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

```
while True; do:
  cp orig.pdf iteration.pdf
  flip-random-bits.sh iteration.pdf
  xpdf iteration.pdf
done
```

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:

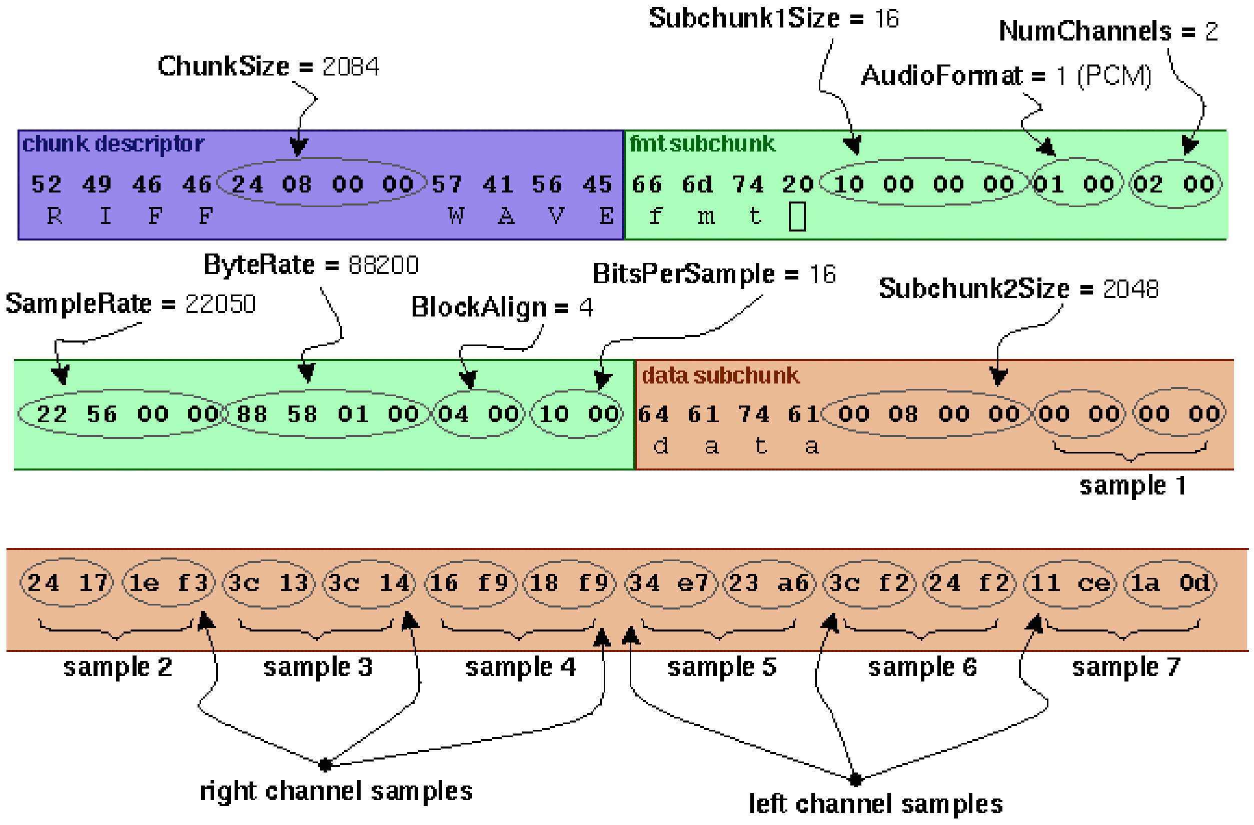
- Define new test sample based on models, templates, RFCs or documentation

Fuzzer: Mutation-based

Mutation fuzzing examples:

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

Take an input file, modify it a bit, continue


ChunkSize = 2084
Subchunk1Size = 16
NumChannels = 2
AudioFormat = 1 (PCM)
chunk descriptor
52 49 46 46 24 08 00 00 57 41 56 45
R I F F W A V E
fmt subchunk
66 6d 74 20 10 00 00 00 01 00 02 00
f m t
ByteRate = 88200
SampleRate = 22050
BlockAlign = 4
BitsPerSample = 16
Subchunk2Size = 2048
22 56 00 00 88 58 01 00 04 00 10 00
data subchunk
64 61 74 61 00 08 00 00 00 00 00 00
d a t a
sample 1
24 17 1e f3 3c 13 3c 14 16 f9 18 f9 34 e7 23 a6 3c f2 24 f2 11 ce 1a 0d
sample 2
sample 3
sample 4
sample 5
sample 6
sample 7
right channel samples
left channel samples

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

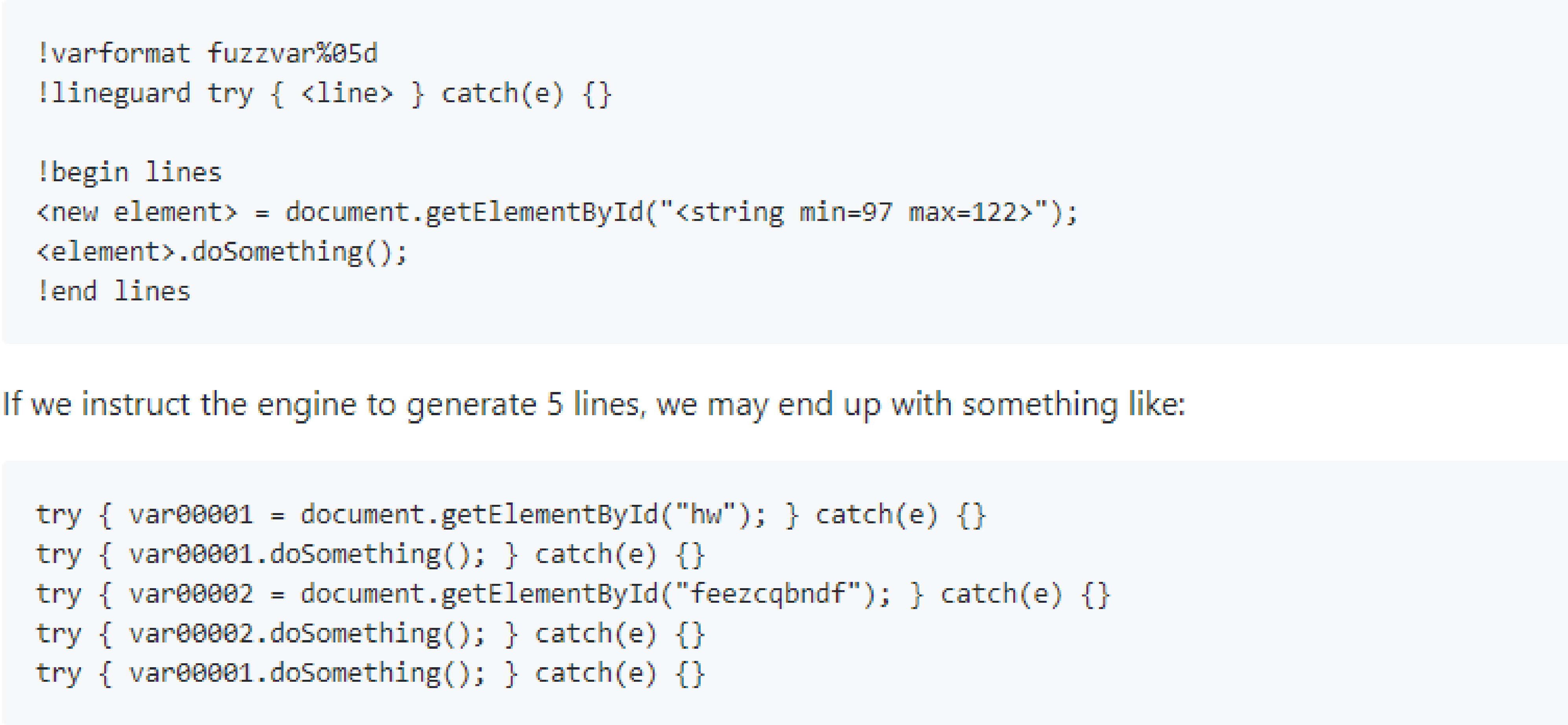
Fuzzer: Grammar-based

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

- Well Known: Peach Fuzzer

Fuzzer: Grammar-based

Domato



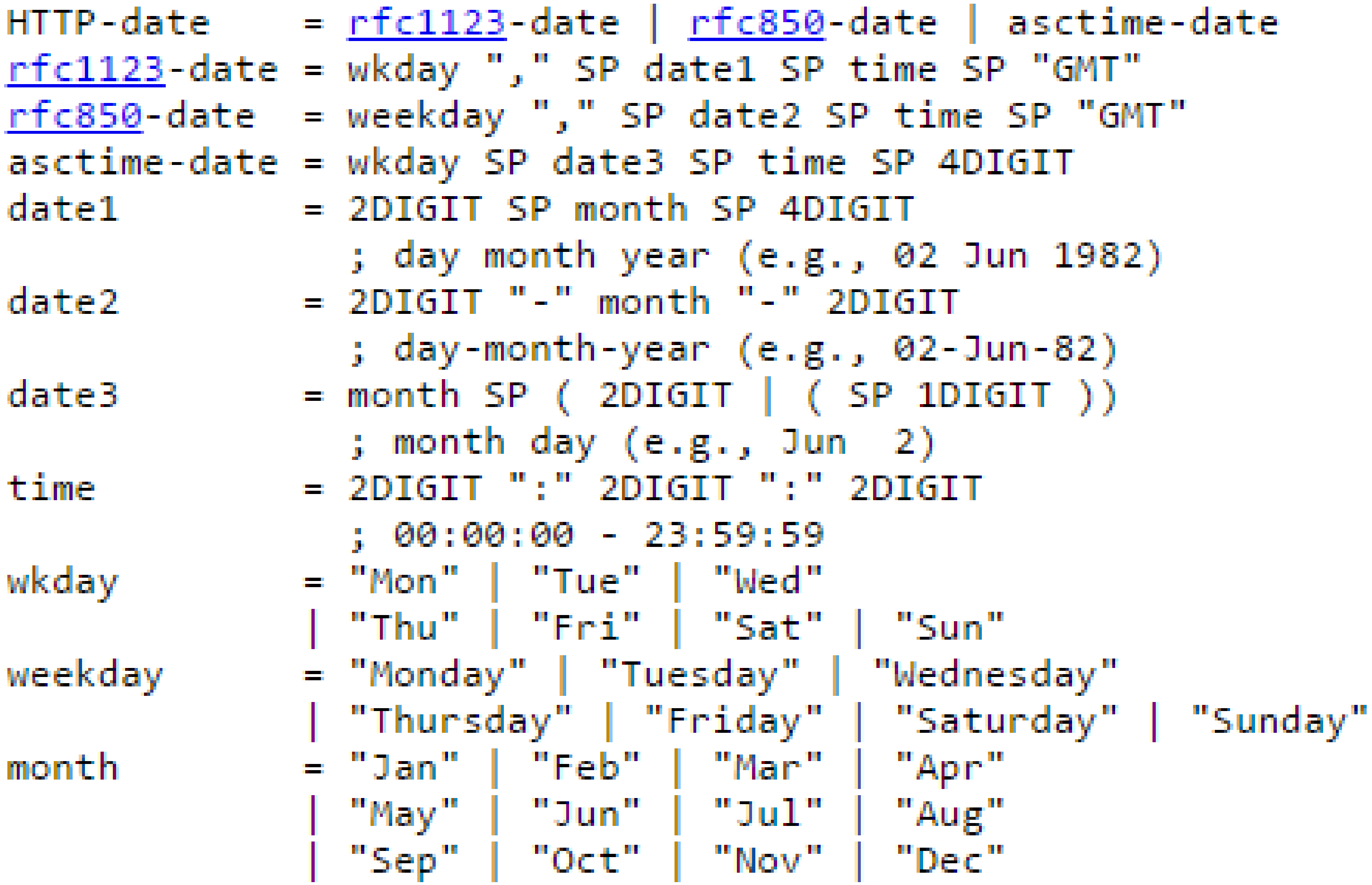
```
!varformat fuzzvar%05d
!lineguard try { <line> } catch(e) {}

!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:

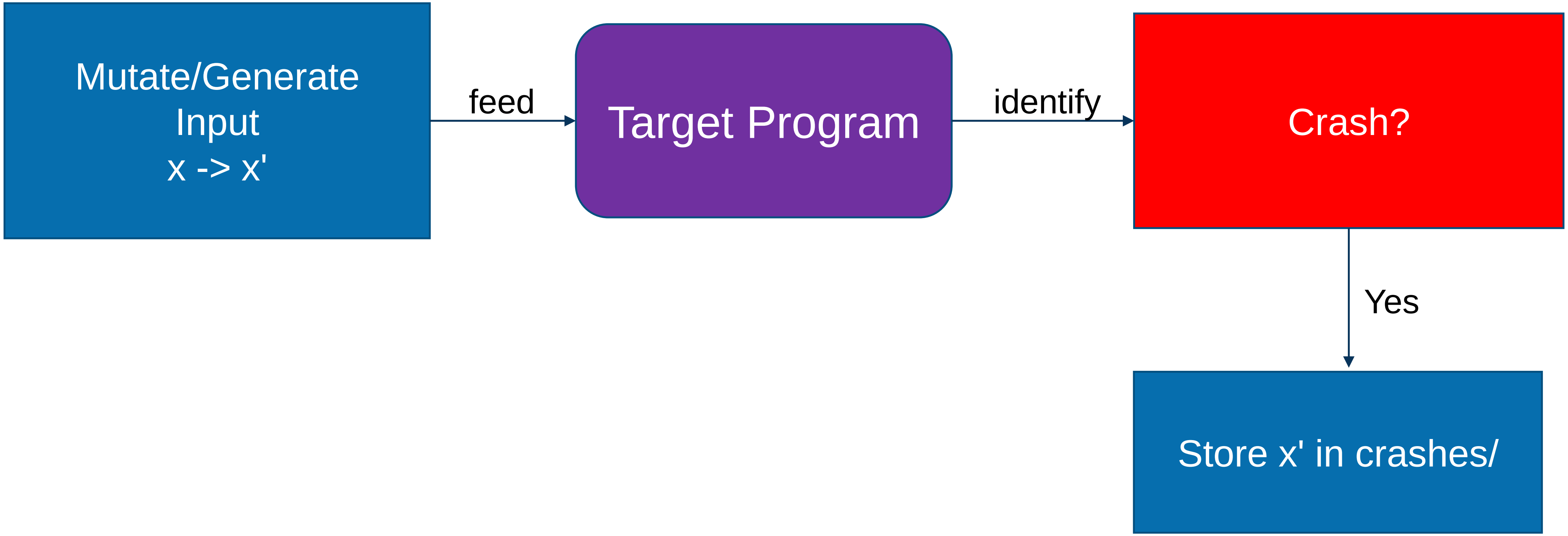
```
try { var00001 = document.getElementById("hw"); } catch(e) {}
try { var00001.doSomething(); } catch(e) {}
try { var00002 = document.getElementById("feezcqbndf"); } catch(e) {}
try { var00002.doSomething(); } catch(e) {}
try { var00001.doSomething(); } catch(e) {}
```

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



Mutate/Generate
Input
x -> x'

feed

Target Program

identify

Crash?

Yes

Store x' in crashes/

AFL

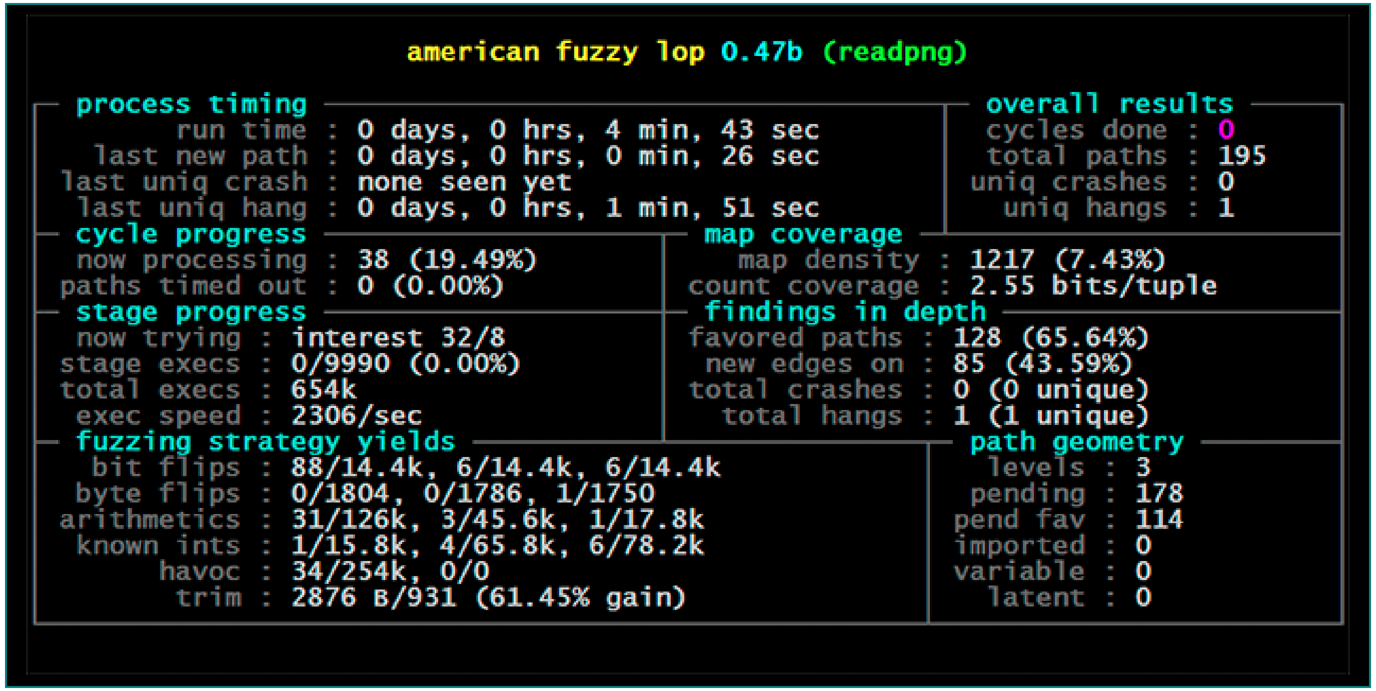
AFL

- Introduced “Code Coverage” to the masses
- Observe program to identify, IF new branches have been taken.
    - Save corresponding input file (which produces new code coverage)

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.

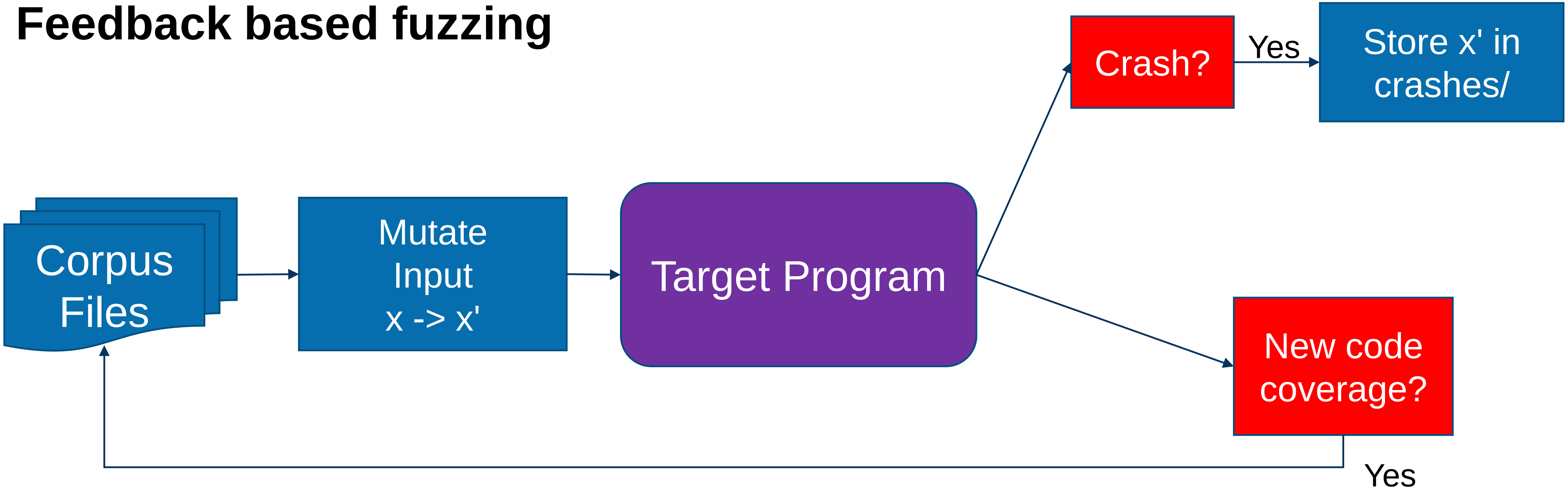


```
                   american fuzzy lop 0.47b (readpng)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 0 hrs, 4 min, 43 sec      │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 0 min, 26 sec      │  total paths : 195    │
│ last uniq crash : none seen yet                     │ uniq crashes : 0      │
│  last uniq hang : 0 days, 0 hrs, 1 min, 51 sec      │   uniq hangs : 1      │
├─ cycle progress ──────────────────┬─ map coverage ──┴───────────────────────┤
│  now processing : 38 (19.49%)     │    map density : 1217 (7.43%)          │
│ paths timed out : 0 (0.00%)       │ count coverage : 2.55 bits/tuple       │
├─ stage progress ──────────────────┼─ findings in depth ────────────────────┤
│  now trying : interest 32/8       │ favored paths : 128 (65.64%)           │
│ stage execs : 0/9990 (0.00%)      │  new edges on : 85 (43.59%)            │
│ total execs : 654k                │ total crashes : 0 (0 unique)           │
│  exec speed : 2306/sec            │   total hangs : 1 (1 unique)           │
├─ fuzzing strategy yields ─────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 88/14.4k, 6/14.4k, 6/14.4k          │    levels : 3          │
│  byte flips : 0/1804, 0/1786, 1/1750              │   pending : 178        │
│ arithmetics : 31/126k, 3/45.6k, 1/17.8k           │  pend fav : 114        │
│  known ints : 1/15.8k, 4/65.8k, 6/78.2k           │  imported : 0          │
│       havoc : 34/254k, 0/0                        │  variable : 0          │
│        trim : 2876 B/931 (61.45% gain)            │    latent : 0          │
└───────────────────────────────────────────────────┴────────────────────────┘
```

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.

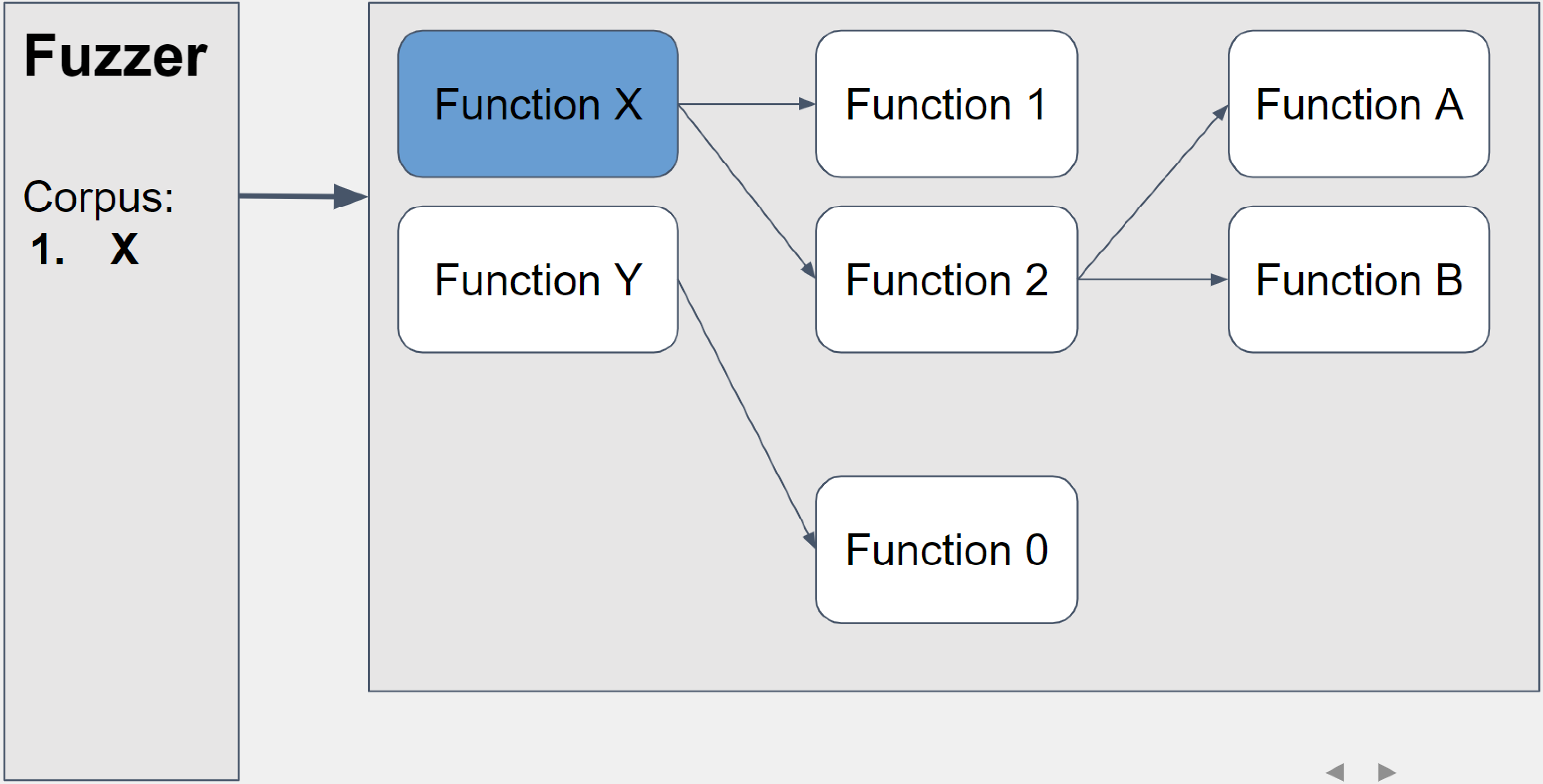
Feedback based fuzzing


Corpus Files
Mutate Input x -> x'
Target Program
Crash?
Yes
Store x' in crashes/
New code coverage?
Yes

add x' to corpus

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

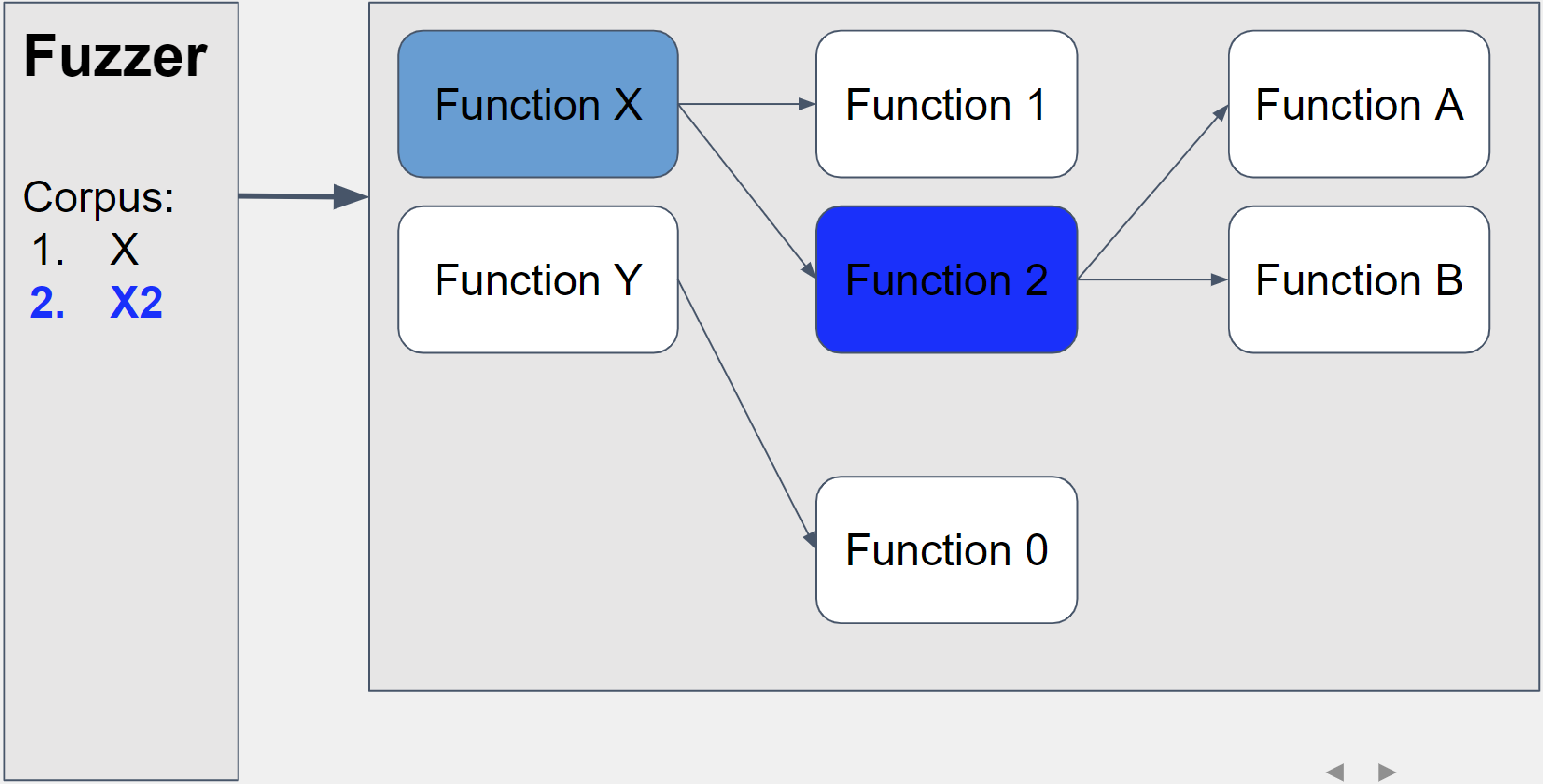


Fuzzer

Corpus:

1. **X**

Function X
Function 1
Function A
Function Y
Function 2
Function B
Function 0



Fuzzer

Corpus:

1. X
2. **X2**

Function X

Function 1

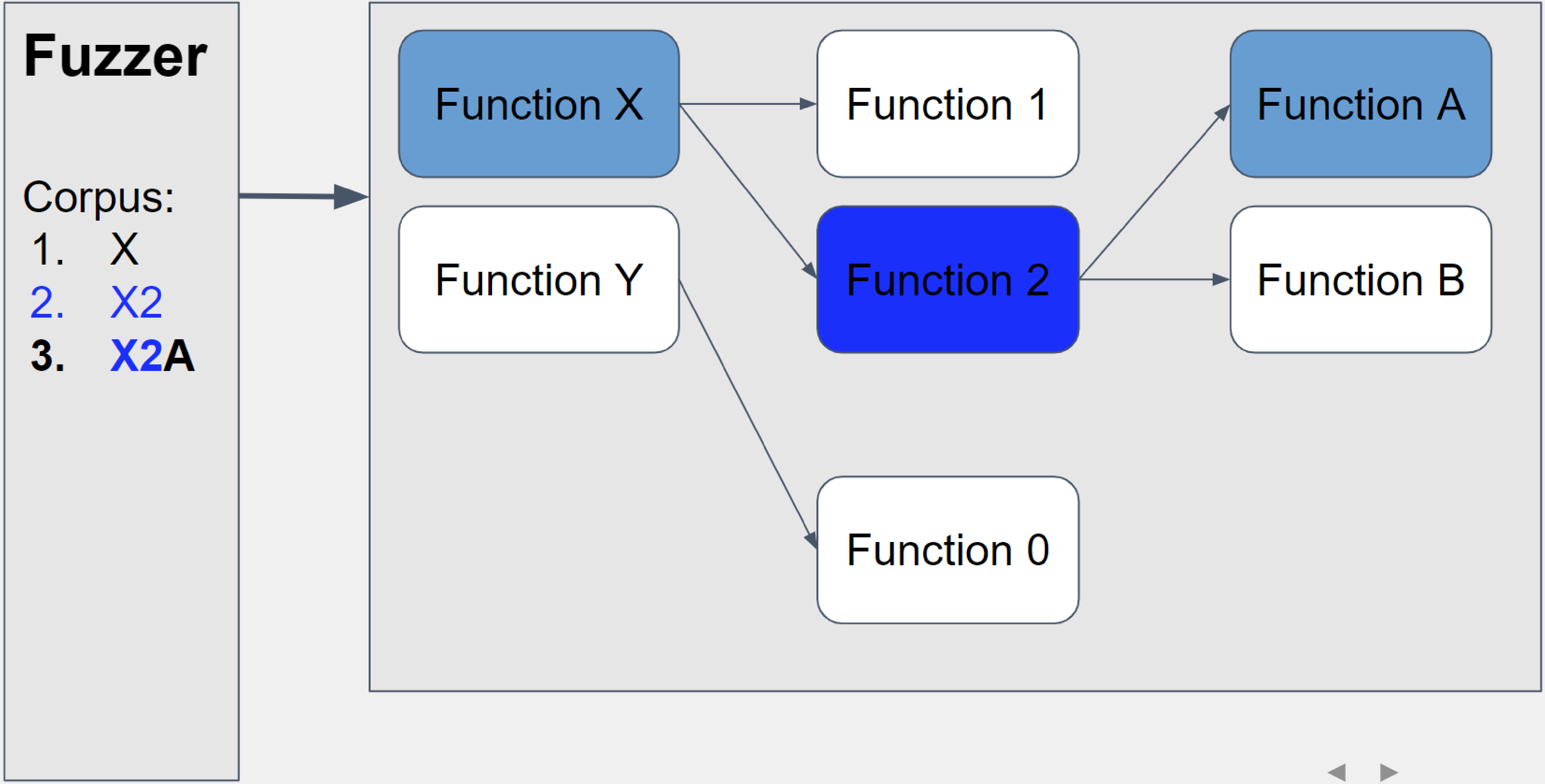
Function A

Function Y

Function 2

Function B

Function 0



Fuzzer

Corpus:

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

Function X

Function 1

Function A

Function Y

Function 2

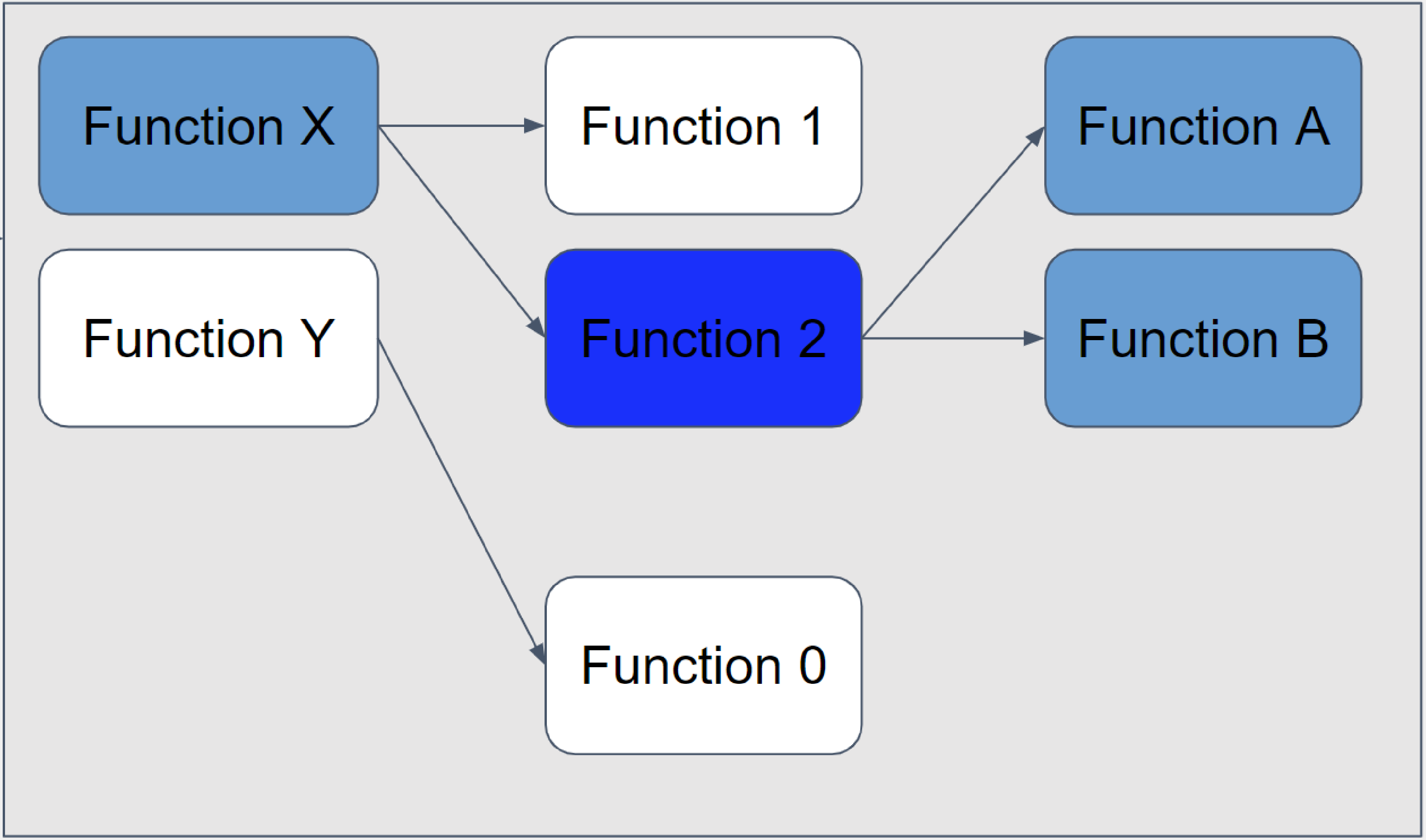
Function B

Function 0

Fuzzer

Corpus:

1. X
2. X2
3. X2A
4. **X2B**



Function X

Function 1

Function A

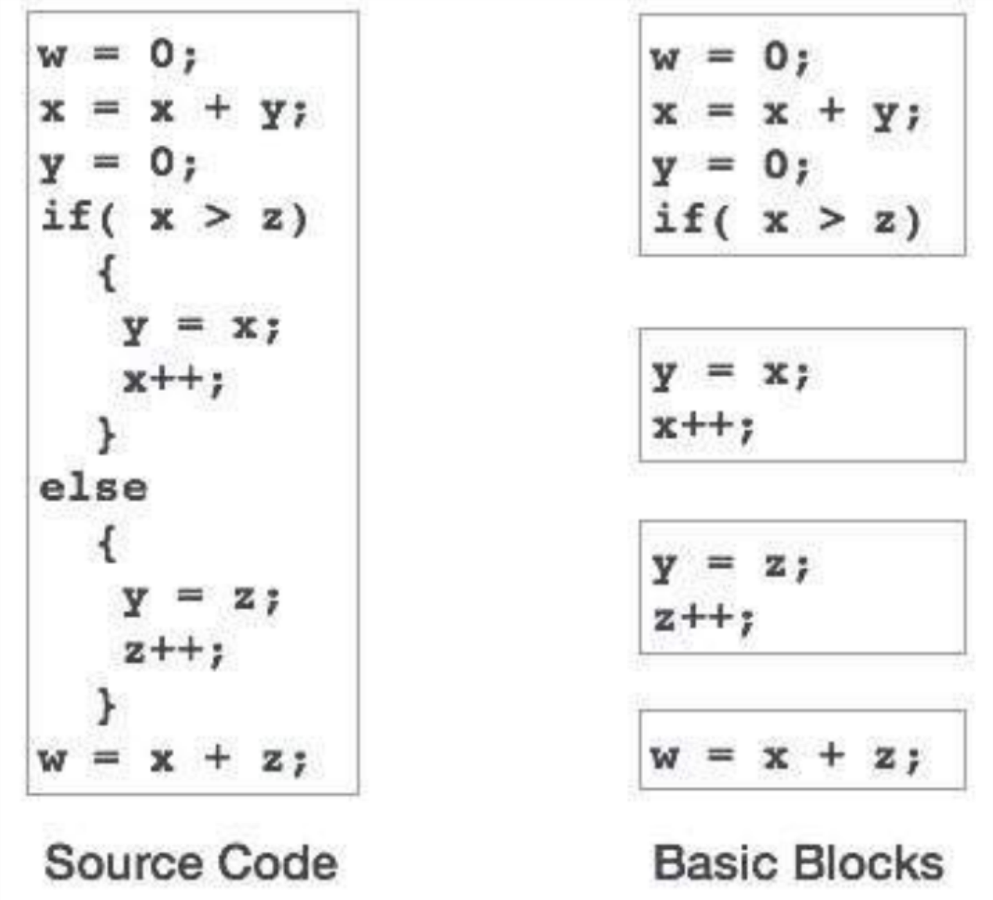
Function Y

Function 2

Function B

Function 0

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

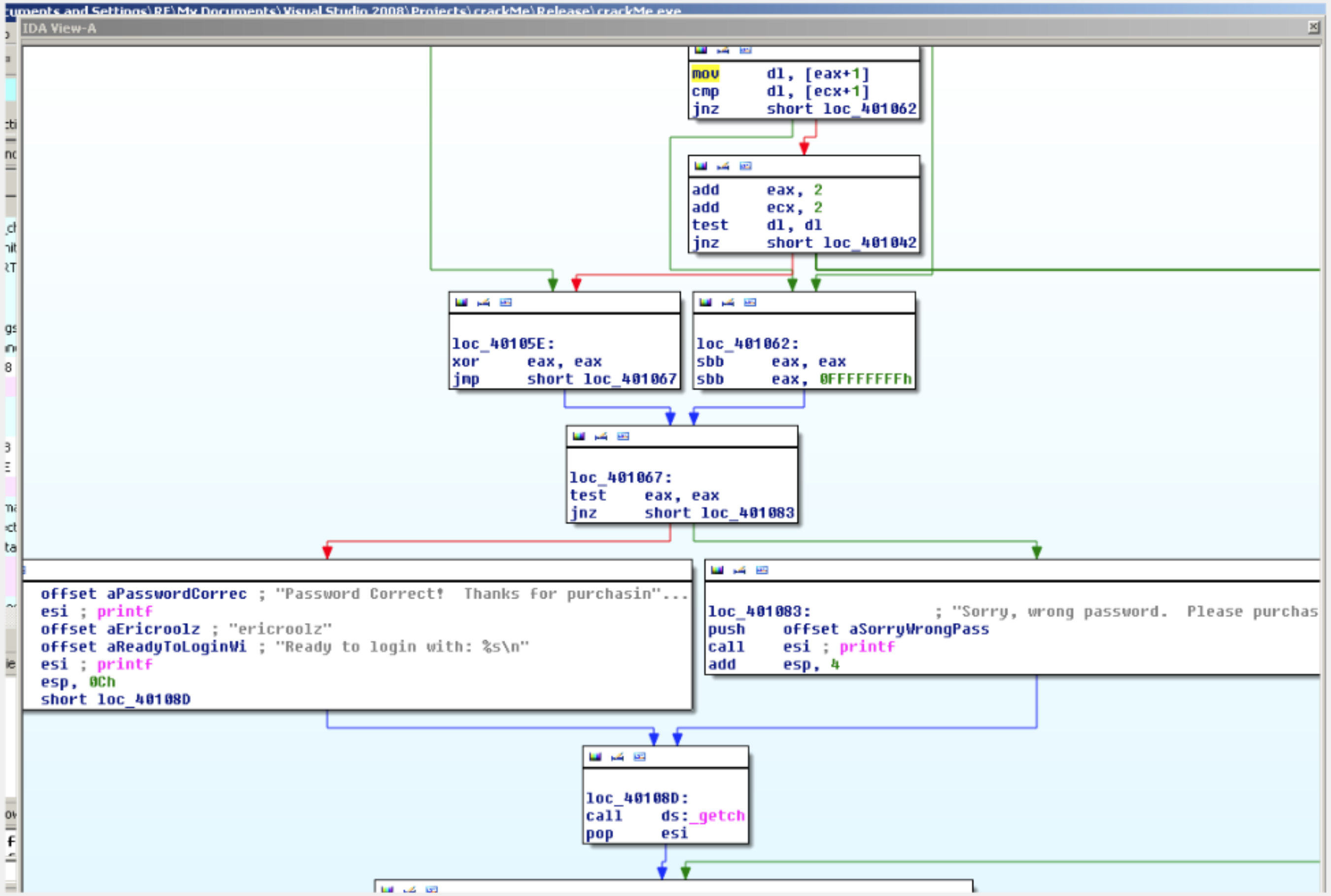
```
w = 0;
x = x + y;
y = 0;
if( x > z)
```

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

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

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

Basic Blocks



uments and Settings\RE\My Documents\Visual Studio 2008\Projects\crackMe\Release\crackMe.exe
IDA View-A

```
mov     dl, [eax+1]
cmp     dl, [ecx+1]
jnz     short loc_401062
```

```
add     eax, 2
add     ecx, 2
test    dl, dl
jnz     short loc_401042
```

```
loc_40105E:
xor     eax, eax
jmp     short loc_401067
```

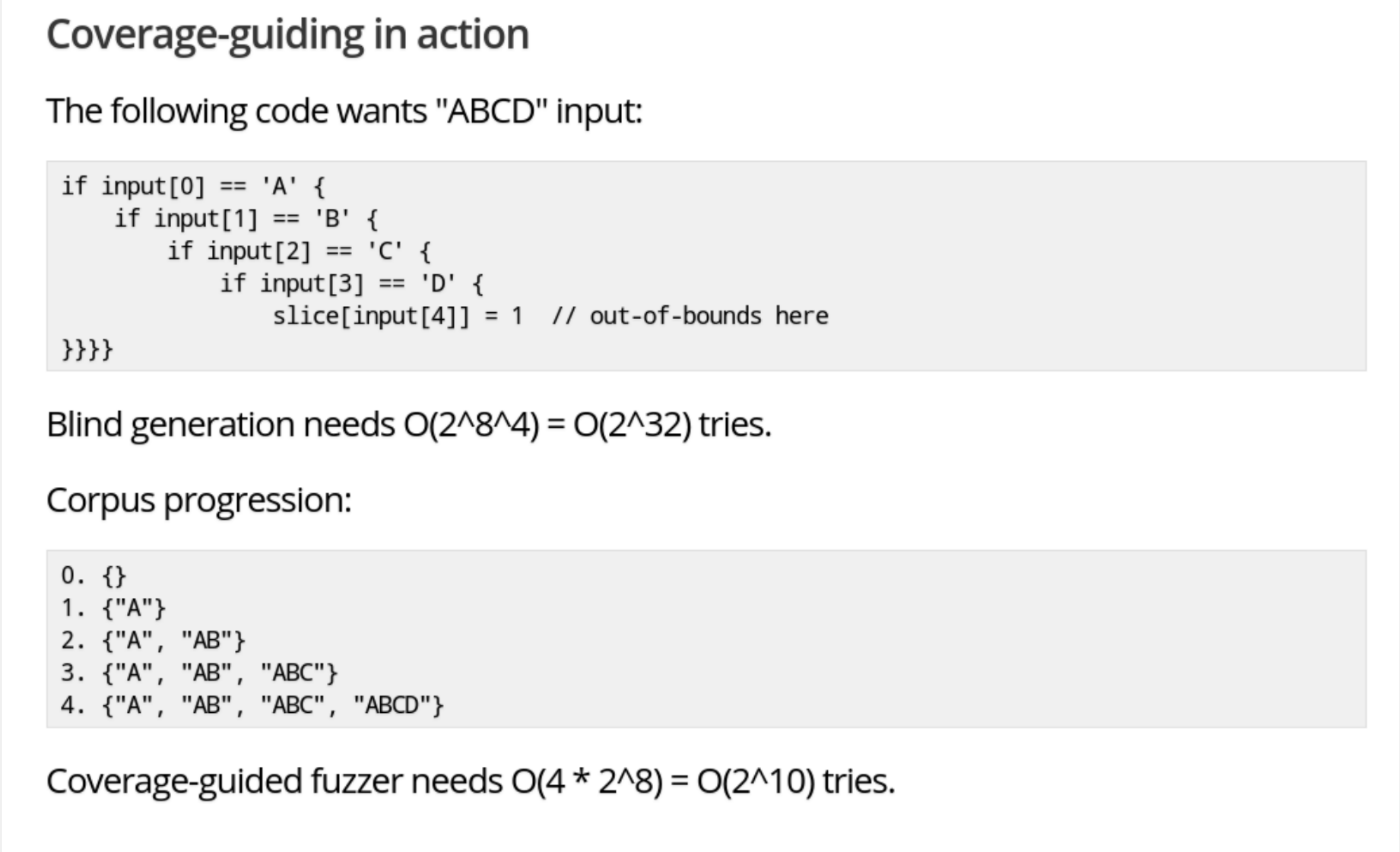
```
loc_401062:
sbb     eax, eax
sbb     eax, 0FFFFFFFFh
```

```
loc_401067:
test    eax, eax
jnz     short loc_401083
```

```
offset aPasswordCorrec ; "Password Correct!  Thanks for purchasin"...
esi ; printf
offset aEricroolz ; "ericroolz"
offset aReadyToLoginWi ; "Ready to login with: %s\n"
esi ; printf
esp, 0Ch
short loc_40108D
```

```
loc_401083:             ; "Sorry, wrong password.  Please purchas
push    offset aSorryWrongPass
call    esi ; printf
add     esp, 4
```

```
loc_40108D:
call    ds:_getch
pop     esi
```



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.

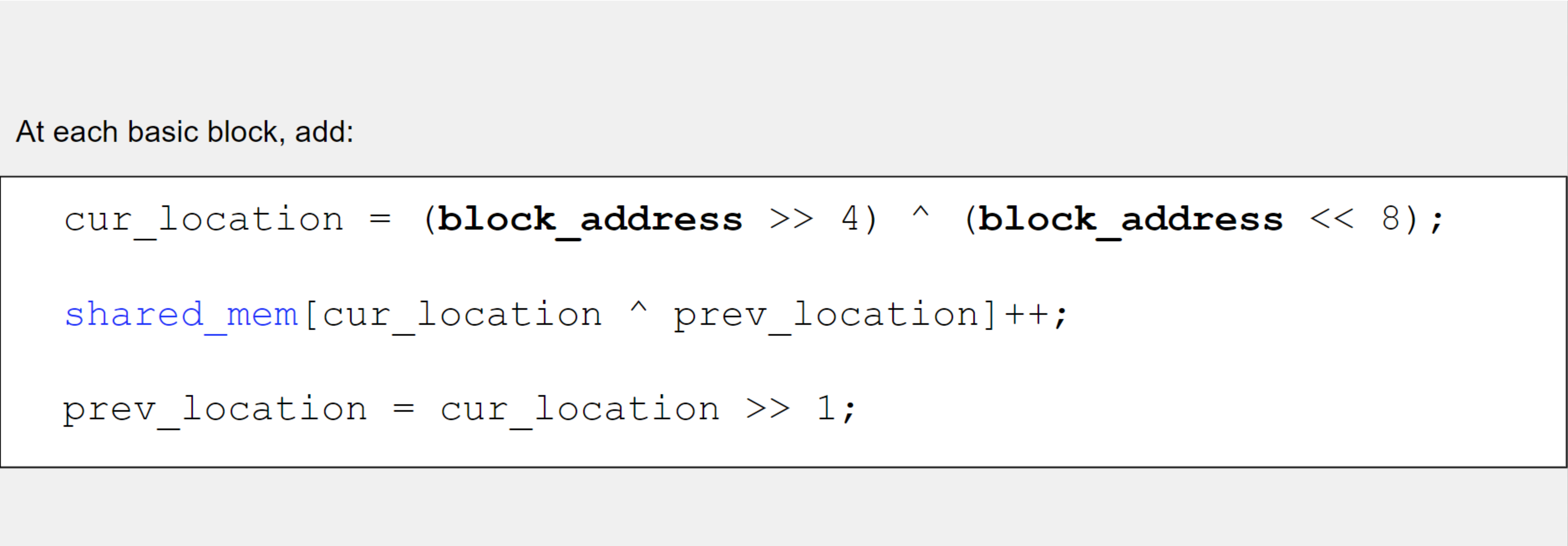
Corpus progression:

```
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

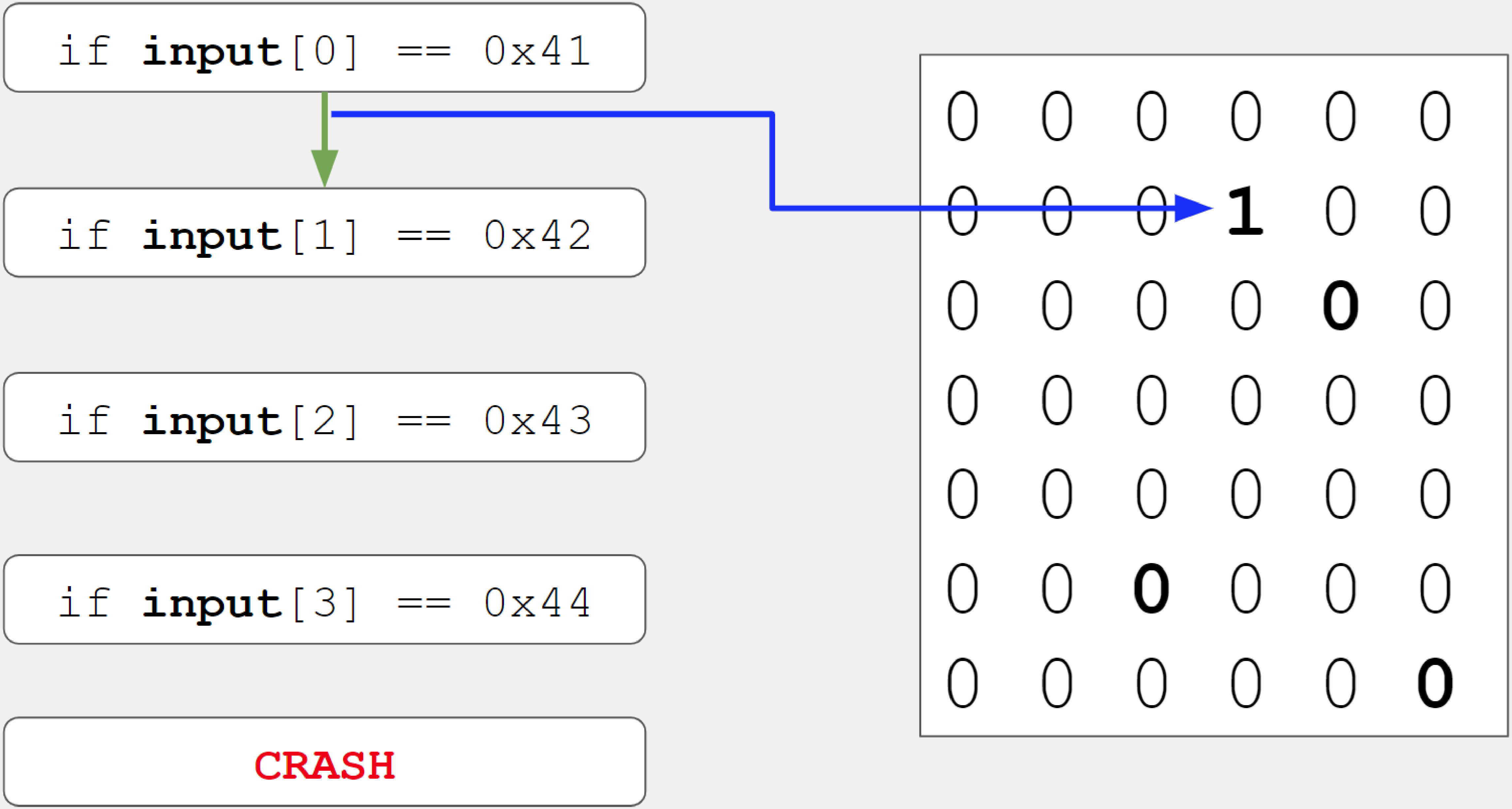


At each basic block, add:

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

shared_mem[cur_location ^ prev_location]++;

prev_location = cur_location >> 1;
```



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

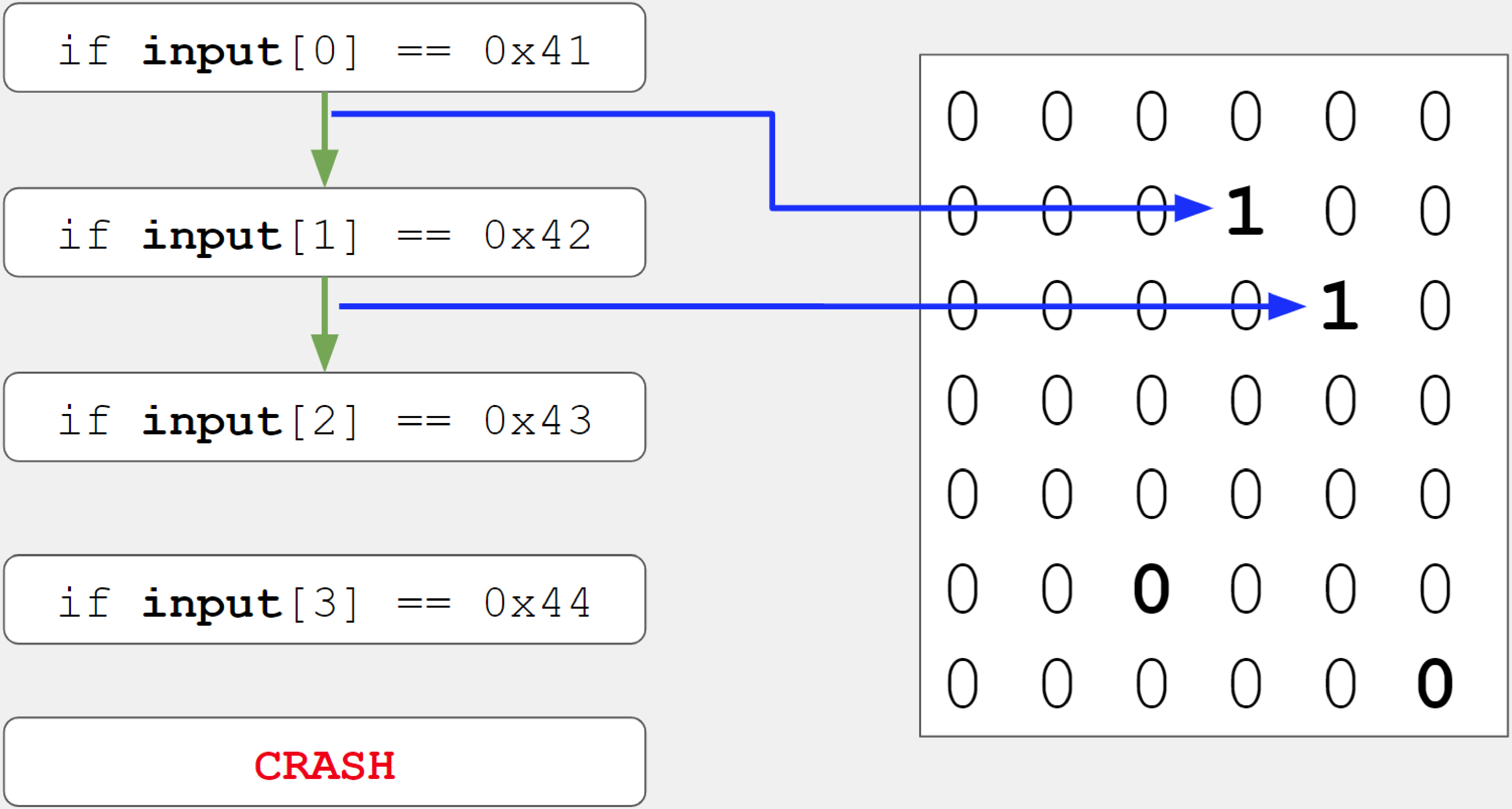
```
if input[1] == 0x42
```

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

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

CRASH

0	0	0	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	0
0	0	0	0	0	**0**



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

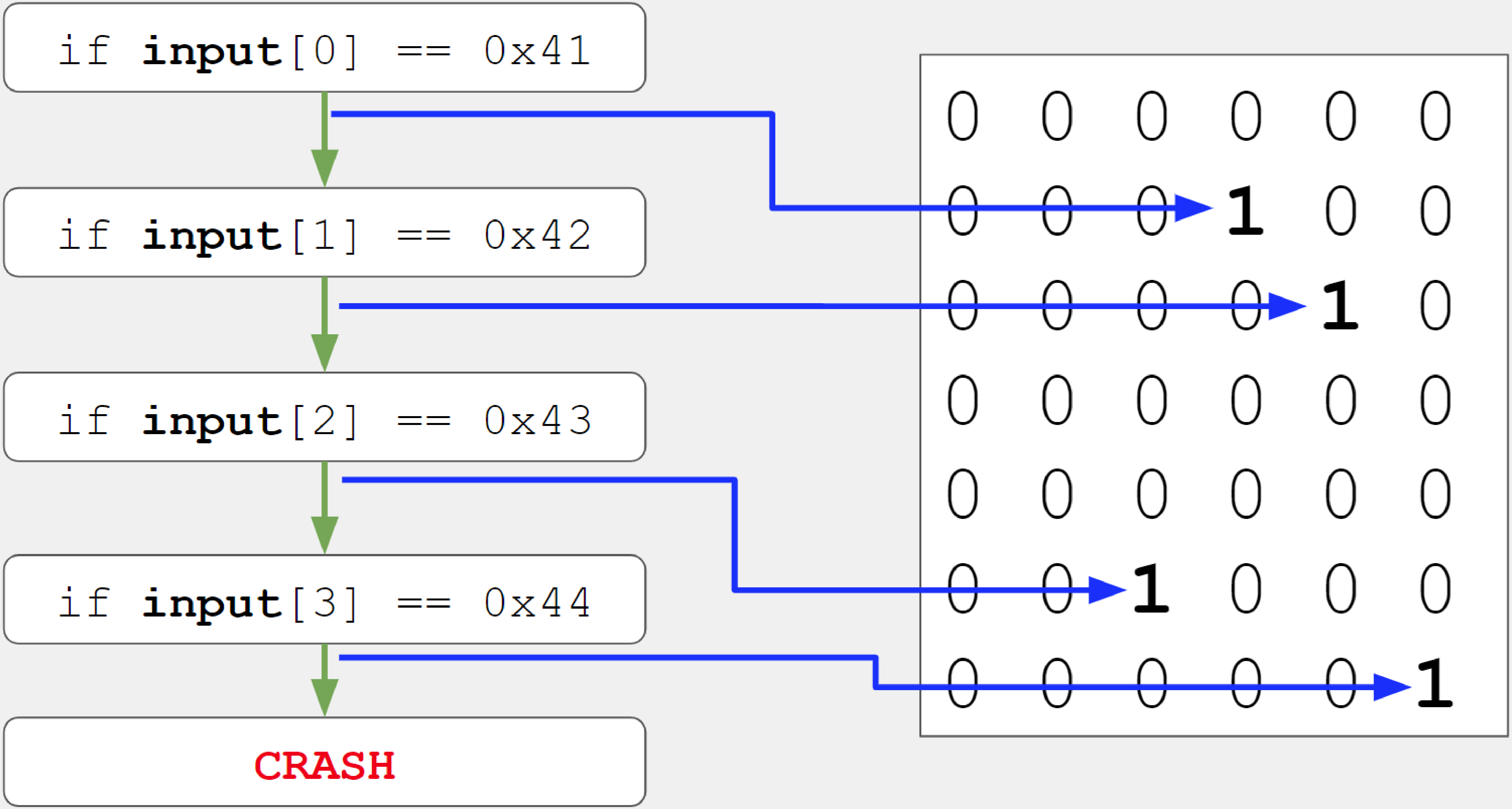
```
if input[1] == 0x42
```

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

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

CRASH

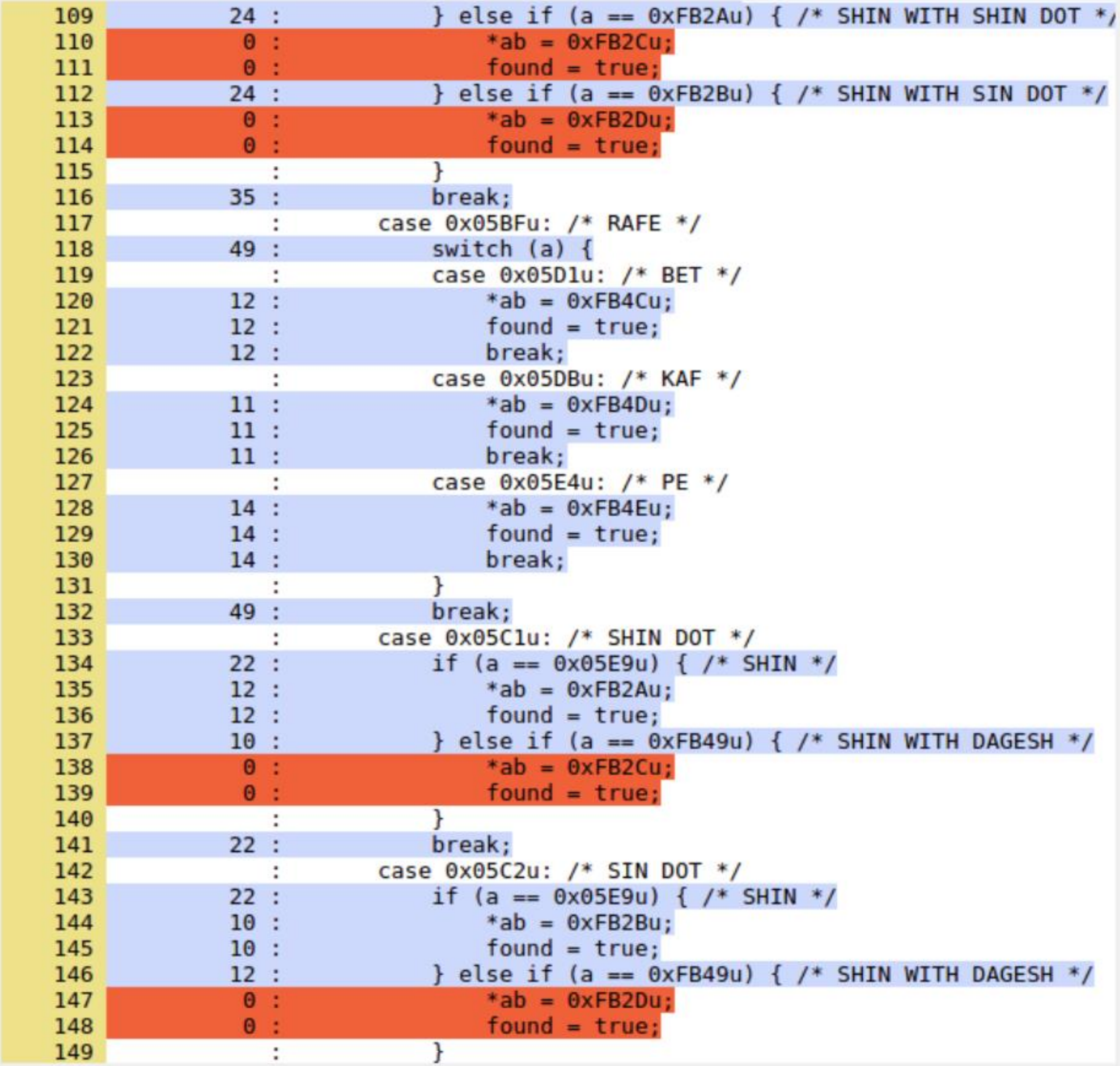
0	0	0	0	0	0
0	0	0	**1**	0	0
0	0	0	0	**1**	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	**0**	0	0	0
0	0	0	0	0	**0**



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

CRASH

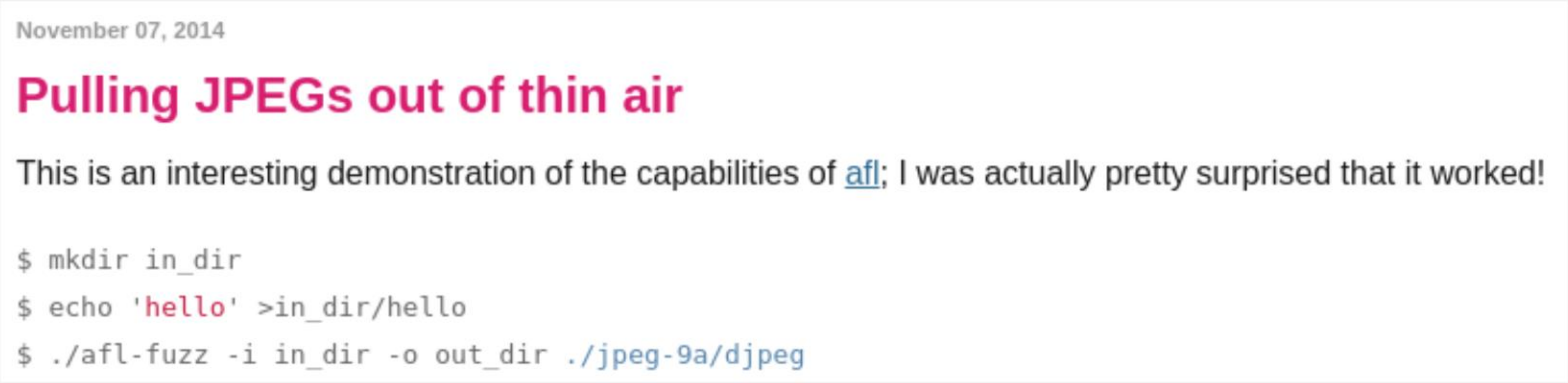
```
0 0 0 0 0 0
0 0 0 1 0 0
0 0 0 0 1 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 1 0 0 0
0 0 0 0 0 1
```



```
      24 :             } else if (a == 0xFB2Au) { /* SHIN WITH SHIN DOT */
       0 :                 *ab = 0xFB2Cu;
       0 :                 found = true;
      24 :             } else if (a == 0xFB2Bu) { /* SHIN WITH SIN DOT */
       0 :                 *ab = 0xFB2Du;
       0 :                 found = true;
         :             }
      35 :             break;
         :         case 0x05BFu: /* RAFE */
      49 :             switch (a) {
         :             case 0x05D1u: /* BET */
      12 :                 *ab = 0xFB4Cu;
      12 :                 found = true;
      12 :                 break;
         :             case 0x05DBu: /* KAF */
      11 :                 *ab = 0xFB4Du;
      11 :                 found = true;
      11 :                 break;
         :             case 0x05E4u: /* PE */
      14 :                 *ab = 0xFB4Eu;
      14 :                 found = true;
      14 :                 break;
         :             }
      49 :             break;
         :         case 0x05C1u: /* SHIN DOT */
      22 :             if (a == 0x05E9u) { /* SHIN */
      12 :                 *ab = 0xFB2Au;
      12 :                 found = true;
      10 :             } else if (a == 0xFB49u) { /* SHIN WITH DAGESH */
       0 :                 *ab = 0xFB2Cu;
       0 :                 found = true;
         :             }
      22 :             break;
         :         case 0x05C2u: /* SIN DOT */
      22 :             if (a == 0x05E9u) { /* SHIN */
      10 :                 *ab = 0xFB2Bu;
      10 :                 found = true;
      12 :             } else if (a == 0xFB49u) { /* SHIN WITH DAGESH */
       0 :                 *ab = 0xFB2Du;
       0 :                 found = true;
         :             }
```

Picture Source:

"Circumventing Fuzzing Roadblocks with Compiler Transformations", lafintel

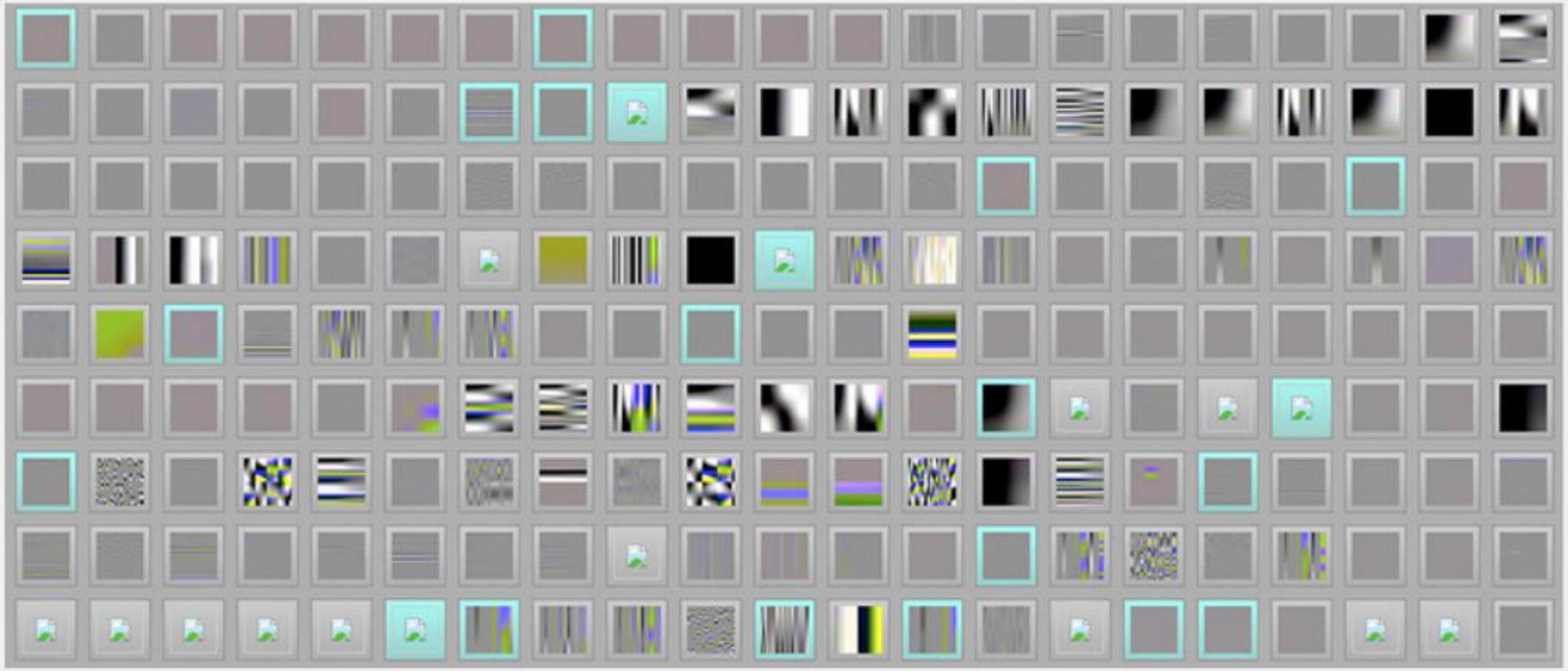


November 07, 2014

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 Challenges

Fuzzing Challenges

- "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 Challenges

low probability of catching:

```
if a == 0x31337

if a == "CONNECT"
```

Fuzzing Challenges

low probability of catching:

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

Solutions:

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

Fuzzing Challenges

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)

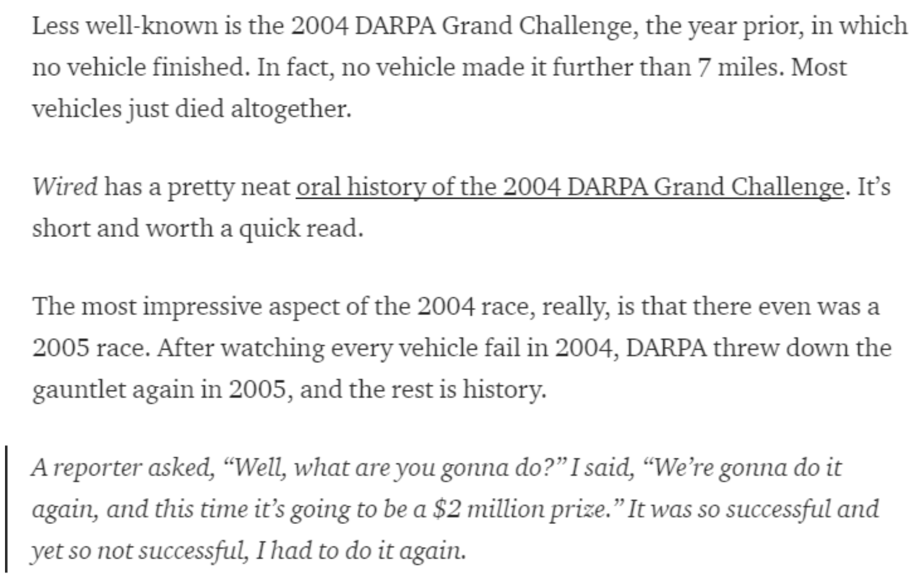
Symbolic Execution

- 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) == 0x534534534534")

DARPA CGC

DARPA Grand Challenge 2004 - Self driving cars

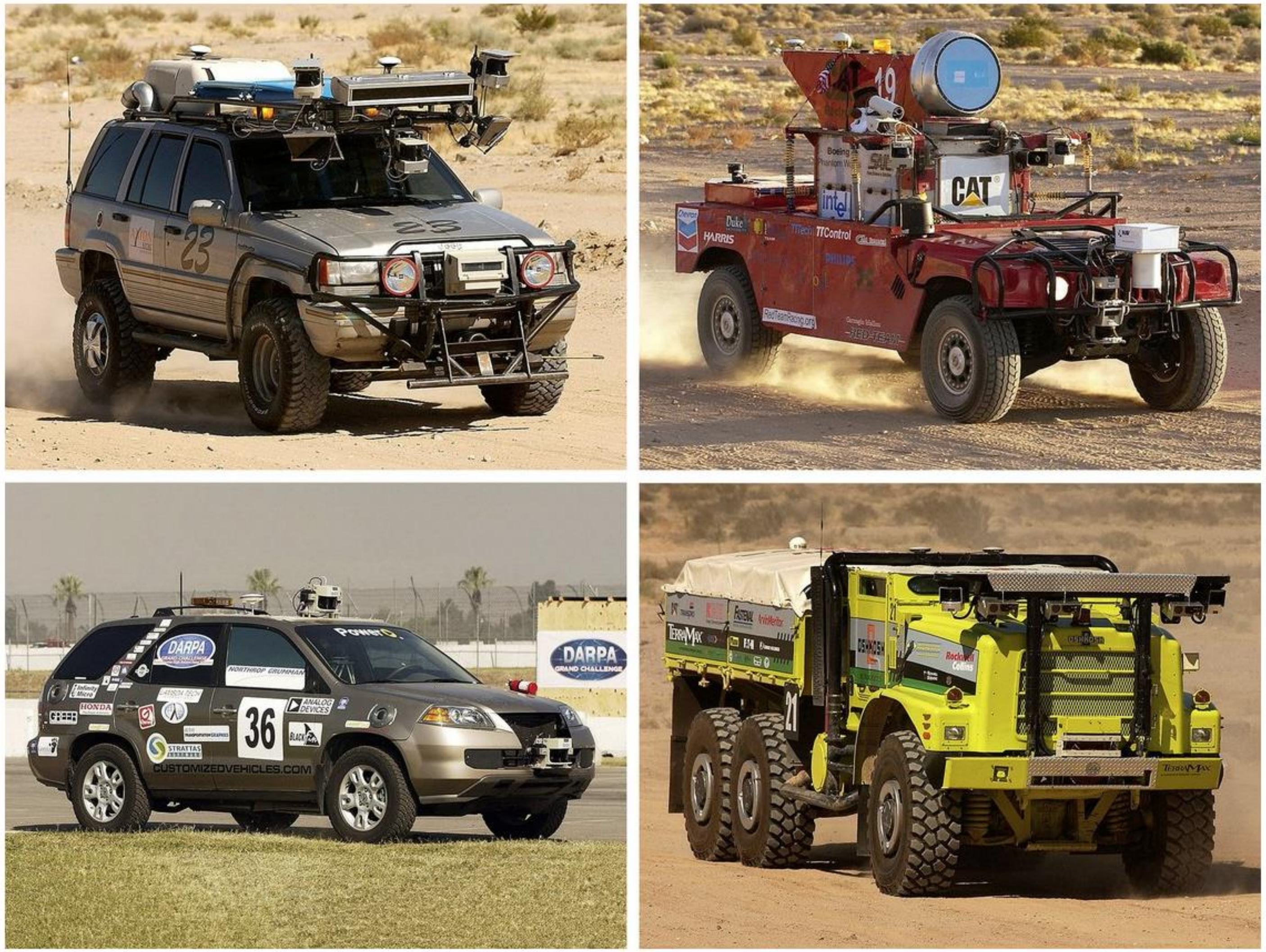


Less well-known is the 2004 DARPA Grand Challenge, the year prior, in which no vehicle finished. In fact, no vehicle made it further than 7 miles. Most vehicles just died altogether.

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.*



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

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***

CGC 2016

CGC
CYBER
GRAND CHALLENGE
DARPA
SECURE
MAYHEM
MECHANICAL PHISH
SHELLPHISH
CYBER SCORING

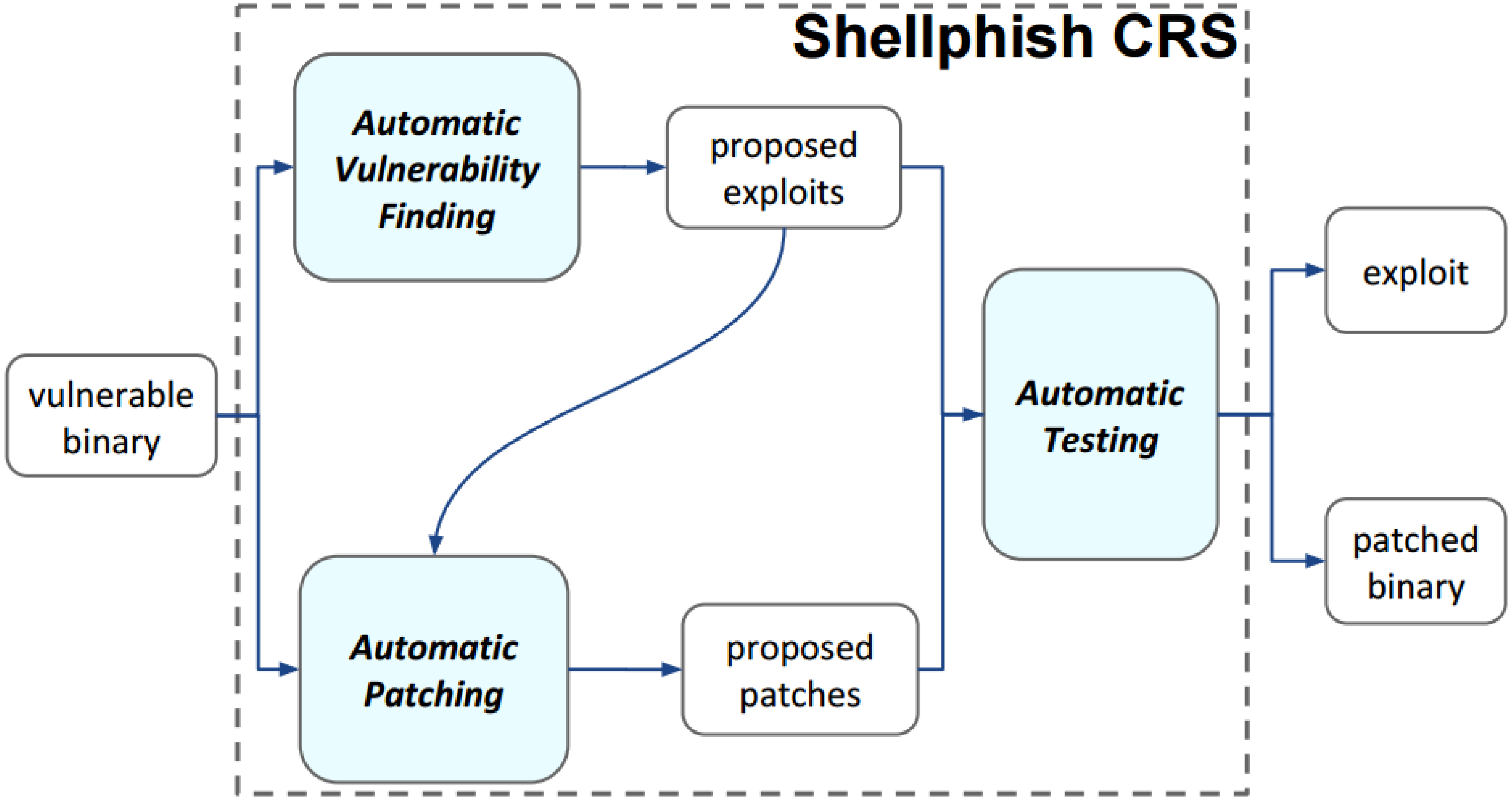
CGC

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 (only 4 system calls; read/write/exit/)
- 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!)

CGC Shellphish

Shellphish CRS


Shellphish CRS

vulnerable binary

Automatic Vulnerability Finding

proposed exploits

Automatic Patching

proposed patches

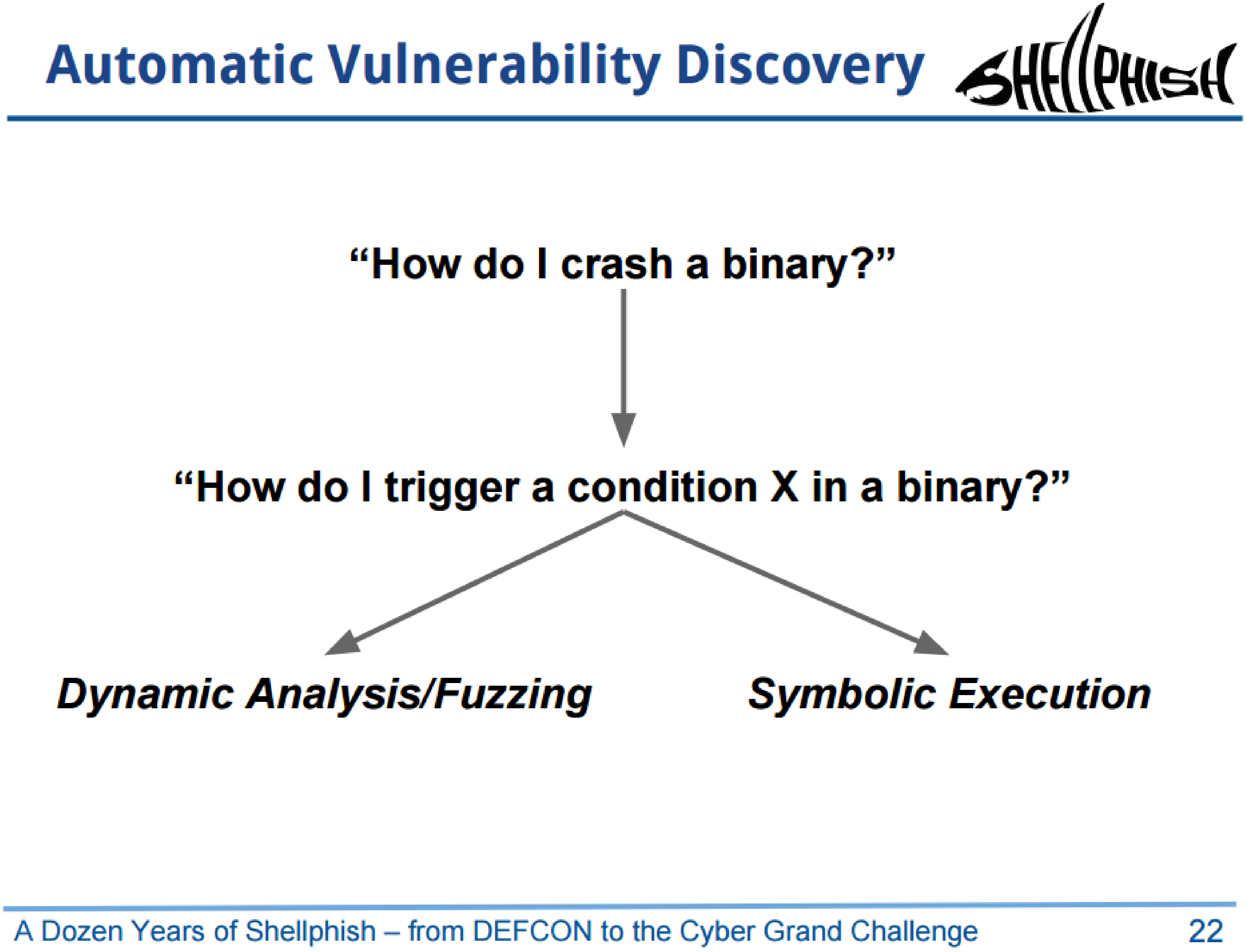
Automatic Testing

exploit

patched binary

A Dozen Years of Shellphish – from DEFCON to the Cyber Grand Challenge 20

CGC Shellphish



Automatic Vulnerability Discovery

“How do I crash a binary?”

“How do I trigger a condition X in a binary?”

Dynamic Analysis/Fuzzing

Symbolic Execution

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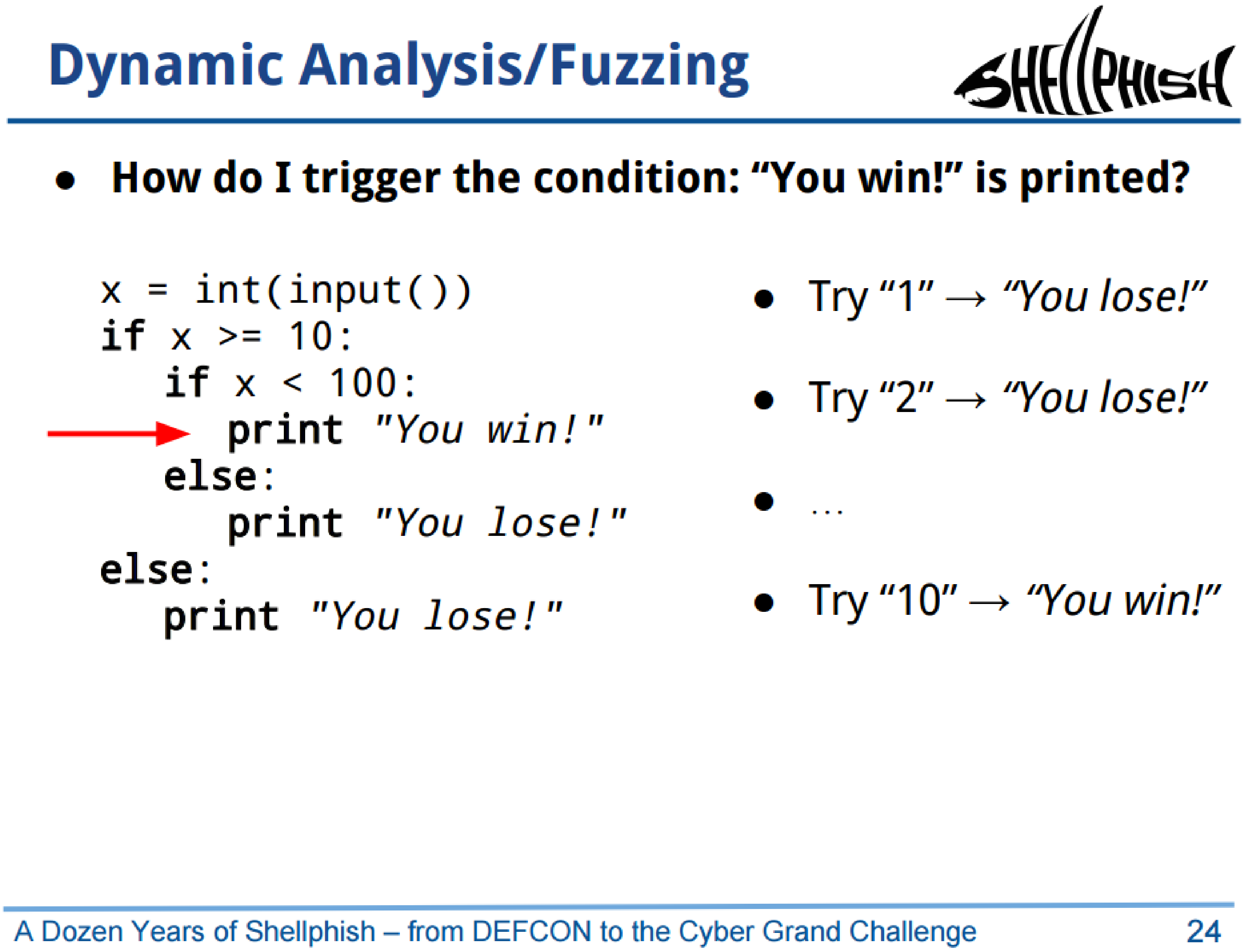
CGC Shellphish



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!”*

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CGC Shellphish

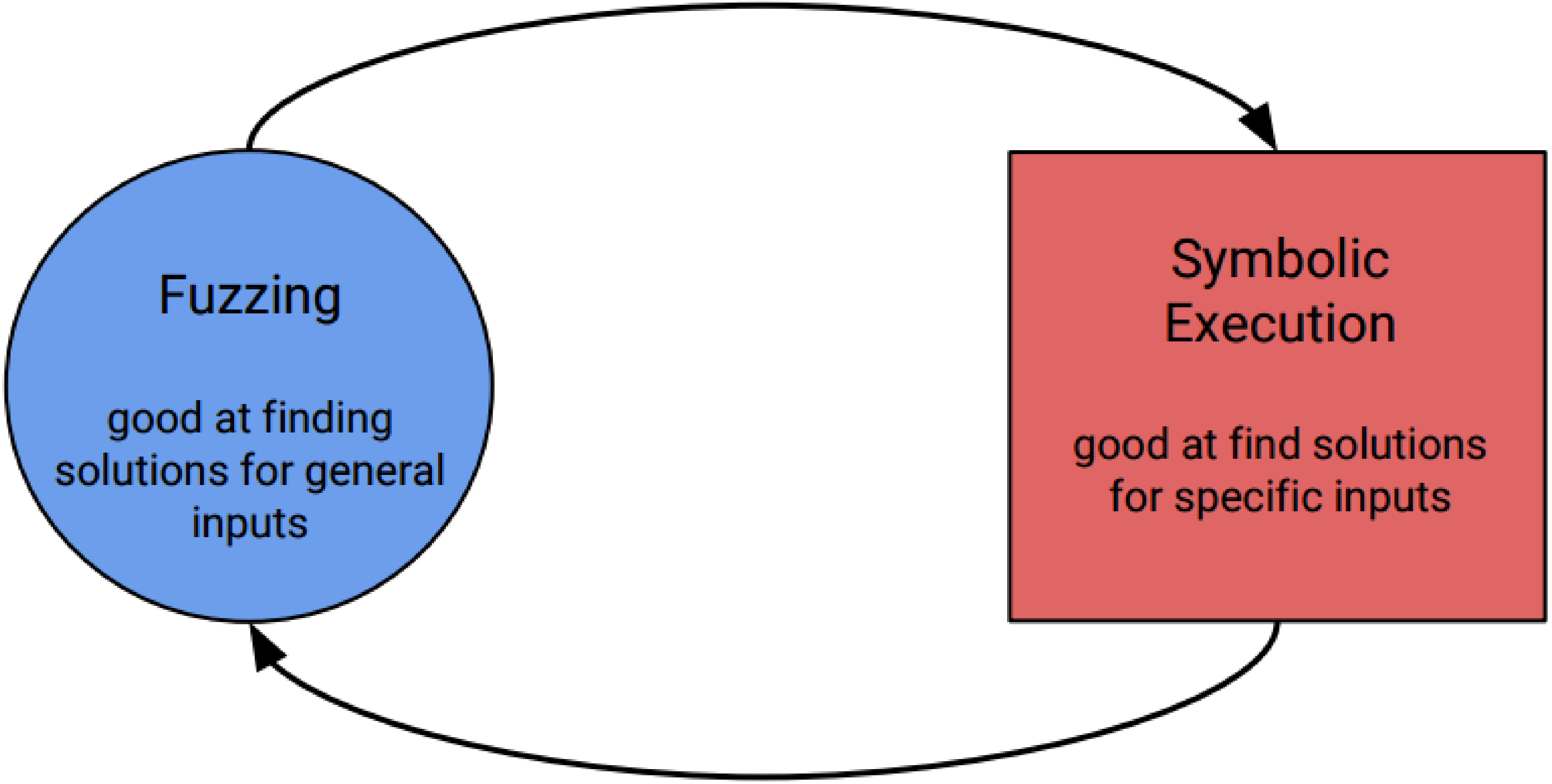
Dynamic Analysis/Fuzzing

- **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

Driller = AFL + angr



Fuzzing

good at finding solutions for general inputs

Symbolic Execution

good at find solutions for specific inputs

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 closed source software

Use software instrumentation framework to inject code

- Code coverage on every basic block
- Heap overflow detector
- Etc..

Libraries:

- Intel PIN
- DynamoRIO

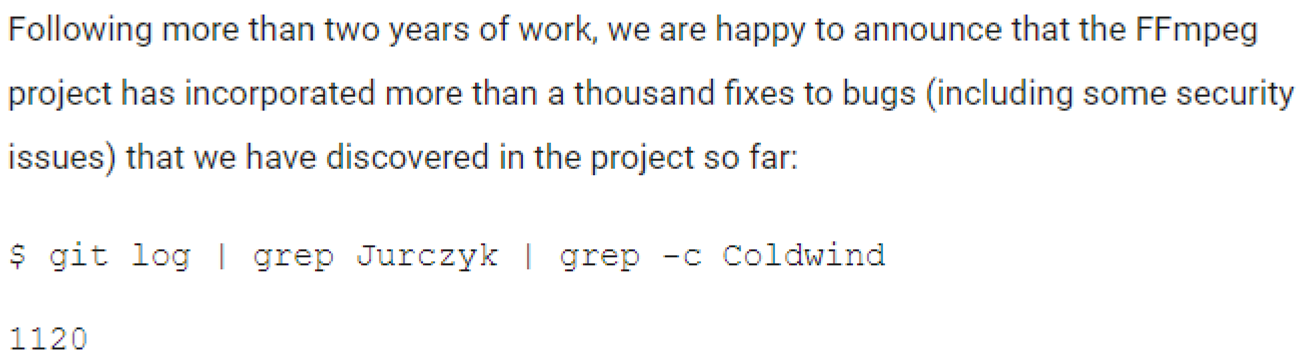
Fuzz parts of software via DLL’s

- Korean Office Malware Identification Library…

Fuzzing: Recap

Google and Fuzzing

https://security.googleblog.com/2014/01/ffmpeg-and-thousand-fixes.html



Following more than two years of work, we are happy to announce that the FFmpeg project has incorporated more than a thousand fixes to bugs (including some security issues) that we have discovered in the project so far:

```
$ git log | grep Jurczyk | grep -c Coldwind

1120
```

Fuzzing Recap

Fuzzing is:

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

Advancements in the last few years:

- High performance code coverage measurements (identify if input triggered new code)
- Symbolic execution (use constraint solver on “if’s” to create data which lead inside the “if’s”, therefore triggering new code)

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

Example:

- https://www.evilsocket.net/2015/04/30/fuzzing-with-afl-fuzz-a-practical-example-afl-vs-binutils/