Process injection

Breaking All macOS Security Layers With a Single Vulnerability

Computest
always on.

>>

```
@implementation AppDelegate

- (void)applicationDidFinishLaunching:(NSNotification *)aNotification {
    // Insert code here to initialize your application
}


- (void)applicationWillTerminate:(NSNotification *)aNotification {
    // Insert code here to tear down your application
}


- (BOOL)applicationSupportsSecureRestorableState:(NSApplication *)app {
    return YES;
}

@end
```

Hello!

I’m Thijs Alkemade

Security researcher at Computest

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About me

- Thijs Alkemade (@xnyhps)
- Security researcher at Computest
- Computest research lab: Sector 7
- Other recent work includes:
  - 0click Zoom RCE at Pwn2Own Vancouver 2021
  - Winning Pwn2Own Miami 2022 with 5 ICS vulnerabilities

In this talk

1. macOS security model
2. CVE-2021-30873: process injection using saved states
3. Using process injection for:
   - Sandbox escape
   - Privilege escalation
   - SIP bypass

macOS security model

In macOS 12 Monterey

Old *NIX security model

- Users are security boundaries, processes are not
- File permissions: POSIX flags
- Attach debugger: target must run as same user
- root has full access

```
-rw-r--r--  1 talkemade  wheel  0 Aug 11 12:57 file
```

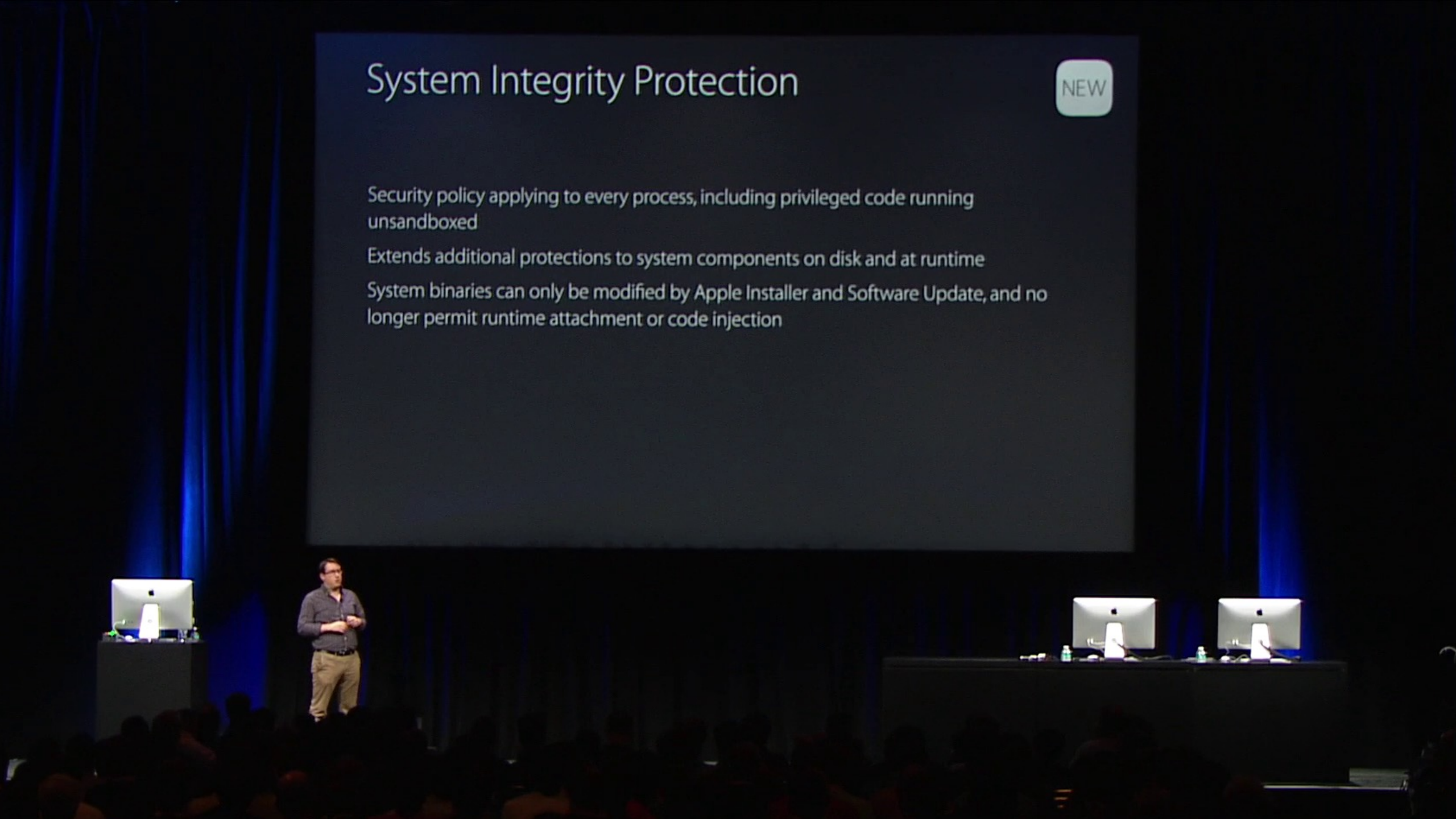
System Integrity Protection

NEW

Security policy applying to every process, including privileged code running unsandboxed

Extends additional protections to system components on disk and at runtime

System binaries can only be modified by Apple Installer and Software Update, and no longer permit runtime attachment or code injection



SIP restrictions

- **“Dangerous” operations now require the application to have an entitlement**
  - Loading a kernel extension
  - Modifying system files
  - Debugging system processes
- **More and more restrictions in each macOS release**
  - Debugging any app is now restricted
  - “Data vaults” with restricted file access

```
$ ls ~/Library/Mail/
ls: /Users/talkemade/Library/Mail/: Operation not permitted
$ sudo ls ~/Library/Mail/
ls: /Users/talkemade/Library/Mail/: Operation not permitted
$
```

```
$ codesign -dvvv --entitlements - /System/Applications/Mail.app/
Executable=/System/Applications/Mail.app/Contents/MacOS/Mail
Identifier=com.apple.mail
Format=app bundle with Mach-O universal (x86_64 arm64e)
[...]
        [Key] com.apple.rootless.storage.Mail
        [Value]
                [Bool] true
```

Process injection

- Process A executing code “as” process B
- Many techniques are restricted by SIP
- Hardened runtime prevents it in apps:
  - No DYLD_* environment variables
  - Library validation
- But macOS is old, and large…

Platform Policy

NEW

Restricted processes

task_for_pid() / processor_set_tasks() fail with EPERM

Mach special ports are reset on exec(2)

dyld environment variables are ignored

dtrace probes unavailable

```
$> sudo lldb -n Finder
(lldb) process attach --name "Finder"
error: attach failed: attach failed: lost connection
```

Process injection

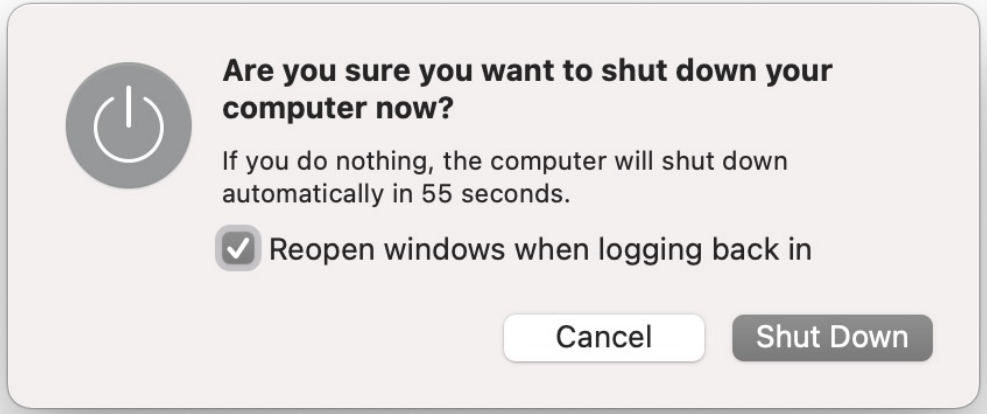
- Common in third-party app
- Abuse TCC permissions: access webcam, microphone, etc.
- Downgrade attacks often work
- What's better than process injection in one app? Process injection everywhere!

CVE-2021-30873

Process injection in AppKit

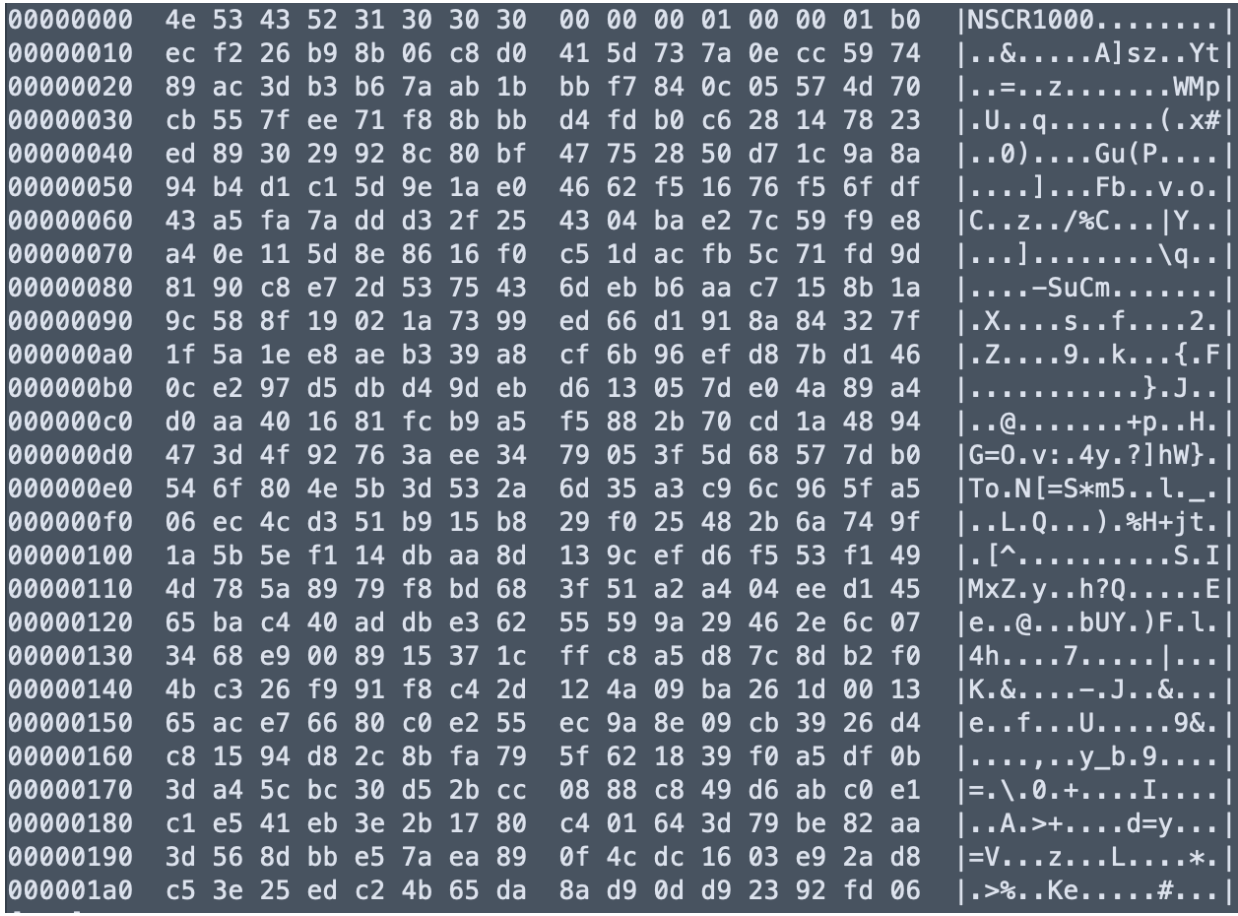
Saved state feature

- Re-opening the windows of an app when relaunched
- Restores unsaved documents
- Works automatically, can be extended by developers



Saved state storage

- **Stored in:**
  - `~/Library/Saved Application State/<ID>.savedState`
- `windows.plist`
  - array of all windows, each with an encryption key
- `data.data`
  - custom format, AES-CBC encrypted serialized object per record



Serialization vulnerabilities

- **Insecure deserialization can lead to RCE**
  - Well known in C#, Java, Python, Ruby…
- **Apple's serialization is `NSCoding`**
- **Added `NSSecureCoding` in 10.8 (2012)**

OS X
Mountain Lion

```
// Insecure
id obj = [decoder decodeObjectForKey:@"myKey"];
if (![obj isKindOfClass:[MyClass class]]) { /* ...fail... */
}
```

```
// Secure
id obj = [decoder decodeObjectOfClass:[MyClass class]
                               forKey:@"myKey"];
```

Exploiting for process injection

1. Create a saved state using a malicious serialized object
2. Write it to the saved state directory of the other app
3. Launch other app
4. App automatically deserializes our object
5. Execute code in the other app!

What object to write?

> ysoserial-objective-c?

> Google Project Zero writeups?

Insecure deserialization with NSCoding

And defeating the hardened runtime by executing Python

Search for an object chain

- Disassemble `-initWithCoder:` methods
- Surprisingly, many classes do not support secure coding!
- …but in most cases it only recursively decodes instance variables

Step 1: NSRuleEditor

- NSRuleEditor creates a binding to a keypath also from the archive:

```
ID NSRuleEditor::initWithCoder:(ID param_1,SEL param_2,ID unarchiver)
{
        ...
        id arrayOwner = [unarchiver decodeObjectForKey:@"NSRuleEditorBoundArrayOwner"];
        ...
        if (arrayOwner) {
          keyPath = [unarchiver decodeObjectForKey:@"NSRuleEditorBoundArrayKeyPath"];
          [self bind:@"rows" toObject:arrayOwner withKeyPath:keyPath options:nil];
        }
        ...
}
```

- Result: call any zero-argument method on a deserialized object

Step 2: NSCustomImageRep

> NSCustomImageRep obtains an object and selector from the archive:

```
ID NSCustomImageRep::initWithCoder:(ID param_1,SEL param_2,ID unarchiver)
{
      ...
      self.drawObject = [unarchiver decodeObjectForKey:@"NSDrawObject"];
      id drawMethod = [unarchiver decodeObjectForKey:@"NSDrawMethod"];
      self.drawMethod = NSSelectorFromString(drawMethod);
      ...
}
```

Step 2: NSCustomImageRep

> NSCustomImageRep in –`draw` then calls the selector on the object:

```
void ___24-[NSCustomImageRep_draw]_block_invoke(long param_1)
{
  ...
  [self.drawObject performSelector:self.drawMethod withObject:self];
  ...
}
```

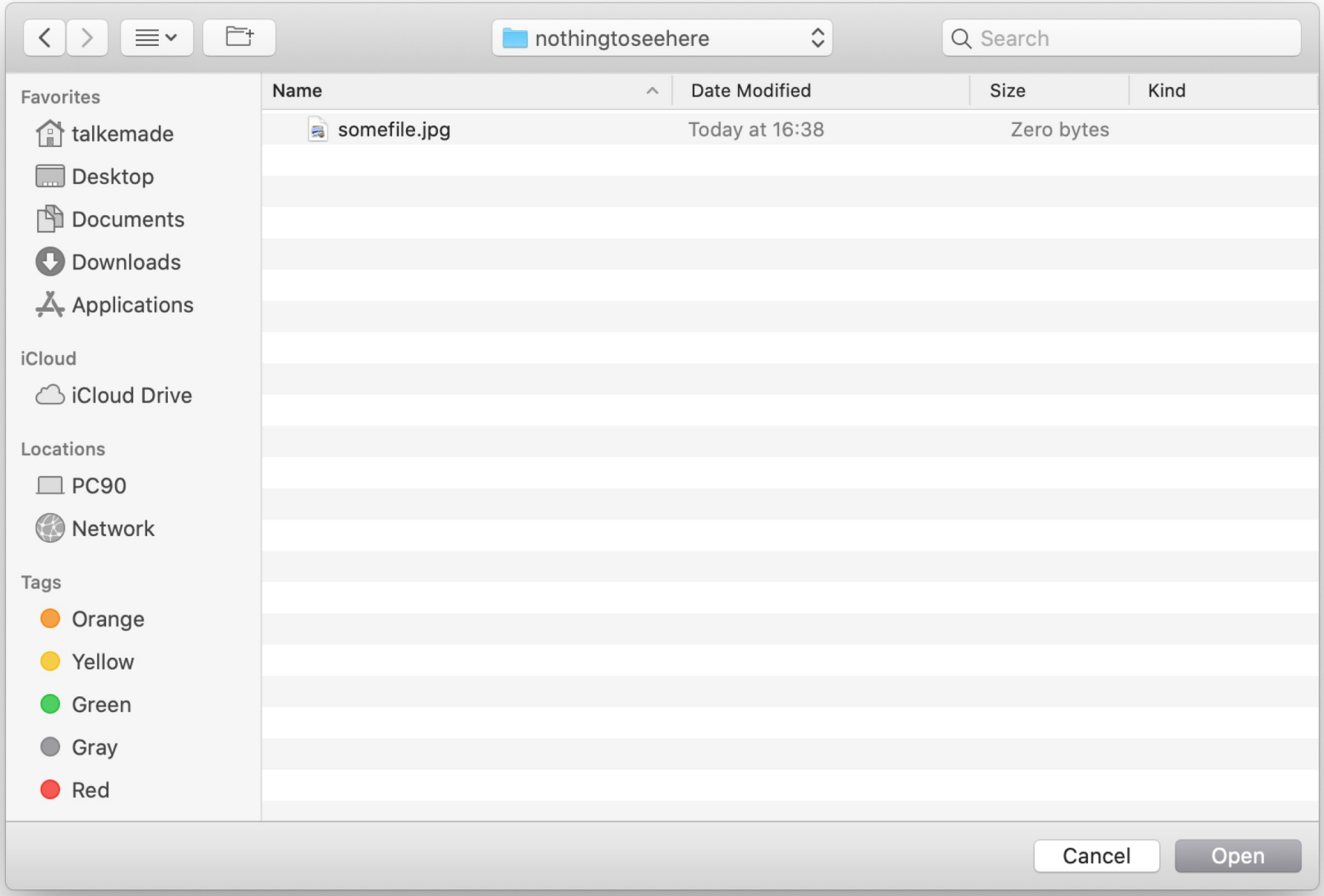
> Result: call any method on a deserialized object (limited control over arguments)

Deserialization to arbitrary code execution

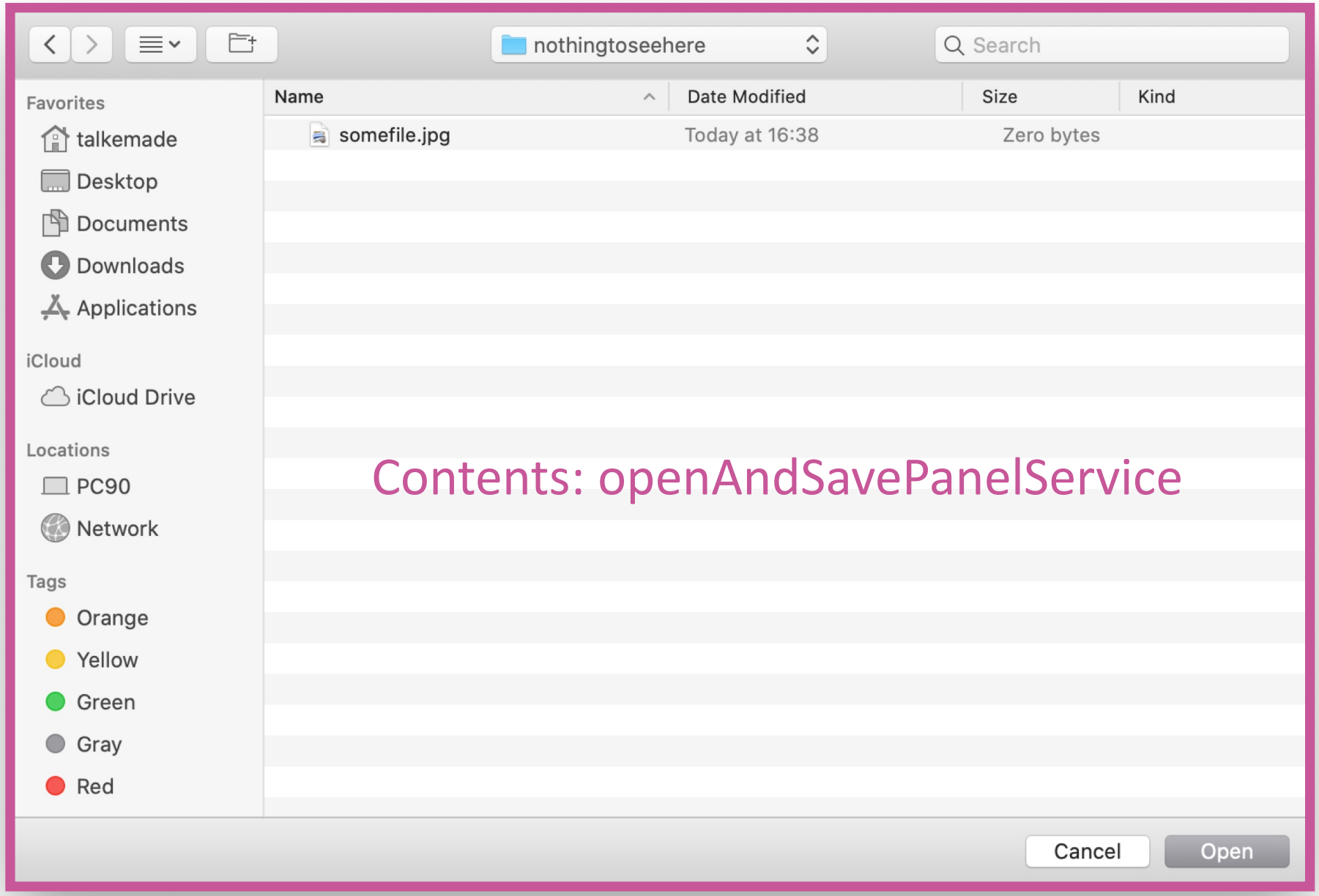
1. Call zero-argument methods on deserialized objects
2. Call any method on deserialized objects
3. Create objects not implementing NSCoder
4. Call zero-argument methods on arbitrary objects
5. Call any method on arbitrary objects
6. Evaluate AppleScript
7. Evaluate AppleScript with the AppleScript-Objective-C bridge
8. Evaluate Python
9. Import ctypes
10. Execute code equivalent to native code

Exploitation

Sandbox escape


nothingtoseehere
Search
Favorites
talkemade
Desktop
Documents
Downloads
Applications
iCloud
iCloud Drive
Locations
PC90
Network
Tags
Orange
Yellow
Green
Gray
Red
Name
Date Modified
Size
Kind
somefile.jpg
Today at 16:38
Zero bytes
Cancel
Open

Window: the app



Contents: openAndSavePanelService

Sandbox escape

- **Open/save panel loaded its saved state from the same files as the app!**
  - Write new object in the app's own saved state directory
  - Open a panel
  - Sandbox escaped!
- **Fixed in 11.3: no long shares directory**

CoreFoundation

Available for: macOS Big Sur

Impact: A malicious application may be able to leak sensitive user information

Description: A validation issue was addressed with improved logic.

CVE-2021-30659: Thijs Alkemade of Computest

Exploitation

Privilege escalation to root

Privelege escalation

- Use the same technique as “Unauthd - Logic bugs FTW” by Ilias Morad
- First, find an app with entitlement:

`com.apple.private.AuthorizationServices`

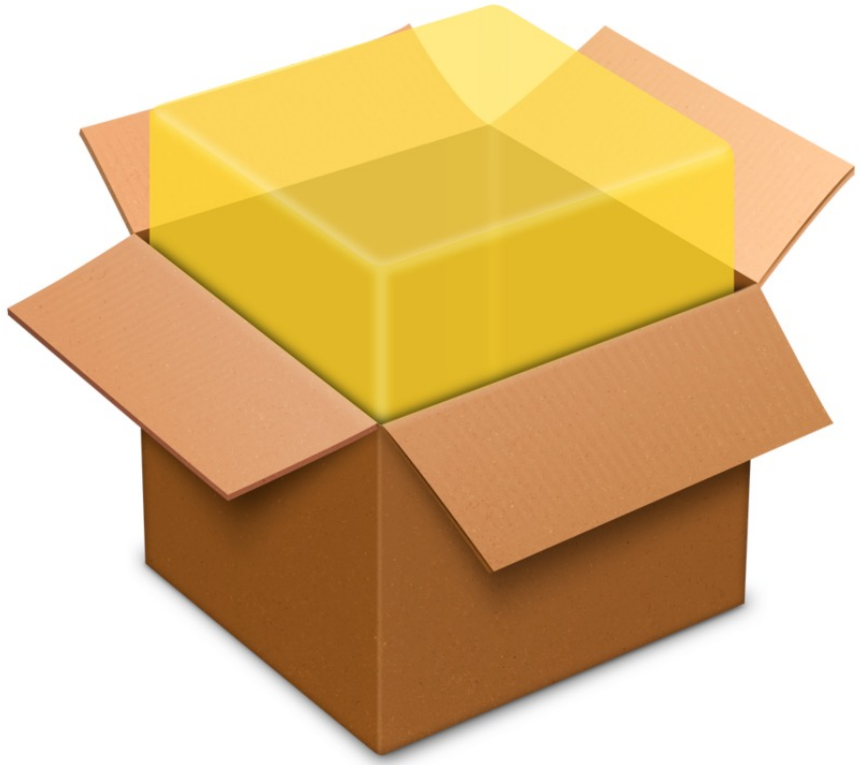
containing:

`system.install.apple-software`

Install Command Line Developer Tools.app

Privilege escalation

- **Then, install this package to a RAM disk**
- **It runs a post-install script from the target disk as root**
  - Target disk may not even have macOS!
  - Mounting a RAM disk does not require root



macOSPublicBetaAccessUtility.pkg
Installer package - 84 KB

Exploitation

SIP filesystem bypass

SIP filesystem bypass

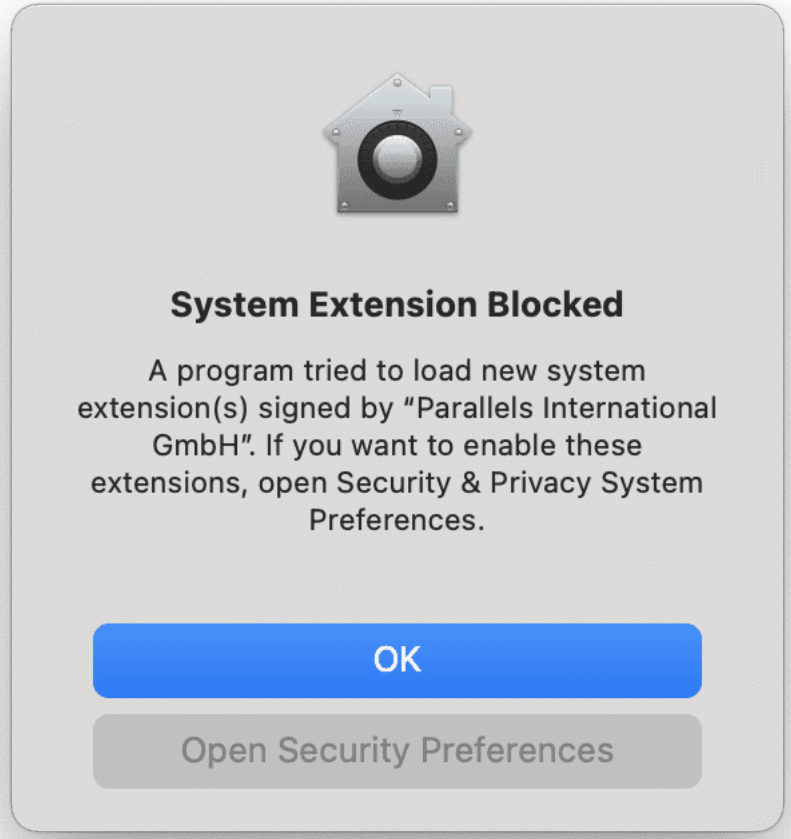
- App from the macOS Big Sur beta installation dmg
- Has the entitlement:
  - `com.apple.rootless.install.heritable`
- Very powerful entitlement: access all SIP protected files!
  - Heritable as a bonus, so can spawn a reverse shell

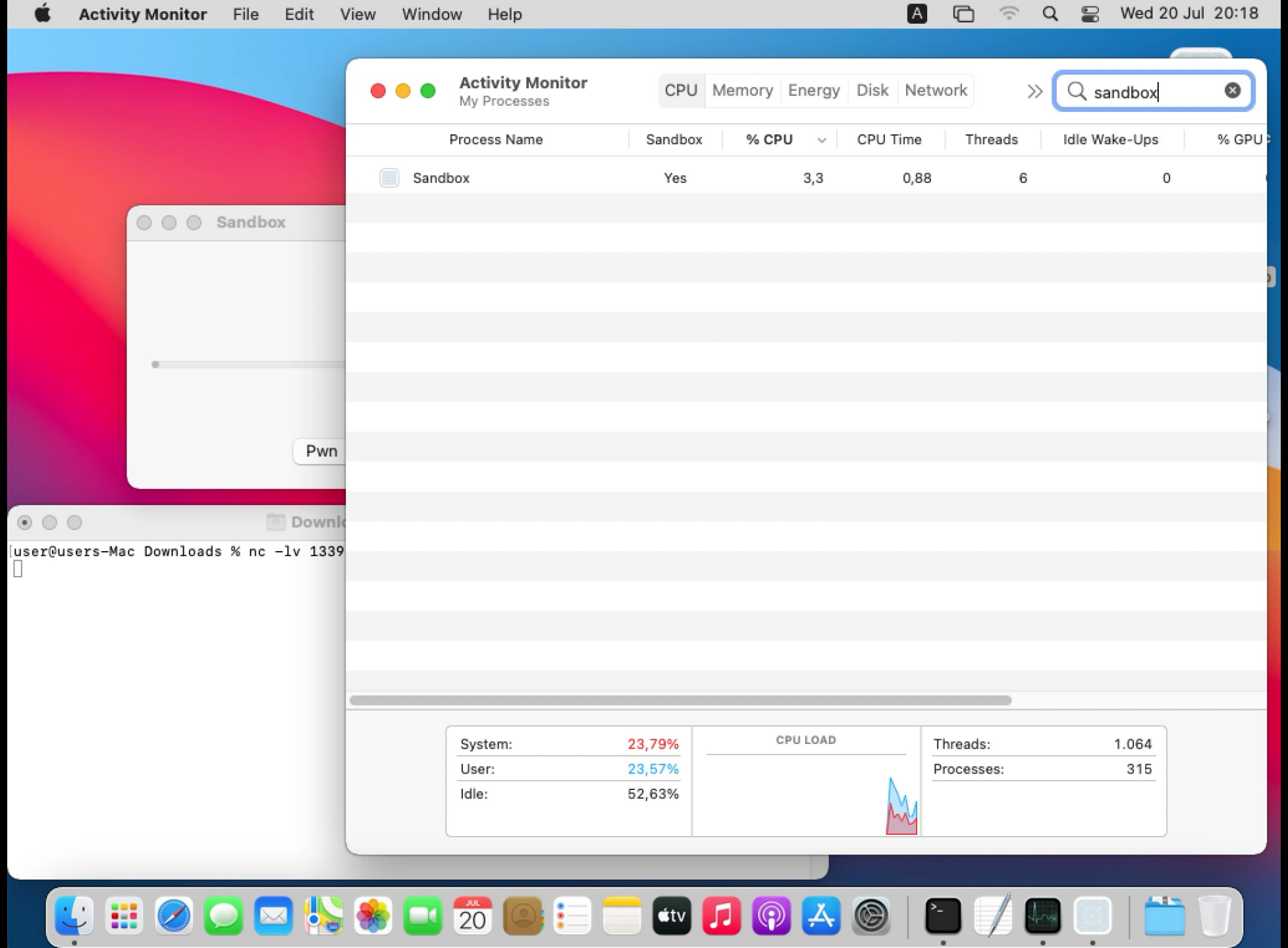
macOS Update Assistant.app

Application - 335 KB

SIP filesystem bypass: result

- Read mail, messages, Safari history, etc. of all users
- Grant ourselves permission for webcam, microphone, etc.
- Powerful persistence (SIP protected locations, delete MRT)
- Load a kernel extension without user approval




Activity Monitor File Edit View Window Help
Wed 20 Jul 20:18
Activity Monitor
My Processes
CPU Memory Energy Disk Network
sandbox
Process Name Sandbox % CPU CPU Time Threads Idle Wake-Ups % GPU
Sandbox Yes 3,3 0,88 6 0
Sandbox
Pwn
user@users-Mac Downloads % nc -lv 1339
System: 23,79%
User: 23,57%
Idle: 52,63%
CPU LOAD
Threads: 1.064
Processes: 315

The fixes

The fixes

- **In Monterey, apps can indicate if it accepts only secure serialized objects in its saved state**
  - Already enabled for Apple's apps
  - Existing apps may want to store objects that do not implement secure deserialization
  - Unclear if exploitable when apps don't use custom serialized objects
- **Reported December 4, 2020**
- **Sandbox escape fixed (CVE-2021-30659) in 11.3 (April 26, 2021)**
- **Fix introduced in macOS Monterey 12.0.1 (October 25, 2021)**
  - Not backported to Big Sur or Catalina!

Conclusion

Conclusion

- macOS has a security boundary between processes
- Process injection vulnerabilities can be used to break those boundaries
- CVE-2021-30873 was a process injection vulnerability affecting AppKit apps
- We used it to escape the sandbox, privilege escalation, bypassing SIP
- Fixed by Apple in Monterey (only!)

Black Hat Sound Bytes

> **macOS security keeps adding more and more defensive layers**

> **Adding new layers to an established system is hard**

- Code written 10+ years ago without security requirements is today's attack surface

> **Effort of attackers may not increase with more layers**

- Use the same bug for multiple layers or skip layers

References

> https://wojciechregula.blog/post/abusing-electron-apps-to-bypass-macos-security-controls/
> https://googleprojectzero.blogspot.com/2020/01/remote-iphone-exploitation-part-1.html
> https://googleprojectzero.blogspot.com/2022/03/forcedentry-sandbox-escape.html
> https://a2nkf.github.io/unauthd_Logic_bugs_FTW/
> https://mjtsai.com/blog/2015/11/08/the-java-deserialization-bug-and-nssecurecoding/
> https://developer.apple.com/documentation/foundation/nssecurecoding?language=objc
> https://github.com/frohoff/ysoserial
> https://github.com/pwntester/ysoserial.net