Escalating privileges on OS X *and iOS*

IOKit edition

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Who am I?

- Vulnerability Researcher with Google Project Zero
- Enjoy browser bugs and sandboxing
  - Chrome
  - Safari
  - Firefox
  - Flash
  - OS X
  - iOS

Overview

- What/Why IOKit?
- How IOKit works
- Bugs

What is IOKit?

- Premier source of Apple kernel bugs
- OS X/iOS kernel driver framework
- Written in C++
  - a subset of C++ with some extra bits
- Sort-of open-source
  - opensource.apple.com is your unreliable friend
- `/System/Library/Extensions/*.kext`

What does IOKit provide?

- Base classes for many driver families
  - Some open-source families (eg IOHIDFamily)
  - Some closed-source families (eg IOAccelerator)
- `libkern` custom C++ standard library
  - OSArray, OSString, OSSet, OSDictionary…
- `OSUnserializeXML`
  - Kernel XML parser
  - Compatibility layer between userspace CoreFoundation + kernel libkern types

Talking to OS X Kernel Services

- BSD kernel interface via `syscall`
- Mach “micro-”kernel interface via `syscall`
- Mach kernel *services* via `mach_msg` *trap*

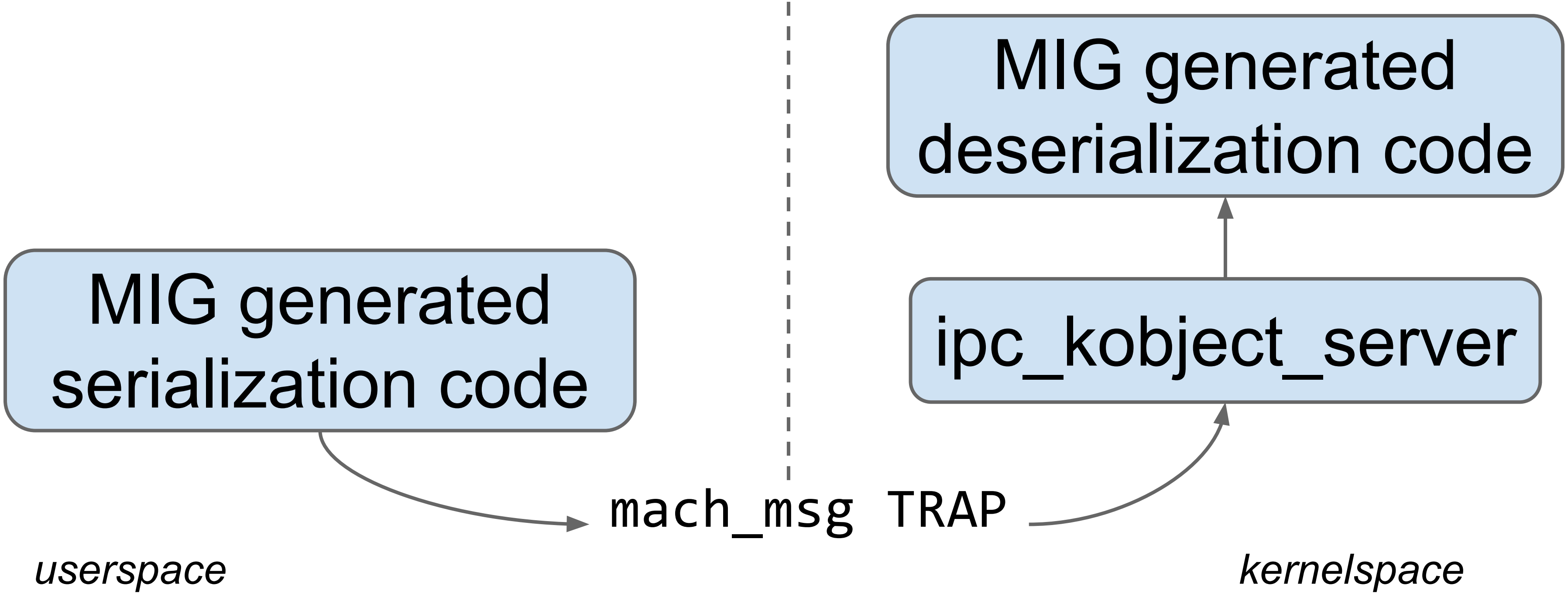
`osfmk/*/*.defs` files define mach kernel service interfaces

uses build-time interface code generation via MIG tool

Example MIG interface definition

```
routine
io_service_get_matching_service(
      master_port : mach_port_t;
  in  matching    : io_string_t;
  out service     : io_object_t
  );
```

Talking to Mach Services:



MIG generated deserialization code

ipc_kobject_server

MIG generated serialization code

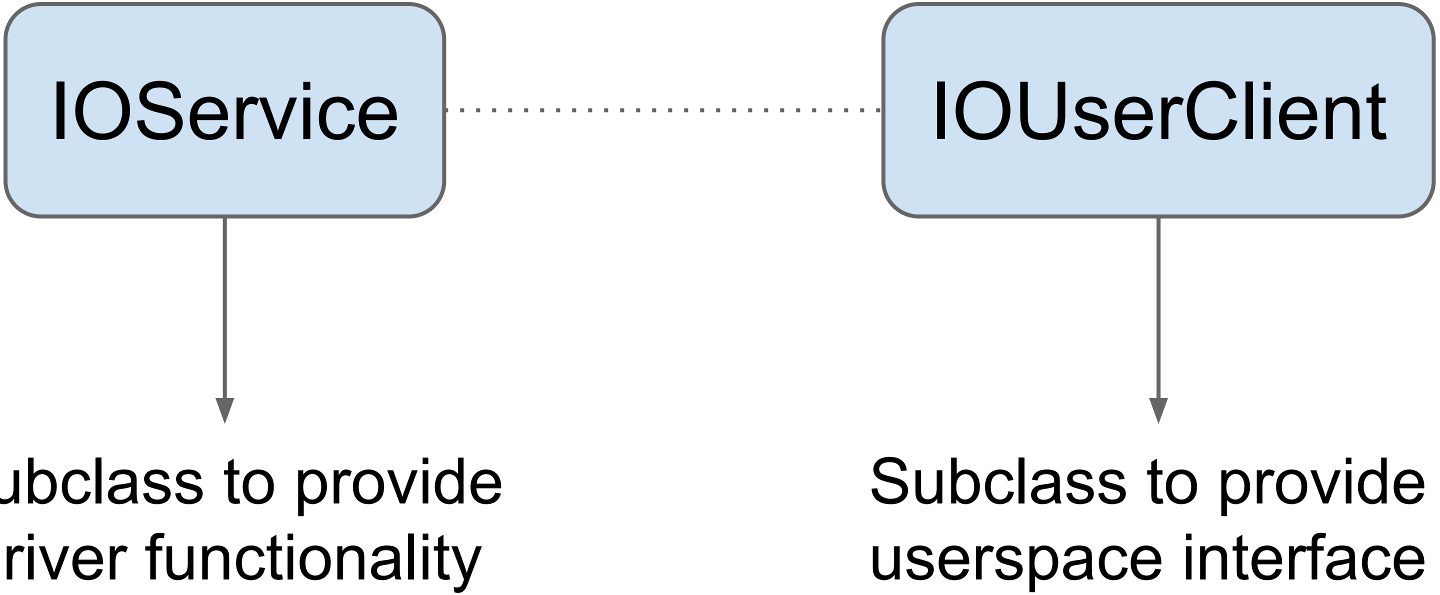
mach_msg TRAP

userspace

kernelspace

IOKit fundamentals

Anatomy of an IOKit driver



IOService

IOUserClient

Subclass to provide driver functionality

Subclass to provide userspace interface

IOKit/Userspace Communication

IOKit userspace interfaces

- External Methods
  - Numbered methods with controlled arguments
- Shared Memory
  - Typically map a kernel heap allocation into userspace
- Registry Properties
  - read and write <Key:Value> pairs

External Methods

IOConnectCallMethod

- Userspace iokit wrapper function around `io_connect_method` MIG service routine
- Allows passing of unstructured data to `IOUserClient` External Methods
- Look for `IOUserClients` overriding:
  - `::externalMethod`
  - `::getTargetAndMethodForIndex`
  - `::getExternalMethodForIndex`

IOKit C++ reflection

- `OSMetaClass`
  - provides runtime dynamic cast
- `OSMetaClass::allocClassWithName`
  - allows instantiation an IOKit object by name
- API too tempting!

Surely that’s not exposed to untrusted input?

well….

IOSurface

- Wrapper around a shared memory buffer for graphics
- `IOSurfaceRootUserClient` reachable in most interesting sandboxes:
  - mobilesafari on iOS
  - chrome renderer on OS X
- Target of jailbreakme 2.0

create_surface example:

Interface is XML based:

```
<dict>
 <key>IOSurfaceBytesPerElement</key>
   <integer size="32">0x4</integer>
 <key>IOSurfaceWidth</key>
   <integer size="32">0x40</integer>
...
</dict>
```

`create_surface` extra key:

We can actually specify an extra key and value:

```
<key>IOSurfaceClass</key>
<string>IOAnythingWeWant</string>
```

The code defaults to using IOSurface as the IOSurfaceClass, but if we specify one, then it will use the reflection API to allocate it for us.

Issues:

Type checking is done after allocating the new object using `OSMetaClass::safeMetaCast`

which is okay, except:

The object pointer has already been cast to an `IOSurface*`

which is okay, except:

If the inheritance check fails, the code calls an `IOSurface` method to destroy it…

which isn't okay! Let's look in more detail

What that actually looks like in code:

```
; r12 is return value from allocClassWithName
mov     rax, [r12]
mov     rdi, r12
call    qword ptr [rax+120h] ; ← bug is here
```

This is a bug because `+120h` is outside the range of the vtable of the base class of all IOKit objects, OSObject

What that means:

We can reliably call the function at offset 120h in ANY IOKit object vtable

We don’t really control the arguments, but we know sort-of what they’ll look like

Super-simple to exploit on OS X for a priv-esc

iOS left as an exercise for the reader

Shared Memory

IOConnectMapMemory

- Userspace iokit wrapper function around `io_connect_map_memory` MIG method
- Asks the UserClient for shared memory
- Look for `IOUserClients` overriding:
  - `::clientMemoryForType`
- Pretty much every UserClient which implemented this got it wrong...

IODataQueue

- Utility class to allow arbitrary data objects to be queued by the kernel in shared memory then dequeued by userspace (or the other way round)
- Used by many `IOUserClients`:
  - `AppleUSBMultitouchUserClient`
  - `IOHIDPointingDevice`
  - `IOBluetoothHCIPacketLogUserClient`

IODataQueueMemory

This structure is at the start of the shared memory buffer:

```
typedef struct _IODataQueueMemory {
      UInt32 queueSize;
      volatile UInt32 head;
      volatile UInt32 tail;
      IODataQueueEntry queue[1];
} IODataQueueMemory;
```

Trusting data in shared memory

Every value was trusted by the kernel:

```
UInt32 queueSize;        ← passed to kmem_free
volatile UInt32 head;
volatile UInt32 tail;         ←used to compute
IODataQueueEntry queue[1];    index into queue to
                              enqueue next entry
```

IOKit Registry Properties

IORegistryEntrySetCFProperty

- Userspace iokit.framework wrapper around `io_registry_entry_set_properties`
- Another XML-based API
- *generally* forbidden in most sandboxes
- look for `::setProperties` overrides

IOHIDKeyboard

```
$ ioreg -l -k IOHIDKeyboard
IOHIDKeyboard  <class IOHIDKeyboard, id 0x1000002cc, registered,
matched, active, busy 0 (0 ms), retain 9>
{
   "HIDVirtualDevice" = No
   "Transport" = "USB"
   "HIDKeyboardRightModifierSupport" = Yes
   "HIDKeyboardKeysDefined" = Yes
...
   "HIDKeyMapping" = <00000b01013802013b03013a040...
```

Curious binary data blob, is it configurable?

IOHIDFamily - Open-Source!

Grep for `HIDKeyMapping`:

```
if((data = OSDynamicCast(OSData,
                         dict->getObject(kIOHIDKeyMappingKey))))
  {
    map = (unsigned char *)IOMalloc( data->getLength() );
    bcopy( data->getBytesNoCopy(), map, data->getLength() );
    _keyMap = IOHIKeyboardMapper::keyboardMapper(this, map, data-
>getLength(), true);
```

::parseKeyMapping

```
/*   Copyright (c) 1992 NeXT Computer, Inc.    All rights reserved.
 *
 * KeyMap.m - Generic keymap string parser and keycode translator.
 *
 * HISTORY
 * 19 June 1992       Mike Paquette at NeXT
 *       Created.
 * 5  Aug 1993  Erik Kay at NeXT
 *   minor API cleanup
 * 11 Nov 1993  Erik Kay at NeXT
 *   fix to allow prevent long sequences from overflowing the event queue
 * 12 Nov 1998  Dan Markarian at Apple
 *       major cleanup of public API's; converted to C++
```

::parseKeyMapping - old-skool c:

```
// read a short from the input buffer
parsedMapping->numSeqs = NextNum(&nmd);

// check a lower-bound - no upper-bounds check
if (parsedMapping->numSeqs <= maxSeqNum)
  return false;

// use as a loop counter to write to seqDefs (a char*[128])
for(i = 0; i < parsedMapping->numSeqs; i++) {
  parsedMapping->seqDefs[i] = (unsigned char *)nmd.bp;
  ...
```

Conclusions

It’s about knowing where to look

- This was just the tip of the iceberg
- None of these bugs were complicated
- Some have been there, trivially exploitable, for the entire lifetime of OS X and iOS
- Not enough people look at OS X security in the public

Any Questions?

https://code.google.com/p/google-security-research/