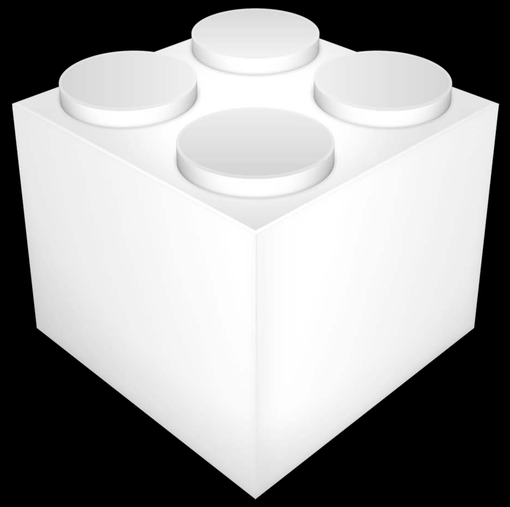
#WWDC19

System Extensions and DriverKit

Modernizing kernel extensions and device drivers

Joe Auricchio, Darwin Runtime
Simon Douglas, Core Kernel
Scott Deandrea, Core I/O

kexts



(Kernel Extensions)

The power to extend the operating system

Part of what makes the Mac, the Mac

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Kexts Have Some Problems

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Difficult to develop and debug

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Risk to data security and privacy

Kexts Have Some Problems

Difficult to develop and debug

Risk to data security and privacy

Risk to reliability

It’s time for an upgrade

NEW

System Extensions and DriverKit

Extend the operating system

Extend the operating system

More reliable

Extend the operating system

More reliable

More secure

Extend the operating system

More reliable

More secure

Easier to develop

Agenda

Agenda

Introducing System Extensions and DriverKit

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Introducing System Extensions and DriverKit

How they avoid the problems of Kernel Extensions

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Building Driver Extensions with DriverKit

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USB Driver Demo

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USB Driver Demo

System Extensions in your apps

A System Extension Is

NEW

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NEW

Part of your app

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NEW

Part of your app

That extends the functionality of the operating system

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NEW

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That extends the functionality of the operating system

In similar ways to a kernel extension

A System Extension Is

NEW

Part of your app

That extends the functionality of
the operating system

In similar ways to a kernel extension

But running in userspace, outside the kernel

Kinds of System Extensions

Network Extensions

Endpoint Security Extensions

Driver Extensions

Network Extensions

Network Extensions

Replacement for Network Kernel Extensions

Network Extensions

Replacement for Network Kernel Extensions

Supported capabilities

- Content filter
- DNS proxy
- VPN client

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Network Extensions for the Modern Mac

Friday, 9:00

Endpoint Security Extensions

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Replacement for `kauth` event monitoring

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Example types of apps

- Endpoint Detection and Response
- Anti-virus
- Data Loss Prevention

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Security Lab 1	Tuesday, 10:00
Security Lab 2	Thursday, 2:00

Driver Extensions

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Replacement for IOKit device drivers

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Control hardware devices and vend services to the system

- USB
- Serial
- NIC (Network Interface Controller)
- HID (Human Interface Device)

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Built using DriverKit

NEW

DriverKit Is...

NEW

DriverKit Is...

A new SDK with all-new frameworks

NEW

DriverKit Is...

based on IOKit, but updated and modernized

NEW

DriverKit Is...

for building device drivers in userspace, outside the kernel

How Do System Extensions Avoid the Problems of Kernel Extensions?

In userspace, outside the kernel

The Kernel Is an Unforgiving Environment

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The kernel must never stop running, must never wait, must never crash

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Code in the kernel has to be

- Fast
- Predictable
- Frugal with resources like memory
- Bug-free

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Difficult to write and debug kernel code

In userspace, outside the kernel

Comfortable, modern programming environment

Kexts vs. System Extensions

Easier development

Kexts vs. System Extensions

Easier development

Restrictions on dynamic memory
allocation, synchronization, latency

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Use any framework in the macOS SDK

Kexts vs. System Extensions

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No such restrictions

Use any framework in the macOS SDK

Use any language, including Swift

Kexts vs. System Extensions

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Exception: Driver Extensions

Direct control of hardware still imposes some restrictions

DriverKit frameworks in tailored runtime

DriverKit API is C++17

Kexts vs. System Extensions

Easier debugging

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Debugging the kernel halts everything

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Two-machine debugging

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- Special debug cables or LAN setup

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Kernel and other apps keep running if system extension stops

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Build, test, debug on one machine

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Full debugger support

Kexts vs. System Extensions

Security, privacy, reliability

Code Signing

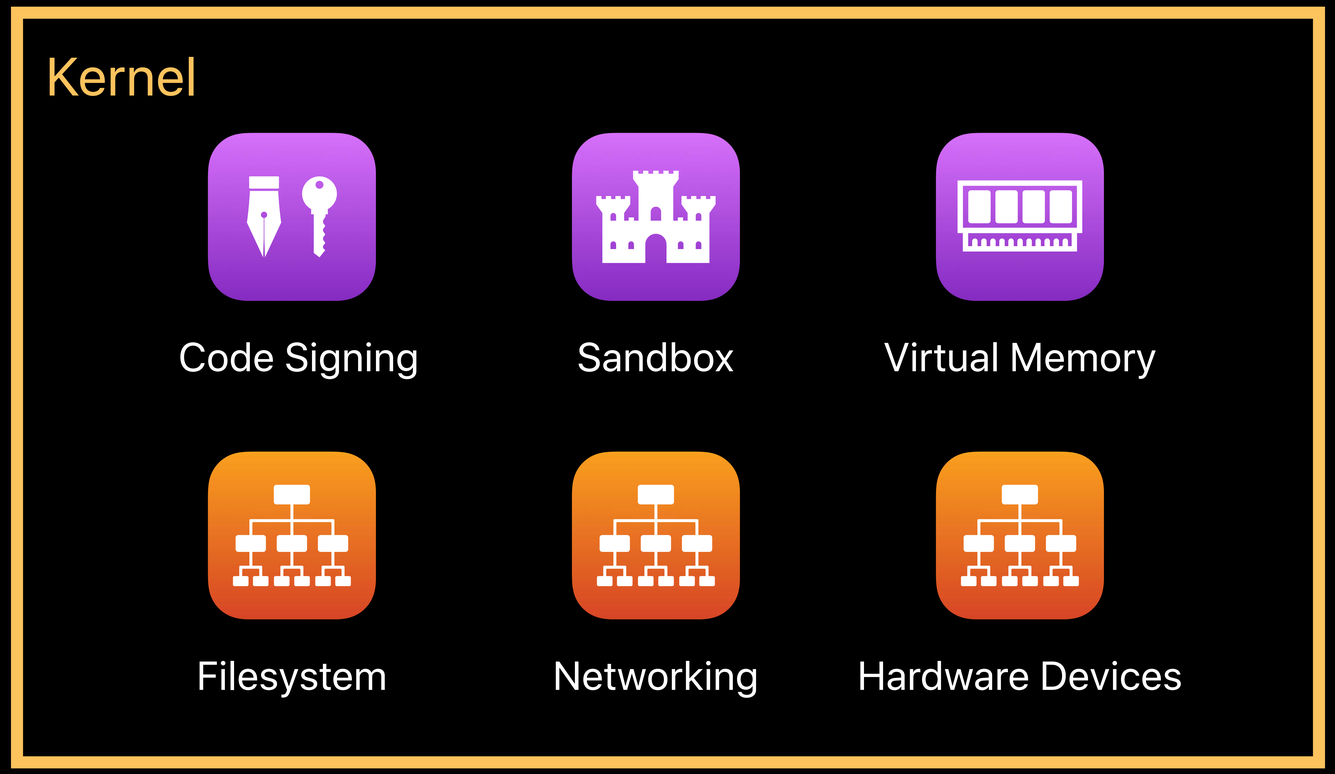
Sandbox

Virtual Memory

Filesystem

Networking

Hardware Devices


Kernel
Code Signing
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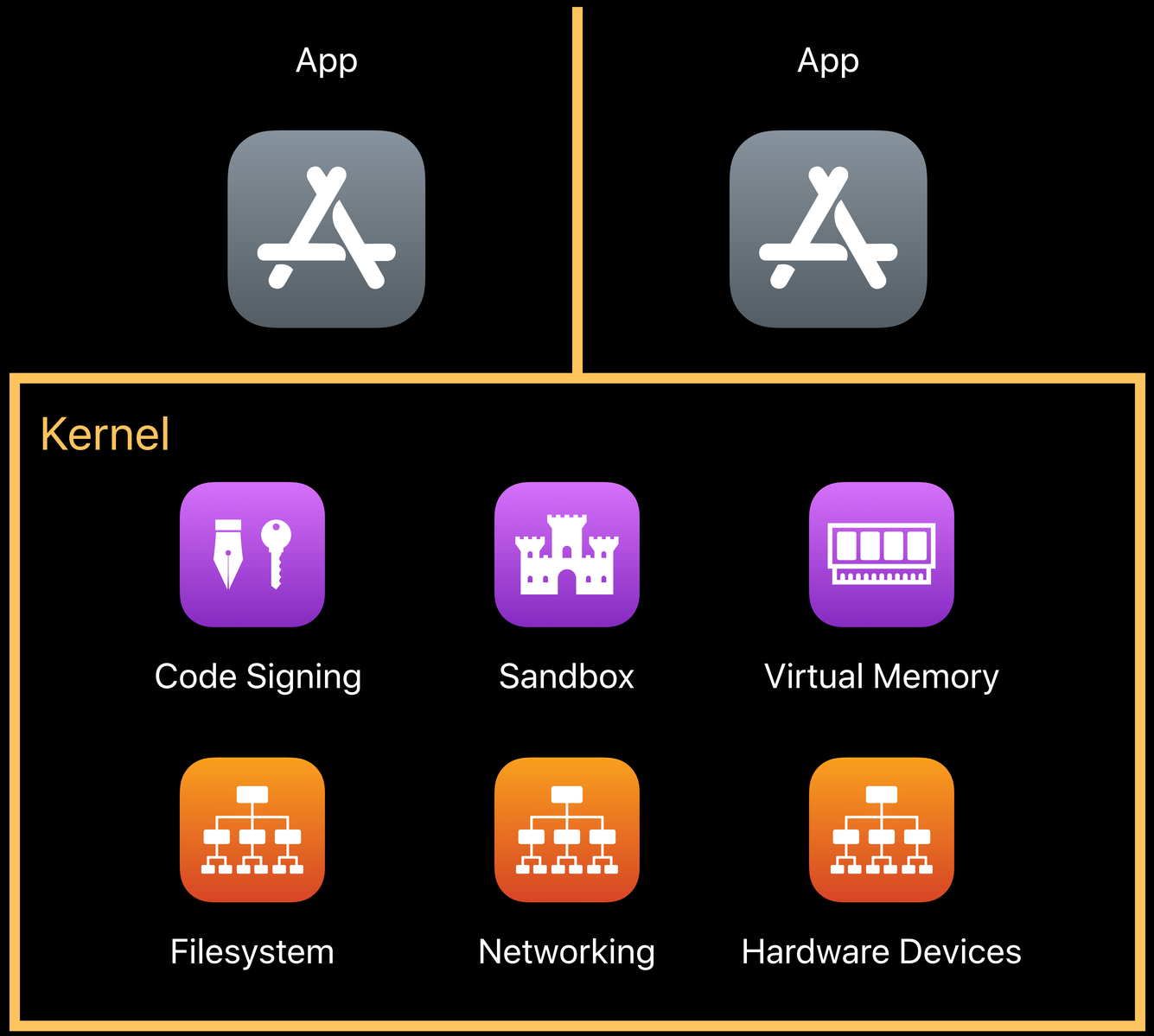
Hardware Devices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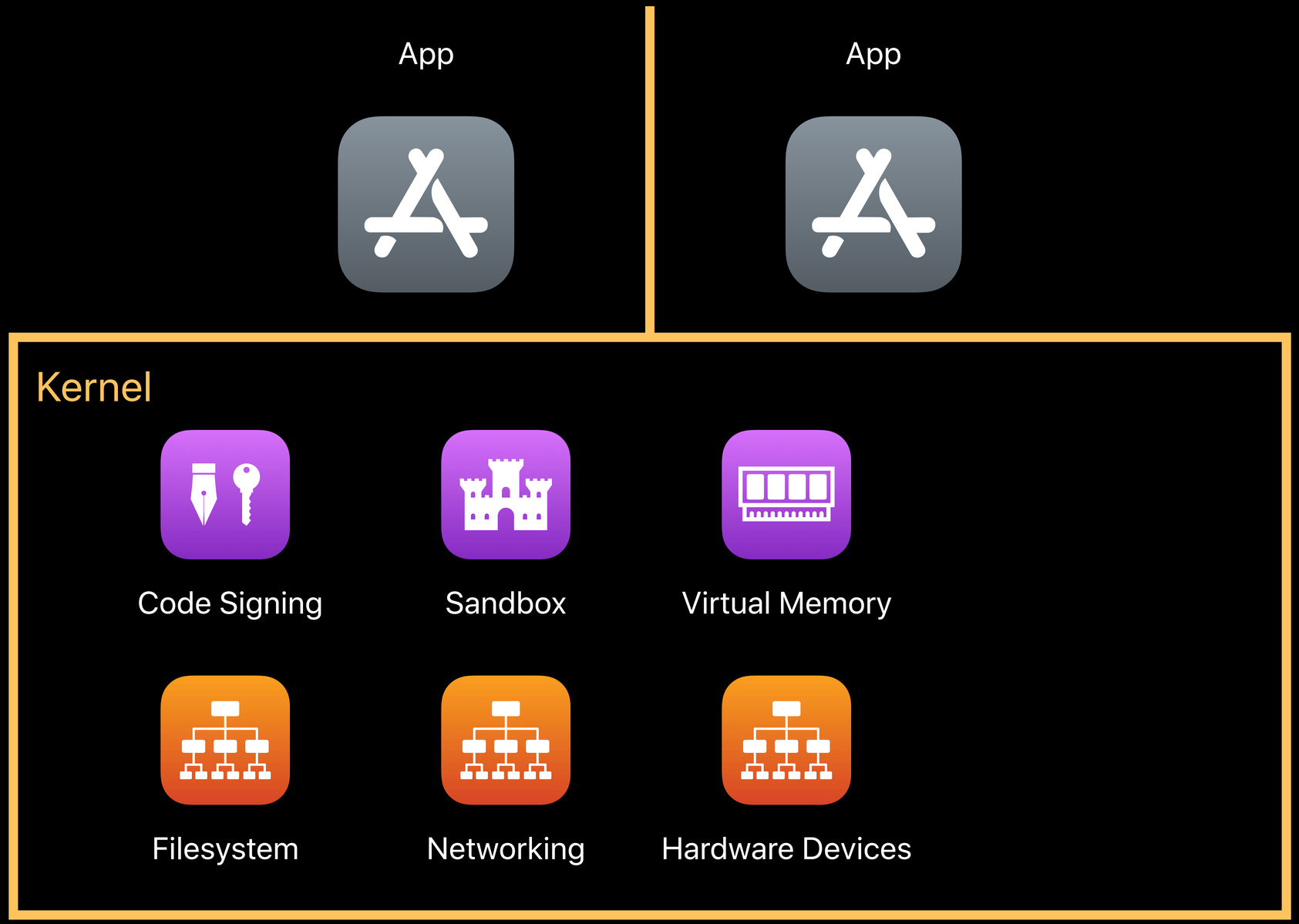
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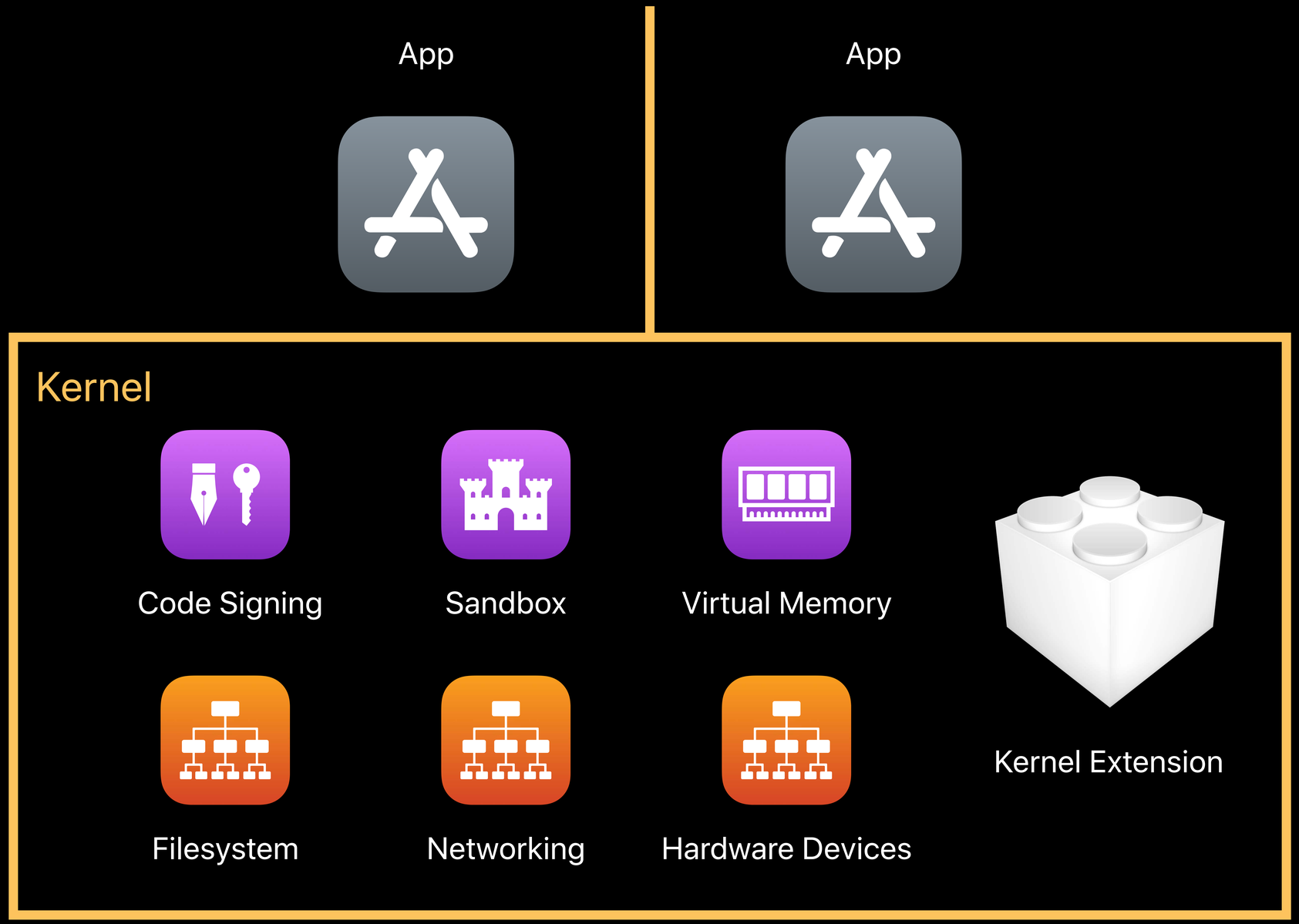
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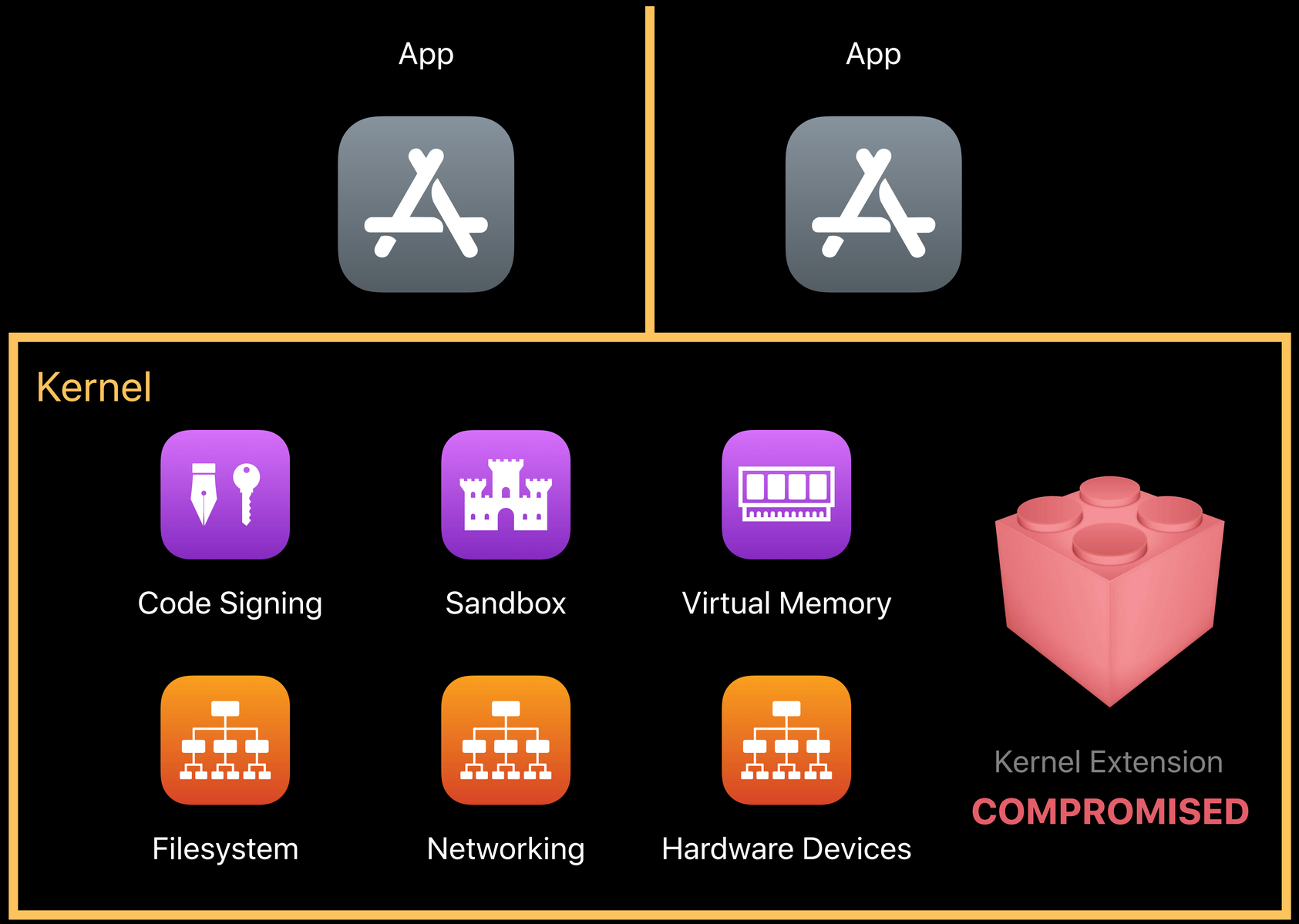
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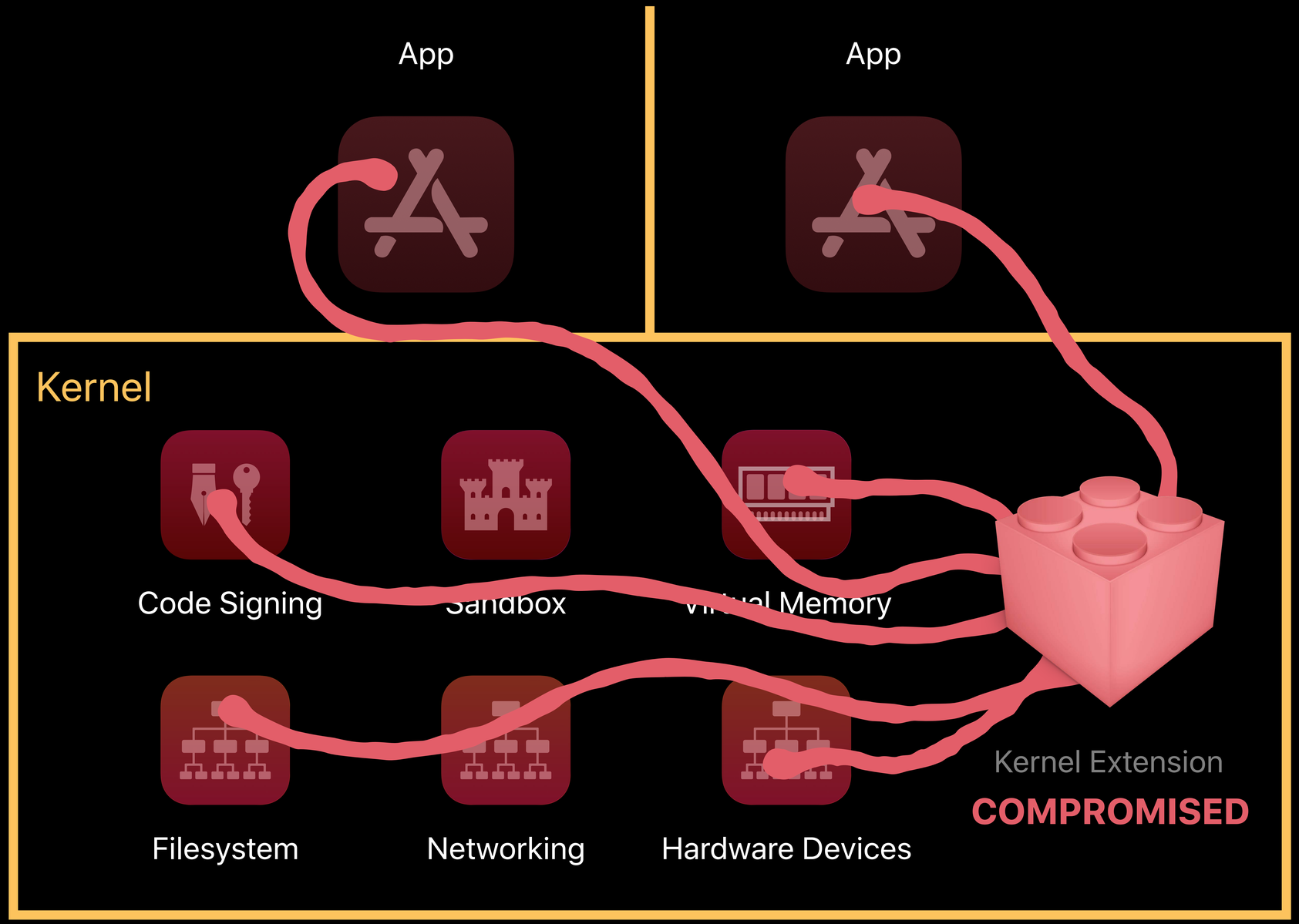
Kernel Extension
COMPROMISED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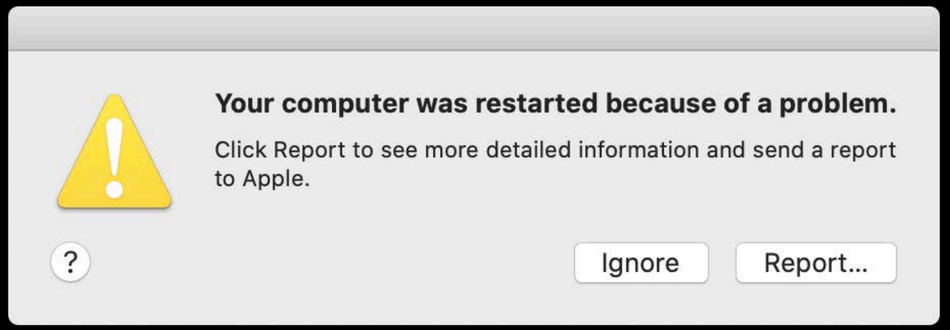
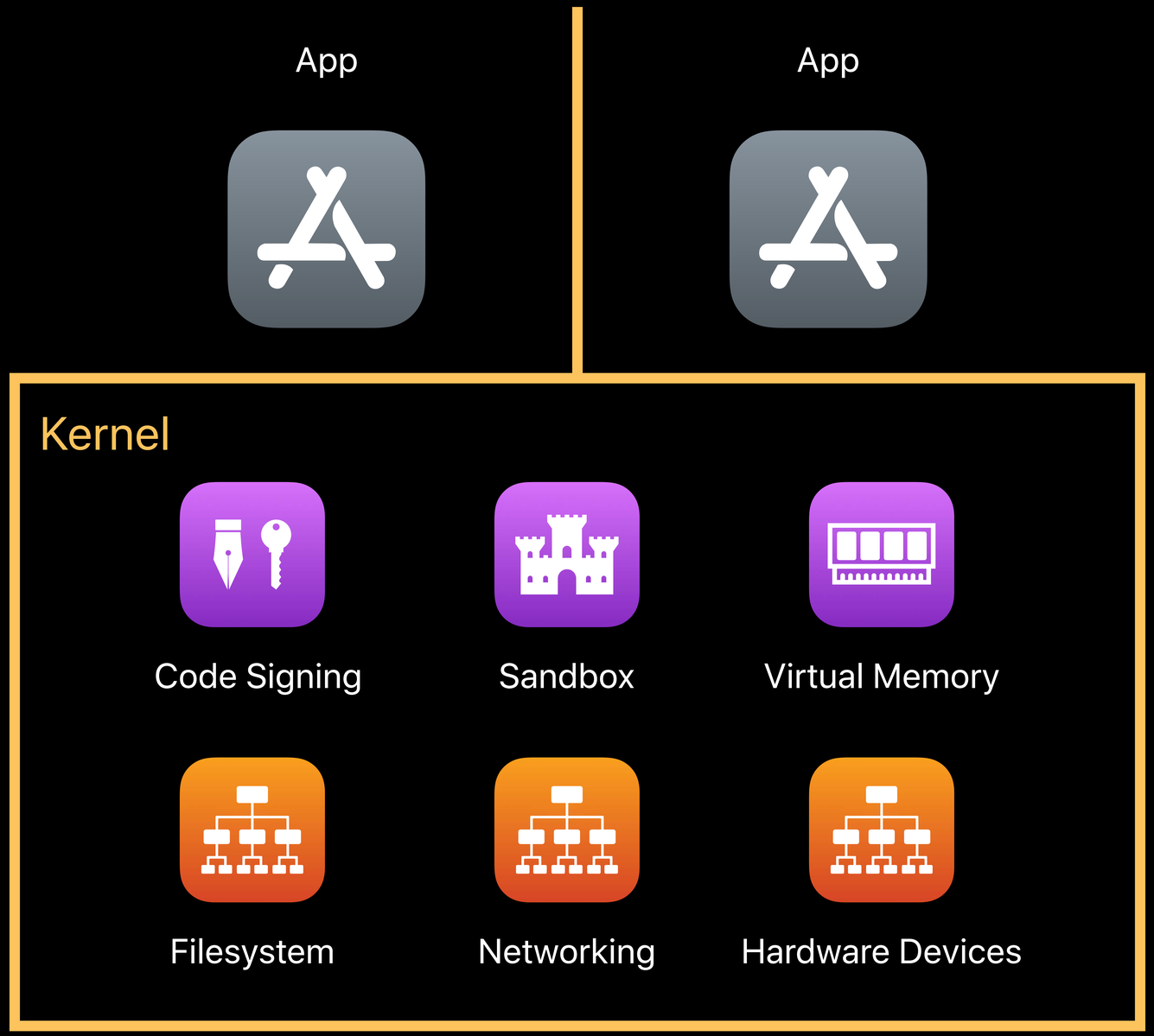

Your computer was restarted because of a problem.
Click Report to see more detailed information and send a report to Apple.
?
Ignore
Report...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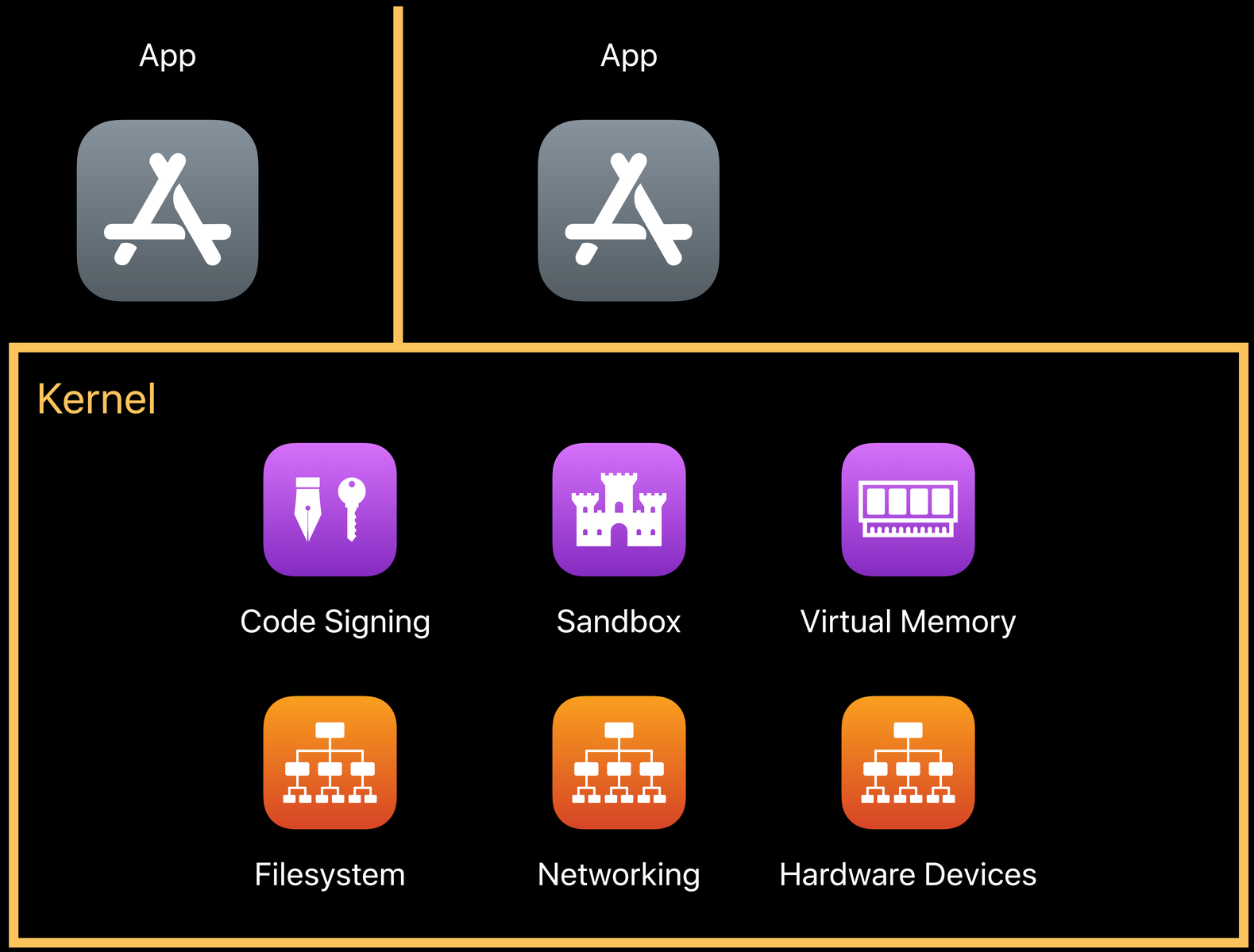
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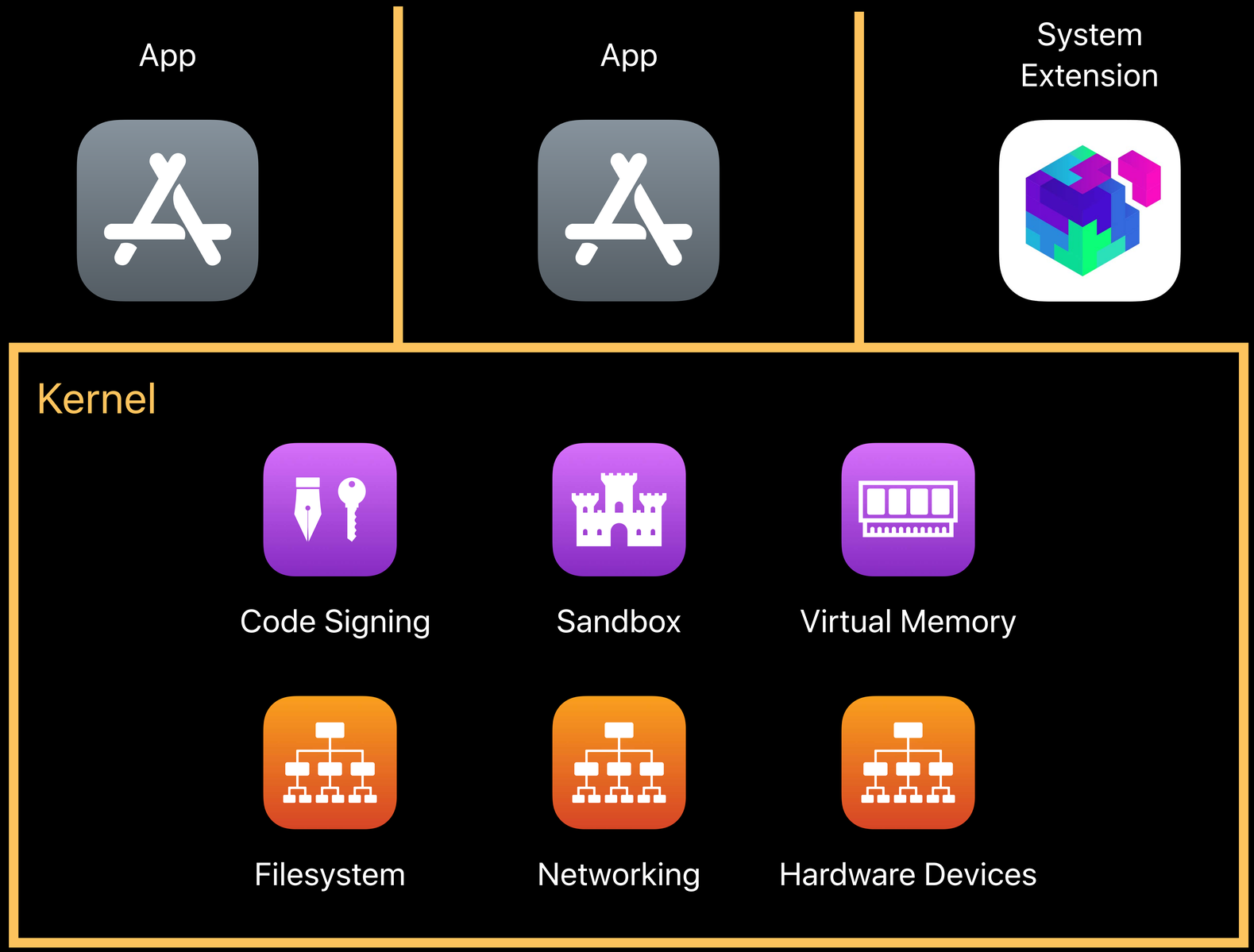
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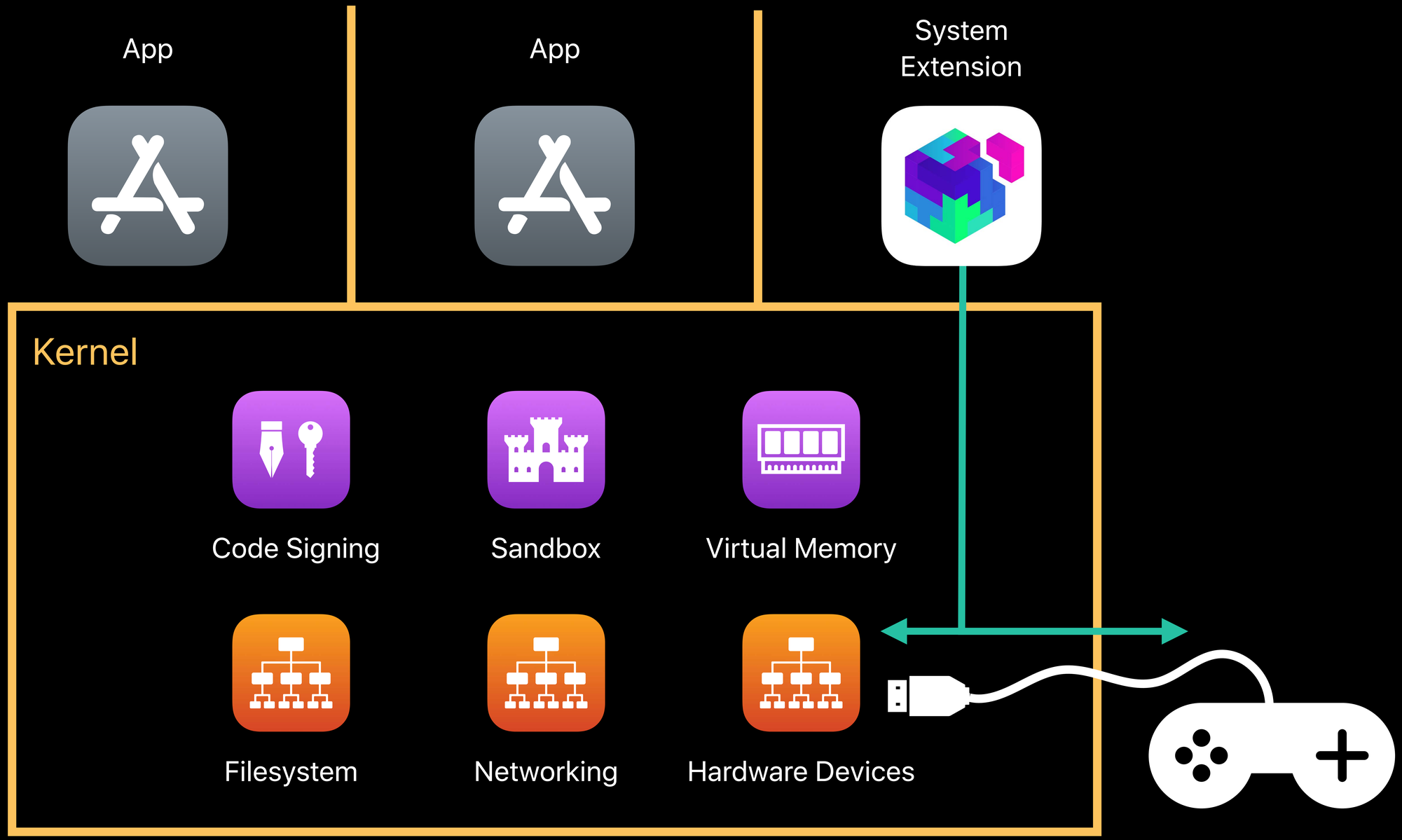
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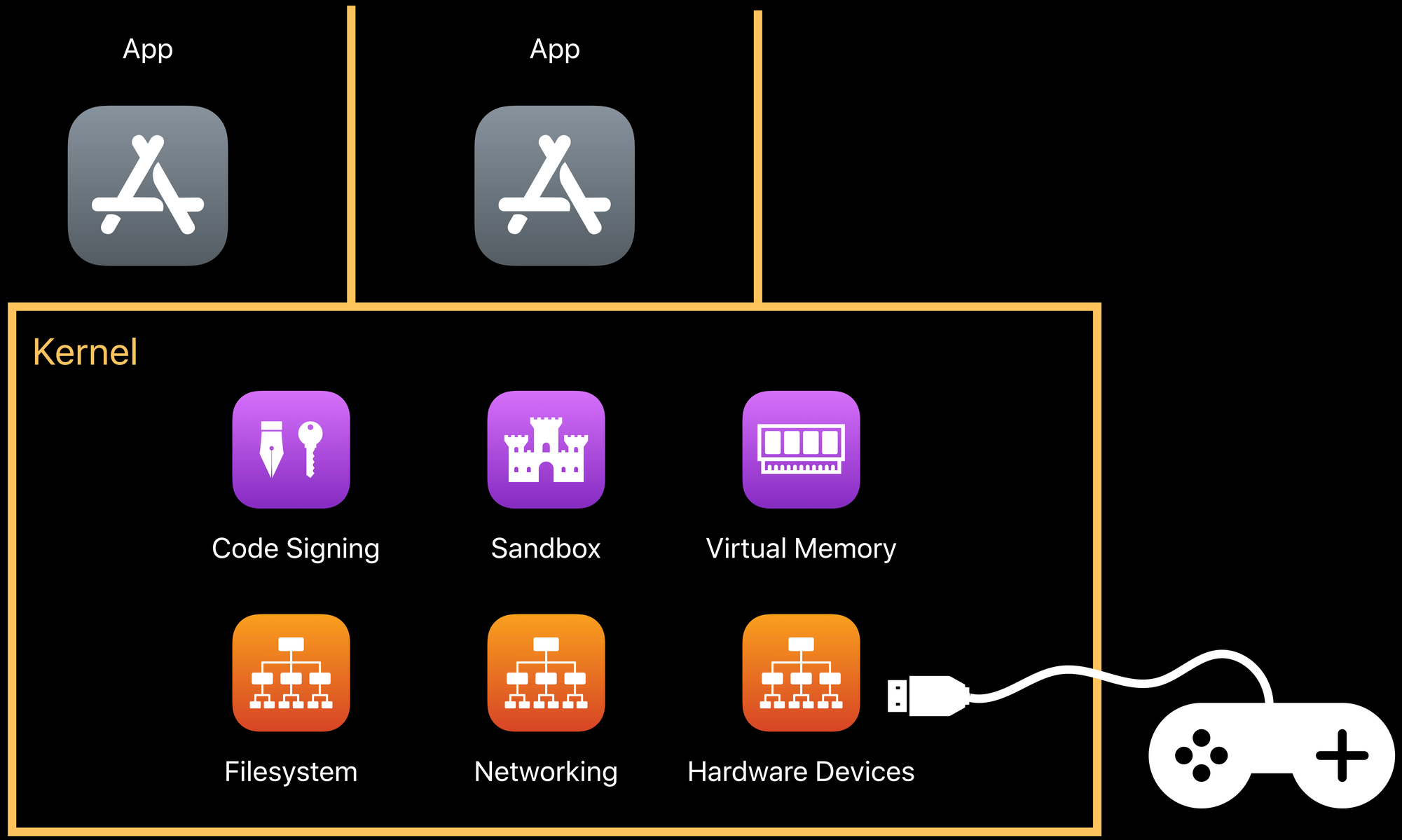
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System Extensions are a big step forward for the Mac platform

Deprecating Kernel Extensions

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macOS 10.15 will be the last release to fully support kexts without compromises

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For the capabilities and device families supported by System Extensions, using a Kernel Extension to perform the same function is deprecated

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macOS 10.15 will be the last release to fully support kexts without compromises

For the capabilities and device families supported by System Extensions, using a Kernel Extension to perform the same function is deprecated

In a future release of macOS, Kernel Extensions of these kinds will not load

Deprecating Kernel Extensions — In the Future

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More kinds of System Extensions will be added

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More kinds of System Extensions will be added

More DriverKit device families will be added

Deprecating Kernel Extensions — In the Future

More kinds of System Extensions will be added

More DriverKit device families will be added

In turn, Kernel Extensions of those kinds will also be deprecated

System Extensions

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Avoid the difficulties and dangers of kernel programming by running in userspace

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Easier to develop and debug

System Extensions

Avoid the difficulties and dangers of kernel programming by running in userspace

Easier to develop and debug

Protect data security, privacy, reliability

Driver Extensions

Using DriverKit to build user space drivers

Simon Douglas, Core Kernel

Driver Extensions

Driver Extensions

System Extensions that control hardware

Driver Extensions

System Extensions that control hardware

Provide a service available to the entire system

Driver Extensions

System Extensions that control hardware

Provide a service available to the entire system

Driver Extension is a “dext”

Driver Extensions

Driver Extensions

Lifecycle

Driver Extensions

Lifecycle

Building

Driver Extensions

Lifecycle

Building

Security

Driver Extensions

Lifecycle

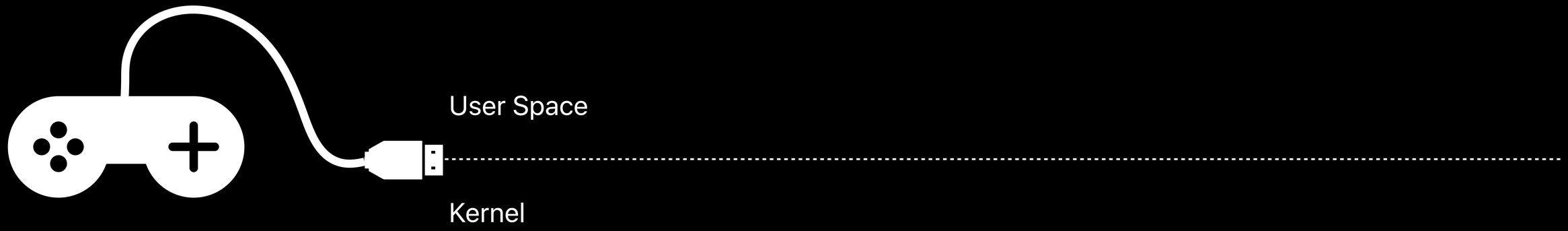
Building

Security

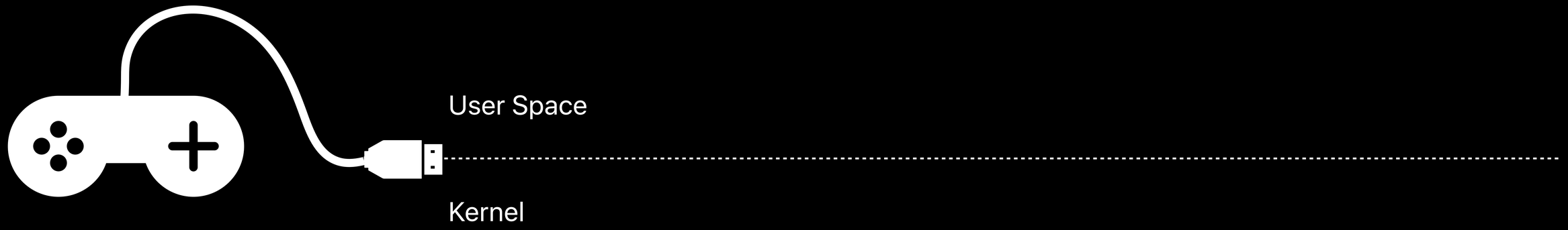
Compatibility

Lifecycle of a Dext

Lifecycle of a Dext



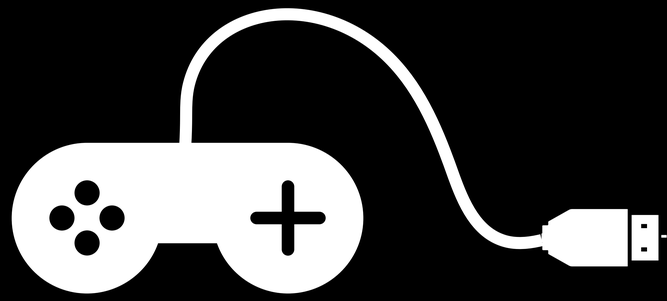
Lifecycle of a Dext



IOKit Matching

USB Device

Lifecycle of a Dext



User Space

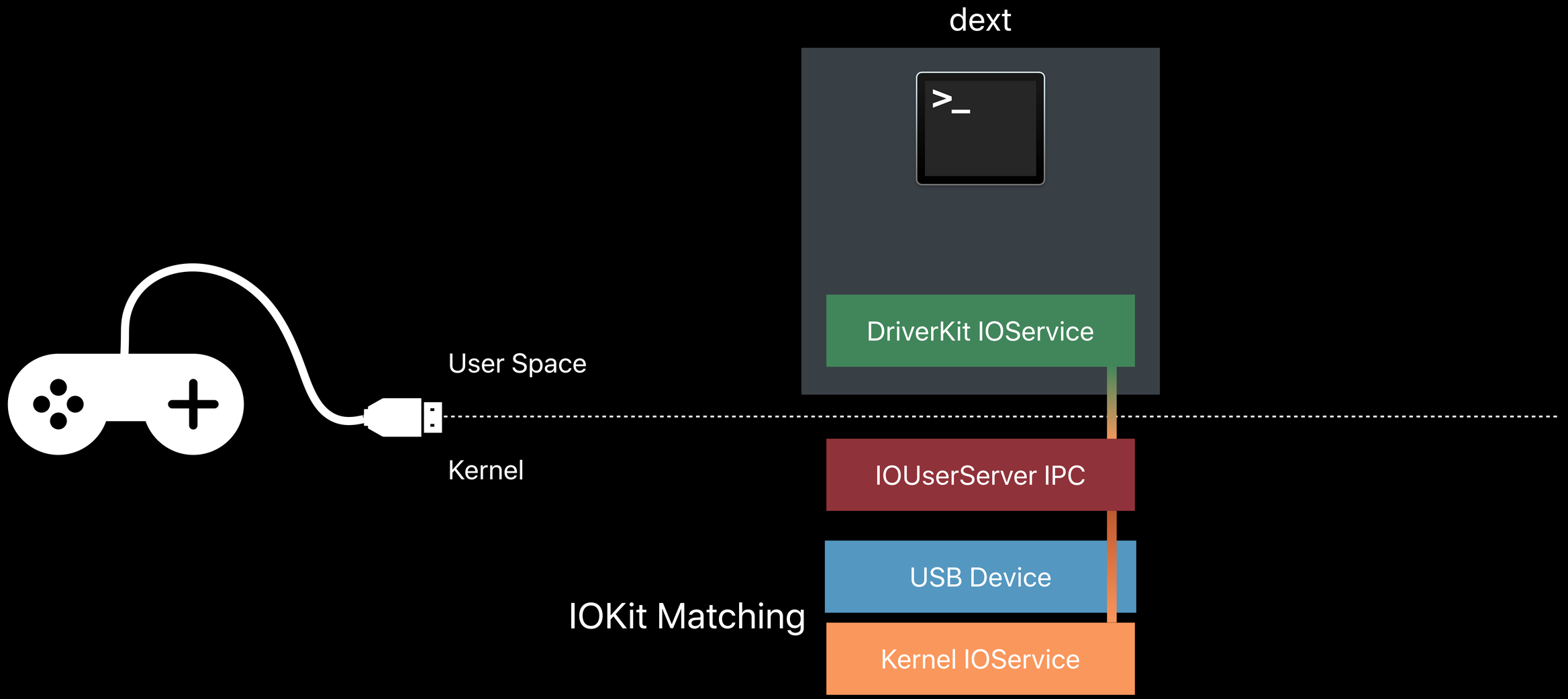
Kernel

IOKit Matching

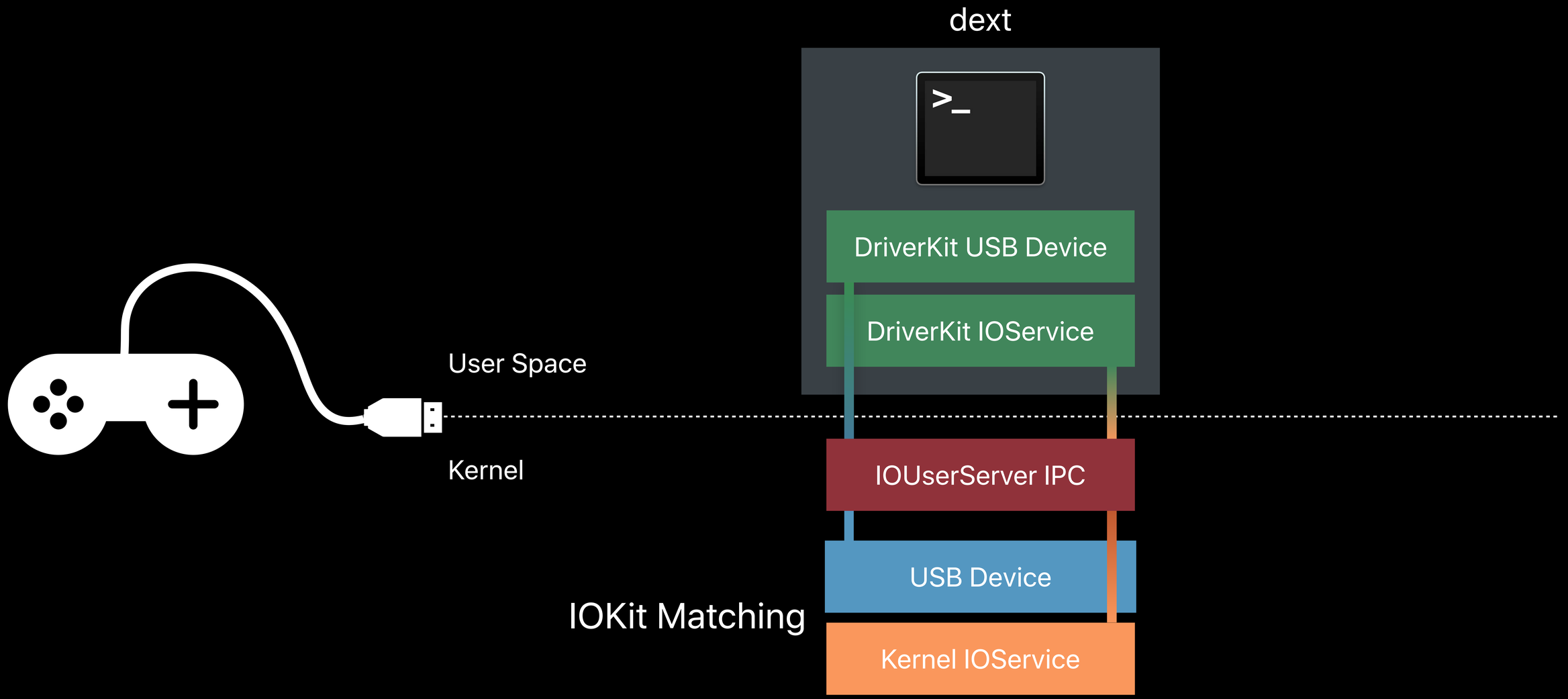
USB Device

Kernel IOService

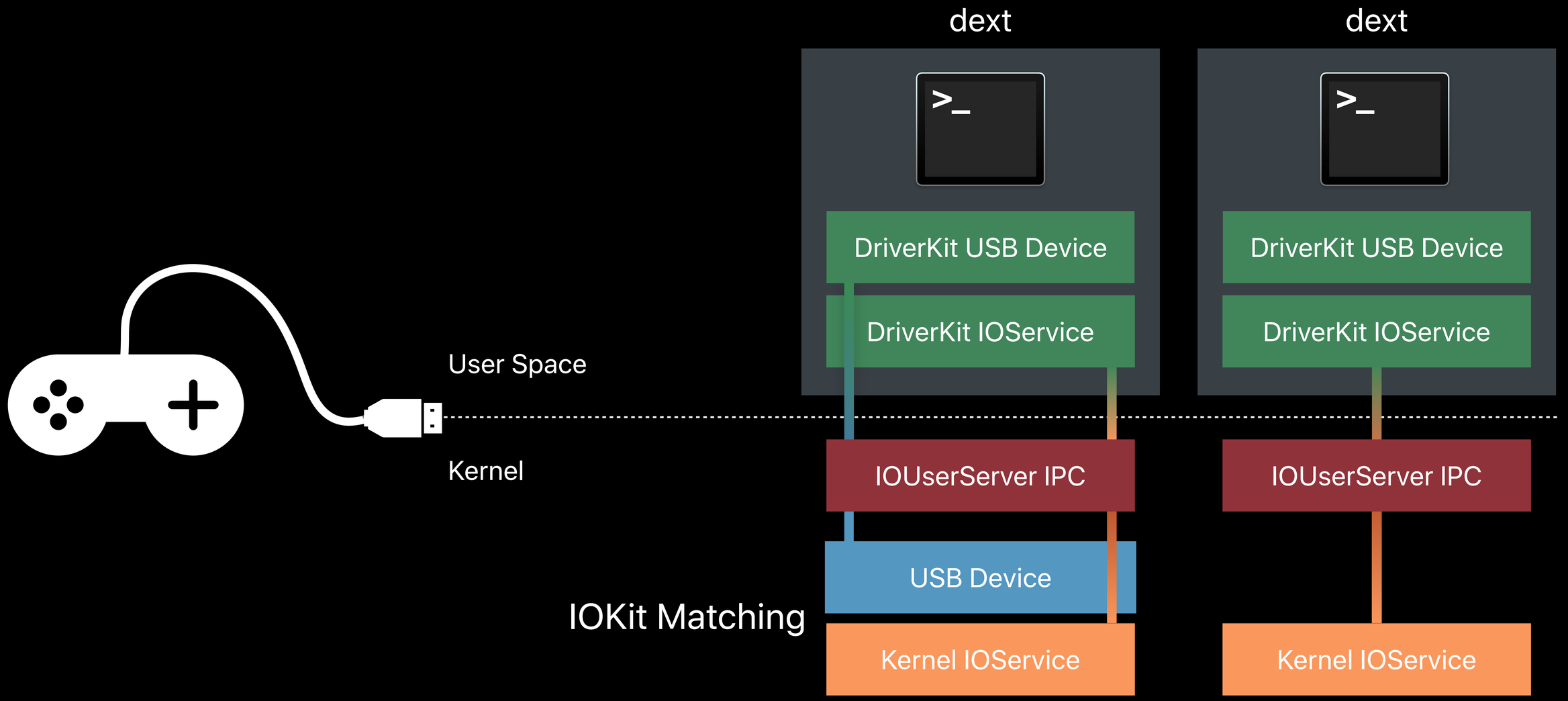
Lifecycle of a Dext



Lifecycle of a Dext



Lifecycle of a Dext



```
// Driver Extensions on macOS

~ % ps -eo user,command | grep ECM
_driverkit       /System/Library/DriverExtensions/AppleUserECM.dext/AppleUserECM
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~ % ps -eo user,command | grep ECM
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~ % ioreg | grep AppleUserECM
    +-o AppleUserECM  <class IOUserNetworkEthernet, id 0x1000003bc, registered, matched…
```

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~ % ioreg | grep IOUserServer
…
    +-o IOUserServer(com.apple.driverkit.AppleUserUSBHostHIDDevice0-0x100000962) …
    +-o IOUserServer(com.apple.driverkit.AppleUserUSBHostHIDDevice0-0x100000960) …
    +-o IOUserServer(com.apple.DriverKit.AppleUSBFTDI-0x1000009a5) …
    +-o IOUserServer(com.apple.driverkit.AppleUserHIDEventDriver-0x1000009cc) …
    +-o IOUserServer(com.apple.DriverKit.AppleUserECM-0x10002db50) …
```

Building with DriverKit SDK

DriverKit SDK

DriverKit SDK

Extension of IOKit APIs

DriverKit SDK

Extension of IOKit APIs

Limited API surface

DriverKit SDK

Extension of IOKit APIs

Limited API surface

No direct access to file system, networking, IPC

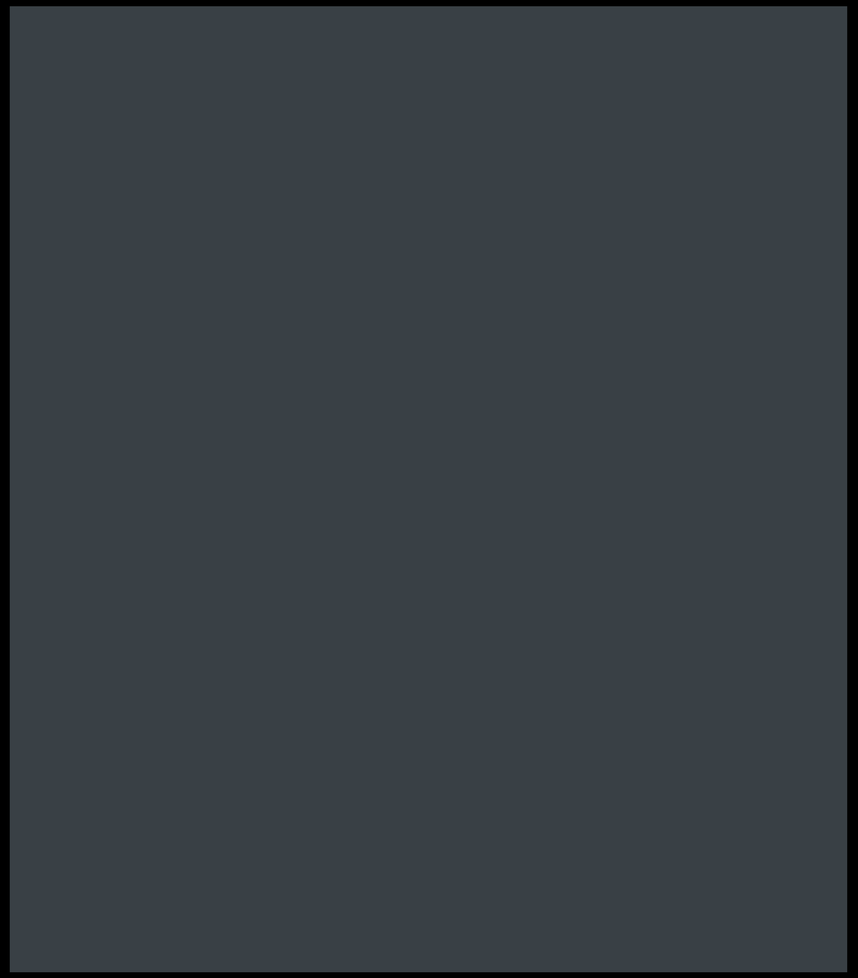
DriverKit SDK

Classes

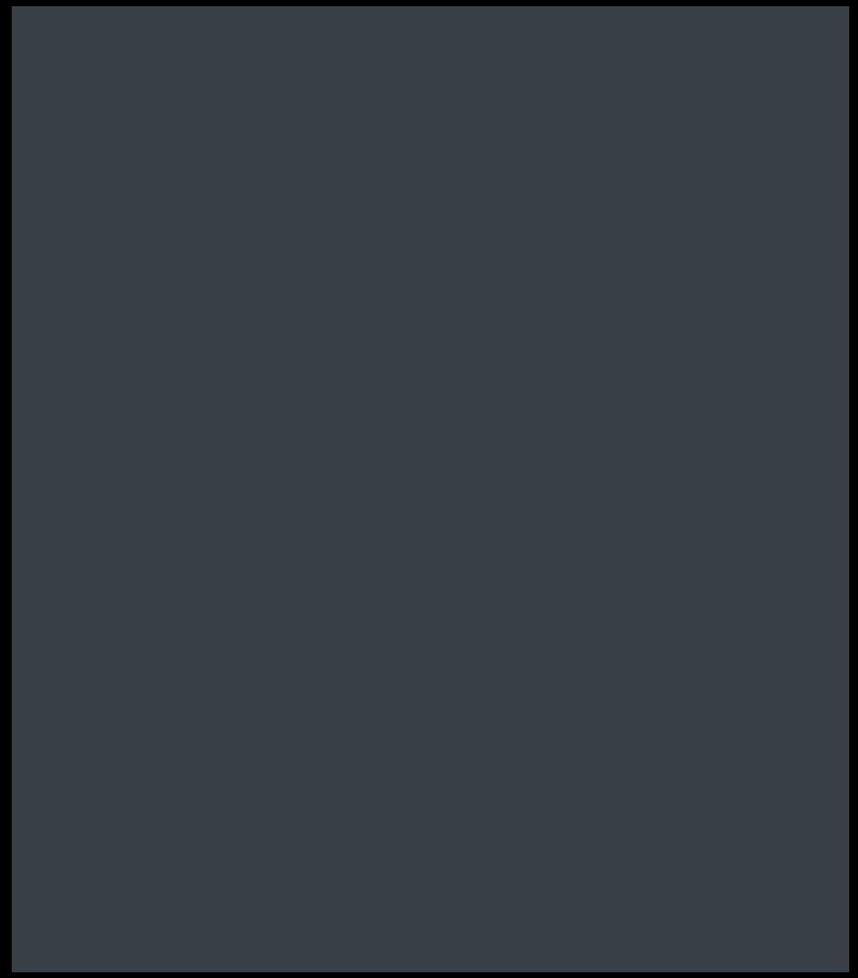
DriverKit SDK

Classes

IOKit Classes



DriverKit SDK



DriverKit SDK

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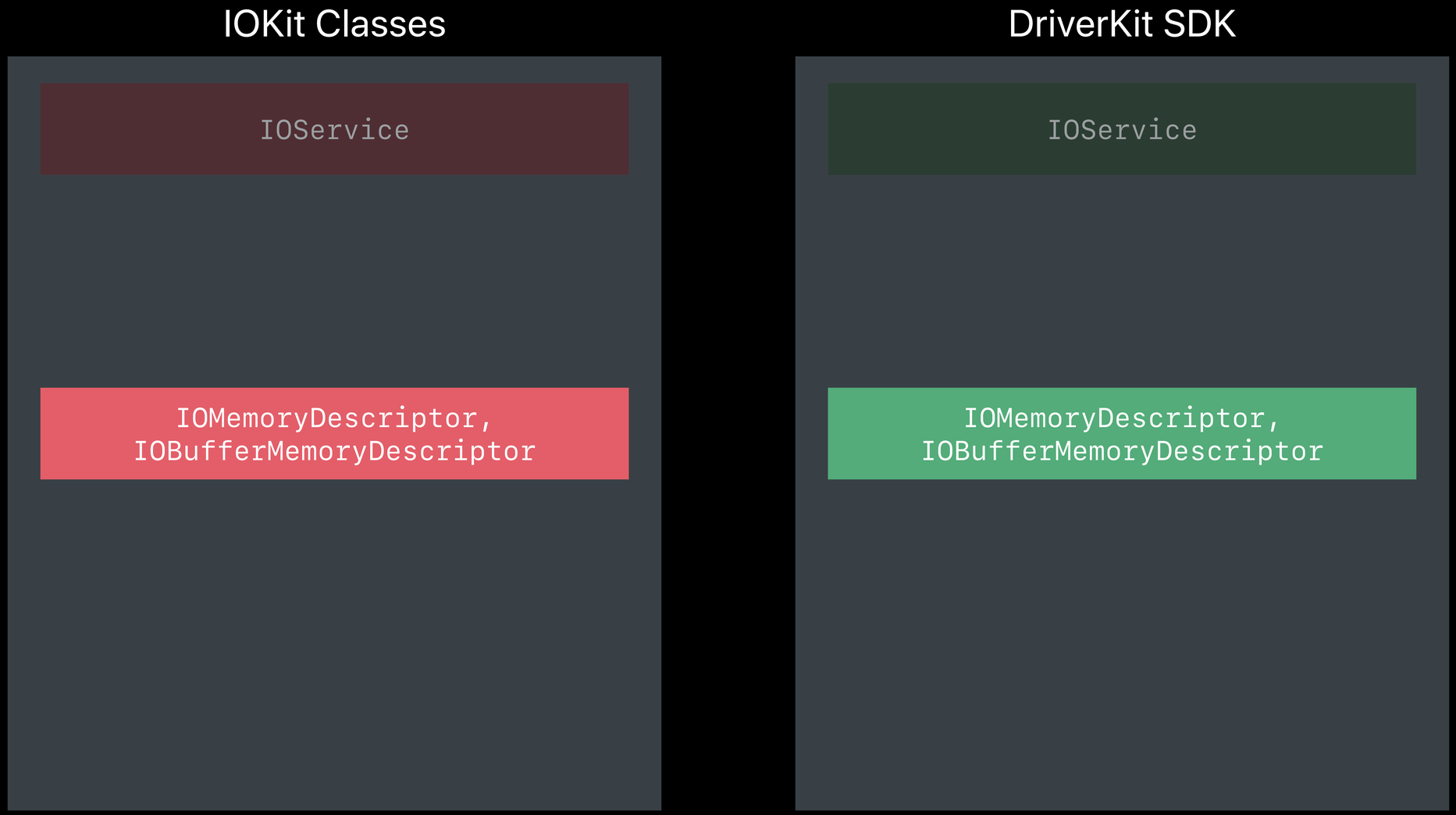
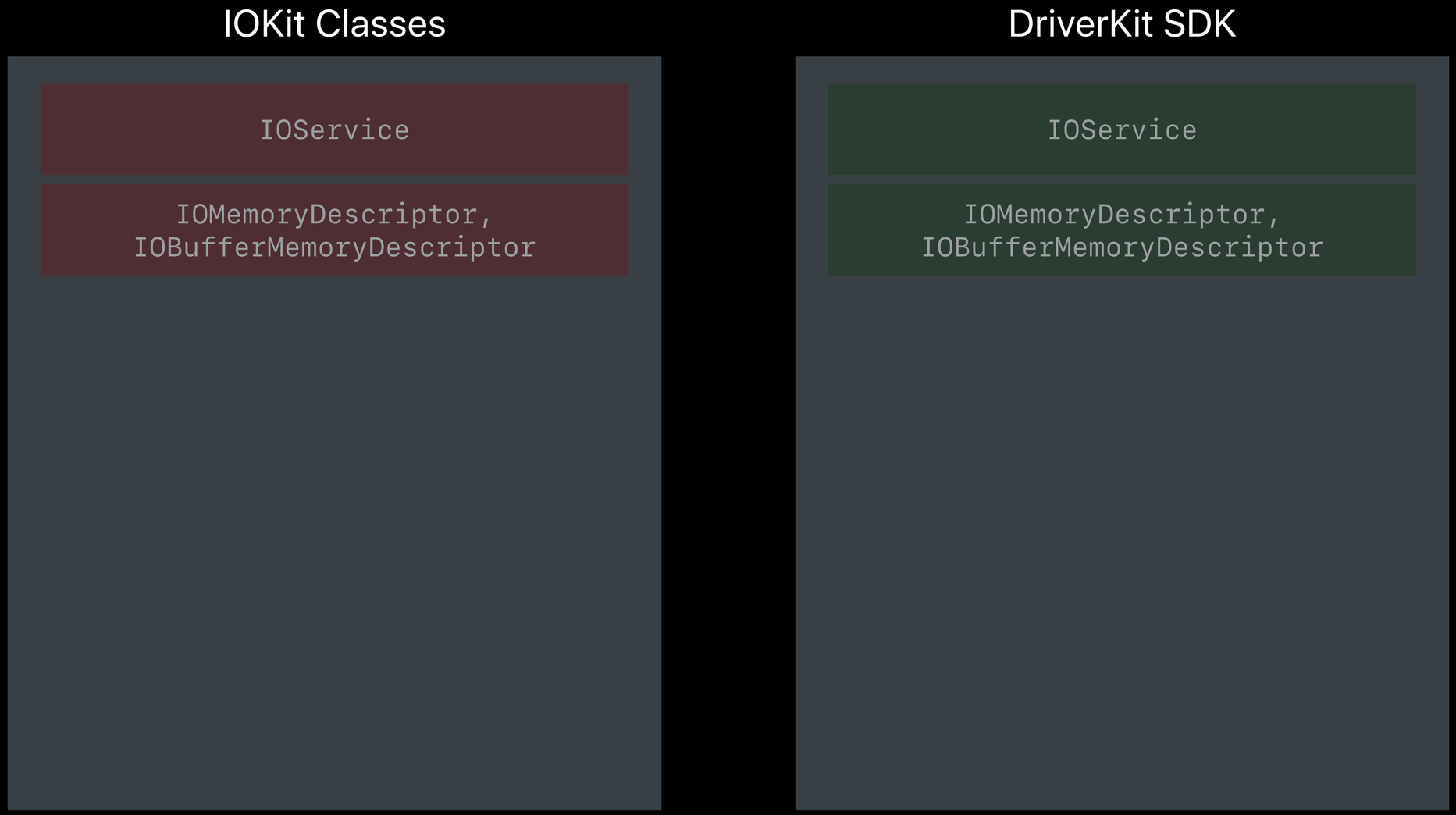


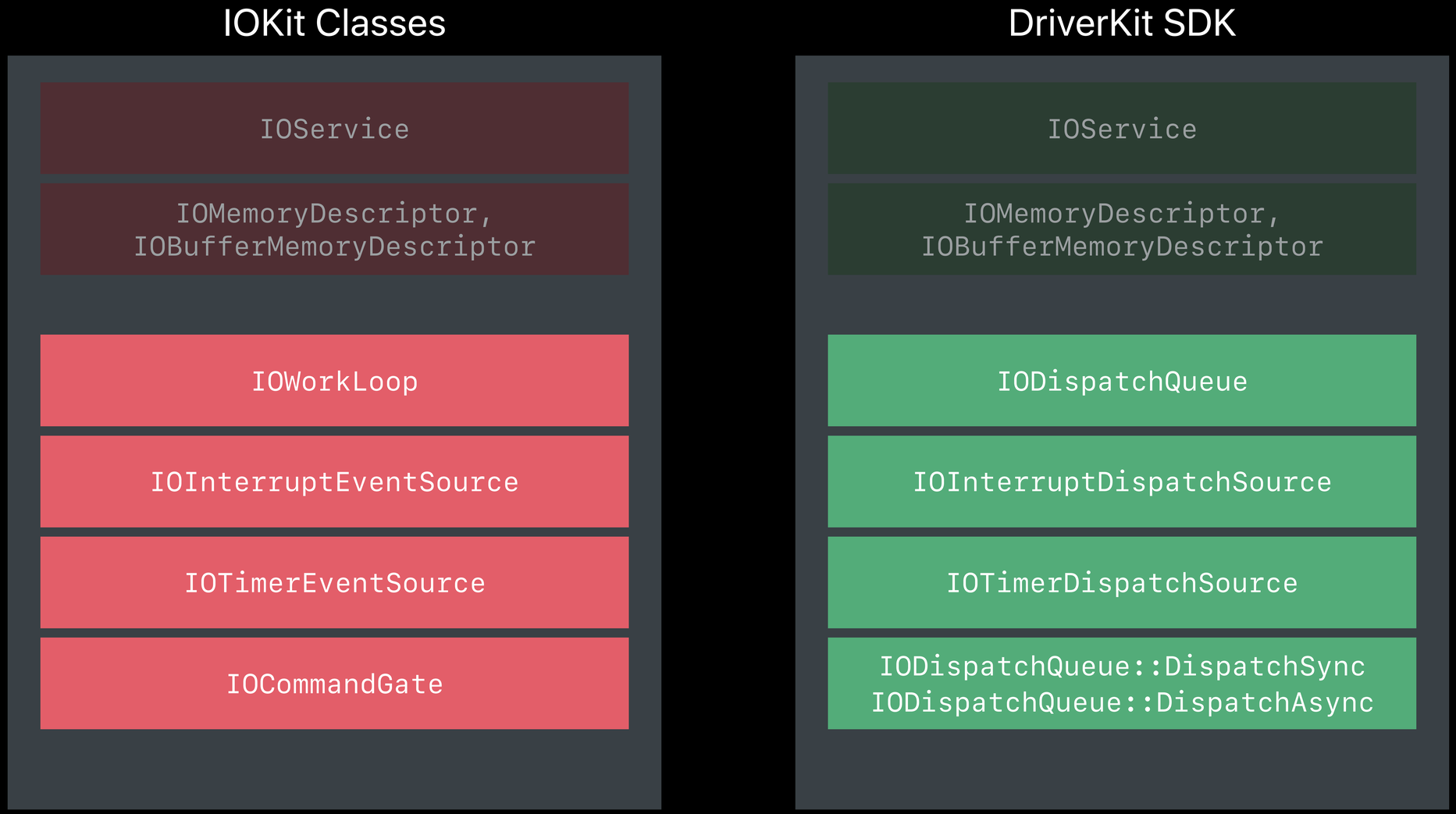
DriverKit SDK

Classes



DriverKit SDK

Classes



DriverKit SDK

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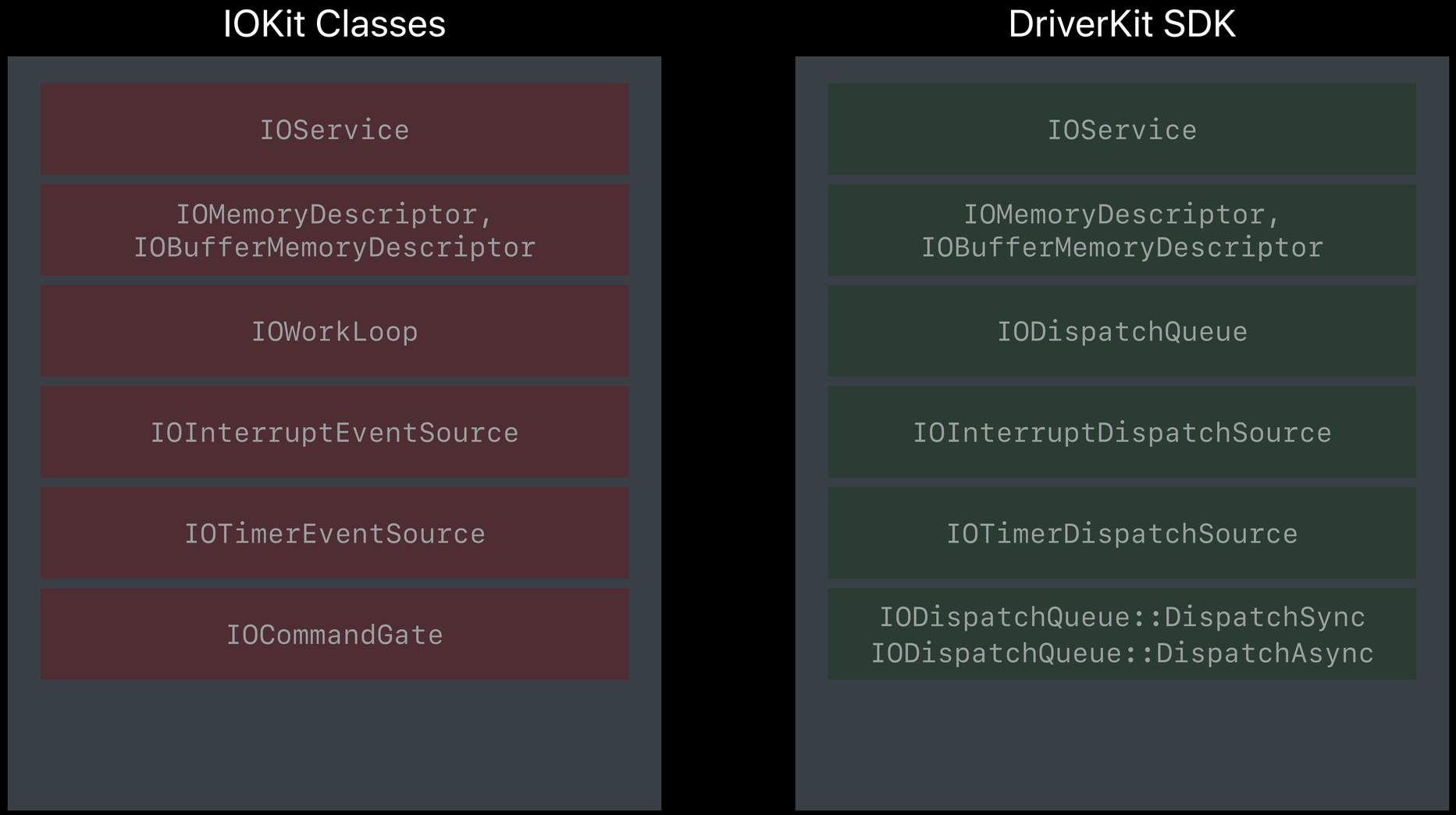

DriverKit SDK

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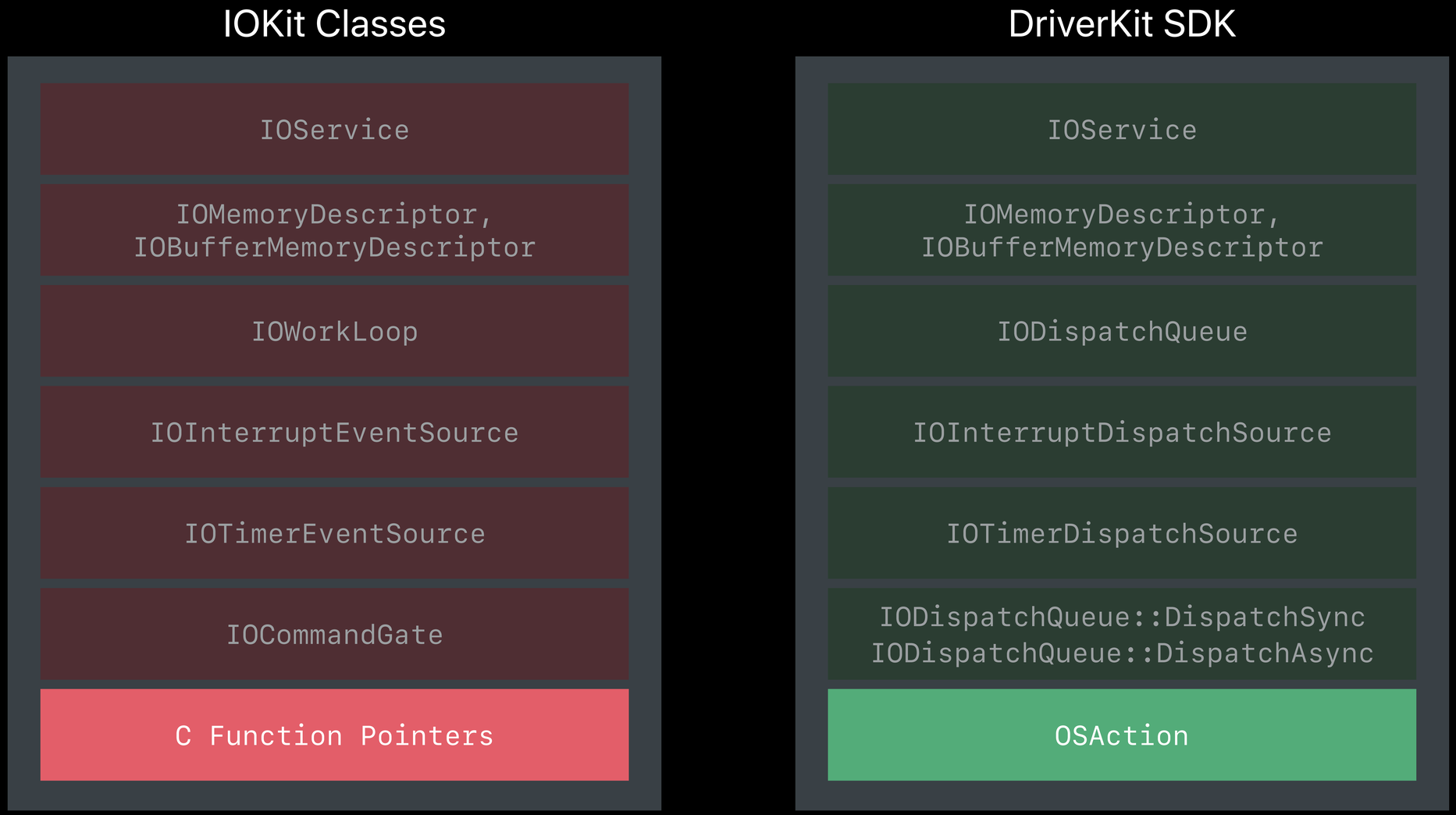

DriverKit SDK

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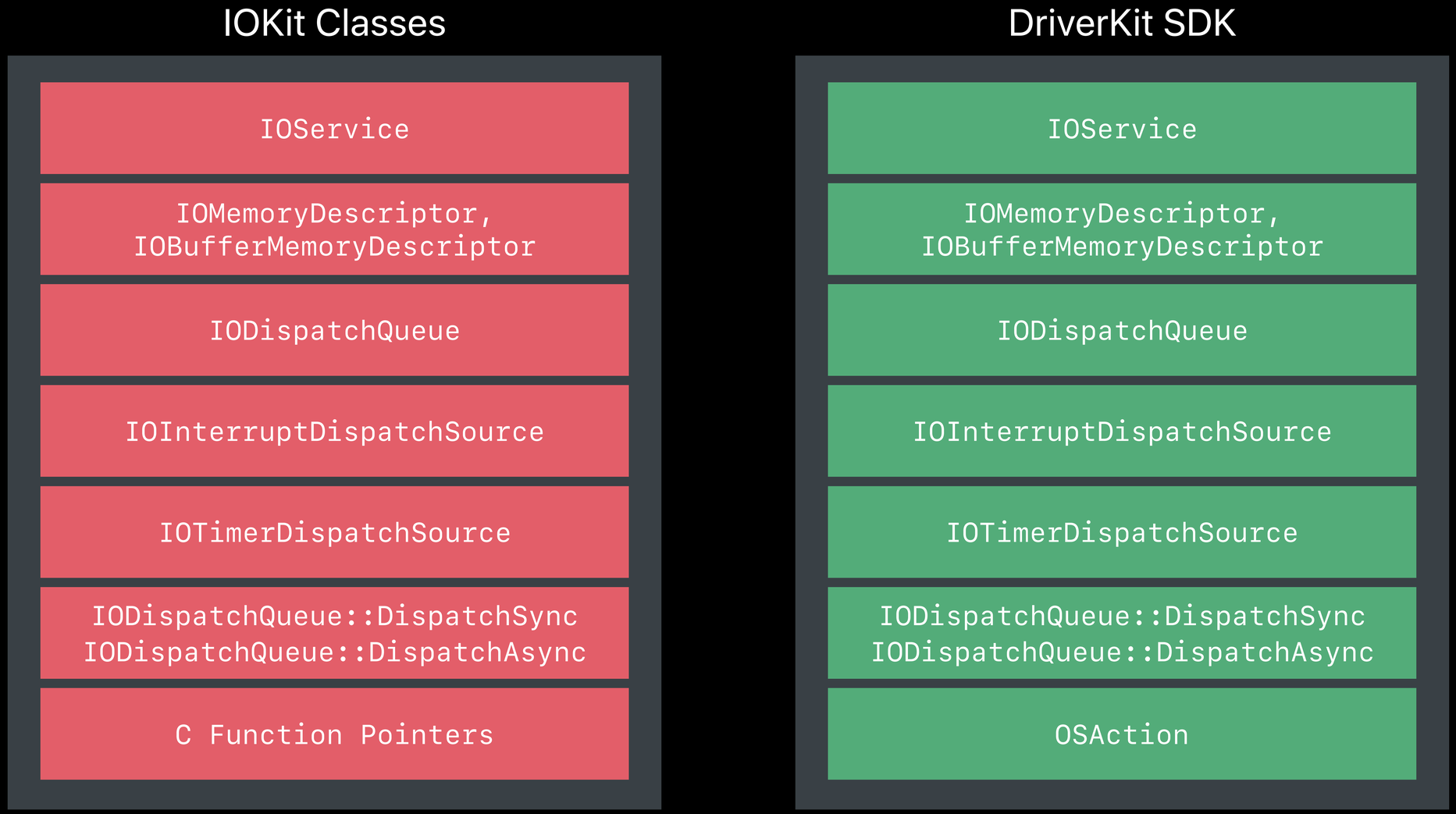
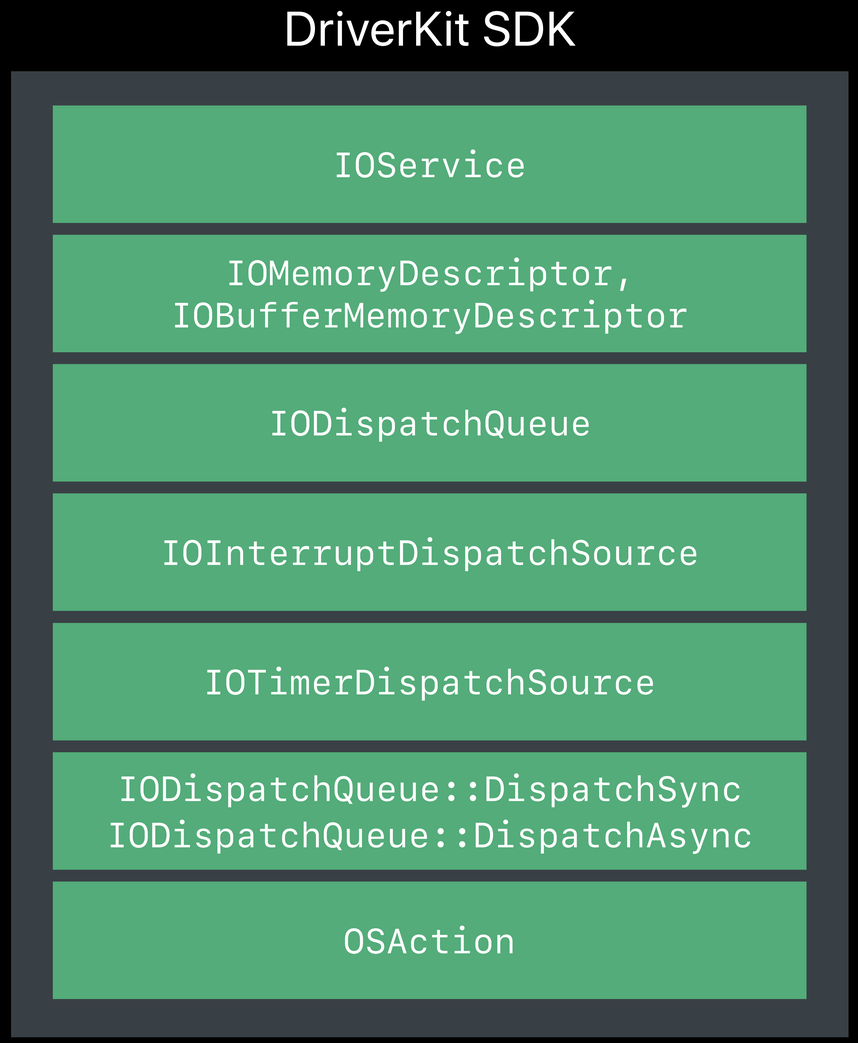


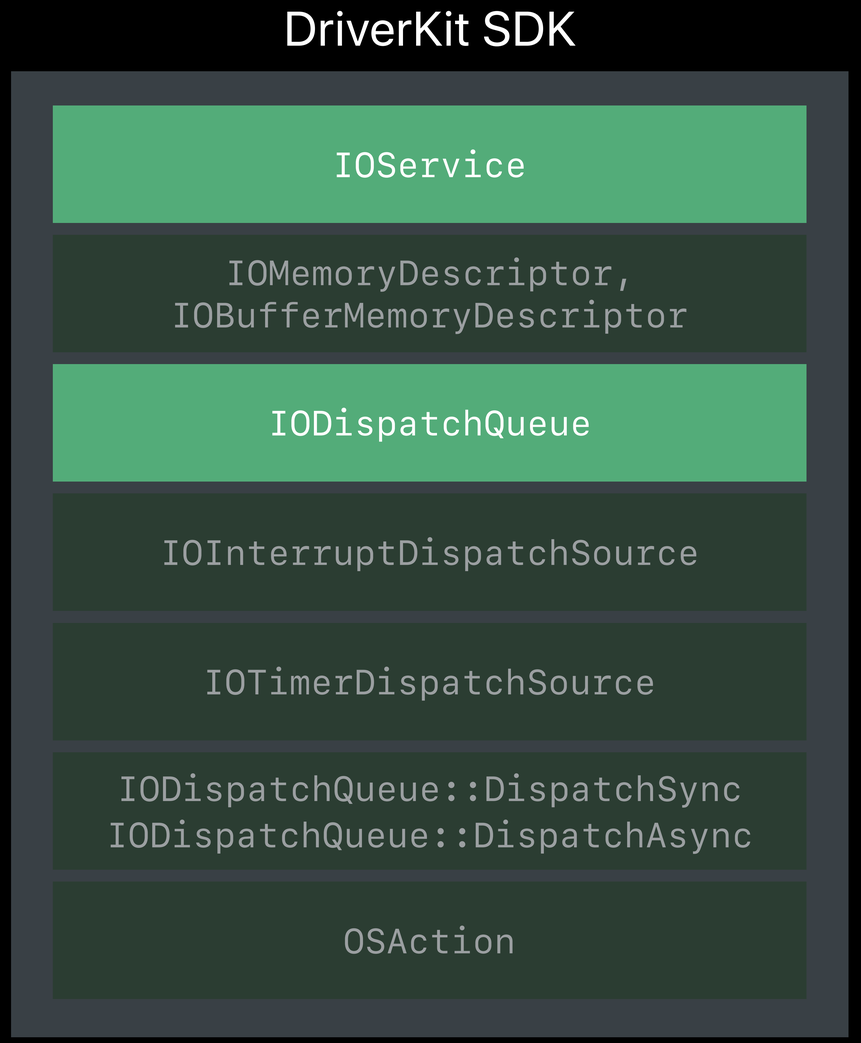
DriverKit SDK

Classes



DriverKit SDK

IOService

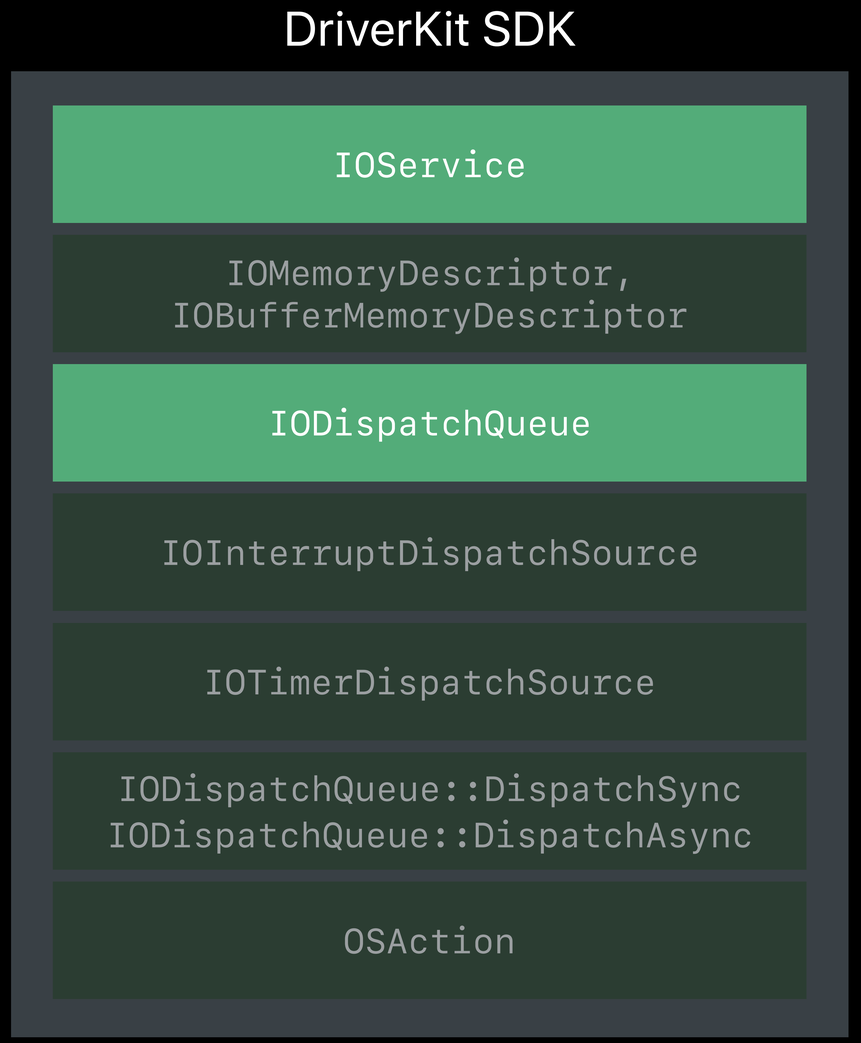


DriverKit SDK

IOService

IOService lifecycle APIs from IOKit

- Start/Stop/Terminate



DriverKit SDK

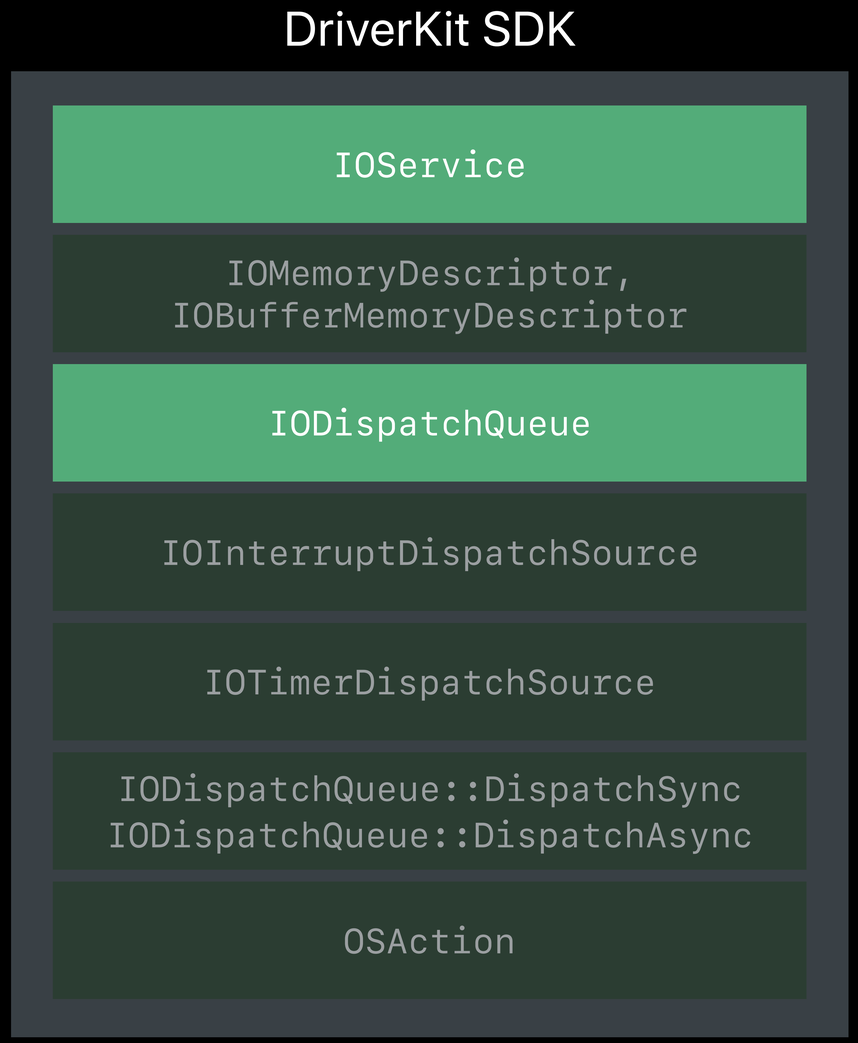
IOService

IOService lifecycle APIs from IOKit

- Start/Stop/Terminate

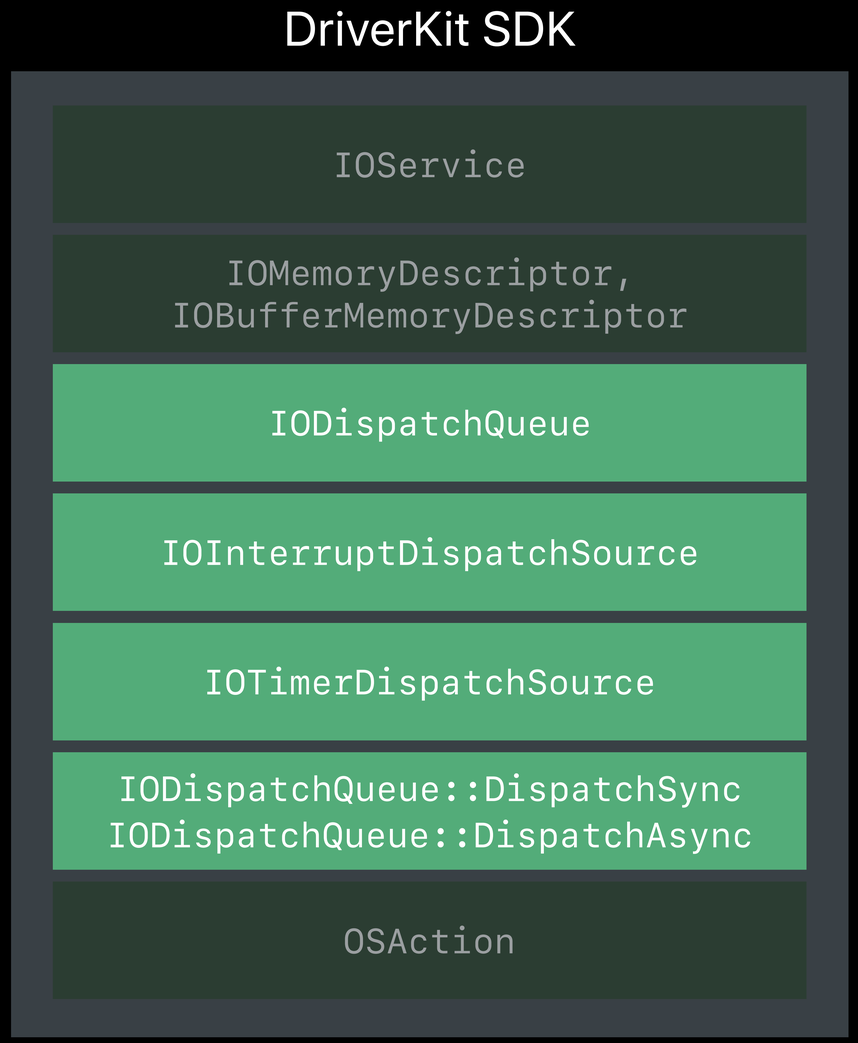
IODispatchQueue from Grand Central Dispatch

- All methods invoked on a queue
- Drivers have control of their queues



DriverKit SDK

Events



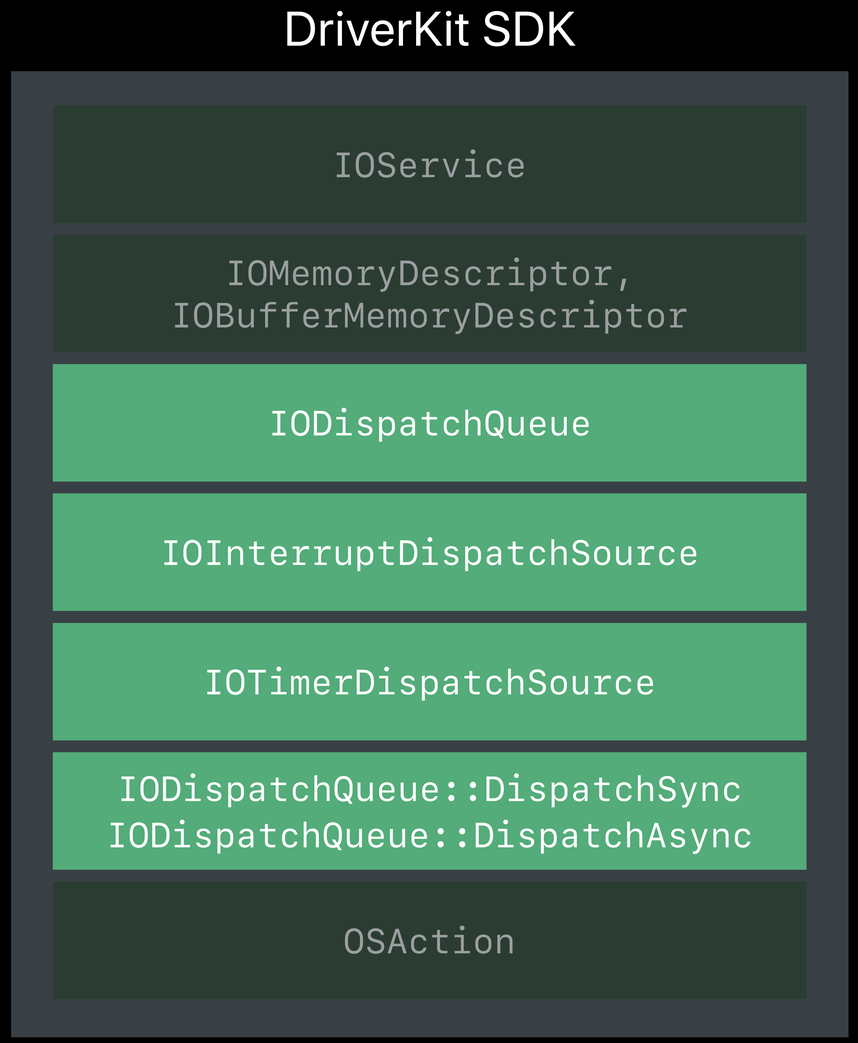
DriverKit SDK

Events

Equivalent to IOWorkLoop model in IOKit

Event handling with GCD

- Queues and dispatch sources



DriverKit SDK

Events

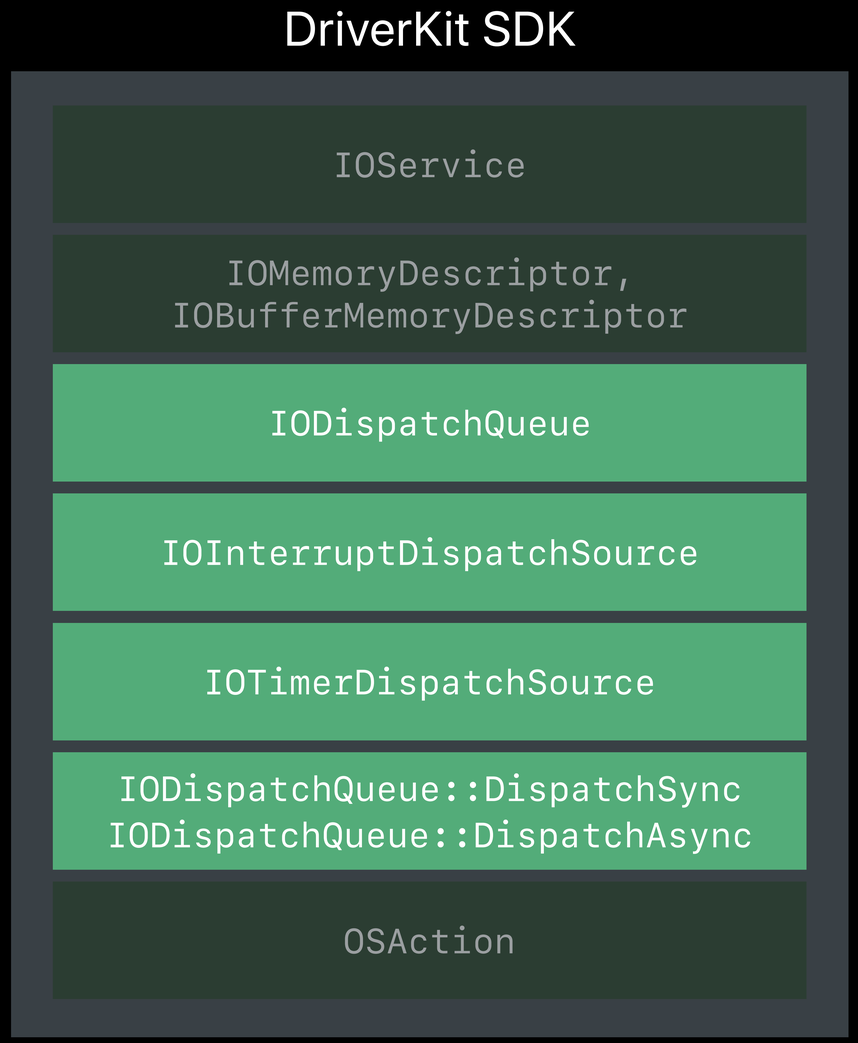
Equivalent to IOWorkLoop model in IOKit

Event handling with GCD

- Queues and dispatch sources

+ IOSharedDataQueueDispatchSource

- Shared memory ring buffer



DriverKit SDK

OSAction

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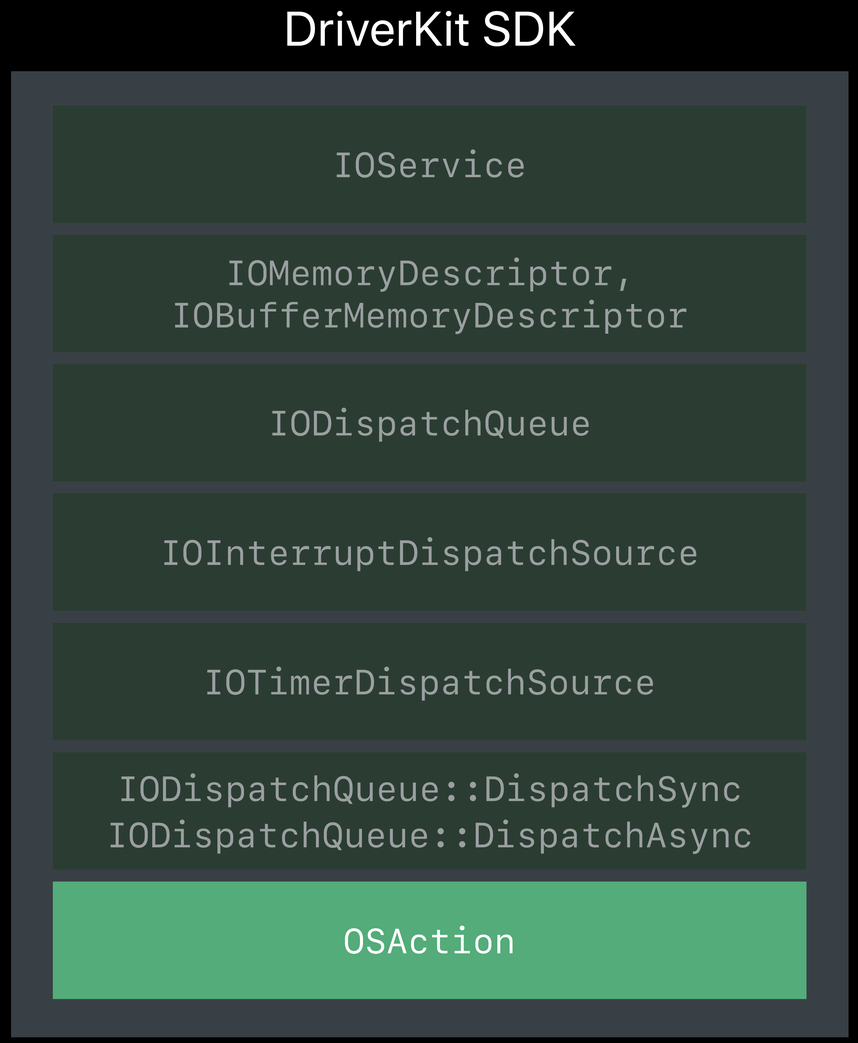
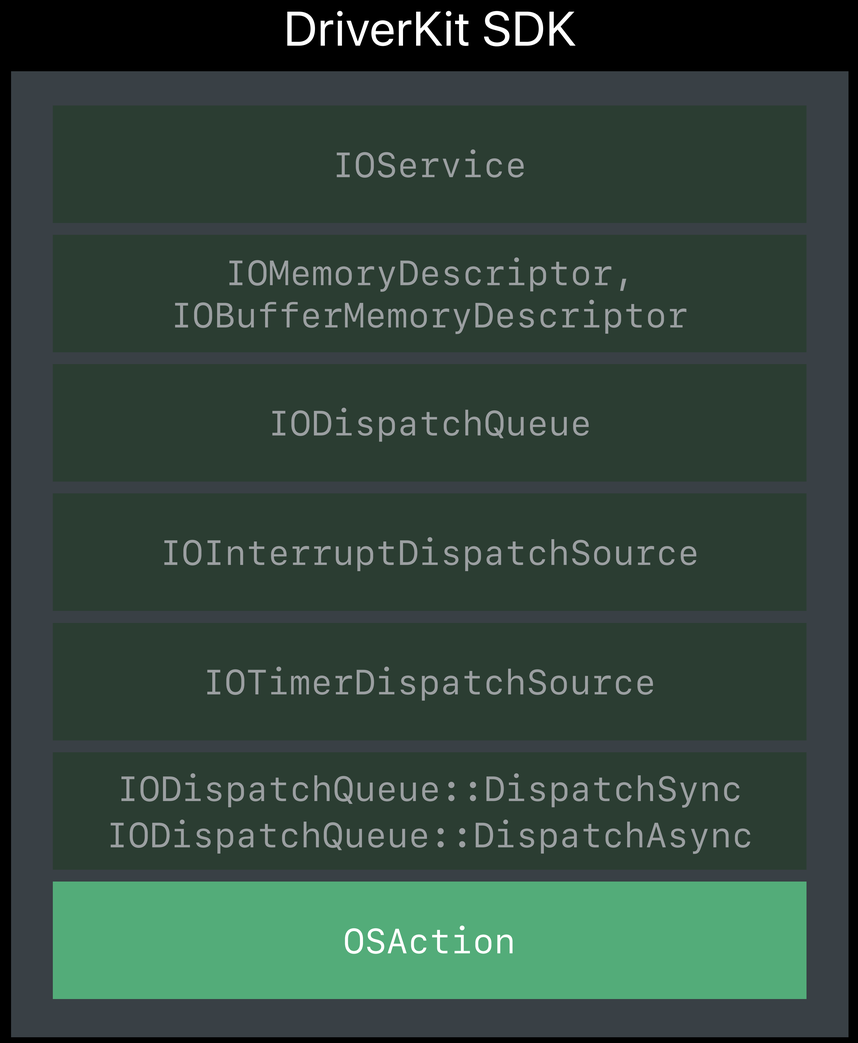


DriverKit SDK

OSAction

Async callbacks use OSAction

- Holds private state for the caller
- Arbitrary arguments with type checking



DriverKit SDK

Interface Definitions

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New filetype: **.iig** defines an interface as a C++ class

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Standard C/C++ types and structure definitions

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Processed by **IOKit Interface Generator** tool — iig

Standard C/C++ types and structure definitions

New attributes for messaging, dispatch queues

```
// DriverKit SDK: Interface Definitions



class KERNEL IOService : public OSObject
{
public:
    virtual kern_return_t Start(IOService *provider) LOCAL;
    virtual kern_return_t Stop(IOService *provider)  LOCAL;
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// DriverKit SDK: Interface Definitions
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KERNEL : class is implemented in the kernel

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LOCAL : method is implemented in the driver

DriverKit SDK

Families

DriverKit SDK

Families

NetworkingDriverKit

DriverKit SDK

Families

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HIDDriverKit

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USBDriverKit

Driver Extension Security

Entitlements

Entitlements

Entitlements required

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- All Driver Extensions: `com.apple.developer.driverkit`
- To attach to a device (transport entitlement, specific to device type)
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- To provide a service to the OS (family entitlement)
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Driver Extension Compatibility

Driver Extension Compatibility

Install a Kernel Extension only on Mojave or earlier

Use SystemExtensions framework to provide a Driver Extension on macOS 10.15

Example

Creating a USB driver with USBDriverKit.framework

Scott Deandrea, Core Transports

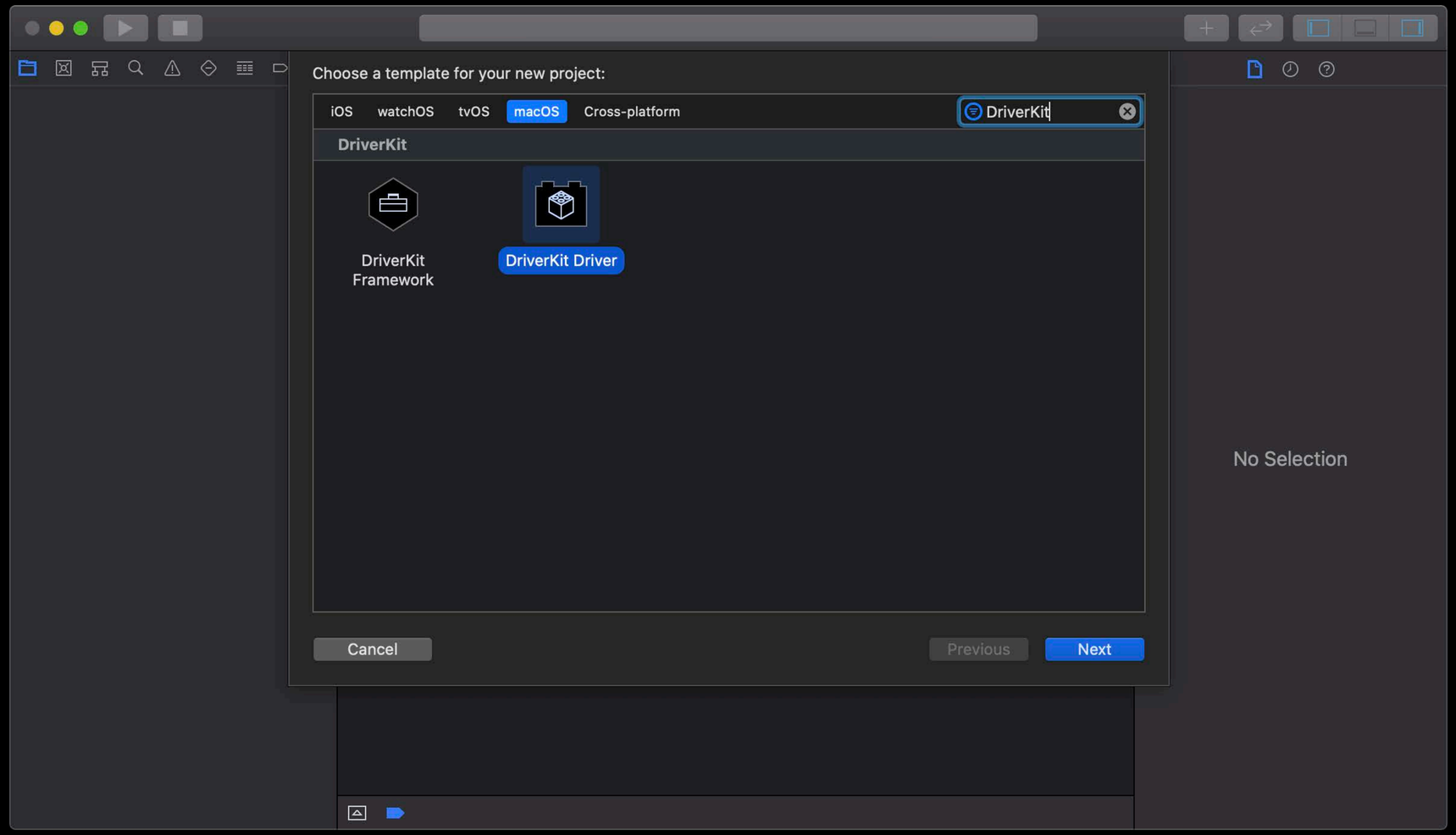
DriverKit Xcode template

MyUserUSBInterfaceDriver class definition

MyUserUSBInterfaceDriver implementation

Demo

Using Xcode's DriverKit Template



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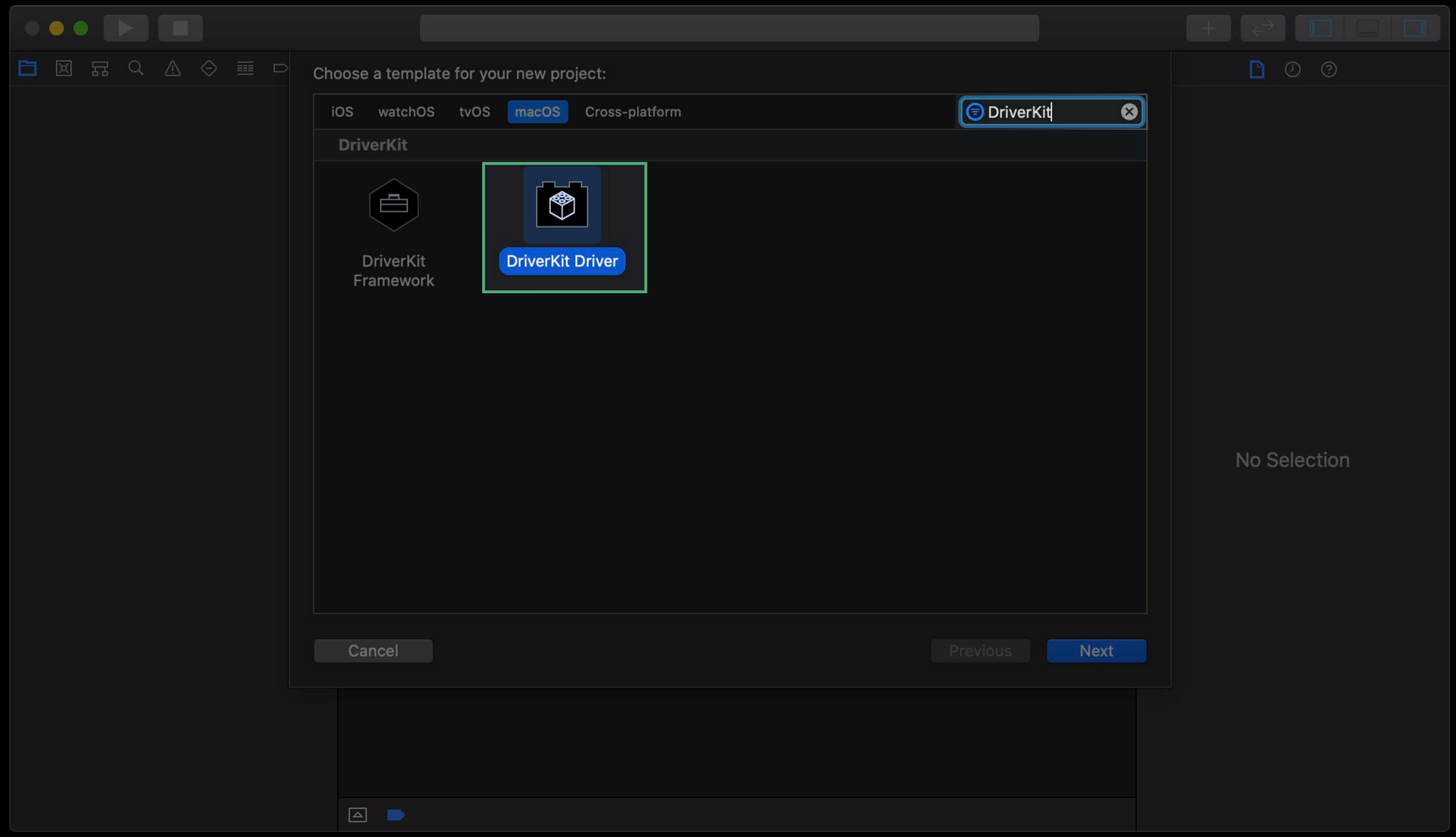

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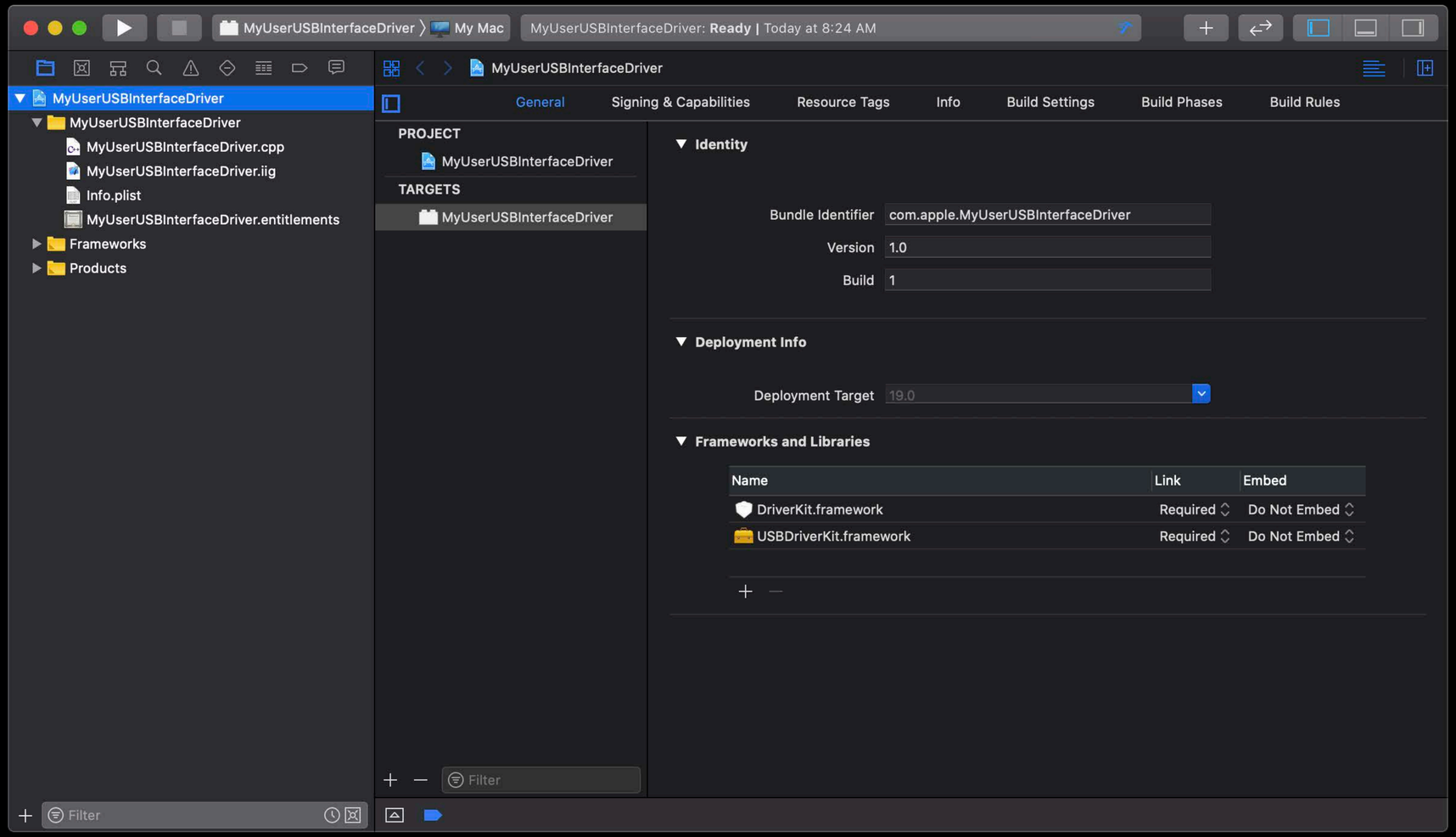

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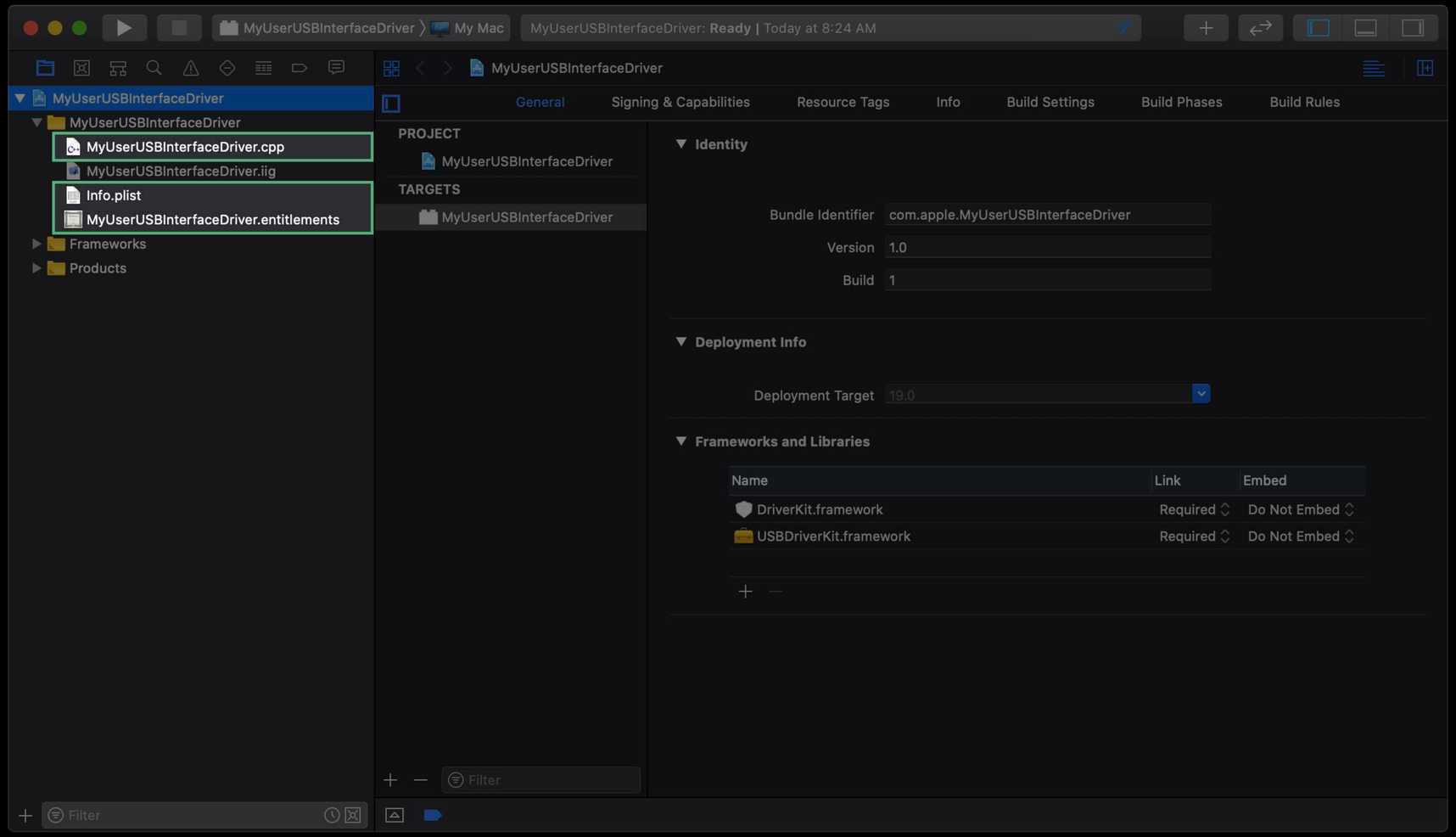

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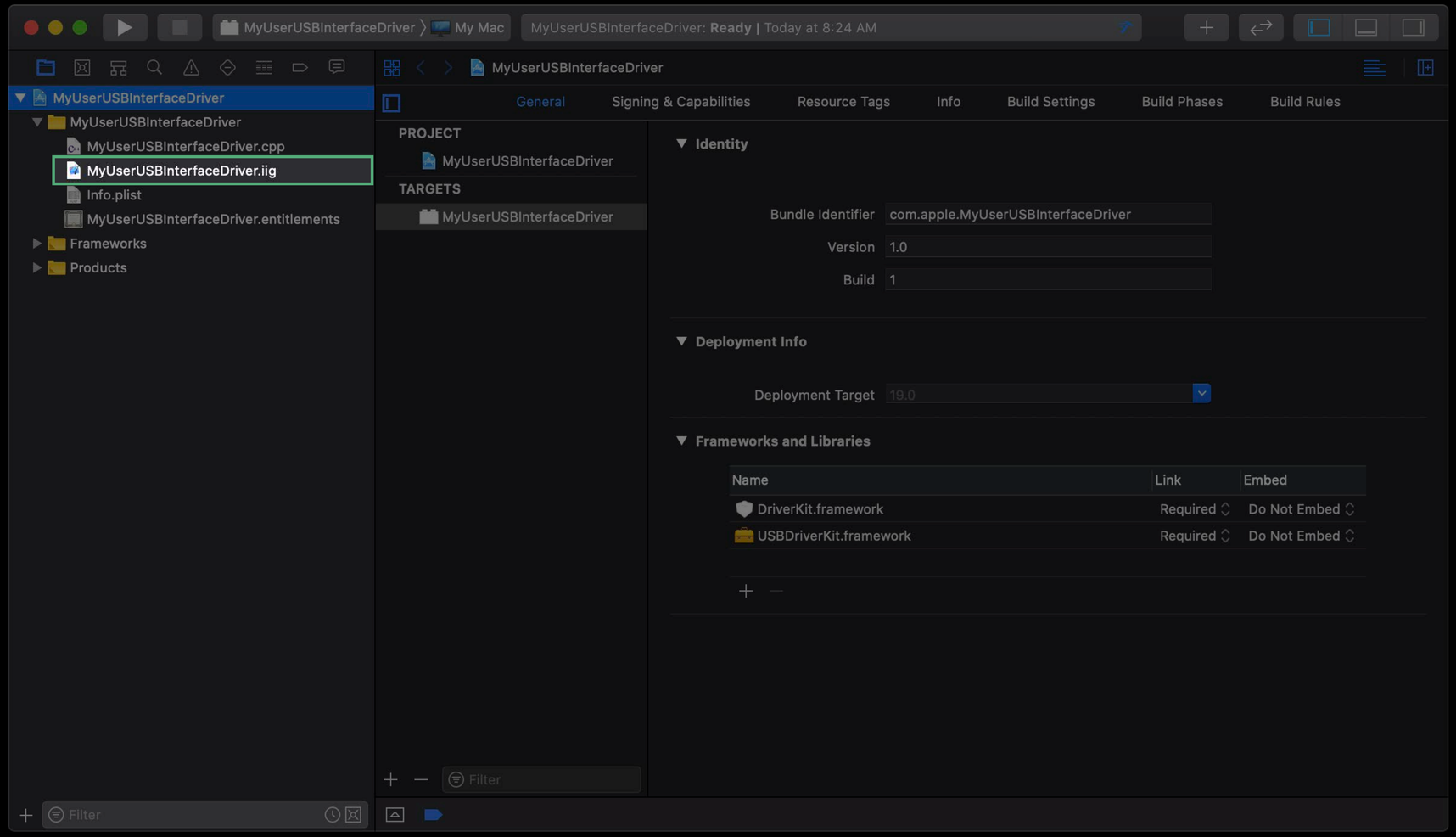

```
// MyUserUSBInterfaceDriver.iig

public:
    virtual bool init () override;
    virtual kern_return_t Start (IOService *provider) override;
    virtual kern_return_t Stop (IOService *provider) override;
    virtual void free () override;

protected:
    virtual void ReadComplete (OSAction *action,
                               IOReturn  status,
                               uint32_t  actualByteCount,
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                               TYPE(IOUSBHostPipe::CompleteAsyncIO);
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// MyUserUSBInterfaceDriver.cpp Instance Variable Definition

struct MyUserUSBInterfaceDriver_IVars
{
    IOUSBHostInterface        *interface;
    IOUSBHostPipe             *inPipe;
    OSAction                  *ioCompleteCallback;
    IOBufferMemoryDescriptor *inData;
    uint16_t                   maxPacketSize;
};
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// MyUserUSBInterfaceDriver.cpp init () method

bool
MyUserUSBInterfaceDriver::init ()
{
    bool result = false;

    result = super::init();
    __Require(true == result, Exit);

    ivars = IONewZero(MyUserUSBInterfaceDriver_IVars, 1);
    __Require_Action(NULL != ivars, Exit, result = false);

Exit:
    return result;
}
```

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// MyUserUSBInterfaceDriver.cpp Start () method

kern_return_t
IMPL (MyUserUSBInterfaceDriver,
      Start)
{
    kern_return_t                   ret;
    IOUSBStandardEndpointDescriptors descriptors;

    ret = Start(provider, SUPERDISPATCH);
    __Require(kIOReturnSuccess == ret, Exit);

    ivars->interface = OSDynamicCast(IOUSBHostInterface, provider);
    __Require_Action(NULL != ivars->interface, Exit, ret = kIOReturnNoDevice);
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__Require(kIOReturnSuccess == ret, Exit);

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// MyUserUSBInterfaceDriver.cpp Start () continued…


ret = OSAction::Create(this,
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Demo

System Extensions in Your Apps

Joe Auricchio, Darwin Runtime

System Extensions in Your Apps

System Extensions in Your Apps

How your extension relates to your app

System Extensions in Your Apps

How your extension relates to your app

Building and packaging the extension bundle

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Code signing and entitlements

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Installing, updating, uninstalling

A System Extension Is Always Part of an App

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Users think in terms of apps

- Apps are what users purchase, install, and run
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App is the user interface to control extension

- Using SystemExtensions framework — more in a moment

Distribute directly with Developer ID

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… or on the Mac App Store

System Extensions Should Be Identifiable

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User should recognize extension as part of your app

- Give a descriptive name with `CFBundleDisplayName` key
- Give a custom icon that relates to your app’s icon

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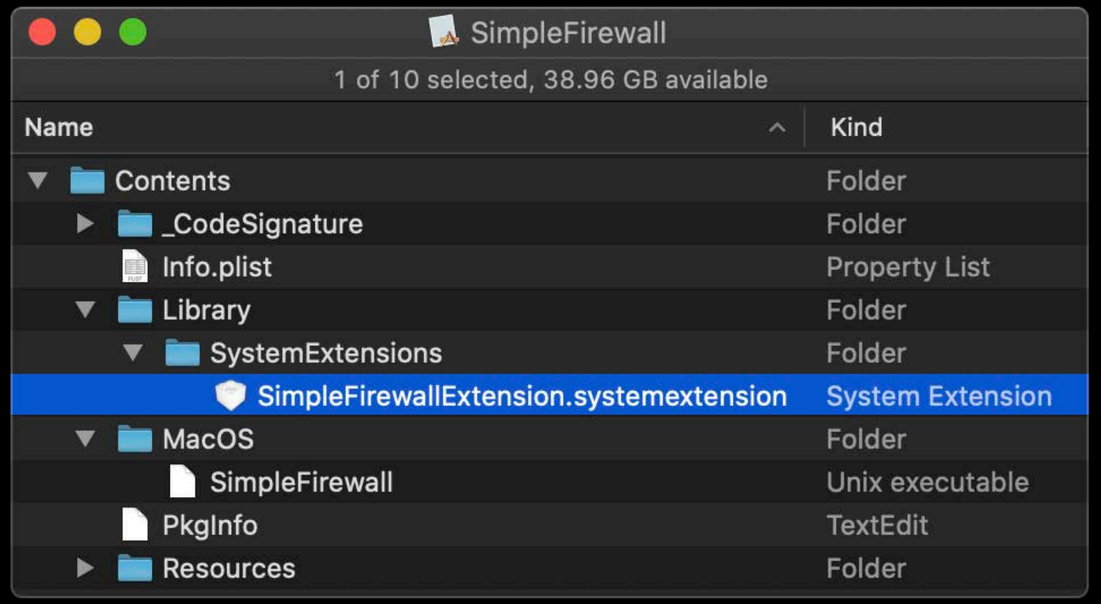
dexts: `OSBundleUsageDescription`, others: `NSSystemExtensionUsageDescription`

System Extension Bundles

System Extension Bundles

Embedded in application

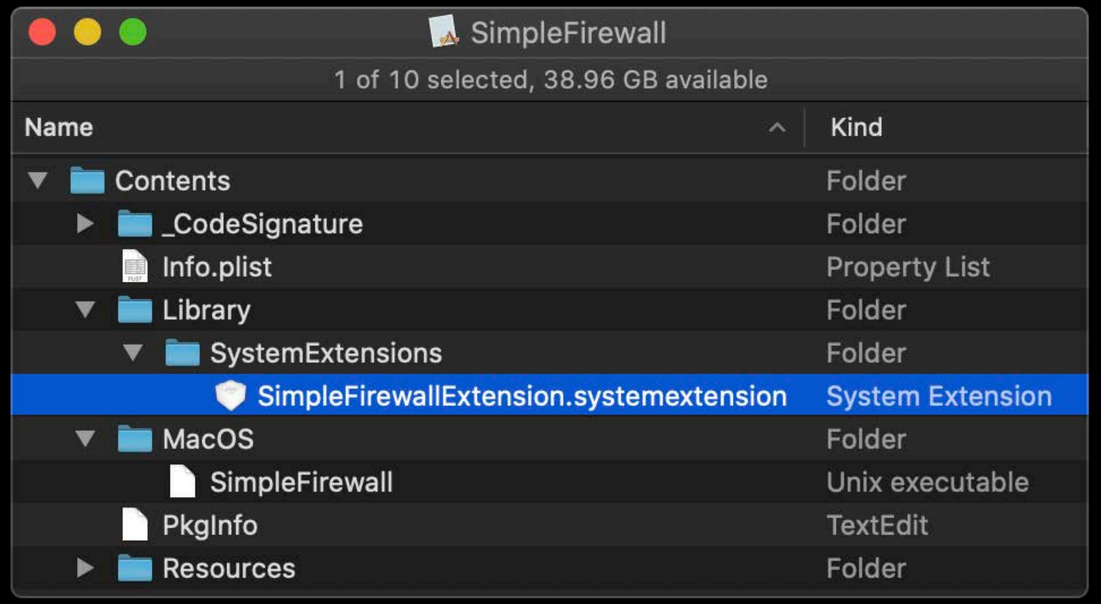


System Extension Bundles

Embedded in application

Driver Extensions

- `.dext` bundle resembling .kext
- `CFBundlePackageType = DEXT`
- Uses `OSBundle*` Info.plist keys
- Flat structure: no `Contents` folder



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Other extensions

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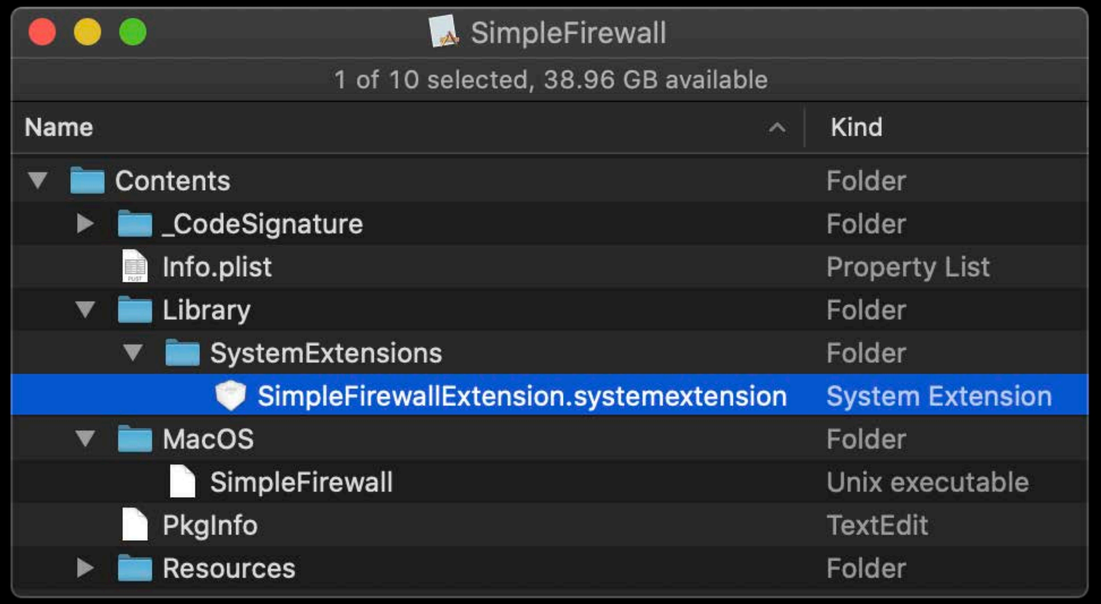
- `CFBundlePackageType = SYSX`



Building in Xcode

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Build extension as another target in your project

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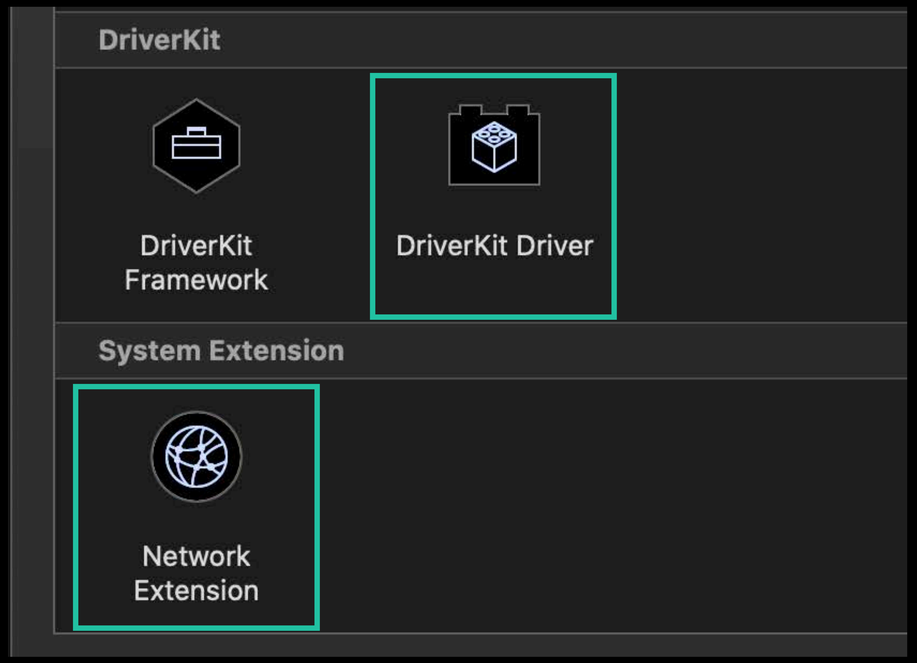
Build extension as another target in your project

Xcode has templates for

- Network Extension
- DriverKit Driver



Building in Xcode

Build extension as another target in your project

Xcode has templates for

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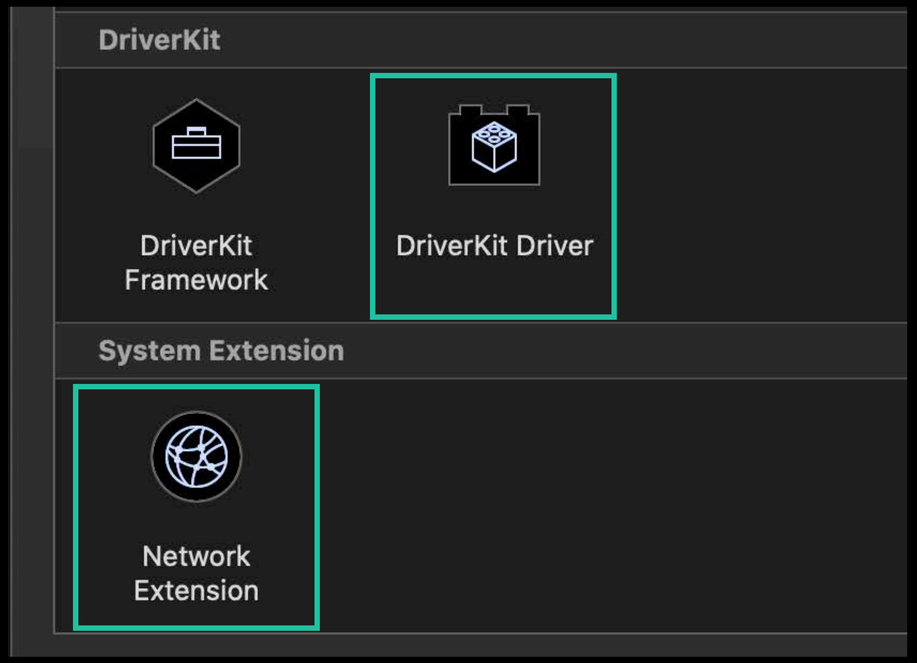
Copy the extension into app bundle

- Copy Files Phase in app target
- `Contents/Library/SystemExtensions`



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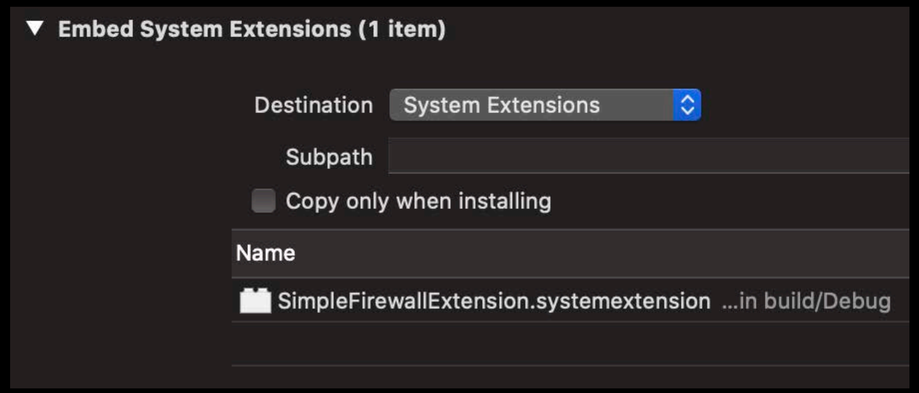

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Sign System Extension with your App’s signing certificate

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Team ID of Extension and App must match

- Exception for extensions designed to be included in other developers’ Apps
- For example, driver for a widely-used interface chip
- Use entitlement: `com.apple.developer.system-extension.redistributable`

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Notarization Lab Tuesday, 4:00

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In Developer Seed, for local development, turn System Integrity Protection off

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Use the new SystemExtensions framework

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- Approved by system administrator
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Extension lifecycle is managed by the system

- Starts whenever needed
- e.g. Driver Extensions start when a matching device is connected

Update and Uninstallation

Update and Uninstallation

To update an extension, update your app

Update and Uninstallation

To update an extension, update your app

System notices extension’s version has changed

- `activationRequest` delegate call to compare versions
- Old version of extension stops, new version starts

Update and Uninstallation

To update an extension, update your app

System notices extension's version has changed

- `activationRequest` delegate call to compare versions
- Old version of extension stops, new version starts

Moving app to Trash deactivates all its extensions

- There is a `deactivationRequest` API, too

Summary

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Building and shipping a System Extension in your app

More Information

developer.apple.com/wwdc19/702

Core OS Lab	Tuesday, 2:00	Thursday, 9:00
Security Lab	Tuesday, 10:00	Thursday, 2:00
Networking Lab	Friday, 9:00	


WWDC19