ALIBABA SECURITY AGENCY

OPTIMIZED FUZZING IOKIT IN IOS

LEI LONG

WHO AM I?

- LEI LONG
- Security Expert in Mobile Security of Alibaba Group
- Focus on Security Research of iOS
- Twitter:@cererdlong

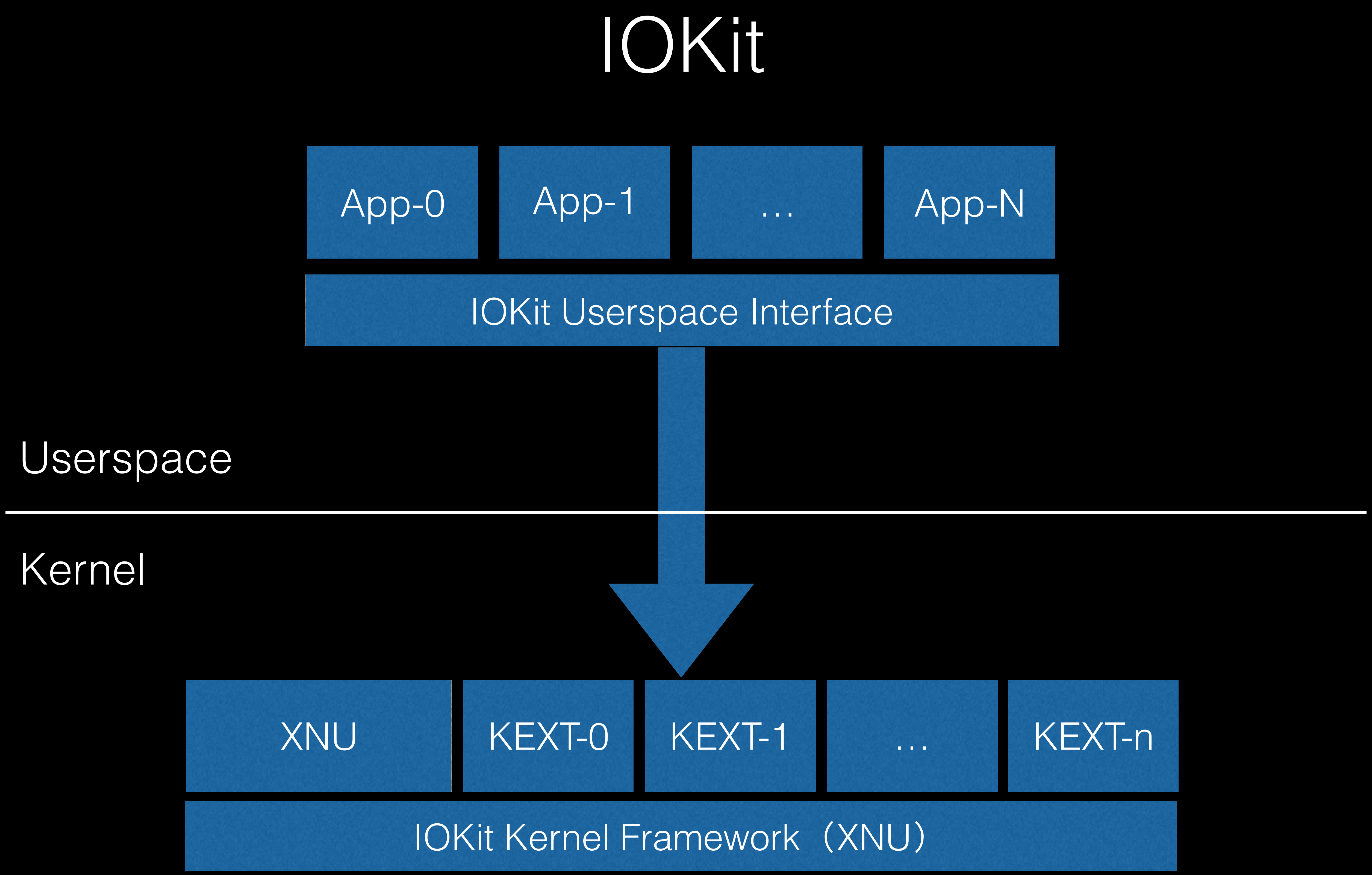
Outlines

- Introduction
- Information Extraction
- Fuzzing
- Results

Part I

Introduction

Introduction(I)



Previous Research

- Focused on IOExternalMethodDispatch
- Base on IDA static analysis
- Disadvantages
  - sMethod symbols required
  - Decrypted kernelcache required
  - Unresolved instructions of some KEXTs
  - Insufficient information

Our Work

- Not only IOExternalMethodDispatch
- Base on dynamically kernel read/write
- Advantages
  - Independent of sMethod symbols
  - A decrypted kernelcache not required
  - More sufficient information

Prerequisite

- Jailbroken device
- tfp0 kernel patch

Part II

Information Extraction

Information Extraction

- Basic Information
- IOUserClients’ Access Info
- IOExternalMethodDispatch
- IOExternalMethod

Basic Information

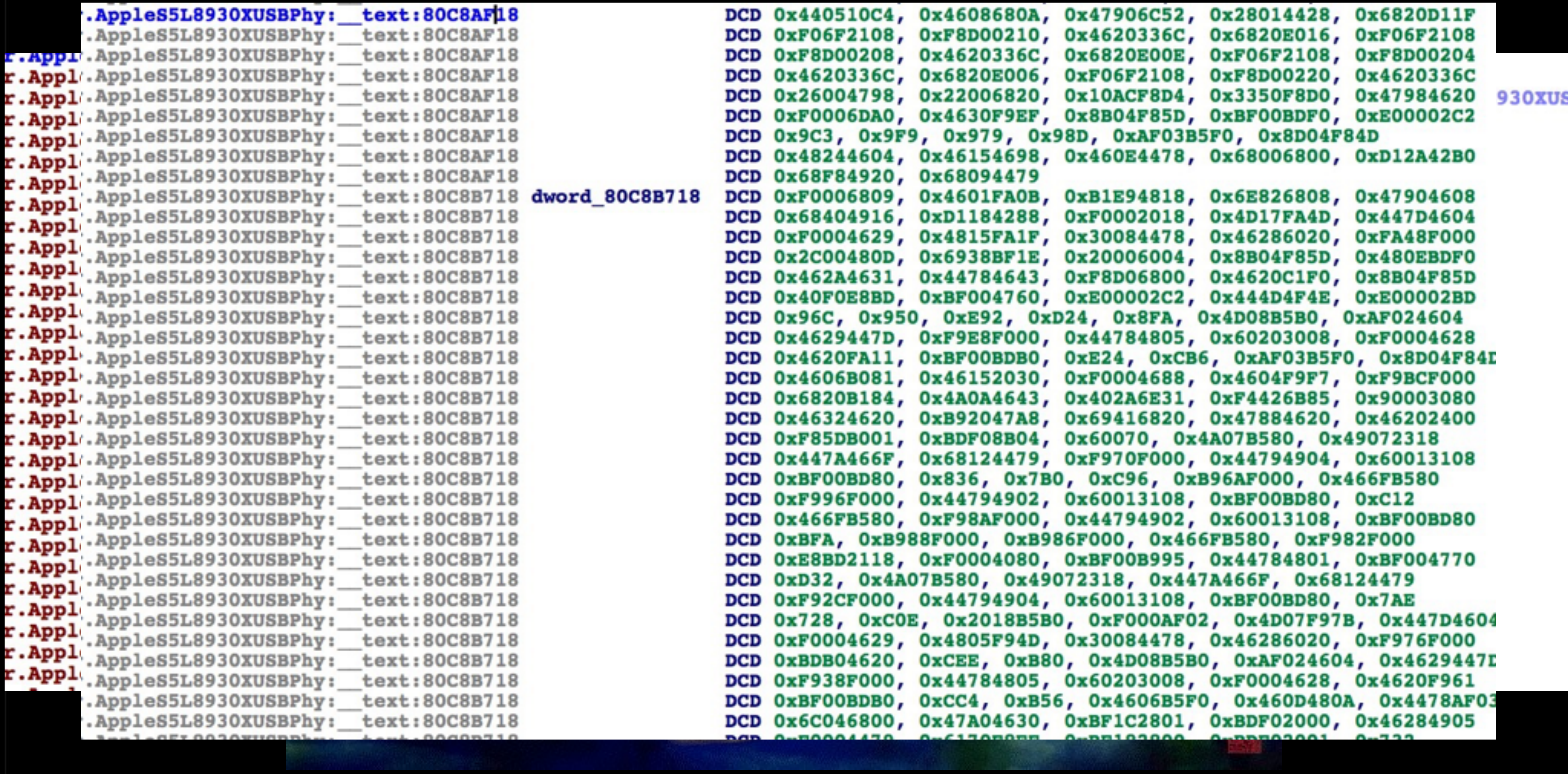
Basic Information

- All OSObject subclasses
- Information Types
  - Class name
  - Vtable start address
  - Virtual method address and its vtable offset
  - Symbol of overwritten virtual method
  - Instance size
  - Inheritance relationships

Basic Information

```
Class:AppleARMPMUPowerSource
        BundleID:com.apple.driver.AppleARMPlatform
        vtableaddr:0x804c71a8
        instance size:0x184
SuperClassNames:
        IOPMPowerSource
        IOService
        IORegistryEntry
        OSObject
Method Virtuals:
        [vtable,0x0] overwrite  at 0x804b4804
        [vtable,0x4] overwrite __ZN15IOPMPowerSourceD0Ev at 0x804b4808
        [vtable,0x1c] overwrite __ZNK15IOPMPowerSource12getMetaClassEv at 0x804b481c
        [vtable,0x50] overwrite __ZN9IOService4initEP12OSDictionary at 0x804b4858
        [vtable,0xac] overwrite __ZN15IORegistryEntry13setPropertiesEP8OSObject at 0x804b5c08
        [vtable,0x168] overwrite __ZN9IOService5startEPS_ at 0x804b4888
        [vtable,0x1d0] overwrite __ZNK9IOService11getWorkLoopEv at 0x804b5458
        [vtable,0x1e8] overwrite __ZN9IOService20callPlatformFunctionEPK8OSSymbolbPvS3_S3_S3_ at
        0x804b5518
        [vtable,0x300] overwrite __ZN9IOService13setPowerStateEmPS_ at 0x804b54e8
        [vtable,0x344] at 0x804b5454
        [vtable,0x348] at 0x804b6070
```

Motivation Of Basic Information Extraction



```
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0x440510C4, 0x4608680A, 0x47906C52, 0x28014428, 0x6820D11F
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0xF06F2108, 0xF8D00210, 0x4620336C, 0x6820E016, 0xF06F2108
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0xF8D00208, 0x4620336C, 0x6820E00E, 0xF06F2108, 0xF8D00204
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0x4620336C, 0x6820E006, 0xF06F2108, 0xF8D00220, 0x4620336C
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0x26004798, 0x22006820, 0x10ACF8D4, 0x3350F8D0, 0x47984620
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0xF0006DA0, 0x4630F9EF, 0x8B04F85D, 0xBF00BDF0, 0xE00002C2
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0x9C3, 0x9F9, 0x979, 0x98D, 0xAF03B5F0, 0x8D04F84D
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0x48244604, 0x46154698, 0x460E4478, 0x68006800, 0xD12A42B0
.AppleS5L8930XUSBPhy:__text:80C8AF18                 DCD 0x68F84920, 0x68094479
.AppleS5L8930XUSBPhy:__text:80C8B718 dword_80C8B718  DCD 0xF0006809, 0x4601FA0B, 0xB1E94818, 0x6E826808, 0x47904608
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x68404916, 0xD1184288, 0xF0002018, 0x4D17FA4D, 0x447D4604
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xF0004629, 0x4815FA1F, 0x30084478, 0x46286020, 0xFA48F000
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x2C00480D, 0x6938BF1E, 0x20006004, 0x8B04F85D, 0x480EBDF0
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x462A4631, 0x44784643, 0xF8D06800, 0x4620C1F0, 0x8B04F85D
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x40F0E8BD, 0xBF004760, 0xE00002C2, 0x444D4F4E, 0xE00002BD
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x96C, 0x950, 0xE92, 0xD24, 0x8FA, 0x4D08B5B0, 0xAF024604
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x4629447D, 0xF9E8F000, 0x44784805, 0x60203008, 0xF0004628
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x4620FA11, 0xBF00BDB0, 0xE24, 0xCB6, 0xAF03B5F0, 0x8D04F84D
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x4606B081, 0x46152030, 0xF0004688, 0x4604F9F7, 0xF9BCF000
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x6820B184, 0x4A0A4643, 0x402A6E31, 0xF4426B85, 0x90003080
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x46324620, 0xB92047A8, 0x69416820, 0x47884620, 0x46202400
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xF85DB001, 0xBDF08B04, 0x60070, 0x4A07B580, 0x49072318
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x447A466F, 0x68124479, 0xF970F000, 0x44794904, 0x60013108
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xBF00BD80, 0x836, 0x7B0, 0xC96, 0xB96AF000, 0x466FB580
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xF996F000, 0x44794902, 0x60013108, 0xBF00BD80, 0xC12
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x466FB580, 0xF98AF000, 0x44794902, 0x60013108, 0xBF00BD80
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xBFA, 0xB988F000, 0xB986F000, 0x466FB580, 0xF982F000
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xE8BD2118, 0xF0004080, 0xBF00B995, 0x44784801, 0xBF004770
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xD32, 0x4A07B580, 0x49072318, 0x447A466F, 0x68124479
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xF92CF000, 0x44794904, 0x60013108, 0xBF00BD80, 0x7AE
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x728, 0xC0E, 0x2018B5B0, 0xF000AF02, 0x4D07F97B, 0x447D4604
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xF0004629, 0x4805F94D, 0x30084478, 0x46286020, 0xF976F000
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xBDB04620, 0xCEE, 0xB80, 0x4D08B5B0, 0xAF024604, 0x4629447D
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xF938F000, 0x44784805, 0x60203008, 0xF0004628, 0x4620F961
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0xBF00BDB0, 0xCC4, 0xB56, 0x4606B5F0, 0x460D480A, 0x4478AF03
.AppleS5L8930XUSBPhy:__text:80C8B718                 DCD 0x6C046800, 0x47A04630, 0xBF1C2801, 0xBDF02000, 0x46284905
```

Pick Out Vtable

- Locating kernel mach-o’s __DATA,__const
    - Kernel
    - Kernel extensions
- Vtable filter
    - Vtable layout
    - Vtable characteristic

Vtable Layout

0(>=4 Byte)
virtual method 0
virtual method 1
virtual method 2
virtual method 3
….
virtual method N-3
virtual method N-2
virtual method N-1

- Thumb virtual method addresses

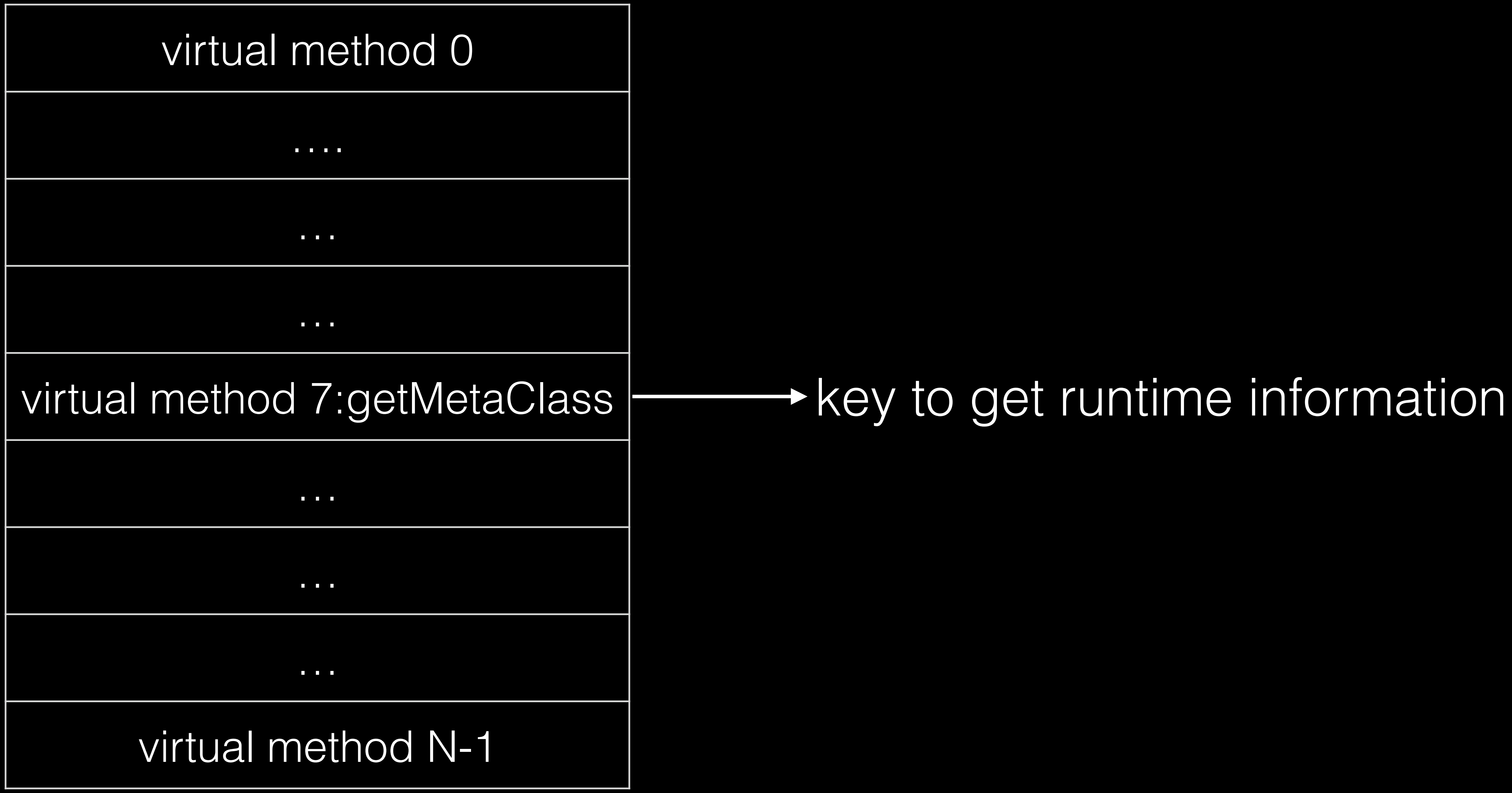
  x∈(TEXT_StartAddrss, TEXT_EndAddress)

  or x∈(PERLINKTEXT_StartAddrss, PERLINKTEXT_EndAddress)

- N∈[14, ∞)

- Starting after at least four all-0 bytes

Vtable Characteristic



getMetaClass Definition

- OSDefineMetaClassAndStructors

```
Define OSDefineMetaClassAndStructors \
....
    const OSMetaClass * className ::getMetaClass() const \
       { return &gMetaClass; }                              \
....
```

- gMetaClass is the key to get runtime information.

gMetaClass address

- KERNEL

```
addr_a1:MOV R0,#imm1
addr_a2:ADD R0,PC
addr_a3:BX    LR
```

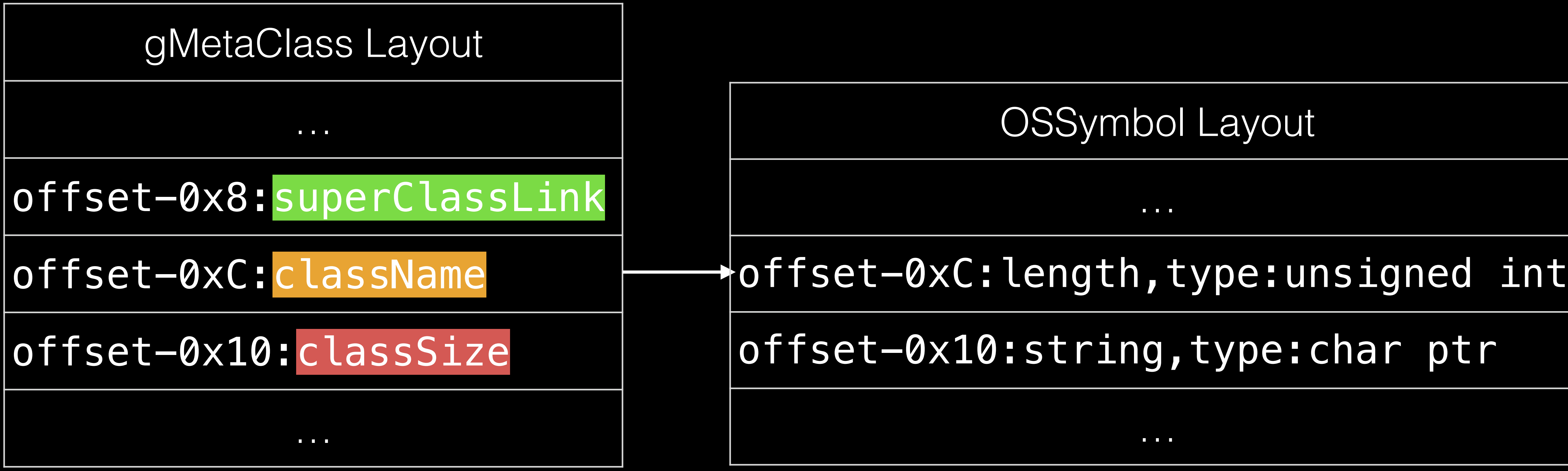
gMetaClass2=addr_b2 + imm1 + 4

- KEXT

```
addr_b1:LDR  R0 =#imm2
addr_b2:ADD R0,PC
addr_b3:BX    LR
```

gMetaClass2=addr_b2 + KernelRead4Byte(addr_b1+(4-(addr_b1+imm2)%4)) + 4

gMetaClass Layout



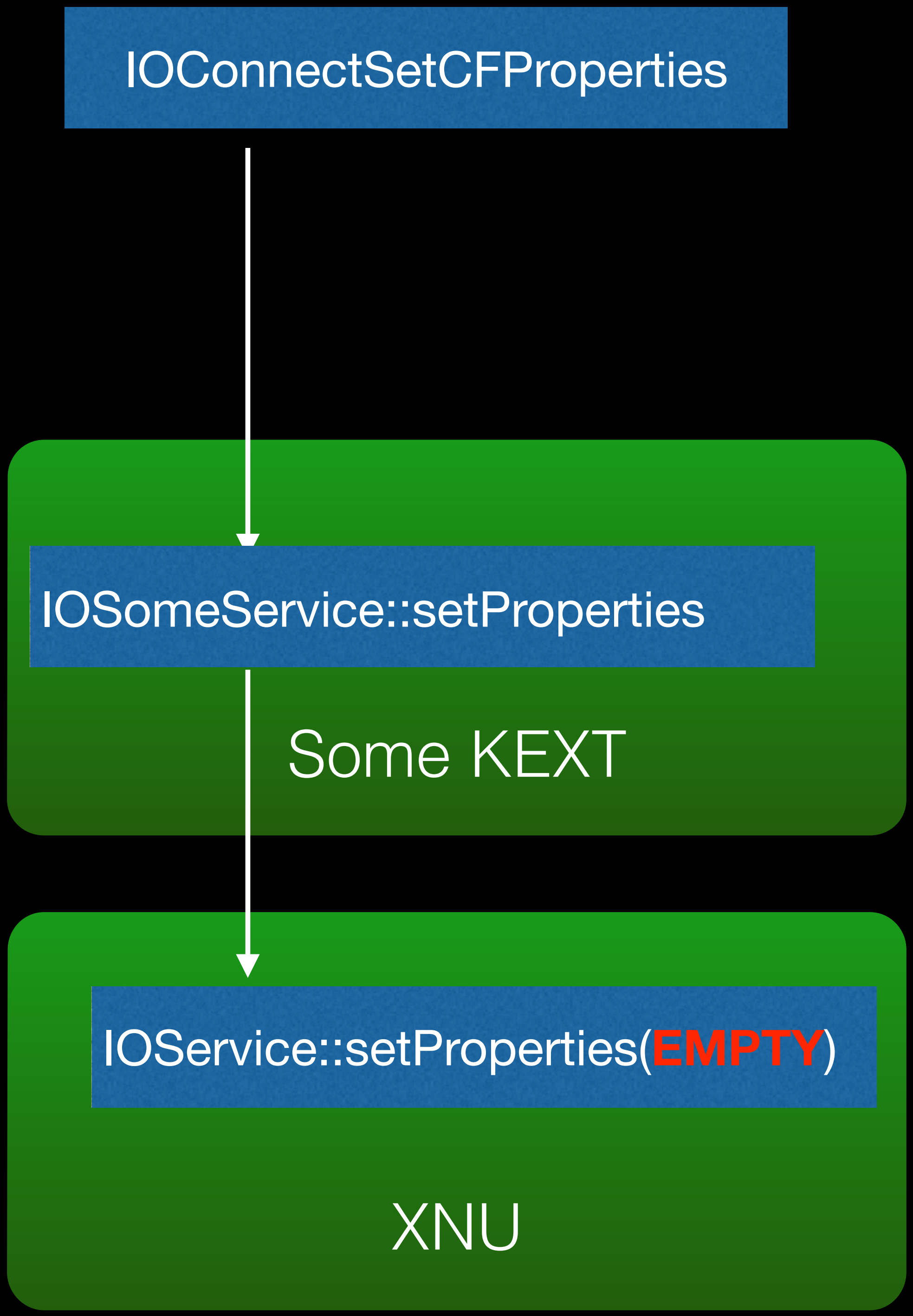
gMetaClass Layout
…
`offset-0x8:superClassLink`
`offset-0xC:className`
`offset-0x10:classSize`
…

OSSymbol Layout
…
`offset-0xC:length,type:unsigned int`
`offset-0x10:string,type:char ptr`
…

- classSize - unsigned int
- superClassLink - OSMetaClass ptr
  - Backwards to OSObject
  - All inheritance relationships

Functionality Provided by KEXT

Example



virtual methods' "overwritten"

virtual method 0
virtual method 1
virtual method 2
virtual method 3
….
virtual method N-3
virtual method N-2
virtual method N-1
virtual method N

```
if( address∈(KERNEL_TEXT_StartAddress,
                    KERNEL_TEXT_EndAddress) {
    //implementation in XNU without overwriting
     ……
} else {
    //overwritten implementation
     ……
}
```

Overwritten virtual methods symbolization

- Assumption
  - The same names and sequences in the same iOS version in different devices
- Obtaining names and sequences from kernelcaches with leaked decrypting-keys

http://theiphonewiki.com/wiki/Firmware_Keys:

kernelcache.release.n94
IV: ae291ecd536ab102e6975a730f065f2f
Key: c45aac2036dea7bf564bd99399e6ff35b241b580afd323a7aee1b6e9162b1d4f

TextBlock 10

- deducing the symbolization in those encrypted kernelcaches without keys

Information Extraction(II): Basic Information

Obtaining names and sequences from decrypted kernelcache

- Command “nm kernelcache”
- Vtable information export
- Name-Address pair matching

Information Extraction(II): IOUserClients’ Access Info

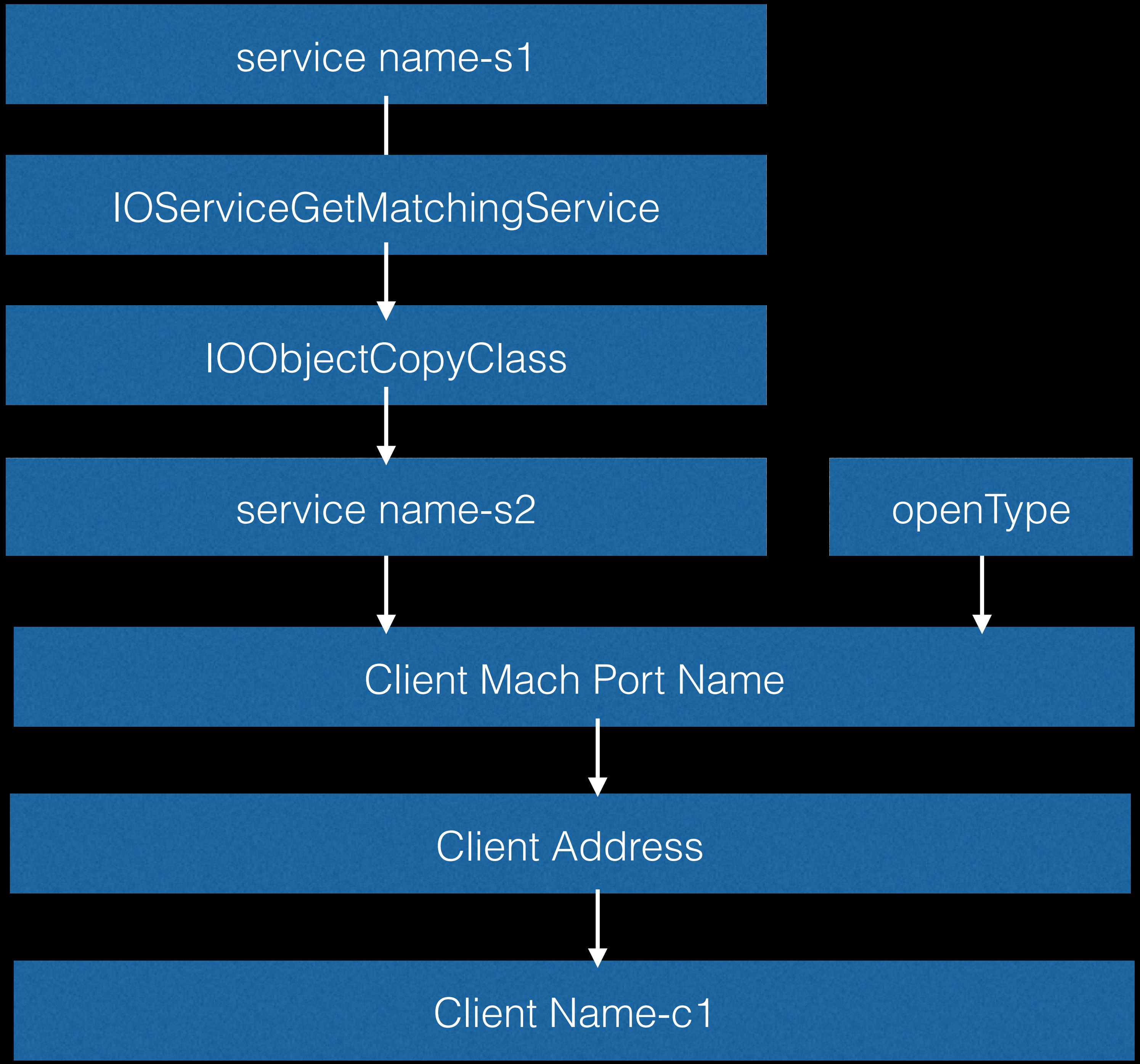
IOUserClients’ Access Info

Information Extraction(II): IOUserClients' Access Info

Example

```
Client:IOPKEAcceleratorUserClient
        Service:AppleSamsungPKE:0
         vtableaddr:0x807341f8
         canOpen:1
         instance size:0x80
```

Access Info Export



(c1, s2, openType)

Detail Steps

- s1: obtain all subclasses of IOService
  - ~~OSKextCopyLoadedKextInfo~~
  - Basic Information Extraction
- openType: try all openTypes
  - 0x00~0xff
  - magicCodes: locating newUserClient
- c1: retrieve Client Name
  - ~~mach_port_kobject~~
  - mach_port_space_info

ipc_port ptr via mach_port_space_info

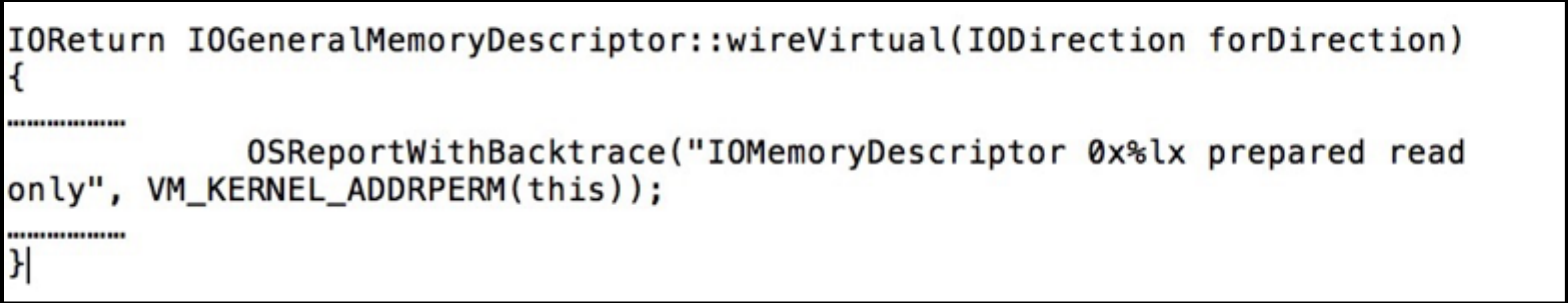
```
vm_address_t cr_mach_port_kobject(vm_address_t portname) {
    ipc_info_space_t info;
    ipc_info_name_array_t table = 0;
    mach_msg_type_number_t tableCount = 0;
    ipc_info_tree_name_array_t tree = 0;
    mach_msg_type_number_t treeCount = 0;
    vm_address_t obaddress = 0;
    mach_port_space_info(mach_task_self(), &info, &table,
&tableCount, &tree, &treeCount);
    for( int index = 0 ; index < tableCount ; index++ ) {
        ipc_info_name_t info = table[index];
        if(portname == info.iin_name) {
            obaddress = info.iin_object;
        }
    }
   obaddress -= vm_kernel_addrperm;
//obaddress is the address of structure ipc_port. By adding
offset
//0x44,we can get ipc_kobject_t kobject in 32-bit devices.
    return CRReadAtAddress(obaddress+0x44);
}
```

TextBlock 13

- ipc_info_name_t->iin_name
  ==
  client port name
- ipc_info_name_t->iin_object
  =
  obfuscated ipc_port ptr
- ipc_port ptr
  =
  obfuscated -
  vm_kernel_addrperm

vm_kernel_addrperm

- By locating a kernel function with
  - VM_KERNEL_ADDRPERM
  - A unique characteristics string
- Luckily, IOGeneralMemoryDescriptor::wireVirtual

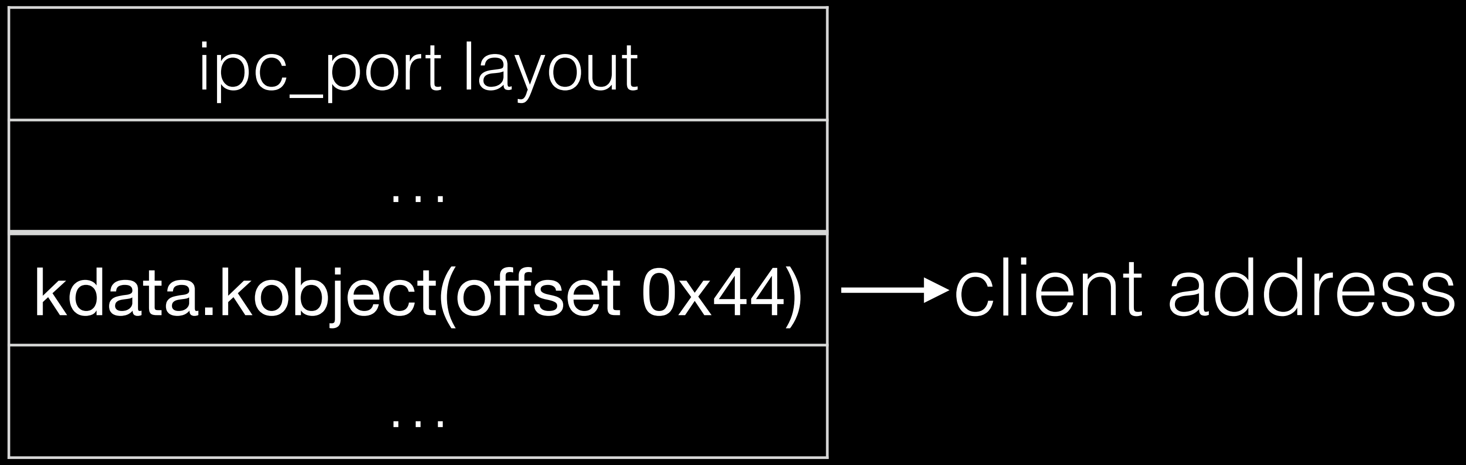


```
IOReturn IOGeneralMemoryDescriptor::wireVirtual(IODirection forDirection)
{
………………
                OSReportWithBacktrace("IOMemoryDescriptor 0x%lx prepared read
only", VM_KERNEL_ADDRPERM(this));
………………
}
```

  - **ipc_port ptr = obfuscated - KernelRead(vm_kernel_addrperm's address)**

Retrieve Client Name

- Client address in struct ipc_port



- Retrieve Client Name Via Client Address
  - Get vtable address
  - Locate getMetaClass()
  - Get gMetaClass ptr
  - Get client name

Information Extraction(II): IOExternalMethodDispatch

IOExternalMethodDispatch

IOExternalMethodDispatch

IOUserClient::externalMethod

- Be overwritten to provide IO services
- Use IOExternalMethodDispatch for input/output check
  - type
  - length
- 0xe00002c2 error if check failed

Extracting IOExternalMethodDispatch

1. Narrow and determine the searching scope.

2. Match IOExternalMethodDispatch Table characteristics.

3. Locate IOExternalMethodDispatch Table address.

4. Dump all.

IOExternalMethodDispatch Table characteristics

- IOExternalMethodDispatch fields

Function	**Function∈(TEXT_START, TEXT_END) Function∈(PRELINK_TEXT_START, PRELINK_TEXT_END)**
checkScalarInputCount	**checkScalarInputCount=0xffffffff or checkScalarInputCount∈[0,0xffff)**
checkScalarInputCount	**checkScalarInputCount=0xffffffff or checkScalarInputCount∈[0,0xffff)**
checkScalarOutputCount	**checkScalarOutputCount=0xffffffff or checkScalarOutputCount∈[0,0xffff)**
checkStructureOutputSize	**checkStructureOutputSize=0xffffffff or checkStructureOutputSize∈[0,0xffff)**

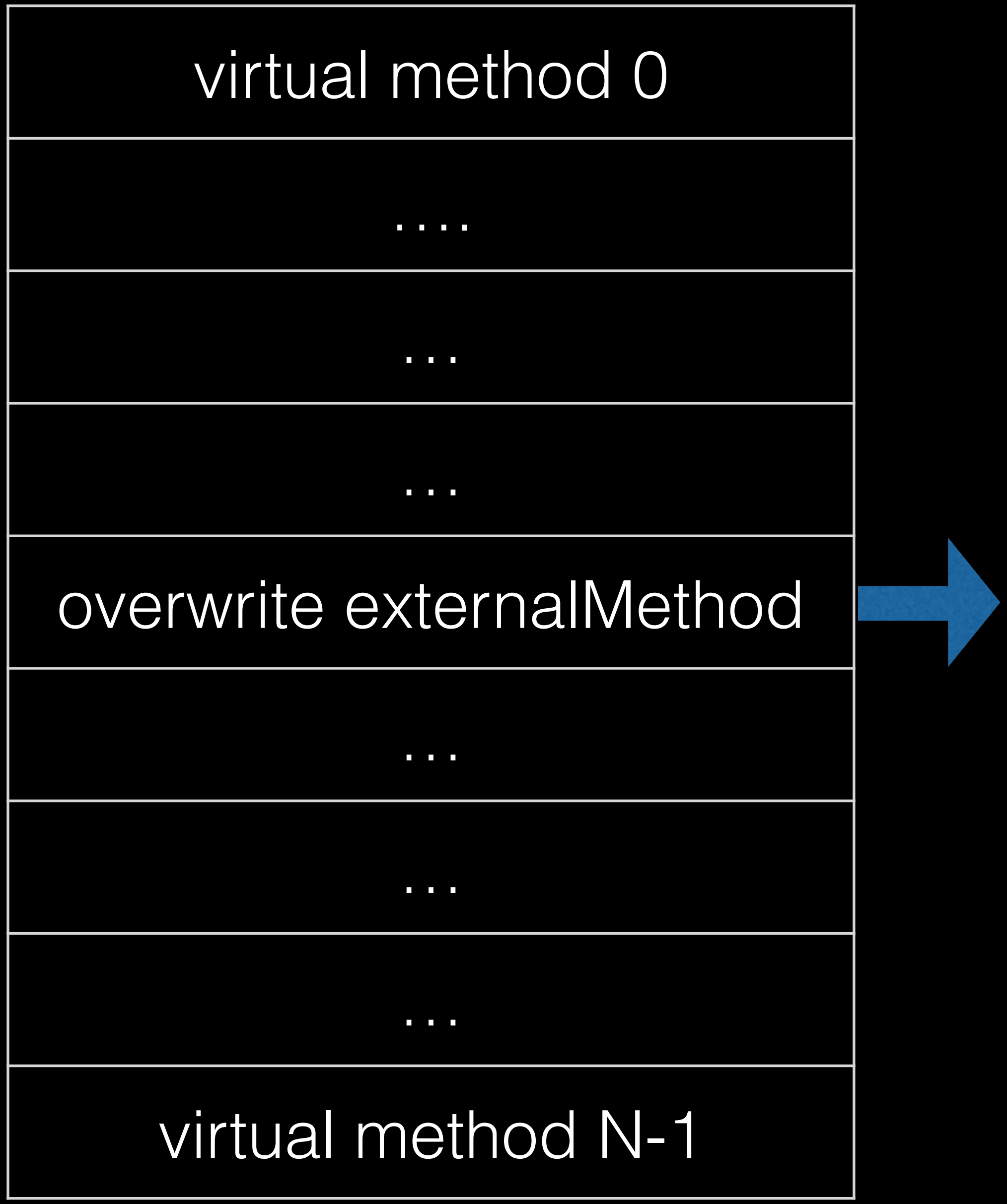
- Table length >= 2

IOExternalMethodDispatch Table Dump

0	
Client virtual method 0	→ client vtable start address
1~N	
Client virtual method N	
....	→ continous all-0 bytes
Client metaClass virtual method 0	→ client meta class vtable start address
1~N	
Client metaClass virtual method N	→ Position-x
....	→ continous all-0 bytes
....	→ Variables block start address（**Rang-x**）
function-0	→ IOExternalMethodDispatch Table block（**Start**）
checkScalarInputCount-0	
checkStructureInputSize-0	
checkScalarOutputCount-0	
checkStructureOutputSize-0	
1~N	
function-N	
checkScalarInputCount-N	
checkScalarInputCount-N	
checkScalarOutputCount-N	
checkStructureOutputSize-N	

$$\begin{tikzcd}
\text{Locating Position-x address} \arrow[d] \\
\text{Searching from Position-x by bytes (in Rang-x)} \arrow[d] \\
\text{at least 2 continuous blocks matching the characteristics (Start)} \arrow[d] \\
\text{IOExternalMethodDispatch Table starting address}
\end{tikzcd}$$

Complemental Mechanism



```
externalMethod START
…
LDR Rn0,#imm0 ⟶ check address-0 with the characteristic
…
ADD Rn0,PC
…
LDR Rn1,#imm1 ⟶ check address-1 with the characteristic
…
ADD Rn1,PC
…
LDR Rnn,#immn ⟶ check address-n with the characteristic
…
ADD Rnn,PC
…
externalMethod END
```

Information Extraction(II): IOExternalMethod

IOExternalMethod

IOExternalMethod

IOUserClient::getTargetAndMethodForIndex

- be overwritten to provide IO services
- use IOExternalMethod for input/output check
    - type
    - length
- 0xe00002c2 error if check failed

Extract IOExternalMethod

- IOExternalMethod Export

  by directly invoking getTargetAndMethodForIndex

- Arbitrary kernel code execution

  Stefan Esser, “Tales from iOS 6 Exploitation and iOS 7”, HITB 2013

Carrier

- Mach Msg OOL Data
- locating OOL Data address

mach_port_space_info->

struct ipc_mqueue->

struct ipc_kmsg_queue messages->

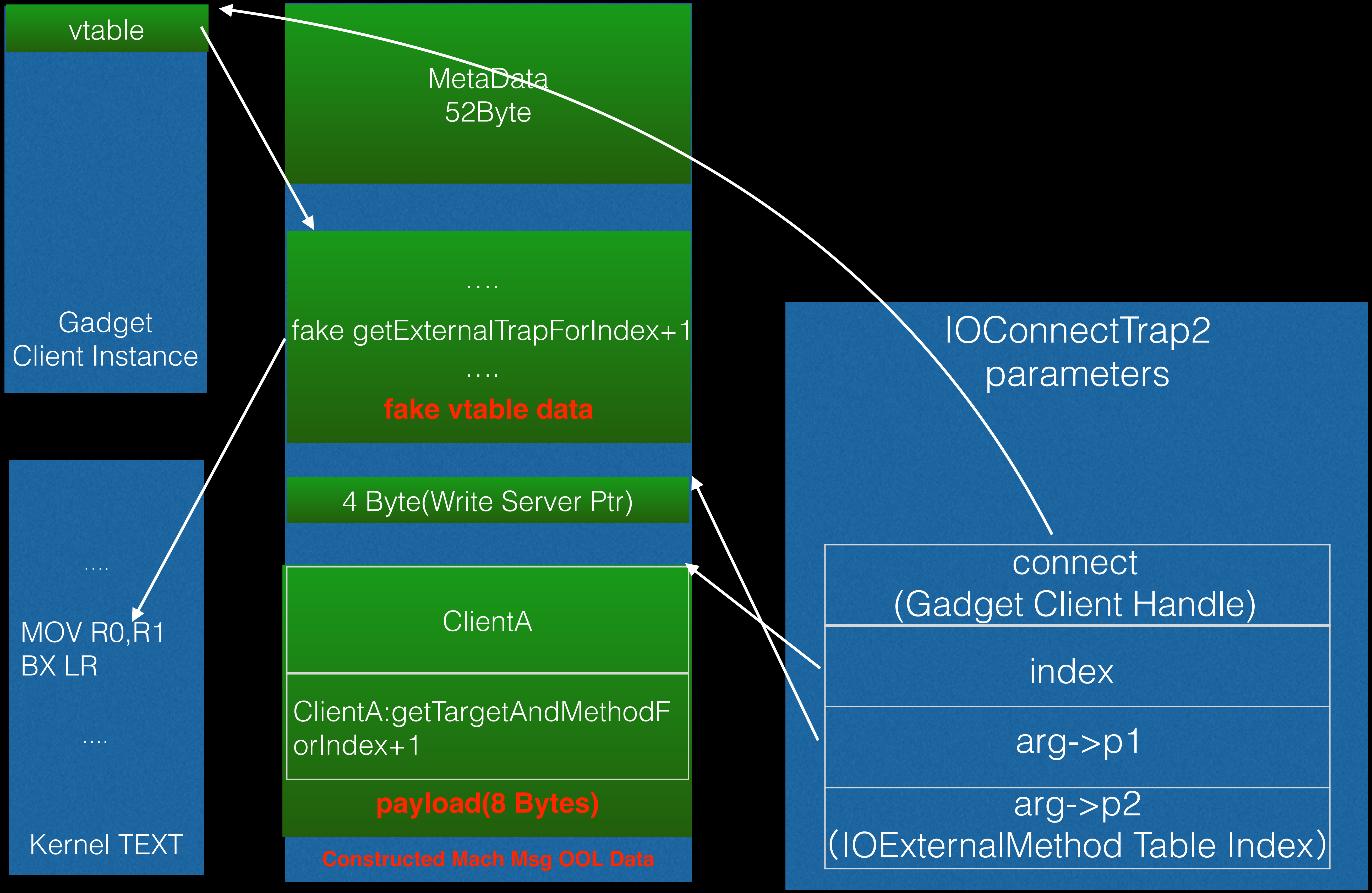
struct ipc_kmsg *ikmq_base->

mach_msg_header_t *ikm_header->

msgh_remote_port（ool address)->

msgh_remote_port + 52

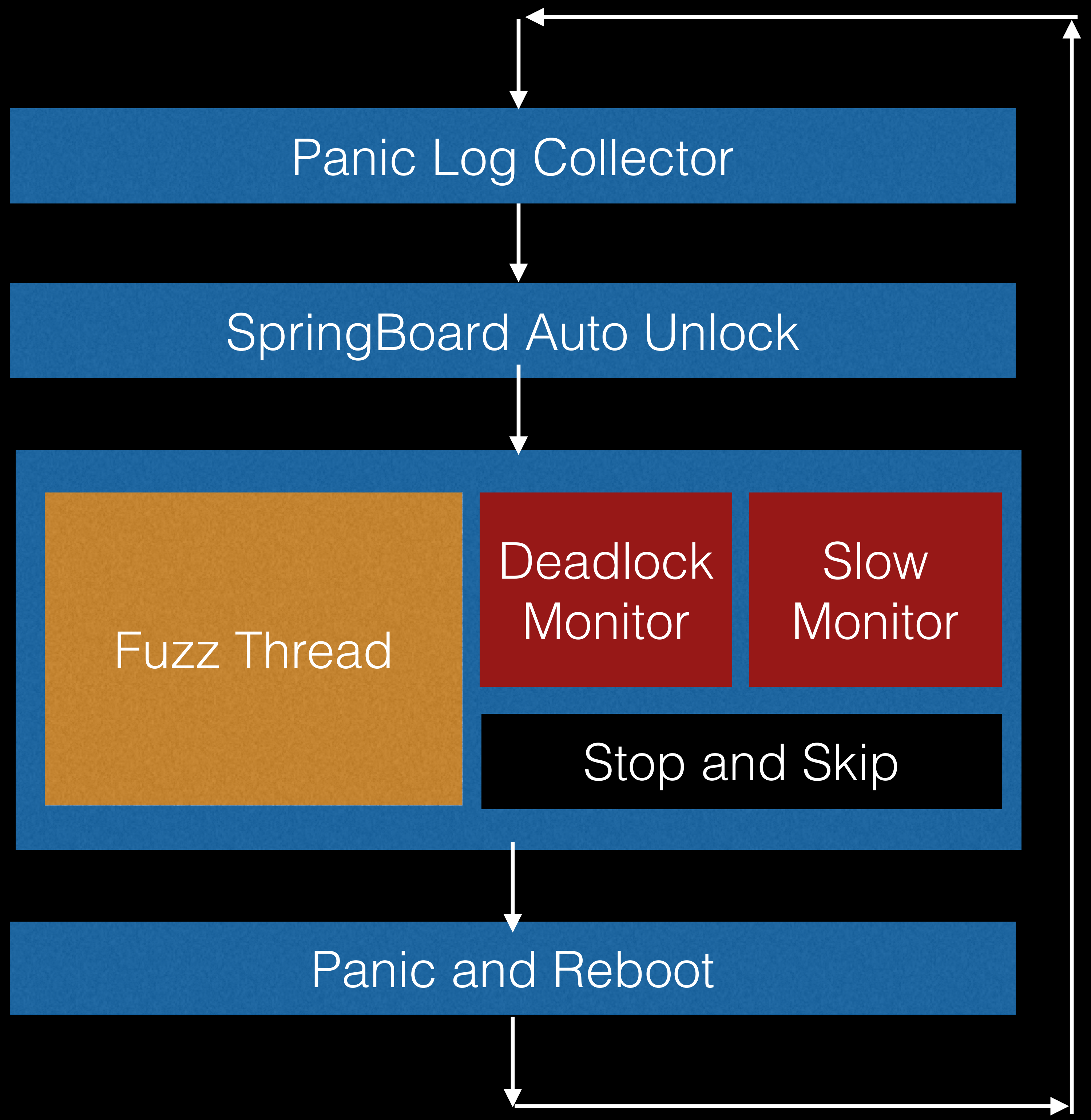
Information Extraction(II): IOExternalMethod


vtable
Gadget Client Instance
....
MOV R0,R1
BX LR
....
Kernel TEXT
MetaData 52Byte
....
fake getExternalTrapForIndex+1
....
fake vtable data
4 Byte(Write Server Ptr)
ClientA
ClientA:getTargetAndMethodForIndex+1
payload(8 Bytes)
Constructed Mach Msg OOL Data
IOConnectTrap2 parameters
connect (Gadget Client Handle)
index
arg->p1
arg->p2 (IOExternalMethod Table Index)

Part III

Fuzzing

Fuzzing Application's Architecture



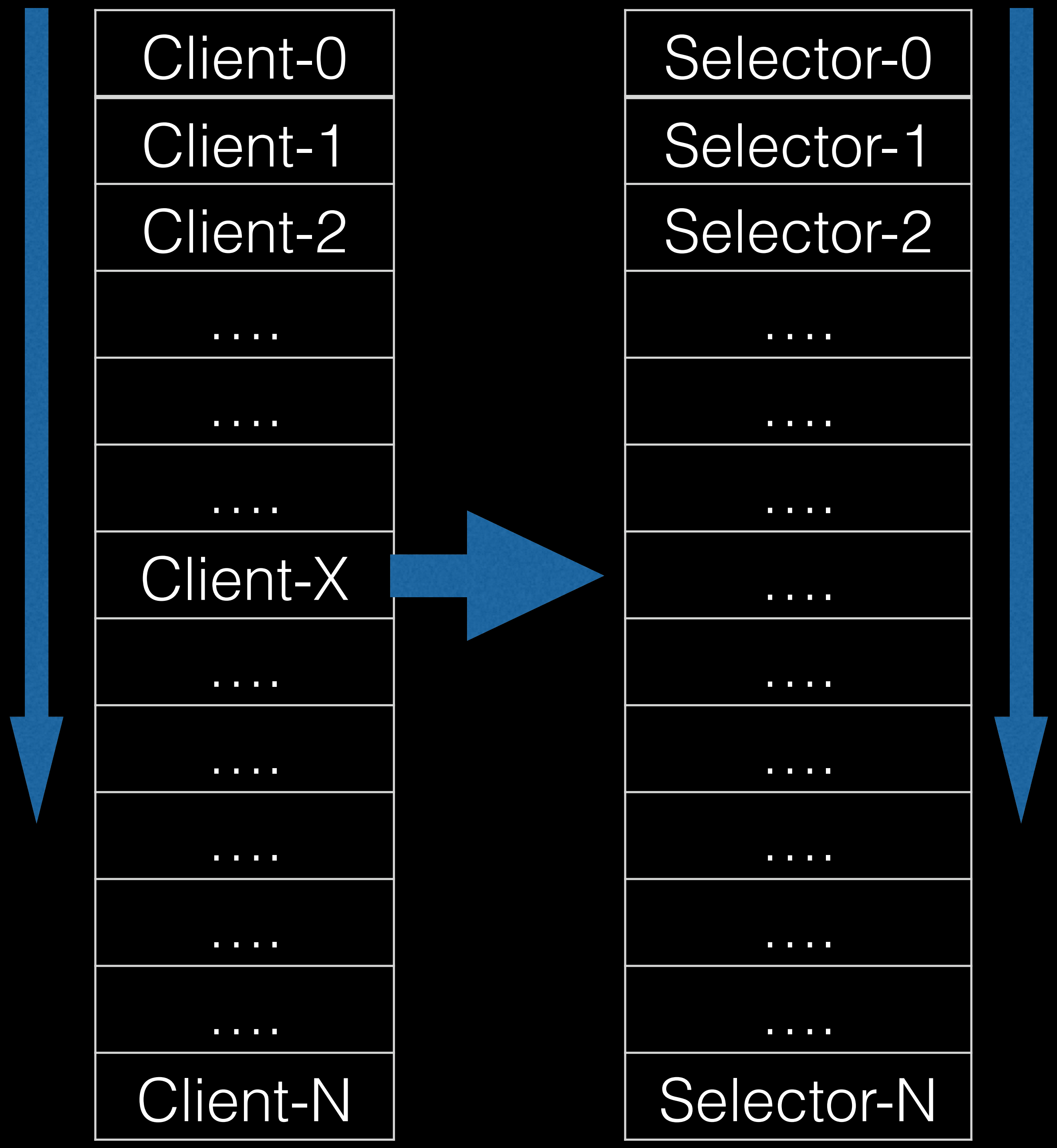
Fuzzing Elements

- Fuzzing IOConnectMapMemory
  - If overwriting clientMemoryForType?
- Fuzzing IOConnectCallMethod
  - If overwriting externalMethod?
  - If overwriting getTargetAndMethodForIndex?
  - If overwriting getExternalMethodForIndex?

Fuzzing Elements

- Fuzzing IOConnectSetCFProperties
  - Client/Service
  - If overwriting setProperties?
- Fuzzing IOConnectTrap
  - If overwriting getTargetAndTrapForIndex?
  - If overwriting getExternalTrapForIndex?

Unavailable Interfaces Identification

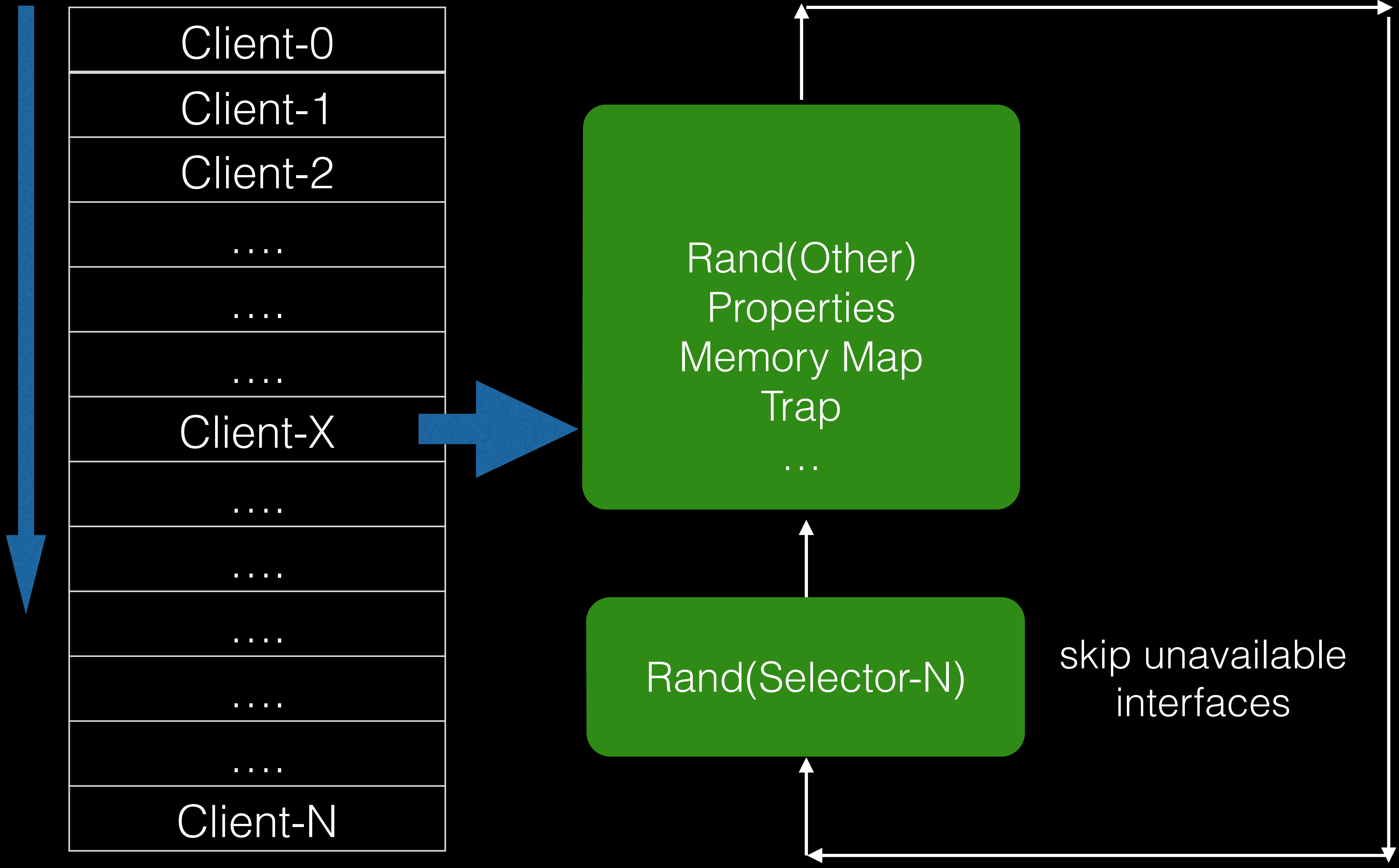


- inevitable panic interfaces
- deadlock interfaces
- slowly processing interfaces

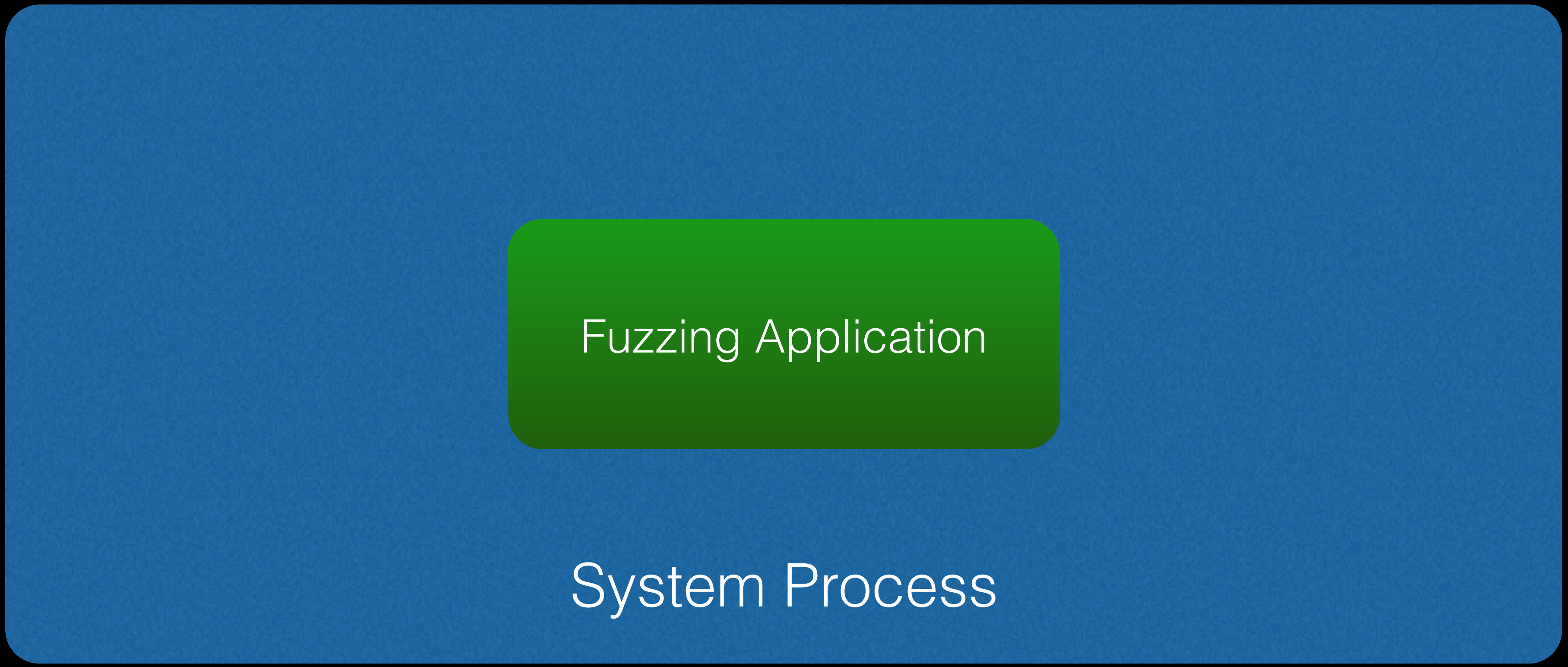
Fuzzing(III): Fuzz Thread

Fuzz Thread

Fuzzing(III): Fuzz Thread



Fuzzing(III): Fuzz Thread



- MobileSubstrate: inject fuzzing into system process
- Implement clients’ initialization in system process
- Use mach_port_space_info to get the client mach port

Part IV

Experimental Results

Experimental Results(IV)

Setup

- Hardware
  - iPhone 4S
  - MacBook
- Software
  - iOS 8.1.2
  - Open-source XNU 2782.1.97

Vulnerability Case 1

IODataQueue

```
void IODataQueue::free()
{
    if (dataQueue) {
        IOFreeAligned(dataQueue, round_page(dataQueue->queueSize +
DATA_QUEUE_MEMORY_HEADER_SIZE));
        dataQueue = NULL;

        if (notifyMsg) {
            IOFree(notifyMsg, sizeof(mach_msg_header_t));
            notifyMsg = NULL;
        }
    }

    super::free();

    return;
}
```

Vulnerability Case 1

- Details
    - HighlandParkAudioDeviceUserClient-clientMemoryForType-44
    - Use IODataQueue to share memories
    - Buffers in kalloc.4096 can be released into bigger kalloc zone
- Panic Logs
    - Unavailable address to read and write
    - A freed zone element has been modified…

Vulnerability Case 2

- IOResources’s setProperties

```
IOReturn IOResources::setProperties( OSObject * properties )
{
…
    while( (key = OSDynamicCast(OSSymbol, iter->getNextObject())))
    {    …
        publishResource( key, dict->getObject(key) );
    }

…
   return( kIOReturnSuccess );
}
```

- IOResources is inherited from IOService

Vulnerability Case 2

- IOService::newUserClient

```
IOReturn IOService::newUserClient( task_t owningTask, void * securityID,
                                   UInt32 type,  OSDictionary * properties,
                                   IOUserClient ** handler )
{
...
    temp = getProperty(gIOUserClientClassKey);
    if (temp) {
        if (OSDynamicCast(OSSymbol, temp))
            userClientClass = (const OSSymbol *) temp;
....
    }
....
    temp = OSMetaClass::allocClassWithName(userClientClass);
    if (!temp)
        return kIOReturnNoMemory;

    if (OSDynamicCast(IOUserClient, temp))
        client = (IOUserClient *) temp;
....
    }
....
}
```

Vulnerability Case 2

Exploiting

- IOResources can be bounded to any client as a service
- A new attack surface
- Fuzzing it

END

Last

Black Hat Sound Bytes

Black Hat Sound Bytes

- An information export approach to dump all OSObject subclasses' information.
- An effective fuzzing framework to fuzz IOKit in iOS
- Several vulnerabilities sharing