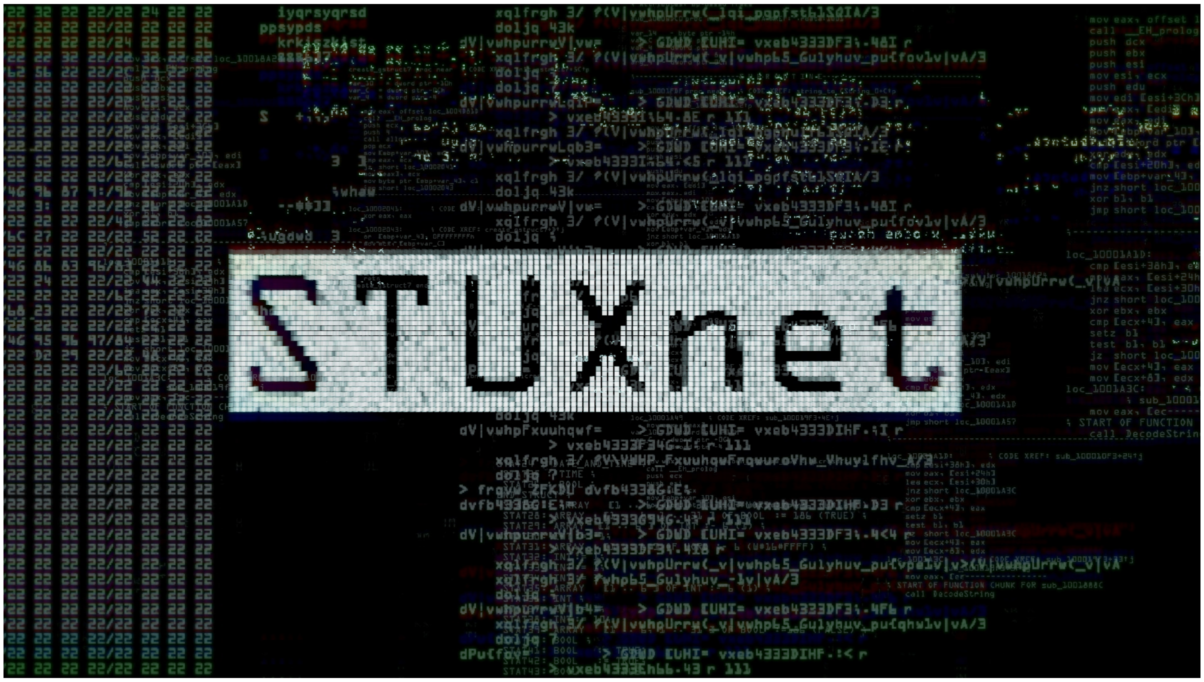
Lab4: Stuxnet (Participation-only)



Objectives and Targets

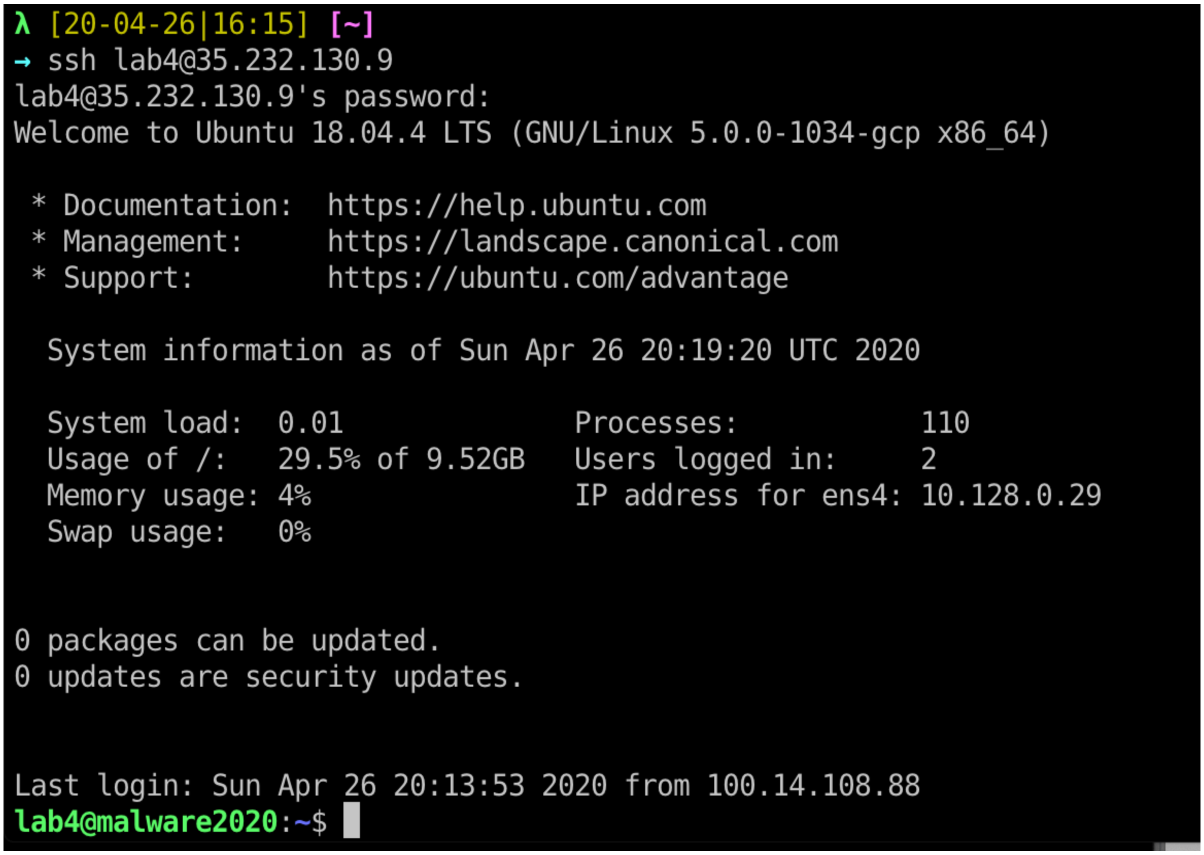
Stuxnet is a malicious computer worm, first uncovered in 2010. Thought to have been in development since at least 2005, Stuxnet targets SCADA systems and is believed to be responsible for causing substantial damage to Iran's nuclear program.

In this lab, we'll examine Stuxnet's footprint in memory using Volatility 2.0 (Link). Please follow the instructions and answer all questions.

Remote Login:

Please use secure shell (SSH) software to login my remote linux server (ubuntu).

```
IP: 35.232.130.9
UserName: lab4
Password: wcupa
```



```
λ [20-04-26|16:15] [~]
→ ssh lab4@35.232.130.9
lab4@35.232.130.9's password:
Welcome to Ubuntu 18.04.4 LTS (GNU/Linux 5.0.0-1034-gcp x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:     https://landscape.canonical.com
 * Support:        https://ubuntu.com/advantage

  System information as of Sun Apr 26 20:19:20 UTC 2020

  System load:  0.01               Processes:           110
  Usage of /:   29.5% of 9.52GB   Users logged in:     2
  Memory usage: 4%                 IP address for ens4: 10.128.0.29
  Swap usage:   0%


0 packages can be updated.
0 updates are security updates.


Last login: Sun Apr 26 20:13:53 2020 from 100.14.108.88
lab4@malware2020:~$
```

title

Target 1: Hollow Process Injection:

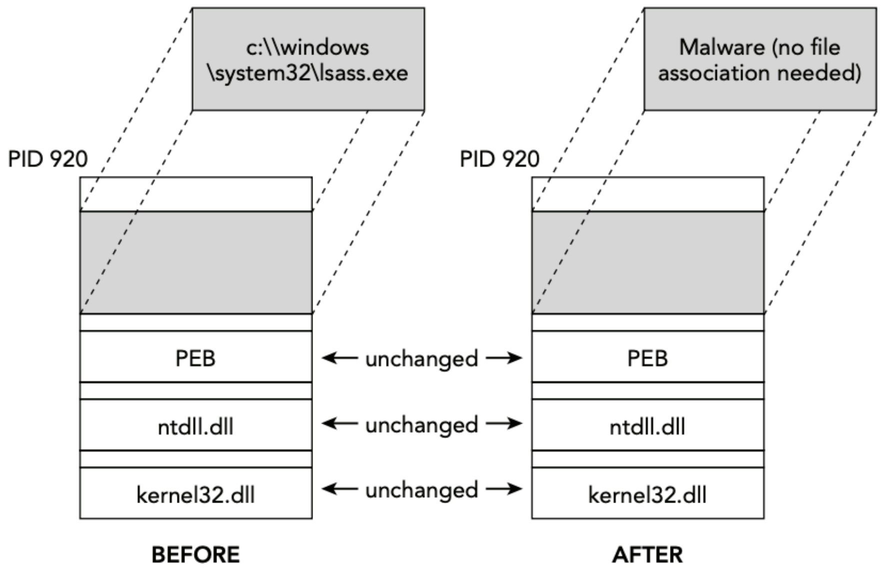
Step 1:
Type `vol.py -f stuxnet.vmem pstree`, it'll shows all running processes.

```
[student@archlinux ~]$ vol.py -f stuxnet.vmem pstree
Volatility Foundation Volatility Framework 2.6.1
Name                                                  Pid   PPid   Thds   Hnds Time
-------------------------------------------------- ------ ------ ------ ------ ----
 0x823c8830:System                                      4      0     59    403 1970-01-01 00:00:00 UTC+0000
. 0x820df020:smss.exe                                 376      4      3     19 2010-10-29 17:08:53 UTC+0000
.. 0x821a2da0:csrss.exe                               600    376     11    395 2010-10-29 17:08:54 UTC+0000
.. 0x81da5650:winlogon.exe                            624    376     19    570 2010-10-29 17:08:54 UTC+0000
... 0x82073020:services.exe                           668    624     21    431 2010-10-29 17:08:54 UTC+0000
.... 0x81fe52d0:vmtoolsd.exe                         1664    668      5    284 2010-10-29 17:09:05 UTC+0000
..... 0x81c0cda0:cmd.exe                              968   1664      0 ------ 2011-06-03 04:31:35 UTC+0000
...... 0x81f14938:ipconfig.exe                        304    968      0 ------ 2011-06-03 04:31:35 UTC+0000
.... 0x822843e8:svchost.exe                          1032    668     61   1169 2010-10-29 17:08:55 UTC+0000
..... 0x822b9a10:wuauclt.exe                          976   1032      3    133 2010-10-29 17:12:03 UTC+0000
..... 0x820ecc10:wscntfy.exe                         2040   1032      1     28 2010-10-29 17:11:49 UTC+0000
.... 0x81e61da0:svchost.exe                           940    668     13    312 2010-10-29 17:08:55 UTC+0000
.... 0x81db8da0:svchost.exe                           856    668     17    193 2010-10-29 17:08:55 UTC+0000
..... 0x81fa5390:wmiprvse.exe                        1872    856      5    134 2011-06-03 04:25:58 UTC+0000
.... 0x821a0568:VMUpgradeHelper                      1816    668      3     96 2010-10-29 17:09:08 UTC+0000
.... 0x81fee8b0:spoolsv.exe                          1412    668     10    118 2010-10-29 17:08:56 UTC+0000
.... 0x81ff7020:svchost.exe                          1200    668     14    197 2010-10-29 17:08:55 UTC+0000
.... 0x81c47c00:lsass.exe                            1928    668      4     65 2011-06-03 04:26:55 UTC+0000
.... 0x81e18b28:svchost.exe                          1080    668      5     80 2010-10-29 17:08:55 UTC+0000
.... 0x8205ada0:alg.exe                               188    668      6    107 2010-10-29 17:09:09 UTC+0000
.... 0x823315d8:vmacthlp.exe                          844    668      1     25 2010-10-29 17:08:55 UTC+0000
.... 0x81e0eda0:jqs.exe                              1580    668      5    148 2010-10-29 17:09:05 UTC+0000
.... 0x81c498c8:lsass.exe                             868    668      2     23 2011-06-03 04:26:55 UTC+0000
.... 0x82279998:imapi.exe                             756    668      4    116 2010-10-29 17:11:54 UTC+0000
... 0x81e70020:lsass.exe                              680    624     19    342 2010-10-29 17:08:54 UTC+0000
 0x820ec7e8:explorer.exe                             1196   1728     16    582 2010-10-29 17:11:49 UTC+0000
. 0x81c543a0:Procmon.exe                              660   1196     13    189 2011-06-03 04:25:56 UTC+0000
. 0x81e86978:TSVNCache.exe                            324   1196      7     54 2010-10-29 17:11:49 UTC+0000
. 0x81e6b660:VMwareUser.exe                          1356   1196      9    251 2010-10-29 17:11:50 UTC+0000
. 0x8210d478:jusched.exe                             1712   1196      1     26 2010-10-29 17:11:50 UTC+0000
. 0x81fc5da0:VMwareTray.exe                          1912   1196      1     50 2010-10-29 17:11:50 UTC+0000
```

A normal Windows XP installation has **just one instance of lsass.exe** that the Winlogon process creates when the system boots. However, the process tree reveals that the two new lsass.exe instances were both created by Services.exe.

Q1: Please write down the process IDs (PIDs) for the fake lsass.exe? (1 Point)

Step 2: In fact, Stuxnet uses **Hollow Process Injection** to switch the code of a legit running process with malicious code.



As a result of being hollowed, the virtual address descriptor (VAD) characteristics for the region are drastically different. Only the legitimate one still has a copy of the lsass.exe file mapped into the region.

Please type `vol.py -f stuxnet.vmem vadinfo -p 1928,868,680 --addr=0x1000000`

```
[student@archlinux ~]$ vol.py -f stuxnet.vmem vadinfo -p 1928,868,680 --addr=0x1000000
Volatility Foundation Volatility Framework 2.6.1
************************************************************************
Pid:    680
VAD node @ 0x81db03c0 Start 0x01000000 End 0x01005fff Tag Vad
Flags: CommitCharge: 1, ImageMap: 1, Protection: 7
Protection: PAGE_EXECUTE_WRITECOPY
ControlArea @823e4008 Segment e1735398
NumberOfSectionReferences:          3 NumberOfPfnReferences:           4
NumberOfMappedViews:                1 NumberOfUserReferences:          4
Control Flags: Accessed: 1, File: 1, HadUserReference: 1, Image: 1
FileObject @82230120, Name: \Device\HarddiskVolume1\WINDOWS\system32\lsass.exe
First prototype PTE: e17353d8 Last contiguous PTE: fffffffc
Flags2: Inherit: 1

************************************************************************
Pid:    868
VAD node @ 0x81f1ef08 Start 0x01000000 End 0x01005fff Tag Vad
Flags: CommitCharge: 2, Protection: 6
Protection: PAGE_EXECUTE_READWRITE
ControlArea @81fbeee0 Segment e24b4c10
NumberOfSectionReferences:          1 NumberOfPfnReferences:           0
NumberOfMappedViews:                1 NumberOfUserReferences:          2
Control Flags: Commit: 1, HadUserReference: 1
First prototype PTE: e24b4c50 Last contiguous PTE: e24b4c78
Flags2: Inherit: 1

************************************************************************
Pid:   1928
VAD node @ 0x82086d40 Start 0x01000000 End 0x01005fff Tag Vad
Flags: CommitCharge: 2, Protection: 6
Protection: PAGE_EXECUTE_READWRITE
ControlArea @81ff33e0 Segment e2343888
NumberOfSectionReferences:          1 NumberOfPfnReferences:           0
NumberOfMappedViews:                1 NumberOfUserReferences:          2
Control Flags: Commit: 1, HadUserReference: 1
First prototype PTE: e23438c8 Last contiguous PTE: e23438f0
Flags2: Inherit: 1
```

Q2: Please find the difference of between the legit lsass.exe VAD and the fake one and write down the differences(1 Point)

Target 2: API Hooking:

Based on Symantec report ([Link](), page 13), Stuxnet has hooked Ntdll.dll to monitor for requests to load specially crafted file names. These specially crafted filenames are mapped to another location instead — a location specified by Stuxnet.

The functions hooked for this purpose in Ntdll.dll are:

- ZwMapViewOfSection
- ZwCreateSection
- ZwOpenFile
- ZwCloseFile
- ZwQueryAttributesFile
- ZwQuerySection"

Step 1:

Type `vol.py -f stuxnet.vmem apihooks`, it'll shows all hooked APIs. I attached the result for ZWQuerySection Function.

```
************************************************************************
Hook mode: Usermode
Hook type: NT Syscall
Process: 940 (svchost.exe)
Victim module: ntdll.dll (0x7c900000 - 0x7c9af000)
Function: ZwOpenFile
Hook address: 0x7c90004c
Hooking module: ntdll.dll

Disassembly(0):
0x7c90d580 b874000000       MOV EAX, 0x74
0x7c90d585 ba4c00907c       MOV EDX, 0x7c90004c
0x7c90d58a ffd2             CALL EDX
0x7c90d58c c21800           RET 0x18
0x7c90d58f 90               NOP
0x7c90d590 b875000000       MOV EAX, 0x75
0x7c90d595 ba               DB 0xba
0x7c90d596 0003             ADD [EBX], AL

Disassembly(1):
0x7c90004c b202             MOV DL, 0x2
0x7c90004e eb0c             JMP 0x7c90005c
0x7c900050 b203             MOV DL, 0x3
0x7c900052 eb08             JMP 0x7c90005c
0x7c900054 b204             MOV DL, 0x4
0x7c900056 eb04             JMP 0x7c90005c
0x7c900058 b205             MOV DL, 0x5
0x7c90005a eb00             JMP 0x7c90005c
0x7c90005c 52               PUSH EDX
0x7c90005d e804000000       CALL 0x7c900066
0x7c900062 f2               DB 0xf2
0x7c900063 00               DB 0x0
```

API Hook Information for ZWQuerySection Function

For `ZwOpenFile` function, the hook address is `0x7c90004c`. Stuxnet uses the “syscall” hooking technique instead of the more common Inline/IAT/EAT hooking. To interactively explore code around the hook address, use the `volshell` command. This time we’ll use it to follow the flow of execution when a hooked API is called.

First you need to break into the shell and switch into the context of a process that has been hooked. Then navigate to the hooked API. I’ll start with `ZWQuerySection` which is at `0x7c90004c`.

Step 2:
Type `vol.py -f stuxnet.vmem volshell`
Inside volshell, Type `cc(pid=940)`
Type `dis(0x7c90004c)`

```
[student@archlinux ~]$ vol.py -f stuxnet.vmem volshell
Volatility Foundation Volatility Framework 2.6.1
Current context: System @ 0x823c8830, pid=4, ppid=0 DTB=0x319000
Welcome to volshell! Current memory image is:
file:///home/student/stuxnet.vmem
To get help, type 'hh()'
>>> cc(pid=940)
Current context: svchost.exe @ 0x81e61da0, pid=940, ppid=668 DTB=0xa940100
>>> dis(0x7c90004c)
0x7c90004c b202                          MOV DL, 0x2
0x7c90004e eb0c                          JMP 0x7c90005c
0x7c900050 b203                          MOV DL, 0x3
0x7c900052 eb08                          JMP 0x7c90005c
0x7c900054 b204                          MOV DL, 0x4
0x7c900056 eb04                          JMP 0x7c90005c
0x7c900058 b205                          MOV DL, 0x5
0x7c90005a eb00                          JMP 0x7c90005c
0x7c90005c 52                            PUSH EDX
0x7c90005d e804000000                    CALL 0x7c900066
0x7c900062 f200bf005aff22                ADD [EDI+0x22ff5a00], BH
0x7c900069 696e20444f5320                IMUL EBP, [ESI+0x20], 0x20534f44
0x7c900070 6d                            INS DWORD [ES:EDI], DX
0x7c900071 6f                            OUTS DX, DWORD [ESI]
0x7c900072 64652e0d0d0a2400              OR EAX, 0x240a0d
0x7c90007a 0000                          ADD [EAX], AL
0x7c90007c 0000                          ADD [EAX], AL
0x7c90007e 0000                          ADD [EAX], AL
0x7c900080 084063                        OR [EAX+0x63], AL
0x7c900083 fe4c210d                      DEC BYTE [ECX+0xd]
0x7c900087 ad                            LODSD
0x7c900088 4c                            DEC ESP
```

```
0x7c900089 210dad4c210d                     AND [0xd214cad], ECX
0x7c90008f ad                               LODSD
0x7c900090 8f                               DB 0x8f
0x7c900091 2e51                             PUSH ECX
0x7c900093 ad                               LODSD
0x7c900094 4d                               DEC EBP
0x7c900095 210dad8f2e53                     AND [0x532e8fad], ECX
0x7c90009b ad                               LODSD
0x7c90009c 4d                               DEC EBP
0x7c90009d 210dad8f2e02                     AND [0x22e8fad], ECX
0x7c9000a3 ad                               LODSD
0x7c9000a4 0c21                             OR AL, 0x21
0x7c9000a6 0dad8f2e6d                       OR EAX, 0x6d2e8fad
0x7c9000ab ad                               LODSD
0x7c9000ac 4f                               DEC EDI
0x7c9000ad 210dad8f2e52                     AND [0x522e8fad], ECX
0x7c9000b3 ad                               LODSD
0x7c9000b4 9d                               POPF
0x7c9000b5 210dad8f2e57                     AND [0x572e8fad], ECX
0x7c9000bb ad                               LODSD
0x7c9000bc 4d                               DEC EBP
0x7c9000bd 210dad526963                     AND [0x636952ad], ECX
0x7c9000c3 684c210dad                       PUSH DWORD 0xad0d214c
0x7c9000c8 0000                             ADD [EAX], AL
0x7c9000ca 0000                             ADD [EAX], AL
```

At `0x7c90005d` there is a CALL to `0x7c900066`. But according to the disassembly, `0x7c900066` is in the middle of the instruction that starts at `0x7c900062`. This is an anti-disassembling trick that Stuxnet uses.

Let's disassemble `0x7c900066`

Type `dis(0x7c900066)`

```
>>> dis(0x7c900066)
0x7c900066 5a                               POP EDX
0x7c900067 ff22                             JMP DWORD [EDX]
```

The first two lines shows `POP EDX; JMP DWORD [EDX]`. Stuxnet plays a little tricks here:

1. When the CALL at `0x7c90005d` is executed, its return address (`0x7c900062`) is pushed onto the stack.
2. The POP EDX instruction at `0x7c900066` then removes that value from the stack and places it in EDX.
3. At `0x7c900067`, EDX is dereferenced and called. So the pointer being

dereferenced is stored in `0x7c900062`.

Q3: Please draw three figures with stack and EDX register to show the little tricks that Stuxnet did. Label it with 1,2,3 (6 Points)

At address `0x7c900062`, the first 4 byte of data is being used as the memory address of the next hop (`JMP DWORD [EDX]`) which I highlighted in the following picture (`f200bf00`)

```
0x7c900062 f200bf005aff22                    ADD [EDI+0x22ff5a00], BH
```

Q4: This value is stored using the little endian format, please convert this value back and write down the actual memory address.(1 point)

Step 3:

Let's disassemble the memory address that contains the rootkit (the answer for Q4, you need to convert `f200bf00` to get the address).
Type `dis(MEMORY_ADDRESS_FROM_Q4)`
It shows the assembly code of the rootkit.

```
>>> dis([redacted])
[redacted] 5a                  POP EDX
[redacted] 84d2                TEST DL, DL
[redacted] 7425                JZ 0xbf011c
[redacted] feca                DEC DL
[redacted] 0f8482000000        JZ 0xbf0181
[redacted] feca                DEC DL
[redacted] 0f84bb000000        JZ 0xbf01c2
[redacted] feca                DEC DL
[redacted] 0f84fe000000        JZ 0xbf020d
[redacted] feca                DEC DL
[redacted] 0f8440010000        JZ 0xbf0257
[redacted] e98c010000          JMP 0xbf02a8
[redacted] e8f9010000          CALL 0xbf031a
[redacted] 85d2                TEST EDX, EDX
[redacted] 7413                JZ 0xbf0138
[redacted] 52                  PUSH EDX
[redacted] 8b5208              MOV EDX, [EDX+0x8]
[redacted] 3b54240c            CMP EDX, [ESP+0xc]
[redacted] 7508                JNZ 0xbf0137
[redacted] c744243040000000    MOV DWORD [ESP+0x30], 0x40
[redacted] 5a                  POP EDX
[redacted] 52                  PUSH EDX
[redacted] e81e020000          CALL 0xbf035c
[redacted] 837a0400            CMP DWORD [EDX+0x4], 0x0
[redacted] 7509                JNZ 0xbf014d
[redacted] 5a                  POP EDX
[redacted] 8d542408            LEA EDX, [ESP+0x8]
[redacted] cd2e                INT 0x2e
[redacted] eb0c                JMP 0xbf0159
[redacted] 5a                  POP EDX
[redacted] 8d542408            LEA EDX, [ESP+0x8]
[redacted] 64ff15c0000000      CALL DWORD [FS:0xc0]
[redacted] 85c0                TEST EAX, EAX
[redacted] 7523                JNZ 0xbf0180
[redacted] e8b8010000          CALL 0xbf031a
[redacted] 85d2                TEST EDX, EDX
[redacted] 7418                JZ 0xbf017e
[redacted] 8b5208              MOV EDX, [EDX+0x8]
[redacted] 3b542408            CMP EDX, [ESP+0x8]
[redacted] 750f                JNZ 0xbf017e
[redacted] 8b                  DB 0x8b
[redacted] 54                  PUSH ESP
[redacted] 24                  DB 0x24
```

The instructions highlighted show how the malware eventually calls the requested system service. It uses the IDT instead of the SSDT. Although Windows itself doesn't use the IDT for system service dispatching anymore (that stopped with Windows 2000), the IDT was still kept around for backward capability.

Check slides (ch10.pptx) answer the following questions:
Q5: What's the meaning of `INT 0x2e`? (1 point)
Q6: What's IDT? What's SSDT? (2 points)

Step 4:
Q7: Find the real memory address of the rest of system API

Repeat Step 1 and 2, and reveal the real memory address for
* ZwCreateSection
* ZwOpenFile
* ZwCloseFile
* ZwQueryAttributesFile
(4 points)

Target 3: Kernel Forensics (Bonus 6 points):

Stuxnet loads two modules: maxnet.sys and mrxcls.sys. The first one installs a file system registration change callback to receive notification when new files systems become available (so it can immediately spread or hide files). The second one installs an image load callback, which is uses to inject code into processes when they try to load other DLL.

Please use Volatility, read the command reference (Link). Find a way to find the malicious kernel drivers, kernel callbacks and point out the malicious devices inside memory.

Deliverables:

- A detailed project report (**lab4_report.pdf**) in **PDF format** to describe what you have done, including screenshots and code snippets.

Submission

- Check lab due date on the course website. Late submission will not be accepted.
- The assignment should be submitted to D2L directly.
- No copy or cheating is tolerated. If your work is based on others', please

give clear attribution. Otherwise, you **WILL FAIL** this course.