AFL – American Fuzzy Lop

A short introduction

by Tobias Ospelt, March, 9th 2015

Silicon Valley Fuzzers, Fuzzing meetup,
Santa Clara, CA

Me

- Penetration Tester (usually CH, DE, UK, once in the USA)
- Android stuff, mona.py unicode alignment, tincd metasploit module, started fuzzing
  - floyd.ch / @floyd_ch
- AFL user (not an expert on all the internals)

Company modzero

- 6 IT security experts
- Keykeriki, Backtrack, Degate, remote-exploit.org, Die Datenkrake, Analysis of the German state trojan
- We do all areas of technical HW & SW security analysis (Penetration Testing, Crypto, Web, medical devices, etc.)

AFL – American Fuzzy Lop

- Fuzzer developed by Michal Zalewski (lcamtuf), Project Zero, Google
  - He's on holiday today ☹
- http://lcamtuf.coredump.cx/afl/
- "Under certain conditions you are crazy if you don't use AFL for your project" - me

Why use AFL?

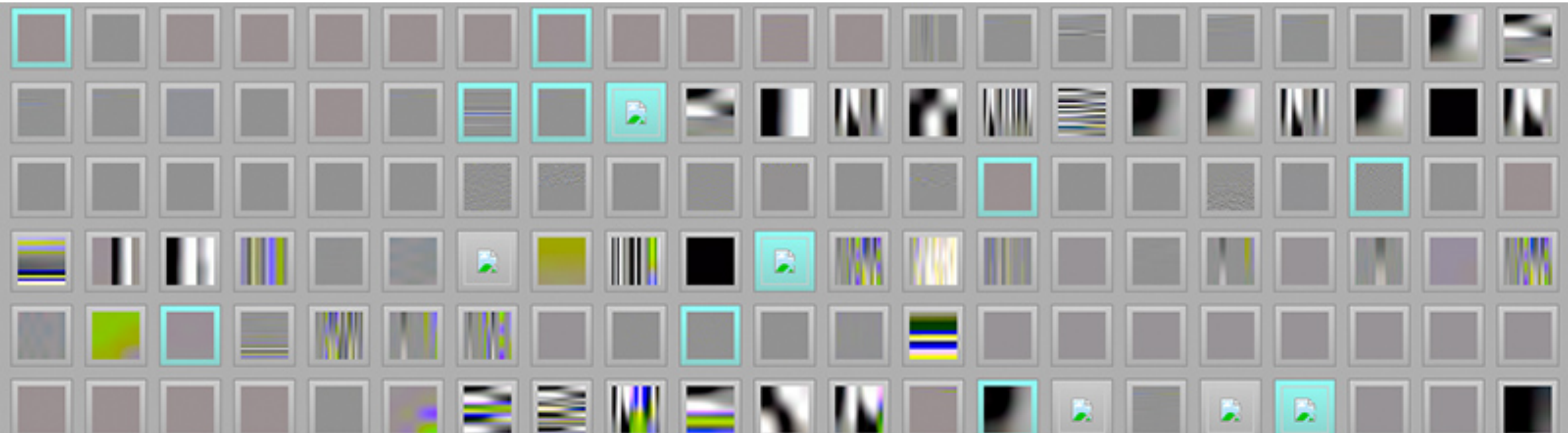
It finds bugs

IJG jpeg 1 libjpeg-turbo 1 2 libpng 1 libtiff 1 2 3 4 5 mozjpeg 1 libbpg (1) Mozilla Firefox 1 2 3 4 5 Google Chrome 1 Internet Explorer 1 2 (3) (4) LibreOffice 1 2 3 4 poppler 1 freetype 1 2 GnuTLS 1 GnuPG 1 2 (3) OpenSSH 1 2 3 bash (post-Shellshock) 1 2 tcpdump 1 2 3 4 5 6 7 Adobe Flash / PCRE 1 2 JavaScriptCore 1 2 3 4 pdfium 1 ffmpeg 1 2 3 4 libmatroska 1 libarchive 1 2 3 4 5 6 … wireshark 1 ImageMagick 1 2 3 4 5 6 7 8 … lcms (1) PHP 1 2 lame 1 FLAC audio library 1 2 libsndfile 1 2 3 less / lesspipe 1 2 3 strings (+ related tools) 1 2 3 4 5 6 7 file 1 2 dpkg 1 rcs 1 systemd-resolved 1 2 sqlite 1 2 3 libyaml 1 Info-Zip unzip 1 2 OpenBSD pfctl 1 NetBSD bpf 1 man & mandoc 1 2 3 4 5 … IDA Pro clamav 1 2 libxml2 1 glibc 1 clang / llvm 1 2 3 4 5 6 nasm 1 2 ctags 1 mutt 1 procmail 1 fontconfig 1 pdksh 1 2 Qt 1 wavpack 1 redis / lua-cmsgpack 1 taglib 1 2 3 privoxy 1 perl 1 2 3 4 5 6 libxmp radare2 1 2 fwknop metacam 1 exifprobe 1 capnproto 1

It's spooky

- Michal gave djpeg (IJG jpeg library) to AFL
- Plus a non-jpeg file as an input

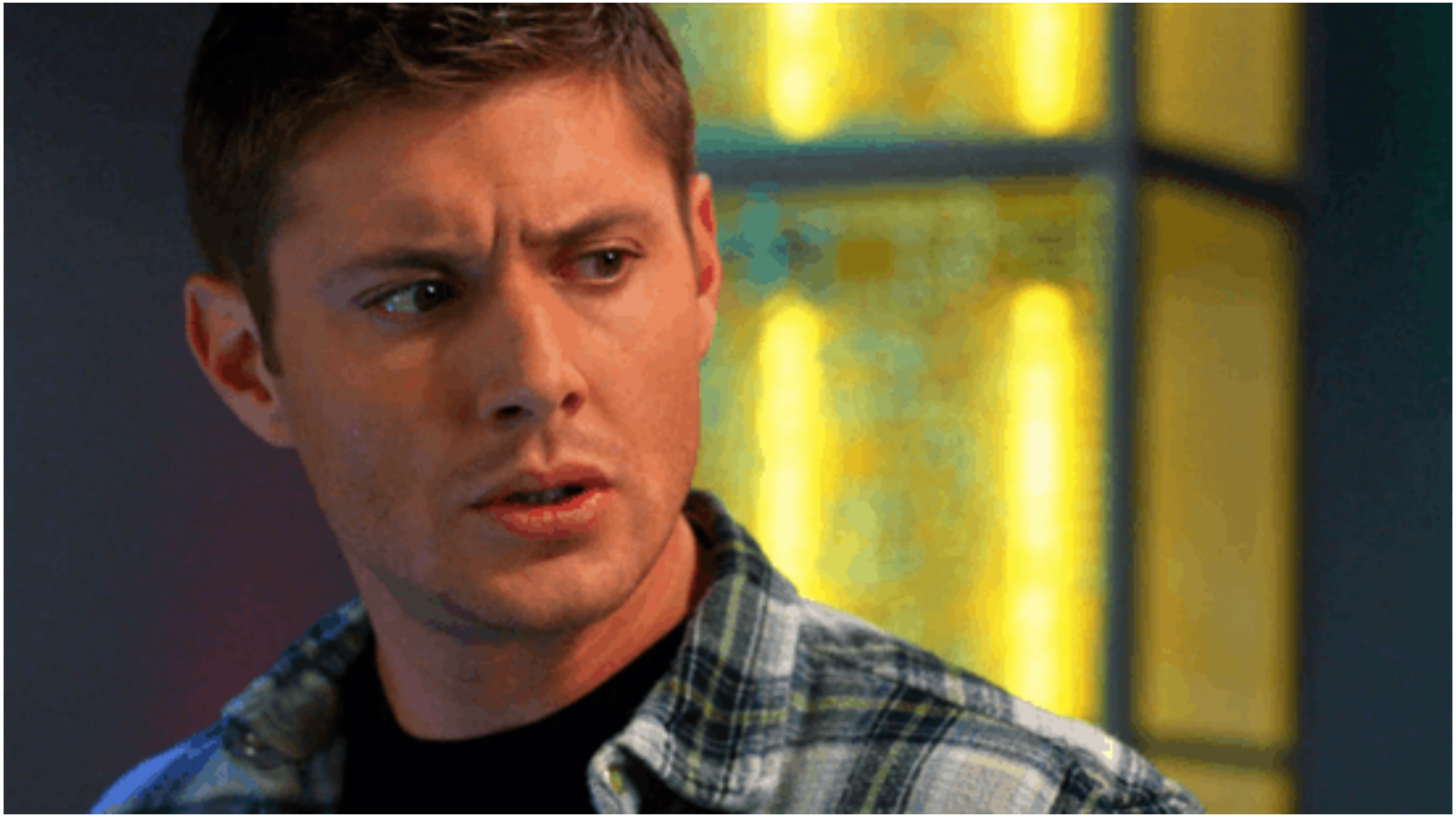
  -
    ```
    $ echo 'hello' >in_dir/hello
    ```
- AFL started to produce valid jpeg files after a day or two



More reasons

- It's dead simple
- No configuration of AFL necessary, robust
- It's cutting edge
- It's fast
- Produces very very good input files (corpus) that can be used in other fuzzers
- Many targets that were never touched by AFL (and it will crush them)

When I read through lcatumf's post on 'less' and 'strings'



Source: http://securityreactions.tumblr.com/page/10

And because you will go

You won't believe what you are reading

- Source: http://lcamtuf.coredump.cx/afl/demo/
- afl-generated, minimized image test sets (partial) [...]
- JPEG XR jxrlib 1.1 JxrDecApp[1] IE → Ditched [2]
- [2] Due to the sheer number of exploitable bugs that allow the fuzzer to jump to arbitrary addresses.

When to use AFL

The usual use case

- You have the source code and you compile with gcc or clang
- Your are on 32bit or 64bit on Linux/OSX/BSD
- The to-be-fuzzed code (e.g. parser) reads it's input from stdin or from a file
- The input file is usually only max. 10kb
- This covers *a lot* of Linux libraries

What if something does not apply?

- No source code?
  - Try the experimental QEMU instrumentation
- Not on 32/64 bit?
  - There is an experimental ARM version
- Not reading from stdin or file?
  - Maybe your project has a utility command line tool that does read from file
  - Or you write a wrapper to do it
  - Same if you want to test (parts of) network protocol parsers

How to use AFL

Steps of fuzzing

1. Compile/install AFL (once)
2. Compile target project with AFL
   – afl-gcc / afl-g++ / afl-clang / afl-clang++ / (afl-as)
3. Chose target binary to fuzz in project
   – Chose its command line options to make it run fast
4. Chose valid input files that cover a wide variety of possible input files
   – afl-cmin / (afl-showmap)

Steps of fuzzing

5. Fuzzing
   – afl-fuzz
6. Check how your fuzzer is doing
   – command line UI / afl-whatsup / afl-plot / afl-gotcpu
7. Analyze crashes
   – afl-tmin / triage_crashes.sh / peruvian were rabbit
   – ASAN / valgrind / exploitable gdb plugin / …
8. Have a lot more work than before
   – CVE assignment / responsible disclosure / …

Installing AFL (step 1)

```
#!/bin/bash
#Download & compile new AFL version:
wget http://lcamtuf.coredump.cx/afl.tgz
tar xfz afl.tgz
rm afl.tgz
cd `find . -type d -iname "afl-*"|sort|head -1`
make
echo "Provide sudo password for sudo make install"
sudo make install
```

AFL binaries

```
/opt/afl-1.56b$ ./afl-
afl-as       afl-fuzz     afl-plot
afl-clang    afl-g++      afl-showmap
afl-clang++  afl-gcc      afl-tmin
afl-cmin     afl-gotcpu   afl-whatsup
```

```
/opt/afl-1.56b$ ./afl-gcc
[...]
This is a helper application for afl-fuzz. It serves
as a drop-in replacementfor gcc or clang, letting you
recompile third-party code with the required runtime
instrumentation.
[...]
```

Instrumenting a project (step 2) – example: libtiff from CVS repository

```
/opt/libtiff-cvs-afl$ export CC=afl-gcc
/opt/libtiff-cvs-afl$ export CXX=afl-g++
/opt/libtiff-cvs-afl$ ./configure --disable-shared
/opt/libtiff-cvs-afl$ make clean
/opt/libtiff-cvs-afl$ make
```

Choosing the binary to fuzz (step 3) – they are all waiting for it

```
/opt/libtiff-cvs-afl$ ./tools/
bmp2tiff    fax2tiff    ppm2tiff    raw2tiff
thumbnail   tiff2pdf    tiff2rgba   tiffcp
tiffdither  tiffinfo    tiffset     fax2ps
gif2tiff    pal2rgb     ras2tiff    rgb2ycbcr
tiff2bw     tiff2ps     tiffcmp     tiffcrop
tiffdump    tiffmedian  tiffsplit
```

```
/opt/libtiff-cvs-afl$ ./tools/bmp2tiff
LIBTIFF, Version 4.0.3
Copyright (c) 1988-1996 Sam Leffler
[...]
usage: bmp2tiff [options] input.bmp [input2.bmp ...]
output.tif
```

Chose initial input files (step 4)

```
/opt/libtiff-cvs-afl$ mkdir input_all
/opt/libtiff-cvs-afl$ scp host:/bmps/ input_all/
/opt/libtiff-cvs-afl$ ls -1 input_all |wc –l
886
```

Chose initial input files (step 4)

```
/opt/libtiff-cvs-afl$ afl-cmin -i input_all -o input
-- /opt/libtiff-cvs-afl/tools/bmp2tiff @@ /dev/null
corpus minimization tool for afl-fuzz by
<lcamtuf@google.com>
[*] Testing the target binary...
[+] OK, 191 tuples recorded.
[*] Obtaining traces for input files in
'input_all'...
Processing file 886/886...
[*] Sorting trace sets (this may take a while)...
[+] Found 4612 unique tuples across 886 files.
[*] Finding best candidates for each tuple...
Processing file 886/886...
[*] Sorting candidate list (be patient)...
[*] Processing candidates and writing output files...
Processing tuple 4612/4612...
[+] Narrowed down to 162 files, saved in 'input'.
```

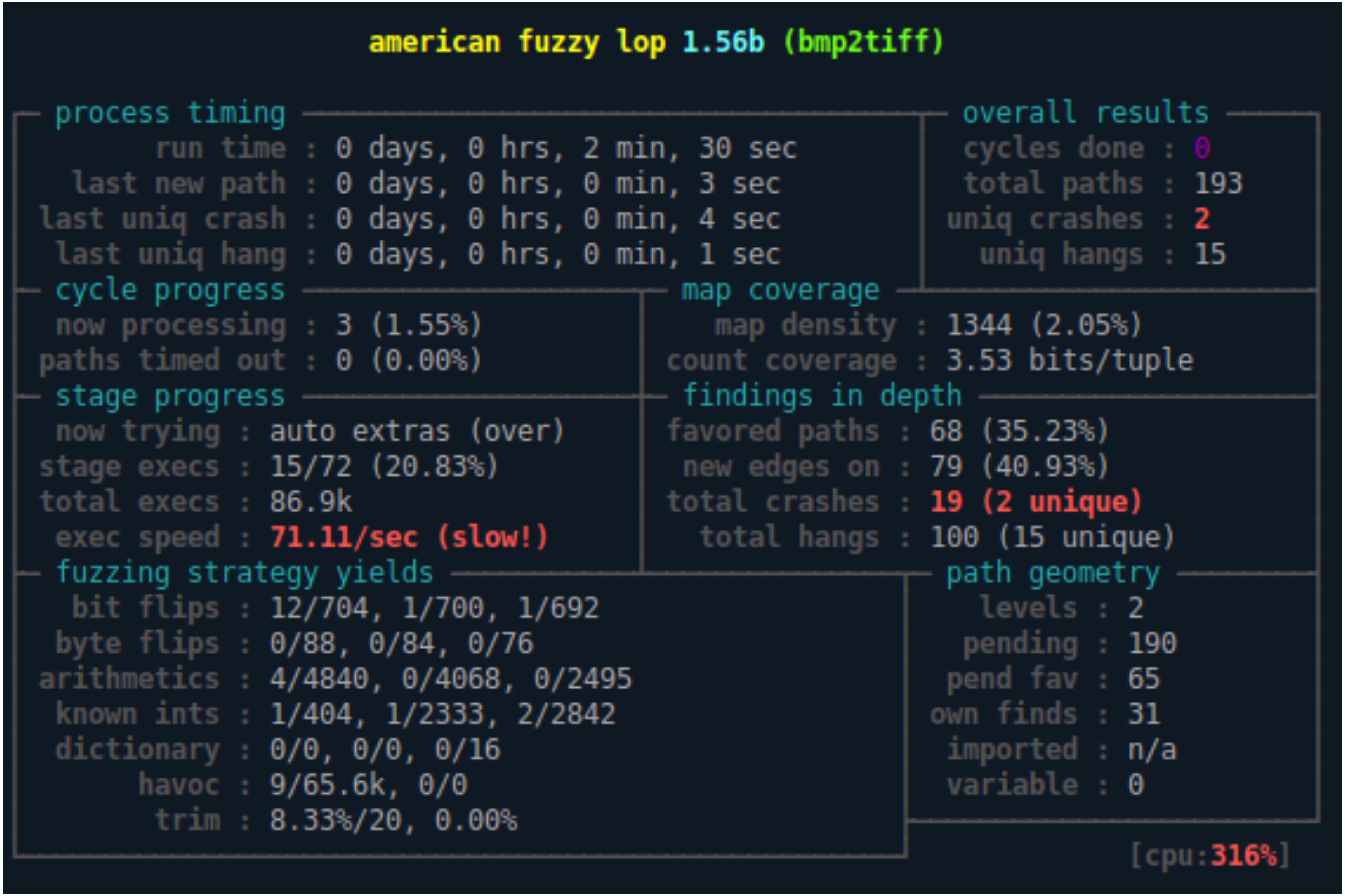
Chose initial input files (step 4)

```
/opt/libtiff-cvs-afl$ ls -1 input |wc –l
162
```

Fuzzing (step 5)

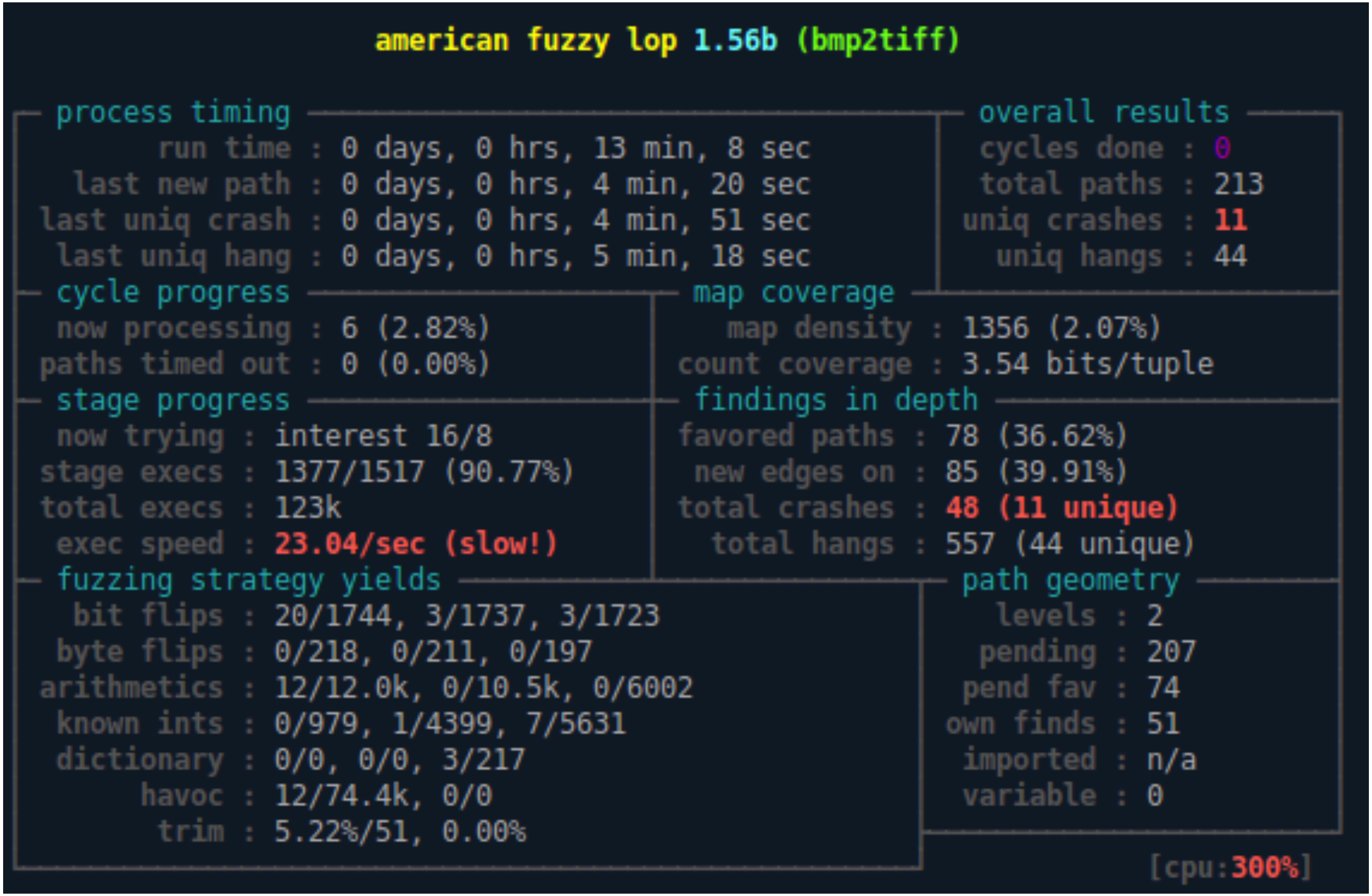
```
/opt/libtiff-cvs-afl$ screen –S fuzzing
/opt/libtiff-cvs-afl$ afl-fuzz -i input –o output
-- /opt/libtiff-cvs-afl/tools/bmp2tiff @@ /dev/null
```

How is our fuzzer doing? (step 6)



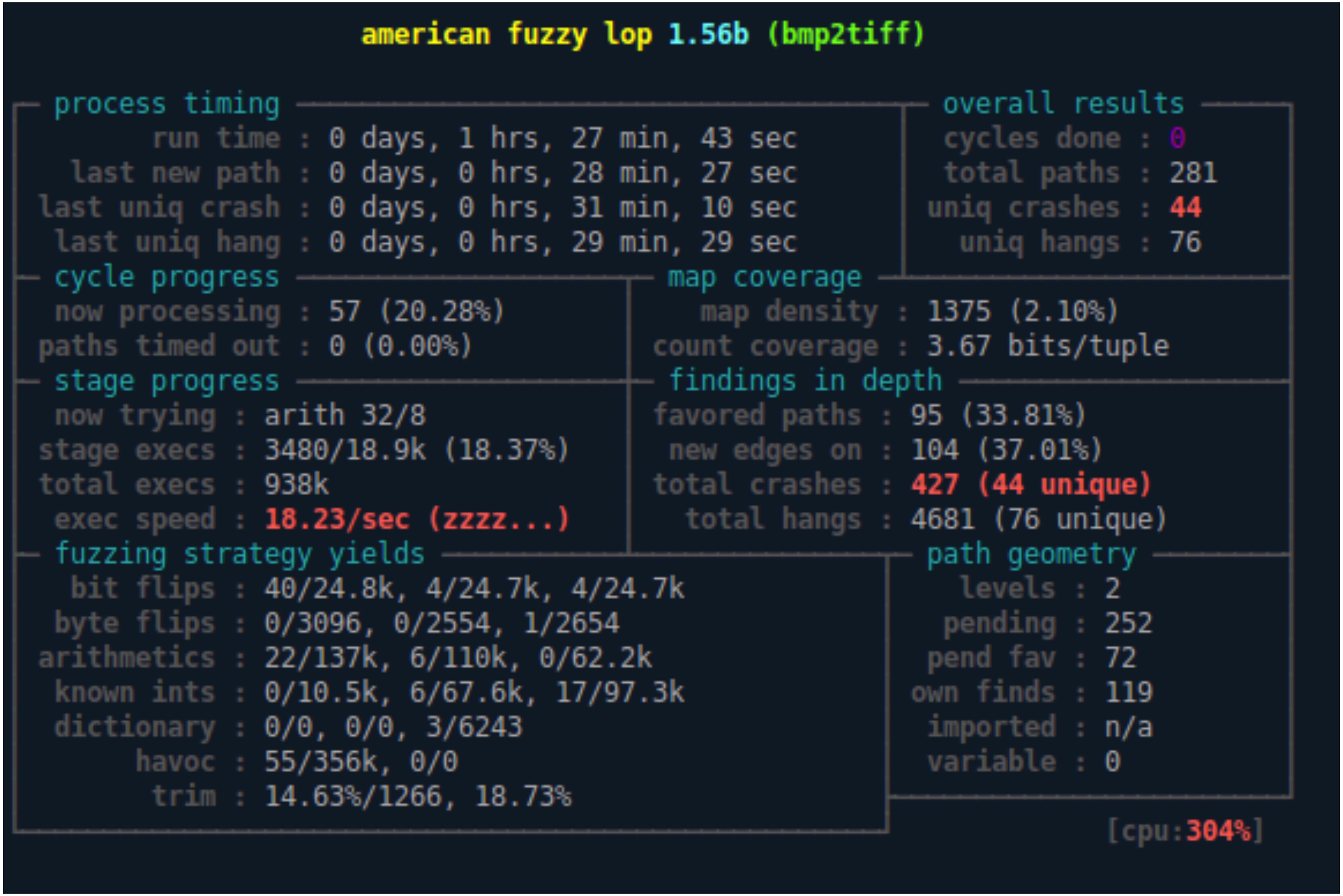
```
                  american fuzzy lop 1.56b (bmp2tiff)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 0 hrs, 2 min, 30 sec       │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 0 min, 3 sec        │  total paths : 193    │
│ last uniq crash : 0 days, 0 hrs, 0 min, 4 sec        │ uniq crashes : 2      │
│  last uniq hang : 0 days, 0 hrs, 0 min, 1 sec        │   uniq hangs : 15     │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 3 (1.55%)         │    map density : 1344 (2.05%)          │
│ paths timed out : 0 (0.00%)         │ count coverage : 3.53 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : auto extras (over)    │ favored paths : 68 (35.23%)            │
│ stage execs : 15/72 (20.83%)        │  new edges on : 79 (40.93%)            │
│ total execs : 86.9k                 │ total crashes : 19 (2 unique)          │
│  exec speed : 71.11/sec (slow!)     │   total hangs : 100 (15 unique)        │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 12/704, 1/700, 1/692                  │    levels : 2          │
│  byte flips : 0/88, 0/84, 0/76                      │   pending : 190        │
│ arithmetics : 4/4840, 0/4068, 0/2495                │  pend fav : 65         │
│  known ints : 1/404, 1/2333, 2/2842                 │ own finds : 31         │
│  dictionary : 0/0, 0/0, 0/16                        │  imported : n/a        │
│       havoc : 9/65.6k, 0/0                          │  variable : 0          │
│        trim : 8.33%/20, 0.00%                       ├────────────────────────┘
└─────────────────────────────────────────────────────┘             [cpu:316%]
```

How is our fuzzer doing? (step 6)



```
                   american fuzzy lop 1.56b (bmp2tiff)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 0 hrs, 13 min, 8 sec       │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 4 min, 20 sec       │  total paths : 213    │
│ last uniq crash : 0 days, 0 hrs, 4 min, 51 sec       │ uniq crashes : 11     │
│  last uniq hang : 0 days, 0 hrs, 5 min, 18 sec       │   uniq hangs : 44     │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 6 (2.82%)         │    map density : 1356 (2.07%)          │
│ paths timed out : 0 (0.00%)         │ count coverage : 3.54 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : interest 16/8         │ favored paths : 78 (36.62%)            │
│ stage execs : 1377/1517 (90.77%)    │  new edges on : 85 (39.91%)            │
│ total execs : 123k                  │ total crashes : 48 (11 unique)         │
│  exec speed : 23.04/sec (slow!)     │   total hangs : 557 (44 unique)        │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 20/1744, 3/1737, 3/1723               │    levels : 2          │
│  byte flips : 0/218, 0/211, 0/197                   │   pending : 207        │
│ arithmetics : 12/12.0k, 0/10.5k, 0/6002             │  pend fav : 74         │
│  known ints : 0/979, 1/4399, 7/5631                 │ own finds : 51         │
│  dictionary : 0/0, 0/0, 3/217                       │  imported : n/a        │
│       havoc : 12/74.4k, 0/0                         │  variable : 0          │
│        trim : 5.22%/51, 0.00%                       ├────────────────────────┘
└─────────────────────────────────────────────────────┘             [cpu:300%]
```

How is our fuzzer doing? (step 6)



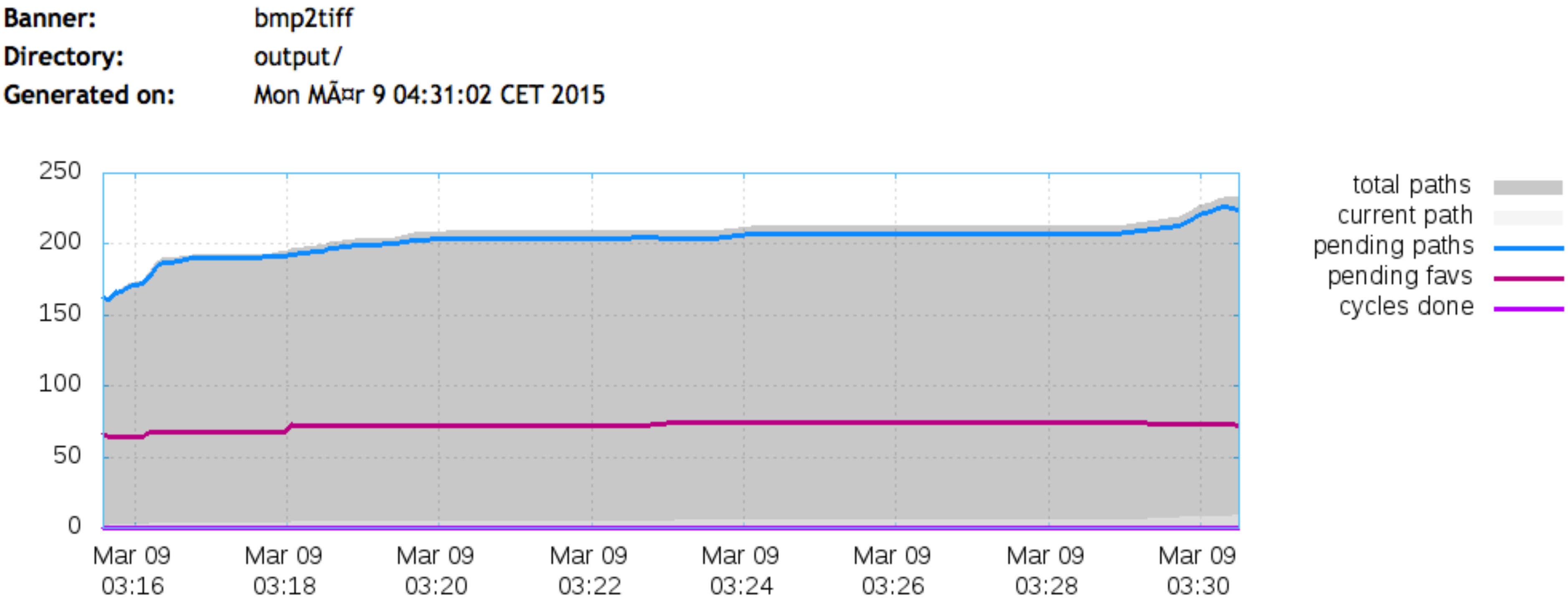
```
                  american fuzzy lop 1.56b (bmp2tiff)

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 0 days, 1 hrs, 27 min, 43 sec      │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 28 min, 27 sec      │  total paths : 281    │
│ last uniq crash : 0 days, 0 hrs, 31 min, 10 sec      │ uniq crashes : 44     │
│  last uniq hang : 0 days, 0 hrs, 29 min, 29 sec      │   uniq hangs : 76     │
├─ cycle progress ─────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 57 (20.28%)        │    map density : 1375 (2.10%)          │
│ paths timed out : 0 (0.00%)          │ count coverage : 3.67 bits/tuple       │
├─ stage progress ─────────────────────┼─ findings in depth ────────────────────┤
│  now trying : arith 32/8             │ favored paths : 95 (33.81%)            │
│ stage execs : 3480/18.9k (18.37%)    │  new edges on : 104 (37.01%)           │
│ total execs : 938k                   │ total crashes : 427 (44 unique)        │
│  exec speed : 18.23/sec (zzzz...)    │   total hangs : 4681 (76 unique)       │
├─ fuzzing strategy yields ────────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 40/24.8k, 4/24.7k, 4/24.7k             │    levels : 2          │
│  byte flips : 0/3096, 0/2554, 1/2654                 │   pending : 252        │
│ arithmetics : 22/137k, 6/110k, 0/62.2k               │  pend fav : 72         │
│  known ints : 0/10.5k, 6/67.6k, 17/97.3k             │ own finds : 119        │
│  dictionary : 0/0, 0/0, 3/6243                       │  imported : n/a        │
│       havoc : 55/356k, 0/0                           │  variable : 0          │
│        trim : 14.63%/1266, 18.73%                    ├────────────────────────┘
└──────────────────────────────────────────────────────┘          [cpu:304%]
```

How is our fuzzer doing? (step 6)

```
/opt/libtiff-cvs-afl$ afl-gotcpu
afl-gotcpu 1.56b (Mar  9 2015 02:50:32) by
<lcamtuf@google.com>
[*] Measuring preemption rate (this will take 5.00
sec)...
[+] Busy loop hit 79 times, real = 5001 ms, slice =
2448 ms.
>>> FAIL: Your CPU is overbooked (204%). <<<
```

How is our fuzzer doing? (step 6)

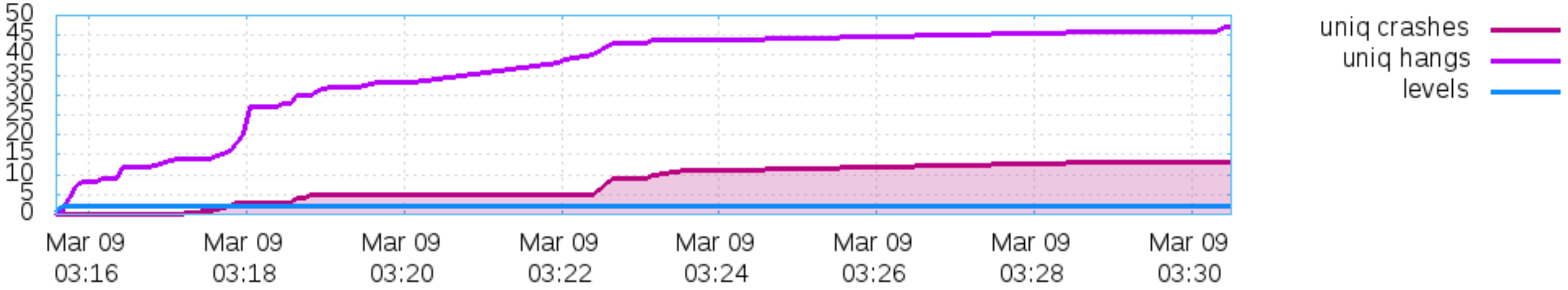
- afl-plot

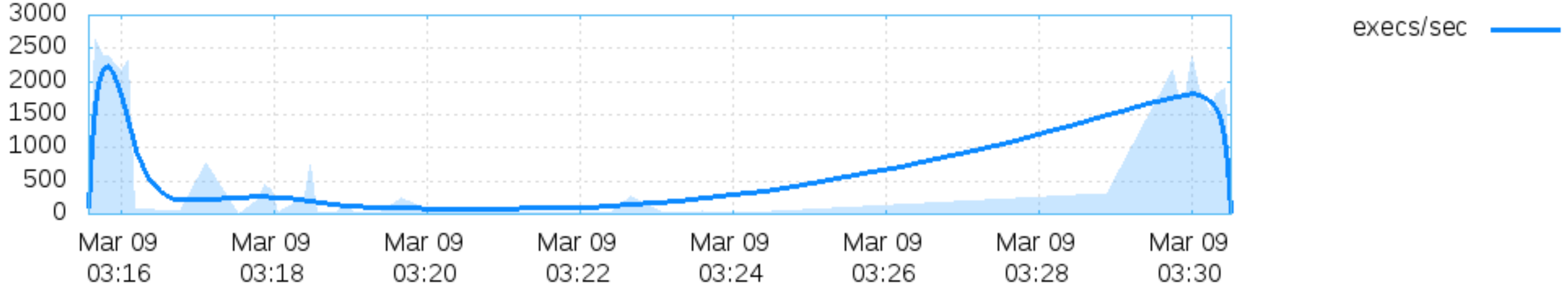


Banner: bmp2tiff
Directory: output/
Generated on: Mon MÃ¤r 9 04:31:02 CET 2015

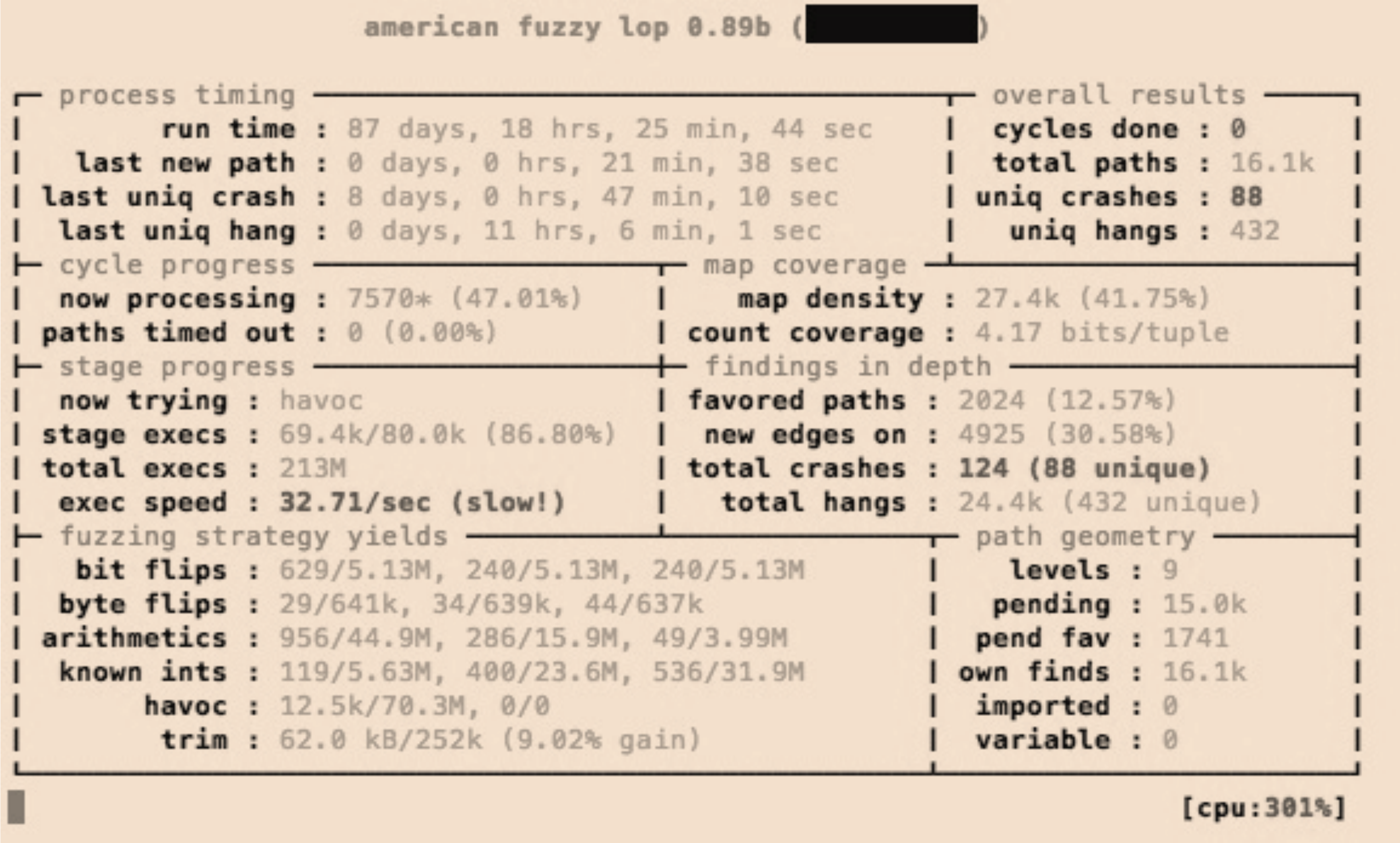
How is our fuzzer doing? (step 6)

- afl-plot





Other examples



```
                    american fuzzy lop 0.89b ([redacted])

┌─ process timing ─────────────────────────────────────┬─ overall results ─────┐
│        run time : 87 days, 18 hrs, 25 min, 44 sec    │  cycles done : 0      │
│   last new path : 0 days, 0 hrs, 21 min, 38 sec      │  total paths : 16.1k  │
│ last uniq crash : 8 days, 0 hrs, 47 min, 10 sec      │ uniq crashes : 88     │
│  last uniq hang : 0 days, 11 hrs, 6 min, 1 sec       │   uniq hangs : 432    │
├─ cycle progress ────────────────────┬─ map coverage ─┴───────────────────────┤
│  now processing : 7570* (47.01%)    │    map density : 27.4k (41.75%)        │
│ paths timed out : 0 (0.00%)         │ count coverage : 4.17 bits/tuple       │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc                 │ favored paths : 2024 (12.57%)          │
│ stage execs : 69.4k/80.0k (86.80%)  │  new edges on : 4925 (30.58%)          │
│ total execs : 213M                  │ total crashes : 124 (88 unique)        │
│  exec speed : 32.71/sec (slow!)     │   total hangs : 24.4k (432 unique)     │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 629/5.13M, 240/5.13M, 240/5.13M       │    levels : 9          │
│  byte flips : 29/641k, 34/639k, 44/637k             │   pending : 15.0k      │
│ arithmetics : 956/44.9M, 286/15.9M, 49/3.99M        │  pend fav : 1741       │
│  known ints : 119/5.63M, 400/23.6M, 536/31.9M       │ own finds : 16.1k      │
│       havoc : 12.5k/70.3M, 0/0                      │  imported : 0          │
│        trim : 62.0 kB/252k (9.02% gain)             │  variable : 0          │
└─────────────────────────────────────────────────────┴────────────────────────┘
                                                                     [cpu:301%]
```

Crash analysis (step 7) minimizing crash input

```
/opt/libtiff-cvs-afl$ afl-tmin -i output/crashes/id\:
000000\,sig\:11\,src\:000003\,op\:int16\,pos\:21\,val
\:+1 -o minimized-crash /opt/libtiff-cvs-afl/tools/
bmp2tiff @@ /dev/null
afl-tmin 1.56b (Mar  9 2015 02:50:31) by
<lcamtuf@google.com>
[+] Read 36 bytes from 'output/crashes/id:000000,sig:
11,src:000003,op:int16,pos:21,val:+1'.
[*] Performing dry run (mem limit = 25 MB, timeout =
1000 ms)...
[+] Program exits with a signal, minimizing in crash
mode.
[*] --- Pass #1 ---
[*] Stage #1:  Removing blocks of data...
Block length = 2, remaining size = 36
Block length = 1, remaining size = 34
[...]
```

Crash analysis (step 7) minimizing malicious input

```
/opt/libtiff-cvs-afl$ ls -als output/crashes/id\:
000000\,sig\:11\,src\:000003\,op\:int16\,pos\:21\,val
\:+14 -rw------- 1 user user 36 Mär  9 04:17 output/
crashes/id:000000,sig:11,src:000003,op:int16,pos:
21,val:+1

/opt/libtiff-cvs-afl$ ls -als minimized-crash 4 -
rw------- 1 user user 34 Mär  9 05:51 minimized-crash
```

Crash analysis (step 7) example of manual analysis

```
uncompr_size = width * length;
...
uncomprbuf = (unsigned char *)_TIFFmalloc(uncompr_size);
```

```
(gdb) p width
$70 = 65536
(gdb) p length
$71 = 65544
(gdb) p uncompr_size
$72 = 524288
```

```
524289 is (65536 * 65544) % MAX_INT
```

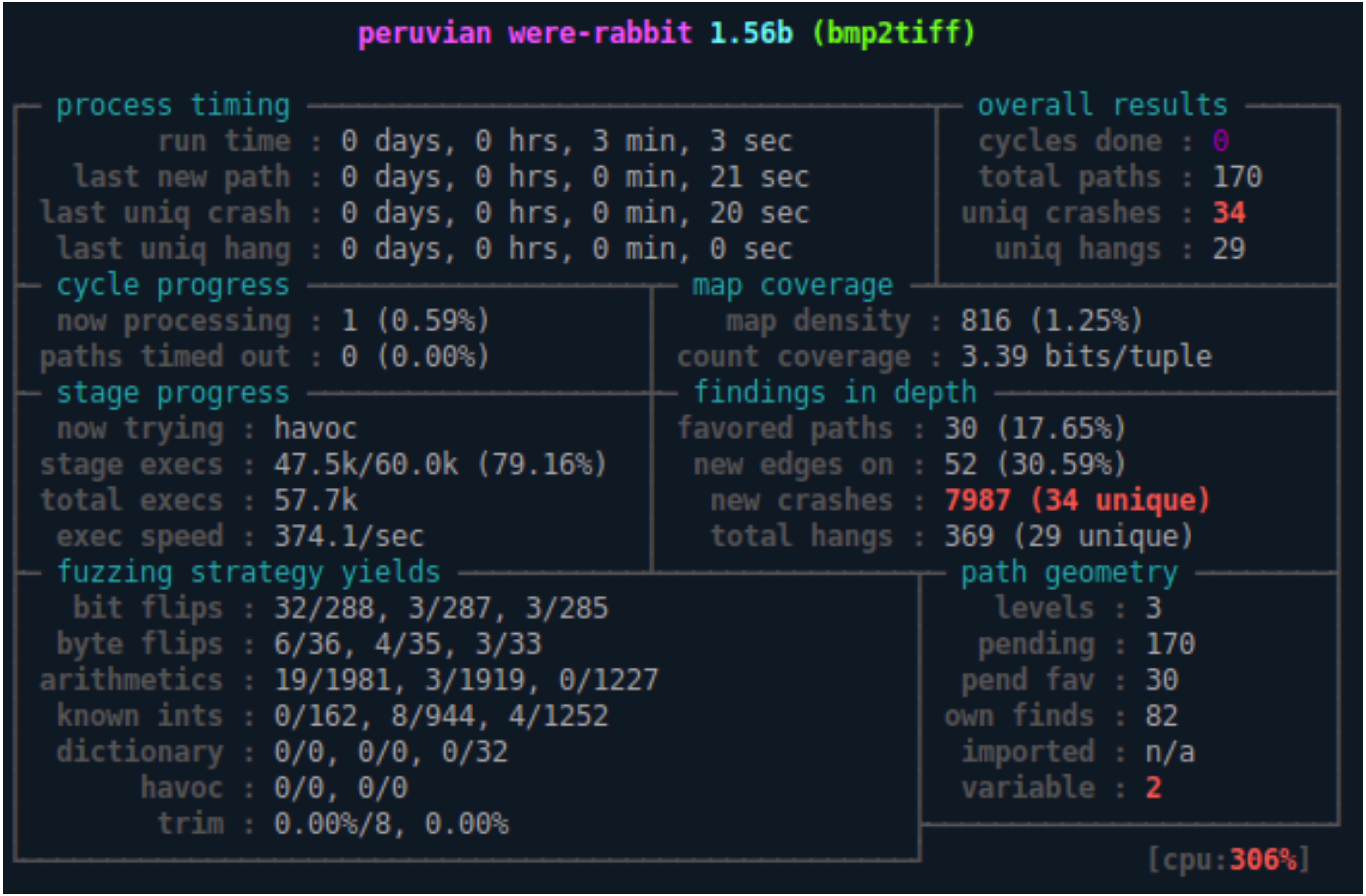
Crash analysis (step 7)
peruvian were-rabbit

Crash analysis (step 7)
peruvian were-rabbit

- Using crashes as inputs, mutate them to find different crashes (that AFL considers "unique")

```
/opt/libtiff-cvs-afl$ afl-fuzz -i output/crashes/ -o
peruvian_crashes -C /opt/libtiff-cvs-afl/tools/bmp2tiff
@@ /dev/null
```

Crash analysis (step 7)
peruvian were-rabbit



```
                  peruvian were-rabbit 1.56b (bmp2tiff)

┌─ process timing ─────────────────────────────────────┬─ overall results ────┐
│        run time : 0 days, 0 hrs, 3 min, 3 sec        │  cycles done : 0     │
│   last new path : 0 days, 0 hrs, 0 min, 21 sec       │  total paths : 170   │
│ last uniq crash : 0 days, 0 hrs, 0 min, 20 sec       │ uniq crashes : 34    │
│  last uniq hang : 0 days, 0 hrs, 0 min, 0 sec        │   uniq hangs : 29    │
├─ cycle progress ────────────────────┬─ map coverage ─┴──────────────────────┤
│  now processing : 1 (0.59%)         │    map density : 816 (1.25%)          │
│ paths timed out : 0 (0.00%)         │ count coverage : 3.39 bits/tuple      │
├─ stage progress ────────────────────┼─ findings in depth ────────────────────┤
│  now trying : havoc                 │ favored paths : 30 (17.65%)           │
│ stage execs : 47.5k/60.0k (79.16%)  │  new edges on : 52 (30.59%)           │
│ total execs : 57.7k                 │ new crashes : 7987 (34 unique)        │
│  exec speed : 374.1/sec             │  total hangs : 369 (29 unique)        │
├─ fuzzing strategy yields ───────────┴───────────────┬─ path geometry ────────┤
│   bit flips : 32/288, 3/287, 3/285                   │    levels : 3          │
│  byte flips : 6/36, 4/35, 3/33                       │   pending : 170        │
│ arithmetics : 19/1981, 3/1919, 0/1227                │  pend fav : 30         │
│  known ints : 0/162, 8/944, 4/1252                   │ own finds : 82         │
│  dictionary : 0/0, 0/0, 0/32                         │  imported : n/a        │
│       havoc : 0/0, 0/0                               │  variable : 2          │
│        trim : 0.00%/8, 0.00%                         ├────────────────────────┘
└──────────────────────────────────────────────────────┘          [cpu:306%]
```

You want more?

- Try it yourself
- Subscribe to afl-users
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int 3

- Twitter: @floyd_ch
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- tobias@modzero.ch
- Twitter: @mod0
- http://www.modzero.ch