# What Malware Authors Don't Want You to Know - Evasive Hollow Process Injection

In this whitepaper, we will look at different types of process hollowing techniques used in the wild to bypass, confuse, deflect and divert the forensic analysis. I also present a Volatility plugin *hollowfind* to detect these different types of process hollowing. Before looking at the different types of process hollowing, let's try to understand the normal process hollowing, its working and detection. To explain the normal process hollowing I will use memory image which is infected with Stuxnet.

## What is Process Hollowing?

Process Hollowing or Hollow Process Injection is a code injection technique in which the executable section of a legitimate process in the memory is replaced with malicious code (mostly malicious executable). This technique is used to blend in malware as a legitimate process and using this technique attackers can cause a legitimate process to execute malicious code. The advantage of this technique is that the path of the process being hollowed out will still point to the legitimate path and by executing within the context of legitimate process the malware can bypass firewalls and host intrusion prevention systems. For example if svchost.exe process is hollowed out the path will still point to the legitimate executable (C:\Windows\system32\svchost.exe), but only in the memory the executable section of svchost.exe is replaced with malicious code, this allows the attackers to remain undetected from live forensic tools.

## Working of Process Hollowing?

The following steps describe how malware normally performs process hollowing. Let's assume there are two processes A and B, in this case process A is the malicious process and process B is the legitimate process (also called as remote process).

- Process A starts a legitimate process B in the suspended mode as a result of that the executable section of process B is loaded in the memory and also the PEB (process environment block) identifies the full path to the legitimate process and PEB's ImageBaseAddress points to the address where the legitimate process executable is loaded.
- Malware process A gets the malicious code (mostly executable) to inject. This code can come from the resource section of the malware process or from the file on the disk
- Malware process A determines the base address of the legitimate process B so that it can unmap the executable section of the legitimate process. Malware can determine the base address by reading the PEB (i.e PEB.ImageBaseAddress).
- Malware process A then deallocates the executable section of the legitimate process
- Malware process then allocates the memory in the legitimate process with read, write and execute permission, this memory allocation can is normally done at the same address where the executable was previously loaded.
- Malware then writes the PE Header and PE sections of the executable to inject in the allocated memory.
- Malware then changes the start address of the suspended thread to the address of entry point of the injected executable.

- Malware then resumes the suspended thread of the legitimate process, as a result of that the legitimate process now starts executing malicious code.

## Detecting Process Hollowing using Memory Forensics

This section focuses on detecting process hollowing technique, since the code injection happens only in memory it is best detected using memory forensics. Stuxnet is one of the malware which performs hollow process injection using the steps mentioned above. In this whitepaper, I will cover some of the steps relevant to detecting process hollowing using memory forensics.

***a) Detecting from Parent Child Process Relationship***

Process listing shows two suspicious lsass.exe process (pid 868 and pid 1928) which was not started by winlogon.exe or wininit.exe but these processes were started by services.exe (pid 668). This is one of the technique to detect process hollowing, on a clean system winlogon.exe will be the parent process of lsass.exe on pre-Vista machines and wininit.exe will be the parent process of lsass.exe on Vista and later systems.

```
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem pslist | grep -i lsass
Volatility Foundation Volatility Framework 2.5
0x81e70020 lsass.exe               680    624     19      342      0      0 2010-10-29
 17:08:54 UTC+0000
0x81c498c8 lsass.exe               868    668      2       23      0      0 2011-06-03
 04:26:55 UTC+0000
0x81c47c00 lsass.exe              1928    668      4       65      0      0 2011-06-03
 04:26:55 UTC+0000
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem pslist -p 668
Volatility Foundation Volatility Framework 2.5
Offset(V)  Name                    PID   PPID   Thds     Hnds   Sess  Wow64 Start
                     Exit
---------- -------------------- ------ ------ ------ -------- ------ ------ ----------
-------------------- ------------------------------
0x82073020 services.exe            668    624     21      431      0      0 2010-10-29
 17:08:54 UTC+0000
```

```
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem pslist -p 624
Volatility Foundation Volatility Framework 2.5
Offset(V)  Name                    PID   PPID   Thds     Hnds   Sess  Wow64 Start
                     Exit
---------- -------------------- ------ ------ ------ -------- ------ ------ ----------
-------------------- ------------------------------
0x81da5650 winlogon.exe            624    376     19      570      0      0 2010-10-29
 17:08:54 UTC+0000
```

***b) Detecting by Comparing the PEB and the VAD structure.***

Hollow process injection can also be detected by comparing the results from the PEB (process environment block) structure and the VAD (Virtual address descriptor) structure. The PEB structure resides in the process memory and keeps tracks of the full path to the executable and its base address, whereas VAD structure resides in the kernel memory and also contains information about the contiguous process virtual address space allocation and if there is an executable loaded the VAD node contains information about the start address, end address and the full path to the executable. Comparing these two structures for discrepancy can tell if a process is hollowed out.

In the below screenshot running the dlllist plugin shows the full path to lsass.exe (pid 868) and the base address (0x01000000) where it is loaded. The dlllist plugin gets this information from the PEB

```
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem dlllist -p 868
Volatility Foundation Volatility Framework 2.5
************************************************************************
lsass.exe pid:    868
Command line : "C:\WINDOWS\\system32\\lsass.exe"
Service Pack 3

Base             Size  LoadCount Path
---------- ---------- ---------- ----
0x01000000     0x6000     0xffff C:\WINDOWS\system32\lsass.exe
0x7c900000    0xaf000     0xffff C:\WINDOWS\system32\ntdll.dll
0x7c800000    0xf6000     0xffff C:\WINDOWS\system32\kernel32.dll
0x77dd0000    0x9b000     0xffff C:\WINDOWS\system32\ADVAPI32.dll
0x77e70000    0x92000     0xffff C:\WINDOWS\system32\RPCRT4.dll
0x77fe0000    0x11000     0xffff C:\WINDOWS\system32\Secur32.dll
0x7e410000    0x91000     0xffff C:\WINDOWS\system32\USER32.dll
0x77f10000    0x49000     0xffff C:\WINDOWS\system32\GDI32.dll
```

In the below screenshot running the ldrmodules plugin (which relies on VAD in the kernel) does not show full path name to the lsass.exe, the reason for this is because the malware umapped the lsass.exe process, as result of that the full path name is no longer associated with the address 0x01000000, looking for this discrepancy can give an indication of hollow process injection.

```
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem ldrmodules -p 868
Volatility Foundation Volatility Framework 2.5
Pid      Process              Base       InLoad InInit InMem MappedPath
-------- -------------------- ---------- ------ ------ ----- ----------
     868 lsass.exe            0x00080000 False  False  False
     868 lsass.exe            0x7c900000 True   True   True  \WINDOWS\system32\ntdll.d
ll
     868 lsass.exe            0x77e70000 True   True   True  \WINDOWS\system32\rpcrt4.
dll
     868 lsass.exe            0x7c800000 True   True   True  \WINDOWS\system32\kernel3
2.dll
     868 lsass.exe            0x77fe0000 True   True   True  \WINDOWS\system32\secur32
.dll
     868 lsass.exe            0x7e410000 True   True   True  \WINDOWS\system32\user32.
dll
     868 lsass.exe            0x01000000 True   False  True
     868 lsass.exe            0x77f10000 True   True   True  \WINDOWS\system32\gdi32.d
ll
     868 lsass.exe            0x77dd0000 True   True   True  \WINDOWS\system32\advapi3
2.dll
```

***c) Detecting using suspicious memory protection***

Hollow process injection can also be detected by looking for suspicious memory protection. Running the malfind plugin (which looks for suspicious memory protections) shows suspicious memory protection (PAGE_EXECUTE_READWRITE) at address 0x1000000 (which is base
address of lsass.exe) indicating that lsass.exe was not loaded normally (but was injected). Any executable that is normally loaded will have a memory protection of PAGE_EXECUTE_WRITECOPY. This further confirms that lsass.exe (pid 868) loaded at 0x1000000 is not legitimate.

```
Process: lsass.exe Pid: 868 Address: 0x1000000
Vad Tag: Vad  Protection: PAGE_EXECUTE_READWRITE
Flags: CommitCharge: 2, Protection: 6

0x01000000  4d 5a 90 00 03 00 00 00 04 00 00 00 ff ff 00 00   MZ..............
0x01000010  b8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00   ........@.......
0x01000020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x01000030  00 00 00 00 00 00 00 00 00 00 00 00 d0 00 00 00   ................

0x01000000 4d              DEC EBP
0x01000001 5a              POP EDX
0x01000002 90              NOP
0x01000003 0003            ADD [EBX], AL
```

## Automating Process Hollow Detection using HollowFind Plugin

HollowFind is a Volatility plugin which automates detection of process hollowing by comparing the discrepancy in the PEB and VAD. Below screenshot shows hollowfind plugin in action. Running the hollowfind plugin on the stuxnet infected memory image identified both lsass.exe processes (pid 1928 and pid 868) and it also reports the the invalid exe memory protection (PAGE_EXECUTE_READWRITE) and process path discrepancy between the VAD and PEB and also it disassembles the address of entry point (read further to know more on this), also notice a jump to the address 0x1003121 at the address of entry point.

```
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem hollowfind
Volatility Foundation Volatility Framework 2.5
Hollowed Process Information:
        Process: lsass.exe PID: 1928 PPID: 668
        Process Base Name(PEB): lsass.exe
        Hollow Type: Invalid EXE Memory Protection and Process Path Discrepancy

VAD and PEB Comparison:
        Base Address(VAD): 0x1000000
        Process Path(VAD):
        Vad Protection: PAGE_EXECUTE_READWRITE
        Vad Tag: Vad

        Base Address(PEB): 0x1000000
        Process Path(PEB): C:\WINDOWS\system32\lsass.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: Vad

Disassembly(Entry Point):
        0x010014bd e95f1c0000       JMP 0x1003121
        0x010014c2 0000             ADD [EAX], AL
        0x010014c4 0000             ADD [EAX], AL
        0x010014c6 0000             ADD [EAX], AL
```

```
Hollowed Process Information:
        Process: lsass.exe PID: 868 PPID: 668
        Process Base Name(PEB): lsass.exe
        Hollow Type: Invalid EXE Memory Protection and Process Path Discrepancy

VAD and PEB Comparison:
        Base Address(VAD): 0x1000000
        Process Path(VAD):
        Vad Protection: PAGE_EXECUTE_READWRITE
        Vad Tag: Vad

        Base Address(PEB): 0x1000000
        Process Path(PEB): C:\WINDOWS\system32\lsass.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: Vad

Disassembly(Entry Point):
        0x010014bd e95f1c0000       JMP 0x1003121
        0x010014c2 0000             ADD [EAX], AL
        0x010014c4 0000             ADD [EAX], AL
```

Once the plugin detects the hollowed process the plugin also displays similar processes which can help in quickly identifying the process anomaly. In the below screenshot notice how both lsass.exe processes (pid 868 and pid 1928) is associated with parent process services.exe (pid 668) indicating that these two processes are not legitimate, whereas the legitimate lsass.exe process (pid 680) has winlogon.exe (pid 624) as its parent. The hollowfind plugin also displays the suspicious memory regions which can help in identifying any injected code. In the below screenshot apart from the address 0x1000000 (which is the executable base address) there is one more address 0x80000 (in pid 868) where a PE File was found and the memory protection is set to PAGE_EXECUTE_READWRITE permission, indicating an executable being injected into this address.

```
        0x010014f8 0000             ADD [EAX], AL
        0x010014fa 0000             ADD [EAX], AL
        0x010014fc 00               DB 0x0

Similar Processes:
        lsass.exe(868) Parent:services.exe(668) Start:2011-06-03 04:26:55 UTC+0000
        lsass.exe(680) Parent:winlogon.exe(624) Start:2010-10-29 17:08:54 UTC+0000
        lsass.exe(1928) Parent:services.exe(668) Start:2011-06-03 04:26:55 UTC+0000

Suspicious Memory Regions:
        0x80000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: Vad
        0x1000000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: Vad
---------------------------------------------------
```

The suspicious memory regions can be dumped with -D option as shown below. After dumping the suspicious memory regions the injected executable at address 0x80000 was submitted to VirusTotal, the VirusTotal results confirm it to be the component of Stuxnet.

```
root@kratos:~/Volatility# python vol.py -f stuxnet.vmem hollowfind -D dump/
Volatility Foundation Volatility Framework 2.5
Hollowed Process Information:
        Process: lsass.exe PID: 1928 PPID: 668
        Process Base Name(PEB): lsass.exe
```

File name: process.868.0x80000.dmp

Detection ratio: 51 / 57

Analysis date: 2016-09-21 20:32:16 UTC ( 0 minutes ago )

3 0

Analysis | File detail | Relationships | Additional information | Comments | Votes

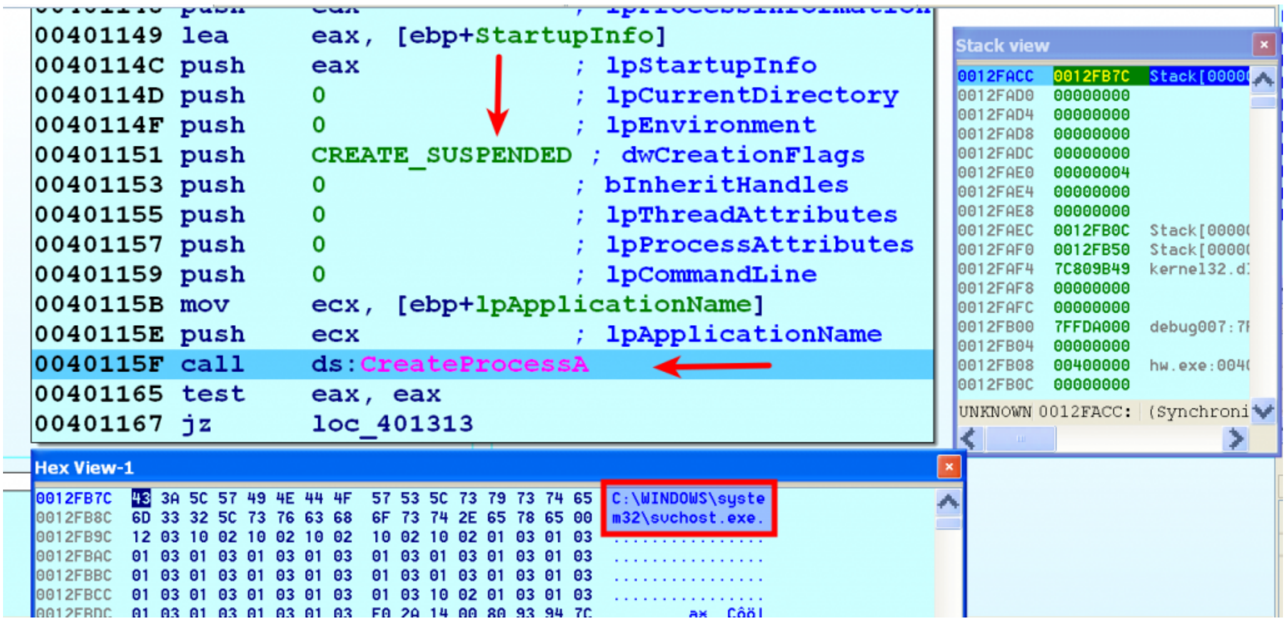
| Antivirus | Result | Update |
|---|---|---|
| ALYac | Backdoor.Generic.577628 | 20160921 |
| AVG | Hider.IRJ | 20160921 |
| AVware | Trojan.Win32.Generic!BT | 20160921 |
| Ad-Aware | Backdoor.Generic.577628 | 20160921 |
| AegisLab | W32.W.Stuxnet.ad!c | 20160921 |
| AhnLab-V3 | Worm/Win32.Stuxnet.N495400904 | 20160921 |
| Antiy-AVL | Worm/Win32.Stuxnet | 20160921 |

## Types of Process Hollowing

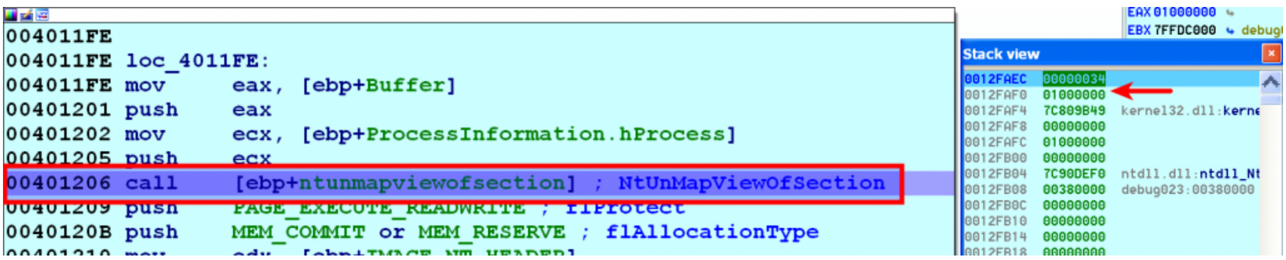
In this section lets focus on different types of process hollowing techniques used by malwares and see how some of these techniques can confuse the security analyst and divert the forensic analysis. Lets also see how hollowfind plugin can help in detecting such attacks.

***a) Example 1: Skeeyah's Process Hollowing (allocation in a different address and PEB modification)***

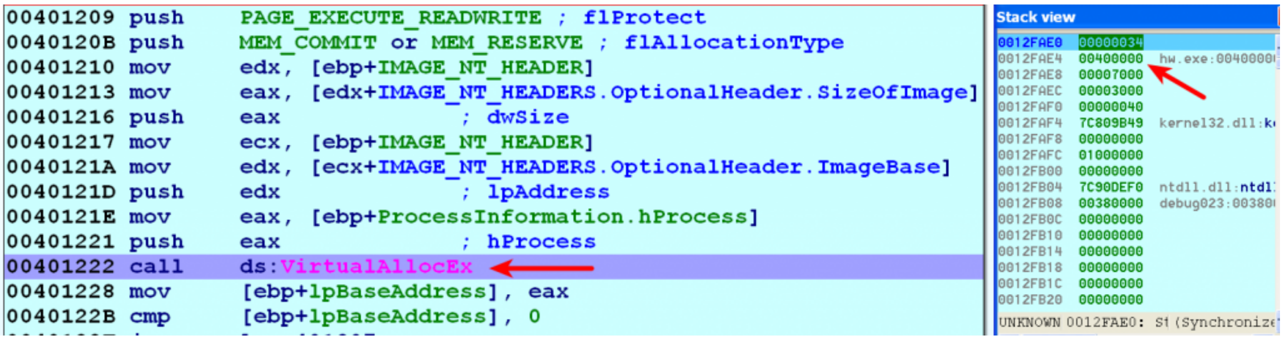
Skeeyah performs all the steps mentioned above with slight difference, malware starts the svchost.exe process in suspended mode which gets loaded into the address 0x01000000 as shown below



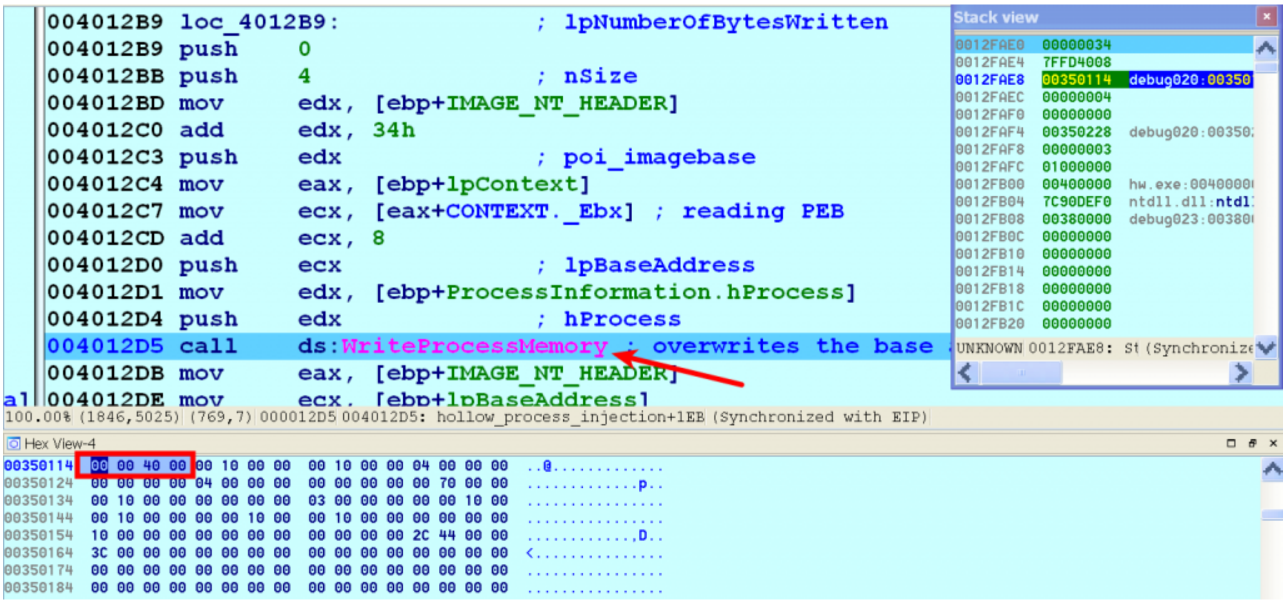

Malware determines the base address of the legitimate process by reading PEB+8 (PEB.ImageBaseAddress) and then deallocates the executable section of the legitimate process as show below



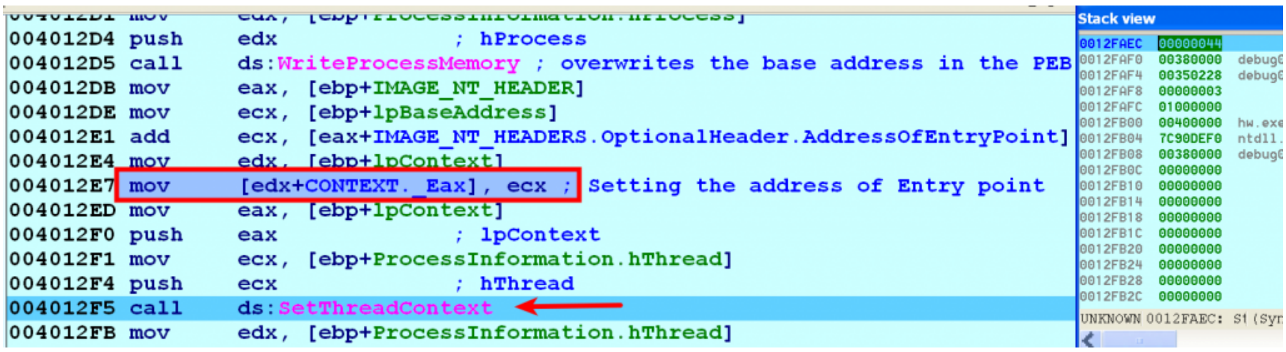

It then allocates the memory in the legitimate process with read, write and execute permission at a different address (0x00400000) and then copies the exectuable to inject into this address.

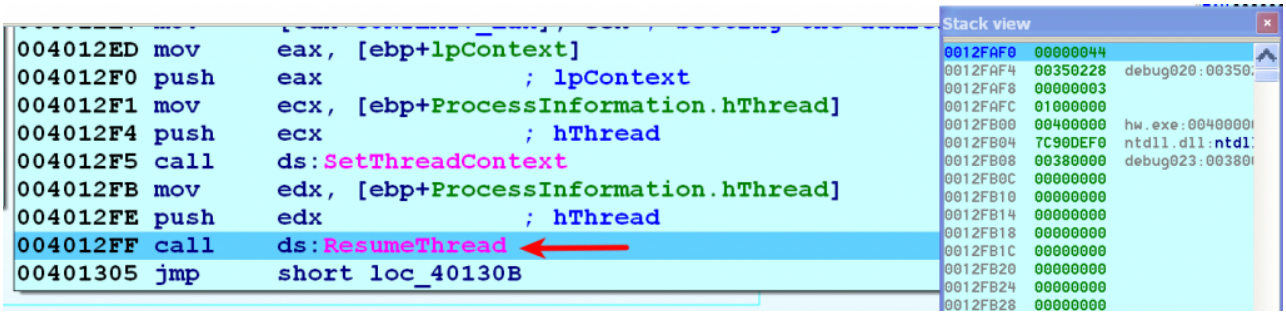



Malware then overwrites the PEB.ImageBaseAdress of the legitimate process with the newly allocated address. In the below screenshot malware overwrites the PEB.ImageBaseAdress of svchost.exe with the new address (0x00400000), this changes the base address of svchost.exe from 0x1000000 to 0x00400000 (which contains injected executable)




Malware then changes the start address of the suspended thread to the address of entry point of the injected executable by setting CONTEXT._Eax and using SetThreadContext api and it then resumes the thread






This type of process hollowing can be detected by comparing the PEB and VAD. In the below screenshots dlllist plugin shows the full path to svchost.exe (pid 1824) and the base address (0x00400000) whereas ldrmodules plugin (which relies on VAD in the kernel) does not show any entry for the svchost.exe, the reason for this is because when the malware hollowed out the svchost.exe process, the entry for that was removed in the VAD, looking for this discrepancy can give an indication of hollow process injection.

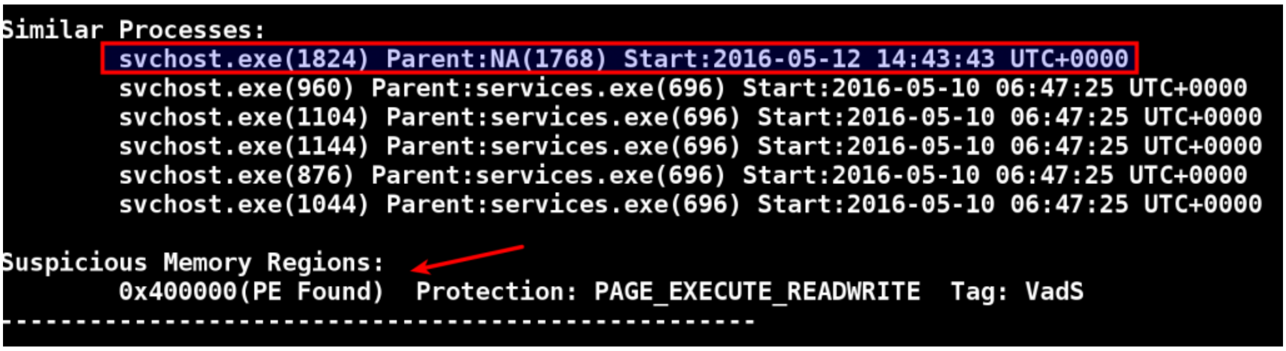
```
root@kratos:~/Volatility# python vol.py -f infected.vmem dlllist -p 1824
Volatility Foundation Volatility Framework 2.5
************************************************************************
svchost.exe pid:   1824
Command line : "C:\WINDOWS\system32\svchost.exe"
Service Pack 3

Base             Size  LoadCount Path
---------- ---------- ---------- ----
0x00400000     0x7000     0xffff C:\WINDOWS\system32\svchost.exe
0x7c900000    0xaf000     0xffff C:\WINDOWS\system32\ntdll.dll
0x7c800000    0xf6000     0xffff C:\WINDOWS\system32\kernel32.dll
0x7e410000    0x91000     0xffff C:\WINDOWS\system32\USER32.dll
0x77f10000    0x49000     0xffff C:\WINDOWS\system32\GDI32.dll
0x5cb70000    0x26000        0x1 C:\WINDOWS\system32\ShimEng.dll
0x6f880000   0x1ca000        0x1 C:\WINDOWS\AppPatch\AcGenral.DLL
0x77dd0000    0x9b000       0x18 C:\WINDOWS\system32\ADVAPI32.dll
0x77e70000    0x92000        0xa C:\WINDOWS\system32\RPCRT4.dll
0x77fe0000    0x11000        0x5 C:\WINDOWS\system32\Secur32.dll
0x76b40000    0x2d000        0x2 C:\WINDOWS\system32\WINMM.dll
0x774e0000   0x13d000        0x2 C:\WINDOWS\system32\ole32.dll
0x77c10000    0x58000        0x9 C:\WINDOWS\system32\msvcrt.dll
0x77120000    0x8b000        0x1 C:\WINDOWS\system32\OLEAUT32.dll
```

```
root@kratos:~/Volatility# python vol.py -f infected.vmem ldrmodules -p 1824
Volatility Foundation Volatility Framework 2.5
Pid      Process              Base       InLoad InInit InMem MappedPath
-------- -------------------- ---------- ------ ------ ----- ----------
    1824 svchost.exe          0x7c900000 True   True   True  \WINDOWS\system32\ntdll.dll
    1824 svchost.exe          0x7c800000 True   True   True  \WINDOWS\system32\kernel32.dll
    1824 svchost.exe          0x773d0000 True   True   True  \WINDOWS\WinSxS\x86_Microsoft.W
-Controls_6595b64144ccf1df_6.0.2600.5512_x-ww_35d4ce83\comctl32.dll
    1824 svchost.exe          0x77f60000 True   True   True  \WINDOWS\system32\shlwapi.dll
    1824 svchost.exe          0x769c0000 True   True   True  \WINDOWS\system32\userenv.dll
    1824 svchost.exe          0x77dd0000 True   True   True  \WINDOWS\system32\advapi32.dll
    1824 svchost.exe          0x77be0000 True   True   True  \WINDOWS\system32\msacm32.dll
    1824 svchost.exe          0x77c00000 True   True   True  \WINDOWS\system32\version.dll
    1824 svchost.exe          0x76b40000 True   True   True  \WINDOWS\system32\winmm.dll
    1824 svchost.exe          0x77e70000 True   True   True  \WINDOWS\system32\rpcrt4.dll
    1824 svchost.exe          0x6f880000 True   True   True  \WINDOWS\AppPatch\AcGenral.dll
    1824 svchost.exe          0x774e0000 True   True   True  \WINDOWS\system32\ole32.dll
    1824 svchost.exe          0x7e410000 True   True   True  \WINDOWS\system32\user32.dll
    1824 svchost.exe          0x77f10000 True   True   True  \WINDOWS\system32\gdi32.dll
    1824 svchost.exe          0x77120000 True   True   True  \WINDOWS\system32\oleaut32.dll
    1824 svchost.exe          0x5cb70000 True   True   True  \WINDOWS\system32\shimeng.dll
    1824 svchost.exe          0x76390000 True   True   True  \WINDOWS\system32\imm32.dll
    1824 svchost.exe          0x7c9c0000 True   True   True  \WINDOWS\system32\shell32.dll
    1824 svchost.exe          0x77c10000 True   True   True  \WINDOWS\system32\msvcrt.dll
    1824 svchost.exe          0x5ad70000 True   True   True  \WINDOWS\system32\uxtheme.dll
    1824 svchost.exe          0x5d090000 True   True   True  \WINDOWS\system32\comctl32.dll
    1824 svchost.exe          0x77fe0000 True   True   True  \WINDOWS\system32\secur32.dll
root@kratos:~/Volatility#
```

This detection is already automated in the hollowfind plugin. In the screenshot below hollowfind plugin shows the hollowed process (svchost.exe with pid 1824), it also reports that the VAD entry for the process executable is missing, it shows the discrepancy between the VAD and PEB and it shows the executable injected at the address 0x00400000

```
root@kratos:~/Volatility# python vol.py -f infected.vmem hollowfind
Volatility Foundation Volatility Framework 2.5
Hollowed Process Information:
        Process: svchost.exe PID: 1824 PPID: 1768
        Process Base Name(PEB): svchost.exe
        Hollow Type: No VAD Entry For Process Executable

VAD and PEB Comparison:
        Base Address(VAD): 0x0
        Process Path(VAD): NA
        Vad Protection: NA
        Vad Tag: NA

        Base Address(PEB): 0x400000
        Process Path(PEB): C:\WINDOWS\system32\svchost.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: VadS

0x00400000  4d 5a 90 00 03 00 00 00 04 00 00 00 ff ff 00 00   MZ..............
0x00400010  b8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00   ........@.......
0x00400020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00400030  00 00 00 00 00 00 00 00 00 00 00 00 e0 00 00 00   ................
```

The hollowfind plugin after detecting the hollowed process, also shows the similar processes. In the screenshot below the hollowed process (svchost.exe with pid 1824) doesn't have a parent process (because the parent process was exited) whereas other legitimate svchost.exe processes have a parent of services.exe (pid 696) and also notice the discrepancy in the creation time. On a clean system, the legitimate svchost.exe process is started by services.exe, this indicates that svchost.exe (pid 1824) is malicious.  The hollowfind also detected the suspicious memory regions (this is the region where executable was injected)

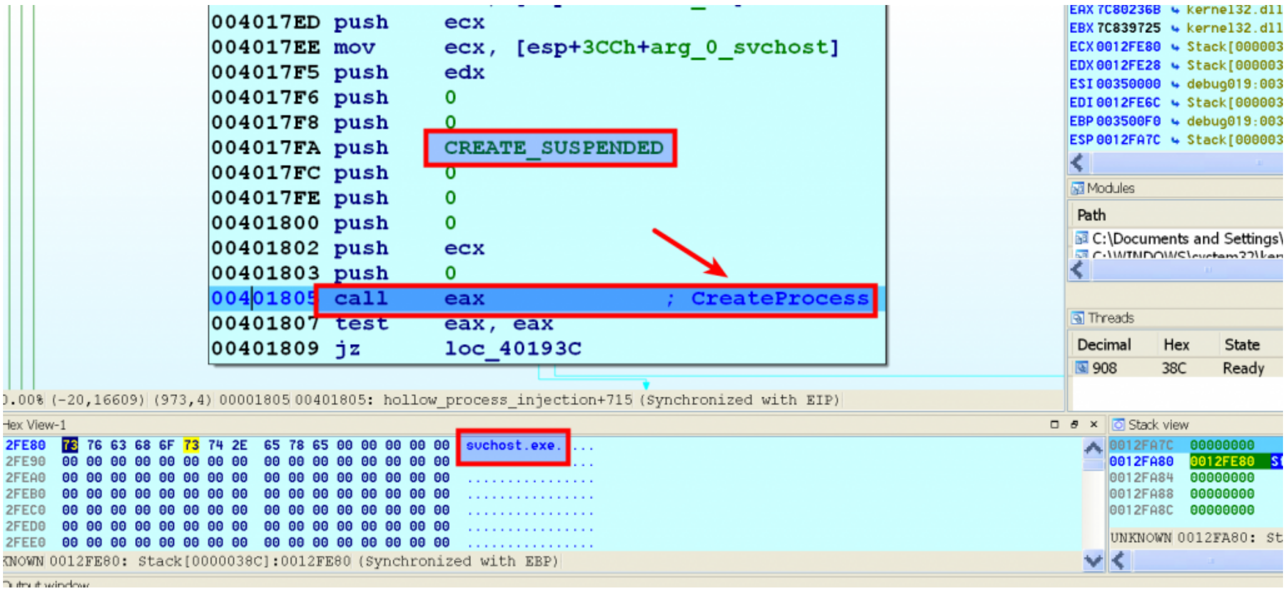


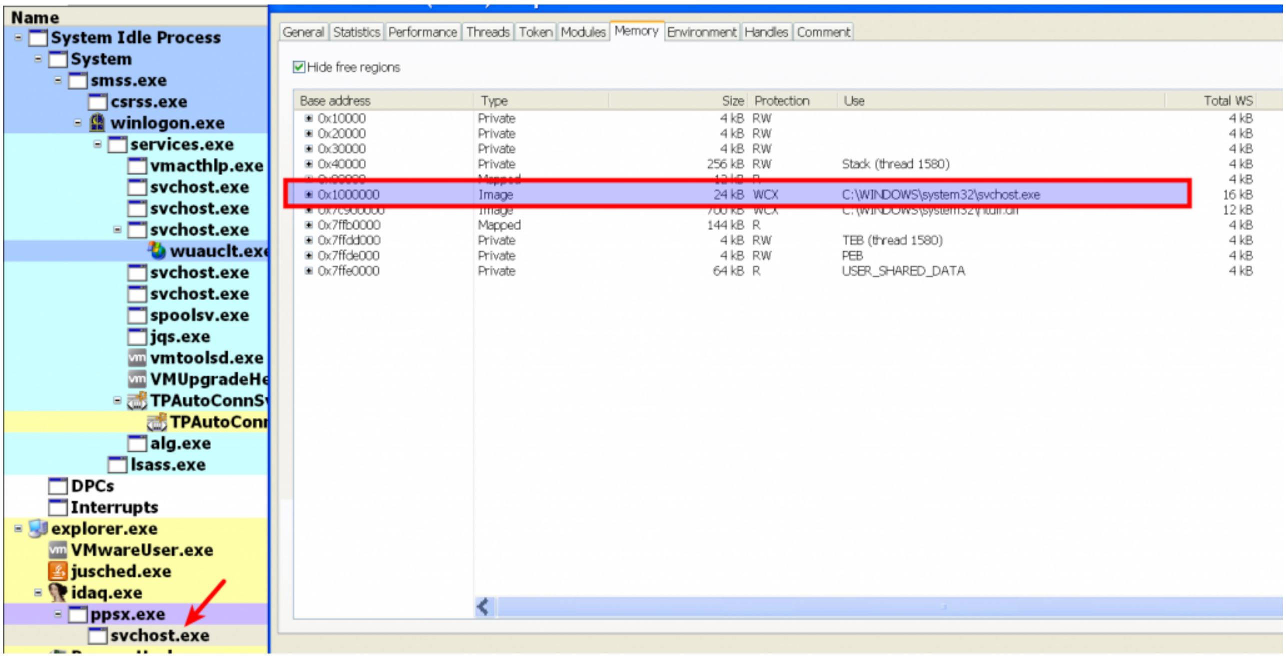
```
Similar Processes:
        svchost.exe(1824) Parent:NA(1768) Start:2016-05-12 14:43:43 UTC+0000
        svchost.exe(960) Parent:services.exe(696) Start:2016-05-10 06:47:25 UTC+0000
        svchost.exe(1104) Parent:services.exe(696) Start:2016-05-10 06:47:25 UTC+0000
        svchost.exe(1144) Parent:services.exe(696) Start:2016-05-10 06:47:25 UTC+0000
        svchost.exe(876) Parent:services.exe(696) Start:2016-05-10 06:47:25 UTC+0000
        svchost.exe(1044) Parent:services.exe(696) Start:2016-05-10 06:47:25 UTC+0000

Suspicious Memory Regions:
        0x400000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: VadS
--------------------------------------------------
```

***b) Example 2: No process hollowing (allocation in a different address and PEB Modification)***

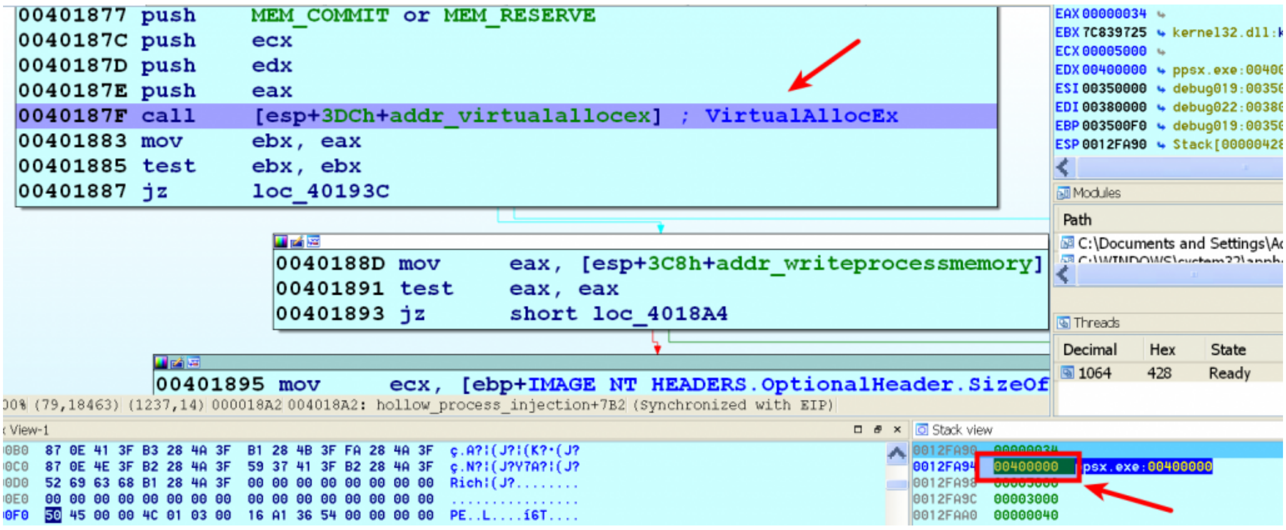
In this section we will look at another malware sample which performs different type of process hollowing which cause discrepancy in some of existing plugins, this could be deliberate attempt to trick security analyst and the forensic tools. Lets first try to understand how the malware performs process hollowing (or no process hollowing)

Malware creates svchost.exe in the suspsended mode which is loaded into the address 0x01000000 as shown below

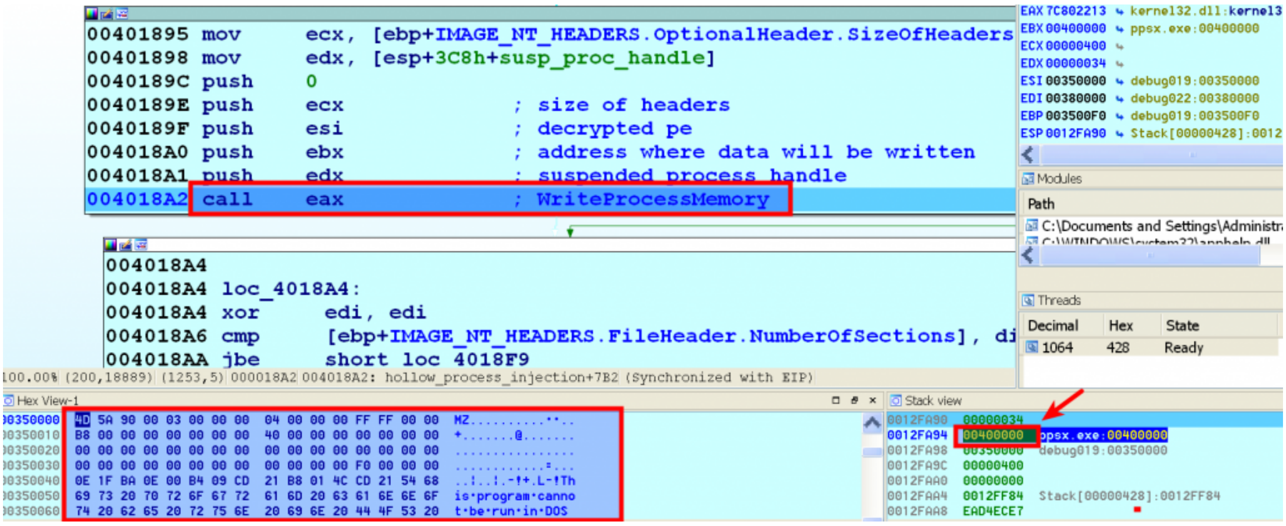




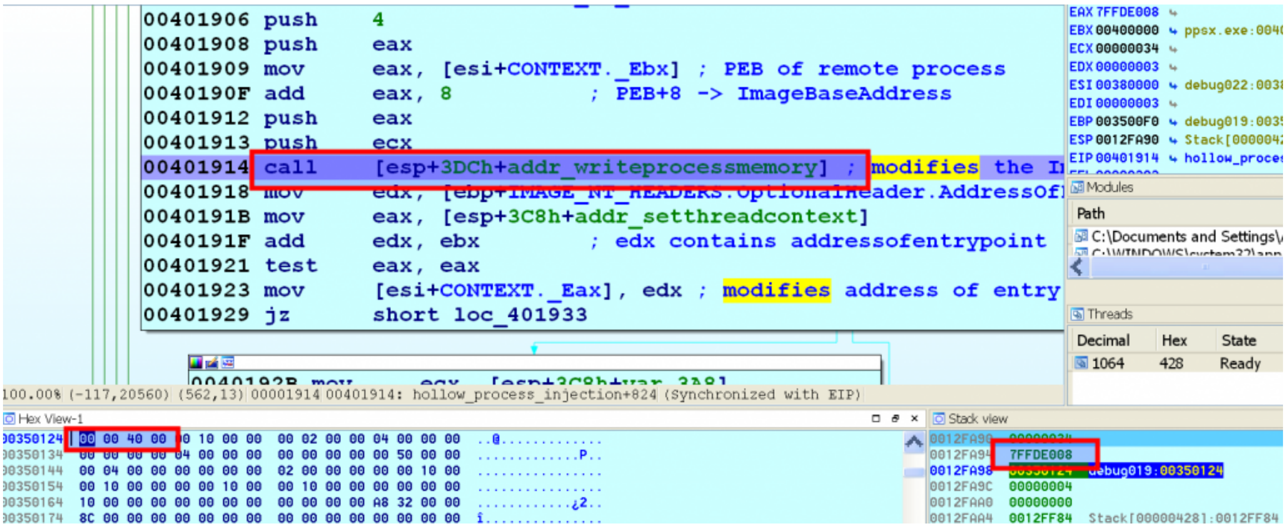

Malware then allocates a memory in the remote process (svchost.exe) at address 0x00400000.This memory is allocated with read, write and execute (RWX) permission. In this case the malware did not unmap (hollow out) the memory at the address 0x01000000 (where suspended svchost.exe was loaded).



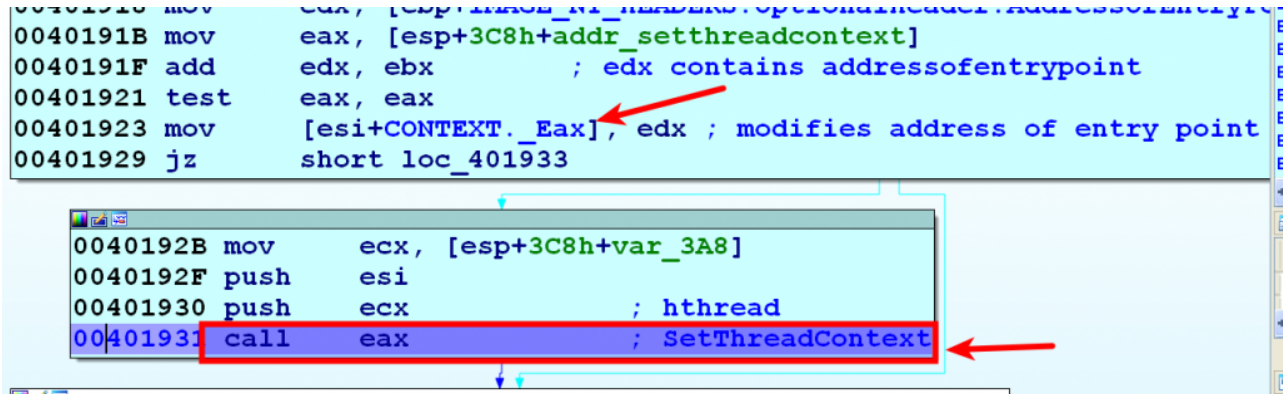

Malware then writes the PE file to inject (which it extracted from resource section) into the remote process (svchost.exe) at the allocated address 0x00400000

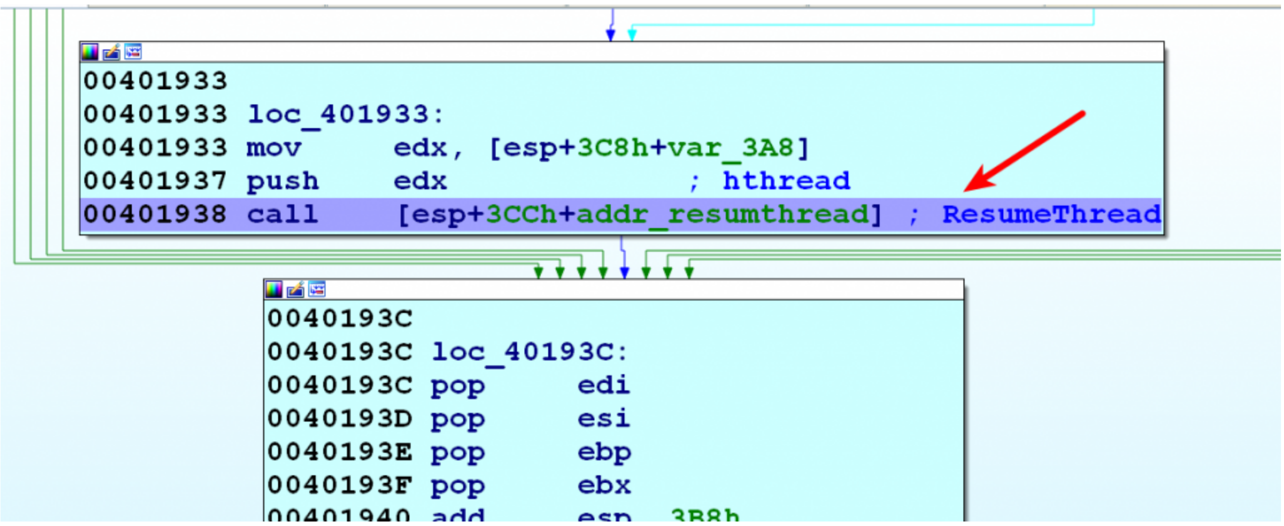



Malware then overwrites the PEB.ImageBaseAdress(PEB+8) of svchost.exe with the new address 0x00400000, at this point according to the PEB the svchost.exe is loaded at 0x00400000 whereas VAD still thinks the svchost.exe is at 0x01000000




Malware then changes the start address of the suspended thread to the address of entry point of the injected executable by setting CONTEXT._Eax and using SetThreadContext api and then it resumes the thread






This technique of not hollowing out the suspended process and modifying the PEB causes discrepancy in some of the plugins. In the screenshot below dlllist plugin (which relies on the PEB which resides in process memory) shows that the base address of svchost.exe (pid 2020) is at 0x00400000 whereas the Module listing from ldrmodules plugin which rely on kernel structures (VAD) shows the discrepancy in the base address indicating that svchost.exe is loaded at 0x01000000. Apart from the base address discrepancy notice the Inload, and InMem values are set to *False* indicating that svchost.exe could be hidden (which is not true because dlllist output shows the presence of svchost.exe). This discrepancy in the base address for the same process (pid 2020) can confuse the security analyst, the normal reaction could be to rely on the ldrmodules output because it relies on kernel structures (and also because it is giving a feeling that svchost.exe is unlinked)

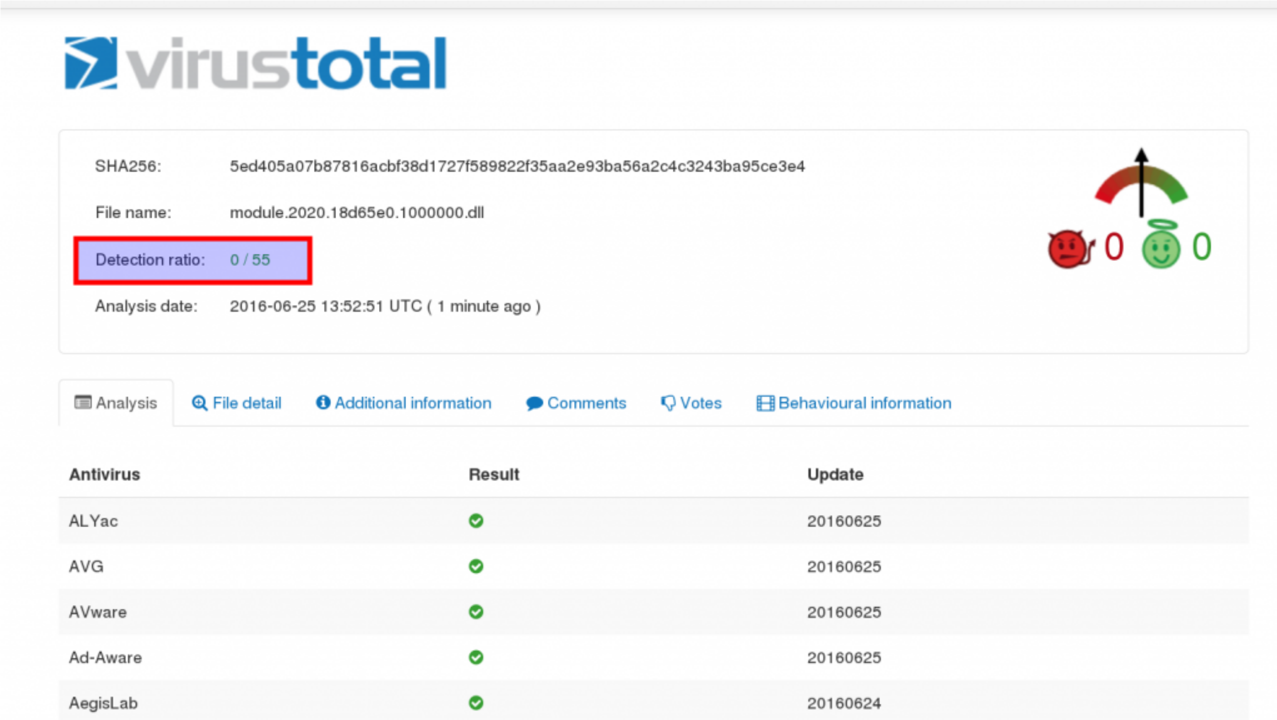
```
root@localhost:~/Volatility# python vol.py -f taidoor.vmem dlllist -p 2020
Volatility Foundation Volatility Framework 2.5
************************************************************************
svchost.exe pid:   2020
Command line : svchost.exe
Service Pack 3

Base             Size  LoadCount Path
---------- ---------- ---------- ----
0x00400000     0x5000     0xffff C:\WINDOWS\system32\svchost.exe
0x7c900000    0xaf000     0xffff C:\WINDOWS\system32\ntdll.dll
0x7c800000    0xf6000     0xffff C:\WINDOWS\system32\kernel32.dll
0x73dd0000    0xfe000     0xffff C:\WINDOWS\system32\MFC42.DLL
0x77c10000    0x58000     0xffff C:\WINDOWS\system32\msvcrt.dll
0x77f10000    0x49000     0xffff C:\WINDOWS\system32\GDI32.dll
```

```
root@localhost:~/Volatility# python vol.py -f taidoor.vmem ldrmodules -p 2020
Volatility Foundation Volatility Framework 2.5
Pid      Process              Base       InLoad InInit InMem MappedPath
-------- -------------------- ---------- ------ ------ ----- ----------
    2020 svchost.exe          0x01000000 False  False  False \WINDOWS\system32\svchost.exe
    2020 svchost.exe          0x00280000 True   True   True  \WINDOWS\system32\normaliz.dll
    2020 svchost.exe          0x78130000 True   True   True  \WINDOWS\system32\urlmon.dll
    2020 svchost.exe          0x76b40000 True   True   True  \WINDOWS\system32\winmm.dll
    2020 svchost.exe          0x77f60000 True   True   True  \WINDOWS\system32\shlwapi.dll
    2020 svchost.exe          0x77c00000 True   True   True  \WINDOWS\system32\version.dll
    2020 svchost.exe          0x5ad70000 True   True   True  \WINDOWS\system32\uxtheme.dll
    2020 svchost.exe          0x78000000 True   True   True  \WINDOWS\system32\iertutil.dll
```

Let's rely on the ldrmodules output (which comes from the kernel structure) and lets use the base address reported by ldrmodules(0x01000000). let's investigate further and see what happens. First lets focus on the svchost.exe with base address 0x01000000 (later we will focus
on the address 0x00400000). Dumping the executable using the base address (0x01000000) reported by ldrmodules confirms that it is an executable. In this case dlldump plugin was used to dump the executable because it allows you to dump any PE file using its base address.

```
root@localhost:~/Volatility# python vol.py -f taidoor.vmem dlldump -p 2020 -b 0x01000000 -
D dump/
Volatility Foundation Volatility Framework 2.5
Process(V) Name                 Module Base Module Name          Result
---------- -------------------- ----------- -------------------- ------
0x816d65e0 svchost.exe          0x001000000 UNKNOWN              OK:
module.2020.18d65e0.1000000.dll

root@localhost:~/Volatility# cd dump/

root@localhost:~/Volatility/dump# file module.2020.18d65e0.1000000.dll
module.2020.18d65e0.1000000.dll: PE32 executable (GUI) Intel 80386, for MS Windows
```

Submitted the PE File dumped using the base address 0x01000000 to VirusTotal does not show any Anti virus detections, indicating that it's not malicious.




Extracting the strings from the PE File dumped using the base address 0x01000000 does not show many strings as shown below (in fact it has very less strings, only 9 strings in the entire executable). So in this case we dumped the suspended (legitimate) svchost.exe process executable (residing at 0x01000000) not the actual malicious component.

```
root@localhost:~/Volatility/dump# strings module.2020.18d65e0.1000000.dll
!This program cannot be run in DOS mode.
5Rich
.text
`.data
.rsrc
ADVAPI32.dll
KERNEL32.dll
NTDLL.DLL
RPCRT4.dll
```

Looking for suspicious memory protections by running the malfind plugin does not shows any suspicious memory protection at the address 0x01000000 whereas it shows a suspicous memory protection at the address 0x00400000 (this is the address where malicious executable was injected, which was also reported by dlllist). This indicates that there is no malicious component at the address 0x01000000 but there is malicious component at address 0x00400000.

```
root@localhost:~/Volatility# python vol.py -f taidoor.vmem malfind -p 2020
Volatility Foundation Volatility Framework 2.5
Process: svchost.exe Pid: 2020 Address: 0x400000
Vad Tag: VadS Protection: PAGE_EXECUTE_READWRITE
Flags: CommitCharge: 5, MemCommit: 1, PrivateMemory: 1, Protection: 6

0x00400000  4d 5a 90 00 03 00 00 00 04 00 00 00 ff ff 00 00   MZ..............
0x00400010  b8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00   ........@.......
0x00400020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00400030  00 00 00 00 00 00 00 00 00 00 00 00 f0 00 00 00   ................
```

Now let's shift our focus to the svchost.exe with base address 0x00400000 (reported by PEB). Dumping the svchost.exe with base address 0x00400000 and submitting to VirusTotal confirms this to be the malicious component.

```
root@localhost:~/Volatility# python vol.py -f taidoor.vmem procdump -p 2020 -D dump/
Volatility Foundation Volatility Framework 2.5
Process(V) ImageBase  Name                 Result
---------- ---------- -------------------- ------
0x816d65e0 0x00400000 svchost.exe          OK: executable.2020.exe
```

File name: executable.2020.exe

Detection ratio: 25 / 54

Analysis date: 2016-06-25 14:41:28 UTC ( 1 minute ago )

0 0

Analysis | File detail | Additional information | Comments | Votes | Behavioural information

| Antivirus | Result | Update |
|---|---|---|
| ALYac | Generic.Malware.Fdld!.05C5C271 | 20160625 |
| AVG | Downloader.Generic14.CXN | 20160625 |
| Ad-Aware | Generic.Malware.Fdld!.05C5C271 | 20160625 |
| AhnLab-V3 | Trojan/Win32.Agent.C74807 | 20160625 |
| Antiy-AVL | Trojan[Downloader]/Win32.Rubinurd | 20160625 |
| Arcabit | Generic.Malware.Fdld!.05C5C271 | 20160625 |
| Avira (no cloud) | TR/ATRAPS.Gen4 | 20160625 |
| BitDefender | Generic.Malware.Fdld!.05C5C271 | 20160625 |

Extracting the strings from the PE file of the of the svchost.exe with base address 0x00400000 this time shows more strings and it also contains references to the C2 ip addresses, indicating that we have detected the malicious executable.

```
211.232.98.9
128.91.197.123
200.2.126.61
/%s.php?id=%06d%s&ext=%s
http://%s:%d/%s.php?id=%06d%s&ext=%s
%temp%\
ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789+/
http://%s:%d/%s.php?id=%06d%s
%c%c%c%c%c
```

As you can see malware was able to create a discrepancy causing confusion and diversion which might trick the analyst to miss the actual malicious component and also it was able to deceive the plugin which rely on kernel structures.

The hollowfind plugin can detect this discrepancy by comparing the VAD and PEB. In the below screenshot the hollowfind plugin detected the discrepancy in the base address and the memory protections, this allows one to quickly identify the malicious component. In this case even though there is discrepancy in the base address but the memory protection of PAGE_EXECUTE_READWRITE at the address 0x400000 tells you that this is the malicious component.

```
Hollowed Process Information:
        Process: svchost.exe PID: 2020 PPID: 2012
        Process Base Name(PEB): svchost.exe
        Hollow Type: Process Base Address and Memory Protection Discrepancy

VAD and PEB Comparison:
        Base Address(VAD): 0x1000000
        Process Path(VAD): \WINDOWS\system32\svchost.exe
        Vad Protection: PAGE_EXECUTE_WRITECOPY
        Vad Tag: Vad

        Base Address(PEB): 0x400000
        Process Path(PEB): C:\WINDOWS\system32\svchost.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: VadS

0x00400000  4d 5a 90 00 03 00 00 00 04 00 00 00 ff ff 00 00   MZ..............
0x00400010  b8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00   ........@.......
0x00400020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00400030  00 00 00 00 00 00 00 00 00 00 00 00 f0 00 00 00   ................
```

The hollowfind plugin also gives the similar processes and the suspicious memory regions which can help you spot the parent process discrepancy, creation time discrepancy and the injected code.

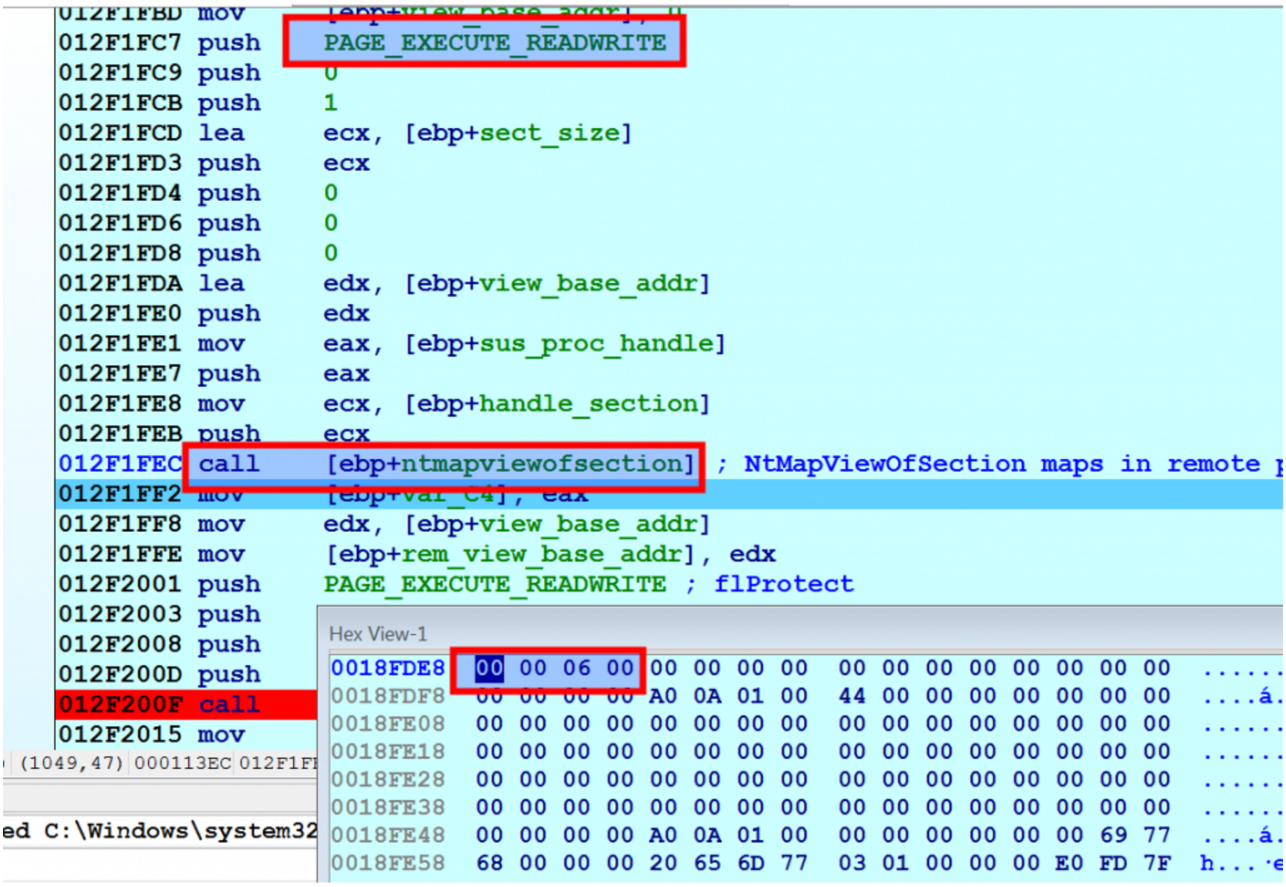
```
Similar Processes:
        svchost.exe(2020) Parent:NA(2012) Start:2016-04-09 15:36:18 UTC+0000
        svchost.exe(960) Parent:services.exe(572) Start:2016-04-03 18:44:53 UTC+0000
        svchost.exe(1064) Parent:services.exe(572) Start:2016-04-03 18:44:55 UTC+0000
        svchost.exe(832) Parent:services.exe(572) Start:2016-04-03 18:44:53 UTC+0000
        svchost.exe(748) Parent:services.exe(572) Start:2016-04-03 18:44:53 UTC+0000
        svchost.exe(892) Parent:services.exe(572) Start:2016-04-03 18:44:53 UTC+0000

Suspicious Memory Regions:
        0x400000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: VadS
--------------------------------------------------
```

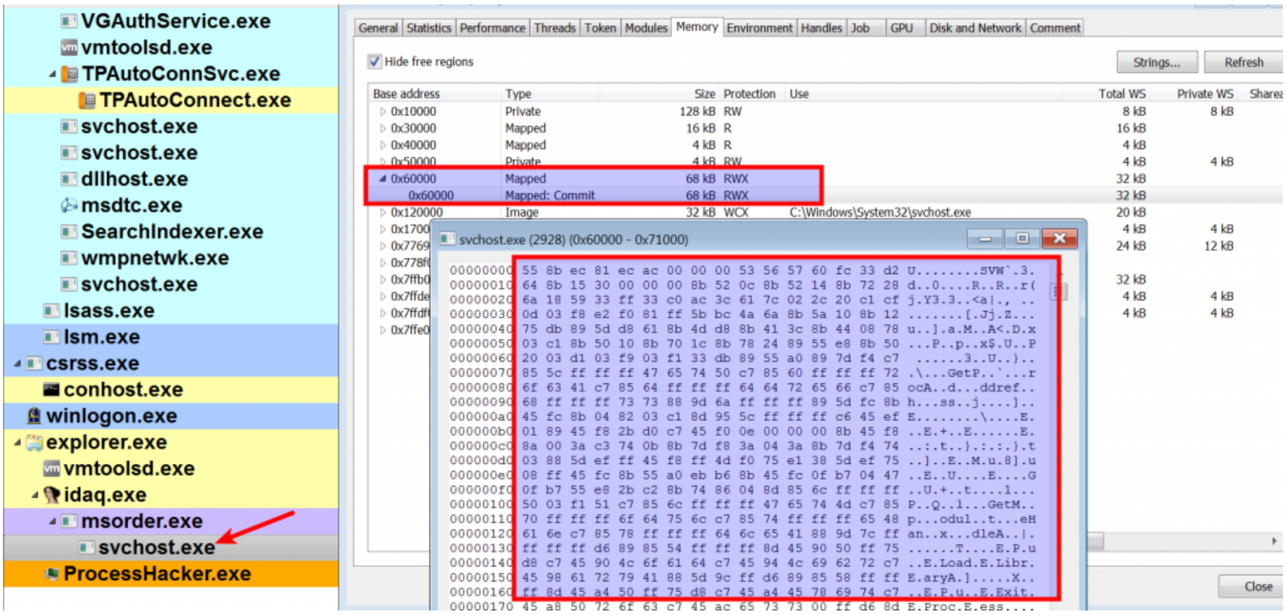
*c) Example 3:  Kuluoz's process hollowing (Address of Entry Point Modification )*

In this section let's try to understand  how Kuluoz causes diversion, by understanding the technique we can better understand how to detect and counter such malware techniques. Kuluoz creates svchost.exe process in the suspended mode which loaded svchost.exe at address 0x120000

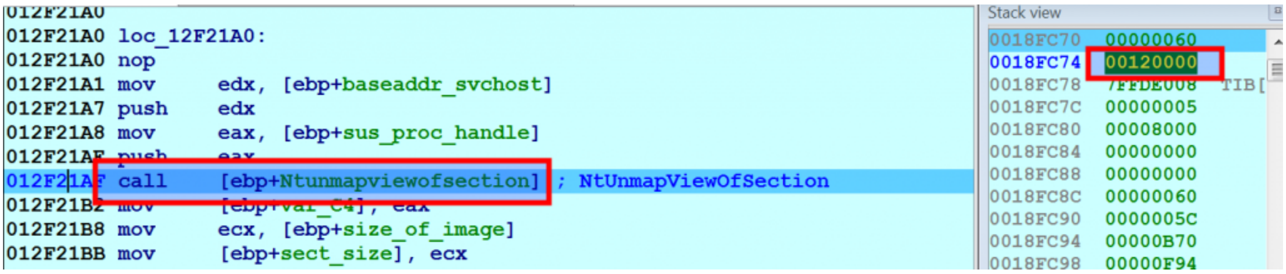
```
012F1E83 lea     edx, [ebp+ProcessInformation]
012F1E89 push    edx              ; lpProcessInformation
012F1E8A lea     eax, [ebp+StartupInfo]
012F1E8D push    eax              ; lpStartupInfo
012F1E8E push    0                ; lpCurrentDirectory
012F1E90 push    0                ; lpEnvironment
012F1E92 push    CREATE_SUSPENDED ; dwCreationFlags
012F1E94 push    0                ; bInheritHandles
012F1E96 push    0                ; lpThreadAttributes
012F1E98 push    0                ; lpProcessAttributes
012F1E9A push    offset CommandLine ; "svchost.exe"
012F1E9F push    0                ; lpApplicationName
012F1EA1 call    CreateProcessA
012F1EA7 mov     ecx, [ebp+ProcessInformation.hProcess]
012F1EAD mov     [ebp+sus_proc_handle], ecx
012F1EB3 mov     edx, [ebp+ProcessInformation.hThread]
012F1EB9 mov     [ebp+var_9C], edx
012F1EBF push    0
```

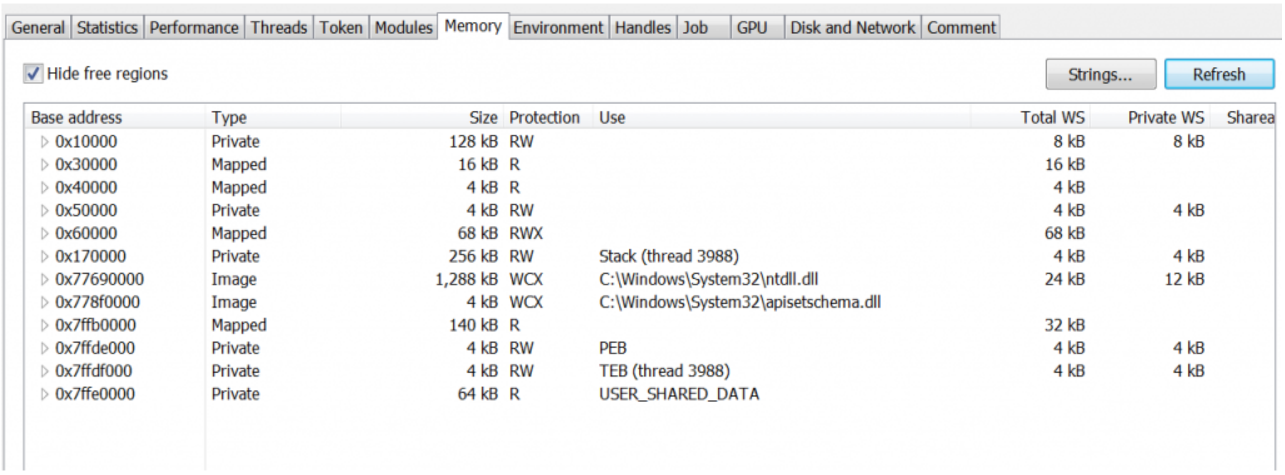
Instead of using VirtualAllocEX and WriteProcessMemory api call, kuluoz uses a different trick. It first creates a section in its own address space, copies the malicious code into the created section and then maps a view of this section with read, write, execute(rwx) protections in the remote process using NtMapViewOfSection API. As a result of this a memory is allocated in the svchost.exe process at address 0x60000 also the malicious code is copied into that address (this is the code which performs the malicious actions)



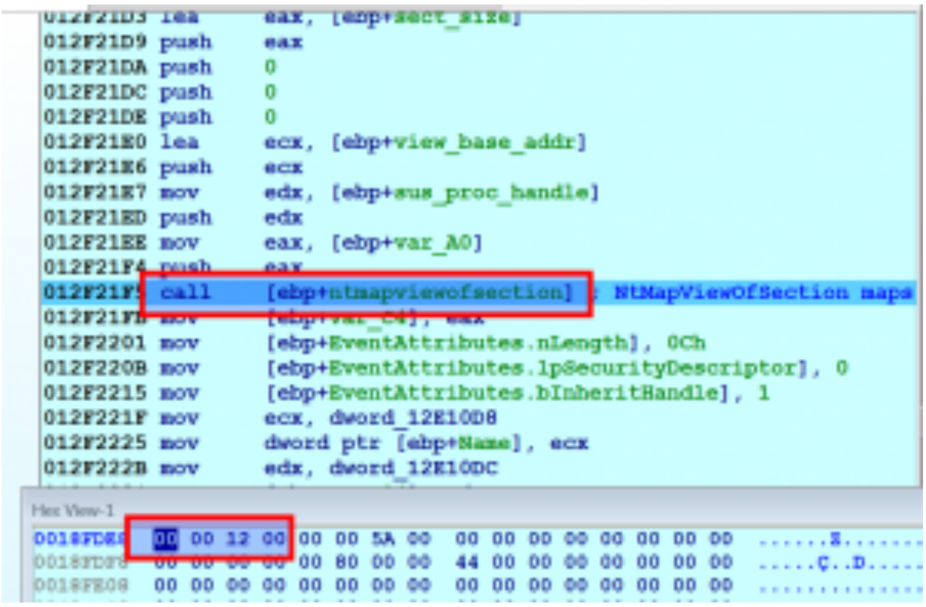




Malware then creates another section in its own address space and copies the svchost.exe content into the created section and then patches the svchost.exe at the address of entry point, it just modifies 7 bytes (i.e. 3 instructions). It then unmaps the section in the svchost.exe where its executable is loaded (i.e 0x120000), at this point the svchost.exe is hollowed out, notice in the below screenshot how the entry for svchost.exe is no longer present.

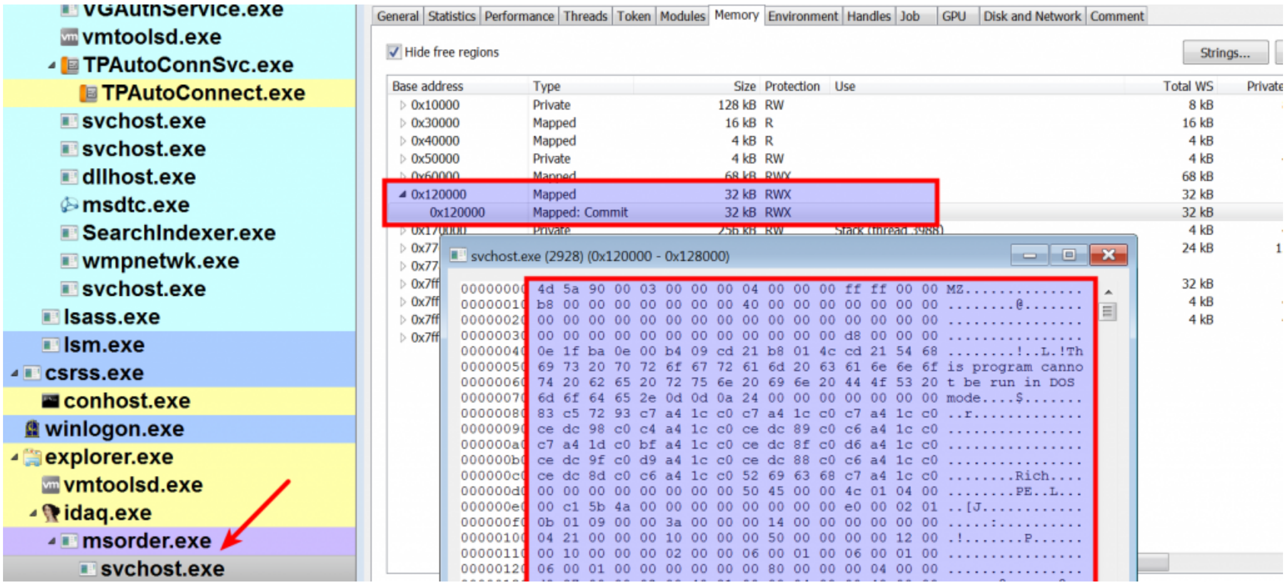



Malware then maps the section (which contains patched svchost.exe) into the remote process (svchost.exe) at the same address 0x120000 with read, write, execute (rwx) protection, also in the screenshot below the tool no longer shows the full path to the svchost.exe (this is because of hollow process technique).

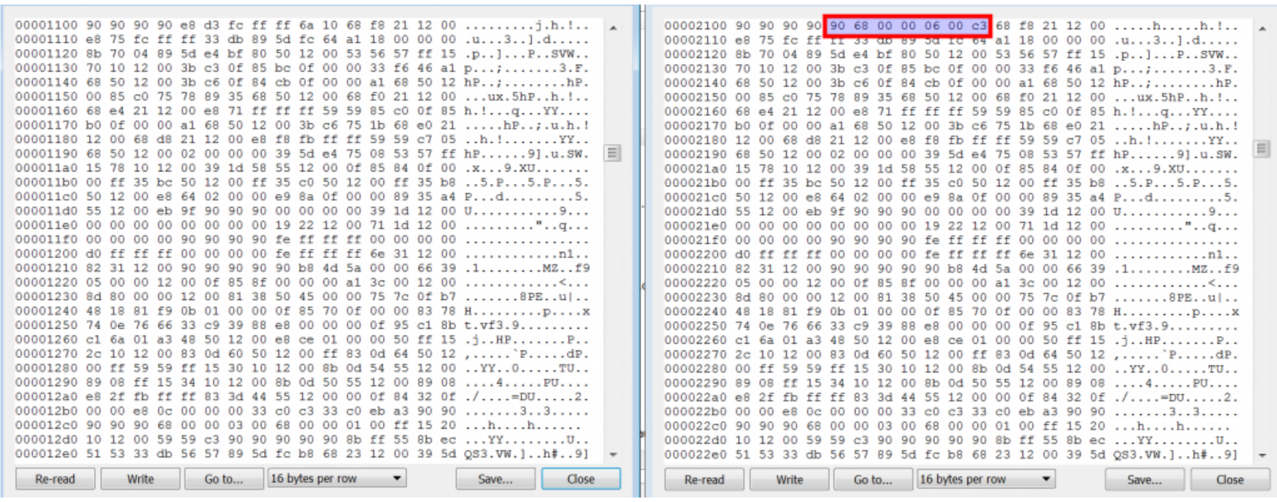


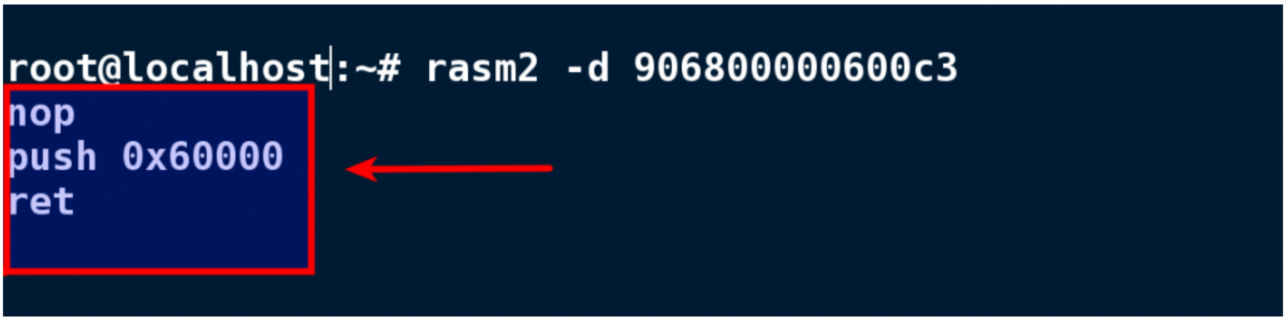

Author: Monnappa K A




Comparing the address of entry point of the legitimate svchost.exe (on the left) and the patched svchost.exe (on the right) process shows the difference in the 7 bytes at the address of entry point, whereas all other bytes are same. These 7 bytes turn out to be 3 instructions which

will redirect the control flow to the malicious code that was injected before (at address 0x60000)



Malware then resumes the suspended thread as result of that malware executes the code at the address of entry point of svchost.exe which will redirect the control to the malicious code (at address 0x60000) which performs malicious actions.

Let's look at a memory image infected with Kulouz, the technique mentioned above attempts to creates confusion and diversion by creating discrepancy in the dlllist and ldrmodules making it look like the suspect svchost.exe process is malicious. In this case, even though the suspect svchost.exe process is patched but it is not completely malicious, the malicious code is at a different location. In the screenshot below the notice the svchost.exe process path discrepancy and the base address is 0x00a00000.

```
root@localhost:~/Volatility# python vol.py -f kuluoz.vmem --profile=Win7SP0x86 dlllist -p
3056
Volatility Foundation Volatility Framework 2.5
************************************************************************
svchost.exe pid:   3056
Command line : svchost.exe


Base             Size  LoadCount Path
0x00a00000     0x8000     0xffff C:\Windows\system32\svchost.exe
0x773c0000    0x13c000    0xffff C:\Windows\SYSTEM32\ntdll.dll
0x75900000    0xd4000     0xffff C:\Windows\system32\kernel32.dll
0x757c0000    0x4a000     0xffff C:\Windows\system32\KERNELBASE.dll
0x75e30000    0xac000     0xffff C:\Windows\system32\msvcrt.dll
0x758e0000    0x19000     0xffff C:\Windows\SYSTEM32\sechost.dll
0x75b20000    0xa1000     0xffff C:\Windows\system32\RPCRT4.dll
```

```
root@localhost:~/Volatility# python vol.py -f kuluoz.vmem --profile=Win7SP0x86 ldrmodules -
p 3056 | grep -i a00000
Volatility Foundation Volatility Framework 2.5
    3056 svchost.exe          0x00a00000 True   False  True
```

Running malfind plugin shows the suspicious memory protection at the address(0x00a00000) where svchost.exe is loaded indicating that svchost.exe was not normally loaded. If you just dump the suspect svchost.exe process and analyze you will be spending time analyzing the legitimate svchost.exe (execpt the 3 instructions which are patched, the rest all are legitimate code). It becomes important to detect the actual malicious code.

```
Process: svchost.exe Pid: 3056 Address: 0xa00000
Vad Tag: Vad  Protection: PAGE_EXECUTE_READWRITE
Flags: Protection: 6

0x00a00000  4d 5a 90 00 03 00 00 00 04 00 00 00 ff ff 00 00   MZ..............
0x00a00010  b8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00   ........@.......
0x00a00020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00a00030  00 00 00 00 00 00 00 00 00 00 00 00 d8 00 00 00   ................

0x00a00000 4d               DEC EBP
0x00a00001 5a               POP EDX
0x00a00002 90               NOP
```

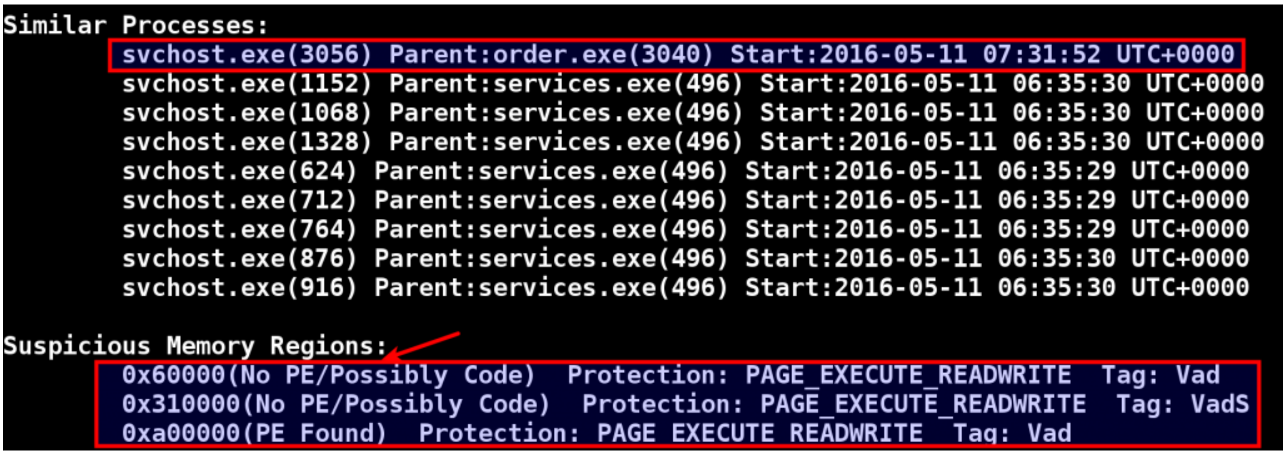
The malfind also detected another address 0x60000, even though it doesn't contain executable but looking at the disassembly it looks like it contains code (where the svchost.exe process execution will be redirected).

```
Volatility Foundation Volatility Framework 2.5
Process: svchost.exe Pid: 3056 Address: 0x60000
Vad Tag: Vad  Protection: PAGE_EXECUTE_READWRITE
Flags: Protection: 6

0x00060000  55 8b ec 81 ec ac 00 00 00 53 56 57 60 fc 33 d2   U........SVW`.3.
0x00060010  64 8b 15 30 00 00 00 8b 52 0c 8b 52 14 8b 72 28   d..0....R..R..r(
0x00060020  6a 18 59 33 ff 33 c0 ac 3c 61 7c 02 2c 20 c1 cf   j.Y3.3..<a|.,...
0x00060030  0d 03 f8 e2 f0 81 ff 5b bc 4a 6a 8b 5a 10 8b 12   .......[.Jj.Z...

0x00060000 55                PUSH EBP
0x00060001 8bec              MOV EBP, ESP
0x00060003 81ecac000000      SUB ESP, 0xac
0x00060009 53                PUSH EBX
0x0006000a 56                PUSH ESI
```

Even though malfind is very useful and helped in detecting the suspicious memory regions it is still possible to miss the actual malicious code injected at address 0x60000 (unless the security analyst is aware of this technique). Hollowfind plugin helps in detecting this type of process hollow technique and also it disassembles the address of entry point which can help in detecting such redirection attack technique. In the below screenshot hollowfind plugin detected the invalid exe memory protection and the process path discrepancy, in addition to that the plugin also shows the disassembly of the address of entrypoint, which shows the redirection to the address 0x60000 (using the push and ret instruction)

```
Hollowed Process Information:
        Process: svchost.exe PID: 3056 PPID: 3040
        Process Base Name(PEB): svchost.exe
        Hollow Type: Invalid EXE Memory Protection and Process Path Discrepancy

VAD and PEB Comparison:
        Base Address(VAD): 0xa00000
        Process Path(VAD):
        Vad Protection: PAGE_EXECUTE_READWRITE
        Vad Tag: Vad

        Base Address(PEB): 0xa00000
        Process Path(PEB): C:\Windows\system32\svchost.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: Vad

Disassembly(Entry Point):
        0x00a02104 90                NOP
        0x00a02105 6800000600        PUSH DWORD 0x60000
        0x00a0210a c3                RET
        0x00a0210b 68f821a000        PUSH DWORD 0xa021f8
        0x00a02110 e875fcffff        CALL 0xa01d8a
```

The plugin also displays similar processes and the suspcious memory regions. In the below screenshot the suspect svchost.exe (pid 3056) process was started by order.exe(pid 3040) and also shows that the address 0x60000 contains code.



```
Similar Processes:
        svchost.exe(3056) Parent:order.exe(3040) Start:2016-05-11 07:31:52 UTC+0000
        svchost.exe(1152) Parent:services.exe(496) Start:2016-05-11 06:35:30 UTC+0000
        svchost.exe(1068) Parent:services.exe(496) Start:2016-05-11 06:35:30 UTC+0000
        svchost.exe(1328) Parent:services.exe(496) Start:2016-05-11 06:35:30 UTC+0000
        svchost.exe(624) Parent:services.exe(496) Start:2016-05-11 06:35:29 UTC+0000
        svchost.exe(712) Parent:services.exe(496) Start:2016-05-11 06:35:29 UTC+0000
        svchost.exe(764) Parent:services.exe(496) Start:2016-05-11 06:35:29 UTC+0000
        svchost.exe(876) Parent:services.exe(496) Start:2016-05-11 06:35:30 UTC+0000
        svchost.exe(916) Parent:services.exe(496) Start:2016-05-11 06:35:30 UTC+0000

Suspicious Memory Regions:
        0x60000(No PE/Possibly Code)  Protection: PAGE_EXECUTE_READWRITE  Tag: Vad
        0x310000(No PE/Possibly Code)  Protection: PAGE_EXECUTE_READWRITE  Tag: VadS
        0xa00000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: Vad
```

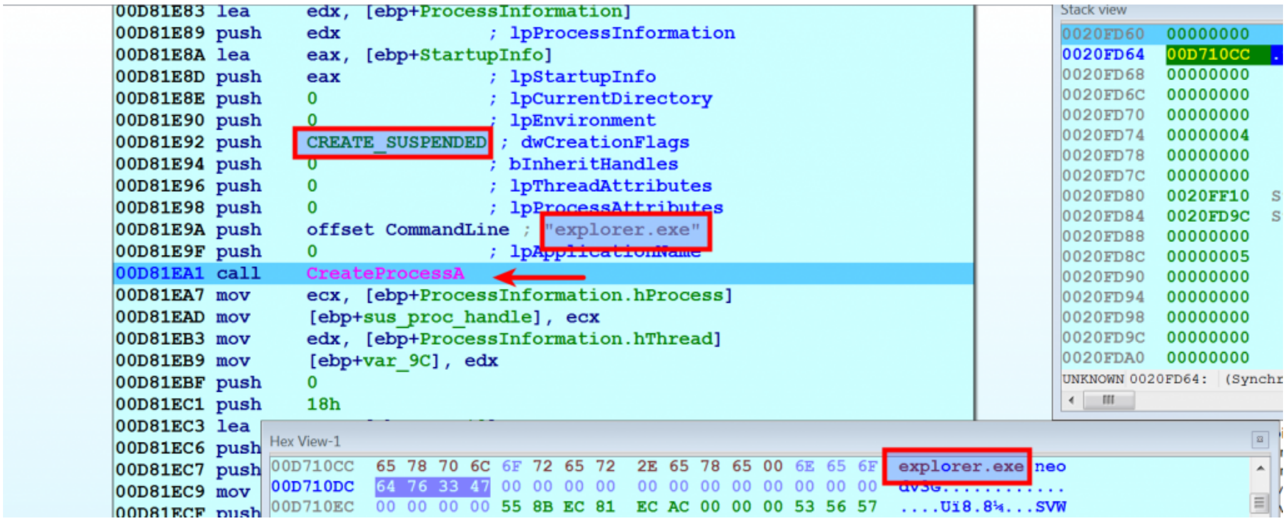
***d) Example 4: Modifying Kuluoz to be more Evasive (Changing the Memory Protection to PAGE_EXECUTE_WRITECOPY)***

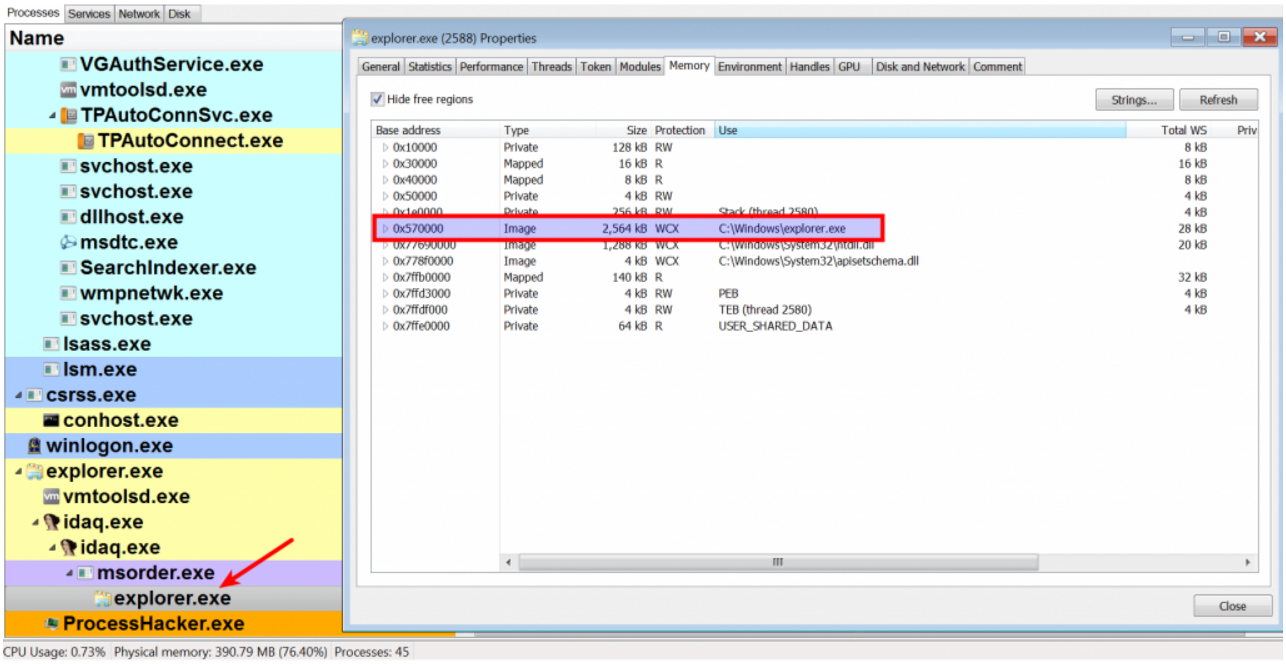
From the previous example, we saw that Kuluoz was able to divert the analysis but its malicious code was detected because of the suspicious memory protections (PAGE_EXECUTE_READWRITE) if there is a way to change that protection at the same time manage to execute code it can bypass the malfind plugin thereby making it even more stealthier. To test this I modified Kuluoz code to do two things

- Instead of creating svchost.exe in the suspended mode, I created explorer.exe in the suspended mode, the reason is because explorer.exe is normally started by userinit.exe and it terminates itself which means userinit.exe will not be in the process listing (and will not show as parent for explorer.exe). So if malware starts explorer.exe, injects code and terminates itself, it can become hard to tell based on the parent process.
- As mentioned in the analysis of Kuluoz, it maps memory section containing malicious code into the remote process using NtMapViewOfSection with read, write, execute(RWX) permission but if we can map that memory section containing malicious code with PAGE_EXECUTE_WRITECOPY protection we should be able to bypass the malfind plugin but the problem is Microsoft does not support this flag PAGE_EXEXCUTE_WRITECOPY in the memory allocation API's like VirtualAllocEx as per the documentation(as shown in the screenshot). It turns out that we can set the PAGE_EXECUTE_WRITECOPY protection by using the native api like NtMapViewOfSection, so I modified the Kuluoz code to do that

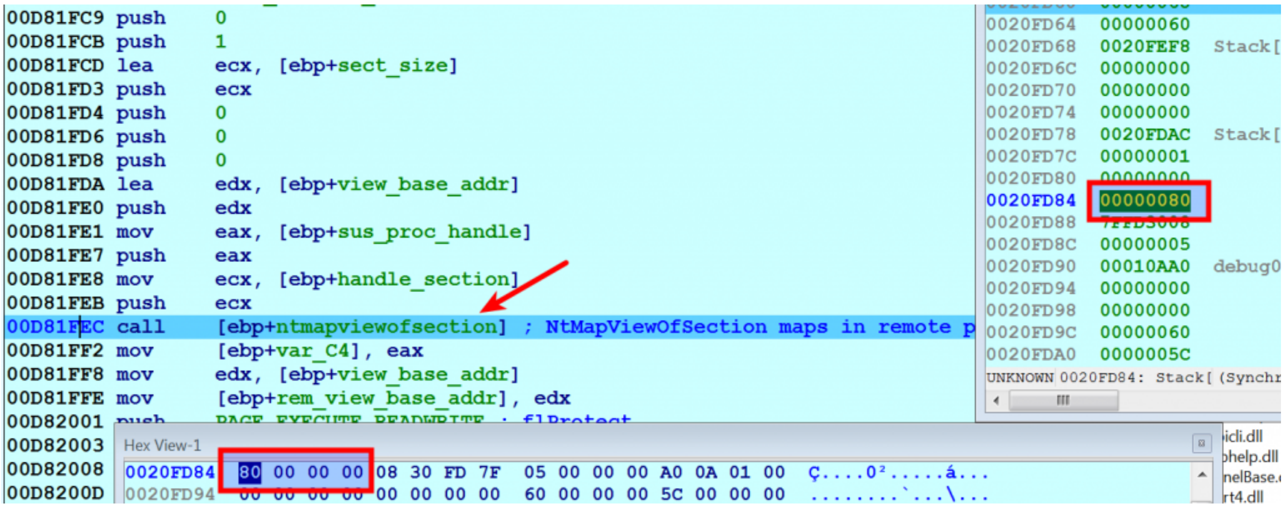

Below are details of the modification done to kuluoz to make it more evasive.

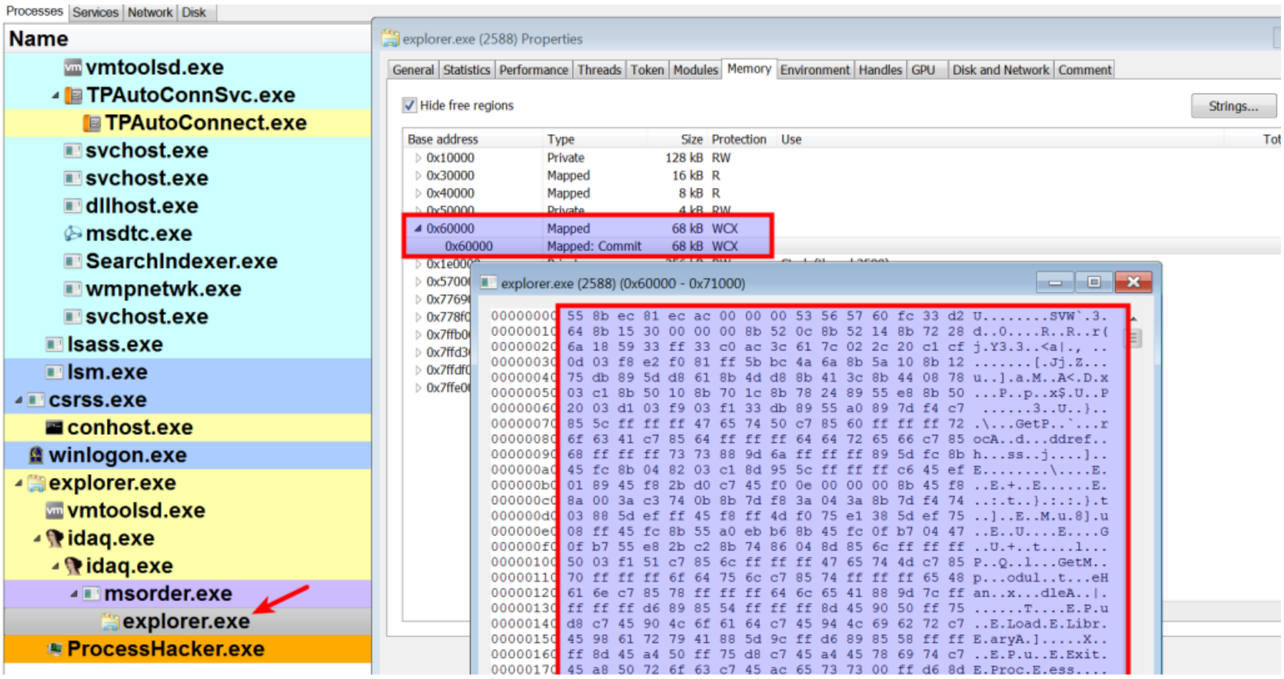
Kuluoz malwares sample was modified to create explorer.exe in the suspended mode instead of svchost.exe. The explorer.exe was loaded at base address 0x570000 with the PAGE_EXECUTE_WRITECOPY(WCX) protection (because at this point it is normally loaded)



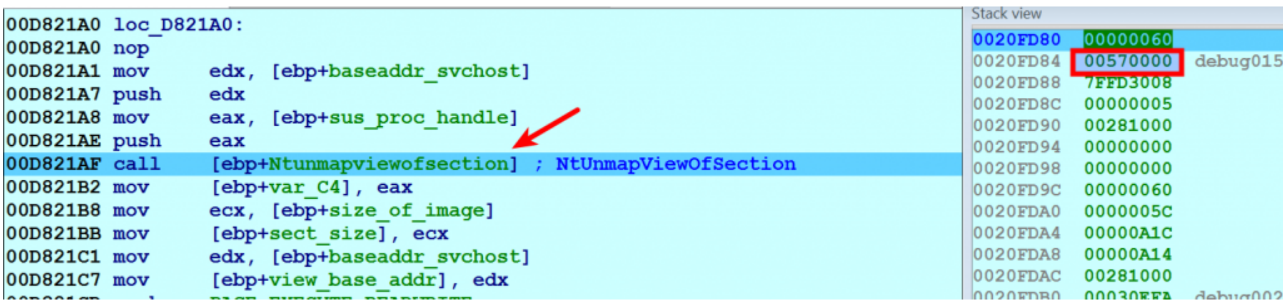




Malware was then allowed to create a section in its own address space, after which it copies the malicious code into the created section and then maps a view of this section in the remote process, at this point instead of allowing the malware to map the section with read, write, execute(RWX) protection (which is constant 0x40), it was modified to map the section with write copy (WCX) protection by changing the constant value to 0x80. As a result of this memory was allocated in the explorer.exe process at address 0x60000 also the malicious code was copied in that address (this is the code which performs the malicious actions). Notice in the below screenshot the memory protection of the allocated memory is set to write copy (WCX) instead of read, write, execute (RWX)

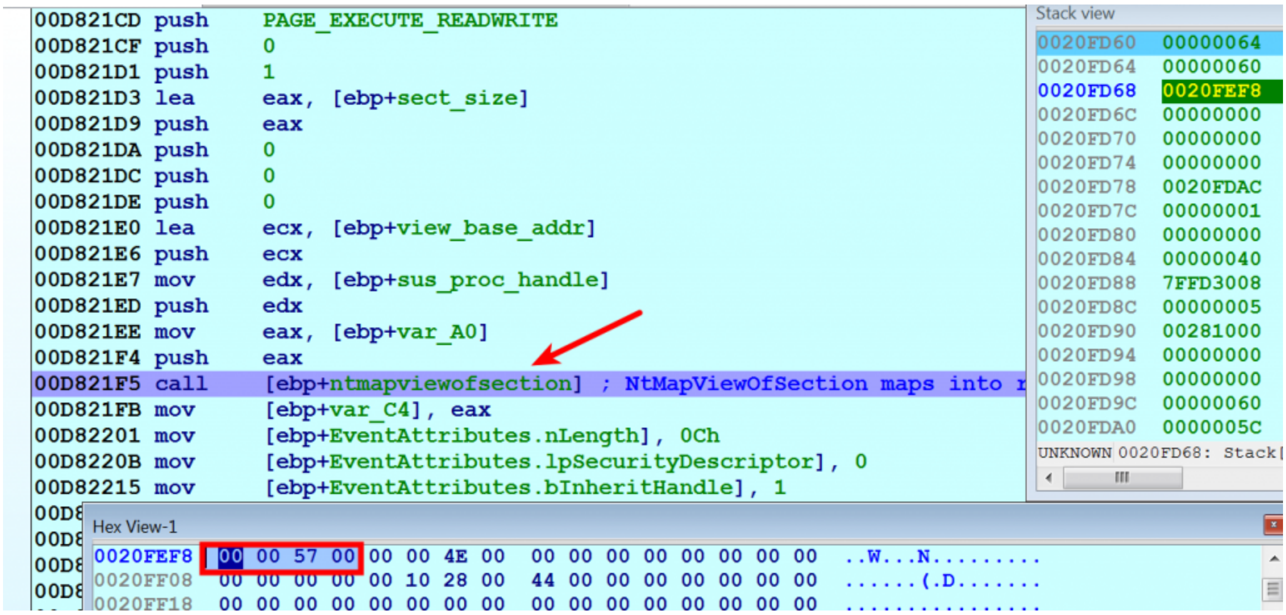


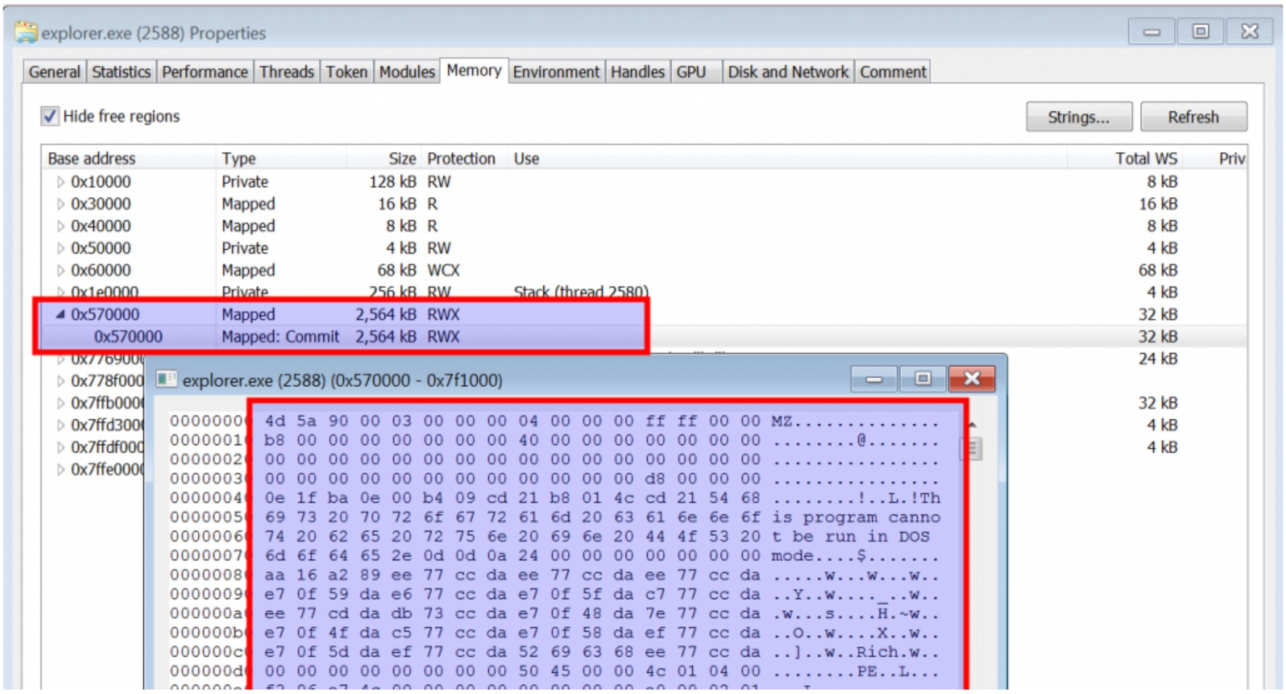




Malware then creates another section in its own address space and copies the explorer.exe content into the created section and then patches the explorer.exe at the address of entry point, it just modifies 7 bytes (i.e. 3 instructions). It then unmaps the section in the explorer.exe where its executable is loaded (i.e. 0x570000), at this point the explorer.exe is hollowed out



Malware then maps the section (which contains patched explorer.exe) into the remote process (explorer.exe) at the same address 0x570000 with read, write, execute (RWX) protection. The below screenshot shows the mapped memory in the explorer.exe process, also notice the tool no longer shows the full path to the explorer.exe (this is because of hollow process technique).




Malware then resumes the suspended thread as result of that malware executes the code at the address of entry point of explorer.exe which will redirect the control to the malicious code (at address 0x60000) which performs malicious actions and also notice after resuming the thread how the patched explorer.exe is running on the system.

Processes | Services | Network | Disk

| Name | PID | CPU | I/O total ... | Private bytes | User name |
|---|---|---|---|---|---|
| audiodg.exe | 1516 | | | 14.64 MB | ...\LOCAL SER\ |
| conhost.exe | 2688 | | | 612 kB | WIN-T9...\test |
| csrss.exe | 356 | | | 1.25 MB | NT ...\SYSTEM |
| csrss.exe | 404 | 0.12 | | 17.36 MB | NT ...\SYSTEM |
| dllhost.exe | 2064 | | | 2.71 MB | NT ...\SYSTEM |
| dwm.exe | 1336 | | | 1.33 MB | WIN-T9...\test |
| explorer.exe | 1348 | 0.03 | | 27.29 MB | WIN-T9...\test |
| explorer.exe | 2588 | | | 14.43 MB | WIN-T9...\test |
| Interrupts | | 0.75 | | 0 | |
| IpOverUsbSvc.exe | 1732 | | | 7.42 MB | NT ...\SYSTEM |
| lsass.exe | 504 | 0.01 | | 2.85 MB | NT ...\SYSTEM |
| lsm.exe | 512 | | | 1.19 MB | NT ...\SYSTEM |
| msdtc.exe | 2240 | | | 2.42 MB | ...\NETWORK S |

Now to check if the modified memory protection of the memory (where the malicious code is injected) can bypass the malfind plugin, memory image was taken and memory forensics was carried out

The screenshot below shows two instances of explorer.exe running on the system and also notice both explorer.exe parent process could not be determined because they are terminated, so this makes it slightly hard to detect based on the parent process. There are other things that can be used to detect, like looking for multiple instances of explorer.exe running on the system and the creation time of the process.

```
root@localhost:~/Volatility# python vol.py -f kuluoz_mod.vmem --profile=Win7SP0x86 pslist
| grep -i explorer
Volatility Foundation Volatility Framework 2.5
0x877e7230 explorer.exe          1348   1328     24      723      1      0 2016-06-24
13:28:21 UTC+0000
0x8256e3d8 explorer.exe          2588    160      6      209      1      0 2016-06-26
10:04:34 UTC+0000

root@localhost:~/Volatility# python vol.py -f kuluoz_mod.vmem --profile=Win7SP0x86 pslist -
p 24
Volatility Foundation Volatility Framework 2.5
ERROR   : volatility.debug    : Cannot find PID 24. If its terminated or unlinked, use
psscan and then supply --offset=OFFSET

root@localhost:~/Volatility# python vol.py -f kuluoz_mod.vmem --profile=Win7SP0x86 pslist -
p 6
Volatility Foundation Volatility Framework 2.5
ERROR   : volatility.debug    : Cannot find PID 6. If its terminated or unlinked, use
psscan and then supply --offset=OFFSET
```

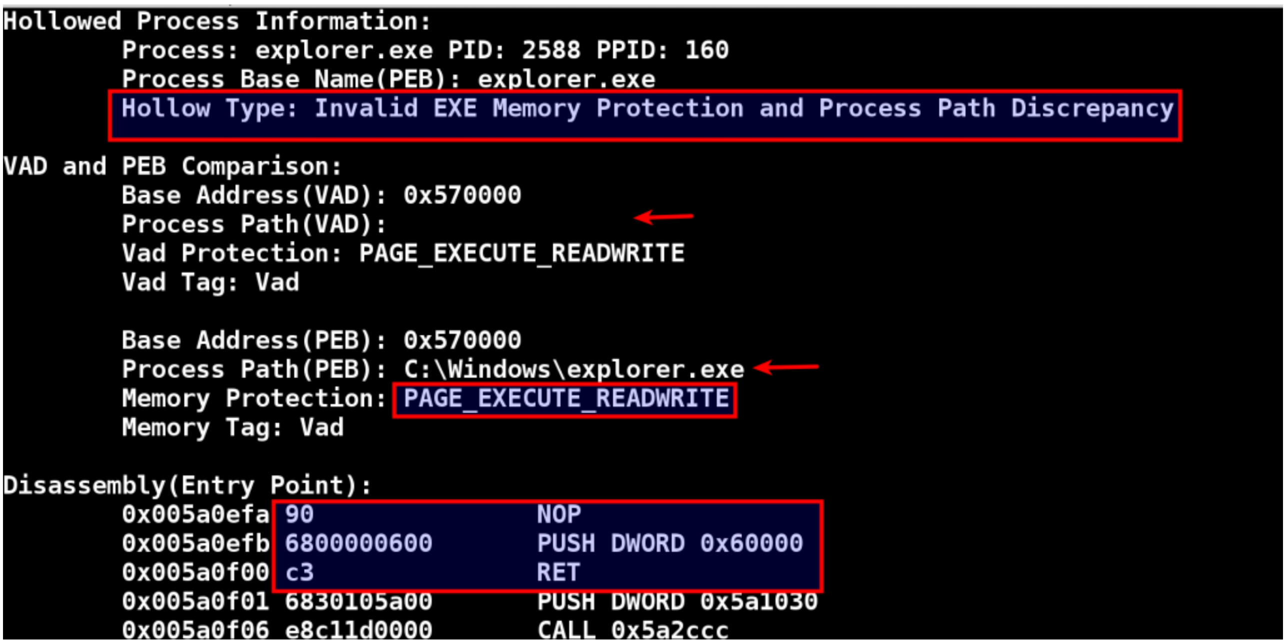
Running the dlllist plugin (which relies on PEB) shows explorer.exe is loaded at base address 0x570000. Whereas using ldrmodules (which relies on VAD structure) and grepping for that base address does not show the full path to the explorer.exe. This kind of behaviour occurs when the legitimate process executable memory is deallocated and then the memory is re-allocated at the same address, at this point comparing the results from the dlllist plugin (PEB) and ldrmodules plugin (VAD) is giving an indication of hollow process injection. But if you dump the explorer.exe from the memory and analyse it will not give you much because that is not performing the malicious actions, it is just redirecting, and this is a diversion tactic

```
root@localhost:~/Volatility# python vol.py -f kuluoz_mod.vmem --profile=Win7SP0x86 dlllist -p 2588
Volatility Foundation Volatility Framework 2.5
************************************************************************
explorer.exe pid:   2588
Command line : explorer.exe
Service Pack 1

Base             Size  LoadCount Path
---------- ---------- ---------- ----
0x00570000   0x281000     0xffff C:\Windows\explorer.exe
0x77690000   0x142000     0xffff C:\Windows\SYSTEM32\ntdll.dll
0x775b0000    0xd5000     0xffff C:\Windows\system32\kernel32.dll
0x75850000    0x4b000     0xffff C:\Windows\system32\KERNELBASE.dll
0x77380000    0xa1000     0xffff C:\Windows\system32\ADVAPI32.dll
0x77430000    0xac000     0xffff C:\Windows\system32\msvcrt.dll
0x77860000    0x19000     0xffff C:\Windows\SYSTEM32\sechost.dll
0x76e50000    0xa2000     0xffff C:\Windows\system32\RPCRT4.dll

root@localhost:~/Volatility# python vol.py -f kuluoz_mod.vmem --profile=Win7SP0x86 ldrmodules -p 2588 | grep -i 0x00570000
Volatility Foundation Volatility Framework 2.5
    2588 explorer.exe          0x00570000 True   False  True
```

Running the malfind plugin only detects the suspicious memory allocation at 0x570000 (where explorer.exe is loaded), this time it did not detect the address 0x60000 (where the malicious code is residing), this is because the memory protection was changed to PAGE_EXECUTE_WRITECOPY and malfind does not look for this memory protection. Again, this diversion tactic can lead an analyst to dump the explorer.exe and analyse it (but they will be missing on the actual malicious component located at 0x60000 and might be wasting time analyzing the explorer.exe)

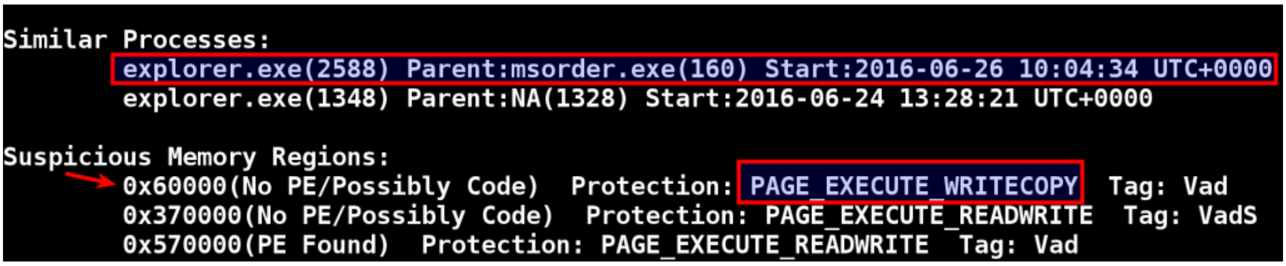
```
Process: explorer.exe Pid: 2588 Address: 0x570000
Vad Tag: Vad  Protection: PAGE_EXECUTE_READWRITE
Flags: Protection: 6

0x00570000  4d 5a 90 00 03 00 00 00 04 00 00 00 ff ff 00 00   MZ..............
0x00570010  b8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00   ........@.......
0x00570020  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00570030  00 00 00 00 00 00 00 00 00 00 00 00 d8 00 00 00   ................

0x00570000 4d               DEC EBP
0x00570001 5a               POP EDX
0x00570002 90               NOP
0x00570003 0003             ADD [EBX], AL
0x00570005 0000             ADD [EAX], AL
0x00570007 000400           ADD [EAX+EAX], AL
0x0057000a 0000             ADD [EAX], AL
```

The hollowfind plugin is designed to detect this type of evasion, the hollowfind plugin detects suspicious memory protections like malfind plugin apart from that it also detects any memory regions which does not contain PE file but has a memory protection of PAGE_EXECUTE_WRITECOPY.  In the below screenshot the hollowfind plugin reports the hollowed process explorer.exe (pid 2588) and it also detected the redirection to the address 0x60000



```
Hollowed Process Information:
        Process: explorer.exe PID: 2588 PPID: 160
        Process Base Name(PEB): explorer.exe
        Hollow Type: Invalid EXE Memory Protection and Process Path Discrepancy

VAD and PEB Comparison:
        Base Address(VAD): 0x570000
        Process Path(VAD):
        Vad Protection: PAGE_EXECUTE_READWRITE
        Vad Tag: Vad

        Base Address(PEB): 0x570000
        Process Path(PEB): C:\Windows\explorer.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: Vad

Disassembly(Entry Point):
        0x005a0efa 90               NOP
        0x005a0efb 6800000600       PUSH DWORD 0x60000
        0x005a0f00 c3               RET
        0x005a0f01 6830105a00       PUSH DWORD 0x5a1030
        0x005a0f06 e8c11d0000       CALL 0x5a2ccc
```

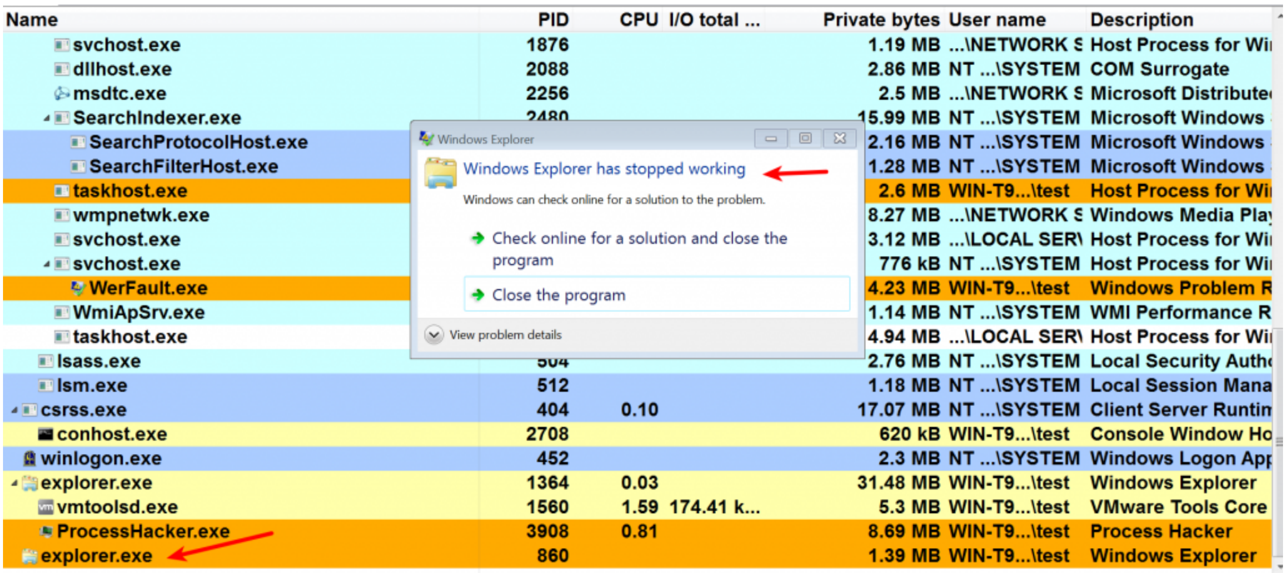
In the below screenshot the hollowfind plugin also detected the similar processes and the suspicious memory regions, and it also detected the address 0x60000 as suspicous because this address does not contain a PE file but still has a memory protection of PAGE_EXECUTE_WRITECOPY.



```
Similar Processes:
        explorer.exe(2588) Parent:msorder.exe(160) Start:2016-06-26 10:04:34 UTC+0000
        explorer.exe(1348) Parent:NA(1328) Start:2016-06-24 13:28:21 UTC+0000

Suspicious Memory Regions:
        0x60000(No PE/Possibly Code)  Protection: PAGE_EXECUTE_WRITECOPY  Tag: Vad
        0x370000(No PE/Possibly Code)  Protection: PAGE_EXECUTE_READWRITE  Tag: VadS
        0x570000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: Vad
```

### *e) Example 5: Kronos Process Hollowing (Changing the Memory Protection to PAGE_EXECUTE_WRITECOPY)*

Few days back I came across a malware sample called Kronos which performs similar redirection mentioned above, this sample hollows out the explorer.exe process, patches the address of entry point and attempts to redirect execution flow inside an executable which was injected with PAGE_EXECUTE_WRITECOPY protections. While testing this executable the explorer.exe crashed as shown below, but still the memory image was taken for further analysis.




Running the hollowfind plugin on the kronos infected memory image detected the suspicious process and the redirection attempt to the address 0x6f60b at the address of entry point

```
root@kratos:~/Volatility# python vol.py -f kronos.vmem --profile=Win7SP0x86 hollowf

Volatility Foundation Volatility Framework 2.5
Hollowed Process Information:
        Process: explorer.exe PID: 860 PPID: 3412
        Process Base Name(PEB): explorer.exe
        Hollow Type: Invalid EXE Memory Protection and Process Path Discrepancy

VAD and PEB Comparison:
        Base Address(VAD): 0x820000
        Process Path(VAD):
        Vad Protection: PAGE_EXECUTE_READWRITE
        Vad Tag: Vad

        Base Address(PEB): 0x820000
        Process Path(PEB): C:\Windows\explorer.exe
        Memory Protection: PAGE_EXECUTE_READWRITE
        Memory Tag: Vad

Disassembly(Entry Point):
        0x00850efa 680bf60600          PUSH DWORD 0x6f60b
        0x00850eff c3                  RET
        0x00850f00 006830              ADD [EAX+0x30], CH
```

The plugin also detects suspicious memory region where a PE File was found with PAGE_EXECUTE_WRITECOPY protection but with no memory mapped file.

```
Similar Processes:
        explorer.exe(860) Parent:NA(3412) Start:2016-09-21 08:00:26 UTC+0000
        explorer.exe(1364) Parent:NA(1324) Start:2016-07-26 18:21:32 UTC+0000

Suspicious Memory Regions:
        0x60000(PE No Mapped File)  Protection: PAGE_EXECUTE_WRITECOPY  Tag: Vad
        0x820000(PE Found)  Protection: PAGE_EXECUTE_READWRITE  Tag: Vad
```

Inspite of executing Kronos malware multiple times it crashed explorer.exe, so it's not clear if the malware will successfully execute if an executable is injected and its protection is modified to PAGE_EXECUTE_WRITECOPY (or there could be a workaround which malware authors are aware, I'm not sure). I tried multiple times but if an executable is injected with PAGE_EXECUTE_WRITECOPY the executable seems to crash, but during the test (as in case of Kuluoz sample) it was detected if a code is injected and the memory protection is modified to PAGE_EXECUTE_WRITECOPY the code executes without any problems. In any case if malware attempts to perform any of these evasive techniques the hollowfind plugin should be able to successfully detect these attacks.

## Conclusion

Process Hollowing is a code injection technique which was used to trick the live forensic tools and to blend in with legitimate processes. It looks like the attackers are now using different types of process hollowing not just to blend in but also to remain stealthy, bypass detection, confuse and divert the forensic analysis tools and the security analysts. From an incident response perspective, it becomes important to understand the working of such stealth techniques, understanding these techniques will help us in better countering and responding to such malware attacks. The hollowfind plugin was written to detect such techniques, the plugin detects such attacks by finding discrepancy in the VAD and PEB, it also disassembles the address of entry point to detect any redirection attempts and also reports any suspicious memory regions which should help in detecting any injected code.

Hollowfind Plugin Download Link: https://github.com/monnappa22/HollowFind

## References


*1) https://github.com/monnappa22/HollowFind*

*2) https://cysinfo.com/7th-meetup-reversing-and-investigating-malware-evasive-tactics-hollow-process-injection/*

*3) http://mnin.blogspot.in/2011/06/examining-stuxnets-footprint-in-memory.html*

*4) https://www.trustwave.com/Resources/SpiderLabs-Blog/Analyzing-Malware-Hollow-Processes/*


## Author Bio

**Monnappa K A** works with Cisco Systems as information security investigator focusing on threat intelligence, investigation of advanced cyber attacks, researching on cyber espionage and APT attacks. He is author of Limon sandbox (for analyzing Linux malwares) and winner of Volatility plugin contest 2016. He is the co-founder of the cyber security research community "Cysinfo" (https://www.cysinfo.com). His fields of interest include malware analysis, reverse engineering, memory forensics, and threat intelligence. He has presented at security conferences like Black Hat, FIRST, 4SICS-SCADA/ICS summit, DSCI, National Cyber Defence Summit and Cysinfo meetings on various topics which include memory forensics, malware analysis, rootkit analysis, and has conducted trainings at FIRST (Forum of

Incident Response and Security teams) conference and 4SICS-SCADA/ICS cyber security summit. He has also authored various articles in Hakin9, eForensics, and Hack[In]sight magazines. You can find some of his contributions to the community in his YouTube channel (http://www.youtube.com/c/MonnappaKA).

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