Week 6: Lecture A

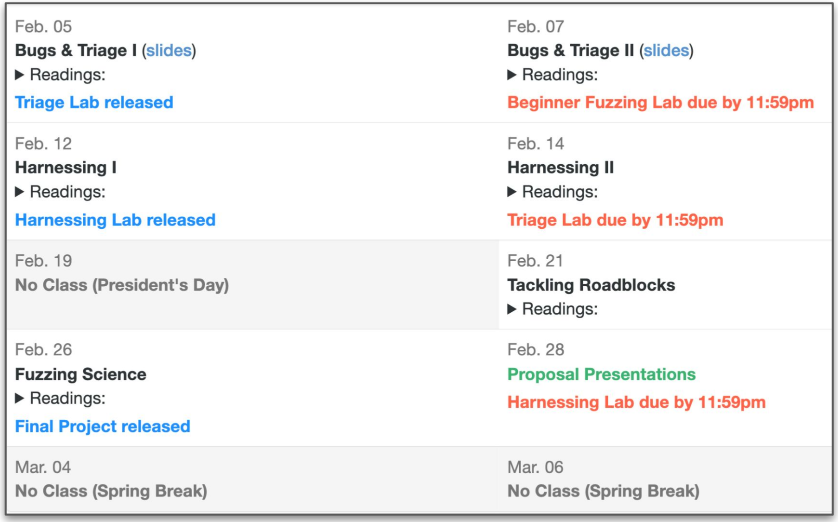
Harnessing I

Monday, February 12, 2024

Recap: Key Dates

Feb. 12	**Lab 3 released**
Feb. 14	**Lab 2 due**
Feb. 19	No class (President's Day)
Feb. 28	**Lab 3 due**
Feb. 28	**5-minute project proposals**
Mar. 04 & 06	No class (Spring Break)
Apr. 17 & 22	**Final project presentations**

cs.utah.edu/~snagy/courses/cs5963/schedule



Feb. 05 **Bugs & Triage I** (slides) ▶ Readings: **Triage Lab released**	Feb. 07 **Bugs & Triage II** (slides) ▶ Readings: **Beginner Fuzzing Lab due by 11:59pm**
Feb. 12 **Harnessing I** ▶ Readings: **Harnessing Lab released**	Feb. 14 **Harnessing II** ▶ Readings: **Triage Lab due by 11:59pm**
Feb. 19 **No Class (President's Day)**	Feb. 21 **Tackling Roadblocks** ▶ Readings:
Feb. 26 **Fuzzing Science** ▶ Readings: **Final Project released**	Feb. 28 **Proposal Presentations** **Harnessing Lab due by 11:59pm**
Mar. 04 **No Class (Spring Break)**	Mar. 06 **No Class (Spring Break)**

Recap: Lab 2 Overview

- **Assignment:** learn how to use AddressSanitizer (ASAN)
  - Read its documentation in https://clang.llvm.org/docs/AddressSanitizer.html

- **Replay the crashes you found in Lab 1 on an ASAN-instrumented binary**
  - Collect information on each crash
  - What do you observe?

- **Deliverable:** a **1–3 page report** detailing your findings
  - Feel free to make it your own (e.g., pictures, text, etc.)

- **Linux environments are recommended**
  - Use a VM if you don't have one!

Recap: Lab 2 Tips

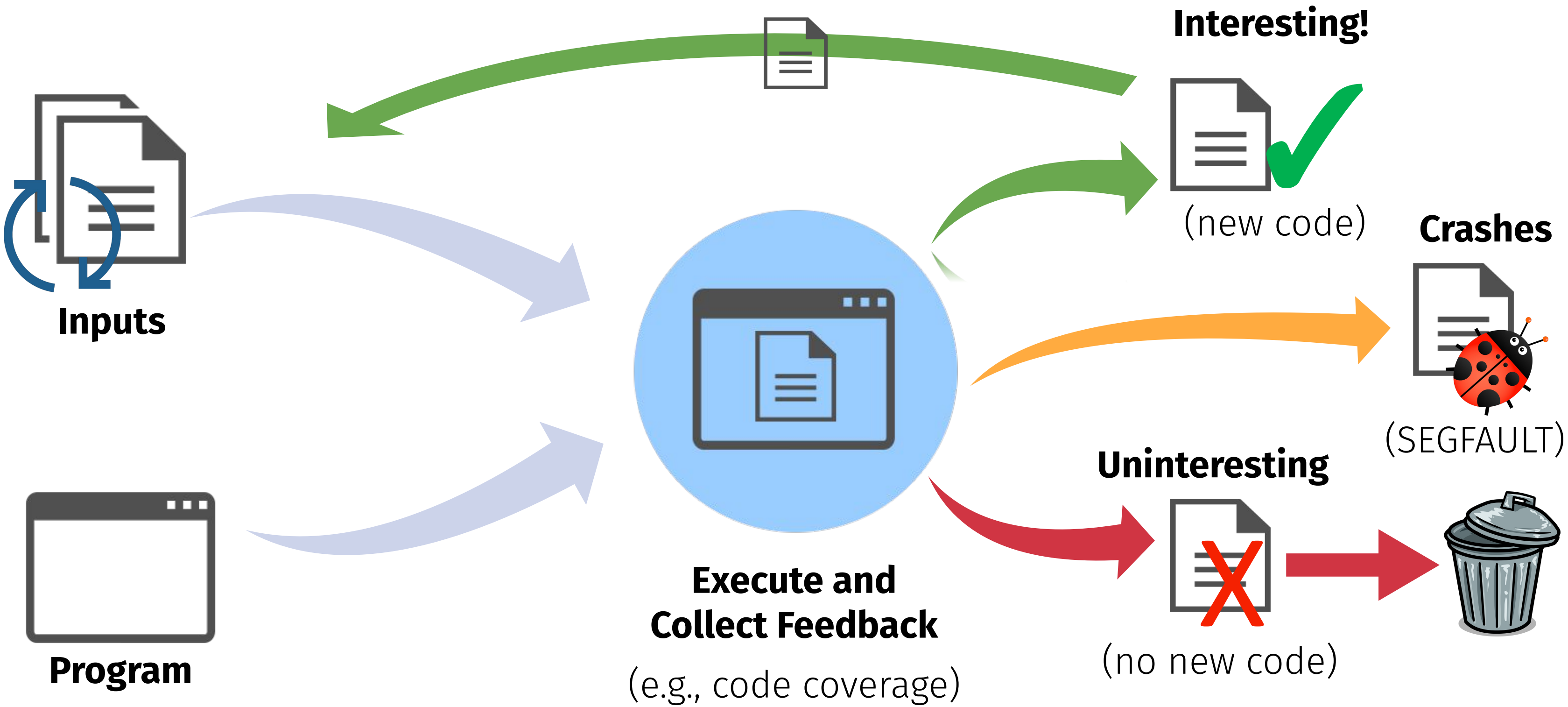
- **Re-run crashes on the ASAN instrumented binary**
  - Use Python to script collection of ASAN outputs
  - Do string post-processing to collect error types, crashing source line, etc.
  - Group and deduplicate crashes as you see fit

- **Didn't find any crashes in Lab 1?**
  - Try fuzzing fuzzgoat from https://github.com/fuzzstati0n/fuzzgoat
  - Should yield **lots** of crashes quickly

Questions?

Harnessing

Recap: Coverage-guided Fuzzing



Interesting!

(new code)

Crashes

(SEGFAULT)

Uninteresting

(no new code)

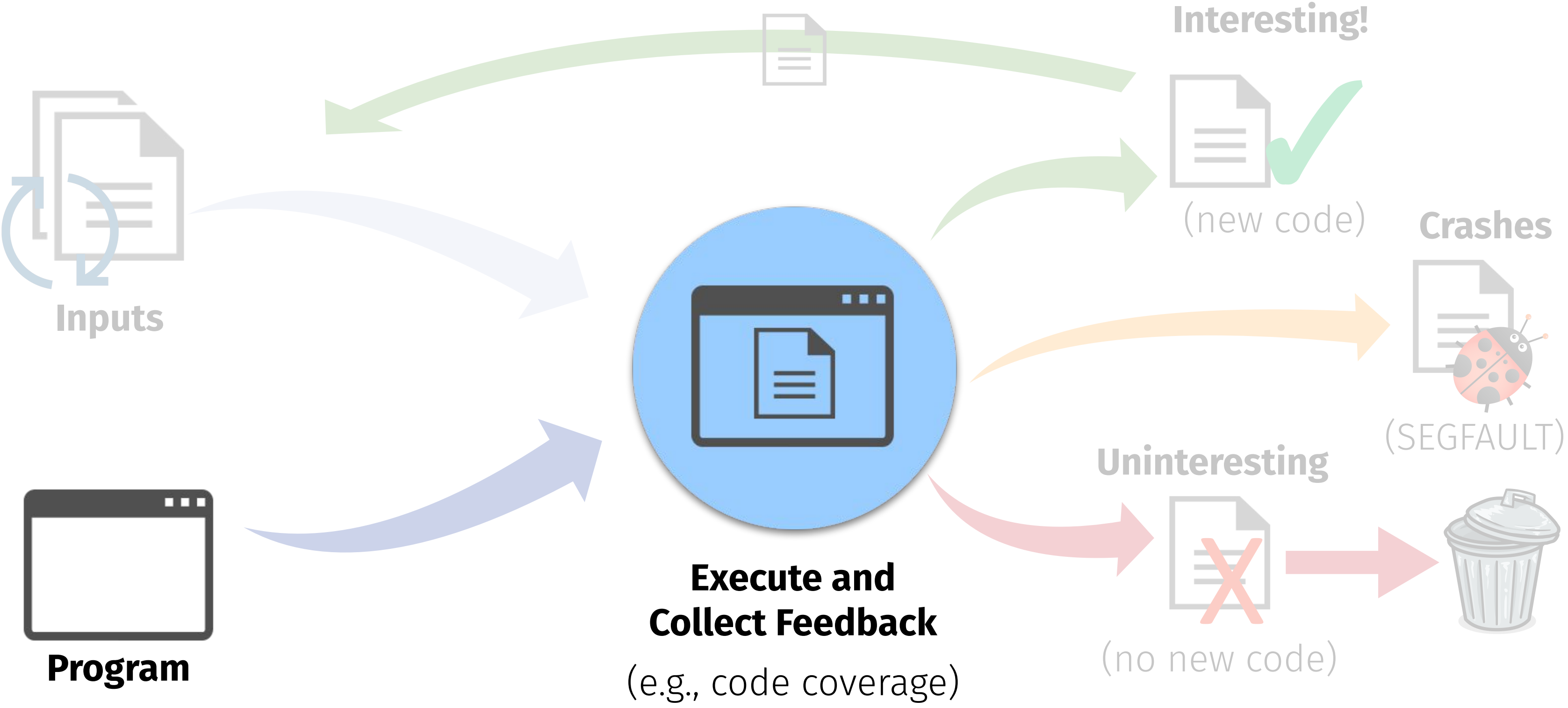
Inputs

Program

Execute and Collect Feedback

(e.g., code coverage)

Recap: Coverage-guided Fuzzing



Harnessing

- **Definition:** making a program **fuzzable**
  - Pass input data to a program’s core logic
  - Skip functionality we don’t care about
  - Drop-in integration with fuzzers (e.g., AFL)

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  - Target a **single** function (libFuzzer-style)
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- **Types of harnesses**
  - Target a **single** function (libFuzzer-style)
  - Target **many** functions (AFL-style)

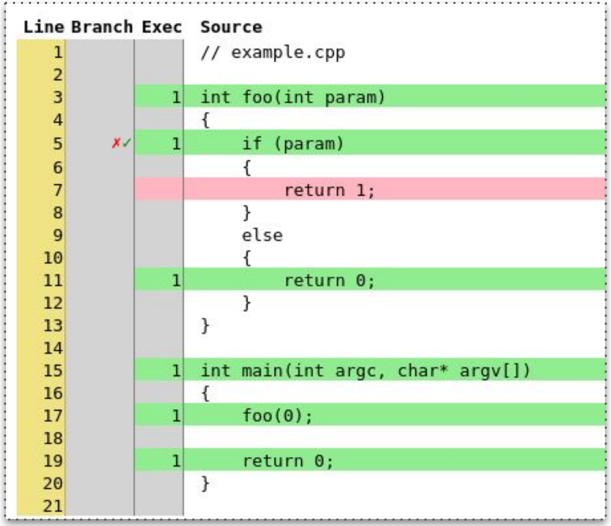
- **One of the most important (and difficult) parts of fuzzing**
  - Lots of domain expertise
  - Automating still an open problem

What makes a good harness?

- **Speed:** avoid re-executing uninteresting code
  - GUI initialization
  - Server/client setup routines
  - Weird developer-added obstacles
  - **Cycles are precious—don't waste them!**

What makes a good harness?

- **Coverage:** invoke interesting parts of the code
  - Higher coverage = more thorough testing
  - Test hard-to-reach functionality
  - Measure and improve harnesses
  - **Coverage blindspots = missed bugs!**

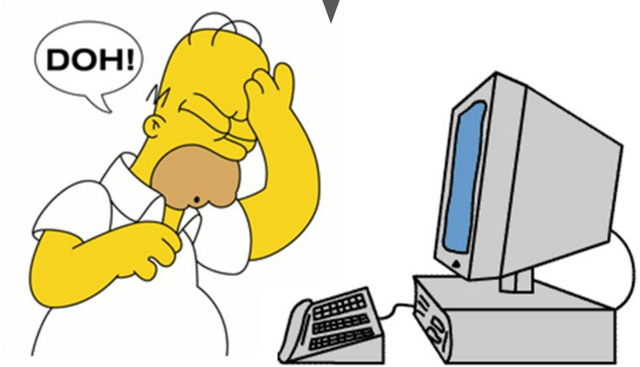


```
Line Branch Exec  Source
   1              // example.cpp
   2
   3           1  int foo(int param)
   4              {
   5      ✗✓   1      if (param)
   6                  {
   7                      return 1;
   8                  }
   9                  else
  10                  {
  11           1          return 0;
  12                  }
  13              }
  14
  15           1  int main(int argc, char* argv[])
  16              {
  17           1      foo(0);
  18
  19           1      return 0;
  20              }
  21
```

What makes a good harness?

- **Correctness:** reset necessary program state
  - Global variable state
  - Stack state
  - Heap state
  - **State errors = false positive crashes!**

crashes: 1,000 (1,000 unique)



Harnessing Open- vs. Closed-source Code

Open Source:

- Publicly-available source codebase
- Achieves security by *transparency*

- **Generally easy to harness**

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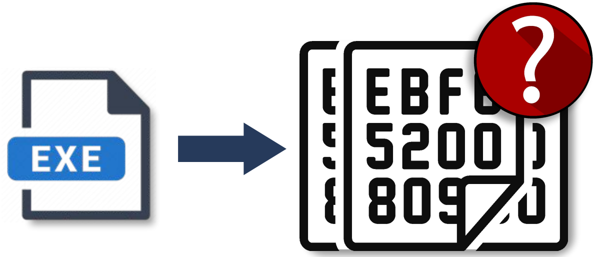
Closed Source:

- Distributed as a precompiled binary
- Opaque to *everyone* but its developer



- **Far more difficult to harness**

Basic Harnessing

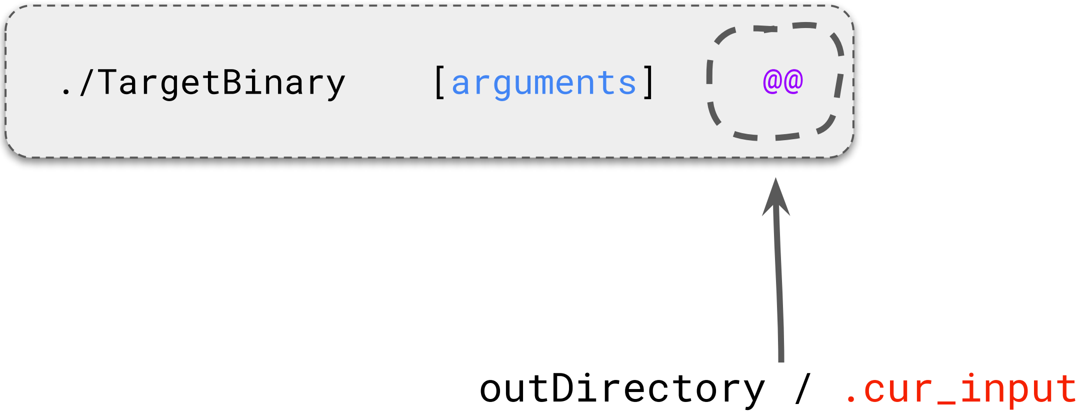
What fuzzers expect…

- **AFL:** program takes **command-line** input

```
./TargetBinary    [arguments]     @@
```

What fuzzers expect...

- **AFL:** program takes **command-line** input
  - Load, send, and store input data as **files**



```
./TargetBinary    [arguments]    @@
```

```
outDirectory / .cur_input
```

What fuzzers expect…

- **libFuzzer:** inputs as **buffered data**

```
int LLVMFuzzerTestOneInput (const char *Data, long Size) {


}
```

What fuzzers expect...

- **libFuzzer:** inputs as **buffered data**
  - Fuzzer alters **Data** and **Size** objects

```
int LLVMFuzzerTestOneInput (const char *Data, long Size) {
  DoSomethingInterestingWithMyAPI (Data, Size);
  return 0;
}
```

So what’s the difference?

- **AFL:** program takes **command-line** input

```
./TargetBinary    [arguments]     @@
```

- **libFuzzer:** inputs as **buffered data**

```
int LLVMFuzzerTestOneInput (const char *Data, long Size) {
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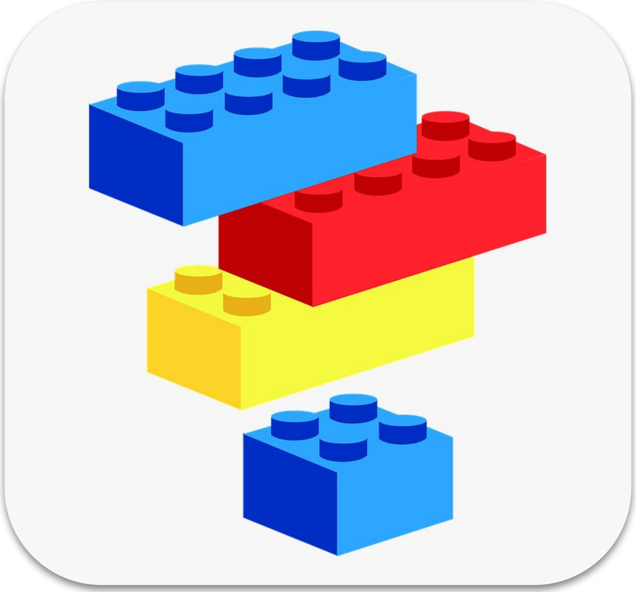
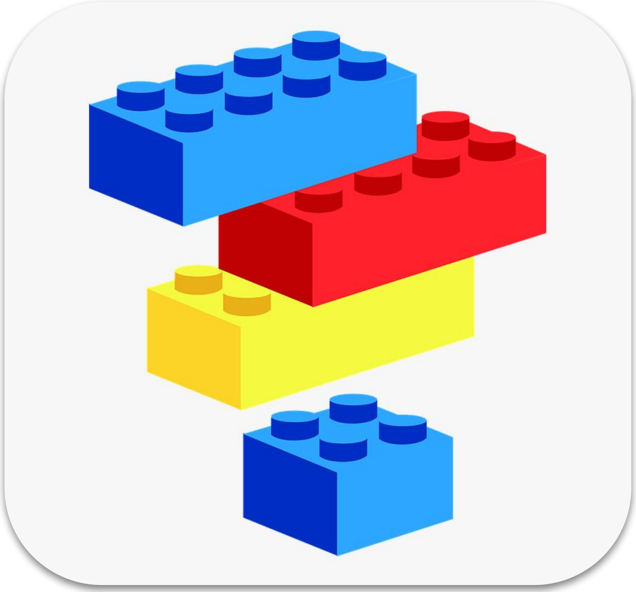
APIs vs Applications

- **API**
  - ???
- **Application**
  - ???



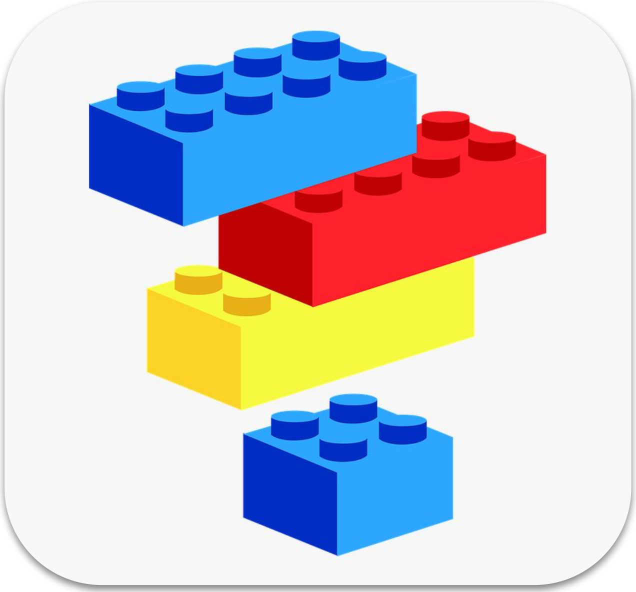
APIs vs Applications

- **API**
  - Application Programming Interface
  - Suite of functions for some niche purpose
  - Intended to be used by other applications
- **Application**
  - ???



APIs vs Applications

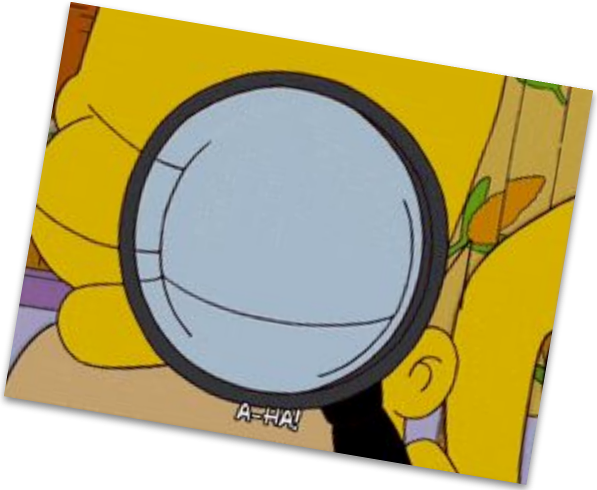
- **API**
  - Application Programming Interface
  - Suite of functions for some niche purpose
  - Intended to be used by other applications
- **Application**
  - Self-contained programs
  - Single- or multi-purpose
  - “Consumes” external APIs



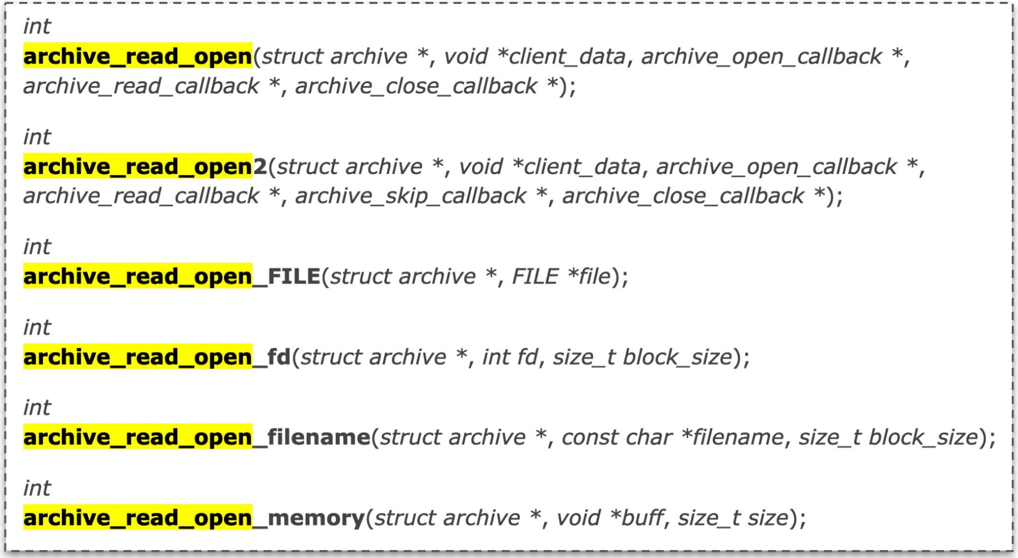
Identifying Suitable Targets

- **For APIs** (e.g., libJPEG):
  - Find API's "consumer" functions
  - Review documentation and figure out how to call it

- **For Applications** (e.g., Adobe Reader):
  - Find what directly loads data (e.g., calls **`fopen()`**)
  - Skip-over irrelevant setup code



Example: libArchive



```
int
archive_read_open(struct archive *, void *client_data, archive_open_callback *,
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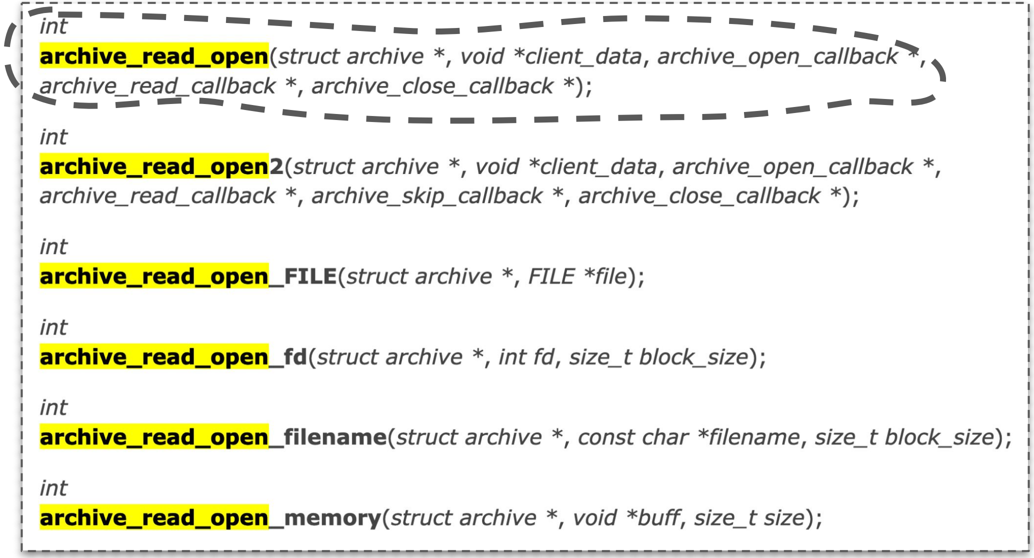

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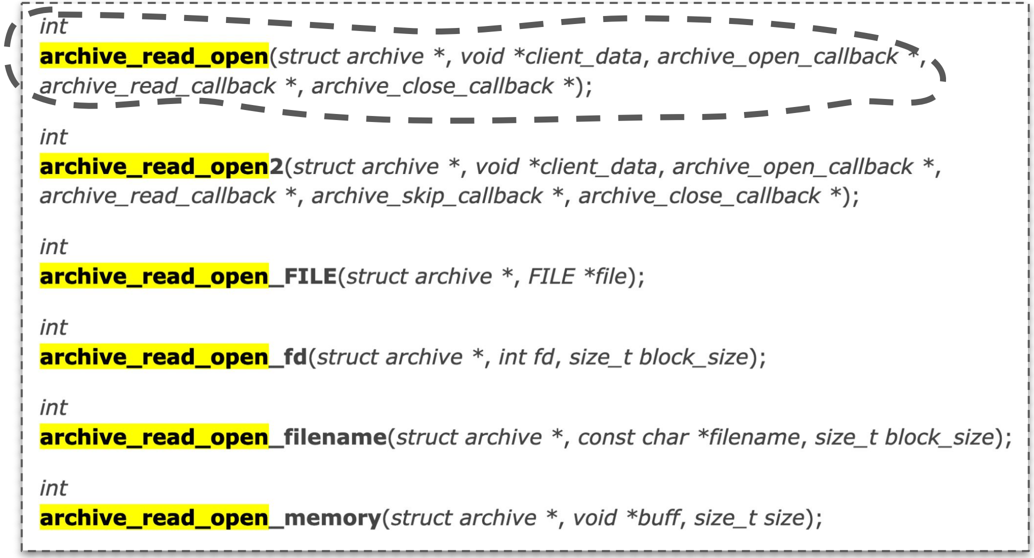

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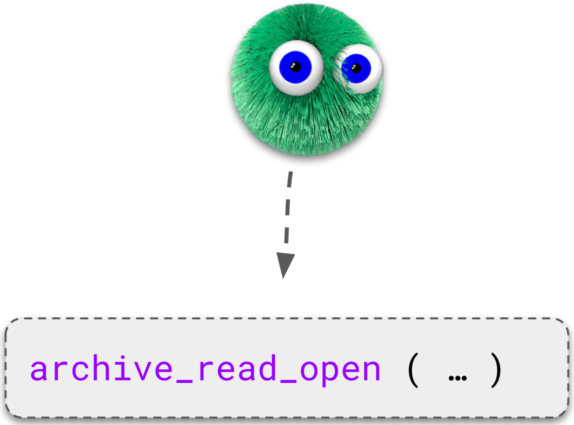

```
archive_read_open ( … )
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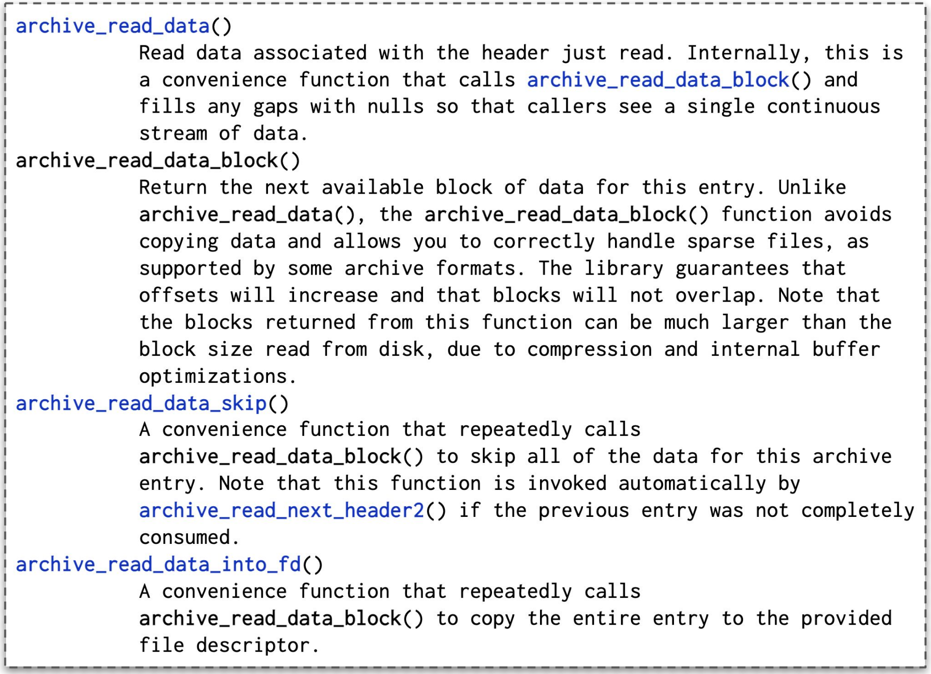

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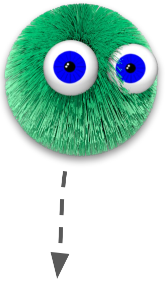

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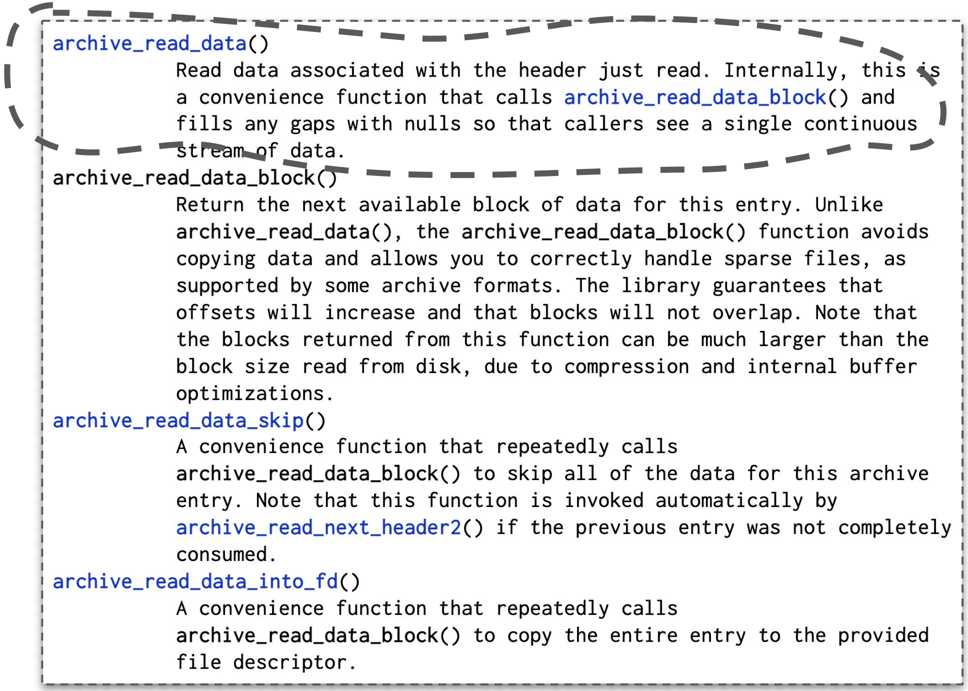

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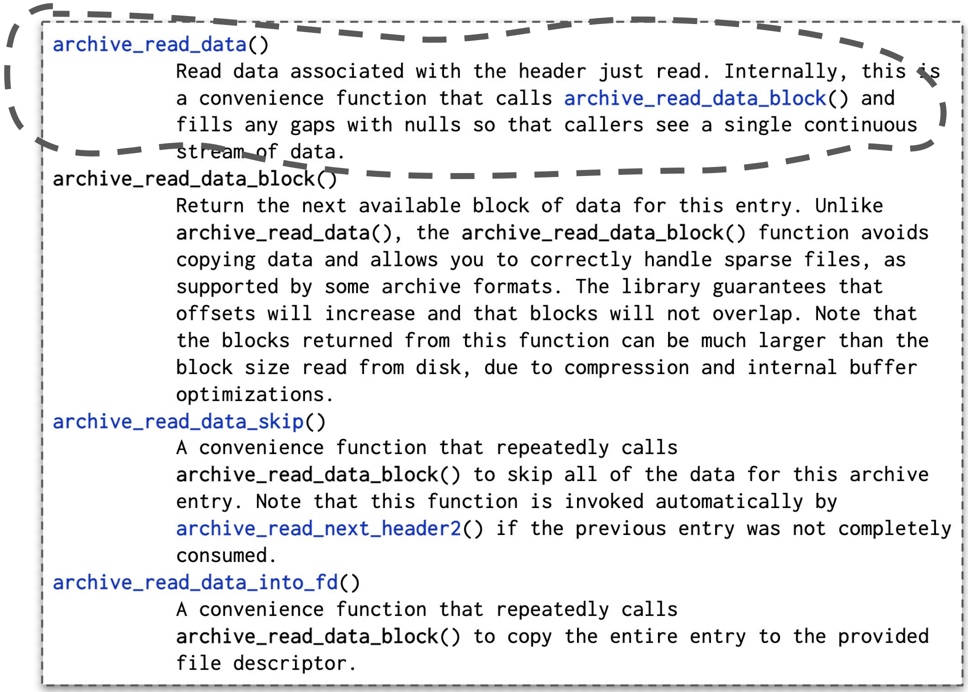

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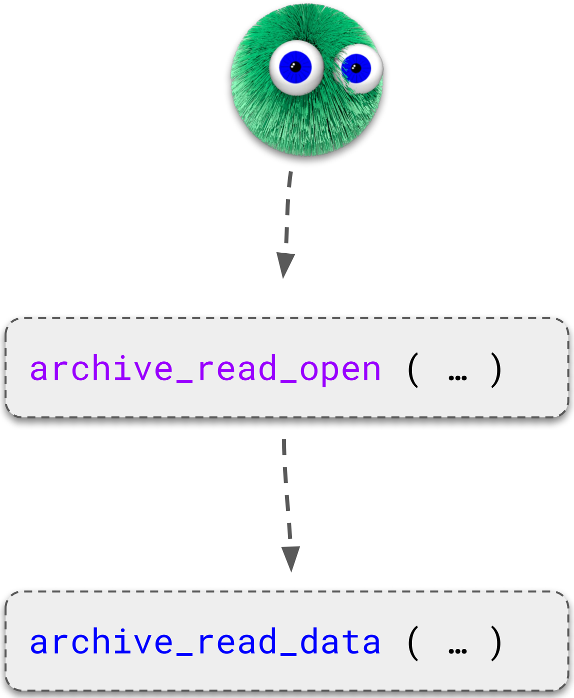

archive_read_open (…)

archive_read_data (…)

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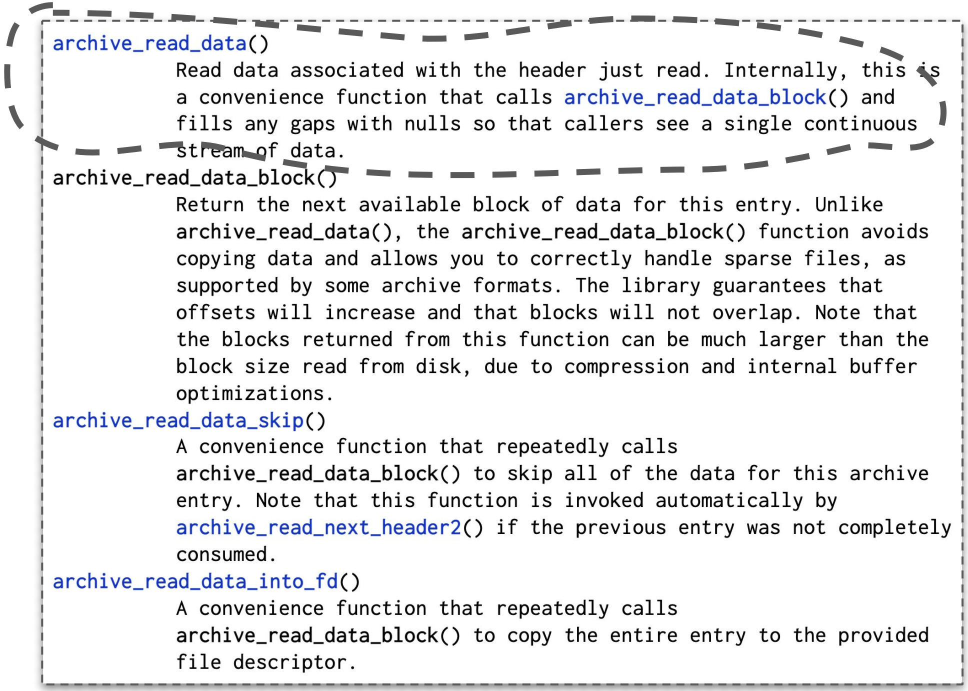

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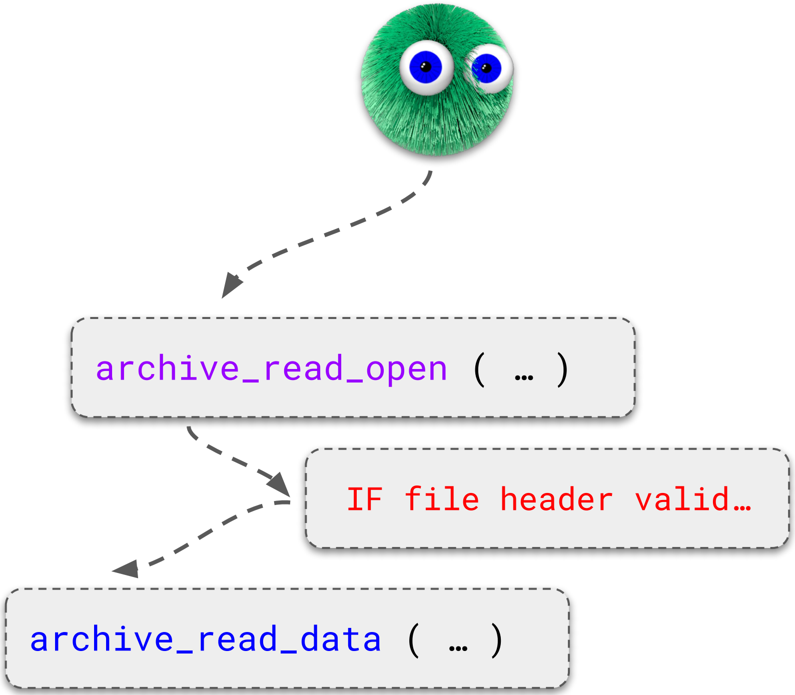


Example: libArchive

```
int LLVMFuzzerTestOneInput(*buf, len) {

  int ret;
  ssize_t r;
  struct archive *a = archive_read_new();

  Buffer buffer = {buf, len};
  archive_read_open(a, &buffer, NULL, …, NULL);

  std::vector<uint8_t> databuf (getpagesize(), 0);
  struct archive_entry *entry;
```

```
while(1) {
    ret = archive_read_next_header(a, &entry);
    if (ret == ARCHIVE_EOF || ARCHIVE_FATAL)
      Break;

    while (r =
      archive_read_data(a,
           databuf.data(),
           databuf.size())
      > 0);

    if (r == ARCHIVE_FATAL)
      break;
  }
  archive_read_free(a);
  return 0;
}
```

Useful Heuristics

- **No source code?**
  - Capture a few **call traces** when running some valid inputs
  - Look for functions that call interesting functions (e.g., **`fopen()`**)
  - **Work backwards and figure out how to call them**
    - E.g., what validity-checking functions to call first

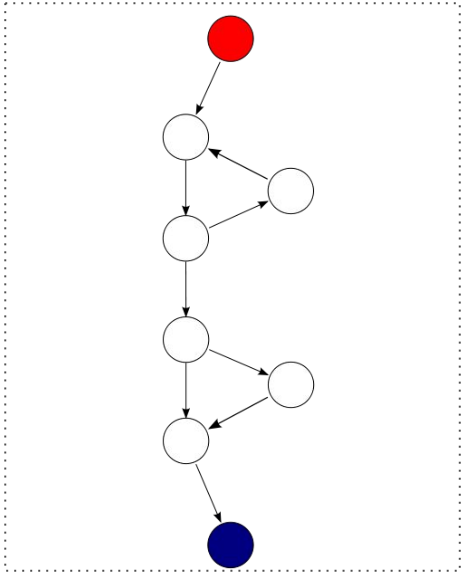
Pin

DynamoRIO

QEMU

Useful Heuristics

- **Have source code?**
  - … or a reasonably-precise decompilation?
  - Consider McCabe's **Cyclomatic Complexity**
    - `#Edges - #Nodes + 2(#ConnectedComponents)`



Source: https://en.wikipedia.org/wiki/Cyclomatic_complexity

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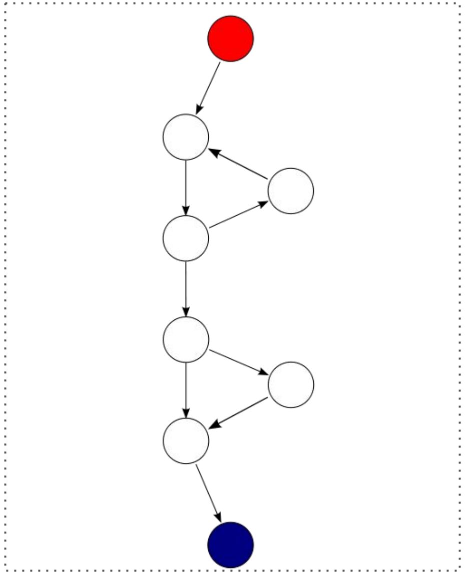
    - Example = `9 - 8 + 2(1) = 3`
  - **Higher score** considered **more interesting target**



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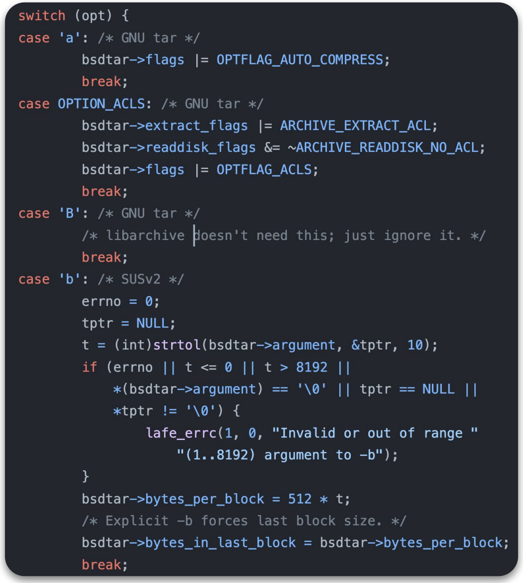
    - **Caveat:** switch table for parsing cmdline opts
    - High CC yet irrelevant to the fuzzer—**why?**



```c
switch (opt) {
case 'a': /* GNU tar */
        bsdtar->flags |= OPTFLAG_AUTO_COMPRESS;
        break;
case OPTION_ACLS: /* GNU tar */
        bsdtar->extract_flags |= ARCHIVE_EXTRACT_ACL;
        bsdtar->readdisk_flags &= ~ARCHIVE_READDISK_NO_ACL;
        bsdtar->flags |= OPTFLAG_ACLS;
        break;
case 'B': /* GNU tar */
        /* libarchive doesn't need this; just ignore it. */
        break;
case 'b': /* SUSv2 */
        errno = 0;
        tptr = NULL;
        t = (int)strtol(bsdtar->argument, &tptr, 10);
        if (errno || t <= 0 || t > 8192 ||
            *(bsdtar->argument) == '\0' || tptr == NULL ||
            *tptr != '\0') {
                lafe_errc(1, 0, "Invalid or out of range "
                    "(1..8192) argument to -b");
        }
        bsdtar->bytes_per_block = 512 * t;
        /* Explicit -b forces last block size. */
        bsdtar->bytes_in_last_block = bsdtar->bytes_per_block;
        break;
```

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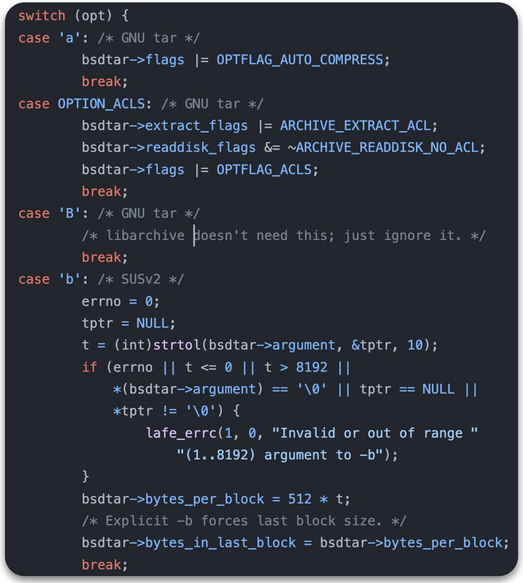
    - High CC yet irrelevant to the fuzzer—**why?**
      - Path is hardcoded pre-fuzzing!



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        /* libarchive doesn't need this; just ignore it. */
        break;
case 'b': /* SUSv2 */
        errno = 0;
        tptr = NULL;
        t = (int)strtol(bsdtar->argument, &tptr, 10);
        if (errno || t <= 0 || t > 8192 ||
            *(bsdtar->argument) == '\0' || tptr == NULL ||
            *tptr != '\0') {
                lafe_errc(1, 0, "Invalid or out of range "
                    "(1..8192) argument to -b");
        }
        bsdtar->bytes_per_block = 512 * t;
        /* Explicit -b forces last block size. */
        bsdtar->bytes_in_last_block = bsdtar->bytes_per_block;
        break;
```

Source: https://en.wikipedia.org/wiki/Cyclomatic_complexity

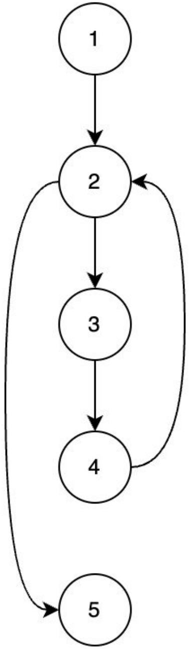
Useful Heuristics

```
int i = 1;
while (i <= 5)
{
    cout<<i<<endl;
    i++;
}
```

CC score

= 5 - 5 + 2(1)

= 2

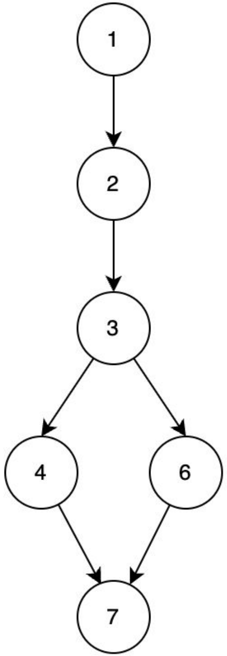


```
int a = 1;
int b = 2;
if (a>b)
  cout<<"a is greater";
else
  cout<<"b is greater";
```

CC score

= 6 - 7 + 2(1)

= 1



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  - Am I executing interesting functionality?
    - **Yes:** coverage increases over time
    - **No:** coverage plateaus after some time
  - **Study your target, and find ways improve your harnesses**

Questions?