Fuzzing

Fuzzing

“Finding bugs by bombarding target with nonconform data”

- Think: Flip a few bits in a PDF, then start Acrobat with that PDF
- Just more automated

Fuzzer

A program which generates new “random” inputs, and feeds it to the target program.

Mutation-based:

- Modify existing test samples
- Shuffle, change, erase, insert

Grammar-based:

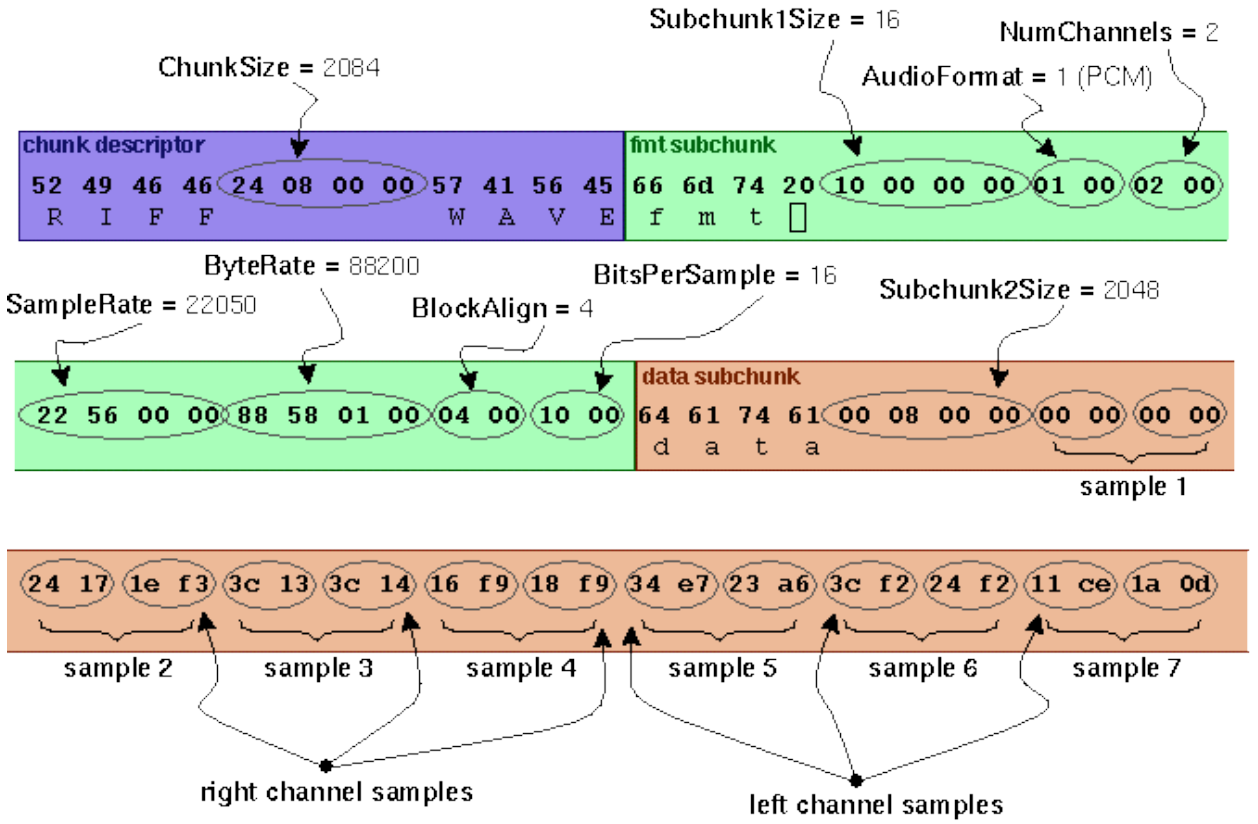
- Define new test sample based on models, templates, RFCs or documentation

Fuzzer: Mutation-based

Mutation fuzzing examples:

- Ffmpeg: Movie files
- Winamp: MP3 files
- Antivirus: ELF files

Take an input file, modify it a bit, continue



Fuzzer: Mutation-based

Steps:

- Create input corpus
- Select an input
- Modify input file (“fuzz it”)
- Start program with input file
- Identify crashes

Fuzzer: Grammar-based

Grammar-based fuzzing:

- Browser: JavaScript
- Browser: HTML
- FTP, HTTP, …

Cannot just bit flip etc, as it is not a binary protocol

```
alert(1);
```

- is valid:

```
alfrt(1);
```

- is garbage

Fuzzer: Grammar-based

- Create a random output based on grammar
- Start program with input file
- Identify crashes

Fuzzer: Grammar-based

Domato

```
!varformat fuzzvar%05d
!lineguard try { <line> } catch(e) {}

!begin lines
<new element> = document.getElementById("<string min=97 max=122>");
<element>.doSomething();
!end lines
```

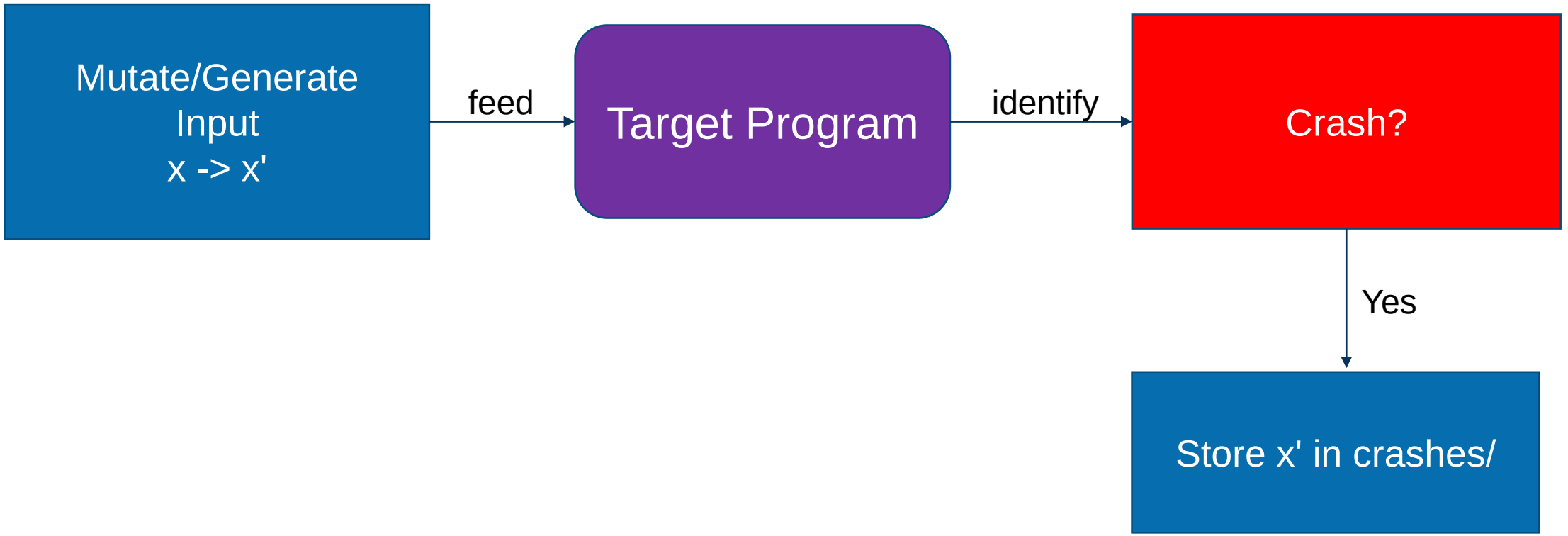
If we instruct the engine to generate 5 lines, we may end up with something like:

```
try { var00001 = document.getElementById("hw"); } catch(e) {}
try { var00001.doSomething(); } catch(e) {}
try { var00002 = document.getElementById("feezcqbndf"); } catch(e) {}
try { var00002.doSomething(); } catch(e) {}
try { var00001.doSomething(); } catch(e) {}
```

Fuzzer: Grammar-based

```
HTTP-date     = rfc1123-date | rfc850-date | asctime-date
rfc1123-date = wkday "," SP date1 SP time SP "GMT"
rfc850-date   = weekday "," SP date2 SP time SP "GMT"
asctime-date = wkday SP date3 SP time SP 4DIGIT
date1         = 2DIGIT SP month SP 4DIGIT
                ; day month year (e.g., 02 Jun 1982)
date2         = 2DIGIT "-" month "-" 2DIGIT
                ; day-month-year (e.g., 02-Jun-82)
date3         = month SP ( 2DIGIT | ( SP 1DIGIT ))
                ; month day (e.g., Jun  2)
time          = 2DIGIT ":" 2DIGIT ":" 2DIGIT
                ; 00:00:00 - 23:59:59
wkday         = "Mon" | "Tue" | "Wed"
              | "Thu" | "Fri" | "Sat" | "Sun"
weekday       = "Monday" | "Tuesday" | "Wednesday"
              | "Thursday" | "Friday" | "Saturday" | "Sunday"
month         = "Jan" | "Feb" | "Mar" | "Apr"
              | "May" | "Jun" | "Jul" | "Aug"
              | "Sep" | "Oct" | "Nov" | "Dec"
```

Traditional fuzzing - dumb, inefficient, brute force

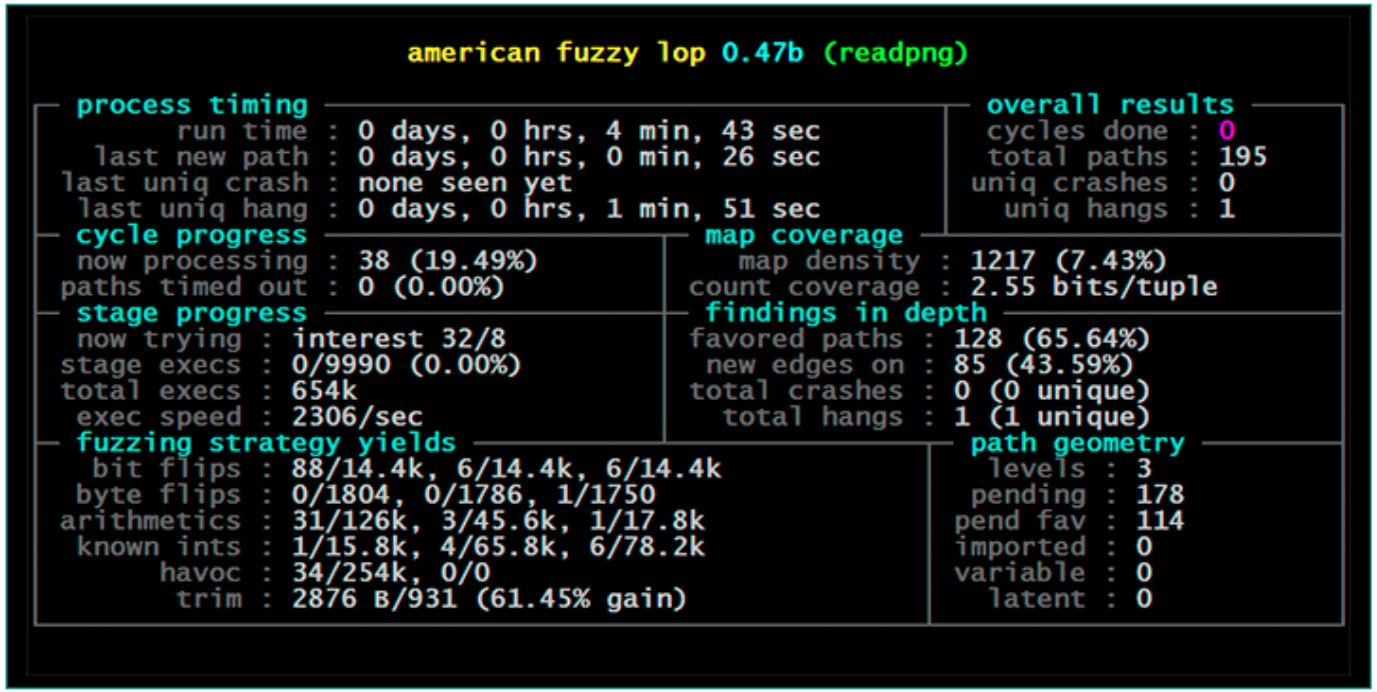


AFL

AFL

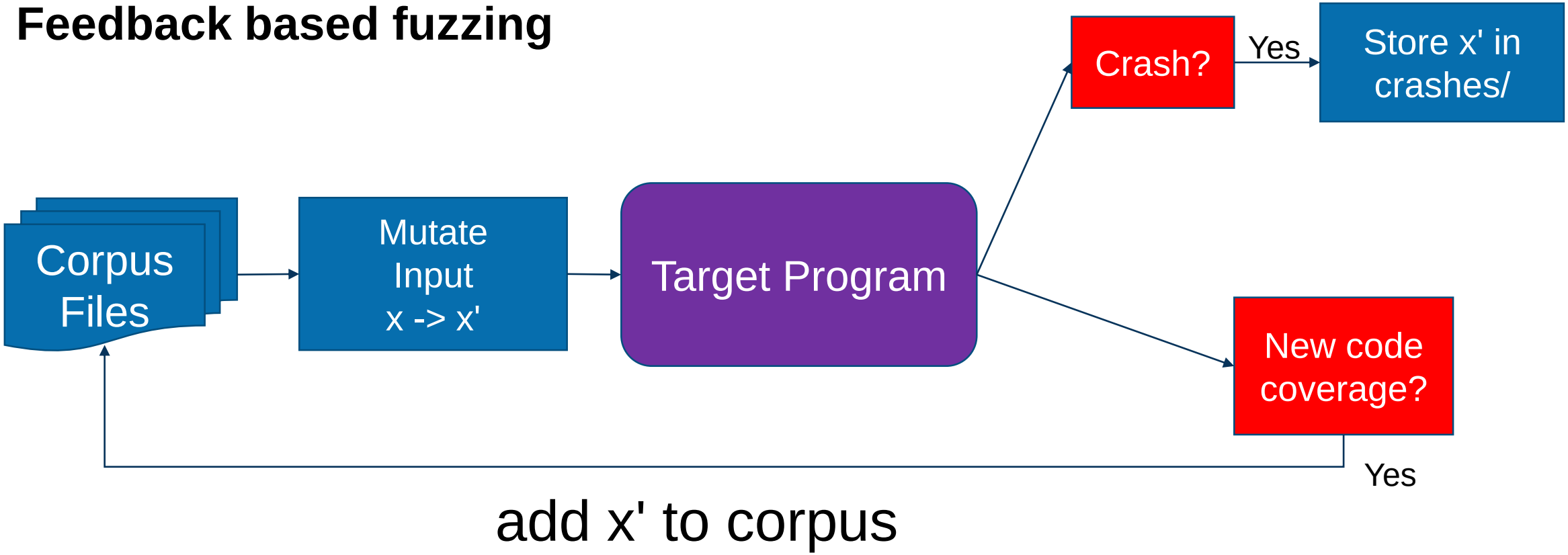
american fuzzy lop (2.38b)

American fuzzy lop is a security-oriented fuzzer that employs a novel type of compile-time instrumentation and genetic algorithms to automatically discover clean, interesting test cases that trigger new internal states in the targeted binary. This substantially improves the functional coverage for the fuzzed code. The compact synthesized corpora produced by the tool are also useful for seeding other, more labor- or resource-intensive testing regimes down the road.



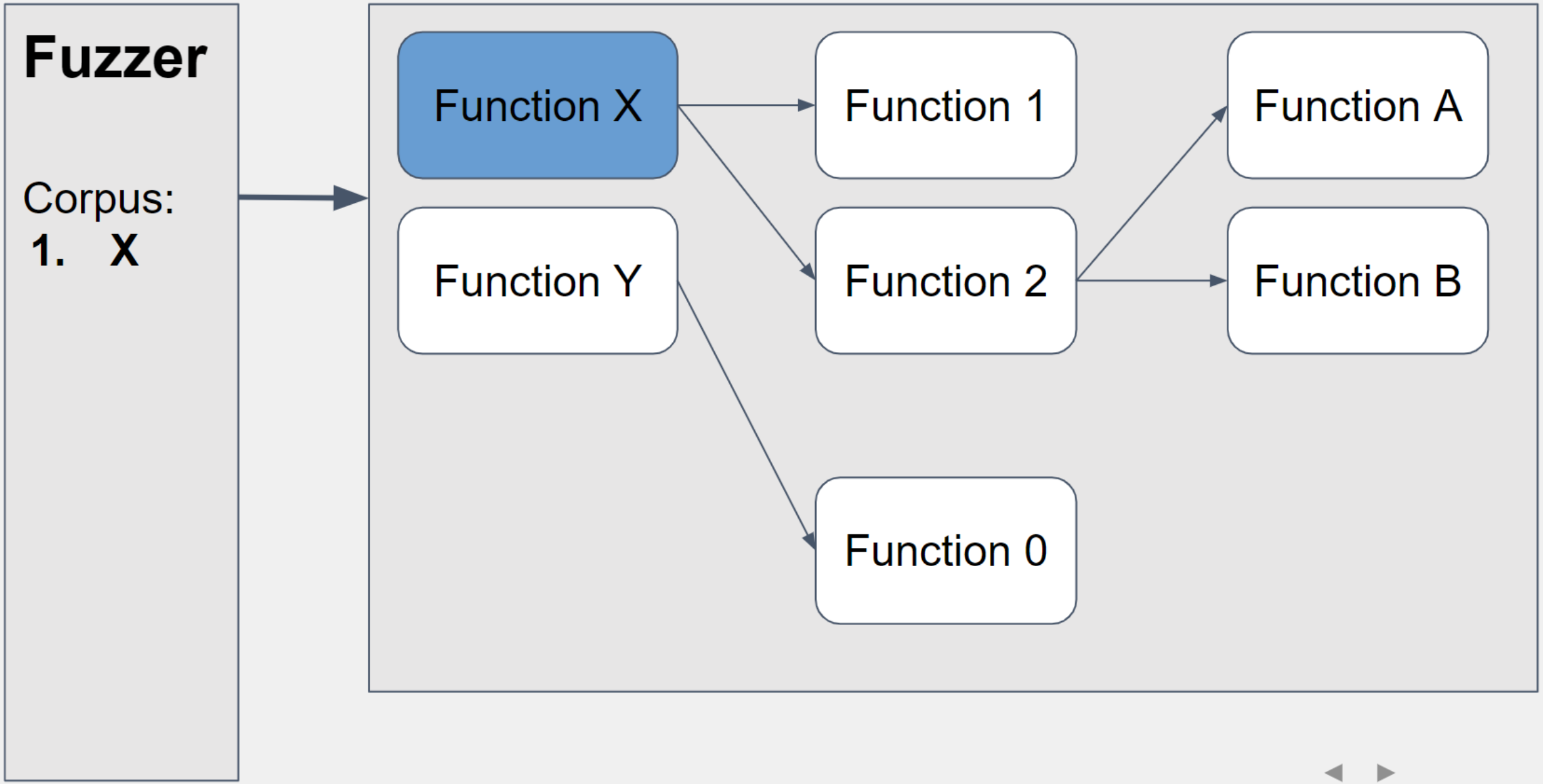
Compared to other instrumented fuzzers, *afl-fuzz* is designed to be practical: it has modest performance overhead, uses a variety of highly effective fuzzing strategies and effort minimization tricks, requires essentially no configuration, and seamlessly handles complex, real-world use cases - say, common image parsing or file compression libraries.

Feedback based fuzzing



Feedback based fuzzing

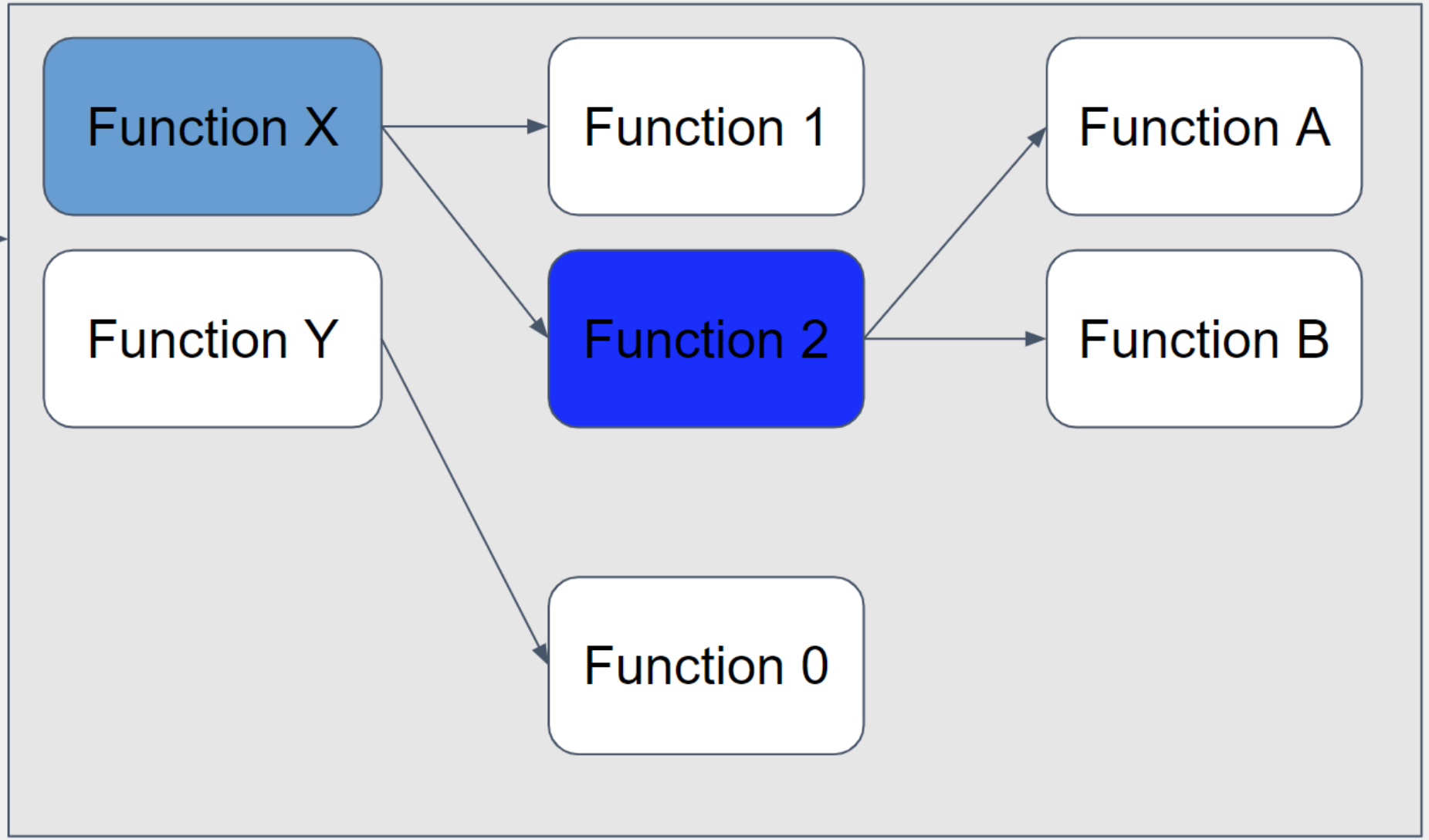
- "Observe" program to see if a new input (mutated from corpus) reaches new code path
  - This is being done by adding code in the compile process which tracks which functions get called in what order


Fuzzer
Corpus:
1. X
Function X
Function Y
Function 1
Function 2
Function 0
Function A
Function B

Fuzzer

Corpus:

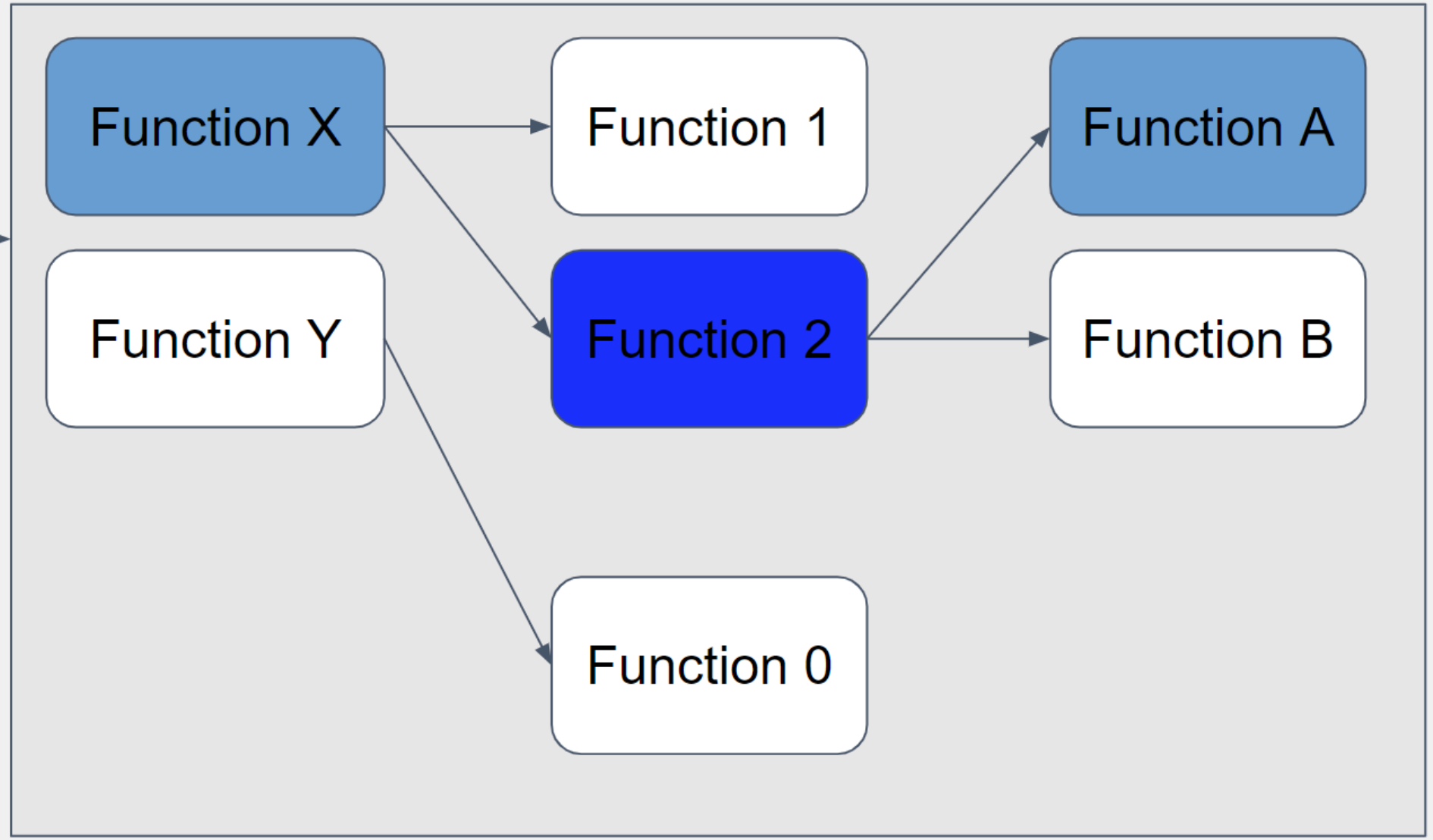
1. X
2. **X2**

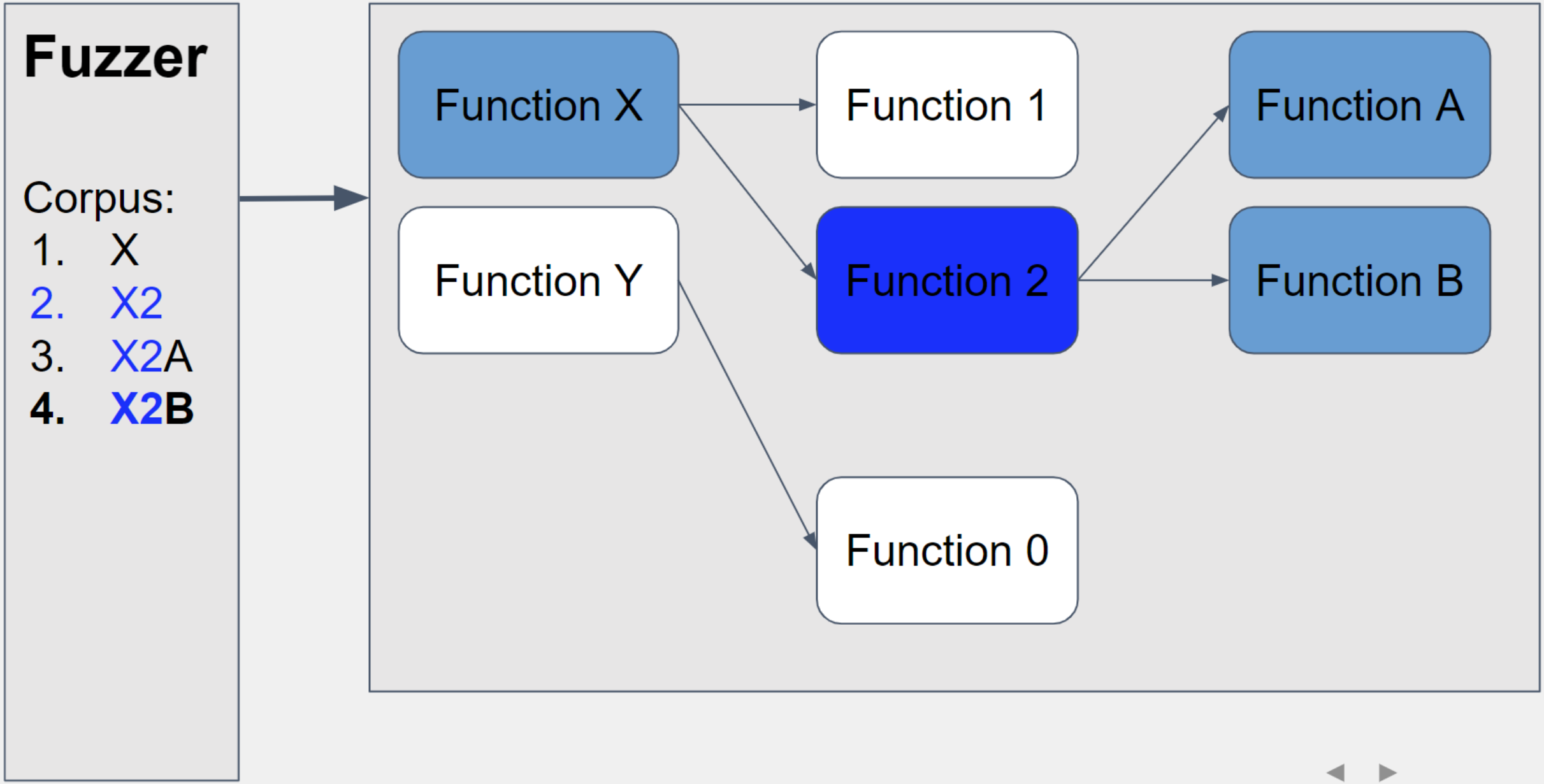


Fuzzer

Corpus:

1. X
2. X2
3. **X2A**




Fuzzer
Corpus:
1. X
2. X2
3. X2A
4. X2B
Function X
Function Y
Function 1
Function 2
Function 0
Function A
Function B

More granularity than functions - basic blocks

```
w = 0;
x = x + y;
y = 0;
if( x > z)
  {
    y = x;
    x++;
  }
else
  {
    y = z;
    z++;
  }
w = x + z;
```

Source Code

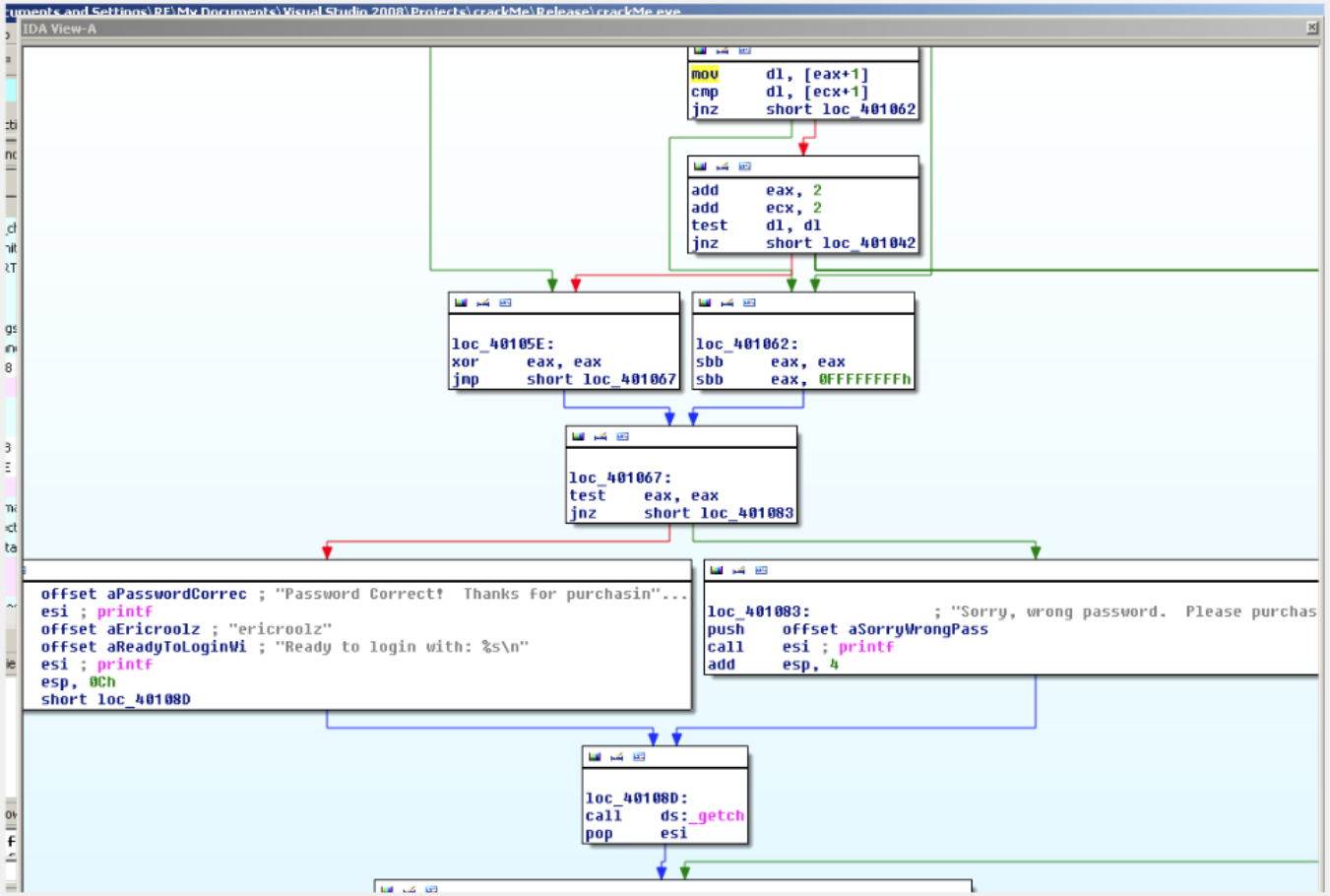
```
w = 0;
x = x + y;
y = 0;
if( x > z)
```

```
y = x;
x++;
```

```
y = z;
z++;
```

```
w = x + z;
```

Basic Blocks



Feedback based fuzzing

- "Observe" program to see if a new input (mutated from corpus) reaches new code path
  - This is being done by adding code in the compile process which tracks which ~~functions~~ **basic blocks** get called in what order

Coverage-guiding in action

The following code wants "ABCD" input:

```
if input[0] == 'A' {
    if input[1] == 'B' {
        if input[2] == 'C' {
            if input[3] == 'D' {
                slice[input[4]] = 1  // out-of-bounds here
}}}}
```

Blind generation needs O(2^8^4) = O(2^32) tries.

Corpus progression:

```
0. {}
1. {"A"}
2. {"A", "AB"}
3. {"A", "AB", "ABC"}
4. {"A", "AB", "ABC", "ABCD"}
```

Coverage-guided fuzzer needs O(4 * 2^8) = O(2^10) tries.

Basic Block based Code Coverage in AFL

- Using a "bloom filter" (byte array)
- Compare bloom filter content after every newly generated input

At each basic block, add:

```
cur_location = (block_address >> 4) ^ (block_address << 8);

shared_mem[cur_location ^ prev_location]++;

prev_location = cur_location >> 1;
```

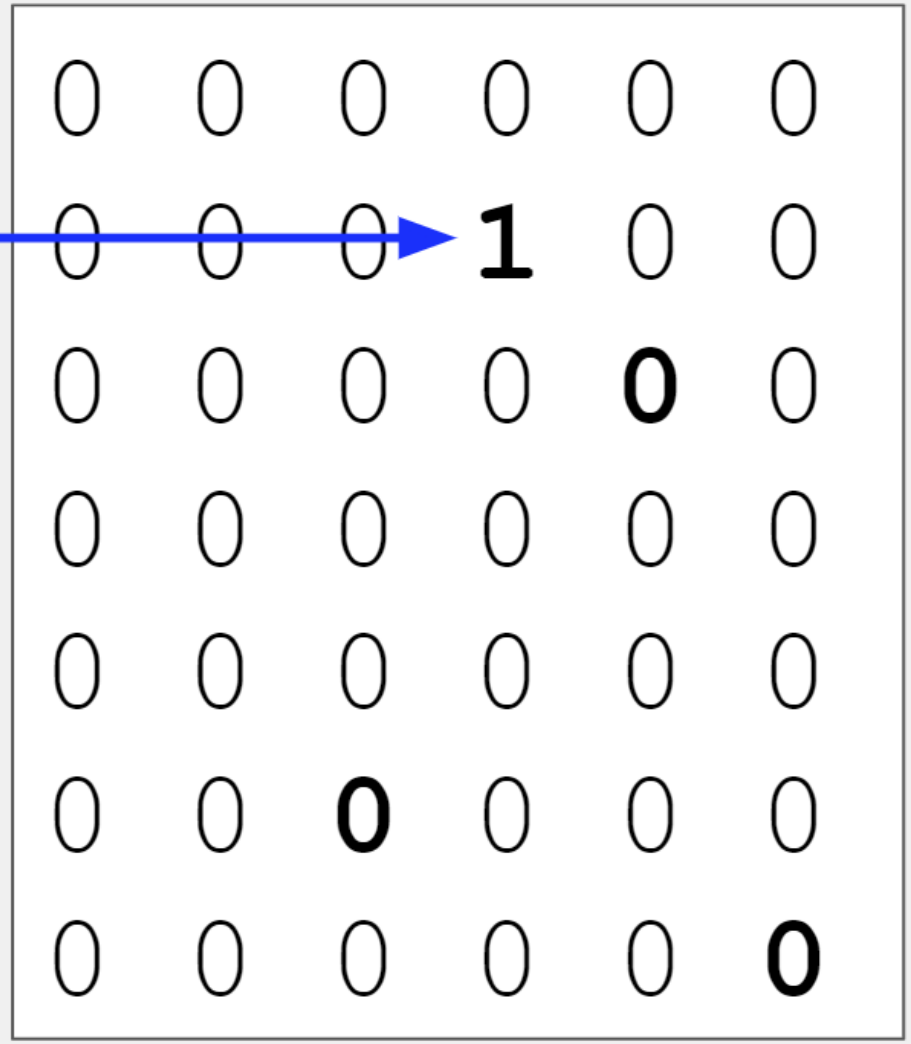
```
if input[0] == 0x41
```

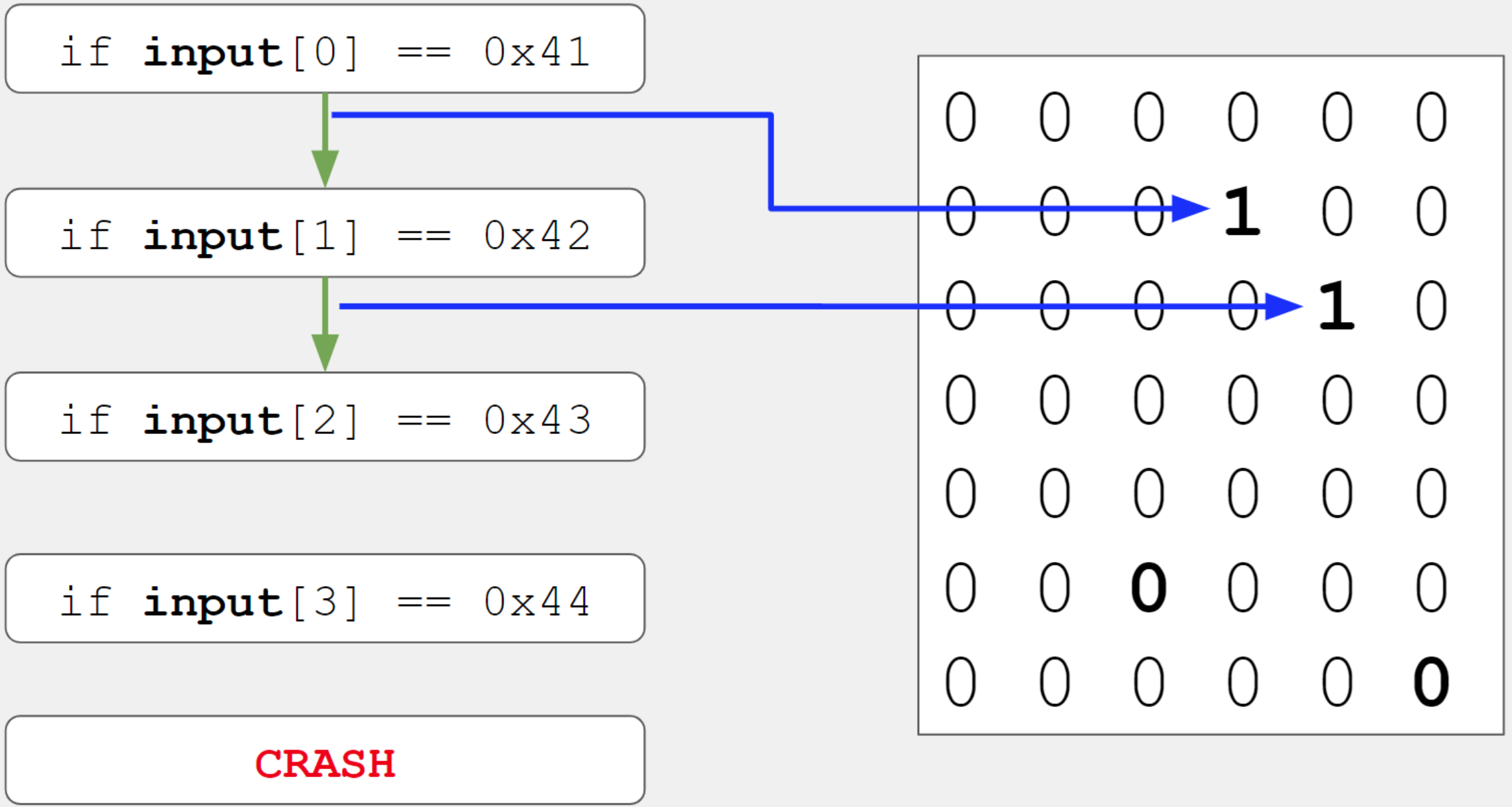
```
if input[1] == 0x42
```

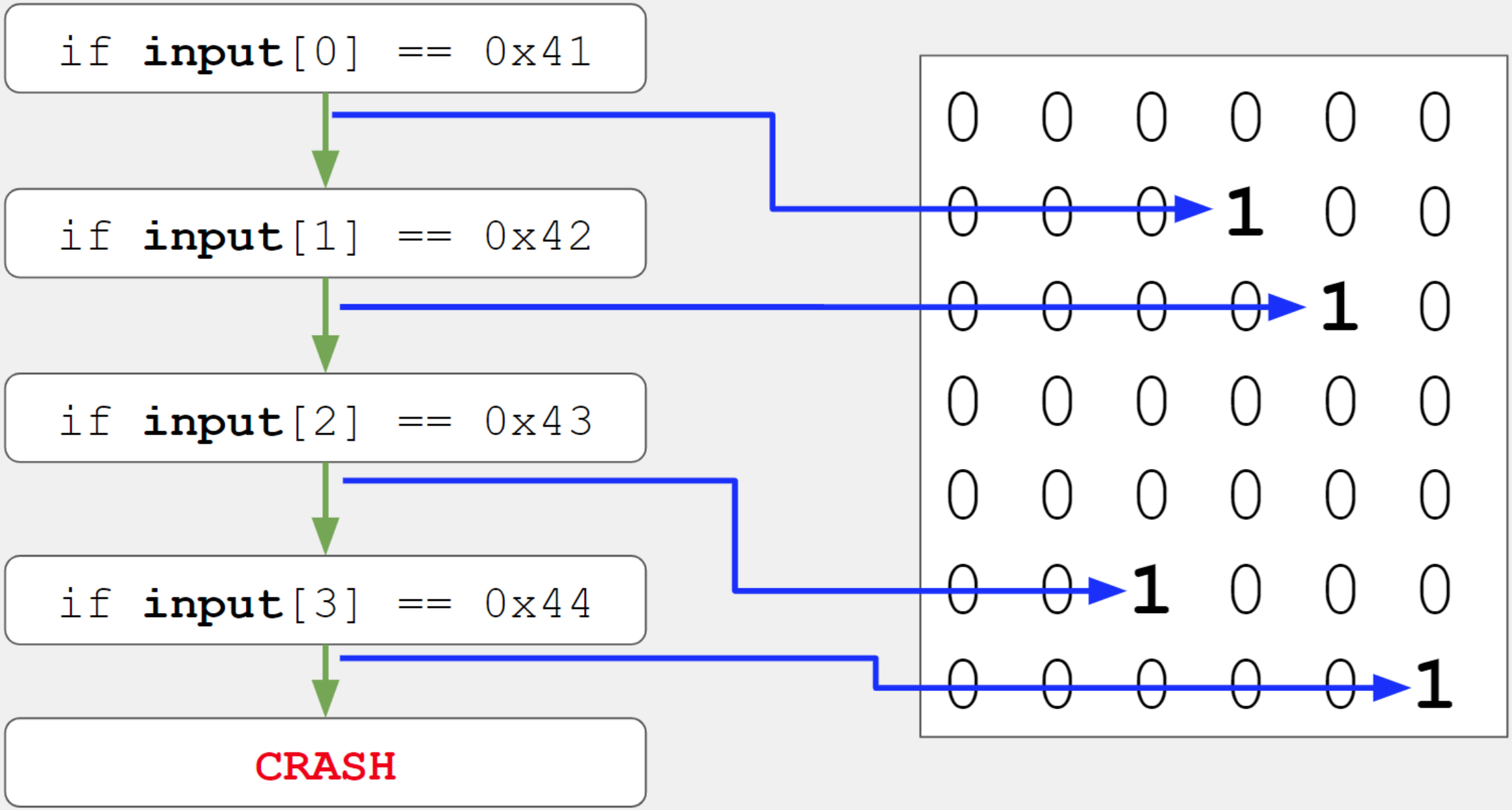
```
if input[2] == 0x43
```

```
if input[3] == 0x44
```

CRASH




if input[0] == 0x41
if input[1] == 0x42
if input[2] == 0x43
if input[3] == 0x44
CRASH
0 0 0 0 0 0
0 0 0 1 0 0
0 0 0 0 1 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0


if input[0] == 0x41
if input[1] == 0x42
if input[2] == 0x43
if input[3] == 0x44
CRASH
0 0 0 0 0 0
0 0 0 1 0 0
0 0 0 0 1 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 1 0 0 0
0 0 0 0 0 1

```
109         24 :             } else if (a == 0xFB2Au) { /* SHIN WITH SHIN DOT */
110          0 :                 *ab = 0xFB2Cu;
111          0 :                 found = true;
112         24 :             } else if (a == 0xFB2Bu) { /* SHIN WITH SIN DOT */
113          0 :                 *ab = 0xFB2Du;
114          0 :                 found = true;
115            :             }
116         35 :             break;
117            :         case 0x05BFu: /* RAFE */
118         49 :             switch (a) {
119            :             case 0x05D1u: /* BET */
120         12 :                 *ab = 0xFB4Cu;
121         12 :                 found = true;
122         12 :                 break;
123            :             case 0x05DBu: /* KAF */
124         11 :                 *ab = 0xFB4Du;
125         11 :                 found = true;
126         11 :                 break;
127            :             case 0x05E4u: /* PE */
128         14 :                 *ab = 0xFB4Eu;
129         14 :                 found = true;
130         14 :                 break;
131            :             }
132         49 :             break;
133            :         case 0x05C1u: /* SHIN DOT */
134         22 :             if (a == 0x05E9u) { /* SHIN */
135         12 :                 *ab = 0xFB2Au;
136         12 :                 found = true;
137         10 :             } else if (a == 0xFB49u) { /* SHIN WITH DAGESH */
138          0 :                 *ab = 0xFB2Cu;
139          0 :                 found = true;
140            :             }
141         22 :             break;
142            :         case 0x05C2u: /* SIN DOT */
143         22 :             if (a == 0x05E9u) { /* SHIN */
144         10 :                 *ab = 0xFB2Bu;
145         10 :                 found = true;
146         12 :             } else if (a == 0xFB49u) { /* SHIN WITH DAGESH */
147          0 :                 *ab = 0xFB2Du;
148          0 :                 found = true;
149            :             }
```

Picture Source:

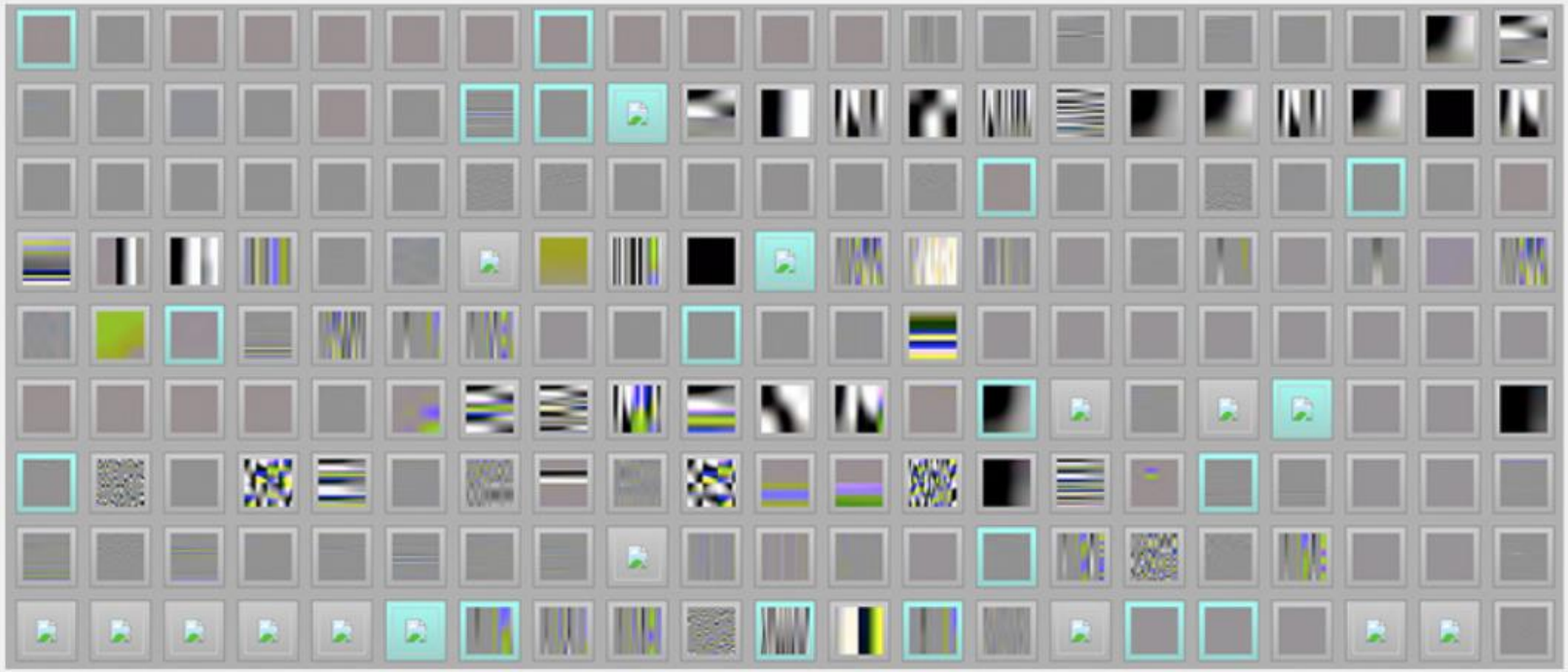
"Circumventing Fuzzing Roadblocks with Compiler Transformations", lafintel

November 07, 2014

Pulling JPEGs out of thin air

This is an interesting demonstration of the capabilities of afl; I was actually pretty surprised that it worked!

```
$ mkdir in_dir
$ echo 'hello' >in_dir/hello
$ ./afl-fuzz -i in_dir -o out_dir ./jpeg-9a/djpeg
```



Fuzzing Problems

Fuzzing Problems

- "Bit flips" only get you this far
- afl:
  - Sequential bit flips with varying lengths and stepovers,
  - Sequential addition and subtraction of small integers,
  - Sequential insertion of known interesting integers (0, 1, INT_MAX, UINT_MAX, 127, 129, etc),
  - With deterministic fuzzing out of the way, the non-deterministic steps include:
    - stacked bit flips, insertions, deletions, arithmetics, and splicing of different test cases.
- Good to identify basic blocks or bugs like:

```
malloc(user_data_size) ...
if a > 100 ...
switch(a) ...
```

Fuzzing problems

low probability of catching:

```
if a == 0x31337
if a == "CONNECT"
```

Fuzzing problems

low probability of catching:

```
if a == 0x31337
if a == "CONNECT"
```

Solutions:

- wordlists
- translate into bytewise compare
- symbolic execution <3

Fuzzing problems

low probability of catching:

```
if (int32) a == 0x31337
if (string) a == "CONNECT"
```

Solutions:

- wordlists
  - "CONNECT", "SEND", "RECEIVE", "OPTIONS"
  - use *strings* commands on the binary
- translate into bytewise compare
  - transform string comparison to per-byte (LD_PRELOAD, code transformation via compiler plugin, ...)
  - if (a[0] == 0x37) { if (a[1] == 0x13) { if (a[2] == 0x03) { ...
- symbolic execution <3
  - constraint solving in code via symbolic execution (angr, KLEE)

Symbolic Execution

- Translate compiled commands (assembly) into a higher-leverl language (e.g. VEX)
- Perform reasoning on it
- Use constraint solver to reach certain code paths

- Problems:
  - state explosion (computational power increases exponentially with code size)
  - uncertain time constraints (try to solve "if md5(input) == 0x53453453453 4")

Demo

DARPA CGC

CGC

DARPA Cyber Grand Challenge 2016

- Like the autonomous car challenge
- Teams create an autonomous system to attack and defend programs
  - No human interaction. Air-gapped for 2 days.
- Programs are not real x86, but a more simplistic version
- Find bugs
  - Patch bugs in your teams computers
  - Exploit bugs in the other team computers
- Some serious HW (one rack per team, ~1000 cores, 16TB RAM)
- Finals @ Defcon Las Vegas 2016 (I was there!)

CDC

DARPA Grand Challenge 2004 - Self driving cars

Less well-known is the 2004 DARPA Grand Challenge, the year prior, in which no vehicle finished. In fact, no vehicle made it further than 7 miles. Most vehicles just died altogether.

Wired has a pretty neat oral history of the 2004 DARPA Grand Challenge. It's short and worth a quick read.

The most impressive aspect of the 2004 race, really, is that there even was a 2005 race. After watching every vehicle fail in 2004, DARPA threw down the gauntlet again in 2005, and the rest is history.

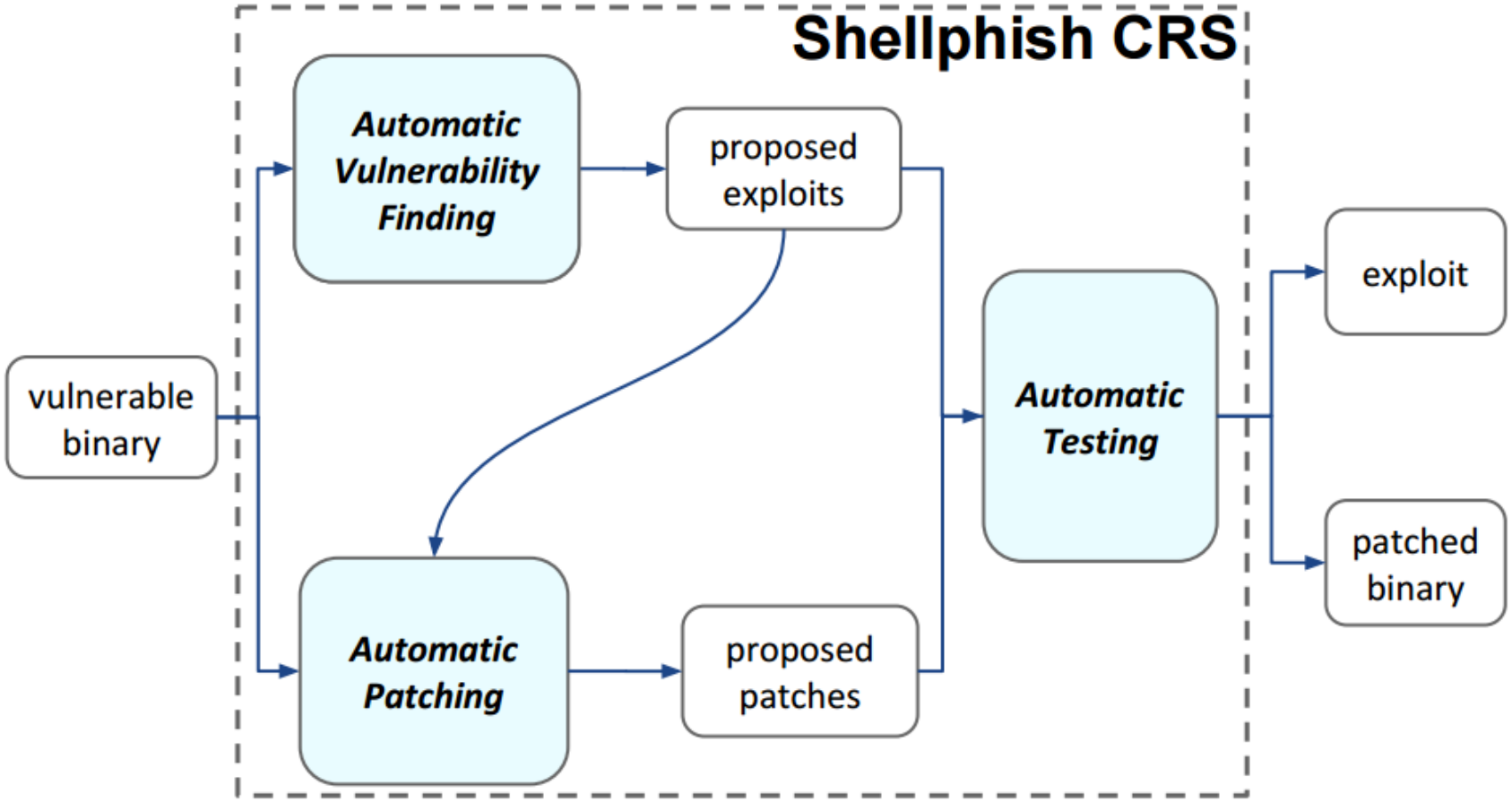
> *A reporter asked, "Well, what are you gonna do?" I said, "We're gonna do it again, and this time it's going to be a $2 million prize." It was so successful and yet so not successful, I had to do it again.*

The second competition of the DARPA Grand Challenge began at 6:40am on October 8, 2005. ***All but one of the 23 finalists*** *in the 2005 race surpassed the 11.78 km (7.32 mi) distance* ***completed by the best vehicle in the 2004 race. Five vehicles successfully completed the 212 km (132 mi) course***

Clockwise from top left: Axion Racing's Jeep Grand Cherokee; "Sandstorm," a stripped-down self-driving Humvee from Carnegie Mellon's Red Team; Team TerraMax's Oshkosh military truck; and Team Palos Verdes High School's Acura SUV, "Doom Buggy." ALAMY

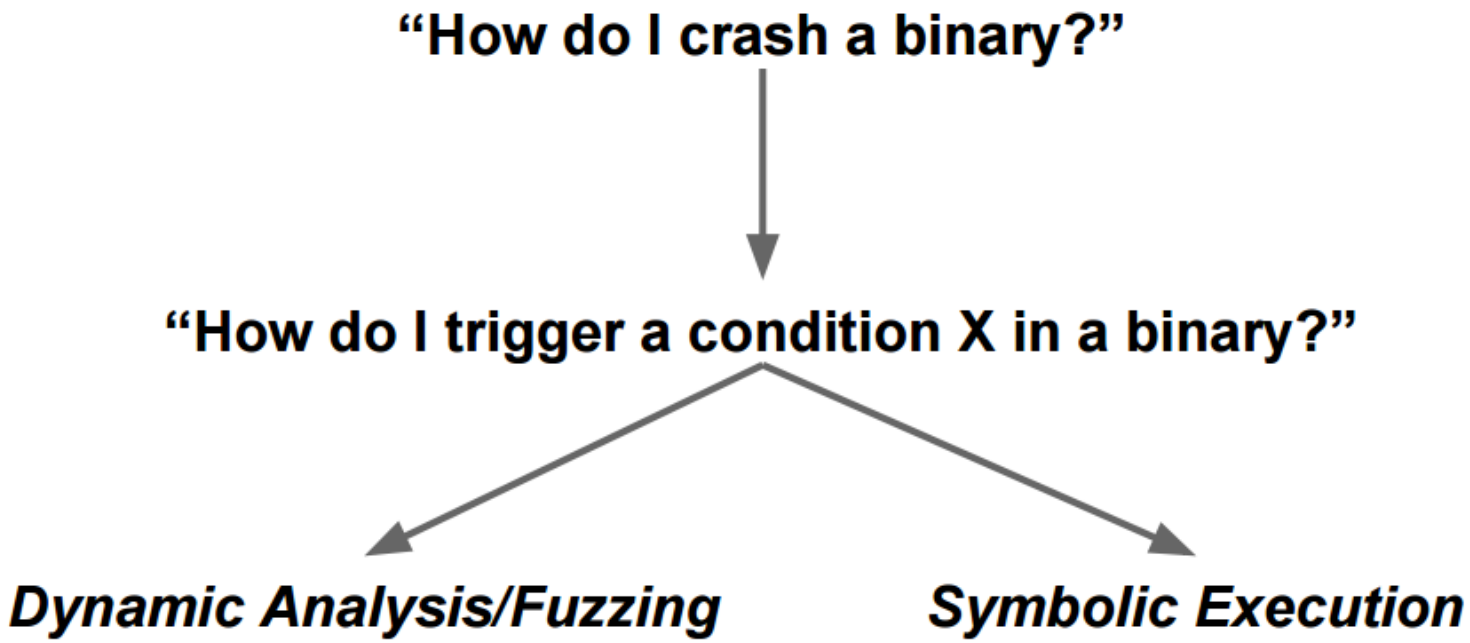
CGC Shellphish

Shellphish CRS



CGC Shellphish

Automatic Vulnerability Discovery



CGC Shellphish

Dynamic Analysis/Fuzzing

- **How do I trigger the condition: "You win!" is printed?**

```
x = int(input())
if x >= 10:
   if x < 100:
      print "You win!"
   else:
      print "You lose!"
else:
   print "You lose!"
```

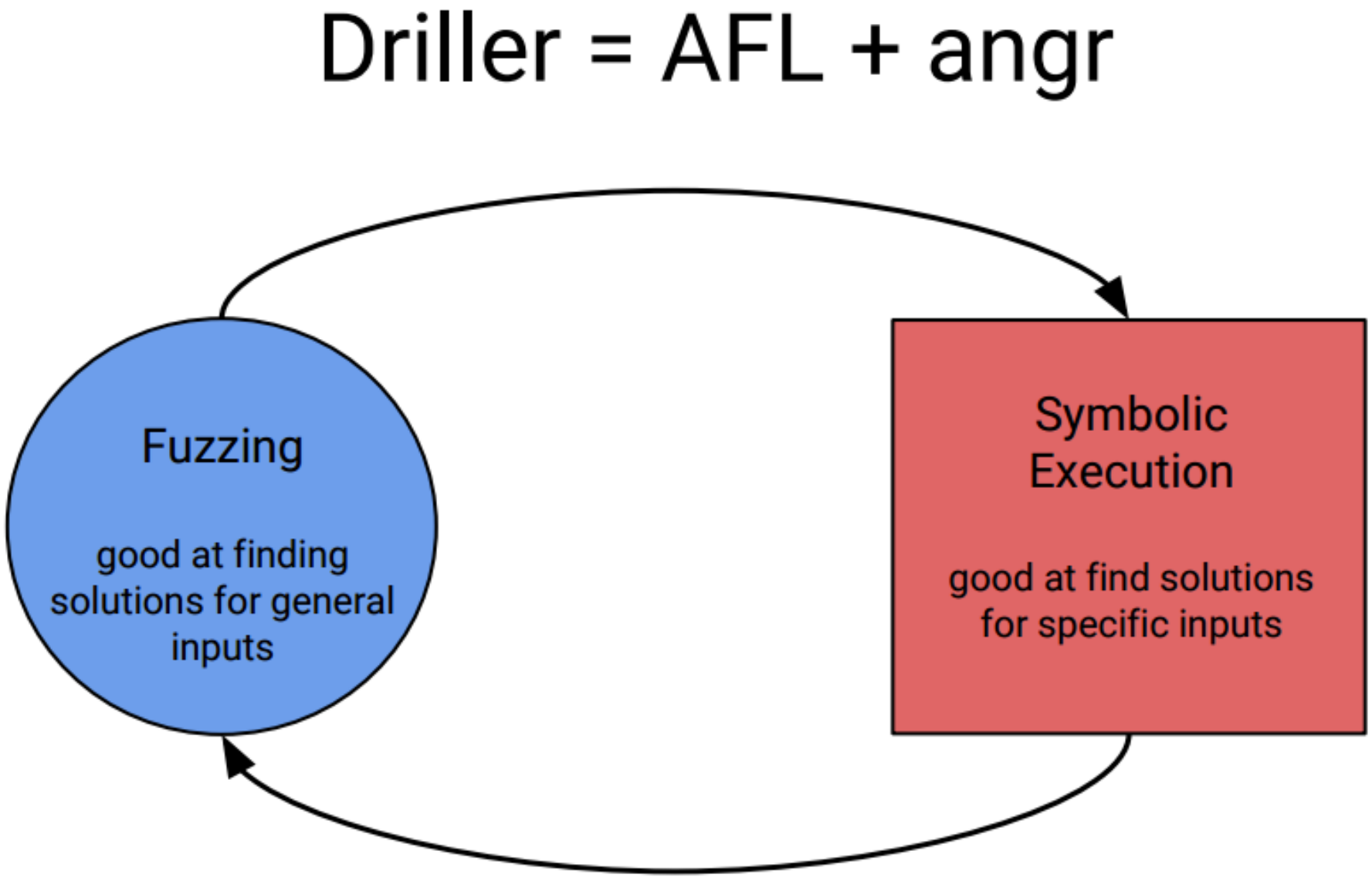
- Try "1" → *"You lose!"*
- Try "2" → *"You lose!"*
- …
- Try "10" → *"You win!"*

CGC Shellphish
Dynamic Analysis/Fuzzing

- **How do I trigger the condition: "You win!" is printed?**

```
x = int(input())
if x >= 10:
   if x == 123456789012:
      print "You win!"
   else:
      print "You lose!"
else:
   print "You lose!"
```

CGC Shellphish



Compiler Flags

Compiler Flags

Compiler options to enable advanced error detection routines

- GCC
- Clang

Will slow down the program massively

Will find bugs which do not directly lead to crash

Use together with fuzzing

Compiler Flags

AddressSanitizer (ASAN)

`-fsanitize=address`

- Fast memory error detector
- Out-of-bounds access to heap, stack, globals
- Use-after-free
- Use-after-return
- Use-after-scope
- Double free, invalid free
- For testing only (do not compile public releases with it!)

UndefinedBehaviourSanitizer (Bsan)

`-fsanitize=undefined`

- Finds various kinds of undefined behaviour
- Null ptr, signed integer overflow, …
- For testing only

Other fuzzing related things…

Intentionally break protocols

The future:

https://cayan.com/developers/blog-articles/how-to-protect-your-api-clients-against-breaking-c

```
Roughtime is like a small “chaos monkey” for protocols, where the Roughtime
server intentionally sends out a small subset of responses with various forms of
protocol error
```

Fuzzing: Recap

Fuzzing Recap

Fuzzing is:

- Finding bugs in programs
  - Especially exploitable bugs
- By bombard a program with:
  - Mutated/modified valid data
  - Generated semi-valid data

References

http://slides.com/revskills/fzbrowsers

- Browser Bug Hunting and Mobile (Syscan 360)

Shellphish:

- http://cs.ucsb.edu/~antoniob/files/hitcon_2015_public.pdf
- https://media.defcon.org/DEF%20CON%2024/DEF%20CON%2024%20presentations/DEFCON-24-Shellphish-Cyber%20Grand%20Shellphish-UPDATED.pdf