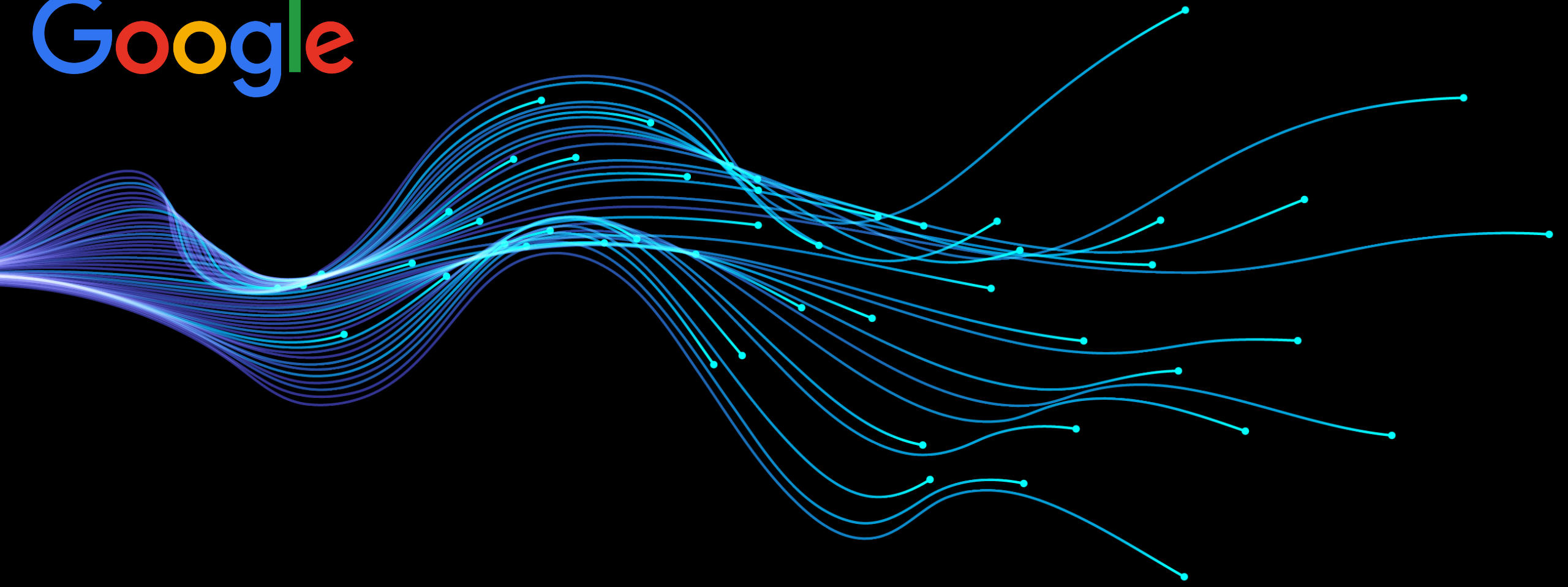
Google



Fuzzing at Mach Speed

Uncovering MacOS and iOS IPC Vulnerabilities with Dillon Franke

Who Am I?

Google

CURRENTLY

Senior Proactive Security Consultant
(Pentesting)
- *Application Security*
- *Source Code Reviews*
- *Embedded Device Assessments*

Project Zero 20% Project

PREVIOUSLY

FLARE Offensive Task Force (OTF)
(Reverse Engineering)
- *Malware reversing*
- *Searching for exploits used in the wild*
- *0-day vulnerability research*
- *Exploit development*

STUDIED

Bachelor's & Master's in Computer Science at Stanford University
Security and Systems Engineering

HOBBIES

Playing Guitar
Cycling in the San Francisco Bay Area
Hacking (obviously)

Who is this talk for?

- Offensive Security Researchers
- Defensive Security Engineers
- Software Developers
- Mobile Application Researchers

Overview

Join me as a I dive into my process searching for low-level vulnerabilities in MacOS over the past year.

Crash Course on Fuzzing and IPC Mechanisms

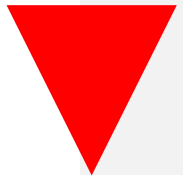
The Fuzzing Cycle

Next Steps

Q&A

CRASH COURSE

What is Fuzzing?

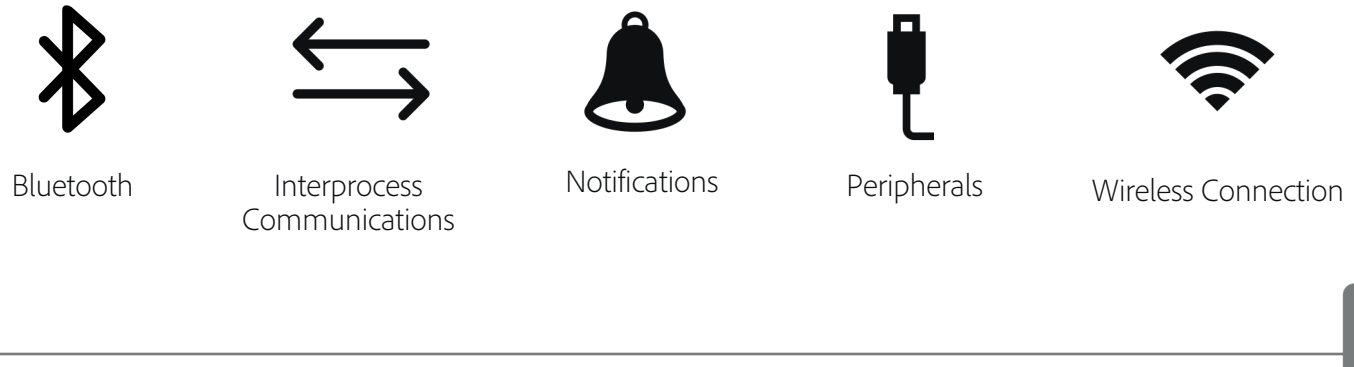


Fuzzing is sending unexpected **inputs** to a **system** in the hopes of making something unexpected happen

CRASH COURSE

What is an Attack Vector?

An attack vector is a channel to send an **input** to a **system**



CRASH COURSE

What is an Attack Vector?

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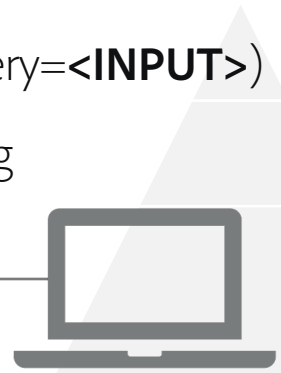
Adobe Acrobat	Open PDF Functionality
Google Search	Query Parameter (https://google.com?query=**<INPUT>**)
Smart Watch	Bluetooth Data Handling

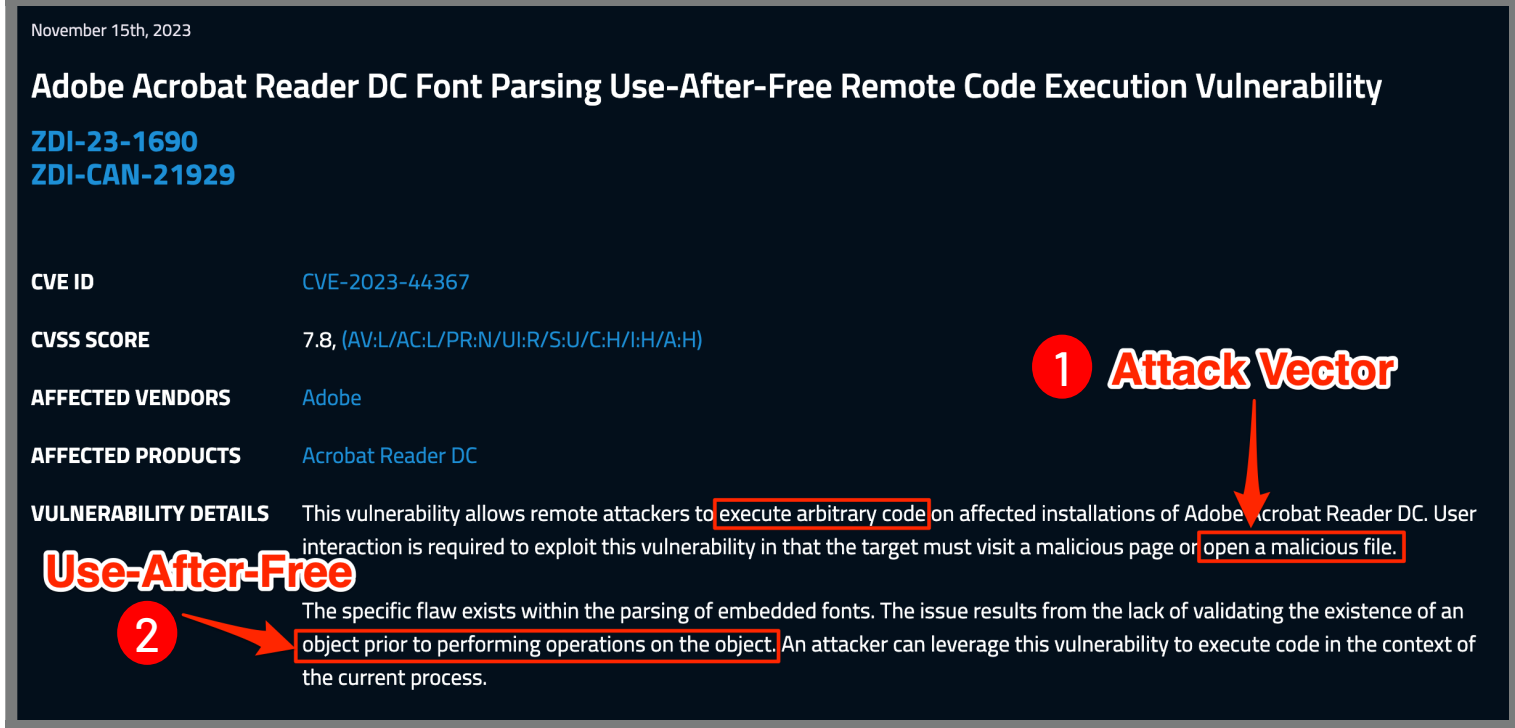


CRASH COURSE

Why Fuzz?

1. In memory-unsafe languages, (C/C++) we want to send input that causes a crash

2. Depending on the type of crash, our input might be able to trigger:
   - Buffer Overflow
   - Heap Overflow
   - Use-After-Free
   - Double Free
   - Memory Leak (bypass ASLR)



CRASH COURSE

Different Types of Fuzzing

Mutation-Based Fuzzing: Modify existing inputs to create new ones, then send them to the program

Grammar-Based Fuzzing: Generate inputs based on specified rules defining the structure of valid inputs

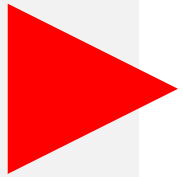
CRASH COURSE

What is the XNU Kernel?

XNU (X is Not Unix) is the kernel that powers macOS.

CRASH COURSE

What is the XNU Kernel?



XNU (X is Not Unix) is the kernel that powers macOS.

Mach Layer: Responsible for low-level tasks like thread management, interprocess communication (IPC), and memory management.

BSD Layer: Handles higher-level POSIX tasks, like file system, network, and security.

I/O Kit: A framework for developing device drivers, designed with a model resembling object-oriented programming.

CRASH COURSE

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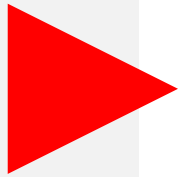

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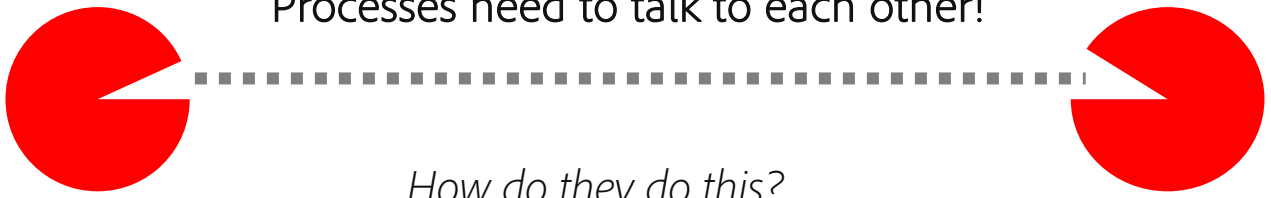
CRASH COURSE

What is Interprocess Communication (IPC)?

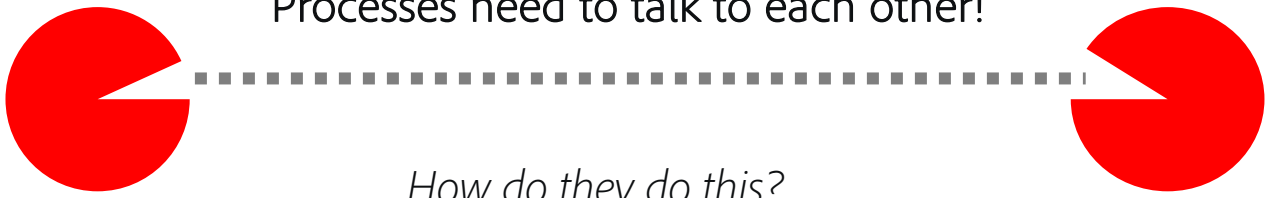


How do they do this?

Mach Messages
Mach exceptions
Unix signals
Unnamed pipes
Named pipes (fifos)
XSI/System V IPC
POSIX IPC
Distributed Objects
Apple Events
Core Foundation IPC mechanisms

CRASH COURSE

What is Interprocess Communication (IPC)?



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Apple Events
Core Foundation IPC mechanisms

Lowest level IPC mechanism and the direct basis for many higher level mechanisms

CRASH COURSE

What are Mach Ports?

IPC message queues, managed by the kernel

Port Right: Handle to a port that allows sending or receiving messages to the port

Receive Right: Allows receiving a mach port's messages

Send Right: Allows sending messages to a mach port

Send Once: Allows sending a single message to a mach port

CRASH COURSE

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```
❯ lsmp -h
Usage: lsmp -p <pid> [-a|-v|-h]
Lists information about mach ports.
Please see man page for description
of each column.
```

```
Process (135) : kextd
  name      ipc-object    rights     flags   boost  reqs  recv  send sonce oref  qlimit  msgcount  context
---------   ----------  ----------  --------  -----  ----  ----- ----- ----- ----  ------  --------  ----------
0x00000103  0xdce4a79b  send        --------          ---           2
0x00000203  0xdd0c45e3  recv        --------      0   ---     1             N       5         0  0x00000000
0x00000307  0xd6247d5b  send        --------          ---           54
0x00000403  0xdd0c41f3  recv        --------      0   ---     1             N       5         0  0x00000000
0x00000503  0xdd0c564b  recv        --------      0   ---     1             N       5         0  0x00000000
0x00000603  0xdce4a8eb  send        --------          ---           1
0x00000703  0xdd0c56f3  recv        --------      0   ---     1             N       5         0  0x00000000
0x00000803  0xd624781b  send        --------          ---           1
0x00000903  0xdcc335a3  recv,send   ---GS---      0   ---     1     2       Y       5         0  0x00000000
0x00000a03  0xdcc690e3  recv,send   ---GS---      0   ---     1     1       Y       5         1  0x00000000
                +       send        --------          ---           1       <-
0x00000b03  0xdcc6957b  send        --------          ---           1       ->      1         0  0x00000000
0x00000c03  0xdcc69623  send        --------          ---           1       ->      1         0  0x00000000
0x00000d0f  0xde2da7db  recv        --------      0   ---     1             Y       5         0  0x00000000
                +       send        --------          D--           1       <-
0x00000e07  0xd6248fbb  send        --------          ---           1       ->      32        0  0x00000000
0x00000f03  0xdcaeff13  send        --------          ---           1       ->      6         0  0x00000000
0x00001003  0xdcaefbcb  send        --------          ---           1
0x00001103  0xd6247e03  send        --------          ---           1
0x00001203  0xdcc6abcb  recv,send   --------      0   ---     1     1       Y       5         0  0x00000000
0x00001303  0xd779214b  send        --------          ---           6       ->      128       0  0x00000000
0x00001403  0xdd0c2cf3  send        --------          ---           1
0x00001507  0xdcb5718b  send        --------          ---           1       ->      6         0  0x00000000
```

```
total     = 845
SEND      = 841
RECEIVE   = 5
SEND_ONCE = 0
PORT_SET  = 0
DEAD_NAME = 0
DNREQUEST = 0
VOUCHERS  = 0
```

CRASH COURSE

Establishing a Mach Connection

Bootstrap Server

- A mach port to help establish connections with other mach ports
- By default, all processes have a send right to the bootstrap server

Mach Service

- A mach port with a name that is registered with the Bootstrap Server (e.g. **com.apple.troopers**)

Communicating with a Service

1. Alice allocates a new mach port, giving her a receive right
2. Alice registers her service using a specific name **com.apple.troopers** with the bootstrap server

   By registering, Alice is giving the bootstrap server a send right to the port Alice has a receive right to
3. Bob asks the bootstrap server for the service named **com.apple.troopers** and the server gives Bob a copy of the send right for Alice's mach port
4. Bob can now send messages to Alice's mach port for Alice to receive

CRASH COURSE

What are Mach Messages?

A struct used to exchange data between mach ports

Sending/Receiving Mach Messages

```
/*
* Routine: mach_msg
* Purpose:
* Send and/or receive a message. If the message operation
* is interrupted, and the user did not request an indication
* of that fact, then restart the appropriate parts of the
* operation silently (trap version does not restart).
*/
__WATCHOS_PROHIBITED __TVOS_PROHIBITED
extern mach_msg_return_t mach_msg(
  mach_msg_header_t *msg,
  mach_msg_option_t option,
  mach_msg_size_t send_size,
  mach_msg_size_t rcv_size,
  mach_port_name_t rcv_name,
  mach_msg_timeout_t timeout,
  mach_port_name_t notify
);
```

Option specifies send/receive!

CRASH COURSE

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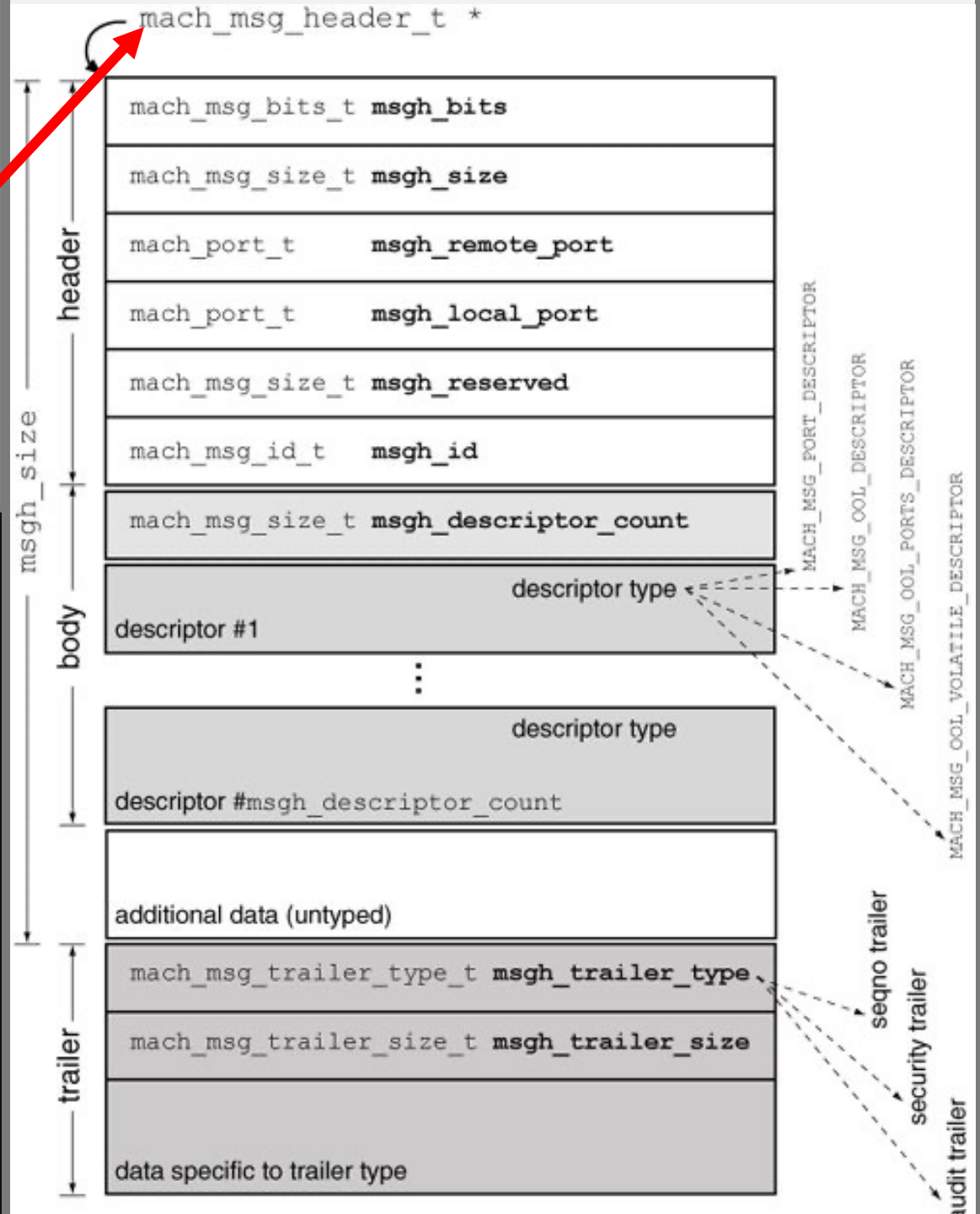

The Fuzzing Cycle

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

The Fuzzing Cycle

Abusing Mach Messages

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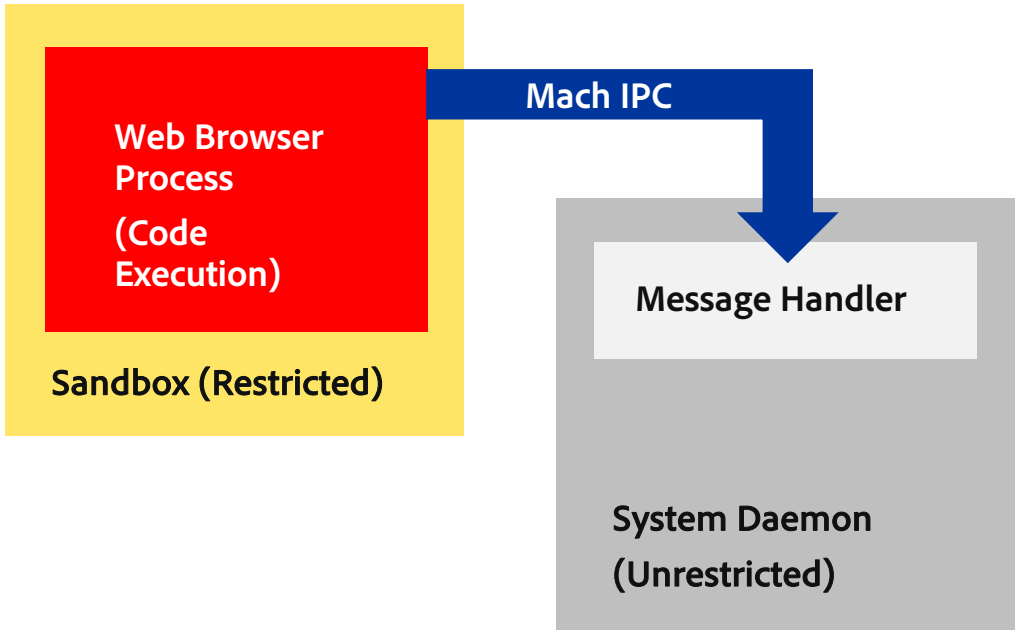
Sandbox Escape



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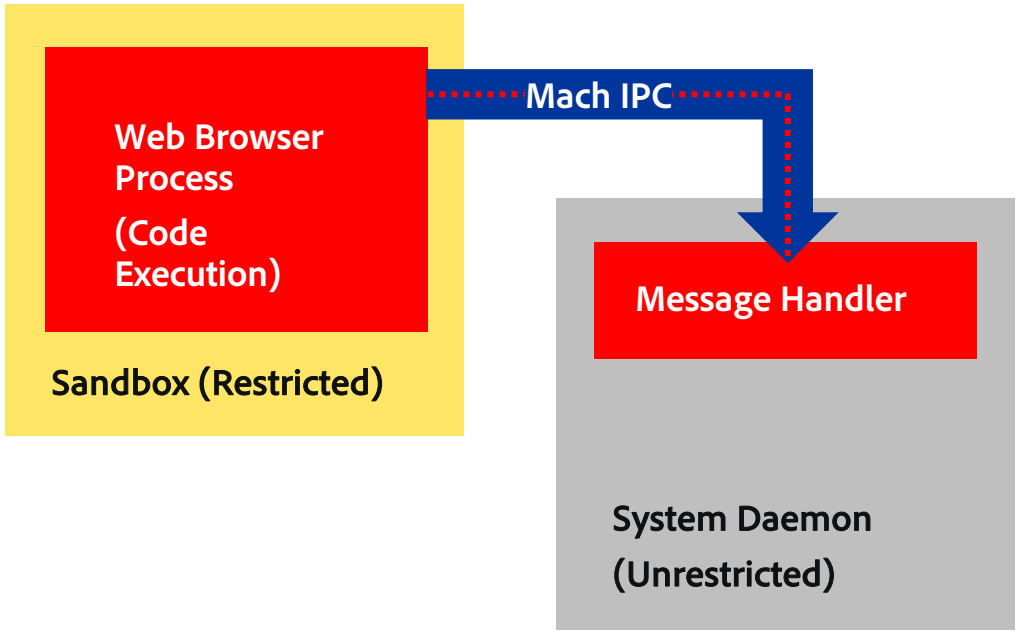

Abusing Mach Messages

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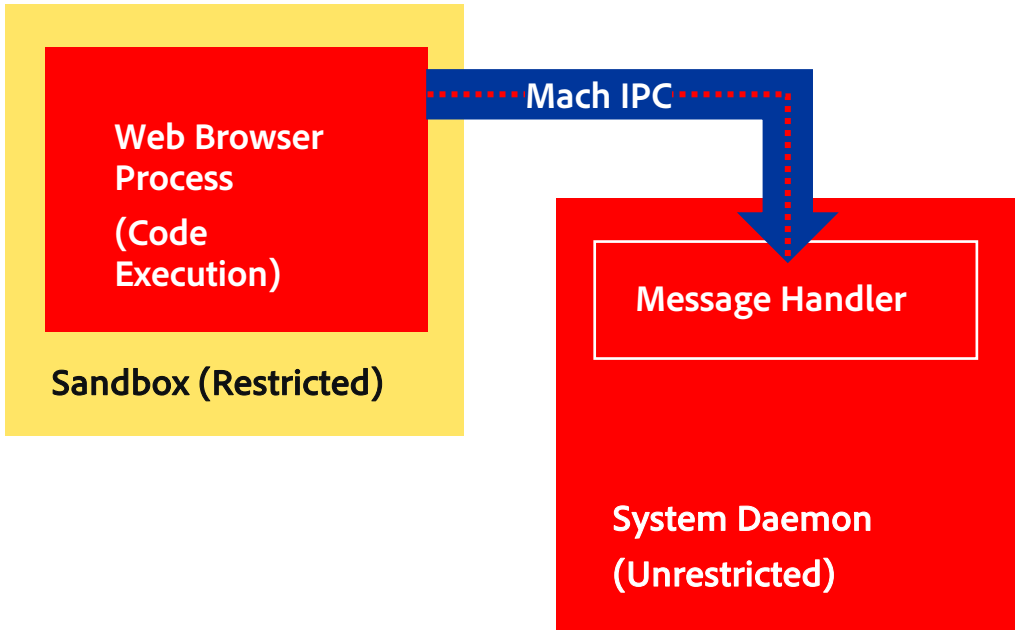

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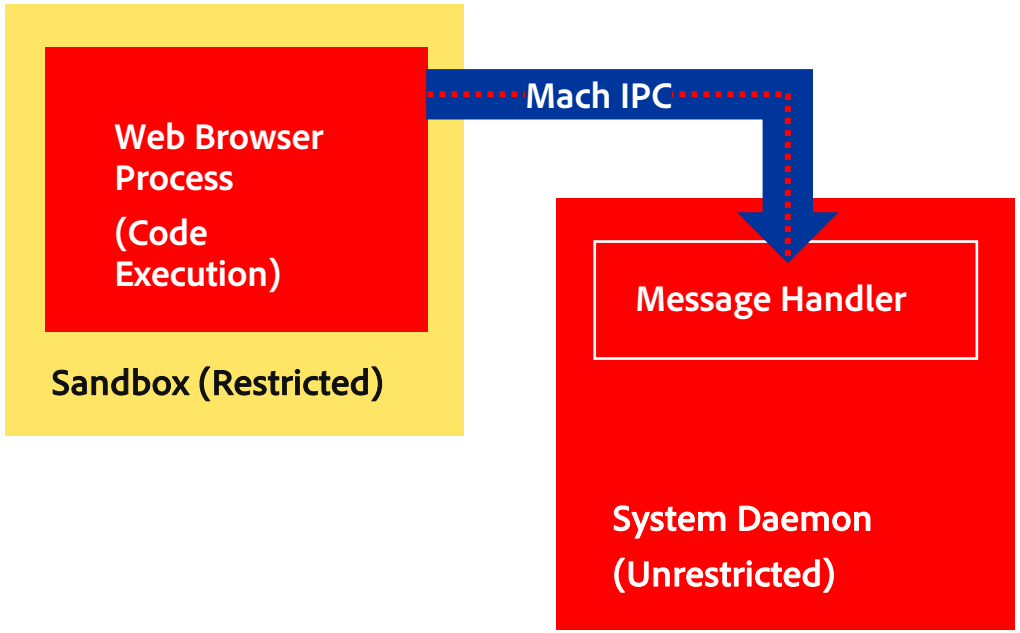

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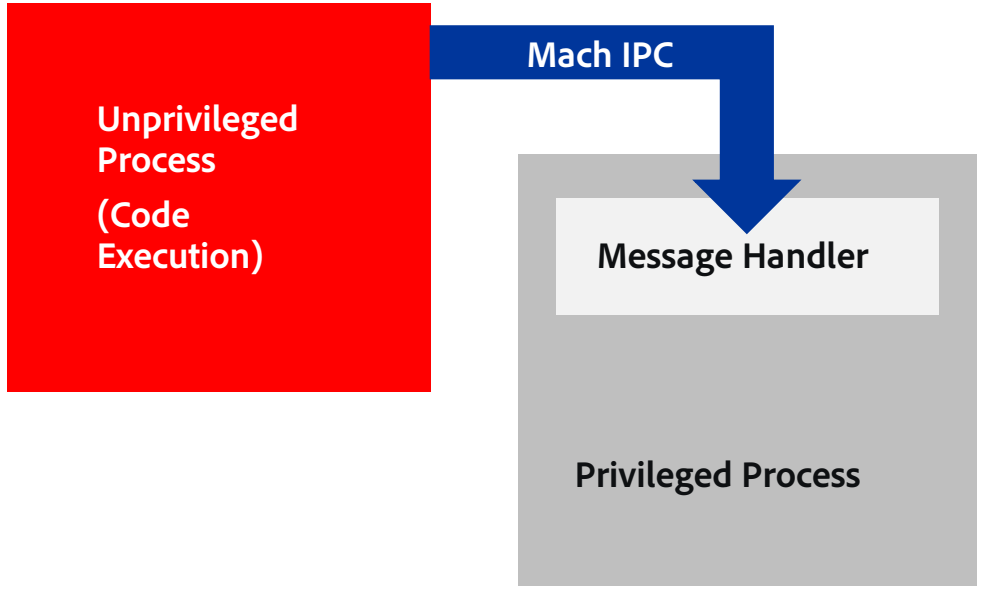

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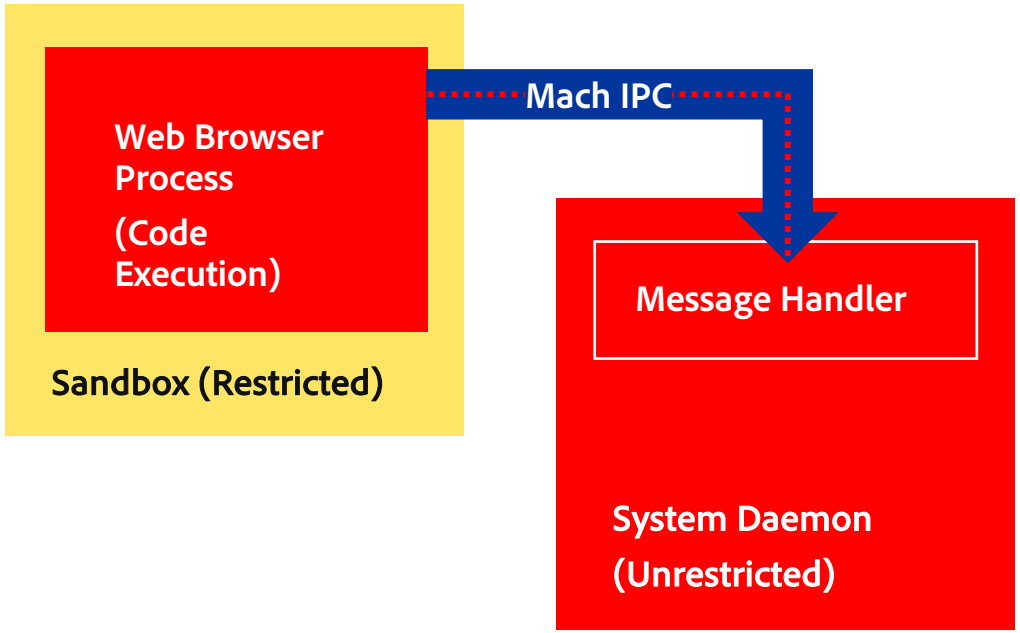

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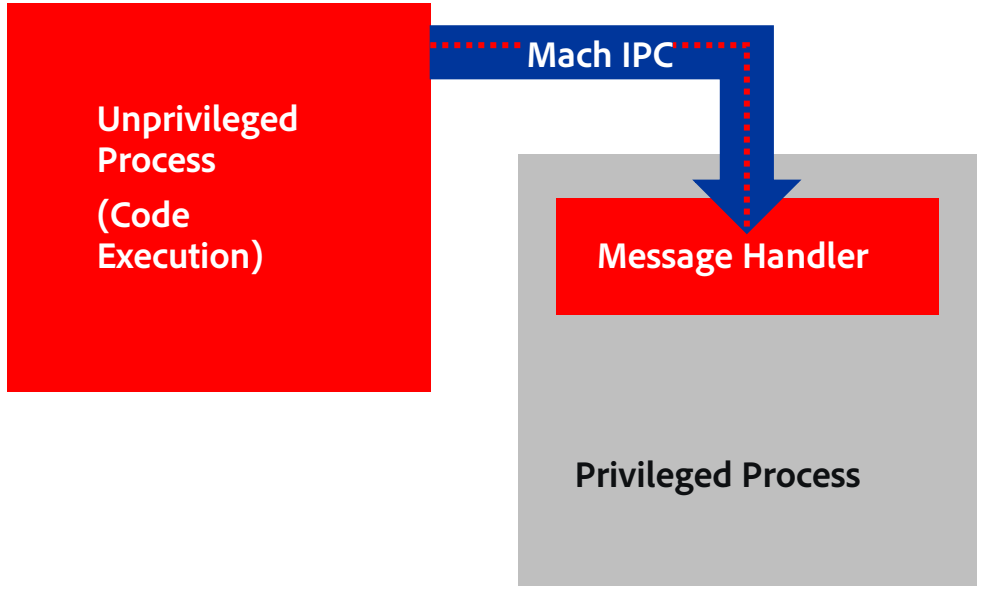

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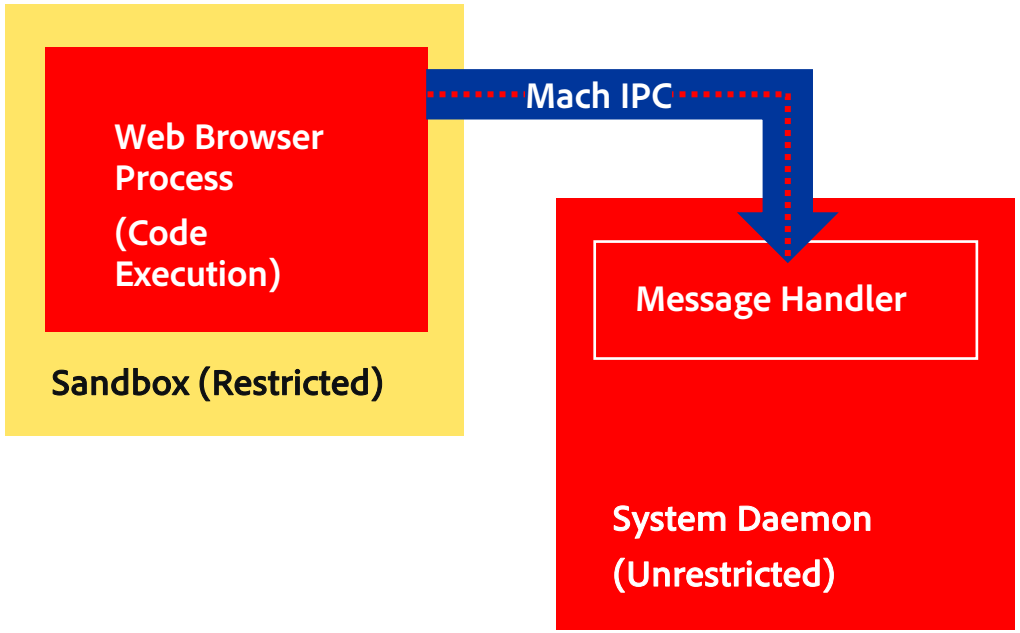

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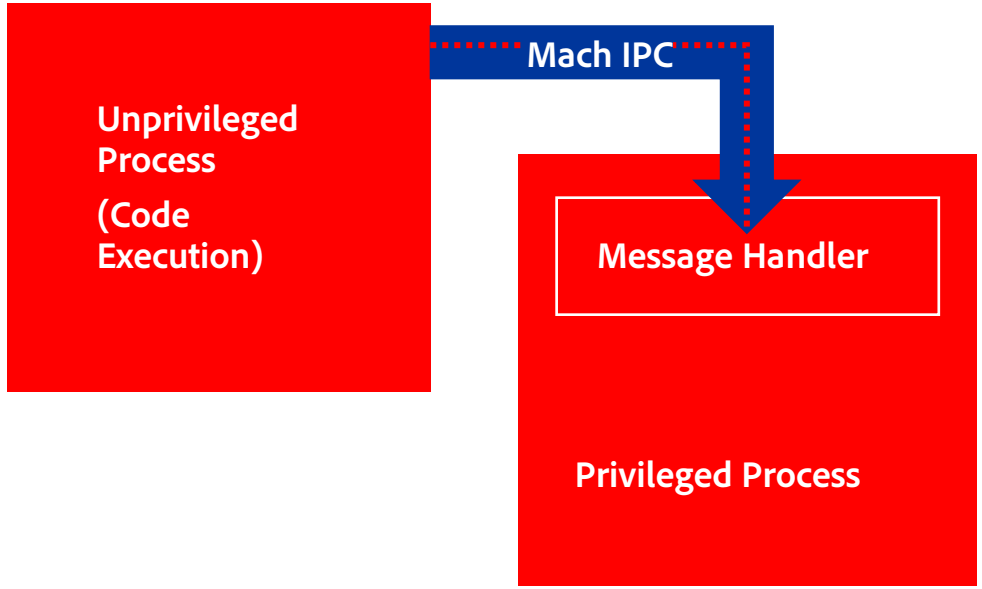

The Fuzzing Cycle

Previous Mach Research

BlackHat: Breaking the Chrome Sandbox with Mojo

- https://i.blackhat.com/USA-22/Wednesday/US-22-Roettger-Breaking-the-Chrome-Sandbox-with-Mojo.pdf
- Race condition + DoS == RCE

A Methodical Approach to Browser Exploitation

- http://blog.ret2.io/2018/06/05/pwn2own-2018-exploit-development/
- Safari sandbox escape via mach IPC messages == RCE

Finding Sandbox-Allowed Communications

How do we know what processes could allow an escape?

sbtool: https://newosxbook.com/src.jl?tree=listings&file=/sbtool.c

- Use built-in **sandbox_check()** function to determine which mach services a process can send to
- Message handlers we can send to → potential for sandbox escapes

```
❯ ./sbtool 2813 mach
com.apple.logd
com.apple.xpc.smd
com.apple.remoted
com.apple.metadata.mds
com.apple.coreduetd
com.apple.apsd
com.apple.coreservices.launchservicesd
com.apple.bsd.dirhelper
com.apple.logind
com.apple.revision
…Truncated…
```

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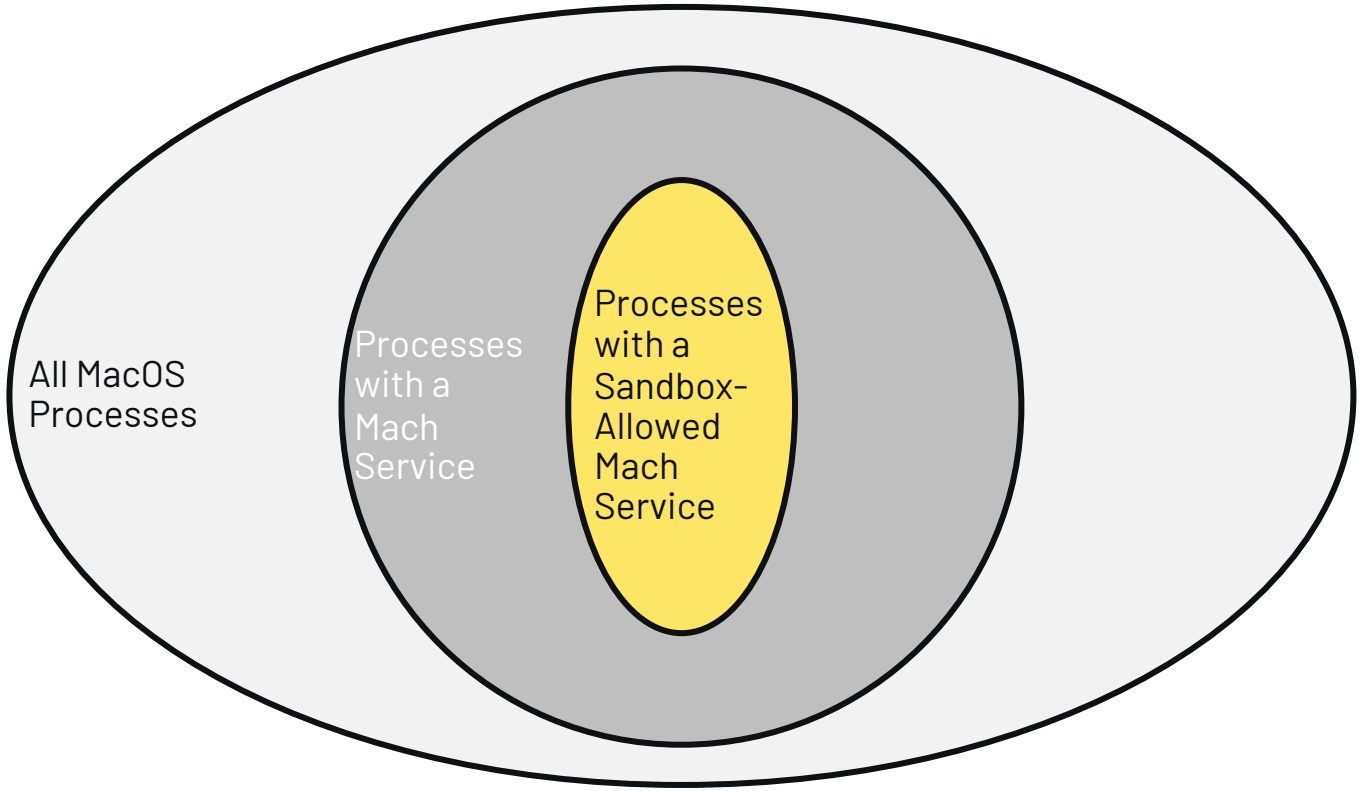
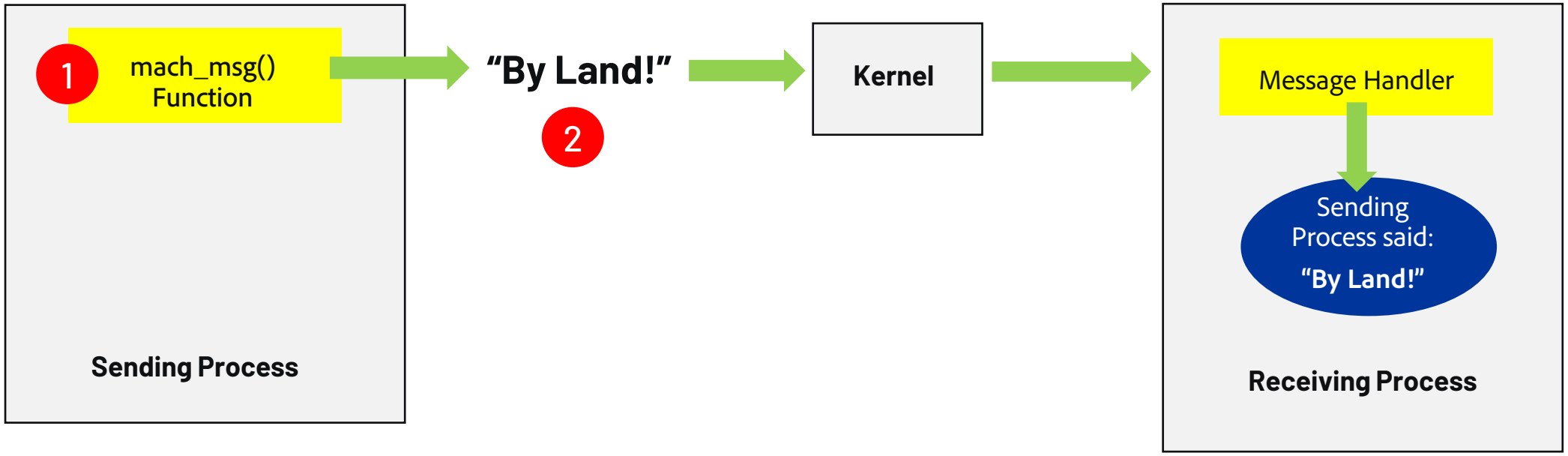


The Fuzzing Cycle

Finding an Entry Point

1. We know that **mach_msg()** is used to send mach messages from one process to another

2. Why not just modify real mach messages being sent?



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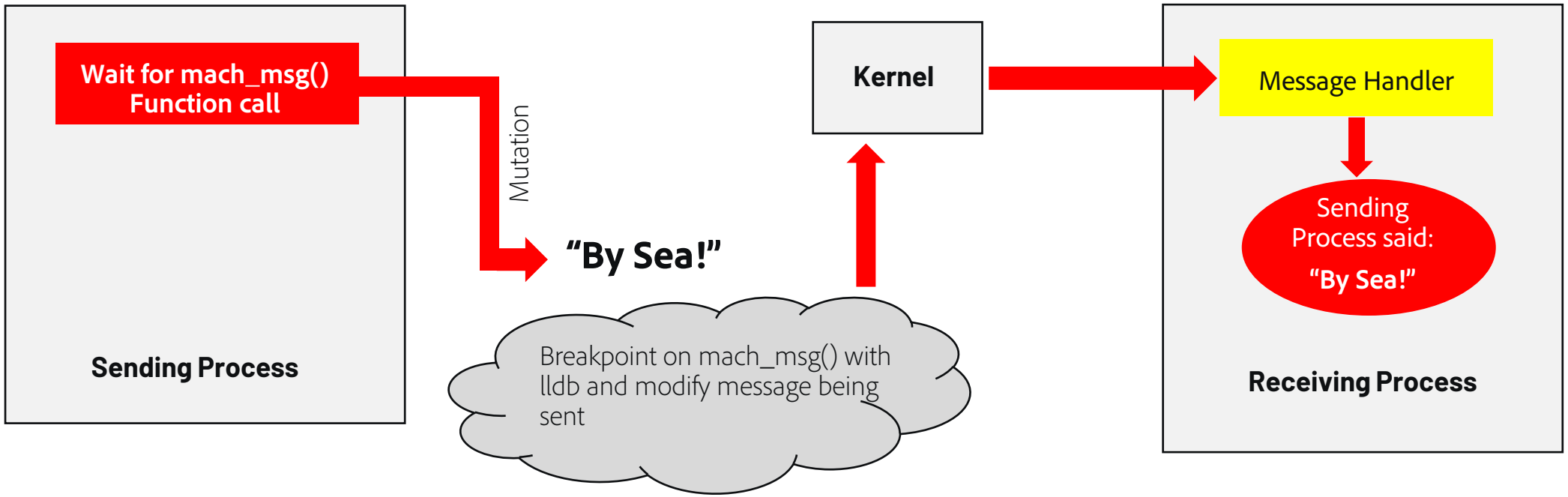

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Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

The Fuzzing Cycle

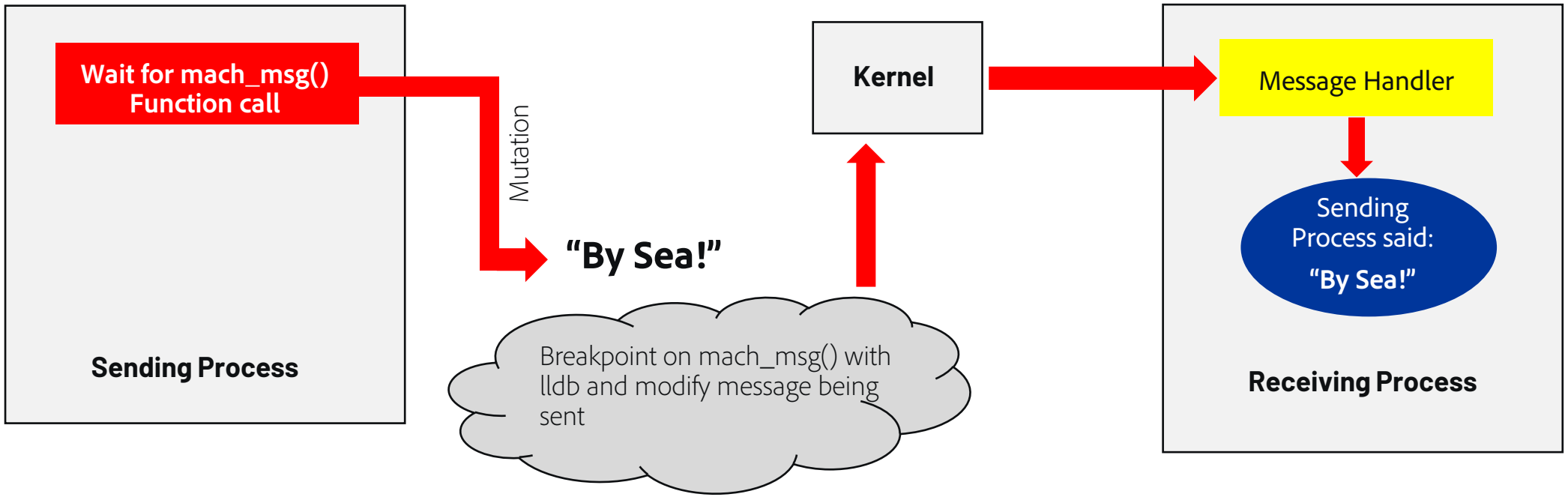
Finding an Entry Point

Pros:

- Simple
- Similar to end exploit

Cons:

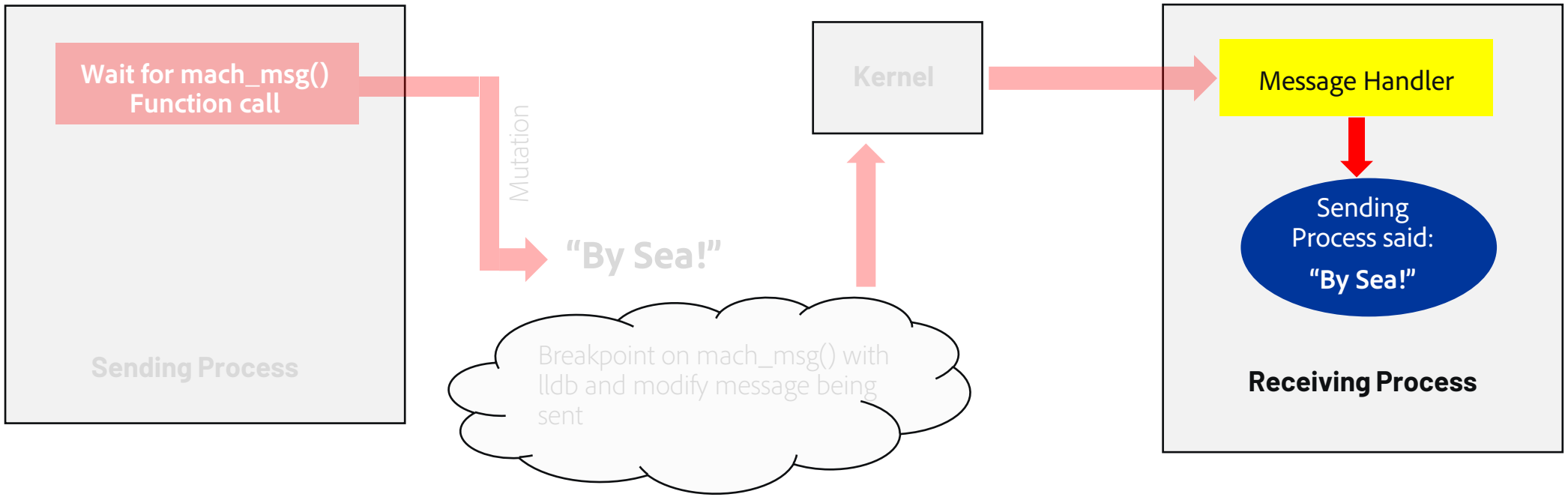
- Slow *(At mercy of the application to send messages)*
- Many points of potential failure
- Two different process spaces (code coverage difficult)
- Difficult to determine which message caused crash



The Fuzzing Cycle

Finding an Entry Point

Instead of waiting for **mach_msg()** to be called, what if we write a program to call it ourselves?



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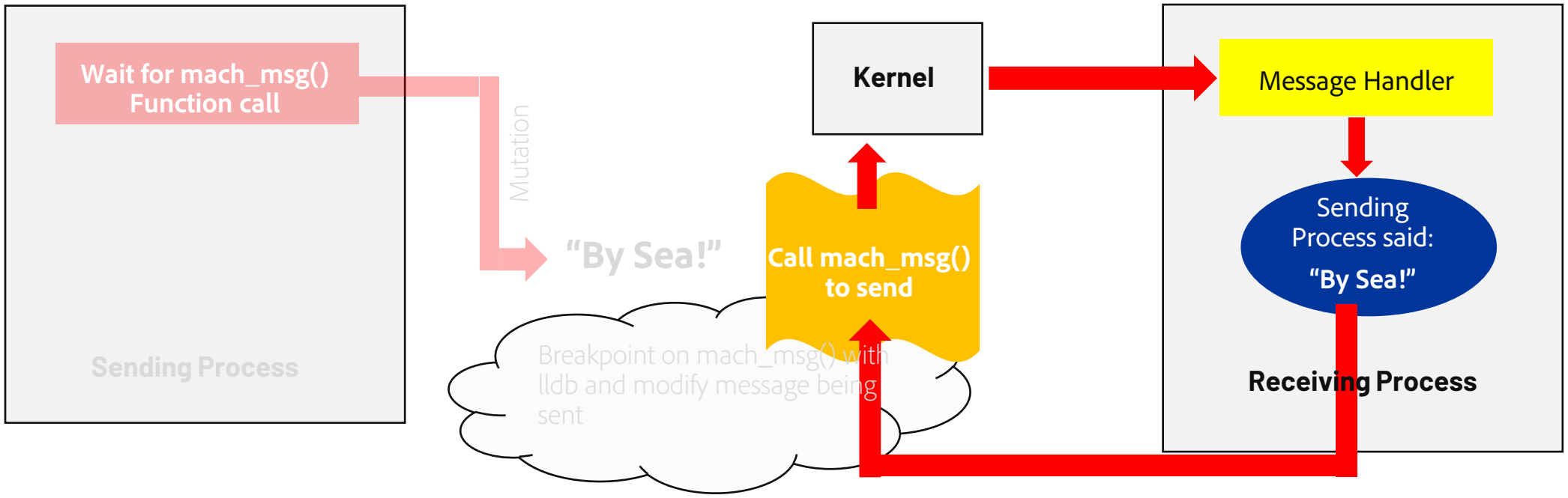


The Fuzzing Cycle

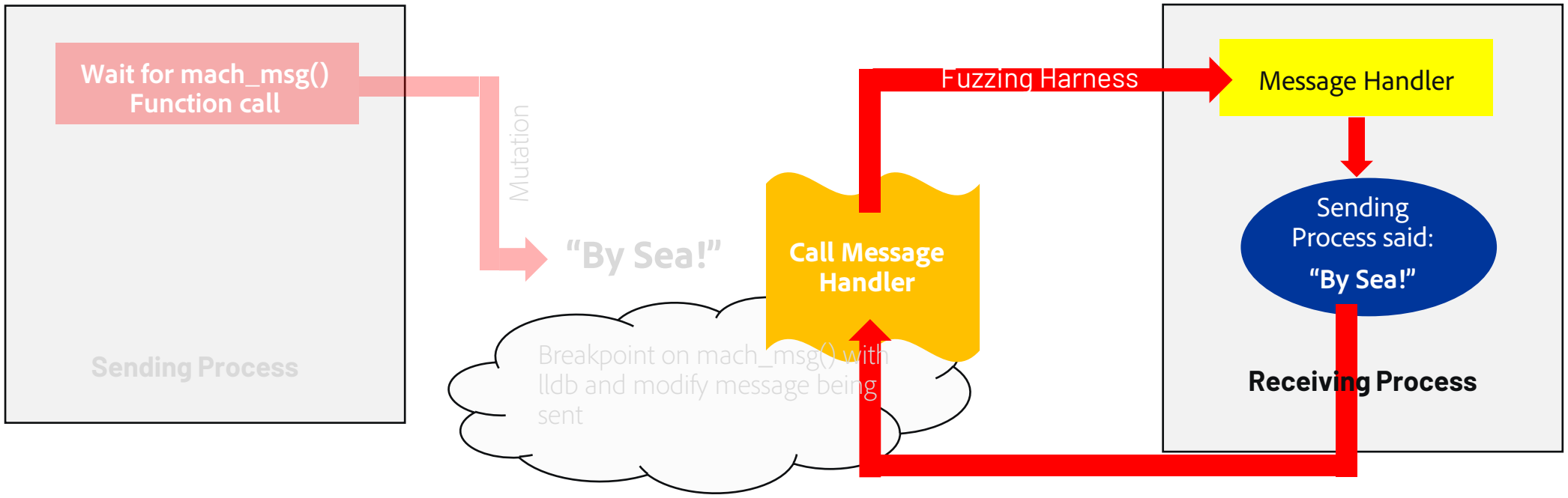
Finding an Entry Point

Instead of waiting for **mach_msg()** to be called, what if we write a program to call it ourselves?

Even Better: What if we just called the message handler directly?

*Some reverse engineering required

Getting "close" to the system of interest



The Fuzzing Cycle

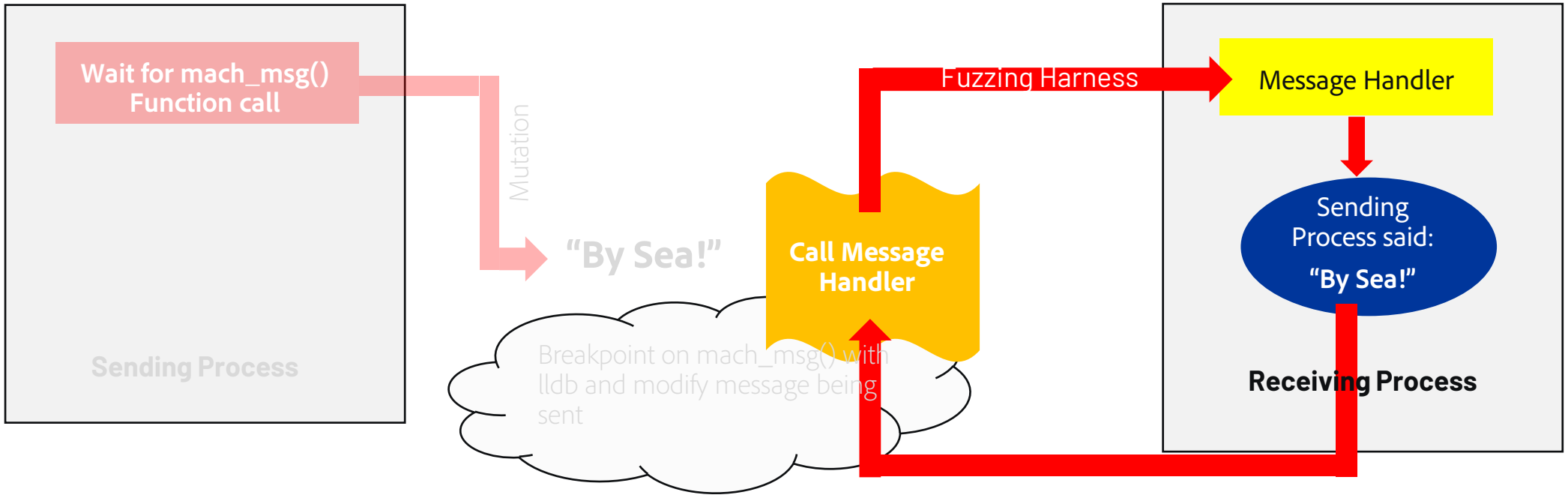
Finding an Entry Point

Pros:

- Very fast
- Same process space easy for instrumentation/code coverage
- Easy to know which input caused crash/replicate

Cons:

- Different from end exploit
- Might be naïve about initialization routines



The Fuzzing Cycle

We have an attack vector – but what should we send?

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

Sending totally random data is not likely to produce meaningful crashes

- Exception handlers
- Input validation

We need to identify examples of valid mach messages (e.g. “corpus building”)

Prep-Work

A number of things to take into consideration when we start debugging on MacOS

1. Setting up a MacOS virtual machine
2. Disabling System Integrity Protection (SIP)
   - `csrutil disable`
3. Disabling ReportCrash
4. Disabling Sleep
   - `systemsetup -setsleep Never`
5. Much more information provided: Jeremy Brown - Summer of Fuzz: MacOS - DEF CON 29 AppSec Village

Finding the Mach Message Handler

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

1 Find a mach service of interest

In our case, will be services sandboxed processes can communicate with

Let's focus on **com.apple.audio.coreaudiod**

- Handles all interactions with audio hardware
- Privileged process
- Allowed to send mach messages from many processes

Identify an attack vector

Generate a Corpus of Inputs

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The Fuzzing Cycle

Finding the Mach Message Handler

2 Find the binary that implements the mach service

- **com.apple.audio.coreaudiod** registered with **launchd**
- Spawns **/usr/sbin/coreaudiod**
- Mach server handled by CoreAudio Framework

```
(lldb) image list
[  0] D5BCB621-948E-308C-AF2C-88489D5569FA 0x000000010f332000 /usr/sbin/coreaudiod
[  1] BB7A0970-8C62-3DCE-A7A2-5CEC9C501F11 0x00007ff80894f000 /usr/lib/dyld
[  2] 66BBA3CA-BCE1-32F8-8269-99FAC92469FC 0x00007ff8123d6000 /System/Library/Privat
eFrameworks/caulk.framework/Versions/A/caulk
[  3] 97A3CD09-7112-376C-9613-7F38D4CF8C41 0x00007ff80ac99000 /System/Library/Framew
orks/CoreAudio.framework/Versions/A/CoreAudio
[  4] BEB5FC0B-7196-3C1D-A59A-F62ADA98F592 0x00007ff808ce4000 /System/Library/Framew
orks/CoreFoundation.framework/Versions/A/CoreFoundation
```

```
fuzzychicken@Fuzzys-Mac HALB_MIGServer_server % stat /System/Library/Frameworks/CoreAudio.framework/Versions/A/CoreAudio
stat: cannot stat '/System/Library/Frameworks/CoreAudio.framework/Versions/A/CoreAudio': No such file or directory
```

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

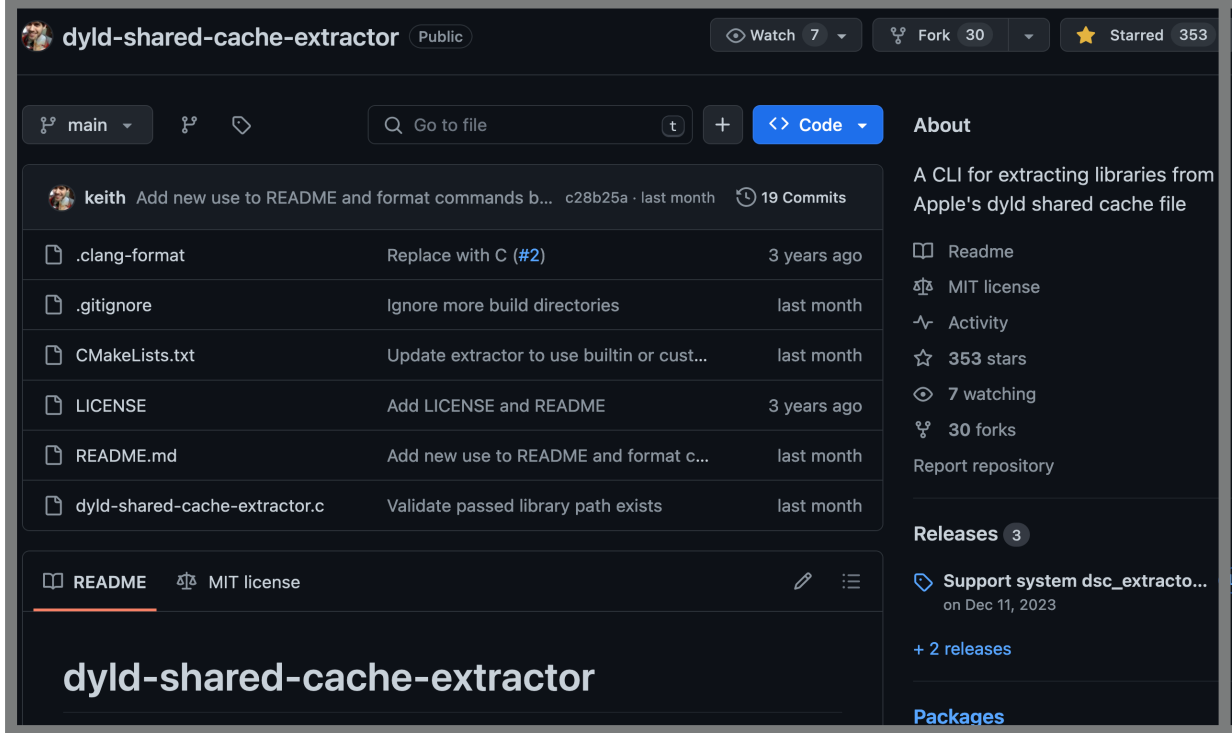
The Fuzzing Cycle

Finding the Mach Message Handler

3 Extract the binary from the dyld shared cache

- **Dyld shared cache:** Starting with Big Sur, most framework binaries are not on disk
- We can extract them!
- https://github.com/keith/dyld-shared-cache-extractor

```
build› ./dyld-shared-cache-extractor /System/Volumes/Preboot/C
ryptexes/OS/System/Library/dyld/dyld_shared_cache_x86_64h extr
acted-binaries
extracted 0/2505
extracted 1/2505
extracted 2/2505
extracted 3/2505
extracted 4/2505
extracted 5/2505
extracted 6/2505
extracted 7/2505
extracted 9/2505
extracted 8/2505
```



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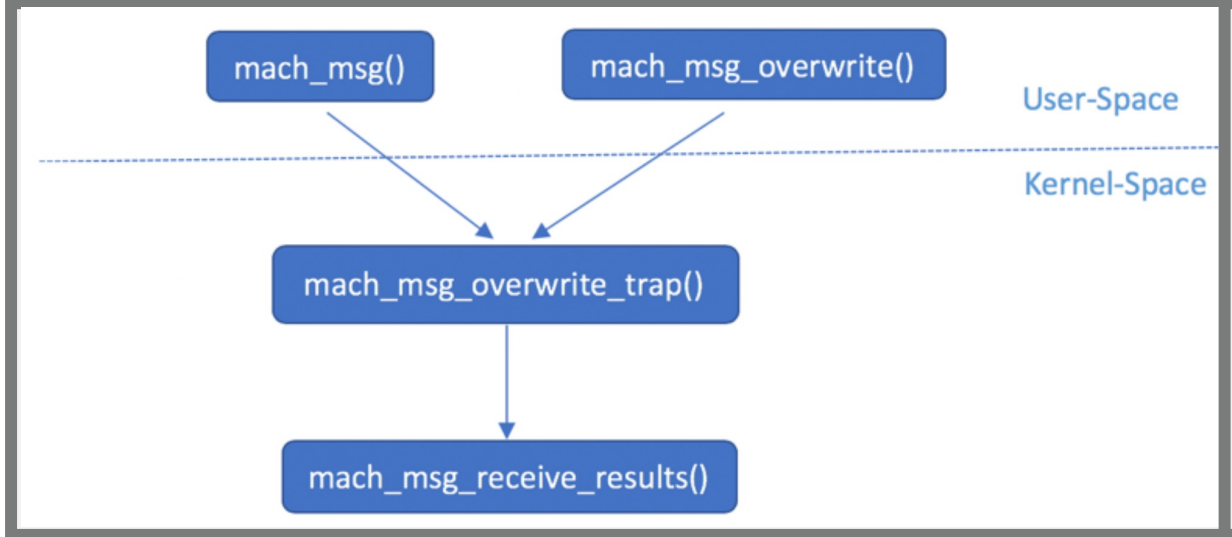
Finding the Mach Message Handler

4 Find function implementing mach receive functionality

- Wait, isn't this just **mach_msg()**?
  - Non-blocking, traps to kernel when a message is received
- Need to perform kernel debugging if we want to intercept incoming mach messages
  - This has been done: https://www.fortinet.com/blog/threat-research/inspect-mach-messages-in-macos-kernel-mode--part-ii--sniffing-th
- Kernel debugging cons:
  - We see all mach messages, difficult to isolate target process
  - Two-machine debugging required
- Is there an easier way?



Finding the Mach Message Handler

Identify an attack vector

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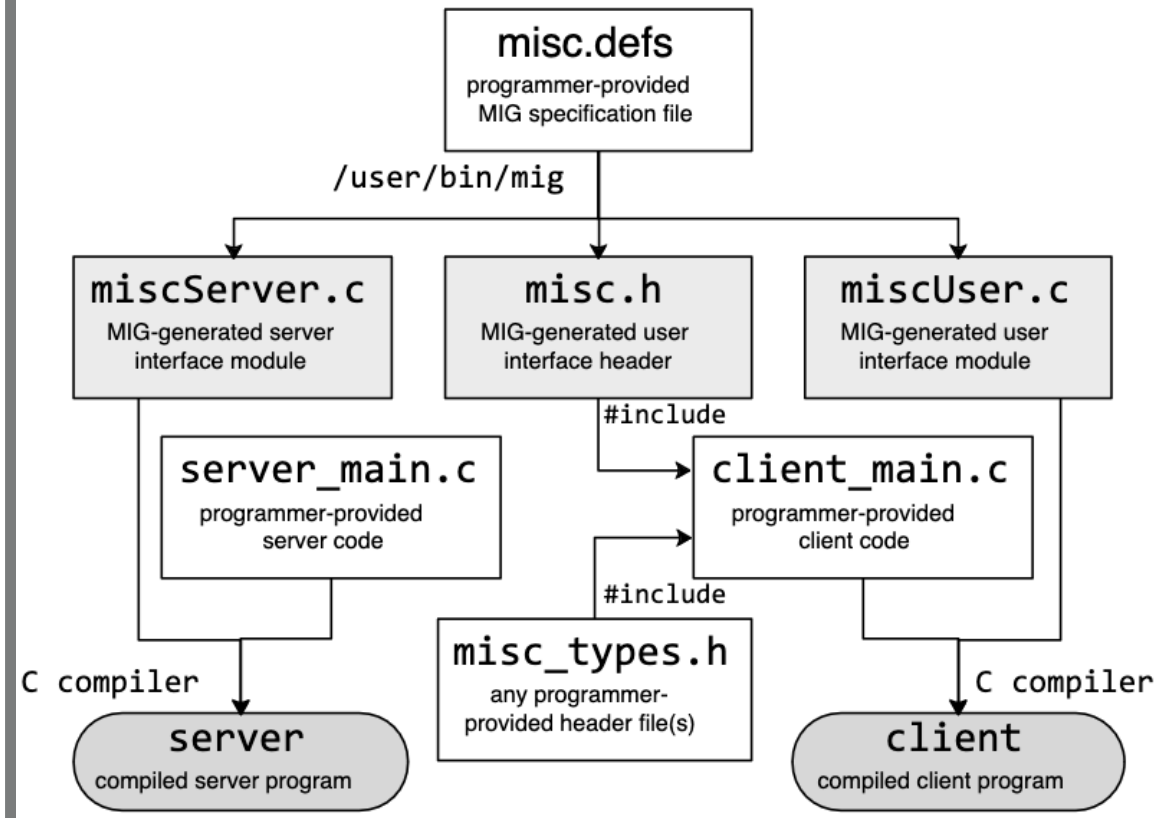
Fuzz and Produce Crashes

Identify Relevant Crashes

Mach Interface Generator (MIG)

- Apple provides MIG to more easily write RPC handlers and clients
- Interface Definition Language (IDL) compiler
- Abstracts much of the mach IPC layer away
- What if we searched for MIG-generated routines and dumped their incoming mach messages?



https://wcventure.github.io/FuzzingPaper/Paper/SRDS19_MachFuzzer.pdf

Finding the Mach Message Handler

3 Find function implementing mach receive functionality

- Hopper script: https://github.com/knightsc/hopper/blob/master/scripts/MIG%20Detect.py

```
build/framework-binaries› nm -m ./System/Library/Frameworks/CoreAudio.framework/Vers
ions/A/CoreAudio | grep -i subsystem

                 (undefined) external _CACentralStateDumpRegisterSubsystem (from Aud
ioToolboxCore)
00007ff8401adec0 (__DATA_CONST,__const) non-external _HALC_HALB_MIGClient_subsystem
00007ff8401adfd0 (__DATA_CONST,__const) non-external _HALS_HALB_MIGServer_subsystem
```

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The Fuzzing Cycle

Finding the Mach Message Handler

3 Find function implementing mach receive functionality

_HALS_HALB_MIGServer_subsystem

- Function lookup table

```
; Attributes: bp-based frame

; __int64 __fastcall HALB_MIGServer_server(mach_msg_header_t *, mach_msg_header_t *)
_HALB_MIGServer_server proc near
push    rbp
mov     rbp, rsp
mov     eax, [rdi]
and     eax, 1Fh
mov     [rsi], eax
mov     eax, [rdi+8]
mov     [rsi+8], eax
mov     dword ptr [rsi+4], 24h ; '$'
xor     eax, eax
mov     [rsi+0Ch], eax
mov     ecx, [rdi+mach_msg_header_t.msgh_id]
add     ecx, 64h ; 'd'
mov     [rsi+14h], ecx
mov     [rsi+10h], eax
mov     ecx, -1010000
add     ecx, [rdi+mach_msg_header_t.msgh_id] ; Get the msg ID
cmp     ecx, 3Dh ; '='
ja      short loc_7FF81DB61D64
```

Incoming msg (rdi)

Get msg ID

```
mov     ecx, ecx
lea     rcx, [rcx+rcx*4]
lea     rdx, _HALS_HALB_MIGServer_subsystem
mov     rcx, [rdx+rcx*8+28h] ; Index into function handler based on msg ID
test    rcx, rcx
jz      short loc_7FF81DB61D64
```

Get subsystem offset

Call function

```
call    rcx             ; Call the function
mov     eax, 1
jmp     short loc_7FF81DB61D79
```

```
loc_7FF81DB61D64:
mov     rcx, cs:7FF85D276FF8h
mov     rcx, [rcx]
mov     [rsi+18h], rcx
mov     dword ptr [rsi+20h], 0FFFFFED1h
```

```
loc_7FF81DB61D79:
pop     rbp
retn
_HALB_MIGServer_server endp
```

Identify an attack vector

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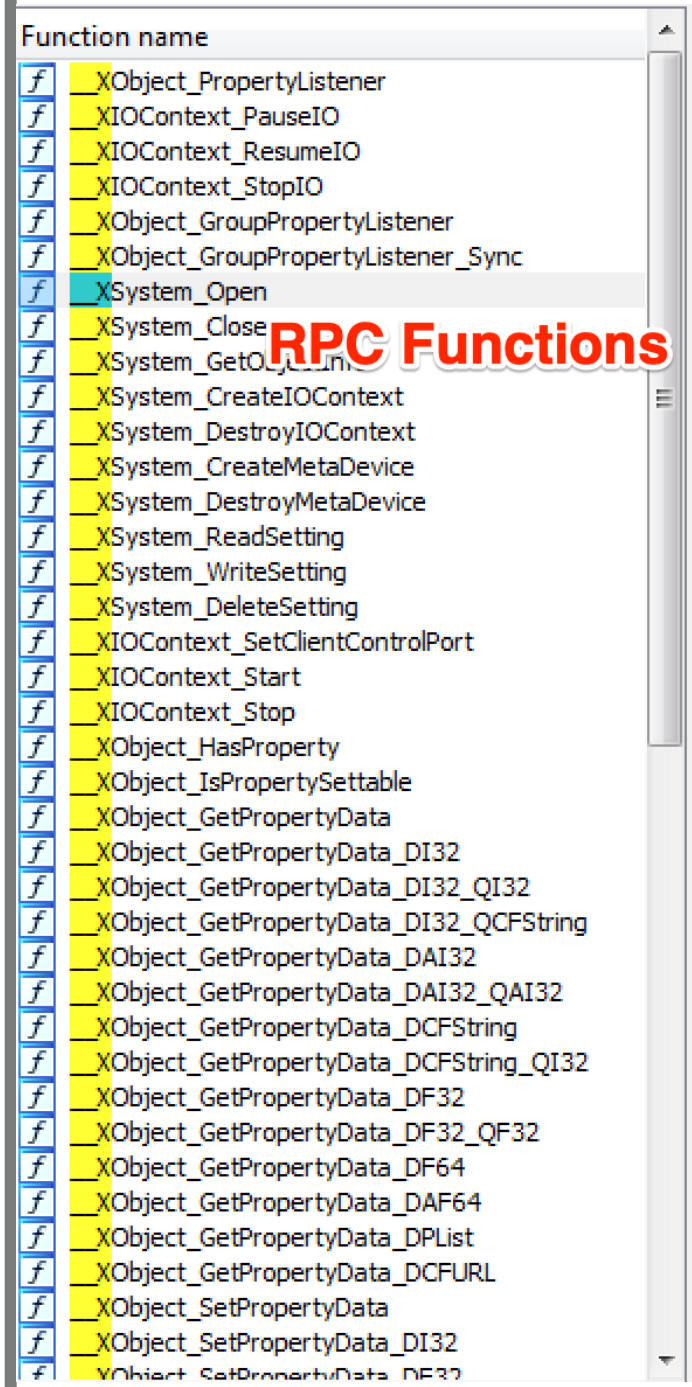
- Function lookup table



The Fuzzing Cycle

Generate a Corpus of Inputs

- Identify an attack vector
- Generate a Corpus of Inputs
- Create a Fuzzing Harness
- Fuzz and Produce Crashes
- Identify Relevant Crashes

I wrote a simple script to hook onto the message handler using LLDB

```
fuzzychicken@Fuzzys-Mac mach-fuzzing % sudo python3 subsystem_mach_msg_dumper.py -h
INFO Adding the LLDB Python library to PATH...
usage: subsystem_mach_msg_dumper.py [-h] -p PID -m MODULE -f FUNCTION

Attach to a process and dump a mach message passed to a specified function. The mach
 message should be passed as the first argument.

options:
  -h, --help            show this help message and exit
  -p PID, --pid PID     Process ID to attach to.
  -m MODULE, --module MODULE
                        Module loaded by the process.
  -f FUNCTION, --function FUNCTION
                        Function to set a breakpoint on.
```

The Fuzzing Cycle

Generate a Corpus of Inputs

- Identify an attack vector
- Generate a Corpus of Inputs
- Create a Fuzzing Harness
- Fuzz and Produce Crashes
- Identify Relevant Crashes

```
fuzzychicken@Fuzzys-Mac mach-fuzzing %
```

What is a Fuzzing Harness?

A **fuzzing harness** is code that allows you to send input through an attack vector.
(Call a desired function)

Calling the Target Function

Target Function: `_HALB_MIGServer_server`

- Simple on Windows:
  - `HMODULE hModule = LoadLibrary(“libexample.dll”)`
  - `pFunction = GetProcAddress(hModule, “DesiredFunction”)`
- On MacOS, similar:
  - `void *lib_handle = dlopen(“libexample.dylib”, RTLD_LAZY)`
  - `pFunction = dlsym(lib_handle, “DesiredFunction”)`
- What if the symbol isn’t exported?
- Write your own Mach-O symbol parser
  - A talk for another time ☺

The Fuzzing Cycle

Calling the Target Function

Targe

- Sim
  - HM
  - pF "D
- On M
  - vo RT
  - pF
- Wha
- Writ
  - A t

```
fuzzychicken@Fuzzys-Mac Release % ./Harness -l /System/Library/Frameworks/CoreAudio.framewo
rk/Versions/A/CoreAudio -s _HALB_MIGServer_server -f ~/mach-fuzzing/subsystem_messages/Core
Audio/HALB_MIGServer_server/a37747c4812a6baf1e4f5e[illegible]3d78d4c3

/System/Library/Frameworks/CoreAudio.framework/Versions/A/CoreAudio loaded at 0x1bbcd000

FUZZ Mach Msg:------ MACH MSG HEADER ------
msg_bits: 4370
msg_size: 48
msg_remote_port: 106187
msg_local_port: 67075
msg_voucher_port: 0
msg_id: 1010013
------ MACH MSG BODY (24 bytes) ------
0x0 0x0 0x0 0x0 0x1 0x0 0x0 0x0 0x66 0x0 0x0 0x0 0x76 0x73 0x63 0x6c 0x62 0x6f 0x6c 0x67 0x
0 0x0 0x0 0x0

Calling the function...
Result: 1

RETURNED Mach Msg:------ MACH MSG HEADER ------
msg_bits: 18
msg_size: 36
msg_remote_port: 106187
msg_local_port: 0
msg_voucher_port: 0
msg_id: 1010113
------ MACH MSG BODY (12 bytes) ------
0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0
fuzzychicken@Fuzzys-Mac Release %
```

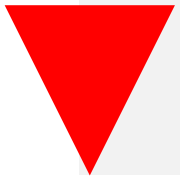
Function (Attack Vector)

Mach Message (Input)

Return Mach Message

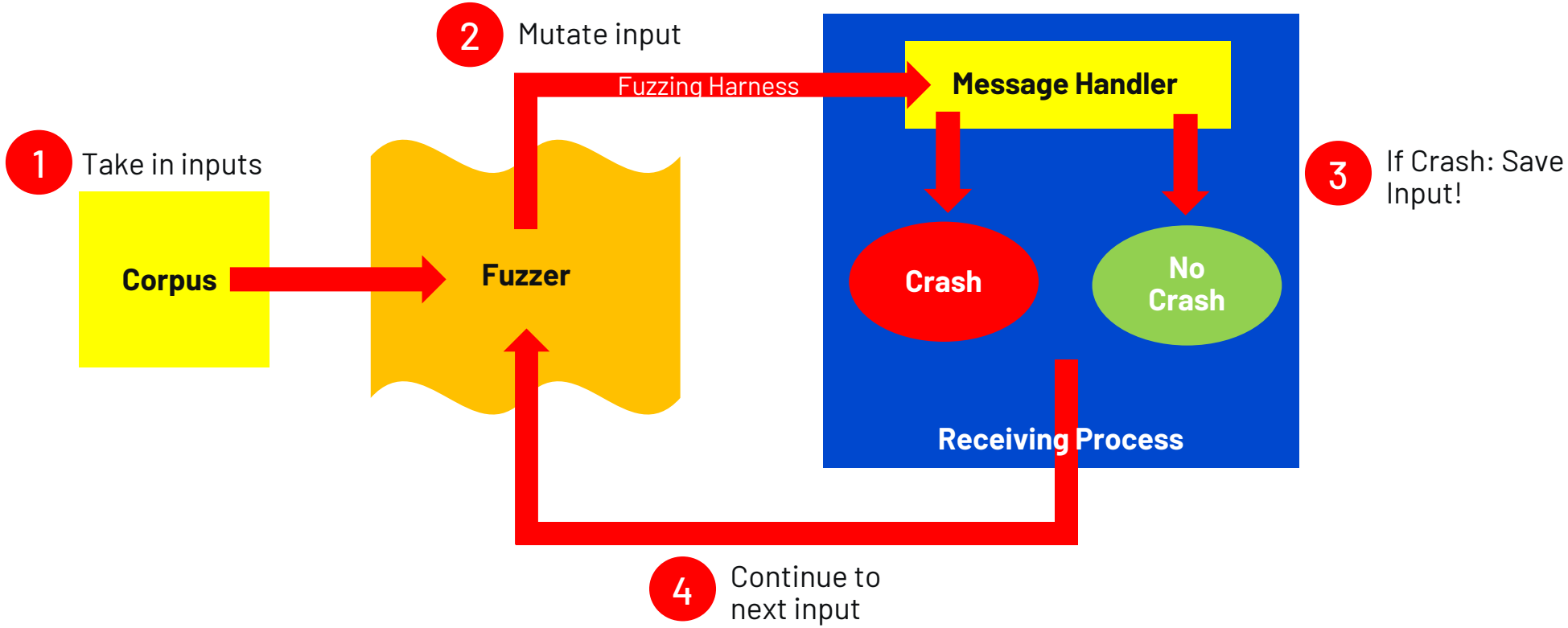
Calendar

What is a Fuzzer?



A **fuzzer** is a program that generates inputs to be sent to a system and monitors for crashes.

What is a Fuzzer?



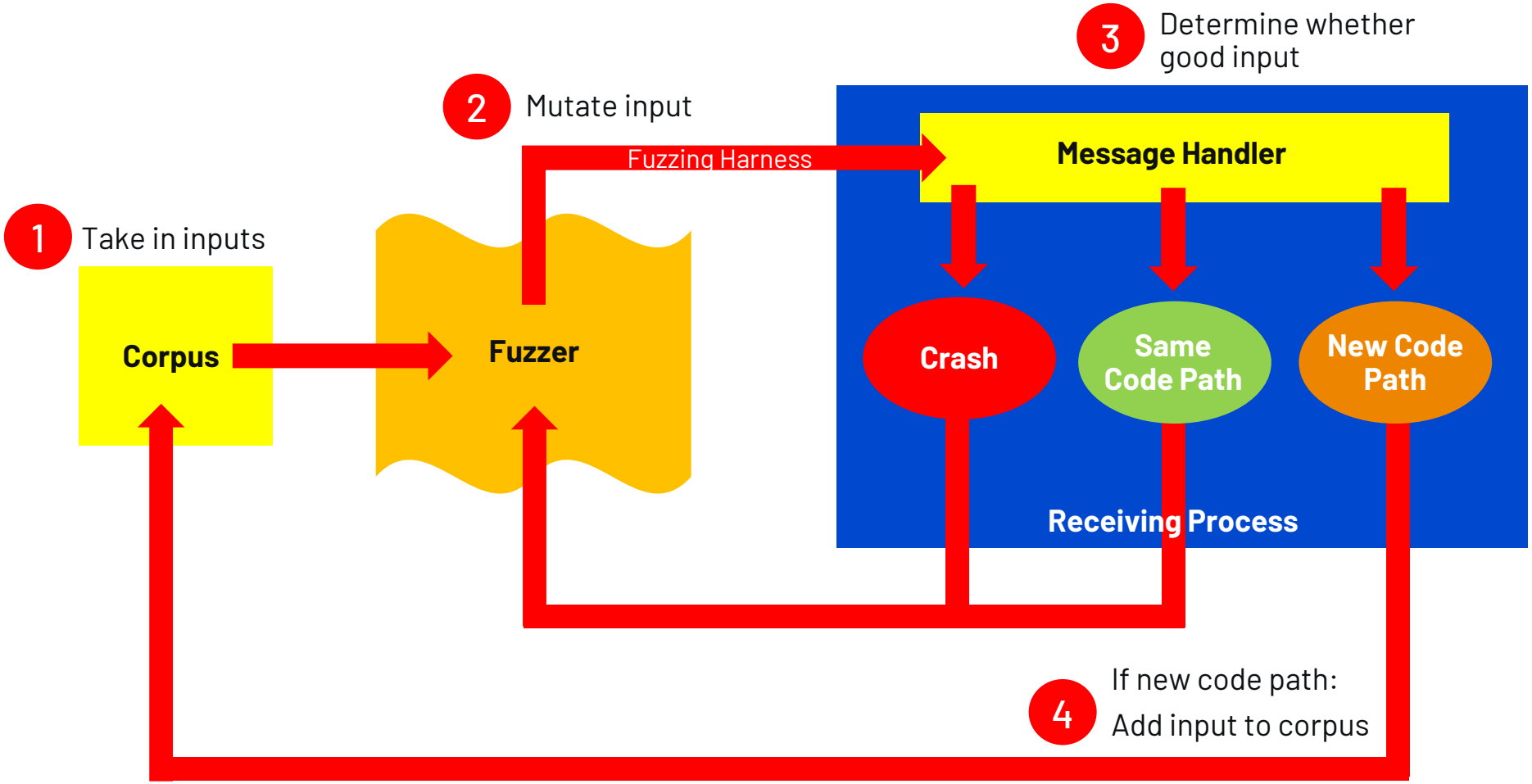
The Need For Code Coverage


```
1   void process_string(const char *input_string) {
2       if (strlen(input_string) > 3) {
3           if (strlen(input_string == 6)) {
4               if (input_string[0] == 's') {
5                   if (strstr(input_string, "secret") != NULL) {
6                       int *ptr = NULL;
7                       *ptr = 1; // CRASH
8                   }
9               }
10          }
11      }
12  }
```

What is Code Coverage

Code coverage traces a program's execution flow to identify new code paths.

How Do We Determine Code Coverage?

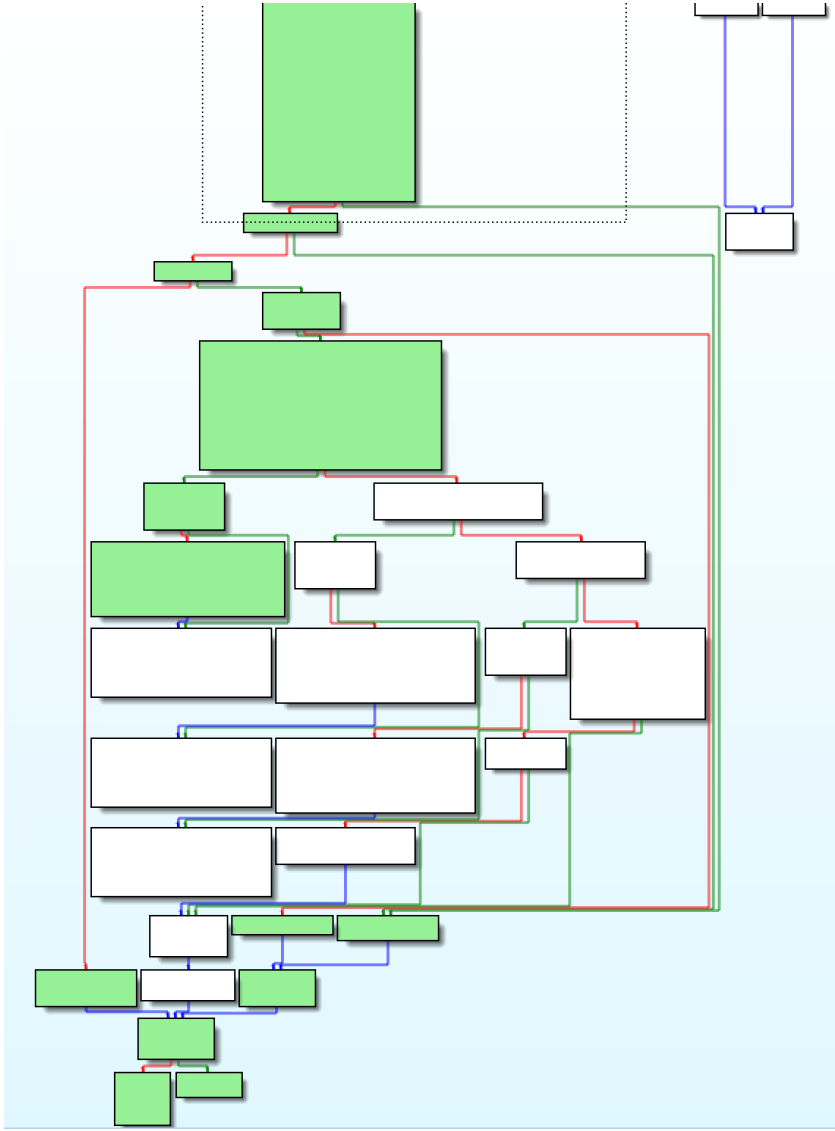


The Fuzzing Cycle

How Do We Determine Code Coverage?

Use instrumentation to monitor basic block execution

- Simple with source code:
  - AFL++ (https://github.com/AFLplusplus/AFLplusplus)
  - LibFuzzer (https://llvm.org/docs/LibFuzzer.html)
  - gCov (https://gcc.gnu.org/onlinedocs/gcc/Gcov.html)
- More difficult with black box binaries:
  - Frida (https://frida.re/)
  - TinyInst (https://github.com/googleprojectzero/TinyInst)
- Interpreting code coverage:
  - LightHouse for IdaPro/BinaryNinja (https://github.com/gaasedelen/lighthouse)



Identify an attack vector

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The Fuzzing Cycle

Actually Fuzzing!

My fuzzing setup

- Jackalope Fuzzer (https://github.com/googleprojectzero/Jackalope)
- Enable Apple's GuardMalloc
  - Restricted pages placed surrounding all allocations
  - `DYLD_INSERT_LIBRARIES=/usr/lib/libgmalloc.dylib`
- TinyInst for dynamic instrumentation to dump coverage
- LightHouse to interpret code coverage

- Identify an attack vector
- Generate a Corpus of Inputs
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The Fuzzing Cycle

Actually Fuzzing!

```
fuzzychicken@Fuzzys-Mac Release % ./fuzzer -in ../../../modified_msg_ids
 -out audio-startup-modified-ids -t 200 -t1 5000 -delivery file -instrum
ent_module CoreAudio -target_module Harness -target_method _fuzz -nargs
1 -iterations 1000 -persist -loop -cmp_coverage -generate_unwind -dump_c
overage -target_env DYLD_INSERT_LIBRARIES=/usr/lib/libgmalloc.dylib  --
 ./Harness -f @@ -l /System/Library/Frameworks/CoreAudio.framework/Versi
ons/A/CoreAudio -s _HALB_MIGServer_server
Fuzzer version 1.00
63 input files read
Running input sample ../../../modified_msg_ids/1010000
GuardMalloc[Harness-3598]: Allocations will be placed on 16 byte boundar
ies.
GuardMalloc[Harness-3598]:  - Some buffer overruns may not be noticed.
GuardMalloc[Harness-3598]:  - Applications using vector instructions (e.
g., SSE) should work.
GuardMalloc[Harness-3598]: version 064555.99.1
Instrumented module CoreAudio, code size: 7462910

Total execs: 2
Unique samples: 0 (0 discarded)
Crashes: 0 (0 unique)
Hangs: 0
Offsets: 0
Execs/s: 2
GuardMalloc[Harness-3599]: Allocations will be placed on 16 byte boundar
ies.
GuardMalloc[Harness-3599]:  - Some buffer overruns may not be noticed.
GuardMalloc[Harness-3599]:  - Applications using vector instructions (e.
g., SSE) should work.
GuardMalloc[Harness-3599]: version 064555.99.1
Instrumented module CoreAudio, code size: 7462910
Exception at address 0x7ff85d79c63b
Access address: 0x108d80000
Exception in instrumented module CoreAudio 0x7ff81bbcd000
Code before:
47 ff ff c6 05 7e 72 bd 01 01
Code after:
41 89 5c 24 20 48 8b 05 b1 29 11 fe 48 8b 00 49
GuardMalloc[Harness-3600]: Allocations will be placed on 16 byte boundar
ies.
```

GuardMalloc

C++ Exception

Instrumentation

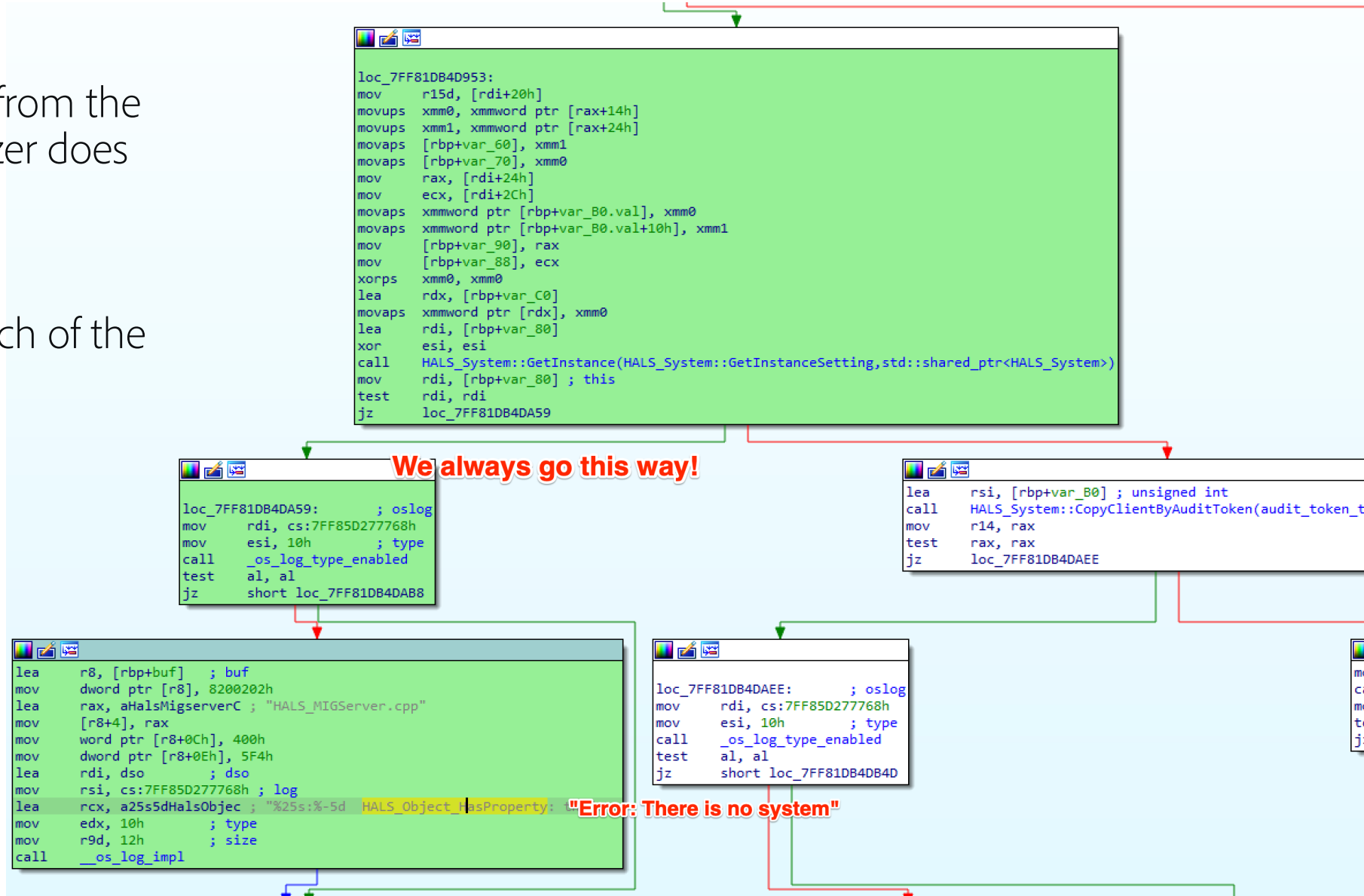
Improving Our Fuzzing

The Fuzzing Cycle

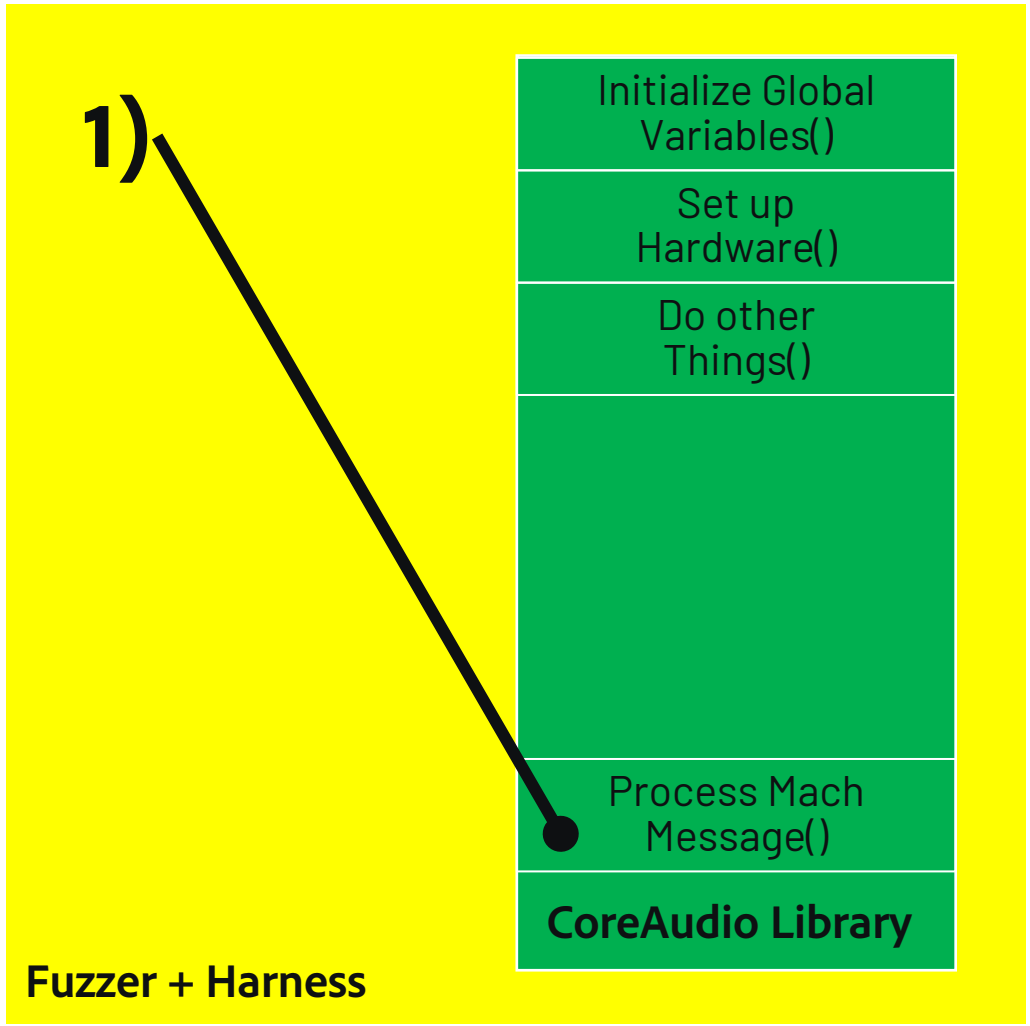
Regularly Check Code Coverage

We can learn a lot from the code paths our fuzzer does and doesn't take

Goal: Cover as much of the binary as possible!



Initialization: It Can Be a Big Problem



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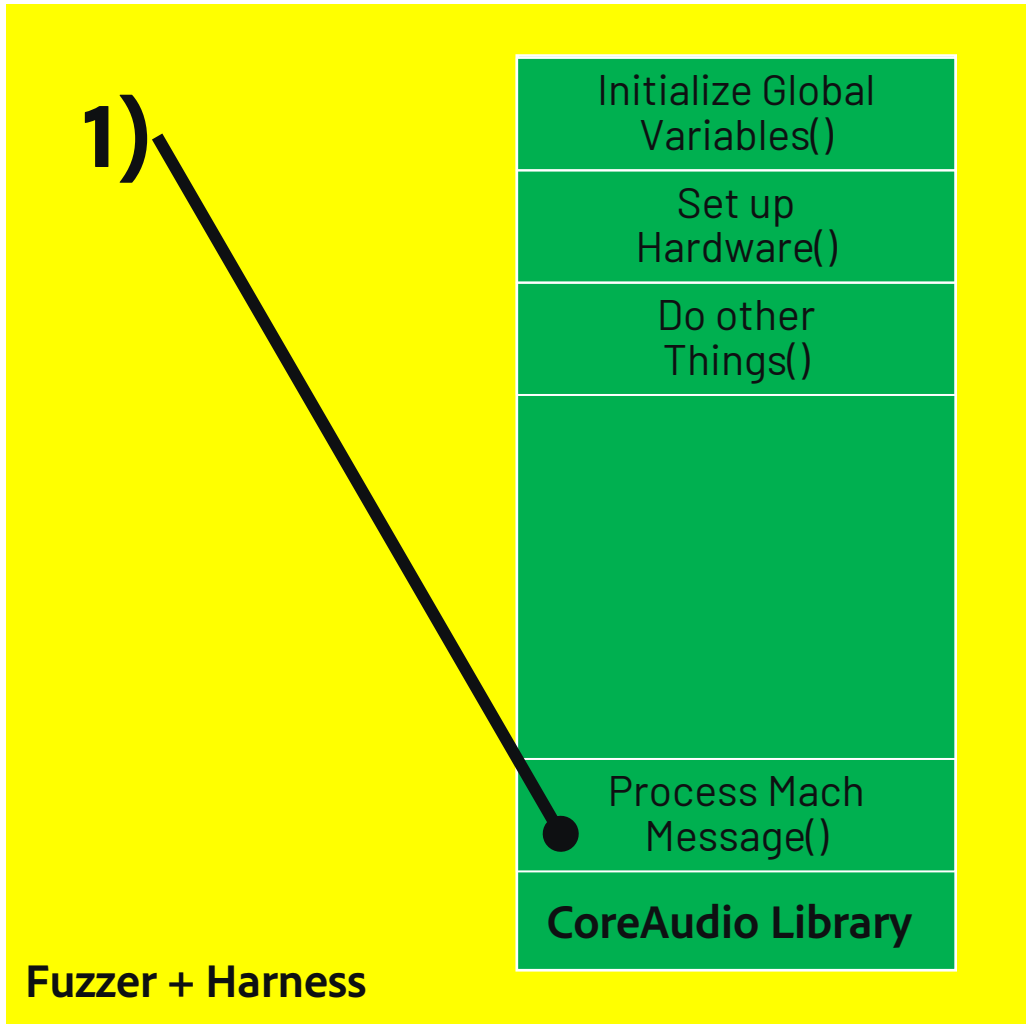

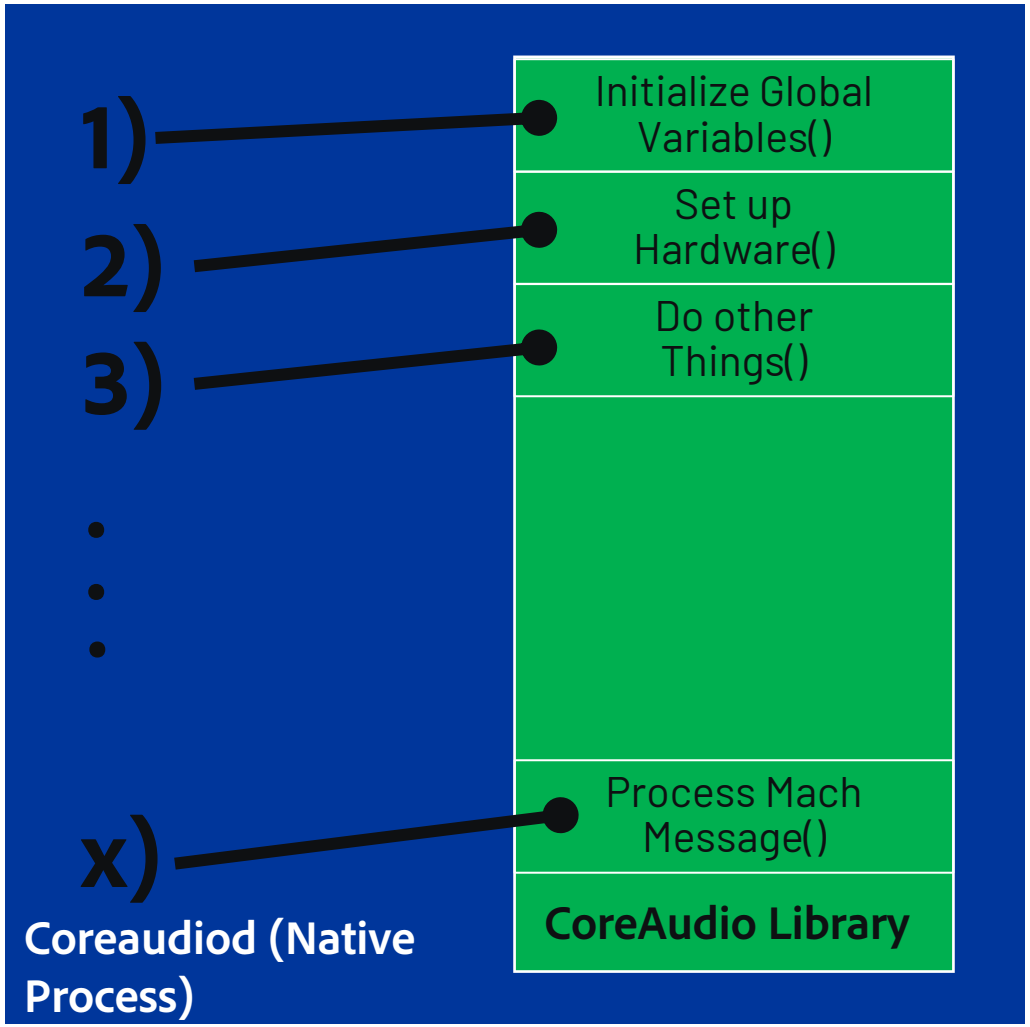

The Fuzzing Cycle

Initialization: It Can Be a Big Problem

I noticed my fuzzer was not getting deep into the code…

Why? The `coreaudiod` process performs initialization and setup for the `CoreAudio` Framework

It normally calls all these functions!

We want our fuzzer to be within the same process space as the initialized state

Coverage Overview

Cov %	Func Name	Address	Blocks Hit
100.00	_CFURLCreateWi…	0x7FF81DB620…	1 / 1
100.00	_CFURLGetString	0x7FF81DB620…	1 / 1
100.00	_CFURLGetTypeID	0x7FF81DB620…	1 / 1
100.00	_CFUUIDGetCons…	0x7FF81DB620…	1 / 1
100.00	_CFUUIDGetUUID…	0x7FF81DB620…	1 / 1
100.00	_IOConnectMapM…	0x7FF81DB621…	1 / 1
100.00	_IOConnectSetN…	0x7FF81DB621…	1 / 1
100.00	_IOIteratorNext	0x7FF81DB621…	1 / 1
100.00	_IOMainPort	0x7FF81DB621…	1 / 1
100.00	_IONotificatio…	0x7FF81DB621…	1 / 1
100.00	_IONotificatio…	0x7FF81DB621…	1 / 1
100.00	_IOObjectConfo…	0x7FF81DB621…	1 / 1
100.00	_IOObjectRelease	0x7FF81DB621…	1 / 1
100.00	_IOObjectRetain	0x7FF81DB621…	1 / 1
100.00	_IOPMGetUserAc…	0x7FF81DB621…	1 / 1
100.00	_IOPMScheduleU…	0x7FF81DB622…	1 / 1
100.00	_IORegisterFor…	0x7FF81DB622…	1 / 1
100.00	_IORegistryEnt…	0x7FF81DB622…	1 / 1
100.00	_IORegistryEnt…	0x7FF81DB622…	1 / 1
100.00	_IORegistryEnt…	0x7FF81DB622…	1 / 1
100.00	_IORegistryEnt…	0x7FF81DB622…	1 / 1
100.00	_IORegistryGet…	0x7FF81DB622…	1 / 1
100.00	_IOServiceAddI…	0x7FF81DB622…	1 / 1
100.00	_IOServiceAddM…	0x7FF81DB622…	1 / 1
100.00	_IOServiceMatc…	0x7FF81DB622…	1 / 1

The Fuzzing Cycle

Initialization: It Can Be a Big Problem

Possible Approaches:

1. Determine the initialization functions that need to be called, then call them within your fuzzing harness before starting fuzzing
   - Great when the initialization is simple
2. Modify a process you know performs proper initialization so it spawns your fuzzer
   - Hook a function through binary patching, `LD_PRELOAD`, detours, etc.
   - Instrument the binary using Frida or TinyInst

The Fuzzing Cycle

Initialization: It Can Be a Big Problem

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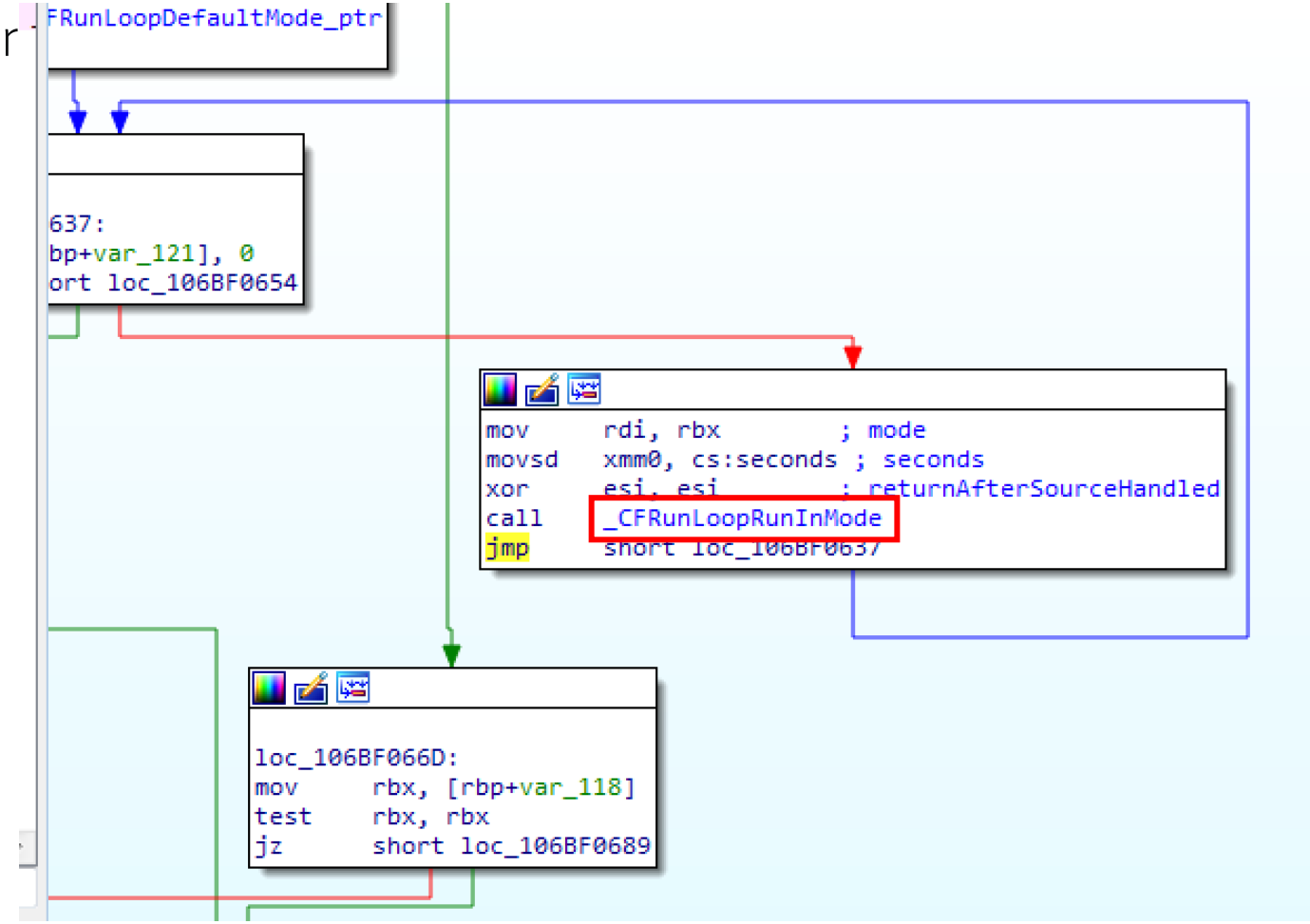
1. Determine the initialization functions that need to be called, then call them within your fuzzing harness before starting fuzzing
   - Great when the initialization is simple
2. Modify a process you know performs proper initialization so it spawns your fuzzer
   - Hook a function through binary patching, `LD_PRELOAD`, detours, etc.
   - **Instrument the binary using Frida or TinyInst**

Identifying Where to Instrument

`coreaudiod` loops continuously after performing the proper setup

`_CFRunLoopRunInMode` function

What if we changed that function so it calls our target?



Injecting Our Fuzzing Harness with Frida


```
'use strict';

const harnessLib = Module.load('libharness.dylib');
const fuzz = new NativeFunction(harnessLib.getExportByName('fuzz'), 'void', []);

Interceptor.attach(Module.findExportByName('CoreFoundation', 'CFRunLoopRunInMode'), {
    onEnter: function(args) {
        console.log('CFRunLoopRunInMode called. Starting Fuzzer!');
        fuzz();
    },
    onLeave: function(retval) {
        console.log('Returning');
    }
});

console.log('Hook applied successfully.');
```

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Injecting Our Fuzzing Harness with Frida

```
(venv) ➜  mach-fuzzing git:(main) ✗ frida -l frida-fuzzer-injector.js -p 7412
     ____
    / _  |   Frida 16.3.3 - A world-class dynamic instrumentation toolkit
   | (_| |
    > _  |   Commands:
   /_/ |_|       help      -> Displays the help system
   . . . .       object?   -> Display information about 'object'
   . . . .       exit/quit -> Exit
   . . . .
   . . . .   More info at https://frida.re/docs/home/
   . . . .
   . . . .   Connected to Local System (id=local)
Attaching...
Hook applied successfully.
[Local::PID::7412 ]-> CFRunLoopRunInMode called. Starting Fuzzer!
Process terminated
[Local::PID::7412 ]->

Thank you for using Frida!
(venv) ➜  mach-fuzzing git:(main) ✗
```

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Injecting Our Fuzzing Harness with Frida

```
(venv) ➜  mach-fuzzing git:(m
    ____
   / _  |   Frida 16.3.3 - A
  | (_| |
   > _  |   Commands:
  /_/ |_|       help      ->
  . . . .       object?   ->
  . . . .       exit/quit ->
  . . . .
  . . . .   More info at htt
  . . . .
  . . . .   Connected to Local System (id=local)
Attaching...
Hook applied successfully.
[Local::PID::7412 ]-> CFRunLoopRunInMode called. Starting Fuzzer!
Process terminated
[Local::PID::7412 ]->

Thank you for using Frida!
(venv) ➜  mach-fuzzing git:(main) ✗
```

```
(lldb) b fuzz
Breakpoint 3: where = libfuzzer.dylib`fuzz, address = 0x00000001000c0830
(lldb) c
Process 8157 resuming
Process 8157 stopped
* thread #1, queue = 'com.apple.main-thread', stop reason = breakpoint 3.1
    frame #0: 0x00000001000c0830 libfuzzer.dylib`fuzz
libfuzzer.dylib`fuzz:
->  0x1000c0830 <+0>: push   rbp
    0x1000c0831 <+1>: mov    rbp, rsp
    0x1000c0834 <+4>: sub    rsp, 0x30
    0x1000c0838 <+8>: mov    qword ptr [rbp - 0x8], rdi
(lldb) x $rdi
0x103636580: 12 00 00 00 80 00 00 00 8f 8e 02 00 03 dc 00 00  ................
0x103636590: 00 00 13 c2 87 69 0f 00 33 00 00 00 00 00 00 00  .....i..3.......
```

The Fuzzing Cycle

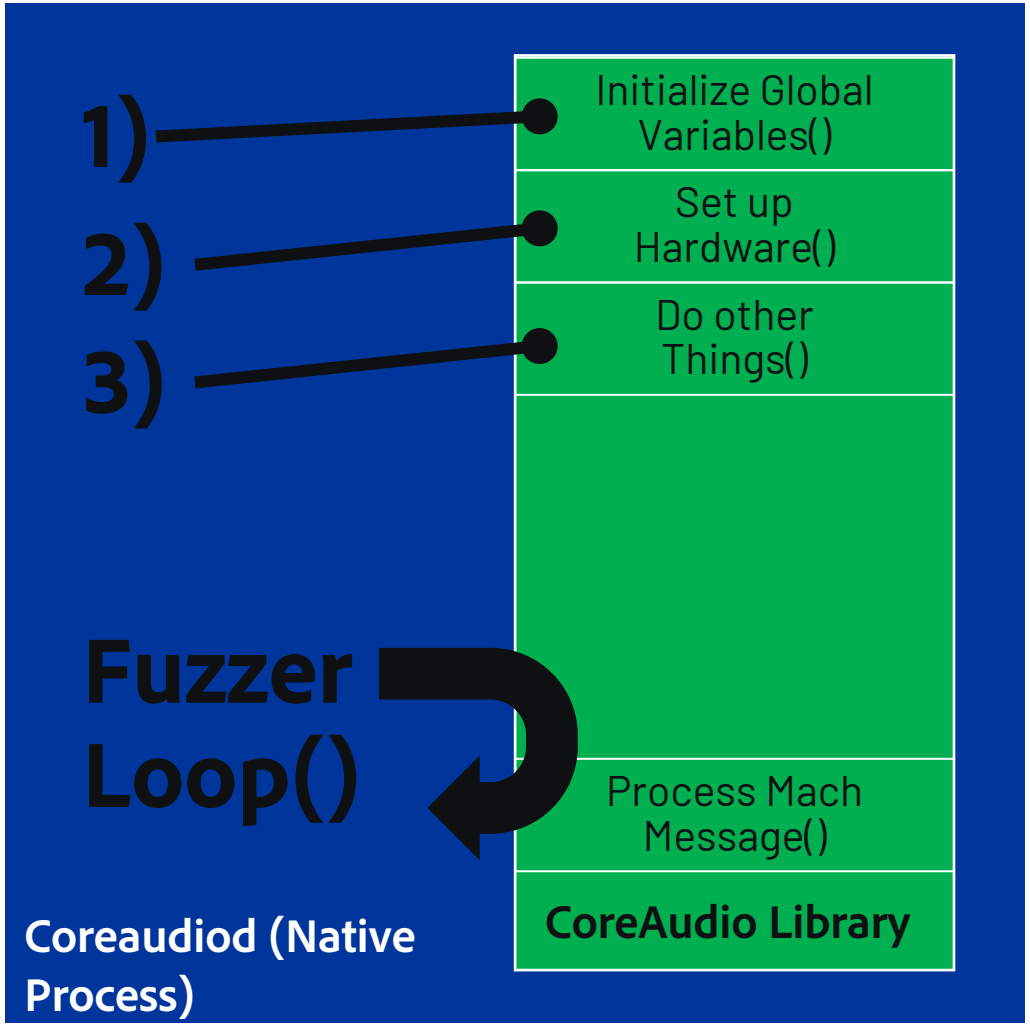
Injecting a Full Fuzzer with Frida (In Progress)

We want to inject a full fuzzer:

- Corpus management
- Mutation/input generation
- Code coverage
- Crash identification

This is not a trivial task

- LibAFL is a library that allows for custom fuzzer design using state-of-the art approaches
  - https://github.com/AFLplusplus/LibAFL
- Can help us run fuzzers in interesting places



Exploitable Versus Non-Exploitable Crashes

Exploitable:

- Crash on write
- Crash on execution
- Illegal instruction
- Heap corruption abort
- Stack trace contains **free**, **malloc**, etc.

Likely Non-Exploitable:

- Crash on read (could be used to leak memory, though)
- Handled exception
- Null pointer dereferences
- Stack recursion

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Useful Tools:

- Apple's CrashWrangler (https://developer.apple.com/library/archive/technotes/tn2334/index.html)
- CrashMon (https://github.com/ant4g0nist/crashmon)

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Crash Reproducibility

- Should be able to run input through harness and reproduce the crash

FUZZING TAKEAWAYS

What We've Covered

- A crash course on fuzzing and Mach IPC mechanisms
- A walkthrough of the attack process:
  - Identifying an attack vector
  - Generating a corpus of fuzzing inputs
  - Writing a custom fuzzing harness
  - Fuzzing and producing crashes
  - Crash triaging
- Common pitfalls and things to consider
- Inspired you to do vulnerability research!

FUZZING TAKEAWAYS

Personal Advice

- Try to get your fuzzer as close to the target function as possible
- The harder something is to fuzz, the more likely there will be vulnerabilities
- Let your code coverage inform your fuzzing modifications

Questions

Thank You!

Twitter: @dillon_franke

Blog: https://dillonfrankesecurity.com