Every Authorization Has Its Black: Tackling Privilege Escalation in macOS

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TEAMT5
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Persistent Cyber Threat Hunters

Whoami

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- Member of 10sec

Research Topic

- System security (Linux, MacOS)
- Malware analysis
- Threat hunting

@In0de_16

Malicious Behavior Overview

MacOS-based Attack Flow

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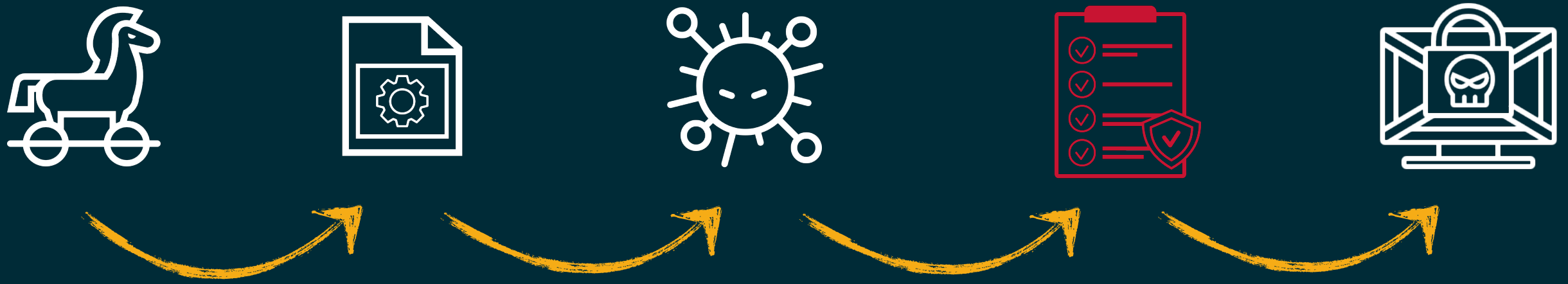
- Malware with privilege escalation exploit
  - XCSSET.2020, MacMa.2021
  - dazzlespy.2022, CloudMensis.2022
  - Others: supply chain, electorn inject, browser hijacking…



Create & Open & Write Execute Privilege Escalation Attack

Our Goals

- Demystify macOS privilege management
- Explain what we saw about the attack surface of privilege escalation
- Building a mitigate module to detect this kind of attack

Takeaway

Understand the macOS privilege attack surface and hunt for techniques that threat actors use to target macOS

Outline

01 Privilege Management on macOS

02 Common Ways to Gain Elevated Access

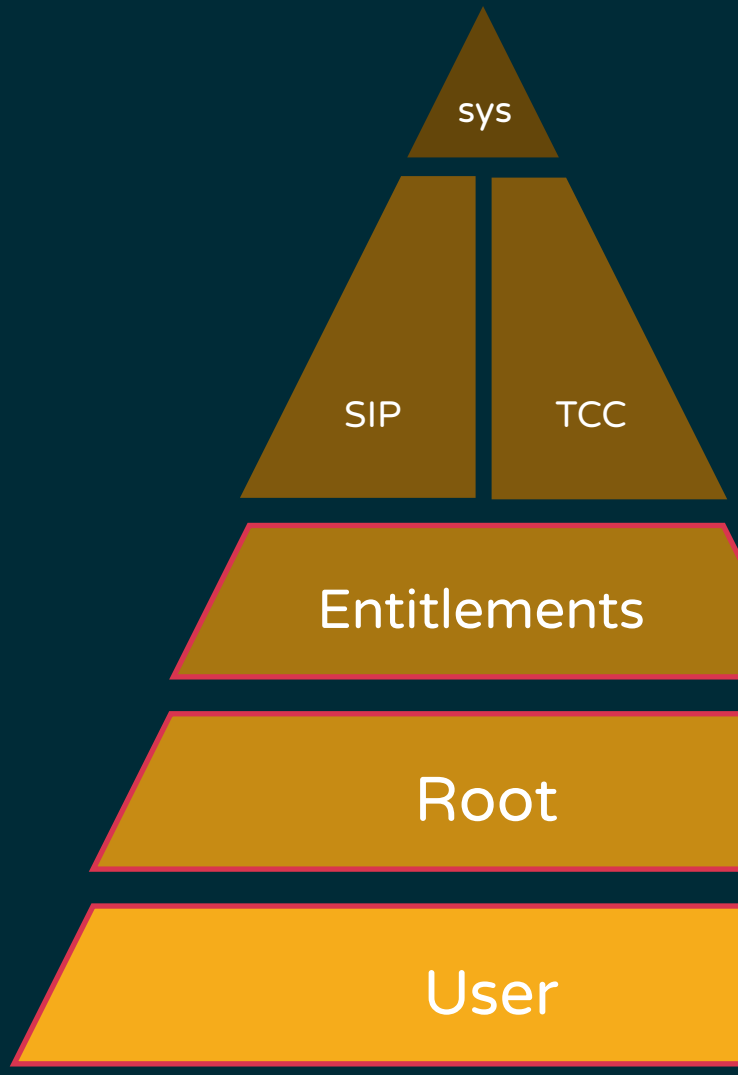
03 EndpointSecurity Framework

04 onPrivilege Detection with ESF

05 Conclusion

Privilege Management on macOS

Privilege Management




```
Executable=/System/Library/PrivateFrameworks/PackageKit.framework/Versions/A/Resources/system_installd
qq<?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.launchservices.cansetapplicationstrusted</key>
        <true/>
        <key>com.apple.private.package_script_service.allow</key>
        <true/>
        <key>com.apple.private.responsibility.set-arbitrary</key>
        <true/>
```

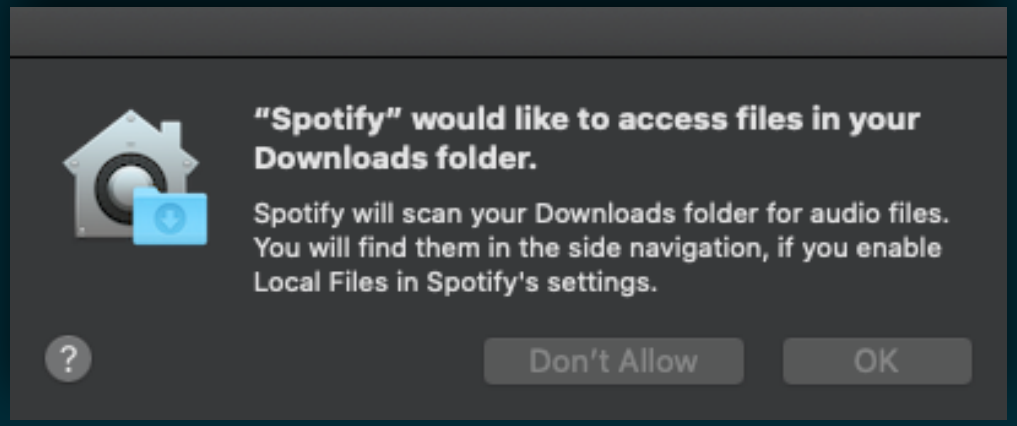
Install package, add autorun item, Debugging

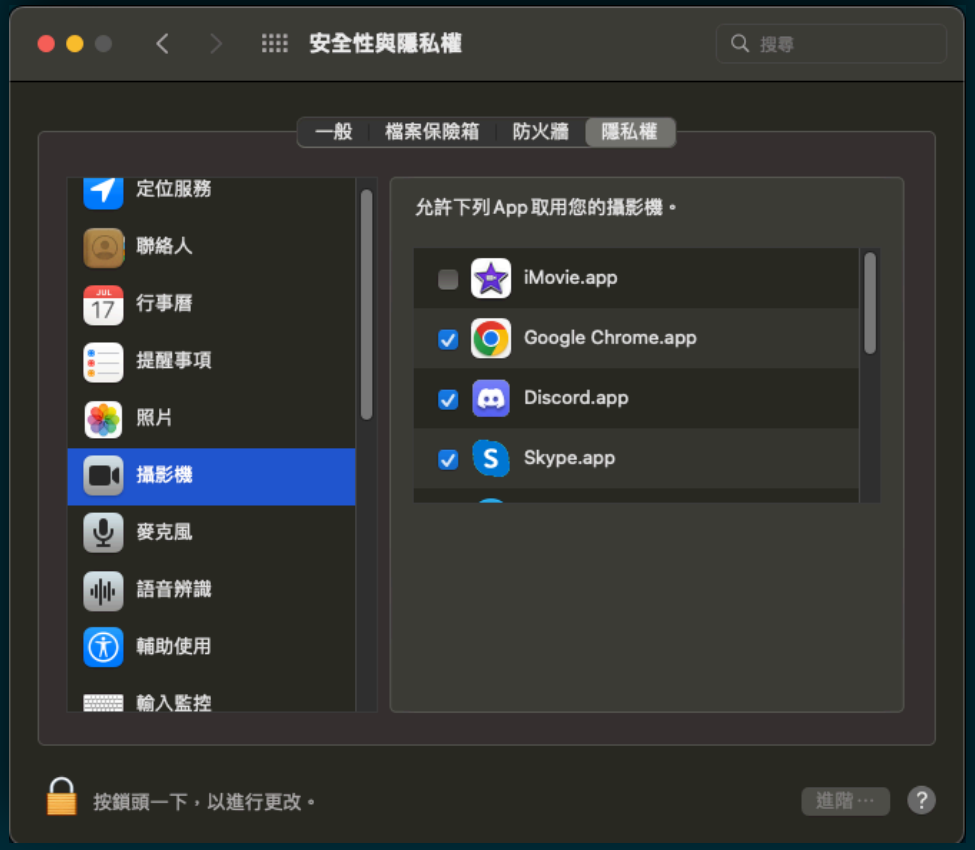
General purpose

Privilege Management

TCC (Transparency, Consent, and Control)

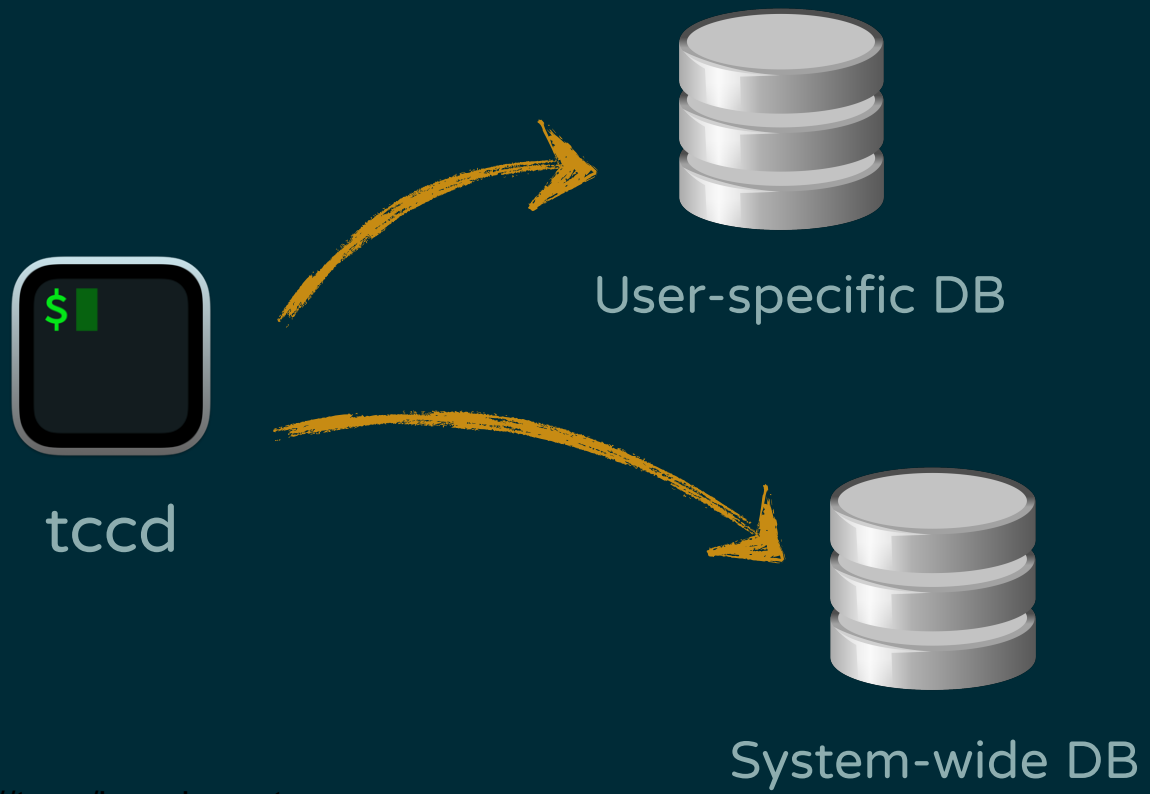
- Restrict installed applications to access sensitive data without permission
- User data access control





TCC

- User-specific database: ~/Library/Application\ Support/com.apple.TCC/TCC.db
- System-wide database: /Library/Application Support/com.apple.TCC/TCC.db



access	
service	TEXT
client	TEXT
client_type	INTEGER
auth_value	INTEGER
auth_reason	INTEGER
auth_version	INTEGER
csreq	BLOB
policy_id	INTEGER
indirect_object_identifier _type	INTEGER
indirect_object_identifier	TEXT
indirect_object_code_identity	BLOB
flags	INTEGER
last_modified	INTEGER

Privilege Management

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SIP (System Integrity Protection)

- Also known as rootless
- Based on Sandbox kernel extension
- Restrict root to access sensitive data

```
lrwxr-xr-x     1 root  wheel  restricted    25  1  1  2020 X11 -> ../private/var/select/X11
lrwxr-xr-x     1 root  wheel  restricted    25  1  1  2020 X11R6 -> ../private/var/select/X11
drwxr-xr-x  1036 root  wheel  restricted 33152  1  1  2020 bin
drwxr-xr-x    38 root  wheel  restricted  1216  1  1  2020 lib
drwxr-xr-x   295 root  wheel  restricted  9440  1  1  2020 libexec
drwxr-xr-x    15 root  wheel  sunlnk       480 12  1 09:56 local
drwxr-xr-x   232 root  wheel  restricted  7424  1  1  2020 sbin
drwxr-xr-x    47 root  wheel  restricted  1504  1  1  2020 share
drwxr-xr-x     6 root  wheel  restricted   192  1  1  2020 standalone
```

Privilege Management

SIP (System Integrity Protection)

- Also known as rootless
- Based on Sandbox kernel extension
- Restrict root to access sensitive data
  - ✓ Loading kernel extensions (only signed extensions are allowed)
  - ✓ Tampering with critical files and directories
  - ✓ Debugging system processes

SIP

com.apple.rootless.install

- Completely bypass SIP filesystem check

com.apple.rootless.install.heritable

- Inherit com.apple.rootless.install to child processes

- Apple won't allow any application to be signed with the above entitlements
- Only a few services have this. ex: system_installd

TCC - Full Disk Access

The TCC policy (Full Disk Access) allows access to SIP-protected directory

TCC - Full Disk Access

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The TCC policy (Full Disk Access) allows access to SIP-protected directory

```
sonar@sonars-Mac-mini Downloads % ls ~/Library/Mail
ls: /Users/sonar/Library/Mail: Operation not permitted
sonar@sonars-Mac-mini Downloads % ls /Library/Application\ Support/com.apple.TCC/
ls: /Library/Application Support/com.apple.TCC/: Operation not permitted
sonar@sonars-Mac-mini Downloads %
```

-zsh

```
sonar@sonars-Mac-mini ~ % ls /Library/Application\ Support/com.apple.TCC/
AdhocSignatureCache     TCC.db
sonar@sonars-Mac-mini ~ % ls ~/Library/Mail
V8
sonar@sonars-Mac-mini ~ %
```

Have “Full Disk Access”

TCC - Full Disk Access

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Full Disk Access

- When admin gives an APP Full Disk Access, all users can use this APP to gain Full Disk Access

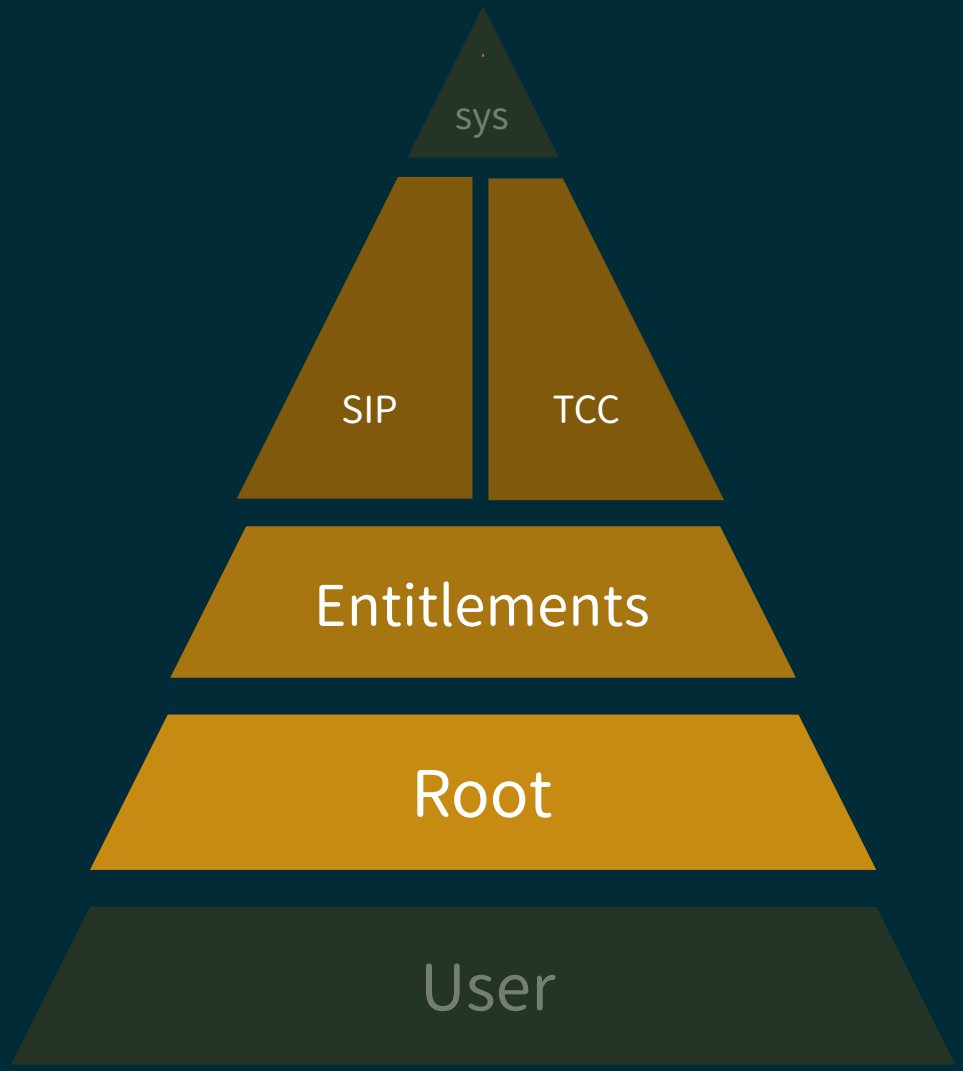
iTerm

(Full Disk Access)

Common Ways to Gain Elevated Access

Gaining Elevated Access

- Get Root
- Bypass SIP
- Bypass TCC



Get Root

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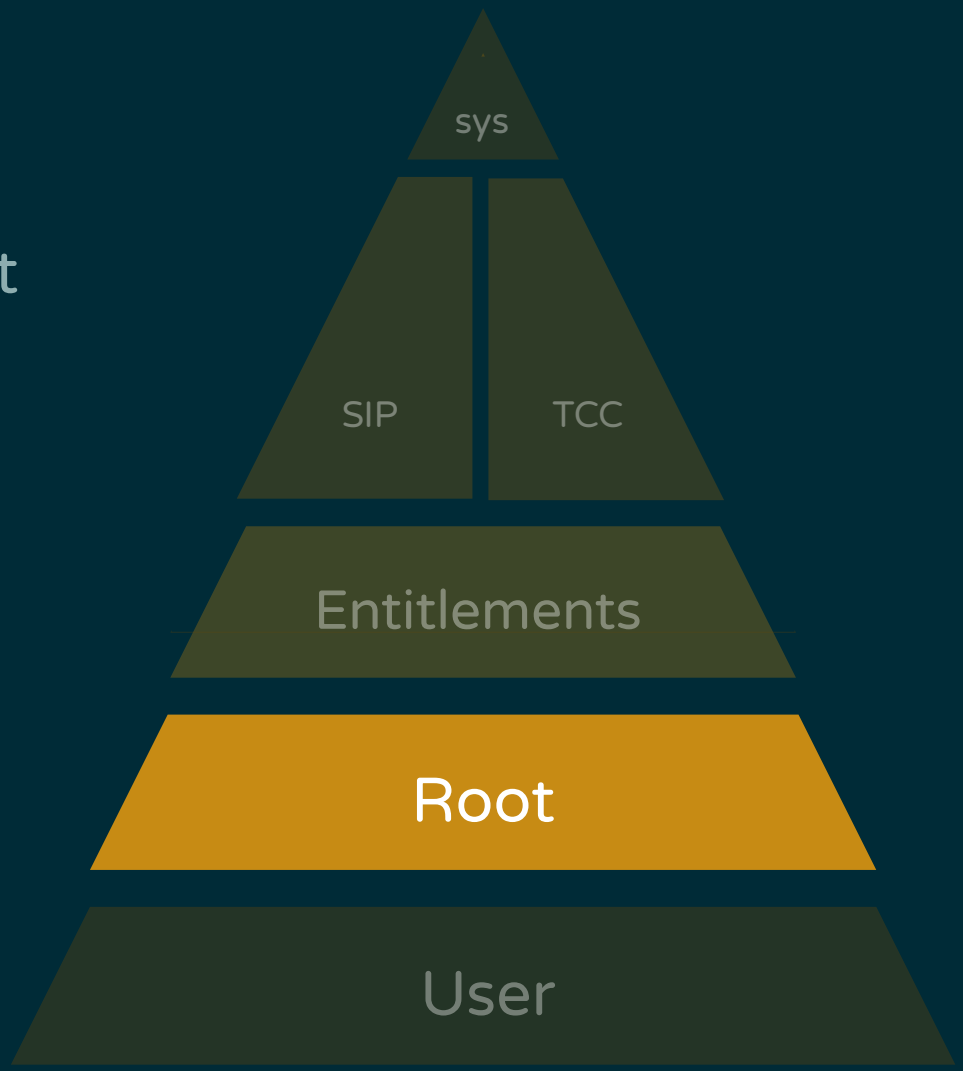
Persistence

- Inject autorun
  - /Library/LaunchDaemon & LaunchAgent
- Hide the malicious file or folder

Under certain conditions, bypassing SIP or TCC needs root privilege



Four Processes Running as Root

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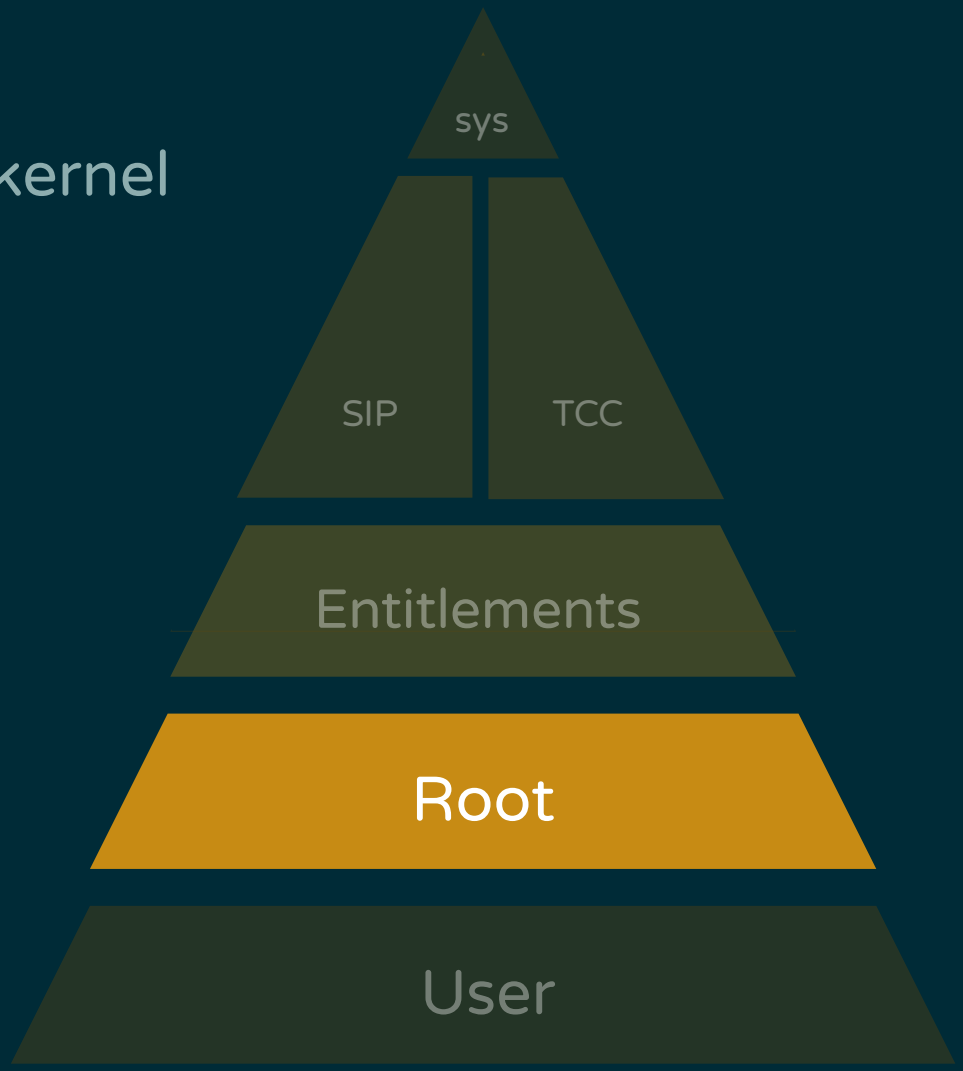
- Launchd
  - Which is the first thing launched, after the kernel
- Helper daemon (a.k.a XPC Service)
- Auto-run process
- SUID binaries



Get Root

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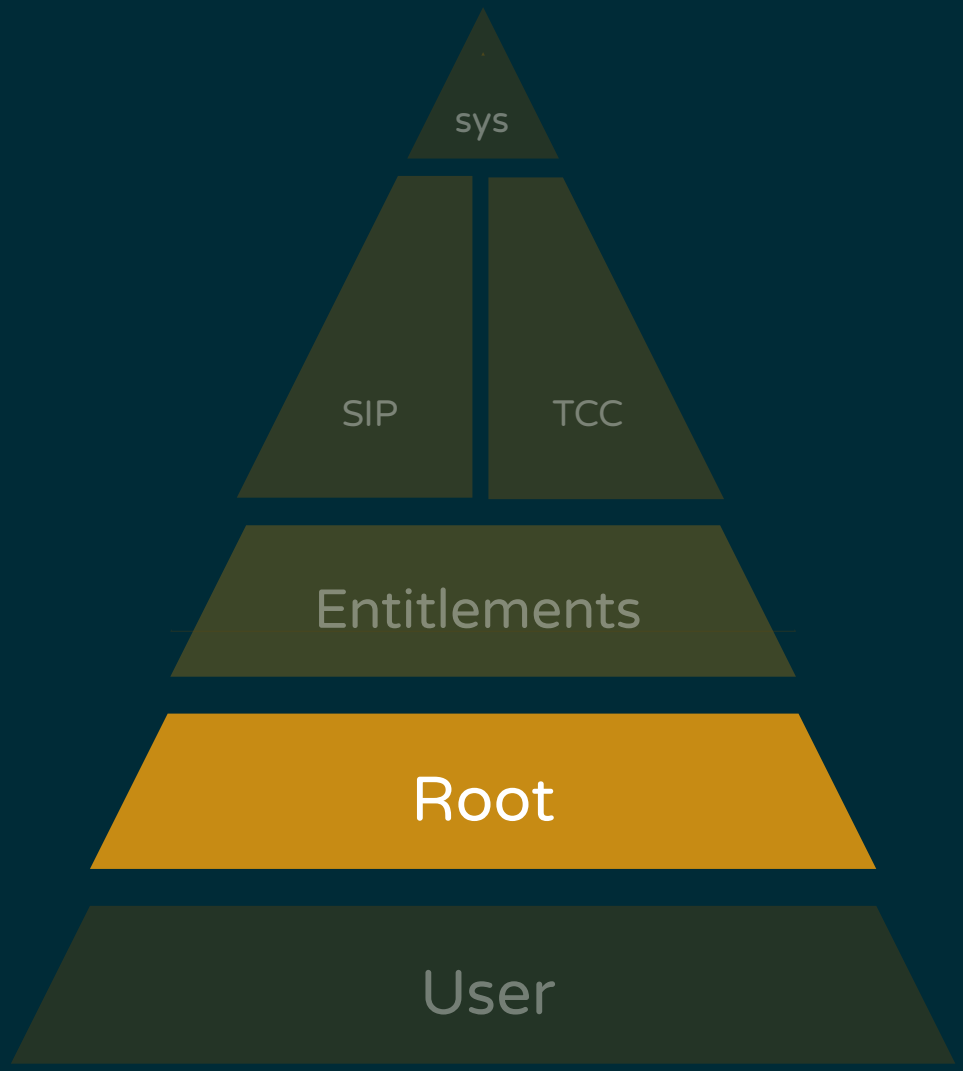
- Logic bug in system daemon
  - ✓ CVE-2022-22639 - SUHelper
  - ✓ CVE-2021-1815 - cfprefsd
- Authentication problem in third-party daemon
  - ✓ Microsoft OneDrive, Zoom, TeamViewer …
- Code sign vulnerability
  - ✓ CVE-2022-26766 CoreTrust



Helper daemon (XPC Service)

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- Launched by Launchd service
- Running in the background without requiring user input
- LaunchDaemons & LaunchAgents

```
will@Willde-MacBook-Air ~ launchctl list
PID     Status  Label
-       0       com.apple.SafariHistoryServiceAgent
704     0       com.apple.progressd
491     0       application.com.microsoft.Word.18098481.18156777
-       0       com.google.keystone.user.xpcservice
21590   0       com.apple.cloudphotod
516     0       com.apple.Finder
504     0       com.apple.homed
-       -9      com.apple.SafeEjectGPUAgent
63925   0       com.apple.quicklook
-       0       com.apple.parentalcontrols.check
526     0       com.apple.mediaremoteagent
471     0       com.apple.FontWorker
444     0       com.apple.bird
```

XPC Service

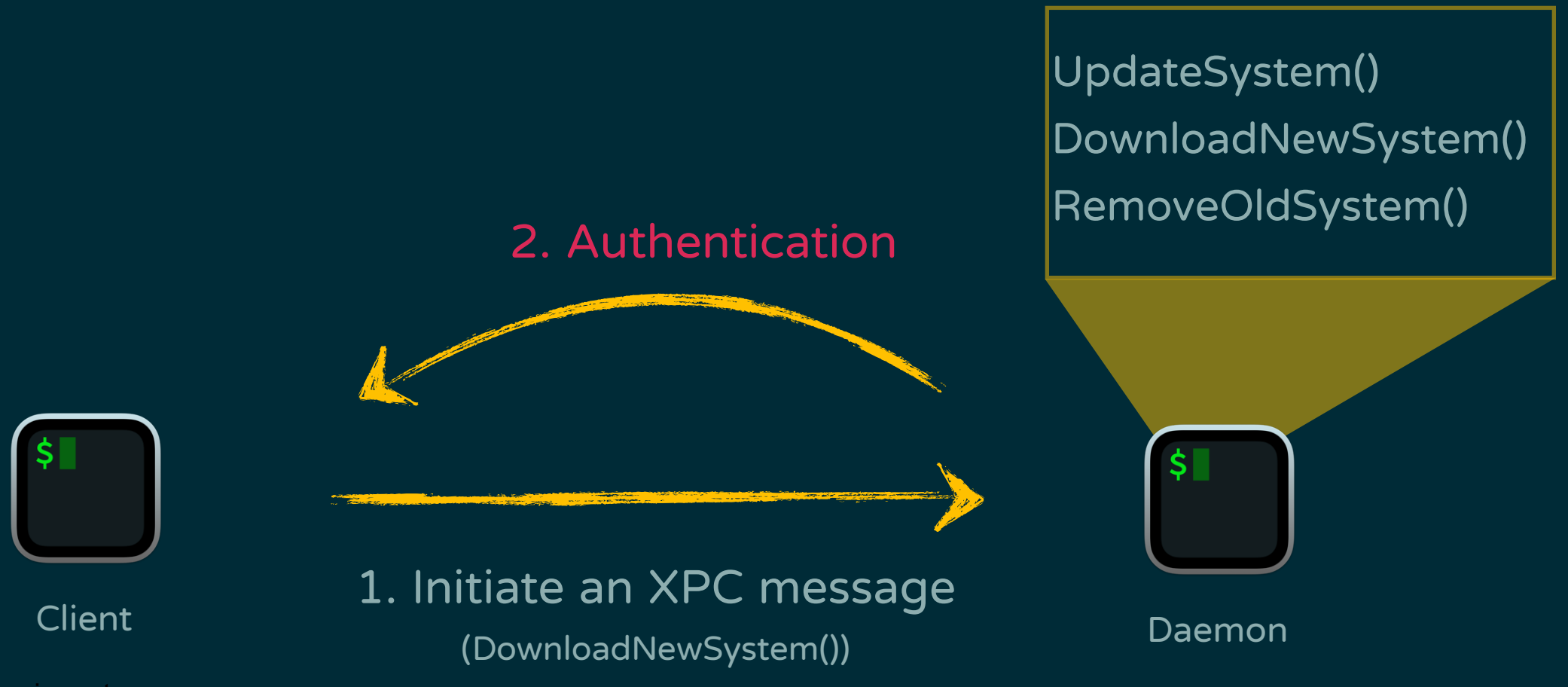
- XPC: APPLE low-level interprocess communication mechanism
- Privilege separation and stability
- Communicate via XPC

XPC Service

- Privilege separation and stability
- Communicate via XPC

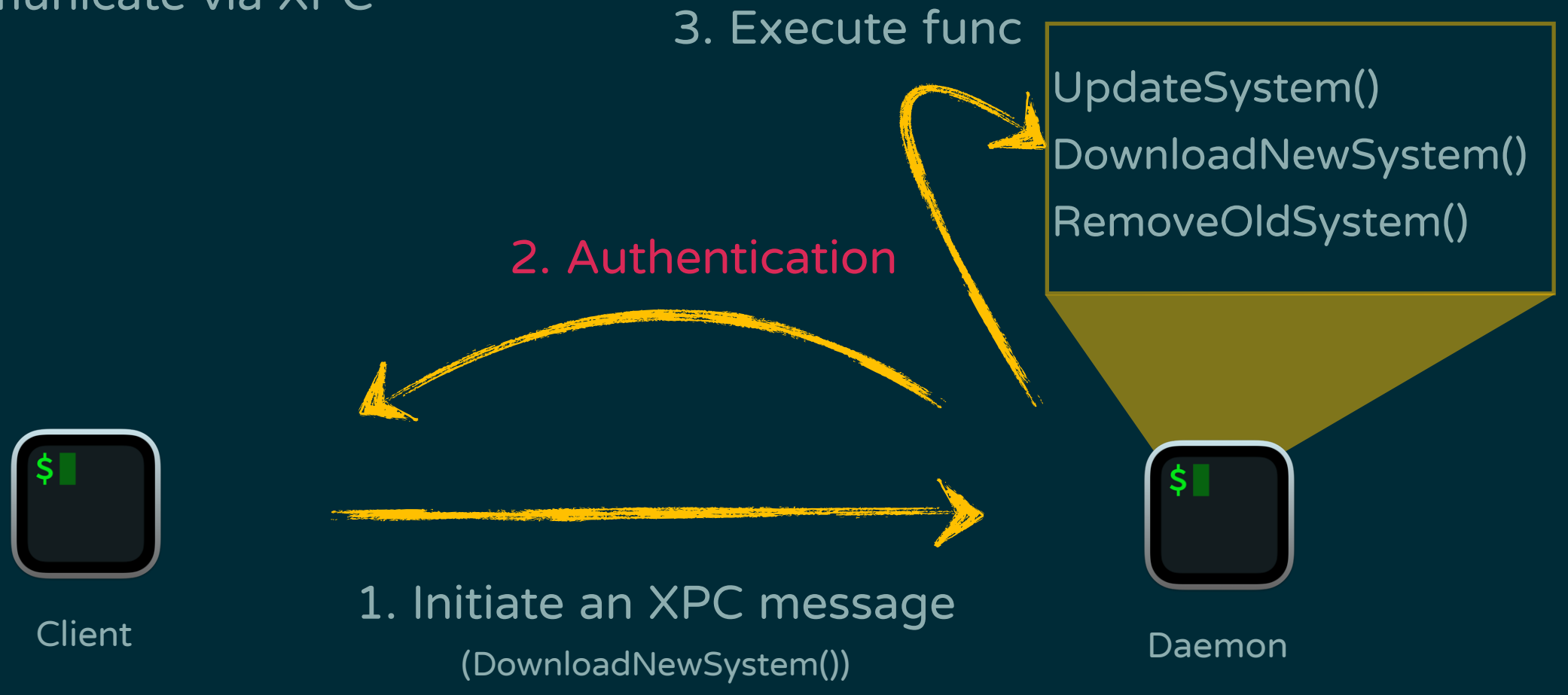
XPC Service

- Privilege separation and stability
- Communicate via XPC



XPC Service

- Privilege separation and stability
- Communicate via XPC



XPC Service

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- How to check client is verified

2. Authentication

Client

??

Daemon

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CVE-2022-22639

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suhelperd

- Prepare for the system upgrade
- ex: authorization, file moving

Install macOS Monterey

softwareupdated

- Responsible for updating system
- Periodically awaken and check for updates
- Can be triggered by manual update

SoftwareUpdate.framework

- MacOS provide the interfaces Install macOS Application need to communicate with suhelperd

SoftwareUpdate.hop

Labels Proc. Str

SUhelperproxy

Tag Scope

Address	Type	Name
0x2a4e	P	+[SUHelperProxy sharedHelperProxy]
0x2a7a	P	___34+[SUHelperProxy sharedHelperProxy]_block_invoke
0x2af1	P	-[SUHelperProxy init]
0x2bce	P	-[SUHelperProxy setRecentRights:]
0x2bd8	P	-[SUHelperProxy authorizeWithEmptyAuthorizationForRights:]
0x2d84	P	-[SUHelperProxy helperQueueReentrantSync:]
0x2dc3	P	___58-[SUHelperProxy authorizeWithEmptyAuthorizationForRights:]_b
0x2e04	P	-[SUHelperProxy recentRights]
0x2e0e	P	-[SUHelperProxy authorizeTool:forRights:]
0x2f3a	P	-[SUHelperProxy isAuthorizedForRights:]
0x2fe7	P	___39-[SUHelperProxy isAuthorizedForRights:]_block_invoke
0x318d	P	___41-[SUHelperProxy authorizeTool:forRights:]_block_invoke
0xcba6	P	-[SUHelperProxy clearAnyUserPreference:]
0xcc43	P	___40-[SUHelperProxy clearAnyUserPreference:]_block_invoke
0xccaf	P	-[SUHelperProxy _isAuthorized]
0xcfd5	P	-[SUHelperProxy setObject:forAnyUserPreference:]
0xd076	P	___48-[SUHelperProxy setObject:forAnyUserPreference:]_block_invoke
0xf8e0	P	___41-[SUHelperProxy authorizeTool:forRights:]_block_invoke.58
0x1651e	P	-[SUHelperProxy makeQueues]
0x165b7	P	___27-[SUHelperProxy makeQueues]_block_invoke
0x1fd7b	P	-[SUHelperProxy readUpdatesIndex]
0x1fe28	P	___33-[SUHelperProxy readUpdatesIndex]_block_invoke
0x22f00	P	___41-[SUHelperProxy authorizeTool:forRights:]_block_invoke_2
0x22f0e	P	___41-[SUHelperProxy authorizeTool:forRights:]_block_invoke_3
0x4eb79	P	+[SUHelperProxy sharedHelperProxyIfAvailable]
0x4ebb1	P	-[SUHelperProxy dealloc]

Install macOS Monterey SoftwareUpdate.framework suhelperd

We can Access suhelperd! But…

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- isClientPort: a rights authorization mechanism to verify the request is from a legitimate client
- No. 16 represents the required permissions

suhelperd

```
if ( Helper_10002F580 )
{
  v3 = (void *)objc_alloc_init(&OBJC_CLASS___NSAutoreleasePool);
  if ( (unsigned __int8)objc_msgSend(Helper_10002F580, "_isClientPort:validForRight:", a2, 16LL, v6) )
  {
    v4 = 0;
    *a3 = (unsigned __int64)objc_msgSend(Helper_10002F580, "prepareForLogoutAndInstall:", 0LL);
  }
  else
  {
    v4 = 8;
  }
  objc_msgSend(v3, "drain");
}
```

We can Access suhelperd! But…

- isClientPort: a rights authorization mechanism to verify the request is from a legitimate client
- No. 16 represents the required permissions

```
if ( (unsigned __int8)objc_msgSend(Helper_10002F580, "_isClientPort:validForRight:", a2, 16LL, v6) )
{
  v4 = 0;
  *a3 = (unsigned __int64)objc_msgSend(Helper_10002F580, "prepareForLogoutAndInstall:", 0LL);
```

```
if ( (unsigned __int8)objc_msgSend(qword_10002F528, "_isClientPort:validForRight:", a2, 8LL, v6) )
{
  *a3 = (char)objc_msgSend(qword_10002F528, "removeUpdatesAvailableCookie");
  v4 = 0;
}
```

```
if ( (unsigned __int8)objc_msgSend(qword_10002F528, "_isClientPort:validForRight:", a3, 1LL, v10) )
{
  v6 = qword_10002F528;
  v7 = objc_msgSend(&OBJC_CLASS___NSString, "stringWithUTF8String:", a4);
  *v4 = (char)objc_msgSend(v6, "moveInstalledPrintersToLibraryFromPath:", v7);
  v8 = 0;
```

CVE-2022-22639

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prepareInstallAssistantWithPath(path)

- The API doesn't use isClientPort to check permissions
- This API is wrapper of initiateMajorOSUpgradeAtPath
- initiateMajorOSUpgradeAtPath input the path from argument

```
char __cdecl -[SUHelper prepareInstallAssistantWithPath:](SUHelper *self, SEL a2, id path)
{
  id _path; // r14
  SUOSUMDMInstallClient *v4; // r15
  __int64 v5; // rax
  void **v7; // [rsp+8h] [rbp-48h]
  __int64 v8; // [rsp+10h] [rbp-40h]
  void *v9; // [rsp+18h] [rbp-38h]
  void *v10; // [rsp+20h] [rbp-30h]
  SUHelper *v11; // [rsp+28h] [rbp-28h]

  _path = path;
  v4 = ((SUOSUMDMInstallClient *(__cdecl *)(SUHelper *, SEL))objc_msgSend)(self, "installClient");
  v5 = NSOpenStepRootDirectory((__int64)self, (__int64)"installClient");
  v7 = _NSConcreteStackBlock;
  v8 = 3254779904LL;
  v9 = &sub_10000C43D;
  v10 = &unk_100028440;
  v11 = self;
  objc_msgSend((void *)v4, "initiateMajorOSUpgradeAtPath:toVolume:forceRestart:withCompletion:", _path, v5, 0LL);
  return 1;
```

CVE-2022-22639

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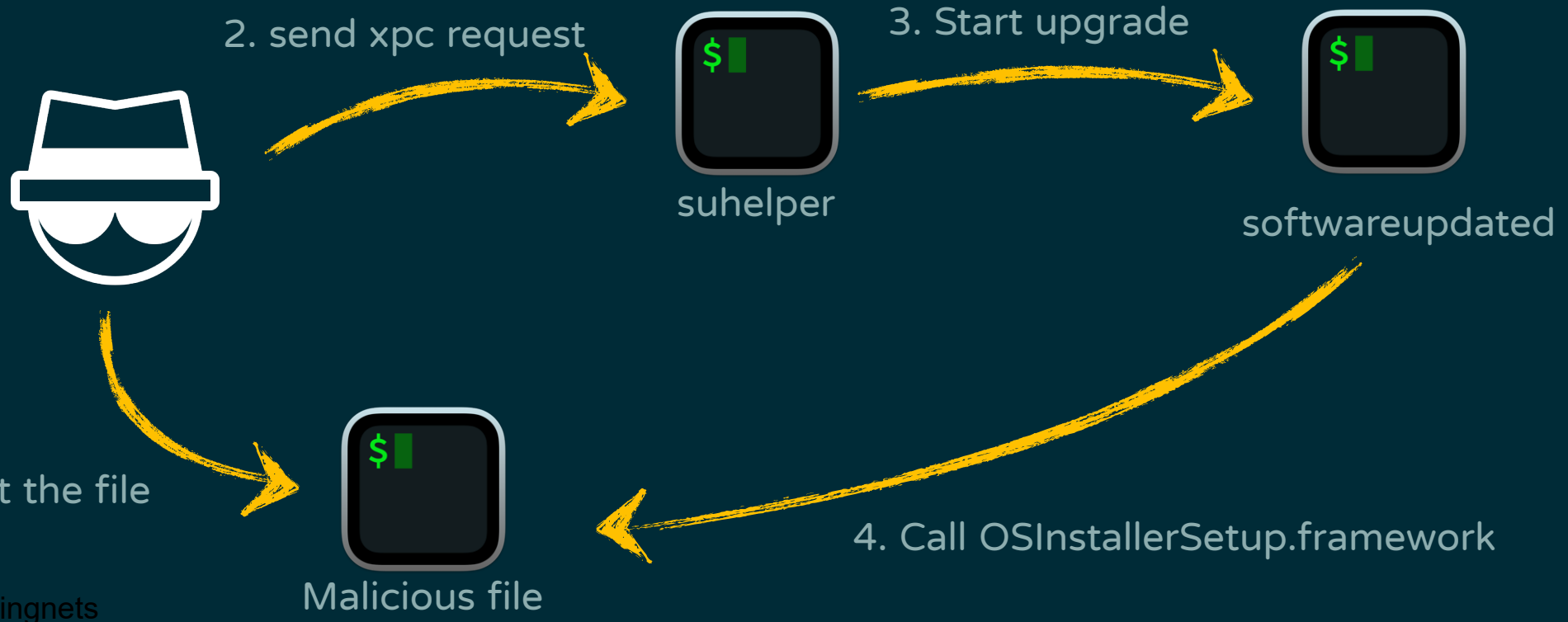
prepareInstallAssistantWithPath(path)

- initiateMajorOSUpgradeAtPath(path)
  - Call ($path)/Contents/Frameworks/OSInstallerSetup.framework



CVE-2021-1815 cfprefsd

- Responsible for setting preferences
- Two instances running on macOS
  - User and root privileges

XPC request

~/Library/Preferences/ZoomChat.plist

cfprefsd

```
will@hello:~/Desktop/projects|⇒  ls ~/Library/Preferences/
ByHost
ContextStoreAgent.plist
MachOView.plist
MobileMeAccounts.plist
Parallels
UBF8T346G9.OneDriveStandaloneSuite.plist
VMware Fusion
ZoomChat.plist
com.apple.AMPLibraryAgent.plist
com.apple.ATS.plist
```

CVE-2021-1815 cfprefsd

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CFPrefsCreatePreferencesDirectory(path)

```
int _CFPrefsCreatePreferencesDirectory(path) {
    int dirfd = open("/", O_DIRECTORY);
    for(slice in path.split("/")) {
        int fd = openat(dirfd, slice, O_DIRECTORY);
        if (fd == -1 && errno == ENOENT && !mkdirat(dirfd, slice, perm)) {
            fd = openat(dirfd, slice, O_DIRECTORY|O_NOFOLLOW);
            if ( fd == -1 ) return -1;
            fchown(fd, uid, gid);
        }
        } // close all fds return 0;
}
```

cfprefsd Daemon

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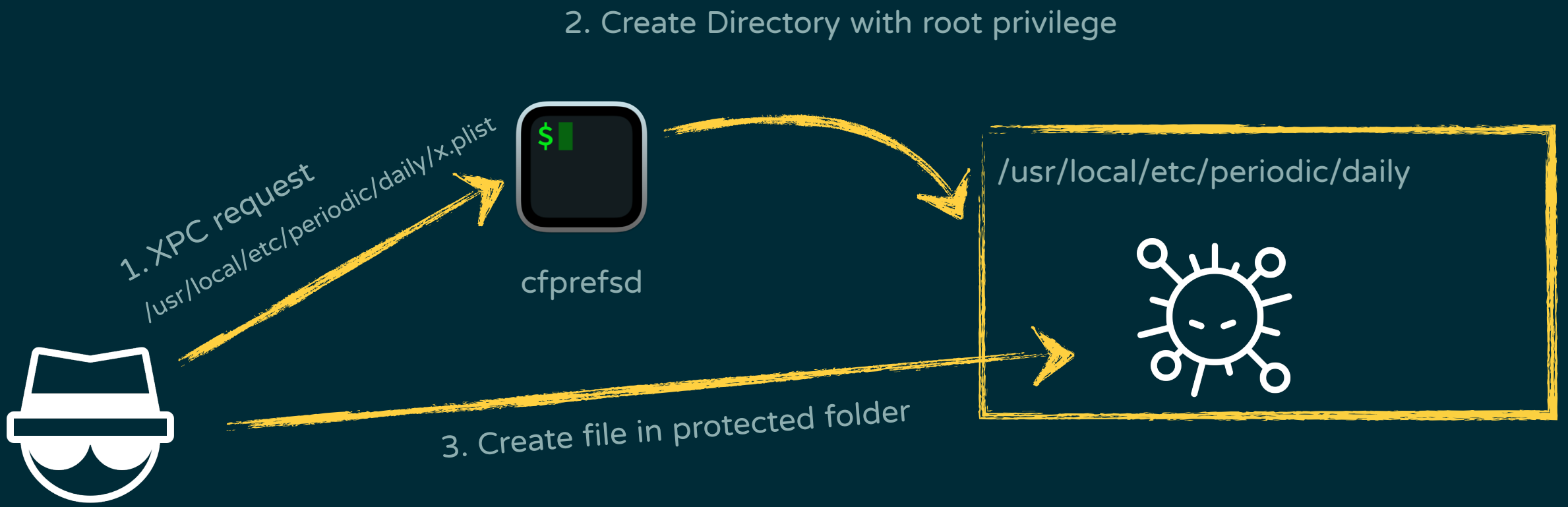
CFPrefsCreatePreferencesDirectory(path)



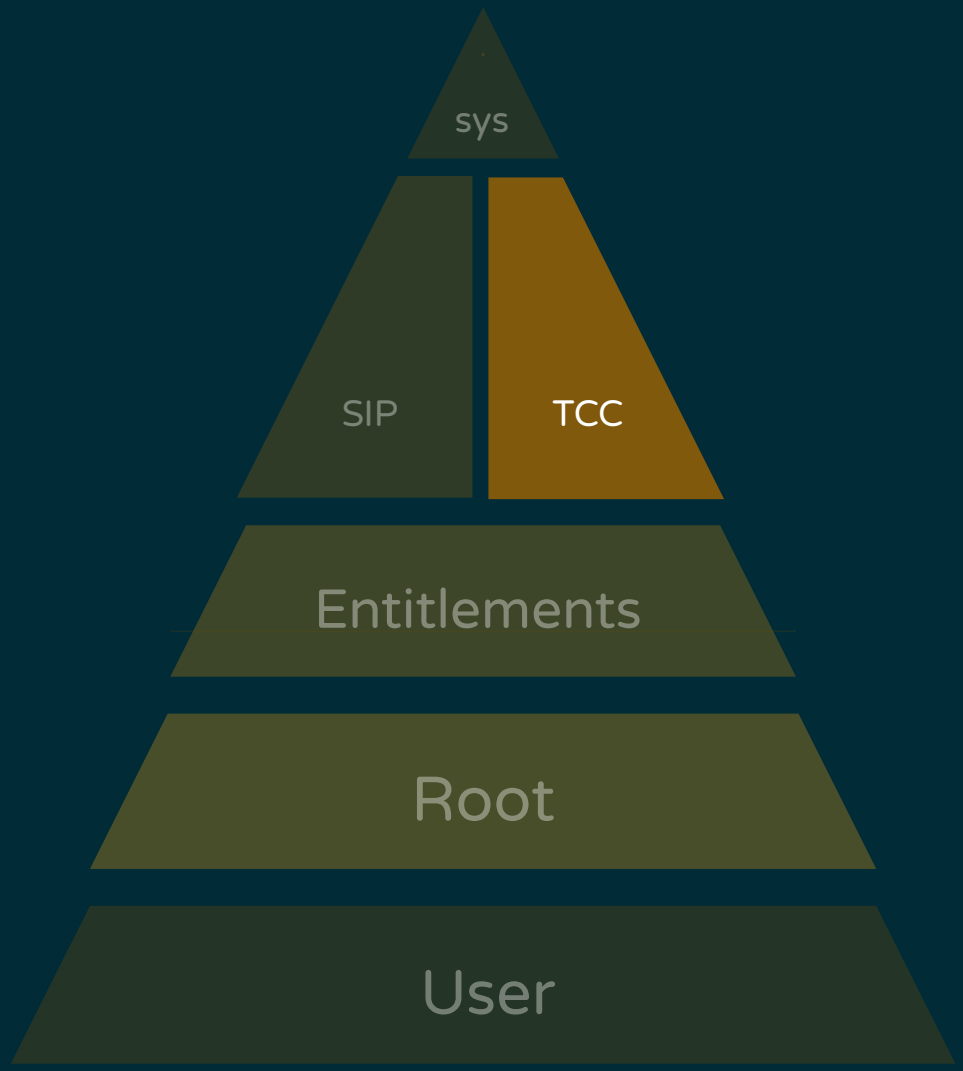
DazzleSpy Malware

- Privilege escalation to root (CVE-2021-30869)
- Use the exploitation to remove the quarantine attribute
- Avoid asking the user to confirm the launch of the unsigned executable file

https://www.welivesecurity.com/2022/01/25/watering-hole-deploys-new-macos-malware-dazzlespy-asia/

Bypass TCC

- Attack with legacy apps
- Manipulate TCC.db
  - ✓ CVE-2021-1784
  - ✓ CVE-2020-9771
  - ✓ CVE-2020-9934
  - ✓ Powerdir
- Inject entitled application
  - ✓ CVE-2021-30713

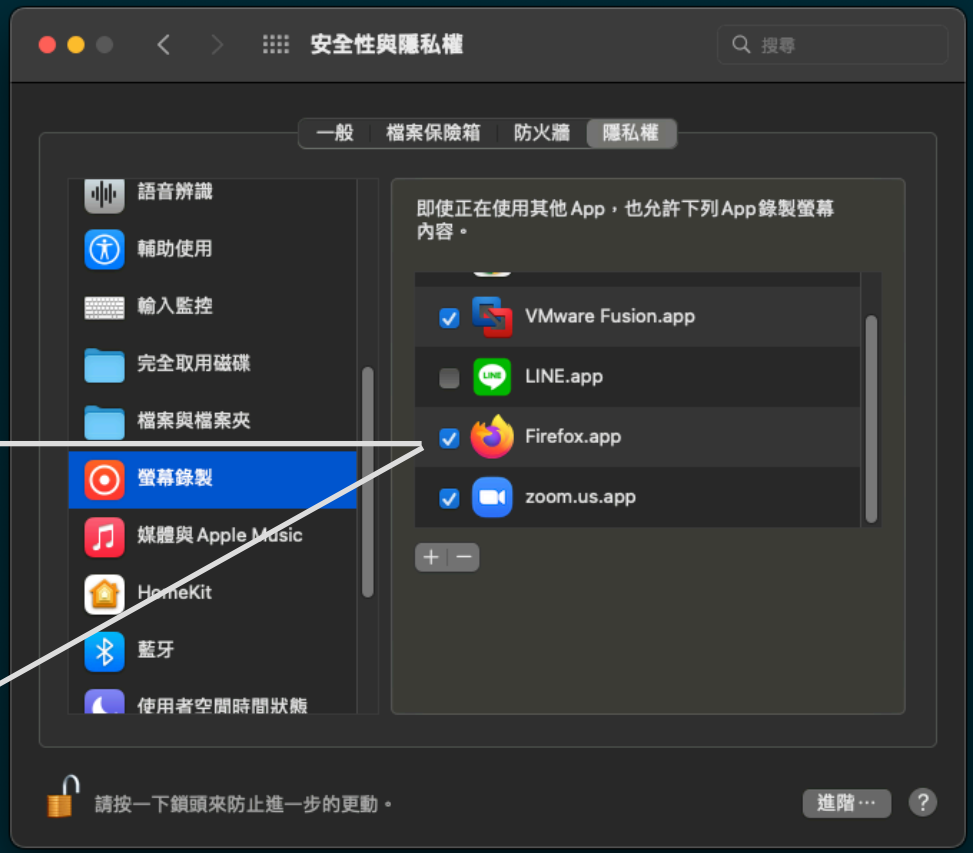


Attacking With legacy apps

- Find the app with high TCC privileges
- Download the old version app
- Inject the evil library in old version app

csreq => anchor apple generic and certificate leaf[field.1.2.840.113635.100.6.1.9] /* exists */ or anchor apple generic and certificate 1[field.1.2.840.113635.100.6.2.6] /* exists */ and certificate leaf[field.1.2.840.113635.100.6.1.13] /* exists */ and certificate leaf[subject.OU] = "43AQ936H96"

Same csreq



Manipulate TCC.db

- TTC.db file is protected
- We can change the filesystem by
  - Mount over “com.apple.TCC”(CVE-2020-9771, CVE-2021-1784)
  - Modify the $HOME env to plant a chosen TCC.db (CVE-2020-9934)

Injecting Entitled Application

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- Dylib inject
- Com.apple.security.get-task-allow

```
qq#<?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.tcc.allow</key>
        <array>
                <string>kTCCServiceSystemPolicyRemovableVolumes</string>
        </array>
```

CloudMensis Spyware

- Privilege escalation to bypass TCC (CVE-2020-9934)
- Gaining access to the screen sharing
- Being able to scan removable storage for documents of interest
- Being able to log keyboard events

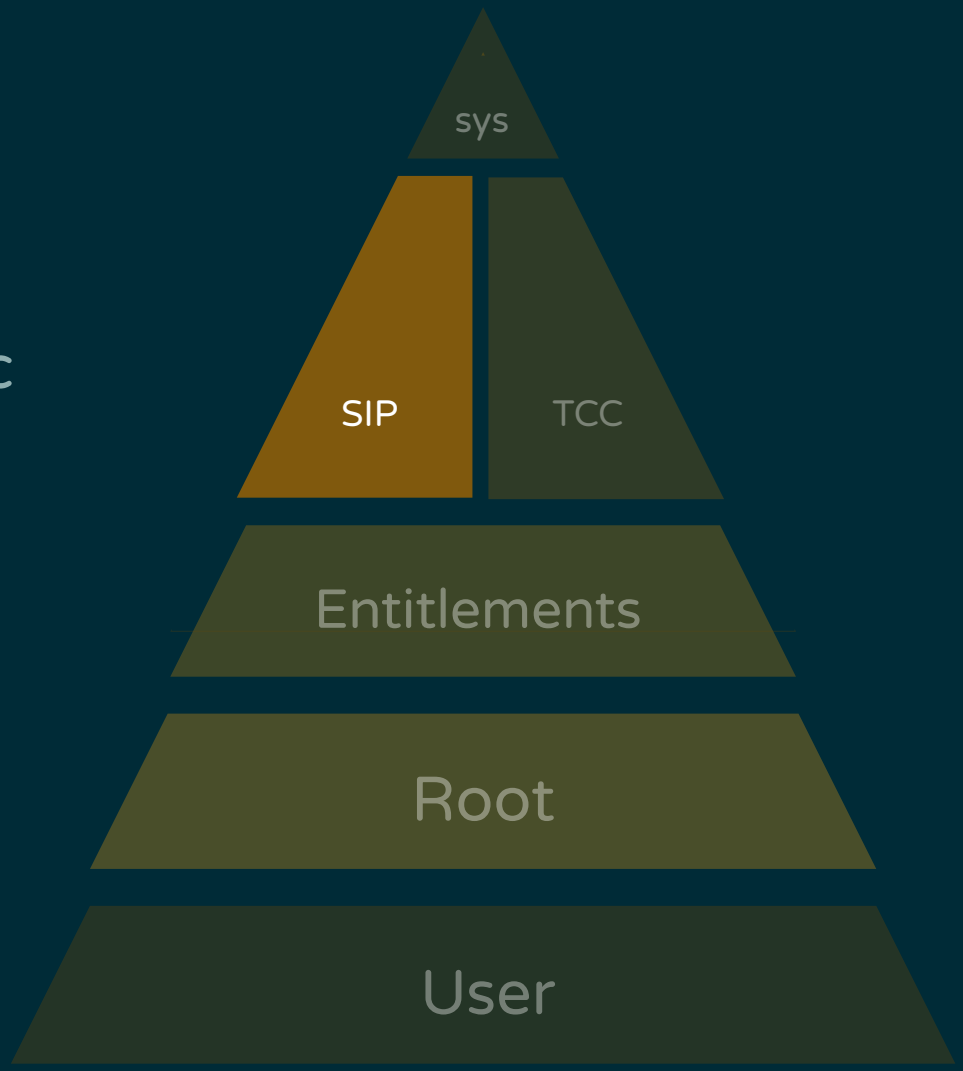
https://www.welivesecurity.com/2022/07/19/i-see-what-you-did-there-look-cloudmensis-macos-spyware/

Case Study: IR Case

- We realize that user didn't know what "Full Disk Access" attribute means
- And give too many APPs this attribute
- It's DANGEROUS!!

Bypass SIP

- Exploit entitled system daemon
  - ✓ CVE-2021-30892 system_installd
  - ✓ CVE-2022-22583 system_installd
  - ✓ CVE-2022-26712 SystemShoveService.xpc
- Inject entitled application
  - ✓ CVE-2022-22582 XAR



CVE-2022-22583 System_installd

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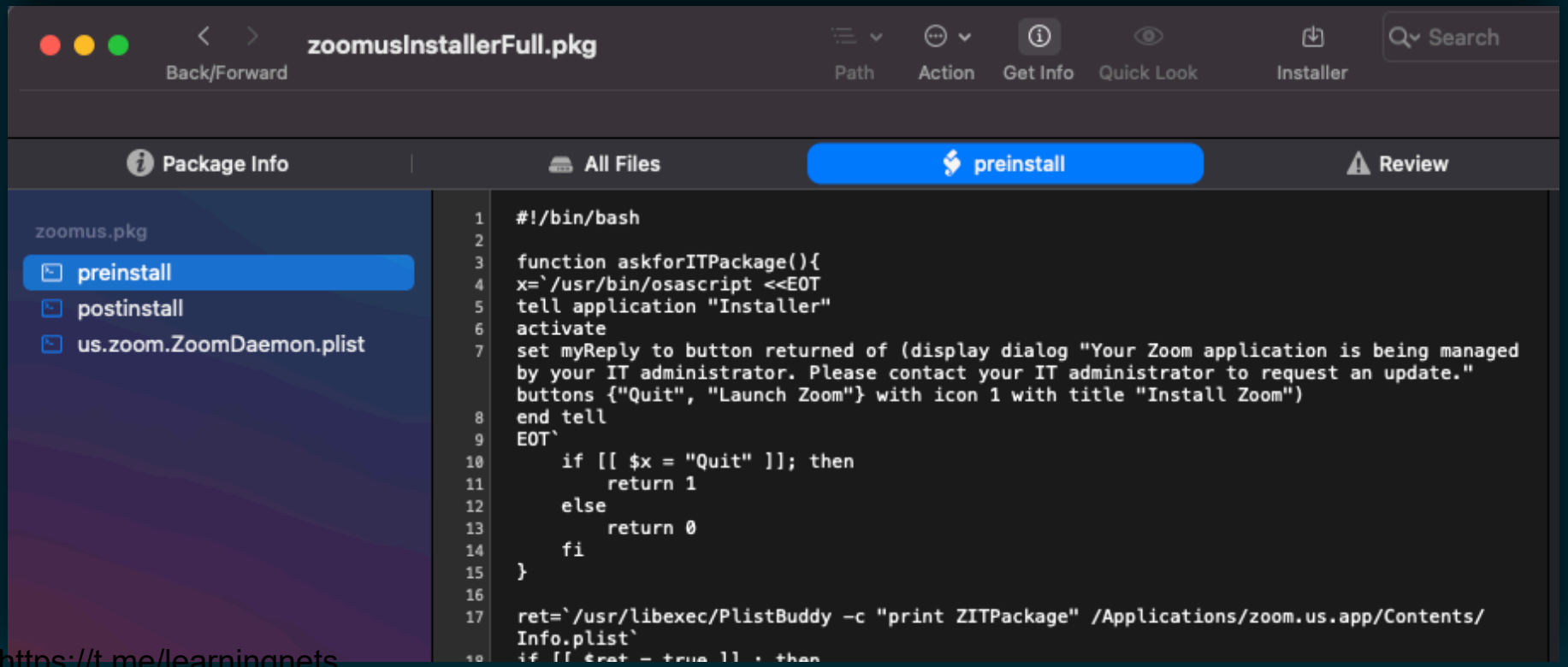
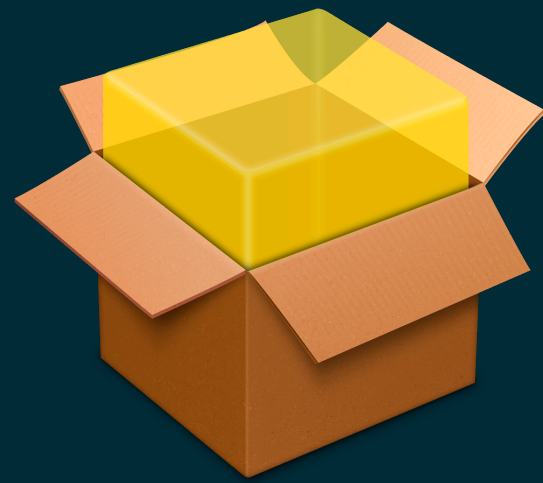
- PackageKit framework's daemon
- Responsible for installing Apple-signed packages





CVE-2022-22583 System_Installd

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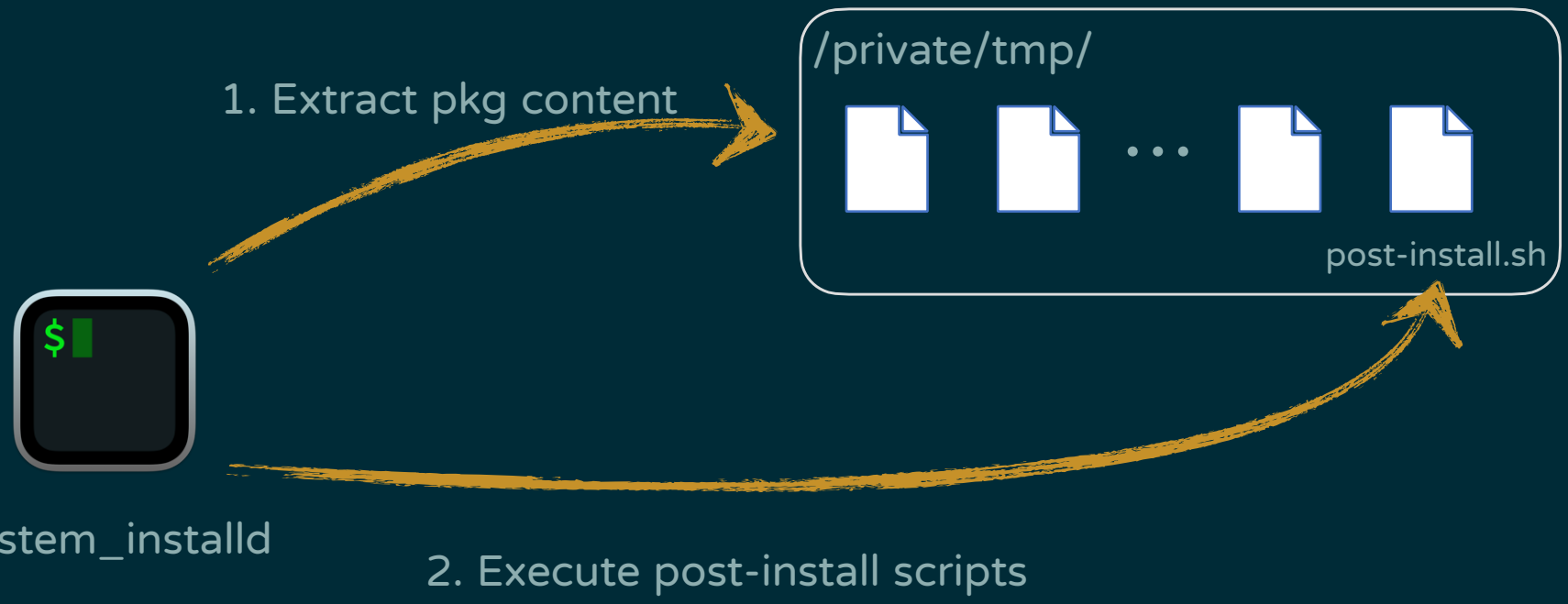
- Daemon extracts all content to /private/tmp
- /private/tmp directory wasn't protected
- We can change the post-install scripts
- Then, system_installd execute post-install script with SIP privilege



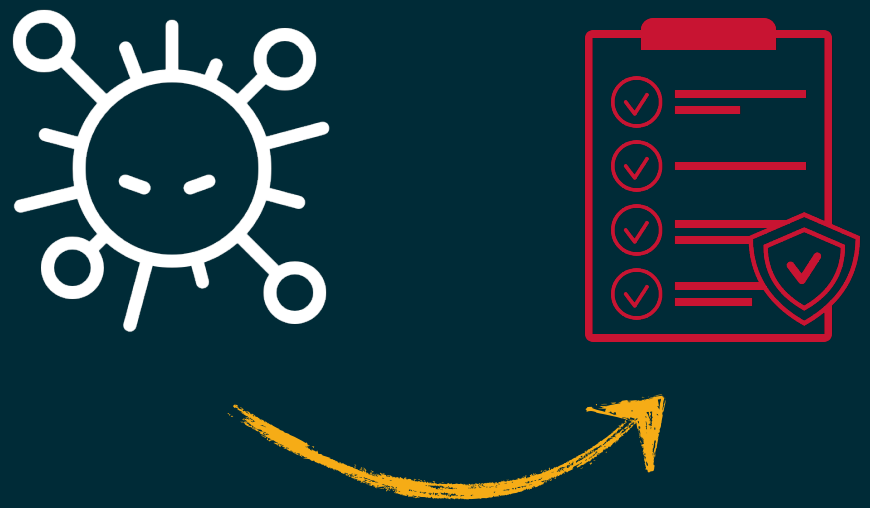
Wrap Up

- Many exploits rely on vulnerable XPC services
- TCC.db and legacy applications are fairly common ways to attack TCC
- Entitled binaries and services should be tag

EndpointSecurity Framework

OnPrivilege

- We analyze recents privilege escalation exploits and set a trap
- We propose a new hunting module on macOS platform
- Hunting the threat when malware try to do privilege escalation



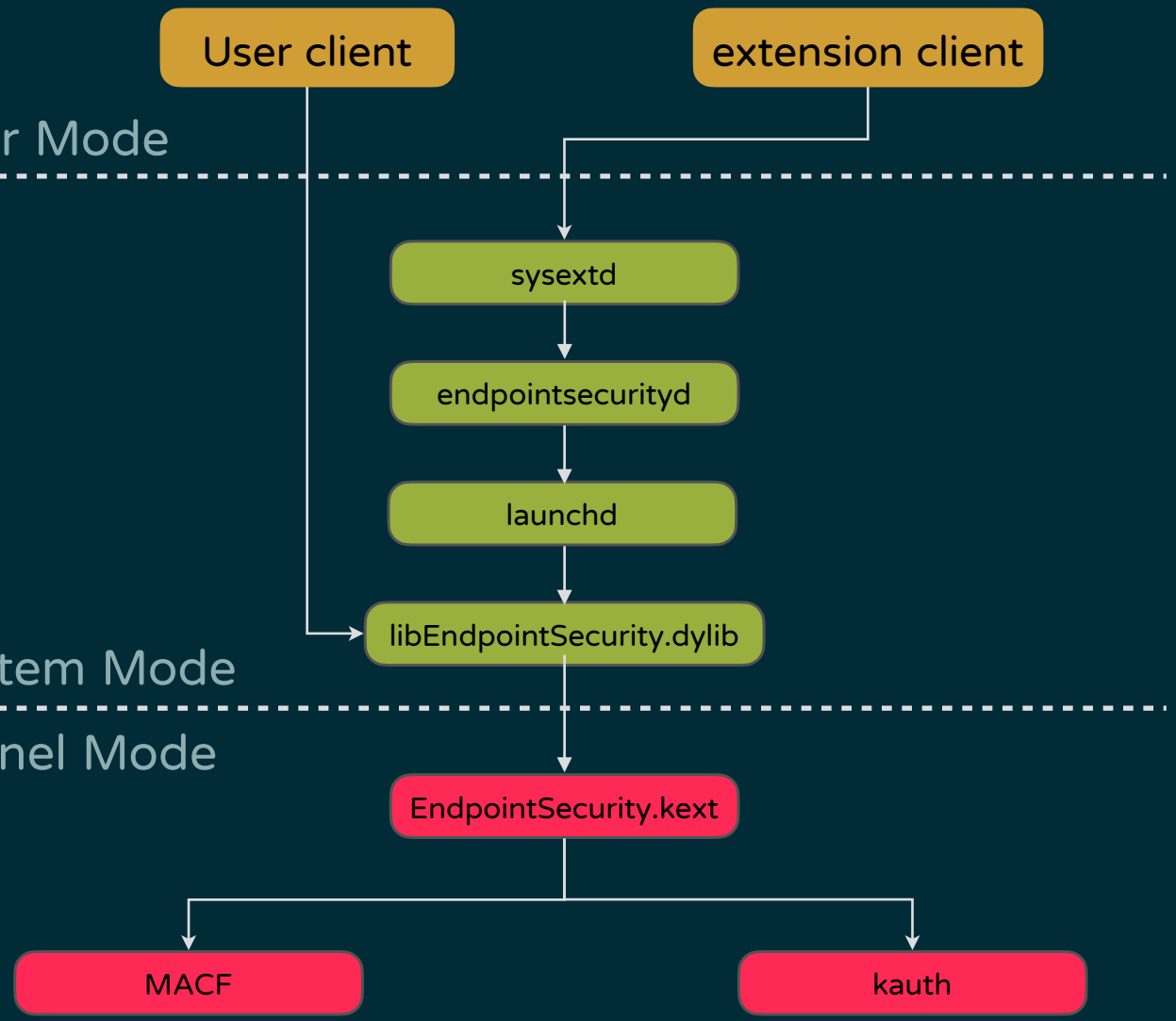
Privilege Escalation

EndpointSecurity Framework

- Apple suggested third-party anti-malware software use SEXT instead of KEXT
- Apple supported ESF various of event to hook user behavior
- Third-party software should apply for ESF client entitlement from Apple
- Events include process executions, mounting file systems, forking processes, and raising signals ...

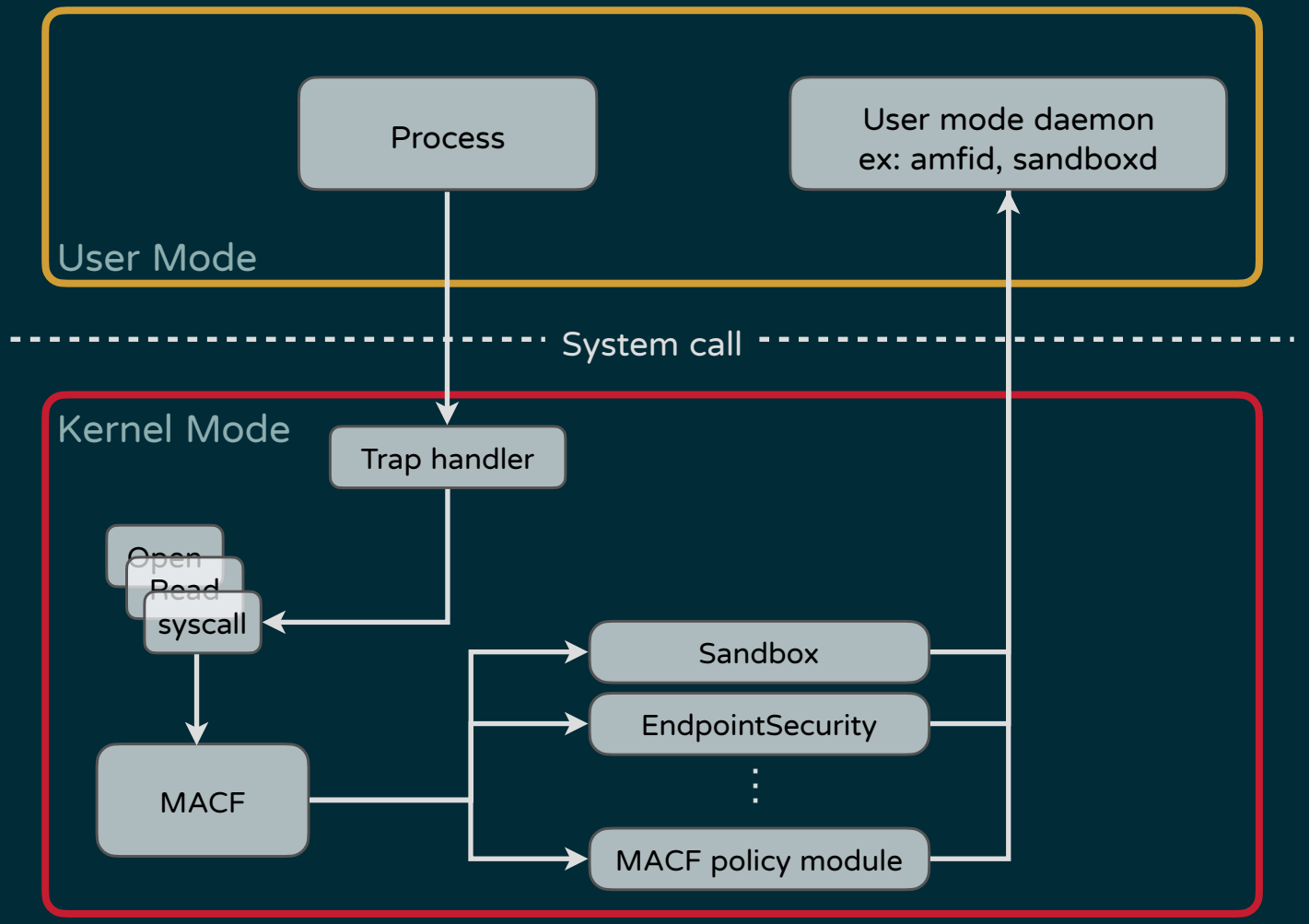
Diving deeper into ESF

- sysextd
  - validate SEXT
- Endpointsecurityd
  - loading SEXT via launchd
- libEndpointSecurity.dylib
  - provide api function for client
- MACF, kauth
  - hooking syscall event



MACF

- Mandatory Access Control Framework
- Implemented in kernel
- A natural hooking mechanism
- MACF policy module:
  - Sandbox
  - AppleMobileFileIntegrity
  - Gatekeeper
  - EndpointSecurity



MACF


```
int
fork1(proc_t parent_proc, thread_t *child_threadp,
                        int kind, coalition_t *coalitions)
{
… …
#if CONFIG_MACF
    /*
     * Determine if MAC policies applied to the process will allow
     * it to fork.  This is an advisory-only check.
     */
    err = mac_proc_check_fork(parent_proc);
    if (err != 0) {
        goto bad;
    }
#endif
… …
```

MACF


```
int
mac_proc_check_fork(proc_t curp)
{
    … …
     cred = kauth_cred_proc_ref(curp);
     MAC_CHECK(proc_check_fork, cred, curp);
     kauth_cred_unref(&cred);

     return error;
}
```

MACF


```
/*
 * MAC_CHECK performs the designated check by walking the policy
 * module list and checking with each as to how it feels about the
 * request.  Note that it returns its value via 'error' in the scope
 * of the caller.
 */
#define MAC_CHECK(check, args...) do {                                  \
    error = 0;                                                          \
    MAC_POLICY_ITERATE({                                                \
        if (mpc->mpc_ops->mpo_ ## check != NULL) {                      \
                DTRACE_MACF3(mac__call__ ## check, void *, mpc, int,
error, int, MAC_ITERATE_CHECK); \
                int __step_err = mpc->mpc_ops->mpo_ ## check (args); \
                DTRACE_MACF2(mac__rslt__ ## check, void *, mpc, int,
__step_err); \
                error = mac_error_select(__step_err, error);            \
        }                                                               \
    });                                                                 \
} while (0)
```

Run program using shell

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```
event: exec
    time: 2022-08-11 22:46:32.926979301
 process:
        PID : 35802
       EUID : 501
       PPID : 1823
        GID : 35802
        SID : 1815
        TID : 1815
       RPID : 406
       Path : /bin/zsh
       ARGS : /tmp/exploit
    cs_flag : 0x22014801
```

xnu/osfmk/kern/cs_blobs.h

```
/* code signing attributes of a process */
#define CS_VALID                    0x00000001  /* dynamically valid */
#define CS_ADHOC                    0x00000002  /* ad hoc signed */
#define CS_GET_TASK_ALLOW           0x00000004  /* has get-task-allow e
#define CS_INSTALLER                0x00000008  /* has installer entitl

#define CS_FORCED_LV                0x00000010  /* Library Validation r
#define CS_INVALID_ALLOWED          0x00000020  /* (macOS Only) Page in

#define CS_HARD                     0x00000100  /* don't load invalid p
#define CS_KILL                     0x00000200  /* kill process if it b
#define CS_CHECK_EXPIRATION         0x00000400  /* force expiration che
#define CS_RESTRICT                 0x00000800  /* tell dyld to treat r

#define CS_ENFORCEMENT              0x00001000  /* require enforcement
#define CS_REQUIRE_LV               0x00002000  /* require library vali
#define CS_ENTITLEMENTS_VALIDATED   0x00004000  /* code signature permi
#define CS_NVRAM_UNRESTRICTED       0x00008000  /* has com.apple.rootle
```

```
CS_SIGNED|CS_RUNTIME|CS_ENTITLEMENTS_VALIDATED|CS_RESTRICT|CS_VALID
```

ES events

- > 100 Hooks can use in ESF

```
typedef enum {
    // The following events are available beginning in macOS 10.15
    ES_EVENT_TYPE_AUTH_EXEC
  , ES_EVENT_TYPE_AUTH_OPEN
  , ES_EVENT_TYPE_AUTH_KEXTLOAD
  , ES_EVENT_TYPE_AUTH_MMAP
  , ES_EVENT_TYPE_AUTH_MPROTECT
  , ES_EVENT_TYPE_AUTH_MOUNT
  , ES_EVENT_TYPE_AUTH_RENAME
  , ES_EVENT_TYPE_AUTH_SIGNAL
  , ES_EVENT_TYPE_AUTH_UNLINK
  , ES_EVENT_TYPE_NOTIFY_EXEC
  , ES_EVENT_TYPE_NOTIFY_OPEN
  , ES_EVENT_TYPE_NOTIFY_FORK
  , ES_EVENT_TYPE_NOTIFY_CLOSE
  , ES_EVENT_TYPE_NOTIFY_CREATE
  , ES_EVENT_TYPE_NOTIFY_EXCHANGEDATA
  , ES_EVENT_TYPE_NOTIFY_EXIT
  , ES_EVENT_TYPE_NOTIFY_GET_TASK
  , ES_EVENT_TYPE_NOTIFY_KEXTLOAD
  , ES_EVENT_TYPE_NOTIFY_KEXTUNLOAD
  , ES_EVENT_TYPE_NOTIFY_LINK
  , ES_EVENT_TYPE_NOTIFY_MMAP
  , ES_EVENT_TYPE_NOTIFY_MPROTECT
  , ES_EVENT_TYPE_NOTIFY_MOUNT
  , ES_EVENT_TYPE_NOTIFY_UNMOUNT
  , ES_EVENT_TYPE_NOTIFY_IOKIT_OPEN
  , ES_EVENT_TYPE_NOTIFY_RENAME
  , ES_EVENT_TYPE_NOTIFY_SETATTRLIST
  , ES_EVENT_TYPE_NOTIFY_SETEXTATTR
  , ES_EVENT_TYPE_NOTIFY_SETFLAGS
  , ES_EVENT_TYPE_NOTIFY_SETMODE
  , ES_EVENT_TYPE_NOTIFY_SETOWNER
  , ES_EVENT_TYPE_NOTIFY_SIGNAL
  , ES_EVENT_TYPE_NOTIFY_UNLINK
  , ES_EVENT_TYPE_NOTIFY_WRITE
  , ES_EVENT_TYPE_AUTH_FILE_PROVIDER_MATERIALIZE
  , ES_EVENT_TYPE_NOTIFY_FILE_PROVIDER_MATERIALIZE
  , ES_EVENT_TYPE_AUTH_FILE_PROVIDER_UPDATE
  , ES_EVENT_TYPE_NOTIFY_FILE_PROVIDER_UPDATE
  , ES_EVENT_TYPE_AUTH_READLINK
  , ES_EVENT_TYPE_NOTIFY_UIPC_CONNECT
  , ES_EVENT_TYPE_AUTH_UIPC_CONNECT
  , ES_EVENT_TYPE_AUTH_EXCHANGEDATA
  , ES_EVENT_TYPE_AUTH_SETACL
  , ES_EVENT_TYPE_NOTIFY_SETACL
  // The following events are available beginning in macOS 10.15.4
  , ES_EVENT_TYPE_NOTIFY_PTY_GRANT
  , ES_EVENT_TYPE_NOTIFY_PTY_CLOSE
  , ES_EVENT_TYPE_AUTH_PROC_CHECK
  , ES_EVENT_TYPE_NOTIFY_PROC_CHECK
  , ES_EVENT_TYPE_AUTH_GET_TASK
  // The following events are available beginning in macOS 11.0
  , ES_EVENT_TYPE_AUTH_SEARCHFS
  , ES_EVENT_TYPE_NOTIFY_SEARCHFS
  , ES_EVENT_TYPE_AUTH_FCNTL
  , ES_EVENT_TYPE_AUTH_IOKIT_OPEN
  , ES_EVENT_TYPE_AUTH_PROC_SUSPEND_RESUME
  , ES_EVENT_TYPE_NOTIFY_PROC_SUSPEND_RESUME
  , ES_EVENT_TYPE_NOTIFY_CS_INVALIDATED
  , ES_EVENT_TYPE_NOTIFY_GET_TASK_NAME
  , ES_EVENT_TYPE_NOTIFY_TRACE
  , ES_EVENT_TYPE_NOTIFY_REMOTE_THREAD_CREATE
  , ES_EVENT_TYPE_AUTH_REMOUNT
  , ES_EVENT_TYPE_NOTIFY_REMOUNT
  // The following events are available beginning in macOS 11.3
  , ES_EVENT_TYPE_AUTH_GET_TASK_READ
  , ES_EVENT_TYPE_NOTIFY_GET_TASK_READ
  , ES_EVENT_TYPE_NOTIFY_GET_TASK_INSPECT
  // The following events are available beginning in macOS 12.0
  , ES_EVENT_TYPE_NOTIFY_SETUID
  , ES_EVENT_TYPE_NOTIFY_SETGID
  , ES_EVENT_TYPE_NOTIFY_SETEUID
  , ES_EVENT_TYPE_NOTIFY_SETEGID
  , ES_EVENT_TYPE_NOTIFY_SETREUID
  , ES_EVENT_TYPE_NOTIFY_SETREGID
  , ES_EVENT_TYPE_AUTH_COPYFILE
  , ES_EVENT_TYPE_NOTIFY_COPYFILE
    // ES_EVENT_TYPE_LAST is not a valid event type but a convenien
    // value for operating on the range of defined event types.
    // This value may change between releases and was available
    // beginning in macOS 10.15
  , ES_EVENT_TYPE_LAST
} es_event_type_t;
```

ES events

- > 100 Hooks can use in ESF
- How to select your hooking events ???

```
typedef enum {
    // The following events are available beginning in macOS 10.15
    ES_EVENT_TYPE_AUTH_EXEC
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  , ES_EVENT_TYPE_AUTH_MPROTECT
  , ES_EVENT_TYPE_AUTH_MOUNT
  , ES_EVENT_TYPE_AUTH_RENAME
  , ES_EVENT_TYPE_AUTH_SIGNAL
  , ES_EVENT_TYPE_AUTH_UNLINK
  , ES_EVENT_TYPE_NOTIFY_EXEC
  , ES_EVENT_TYPE_NOTIFY_OPEN
  , ES_EVENT_TYPE_NOTIFY_FORK
  , ES_EVENT_TYPE_NOTIFY_CLOSE
  , ES_EVENT_TYPE_NOTIFY_CREATE
  , ES_EVENT_TYPE_NOTIFY_EXCHANGEDATA
  , ES_EVENT_TYPE_NOTIFY_EXIT
  , ES_EVENT_TYPE_NOTIFY_GET_TASK
  , ES_EVENT_TYPE_NOTIFY_KEXTLOAD
  , ES_EVENT_TYPE_NOTIFY_KEXTUNLOAD
  , ES_EVENT_TYPE_NOTIFY_LINK
  , ES_EVENT_TYPE_NOTIFY_MMAP
  , ES_EVENT_TYPE_NOTIFY_MPROTECT
  , ES_EVENT_TYPE_NOTIFY_MOUNT
  , ES_EVENT_TYPE_NOTIFY_UNMOUNT
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  , ES_EVENT_TYPE_NOTIFY_RENAME
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  , ES_EVENT_TYPE_NOTIFY_SETFLAGS
  , ES_EVENT_TYPE_NOTIFY_SETMODE
  , ES_EVENT_TYPE_NOTIFY_SETOWNER
  , ES_EVENT_TYPE_NOTIFY_SIGNAL
  , ES_EVENT_TYPE_NOTIFY_UNLINK
  , ES_EVENT_TYPE_NOTIFY_WRITE
  , ES_EVENT_TYPE_AUTH_FILE_PROVIDER_MATERIALIZE
  , ES_EVENT_TYPE_NOTIFY_FILE_PROVIDER_MATERIALIZE
  , ES_EVENT_TYPE_AUTH_FILE_PROVIDER_UPDATE
  , ES_EVENT_TYPE_NOTIFY_FILE_PROVIDER_UPDATE
  , ES_EVENT_TYPE_AUTH_READLINK
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  , ES_EVENT_TYPE_AUTH_PROC_CHECK
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  , ES_EVENT_TYPE_AUTH_IOKIT_OPEN
  , ES_EVENT_TYPE_AUTH_PROC_SUSPEND_RESUME
  , ES_EVENT_TYPE_NOTIFY_PROC_SUSPEND_RESUME
  , ES_EVENT_TYPE_NOTIFY_CS_INVALIDATED
  , ES_EVENT_TYPE_NOTIFY_GET_TASK_NAME
  , ES_EVENT_TYPE_NOTIFY_TRACE
  , ES_EVENT_TYPE_NOTIFY_REMOTE_THREAD_CREATE
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  , ES_EVENT_TYPE_NOTIFY_SETUID
  , ES_EVENT_TYPE_NOTIFY_SETGID
  , ES_EVENT_TYPE_NOTIFY_SETEUID
  , ES_EVENT_TYPE_NOTIFY_SETEGID
  , ES_EVENT_TYPE_NOTIFY_SETREUID
  , ES_EVENT_TYPE_NOTIFY_SETREGID
  , ES_EVENT_TYPE_AUTH_COPYFILE
  , ES_EVENT_TYPE_NOTIFY_COPYFILE
    // ES_EVENT_TYPE_LAST is not a valid event type but a convenien
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    // beginning in macOS 10.15
  , ES_EVENT_TYPE_LAST
} es_event_type_t;
```
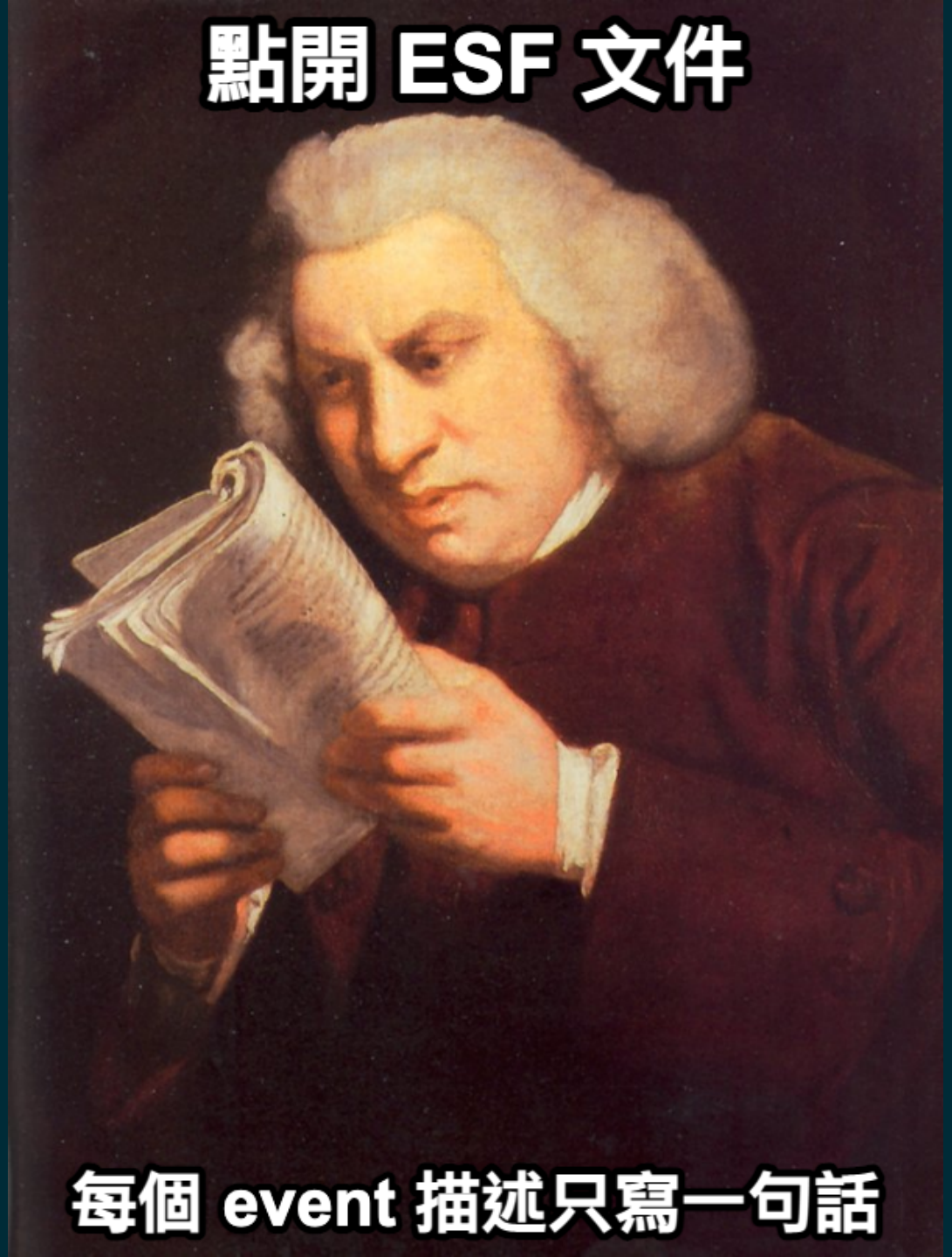

ES events



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Triggering onPrivilege with ESF

OnPrivilege Project

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- https://github.com/will03/onPrivilege
- Detect privilege changing behavior
- Including …
  - Process rooting detection
  - TCC.db file protection
  - Legacy APP detection
  - Special entitlement file tracking

Hunt Process Rooting

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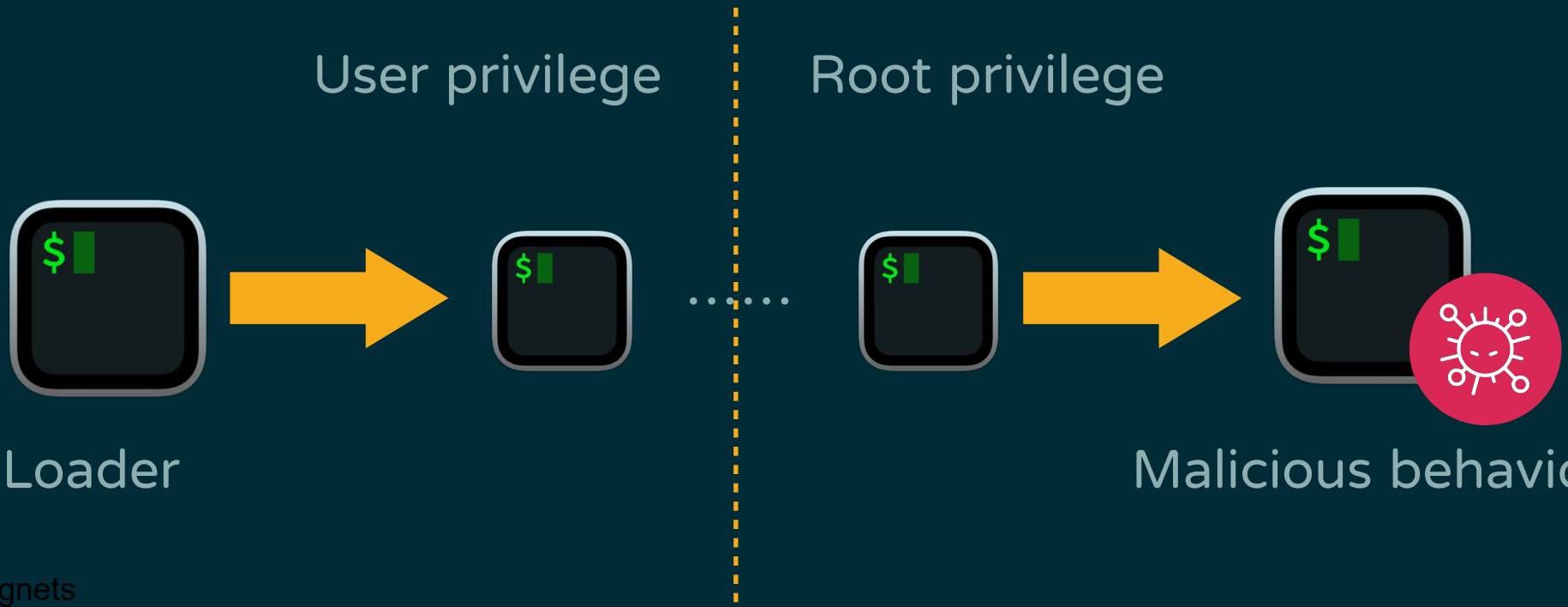
- Enhance XPC client and service relationship
- Detect High privileged process execution
- Find the original Initiator



xpcproxy trampoline

- When client request, xpcproxy is responsible for executing daemon

```
event: exec
process:
        PID : 48305
       EUID : 0
       PPID : 1
        GID : 1
        SID : 1
   threadid : 1
       RPID : 48305
       path : /sbin/launchd
       ARGS : xpcproxy com.apple.install.osinstallersetupd
    cs_flag : 0x22014a21
```

Tracking XPC

- When client using XPC to request daemon to do something
- There is no sign for connection between client and daemon
- It's an important issue when we design onPrivilege

Tracking XPC

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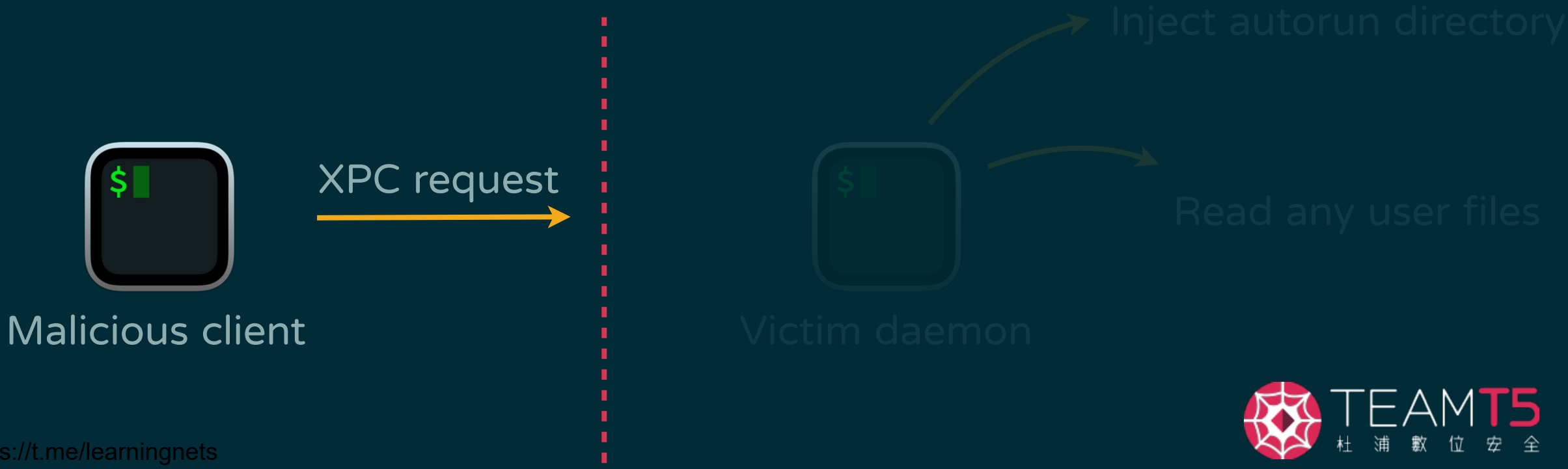


Tracking XPC

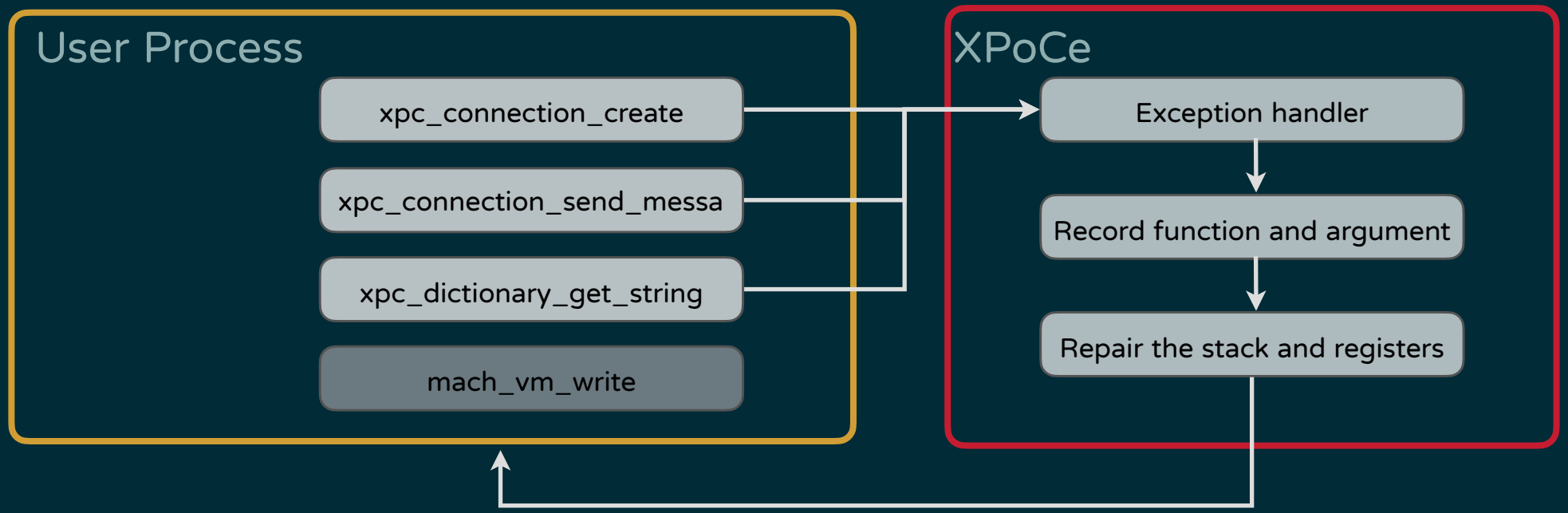
- When client using XPC to request daemon to do something
- There is no sign for connection between client and daemon
- It's an important issue when we design onPrivilege

Tracking XPC

- Hooking XPC connection is the only solution for the moment
- What process can be hooked
  - ✓ No SIP-protected process
  - ✓ No entitlements process

Tracking XPC

- XPoCe - XPC Snooping utility
- http://newosxbook.com/tools/XPoCe2.html



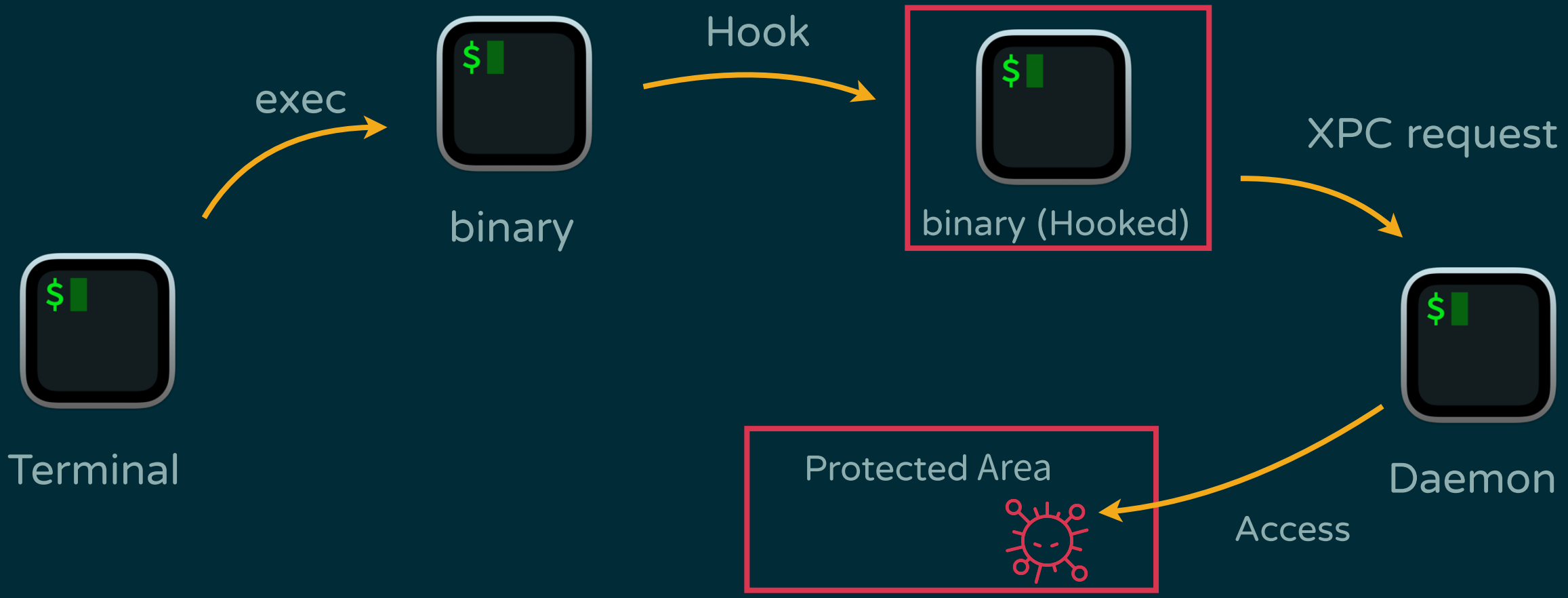
Tracking XPC

- Hooking the low privileged program


```
xpc_connection_create_mach_service ( "com.apple.cfprefsd.daemon",0x0)  = 0x7fd03ec08e10 ()
xpc_dictionary_get_uint64 ( dictionary@0x7fd03ec08a10,"req_pid")
 = "<dictionary: 0x7fd03ec08a10> { count = 3, transaction: 0, voucher = 0x0, contents =
        "rec_execcnt" => <uint64: 0x723946d8c1665ff9>: 5011
        "req_pid" => <uint64: 0x723946d8c0da4ff9>: 2130
        "port" => <mach send right: 0x7fd03ec08360> { name = 10499, right = send, urefs = 1
```

Tracking XPC

- Hooking the low privileged program



Tracking XPC

- Connecting malicious client and behaviors

TCC Protection

- Old app detection
- Library inject detection
- Get-task-allow inject detection
- TCC.db protection
  - Mount/read/write

Hunting Duplicate APP bundles

- Record Application bundle version

```
will@hello:~|⇒  codesign -d -v -r- /tmp/Firefox.app
Executable=/private/tmp/Firefox.app/Contents/MacOS/firefox
Identifier=org.mozilla.firefox
Format=app bundle with Mach-O thin (x86_64)
CodeDirectory v=20500 size=447 flags=0x10000(runtime) hashes=5+5
Signature size=9019
Timestamp=Jul 6, 2020 at 10:35:02 AM
Info.plist entries=27
TeamIdentifier=43AQ936H96
Runtime Version=10.11.0
Sealed Resources version=2 rules=13 files=92
designated => anchor apple generic and certificate leaf[field.1.2.
13635.100.6.2.6] /* exists */ and certificate leaf[field.1.2.840.
```

```
will@hello:~|⇒  codesign -d -v -r- /Applications/Firefox.app
Executable=/Applications/Firefox.app/Contents/MacOS/firefox
Identifier=org.mozilla.firefox
Format=app bundle with Mach-O universal (x86_64 arm64)
CodeDirectory v=20500 size=479 flags=0x10000(runtime) hashes=6+5 lo
Signature size=8989
Timestamp=Jun 23, 2022 at 4:45:24 PM
Info.plist entries=25
TeamIdentifier=43AQ936H96
Runtime Version=11.0.0
Sealed Resources version=2 rules=13 files=82
designated => anchor apple generic and certificate leaf[field.1.2.8
13635.100.6.2.6] /* exists */ and certificate leaf[field.1.2.840.11
```

Hunt Process Rooting

- Hook XPC connection when low privileged program execute
- Check if program or service try to write high privileged area

```
std::map<string, es_event_type_t> NOTIFYEVENTS = {
    {"exec", ES_EVENT_TYPE_NOTIFY_EXEC},
    {"write", ES_EVENT_TYPE_NOTIFY_WRITE},
    {"create", ES_EVENT_TYPE_NOTIFY_CREATE}
};
```

Hunting TCC-bypass

- Detect get-task and library injection
- Check the mount point is covering TCC database directory
- Monitor duplicate APP bundles

```
std::map<string, es_event_type_t> NOTIFYEVENTS = {
    {"exec", ES_EVENT_TYPE_NOTIFY_EXEC},
    {"mount", ES_EVENT_TYPE_NOTIFY_MOUNT},
    {“write", ES_EVENT_TYPE_NOTIFY_WRITE},
    {"get_task", ES_EVENT_TYPE_NOTIFY_GET_TASK},
    {"get_task_name", ES_EVENT_TYPE_NOTIFY_GET_TASK_READ},
    {"get_task_inspect", ES_EVENT_TYPE_NOTIFY_GET_TASK_INSPECT}
    };
```

Hunting SIP-Bypass

- Check get task and library injection
- Hunting user program trying to connect SIP privilege service

```
std::map<string, es_event_type_t> NOTIFYEVENTS = {
    {"exec", ES_EVENT_TYPE_NOTIFY_EXEC},
    {“get_task", ES_EVENT_TYPE_NOTIFY_GET_TASK},
    {"get_task_name", ES_EVENT_TYPE_NOTIFY_GET_TASK_READ},
    {"get_task_inspect", ES_EVENT_TYPE_NOTIFY_GET_TASK_INSPECT}
    };
```

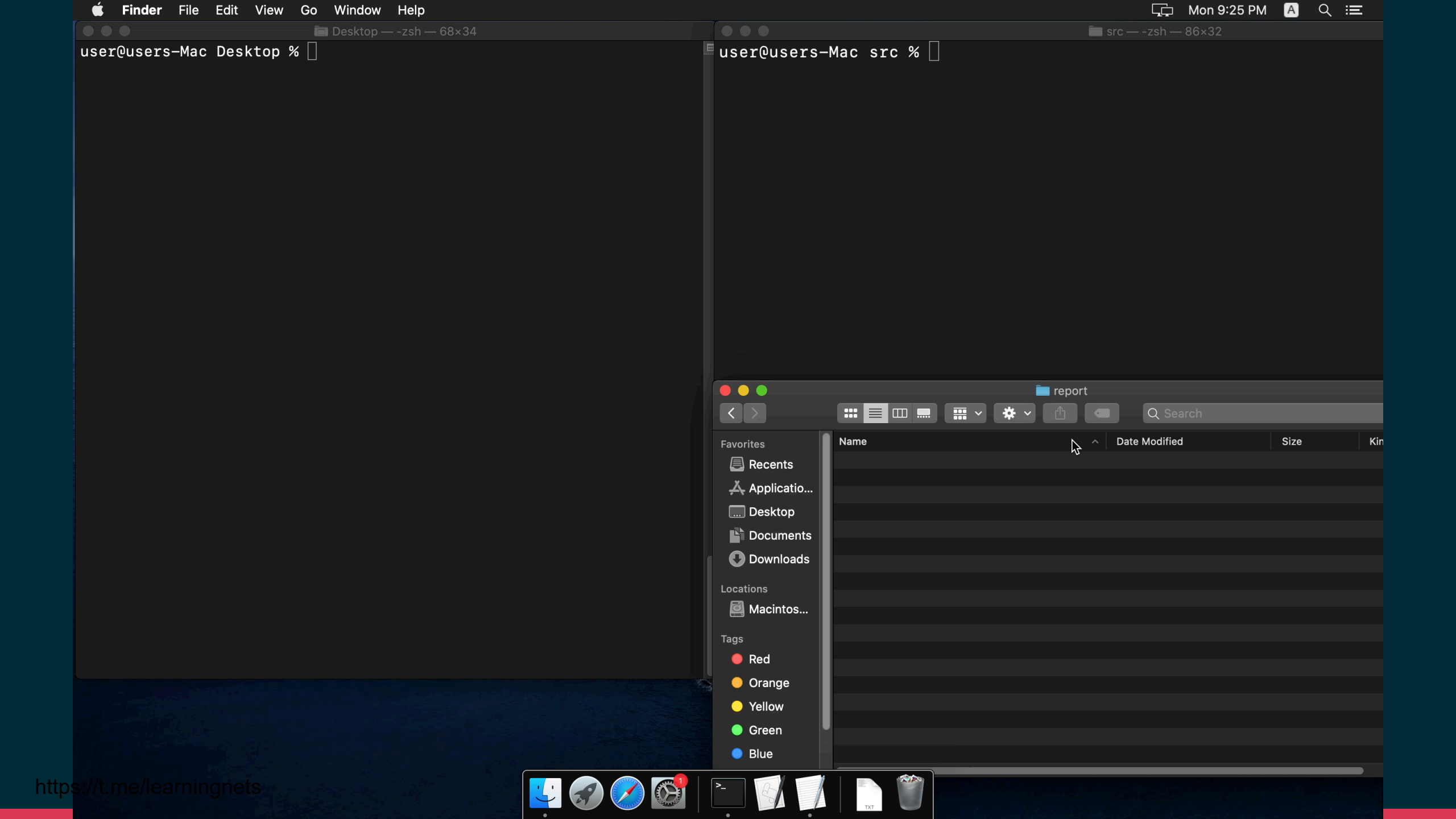
DEMO

Notify mode

- Hunting CVE-2021-1815 (cfprefsd)
- Pupop the alert message and generate raw report for user

Blocking mode

- Hunting CVE-2022-22639 (suhelperd)
- Reject the Terminal open with root



will@hello:~/Desktop/research/OnPrivilege/Sanjar/src

..VE-2022-22639 (-zsh)

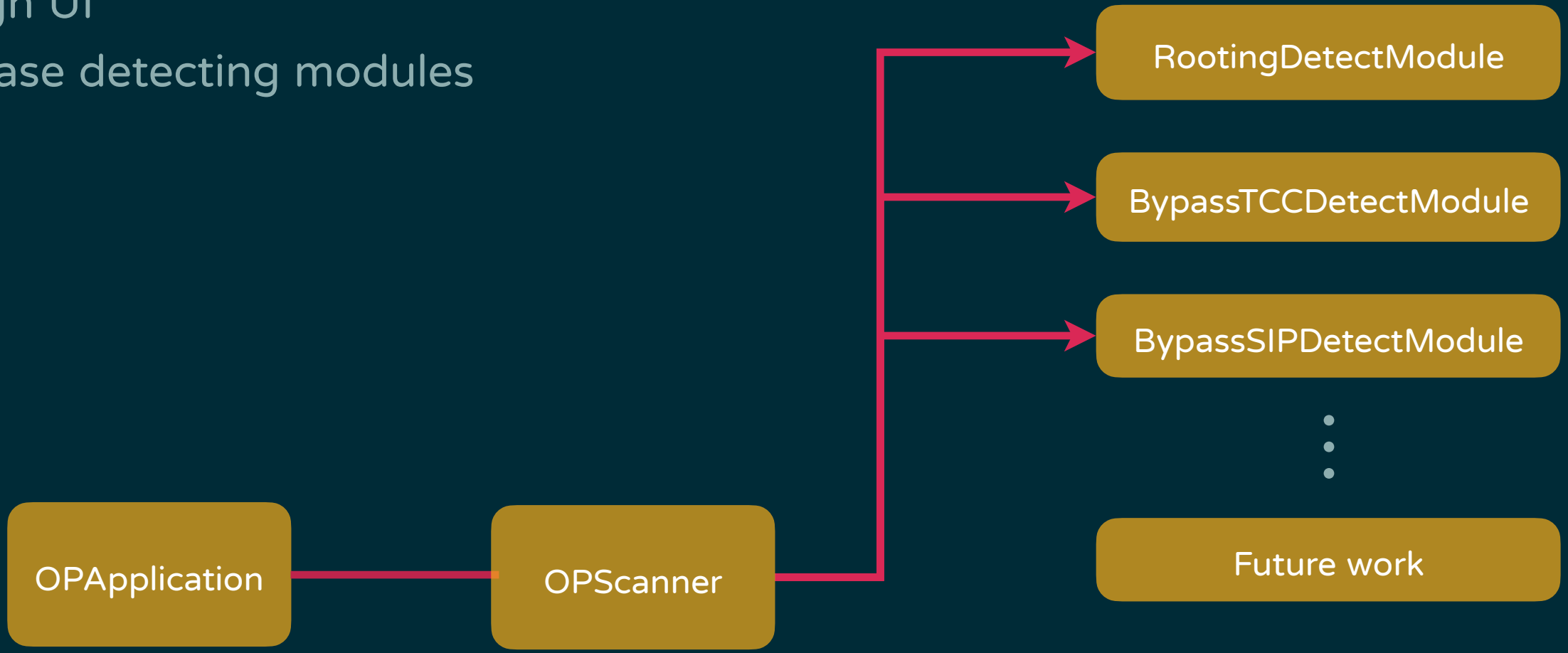
```
will@hello:~/Desktop/research/rootless/suhelperd_daemon/CVE-2022-22639|
main⚡  ⇒
```

..ge/Sanjar/src (-zsh)

```
ilege
will@hello:~/Desktop/research/OnPrivilege/Sanjar/src|main⚡  ⇒  sudo ./OnPrivilege
```

Future work

- Design UI
- Increase detecting modules



Related Topics

- Leveraging the Apple ESF for Behavioral Detections - Black hat USA 22
- Mitigating exploits using Apple's Endpoint Security - VB2021
- Endpoint Security and Insecurity - OBTS 2020

Conclusion

- Only rely on ESF is not enough when encounter advanced attack
- Developer must add additional heuristic detection logic
- Spyware uses various 1-day exploits to privilege escape
- Don’t give terminal too many privilege (ex: full disk access)
- macOS 13 released new helpful ESF events
- Apple propose new binary: ESFlogger
- ESF become more important in Apple system
- Look forward to Lockdown mode

Reference

- https://www.trendmicro.com/en_us/research/22/d/macos-suhelper-root-privilege-escalation-vulnerability-a-deep-di.html
- https://www.offensive-security.com/offsec/macos-preferences-priv-escalation/
- https://jhftss.github.io/CVE-2022-26712-The-POC-For-SIP-Bypass-Is-Even-Tweetable/
- http://newosxbook.com/tools/XPoCe.html
- http://newosxbook.com/articles/jlaunchctl.html

THANK YOU!

Will

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Persistent Cyber Threat Hunters