Fuzz Everything, Everywhere, All at Once

Advanced QEMU-based fuzzing

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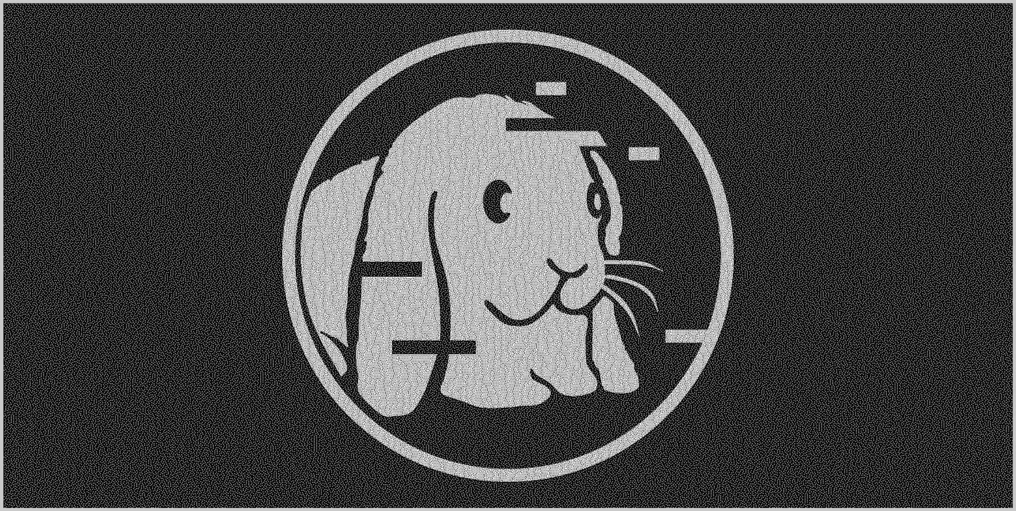
AFLplusplus Project

- Started with the AFL fork AFL++
- In 2019
- Added a ton of community features



LibAFL is rewritten from scratch in Rust 🦀🦀🦀

Today we will talk about Fuzzing, LibAFL, and QEMU(lation)

```
fuzz_regex_match (default)                         charts (`g` switch)
                                                   speed | corpus | objectives
generic
run time
clients
executions
exec/sec

client #1 (l/r a
executions
exec/sec
corpus
objectives
edges
stability
                                                                             time
                                                                       0h-0m-32s
clients logs (`t
[Stats        #1]
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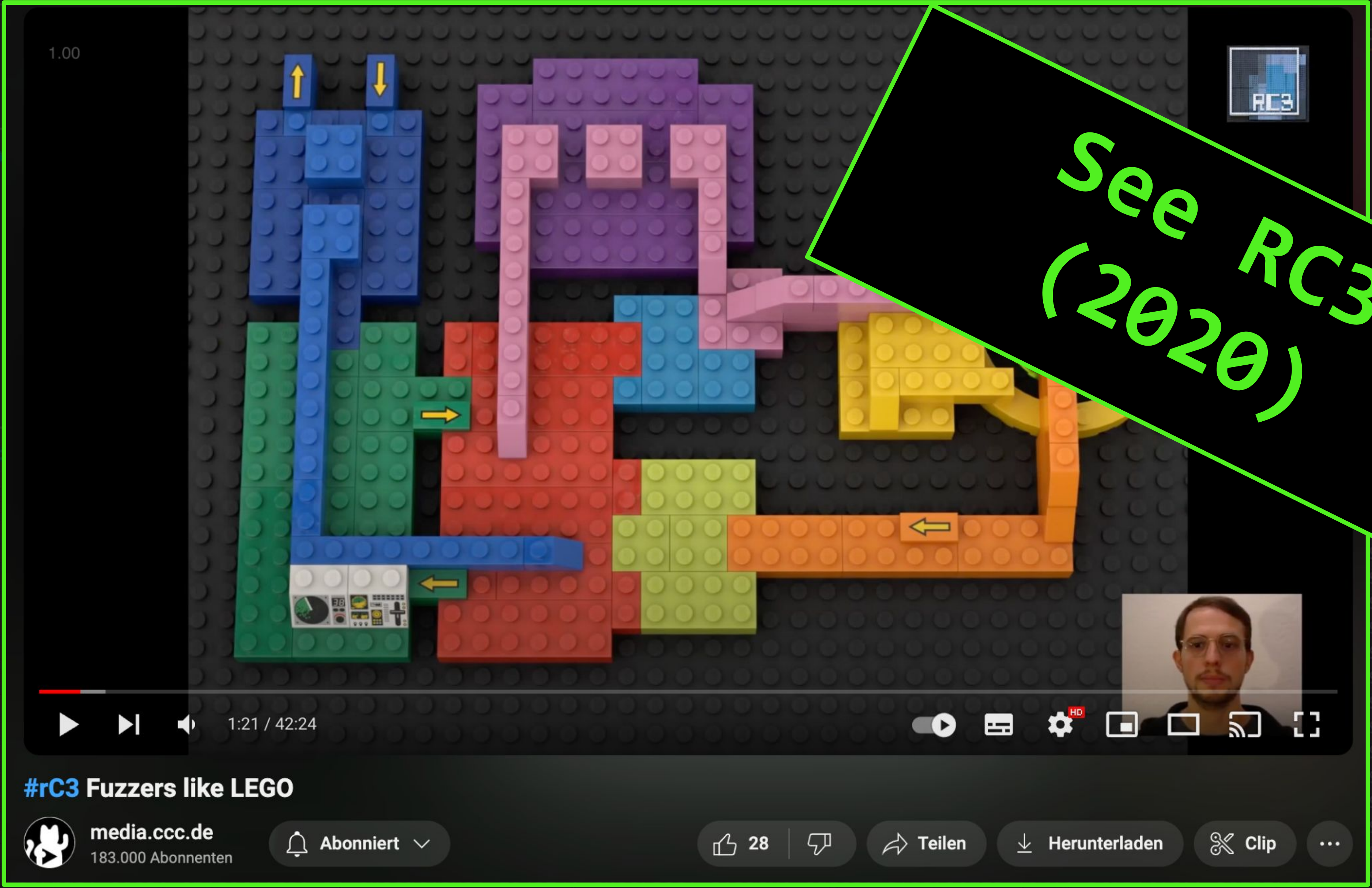

#rC3 Fuzzers like LEGO

media.ccc.de
183.000 Abonnenten

See RC3 (2020)

The AFLplusplus Project

Marc “vanHauser” Heuse

Andrea Fioraldi

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voluntary contributors,
Full-time working/
researching at:

Security Research Labs

EURECOM
Sophia Antipolis

CISPA

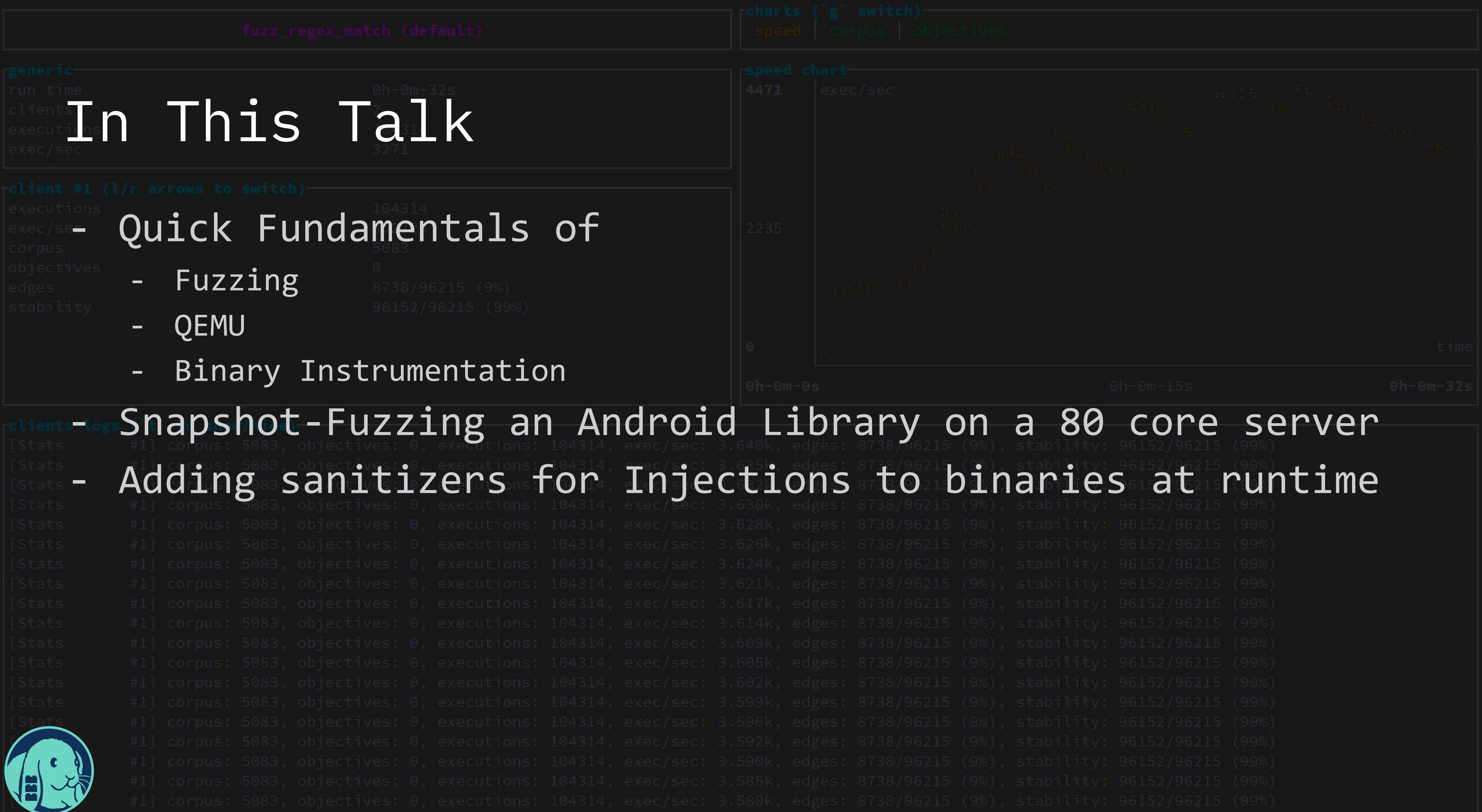
Google

and more

and a large community!

In This Talk

- Quick Fundamentals of
  - Fuzzing
  - QEMU
  - Binary Instrumentation
- Snapshot-Fuzzing an Android Library on a 80 core server
- Adding sanitizers for Injections to binaries at runtime



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fuzz_regex_match (default)                      charts (`g` switch)
                                                 speed | corpus | objectives
generic                                          speed chart
run time                 0h-0m-32s               4471    exec/sec
clients
executions
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client #1 (l/r arrows to switch)
executions               104314
exec/sec                                         2235
corpus                   5083
objectives               0
edges                    8738/96215 (9%)
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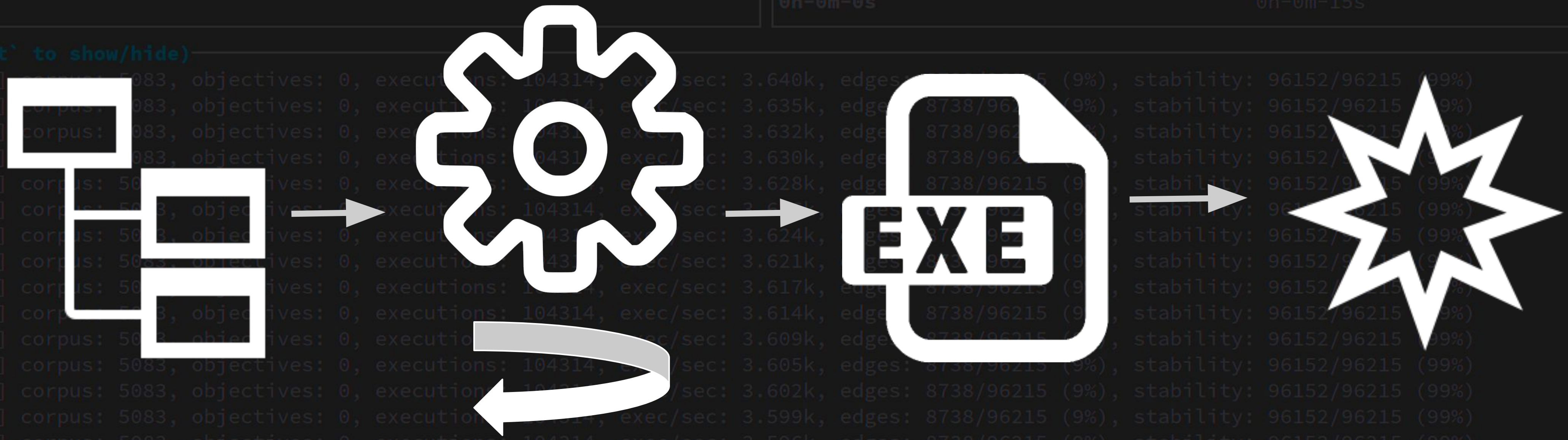
Fuzz

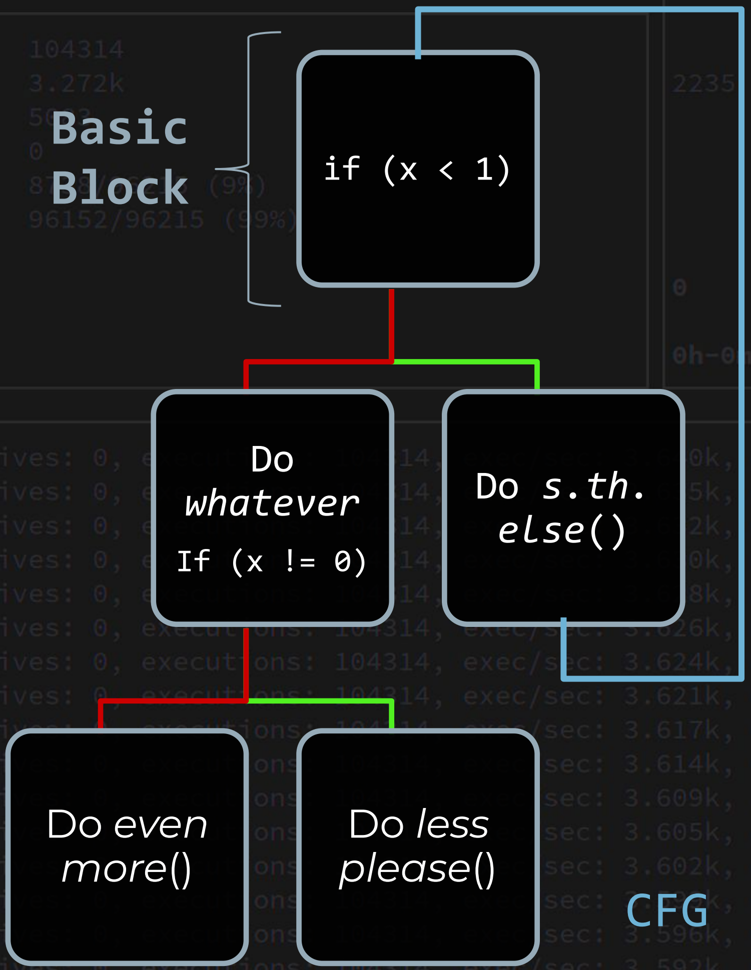
Everything, Everywhere, All at Once

Fuzzing in a Nutshell

Fuzzing delivers a large amount of machine-generated inputs as quickly as possible to the target in order to find some objectives.



Coverage-Guided Fuzzing



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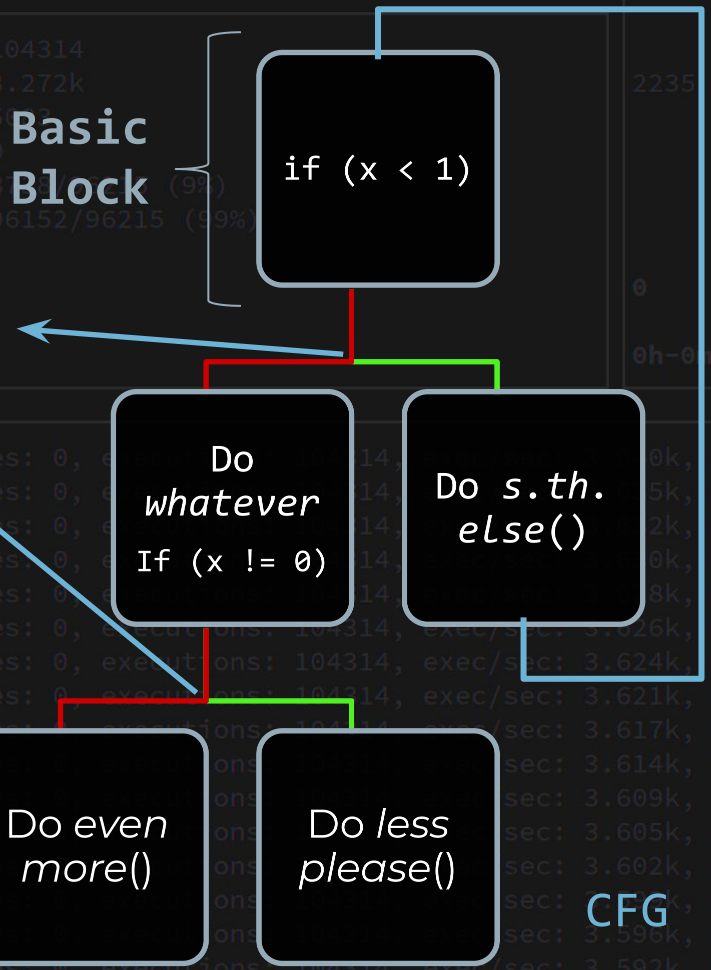


Count how often these happen.

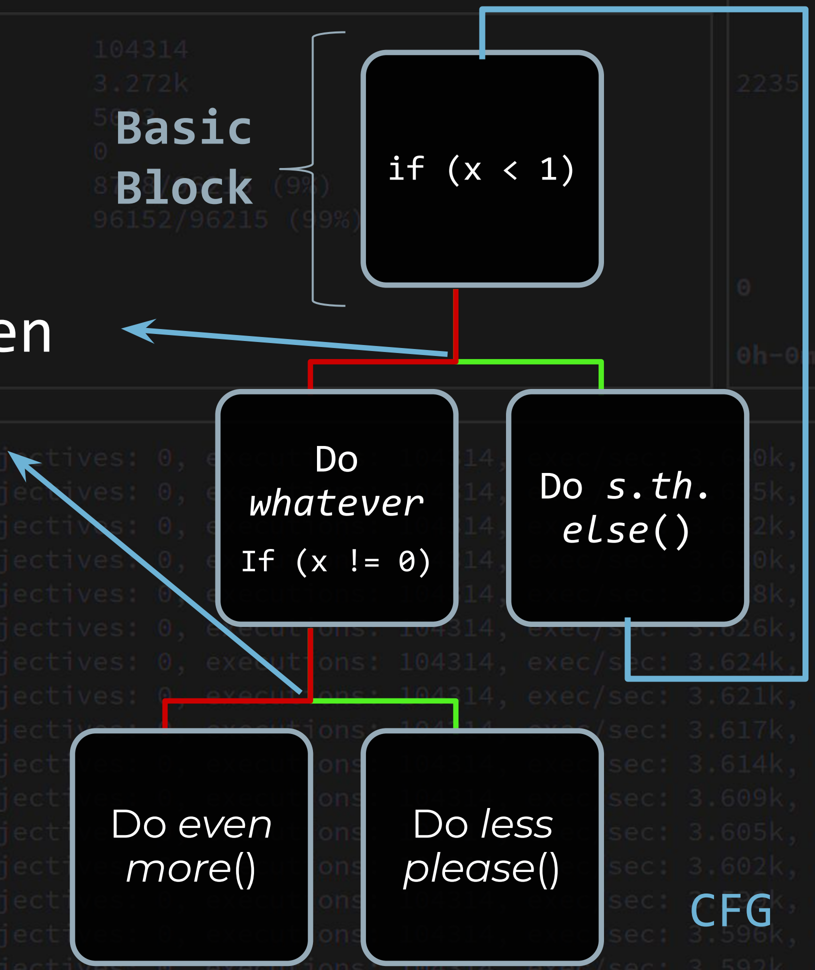
- Fuzzer takes reached coverage as feedback

Coverage-Guided Fuzzing

Count how often these happen.

↳ **Feedback**

↳ Favor Inputs leading to new edges



- Fuzzer takes reached coverage as feedback
- Keeps the track of edges and favors new coverage
- Orders of magnitude faster!

Fuzz

Everything,

Everywhere,

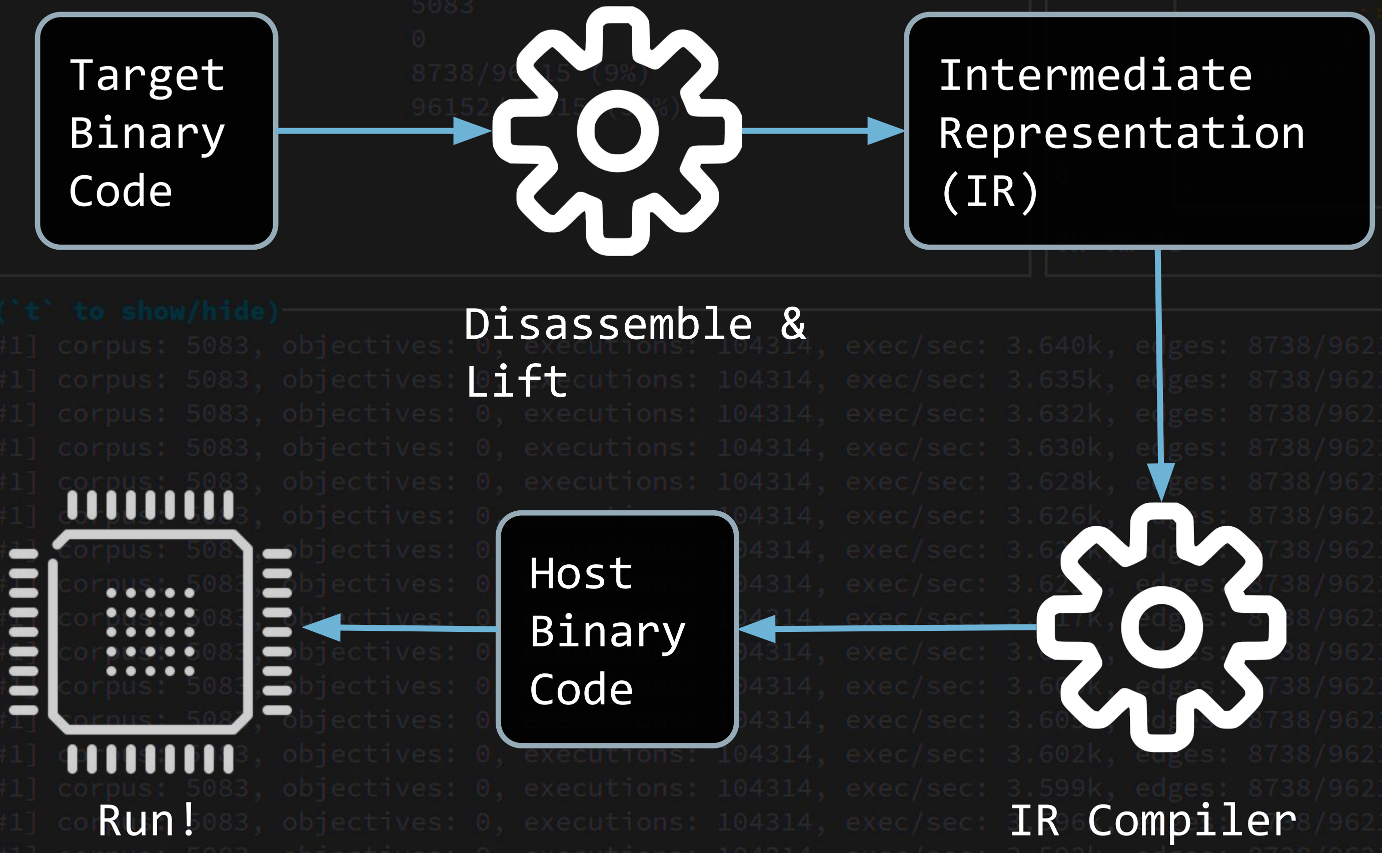
All at Once

Dynamic
Binary
Instrumentation

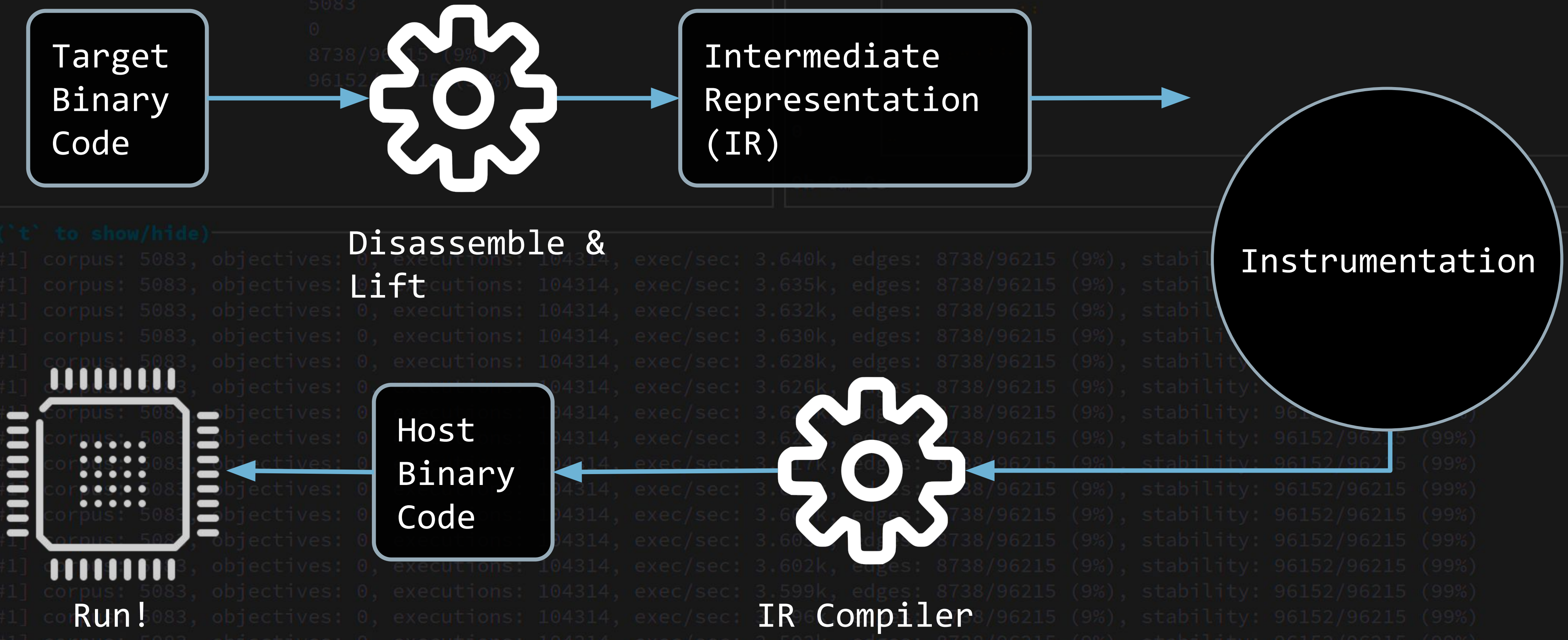
Meet QEMU, the Quick Emulator

- Very popular full-system emulator
  - CPU
  - Memory
  - Peripherals
- Support for a variety of ISAs (x86, aarch64, …, even hexagon)
- user-mode emulation support:
  - Emulation of userspace software
  - System call translation layer
  - Can be (ab-)used to change syscall behavior :)

JIT Code Rewriting



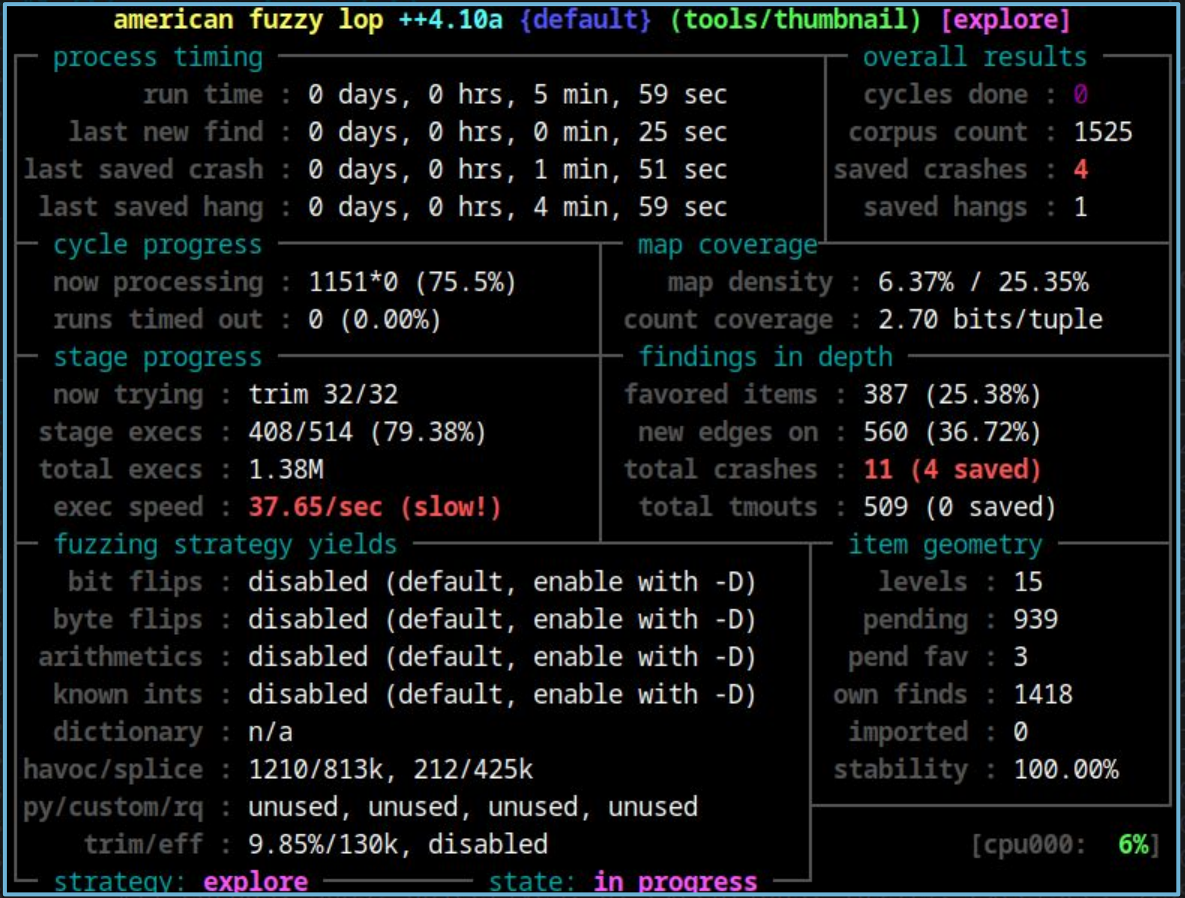
JIT Code Instrumentation



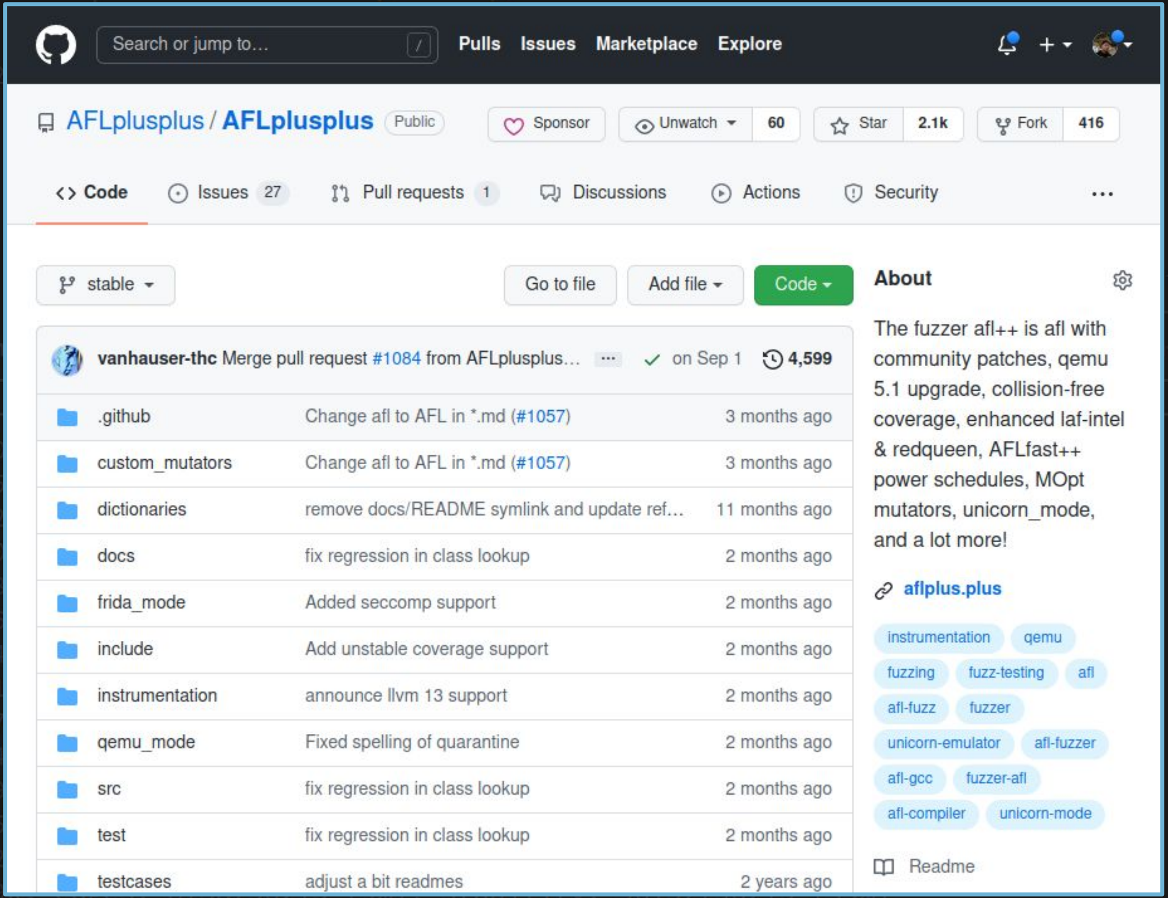
Fuzz Everything, Everywhere, All at Once

LibAFL

AFL++ pew pew! bugs!



```
         american fuzzy lop ++4.10a {default} (tools/thumbnail) [explore]
┌─ process timing ────────────────────────────────────┬─ overall results ────┐
│        run time : 0 days, 0 hrs, 5 min, 59 sec      │  cycles done : 0     │
│   last new find : 0 days, 0 hrs, 0 min, 25 sec      │ corpus count : 1525  │
│last saved crash : 0 days, 0 hrs, 1 min, 51 sec      │saved crashes : 4     │
│ last saved hang : 0 days, 0 hrs, 4 min, 59 sec      │  saved hangs : 1     │
├─ cycle progress ─────────────────────┬─ map coverage┴──────────────────────┤
│  now processing : 1151*0 (75.5%)     │    map density : 6.37% / 25.35%      │
│  runs timed out : 0 (0.00%)          │ count coverage : 2.70 bits/tuple     │
├─ stage progress ─────────────────────┼─ findings in depth ─────────────────┤
│  now trying : trim 32/32             │ favored items : 387 (25.38%)         │
│ stage execs : 408/514 (79.38%)       │  new edges on : 560 (36.72%)         │
│ total execs : 1.38M                  │ total crashes : 11 (4 saved)         │
│  exec speed : 37.65/sec (slow!)      │  total tmouts : 509 (0 saved)        │
├─ fuzzing strategy yields ────────────┴─────────────┬─ item geometry ───────┤
│   bit flips : disabled (default, enable with -D)   │    levels : 15        │
│  byte flips : disabled (default, enable with -D)   │   pending : 939       │
│ arithmetics : disabled (default, enable with -D)   │  pend fav : 3         │
│  known ints : disabled (default, enable with -D)   │ own finds : 1418      │
│  dictionary : n/a                                  │  imported : 0         │
│havoc/splice : 1210/813k, 212/425k                  │ stability : 100.00%   │
│py/custom/rq : unused, unused, unused, unused       ├───────────────────────┘
│    trim/eff : 9.85%/130k, disabled                 │          [cpu000:  6%]
└─ strategy: explore ────────── state: in progress ──┘
```



AFLplusplus / AFLplusplus Public

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Code | Issues 27 | Pull requests 1 | Discussions | Actions | Security | ...

stable | Go to file | Add file | Code

vanhauser-thc Merge pull request #1084 from AFLplusplus... ✓ on Sep 1 4,599

.github	Change afl to AFL in *.md (#1057)	3 months ago
custom_mutators	Change afl to AFL in *.md (#1057)	3 months ago
dictionaries	remove docs/README symlink and update ref...	11 months ago
docs	fix regression in class lookup	2 months ago
frida_mode	Added seccomp support	2 months ago
include	Add unstable coverage support	2 months ago
instrumentation	announce llvm 13 support	2 months ago
qemu_mode	Fixed spelling of quarantine	2 months ago
src	fix regression in class lookup	2 months ago
test	fix regression in class lookup	2 months ago
testcases	adjust a bit readmes	2 years ago

About

The fuzzer afl++ is afl with community patches, qemu 5.1 upgrade, collision-free coverage, enhanced laf-intel & redqueen, AFLfast++ power schedules, MOpt mutators, unicorn_mode, and a lot more!

aflplus.plus

instrumentation qemu fuzzing fuzz-testing afl afl-fuzz fuzzer unicorn-emulator afl-fuzzer afl-gcc fuzzer-afl afl-compiler unicorn-mode

Readme

```
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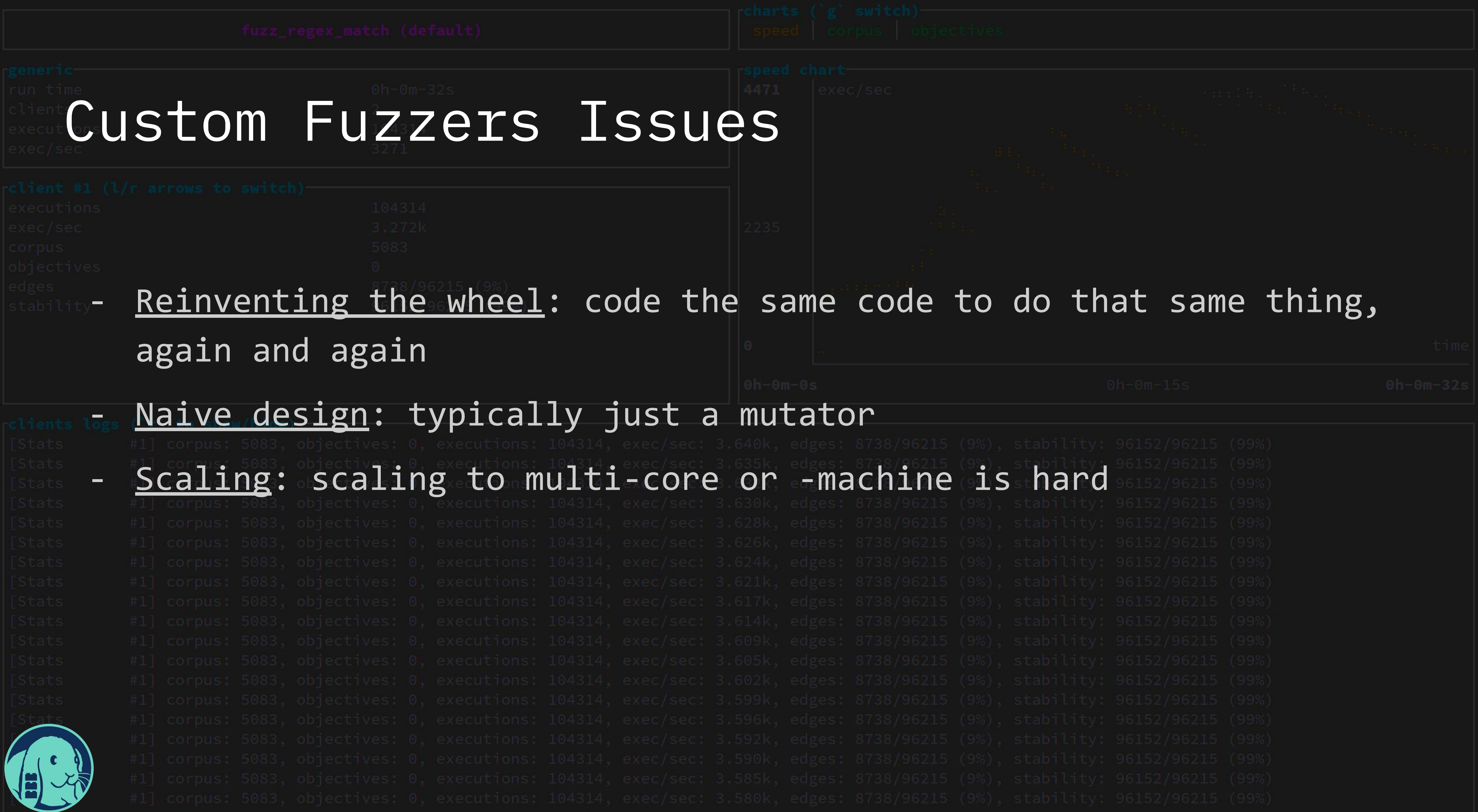
Custom Fuzzers Issues

- Reinventing the wheel: code the same code to do that same thing, again and again
- Naive design: typically just a mutator
- Scaling: scaling to multi-core or -machine is hard



```
generic
run time                              0h-0m-32s
clients                               2
executions                            [illegible]
exec/sec                              3271

client #1 (l/r arrows to switch)
executions                            104314
exec/sec                              3.272k
corpus                                5083
objectives                            0
edges                                 8738/96215 (9%)
stability                             [illegible]

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LibAFL

- State-of-the-Art
- Portable
- Extensible
- Scalable
- Performant, thanks to compile-time abstractions in Rust

```
fuzz_regex_match (default)

generic
run time                                  0h-0m-32s
clients                                   2
executions                                104314
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charts (`g` switch)
 speed | corpus | objectives

speed chart
4471   exec/sec
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```

High level design

- LibAFL Core, the main library
- LibAFL Targets, the runtime code that lives in the target
- LibAFL CC, the library to write compiler wrappers

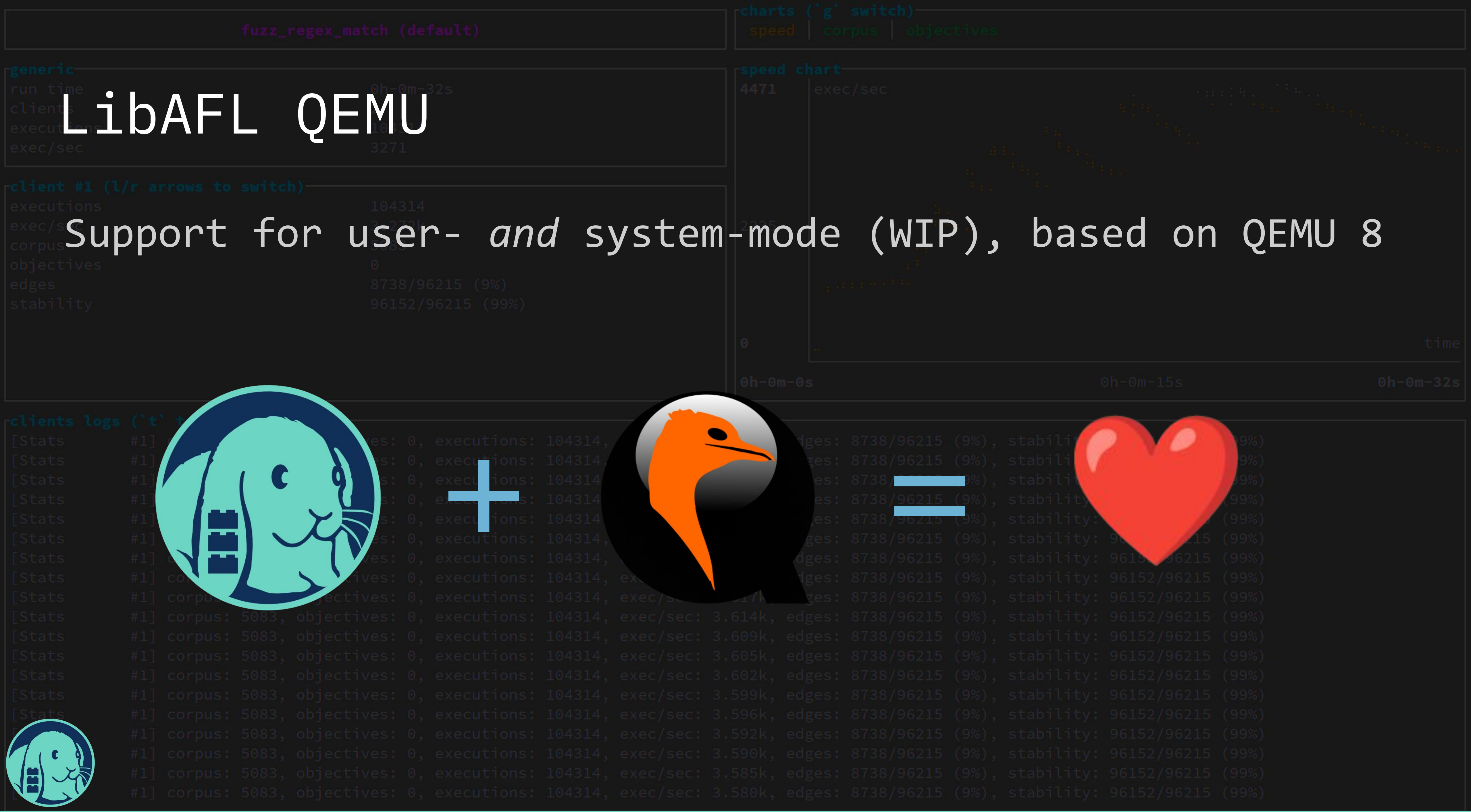
+

Many instrumentation options

LibAFL QEMU

Support for user- *and* system-mode (WIP), based on QEMU 8

+ =



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             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```
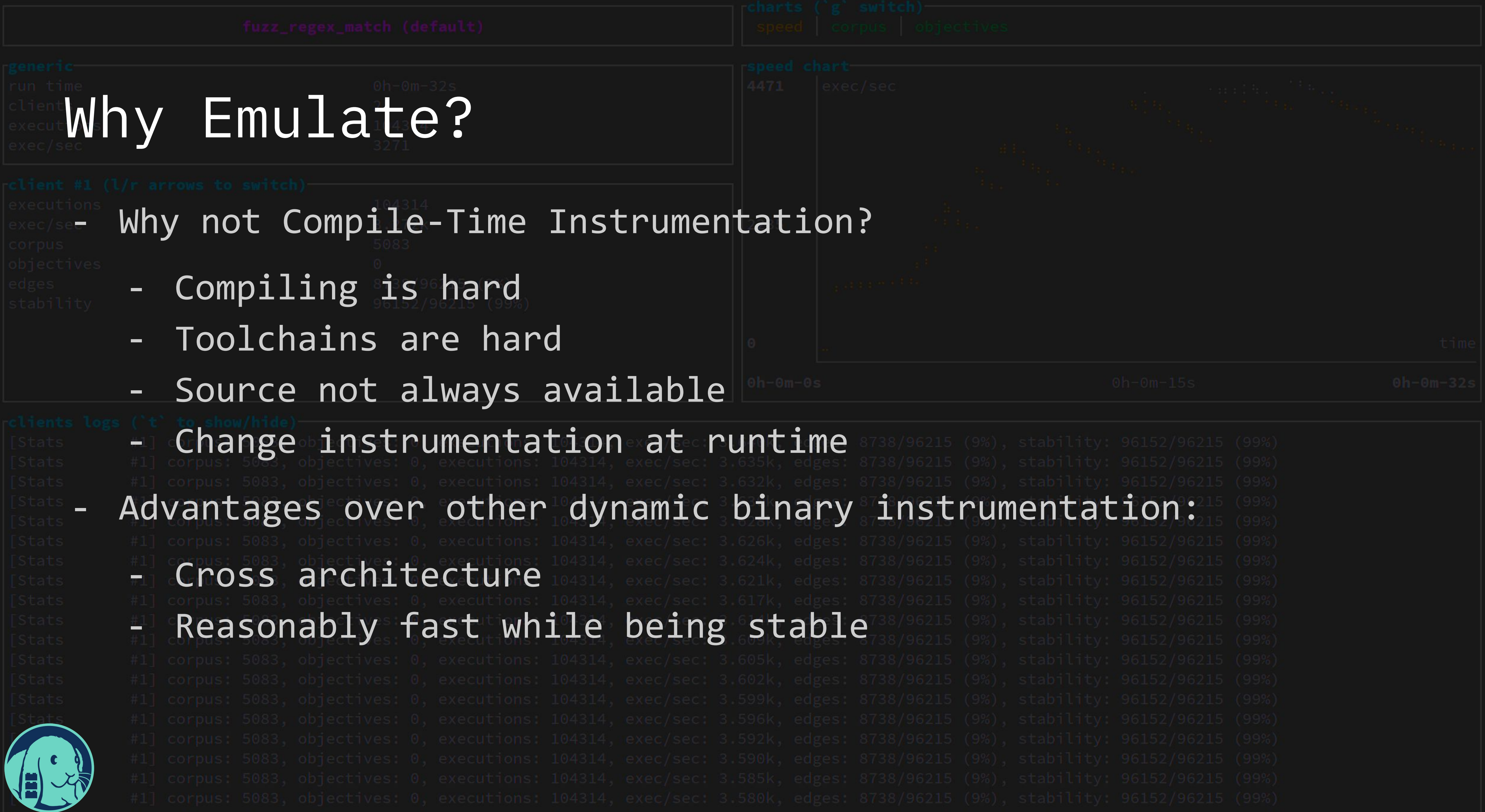

Why Emulate?

- Why not Compile-Time Instrumentation?
  - Compiling is hard
  - Toolchains are hard
  - Source not always available
  - Change instrumentation at runtime
- Advantages over other dynamic binary instrumentation:
  - Cross architecture
  - Reasonably fast while being stable

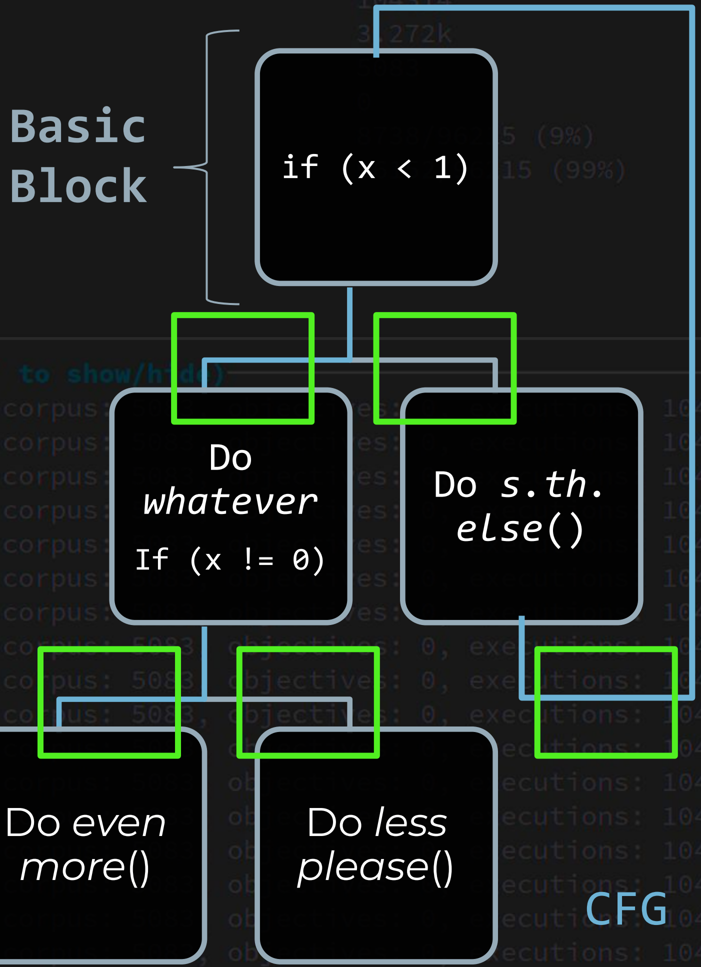


```
fuzz_regex_match (default)

generic
run time       0h-0m-32s
clients        2
executions     104314
exec/sec       3271

client #1 (l/r arrows to switch)
executions     104314
exec/sec       [illegible]
corpus         5083
objectives     0
edges          8738/96215 (9%)
stability      96152/96215 (99%)

clients logs (`t` to show/hide)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats  #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
        #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
        #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
        #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
        #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

Fuzz
Everything,
Everywhere,
All at Once

LibAFL
<3
QEMU

LibAFL QEMU Hooks



Example: Edge Hooks

Instrumentation (in JIT) that is running callback functions

Before any jump, reports a unique id for the taken edge to a hook

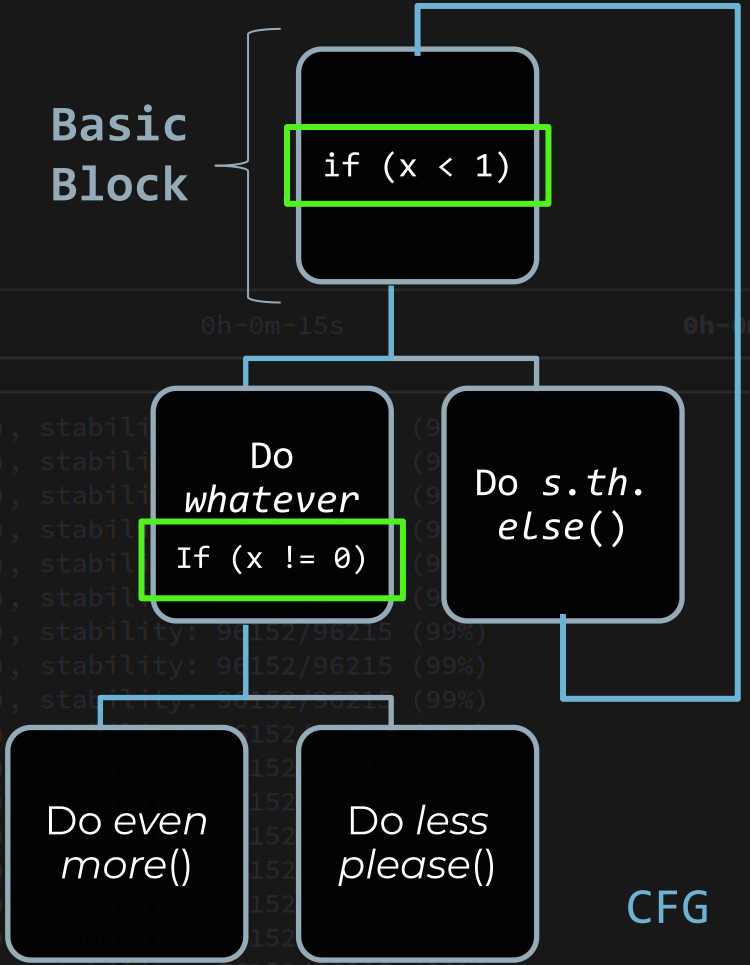
```
Generation Hook:
fn(&mut Self, Option<&mut S>, src: GuestAddr, dest: GuestAddr) ->
Option<u64> { … }
```

```
Execution Hook:
FnMut(&'a mut Self, Option<&'a mut S>, u64)
```

LibAFL QEMU Hooks

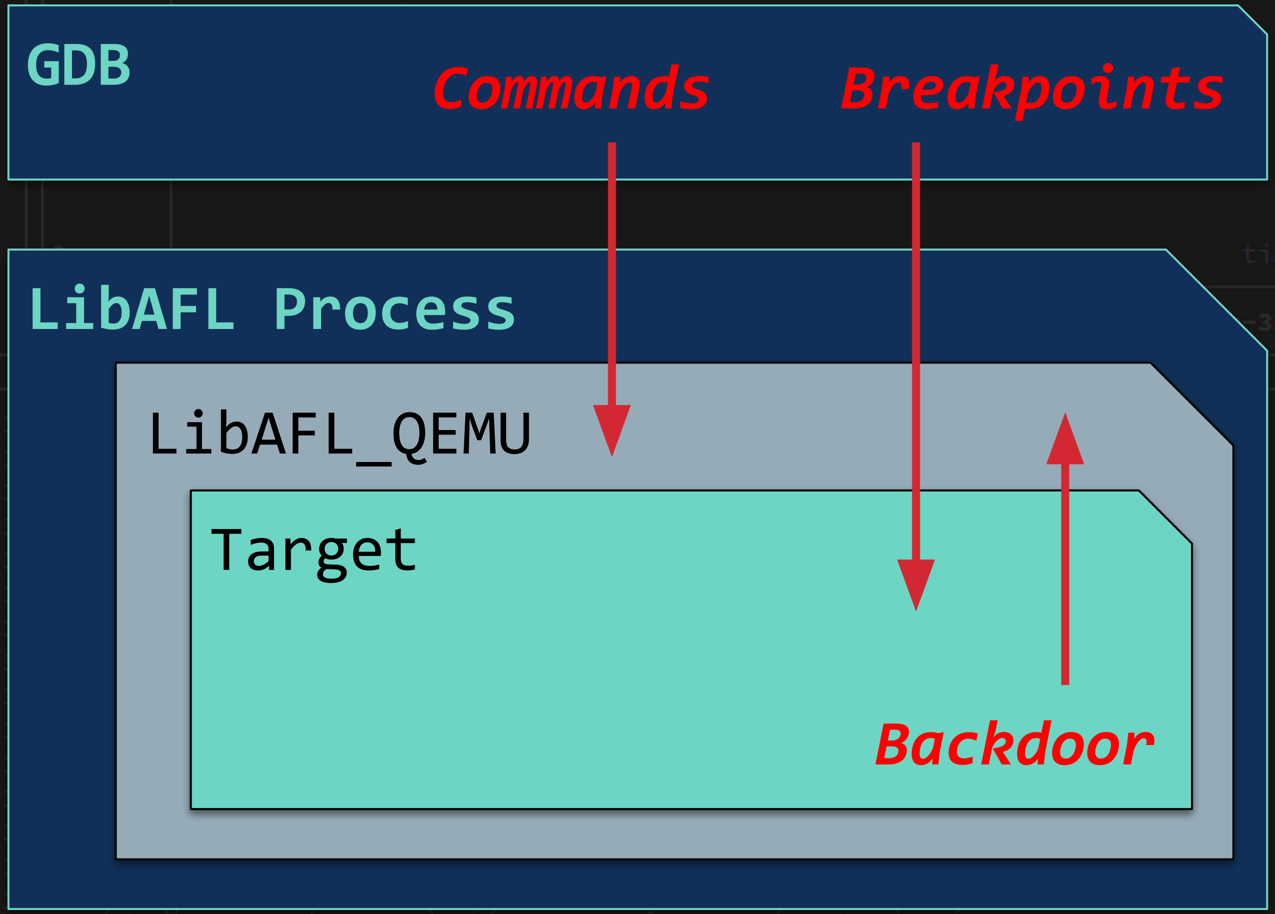
- Instructions
- Blocks
- Edges
- Read and write

- Comparisons
- Threads
- Syscalls
- Crashes



Fuzzing With QEMU: Execution Control

- Backdoor: *target-defined* point at which execution halts
- Breakpoint: *fuzzer-defined* point at which execution halts
- Commands: *custom GDB commands* to interact with the target state

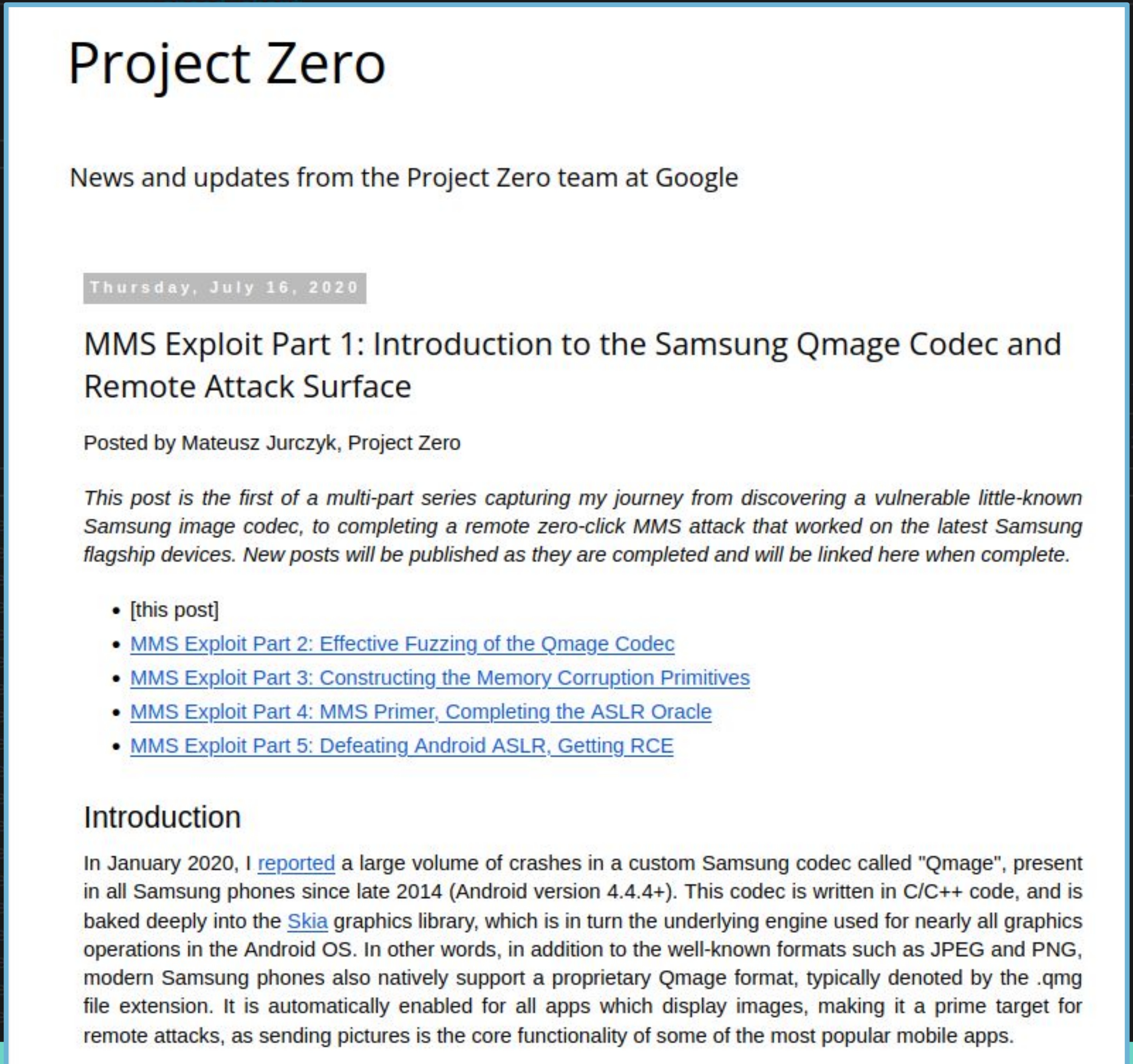


Fuzz Everything, Everywhere, All at Once

Sanitized
Android
Snapshot
Fuzzing

Target Library

```
fuzz_regex_match (default)                    charts (`g` switch)
                                               speed | corpus | objectives
generic
run time                          0h-0m-32s
clients                           2
client #1 (l/r arrows to switch)
executions                        104314
exec/sec                          3.272k
corpus                            5083
objectives                        0
edges                             8738/96215 (9%)
stability                         96152/96215 (99%)

clients logs (`t` to show/hide)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, e
             #1] corpus: 5083, objectives: 0, executions: 104314, e
             #1] corpus: 5083, objectives: 0, executions: 104314, e
             #1] corpus: 5083, objectives: 0, executions: 104314, e
             #1] corpus: 5083, objectives: 0, executions: 104314, e
```



Project Zero

News and updates from the Project Zero team at Google

Thursday, July 16, 2020

MMS Exploit Part 1: Introduction to the Samsung Qmage Codec and Remote Attack Surface

Posted by Mateusz Jurczyk, Project Zero

This post is the first of a multi-part series capturing my journey from discovering a vulnerable little-known Samsung image codec, to completing a remote zero-click MMS attack that worked on the latest Samsung flagship devices. New posts will be published as they are completed and will be linked here when complete.

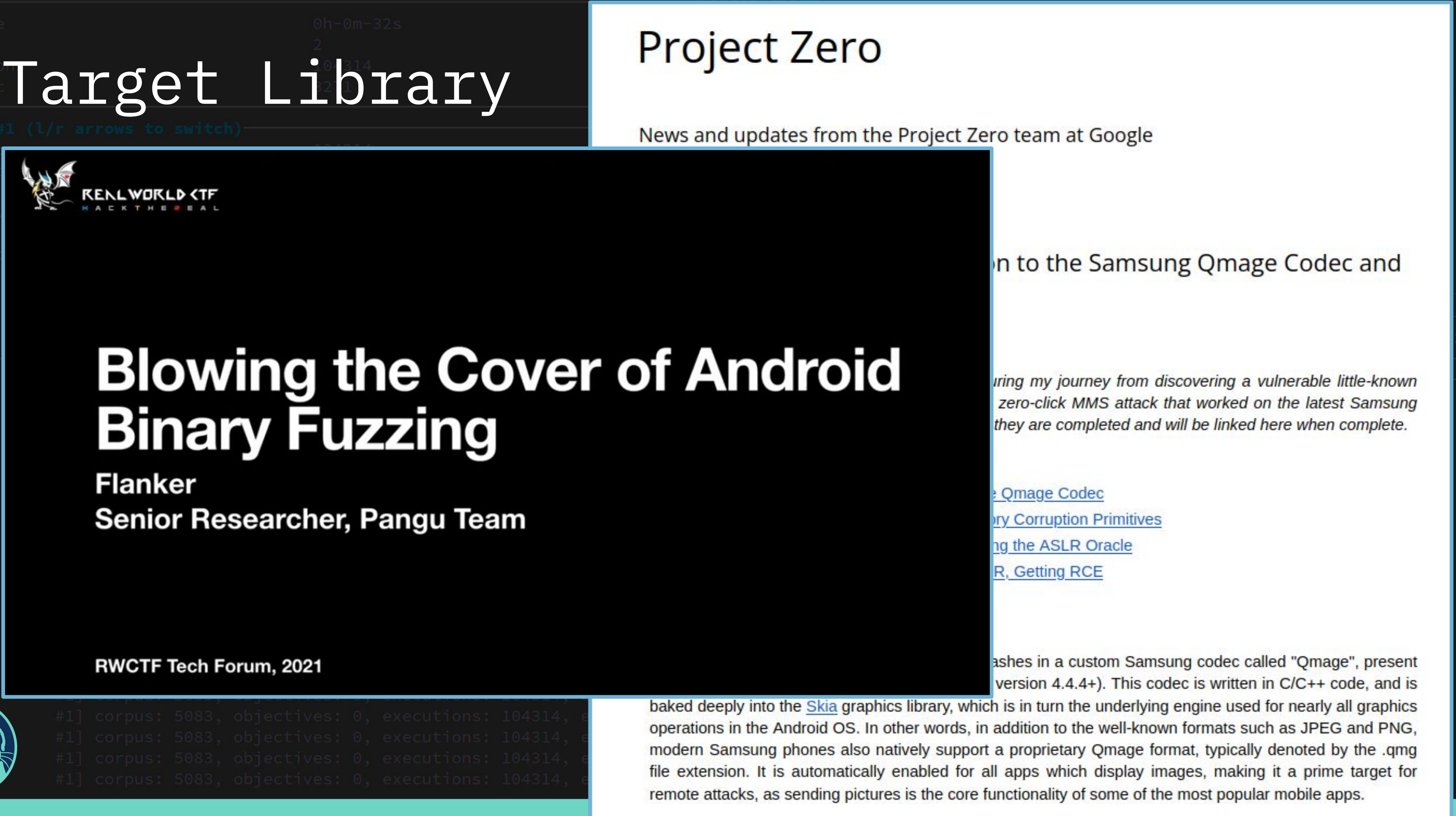
- [this post]
- MMS Exploit Part 2: Effective Fuzzing of the Qmage Codec
- MMS Exploit Part 3: Constructing the Memory Corruption Primitives
- MMS Exploit Part 4: MMS Primer, Completing the ASLR Oracle
- MMS Exploit Part 5: Defeating Android ASLR, Getting RCE

Introduction

In January 2020, I reported a large volume of crashes in a custom Samsung codec called "Qmage", present in all Samsung phones since late 2014 (Android version 4.4.4+). This codec is written in C/C++ code, and is baked deeply into the Skia graphics library, which is in turn the underlying engine used for nearly all graphics operations in the Android OS. In other words, in addition to the well-known formats such as JPEG and PNG, modern Samsung phones also natively support a proprietary Qmage format, typically denoted by the .qmg file extension. It is automatically enabled for all apps which display images, making it a prime target for remote attacks, as sending pictures is the core functionality of some of the most popular mobile apps.

```
                    fuzz_regex_match (default)          charts (`g` switch)
                                                        speed | corpus | objectives
generic
run time                                 0h-0m-32s
clients                                  2
executio                                 104314
exec/sec
client #1 (l/r arrows to switch)
executi
exec/se
corpus
objectiv
edges
stabilit
clients
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
[Stats
      #1] corpus: 5083, objectives: 0, executions: 104314, e
      #1] corpus: 5083, objectives: 0, executions: 104314, e
      #1] corpus: 5083, objectives: 0, executions: 104314, e
      #1] corpus: 5083, objectives: 0, executions: 104314, e
```

Target Library



REALWORLD CTF

HACK THE REAL

Blowing the Cover of Android Binary Fuzzing

Flanker

Senior Researcher, Pangu Team

RWCTF Tech Forum, 2021

Project Zero

News and updates from the Project Zero team at Google

n to the Samsung Qmage Codec and

uring my journey from discovering a vulnerable little-known zero-click MMS attack that worked on the latest Samsung they are completed and will be linked here when complete.

Qmage Codec

ory Corruption Primitives

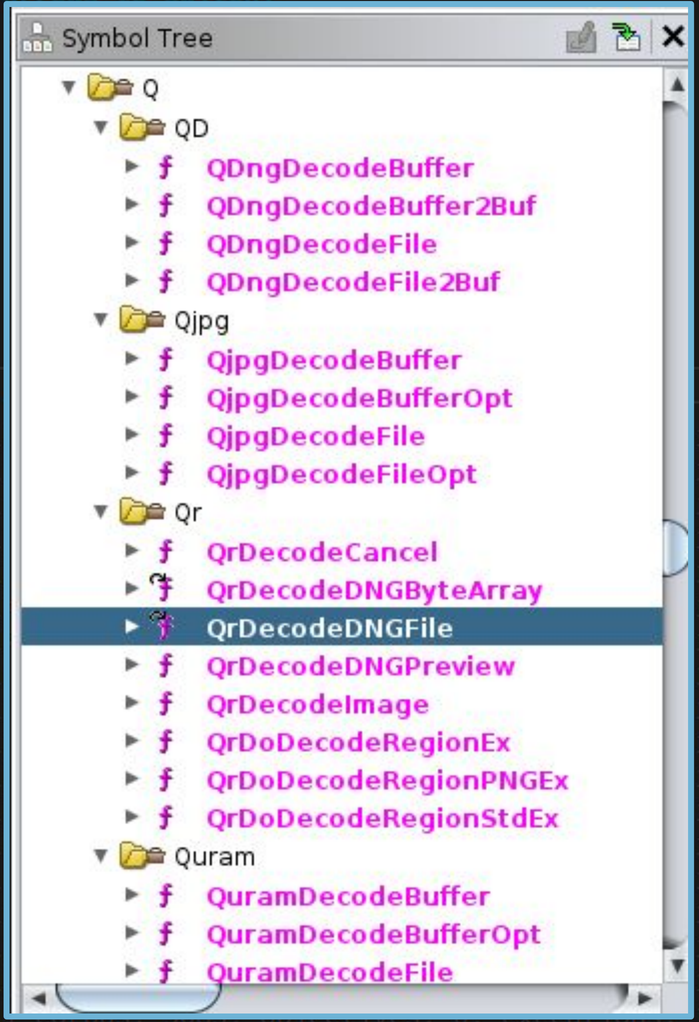
ng the ASLR Oracle

R, Getting RCE

ashes in a custom Samsung codec called "Qmage", present version 4.4.4+). This codec is written in C/C++ code, and is baked deeply into the Skia graphics library, which is in turn the underlying engine used for nearly all graphics operations in the Android OS. In other words, in addition to the well-known formats such as JPEG and PNG, modern Samsung phones also natively support a proprietary Qmage format, typically denoted by the .qmg file extension. It is automatically enabled for all apps which display images, making it a prime target for remote attacks, as sending pictures is the core functionality of some of the most popular mobile apps.

Reversing

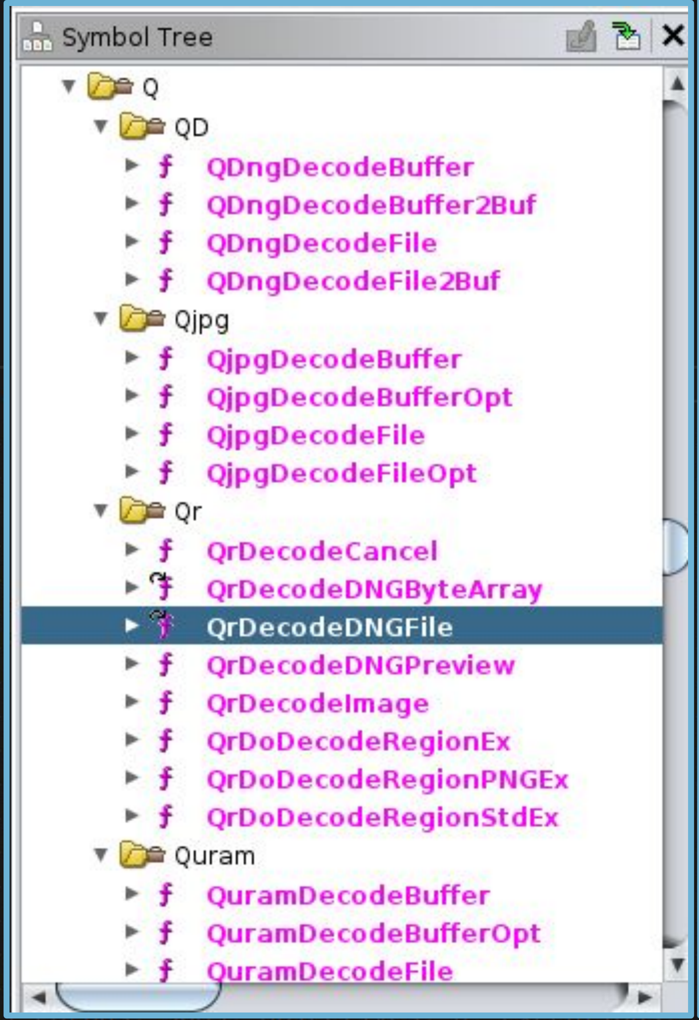
```
fuzz_regex_match (default)                                   charts (`g` switch)
                                                             speed | corpus | objectives
generic                                                      speed chart
run time                      0h-0m-32s                      4471   exec/sec
clients                       2
executio                      104314
exec/sec                      271                            2235
client #1 (l/r arrows to switch)
executions
exec/sec
corpus                                                       0                                    time
objectives                                                   0h-0m-0s        0h-0m-15s       0h-0m-32s
edges
stability

clients logs (`
[Stats      #1   104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1   104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1   104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1   104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```



Symbol Tree

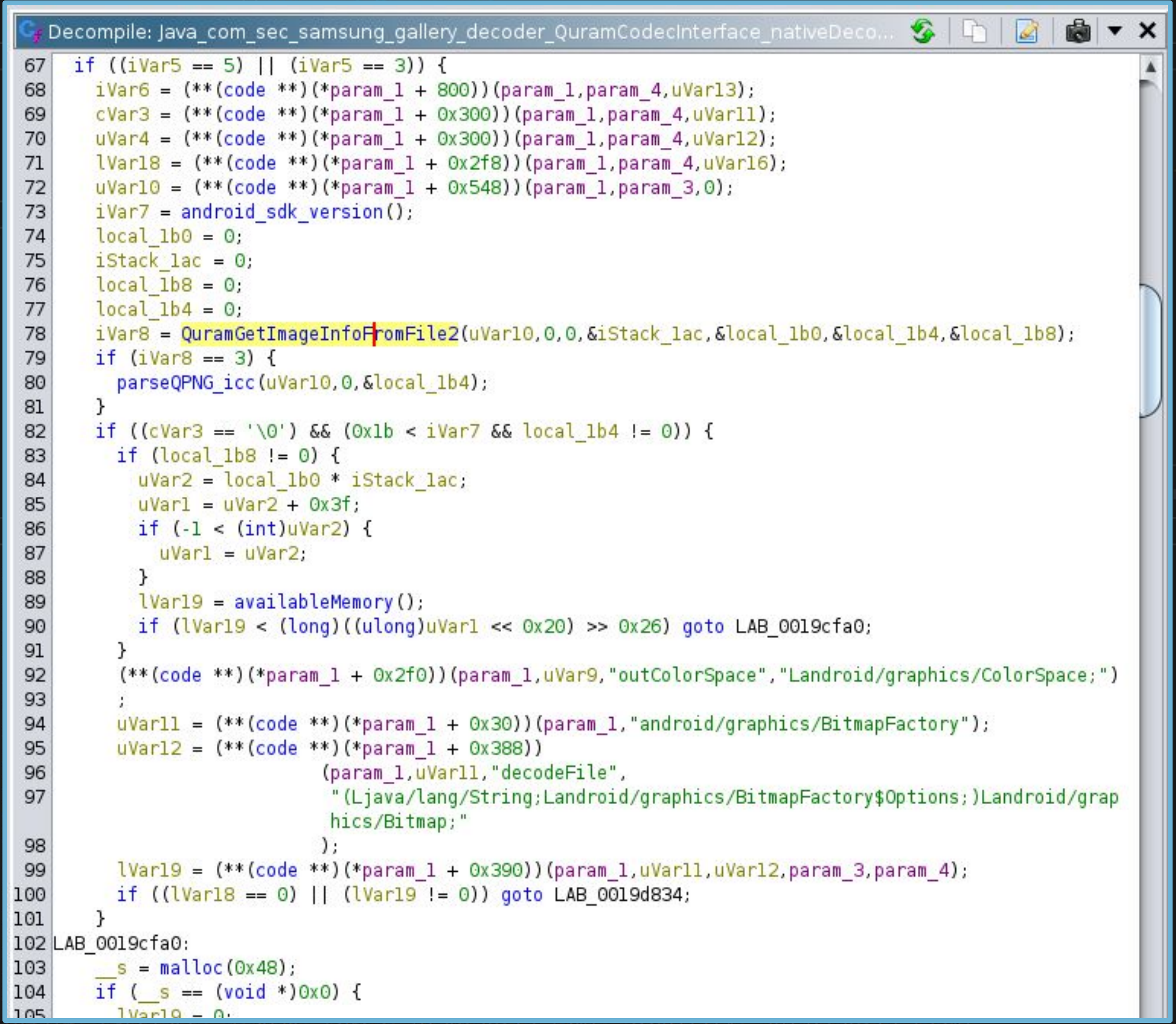
```
▼ Q
  ▼ QD
    ▶ ƒ QDngDecodeBuffer
    ▶ ƒ QDngDecodeBuffer2Buf
    ▶ ƒ QDngDecodeFile
    ▶ ƒ QDngDecodeFile2Buf
  ▼ Qjpg
    ▶ ƒ QjpgDecodeBuffer
    ▶ ƒ QjpgDecodeBufferOpt
    ▶ ƒ QjpgDecodeFile
    ▶ ƒ QjpgDecodeFileOpt
  ▼ Qr
    ▶ ƒ QrDecodeCancel
    ▶ ƒ QrDecodeDNGByteArray
    ▶ ƒ QrDecodeDNGFile
    ▶ ƒ QrDecodeDNGPreview
    ▶ ƒ QrDecodeImage
    ▶ ƒ QrDoDecodeRegionEx
    ▶ ƒ QrDoDecodeRegionPNGEx
    ▶ ƒ QrDoDecodeRegionStdEx
  ▼ Quram
    ▶ ƒ QuramDecodeBuffer
    ▶ ƒ QuramDecodeBufferOpt
    ▶ ƒ QuramDecodeFile
```

Reversing



Symbol Tree

- Q
  - QD
    - QDngDecodeBuffer
    - QDngDecodeBuffer2Buf
    - QDngDecodeFile
    - QDngDecodeFile2Buf
  - Qjpg
    - QjpgDecodeBuffer
    - QjpgDecodeBufferOpt
    - QjpgDecodeFile
    - QjpgDecodeFileOpt
  - Qr
    - QrDecodeCancel
    - QrDecodeDNGByteArray
    - QrDecodeDNGFile
    - QrDecodeDNGPreview
    - QrDecodeImage
    - QrDoDecodeRegionEx
    - QrDoDecodeRegionPNGEx
    - QrDoDecodeRegionStdEx
  - Quram
    - QuramDecodeBuffer
    - QuramDecodeBufferOpt
    - QuramDecodeFile

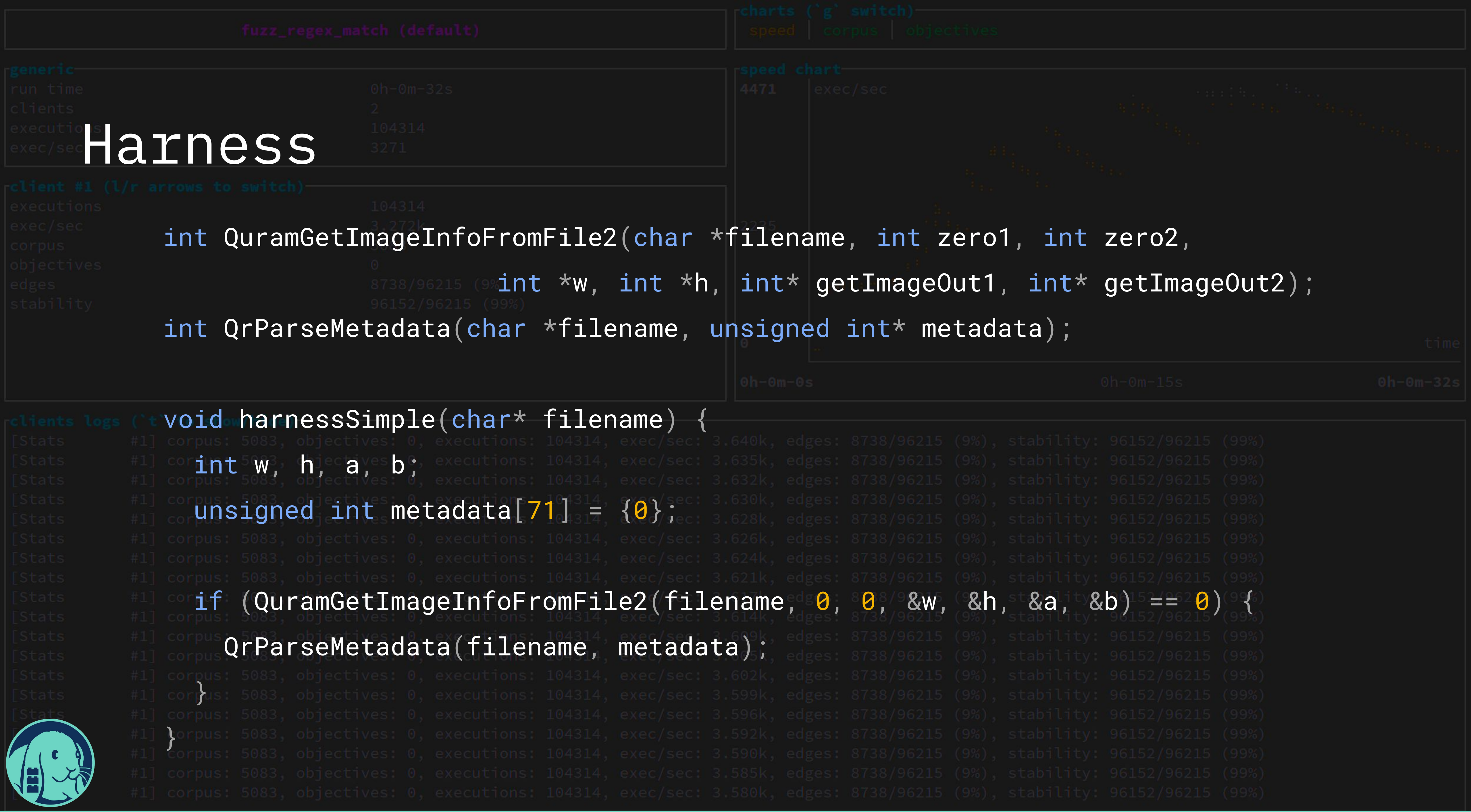


Decompile: Java_com_sec_samsung_gallery_decoder_QuramCodecInterface_nativeDeco...

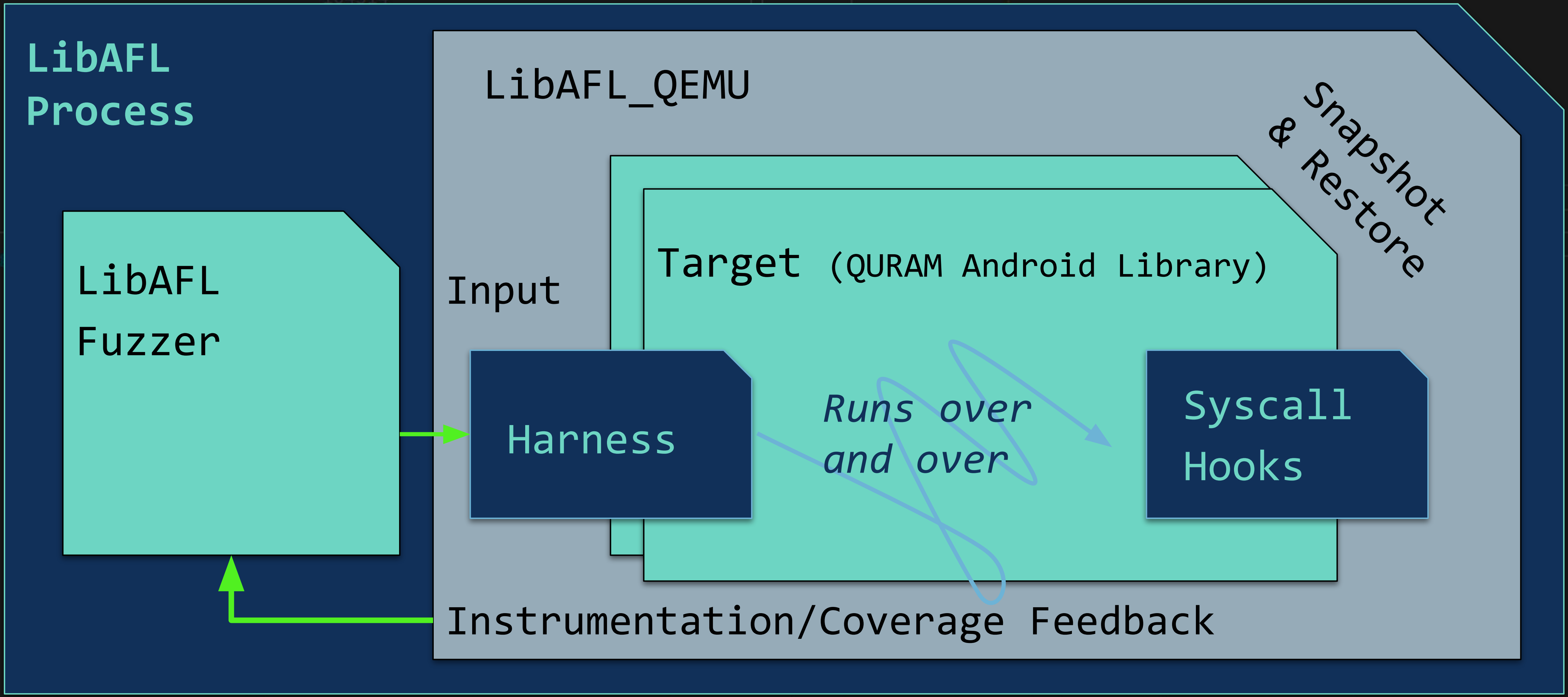
```
  if ((iVar5 == 5) || (iVar5 == 3)) {
    iVar6 = (**(code **)(*param_1 + 800))(param_1,param_4,uVar13);
    cVar3 = (**(code **)(*param_1 + 0x300))(param_1,param_4,uVar11);
    uVar4 = (**(code **)(*param_1 + 0x300))(param_1,param_4,uVar12);
    lVar18 = (**(code **)(*param_1 + 0x2f8))(param_1,param_4,uVar16);
    uVar10 = (**(code **)(*param_1 + 0x548))(param_1,param_3,0);
    iVar7 = android_sdk_version();
    local_1b0 = 0;
    iStack_1ac = 0;
    local_1b8 = 0;
    local_1b4 = 0;
    iVar8 = QuramGetImageInfoFromFile2(uVar10,0,0,&iStack_1ac,&local_1b0,&local_1b4,&local_1b8);
    if (iVar8 == 3) {
      parseQPNG_icc(uVar10,0,&local_1b4);
    }
    if ((cVar3 == '\0') && (0x1b < iVar7 && local_1b4 != 0)) {
      if (local_1b8 != 0) {
        uVar2 = local_1b0 * iStack_1ac;
        uVar1 = uVar2 + 0x3f;
        if (-1 < (int)uVar2) {
          uVar1 = uVar2;
        }
        lVar19 = availableMemory();
        if (lVar19 < (long)((ulong)uVar1 << 0x20) >> 0x26) goto LAB_0019cfa0;
      }
      (**(code **)(*param_1 + 0x2f0))(param_1,uVar9,"outColorSpace","Landroid/graphics/ColorSpace;")
      ;
      uVar11 = (**(code **)(*param_1 + 0x30))(param_1,"android/graphics/BitmapFactory");
      uVar12 = (**(code **)(*param_1 + 0x388))
                         (param_1,uVar11,"decodeFile",
                          "(Ljava/lang/String;Landroid/graphics/BitmapFactory$Options;)Landroid/grap
                          hics/Bitmap;"
                         );
      lVar19 = (**(code **)(*param_1 + 0x390))(param_1,uVar11,uVar12,param_3,param_4);
      if ((lVar18 == 0) || (lVar19 != 0)) goto LAB_0019d834;
    }
LAB_0019cfa0:
    __s = malloc(0x48);
    if (__s == (void *)0x0) {
      lVar19 = 0;
```

Harness

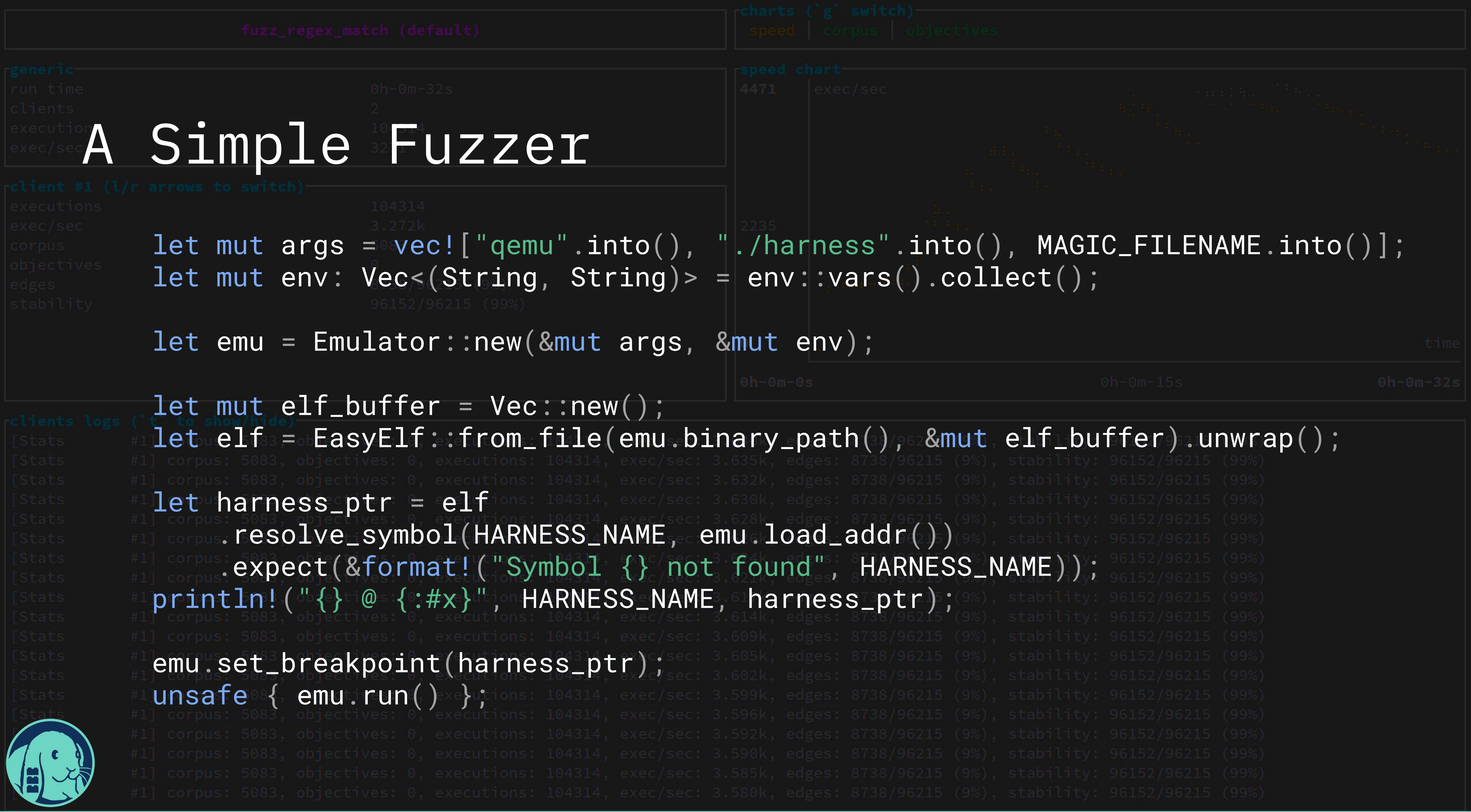
```c
int QuramGetImageInfoFromFile2(char *filename, int zero1, int zero2,
                               int *w, int *h, int* getImageOut1, int* getImageOut2);
int QrParseMetadata(char *filename, unsigned int* metadata);

void harnessSimple(char* filename) {
  int w, h, a, b;
  unsigned int metadata[71] = {0};

  if (QuramGetImageInfoFromFile2(filename, 0, 0, &w, &h, &a, &b) == 0) {
    QrParseMetadata(filename, metadata);
  }
}
```



Fuzzing Android Libs on a Host



A Simple Fuzzer



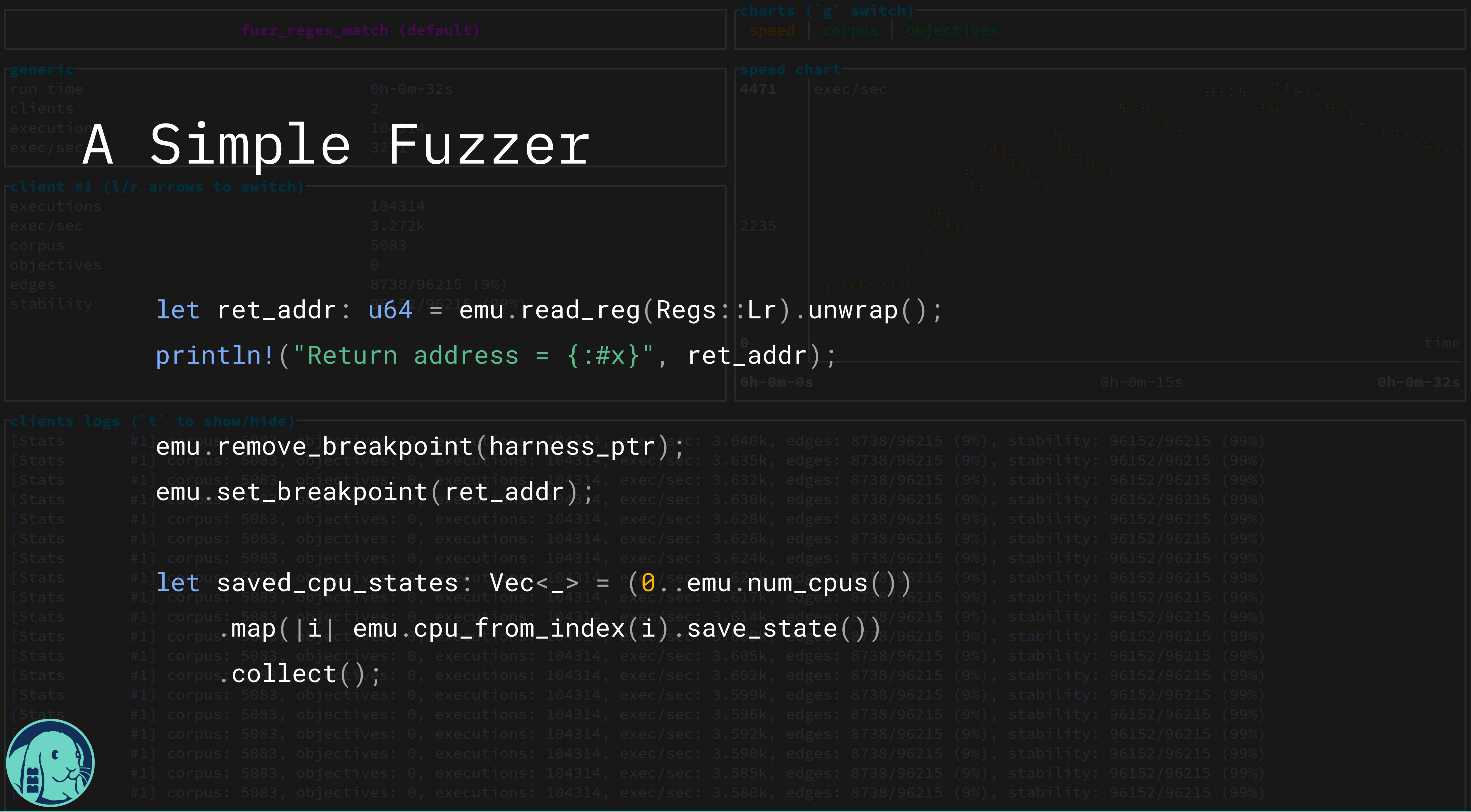
```
let mut args = vec!["qemu".into(), "./harness".into(), MAGIC_FILENAME.into()];
let mut env: Vec<(String, String)> = env::vars().collect();

let emu = Emulator::new(&mut args, &mut env);

let mut elf_buffer = Vec::new();
let elf = EasyElf::from_file(emu.binary_path(), &mut elf_buffer).unwrap();

let harness_ptr = elf
    .resolve_symbol(HARNESS_NAME, emu.load_addr())
    .expect(&format!("Symbol {} not found", HARNESS_NAME));
println!("{} @ {:#x}", HARNESS_NAME, harness_ptr);

emu.set_breakpoint(harness_ptr);
unsafe { emu.run() };
```

A Simple Fuzzer

```rust
let mut args = vec!["qemu".into(), "./harness".into(), MAGIC_FILENAME.into()];
let mut env: Vec<(String, String)> = env::vars().collect();

let emu = Emulator::new(&mut args, &mut env);

let mut elf_buffer = Vec::new();
let elf = EasyElf::from_file(emu.binary_path(), &mut elf_buffer).unwrap();

let harness_ptr = elf
    .resolve_symbol(HARNESS_NAME, emu.load_addr())
    .expect(&format!("Symbol {} not found", HARNESS_NAME));
println!("{} @ {:#x}", HARNESS_NAME, harness_ptr);

emu.set_breakpoint(harness_ptr);
unsafe { emu.run() };
```

A Simple Fuzzer

```rust
let ret_addr: u64 = emu.read_reg(Regs::Lr).unwrap();
println!("Return address = {:#x}", ret_addr);

emu.remove_breakpoint(harness_ptr);
emu.set_breakpoint(ret_addr);

let saved_cpu_states: Vec<_> = (0..emu.num_cpus())
    .map(|i| emu.cpu_from_index(i).save_state())
    .collect();
```



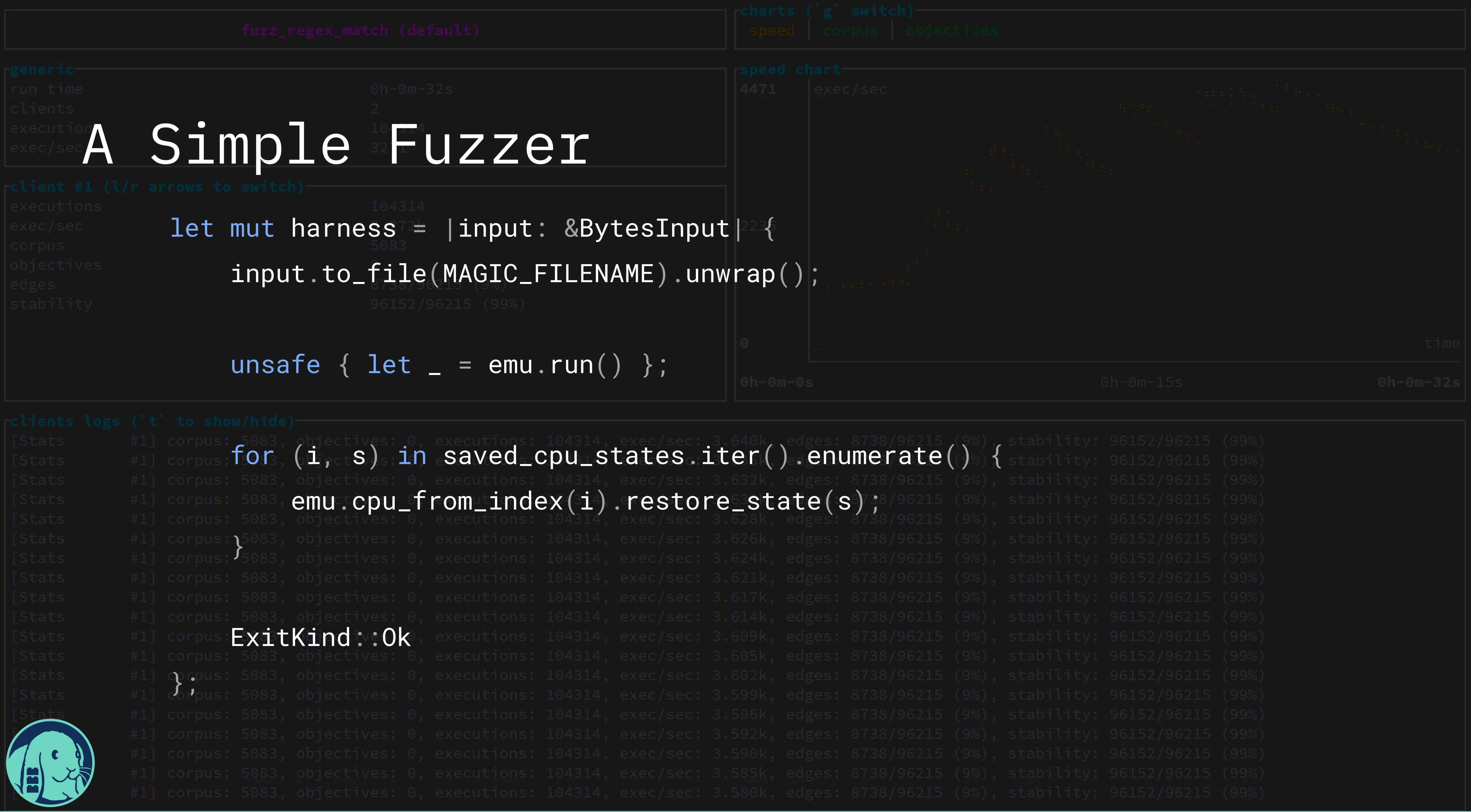
```
fuzz_regex_match (default)                 charts (`g` switch)
                                           speed | corpus | objectives

generic                                    speed chart
run time          0h-0m-32s                4471  exec/sec
clients           2
executions        10[illegible]14
exec/sec          32[illegible]

client #1 (l/r arrows to switch)
executions        104314                   2235
exec/sec          3.272k
corpus            5083
objectives        0
edges             8738/96215 (9%)
stability         96[illegible]/96215 (99%)                  0                                   time
                                           0h-0m-0s          0h-0m-15s          0h-0m-32s

clients logs (`t` to show/hide)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.60[illegible]k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats     #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

A Simple Fuzzer

```rust
let ret_addr: u64 = emu.read_reg(Regs::Lr).unwrap();
println!("Return address = {:#x}", ret_addr);

emu.remove_breakpoint(harness_ptr);
emu.set_breakpoint(ret_addr);

let saved_cpu_states: Vec<_> = (0..emu.num_cpus())
    .map(|i| emu.cpu_from_index(i).save_state())
    .collect();
```

A Simple Fuzzer

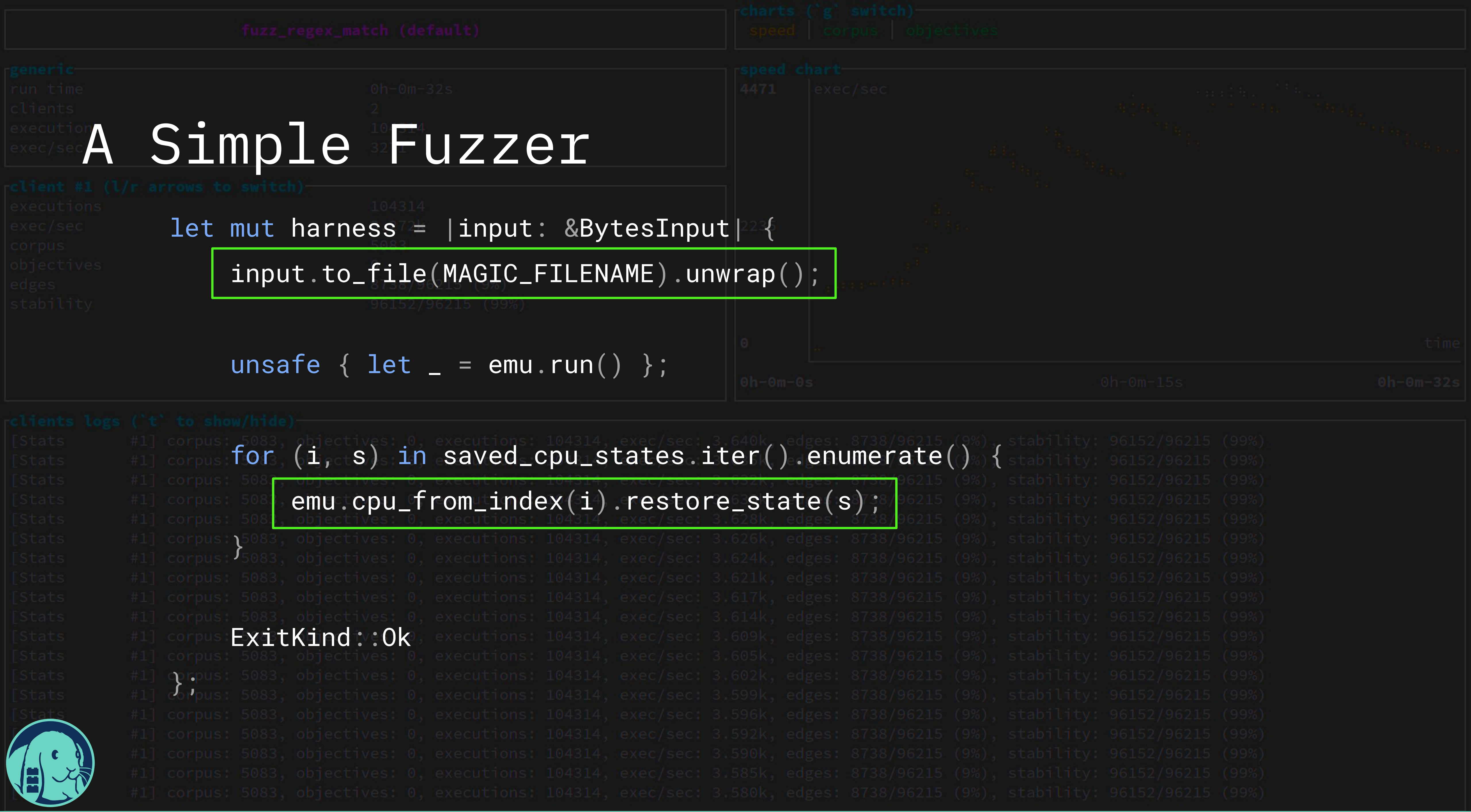
```rust
let mut harness = |input: &BytesInput| {
    input.to_file(MAGIC_FILENAME).unwrap();

    unsafe { let _ = emu.run() };

    for (i, s) in saved_cpu_states.iter().enumerate() {
        emu.cpu_from_index(i).restore_state(s);
    }

    ExitKind::Ok
};
```



```
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

A Simple Fuzzer

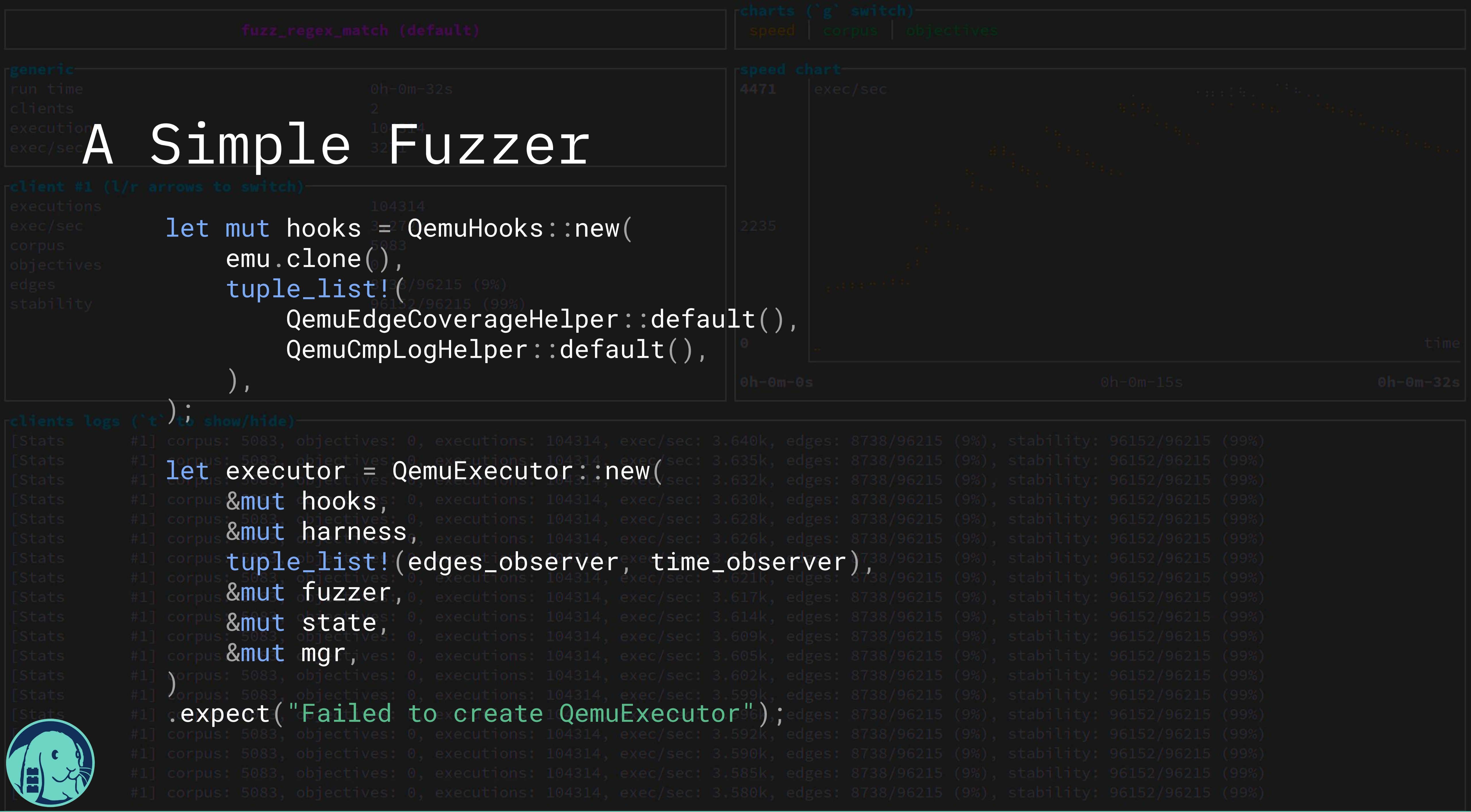
```rust
let mut harness = |input: &BytesInput| {
    input.to_file(MAGIC_FILENAME).unwrap();

    unsafe { let _ = emu.run() };

    for (i, s) in saved_cpu_states.iter().enumerate() {
        emu.cpu_from_index(i).restore_state(s);
    }

    ExitKind::Ok
};
```



```
fuzz_regex_match (default)

generic
run time        0h-0m-32s
clients         2
executions      104314
exec/sec        3271

client #1 (l/r arrows to switch)
executions      104314
exec/sec        3.272k
corpus          5083
objectives      0
edges           8738/96215 (9%)
stability       96152/96215 (99%)

charts (`g` switch)
 speed | corpus | objectives

speed chart
4471   exec/sec
2235
0                                             time
0h-0m-0s           0h-0m-15s           0h-0m-32s

clients logs (`t` to show/hide)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: [illegible], edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: [illegible], edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

A Simple Fuzzer

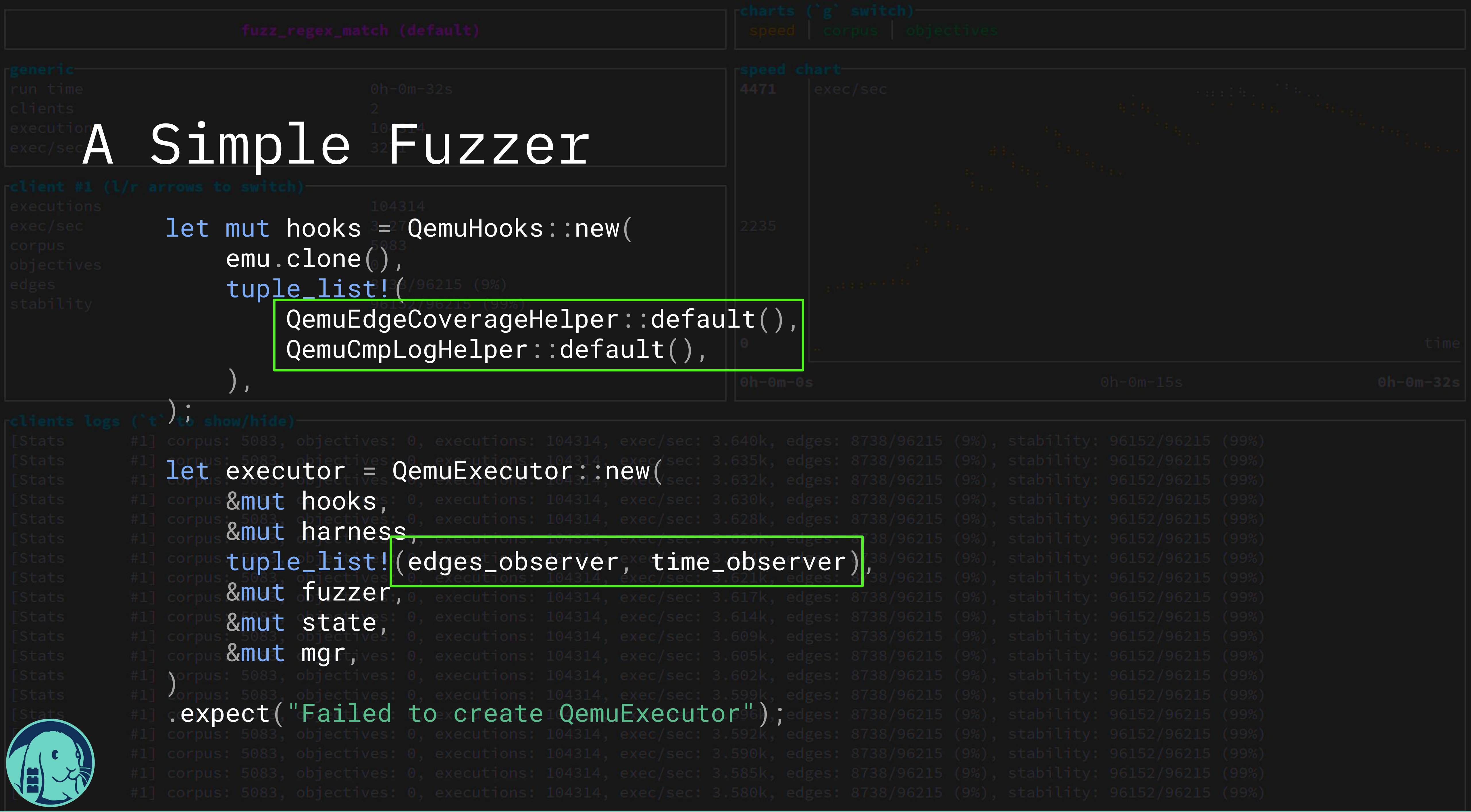
```rust
let mut hooks = QemuHooks::new(
    emu.clone(),
    tuple_list!(
        QemuEdgeCoverageHelper::default(),
        QemuCmpLogHelper::default(),
    ),
);

let executor = QemuExecutor::new(
    &mut hooks,
    &mut harness,
    tuple_list!(edges_observer, time_observer),
    &mut fuzzer,
    &mut state,
    &mut mgr,
)
.expect("Failed to create QemuExecutor");
```



```
fuzz_regex_match (default)

generic
run time            0h-0m-32s
clients             2
execution           10[illegible]
exec/sec            32[illegible]

client #1 (l/r arrows to switch)
executions          104314
exec/sec            3[illegible]27[illegible]
corpus              5083
objectives          0
edges               8738/96215 (9%)
stability           96152/96215 (99%)

clients logs (`t` to show/hide)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: [illegible], edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats    #1] [illegible] 6), edges: 8738/96215 (9%), stability: 96152/96215 (99%)
          #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
          #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
          #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
          #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

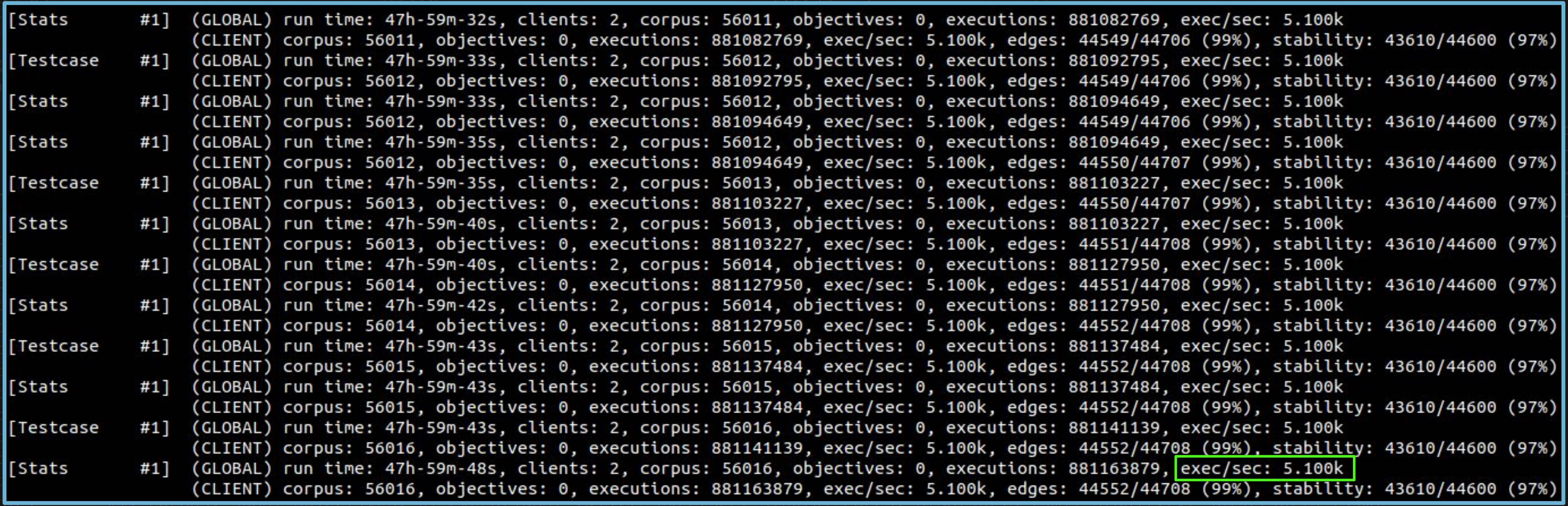
A Simple Fuzzer

```rust
let mut hooks = QemuHooks::new(
    emu.clone(),
    tuple_list!(
        QemuEdgeCoverageHelper::default(),
        QemuCmpLogHelper::default(),
    ),
);

let executor = QemuExecutor::new(
    &mut hooks,
    &mut harness,
    tuple_list!(edges_observer, time_observer),
    &mut fuzzer,
    &mut state,
    &mut mgr,
)
.expect("Failed to create QemuExecutor");
```



```
fuzz_regex_match (default)

charts (`g` switch)
speed | corpus | objectives

generic
run time        0h-0m-32s
clients         2
executions      104314
exec/sec        3271

speed chart
4471  exec/sec
2235
0                                        time
0h-0m-0s          0h-0m-15s          0h-0m-32s

client #1 (l/r arrows to switch)
executions      104314
exec/sec        3.27[illegible]
corpus          5083
objectives      0
edges           8738/96215 (9%)
stability       96152/96215 (99%)

clients logs (`t` to show/hide)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

A Simple Fuzzer

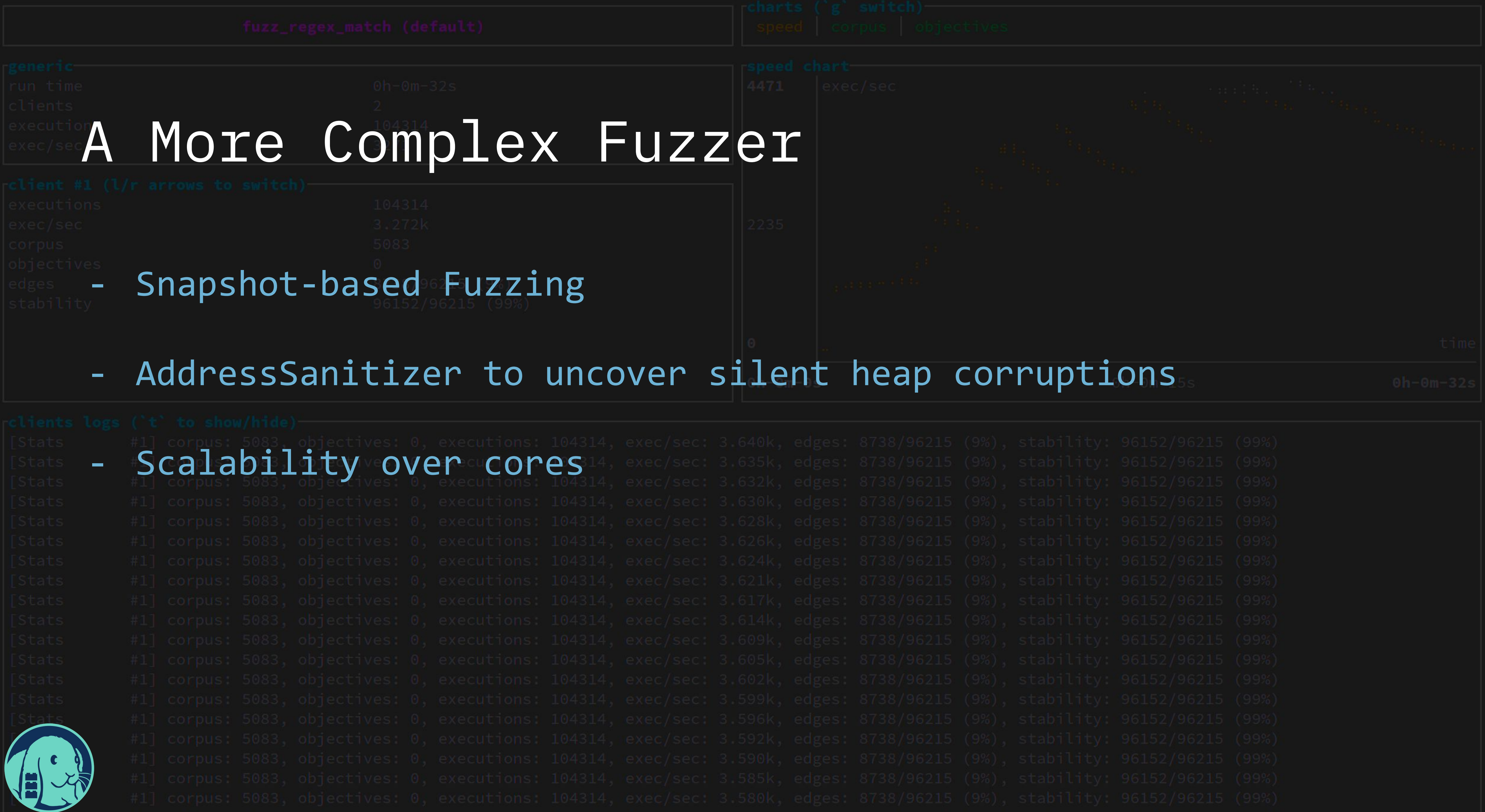


```
[Stats       #1]  (GLOBAL) run time: 47h-59m-32s, clients: 2, corpus: 56011, objectives: 0, executions: 881082769, exec/sec: 5.100k
                  (CLIENT) corpus: 56011, objectives: 0, executions: 881082769, exec/sec: 5.100k, edges: 44549/44706 (99%), stability: 43610/44600 (97%)
[Testcase    #1]  (GLOBAL) run time: 47h-59m-33s, clients: 2, corpus: 56012, objectives: 0, executions: 881092795, exec/sec: 5.100k
                  (CLIENT) corpus: 56012, objectives: 0, executions: 881092795, exec/sec: 5.100k, edges: 44549/44706 (99%), stability: 43610/44600 (97%)
[Stats       #1]  (GLOBAL) run time: 47h-59m-33s, clients: 2, corpus: 56012, objectives: 0, executions: 881094649, exec/sec: 5.100k
                  (CLIENT) corpus: 56012, objectives: 0, executions: 881094649, exec/sec: 5.100k, edges: 44549/44706 (99%), stability: 43610/44600 (97%)
[Stats       #1]  (GLOBAL) run time: 47h-59m-35s, clients: 2, corpus: 56012, objectives: 0, executions: 881094649, exec/sec: 5.100k
                  (CLIENT) corpus: 56012, objectives: 0, executions: 881094649, exec/sec: 5.100k, edges: 44550/44707 (99%), stability: 43610/44600 (97%)
[Testcase    #1]  (GLOBAL) run time: 47h-59m-35s, clients: 2, corpus: 56013, objectives: 0, executions: 881103227, exec/sec: 5.100k
                  (CLIENT) corpus: 56013, objectives: 0, executions: 881103227, exec/sec: 5.100k, edges: 44550/44707 (99%), stability: 43610/44600 (97%)
[Stats       #1]  (GLOBAL) run time: 47h-59m-40s, clients: 2, corpus: 56013, objectives: 0, executions: 881103227, exec/sec: 5.100k
                  (CLIENT) corpus: 56013, objectives: 0, executions: 881103227, exec/sec: 5.100k, edges: 44551/44708 (99%), stability: 43610/44600 (97%)
[Testcase    #1]  (GLOBAL) run time: 47h-59m-40s, clients: 2, corpus: 56014, objectives: 0, executions: 881127950, exec/sec: 5.100k
                  (CLIENT) corpus: 56014, objectives: 0, executions: 881127950, exec/sec: 5.100k, edges: 44551/44708 (99%), stability: 43610/44600 (97%)
[Stats       #1]  (GLOBAL) run time: 47h-59m-42s, clients: 2, corpus: 56014, objectives: 0, executions: 881127950, exec/sec: 5.100k
                  (CLIENT) corpus: 56014, objectives: 0, executions: 881127950, exec/sec: 5.100k, edges: 44552/44708 (99%), stability: 43610/44600 (97%)
[Testcase    #1]  (GLOBAL) run time: 47h-59m-43s, clients: 2, corpus: 56015, objectives: 0, executions: 881137484, exec/sec: 5.100k
                  (CLIENT) corpus: 56015, objectives: 0, executions: 881137484, exec/sec: 5.100k, edges: 44552/44708 (99%), stability: 43610/44600 (97%)
[Stats       #1]  (GLOBAL) run time: 47h-59m-43s, clients: 2, corpus: 56015, objectives: 0, executions: 881137484, exec/sec: 5.100k
                  (CLIENT) corpus: 56015, objectives: 0, executions: 881137484, exec/sec: 5.100k, edges: 44552/44708 (99%), stability: 43610/44600 (97%)
[Testcase    #1]  (GLOBAL) run time: 47h-59m-43s, clients: 2, corpus: 56016, objectives: 0, executions: 881141139, exec/sec: 5.100k
                  (CLIENT) corpus: 56016, objectives: 0, executions: 881141139, exec/sec: 5.100k, edges: 44552/44708 (99%), stability: 43610/44600 (97%)
[Stats       #1]  (GLOBAL) run time: 47h-59m-48s, clients: 2, corpus: 56016, objectives: 0, executions: 881163879, exec/sec: 5.100k
                  (CLIENT) corpus: 56016, objectives: 0, executions: 881163879, exec/sec: 5.100k, edges: 44552/44708 (99%), stability: 43610/44600 (97%)
```

5.1k executions per second

A More Complex Fuzzer

- Snapshot-based Fuzzing
- AddressSanitizer to uncover silent heap corruptions
- Scalability over cores

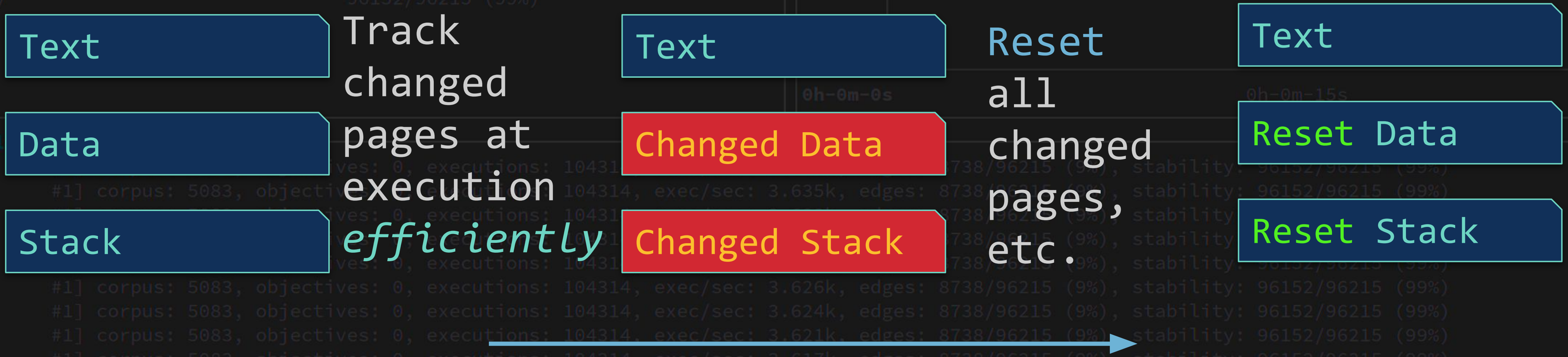


```
fuzz_regex_match (default)

generic
run time                 0h-0m-32s
clients                  2
execution                104314
exec/sec

client #1 (l/r arrows to switch)
executions               104314
exec/sec                 3.272k
corpus                   5083
objectives               0
edges                    
stability                96152/96215 (99%)

clients logs (`t` to show/hide)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats      #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
            #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

QASAN Sanitization

- Sanitizers checks wider range of errors at runtime
  - e.g. Illegal memory access
- Track all memory accesses
- Hook known libc/allocation functions (malloc/free, strcpy, …)
- Crash on out-of-bounds accesses, uaf, etc.

Userspace Snapshot

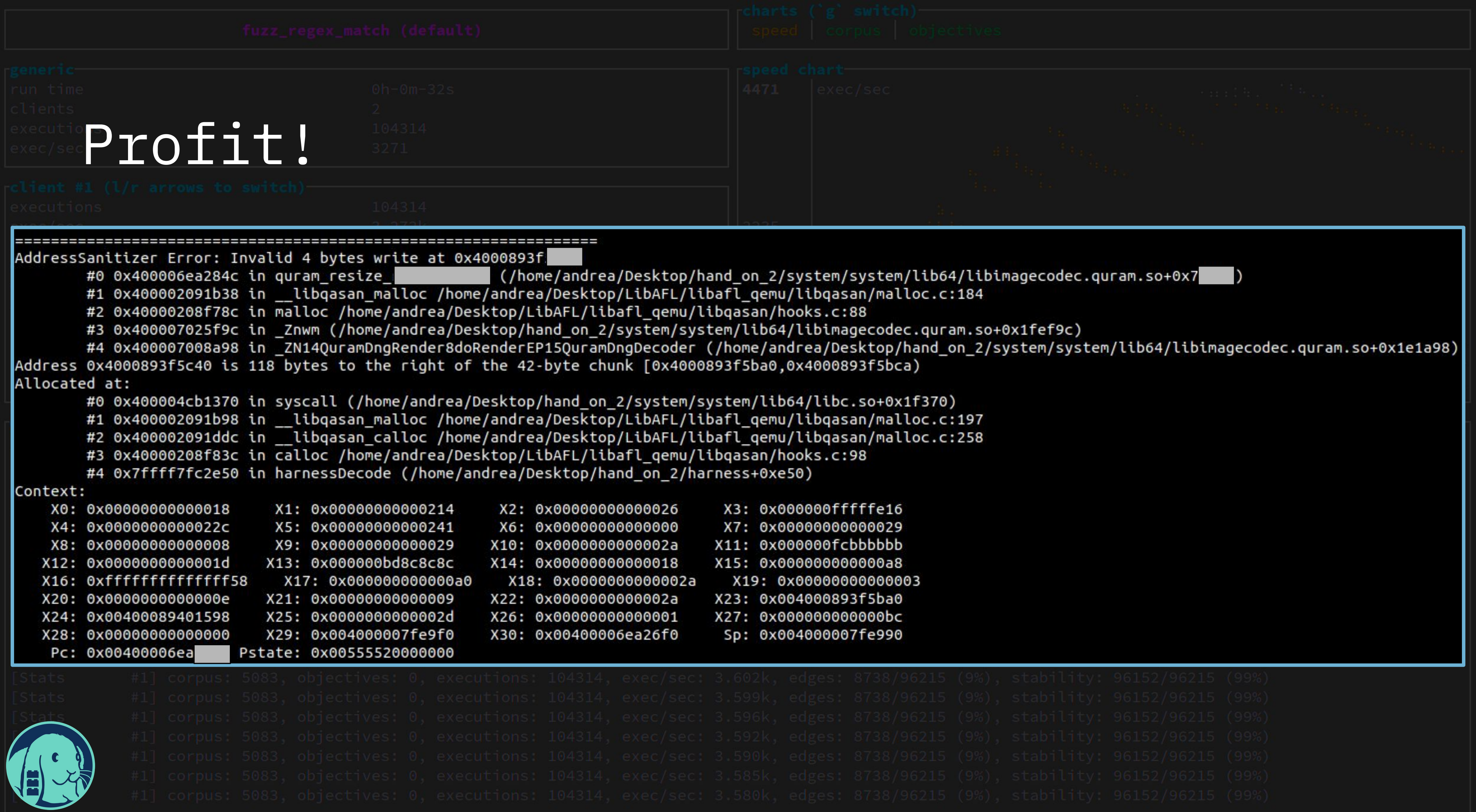


Text
Data
Stack
Track changed pages at execution *efficiently*
Text
Changed Data
Changed Stack
Reset all changed pages, etc.
Text
Reset Data
Reset Stack

```
fuzz_regex_match (default)                    charts (`g` switch)
                                              speed | corpus | objectives
generic                                       speed chart
run time                0h-0m-32s             4471 | exec/sec
clients                 2
executions              104314
exec/sec                ...71
client #1 (l/r arrows to switch)
executions              104314
exec/sec                3.272k                2235
corpus                  5083
objectives              0
edges                   8738/96215 (9%)
stability               96152/96215 (99%)
                                                                                  time
                                              0h-0m-0s     0h-0m-15s       0h-0m-32s
clients l
[Stats       #1] corpus: 5083, objectives: 0, executions: 10431...8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objecti... 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       ...ives: 0, executions: 10431...8738/96215 (9%), stability
[Stats       ...8738/96215 (9%), stability
[Stats       ...ves: 0, executions: 10431...8738/96215 (9%), stability
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

```
andrea@libaflexp:~/android_fuzzing/demo$
```

Profit!



```
fuzz_regex_match (default)

charts (`g` switch)
speed | corpus | objectives

generic
run time                        0h-0m-32s
clients                         2
executions                      104314
exec/sec                        3271

speed chart
4471 | exec/sec

client #1 (l/r arrows to switch)
executions                      104314
```

```
=================================================================
AddressSanitizer Error: Invalid 4 bytes write at 0x4000893f[redacted]
        #0 0x400006ea284c in quram_resize_[redacted] (/home/andrea/Desktop/hand_on_2/system/system/lib64/libimagecodec.quram.so+0x7[redacted])
        #1 0x400002091b38 in __libqasan_malloc /home/andrea/Desktop/LibAFL/libafl_qemu/libqasan/malloc.c:184
        #2 0x40000208f78c in malloc /home/andrea/Desktop/LibAFL/libafl_qemu/libqasan/hooks.c:88
        #3 0x400007025f9c in _Znwm (/home/andrea/Desktop/hand_on_2/system/system/lib64/libimagecodec.quram.so+0x1fef9c)
        #4 0x400007008a98 in _ZN14QuramDngRender8doRenderEP15QuramDngDecoder (/home/andrea/Desktop/hand_on_2/system/system/lib64/libimagecodec.quram.so+0x1e1a98)
Address 0x4000893f5c40 is 118 bytes to the right of the 42-byte chunk [0x4000893f5ba0,0x4000893f5bca)
Allocated at:
        #0 0x400004cb1370 in syscall (/home/andrea/Desktop/hand_on_2/system/system/lib64/libc.so+0x1f370)
        #1 0x400002091b98 in __libqasan_malloc /home/andrea/Desktop/LibAFL/libafl_qemu/libqasan/malloc.c:197
        #2 0x400002091ddc in __libqasan_calloc /home/andrea/Desktop/LibAFL/libafl_qemu/libqasan/malloc.c:258
        #3 0x40000208f83c in calloc /home/andrea/Desktop/LibAFL/libafl_qemu/libqasan/hooks.c:98
        #4 0x7ffff7fc2e50 in harnessDecode (/home/andrea/Desktop/hand_on_2/harness+0xe50)
Context:
    X0: 0x0000000000000018     X1: 0x0000000000000214     X2: 0x0000000000000026     X3: 0x000000fffffe16
    X4: 0x000000000000022c     X5: 0x0000000000000241     X6: 0x0000000000000000     X7: 0x0000000000000029
    X8: 0x0000000000000008     X9: 0x0000000000000029    X10: 0x000000000000002a    X11: 0x000000fcbbbbbb
   X12: 0x000000000000001d    X13: 0x000000bd8c8c8c    X14: 0x0000000000000018    X15: 0x00000000000000a8
   X16: 0xffffffffffffff58     X17: 0x00000000000000a0     X18: 0x000000000000002a     X19: 0x0000000000000003
   X20: 0x000000000000000e    X21: 0x0000000000000009    X22: 0x000000000000002a    X23: 0x004000893f5ba0
   X24: 0x00400089401598    X25: 0x000000000000002d    X26: 0x0000000000000001    X27: 0x00000000000000bc
   X28: 0x0000000000000000    X29: 0x004000007fe9f0    X30: 0x00400006ea26f0     Sp: 0x004000007fe990
    Pc: 0x00400006ea[redacted]  Pstate: 0x00555520000000
```

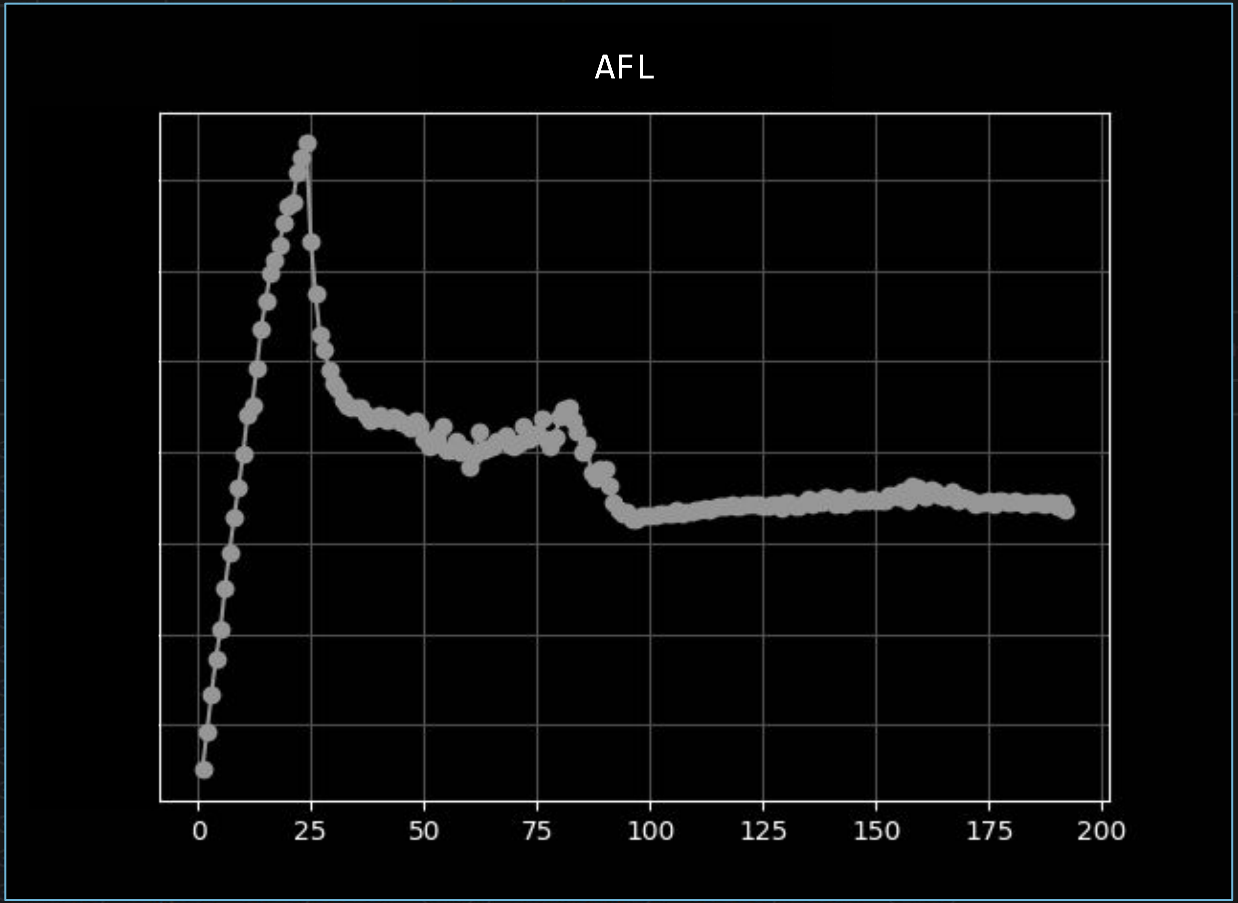
```
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

Fuzz Everything, Everywhere, All at Once

Scaling to cores and machines

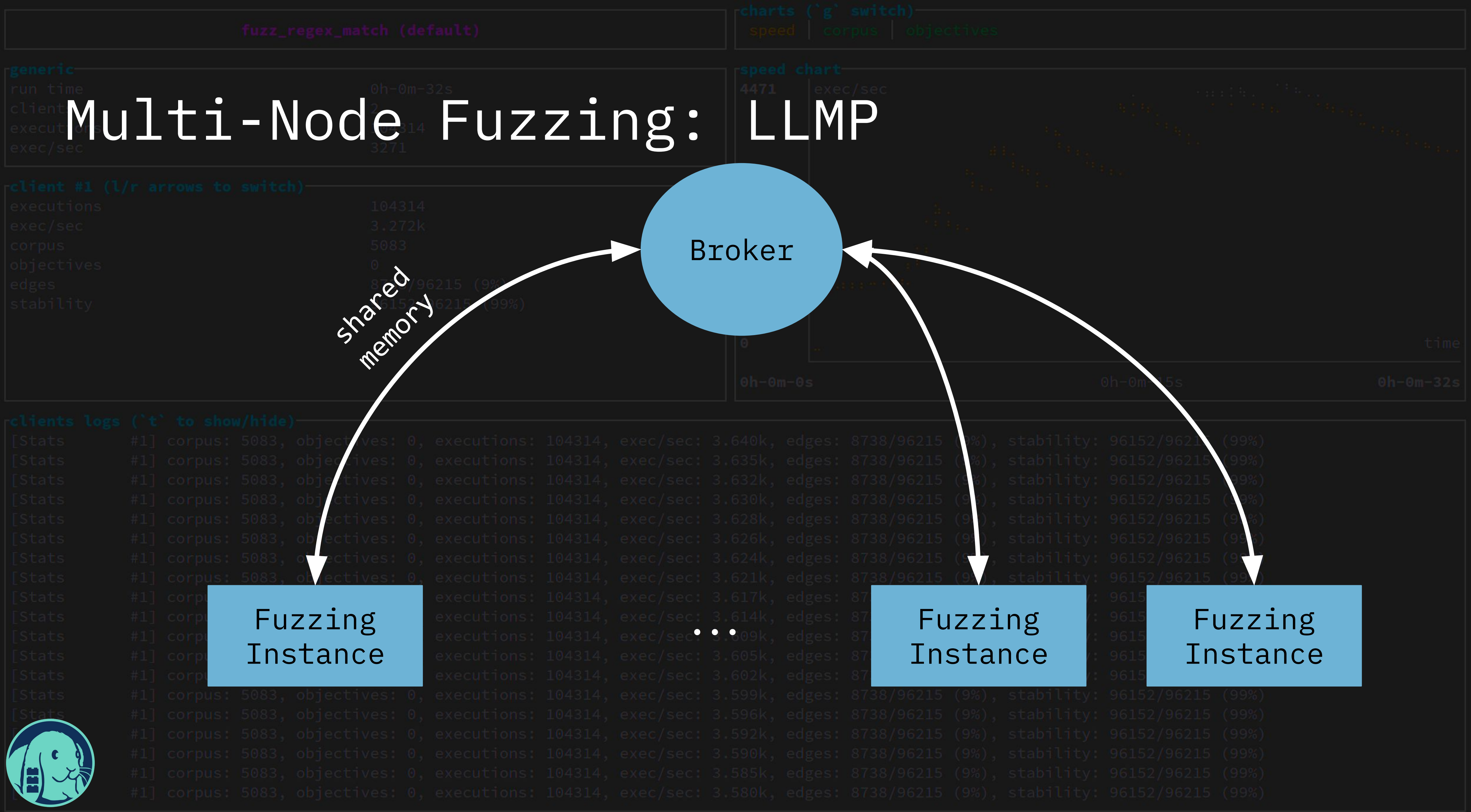
Fuzzer Scaling

- Scaling is *hard*
- Not sharing events means lots of duplicated effort
- Communication slows them down
- Communication via:
  - disk?
  - network?
  - intermittent restarts?
  - something else?



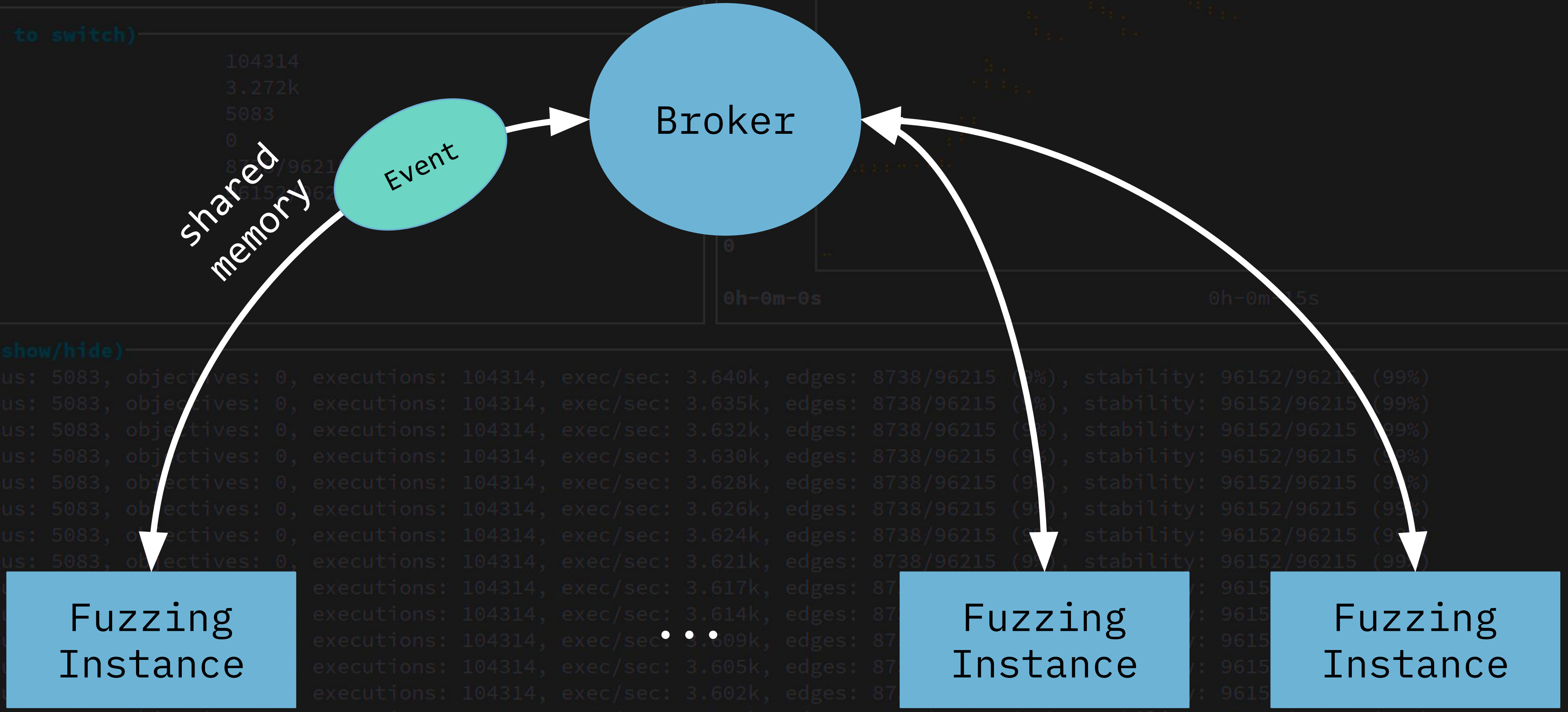
From: https://github.com/gamozolabs/aflbench

Multi-Node Fuzzing: LLMP



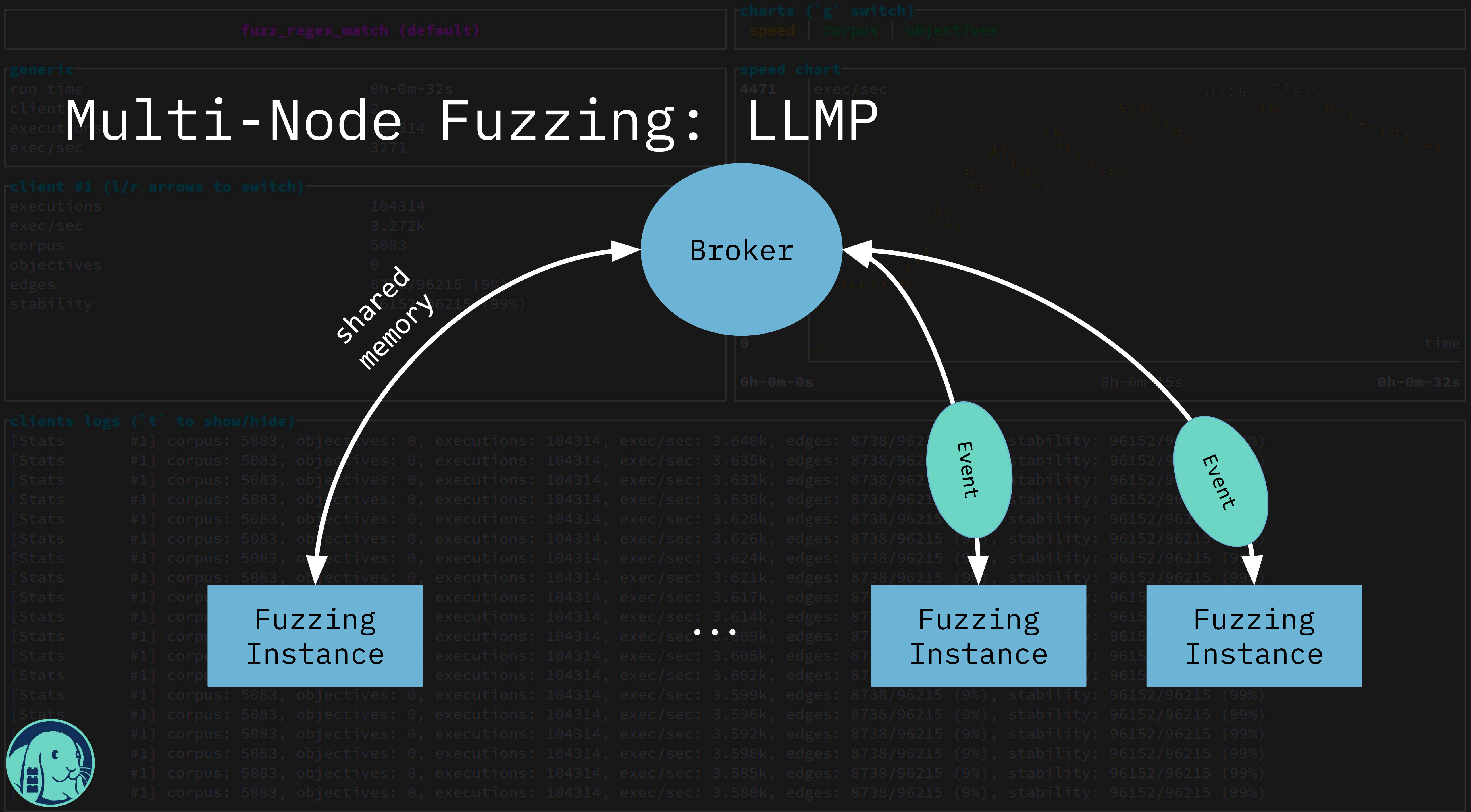
```
fuzz_regex_match (default)

generic
run time          0h-0m-32s
clients           2
executions        104314
exec/sec          3271

client #1 (l/r arrows to switch)
executions        104314
exec/sec          3.272k
corpus            5083
objectives        0
edges             8738/96215 (9%)
stability         96152/96215 (99%)

charts (`g` switch)
 speed | corpus | objectives

speed chart
4471    exec/sec
0                                           time
0h-0m-0s          0h-0m-15s          0h-0m-32s

clients logs (`t` to show/hide)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

Multi-Node Fuzzing: LLMP



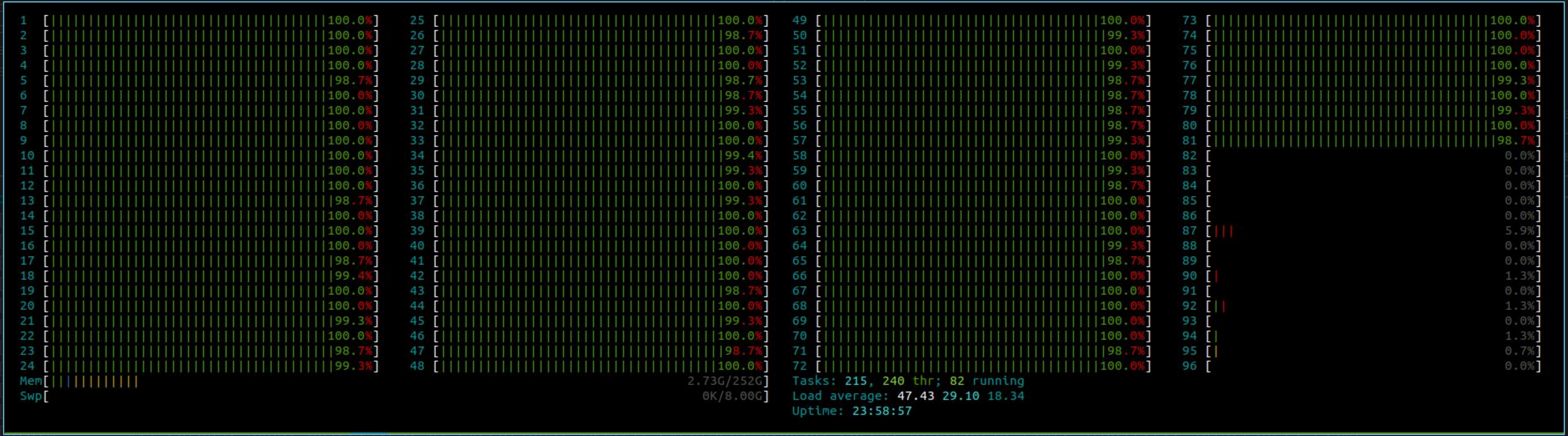
```
fuzz_regex_match (default)                         charts (`g` switch)
                                                   speed | corpus | objectives

generic                                            speed chart
run time                  0h-0m-32s                4471 | exec/sec
clients                   2
executions                104314
exec/sec                  3271

client #1 (l/r arrows to switch)
executions                104314
exec/sec                  3.272k
corpus                    5083
objectives                0
edges                     8738/9621
stability                 96152/962
                                                   0                                   time
                                                   0h-0m-0s        0h-0m-15s      0h-0m-32s

clients logs (`t` to show/hide)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corp                     executions: 104314, exec/sec: 3.617k, edges: 87                         : 9615
[Stats       #1] corp                     executions: 104314, exec/sec: 3.614k, edges: 87                         : 9615
[Stats       #1] corp                     executions: 104314, exec/sec: 3.609k, edges: 87                         : 9615
[Stats       #1] corp                     executions: 104314, exec/sec: 3.605k, edges: 87                         : 9615
[Stats       #1] corp                     executions: 104314, exec/sec: 3.602k, edges: 87                         : 9615
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

Multi-Node Fuzzing: LLMP



Scaling to 80 cores

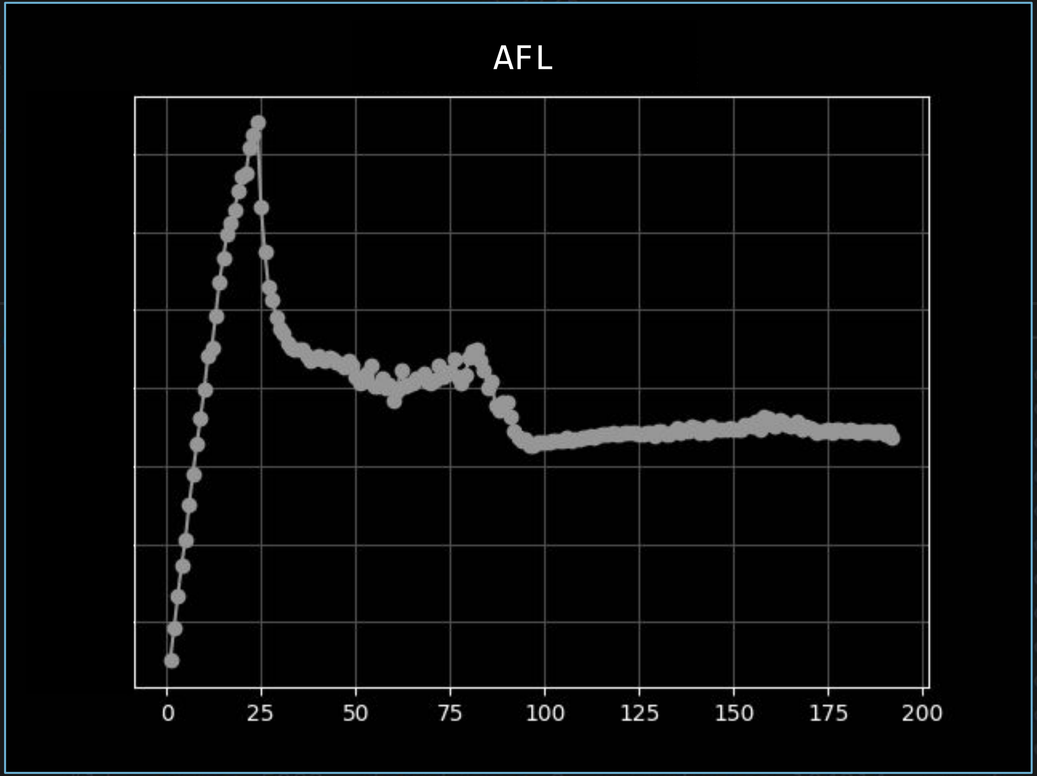
```
fuzz_regex_match (default)                         charts (`g` switch)
                                                   speed | corpus | objectives
generic                                            speed chart
run time                   0h-0m-32s               4471 | exec/sec
clients                    2
executions                 104314
exec/sec                   3.2..

client #1 (l/r arrows to switch)
executions                 104314                  2235
exec/sec                   3.272k
```

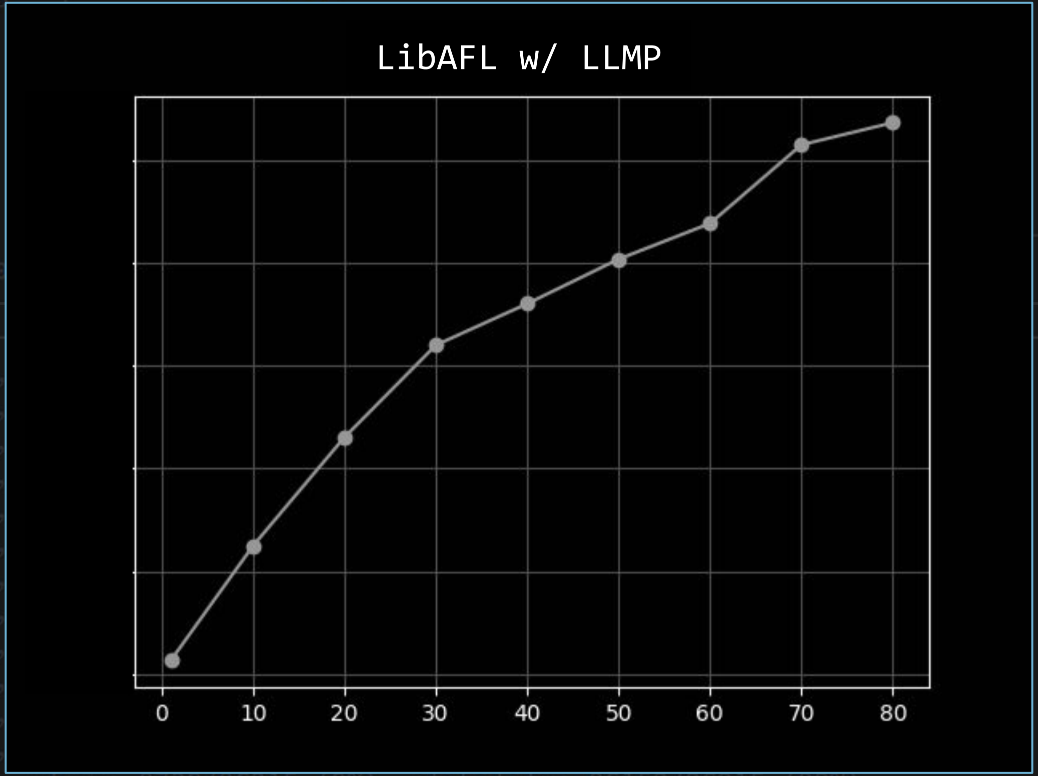


```
 1 [||||||||||||||||||||||||||||||100.0%]  25 [||||||||||||||||||||||||||||||100.0%]  49 [||||||||||||||||||||||||||||||100.0%]  73 [||||||||||||||||||||||||||||||100.0%]
 2 [||||||||||||||||||||||||||||||100.0%]  26 [|||||||||||||||||||||||||||||||98.7%]  50 [|||||||||||||||||||||||||||||||99.3%]  74 [||||||||||||||||||||||||||||||100.0%]
 3 [||||||||||||||||||||||||||||||100.0%]  27 [||||||||||||||||||||||||||||||100.0%]  51 [||||||||||||||||||||||||||||||100.0%]  75 [||||||||||||||||||||||||||||||100.0%]
 4 [||||||||||||||||||||||||||||||100.0%]  28 [||||||||||||||||||||||||||||||100.0%]  52 [|||||||||||||||||||||||||||||||99.3%]  76 [||||||||||||||||||||||||||||||100.0%]
 5 [|||||||||||||||||||||||||||||||98.7%]  29 [|||||||||||||||||||||||||||||||98.7%]  53 [|||||||||||||||||||||||||||||||98.7%]  77 [|||||||||||||||||||||||||||||||99.3%]
 6 [||||||||||||||||||||||||||||||100.0%]  30 [|||||||||||||||||||||||||||||||98.7%]  54 [|||||||||||||||||||||||||||||||98.7%]  78 [||||||||||||||||||||||||||||||100.0%]
 7 [||||||||||||||||||||||||||||||100.0%]  31 [|||||||||||||||||||||||||||||||99.3%]  55 [|||||||||||||||||||||||||||||||98.7%]  79 [|||||||||||||||||||||||||||||||99.3%]
 8 [||||||||||||||||||||||||||||||100.0%]  32 [||||||||||||||||||||||||||||||100.0%]  56 [|||||||||||||||||||||||||||||||98.7%]  80 [||||||||||||||||||||||||||||||100.0%]
 9 [||||||||||||||||||||||||||||||100.0%]  33 [||||||||||||||||||||||||||||||100.0%]  57 [|||||||||||||||||||||||||||||||99.3%]  81 [|||||||||||||||||||||||||||||||98.7%]
10 [||||||||||||||||||||||||||||||100.0%]  34 [|||||||||||||||||||||||||||||||99.4%]  58 [||||||||||||||||||||||||||||||100.0%]  82 [                                0.0%]
11 [||||||||||||||||||||||||||||||100.0%]  35 [|||||||||||||||||||||||||||||||99.3%]  59 [|||||||||||||||||||||||||||||||99.3%]  83 [                                0.0%]
12 [||||||||||||||||||||||||||||||100.0%]  36 [||||||||||||||||||||||||||||||100.0%]  60 [|||||||||||||||||||||||||||||||98.7%]  84 [                                0.0%]
13 [|||||||||||||||||||||||||||||||98.7%]  37 [|||||||||||||||||||||||||||||||99.3%]  61 [||||||||||||||||||||||||||||||100.0%]  85 [                                0.0%]
14 [||||||||||||||||||||||||||||||100.0%]  38 [||||||||||||||||||||||||||||||100.0%]  62 [||||||||||||||||||||||||||||||100.0%]  86 [                                0.0%]
15 [||||||||||||||||||||||||||||||100.0%]  39 [||||||||||||||||||||||||||||||100.0%]  63 [||||||||||||||||||||||||||||||100.0%]  87 [|||                             5.9%]
16 [||||||||||||||||||||||||||||||100.0%]  40 [||||||||||||||||||||||||||||||100.0%]  64 [|||||||||||||||||||||||||||||||99.3%]  88 [                                0.0%]
17 [|||||||||||||||||||||||||||||||98.7%]  41 [||||||||||||||||||||||||||||||100.0%]  65 [|||||||||||||||||||||||||||||||98.7%]  89 [                                0.0%]
18 [|||||||||||||||||||||||||||||||99.4%]  42 [||||||||||||||||||||||||||||||100.0%]  66 [||||||||||||||||||||||||||||||100.0%]  90 [|                               1.3%]
19 [||||||||||||||||||||||||||||||100.0%]  43 [|||||||||||||||||||||||||||||||98.7%]  67 [||||||||||||||||||||||||||||||100.0%]  91 [                                0.0%]
20 [||||||||||||||||||||||||||||||100.0%]  44 [||||||||||||||||||||||||||||||100.0%]  68 [||||||||||||||||||||||||||||||100.0%]  92 [||                              1.3%]
21 [|||||||||||||||||||||||||||||||99.3%]  45 [|||||||||||||||||||||||||||||||99.3%]  69 [||||||||||||||||||||||||||||||100.0%]  93 [                                0.0%]
22 [||||||||||||||||||||||||||||||100.0%]  46 [||||||||||||||||||||||||||||||100.0%]  70 [||||||||||||||||||||||||||||||100.0%]  94 [|                               1.3%]
23 [|||||||||||||||||||||||||||||||98.7%]  47 [|||||||||||||||||||||||||||||||98.7%]  71 [|||||||||||||||||||||||||||||||98.7%]  95 [|                               0.7%]
24 [|||||||||||||||||||||||||||||||99.3%]  48 [||||||||||||||||||||||||||||||100.0%]  72 [||||||||||||||||||||||||||||||100.0%]  96 [                                0.0%]
Mem[|||||||||||                           2.73G/252G]  Tasks: 215, 240 thr; 82 running
Swp[                                        0K/8.00G]  Load average: 47.43 29.10 18.34
                                                       Uptime: 23:58:57
```

```
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

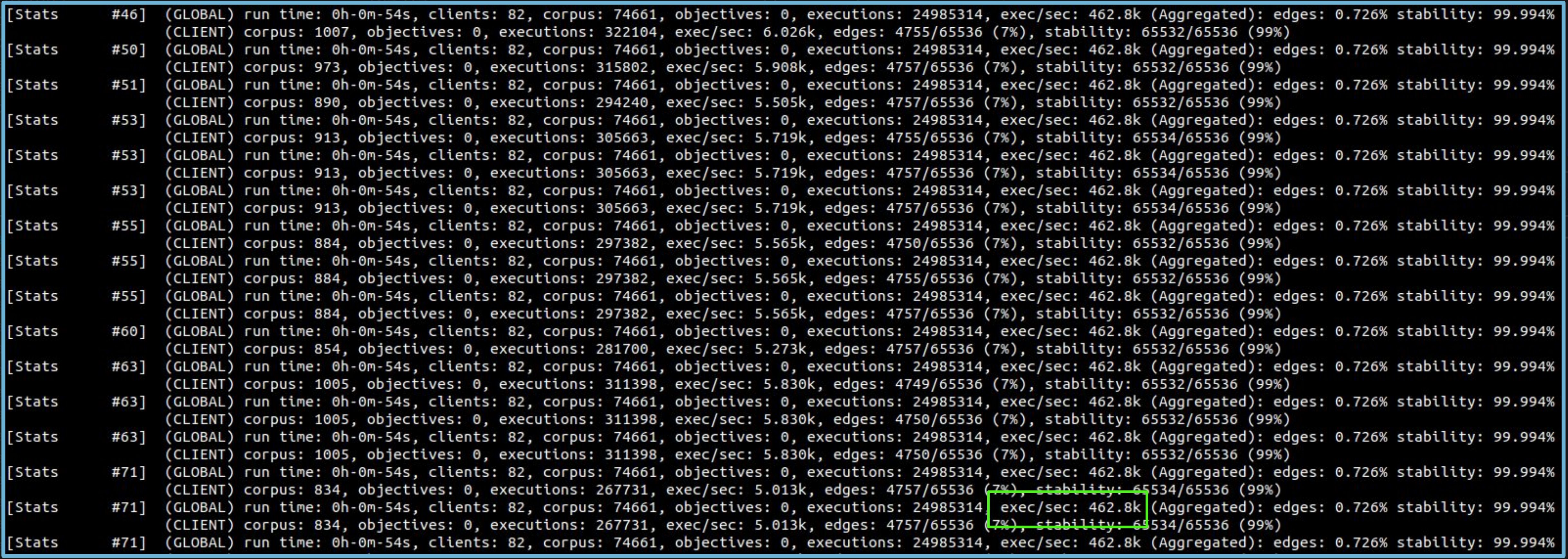
Scaling Comparison: AFL and LLMP





```
fuzz_regex_match (default)                 charts (`g` switch)
                                            speed │ corpus │ objectives
generic                                    speed chart
run time                 0h-0m-32s         4471 │ exec/sec
clients                  2
executio                 104314
exec/sec                 321
client #1 (l/r arrows to switch)
executions               104314
exec/sec                 3.272k            2235
corpus
objective
edges
stability                                  0                                  time
                                           0h-0                          0h-0m-32s
clients l
[Stats                                        c: 3.640k,
[Stats                                        c: 3.635k,
[Stats                                        c: 3.632k,
[Stats                                        c: 3.630k,
[Stats                                        c: 3.628k,
[Stats                                        c: 3.626k,
[Stats                                        c: 3.624k,
[Stats                                        c: 3.621k,
[Stats                                        c: 3.617k,
[Stats                                        c: 3.614k,
[Stats                                        c: 3.609k,
[Stats                                        c: 3.605k,
[Stats   #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats   #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats   #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
         #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
         #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
         #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
         #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

Scaling to 80 cores

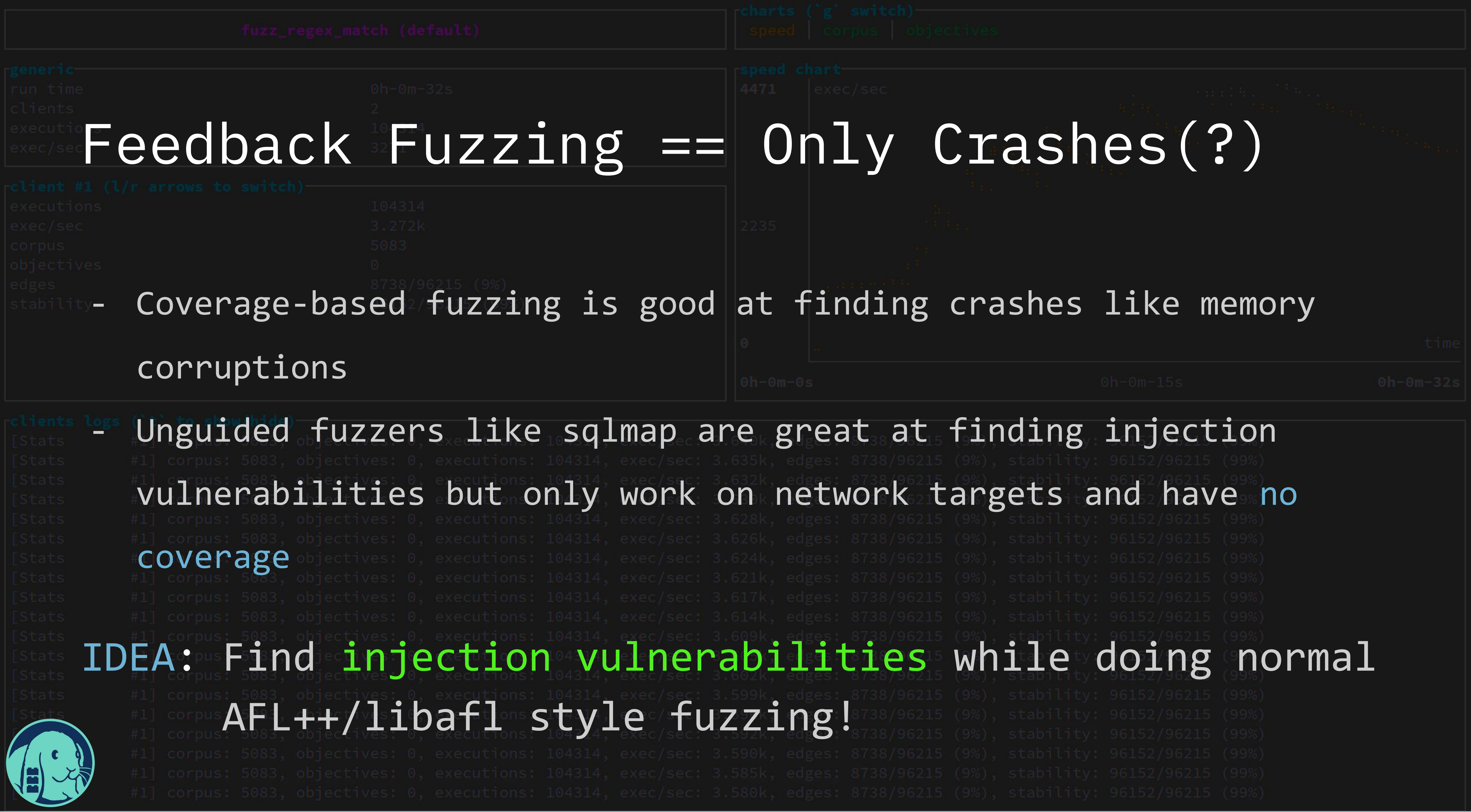


```
[Stats       #46]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 1007, objectives: 0, executions: 322104, exec/sec: 6.026k, edges: 4755/65536 (7%), stability: 65532/65536 (99%)
[Stats       #50]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 973, objectives: 0, executions: 315802, exec/sec: 5.908k, edges: 4757/65536 (7%), stability: 65532/65536 (99%)
[Stats       #51]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 890, objectives: 0, executions: 294240, exec/sec: 5.505k, edges: 4757/65536 (7%), stability: 65532/65536 (99%)
[Stats       #53]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 913, objectives: 0, executions: 305663, exec/sec: 5.719k, edges: 4755/65536 (7%), stability: 65534/65536 (99%)
[Stats       #53]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 913, objectives: 0, executions: 305663, exec/sec: 5.719k, edges: 4757/65536 (7%), stability: 65534/65536 (99%)
[Stats       #53]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 913, objectives: 0, executions: 305663, exec/sec: 5.719k, edges: 4757/65536 (7%), stability: 65534/65536 (99%)
[Stats       #55]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 884, objectives: 0, executions: 297382, exec/sec: 5.565k, edges: 4750/65536 (7%), stability: 65532/65536 (99%)
[Stats       #55]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 884, objectives: 0, executions: 297382, exec/sec: 5.565k, edges: 4755/65536 (7%), stability: 65532/65536 (99%)
[Stats       #55]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 884, objectives: 0, executions: 297382, exec/sec: 5.565k, edges: 4757/65536 (7%), stability: 65532/65536 (99%)
[Stats       #60]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 854, objectives: 0, executions: 281700, exec/sec: 5.273k, edges: 4757/65536 (7%), stability: 65532/65536 (99%)
[Stats       #63]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 1005, objectives: 0, executions: 311398, exec/sec: 5.830k, edges: 4749/65536 (7%), stability: 65532/65536 (99%)
[Stats       #63]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 1005, objectives: 0, executions: 311398, exec/sec: 5.830k, edges: 4750/65536 (7%), stability: 65532/65536 (99%)
[Stats       #63]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 1005, objectives: 0, executions: 311398, exec/sec: 5.830k, edges: 4750/65536 (7%), stability: 65532/65536 (99%)
[Stats       #71]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 834, objectives: 0, executions: 267731, exec/sec: 5.013k, edges: 4757/65536 (7%), stability: 65534/65536 (99%)
[Stats       #71]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
                   (CLIENT) corpus: 834, objectives: 0, executions: 267731, exec/sec: 5.013k, edges: 4757/65536 (7%), stability: 65534/65536 (99%)
[Stats       #71]  (GLOBAL) run time: 0h-0m-54s, clients: 82, corpus: 74661, objectives: 0, executions: 24985314, exec/sec: 462.8k (Aggregated): edges: 0.726% stability: 99.994%
```

462.8k executions per second

Fuzz Everything, Everywhere, All at Once

catch injections
& corruptions
at the same time



Feedback Fuzzing == Only Crashes(?)

- Coverage-based fuzzing is good at finding crashes like memory corruptions
- Unguided fuzzers like sqlmap are great at finding injection vulnerabilities but only work on network targets and have no coverage

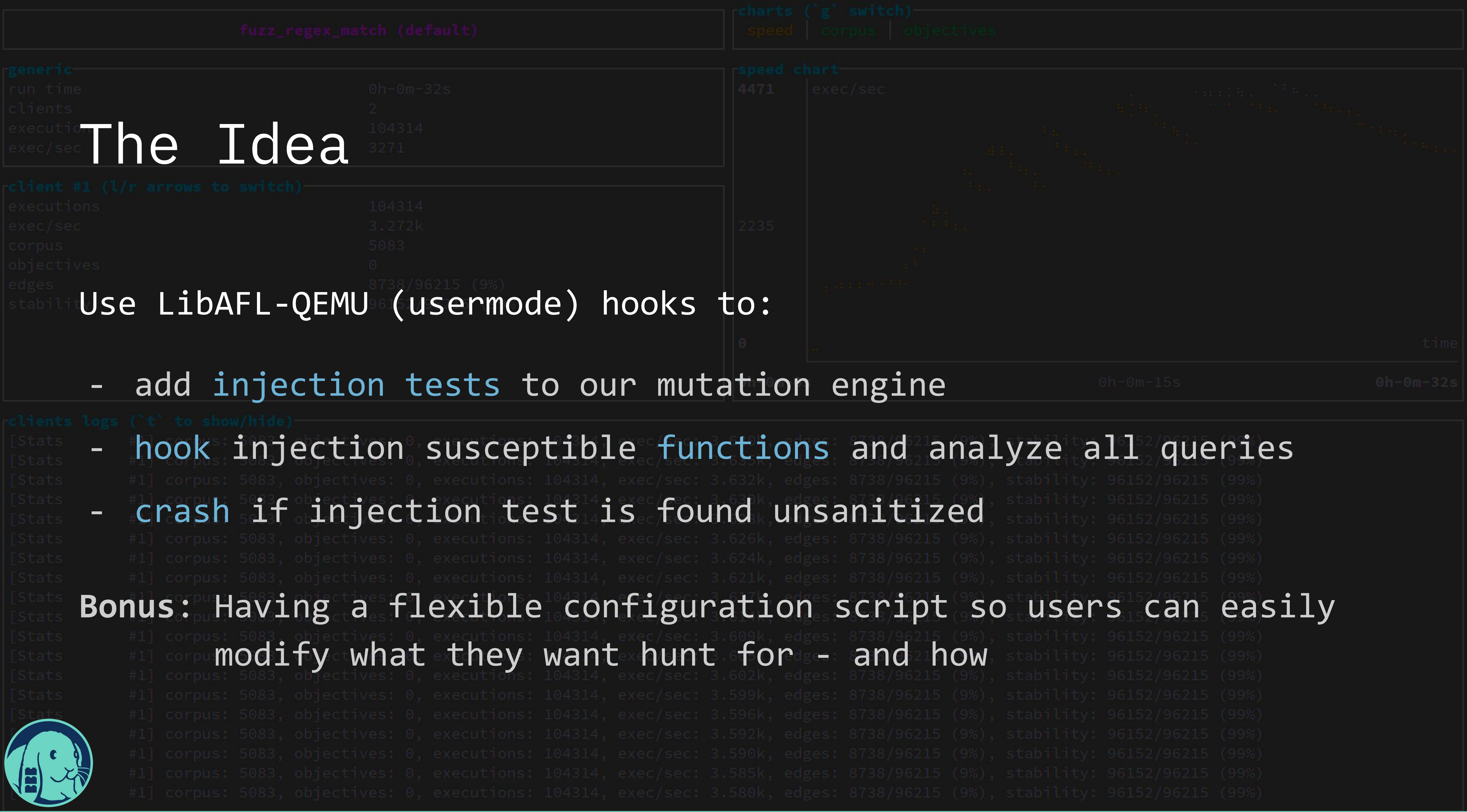
IDEA: Find injection vulnerabilities while doing normal AFL++/libafl style fuzzing!

The Idea

Use LibAFL-QEMU (usermode) hooks to:

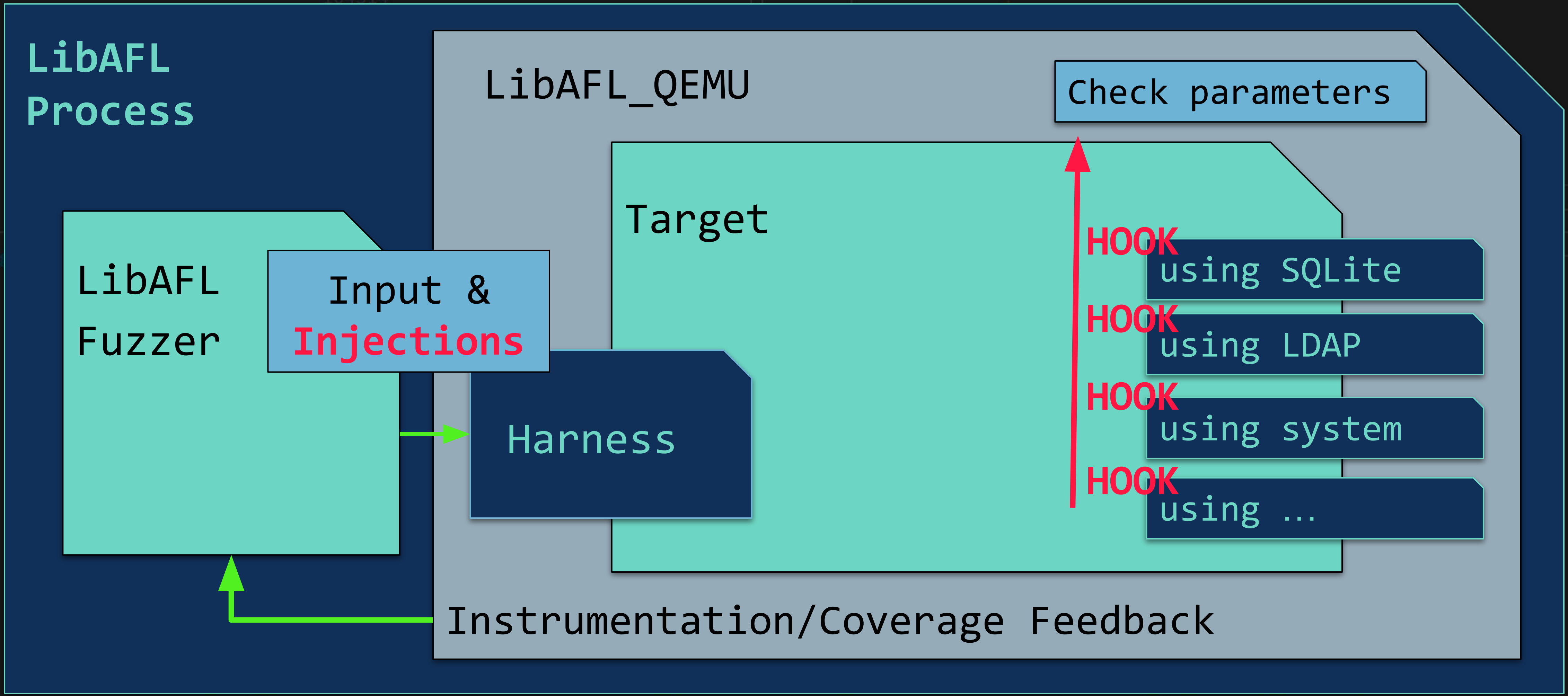
- add injection tests to our mutation engine
- hook injection susceptible functions and analyze all queries
- crash if injection test is found unsanitized

Bonus: Having a flexible configuration script so users can easily modify what they want hunt for - and how



```
fuzz_regex_match (default)          charts (`g` switch)
                                    speed | corpus | objectives
generic                             speed chart
run time       0h-0m-32s            4471   exec/sec
clients        2
executions     104314
exec/sec       3271
client #1 (l/r arrows to switch)
executions     104314               2235
exec/sec       3.272k
corpus         5083
objectives     0
edges          8738/96215 (9%)
stability      96152/96215 (99%)    0                                time
                                           0h-0m-15s          0h-0m-32s
clients logs (`t` to show/hide)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.633k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.632k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.624k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.613k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.609k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

Fuzzing for Injections



Example: SQL injection configuration

injections.yml

```yaml
- name: "sql"
  functions:
    - function: "sqlite3_exec"
      parameter: 1
    - function: "mysql_query"
      parameter: 1
  tests:
    - input_value: "'\"\"'"
      match_value: "'\"\"'"
    - input_value: "1\"' OR \""
      match_value: "1\"' OR"
```

sqlite3_exec() - Execute SQL statements

Definition:

```c
int sqlite3_exec( sqlite3 *db,
const char* sql, ... )
```

Injection into the 2nd parameter!

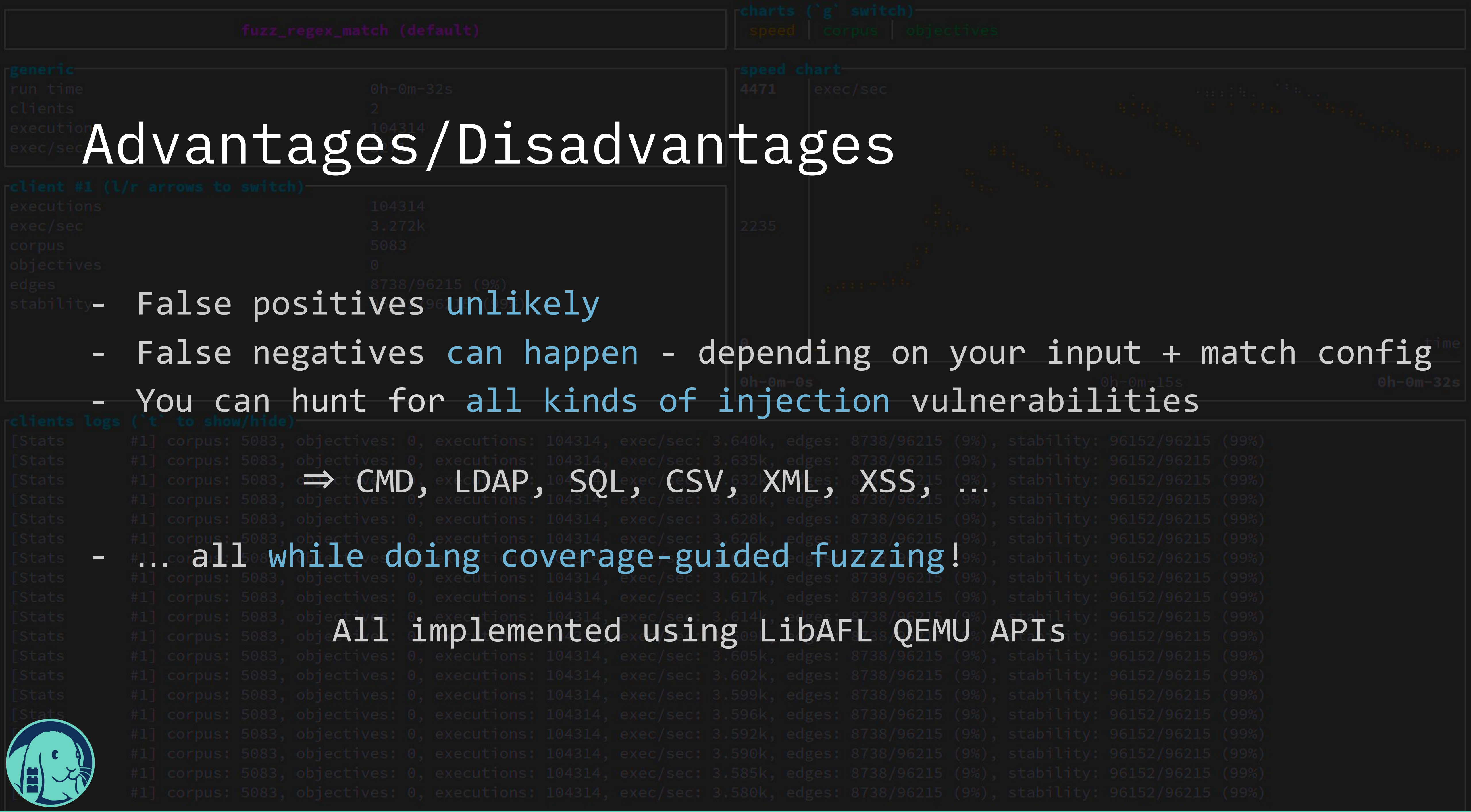
Advantages/Disadvantages

- False positives unlikely
- False negatives can happen - depending on your input + match config
- You can hunt for all kinds of injection vulnerabilities

⇒ CMD, LDAP, SQL, CSV, XML, XSS, …

- … all while doing coverage-guided fuzzing!

All implemented using LibAFL QEMU APIs



```
fuzz_regex_match (default)
charts (`g` switch)
speed | corpus | objectives

generic
run time                  0h-0m-32s
clients                   2
executions                104314

speed chart
4471 | exec/sec
2235
0                                                        time
0h-0m-0s                 0h-0m-15s                0h-0m-32s

client #1 (l/r arrows to switch)
executions                104314
exec/sec                  3.272k
corpus                    5083
objectives                0
edges                     8738/96215 (9%)

clients logs (`t` to show/hide)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.640k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.635k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.630k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.628k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.626k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.621k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.617k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.614k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, obj [illegible] ty: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.605k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.602k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.599k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
[Stats       #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.596k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.592k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.590k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.585k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
             #1] corpus: 5083, objectives: 0, executions: 104314, exec/sec: 3.580k, edges: 8738/96215 (9%), stability: 96152/96215 (99%)
```

```
marc /prg/libafl/fuzzers/qemu_injections (vhqemu) $
```

Final Words

Fuzz Everything, Everywhere, All at Once

LibAFL is FOSS!

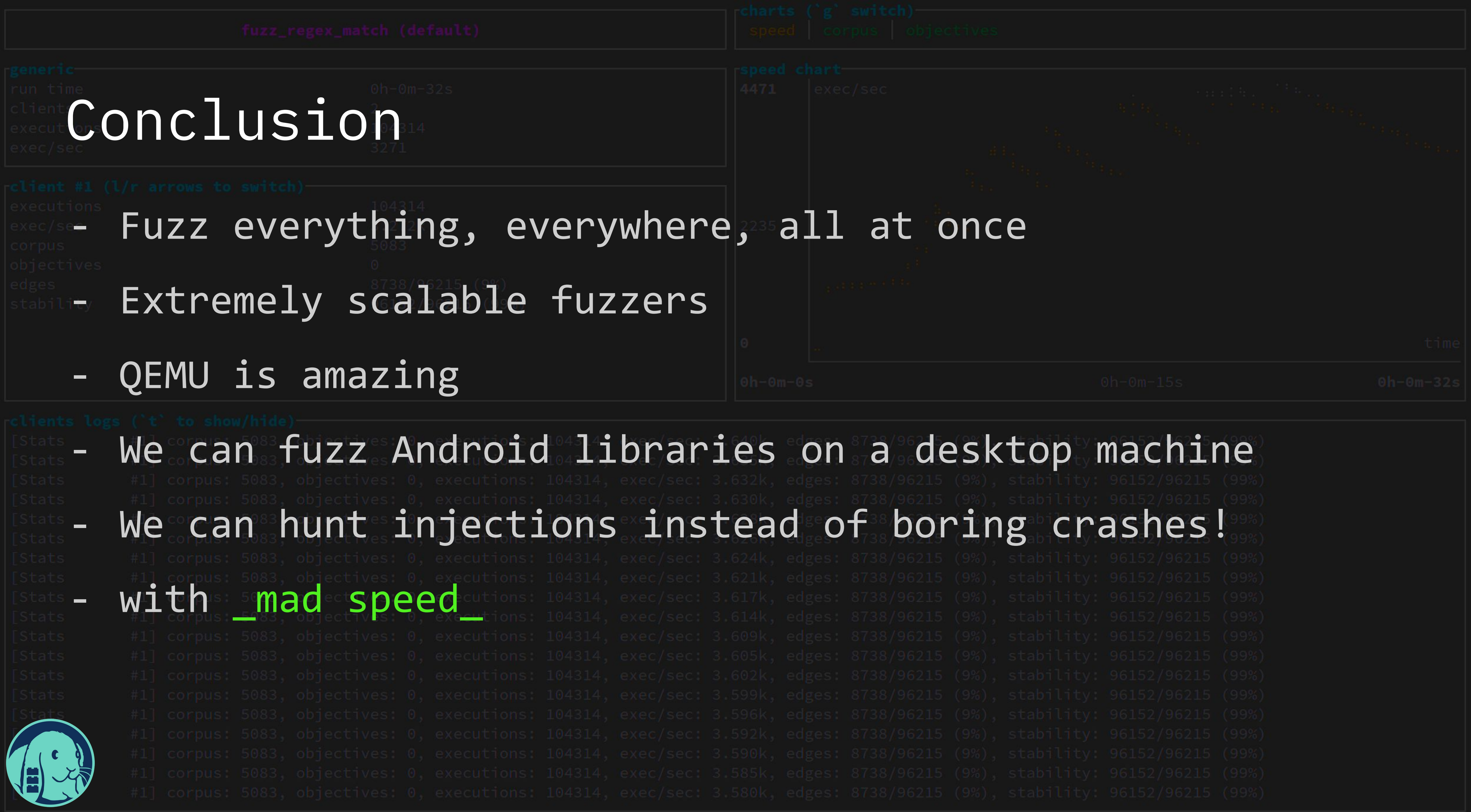
JOIN THE CULT

https://github.com/AFLplusplus/LibAFL

108	203	11	2k	231
Contributors	Used by	Discussions	Stars	Forks

Conclusion

- Fuzz everything, everywhere, all at once
- Extremely scalable fuzzers
- QEMU is amazing
- We can fuzz Android libraries on a desktop machine
- We can hunt injections instead of boring crashes!
- with _mad speed_



```
while (questions());

char buf[16];
strncpy(buf, ""
    "Thank you for your attention."
    "\n", sizeof(buf));
printf("%s", buf);
```

Thanks y’all