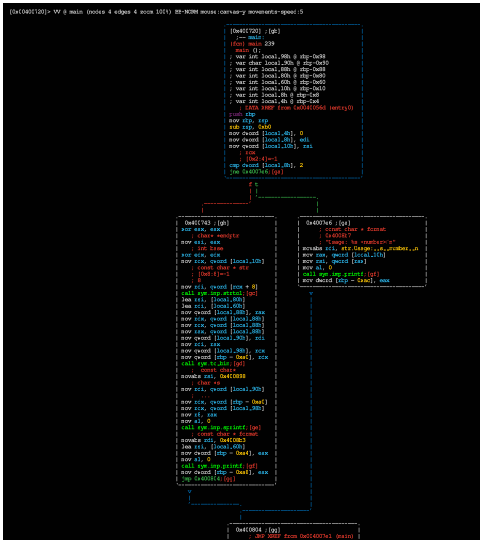

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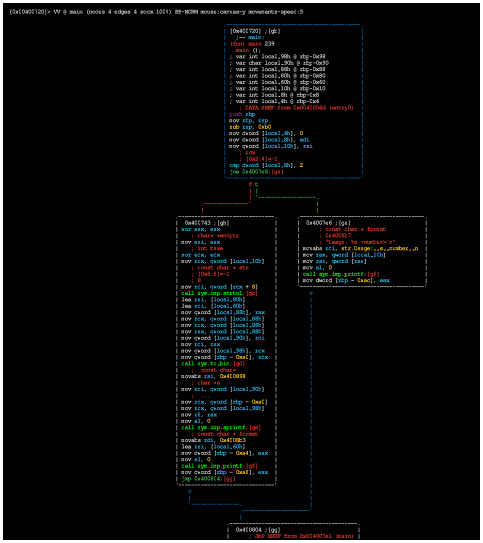

- Given a binary with an unknown bug
- The vendor released a patch, fixing the vulnerability
- Fixed bug has no documentation...
- ...but we have both the patched (`patched`) and original (`vuln`) binary


```
% ./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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```

```
              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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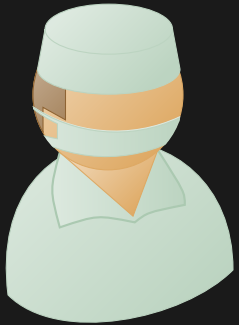

Practical Example Analysis: 1-day (Binary Diffing)

1-day (Binary Diffing)


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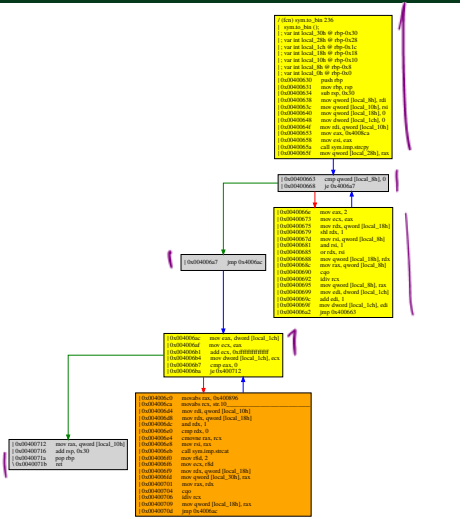
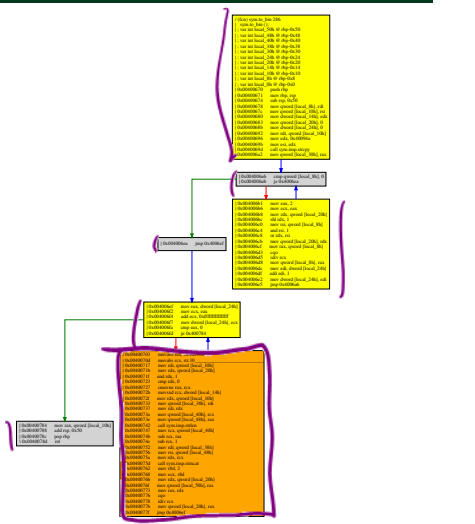


```
% radiff2 -g sym.to_bin patched vuln | xdot -
```




```
| 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
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Good: `strncat`

Patched (`patched`)


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

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


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Dec: 9999999999
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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)

- Binary diffing is a way to reverse engineer patches

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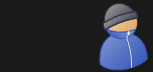
- If there are not many changes, vulnerability can be quickly spotted



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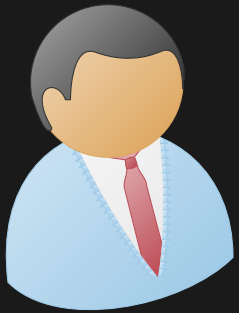
- As long as patches are not applied, such 1-days are effective
- Also a starting point for same/similar bugs in the program



Real-world Example: Apple's Password Hint Bug

Apple's Password Hint Bug

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

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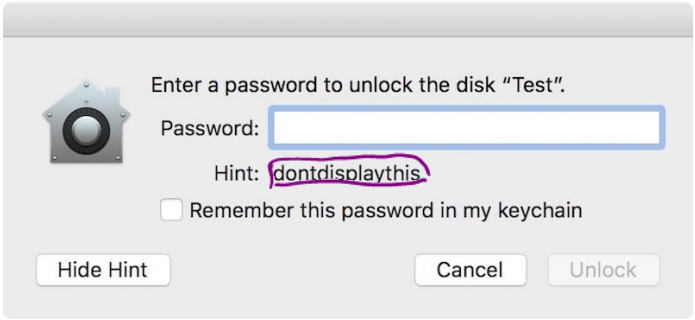
- ...the password was shown instead



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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```

...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"));
U:---  NewStorageKit.txt   All (5,0)       [i] (ObjC/l FlyC- Projectile[-] SP/s)
```

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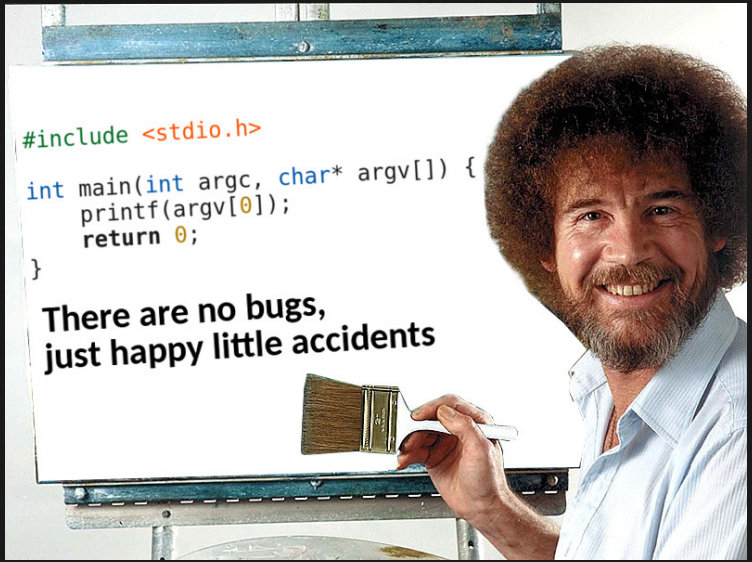
- It does not cost a lot to compile with sanitizers, run static code analysis, fuzz your software, ...
- ...but it eliminates many bugs (for free)

Questions?


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


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.


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.