

METHODS OF MALWARE PERSISTENCE ON MAC OS X

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ABSTRACT

As *Mac OS X* continues to increase in popularity, *OS X* malware (once a rare phenomenon) is now more common than ever. Therefore, it is essential for cybersecurity and malware analysts to possess an in-depth understanding of *OS X* and how it may be attacked by persistent, malicious code.

This paper presents a detailed analysis of *Apple's* anti-malware mechanisms (revealing several significant weaknesses), before diving into the bowels of the Mac startup process. Here, points of persistence are detailed comprehensively. Following this, examples of *OS X* malware are examined to illustrate how code may abuse the OS in order to achieve reboot persistence.

Finally, a novel open-source tool is discussed that can enumerate and display persistent *OS X* binaries that are set to execute automatically upon reboot. Armed with such a tool, users can ensure that they are protected against both current and future persistent *OS X* threats.

BACKGROUND

Before diving into methods of persistence abused by *OS X* malware, it is important to understand why such a topic is truly relevant.

As is obvious to even the most naïve amongst us, Macs have become more prevalent than ever. According to a recent study by the *International Data Corporation (IDC)*, *Apple* is now the number three US computer vendor, making up almost 15% of computer sales [1]. Moreover, if 'iDevices' (*iPhones*, *iPads*, etc.) are added to the equation, *Apple* devices outsold *Windows* PCs globally in Q4 of 2013 [2].

One of the driving forces behind the increased adoption of *Apple* computers is the notion that *OS X* is immune to malware. This claim was propagated by *Apple*, who claimed '[*Mac OS X*] doesn't get PC viruses. A Mac isn't susceptible to the thousands of viruses plaguing *Windows*-based computers' [3].

Ironically, the first personal computer virus discovered in the wild (Elk Cloner), was a Mac virus that infected *Apple IIs* [4]. Since then, Mac malware has flourished. Just last year, over 30 new *OS X* malware families were discovered, some infecting the corporate systems of companies such as *Apple*, *Facebook*, and *Twitter* [5, 6].

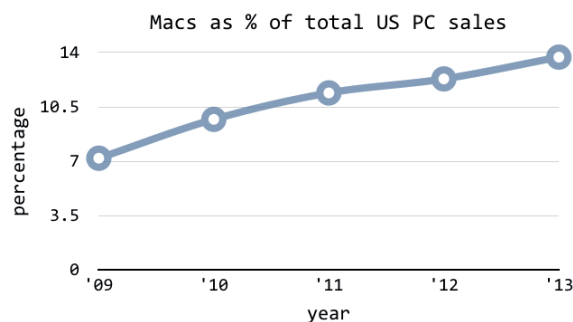


Figure 1: Mac's growth 2009–2013.

APPLE'S ANTI-MALWARE ENHANCEMENTS AND THEIR FLAWS

In recent versions of *OS X*, *Apple* has introduced a myriad of security enhancements which aim to thwart malware. Examples of these enhancements include: *XProtect* (*Apple's* built-in anti-virus solution), *Gatekeeper* (which verifies downloaded software), sandboxing (which prevents *Mac Store* applications from accessing OS-level components), and signed-code requirements (where signatures are verified and only signed kernel extensions can be loaded). While these are spun by *Apple's* marketing team as proactive security measures, in reality they are more reactive and act as an acknowledgement of the *OS X* malware problem. Moreover, while they are a step in the right direction, many of these security enhancements are trivial to bypass.

XProtect

Apple's attempt at an anti-virus product is internally referred to as *XProtect*. Implemented within the *CoreServicesUIAgent*, it uses signatures from */System/Library/CoreServices/CoreTypes.bundle/Contents/Resources/XProtect.plist* to detect *OS X* malware.

Figure 2 shows an entry from the *XProtect* signature file.

Key	Type	Value
Root	Array	(38 items)
Item 0	Dictionary	(3 items)
Item 1	Dictionary	(3 items)
Item 2	Dictionary	(3 items)
Item 3	Dictionary	(3 items)
Description	String	OSX.LaoShu.A
LaunchServices	Dictionary	(1 item)
LSItemContentType	String	com.apple.application-bundle
Matches	Array	(1 item)
Item 0	Dictionary	(3 items)
Identity	Data	<2e243393 a4e997d5 3d3d8051 6571a64f 10313116>
MatchFile	Dictionary	(1 item)
NSURLNameKey	String	worty
MatchType	String	Match

Figure 2: *XProtect's* signature for *LaoShu.A*.

The highlighted entry in Figure 2 aims to detect the OSX/LaoShu.A malware by matching a SHA1 hash and a filename ('werty'). While the benefit of such an exact match/detection scheme is zero false positives, there are several major downsides. For one, a slight change in the malware (the renaming of a file, or a recompilation to change the hash), will prevent a match, and thus detection, from being made. The malware will remain undetected and will be able to execute. Another obvious downside to *XProtect*'s signature-based malware detection scheme is that new malware will never be detected.

Besides the weaknesses in the detection scheme used by *XProtect*, it is plagued by other design issues. In its current implementation, *XProtect* only scans binaries that contain a quarantine attribute. This attribute is set by the application that downloaded the binary (e.g. a browser), not the OS. This is problematic, as an exploit-based attack that manually downloads malware will, of course, do so without setting the quarantine attribute. As such, these binaries will not be scanned, allowing downloaded malware to execute without fear of detection.

Gatekeeper

According to *Apple*, *Gatekeeper* helps protect Macs from malicious apps that are downloaded and installed from the Internet [6].

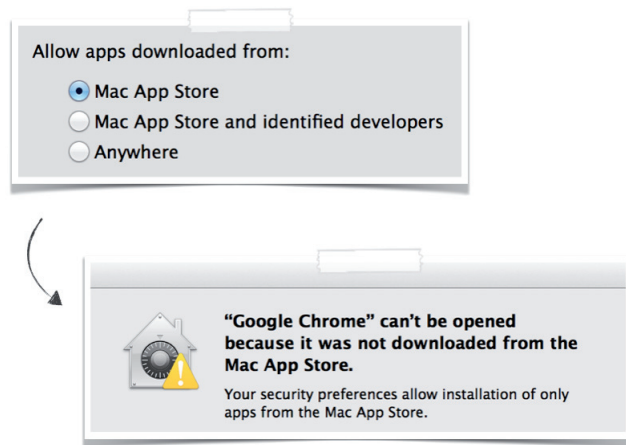


Figure 3: Gatekeeper in action.

Contrary to popular belief, *Gatekeeper* (like *XProtect*), is fairly limited in the attacks it can prevent. Specifically, it is limited to only preventing attacks where users are coerced into downloading and installing malicious content (e.g. fake Flash installers or 'media plug-ins'), from infected or rogue websites. This is due to the fact that *Gatekeeper* will only examine binaries that contain a quarantine attribute. As previously mentioned, this attribute must be set by the downloading application. Thus binaries downloaded as the result of a 'drive-by' exploit-based attack will not be subjected to examination. Interestingly, this is precisely how employees of *Apple*, *Facebook* and *Twitter* were recently infected by malware which 'bypassed *OS X Gatekeeper* protection' [7].

Another shortcoming is based on the fact that, in its default configuration, *Gatekeeper* may allow any signed application to

execute. Hence if a malware sample is signed with a valid *Apple* Developer ID (code-signing certificate), it may be able to 'bypass the *Gatekeeper* security feature' [8].

Signed applications

Borrowing from *iOS*, *OS X* now verifies all binary signatures. This is important as it allows the OS to verify that binaries have not been subverted (e.g. infected by a virus). Binary infection is a powerful technique as it affords an attacker a way to persist, hide, and inherit trust. For example, imagine a malicious piece of code that infects *Safari*. Every time the user launches *Safari*, the malicious code is also executed (persistence). Since the malicious code may exist solely within the infected binary, no external malicious files or processes are required (stealth). Finally, as the browser is expected to access network resources, malicious code hosted within its process space should also be able to access the network (inheriting trust), even if a personal firewall is installed.

So what happens if malware infects a signed application or binary? Well, when loading signed binaries (or applications), the OS loader will check the digital signature. Any modifications will invalidate this signature, easily allowing the loader to detect any subversions. By design, the OS loader will then immediately terminate (crash) the modified binary.

Process:	Safari [1599]
Path:	/Applications/Safari.app/Contents/MacOS/Safari
Crashed Thread:	0
Exception Type:	EXC_CRASH (Code Signature Invalid)
Exception Codes:	0x0000000000000000, 0x0000000000000000

Figure 4: OS X loader terminating a modified signed application.

On *OS X* (unlike *iOS*), unsigned apps are allowed to execute freely. During the loading process, the OS loader checks whether the binary is signed by looking for an embedded LC_CODE_SIGNATURE block. If it finds one, it verifies the binary's signature. However, research has revealed that if the LC_CODE_SIGNATURE signature block is removed, the loader performs no verifications, allowing the binary to be modified with no consequences. This is a rather big security issue, as any signed application can be unsigned, then infected with viral code, and will still be allowed to execute.

To illustrate this security weakness, a python script (unsign.py) was created to 'unsign' and infect *Apple*'s signed applications. The script is shown in Figure 5.

```
# md5 Safari.app/Contents/MacOS/Safari
633d043cf9742d6f0787acdee742c10d

# unsign.py Safari.app/Contents/MacOS/Safari
Safari code signature removed

# md5 Safari.app/Contents/MacOS/Safari
825edd6a1e3aefa98d7cf99a60bac409

# open Safari.app/Contents/MacOS/Safari

# ps aux | grep Safari
patrick 15099 /Applications/Safari.app/Contents/MacOS/Safari
```

Figure 5: Unsigning (and modifying) an *Apple* signed application.

As shown in Figure 4, *Safari* was previously terminated when the OS loader detected a modification. However, as Figure 5 illustrates, once unsigned, *Safari*, can be modified, and still able to execute without interference or termination.

Signed kernel extensions

In order to protect the kernel from malicious code (i.e. rootkits), all kernel extensions (or 'kexts') are required to be signed on *OS X Mavericks*. An unsigned or modified kext will fail to load. Unfortunately for *Apple*, it turns out that this anti-malware mechanism is trivial to bypass. The first method of bypassing these code-signing requirements is described in [9]. In a nutshell, the user-mode daemon that loads kernel extensions (kextd) is responsible for verifying the signature. Yes, the signature is verified in user mode – fail! This is clearly a security issue, since it means that an attacker can easily subvert (turn off) the user-mode checks, then load any unsigned kext. As described in [9], this can be accomplished by injecting code into the kextd, then patching out the code-signing checks (in the `checkKextSignature()` function). For illustrative purposes, this can also be accomplished via a debugger, as shown in Figure 6.

```
# lladb -p <pid of kextd>

(lladb) disassemble --start-address <addr>
0x10087c0df: mov    %eax, %ebx
...
0x10087c0ef: ret

(lladb) memory write -s 2 <addr> 0xc031

(lladb) disassemble --start-address <addr>
0x10087c0df: xorl   %eax, %eax
...
0x10087c0ef: ret

sh-3.2# kextload unsigned.kext

sh-3.2# kextstat | grep -i unsigned
0xffffffff7f81bb0000 com.synack.unsigned
```

Figure 6: Patching out kext code-signing requirements.

The publicly described technique requires some pretty low-level hacking (e.g. code injection and in-memory patching). Research performed at the start of the year revealed a non-public, 0-day technique that allowed any unsigned kext to be loaded¹. By first stopping the daemon that is responsible for loading kernel extensions (kextd), then attempting to load the unsigned kext with the `kextload` command, an alternate code path is executed. This code path loads the kext directly into the kernel, bypassing the logic that enforces the kext code-signing requirements.

In the case of computer security, ignorance is not bliss. The various weaknesses in the *OS X* anti-malware/security mechanisms presented above should be a cause for concern for the ever-growing Mac user base, especially as *OS X* malware is an ever-growing threat. One way to combat such threats is to gain a thorough understanding of the Mac system startup process, identifying methods of persistence that are abused by

¹ This technique (or a slight variation) was later discussed independently at Black Hat Asia by Team T5 [10].

OS X malware. With this information, persistent malware may be detected generically or, ideally, even prevented.

MAC SYSTEM STARTUP

Before cataloguing methods of persistence abused by *OS X* malware, it is important to understand what happens when a Mac is powered on.

The boot/startup process is somewhat complex, but can be broken down into easily understandable stages. These stages include power-on/boot, kernel initialization, the execution of `launchd` daemon, and the `LoginWindow` process. It should be noted that many of the low-level technical details of the startup process are beyond the scope of this paper. However, interested readers are encouraged to consult [11] for a very comprehensive and thorough discussion of the entire startup process.

Early startup covers everything from power-on, until the kernel (*OS X*) begins execution. Once power is present, the bootROM takes over. The bootROM, or firmware, is the first code to execute. It verifies memory, begins hardware initialization and selects the OS partition. Once complete, the bootROM executes the `boot.efi` program. This performs a variety of actions such as initializing the device tree (IO registry), locating and loading the kernel into memory, loading any boot kernel extensions, and finally jumping to the kernel's entry point.

Once the early boot stage is complete, *OS X* begins its initialization. This starts with the kernel, which is composed of various sub-systems (each of which must be initialized). First, the Mach subsystem is initialized, then IOKit loads all device-specific kexts. Finally, the BSD subsystem initializes, which most notably includes executing `launchd`, the first user-mode process.

`Launchd`, as its name suggests, launches all daemons and agents (both of which are somewhat conceptually similar to *Windows* services). As the first process (pid of 0x1), it is an ancestor of all other processes.

The final step before reaching the desktop is authenticating the user. This is handled by the `LoginWindow` process, which authenticates the user, sets up their environment, and then hangs around to manage the user's session. Once the user is presented with their desktop, the Mac system startup process is complete.

METHODS OF PERSISTENCE

A decent understanding of the Mac startup process provides the necessary background for examining the ways in which it may be abused to achieve persistence. Before diving in, recall that persistence is essential for malware, as it ensures that whenever a computer is restarted, the malicious code is automatically re-executed by the OS.

Low-level/pre-OS X

Starting at the lowest level, there are several options for persistence. While these options are complex, and often hardware specific, they run 'below' (before) the OS, and thus are very difficult to detect. Possible low-level options for persistence may include: re-flashing the firmware, installing a

malicious EFI component, or even infecting boot.efi. It should be noted that, due to the complexities of these techniques, each could fill a paper unto themselves. For a more in-depth analysis of low-level methods of persistence, interested readers should consult [12], an intriguing paper on Mac EFI rootkits.

Kernel extensions

Since code in the kernel runs at the highest privilege level, it is a great place for advanced malware to live. Malware that executes here is often referred to as a rootkit. It is fairly trivial to create a persistent kernel extension that will automatically be executed by the OS whenever the computer is restarted. First, a kext can be created via the ‘Generic Kernel Extension’ template in XCode, as described in *Apple’s* documentation [13]. It is important to set the kext’s match category (in its Info.plist) to ‘IOResources.’ As described in [11], this is ‘a special provider class that provides system-wide resources’ and ensures that, once installed, the kext will automatically be started by *OS X*.

To install a kext persistently, it should be copied into one of the *OS X* kext directories: `/System/Library/Extensions` or `/Library/Extensions`.

Once copied to an install directory, the kext should be set to be owned by root and, optionally, the kernel cache rebuilt. If these steps are followed, the kext will automatically be loaded each time the OS is (re)loaded.

```
# cp -R persist.kext /Library/Extensions
# chown -R root:wheel /Library/Extensions/persist.kext
# kextcache -system-prelinked-kernel
# kextcache -system-caches
```

Figure 7: Installing a persistent kernel extension.

As mentioned previously, starting with *OS X Mavericks*, kext extensions must be signed. However, malware may abuse several previously stated methods in order to bypass this requirement.

Launch daemons/agents

While code that runs in the kernel is very powerful, it is difficult to get right. Running in user mode is far simpler and thus often preferable. Launch daemons and agents are the ‘*Apple*-approved’ way to persist non-application binaries (e.g. software updaters, anti-virus products, etc.). Both launch daemons and launch agents are commonly abused by *OS X* malware as a means to gain persistence. Launch daemons are non-interactive, and run before user login. On the other hand, launch agents run once the user has logged in, and may be interactive. Creating a persistent launched daemon or agent is as simple as creating the binary, then placing a configuration property list in one of the launch daemon or agent directories, as shown in Table 1.

Property lists (or ‘*plists*’ in *Apple* parlance) are xml files that are used by *OS X* to store serialized objects. In the case of the launch daemons and agents, there is a plist for each daemon or

Launch daemon (plist) directories	Launch agent (plist) directories
<code>/System/Library/LaunchDaemons</code>	<code>/System/Library/LaunchAgents</code>
<code>/Library/LaunchDaemons</code>	<code>/Library/LaunchAgents</code> and <code>~/Library/LaunchAgents</code>

Table 1: Launch daemon/agent plist directories.

agent that contains required configuration information. These files are processed by the OS as part of its initialization process and can contain key value pairs that may instruct the OS to automatically start the daemon or agent. Figure 8 shows a snippet from an example launch daemon/agent configuration plist file. Besides containing the path to the binary image of the daemon or agent (and any program arguments), it also contains a key value pair (`RunAtLoad: true`), to indicate that it should be started automatically by the OS.

```
<dict>
  <key>ProgramArguments</key>
  <array>
    <string>/path/to/persist</string>
    <string>args...</string>
  </array>
  <key>RunAtLoad</key>
  <true/>
</dict>
```

Figure 8: A launch daemon/agent plist.

Cron jobs

Containing a large amount of BSD code and logic within its core, *OS X* presents many ‘*Unix-y*’ flavoured persistence mechanisms that may be abused by *OS X* malware. Cron jobs are an example of exactly this. *OS X* supports cron jobs, which can be used to execute a command or script at certain intervals. For example, Figure 9 illustrates how a cron job can be created to echo some text each minute. To register the cron job, the command to execute is saved to file, then registered via the `crontab` command. To confirm the registration of the command, the `crontab` command is re-executed with the ‘`-l`’ parameter.

```
$ echo "* * * * * echo \"I'm persisting\""
> /tmp/persistJob
$ crontab /tmp/persistJob
$ crontab -l
* * * * * echo "I'm persisting"
```

Figure 9: Cron job creation/enumeration.

Login/logout hooks

By creating a login or logout hook, a script or command can automatically be executed whenever a user logs in or out. *Apple* states that these hooks are deprecated [14], but they still work

on *OS X Mavericks*. The ‘defaults’ command can be used to create such a hook. Simply specify a write action, the com.apple.loginwindow.plist file, and then script or command to persist (see Figure 10).

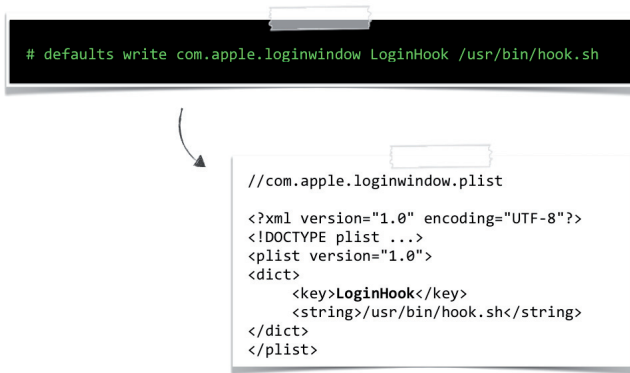


Figure 10: Creation of a login hook.

Login items

For applications, login items are the ‘Apple-approved’ way to persist. Anything that’s registered as a login item is visible in a GUI, via the System Preferences app. Login items are stored in the user’s Library/Preferences directory, in a plist file named com.apple.loginitems.plist. This file contains an entry for each login item, which contains the name of the item, whether it should be hidden, and base64-encoded data containing the path to the persistent application. Login items can be created via the GUI, programmatically by utilizing the ‘launch services’ API, or by directly manipulating the login item’s plist (com.apple.loginitems.plist).

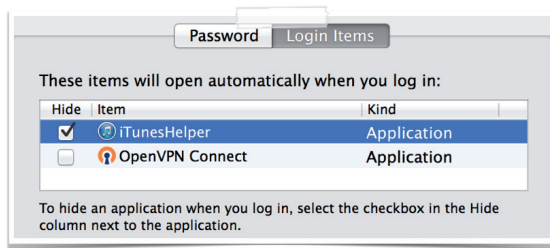


Figure 11: Login item: in the GUI and plist.

Sandboxed login items

With the introduction of the application sandbox, applications downloaded from the Mac application store can no longer create or register themselves as traditional login items. To maintain compatibility, *Apple* designed a new way in which sandboxed applications could create login items. In order to register an application persistently in this manner, two applications are required: a main application and a helper. The application to persist (the helper), should be placed into a LoginItems sub-directory of the main application, as shown in Figure 12.

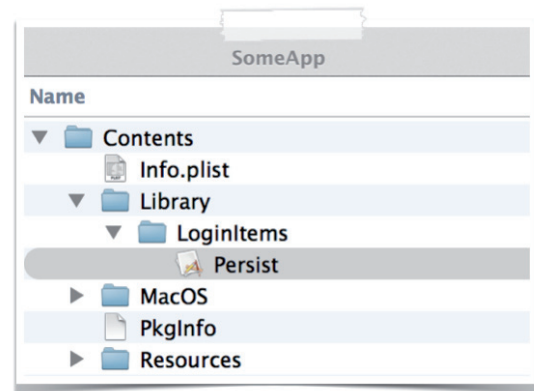


Figure 12: Required layout for a sandboxed login item.

Once executed, the main application should invoke the `SMLoginItemSetEnabled()` function. This function causes the helper application to persist, and ensures that it will automatically be executed whenever the user logs in.

```
//enable login item
// ->use application bundle as identifier
SMLoginItemSetEnabled((__bridge CFStringRef)@"com.company.persist", YES);
```

Figure 13: Code to persist a sandboxed login item.

Re-opened applications

OS X recently introduced a feature that automatically reopens applications whenever the user (re)logs in. The applications to reopen are stored in a plist within the user’s Library/Preferences/ByHost directory. Viewing the contents of this plist reveals keys such as the ID of the application, whether to hide it,

```
$ less com.apple.loginwindow.<uuid>.plist
<dict>
  <key>TALAppsToRelaunchAtLogin</key>
  <array>
    <dict>
      <key>BundleID</key>
      <string>com.apple.terminal</string>
      <key>Hide</key>
      <false/>
      <key>Path</key>
      <string>/Applications/Utilities/Terminal.app</string>
    </dict>
    ...
  </array>
</dict>
```

Figure 14: Plist entry of a re-launched application (terminal.app).

and of course the path to the application. While there is not a (documented) programmatic API to manipulate the re-opened application plist directly, it may be possible to modify it directly in order to gain persistence.

Startup items

Another deprecated technique that still works on *OS X Mavericks* is ‘startup items’. *Apple* documentation explains that startup items allow a command or script to automatically be executed during *OS X* initialization. Creating a startup item involves placing two files into a startup item directory. The first file is a script that is to be executed automatically. The other file must be named ‘StartupParameters.plist’ and must contain a ‘Provides’ key that contains the name of the script file. Both of these files should be placed in a sub-directory in either the /System/Library/StartupItems or /Library/StartupItems directory. The name of the sub-directory must be the same as the name of the script file (and the value of the ‘Provides’ key in the StartupParameters.plist). Figure 15 illustrates the required file-system layout of a startup item.

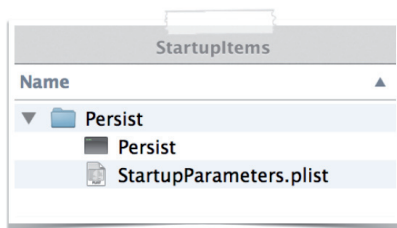


Figure 15: Directory structure of a startup item.

Rc.common

RC scripts are used in another BSD-flavoured persistence technique that works on *OS X*, allowing scripts or commands to automatically be executed. For example, the rc.common file can be edited to insert arbitrary commands that will automatically execute when *OS X* starts.

```
# vim /etc/rc.common

...

add any commands (at end)
```

Figure 16: Injecting commands into rc.common.

Launchd.conf

Recall that launchd is the first user-mode program to execute during *OS X*’s initialization. The launchd.conf file, as its name suggests, contains configuration parameters for launchd. As launchd.conf can contain arbitrary commands (via the bsexec command), malware can inject malicious instructions in order to achieve persistence.

```
# echo bsexec 1 /bin/bash <anything.script> > /etc/launchd.conf
```

Figure 17: Injecting commands into launchd.conf.

DYLD_INSERT_LIBRARIES

Via the DYLD_INSERT_LIBRARIES environment variable, *OS X* provides a way to load arbitrary dynamic libraries (‘dylibs’) into a process. Specifically, when loading a process, the dynamic loader will examine the DYLD_INSERT_LIBRARIES variable and load any libraries it specifies. By abusing this technique, an attacker can ensure that a malicious library will persistently be loaded into a targeted process whenever that process is started.

There are two main ways to set the DYLD_INSERT_LIBRARIES environment variable so that arbitrary libraries will be loaded into a specific (targeted) process. When targeting a launch daemon or agent, an ‘EnvironmentVariables’ dictionary may be added to launch item’s plist. For targeting an application, the application’s Info.plist can be altered to contain a ‘LSEnvironment’ dictionary, see Figure 18.

```
$ less /Applications/Safari.app/Contents/Info.plist
...
<key>LSEnvironment</key>
<dict>
  <key>DYLD_INSERT_LIBRARIES</key>
  <string>/Applications/Safari.app/Contents/evil.dylib</string>
</dict>
```

Figure 18: The application’s Info.plist is altered to contain a ‘LSEnvironment’ dictionary.

Mach-O binary infection

Computer viruses are one of the oldest forms of malware. Viruses infect files by injecting viral code in order to replicate. However, this viral code can also provide persistence: any time the infected binary is executed, the virus code will be executed as well. Since *OS X* binaries (and applications) can be unsigned, viral infection may be back in fashion! There are many ways to infect an *OS X* (mach-O) binary. The simplest method, described initially by the (in)famous VX’er roy g biv, involves injecting some viral code into a target binary, then hijacking the entry point to point to the virus code.

Figure 19 shows the LC_MAIN load command within an uninfected macho-O binary. This load command contains the ‘Entry Offset,’ or entry point, which may be hijacked during infection (to point to the viral code).

Offset	Data	Description	Value
00000410	00000028	Command	LC_MAIN
00000414	00000018	Command Size	24
00000418	00000000000000F8	Entry Offset	3980
00000420	0000000000000000	StackSize	0

Figure 19: Mach-O binary structure/entry offset.

Application-specific persistence

The final persistence mechanism covered in this paper is more of a generic class: application-specific persistence. Many applications (such as browsers) support plug-ins, which are generally dynamic libraries that are loaded automatically when the application is run. While plug-ins can legitimately extend the functionality of an application, malware can abuse this functionality to gain persistence. Applications that may be subverted include browsers such as *Safari*, *Firefox* and *Chrome*, or others such as *iTunes* [15].

It should be noted that sometimes it may be challenging to coerce an application to execute a malicious plug-in (it might load the plug-in, then decide it doesn't like it). However, if the persistent plug-in exports a constructor (see Figure 19), it will automatically be executed (by the OS loader) as soon as it is loaded. Thus, even if the host application rejects the plug-in, it is too late as persistent code execution has already been achieved.

```
#include <syslog.h>

//automatically invoked when loaded
__attribute__((constructor)) void myConstructor()
{
    //dbg msg
    syslog(LOG_ERR, "loaded in process %d", getpid());

    //do anything else here!

    return;
}
```

Figure 20: Dynamic library (plug-in) constructor.

Rest in peace

While researching methods of malware persistence, several previously functional persistence techniques were found to have either been fully deprecated or removed in *OS X*

Mavericks. These include modifying `environment.plist`, modifying `com.apple.SystemLoginItems.plist` and setting an 'AutoLaunchedApplicationDictionary' within the `/Library/Preferences/loginwindow` file.

While these methods of persistence are (or were?) common in older *OS X* malware samples, they are likely to fade into oblivion as they no longer work on the latest version of *OS X*.

PERSISTENT OS X MALWARE

While not all of the methods of persistence presented are (yet) abused by *OS X* malware, many are. The following section examines several *OS X* malware samples and reveals their persistence mechanisms.

OSX/CallMe

A few years ago, somebody (likely the Chinese government), started targeting Tibetan activists with malicious *Word* documents that attempted to exploit CVE-2009-0563. The payload of these attacks was named *OSX/CallMe* [16]. This malware was fairly basic, providing the attackers with the ability to execute arbitrary commands on an infected host, as well as exfiltrating the victim's contacts (address book) [17]. In order to persist, *CallMe* installs itself as an auto launched launch daemon. Specifically, it creates a launch daemon plist, `realPlayerUpdate.plist`, within the `/Library/LaunchDaemons` directory that references the malware's binary, `.realPlayerUpdate` (see Figure 21).

OSX/Flashback

Flashback shattered the notion that *OS X* was immune to malware. By exploiting a known, but unpatched Java vulnerability, Flashback was able to automatically infect users as they visited a compromised or malicious website. At its height, it amassed over 600,000 infected hosts, making it the most 'successful' *OS X* malware to date [18]. Flashback's goal

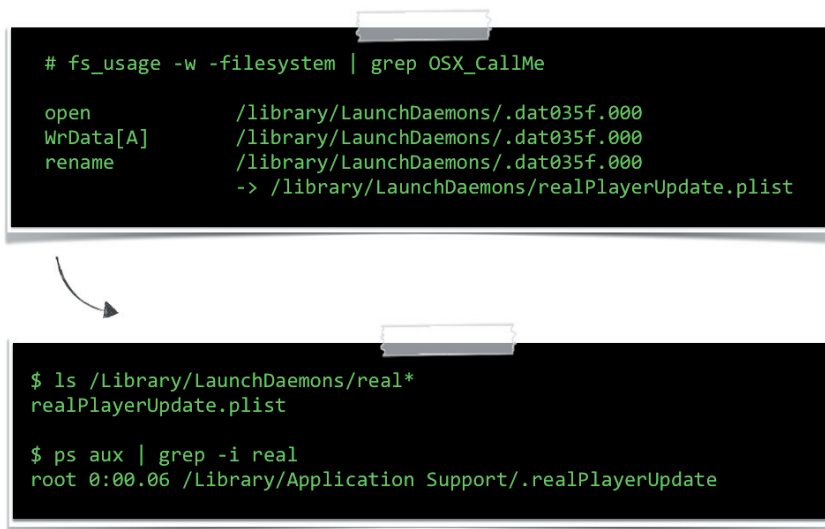


Figure 21: *CallMe*'s launch daemon persistence.

was simply financial gain – by injecting ads into users' web sessions. To ensure it was (re)executed each time an infected computer was rebooted, it installed itself as a user launch agent (com.java.update.plist, .jupdate). (See Figure 22.)

OSX/Crisis

According to online sources, OSX/Crisis is 'an expensive rootkit used by governments' [19]. Delivered via targeted exploits, it provides extensive surveillance capabilities by collecting audio, images, screenshots and keystrokes. Crisis also employs some fairly sophisticated stealth capabilities via a rootkit (kernel) component that can hide processes and files. Figure 23 illustrates some pseudo-disassembly, revealing the malware building a path to a file within the user's launch agent directory. In other words, the disassembly shows the malware preparing to persist as a launch agent.

OSX/Janicab

Janicab is a somewhat unique OS X malware sample, as it is written in Python (though compiled for distribution). The malware is also signed with an Apple Developer ID, probably in an attempt to hide its maliciousness and thwart Gatekeeper. Since it is written in Python, the malware is easy to analyse and uncovering its persistence mechanism is trivial. As may be seen in the malware installer's code, a cron job (set to execute every minute) is created to ensure that the malware is persisted (see Figure 24). It should be noted that once the malware is installed, the `crontab -l` command easily reveals the malicious cron job.

OSX/Kitmos

Kitmos is another OS X malware sample that targets activists. Discovered on an activist's computer during the Oslo Freedom Forum Workshop, Kitmos takes screenshots and uploads them to a remote command and control server [20]. As the disassembly in Figure 25 shows, the malware invokes the `LSSharedFileListItemURL()` function to add itself as a login item for the current user. Once registered as a login item, the malware will automatically be (re)executed by the OS whenever the user logs in.

```
$ less ~/Library/LaunchAgents/com.java.update.plist
<?xml version="1.0" encoding="UTF-8"?>
...
<dict>
  <key>Label</key>
  <string>com.java.update.plist</string>
  <key>ProgramArguments</key>
  <array>
    <string>/Users/user/.jupdate</string>
  </array>
  <key>RunAtLoad</key>
  <true/>
  ...

```

Figure 22: Flashback's launch agent persistence.

```
;build path for malware's launch agent plist

-[RCSMUtils createLaunchAgentPlist:forBinary:]
call    NSHomeDirectory
mov     [esp+0Ch], eax
lea     edx, @"Library/LaunchAgents/com.apple.mdworker.plist"
mov     [esp+10h], edx
lea     edx, "%@/%@"
mov     [esp+8], edx
mov     [esp+4], stringWithFormat_message_refs
mov     [esp], NSString_clsRef
call    _objc_msgSend

```

Figure 23: Crisis' launch agent persistence.

```
""" add to crontab """

#add the script to crontab
subprocess.call("echo \"* * * * *
python ~/.t/runner.pyc \" >>/tmp/dump", shell=True)

#import the new crontab
subprocess.call("crontab /tmp/dump", shell=True)
subprocess.call("rm -f /tmp/dump", shell=True)

```

```
$ crontab -l
* * * * * python ~/.t/runner.pyc

```

Figure 24: Janicab's cron job persistence.

```
;build path for malware's launch agent plist

-[FileBackupAppDelegate checkAutonrun]
mov     dword ptr [esp+18h], 0
mov     dword ptr [esp+14h], 0
mov     [esp+10h], ebx
mov     dword ptr [esp+0Ch], 0
mov     dword ptr [esp+8], 0
mov     [esp+4], eax          ; _kLSSharedFileListItemLast_ptr
mov     [esp], edi           ; _LSSharedFileListItemCreate
call    LSSharedFileListItemURL

```

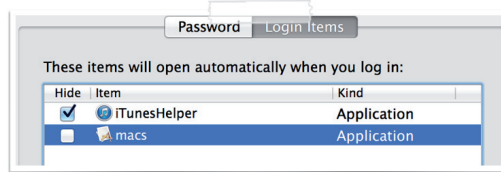


Figure 25: Kitmos' login item persistence.

```

;create paths for installing malicious plugins

lea edi, cfstr_InstallingExte ; "Installing extensions"
lea ebx, cfstr_Ok             ; "Ok"
...

+[ExtensionsInstaller installSafariExtension:]
"~/Library/Safari/Extensions/Extensions.plist"

+[ExtensionsInstaller installFirefoxExtension:]
"~/Library/Application Support/Mozilla/Extensions"

+[ExtensionsInstaller installChromeExtension:]
"~/Library/Application Support/Google/Chrome/External Extensions"

```

Figure 26: Yontoo's browser extension(s) persistence.

```

# less OSX_Renepo

scriptpath='pwd'
scriptfolder='basename $scriptpath'
scriptname='basename $0'

mkdir /System/Library/StartupItems/"${scriptname}"
cp "${scriptpath}/${scriptname}"
/System/Library/StartupItems/"${scriptname}/${scriptname}"

# The lines below echo out the StartupParameters.plist file.
echo "<plist version=\\"0.9\\"" >>
/System/Library/StartupItems/${scriptname}/StartupParameters.plist
...

```

Figure 27: Renepo's startup item persistence.

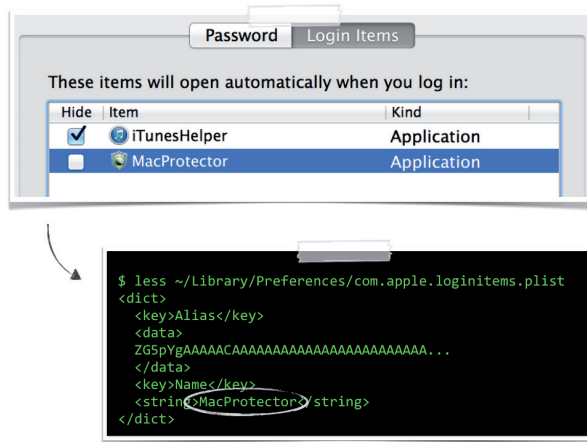


Figure 28: MacProtector's login item persistence.

OSX/Yontoo

It is fairly common for malware to use social engineering tricks to coerce the user into infecting themselves. Yontoo masquerades as an 'HD video codec' to trick users who visit compromised or malicious websites into installing the malware. The malware creates malicious plug-ins for *Safari*, *Firefox* and *Chrome*. This allows the malware to automatically be executed whenever the user launches their browser. Once loaded into the context of the browser's process content, the plug-ins transmit information about the loaded pages to a remote server as well as injecting ads into the user's browsing session (see Figure 26).

OSX/Renepo

Renepo is an older OS X malware sample that disables security mechanisms before downloading and executing other 'hacker tools' such as password crackers [21]. Since this malware is a script (which helpfully includes comments), it is easy to understand its installation and persistence logic. As shown in Figure 27, it persists as a startup item.

OSX/MacProtector

MacProtector is a fake (or 'rogue') anti-virus product. When a user visits a compromised or malicious website, MacProtector tries to convince the user that their computer is infected and that they should download an application to 'fix' it [22]. Unfortunately, if the user allows the downloaded installer to complete, they become infected with MacProtector. Reverse engineering this malware reveals that it installs itself as a login item. Though this will cause the malware to persist, it will also make it appear in the GUI (as well as in the login item's plist). (See Figure 28.)

OSX/Clapzok

The previously discussed OS X malware samples are generally all stand-alone binaries or applications. OSX/Clapzok bucks this trend: it is a classic virus that infects binaries both to spread and to gain persistence [23]. It works by injecting viral code into a binary, then hijacking the entry point. However, since Clapzok infects signed apps (without un-signing them), it will likely

Offset	Data	Description	Value
0000001C	00000001	Command	LC_SEGMENT
00000020	00000038	Command Size	56
00000024	5F5F04147455A45524F000...	Segment Name	_PAGEZERO
00000034	00000000	VM Address	0x0
00000038	00001000	VM Size	4096
0000003C	00005000	File Offset	28480
00000040	00000B3A	File Size	2874
00000044	00000005	Maximum VM Protection	00000001
			VM_PROT_READ
			VM_PROT_EXECUTE
00000048	00000005	Initial VM Protection	00000001
			VM_PROT_READ
			VM_PROT_EXECUTE
0000004C	00000000	Number of Sections	0
00000050	00000000	Flags	

Figure 29: Clapzok's mach-O infection persistence [23].

cause major annoyances and, as a result, will be easily discovered (see Figure 29).

KNOCKKNOCK

Research into persistence mechanisms on *OS X* has revealed many locations within the boot process and OS startup sequence that can be abused by malicious code. As we have shown in this paper, many *OS X* malware variants exist in the wild that are abusing several of these persistence mechanisms. Although *Apple* has introduced several anti-malware mitigations, these clearly fall short, as *OS X* users worldwide continue to be infected.

In order to generically detect persistent *OS X* malware, a new tool has been created that can enumerate and display persistent *OS X* binaries. Named *KnockKnock*, its goal is simple: to tell you who's there! Armed with this tool, users can ensure that they are protected against both current and future *OS X* threats.

There are many methods of persistence on *OS X* – and new ones are sure to be found. As such, the open-source, Python-based *KnockKnock* [24] was designed to use a plug-in-based architecture, where each plug-in can scan for a particular persistence technique. When new persistence techniques are discovered, *KnockKnock* can easily be extended with new plug-ins. Luckily, as its core performs most of the work, writing a plug-in is incredibly simple. This is illustrated in the example in Figure 30, which shows the main logic for a plug-in that enumerates all launch daemons that are set to execute automatically as a Mac computer boots up.

As the code snippet in Figure 30 illustrates, it only takes about 10 lines of Python code for this plug-in to enumerate a specific persistence class. (For more details, including a comprehensive plug-in-writing guide, see [24].)

KnockKnock has the ability to display persistent *OS X* binaries that are set to execute automatically at each boot. Since *KnockKnock* takes such an unbiased approach, it can generically detect persistent *OS X* malware today, as well as in the future. It should be noted though, that this approach will also list legitimate binaries. However, as *KnockKnock* can filter out

```
# python knockknock.py -p cron job

who's there?

[cron jobs]
* * * * * python ~/.t/runner.pyc
```

Figure 31: *KnockKnock Janicab (runner.pyc) detection.*

```
# python knockknock.py -p launchDandA

who's there?

[launchDaemons]
realPlayerUpdate
  path: /Library/Application Support/.realPlayerUpdate
  hash: 544539ea546e88ff462814ba96afef1a

[launchAgents]
Little Snitch Agent
  path: /Library/Little Snitch/Little Snitch Agent.app/
  hash: 1a4a575ba98acd455bbb0712abee8df7
```

Figure 32: *KnockKnock CallMe (.realPlayerUpdate) detection.*

unmodified *Apple*-signed binaries, the output is reduced by a factor of roughly 90%, generally leaving a handful of binaries that can quickly be examined and verified manually.

The screenshots in Figures 31 and 32 show *KnockKnock* revealing various *OS X* malware infections, including *OSX/Janicab* (cron job) and *OSX/CallMe* (launch daemon).

CONCLUSION

Even in the latest version of *Mac OS X*, *Apple*'s anti-malware mitigations fall far short, allowing *OS X* malware to become an ever more pervasive reality. However, by thoroughly

```
#launch daemon directories
LAUNCH_DAEMON_DIRS = ['/System/Library/LaunchDaemons/', '/Library/LaunchDaemons/']

#init results
results['launchAgents'] = []

#get all files in each launch daemon directory
for directory in LAUNCH_DAEMON_DIRS:
    launchItems.extend(glob.glob(directory + '**'))

#iterate over these files (plists)
# ->save the program of those that have 'RunAtLoad' set
for item in launchItems:
    plistData = utils.loadPlist(item)
    if plistData['RunAtLoad']:
        results.append(file.File(plistData['ProgramArguments'][0]))
```

Figure 30: *KnockKnock launch daemon plug-in.*

understanding the Mac's startup process, points of persistence can be identified, which allow for the generic detection of malware. *KnockKnock*, an open-source tool, aims to aid in this detection and to ensure that everyday users are protected against both current and future OS X threats.

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