Software Testing, Quality Assurance & Maintenance—Lecture 7

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Part I

Fuzzing

Some JavaScript Code

```
function test() {
    var f = function g() {
        if (this != 10) f();
    };
    var a = f();
}
test();
```

Huh?

- this code used to crash WebKit (`https://bugs.webkit.org/show_bug.cgi?id=116853`).
- automatically generated by the Fuzzinator tool, based on a grammar for JavaScript.

Fuzzing effectively finds software bugs, especially security-based bugs (e.g. insufficient input validation.)

Fuzzing Origin Story

- 1988.
- Prof. Barton Miller was using a modem,
  on a dark and stormy night.
- Line noise caused UNIX utilities to crash!

Fuzzing Origin Story Part 2

- he got grad students in his Advanced Operating Systems class to write a fuzzer
  (generating unstructured ASCII random inputs)
- result: 25%-33% of UNIX utilties crashed on random inputs[1]

[1] http://pages.cs.wisc.edu/~bart/fuzz/Foreword1.html

(an earlier use of Fuzzing)

- 1983: Apple's "The Monkey[2]"
- Generated random events for MacPaint, MacWrite.
- Found lots of bugs,
  but eventually the monkey hit the Quit command.

- Solution: "MonkeyLives" system flag, ignore Quit.

[2] http://www.folklore.org/StoryView.py?story=Monkey_Lives.txt

Experience report: Fuzzinator author

More than a year ago, when I started fuzzing, I was mostly focusing on mutation-based fuzzer technologies since they were easy to build and pretty effective. Having a nice error-prone test suite (e.g. LayoutTests) was the warrant for fresh new bugs. At least for a while.

As expected, the test generator based on the knowledge extracted from a finite set of test cases reached the edge of its possibilities after some time and didn't generate essentially new test cases anymore.

At this point, a fuzzer girl can reload her gun with new input test sets and will probably find new bugs. This works a few times but she will soon find herself in a loop testing the common code paths and running into the same bugs again and again.[3]

[3] `http://webkit.sed.hu/blog/20141023/fuzzinator-reloaded`

How Fuzzing Works

Two kinds of fuzzing:

- mutation-based: start with existing tests, randomly modify
- generation-based: start with grammar, generate inputs

What you do:

- feed randomly-generated inputs to the program;
- look for crashes or assertion errors;
- or run under a dynamic analysis tool (e.g. Valgrind) and observe runtime errors (implicit oracles).

Level 0 Fuzzing

Generation-based testing for HTML5.

Use the regular expression:

```
.*
```

that is: “any character”, “0 or more times”.

Found a WebKit assertion failure:
`https://bugs.webkit.org/show_bug.cgi?id=132179`.

Process:

- Take the regular expression and generate random strings from it.
- Feed them to the browser and see what happens.
- Find an assertion failure/crash.

Worked example: fuzzing bc

bc: one of the UNIX calculator utilities.

```
plam@poneke ~> bc
bc 1.07.1
Copyright 1991-1994, 1997, 1998, 2000, 2004, 2006, 2008, 2012-2017 Free Software
Foundation, Inc.
This is free software with ABSOLUTELY NO WARRANTY.
For details type `warranty'.
scale=2
4+6+5
15
6*5/3
10.00
4^5/7
146.28
quit
plam@poneke ~>
```

Generating random input

```
import random

def fuzzer(max_length: int = 100, char_start: int = 32,
           char_range: int = 32) -> str:
    """A␣string␣of␣up␣to␣`max_length`␣characters
␣␣␣␣␣␣␣␣in␣the␣range␣[`char_start`,␣`char_start`␣+␣`char_range`)"""
    string_length = random.randrange(0, max_length + 1)
    out = ""
    for i in range(0, string_length):
        out += chr(random.randrange(char_start, char_start + char_range))
    return out
```

I've created a wrapper, `code/L07/run_fuzzer.py`, that you can just run; there are also wrappers for the subsequent runs too.

Roundtripping from disk: `roundtrip_to_disk.py`

```
from fuzzer import *

import os
import tempfile
import random

basename = "input.txt"
tempdir = tempfile.mkdtemp()
FILE = os.path.join(tempdir, basename)
print(FILE)

data = fuzzer()
with open(FILE, "w") as f:
    f.write(data)

contents = open(FILE).read()
print(contents)
assert(contents == data)
```

This writes fuzzer-created input to disk, reads it back, and compares.
(*Secure temp file creation must be in one step like this.)

Running bc once: `run_bc_once.py`

```
import os
import tempfile
import subprocess

program = "bc"
basename = "input.txt"
tempdir = tempfile.mkdtemp()
FILE = os.path.join(tempdir, basename)
print(FILE)
with open(FILE, "w") as f:
    f.write("2␣+␣2\n")
result = subprocess.run([program, FILE],
                        stdin=subprocess.DEVNULL,
                        stdout=subprocess.PIPE,
                        stderr=subprocess.PIPE,
                        universal_newlines=True)  # Will be "text" in Pyth

print (result.stdout)
print (result.returncode)
```

Our Very Own Fuzzing Campaign:

`fuzzing_campaign.py`

```
from fuzzer import *
import os
import tempfile
import subprocess

def fuzzing_campaign():
    trials = 100
    program = "bc"
    runs = []
    basename = "input.txt"
    tempdir = tempfile.mkdtemp()
    FILE = os.path.join(tempdir, basename)

    for i in range(trials):
        data = fuzzer()
        with open(FILE, "w") as f:
            f.write(data)
        result = subprocess.run([program, FILE],
                                stdin=subprocess.DEVNULL,
                                stdout=subprocess.PIPE,
                                stderr=subprocess.PIPE,
                                universal_newlines=True)
        runs.append((data, result))
    return runs
```

Queries: run_fuzzing_campaign.py

```
from fuzzing_campaign import *

if __name__ == "__main__":
    runs = fuzzing_campaign()

    # how many runs don't result in error messages?
    count_no_errors = sum(1 for (data, result) in runs if result.stderr ==
    print ("# runs: {}".format(len(runs)))
    print ("# no-errors: {}".format(count_no_errors))

    # let's look at the first error message
    errors = [(data, result) for (data, result) in runs if result.stderr !
    (first_data, first_result) = errors[0]

    print ("first error input: {}".format(repr(first_data)))
    print ("stderr output for first error input: {}".format(first_result.s

    # are there any non-error outputs?
    non_errors = [result.stdout for (data, result) in runs if
     "illegal character" not in result.stderr
     and "parse error" not in result.stderr
     and "syntax error" not in result.stderr]
    print ("stdout on non-error runs: {}".format(non_errors))
```

More on crashing: buffer overflows

We saw this recently:

```
plam@poneke ~/c/s/n/c/L05 (main)> cat segfault.c
#include <stdlib.h>

int main()
{
  int * q = malloc(5*sizeof(int));
  q[2000000] = 4;
}
plam@poneke ~/c/s/n/c/L05 (main)> gcc segfault.c -o segfault
plam@poneke ~/c/s/n/c/L05 (main)> ./segfault
fish: Job 5, './segfault' terminated by signal SIGSEGV (Address boundary error)
plam@poneke ~/c/s/n/c/L05 (main) [SIGSEGV]>
```

That's bad. So is this:

```
// input = "Wednesday"
char weekday[9];
strcpy(weekday, input);
```

Buffer overflows are always wrong.

Choose your language

C/C++ are rife with buffer overflows.

Safe Rust, Python don’t have buffer overflows.

They will fail fast instead.

Failing to check errors

```
while (getchar() != '■') /* ... */ ;
```

Turns out that `getchar()` might return EOF—especially likely for fuzz-generated inputs.

If so, this code causes an infinite loop;
can detect with timeouts.

Not just a C problem.

Other unexpected unsanitized inputs

```
char *read_input() {
  size_t size = read_buffer_size(); //<--
  char *buffer = (char *)malloc(size);
  // fill buffer
  return (buffer);
}
```

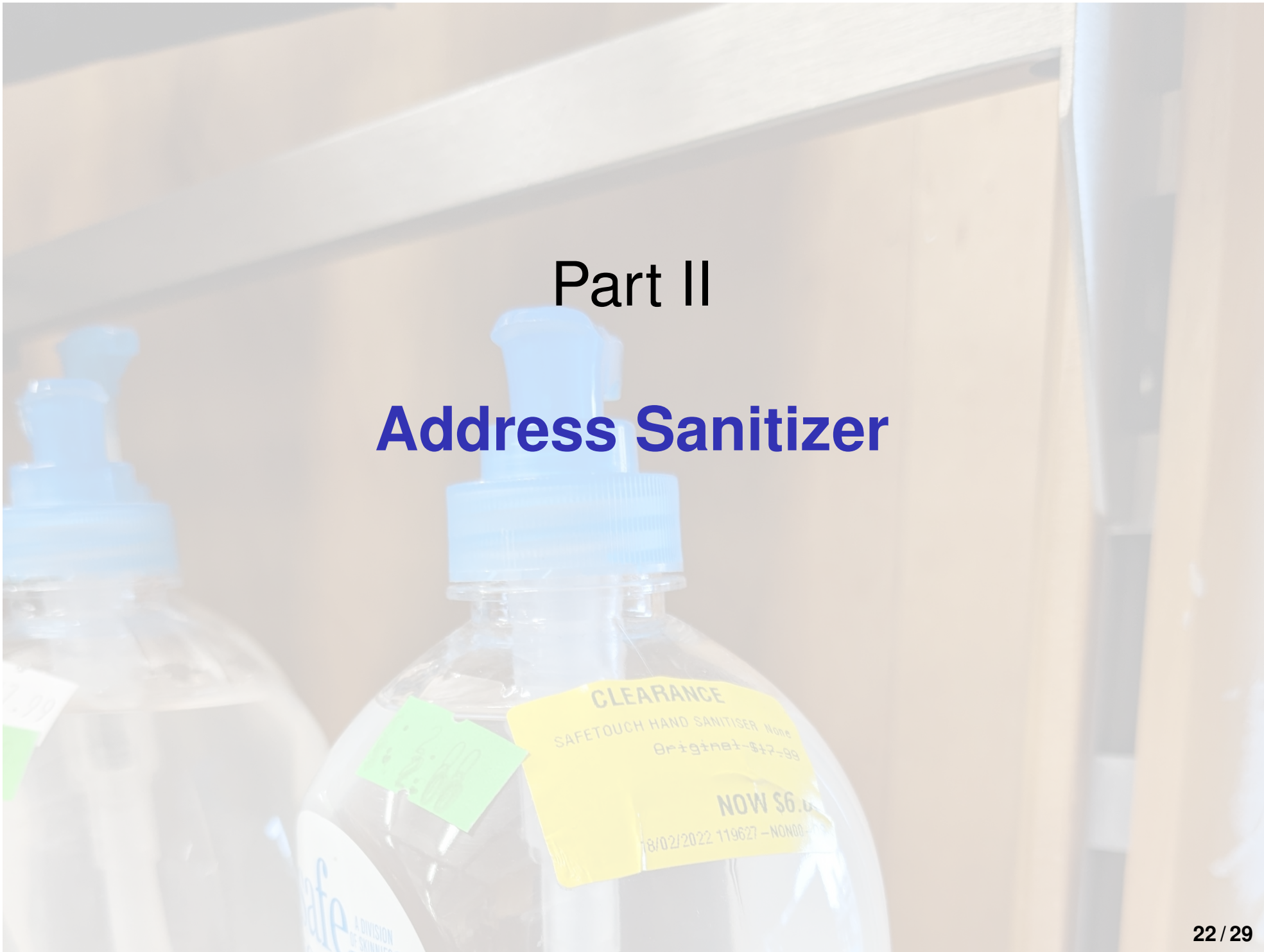
`size` may not be a valid size:
too big, too small;
conceptually, negative (but `size_t` can't be).

Fuzzing Summary

Fuzzing finds interesting test cases.

Works best at interfaces between components
(including system/user interface).

Advantages: it runs automatically and really works.
Disadvantages: without significant work, it won't find sophisticated domain-specific issues.



Part II

Address Sanitizer

Buffer Overflow On Demand

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

int main(int argc, char** argv) {
    /* Create an array with 100 bytes, initialized wit
    char *buf = malloc(100);
    memset(buf, 42, 100);

    /* Read the N-th element, with N being the first c
    int index = atoi(argv[1]);
    char val = buf[index];

    /* Clean up memory so we don't leak */
    free(buf);
    return val;
}
```

About that `free()`

In this context, `buf` would be freed on exit anyway.

Relying on free-upon-exit is less tidy,
and it would be a problem in not-`main()`.

The Demand

```
$ clang -fsanitize=address -g buffer-overflow-on-demand.c
$ ./a.out 5000
=================================================================
==638062==ERROR: AddressSanitizer: heap-buffer-overflow on address 0x7bbdc
READ of size 1 at 0x7c21313e13c8 thread T0
    #0 0x55e13d86cb4f in main /home/plam/courses/stqam-2026-working-notes/
    #1 0x7f7132029f74  (/usr/lib/x86_64-linux-gnu/libc.so.6+0x29f74) (Buil
    #2 0x7f713202a026 in __libc_start_main (/usr/lib/x86_64-linux-gnu/libc
    #3 0x55e13d783360 in _start (/home/plam/courses/stqam-2026-working-not

Address 0x7c21313e13c8 is a wild pointer inside of access range of size 0x
SUMMARY: AddressSanitizer: heap-buffer-overflow /home/plam/courses/stqam-2
Shadow bytes around the buggy address:
  0x7c21313e1100: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1180: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1200: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1280: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1300: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
=>0x7c21313e1380: fa fa fa fa fa fa fa fa fa[fa]fa fa fa fa fa fa
  0x7c21313e1400: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1480: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1500: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1580: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x7c21313e1600: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
```

Fuzzing & AddressSanitizer

Wikimedia Commons, Evan-Amos, public domain

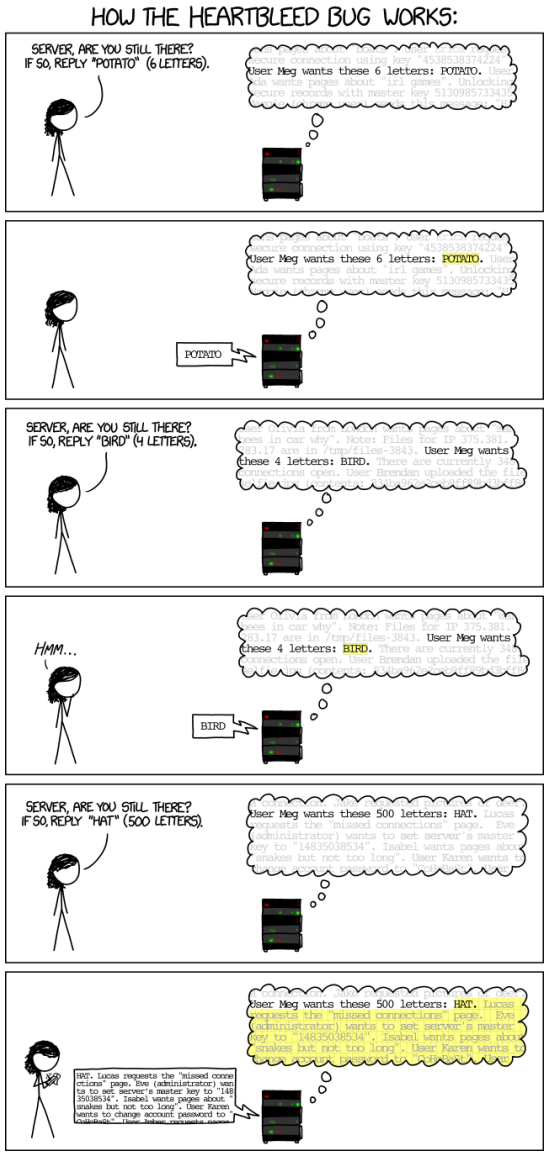
Two Great Tastes. . .

Fuzzing & AddressSanitizer

Fuzzing causes (memory and other) problems; AddressSanitizer detects them.

The program runs like 2× slower in AddressSanitizer.
Or, choose Valgrind: find more bugs, program runs like 100× slower.

Found w/sanitizer: Heartbleed (thx xkcd)



How Found?

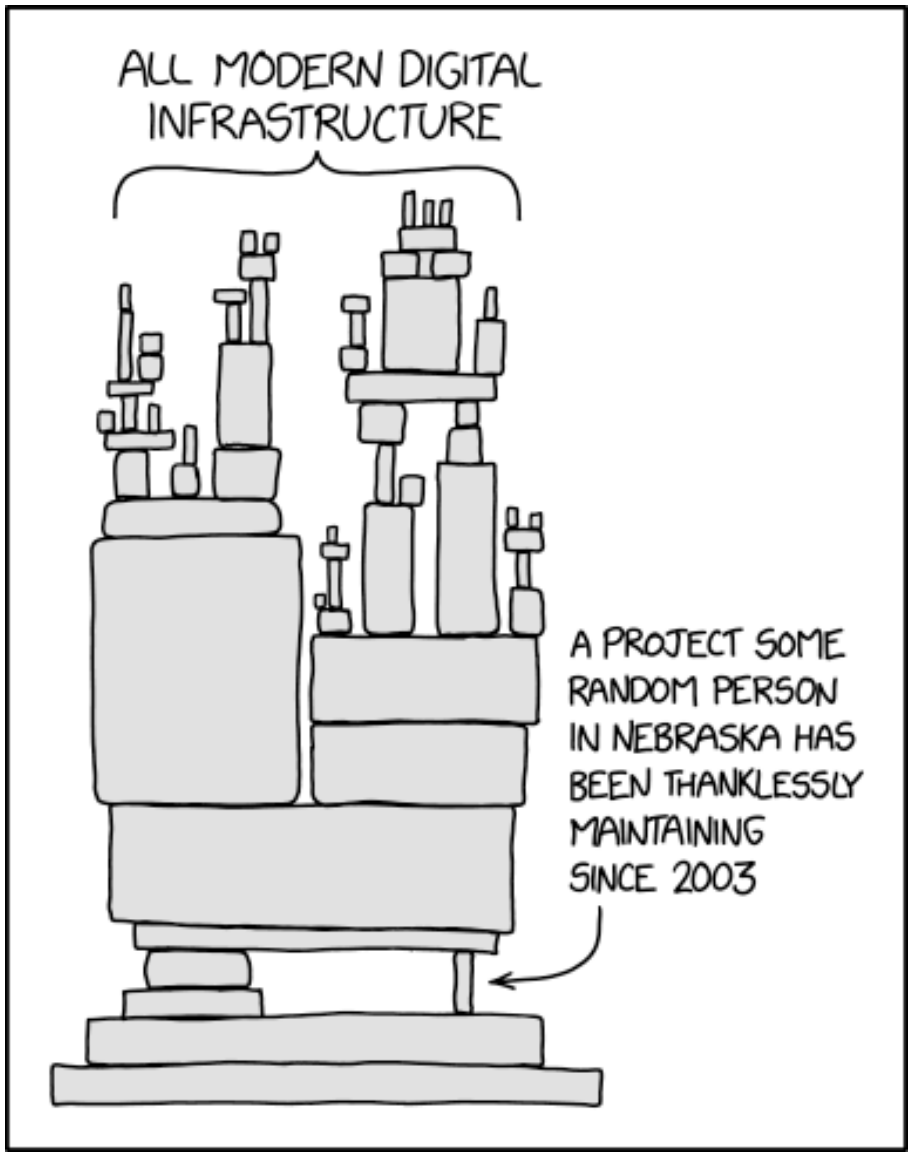
Researchers at Google and Codenomicon found Heartbleed via memory sanitizer.

Fed fuzzed inputs to OpenSSL.

Sanitizer found illegal accesses; easy to fix.

(Note: use responsible disclosure if you find something.)

Side note: on Open Source



but note also `https://cryptography.io/en/latest/statements/state-of-openssl/`