FinFisher exposed: A researcher’s tale of defeating traps, tricks, and complex virtual machines

cloudblogs.microsoft.com/microsoftsecure/2018/03/01/finfisher-exposed-a-researchers-tale-of-defeating-traps-tricks-and-complex-virtual-machines/

March 1, 2018

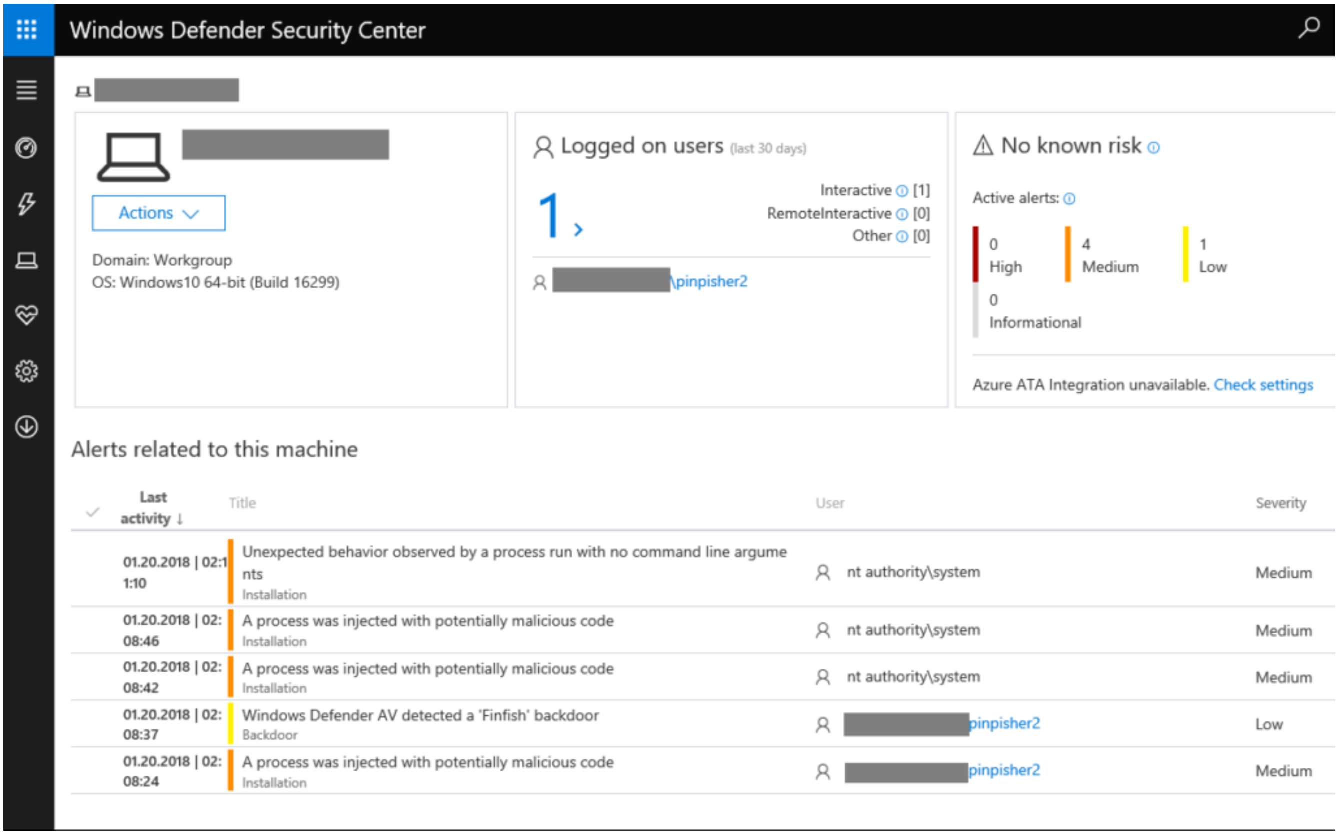
Office 365 Advanced Threat Protection (Office 365 ATP) blocked many notable zero-day exploits in 2017. In our analysis, one activity group stood out: NEODYMIUM. This threat actor is remarkable for two reasons:

- Its access to sophisticated zero-day exploits for Microsoft and Adobe software
- Its use of an advanced piece of government-grade surveillance spyware FinFisher, also known as FinSpy and detected by Microsoft security products as Wingbird

FinFisher is such a complex piece of malware that, like other researchers, we had to devise special methods to crack it. We needed to do this to understand the techniques FinFisher uses to compromise and persist on a machine, and to validate the effectiveness of Office 365 ATP detonation sandbox, Windows Defender Advanced Threat Protection (Windows Defender ATP) generic detections, and other Microsoft security solutions.

This task proved to be nontrivial. FinFisher is not afraid of using all kinds of tricks, ranging from junk instructions and “spaghetti code” to multiple layers of virtual machines and several known and lesser-known anti-debug and defensive measures. Security analysts are typically equipped with the tools to defeat a good number of similar tricks during malware investigations. However, FinFisher is in a different category of malware for the level of its anti-analysis protection. It’s a complicated puzzle that can be solved by skilled reverse engineers only with good amount of time, code, automation, and creativity. The intricate anti-analysis methods reveal how much effort the FinFisher authors exerted to keep the malware hidden and difficult to analyze.

This exercise revealed tons of information about techniques used by FinFisher that we used to make Office 365 ATP more resistant to sandbox detection and Windows Defender ATP to catch similar techniques and generic behaviors. Using intelligence from our in-depth investigation, Windows Defender ATP can raise alerts for malicious behavior employed by FinFisher (such as memory injection in persistence) in different stages of the attack kill chain. Machine learning in Windows Defender ATP further flags suspicious behaviors observed related to the manipulation of legitimate Windows binaries.



Windows Defender Security Center

[redacted]

[redacted]

Actions

Domain: Workgroup
OS: Windows10 64-bit (Build 16299)

Logged on users (last 30 days)

1

Interactive [1]
RemoteInteractive [0]
Other [0]

[redacted]\pinpisher2

No known risk

Active alerts:

0 High
4 Medium
1 Low
0 Informational

Azure ATA Integration unavailable. Check settings

Alerts related to this machine

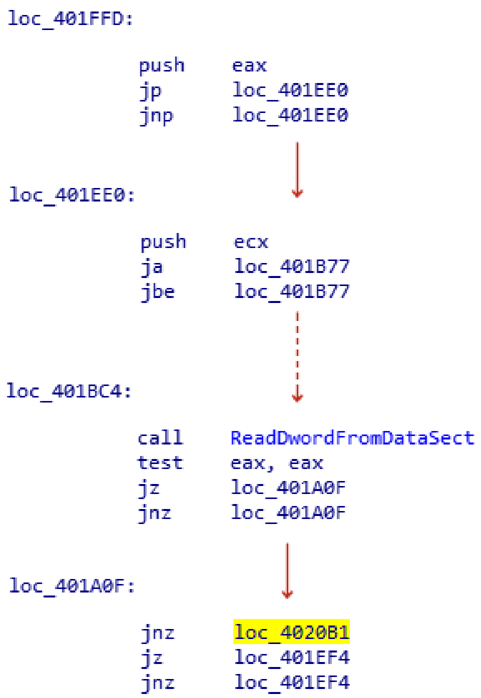
Last activity ↓	Title	User	Severity
01.20.2018 | 02:11:10	Unexpected behavior observed by a process run with no command line arguments Installation	nt authority\system	Medium
01.20.2018 | 02:08:46	A process was injected with potentially malicious code Installation	nt authority\system	Medium
01.20.2018 | 02:08:42	A process was injected with potentially malicious code Installation	nt authority\system	Medium
01.20.2018 | 02:08:37	Windows Defender AV detected a 'Finfish' backdoor Backdoor	[redacted]pinpisher2	Low
01.20.2018 | 02:08:24	A process was injected with potentially malicious code Installation	[redacted]pinpisher2	Medium

Figure 1. Generic Windows Defender ATP detections trigger alerts on FinFisher behavior

While our analysis has allowed us to immediately protect our customers, we'd like to share our insights and add to the growing number of published analyses by other talented researchers (listed below this blog post). We hope that this blog post helps other researchers to understand and analyze FinFisher samples and that this industry-wide information-sharing translate to the protection of as many customers as possible.

Spaghetti and junk codes make common analyst tools ineffective

In analyzing FinFisher, the first obfuscation problem that requires a solution is the removal of junk instructions and "spaghetti code", which is a technique that aims to confuse disassembly programs. Spaghetti code makes the program flow hard to read by adding continuous code jumps, hence the name. An example of FinFisher's spaghetti code is shown below.



```
loc_401FFD:

        push    eax
        jp      loc_401EE0
        jnp     loc_401EE0

loc_401EE0:

        push    ecx
        ja      loc_401B77
        jbe     loc_401B77

loc_401BC4:

        call    ReadDwordFromDataSect
        test    eax, eax
        jz      loc_401A0F
        jnz     loc_401A0F

loc_401A0F:

        jnz     loc_4020B1
        jz      loc_401EF4
        jnz     loc_401EF4
```

Figure 2. The spaghetti code in FinFisher dropper

This problem is not novel, and in common situations there are known reversing plugins that may help for this task. In the case of FinFisher, however, we could not find a good existing interactive disassembler (IDA) plugin that can normalize the code flow. So we decided to write our own plugin code using IDA Python. Armed with this code, we removed this first layer of anti-analysis protection.

Removing the junk instructions revealed a readable block of code. This code starts by allocating two chunks of memory: a global 1 MB buffer and one 64 KB buffer per thread. The big first buffer is used as index for multiple concurrent threads. A big chunk of data is extracted from the portable executable (PE) file itself and decrypted two times using a custom XOR algorithm. We determined that this chunk of data contains an array of opcode instructions ready to be interpreted by a custom virtual machine program (from this point on referenced generically as “VM”) implemented by FinFisher authors.

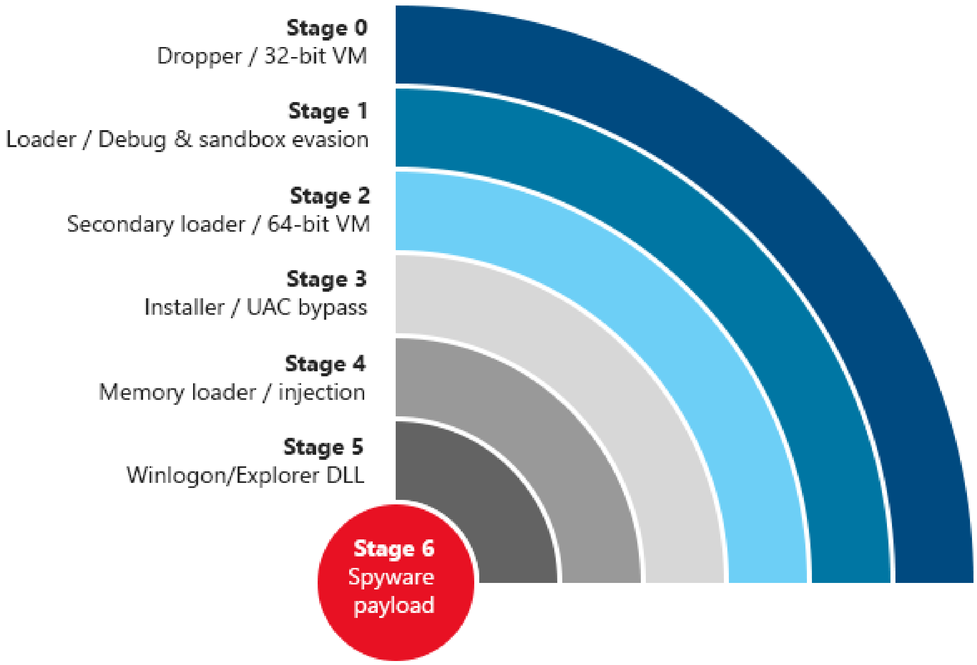
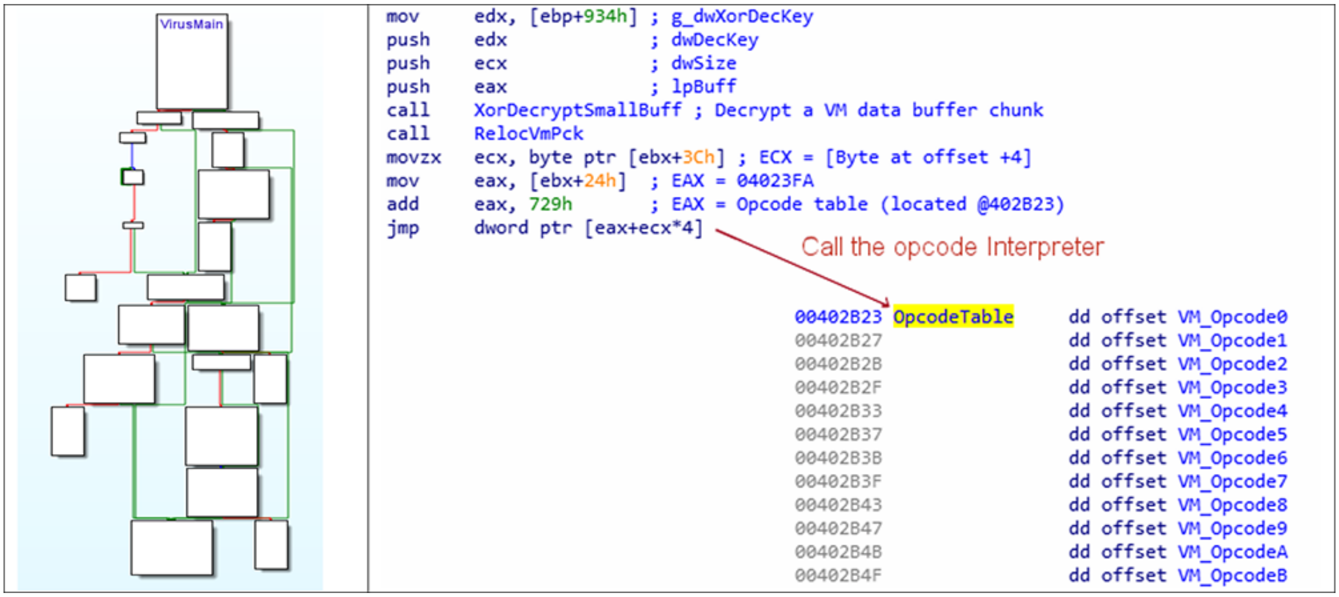


Figure 3. The stages of the FinFisher multi-layered protection mechanisms

Stage 0: Dropper with custom virtual machine

The main dropper implements the VM dispatcher loop and can use 32 different opcodes handlers. Th 64KB buffer is used as a VM descriptor data structure to store data and the just-in-time (JIT) generated code to run. The VM dispatcher loop routine ends with a JMP to another routine. In total, there are 32 different routines, each of them implementing a different opcode and some basic functionality that the malware program may execute.



```
mov     edx, [ebp+934h] ; g_dwXorDecKey
push    edx             ; dwDecKey
push    ecx             ; dwSize
push    eax             ; lpBuff
call    XorDecryptSmallBuff ; Decrypt a VM data buffer chunk
call    RelocVmPck
movzx   ecx, byte ptr [ebx+3Ch] ; ECX = [Byte at offset +4]
mov     eax, [ebx+24h]  ; EAX = 04023FA
add     eax, 729h       ; EAX = Opcode table (located @402B23)
jmp     dword ptr [eax+ecx*4]

                          00402B23 OpcodeTable      dd offset VM_Opcode0
                          00402B27                  dd offset VM_Opcode1
                          00402B2B                  dd offset VM_Opcode2
                          00402B2F                  dd offset VM_Opcode3
                          00402B33                  dd offset VM_Opcode4
                          00402B37                  dd offset VM_Opcode5
                          00402B3B                  dd offset VM_Opcode6
                          00402B3F                  dd offset VM_Opcode7
                          00402B43                  dd offset VM_Opcode8
                          00402B47                  dd offset VM_Opcode9
                          00402B4B                  dd offset VM_OpcodeA
                          00402B4F                  dd offset VM_OpcodeB
```

Figure 4. A snapshot of the code that processes each VM opcode and the associate interpreter

The presence of a VM and virtualized instruction blocks can be described in simpler terms: Essentially, the creators of FinFisher interposed a layer of dynamic code translation (the virtual machine) that makes analysis using regular tools practically impossible. Static analysis tools like IDA may not be useful in analyzing custom code that is interpreted and executed through a VM and a new set of instructions. On the other hand, dynamic analysis tools (like debuggers or sandbox) face the anti-debug and anti-analysis tricks hidden in the virtualized code itself that detects sandbox environments and alters the behavior of the malware.

At this stage, the analysis can only continue by manually investigating the individual code blocks and opcode handlers, which are highly obfuscated (also using spaghetti code). Reusing our deobfuscation tool and some other tricks, we have been able to reverse and analyze these opcodes and map them to a finite list that can be used later to automate the analysis process with some scripting.

The opcode instructions generated by this custom VM are divided into different categories:

1. Logical opcodes, which implement bit-logic operators (OR, AND, NOT, XOR) and mathematical operators
2. Conditional branching opcodes, which implement a code branch based on conditions (equals to JC, JE, JZ, other similar branching opcodes)
3. Load/Store opcodes, which write to or read from particular addresses of the virtual address space of the process
4. Specialized opcodes for various purposes, like execute specialized machine instruction that are not virtualized

We are publishing below the (hopefully) complete list of opcodes used by FinFisher VM that we found during our analysis and integrated into our de-virtualization script:

INDEX	MNEMONIC	DESCRIPTION
0x0	EXEC	Execute machine code
0x1	JG	Jump if greater/Jump if not less or equal
0x2	WRITE	Write a value into the dereferenced internal VM value (treated as a pointer)
0x3	JNO	Jump if not overflow
0x4	JLE	Jump if less or equal (signed)
0x5	MOV	Move the value of a register into the VM descriptor (same as opcode 0x1F)
0x6	JO	Jump if overflow
0x7	PUSH	Push the internal VM value to the stack
0x8	ZERO	Reset the internal VM value to 0 (zero)
0x9	JP	Jump if parity even
0xA	WRITE	Write into an address
0xB	ADD	Add the value of a register to the internal VM value
0xC	JNS	Jump if not signed
0xD	JL	Jump if less (signed)
0xE	EXEC	Execute machine code and branch
0xF	JBE	Jump if below or equal or Jump if not above
0x10	SHL	Shift left the internal value the number of times specified into the opcodes
0x11	JA	Jump if above/Jump if not below or equal
0x12	MOV	Move the internal VM value into a register
0x13	JZ	JMP if zero
0x14	ADD	Add an immediate value to the internal Vm descriptor
0x15	JB	Jump if below (unsigned)
0x16	JS	Jump if signed
0x17	EXEC	Execute machine code (same as opcode *0x0*)
0x18	JGE	Jump if greater or equal/Jump if not less
0x19	DEREF	Write a register value into a dereferenced pointer
0x1A	JMP	Special obfuscated “Jump if below” opcode
0x1B	*	Resolve a pointer
0x1C	LOAD	Load a value into the internal VM descriptor
0x1D	JNE	Jump if not equal/Jump if not zero
0x1E	CALL	Call an external function or a function located in the dropper

0x1F	MOV	Move the value of a register into the VM descriptor
0x20	JNB	Jump if not below/Jump if above or equal/Jump if not carry
0x21	JNP	Jump if not parity/Jump if parity odd

Each virtual instruction is stored in a special data structure that contains all the information needed to be properly read and executed by the VM. This data structure is 24 bytes and is composed of some fixed fields and a variable portion that depends on the opcode. Before interpreting the opcode, the VM decrypts the opcode's content (through a simple XOR algorithm), which it then relocates (if needed), using the relocation fields.

Here is an approximate diagram of the opcode data structure:

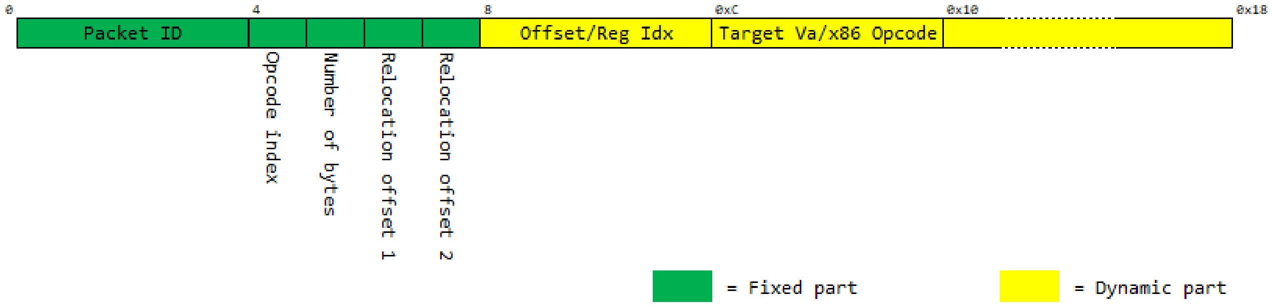
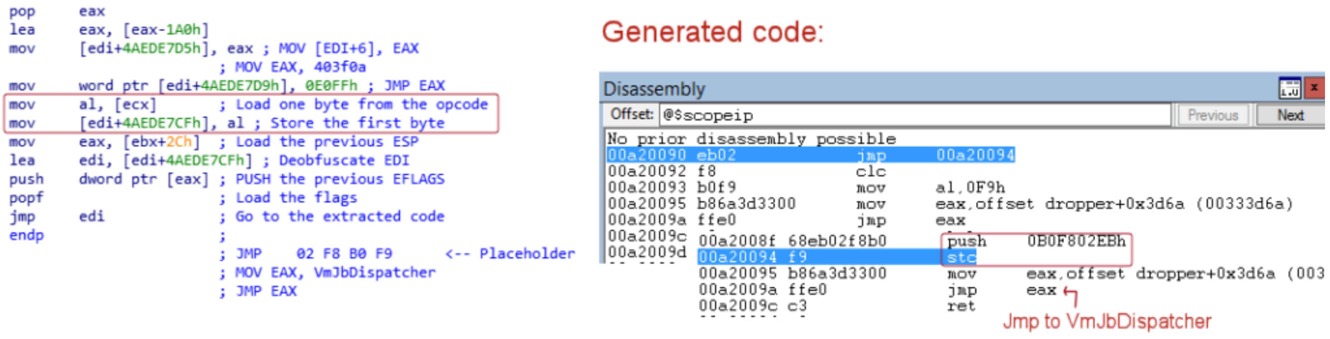


Figure 5. A graphical representation of the data structure used to store each VM opcode

The VM handler is completely able to generate different code blocks and deal with relocated code due to address space layout randomization (ASLR). It is also able to move code execution into different locations if needed. For instance, in the case of the "Execute" opcode (*0x17*), the 32-bit code to run is stored entirely into the variable section with the value at offset 5 specifying the number of bytes to be copied and executed. Otherwise, in the case of conditional opcodes, the variable part can contain the next JIT packet ID or the next relative virtual address (RVA) where code execution should continue.

Of course, not all the opcodes are can be easily read and understood due to additional steps that the authors have taken to make analysis extremely complicated. For example, this is how opcode *0x1A* is implemented: The opcode should represent a JB (Jump if below) function, but it's implemented through set carry (STC) instruction followed by a JMP into the dispatcher code that will verify the carry flag condition set by STC.



```
pop     eax
lea     eax, [eax-1A0h]
mov     [edi+4AEDE7D5h], eax ; MOV [EDI+6], EAX
                     ; MOV EAX, 403f0a
mov     word ptr [edi+4AEDE7D9h], 0E0FFh ; JMP EAX
mov     al, [ecx]          ; Load one byte from the opcode
mov     [edi+4AEDE7CFh], al ; Store the first byte
mov     eax, [ebx+2Ch]    ; Load the previous ESP
lea     edi, [edi+4AEDE7CFh] ; Deobfuscate EDI
push    dword ptr [eax] ; PUSH the previous EFLAGS
popf                       ; Load the flags
jmp     edi                ; Go to the extracted code
endp                       ;
                           ; JMP    02 F8 B0 F9      <-- Placeholder
                           ; MOV EAX, VmJbDispatcher
                           ; JMP EAX
```

Generated code:

```
No prior disassembly possible
00a20090 eb02            jmp     00a20094
00a20092 f8              clc
00a20093 b0f9            mov     al,0F9h
00a20095 b86a3d3300      mov     eax,offset dropper+0x3d6a (00333d6a)
00a2009a ffe0            jmp     eax
00a2009c
00a2009d
```

```
00a2008f 68eb02f8b0      push    0B0F802EBh
00a20094 f9              stc
00a20095 b86a3d3300      mov     eax,offset dropper+0x3d6a (003
00a2009a ffe0            jmp     eax
00a2009c c3              ret
```

Jmp to VmJbDispatcher

Figure 6. One of the obfuscation tricks included by the malware authors in a VM opcode dispatcher

Even armed with the knowledge we have described so far, it still took us many hours to write a full-fledged opcode interpreter that's able to reconstruct the real code executed by FinFisher.

Stage 1: Loader malware keeps sandbox and debuggers away

The first stage of FinFisher running through this complicated virtual machine is a loader malware designed to probe the system and determine whether it's running in a sandbox environment (typical for cloud-based detonation solution like Office 365 ATP).

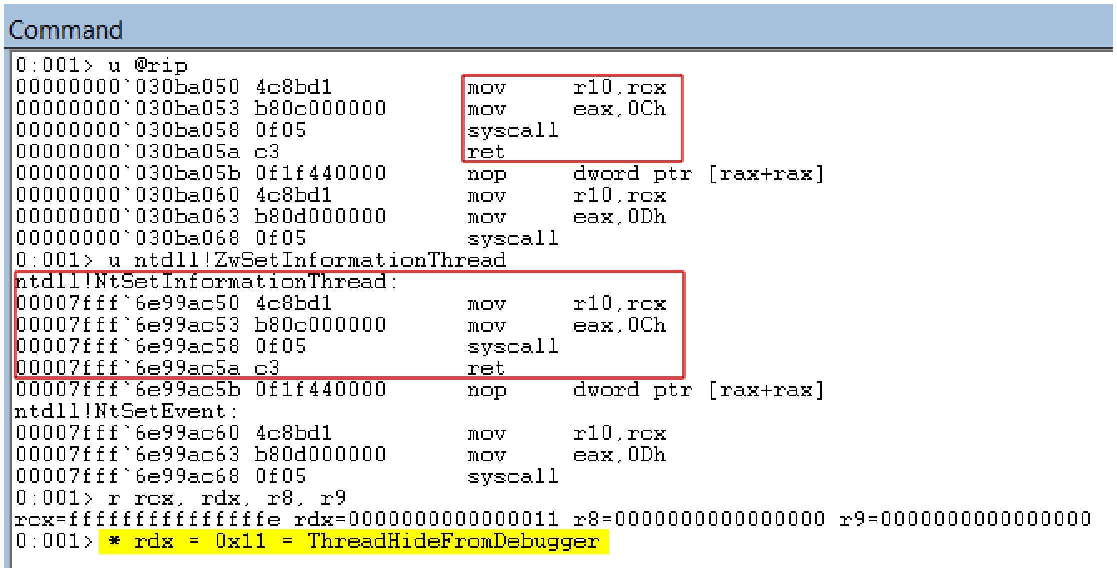
The loader first dynamically rebuilds a simple import address table (IAT), resolving all the API needed from Kernel32 and NtDll libraries. It then continues executing in a spawned new thread that checks if there are additional undesired modules inside its own virtual address space (for example, modules injected by certain security solutions). It eventually kills all threads that belong to these undesired modules (using *ZwQueryInformationThread* native API with *ThreadQuerySetWin32StartAddress* information class).

The first anti-sandbox technique is the loader checking the code segment. If it's not *0x1B* (for 32-bit systems) or *0x23* (for 32-bit system under Wow64), the loader exits.

Next, the dropper checks its own parent process for indications that it is running in a sandbox setup. It calculates the MD5 hash of the lower-case process image name and terminates if one of the following conditions are met:

1. The MD5 hash of the parent process image name is either D0C4DBFA1F3962AED583F6FCE666F8BC or 3CE30F5FED4C67053379518EACFCF879
2. The parent process's full image path is equal to its own process path

If these initial checks are passed, the loader builds a complete IAT by reading four imported libraries from disk (*ntdll.dll*, *kernel32.dll*, *advapi32.dll*, and *version.dll*) and remapping them in memory. This technique makes use of debuggers and software breakpoints useless. During this stage, the loader may also call a certain API using native system calls, which is another way to bypass breakpoints on API and security solutions using hooks.



```
0:001> u @rip
00000000`030ba050 4c8bd1          mov     r10,rcx
00000000`030ba053 b80c000000      mov     eax,0Ch
00000000`030ba058 0f05            syscall
00000000`030ba05a c3              ret
00000000`030ba05b 0f1f440000      nop     dword ptr [rax+rax]
00000000`030ba060 4c8bd1          mov     r10,rcx
00000000`030ba063 b80d000000      mov     eax,0Dh
00000000`030ba068 0f05            syscall
0:001> u ntdll!ZwSetInformationThread
ntdll!NtSetInformationThread:
00007fff`6e99ac50 4c8bd1          mov     r10,rcx
00007fff`6e99ac53 b80c000000      mov     eax,0Ch
00007fff`6e99ac58 0f05            syscall
00007fff`6e99ac5a c3              ret
00007fff`6e99ac5b 0f1f440000      nop     dword ptr [rax+rax]
ntdll!NtSetEvent:
00007fff`6e99ac60 4c8bd1          mov     r10,rcx
00007fff`6e99ac63 b80d000000      mov     eax,0Dh
00007fff`6e99ac68 0f05            syscall
0:001> r rcx, rdx, r8, r9
rcx=fffffffffffffffe rdx=0000000000000011 r8=0000000000000000 r9=0000000000000000
0:001> * rdx = 0x11 = ThreadHideFromDebugger
```

Figure 7. FinFisher loader calling native Windows API to perform anti-debugging tricks

At this point, the fun in analysis is not over. A lot of additional anti-sandbox checks are performed in this exact order:

1. Check that the malware is not executed under the root folder of a drive
2. Check that the malware file is readable from an external source
3. Check that the hash of base path is not 3D6D62AF1A7C8053DBC8E110A530C679
4. Check that the full malware path contains only human readable characters ("a-z", "A-Z", and "0-9")
5. Check that no node in the full path contains the MD5 string of the malware file

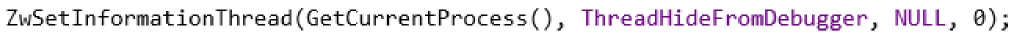
6. Fingerprint the system and check the following registry values:
    1. *HKLM\SOFTWARE\Microsoft\Cryptography\MachineGuid* should not be “6ba1d002-21ed-4dbe-afb5-08cf8b81ca32”
    2. *HKLM\SOFTWARE\Microsoft\Windows NT\CurrentVersion\DigitalProductId* should not be “55274-649-6478953-23109”, “A22-00001”, or “47220”
    3. *HARDWARE\Description\System\SystemBiosDate* should not contain “01/02/03”
7. Check that the mutex *WininetStartupMutex0* does not already exist
8. Check that no DLL whose base name has hash value of 0xC9CEF3E4 is mapped into the malware address space

The hashes in these checks are most likely correspond to sandbox or security products that the FinFisher authors want to avoid.

Next, the loader checks that it’s not running in a virtualized environment (VMWare or Hyper-V) or under a debugger. For the hardware virtualization check, the loader obtains the hardware device list and checks if the MD5 of the vendor ID is equal to a predefined list. In our tests, the malware sample was able to easily detect both VMWare and Hyper-V environments through the detection of the virtualized peripherals (for example, Vmware has VEN_15AD as vendor ID, HyperV has VMBus as bus name). Office 365 ATP sandbox employs special mechanisms to avoid being detected by similar checks.

The loader’s anti-debugger code is based on the following three methods:

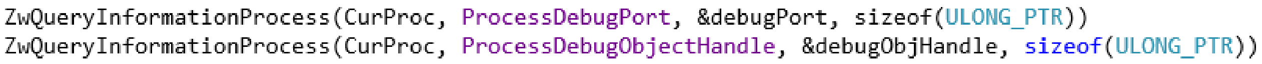
1. The first call aims to destroy the debugger connection:



```
ZwSetInformationThread(GetCurrentProcess(), ThreadHideFromDebugger, NULL, 0);
```

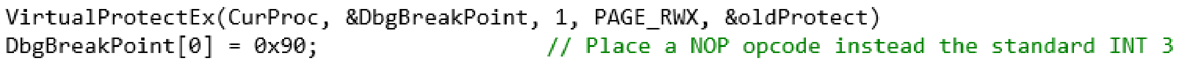
NOTE: This call completely stops the execution of WinDbg and other debuggers

1. The second call tries to detect the presence of a debugger:



```
ZwQueryInformationProcess(CurProc, ProcessDebugPort, &debugPort, sizeof(ULONG_PTR))
ZwQueryInformationProcess(CurProc, ProcessDebugObjectHandle, &debugObjHandle, sizeof(ULONG_PTR))
```

1. The final call tries to destroy the possibility of adding software breakpoint:



```
VirtualProtectEx(CurProc, &DbgBreakPoint, 1, PAGE_RWX, &oldProtect)
DbgBreakPoint[0] = 0x90;                    // Place a NOP opcode instead the standard INT 3
```

Finally, if the loader is happy with all the checks done so far, based on the victim operating system (32 or 64-bit) it proceeds to decrypt a set of fake bitmap resources (stage 2) embedded in the executable and prepares the execution of a new layer of VM decoding.

Each bitmap resource is extracted, stripped of the first 0x428 bytes (BMP headers and garbage data), and combined into one file. The block is decrypted using a customized algorithm that uses a key derived from the original malware dropper’s *TimeDateStamp* field multiplied by 5.

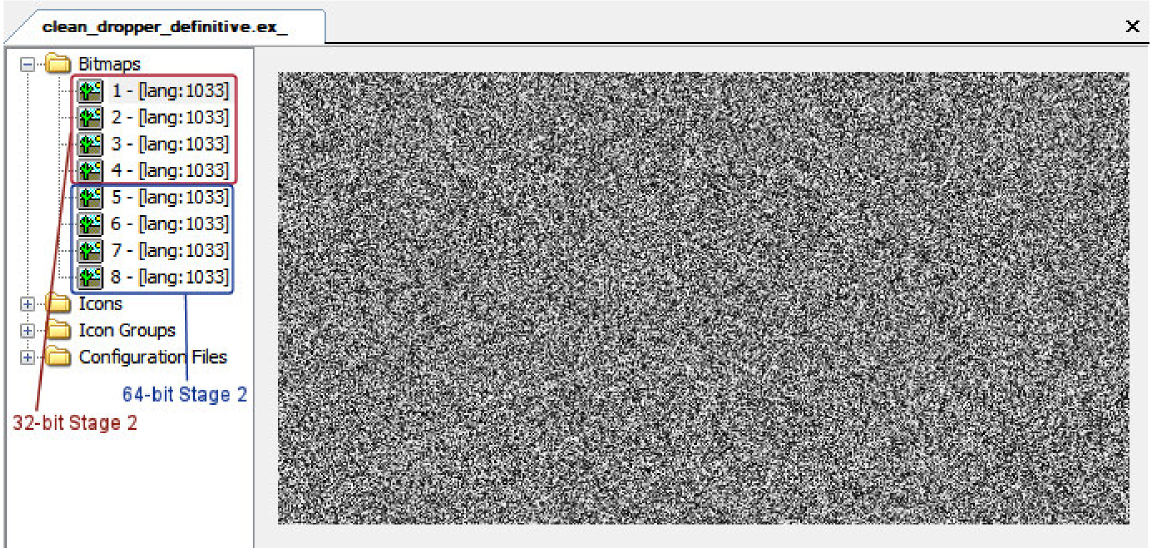
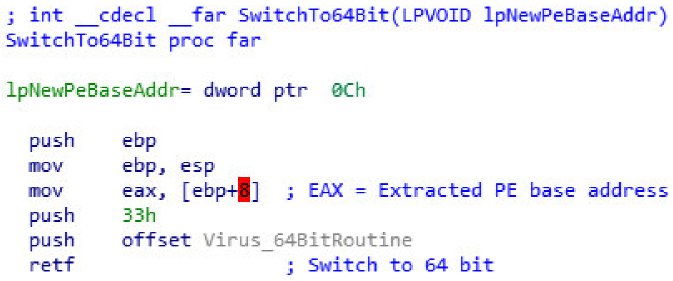


Figure 8. The fake bitmap image embedded as resource

The 32-bit stage 2 malware uses a customized loading mechanism (i.e., the PE file has a scrambled IAT and relocation table) and exports only one function. For the 64-bit stage 2 malware, the code execution is transferred from the loader using a well-known technique called Heaven's Gate. In the next sections, for simplicity, we will continue the analysis only on the 64-bit payload.



```
; int __cdecl __far SwitchTo64Bit(LPVOID lpNewPeBaseAddr)
SwitchTo64Bit proc far

lpNewPeBaseAddr= dword ptr  0Ch

  push    ebp
  mov     ebp, esp
  mov     eax, [ebp+8]  ; EAX = Extracted PE base address
  push    33h
  push    offset Virus_64BitRoutine
  retf                  ; Switch to 64 bit
```

Figure 9. Heaven's gate is still in use in 2017

Stage 2: A second multi-platform virtual machine

The 64-bit stage 2 malware implements another loader combined with another virtual machine. The architecture is quite similar to the one described previously, but the opcodes are slightly different. After reversing these opcodes, we were able to update our interpreter script to support both 32-bit and 64-bit virtual machines used by FinFisher.

INDEX	MNEMONIC	DESCRIPTION
0x0	JMP	Special obfuscated conditional Jump (always taken or always ignored)
0x1	JMP	Jump to a function (same as opcode 0x10)
0x2	CALL	Call to the function pointed by the internal VM value
0x3	CALL	Optimized CALL function (like the 0x1E opcode of the 32-bit VM)
0x4	EXEC	Execute code and move to the next packet
0x5	JMP	Jump to an internal function
0x6	NOP	No operation, move to the next packet

0x7	CALL	Call an imported API (whose address is stored in the internal VM value)
0x8	LOAD	Load a value into the VM descriptor structure *
0x9	STORE	Store the internal VM value inside a register
0xA	WRITE	Resolve a pointer and store the value of a register in its content
0xB	READ	Move the value pointed by the VM internal value into a register
0xC	LOAD	Load a value into the VM descriptor structure (not optimized)
0xD	CMP	Compare the value pointed by the internal VM descriptor with a register
0xE	CMP	Compare the value pointed by the internal VM descriptor with an immediate value
0xF	XCHG	Exchange the value pointed by the internal VM descriptor with a register
0x10	SHL	Jump to a function (same as opcode 0x1)

This additional virtual machine performs the same duties as the one already described but in a 64-bit environment. It extracts and decrypts the stage 3 malware, which is stored in encrypted resources such as fake dialog boxes. The extraction method is the same, but the encryption algorithm (also XOR) is much simpler. The new payload is decrypted, remapped, and executed in memory, and represents the installation and persistence stage of the malware.

Stage 3: Installer that takes DLL side-loading to a new level

Stage 3 represents the setup program for FinFisher. It is the first plain stage that does not employ a VM or obfuscation. The code supports two different installation methods: setup in a UAC-enforced environment (with limited privileges), or an installation with full-administrative privileges enabled (in cases where the malware gains the ability to run with elevated permissions). We were a bit disappointed that we did not see traces of a true privilege escalation exploit after all this deobfuscation work, but it seems these FinFisher samples were designed to work just using UAC bypasses.

The setup code receives an installation command from the previous stage. In our test, this command was the value *3*. The malware creates a global event named *0x0A7F1FFAB12BB2* and drops some files under a folder located in *C:\ProgramData* or in the user application data folder. The name of the folder and the malware configuration are read from a customized configuration file stored in the resource section of the setup program.

Here the list of the files potentially dropped during the installation stage:

FILE NAME	STAGE	DESCRIPTION
d3d9.dll	Stage 4	Malware loader used for UAC environments with limited privileges; also protected by VM obfuscation
aepic.dll, sspisrv.dll, userenv.dll	Stage 4	Malware loader used in presence of administrative privileges; executed from (and injected into) a fake service; also protected by VM obfuscation
msvcr90.dll	Stage 5	Malware payload injected into the *explorer.exe* or *winlogon.exe* process; also protected by VM obfuscation
<randomName>.cab	Config	Main configuration file; encrypted
setup.cab	Unknown	Last section of the setup executable; content still unknown
<randomName>.7z	Plugin	Malware plugin used to spy the victim network communications

wsecedit.rar	Stage 6	Main malware executable

After writing some of these files, the malware decides which kind of installation to perform based on the current privilege provided by the hosting process (for example, if a Microsoft Office process was used as exploit vector):

1. **Installation process under UAC**

When running under a limited UAC account, the installer extracts d3d9.dll and creates a persistence key under *HKCU\Software\Microsoft\Windows\Run*. The malware sets a registry value (whose name is read from the configuration file) to *“C:\Windows\system32\rundll32.exe c:\ProgramData\AuditApp\d3d9.dll, Control_Run”*. Before doing this, the malware makes a screenshot of the screen and displays it on top of all other windows for few seconds. This indicates that the authors are trying to hide some messages showed by the system during the setup process.

When loaded with startup command *2*, the installer can copy the original *explorer.exe* file inside its current running directory and rename *d3d9.dll* to *uxtheme.dll*. In this case the persistence is achieved by loading the original explorer.exe from its startup location and, using DLL side-loading, passing the execution control to the stage 4 malware (discussed in next section).

Finally, the malware spawns a thread that has the goal to load, remap, and relocate the stage 5 malware. In this context, there is indeed no need to execute the stage 4 malware. The *msvcr90.dll* file is opened, read, and decrypted, and the code execution control is transferred to the *RunDll* exported routine.

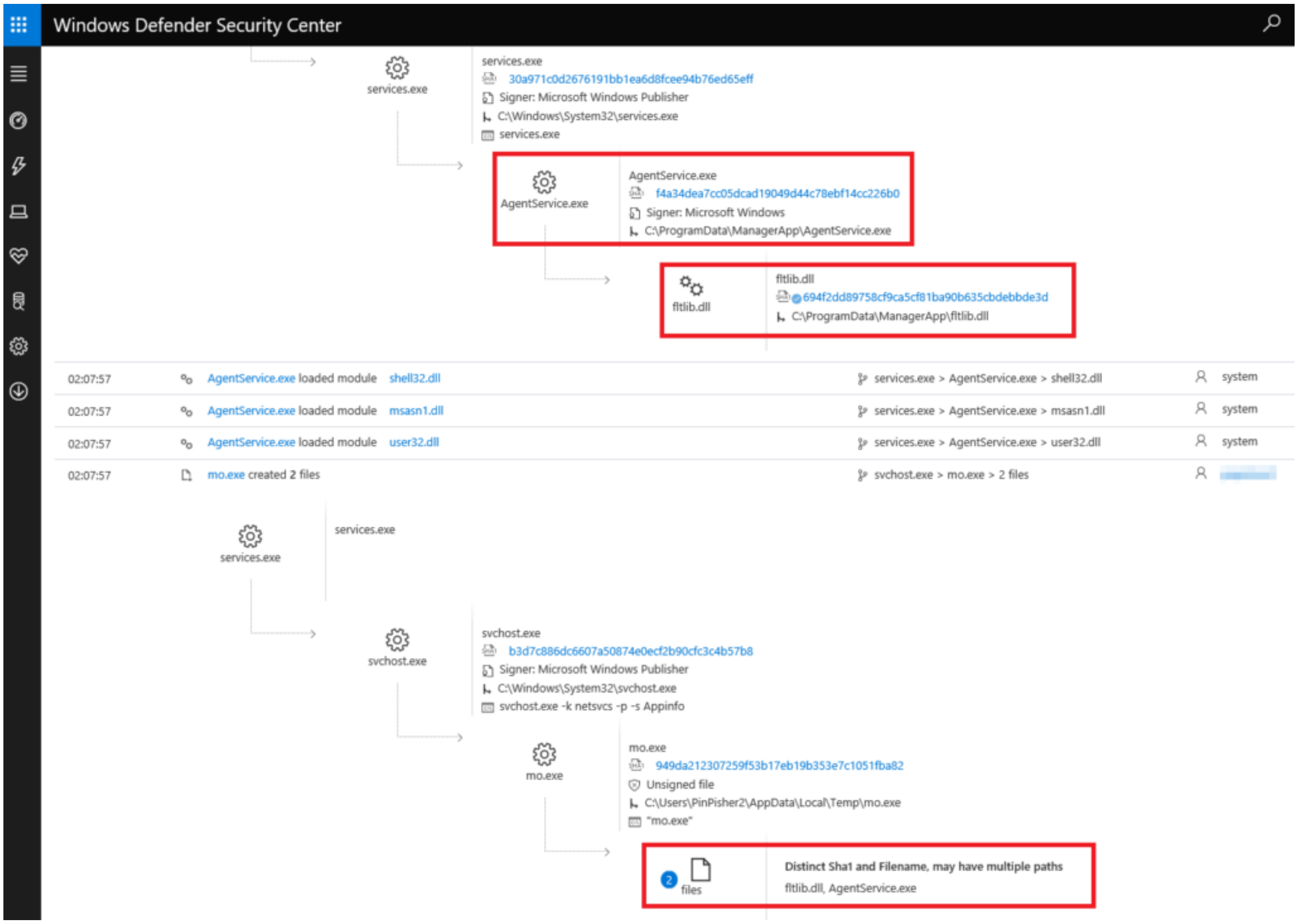
In the case of 32-bit systems, the malware may attempt a known UAC bypass by launching *printui.exe* system process and using token manipulation with *NtFilterToken* as described in this blog post.

1. **Installation process with administrative privilege**

This installation method is more interesting because it reveals how the malware tries to achieve stealthier persistence on the machine. The method is a well-known trick used by penetration testers that was automated and generalized by FinFisher

The procedure starts by enumerating the *KnownDlls* object directory and then scanning for section objects of the cached system DLLs. Next, the malware enumerates all .exe programs in the *%System%* folder and looks for an original signed Windows binary that imports from at least one *KnownDll* and from a library that is not in the *KnownDll* directory. When a suitable .exe file candidate is found, it is copied into the malware installation folder (for example, *C:\ProgramData*). At this point the malware extracts and decrypts a stub DLL from its own resources (ID 101). It then calls a routine that adds a code section to a target module. This section will contain a fake export table mimicking the same export table of the original system DLL chosen. At the time of writing, the dropper supports *aepic.dll*, *sspisrv.dll*, *ftllib.dll*, and *userenv.dll* to host the malicious FinFisher payload. Finally, a new Windows service is created with the service path pointing to the candidate .exe located in this new directory together with the freshly created, benign-looking DLL.

In this way, when the service runs during boot, the original Windows executable is executed from a different location and it will automatically load and map the malicious DLL inside its address space, instead of using the genuine system library. This routine is a form of generic and variable generator of DLL side-loading combinations.



```
services.exe
30a971c0d2676191bb1ea6d8fcee94b76ed65eff
Signer: Microsoft Windows Publisher
C:\Windows\System32\services.exe
services.exe

AgentService.exe
f4a34dea7cc05dcad19049d44c78ebf14cc226b0
Signer: Microsoft Windows
C:\ProgramData\ManagerApp\AgentService.exe

fltlib.dll
694f2dd89758cf9ca5cf81ba90b635cbdebbde3d
C:\ProgramData\ManagerApp\fltlib.dll
```

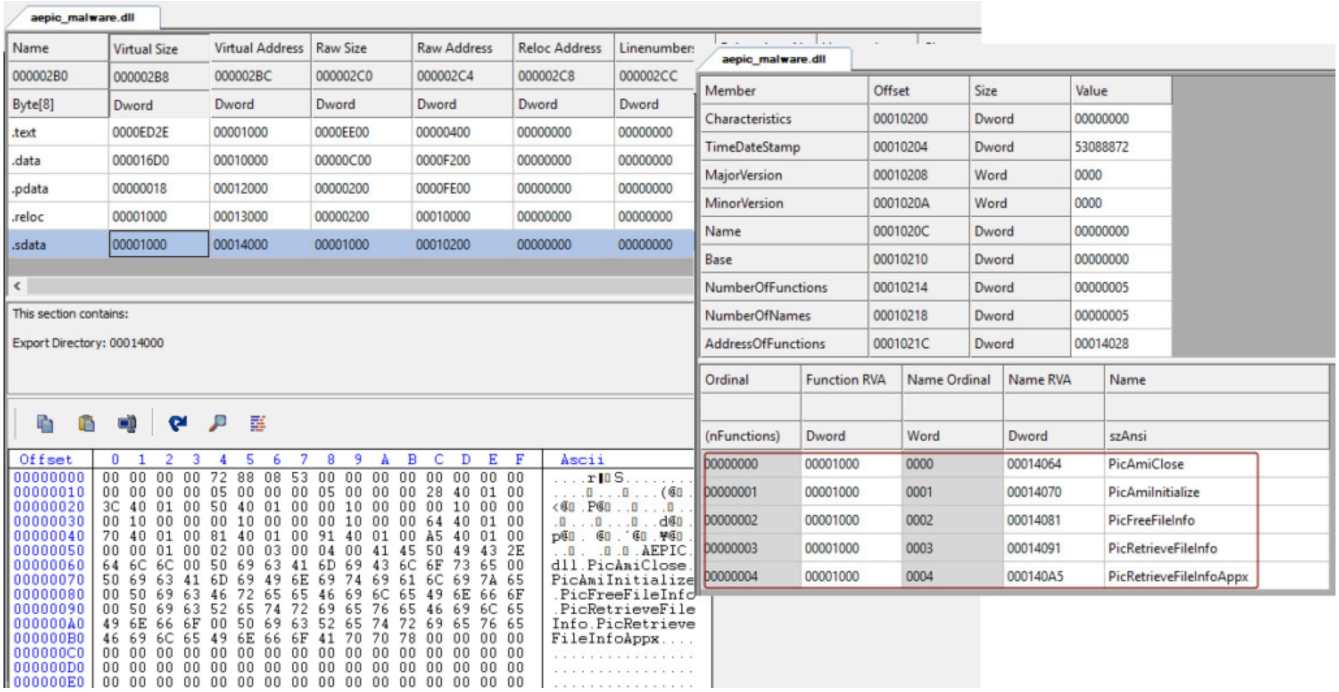
```
02:07:57   AgentService.exe loaded module  shell32.dll   services.exe > AgentService.exe > shell32.dll   system
02:07:57   AgentService.exe loaded module  msasn1.dll    services.exe > AgentService.exe > msasn1.dll    system
02:07:57   AgentService.exe loaded module  user32.dll    services.exe > AgentService.exe > user32.dll    system
02:07:57   mo.exe created 2 files                        svchost.exe > mo.exe > 2 files                  [redacted]
```

```
services.exe

svchost.exe
b3d7c886dc6607a50874e0ecf2b90cfc3c4b57b8
Signer: Microsoft Windows Publisher
C:\Windows\System32\svchost.exe
svchost.exe -k netsvcs -p -s Appinfo

mo.exe
949da212307259f53b17eb19b353e7c1051fba82
Unsigned file
C:\Users\PinPisher2\AppData\Local\Temp\mo.exe
"mo.exe"

Distinct Sha1 and Filename, may have multiple paths
fltlib.dll, AgentService.exe
```

Figure 10. Windows Defender ATP timeline can pinpoint the service DLL side-loading trick (in this example, using fltlib.dll).

In the past, we have seen other activity groups like LEAD employ a similar attacker technique named “proxy-library” to achieve persistence, but not with this professionalism. The said technique brings the advantage of avoiding auto-start extensibility points (ASEP) scanners and programs that checks for binaries installed as service (for the latter, the service chosen by FinFisher will show up as a clean Windows signed binary).

The malware cleans the system event logs using *OpenEventLog/ClearEventLog* APIs, and then terminates the setup procedure with a call to *StartService* to run the stage 4 malware.



aepic_malware.dll

Name	Virtual Size	Virtual Address	Raw Size	Raw Address	Reloc Address	Linenumber:
000002B0	000002B8	000002BC	000002C0	000002C4	000002C8	000002CC
Byte[8]	Dword	Dword	Dword	Dword	Dword	Dword
.text	0000ED2E	00001000	0000EE00	00000400	00000000	00000000
.data	000016D0	00010000	00000C00	0000F200	00000000	00000000
.pdata	00000018	00012000	00000200	0000FE00	00000000	00000000
.reloc	00001000	00013000	00000200	00010000	00000000	00000000
.sdata	00001000	00014000	00001000	00010200	00000000	00000000

This section contains:

Export Directory: 00014000

```
 Offset    0  1  2  3  4  5  6  7  8  9  A  B  C  D  E  F    Ascii
00000000  00 00 00 00 72 88 08 53 00 00 00 00 00 00 00 00   ....r▮▯S........
00000010  00 00 00 00 05 00 00 00 05 00 00 00 28 40 01 00   ....▯...▯...(@▯.
00000020  3C 40 01 00 50 40 01 00 00 10 00 00 00 10 00 00   <@▯.P@▯..▯...▯..
00000030  00 10 00 00 00 10 00 00 00 10 00 00 64 40 01 00   .▯...▯...▯..d@▯.
00000040  70 40 01 00 81 40 01 00 91 40 01 00 A5 40 01 00   p@▯. @▯.´@▯.¥@▯.
00000050  00 00 01 00 02 00 03 00 04 00 41 45 50 49 43 2E   ..▯. .▯.▯.AEPIC.
00000060  64 6C 6C 00 50 69 63 41 6D 69 43 6C 6F 73 65 00   dll.PicAmiClose.
00000070  50 69 63 41 6D 69 49 6E 69 74 69 61 6C 69 7A 65   PicAmiInitialize
00000080  00 50 69 63 46 72 65 65 46 69 6C 65 49 6E 66 6F   .PicFreeFileInfo
00000090  00 50 69 63 52 65 74 72 69 65 76 65 46 69 6C 65   .PicRetrieveFile
000000A0  49 6E 66 6F 00 50 69 63 52 65 74 72 69 65 76 65   Info.PicRetrieve
000000B0  46 69 6C 65 49 6E 66 6F 41 70 70 78 00 00 00 00   FileInfoAppx....
000000C0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
000000D0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
000000E0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```

aepic_malware.dll

Member	Offset	Size	Value
Characteristics	00010200	Dword	00000000
TimeDateStamp	00010204	Dword	53088872
MajorVersion	00010208	Word	0000
MinorVersion	0001020A	Word	0000
Name	0001020C	Dword	00000000
Base	00010210	Dword	00000000
NumberOfFunctions	00010214	Dword	00000005
NumberOfNames	00010218	Dword	00000005
AddressOfFunctions	0001021C	Dword	00014028

Ordinal	Function RVA	Name Ordinal	Name RVA	Name
(nFunctions)	Dword	Word	Dword	szAnsi
00000000	00001000	0000	00014064	PicAmiClose
00000001	00001000	0001	00014070	PicAmiInitialize
00000002	00001000	0002	00014081	PicFreeFileInfo
00000003	00001000	0003	00014091	PicRetrieveFileInfo
00000004	00001000	0004	000140A5	PicRetrieveFileInfoAppx

Figure 11. The DLL side-loaded stage 4 malware mimicking a real export table to avoid detection

Stage 4: The memory loader – Fun injection with GDI function hijacking

Depending on how stage 4 was launched, two different things may happen:

- In the low-integrity case (under UAC) the installer simply injects the stage 5 malware into the bogus *explorer.exe* process started earlier and terminates
- In the high-integrity case (with administrative privileges or after UAC bypass), the code searches for the process hosting the Plug and Play service (usually *svchost.exe*) loaded in memory and injects itself into it

For the second scenario, the injection process works like this:

1. The malware opens the target service process.
2. It allocates and fills four chunks of memory inside the service process. One chunk contains the entire malware DLL code (without PE headers). Another chunk is used to copy a basic *Ntdll* and *Kernel32* import address table. Two chunks are filled with an asynchronous procedure call (APC) routine code and a stub.
3. It opens the service thread of the service process and uses the *ZwQueueApcThread* native API to inject an APC.

The APC routine creates a thread in the context of the svchost.exe process that will map and execute the stage 5 malware into the *winlogon.exe* process.

The injection method used for *winlogon.exe* is also interesting and quite unusual. We believe that this method is engineered to avoid trivial detection of process injection using the well-detected *CreateRemoteThread* or *ZwQueueApcThread API*.

The malware takes these steps:

1. Check if the system master boot record (MBR) contains an infection marker (*0xD289C989C089* 8-bytes value at offset *0x2C*), and, if so, terminate itself
2. Check again if the process is attached to a debugger (using the techniques described previously)
3. Read, decrypt, and map the stage 5 malware (written in the previous stage in *msvcr90.dll*)
4. Open *winlogon.exe* process

5. Load *user32.dll* system library and read the *KernelCallbackTable* pointer from its own process environment block (PEB) (Note: The *KernelCallbackTable* points to an array of graphic functions used by Win32 kernel subsystem module *win32k.sys* as call-back into user-mode.)
6. Calculate the difference between this pointer and the User32 base address.
7. Copy the stage 5 DLL into winlogon.exe
8. Allocate a chunk of memory in winlogon.exe process and copy the same APC routine seen previously
9. Read and save the original pointer of the *__fnDWORD* internal User32 routine (located at offset *+0x10* of the *KernelCallbackTable*) and replace this pointer with the address of the APC stub routine

After this function pointer hijacking, when *winlogon.exe* makes any graphical call (GDI), the malicious code can execute without using *CreateRemoteThread* or similar triggers that are easily detectable. After execution it takes care of restoring the original *KernelCallbackTable*.

Stage 5: The final loader takes control

The stage 5 malware is needed only to provide one more layer of obfuscation, through the VM, of the final malware payload and to set up a special Structured Exception Hander routine, which is inserted as *Wow64PrepareForException* in *Ntdll*. This special exception handler is needed to manage some memory buffers protection and special exceptions that are used to provide more stealthy execution.

After the VM code has checked again the user environment, it proceeds to extract and execute the final un-obfuscated payload sample directly into winlogon.exe (alternatively, into *explorer.exe*) process. After the payload is extracted, decrypted, and mapped in the process memory, the malware calls the new DLL entry point, and then the *RunDll* exported function. The latter implements the entire spyware program.

Stage 6: The payload is a modular spyware framework for further analysis

Our journey to deobfuscating FinFisher has allowed us to uncover the complex anti-analysis techniques used by this malware, as well as to use this intel to protect our customers, which is our top priority. Analysis of the additional spyware modules is future work.

It is evident that the ultimate goal of this program is to steal information. The malware architecture is modular, which means that it can execute plugins. The plugins are stored in its resource section and can be protected by the same VM. The sample we analyzed in October, for example, contains a plugin that is able to spy on internet connections, and can even divert some SSL connections and steal data from encrypted traffic.

Some FinFisher variants incorporate an MBR rootkit, the exact purpose of which is not clear. Quite possibly, this routine targets older platforms like Windows 7 and machines not taking advantage of hardware protections like UEFI and SecureBoot, available on Windows 10. Describing this additional piece of code in detail is outside the scope of this analysis and may require a new dedicated blog post.

Defense against FinFisher

Exposing as much of FinFisher's riddles as possible during this painstaking analysis has allowed us to ensure our customers are protected against this advanced piece of malware.

Windows 10 S devices are naturally protected against FinFisher and other threats thanks to the strong code integrity policies that don't allow unknown unsigned binaries to run (thus stopping FinFisher's PE installer) or loaded (blocking FinFisher's DLL persistence). On Windows 10, similar code integrity policies can be configured using Windows Defender Application Control.

Office 365 Advanced Threat Protection secures mailboxes from email campaigns that use zero-day exploits to deliver threats like FinFisher. Office 365 ATP blocks unsafe attachments, malicious links, and linked-to files using time-of-click protection. Using intel from this research, we have made Office 365 ATP more resistant to FinFisher's anti-sandbox checks.

Generic detections, advanced behavioral analytics, and machine learning technologies in Windows Defender Advanced Threat Protection detect FinFisher's malicious behavior throughout the attack kill chain and alert SecOps personnel. Windows Defender ATP also integrates with the Windows protection stack so that protections from Windows Defender AV and Windows Defender Exploit Guard are reported in Windows Defender ATP portal, enabling SecOps personnel to centrally manage security, and as well as promptly investigate and respond to hostile activity in the network.

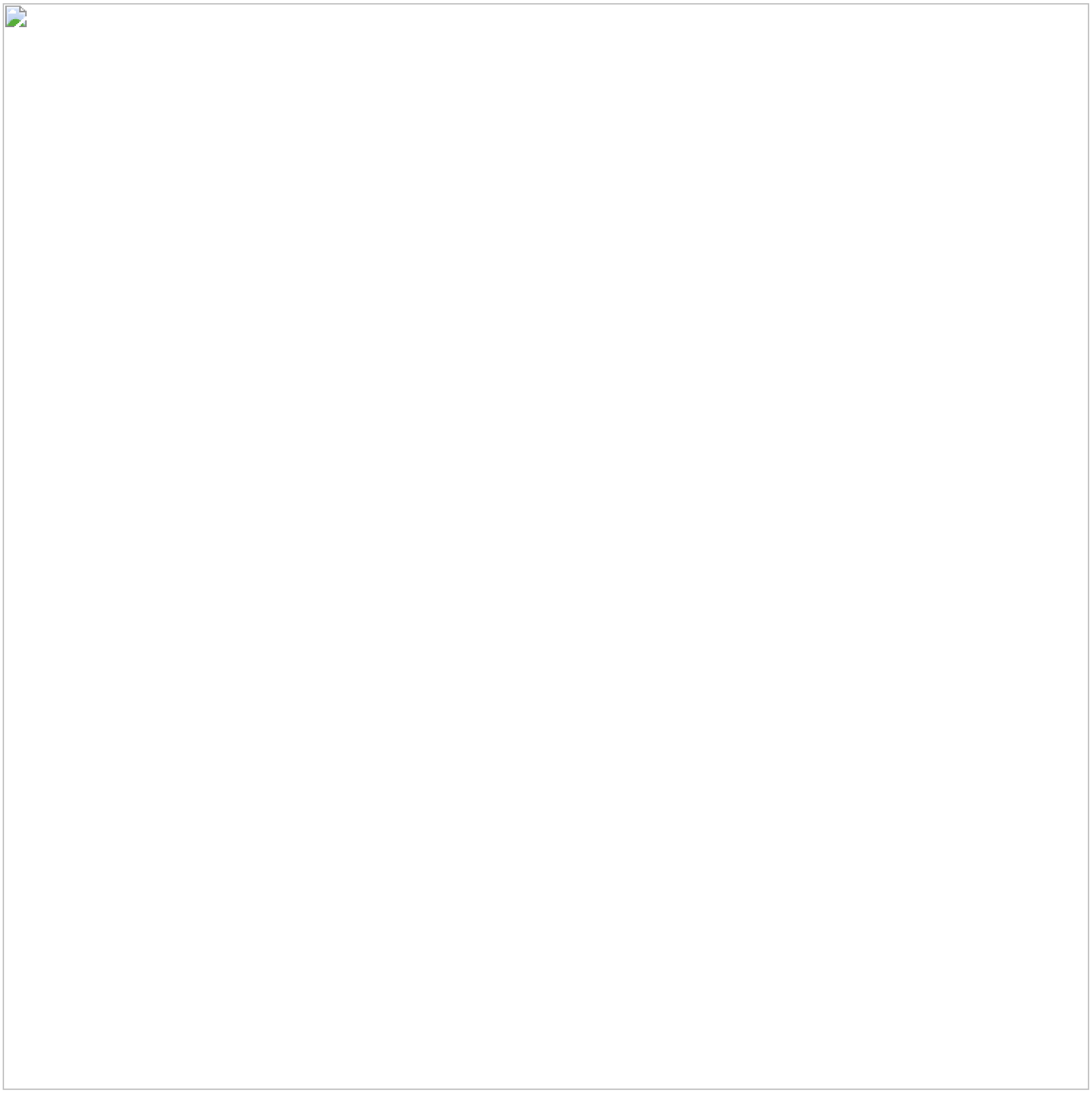
We hope that this writeup of our journey through all the multiple layers of protection, obfuscation, and anti-analysis techniques of FinFisher will be useful to other researchers studying this malware. We believe that an industry-wide collaboration and information-sharing is important in defending customers against this complex piece of malware. For further reading, we recommend these other great references:

To test how Windows Defender ATP can help your organization detect, investigate, and respond to advanced attacks, **sign up for a free trial**.

***Andrea Allievi**, Office 365 ATP Research team*
*with **Elia Florio**, Windows Defender ATP Research team*

Sample analyzed:

MD5: a7b990d5f57b244dd17e9a937a41e7f5
SHA-1: c217d48c4ac1555491348721cc7cfd1143fe0b16
SHA-256: b035ca2d174e5e4fd2d66fd3c8ce4ae5c1e75cf3290af872d1adb2658852afb8



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