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

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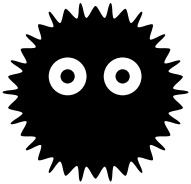
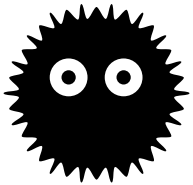
- Explaining *source code* helps in finding bugs
- Adding print statements to *source code* can assist in finding bugs
- Stepping through *source code* with a debugger often reveals bugs


FUZZER



- Fuzzing is an automated software testing method

Fuzzing



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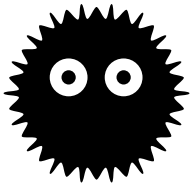
- Provide invalid, unexpected, or random data as input



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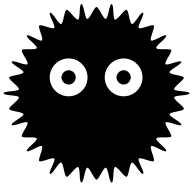
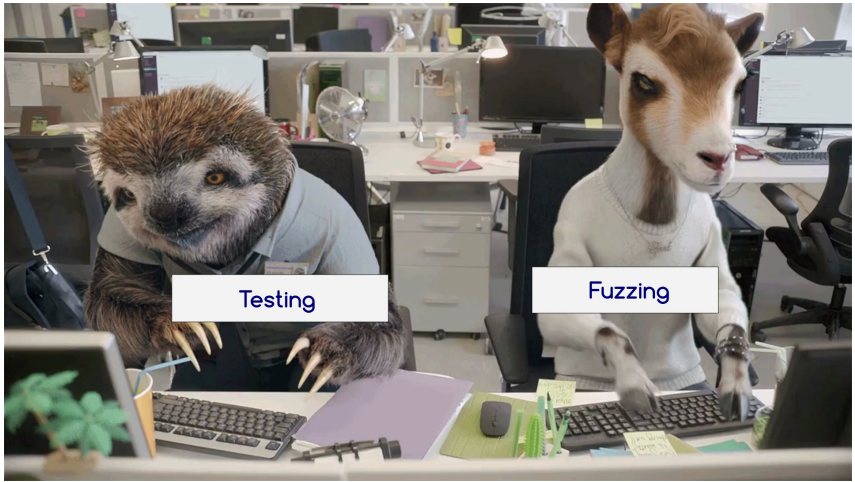


- Fuzzing is an automated software testing method
- Provide invalid, unexpected, or random data as input
- Monitor program behavior (e.g., crash, assertion, ...)
- Typically used for file formats or protocols


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

Fuzzing vs. Testing

Fuzzing

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

Testing

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

Fuzzing vs. Testing

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

Testing

- Normal, valid, well-formed data as input
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- Boring ☹

Fuzzing vs. Testing

Fuzzing

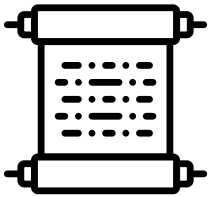
- Invalid, unexpected, or random data as input
- Automatically generated testcases
- Fun ☺
- Goal: Find exploitable errors

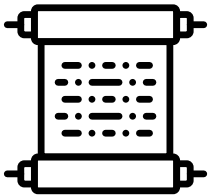
Testing

- 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





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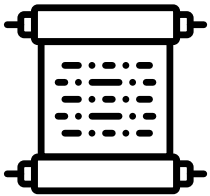

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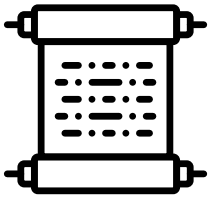

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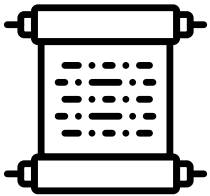

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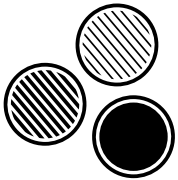
- american fuzzy lop (AFL) regularly finds bugs in open source programs

Types of Fuzzing



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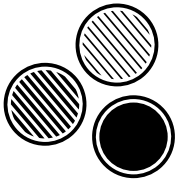

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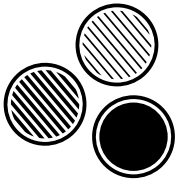

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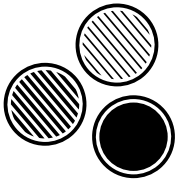
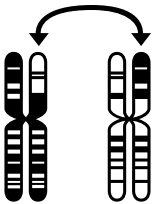


- Different types of fuzzing
- Fuzzing can be somewhere between dumb and smart
- The smarter the fuzzing, the harder the setup
- However, smarter fuzzing finds more bugs

Mutation Based ("Dumb Fuzzing")



- Mutate existing data sets to generate new testcases

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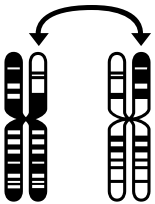

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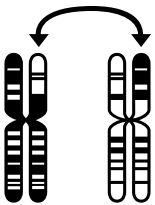

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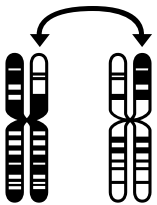

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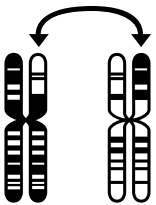

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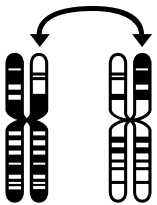

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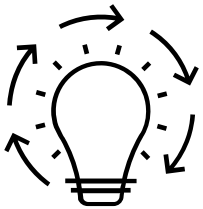

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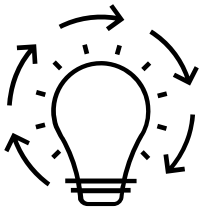

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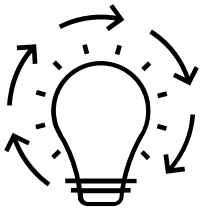

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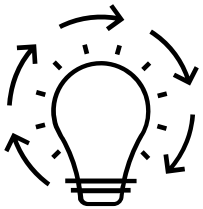

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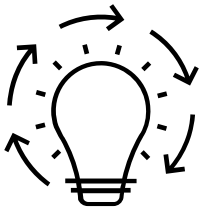

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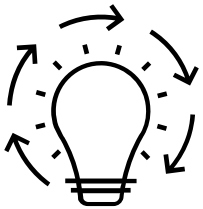

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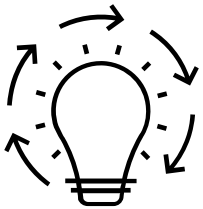

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\- Writing testcase generator is a lot of work

- Generate inputs/mutations based on program response

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Evolutionary Fuzzing

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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


```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>
afl-as 2.51b by <lcamtuf@google.com>
[+] Instrumented 14 locations (64-bit, ASAN/MSAN mode, ratio 33%).
```


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% cat afl-in/small
echo hi
ping
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% cat afl-in/small
echo hi
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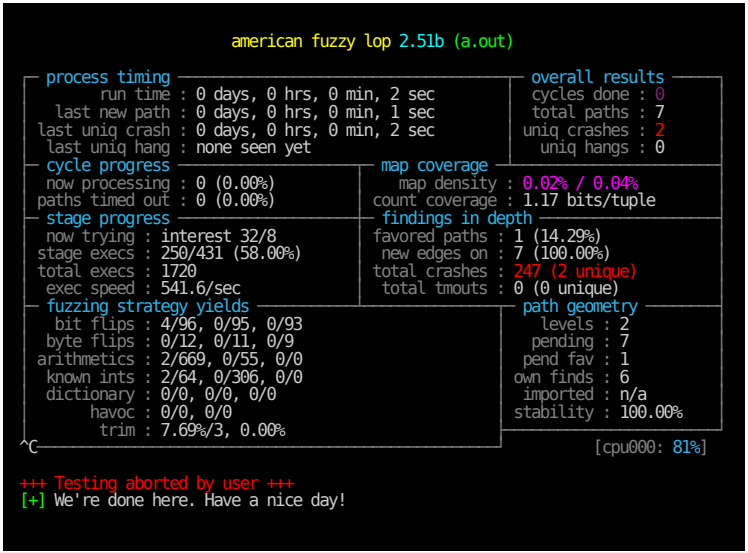
```

```
% afl-fuzz -m none -i afl-in -o afl-out -- ./a.out @@
afl-fuzz 2.51b by <lcamtuf@google.com>
[+] 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!


```
% cat afl-out/crashes/id*
pingJecho Hi
```


```
% cat afl-out/crashes/id*
pingJecho Hi
```

```
% 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
```

The bug must be somewhere in `is_valid` and/or `execute`...

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```

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The bug must be somewhere in `is_valid` and/or `execute`...

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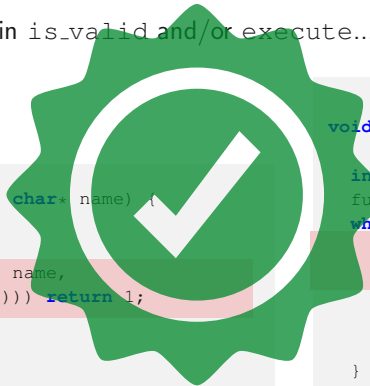

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```
% AFL_USE_ASAN=1 afl-gcc fuzz.c
afl-cc 2.51b by <lcamtuf@google.com>
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[+] Instrumented 18 locations (64-bit, ASAN/MSAN mode, ratio 33%).
```


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```
% cat afl-in/small
echo hi
ping
```


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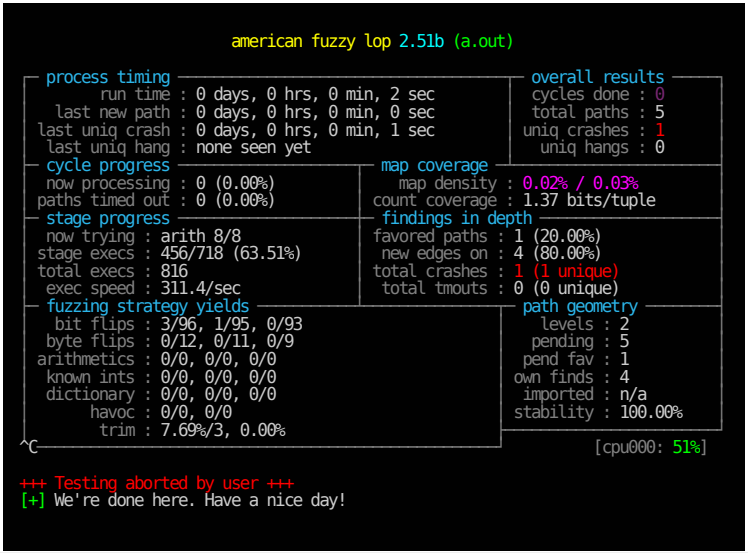
```

```
% afl-fuzz -m none -i afl-in -o afl-out -- ./a.out @@
afl-fuzz 2.51b by <lcamtuf@google.com>
[+] 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, 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%]
+++ Testing aborted by user +++
[+] We're done here. Have a nice day!


```
% cat afl-out/crashes/id*
echo Hi
pong
```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% cat afl-out/crashes/id*
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pong
```

```
% 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  0x00000000004008d0 in execute (list=0x7fffffffdad0,
      name=0x7fffffffdb10 "pong", cmd=0x0) at fuzz.c:30
#2  0x0000000000400a3b in main (argc=2, argv=0x7fffffffdc48) at fuzz.c:60
```

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

```
int is_valid(functions* list, char* name) {
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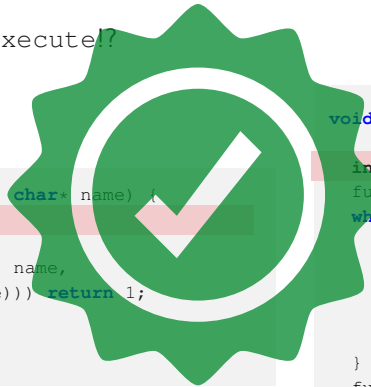

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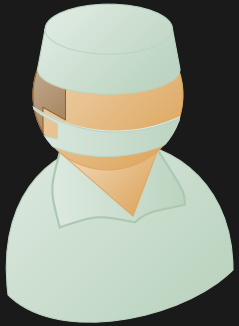
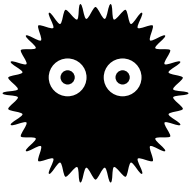
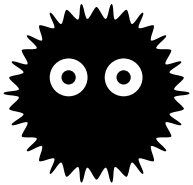


Practical Example Analysis: Fuzzing



✚ Fuzzing can be fast and efficient $\rightarrow \approx 4\,\text{s}$ for 2 bugs



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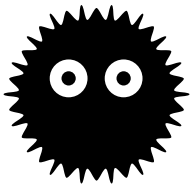
- ✚ Setting up a (rather dumb) fuzzer is easy



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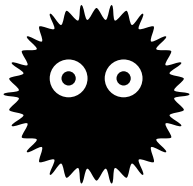

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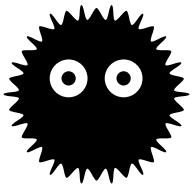

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- ✚ Setting up a (rather dumb) fuzzer is easy
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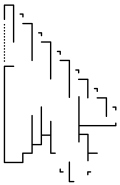
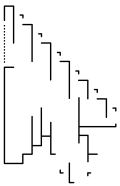
- ━ Understanding the input leading to a crash can be complicated
- ━ Never sure if all bugs were found

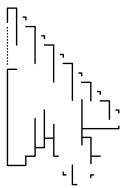
Practical Example Impact: Fuzzing

- In this case, only a NULL pointer





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



- 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);
```

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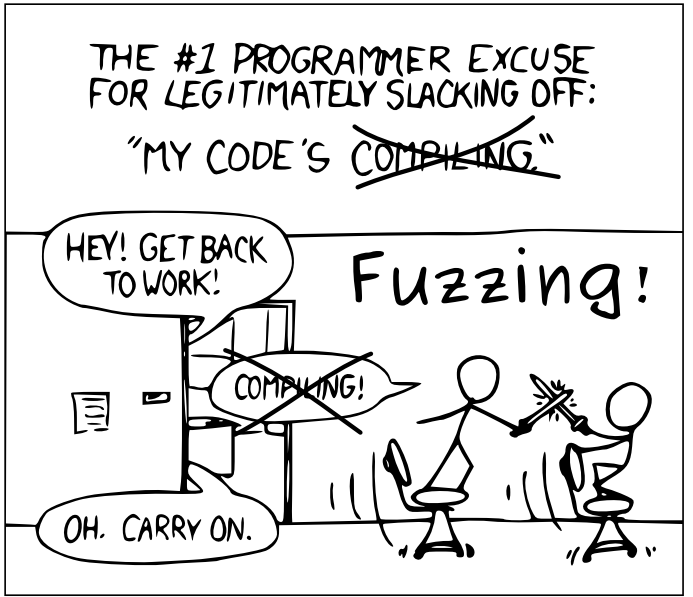
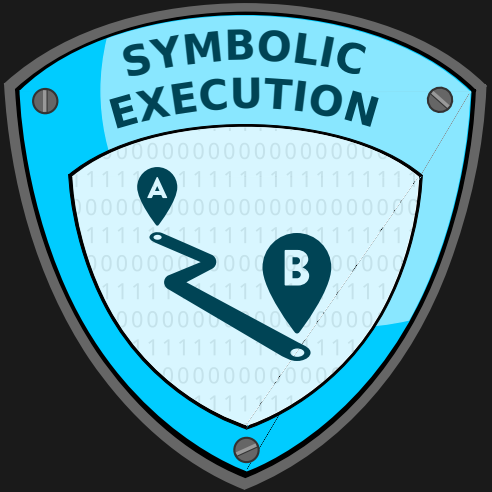
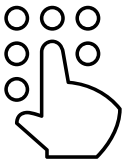

THE #1 PROGRAMMER EXCUSE FOR LEGITIMATELY SLACKING OFF:
"MY CODE'S COMPILING."
HEY! GET BACK TO WORK!
COMPILING!
OH. CARRY ON.
Fuzzing!


SYMBOLIC
EXECUTION
A
B

- Symbolic execution finds the required input to reach a certain position



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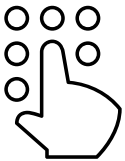

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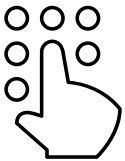

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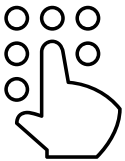

- Symbolic execution finds the required input to reach a certain position
- Programs are interpreted, input is modelled using symbolic values
- Variables can be expressed using the symbolic values
- Conditional jumps are constraint by the symbolic values
- Expressions consisting of symbolic values are 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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SAT solver:

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Symbolic Execution

SAT solver:

$12 = 2 \cdot \lambda + 4 \Rightarrow \lambda = 4$

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Symbolic Execution - Limitations

- Symbolic execution does not scale - possible paths grow exponentially
- Unbounded loops (*i.e.*, iterations depend on user input) have to be approximated
- Environment interaction is hard to model (e.g., syscalls, file system, ...)
- 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");
  } else {
    printf("Invalid number\n");
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Go here

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  return 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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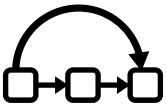

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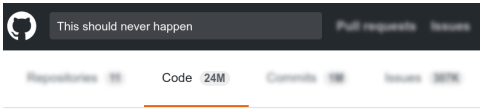

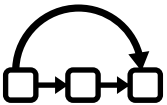

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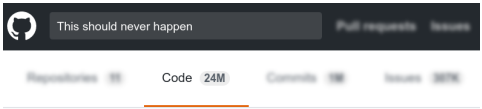


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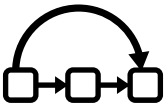

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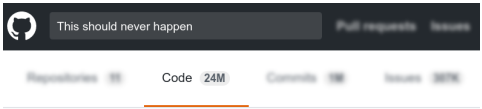


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- Find flawed authentication (can it be bypassed?)

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 some disassembler `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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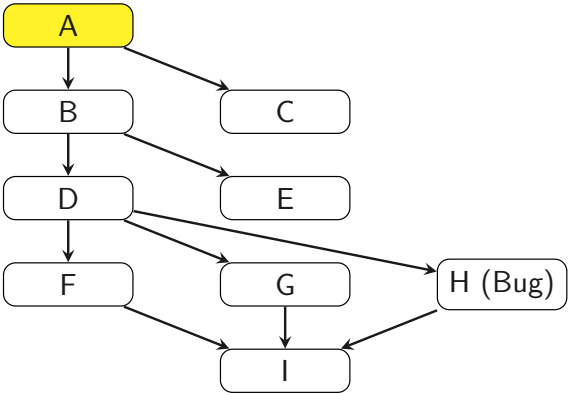
- Open-source implementation Driller: uses AFL + angr



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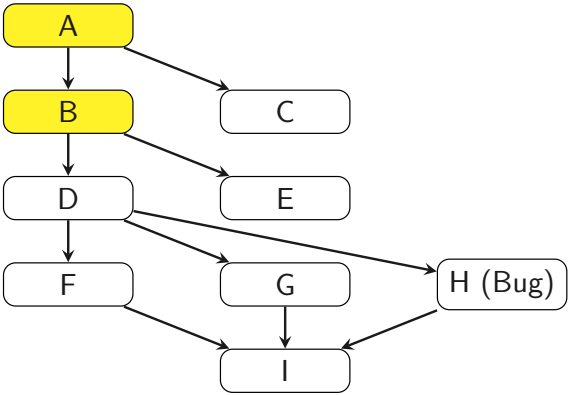

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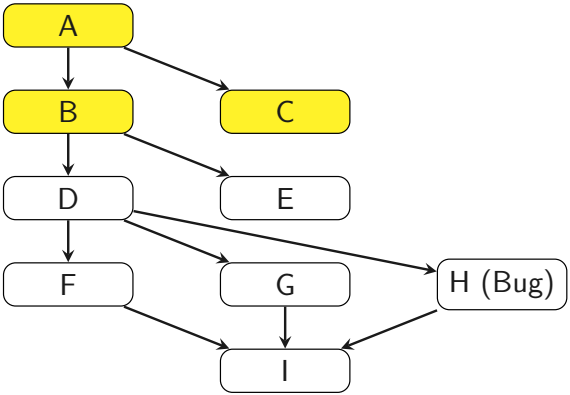

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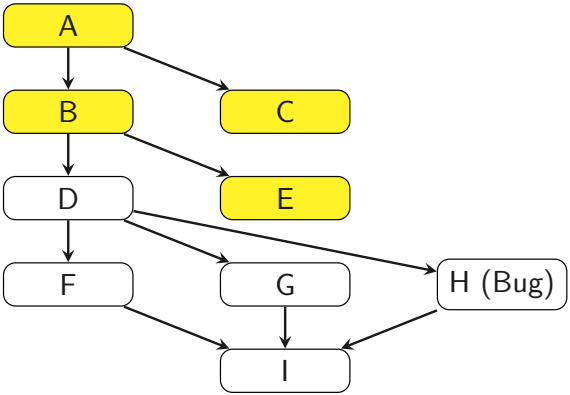

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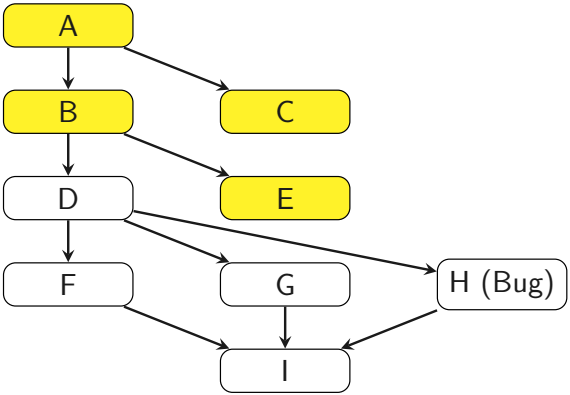

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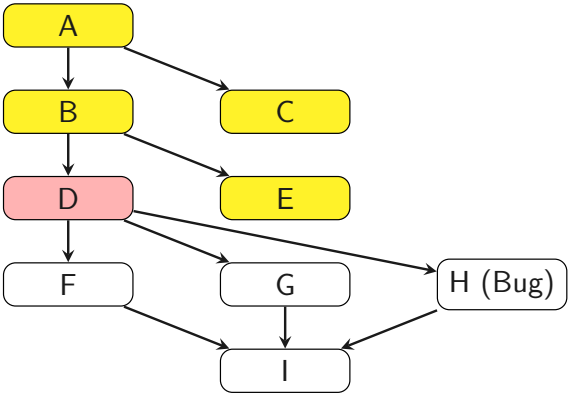

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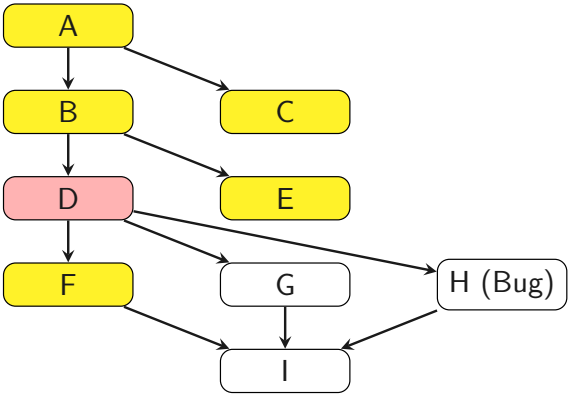

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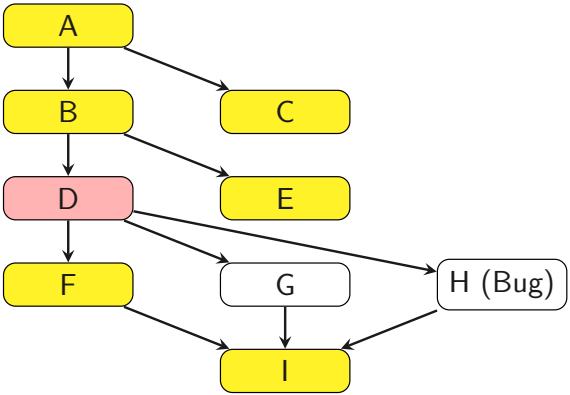

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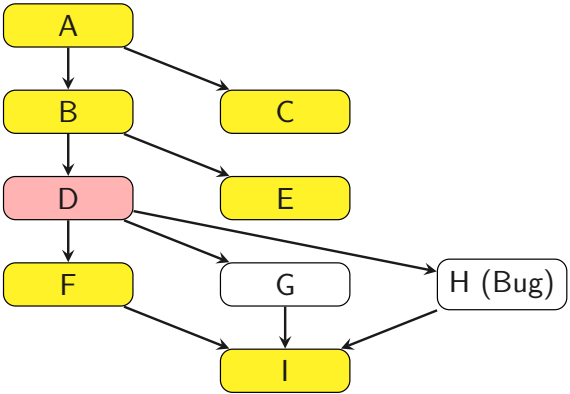

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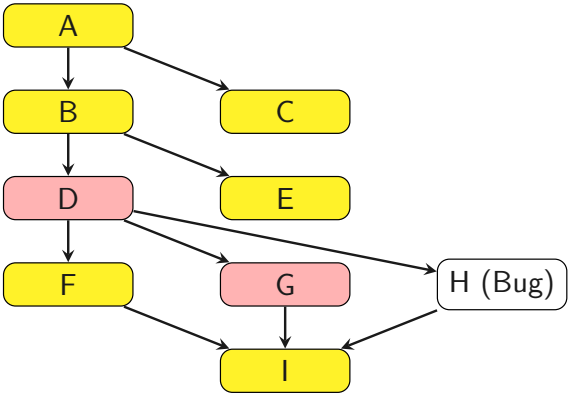

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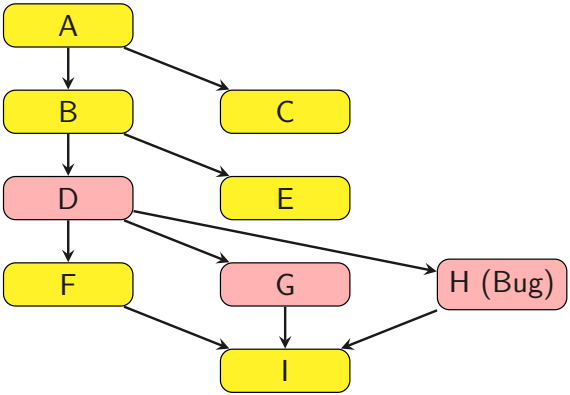

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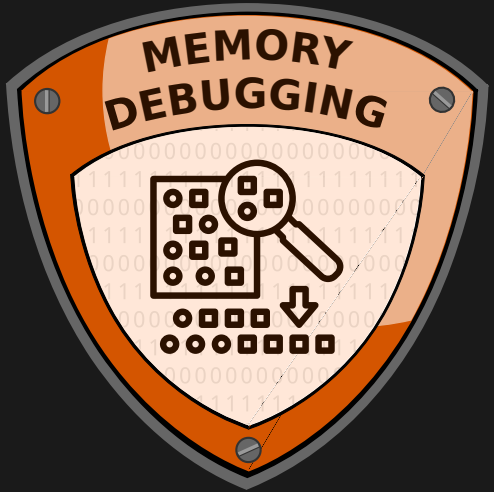
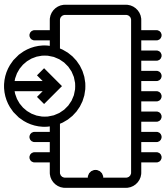

MEMORY
DEBUGGING



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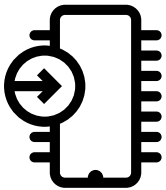

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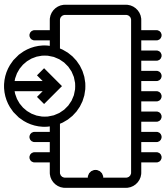

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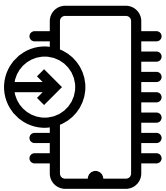

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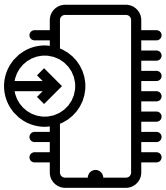

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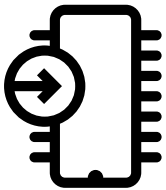

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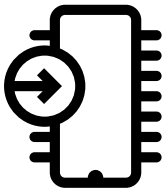

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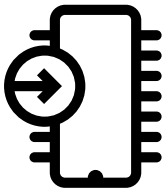

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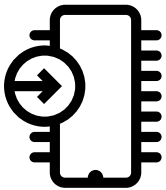

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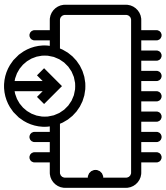

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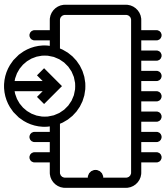

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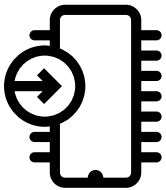

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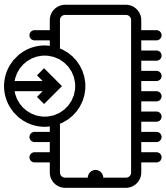

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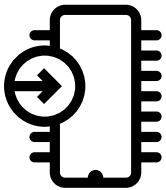

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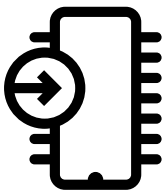

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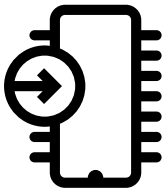

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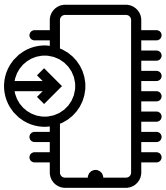

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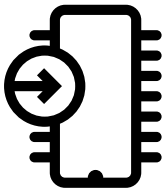

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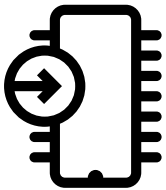

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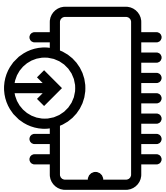

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- Memory reads/writes are not functions
- How can dynamic-linking-based techniques detect such errors?

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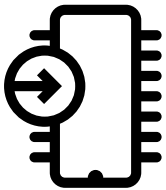
- Out-of-bounds read/write crashes the program (segfault)



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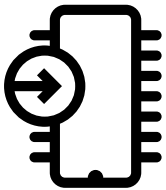

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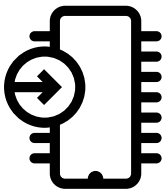

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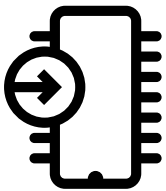
- \+ Can find many types of errors



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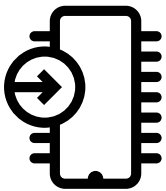

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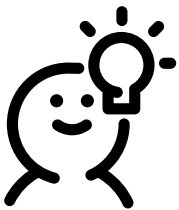

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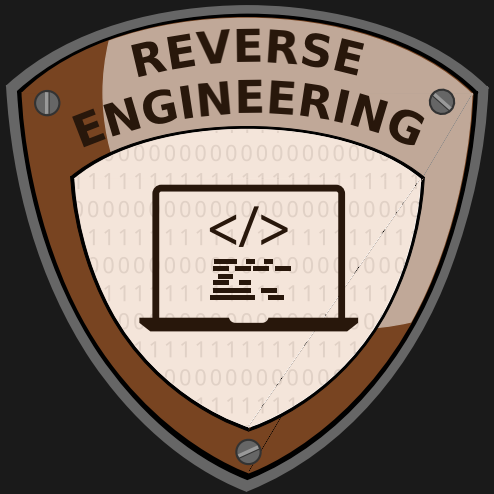
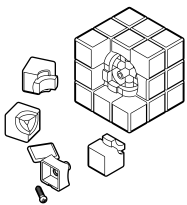
- Syscalls are wrapped to track operating system accesses to memory
- Valgrind framework supports plugins to write arbitrary instrumentation tools


REVERSE
ENGINEERING
</>



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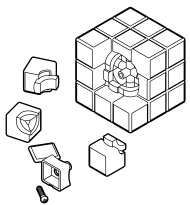

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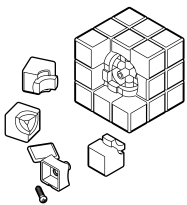

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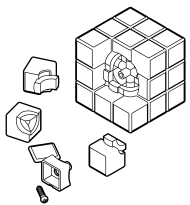
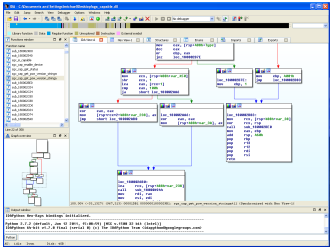
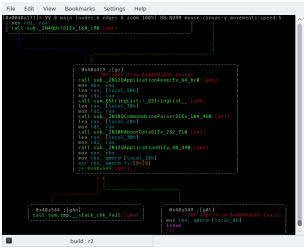


- Reverse Engineering is the process of getting back source code from a binary
- Identify bugs (or hidden features) if only the binary is available
- Allows to find compiler-introduced bugs
- Re-engineering allows to build a new binary from the reverse engineered binary

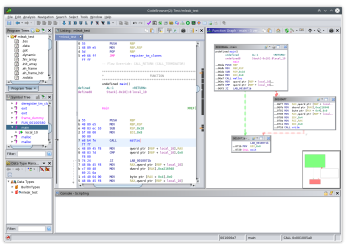
IDA Pro ($\geq$ 1200 €)

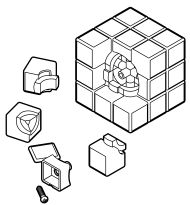


radare2 (open source)



Ghidra (open source)





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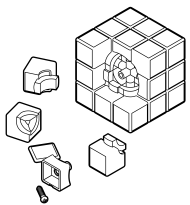

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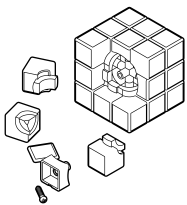

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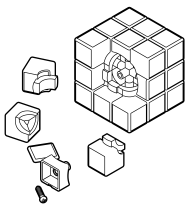

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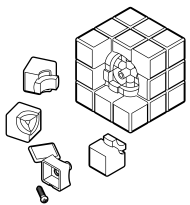

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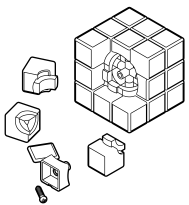

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  - debug programs (see actual register values, step through code)
- Decompilers further convert code to high-level language (C or pseudo code)
- Good decompilers cost a lot of money ☹ (IDA Pro - HexRays)

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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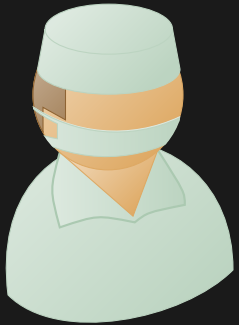
```

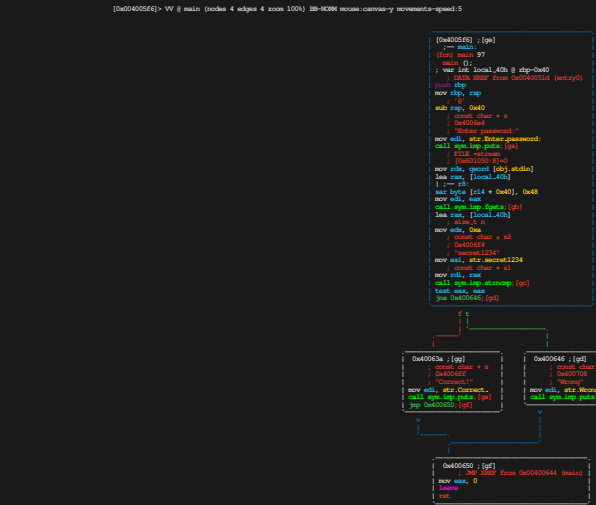
```
% gcc re.c -o re
```



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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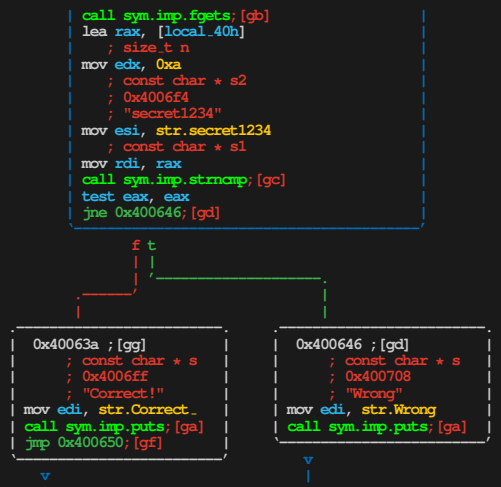

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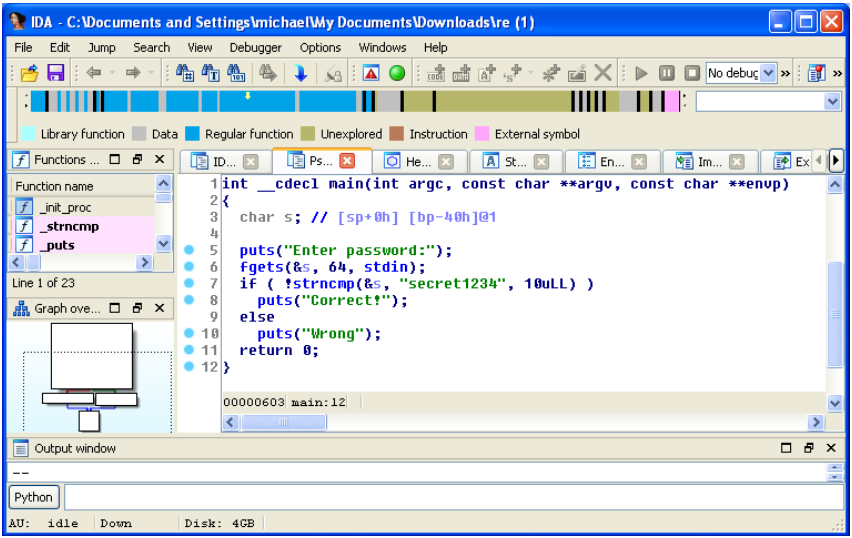

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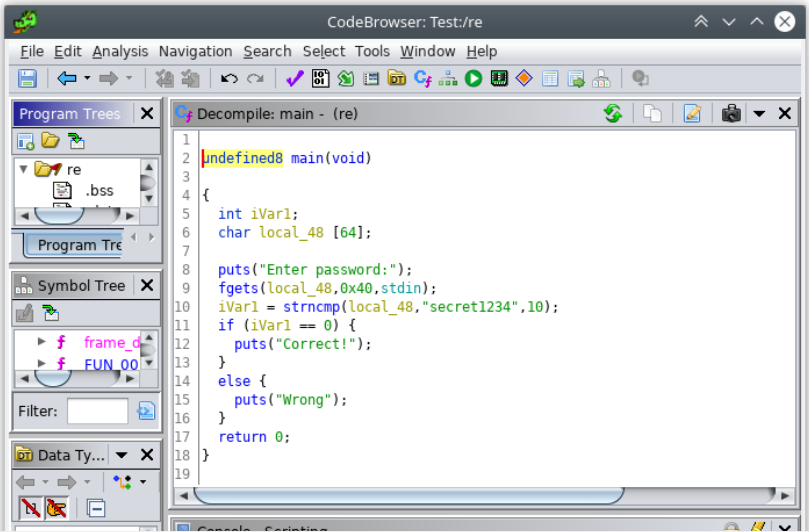
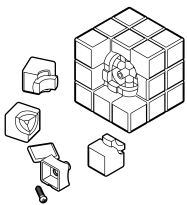
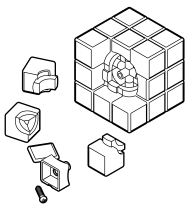


Practical Example Impact: Disassembly vs. Decompilation

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





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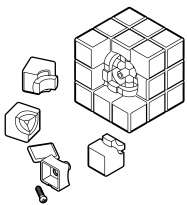

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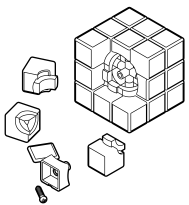

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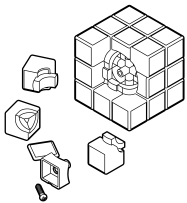

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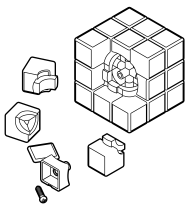

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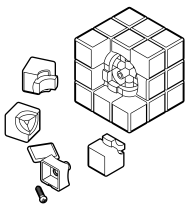

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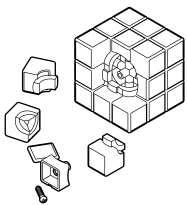

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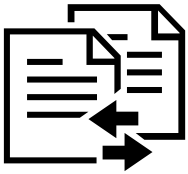
- If it works, it gives a quick overview for further investigations


BINARY
DIFFING



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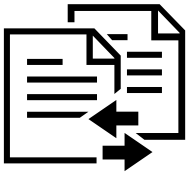

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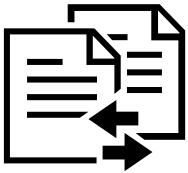

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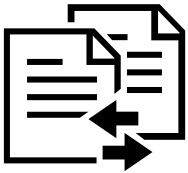

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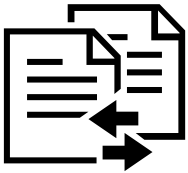

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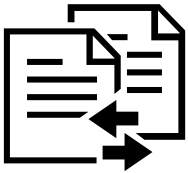
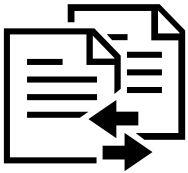
- Can also be used to find vulnerable functions by comparing binary with known vulnerable functions

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





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  - Same function name
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  - Equal number of calls to and from function
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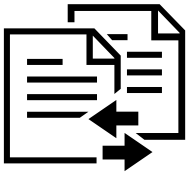
  - ...



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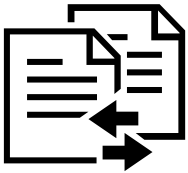

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  - ...
- Most diff tools rely on the control-flow graph from a disassembler
- The basic blocks are then matched using some heuristic

Practical Example: 1-day (Binary Diffing)

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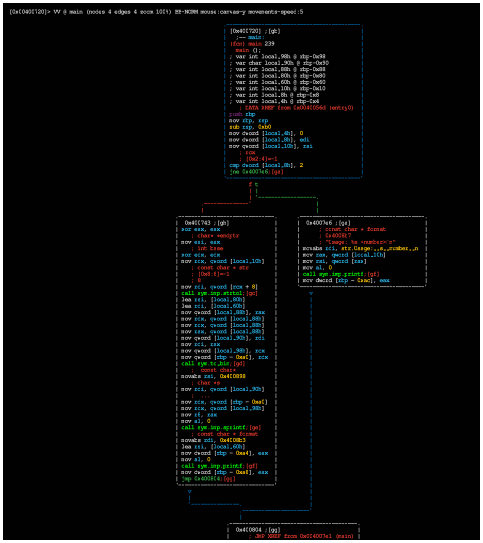
- Given a binary with an unknown bug

1-day (Binary Diffing)



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- Fixed bug has no documentation...

1-day (Binary Diffing)

- 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
```


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


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

```
                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)
```


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

```
                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
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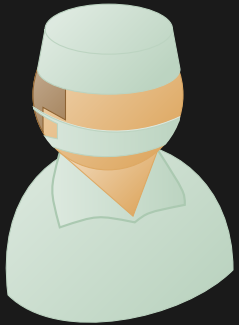
          sym.imp.strncat  48 0x400540 |     NEW  (0.000000)
```



Practical Example Analysis: 1-day (Binary Diffing)


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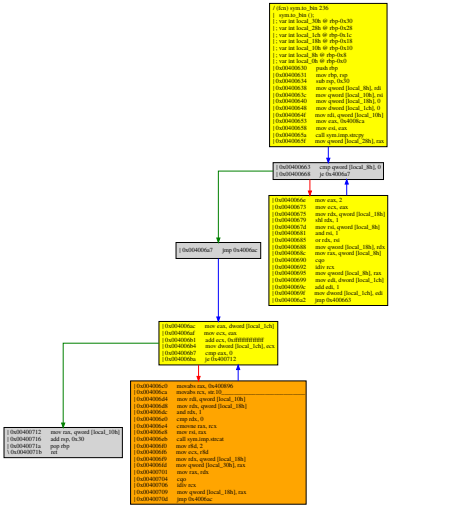
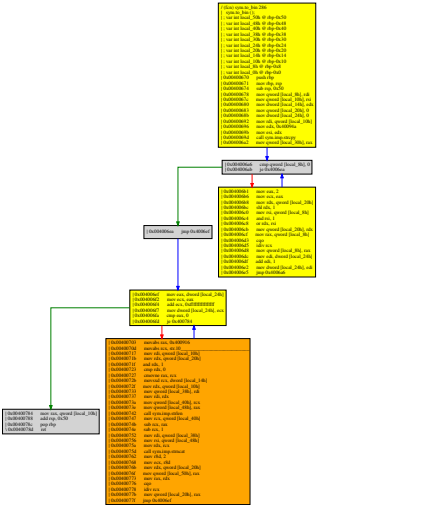


```
% radiff2 -g sym.to_bin patched vuln | xdot -
```




```
| 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
| 0x0040077b    mov qword [local_20h], rax
| 0x0040077f    jmp 0x4006ef
```

Patched (`patched`)

```
| 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
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```

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```

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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
```


```
% ./vuln 9999999999
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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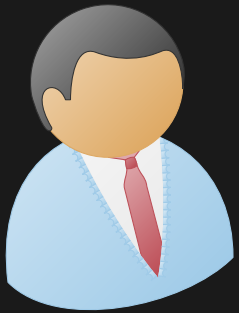
- If there are not many changes, vulnerability can be quickly spotted
- Knowledge of the vulnerability allows attackers to craft exploits
- As long as patches are not applied, such 1-days are effective
- Also a starting point for same/similar bugs in the program



Real-world Example: Apple's Password Hint Bug

Apple's Password Hint Bug

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

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Apple's Password Hint Bug

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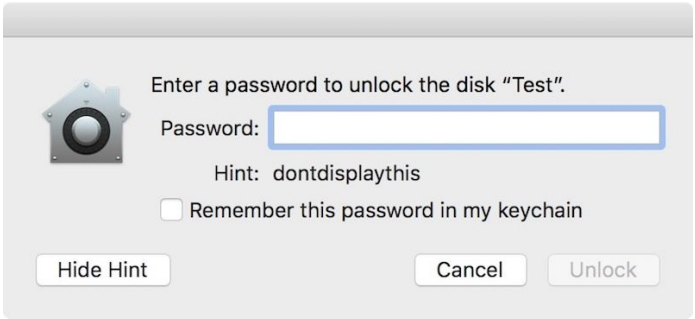
- ...the password was shown instead



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"));
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```

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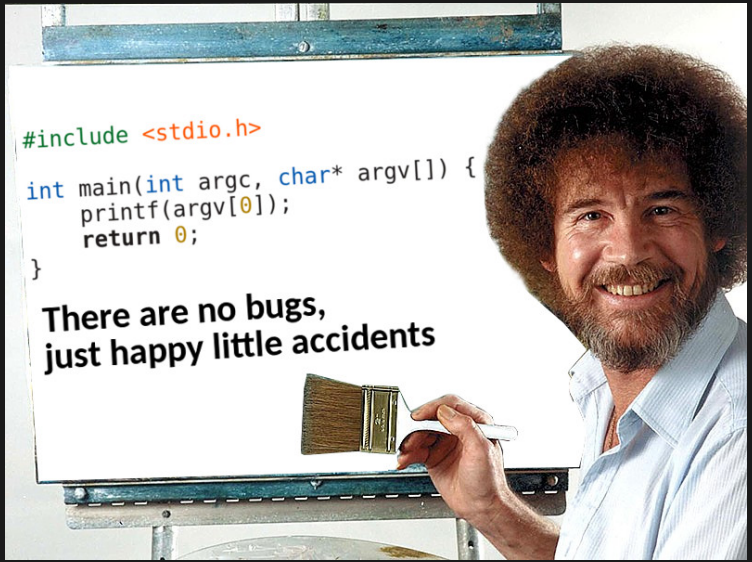
- Incorporate bug finding tools into your development process
- It does not cost a lot to compile with sanitizers, run static code analysis, fuzz your software, ...
- ...but it eliminates many bugs (for free)

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.