Control Flow Obfuscations in Malwares

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Introduction

In this paper I will discuss about the control flow obfuscations used in malwares. The purpose of using these control-flow obfuscations, how they are done and how they are used to deter reverse engineering will be discussed.

The term control flow obfuscation is used in this article to indicate code sections in the binary, which are added in order to make the comprehension of program more difficult.

After this, I also present a pintool I have written to help detect some important sequence of instructions, which will be of interest to the virus analyst.

Note: You may need to zoom into the screenshots of disassembly included to view them clearly.

Purpose of Control Flow Obfuscations

The two main reasons of using control flow obfuscations in malwares are:

1. To deter the static reverse engineering of malwares. It becomes more difficult to target the code sections of interest.
2. To defeat the static signatures used by AV vendors, which rely on specific byte sequences in the binary to detect them.

Application Defined Callback Functions

There are certain APIs provided by Microsoft, which allow us to register a Callback Function. These can be used by malwares to hide the main logic of their code. They can pass a pointer to the malicious subroutine as the callback function parameter for the API.

Window Procedure

Using **RegisterClassExA**(), a Window Procedure can be registered for a specific Class Name. All the windows with that class name will have the same Window Procedure.

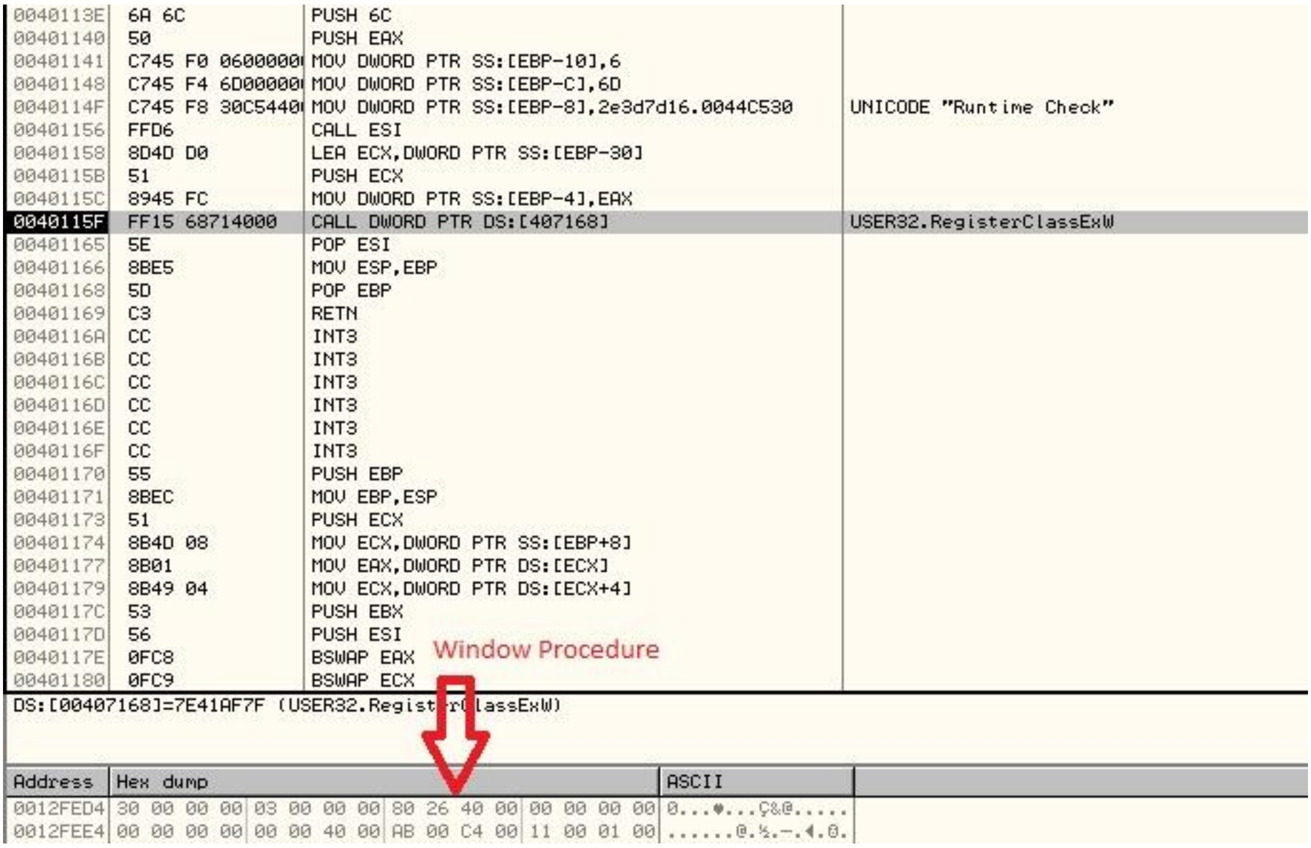
When a window is created using **CreateWindowA**(), the Window Procedure is invoked with certain default window messages like WM_CREATE, WM_NCCREATE and so on.

However, the main virus code will be executed only when a particular windows message is received.

Let us take as an example a virus which calls malicious subroutine indirectly:

After unpacking the malware, the first thing it does is to register a Window Class with the name, "Runtime Check" with the Window Procedure subroutine at address, 00402680. It then creates the

Window. During the creation of the Window, the Window Procedure is invoked which handles the initial window messages like WM_CREATE.



After the Window is created, it retrieves the message from the Thread's queue using GetMessage() and dispatches it to the Window Procedure using DispatchMessage().

Inside the Window Procedure, it reads the code of the Window Message from the stack and stores it in the EAX register. It then checks whether the window message code is greater than 0xF. If it is equal to 0x113, then it sets up a Timer that elapses after 1 second. Since the last parameter to the **SetTimer()** function is NULL, the system will post a **WM_TIMER** message to the queue every time the timer elapses. Each time a **WM_TIMER** message is retrieved from the application thread's message queue using GetMessage(), it increments a counter. Once the counter is equal to 5, it calls the malicious subroutine. Since the timer is set to elapse after 1 second, so overall delay introduced is approximately, 5 seconds.

Window Procedure:

```
00402680  55              PUSH EBP
00402681  8BEC            MOV EBP,ESP
00402683  83E4 F8         AND ESP,FFFFFFF8
00402686  83EC 4C         SUB ESP,4C
00402689  A1 04A04000     MOV EAX,DWORD PTR DS:[40A004]
0040268E  33C4            XOR EAX,ESP
00402690  894424 48       MOV DWORD PTR SS:[ESP+48],EAX
00402694  8B45 0C         MOV EAX,DWORD PTR SS:[EBP+C]          <-- Read Window Message Code
00402697  56              PUSH ESI
00402698  8B75 08         MOV ESI,DWORD PTR SS:[EBP+8]
0040269B  83F8 0F         CMP EAX,0F  <-- WM_PAINT
0040269E  77 75           JA SHORT 2e3d7d16.00402715
004026A0  74 47           JE SHORT 2e3d7d16.004026E9
004026A2  8BC8            MOV ECX,EAX
004026A4  49              DEC ECX
004026A5  74 1E           JE SHORT 2e3d7d16.004026C5
004026A7  49              DEC ECX
```

Set the Timer:

```
004026A8  75 7A           JNZ SHORT 2e3d7d16.00402724
004026AA  51              PUSH ECX
004026AB  FF15 44714000   CALL DWORD PTR DS:[407144]            USER32.PostQuitMessage
004026B1  33C0            XOR EAX,EAX
004026B3  5E              POP ESI
004026B4  8B4C24 48       MOV ECX,DWORD PTR SS:[ESP+48]
004026B8  33CC            XOR ECX,ESP
004026BA  E8 5D010000     CALL 2e3d7d16.0040281C
004026BF  8BE5            MOV ESP,EBP
004026C1  5D              POP EBP
004026C2  C2 1000         RETN 10
004026C5  6A 00           PUSH 0
004026C7  68 E8030000     PUSH 3E8
004026CC  6A 01           PUSH 1
004026CE  56              PUSH ESI
004026CF  FF15 5C714000   CALL DWORD PTR DS:[40715C]            USER32.SetTimer
004026D5  33C0            XOR EAX,EAX
004026D7  5E              POP ESI
004026D8  8B4C24 48       MOV ECX,DWORD PTR SS:[ESP+48]
```

Check the Window Message Code:

```
00402715  8BC8            MOV ECX,EAX
00402717  81E9 11010000   SUB ECX,111
0040271D  74 57           JE SHORT 2e3d7d16.00402776  <-- WM_COMMAND
0040271F  83E9 02         SUB ECX,2
00402722  74 22           JE SHORT 2e3d7d16.00402746  <-- WM_TIMER
00402724  8B55 14         MOV EDX,DWORD PTR SS:[EBP+14]
00402727  8B4D 10         MOV ECX,DWORD PTR SS:[EBP+10]
0040272A  52              PUSH EDX
0040272B  51              PUSH ECX
0040272C  50              PUSH EAX
0040272D  56              PUSH ESI
0040272E  FF15 50714000   CALL DWORD PTR DS:[407150]            USER32.DefWindowProcW
00402734  5E              POP ESI
00402735  8B4C24 48       MOV ECX,DWORD PTR SS:[ESP+48]
00402739  33CC            XOR ECX,ESP
0040273B  E8 DC000000     CALL 2e3d7d16.0040281C
00402740  8BE5            MOV ESP,EBP
00402742  5D              POP EBP
00402743  C2 1000         RETN 10
00402746  A1 C4C64400     MOV EAX,DWORD PTR DS:[44C6C4]
0040274B  40              INC EAX  <-- Increment Counter
0040274C  A3 C4C64400     MOV DWORD PTR DS:[44C6C4],EAX
00402751  83F8 05         CMP EAX,5
00402754  75 67           JNZ SHORT 2e3d7d16.004027BD
00402756  E8 75FBFFFF     CALL 2e3d7d16.004022D0 <-- Call Main Subroutine if Counter == 0x5
0040275B  56              PUSH ESI
0040275C  FF15 58714000   CALL DWORD PTR DS:[407158]            USER32.DestroyWindow
00402762  33C0            XOR EAX,EAX
00402764  5E              POP ESI
```

Below are the corresponding sections of code:

https://gist.github.com/c0d3inj3cT/7611371#file-wmtimer-asm

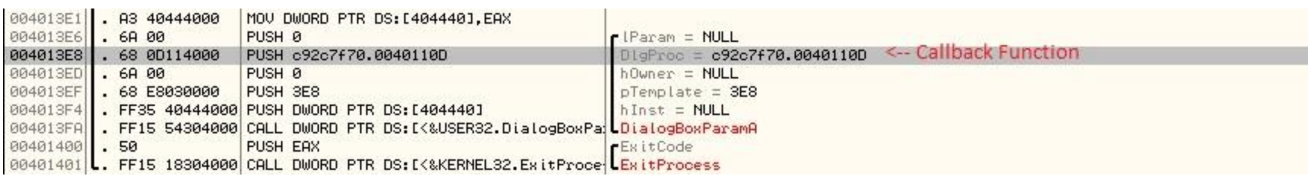
And here is the code rewritten in C:

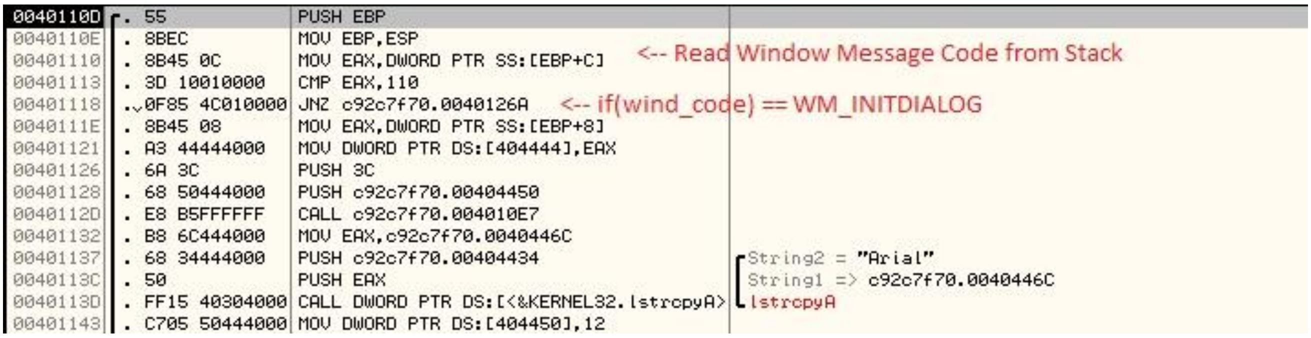
```
if(wind_code > 0xF)
{
   if(wind_code == 0x113)
   {
      counter++;
      if(counter == 0x5)
      {
         call malicious_code;
      }
   }
}
else if(wind_code == 0xF)
{
   // code for handling the WM_PAINT message
}
else if(wind_code == 0x1)
{
   SetTimer(hWnd, 1, 0x3e8, 0)
}
```

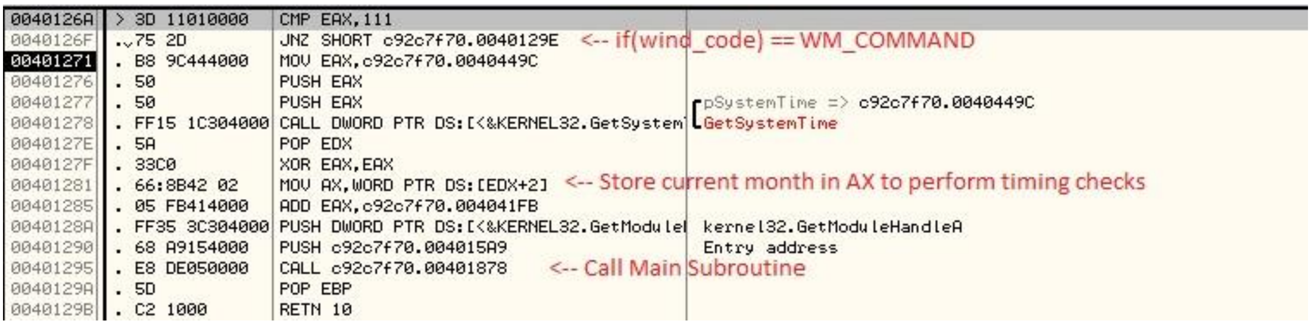
As can be seen, this method can be used to introduce any amount of delay in execution. Since, most automated sandboxes detect the delays in Execution by checking for Sleep()/SleepEx()/NtDelayExecution() API calls, this method would bypass such detections.

DialogBoxParamA():

This is another API, which takes the address of the Window Procedure as one of the input parameters. Below is an example of a virus that executes the main code section only when it receives the **WM_COMMAND** window message.



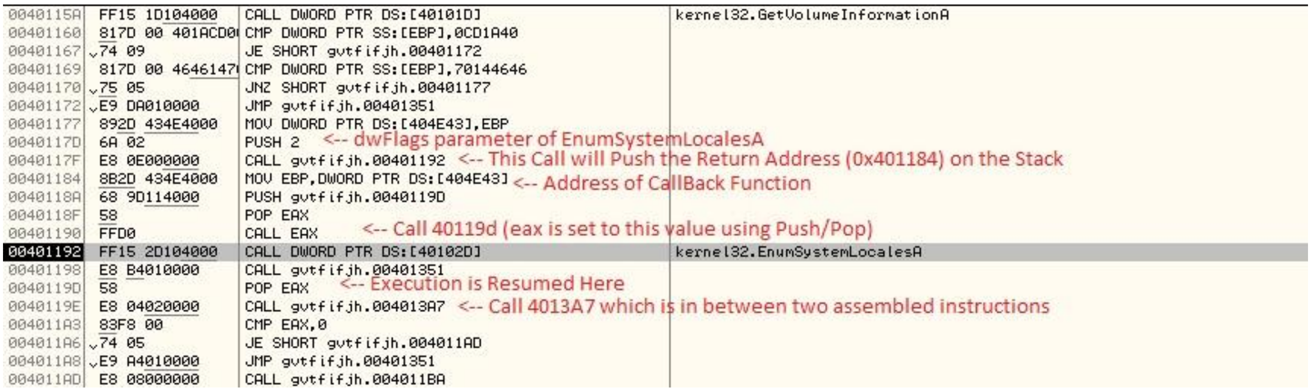




EnumSystemLocalesA():

Here is another example of a Windows API, which takes an application defined callback function as one of the input parameters.

By passing the pointer to malicious subroutine as the callback function, we can invoke it indirectly through **EnumSystemLocalesA()** as shown below:



Also, it can be seen that there is a control flow obfuscation which finally redirects the execution to the address 0x4013A7 which is in between two assembled instructions. This would result in updating the view of Debugger since the disassembly changes.

The main impact of using this technique is that the code will be executed if we step over the call to these APIs. As a result of this, we need to set a breakpoint at the callback function just before the API is invoked. We will break at the callback function in the debugger as soon as the API is executed, this way we can continue stepping through the code.

While this technique may appear to be easy for a seasoned reverse engineer, its usage is becoming increasingly common among malwares these days.

There are several other Window APIs provided which accept an application defined callback function as one of the input parameters.

Execution through Exception Handlers

Malwares could also redirect the execution to the malicious subroutine by triggering an exception. In order to do this, they first register an exception handler using either **RtlAddVectoredExceptionHandler**() or by registering a new Structured Exception Handler.

The exception can be invoked using either of the following:

1. Triggering a memory access violation (**0xc0000005**) by attempting to write to a memory address to which there is no write access or by attempting to call an invalid memory address.

2. Executing a privileged instruction like STI or CLI, which would result in a Privileged Exception in protected mode (**0xc0000096**).

3. Performing a division by zero to trigger the exception (**0xC0000094**).

Execution through Exception Handler for 0xc0000096:

Below is an example of a malware, which calls the malicious code by triggering a Privileged Instruction exception.

It first registers an exception handler. Then it decrypts the code of that exception handler.

```
0040174C   34 43           XOR AL,43                              <-- Single Byte XOR Decryption of the Exception Handler
0040174E  vEB 0A           JMP SHORT gvtfifjh.0040175A
00401750  ^EB FA           JMP SHORT gvtfifjh.0040174C
00401752   8D844B 52174000 LEA EAX,DWORD PTR DS:[EBX+ECX*2+401752]
00401759   7A AA           JPE SHORT gvtfifjh.00401705
0040175B  ^E2 E4           LOOPD SHORT gvtfifjh.00401741
0040175D   FA              CLI
```

```
0040175A   AA              STOS BYTE PTR ES:[EDI]          <-- Write the decrypted byte to the Exception Handler code
0040175B  ^E2 E4           LOOPD SHORT gvtfifjh.00401741
0040175D   FA              CLI                             <-- Trigger the 0xc0000096 exception here
0040175E   4C              DEC ESP
0040175F   017416 1C       ADD DWORD PTR DS:[ESI+EDX+1C],ESI
```

Once this is done, it triggers an exception by executing a privileged instruction like CLI or STI (both these instructions are privileged in the protected mode).

Since an exception is triggered, the corresponding exception handler from the SEH chain will be invoked. This is a control flow obfuscation trick. Below screenshots show an exception triggered after executing the CLI instruction. On the stack we can see the exception handler address as: 0x00401610.

```
0006FFC0   00401610  SE handler   <-- Exception Handler registered at top of stack
0006FFC4   7C817077  RETURN to kernel32.7C817077
0006FFC8   7C910228  ntdll.7C910228
0006FFCC   FFFFFFFF
0006FFD0   7FFD8000
0006FFD4   80544CFD
```

To continue the analysis in Olly Debugger, we can press, Shift + F9 and pass the exception to the exception handler or we can just set the EIP to 0x00401610.

```
00401610  E8 04000000    CALL gvtfifjh.00401619 <-- Resume Execution from the Exception Handler
00401615  BA DCFE0068    MOV EDX,6800FEDC
0040161A  2016           AND BYTE PTR DS:[ESI],DL
0040161C  40             INC EAX
0040161D  00EB           ADD BL,CH
0040161F  04 BA          ADD AL,0BA
00401621  DCEE           FSUB ST(6),ST
00401623  0059 EB        ADD BYTE PTR DS:[ECX-15],BL
```

Execution through Vectored Exception Handler:

Below is an example of a malware, which calls the malicious subroutine through a Vectored Exception Handler.

```
00401ABE  . 55             PUSH EBP
00401ABF  . 8BEC           MOV EBP,ESP
00401AC1  . 53             PUSH EBX
00401AC2  . 8B45 08        MOV EAX,DWORD PTR SS:[EBP+8]                 EXCEPTION_POINTERS
00401AC5  . 8B58 04        MOV EBX,DWORD PTR DS:[EAX+4]                 CONTEXT_RECORD
00401AC8  . 8B00           MOV EAX,DWORD PTR DS:[EAX]                   EXCEPTION_RECORD
00401ACA  . 8138 050000C0  CMP DWORD PTR DS:[EAX],C0000005              Check for memory access violation
00401AD0  .v75 34          JNZ SHORT virus.00401B06
00401AD2  . 8178 0C ED1E4  CMP DWORD PTR DS:[EAX+C],virus.00401EED      Check the faulting instruction address
00401AD9  .v75 2B          JNZ SHORT virus.00401B06
00401ADB  . 8B93 C4000000  MOV EDX,DWORD PTR DS:[EBX+C4]                Set ESP in Context Structure
00401AE1  . C702 40000000  MOV DWORD PTR DS:[EDX],40
00401AE7  . C742 04 B0204  MOV DWORD PTR DS:[EDX+4],virus.004020B0
00401AEE  . C742 08 A41A4  MOV DWORD PTR DS:[EDX+8],virus.00401AA4
00401AF5  . C783 B8000000  MOV DWORD PTR DS:[EBX+B8],virus.00401F03     Set EIP in Context Structure
00401AFF  . B8 FFFFFFFF    MOV EAX,-1
00401B04  .vEB 05          JMP SHORT virus.00401B0B
00401B06  > B8 00000000    MOV EAX,0
00401B0B  > 5B             POP EBX
00401B0C  . C9             LEAVE
00401B0D  . C2 0400        RETN 4
```

The handler checks only for memory access violation (**0xc0000005**) exception. It retrieves the address of the faulting instruction from EXCEPTION_RECORD structure and compares it with the address it expects. If they are equal it will set the value of EIP in the CONTEXT structure to malicious subroutine address (0x00401f03 in this case) so that execution resumes there after exception handling completes.

Execution through RaiseException:

There are also some cases where debuggers like Olly Debugger do not pause at the exception Handler when an exception is triggered and instead run the code.

One such case is when we trigger an exception by calling **RaiseException()** with the exception code, 0x80000003.

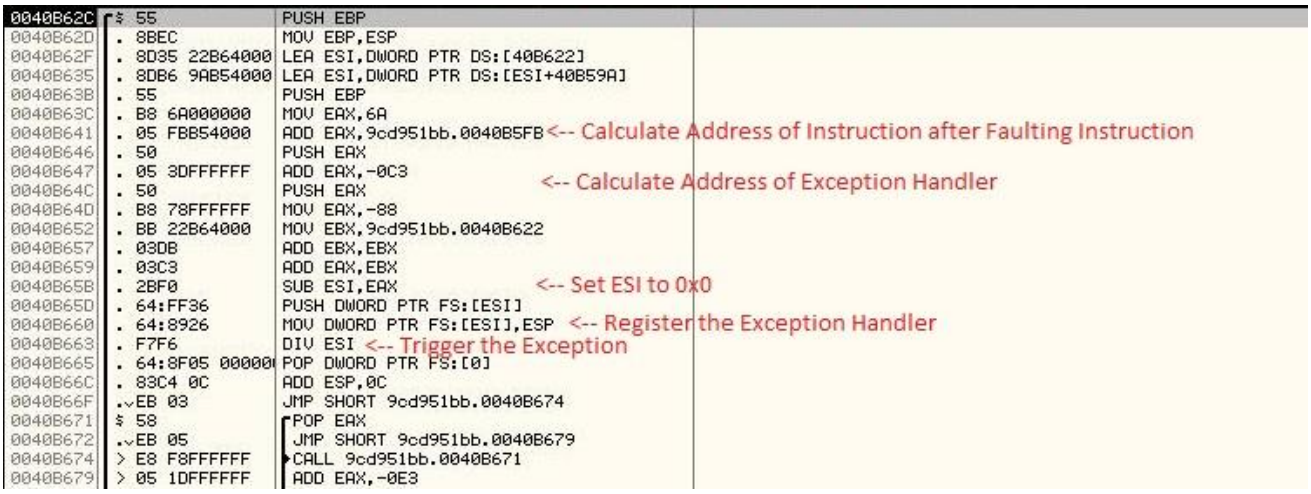
It first registers an exception handler, which has the malicious subroutine code and then triggers the exception by calling RaiseException.

```
0006F324  0040124A  CALL to RaiseException
0006F328  80000003  ExceptionCode = 80000003
0006F32C  00000000  ExceptionFlags = EXCEPTION_CONTINUABLE
0006F330  00000001  nArguments = 1
0006F334  00000000  pArguments = NULL
0006F338  0006F83C  Pointer to next SEH record
0006F33C  0040126D  SE handler
```

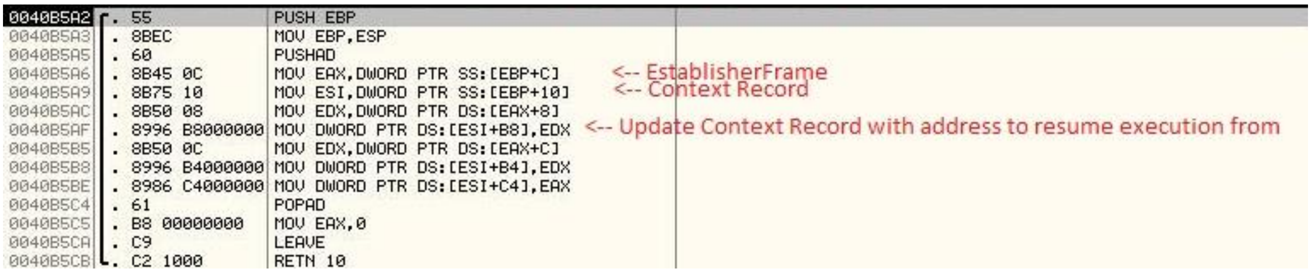
In this case, we can manually set the EIP to 0x0040126D (Structured Exception Handler) and continue debugging from there.

Execution through Exception Handler for 0xC0000094:

In the case below, the virus redirects execution to exception handler by triggering the exception, division by zero.



Inside the Exception Handler, it sets the address to resume execution from in the CONTEXT Record as the address right after execution point of exception (in our case, 0x40B665)



Execution Slide

There are certain special instructions or sequence of instructions which when executed in the debugger change the default behavior of the debugger (to trap at every instruction).

Below are a few examples:

INT 2D Instruction: INT 2D has a special behavior in Olly Debugger. Olly will skip the next byte in execution as a result of which the control flow is obfuscated. This technique is often referred to as **byte scission**.

It also has a dynamic behavior under different environments (different combinations of user mode/kernel mode debuggers and in case of no debuggers).

Overwrite RETN: This is a special behavior observed in Olly Debugger. If we overwrite the RETN instruction with the opcode, 0xC3 (which is the opcode of RETN) just before executing RETN, the debugger does not pause at the RETN address but instead runs the code inside debugger.

Below is a proof of concept I have written for this:

```
; Overwrite RETN opcode
; Control Flow Obfuscation
; Sudeep Singh

include \masm32\include\masm32rt.inc

.data
hMod dd 0

.code
start:
push cfm$("RETN -- 0xc3 Overwrite\n")
call crt_printf
push cfm$("Make the code section writable\n")
call crt_printf
call nextaddr
nextaddr: pop eax
mov ebx, eax
push 4
call crt_malloc
mov esi, eax
invoke LoadLibrary, chr$("kernel32.dll")
mov hMod, eax
invoke GetProcAddress, hMod, chr$("VirtualProtect")
mov ecx, eax
push esi
push 040h
push 0100h
push ebx
call ecx
pushad
push cfm$("Enter the proof of concept routine\n")
call crt_printf
call label1
popad   ; Debugger will not trap here and instead execute the code
mov eax, 01h
shl eax, 08h
push eax
push cfm$("2 ^ 8 is: %#0x\n")
call crt_printf
call ExitProcess
label1:
call label2
label3: retn
label2:
pop eax
sub eax, offset label3
lea esi, dword ptr [eax+label3]
lea edi, dword ptr [eax+label4]
mov ecx, 1
rep movs byte ptr [edi], byte ptr [esi]
label4: retn

end start
```

Trap Flag Check: We can recover the true value of the Trap Flag bit which is used by Debuggers for single stepping by making the processor suspend the interrupts for the next instruction to be executed.

This can be done by writing to the Stack Segment register using either of the following pairs of instructions:

```
Push SS
Pop SS
PUSHF
```

Or

```
Mov ax, ss
Mov ss, ax
PUSHF
```

This will allow us to recover the true value of EFLAGS register and check for the Trap Flag bit in it. This method has been known for quite some time however not used so often in malwares.

Junk Instructions

There are several Polymorphic Engines which are used by malware authors to generate modified versions of their binary which perform the same activities on the machine however their code is modified.

This is often used to bypass static signatures written for malwares by security vendors.

One of the important features of a Polymorphic Engine is the junk instruction generator. Junk instructions are sequence of instructions that do not impact the overall logic of the code in anyway but are placed to deter reverse engineering.

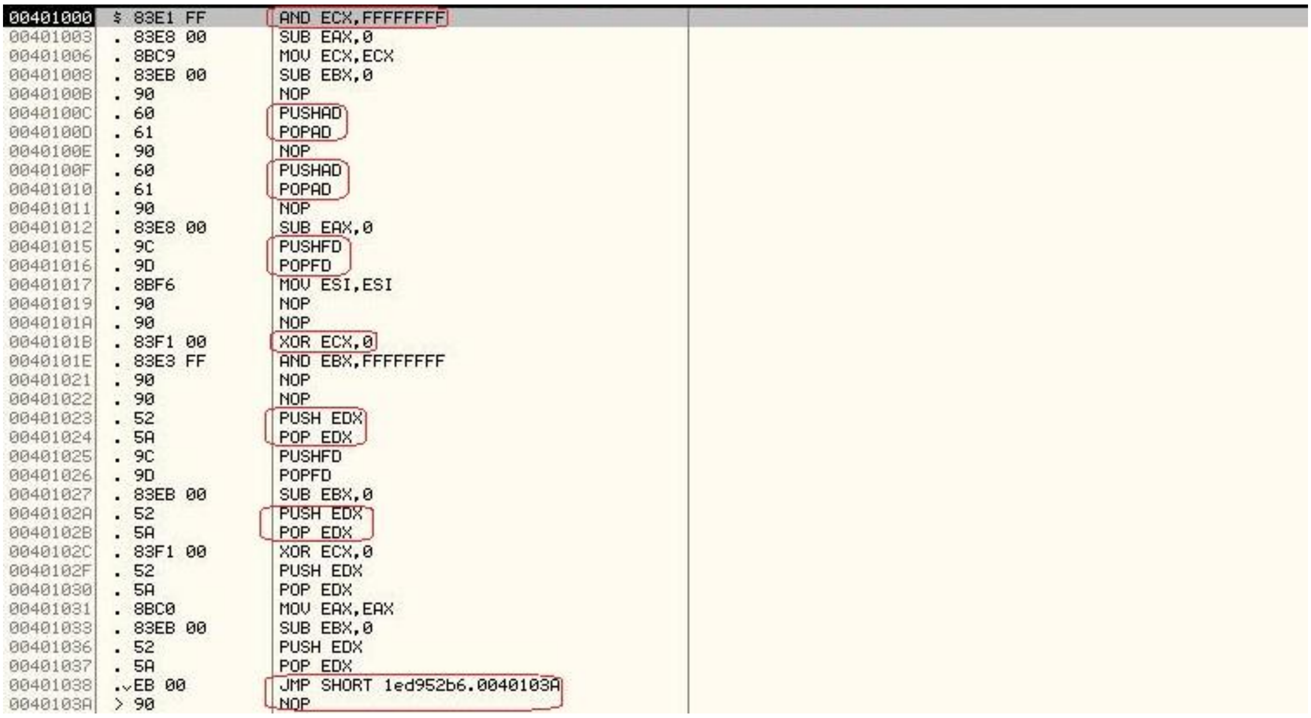
Between every useful instruction, several junk bytes are placed.

The main reasons for injecting junk bytes into the code section are:

1. These junk bytes could correspond to complete instructions which do not alter the overall logic of the code. They increase the size of code section and deter reverse engineering since even though these instructions appear to be legitimate, they have no impact on the main behavior of virus.
2. The junk bytes injected into the code section correspond to partial instructions. This is done to confuse the disassemblers which rely on algorithms like **Linear Sweep** and **Recursive Traversals.**
3. The code can be obfuscated even further by using **opaque predicates** which can be combined with Windows APIs that will always return a fixed value.

Let us now look at each of the above methods by taking real world virus examples:

At first, let us look at a simple example which places a lot of junk bytes at the Entry Point of the Program which correspond to NOPs:



In this case, by combining an easy sequence of instructions like PUSH/POP, a long chain of NOPs is generated. However, once such a pattern is identified, it becomes easy for the reverse engineer to skip such sections of code.

Now, let us look at an example where Window APIs are used in such a way that their return value is constant. By combining multiple calls to Window APIs in this way, a sequence of junk instructions can be generated:

1. **LoadIconA**() is called with an invalid Resource Name so that its return value is always 0x0. As a result of this, the conditional test that follows it becomes an opaque predicate.

2. **GetCurrentThread()** will always return the value 0xfffffffe as a result of which Z flag will be set by the conditional test.
3. **GetStockObject()** is called in such a way that return value is always 0x0 so that it falls through the next conditional test.

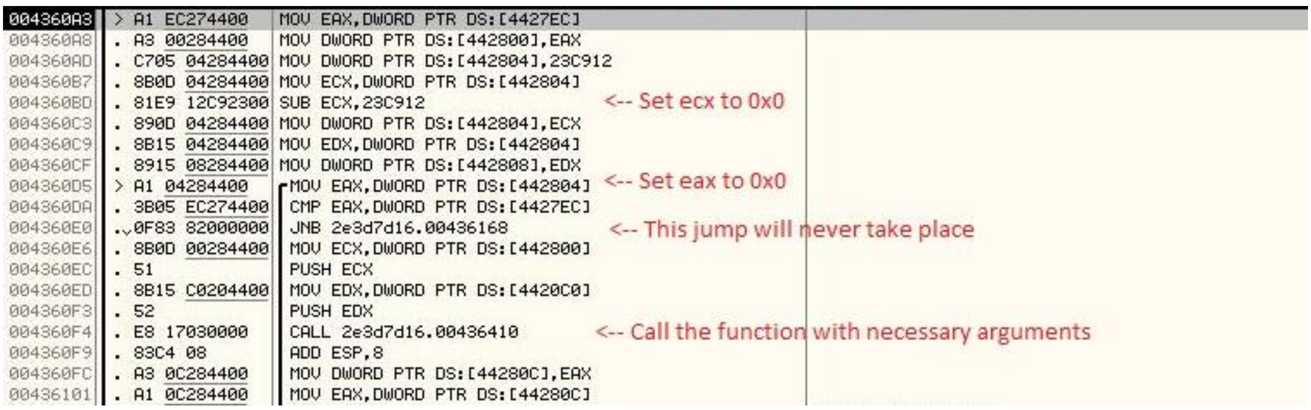
Here is another example of using Windows APIs along with some junk instruction sequences:

```
00435E10  $ 55             PUSH EBP
00435E11  . 8BEC           MOV EBP,ESP
00435E13  . 83EC 14        SUB ESP,14
00435E16  . C705 E0274400  MOV DWORD PTR DS:[4427E0],0CC79
00435E20  . A1 E0274400    MOV EAX,DWORD PTR DS:[4427E0]
00435E25  . 2D 79CC0000    SUB EAX,0CC79                              <-- Set eax to 0x0
00435E2A  . A3 E0274400    MOV DWORD PTR DS:[4427E0],EAX
00435E2F  . FF15 44234400  CALL DWORD PTR DS:[<&KERNEL32.GetOEMCP>]   [GetOEMCP
00435E35  . 85C0           TEST EAX,EAX
00435E37  .v0F84 E4000000  JE 2e3d7d16.00435F21
00435E3D  . FF15 8C214400  CALL DWORD PTR DS:[44218C]                 [GetCurrentThread
00435E43  . 83F8 FE        CMP EAX,-2
00435E46  .v0F85 D5000000  JNZ 2e3d7d16.00435F21                      <-- This jump will never take place
00435E4C  . 68 83841700    PUSH 178483                                ObjType = 1541251.
00435E51  . FF15 90214400  CALL DWORD PTR DS:[442190]                 GetStockObject
00435E57  . 85C0           TEST EAX,EAX
00435E59  .v0F85 C2000000  JNZ 2e3d7d16.00435F21
00435E5F  . 6A 00          PUSH 0                                     ObjType = WHITE_BRUSH
00435E61  . FF15 90214400  CALL DWORD PTR DS:[442190]                 GetStockObject
00435E67  . 85C0           TEST EAX,EAX
00435E69  .v0F84 B2000000  JE 2e3d7d16.00435F21                       <-- This jump will never take place
00435E6F  > 68 755E4300    PUSH 2e3d7d16.00435E75
00435E74  . C3             RETN                                       RET used as a jump to 00435E75
00435E75  > 8B0D E0274400  MOV ECX,DWORD PTR DS:[4427E0]              <-- PUSH/RET instruction above will redirect execution here
00435E7B  . 3B4D 0C        CMP ECX,DWORD PTR SS:[EBP+C]
00435E7E  .v72 05          JB SHORT 2e3d7d16.00435E85
00435E80  .vE9 9C000000    JMP 2e3d7d16.00435F21
00435E85  > C705 88214400  MOV DWORD PTR DS:[442188],0D13A
00435E8F  . 8B55 08        MOV EDX,DWORD PTR SS:[EBP+8]
00435E92  . 0315 E0274400  ADD EDX,DWORD PTR DS:[4427E0]
00435E98  . 8B02           MOV EAX,DWORD PTR DS:[EDX]
```

1. In this case we can see that a bit of variation is added by calling GetStockObject() twice, once such that it always returns 0x0 and the second time it is called with a valid parameter (WHITE_BRUSH), so that it returns a non-zero value.
2. A PUSH/RET sequence is used to jump to the next address.

Even though this sequence of instructions might appear to be easy to analyze, when a lot of such sequences are combined together, it can help deter analysis to an extent.

Now, we will look at a sequence of instructions where opaque predicates are created without using Window APIs:



```
004360A3  > A1 EC274400    MOV EAX,DWORD PTR DS:[4427EC]
004360A8  . A3 00284400    MOV DWORD PTR DS:[442800],EAX
004360AD  . C705 04284400  MOV DWORD PTR DS:[442804],23C912
004360B7  . 8B0D 04284400  MOV ECX,DWORD PTR DS:[442804]
004360BD  . 81E9 12C92300  SUB ECX,23C912                    <-- Set ecx to 0x0
004360C3  . 890D 04284400  MOV DWORD PTR DS:[442804],ECX
004360C9  . 8B15 04284400  MOV EDX,DWORD PTR DS:[442804]
004360CF  . 8915 08284400  MOV DWORD PTR DS:[442808],EDX
004360D5  > A1 04284400    MOV EAX,DWORD PTR DS:[442804]     <-- Set eax to 0x0
004360DA  . 3B05 EC274400  CMP EAX,DWORD PTR DS:[4427EC]
004360E0  .v0F83 82000000  JNB 2e3d7d16.00436168             <-- This jump will never take place
004360E6  . 8B0D 00284400  MOV ECX,DWORD PTR DS:[442800]
004360EC  . 51             PUSH ECX
004360ED  . 8B15 C0204400  MOV EDX,DWORD PTR DS:[4420C0]
004360F3  . 52             PUSH EDX
004360F4  . E8 17030000    CALL 2e3d7d16.00436410            <-- Call the function with necessary arguments
004360F9  . 83C4 08        ADD ESP,8
004360FC  . A3 0C284400    MOV DWORD PTR DS:[44280C],EAX
00436101  . A1 0C284400    MOV EAX,DWORD PTR DS:[44280C]
```

Let us now look at examples where control flow is obfuscated by injecting junk bytes in such a way that they form partial instructions and are never executed.

Below example shows the disassembly produced by Olly Debugger when the EIP is at the address 00401610. It is important to note that Linear Sweep algorithm is used in this case to generate the disassembly (without the "Analyze Code" option). So, it keeps disassembling the bytes to x86 instructions in sequence as and when it is able form a valid instruction.

```
00401610    E8 04000000        CALL 00401619
00401615    BA DCFE0068        MOV EDX,6800FEDC
0040161A    2016               AND BYTE PTR DS:[ESI],DL
0040161C    40                 INC EAX
0040161D    00EB               ADD BL,CH
0040161F    04 BA              ADD AL,0BA
00401621    DCEE               FSUB ST(6),ST
00401623    0059 EB            ADD BYTE PTR DS:[ECX-15],BL
```

The actual control flow for above code when executed is:

```
00401610    E8 04000000        CALL 00401619
00401619    68 20164000        PUSH 00401620
0040161E    EB 04              JMP SHORT 00401624
00401624    59                 POP ECX
```

Let us now understand how the junk bytes were injected and how they confused the disassembler.

There were 4 bytes injected in between the valid instructions at addresses, **00401610** and **00401619**.

4 junk bytes injected = **BA DC FE 00**

BA = opcode of instruction, **mov edx, <DWORD>**

This is a 5 byte instruction. However, we can see that only 4 bytes are injected which makes the instruction incomplete.

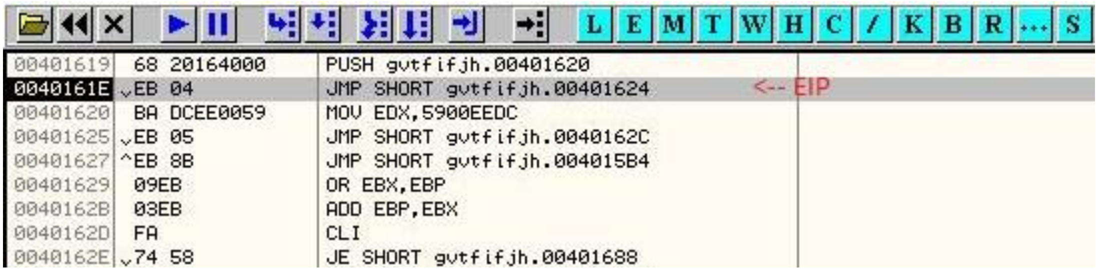
The last byte required to complete the instruction is used from the valid instruction at address, 00401619. The byte in this case corresponds to the PUSH instruction at 00401619.

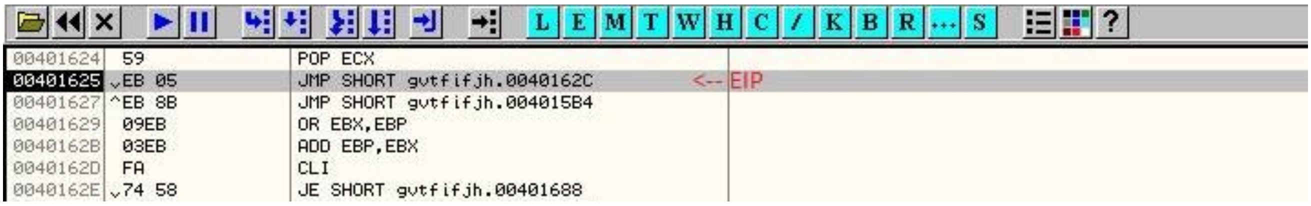
Since the disassembler is making use of Linear Sweep algorithm, it disassembles the 5 bytes to:

```
MOV EDX,6800FEDC
```

As a result of this, the remaining bytes are disassembled incorrectly as well.

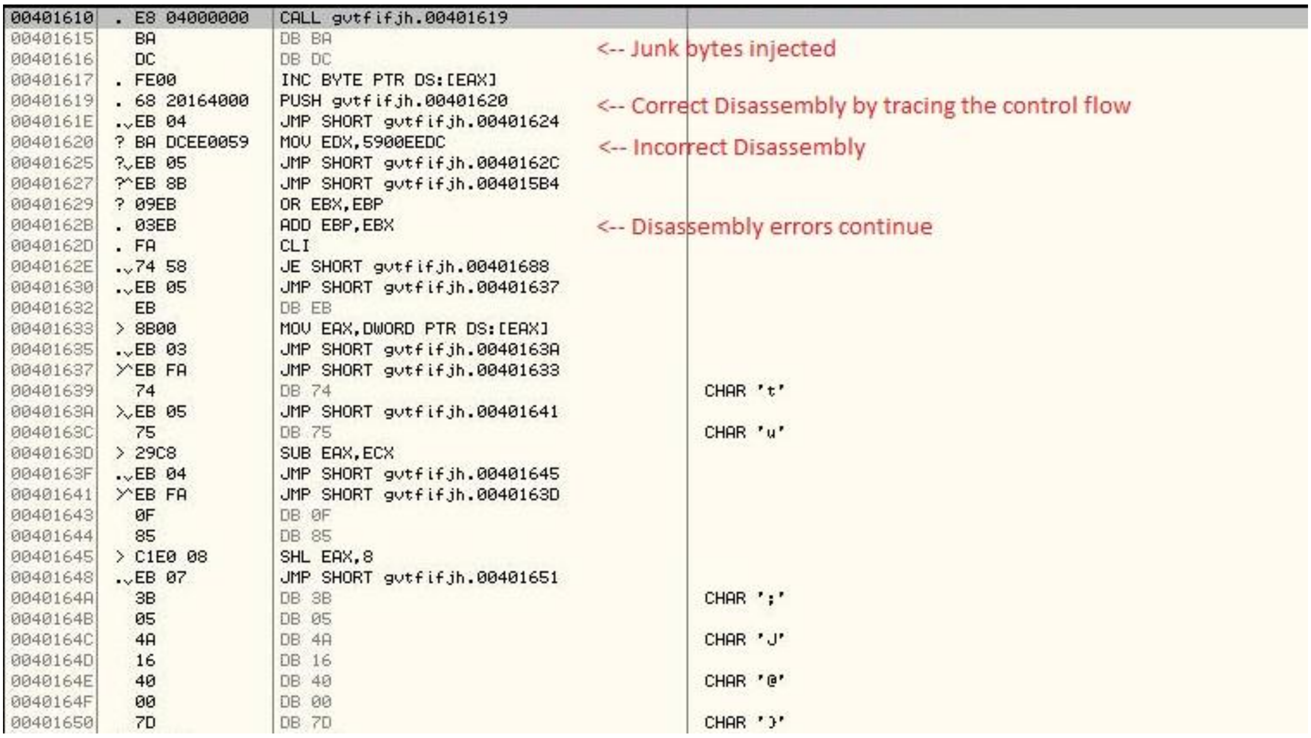
Now, let us look at this code in Olly debugger. When we step through the instructions, debugger will follow the proper control flow. However, since the initial disassembly displayed was not as per the control flow of the code, it will be updated each time we step through it as shown below:





Observe how the disassembly changes each time we step through the code and every time the disassembly changes, the view is updated and instruction at EIP will be at the top of the view.

Olly Debugger is capable of using a **Recursive Traversal** algorithm for disassembling the code as well. It provides us an option to use the “Analyze Code” feature which will disassemble the code based on the control flow. Let us use this feature and apply it to the above code.



We can see that though recursive traversal algorithm is better than linear sweep algorithm at identifying the junk bytes, it is still susceptible to disassembly errors.

The “?” symbol next to the opcodes seen above in Olly Debugger indicates that these instructions were not disassembled properly.

Also, when injecting junk bytes in the code section, we have to make sure that these junk bytes are not executed. In order to do this, unconditional jump instructions are placed before the junk bytes.

Below is an example which shows the initial disassembly and the actual control flow:

```
00401610   E8 04000000      CALL 00401619
00401615   BA DCFE0068      MOV EDX,6800FEDC
0040161A   2016             AND BYTE PTR DS:[ESI],DL
0040161C   40               INC EAX
0040161D   00EB             ADD BL,CH
0040161F   04 BA            ADD AL,0BA
00401621   DCEE             FSUB ST(6),ST
00401623   0059 EB          ADD BYTE PTR DS:[ECX-15],BL
00401626   05 EB8B09EB      ADD EAX,EB098BEB
0040162B   03EB             ADD EBP,EBX
0040162D   FA               CLI
0040162E   74 58            JE SHORT 00401688
00401630   EB 05            JMP SHORT 00401637
00401632  ^EB 8B            JMP SHORT 004015BF
00401634   00EB             ADD BL,CH
00401636   03EB             ADD EBP,EBX
00401638   FA               CLI
00401639  ^74 EB            JE SHORT 00401626
0040163B   05 7529C8EB      ADD EAX,EBC82975
00401640   04 EB            ADD AL,0EB
00401642   FA               CLI
00401643  -0F85 C1E008EB    JNZ EB48F70A
00401649   07               POP ES
0040164A   3B05 4A164000    CMP EAX,DWORD PTR DS:[40164A]
00401650   7D 6A            JGE SHORT 004016BC
00401652   030F             ADD ECX,DWORD PTR DS:[EDI]
00401654   C8 EB05EB        ENTER 5EB,0EB
```

The actual control flow:

```
00401610   E8 04000000      CALL 00401619
00401619   68 20164000      PUSH 00401620
0040161E   EB 04            JMP SHORT 00401624
00401624   59               POP ECX
00401625   EB 05            JMP SHORT 0040162C
0040162C  ^EB FA            JMP SHORT 00401628
00401628   8B09             MOV ECX,DWORD PTR DS:[ECX]
0040162A   EB 03            JMP SHORT 0040162F
0040162F   58               POP EAX
00401630   EB 05            JMP SHORT 00401637
00401637  ^EB FA            JMP SHORT 00401633
00401633   8B00              MOV EAX,DWORD PTR DS:[EAX]
00401635   EB 03             JMP SHORT 0040163A
0040163A   EB 05             JMP SHORT 00401641
00401641  ^EB FA             JMP SHORT 0040163D
0040163D   29C8              SUB EAX,ECX
0040163F   EB 04             JMP SHORT 00401645
00401645   C1E0 08           SHL EAX,8
00401648   EB 07             JMP SHORT 00401651
00401651   6A 03             PUSH 3
```

```
00401653    0FC8              BSWAP EAX
00401655    EB 05             JMP SHORT 0040165C
```

You can observe the excessive use of unconditional jumps to prevent the junk bytes from executing.

Detection of Interesting Instructions using Pintool

Now, let us look at the pintool, which I have written to detect interesting sequence of instructions in malwares.

The reason I wrote a Pintool to do this is because if we rely on Static Byte Signatures, then we are limited to static analysis of the binary (on disk). If the binary is packed then we might not be able to detect the interesting instructions, which would be executed after the binary is unpacked in memory.

Since pintool allows us to perform Dynamic Binary Instrumentation, it would be good to make use of it for this purpose.

Please note that this pintool is not specifically related to control flow obfuscations.

It can be used to detect the following:

1. Obfuscated code sections of the malware.
2. Encryption/Decryption Routines.
3. Function Name Hash generation routines.
4. Junk Instructions inserted by Polymorphic Engines.
5. Privileged Instructions
6. Some methods like GetPC, which are often used by shellcode to be position independent.
7. Execution of special instructions like SIDT, SLDT, SGDT, which indicate the usage of Anti VM, tricks.
8. Execution of RDTSC, which may indicate the usage of Anti Debugging Tricks.
9. And some more interesting instructions can be discovered.

I wrote this tool to help me while analyzing malwares and also to discover interesting viruses in the wild. This is more of a concept at present and it can be extended to discover more malware attributes at an instruction level.

Please note that some of the characteristics mentioned above will also be observed in known packers like UPX, ASPack and so on. You can quickly identify the known packers with PEiD and a good database of known packers byte signatures.

Interestingly, if you run this pintool against a benign binary, you will observe very little to almost no output. As a result of this, it can also be used to detect malicious binaries based on the type of instructions executed.

Below is the code written:

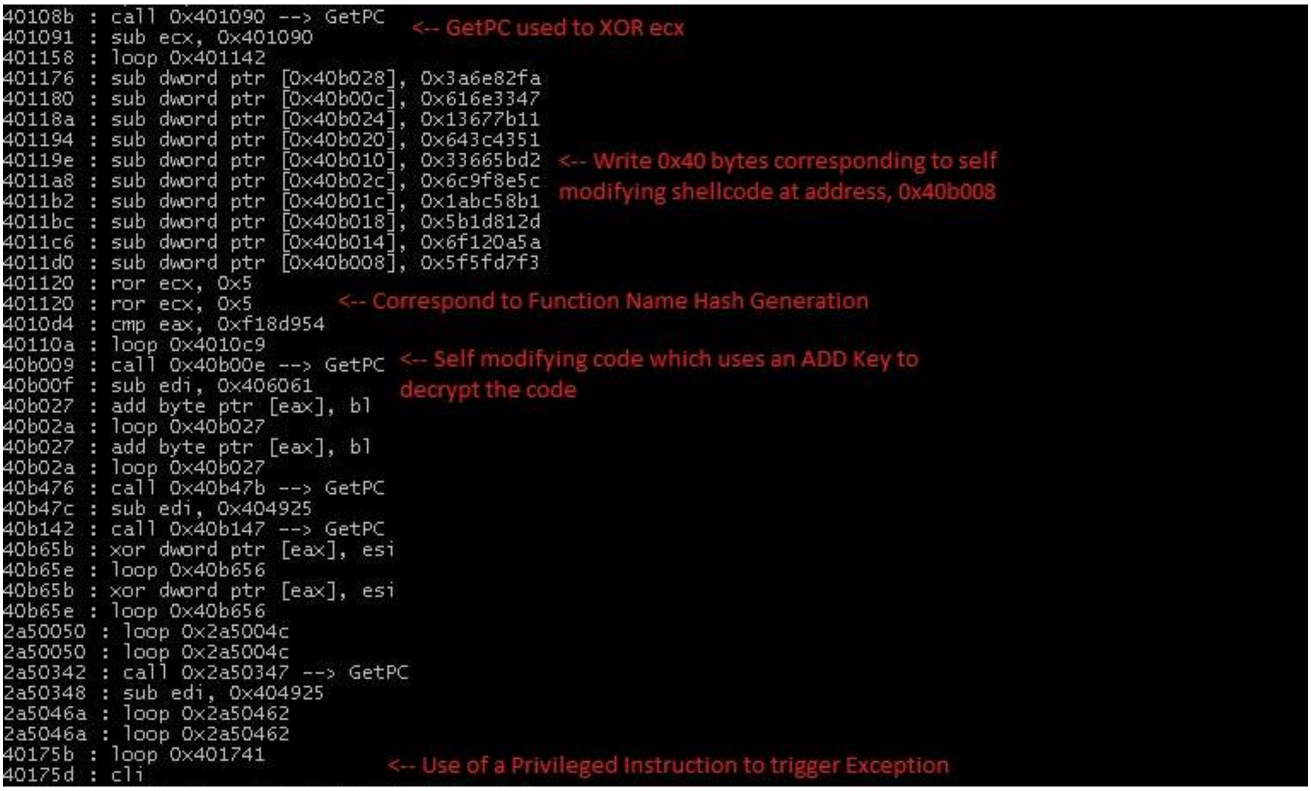
```
/*
Instruction Tracer to identify
interesting sequence of instructions
in malwares.

Sudeep Singh
*/

#include <stdio.h>
#include <iostream>
#include "pin.H"

VOID Instruction(INS ins, VOID *v)
{
    if(INS_Opcode(ins) == XED_ICLASS_XOR && INS_Address(ins) < 0x3d930000)
    {
        if(INS_MaxNumRRegs(ins) == 1)
        {
            cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) <<
endl;
        }
        else
        {
            string regRead;
            string regWrite;
            regWrite = REG_StringShort(INS_RegW(ins, 0));
            regRead = REG_StringShort(INS_RegR(ins, 0));
            if(regRead.compare(regWrite) != 0 && regRead.compare("ebp") != 0 &&
regWrite.compare("ebp") != 0)
            {
                cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins)
<< endl;
            }
        }
    }
    else if(INS_Opcode(ins) == XED_ICLASS_ADD && INS_Address(ins) < 0x3d930000)
    {
        if(INS_MaxNumRRegs(ins) == 1 && INS_RegWContain(ins, REG_ESP) == 0 &&
(INS_OperandImmediate(ins, 1) & 0x00ff0000) != 0 && ((INS_OperandImmediate(ins,
1) & 0x00ffff00) ^ 0x00ffff00) != 0)
        {
            cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) <<
endl;
        }
        else
        {
            string regRead;
            string regWrite;
            regWrite = REG_StringShort(INS_RegW(ins, 0));
            regRead = REG_StringShort(INS_RegR(ins, 0));
            if(regRead.compare(regWrite) != 0 && regRead.compare("ebp") != 0 &&
regWrite.compare("ebp") != 0 && regRead.compare("esp") != 0 &&
regWrite.compare("esp") != 0)
            {
                cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins)
<< endl;
            }
        }
    }
```

```
    else if(INS_Opcode(ins) == XED_ICLASS_SIDT || INS_Opcode(ins) ==
XED_ICLASS_SGDT || INS_Opcode(ins) == XED_ICLASS_SLDT)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_Opcode(ins) == XED_ICLASS_STI || INS_Opcode(ins) ==
XED_ICLASS_CLI)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_Opcode(ins) == XED_ICLASS_SUB && INS_MaxNumRRegs(ins) == 1 &&
INS_RegWContain(ins, REG_ESP) == 0 && (INS_OperandImmediate(ins, 1) & 0x0000ff00)
!= 0 && INS_Address(ins) < 0x3d930000)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_Opcode(ins) == XED_ICLASS_CMP && INS_MaxNumRRegs(ins) == 1 &&
INS_Size(ins) > 0x3 && INS_IsMemoryRead(ins) == 0 && (INS_OperandImmediate(ins,
1) & 0xff000000) != 0 && ((INS_OperandImmediate(ins, 1) & 0x00ffff00) ^
0x00ffff00) != 0 && INS_Address(ins) < 0x3d930000)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_Opcode(ins) == XED_ICLASS_LOOP && INS_Address(ins) < 0x3d930000)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_Opcode(ins) == XED_ICLASS_ROR && INS_MaxNumRRegs(ins) == 1 &&
INS_Address(ins) < 0x3d930000)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_IsCall(ins) && INS_IsIndirectBranchOrCall(ins) == 0)
    {
        if(INS_DirectBranchOrCallTargetAddress(ins) == INS_Address(ins) + 0x5)
        {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << " -->
GetPC " << endl;
        }
    }
    else if(INS_Opcode(ins) == XED_ICLASS_RDTSC)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << endl;
    }
    else if(INS_Opcode(ins) == XED_ICLASS_INT || INS_Opcode(ins) ==
XED_ICLASS_INT1 || INS_Opcode(ins) == XED_ICLASS_INT3)
    {
        cout << hex << INS_Address(ins) << " : " << INS_Disassemble(ins) << "<--
INT instruction" << endl;
    }
}

VOID Fini(INT32 code, VOID *v)
{
    printf("Instrumentation has completed!\n");
}

INT32 Usage()
{
    return -1;
}
```

```
int main(int argc, char * argv[])
{
    if (PIN_Init(argc, argv))
    return Usage();

    INS_AddInstrumentFunction(Instruction, 0);

    PIN_AddFiniFunction(Fini, 0);

    PIN_StartProgram();

    return 0;
}
```

Now, let us run it against some of the viruses discussed previously and understand the output generated.

Below is the output from the pintool for one of the viruses:



We have the addresses corresponding to the instructions of interest. Let us now look at the code sections which have these instructions in the debugger.

```
00401176  . 812D 28B04000  SUB DWORD PTR DS:[40B028],3A6E82FA
00401180  . 812D 0CB04000  SUB DWORD PTR DS:[40B00C],616E3347   <-- Write 0x40 bytes corresponding to self modifying
0040118A  . 812D 24B04000  SUB DWORD PTR DS:[40B024],13677B11       shellcode at 0040b008
00401194  . 812D 20B04000  SUB DWORD PTR DS:[40B020],643C4351
0040119E  . 812D 10B04000  SUB DWORD PTR DS:[40B010],33665BD2
004011A8  . 812D 2CB04000  SUB DWORD PTR DS:[40B02C],6C9F8E5C
004011B2  . 812D 1CB04000  SUB DWORD PTR DS:[40B01C],1ABC58B1
004011BC  . 812D 18B04000  SUB DWORD PTR DS:[40B018],5B1D812D
004011C6  . 812D 14B04000  SUB DWORD PTR DS:[40B014],6F120A5A
004011D0  . 812D 08B04000  SUB DWORD PTR DS:[40B008],5F5FD7F3
004011DA  . 60             PUSHAD
004011DB  . E8 C5FEFFFF    CALL gvtfifjh.004010A5
004011E0  . 68 04B04000    PUSH gvtfifjh.0040B004
004011E5  . 6A 40          PUSH 40
004011E7  . 68 00100000    PUSH 1000
004011EC  . 68 08B04000    PUSH gvtfifjh.0040B008
004011F1  . FFD0           CALL EAX
004011F3  . 61             POPAD
004011F4  .-E9 0F9E0000    JMP gvtfifjh.0040B008                <-- Transfer control to the Shellcode
```

The instructions in the pintools output can be used to identify the Function Name hash generation routine as shown below:

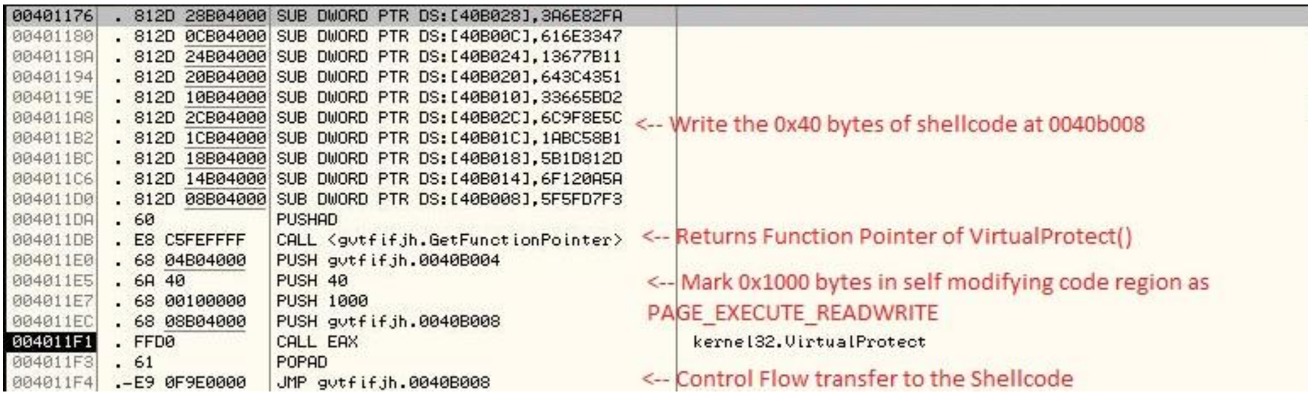
```
00401110 r$ 55            PUSH EBP
00401111 |. 8BEC          MOV EBP,ESP
00401113 |. 56            PUSH ESI
00401114 |. 8B75 08       MOV ESI,DWORD PTR SS:[EBP+8]   <-- Function Name is passed as an argument
00401117 |. 33C9          XOR ECX,ECX
00401119 |> AC            rLODS BYTE PTR DS:[ESI]        <-- Read a byte from the Function Name
0040111A |. 0AC0          |OR AL,AL
0040111C |.v74 07         |JE SHORT gvtfifjh.00401125
0040111E |. 32C8          |XOR CL,AL
00401120 |. C1C9 05       |ROR ECX,5                     <-- Function Name hash will be stored in ECX
00401123 |.^EB F4         LJMP SHORT gvtfifjh.00401119
00401125 |> 8BC1          MOV EAX,ECX                    <-- Return the Function Name Hash
00401127 |. 5E            POP ESI
00401128 |. C9            LEAVE
00401129 L. C2 0400       RETN 4
```

Let us label the subroutine at 00401110 as "**GetFunctionNameHash()**"
If we look up the instruction at address, 004010d4, it brings us to the subroutine used to calculate the Function Pointer.

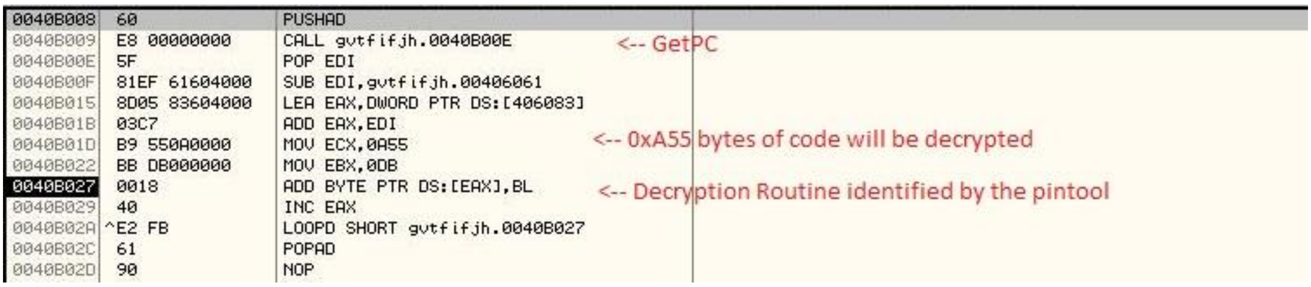
```
004010A5 r$ 53            PUSH EBX
004010A6 |. 56            PUSH ESI
004010A7 |. 57            PUSH EDI
004010A8 |. 64:A1 3000000 MOV EAX,DWORD PTR FS:[30]
004010AE |. 8B40 0C       MOV EAX,DWORD PTR DS:[EAX+C]
004010B1 |. 8B70 1C       MOV ESI,DWORD PTR DS:[EAX+1C]
004010B4 |. AD            LODS DWORD PTR DS:[ESI]
004010B5 |. 8B58 08       MOV EBX,DWORD PTR DS:[EAX+8]
004010B8 |. 8B7B 3C       MOV EDI,DWORD PTR DS:[EBX+3C]
004010BB |. 8B7C1F 78     MOV EDI,DWORD PTR DS:[EDI+EBX+78]
004010BF |. 03FB          ADD EDI,EBX
004010C1 |. 8B4F 18       MOV ECX,DWORD PTR DS:[EDI+18]
004010C4 |. 8B77 20       MOV ESI,DWORD PTR DS:[EDI+20]
004010C7 |. 03F3          ADD ESI,EBX
004010C9 |> 60            rPUSHAD
004010CA |. 8B36          |MOV ESI,DWORD PTR DS:[ESI]
004010CC |. 03F3          |ADD ESI,EBX
004010CE |. 56            |PUSH ESI
004010CF |. E8 3C000000   |CALL <gvtfifjh.GetFunctionNameHash>
004010D4 |. 3D 54D9180F   |CMP EAX,0F18D954        <-- Compare with the Hash of VirtualProtect()
004010D9 |.v75 2B         |JNZ SHORT gvtfifjh.00401106
004010DB |. 61            |POPAD
004010DC |. 8B57 20       |MOV EDX,DWORD PTR DS:[EDI+20]
004010DF |. 03D3          |ADD EDX,EBX
004010E1 |. 2BF2          |SUB ESI,EDX
004010E3 |. D1EE          |SHR ESI,1
004010E5 |. 8B47 24       |MOV EAX,DWORD PTR DS:[EDI+24]
004010E8 |. 03C3          |ADD EAX,EBX
004010EA |. 03C6          |ADD EAX,ESI
004010EC |. B9 00000000   |MOV ECX,0
004010F1 |. 66:8B08       |MOV CX,WORD PTR DS:[EAX]
004010F4 |. C1E1 02       |SHL ECX,2
004010F7 |. 8B47 1C       |MOV EAX,DWORD PTR DS:[EDI+1C]
004010FA |. 03C3          |ADD EAX,EBX
004010FC |. 03C1          |ADD EAX,ECX             <-- Return the Function Pointer of VirtualProtect()
004010FE |. 8B00          |MOV EAX,DWORD PTR DS:[EAX]
```

Let us label the subroutine at address, 004010A5 as **GetFunctionPointer()**

We will look up the instruction at address, 00401176 in debugger:



If we trace the code to the shellcode at address, 0040b008 we can see that the pintool identified the decryption routine correctly.



By putting all this together we have the flow as:

1. The code manually crafts a 0x40 bytes shellcode at address 0x0040b00e using a sequence of Sub instructions.
2. It calculates the function pointer of VirtualProtect() using a precalculated function name hash and by parsing the export directory of kernel32.dll
3. It calls VirtualProtect() to mark 0x1000 bytes at address, 0x0040b00e as PAGE_EXECUTE_READWRITE since this region of code will be self modified and then executed.
4. Transfers the control flow to 0x0040b00e.
5. Uses GetPC to identify the address of code to be decrypted.
6. Uses a one byte ADD key, 0xDB to decrypt 0xA55 bytes of code and then continues executing the decrypted code.

This way, we can see how the pintool helped us quickly identify the useful sections of code. This will help us in performing an indepth analysis of the control flow of the code, to understand the packer used and the decryption routines used as well.

Conclusion

After reading this paper you will have an understanding of the various techniques used by viruses in the real world to obfuscate the code to deter reverse engineering.

This should help in analyzing viruses which use similar techniques as it is becomingly increasingly common for viruses to prevent the analysis of their code.

References

Pintool: http://software.intel.com/sites/landingpage/pintool/docs/49306/Pin/html/
MSDN: http://msdn.microsoft.com/
OllyDbg: http://www.ollydbg.de/
RaiseException Reference: http://waleedassar.blogspot.in/2012/11/ollydbg-raiseexception-bug.html