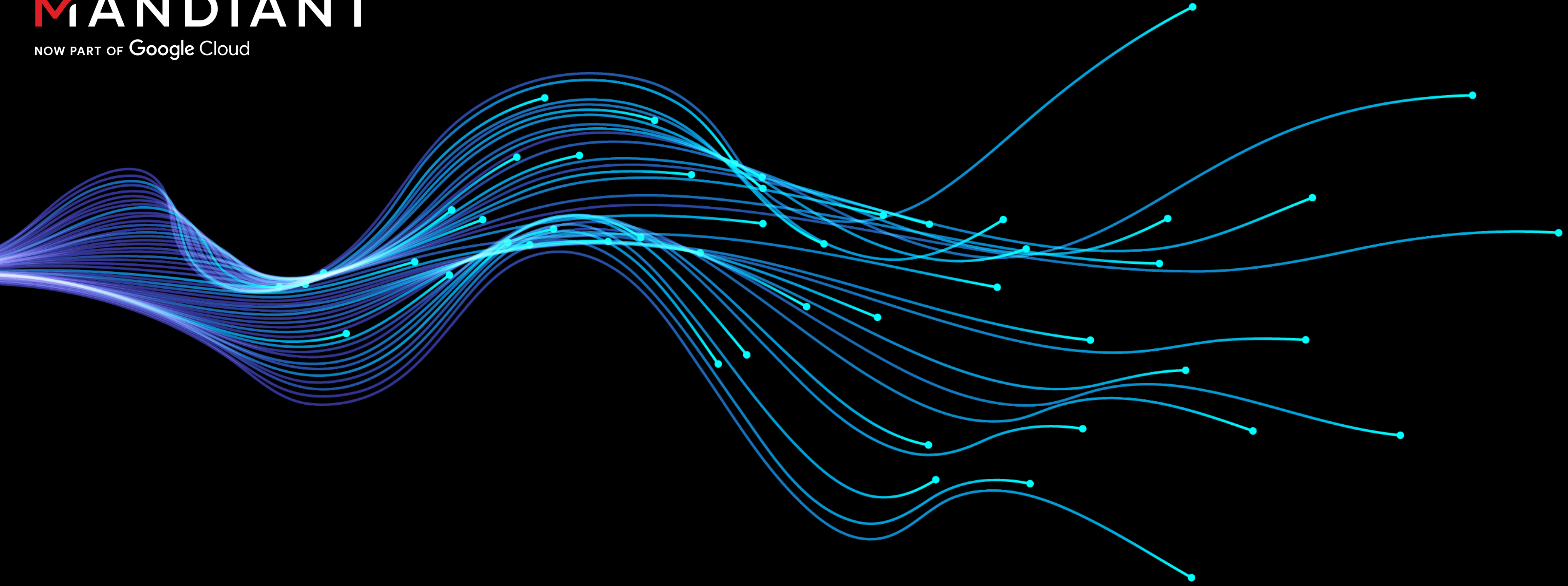
MANDIANT
NOW PART OF Google Cloud



Fuzzing at Mach Speed

Uncovering MacOS and iOS IPC Vulnerabilities with Dillon Franke

Who Am I?

MANDIANT
NOW PART OF Google Cloud

CURRENTLY

Senior Proactive Security Consultant
(Pentesting)

Application Security
Source Code Reviews
Embedded Device Assessments

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 Attack 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**

Bluetooth

Interprocess Communications

Notifications

Peripherals

Wireless Connection

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CRASH COURSE

What is an Attack Vector?

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

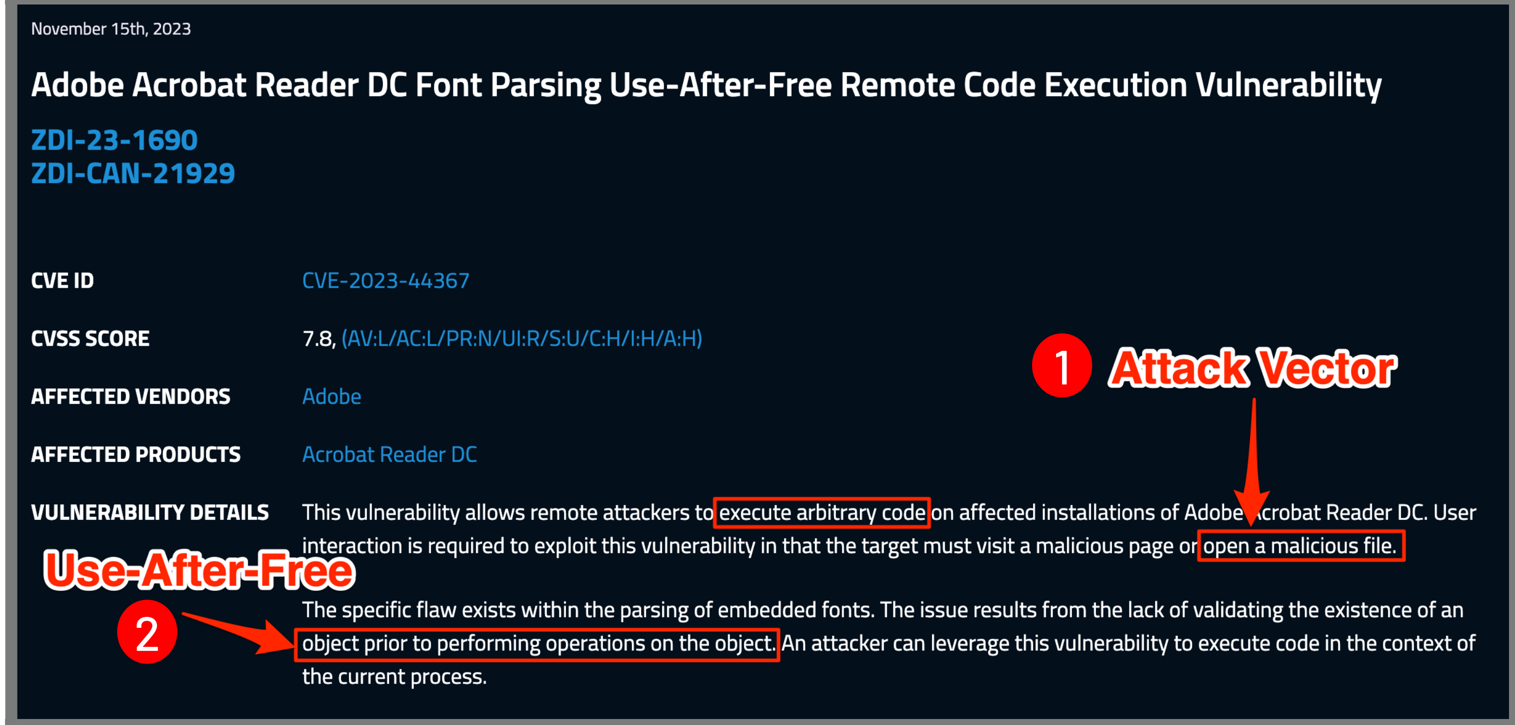
Adobe Acrobat	Open PDF Functionality
Google Search	Query Parameter (https://google.com?query=**<INPUT>**)
Smart Watch	Bluetooth Data Handling

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)



November 15th, 2023

Adobe Acrobat Reader DC Font Parsing Use-After-Free Remote Code Execution Vulnerability

ZDI-23-1690
ZDI-CAN-21929

CVE ID	CVE-2023-44367
CVSS SCORE	7.8, (AV:L/AC:L/PR:N/UI:R/S:U/C:H/I:H/A:H)
AFFECTED VENDORS	Adobe
AFFECTED PRODUCTS	Acrobat Reader DC
VULNERABILITY DETAILS	This vulnerability allows remote attackers to execute arbitrary code on affected installations of Adobe Acrobat Reader DC. User interaction is required to exploit this vulnerability in that the target must visit a malicious page or open a malicious file. The specific flaw exists within the parsing of embedded fonts. The issue results from the lack of validating the existence of an object prior to performing operations on the object. An attacker can leverage this vulnerability to execute code in the context of the current process.

1 Attack Vector

Use-After-Free 2

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

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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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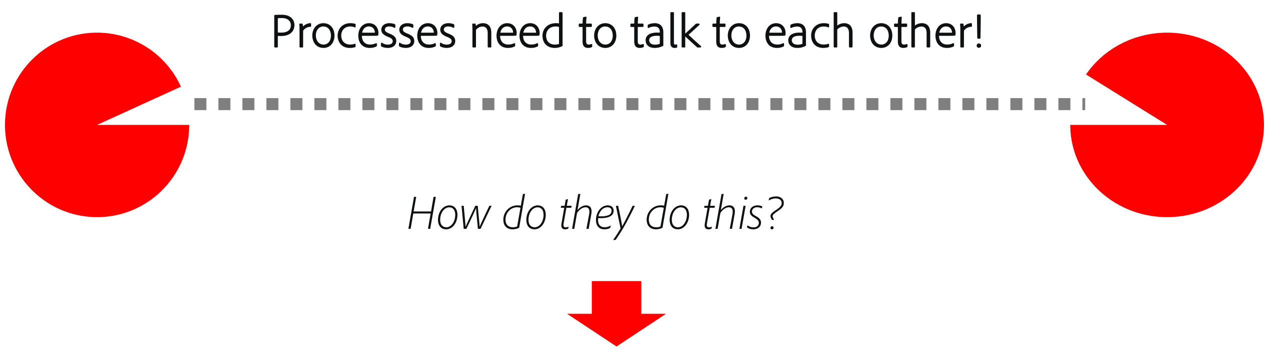
CRASH COURSE

What are Interprocess Communications?



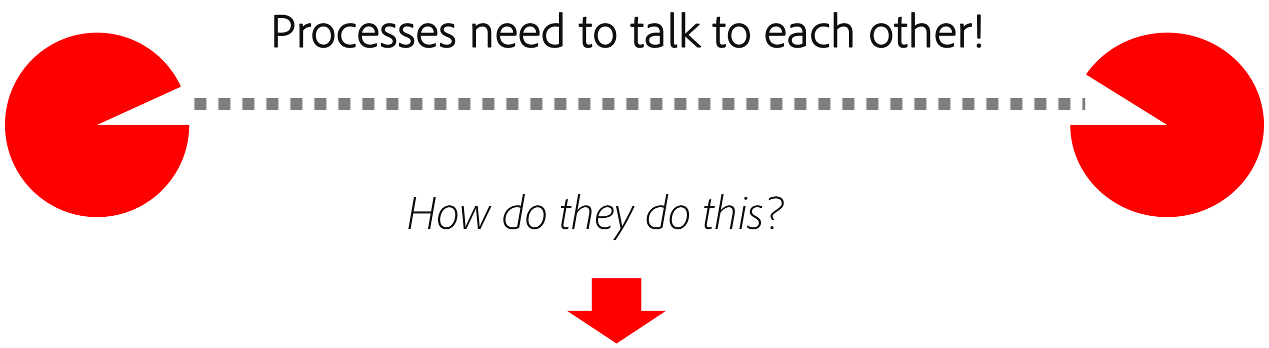
Processes need to talk to each other!

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 are Interprocess Communications?



Processes need to talk to each other!

How do they do this?

- <span>Mach Messages</span> — Lowest level IPC mechanism and the direct basis for many higher level mechanisms
- 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 are Mach Ports?

An IPC message queue, 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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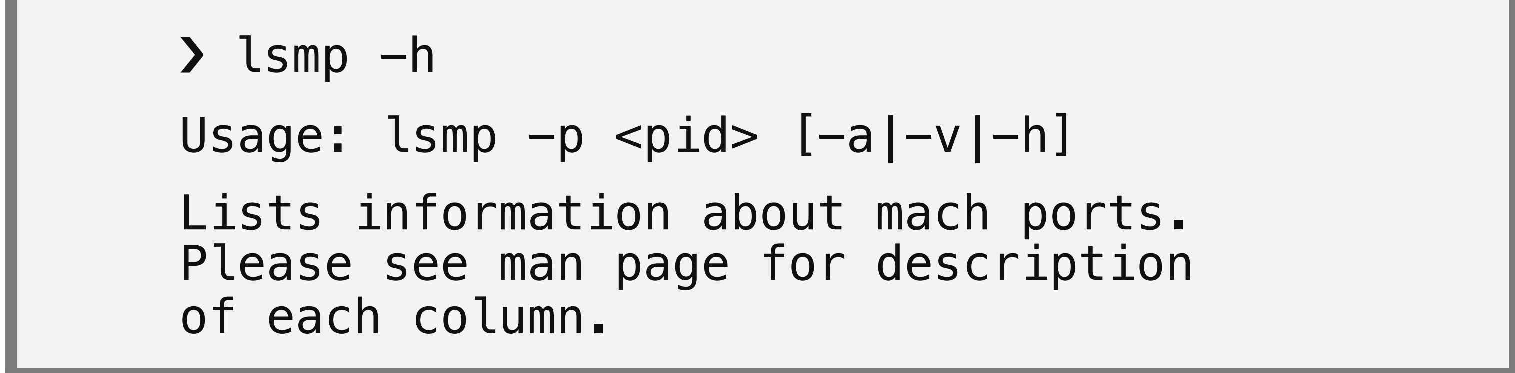
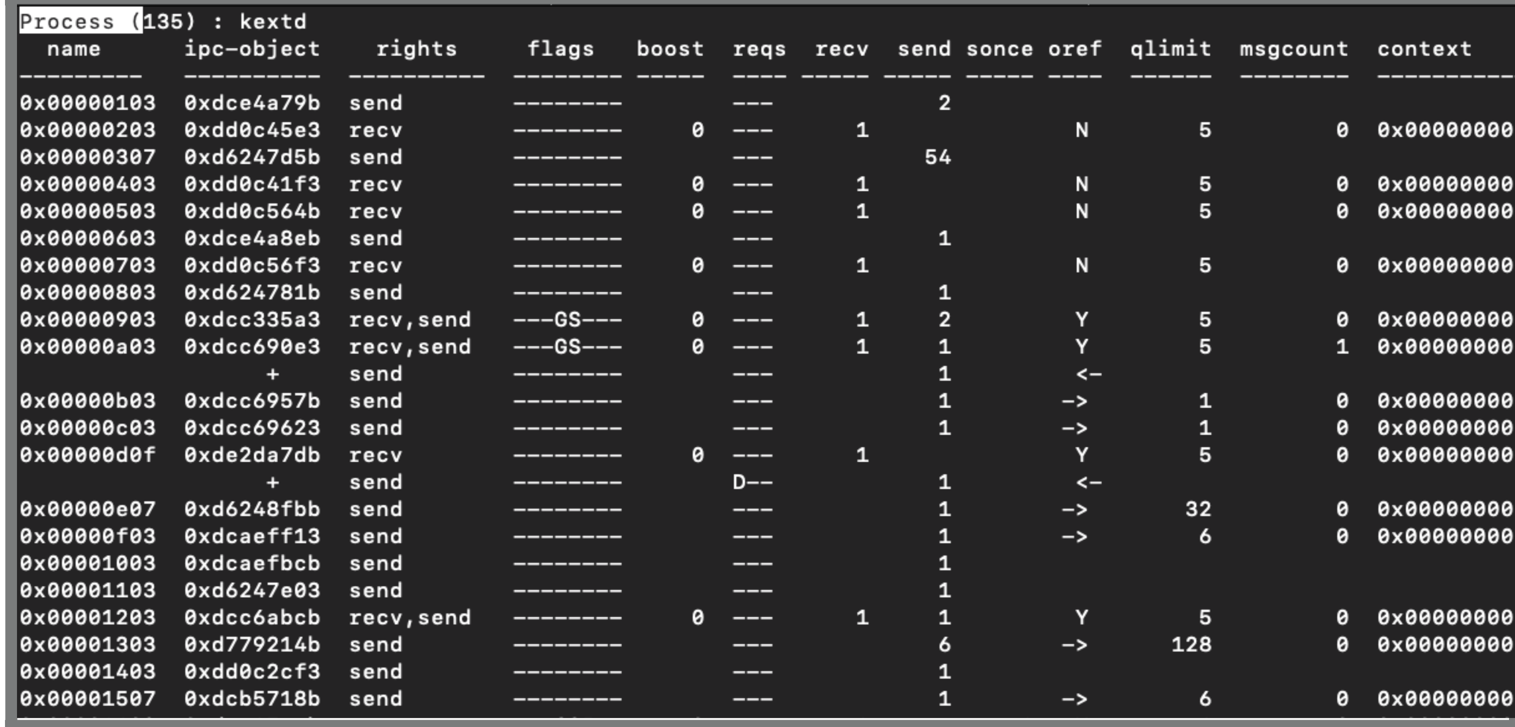
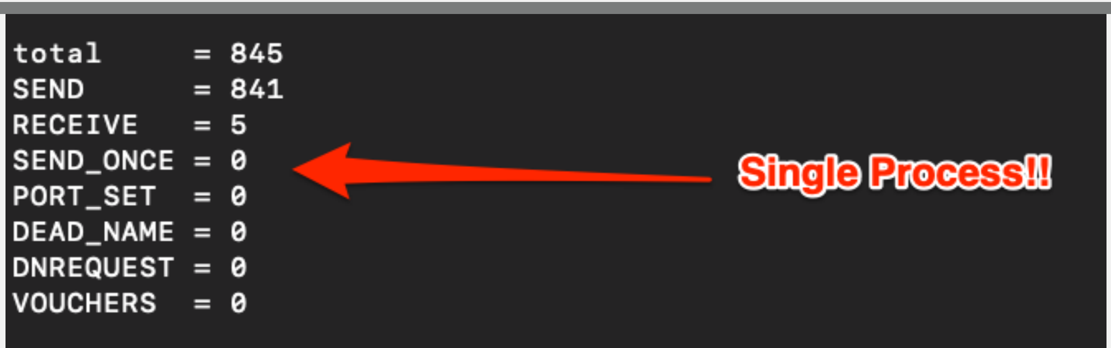


```
❯ lsmp -h
Usage: lsmp -p <pid> [-a|-v|-h]
Lists information about mach ports.
Please see man page for description
of each column.
```



```
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
```

Single Process!!

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.cansecwest**)

Communicating with a Service

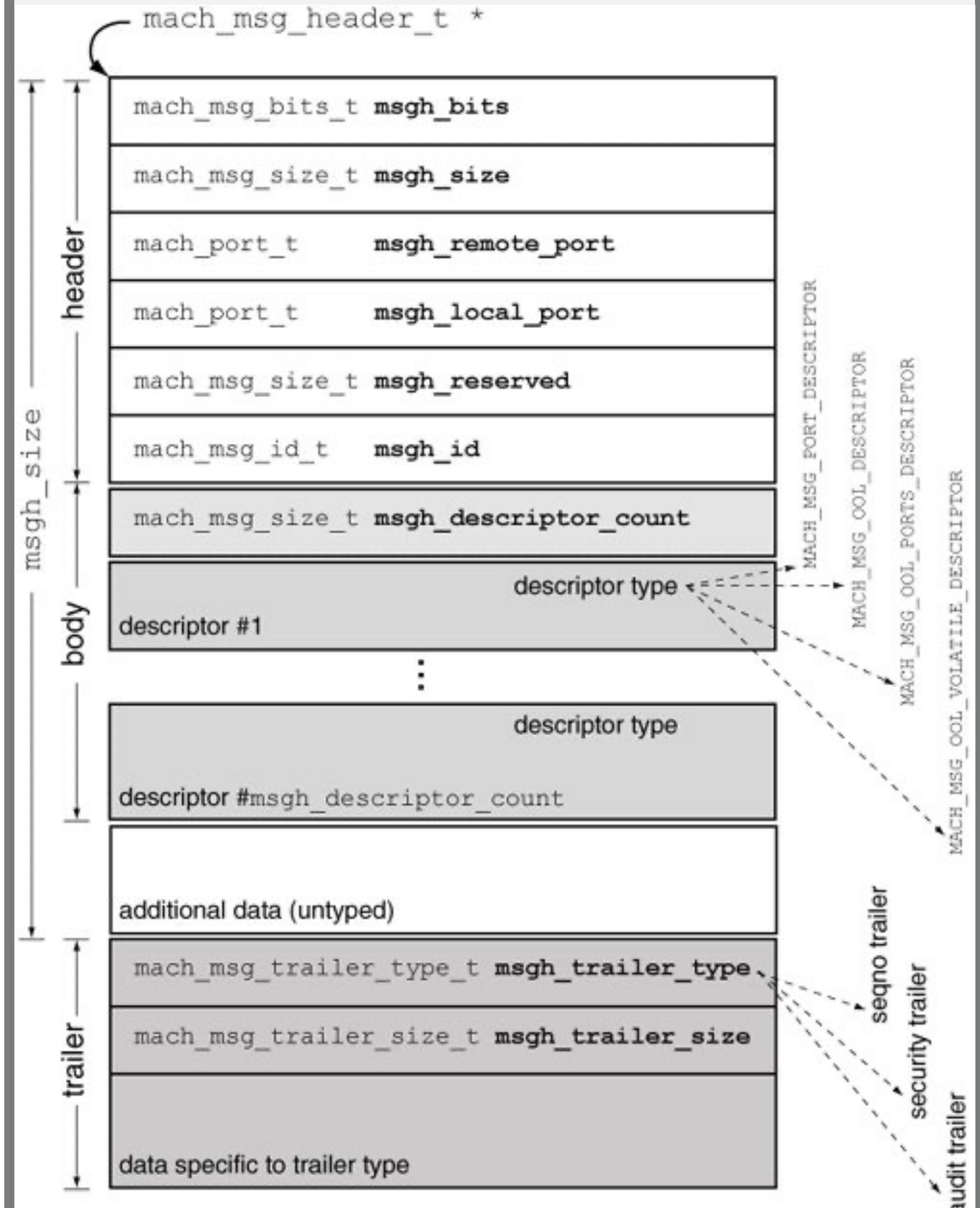
1. Alice allocates a new mach port with a receive right
2. Alice registers her service using a specific name **com.apple.cansecwest**

   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.cansecwest** 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



mach_msg_header_t *

mach_msg_bits_t **msgh_bits**

mach_msg_size_t **msgh_size**

mach_port_t **msgh_remote_port**

mach_port_t **msgh_local_port**

mach_msg_size_t **msgh_reserved**

mach_msg_id_t **msgh_id**

mach_msg_size_t **msgh_descriptor_count**

descriptor type
descriptor #1

⋮

descriptor type
descriptor #msgh_descriptor_count

additional data (untyped)

mach_msg_trailer_type_t **msgh_trailer_type**

mach_msg_trailer_size_t **msgh_trailer_size**

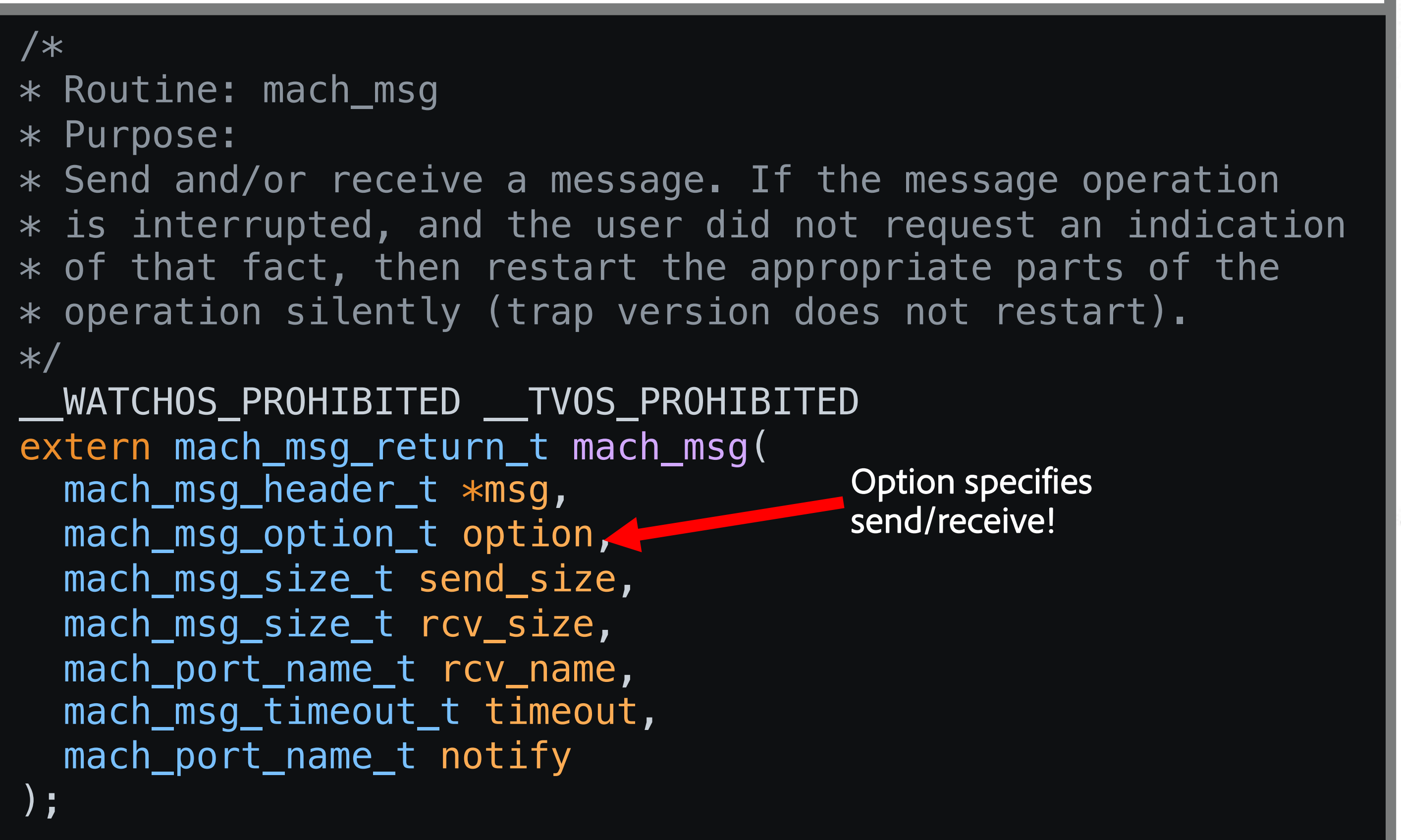
data specific to trailer type

CRASH COURSE

What are Mach Messages?

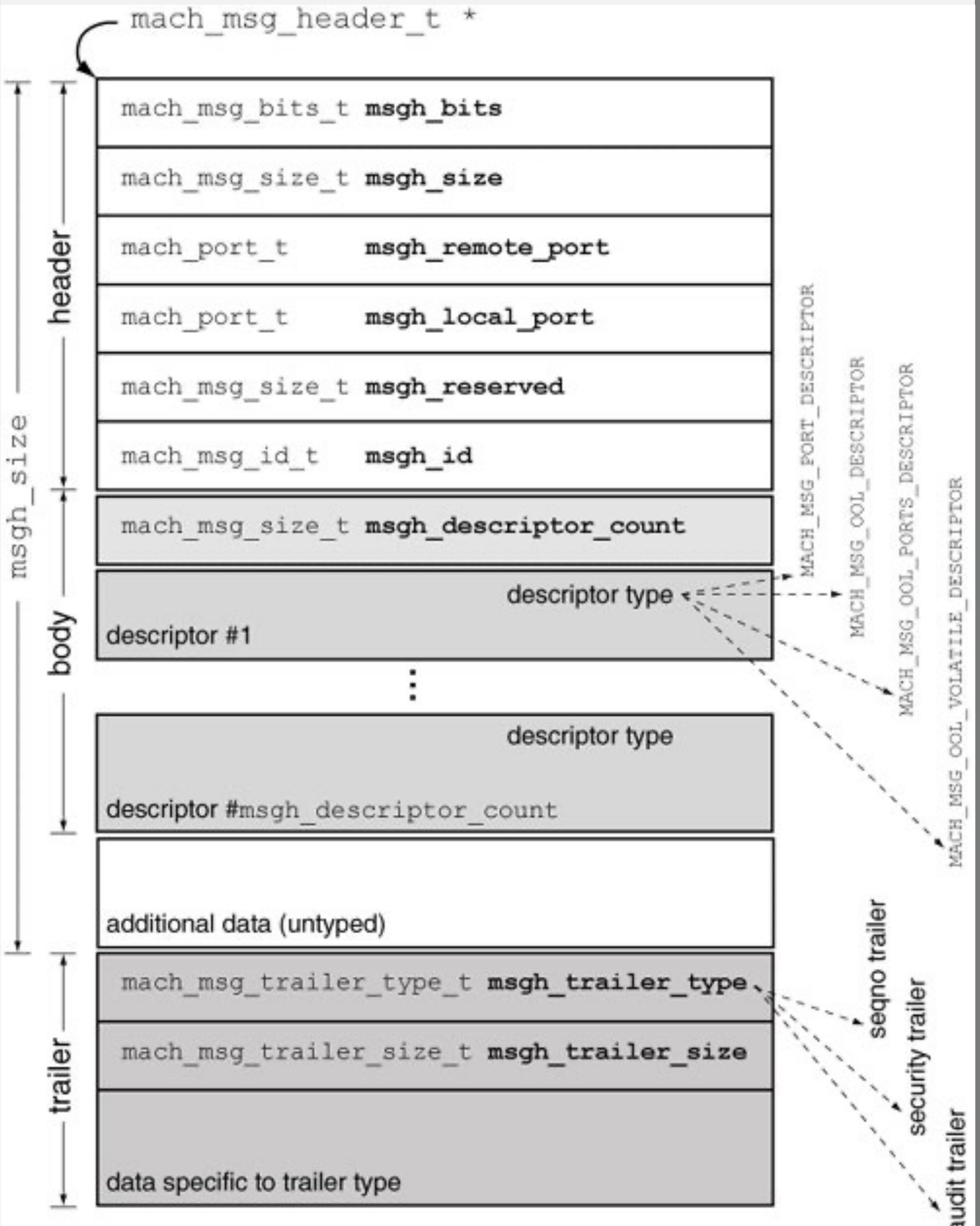
A struct used to exchange data between mach ports

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!


mach_msg_header_t *
mach_msg_bits_t msgh_bits
mach_msg_size_t msgh_size
mach_port_t msgh_remote_port
mach_port_t msgh_local_port
mach_msg_size_t msgh_reserved
mach_msg_id_t msgh_id
mach_msg_size_t msgh_descriptor_count
descriptor type
descriptor #1
descriptor type
descriptor #msgh_descriptor_count
additional data (untyped)
mach_msg_trailer_type_t msgh_trailer_type
mach_msg_trailer_size_t msgh_trailer_size
data specific to trailer type
msgh_size
header
body
trailer
MACH_MSG_PORT_DESCRIPTOR
MACH_MSG_OOL_DESCRIPTOR
MACH_MSG_OOL_PORTS_DESCRIPTOR
MACH_MSG_OOL_VOLATILE_DESCRIPTOR
seqno trailer
security trailer
audit trailer

The (Memory Corruption) Attack Cycle

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

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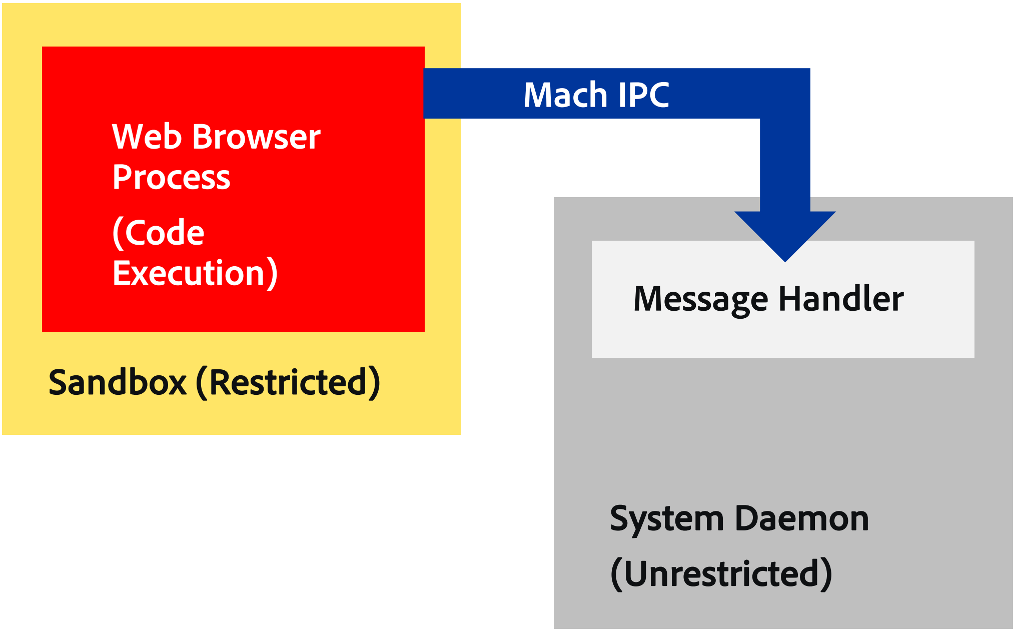
THE ATTACK CYCLE

Abusing Mach Messages

Sandbox Escape



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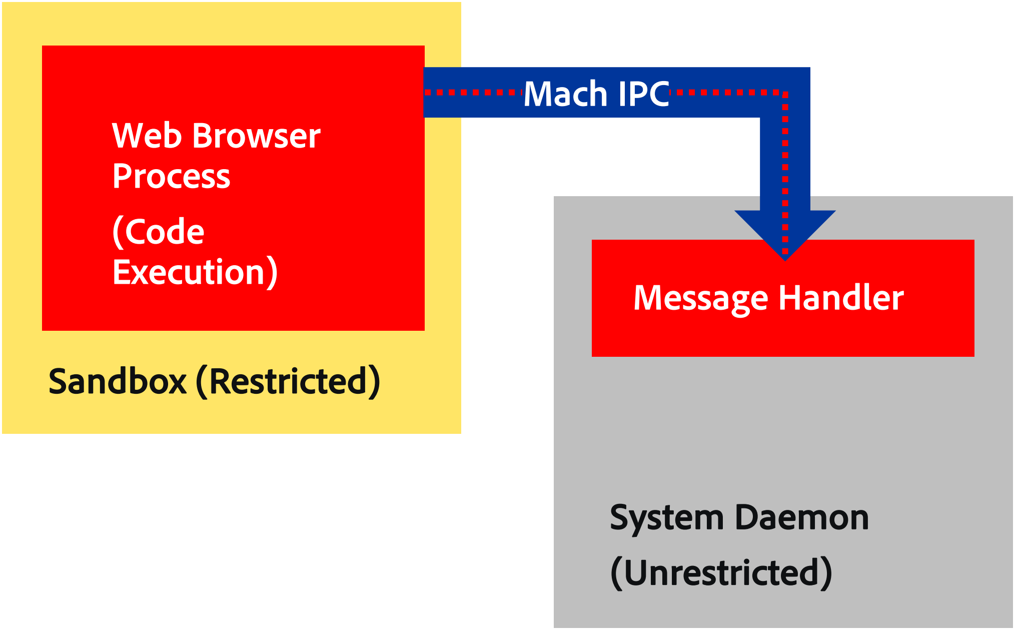

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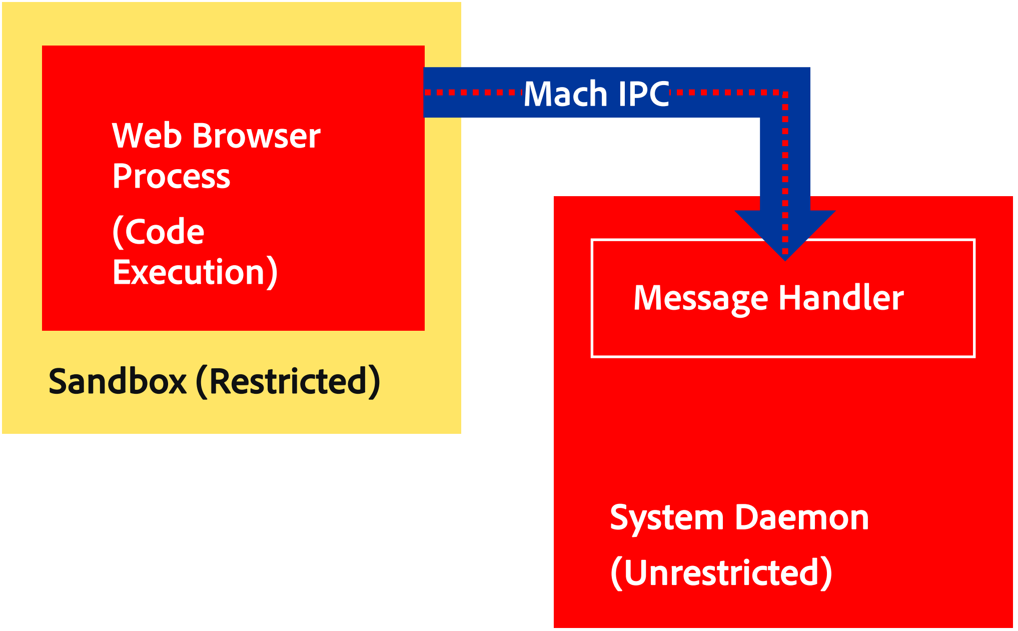

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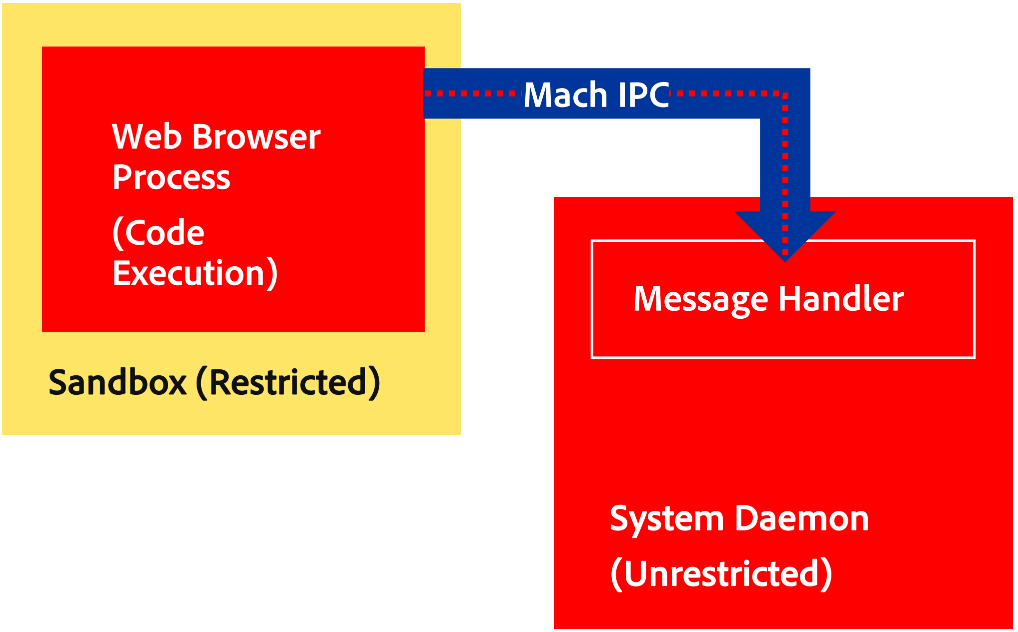
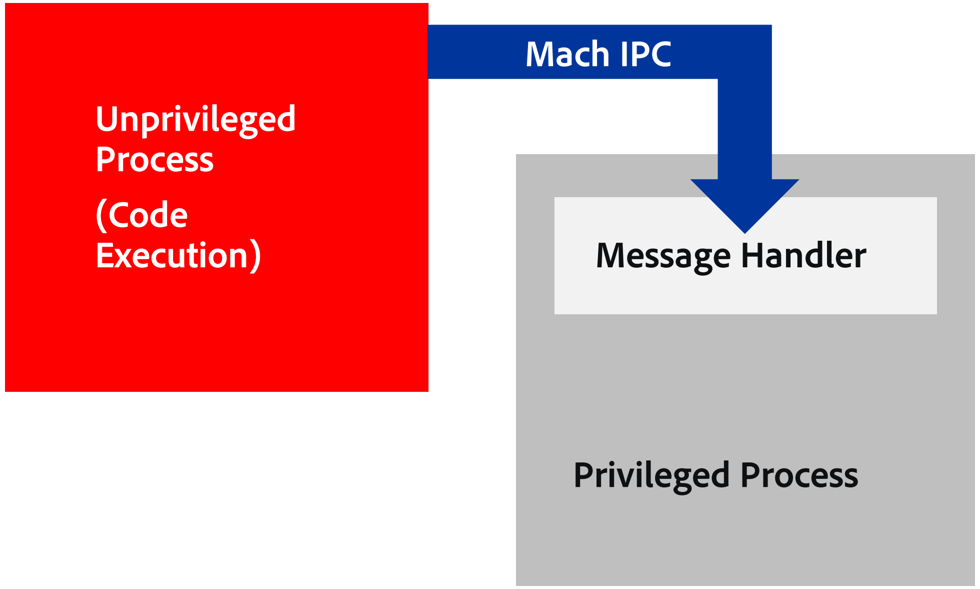


Privilege Escalation



THE ATTACK CYCLE

Abusing Mach Messages

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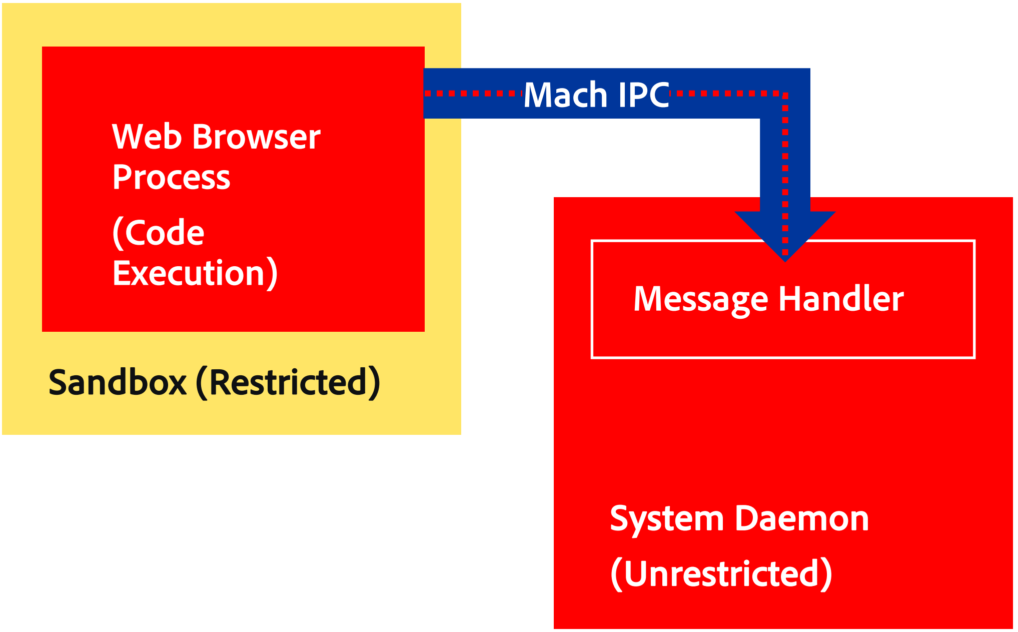

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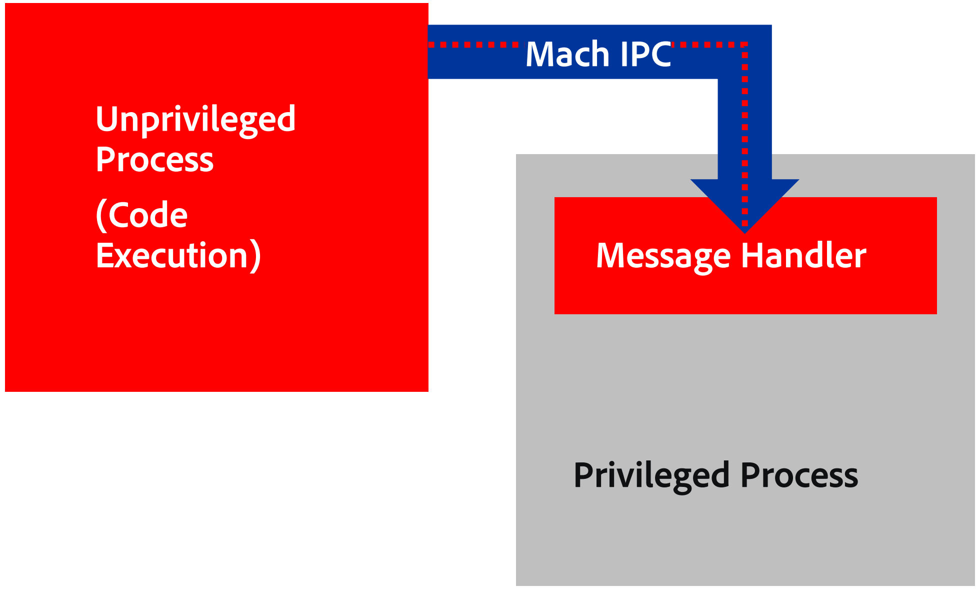

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THE ATTACK CYCLE

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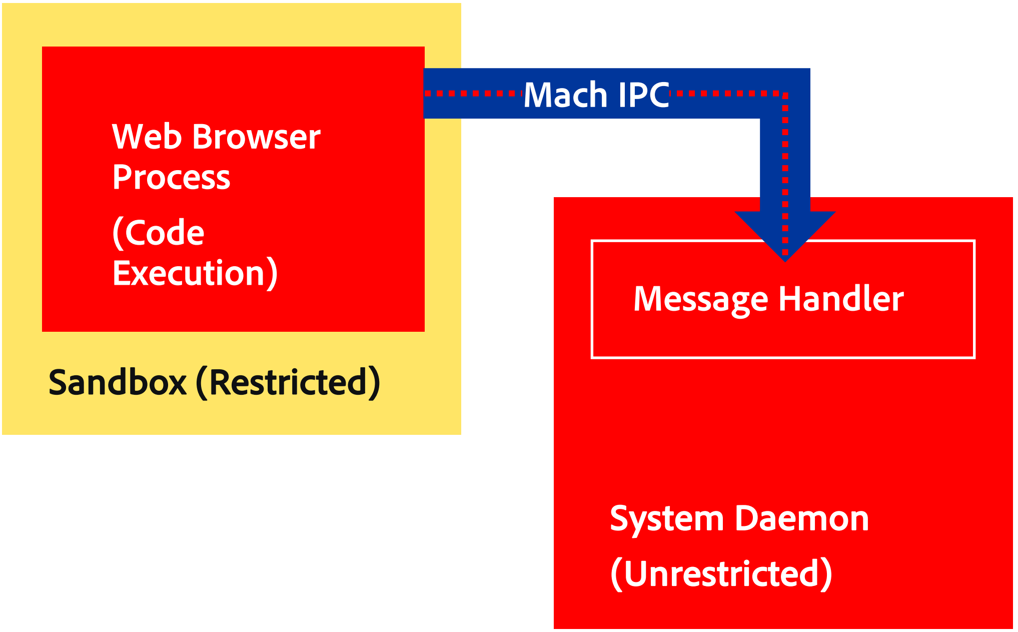

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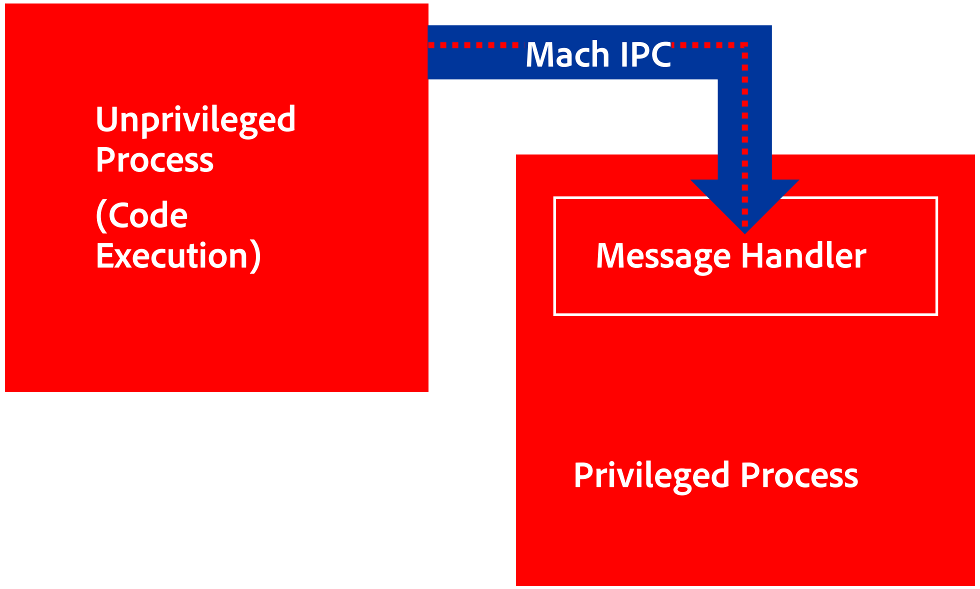

Identify an attack vector

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THE ATTACK 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

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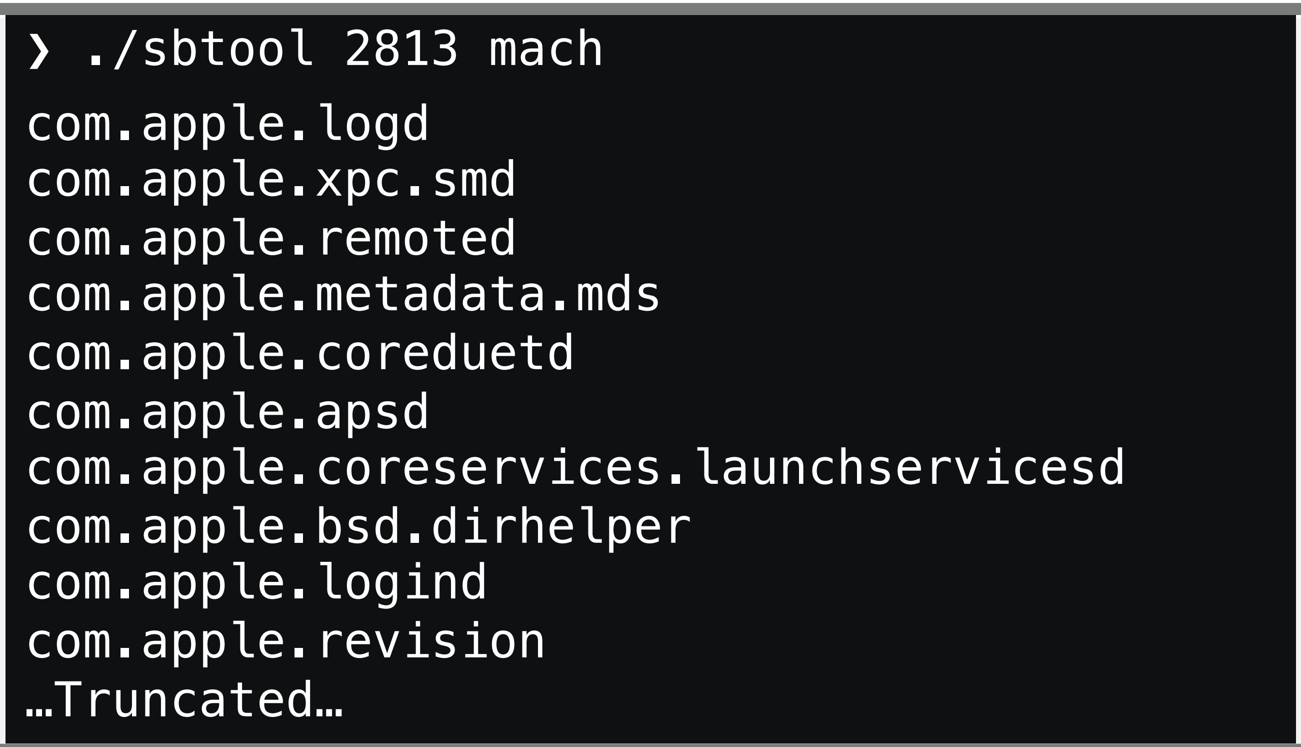
THE ATTACK CYCLE

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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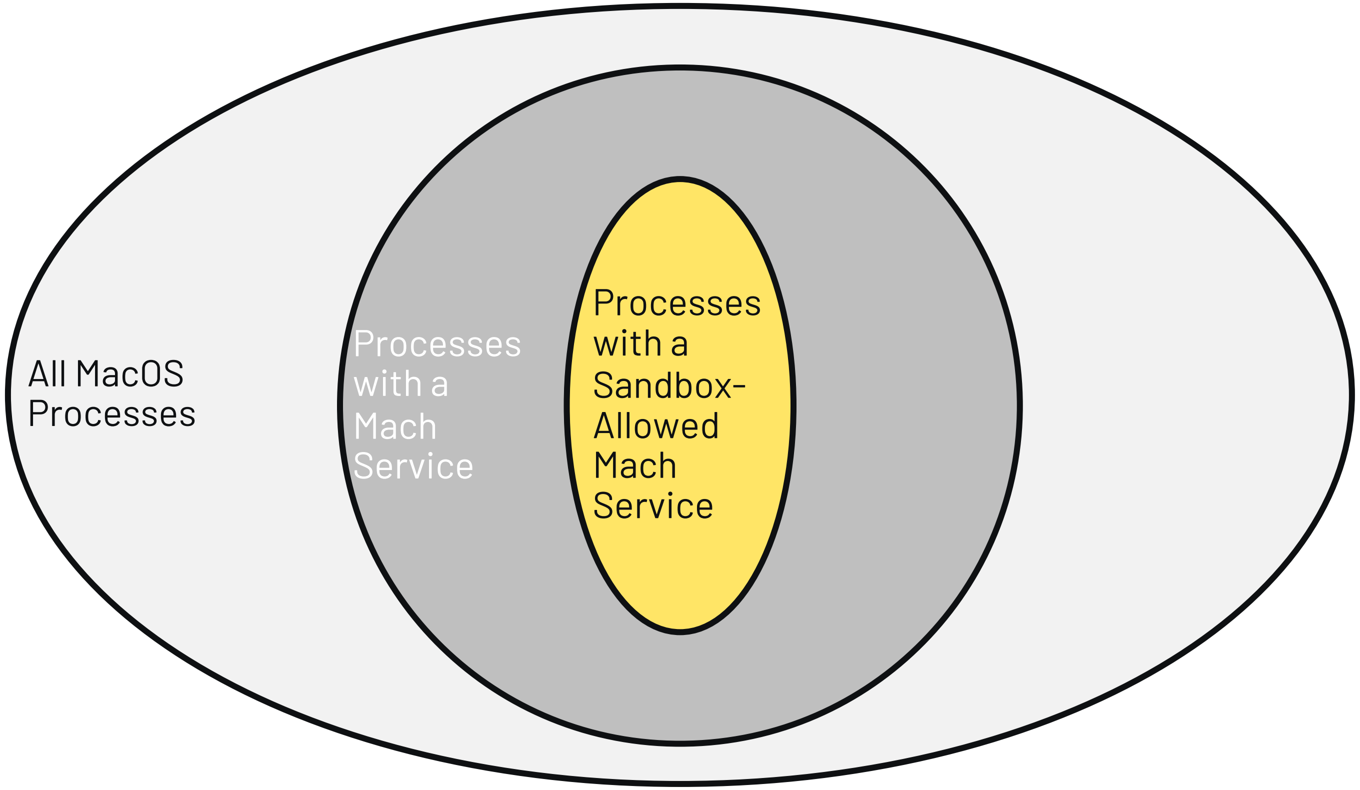
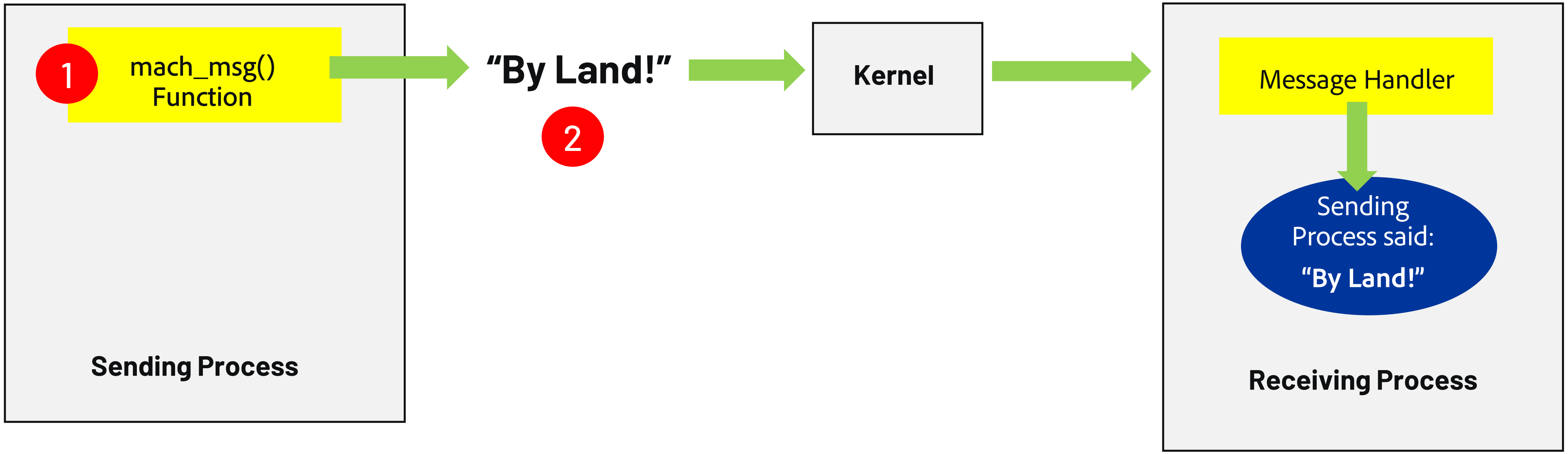

All MacOS Processes
Processes with a Mach Service
Processes with a Sandbox-Allowed Mach Service

THE ATTACK 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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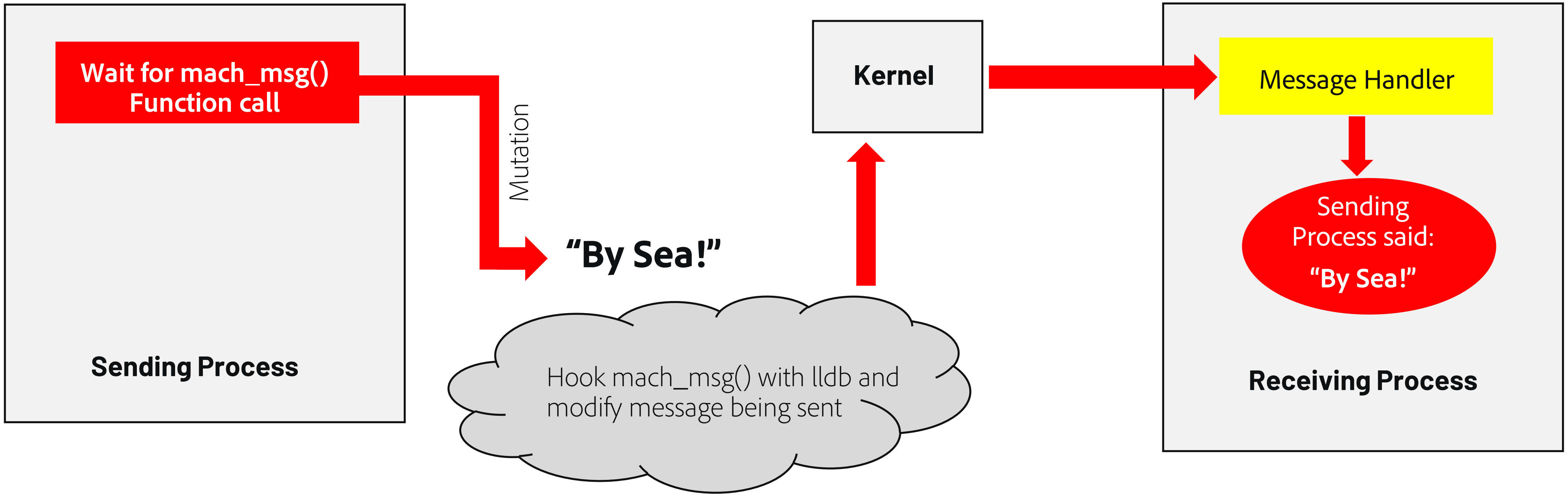

Wait for mach_msg() Function call
Sending Process
Mutation
"By Sea!"
Hook mach_msg() with lldb and modify message being sent
Kernel
Message Handler
Sending Process said: "By Sea!"
Receiving Process

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

THE ATTACK CYCLE

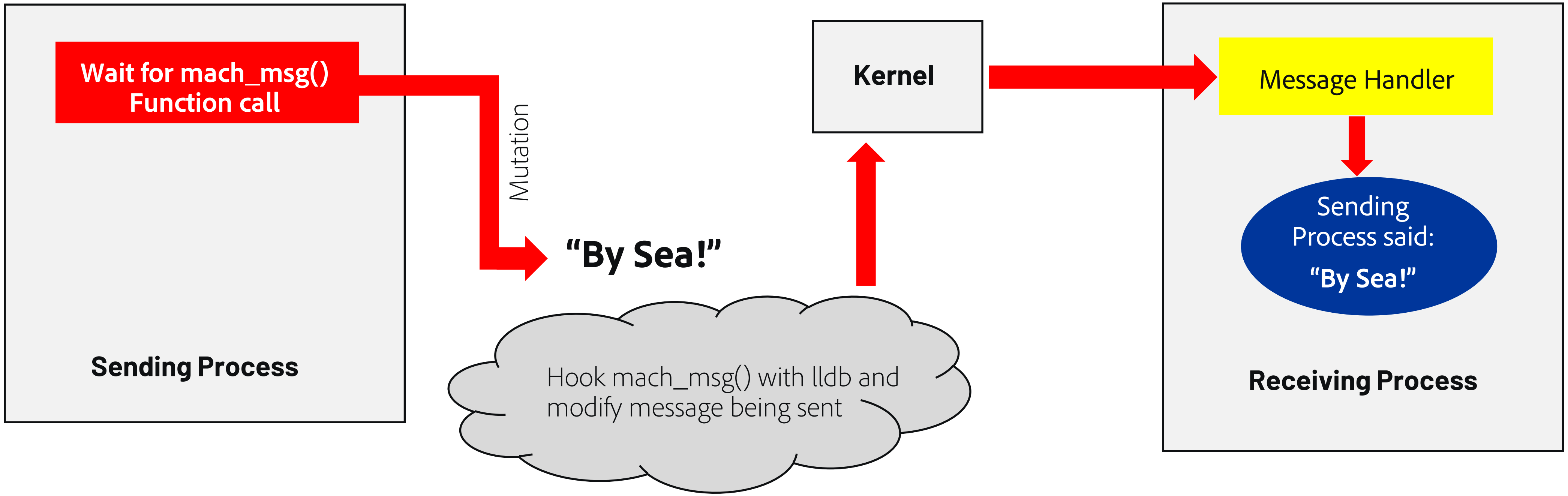
Finding an Entry Point

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



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Identify an attack vector

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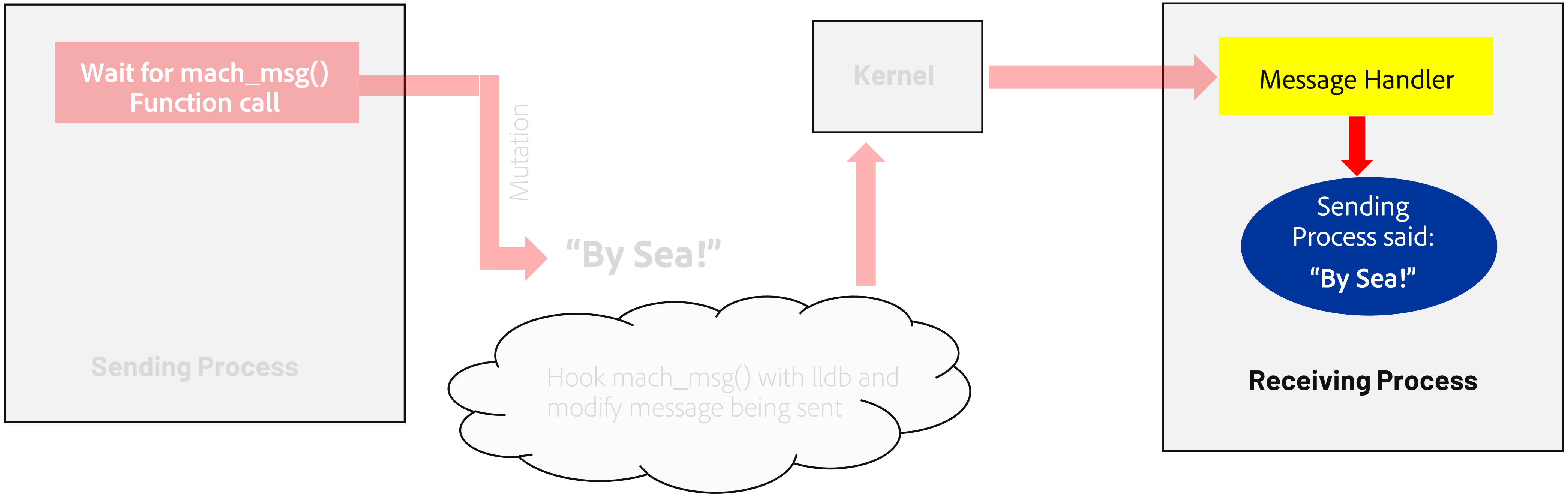
Fuzz and Produce Crashes

Identify Relevant Crashes

THE ATTACK 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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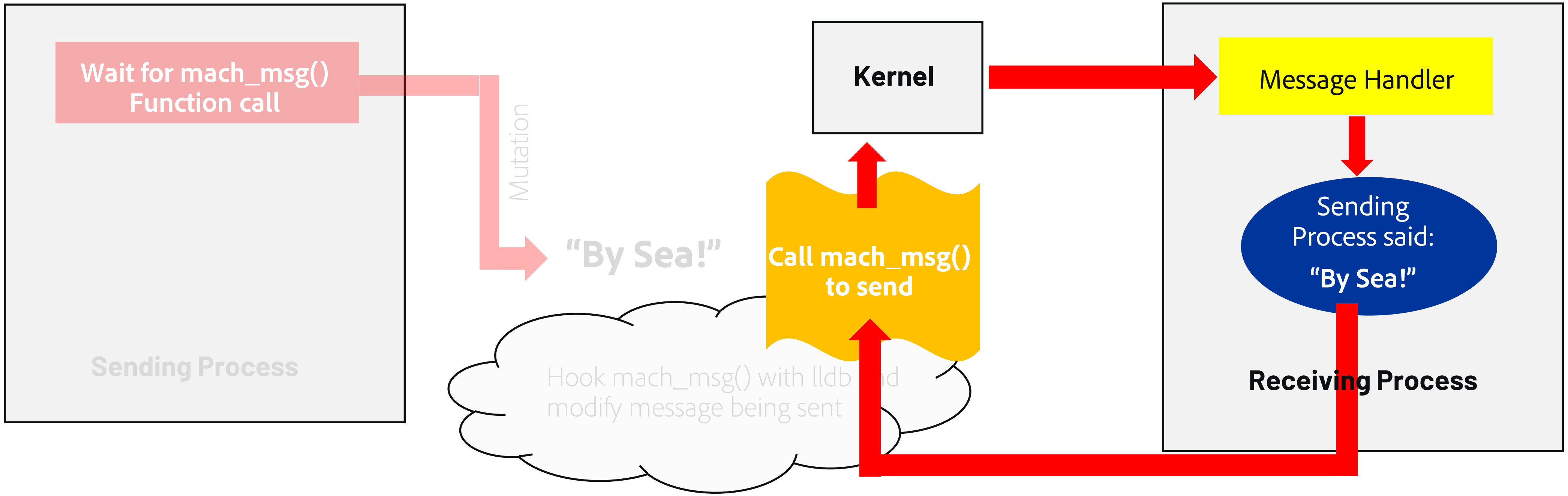


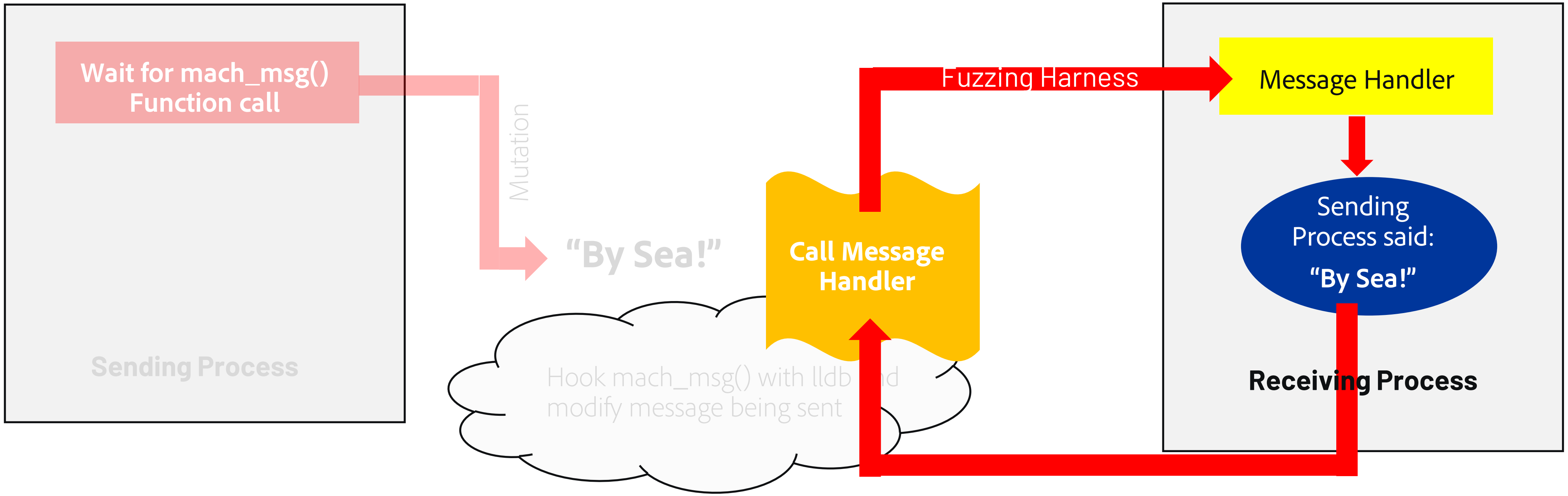
THE ATTACK CYCLE

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?

Getting "close" to the system of interest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Hook mach_msg() with lldb and modify message being sent
Call Message Handler
Fuzzing Harness
Message Handler
Sending Process said: "By Sea!"
Receiving Process

THE ATTACK CYCLE

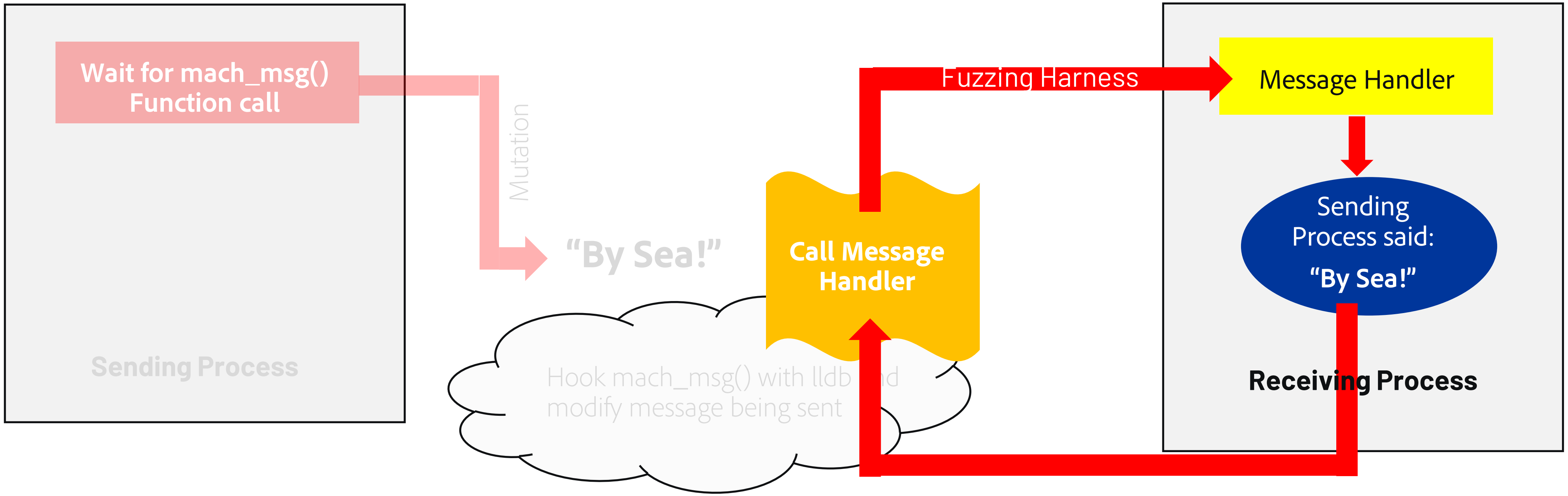
Finding an Entry Point

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 have to invoke initialization routines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Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

Identify Relevant Crashes

THE ATTACK CYCLE

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

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”)

Identify an attack vector

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THE ATTACK CYCLE

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

THE ATTACK CYCLE

Finding the Mach Message Handler

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

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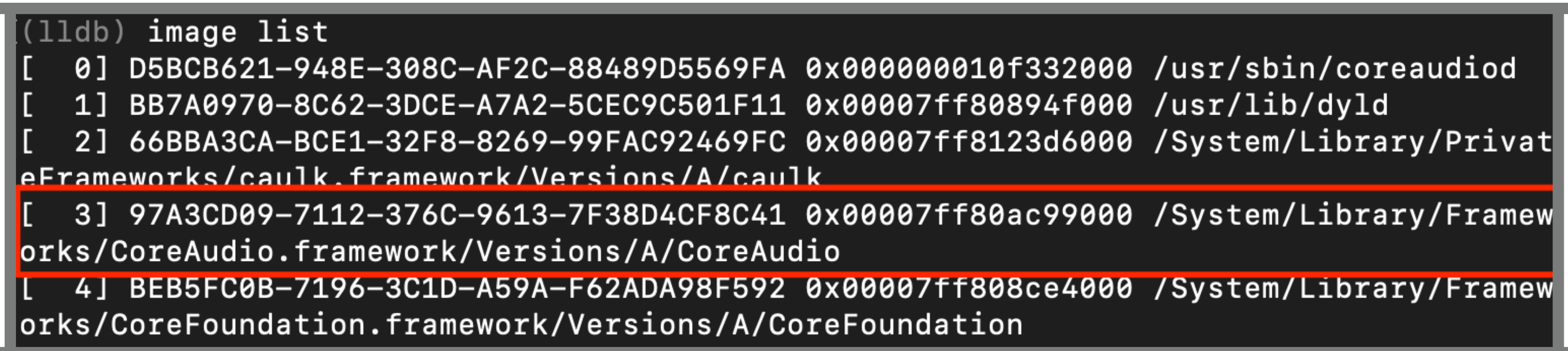
THE ATTACK CYCLE

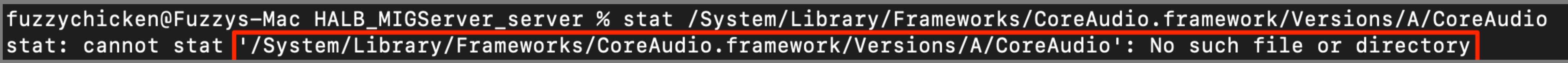
Finding the Mach Message Handler

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

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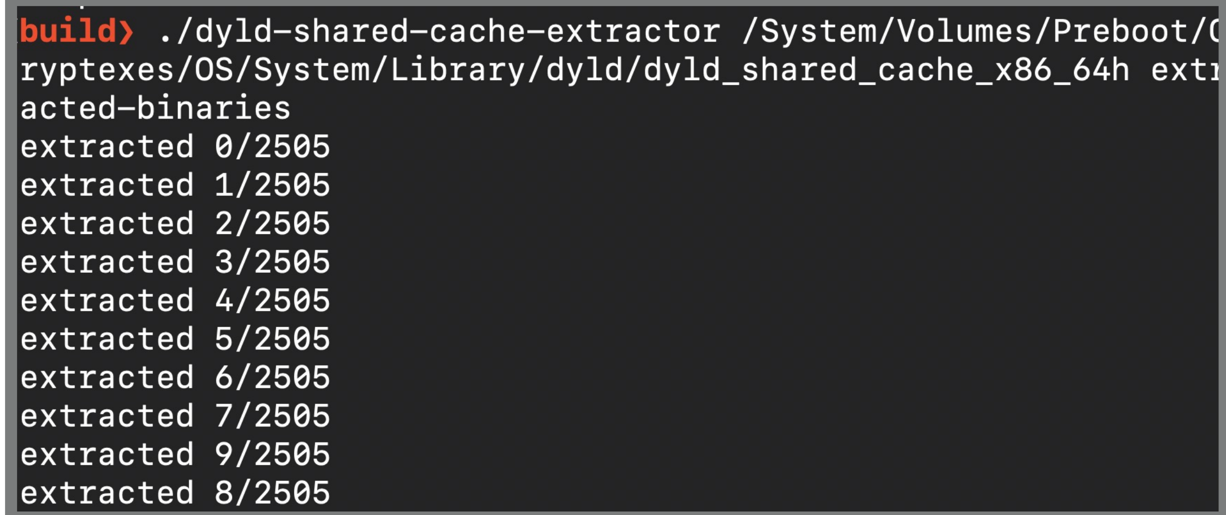
THE ATTACK CYCLE

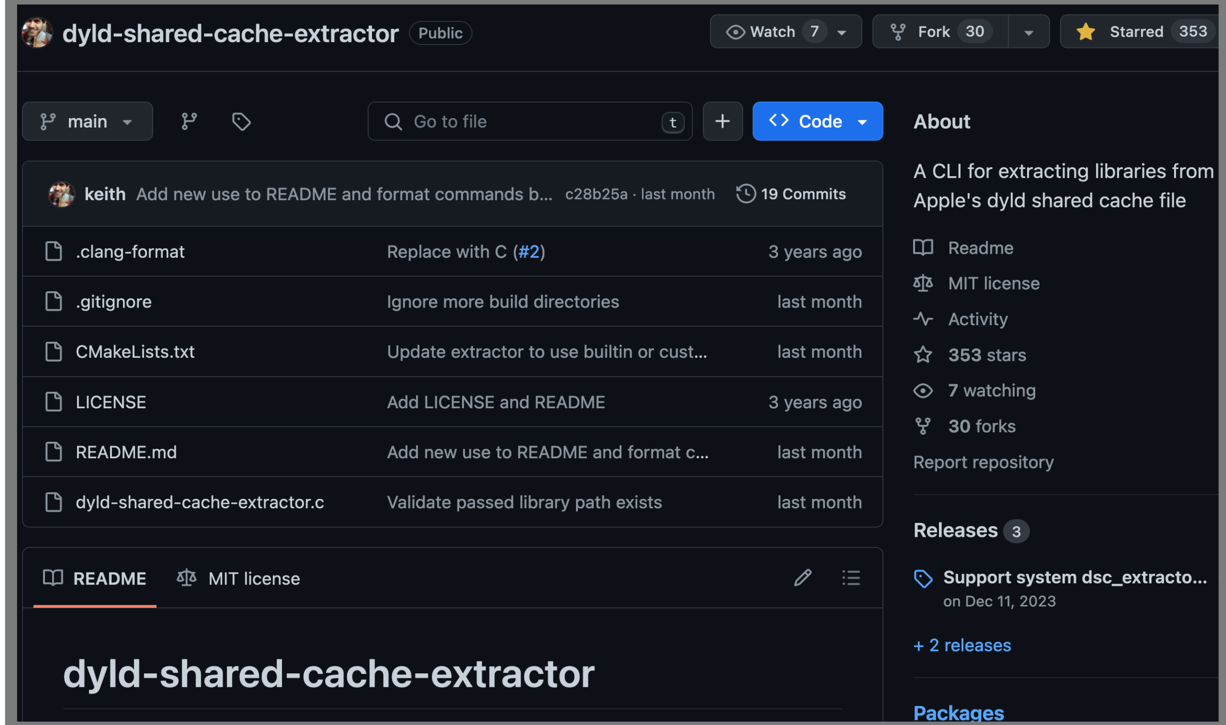
Finding the Mach Message Handler

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
```



keith Add new use to README and format commands b... c28b25a · last month 19 Commits

.clang-format	Replace with C (#2)	3 years ago
.gitignore	Ignore more build directories	last month
CMakeLists.txt	Update extractor to use builtin or cust...	last month
LICENSE	Add LICENSE and README	3 years ago
README.md	Add new use to README and format c...	last month
dyld-shared-cache-extractor.c	Validate passed library path exists	last month

About

A CLI for extracting libraries from Apple's dyld shared cache file

Readme
MIT license
Activity
353 stars
7 watching
30 forks
Report repository

Releases 3

Support system dsc_extracto...
on Dec 11, 2023

+ 2 releases

Packages

dyld-shared-cache-extractor

Identify an attack vector

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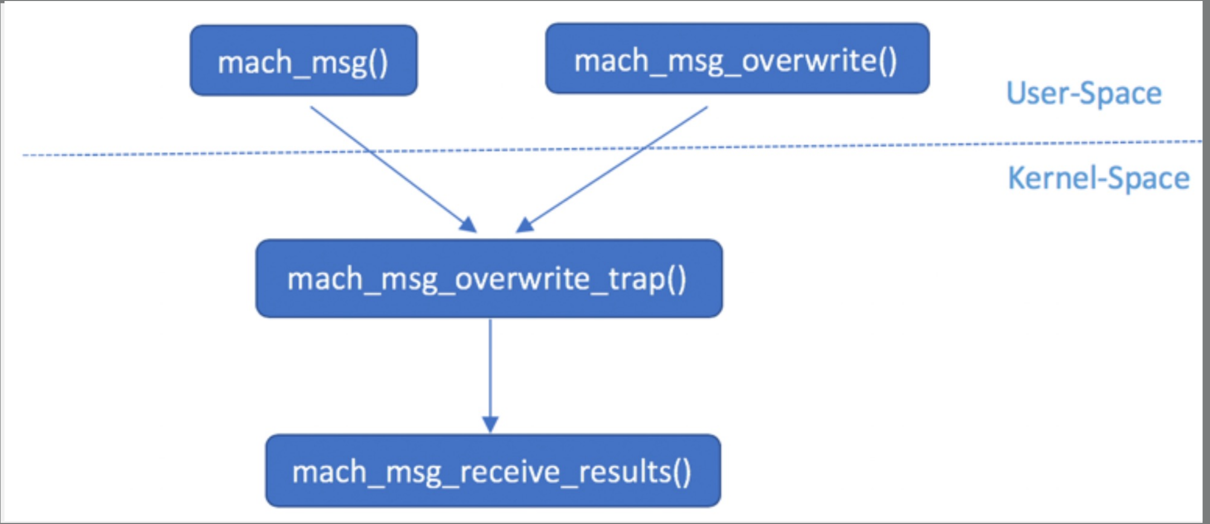
THE ATTACK CYCLE

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?



Identify an attack vector

Generate a Corpus of Inputs

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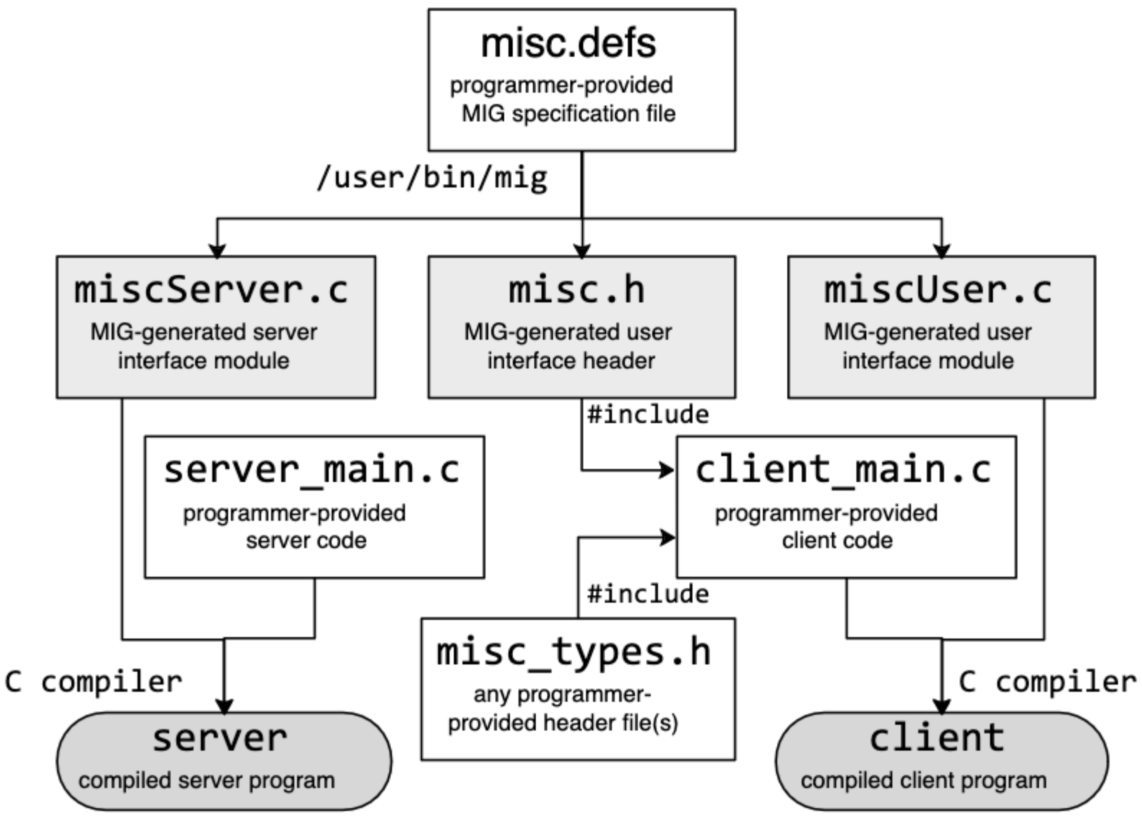
Identify Relevant Crashes

THE ATTACK CYCLE

Finding the Mach Message Handler

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?


misc.defs
programmer-provided MIG specification file
/user/bin/mig
miscServer.c
MIG-generated server interface module
misc.h
MIG-generated user interface header
miscUser.c
MIG-generated user interface module
#include
server_main.c
programmer-provided server code
client_main.c
programmer-provided client code
#include
misc_types.h
any programmer-provided header file(s)
C compiler
server
compiled server program
C compiler
client
compiled client program

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

Identify an attack vector

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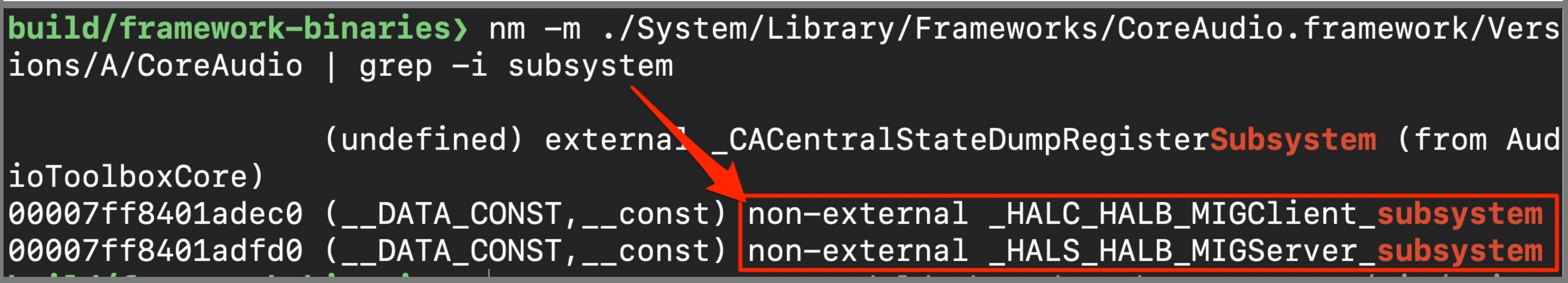
THE ATTACK CYCLE

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
```

Identify an attack vector

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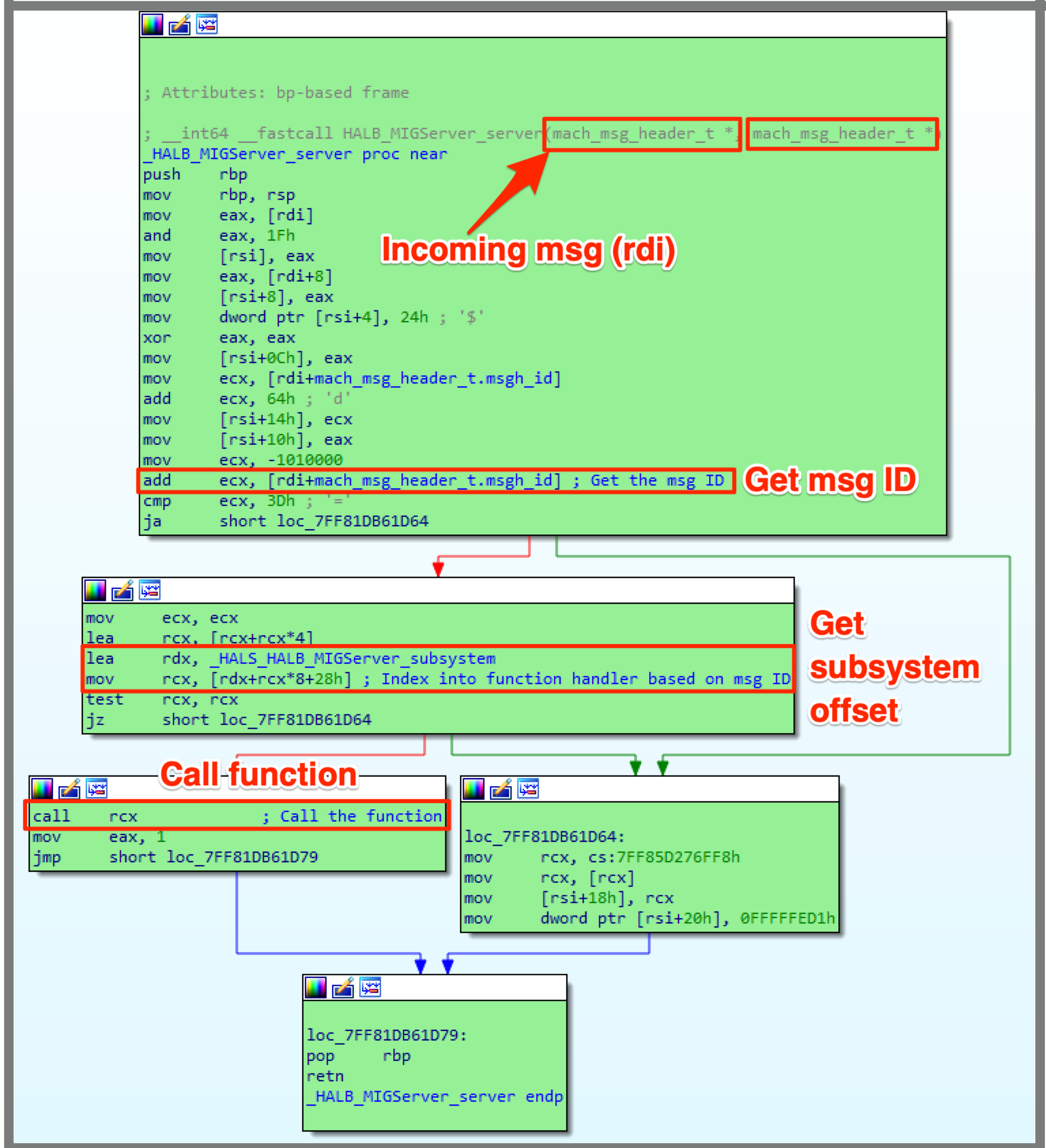
THE ATTACK CYCLE

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
```

```
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
```

```
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
```

Incoming msg (rdi)

Get msg ID

Get subsystem offset

Call function

Identify an attack vector

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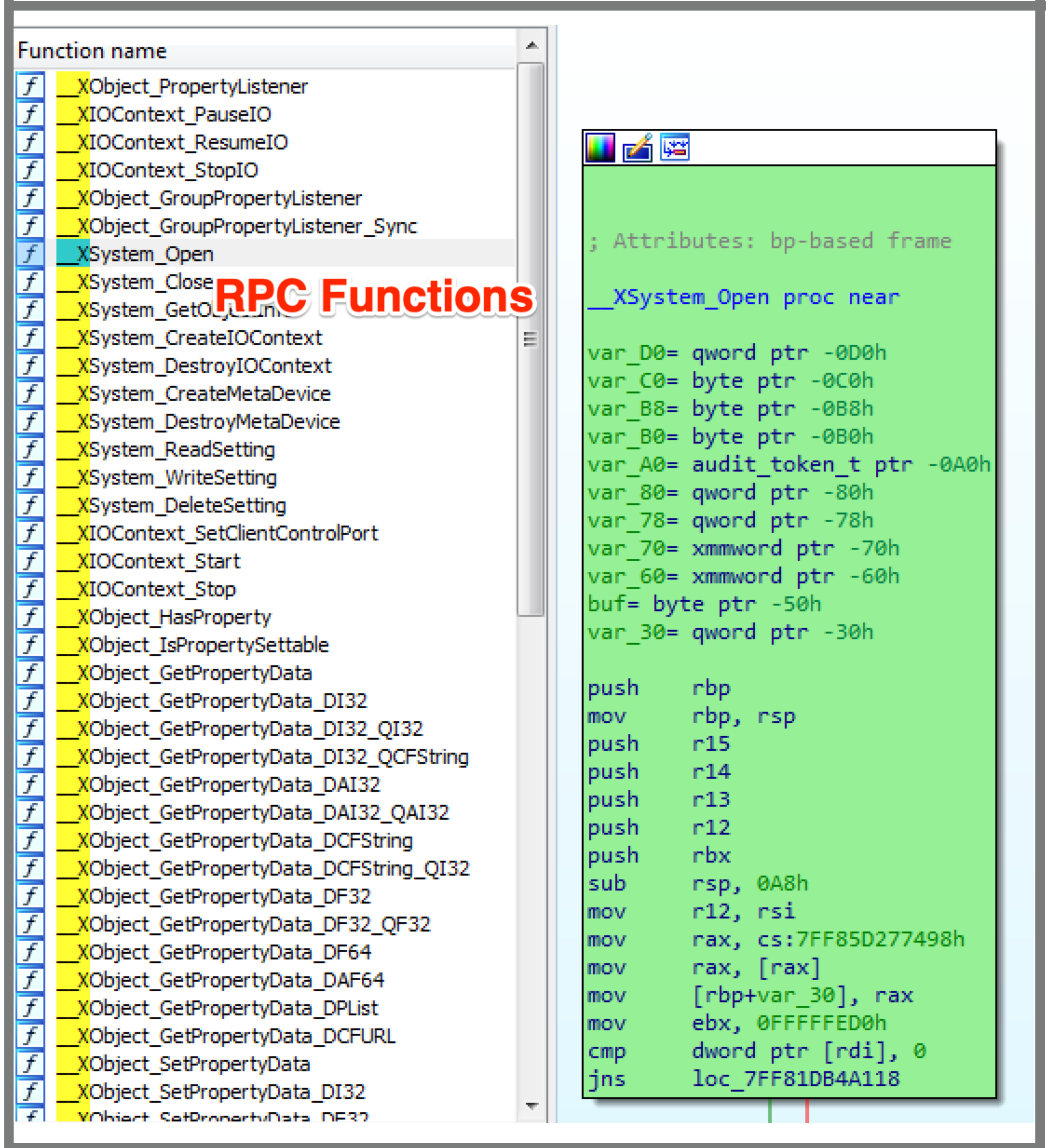
THE ATTACK CYCLE

Finding the Mach Message Handler

3 Find function implementing mach receive functionality

_HALS_HALB_MIGServer_subsystem

- Function lookup table



RPC Functions

```
Function name
__XObject_PropertyListener
__XIOContext_PauseIO
__XIOContext_ResumeIO
__XIOContext_StopIO
__XObject_GroupPropertyListener
__XObject_GroupPropertyListener_Sync
__XSystem_Open
__XSystem_Close
__XSystem_GetObjectInfo
__XSystem_CreateIOContext
__XSystem_DestroyIOContext
__XSystem_CreateMetaDevice
__XSystem_DestroyMetaDevice
__XSystem_ReadSetting
__XSystem_WriteSetting
__XSystem_DeleteSetting
__XIOContext_SetClientControlPort
__XIOContext_Start
__XIOContext_Stop
__XObject_HasProperty
__XObject_IsPropertySettable
__XObject_GetPropertyData
__XObject_GetPropertyData_DI32
__XObject_GetPropertyData_DI32_QI32
__XObject_GetPropertyData_DI32_QCFString
__XObject_GetPropertyData_DAI32
__XObject_GetPropertyData_DAI32_QAI32
__XObject_GetPropertyData_DCFString
__XObject_GetPropertyData_DCFString_QI32
__XObject_GetPropertyData_DF32
__XObject_GetPropertyData_DF32_QF32
__XObject_GetPropertyData_DF64
__XObject_GetPropertyData_DAF64
__XObject_GetPropertyData_DPList
__XObject_GetPropertyData_DCFURL
__XObject_SetPropertyData
__XObject_SetPropertyData_DI32
__XObject_SetPropertyData_DF32
```

```
; Attributes: bp-based frame

__XSystem_Open proc near

var_D0= qword ptr -0D0h
var_C0= byte ptr -0C0h
var_B8= byte ptr -0B8h
var_B0= byte ptr -0B0h
var_A0= audit_token_t ptr -0A0h
var_80= qword ptr -80h
var_78= qword ptr -78h
var_70= xmmword ptr -70h
var_60= xmmword ptr -60h
buf= byte ptr -50h
var_30= qword ptr -30h

push    rbp
mov     rbp, rsp
push    r15
push    r14
push    r13
push    r12
push    rbx
sub     rsp, 0A8h
mov     r12, rsi
mov     rax, cs:7FF85D277498h
mov     rax, [rax]
mov     [rbp+var_30], rax
mov     ebx, 0FFFFFED0h
cmp     dword ptr [rdi], 0
jns     loc_7FF81DB4A118
```

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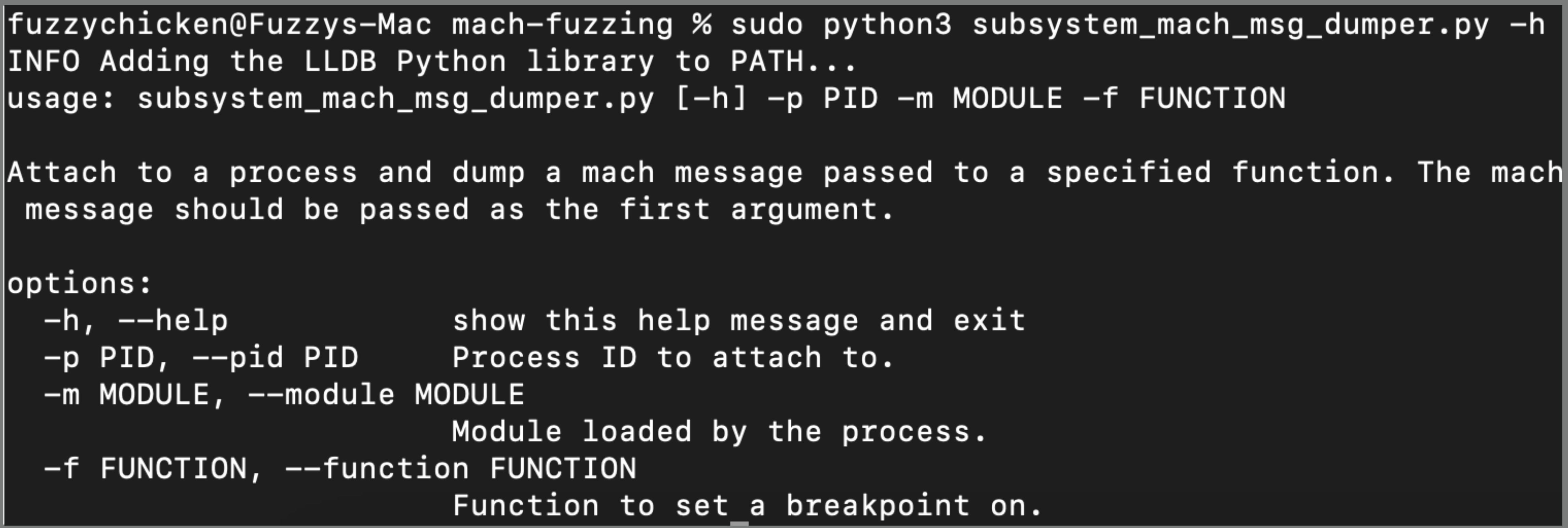
THE ATTACK CYCLE

Generate a Corpus of Inputs

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.
```

Identify an attack vector

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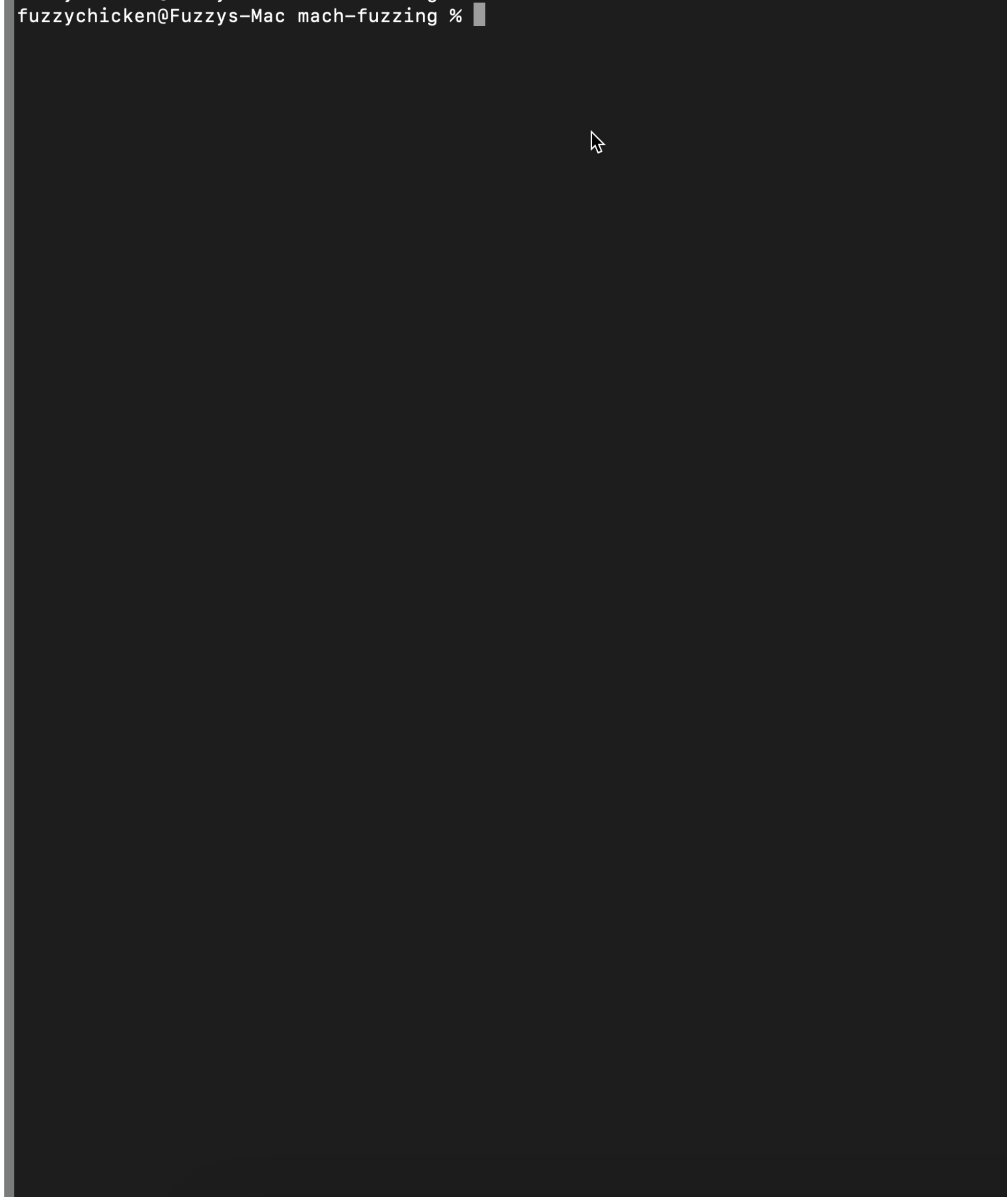
THE ATTACK CYCLE

Generate a Corpus of Inputs



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

Identify an attack vector

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THE ATTACK CYCLE

What is a Fuzzing Harness?

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

Identify an attack vector

Generate a Corpus of Inputs

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Identify Relevant Crashes

THE ATTACK CYCLE

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 ☺

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

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Identify Relevant Crashes

THE ATTACK CYCLE

Calling the Target Function

Targe

- Sim
  - HM
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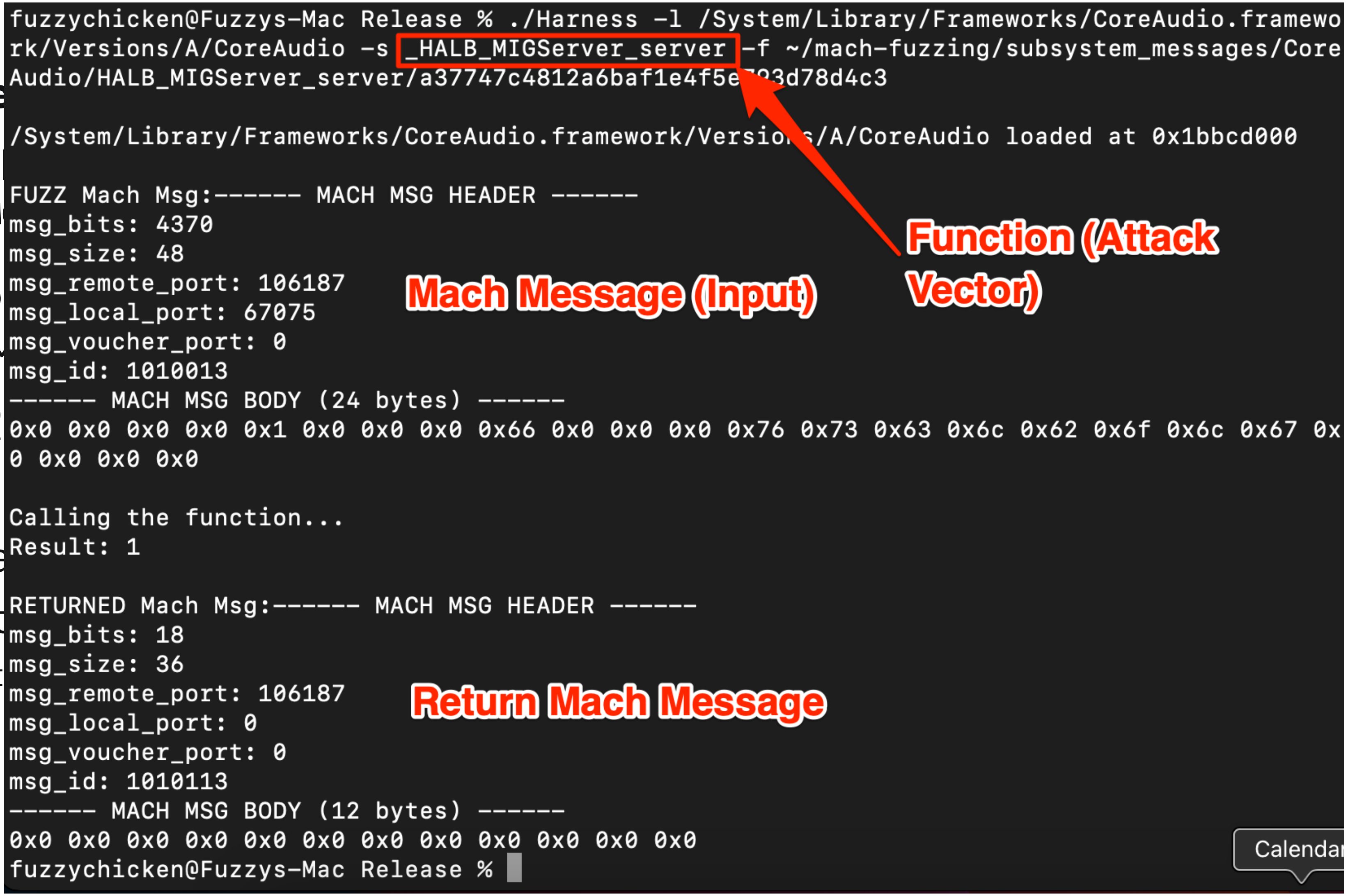
  - vo RT
  - pF
- Wha
- Writ
  - A t



```
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/a37747c4812a6baf1e4f5e793d78d4c3

/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 %
```

Identify an attack vector

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THE ATTACK CYCLE

What is a Fuzzer?

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

Identify an attack vector

Generate a Corpus of Inputs

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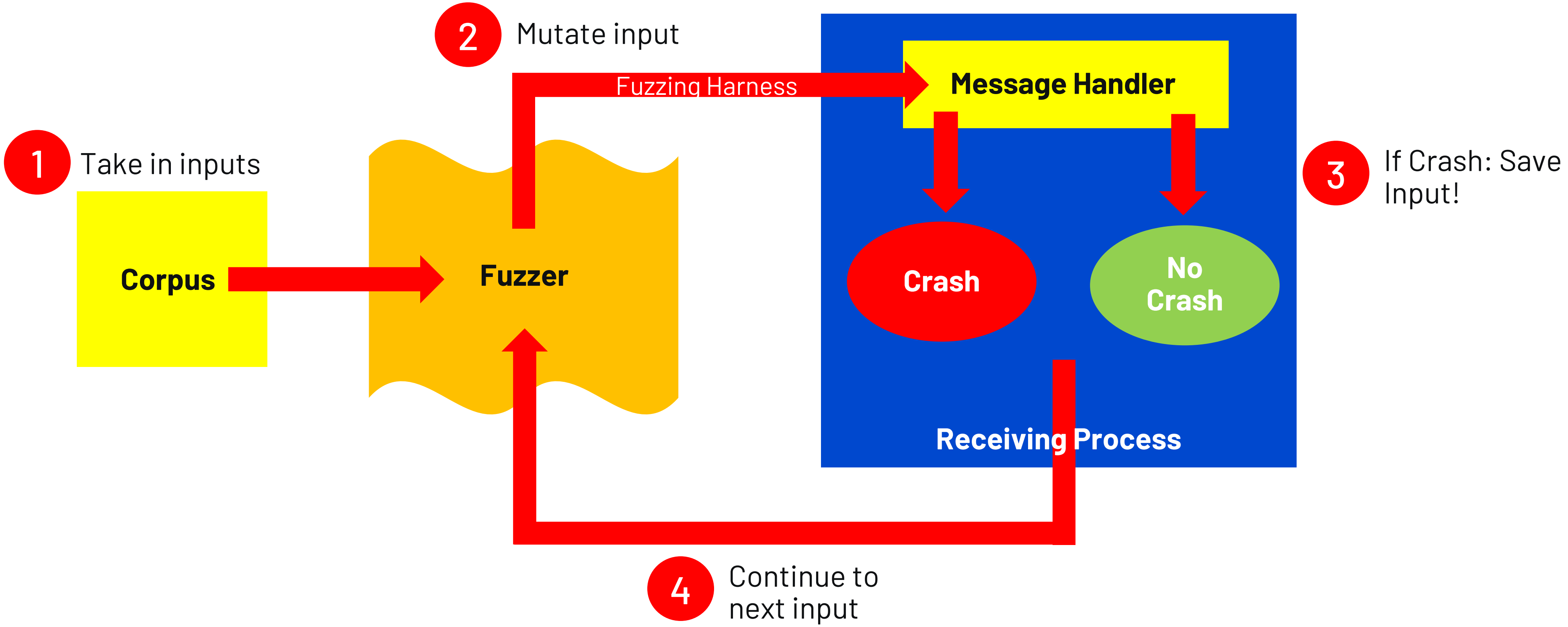
THE ATTACK CYCLE

What is a Fuzzer?



1 Take in inputs

2 Mutate input

3 If Crash: Save Input!

4 Continue to next input

Corpus

Fuzzer

Fuzzing Harness

Message Handler

Crash

No Crash

Receiving Process

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

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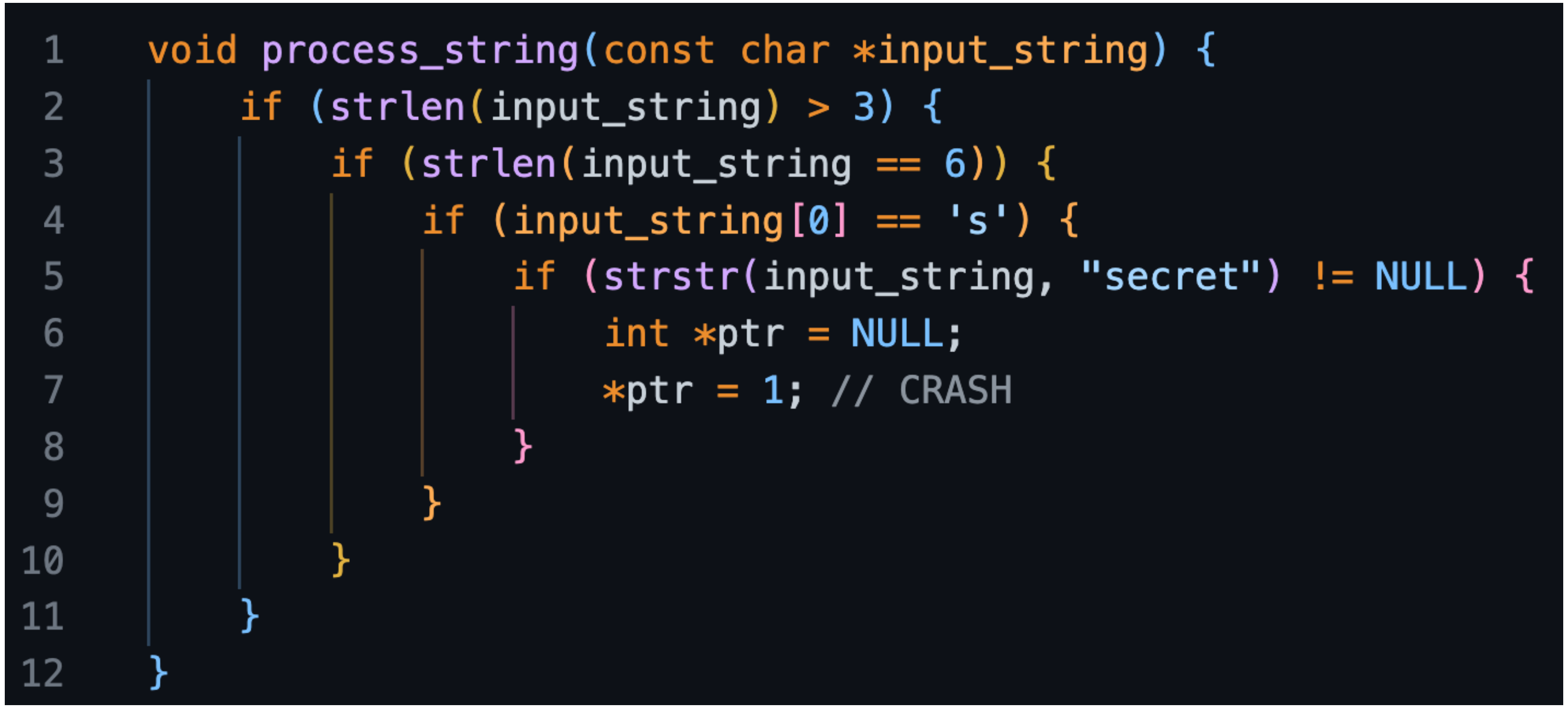
Identify Relevant Crashes

THE ATTACK CYCLE

The Need For Code Coverage



```
void process_string(const char *input_string) {
    if (strlen(input_string) > 3) {
        if (strlen(input_string == 6)) {
            if (input_string[0] == 's') {
                if (strstr(input_string, "secret") != NULL) {
                    int *ptr = NULL;
                    *ptr = 1; // CRASH
                }
            }
        }
    }
}
```

What is Code Coverage

Identify an attack vector

Generate a Corpus of Inputs

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Fuzz and Produce Crashes

Identify Relevant Crashes

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

Identify an attack vector

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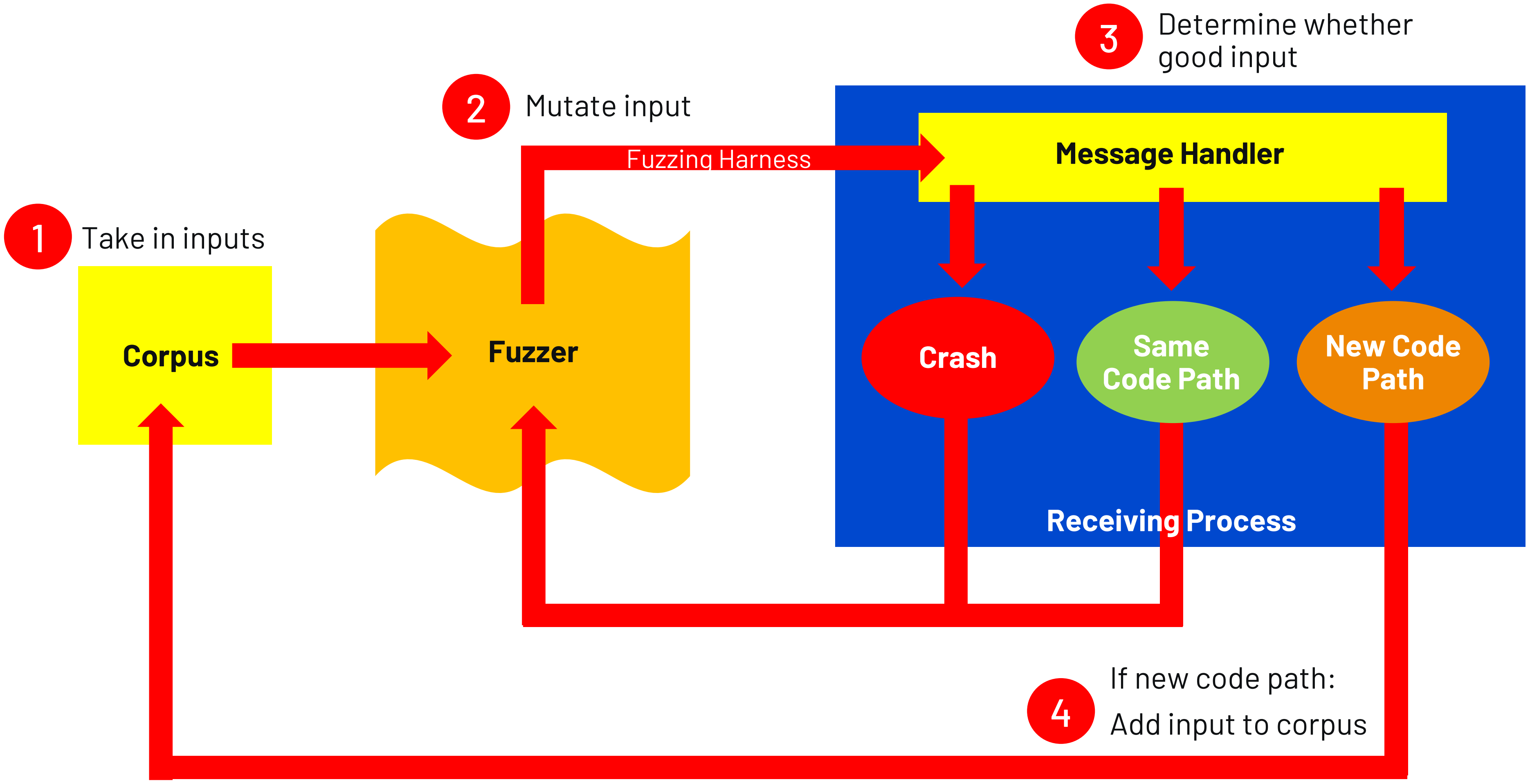
THE ATTACK CYCLE

How Do We Determine Code Coverage?



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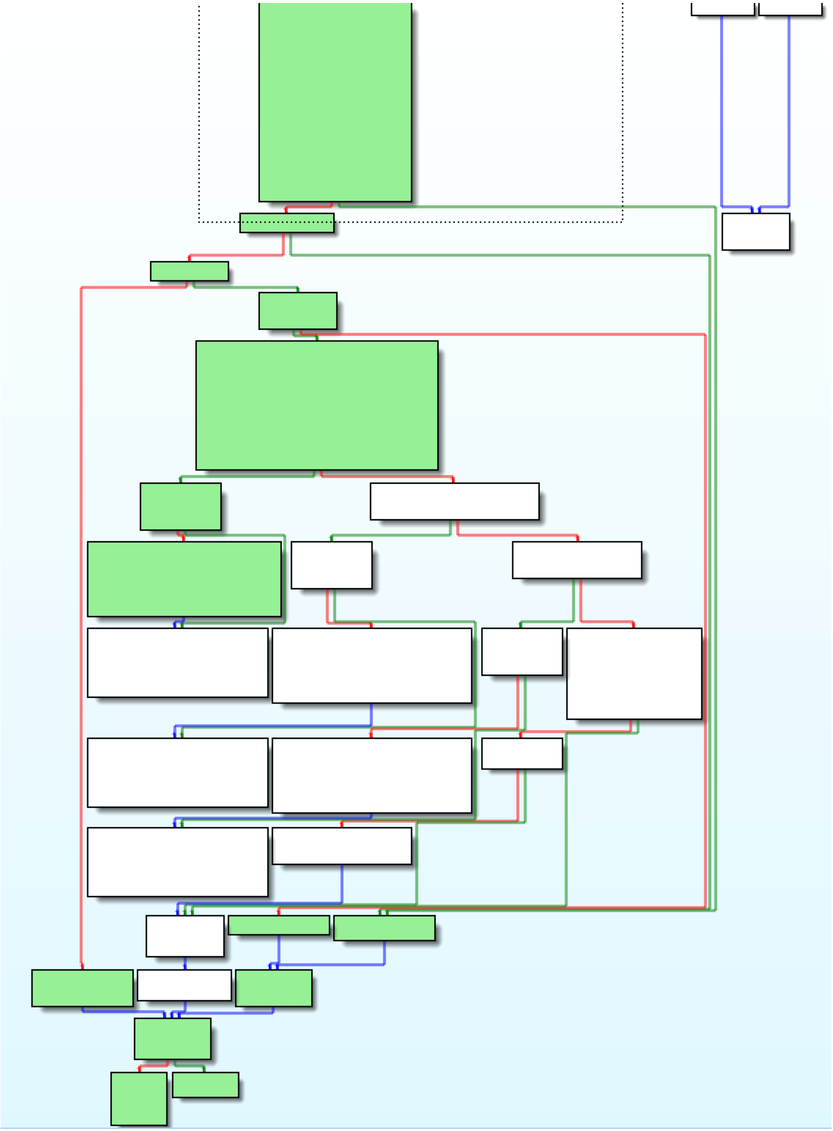
THE ATTACK CYCLE

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 ATTACK 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

THE ATTACK CYCLE

Actually Fuzzing!

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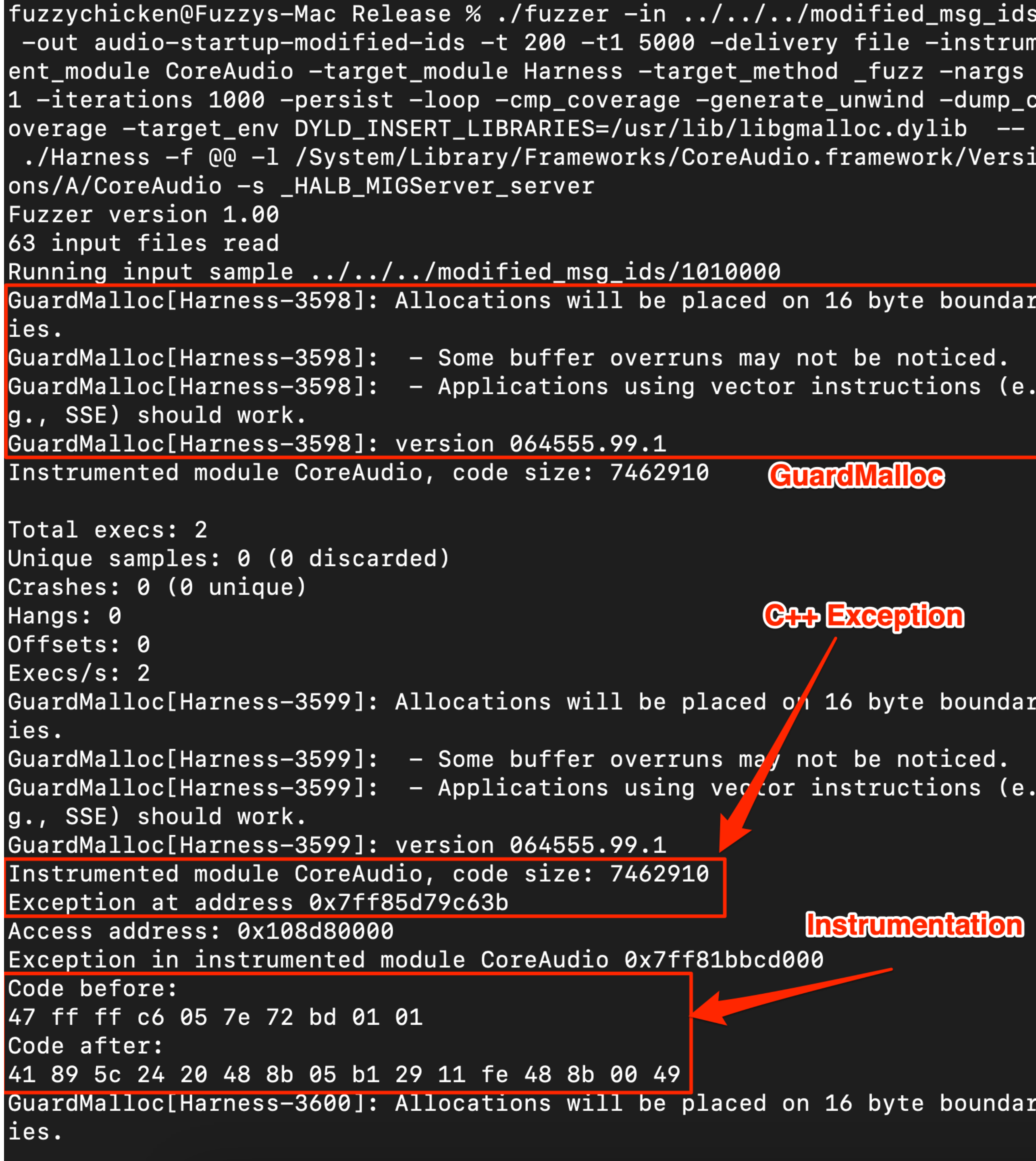


```
fuzzychicken@Fuzzys-Mac Release % ./fuzzer -in ../../../modified_msg_ids
 -out audio-startup-modified-ids -t 200 -t1 5000 -delivery file -instrum
ent_module CoreAudio -target_module Harness -target_method _fuzz -nargs
1 -iterations 1000 -persist -loop -cmp_coverage -generate_unwind -dump_c
overage -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.
```

Identify an attack vector

Generate a Corpus of Inputs

Create a Fuzzing Harness

Fuzz and Produce Crashes

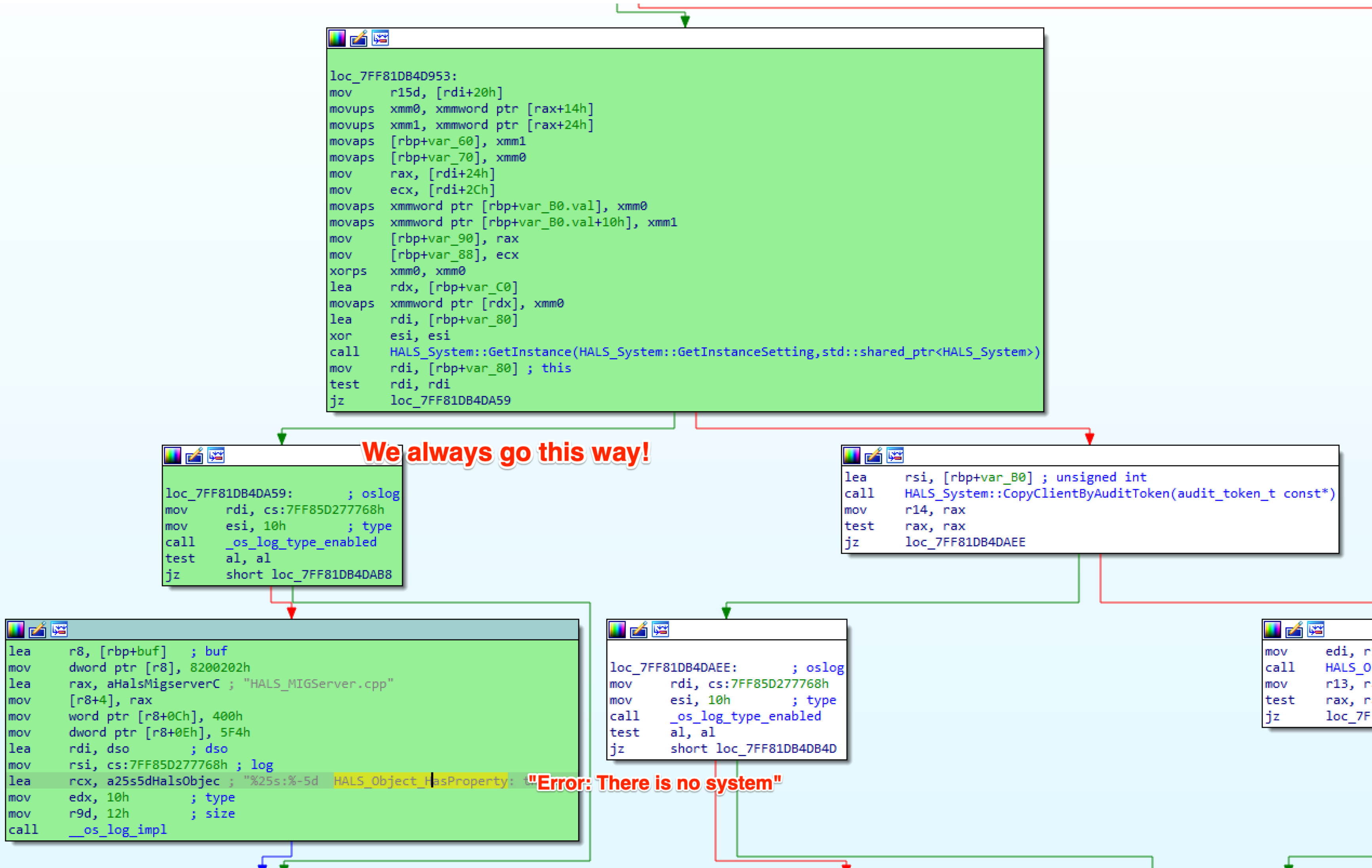
Identify Relevant Crashes

THE ATTACK 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!



```
loc_7FF81DB4D953:
mov     r15d, [rdi+20h]
movups  xmm0, xmmword ptr [rax+14h]
movups  xmm1, xmmword ptr [rax+24h]
movaps  [rbp+var_60], xmm1
movaps  [rbp+var_70], xmm0
mov     rax, [rdi+24h]
mov     ecx, [rdi+2Ch]
movaps  xmmword ptr [rbp+var_B0.val], xmm0
movaps  xmmword ptr [rbp+var_B0.val+10h], xmm1
mov     [rbp+var_90], rax
mov     [rbp+var_88], ecx
xorps   xmm0, xmm0
lea     rdx, [rbp+var_C0]
movaps  xmmword ptr [rdx], xmm0
lea     rdi, [rbp+var_80]
xor     esi, esi
call    HALS_System::GetInstance(HALS_System::GetInstanceSetting,std::shared_ptr<HALS_System>)
mov     rdi, [rbp+var_80] ; this
test    rdi, rdi
jz      loc_7FF81DB4DA59
```

We always go this way!

```
loc_7FF81DB4DA59:        ; oslog
mov     rdi, cs:7FF85D277768h
mov     esi, 10h         ; type
call    _os_log_type_enabled
test    al, al
jz      short loc_7FF81DB4DAB8
```

```
lea     rsi, [rbp+var_B0] ; unsigned int
call    HALS_System::CopyClientByAuditToken(audit_token_t const*)
mov     r14, rax
test    rax, rax
jz      loc_7FF81DB4DAEE
```

```
lea     r8, [rbp+buf]    ; buf
mov     dword ptr [r8], 8200202h
lea     rax, aHalsMigserverC ; "HALS_MIGServer.cpp"
mov     [r8+4], rax
mov     word ptr [r8+0Ch], 400h
mov     dword ptr [r8+0Eh], 5F4h
lea     rdi, dso         ; dso
mov     rsi, cs:7FF85D277768h ; log
lea     rcx, a25s5dHalsObjec ; "%25s:%-5d  HALS_Object_HasProperty: t
mov     edx, 10h         ; type
mov     r9d, 12h         ; size
call    __os_log_impl
```

"Error: There is no system"

```
loc_7FF81DB4DAEE:        ; oslog
mov     rdi, cs:7FF85D277768h
mov     esi, 10h         ; type
call    _os_log_type_enabled
test    al, al
jz      short loc_7FF81DB4DB4D
```

```
mov     edi, r
call    HALS_O
mov     r13, r
test    rax, r
jz      loc_7F
```

Identify an attack vector

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THE ATTACK CYCLE

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

Next Steps

- Increase code coverage of Mach IPC handlers
  - Stateful Mach message fuzzing (determining message order when it matters)
  - Automatic initialization of Mach service binaries
- Scale up fuzzing power using Google Cloud resources
- Open-source my Mach message dumper and fuzzing harness
  - Currently in progress, getting approval to release
- Collaborate with YOU!
  - Always looking for others to collaborate on research with

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FUZZING TAKEAWAYS

Questions

Thank You!

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