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ADVANCED MALWARE REVERSE ENGINEERING:

Dealing with anti-analysis techniques from scratch

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JSAC 2026

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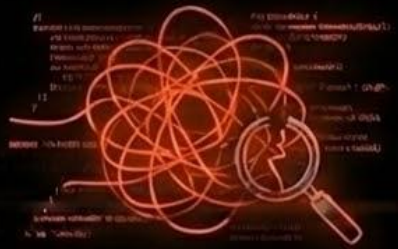
- Based in Singapore
- Love to go for long jogs

Target Audience

Are you frequently encountering binaries from threat intelligence reports or your own environment that leave you **wanting more information**?

Perhaps you've tried the usual routes – running them in a sandbox or submitting them to VirusTotal – only to find the resulting **intelligence lacking**.



You might have even attempted a deeper dive into the sample yourself, only to be **overwhelmed by sophisticated anti-analysis techniques** that leave you feeling lost and unsure how to proceed.

The flow of the workshop

1. LEARN THE THEORY

Understand the underlying concepts and techniques.

2. GET A TASK

Receive a practical, real-world challenge.

3. SOLVE THE PROBLEM

Apply your knowledge to solve it independently.

4. TRAINER REVIEW & Q&A

Discuss solutions, difficulties, and get answers.

OUTLINE

- Introduction
- Lab Preparation and Environment Setup
- Phase 1: VBS file
- Phase 2: Powershell
- Phase 3: shellcode stage 1

Coffee Break (15:20 - 15:50)

- Phase 4: shellcode stage 2
- Phase 5: Malware Configuration Extraction

WARNING!

1. Isolate infected systems: Disconnect from networks and external devices.

2. Utilize virtual machines

3. Backup data: Ensure critical data is safely backed up.

4. **You release and hold harmless Palo Alto Networks and JSAC, its affiliates, and contributors from any liability, claims, or damages arising from handling live computer viruses.**

Get the stuff!

- https://tinyurl.com/JSAC26RE

Lab Preparation and Environment Setup

Lab Preparation and Environment Setup

ANALYSIS ENVIRONMENT & GOALS

Know what OS you are analysing on

- OS patch levels
- Win 7 vs Win 10 vs Win 11

Analysis Tools

- Static and dynamic analysis

Goal of the analysis

- Extract indicators of Compromise (IOCs)
- Quick triage vs deep analysis

VM CONFIGURATION & SETUP

Set up your own analysis image

- Make it as close to the victim's environment
- E.g. timezone, language, keyboard layout, connect to AD ?

Networking

- Connect to internet/ FakeNet/ ?
- MAC address configuration

Type of hypervisor

- VMware, Vbox, Hyper V
- Vmware Tools ?

You should know your environment better than the malware.

A Laptop bought off the shelf is very different from OS installed from ISO

Lab Preparation and Environment Setup

REQUIREMENTS

Laptops that has at least 8GB RAM and 100GB of free SSD space

ADVANCE PREPARATION

Please setup a Windows 10 Flare VM image (https://cloud.google.com/blog/topics/threat-intelligence/flarevm-open-to-public/

SOFTWARE CHECKLIST

- Visual Studio Community 2022 (Able to develop and compile C#)
- IDA Pro latest version (Free version is good enough)
- Python 3.13 (x64)
- Unicorn Framework (https://www.unicorne.org/)
- DnSpy (https://github.com/dnSpyEx/dnSpy)
- Visual Studio Code with Powershell extension (https://marketplace.visualstudio.com/items?itemName=ms-vscode.PowerShell)

Guloader

Phishing Email

.7z Attachment

VBS file extracted

POWERSHELL executed

Download Guloader Payload

Guloader shellcode Stage1

Guloader shellcode Stage2

Retrieves Gremlin Stealer

Phase I: VBS file

Guloader

VBS file

Static analysis

Analyse the script without running it

Step 1: Identifying Junk Code
The script will contain hundreds of lines of random variable assignments that do nothing.

- *Technique*: Look for the Execute or Eval statement at the bottom of the script. Trace the variable passed to it (e.g., Execute(FinalString), CreateObject(), Call, Run()).
- *Trace Back*: Work backward from FinalString. You will see it is constructed by concatenating other variables.
- *Optimization*: Use a text editor like Notepad++ or VS Code. Highlight the variable name to see all occurrences. If a variable is assigned a value but never referenced again, it is junk.

Step 2: String Reconstruction with Python or other similar tools
GuLoader uses standard VBS string functions to hide its intent.

- Chr() Encoding: Converts decimal ASCII values to characters (e.g., Chr(80) is 'P').
- StrReverse(): Reverses a string (e.g., "llehsrewoP" becomes "PowerShell").
- Replace(): Removes specific junk characters inserted to break signatures.
- Base64 encoding ?

Insight: The output from an obfuscated script is rarely cleartext. It is usually a **PowerShell** command line or similar, often Base64 encoded. This illustrates the "matryoshka doll" nature of modern loaders—one language wraps another.

Exercise 1

Initial Triage

- What are the hashes of the samples?
- What are the file types of the samples?

Deep dive

- What are the anti-analysis techniques involved?
- What are the external components called?

Goal

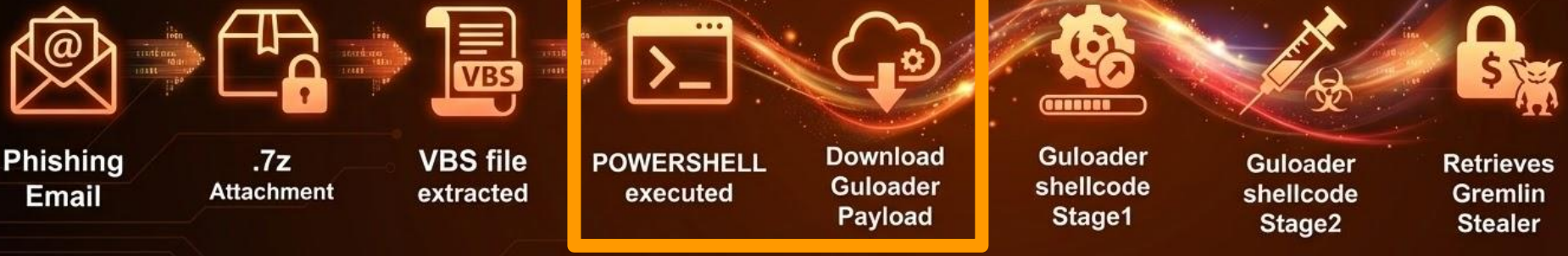
- Obtain the Powershell from VBS file

Exercise 1

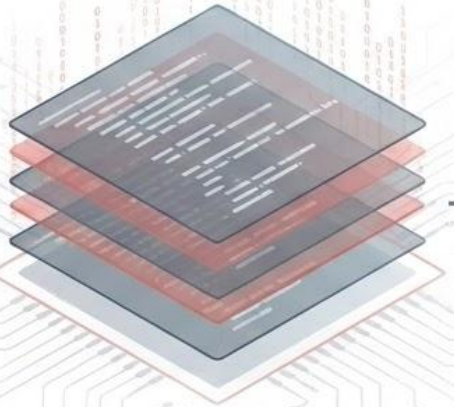
Walk-through and Demo

Phase II: Powershell

Guloader



MALICIOUS POWERSHELL SCRIPTS



USUALLY HAS MULTIPLE LAYERS

ACTIVITIES

- DOWNLOAD PAYLOAD
- EXTRACT AND DECODE PAYLOAD
- EXECUTE PAYLOAD

ANALYSIS TIPS & NOTES

- TAKE NOTE OF OBFUSCATION TECHNIQUES
- TAKE NOTE OF ANTI-DEBUGGING
- USE ‘WRITE-HOST $VARIABLE’ TO AID IN DEBUGGING

Powershell

Most Common Obfuscation Techniques.

Nonsensical Naming and Formatting

- **Random Names:** Variables and functions have meaningless names (e.g., $asfgr, $var1, $Krydshovedmotor).
- **Backticks (`):** Used to break up commands and keywords (e.g., `` `I`E`X` ``, `` `S`e`t-`V`a`r`ia`b`l`e` ``).
- **Inconsistent Casing:** Mixing cases to fool detection (e.g., iNvoKe-eXpReSsiOn).
- **Whitespace:** Excessive newlines, tabs, and spaces to make the script hard to read.

String Manipulation

Commands are built at runtime, rarely typed out.

- **Character Extraction:** Building commands by picking out individual characters from a garbled string.
- **Encoding and Compression:** Encoding (Base64) or compressing scripts to hide them.

Concatenation

- **Simple Concatenation:** `` `I' + 'E' + 'X' `` builds the command `` `IEX` ``.
- **-f Format Operator:** `` `{0}{1}' -f 'I','EX' `` builds `` `IEX` ``.
- **-join Operator:** `('I','E','X') -join ''` builds `` `IEX` ``.
- **String Reversal:** `-join ('XEI'[2,1,0])` reverses a string to get the command.
- **-replace Operator:** `'IaxbEX'.replace('axb','')` removes junk characters.

Powershell

The Analysis Methodology (How to Deobfuscate)

WARNING: NEVER run a suspicious script on your machine or a production system. Use an isolated virtual machine (VM) that is disconnected from the network.

Static Analysis (Safe Reading)

- Open the script in a text editor (like VS Code with the PowerShell extension).
- Look for the patterns from Step 1. Goal is to find the deobfuscation routine (builds strings) and the execution command (like iex).
- **Example**: Deobfuscation routine is the 'Piftet' function, execution command is 'iex' (hidden in 'Udeblivelsens220' function).

'Neutering' the Script

- **Key:** Let the script deobfuscate itself without executing malicious commands.
- Find the final execution point. Search for **Invoke-Expression**, **iex**, **&**, or other dynamic execution methods.
- Replace execution with printing. Change command to Write-Host or Write-Output.
- **Example**: Change 'iex $ObfuscatedCommand' to 'Write-Host $ObfuscatedCommand'.

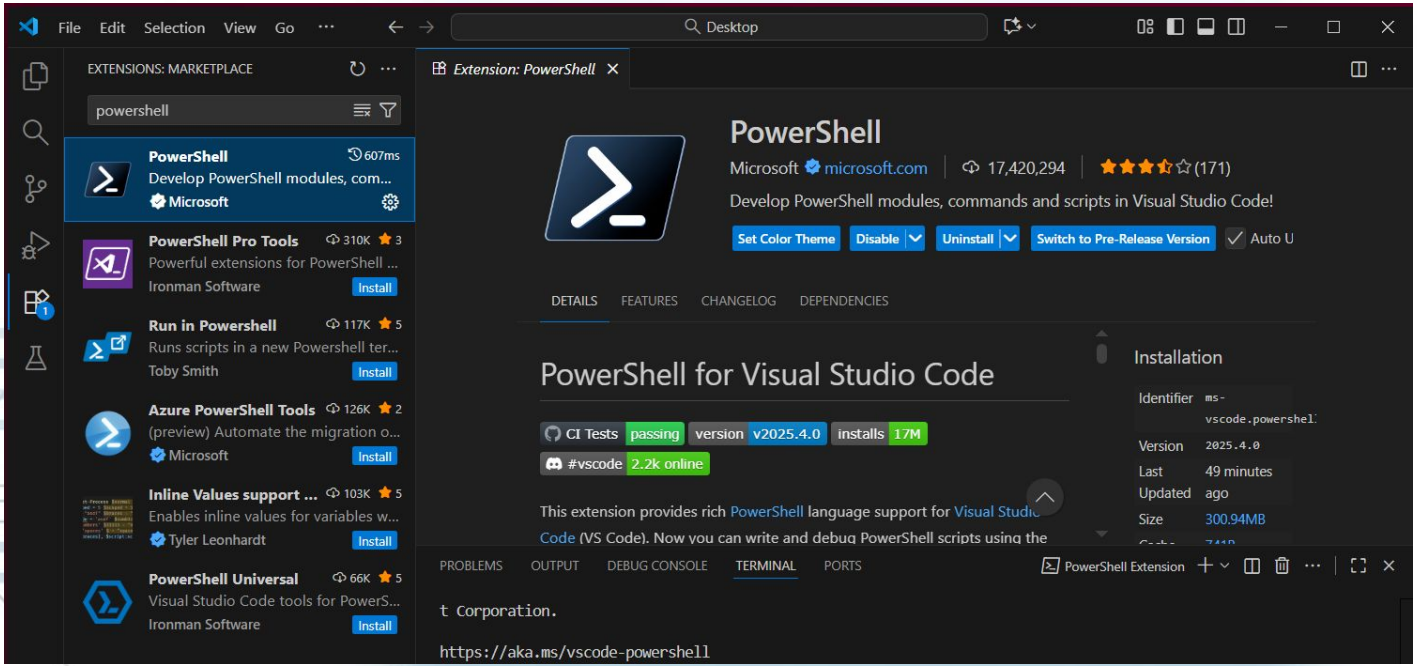
```
powershell\
Write-Host $ObfuscatedCommand
```

Creating a Decoder

- For complex scripts, create a separate 'decoder' script.
- Create a new, blank .ps1 file.
- Copy the deobfuscation functions (like 'Piftet') into your new script.
- Copy obfuscated strings and pass them to the function, wrapped in Write-Host.

Powershell

Debugging .ps1 using **Visual Studio Code**
Install **Powershell extension** from **Microsoft**



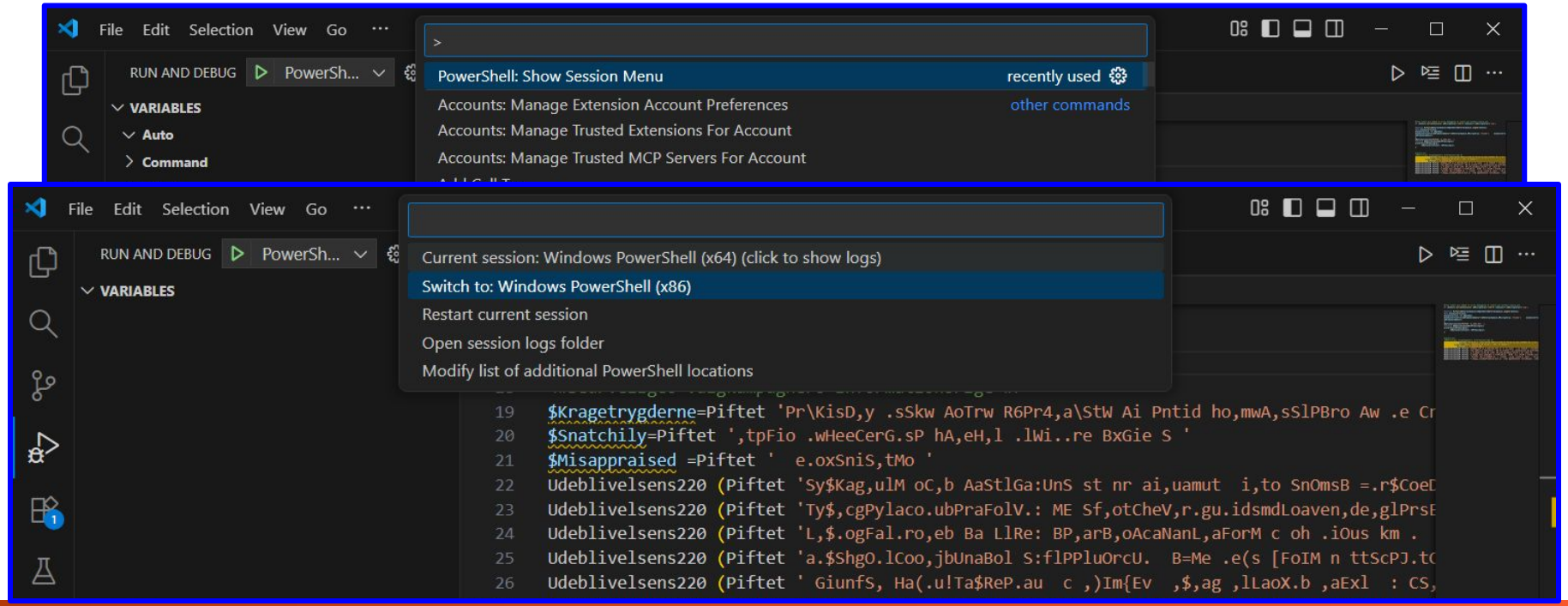
Powershell

Switch to Powershell x86 (if needed)

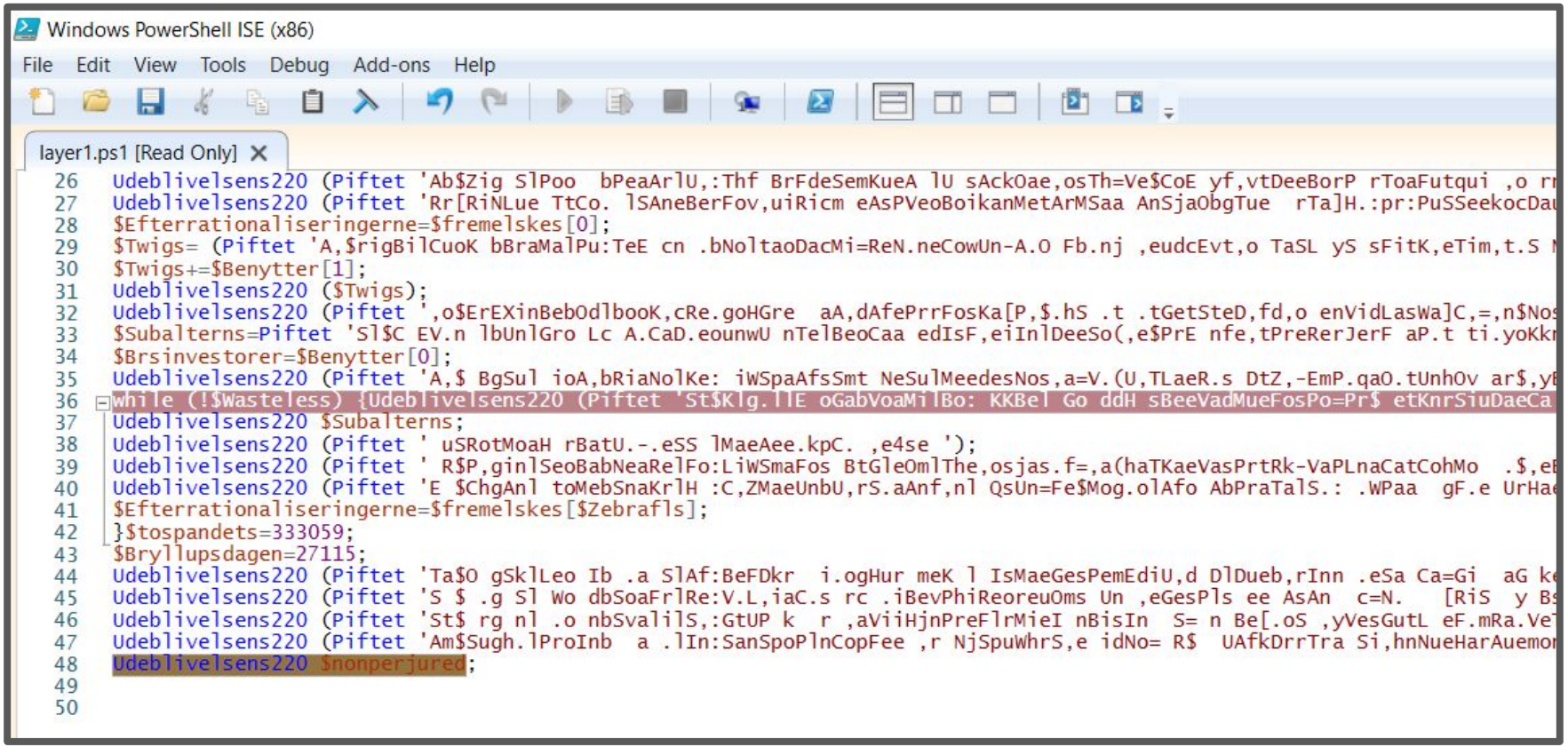
1. Open the Command Palette (`Ctrl+Shift+P`)
2. Type and select "**PowerShell: Show Session Menu**"
3. Type and select "**Switch to: Windows Powershell (x86)**"

To delete variables created in session (if needed)

1. Open the Command Palette (`Ctrl+Shift+P`)
2. Type and select: "**`PowerShell: Restart Session`**."



Powershell



Powershell (Guloader)

1. **Download** and **extract** payload from the internet

2. **Self-Relaunch:** The script first checks if it's running in a 64-bit process. If so, it relaunches itself using the 32-bit version of PowerShell.

3. **Dynamic API Loading:** It dynamically resolves addresses of several Windows API functions need for code injection

4. **Shellcode Injection and Execution** into its own process

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Powershell (Guloader)

Shellcode Injection and Execution

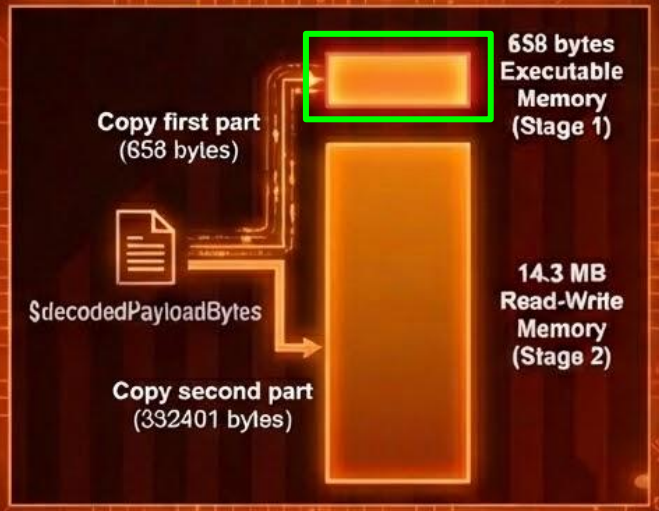
Allocate a small (658 bytes) executable memory region.

Allocate a large (14.3 MB) read-write memory region.

Copy the first part of the $decodedPayloadBytes (658 bytes) into the **first** executable region.

Copy the second part of the $decodedPayloadBytes (332401 bytes) into the **second** read-write region.

Use **CallWindowProcA** to jump to the **first** shellcode address



Exercise 2

Analysis Goals & Tasks

- Analyse the powershell (layers) to figure out how it works
- Figure out what to do with the file ‘Eyeable49.xtp’
- Determine the URL that hosted the encrypted payload
- Take note how the powershell layers interact with one another
- How was the payload encrypted ?
- Explain how the payload is extracted, decrypted and executed by powershell
- What were the Windows APIs used for calling the shellcode(s) ?

Goal:

Obtain the shellcode(s)

Exercise 2

Walk-through and Demo

Guided analysis and live demonstration of the techniques.

Exercise 2

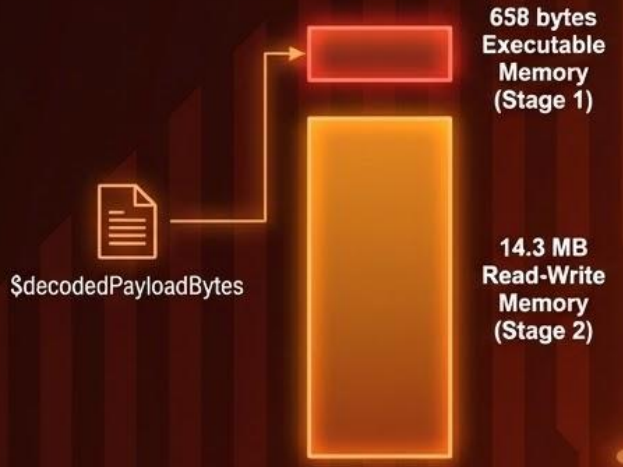
STAGE 1: PAYLOAD & EXECUTION

1. Download payload from "ht-tps://softiq.ro/event/update/Eyeable49.xtp"
2. Copy payload file to "%appdata%\skaberevners.Dam"
3. Continue to download payload till successful
4. Read contents into $decodedPayloadBytes
5. Base64 decode $decodedPayloadBytes
6. Extract NEXT layer of powershell script
7. Continue execution into NEXT layer

STAGE 2: PROCESS HOLLOWING & INJECTION

8. Relaunch current script in x86 powershell.exe if running in x64
9. Dynamically resolve Windows APIs (VirtualAlloc, ShowWindow, CallWindowProcA, NtProtectVirtualMemory)
10. Call ShowWindow with CmdShow = SH_HIDE for anti-debugging
11. Allocate small (658 bytes) executable memory region
12. Allocate large (14.3 MB) read-write memory region
13. Copy first part of $decodedPayloadBytes (658 bytes) to first region
14. Copy second part (332401 bytes) to second region
15. Use CallWindowProcA to jump to shellcode address (lpPrevWndFunc = shellcode, hWnd = second stage pointer, Msg = NtProtectVirtualMemory address)

Exercise 2




```
# --- Allocate memory and copy shellcode ---

# First part of $decodedPayloadBytes contains 2 shellcodes (658 bytes and 332401 bytes)
# Constants for VirtualAlloc
$MEM_COMMIT_RESERVE = 0x3000 # 12288
$PAGE_EXECUTE_READWRITE = 0x40 # 64
$PAGE_READWRITE = 0x04 # 4

# Allocate a small (658 bytes) executable memory region.
$firstStageShellcodePtr = $virtualAllocDelegate.Invoke([IntPtr]::Zero, 658,
$MEM_COMMIT_RESERVE, $PAGE_EXECUTE_READWRITE)

# Allocate a large (14.3 MB) read-write memory region.
$secondStageShellcodePtr = $virtualAllocDelegate.Invoke([IntPtr]::Zero, 14991360,
$MEM_COMMIT_RESERVE, $PAGE_READWRITE)

# Copy the first part of the $decodedPayloadBytes (658 bytes) into the first executable region.
[System.Runtime.InteropServices.Marshal]::Copy($decodedPayloadBytes, 0,
$firstStageShellcodePtr, 658)

# Copy the second part of the $decodedPayloadBytes (332401 bytes) into the second read-write
region.
$secondStageSize = 332401
[System.Runtime.InteropServices.Marshal]::Copy($decodedPayloadBytes, 658,
$secondStageShellcodePtr, $secondStageSize)
```

Exercise 2: Executing Shellcode via Callbacks

Technique: Abusing Windows Callbacks

Utilizing `CallWindowProcA` to divert execution flow to shellcode. Parameters are repurposed for this technique.

- `lpPrevWndFunc`: Address of shellcode to execute.
- `hWnd`: Pointer to second stage shellcode.
- `Msg`, `wParam`, `lParam`: Unused parameters.

PowerShell Execution

```
# --- Execute the shellcode ---

# Use CallWindowProcA to jump to shellcode address.
# Parameters repurposed as described.

$callWindowProcADelegate.Invoke(
    $firstStageShellcodePtr,    # lpPrevWndFunc
    $secondStageShellcodePtr,   # hWnd
    $ntProtectVirtualMemoryPtr,# Msg
    [IntPtr]::Zero,             # wParam
    [IntPtr]::Zero              # lParam
)
```

🔗 Reference: https://osandamalith.com/2021/04/01/executing-shellcode-via-callbacks/

Phase III: Shellcode Stage1

Guloader

Shellcode Stage 1

Core Concepts

PowerShell as a Loader: PowerShell is often used to download and execute more potent, native code (shellcode) because it's powerful and present on all modern Windows systems.

Staged Payloads: Malware frequently uses a small "stager" shellcode to prepare and execute a larger, main payload. The stager's job is often just to make the main payload executable.

Step 1: Extract the Shellcode

1. **Examine the PowerShell Script**: Look for how the shellcode is stored. It's usually in a byte array ([Byte[]]) that has been decoded from a Base64 or hex string.
2. **Find the Injection**: Locate the part of the script that copies the shellcode into memory. This is often done with [System.Runtime.InteropServices.Marshal]::Copy.

```
# Generic Shellcode Dumper
# In the script, find the variable holding the shellcode byte array.
# Let's assume it's called $shellcodeBytes

# Use this command in the PowerShell ISE debugger or a modified script
# to dump the contents to a file.
[System.IO.File]::WriteAllBytes("C:\\path\\to\\your\\analysis\\folder\\
shellcode.bin", $shellcodeBytes)

Write-Host "[+] Shellcode dumped to shellcode.bin"
```

Shellcode Stage 1

Step 2: Static Analysis (A Quick Look)

Preparation

Before running the code, use a disassembler to get clues about its function.

1. Open shellcode.bin in Ghidra or IDA.
2. Set the correct architecture (x86 or x64) based on your findings from the script.
3. Load it at address 0x00000000 and start disassembling.

What to look for:

API Resolving: Look for loops that perform bitwise operations (ROR, ROL, XOR). This is a classic sign of API hashing, a technique to find functions like VirtualAlloc without using readable strings.

Memory Protection Changes: Search for calls to VirtualProtect or NtProtectVirtualMemory. A stager shellcode will often use these to change a region of memory containing the main payload to be executable.

Shellcode Stage 1

Step 3: Dynamic Analysis (Live Debugging)

1. Modify the Script for Debugging:

- Find the line that triggers the shellcode execution (e.g., CreateThread or a delegate's .Invoke() method).
- Insert an infinite loop right before it. This freezes the script, giving you time to attach your debugger.

```
Write-Host "Pausing for debugger attachment. PID: $PID"
while ($true) { Start-Sleep -Seconds 1 }

# ... original line that executes the shellcode ...
```

process with the matching PID.

3. Find the Shellcode and Set a Breakpoint:

- In the debugger, go to the **Memory Map** tab.
- Look for memory regions with **PAGE_EXECUTE__** permissions. Your shellcode will be in one of these. You can often identify it by its size, which you know from the script's VirtualAlloc call.
- Go to that address in the **CPU (Disassembly)** view. You should see the same instructions you saw in your disassembler.
- Set a breakpoint (**F2**) on the first instruction of the shellcode.

2. Run and Attach:

- Run the modified script in the correct PowerShell environment (32-bit or 64-bit).
- Note the Process ID (PID) it prints.
- Open x32dbg/x64dbg, go to File -> Attach, and select the powershell.exe process with the matching PID.

4. Trace and Analyze:

- Return to the PowerShell window and press **Ctrl+C** to break the infinite loop.
- The script will resume and immediately hit your breakpoint in the debugger.
- You are now at the start of the shellcode. Use **F7 (Step-Into)** and **F8 (Step-Over)** to trace its execution.
- Watch the registers and memory to understand what it's doing. Confirm your static analysis theories, such as watching it call VirtualProtect and then jump to the next stage.

Shellcode Stage 1

Debugging Shellcode

- From powershell to shellcode Stage1
- Debugging shellcode Stage1
- Setting Breakpoint at CallWindowProcA() the caller of shellcode

Key Questions

- What does **firststageshellcode** do ?
- What does **secondstageshellcode** do ?

DEBUGGER VIEW

```
user32.dll:75714BB0 ; Attributes: bp-based frame
user32.dll:75714BB0
user32.dll:75714BB0 user32_CallWindowProcA proc near
user32.dll:75714BB0
user32.dll:75714BB0 arg_0= dword ptr  8
user32.dll:75714BB0 arg_4= dword ptr  0Ch
user32.dll:75714BB0 arg_8= dword ptr  10h
user32.dll:75714BB0 arg_C= dword ptr  14h
user32.dll:75714BB0 arg_10= dword ptr  18h
user32.dll:75714BB0
user32.dll:75714BB0 mov     edi, edi
user32.dll:75714BB2 push    ebp
user32.dll:75714BB3 mov     ebp, esp
user32.dll:75714BB5 mov     edx, [ebp+arg_4]
user32.dll:75714BB8 mov     ecx, [ebp+arg_0]
user32.dll:75714BBB push    1
```

CallWindowProcA	user32_CallWindowProcA
CallWindowProcW	user32.dll:user32_CallWindowProcW
CallMsgFilterW	user32.dll:user32_CallMsgFilterW
CallNextHookEx	user32.dll:user32_CallNextHookEx
SendMessageCallbackW	user32.dll:user32_SendMessageCallbackW
DdeEnableCallback	user32.dll:user32_DdeEnableCallback
CallMsgFilter	user32.dll:user32_CallMsgFilter
CallMsgFilterA	user32.dll:user32_CallMsgFilter
SendMessageCallbackA	user32.dll:user32_SendMessageCallbackA

Shellcode Stage 1

- **Debugging** Stage 1 shellcode

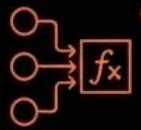
Attaching debugger to powershell.exe process to set breakpoint at the callback API (**CallWindowsProcA**) to locate the Stage 1 shellcode entry point.

Please watch DebugStage1ShellCode.mp4

Exercise 3

- Analyse the shellcode **firststageshellcode** to figure out how it works

- Determine the important **execution loops** in **firststageshellcode** and their purpose



- How are the 3 parameters to **callWindowProcA()** utilised in the **firststageshellcode** ?

Goal:

What does **firststageshellcode** do ?

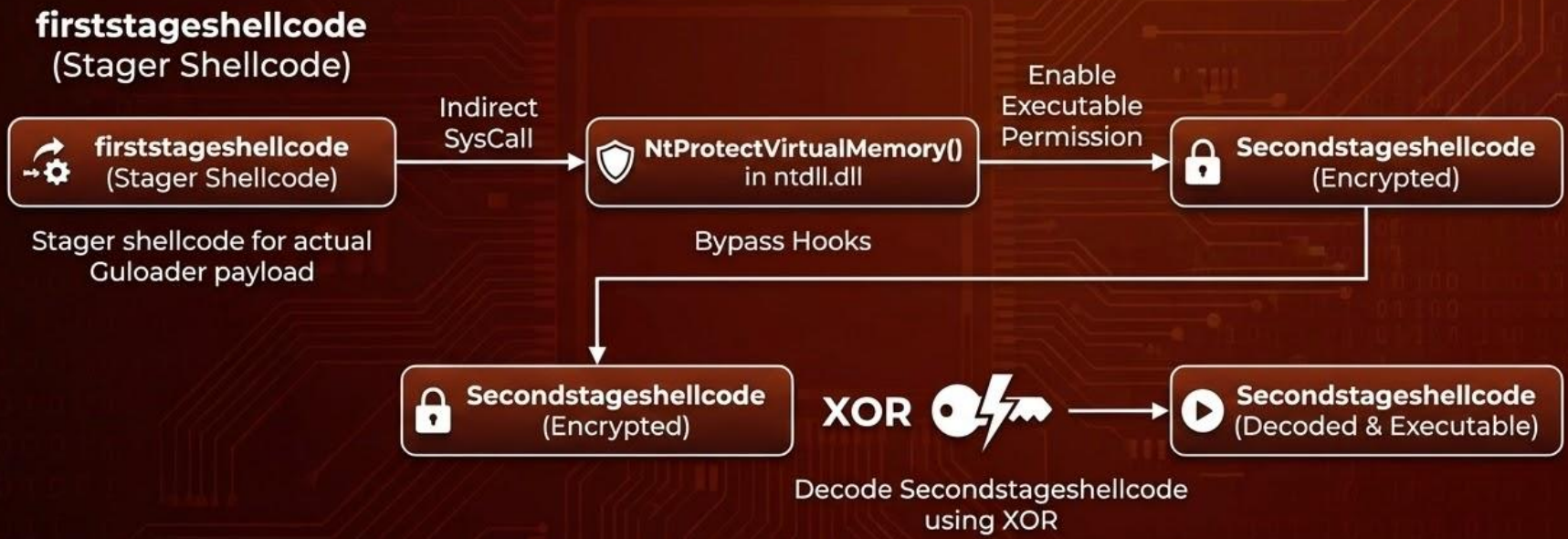
Exercise 3

Walk-through and Demo

Guided analysis and live demonstration of the techniques.

Exercise 3

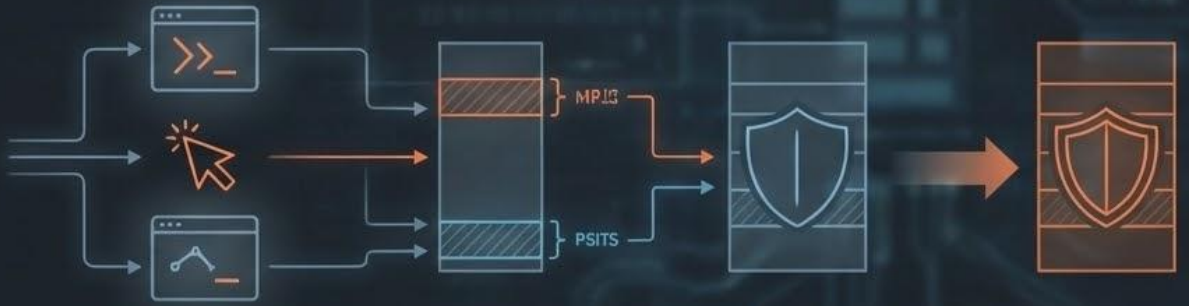
firststageshellcode



Exercise 3

```
/**
 * The NtProtectVirtualMemory routine changes the protection on a region of virtual memory.
 *
 * \param ProcessHandle A handle to the process whose memory protection is to be changed.
 * \param BaseAddress A pointer to the base address of the region of pages whose access protection attributes are to be changed.
 * \param RegionSize A pointer to a variable that specifies the size of the region whose access protection attributes are to be changed.
 * \param NewProtection The memory protection option. This parameter can be one of the memory protection constants.
 * \param OldProtection A pointer to a variable that receives the previous access protection of the first page in the specified region of pages.
 * \return NTSTATUS Successful or errant status.
 */

NTSYSCALLAPI NTAPI NTSSTATUS
NtProtectVirtualMemory(
    _In_ HANDLE ProcessHandle,
    _Inout_ PVOID *BaseAddress,
    _Inout_ PSIZE_T RegionSize,
    _In_ ULONG NewProtection,
    _Out_ PULONG OldProtection
    );
```



Exercise 3

Indirect Syscalls Explained

1. The Problem: Inline Hooks

- **Normal Execution:** App → NtFunction (Hooked by EDR) → EDR Inspection → Kernel.
- **The Hook:** EDRs overwrite the first 5 bytes (prologue) of the API with a JMP to their inspection DLL.

Direct vs. Indirect Syscalls

Feature	Direct Syscalls	Indirect Syscalls
Syscall Instruction Location	Inside Malware (.text or Heap) 	Inside ntdll.dll 
Bypasses Prologue Hooks?	No 	Yes 
Bypasses RIP/Sanity Checks?	No (Flagged as anomalous) 	Yes (Looks legitimate) 
Implementation Complexity	Low/Medium 	High (Requires gadget finding) 

Exercise 3

Indirect SysCalls

```
ntdll.dll:774836E0 _ZwProtectVirtualMemory@20:              ; CO
ntdll.dll:774836E0                                         ; Rt
ntdll.dll:774836E0 mov     eax, 50h ; 'p'
ntdll.dll:774836E5
ntdll.dll:774836E5 loc_774836E5:
ntdll.dll:774836E5 mov     edx, offset _Wow64SystemServiceCall@
ntdll.dll:774836E5 call    edx ; Wow64SystemServiceCall()  ; Wo
ntdll.dll:774836EC retn    14h
ntdll.dll:774836EC ; ---------------------------------------
ntdll.dll:774836EF db  90h
ntdll.dll:774836F0
```

```
EAX 00000050
EBX 4991f0BA
ECX 00000010
EDX 774836E5  ntdll.dll:ntdll_NtProtectVirtualMemory+5
ESI 00000001
EDI 12F70000  debug793:12F70000
EBP 0D17DFC8  Stack[00000AA0]:0017DFC8
ESP 0D17E288  Stack[00000AA0]:0017E288
EIP 774836E5  ntdll.dll:ntdll_NtProtectVirtualMemory+5
```

JMP into 5 bytes after function prologue to bypass possible EDR hook

EDR Hook

NTDLL.dll

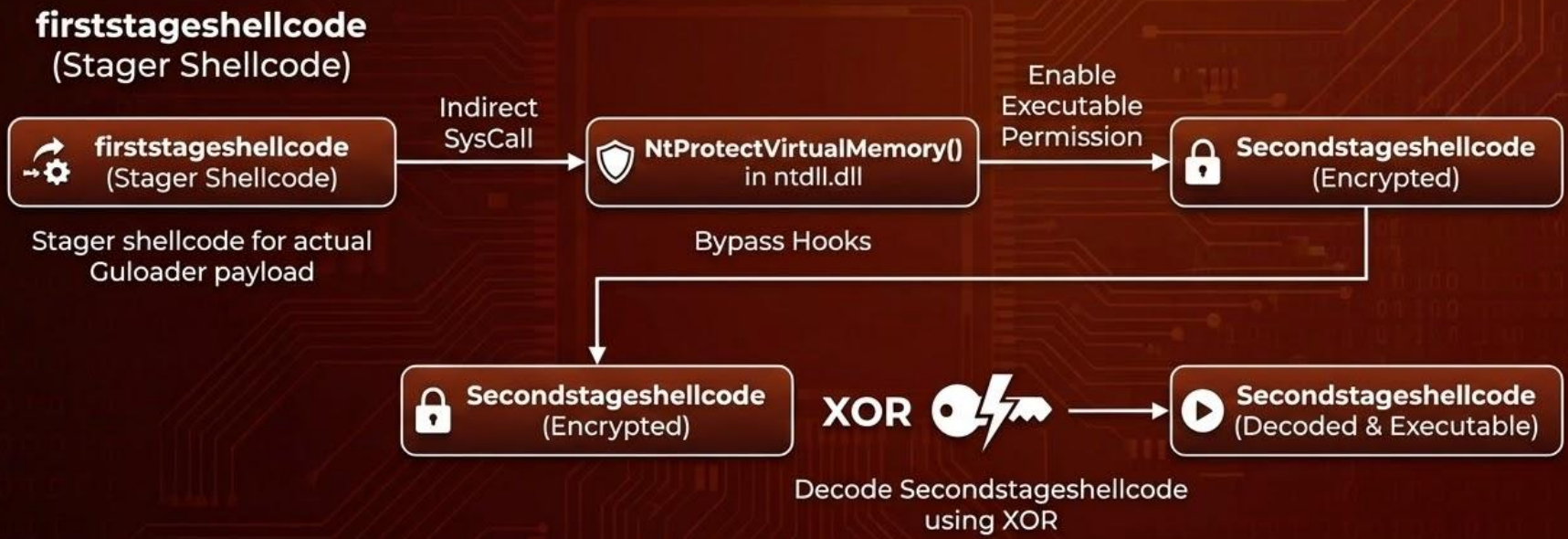
SysCall instruction **INSIDE** NTDLL.dll

Phase IV: Shellcode Stage2
Guloader
the downloader

Guloader

Exercise 3

firststageshellcode



Constant Unfolding (or Value Splitting)

```
debug750:121C14C9 test    bl, al
debug750:121C14CB cmp     bh, ch
debug750:121C14CD mov     ebp, esp
debug750:121C14CF sub     esp, 2B4B200h
debug750:121C14D5 add     esp, 2B4AF00h
debug750:121C14DB push    ebp
debug750:121C14DC mov     ebp, esp
debug750:121C14DE mov     ecx, 0CC4599Ah
debug750:121C14E3 xor     ecx, 8B49813Ch
debug750:121C14E9 xor     ecx, 295CA7C4h
debug750:121C14EF xor     ecx, 0AED17F7Ah
```

Guloader **stage2shellcode** entry point

CONSTANT UNFOLDING: HIDING VALUES IN PLAIN SIGHT

A Code Obfuscation Technique

1. WHAT IS CONSTANT UNFOLDING?

A code obfuscation technique where a single, literal constant value is replaced by a sequence of arithmetic or logical instructions that compute the value dynamically at runtime.

The Mechanism: Instead of directly embedding important data (like magic numbers, IP addresses, or encryption keys), the program constructs them on the fly. **The Transformation:** It effectively turns static data into executable code.

2. CONCEPTUAL EXAMPLE

ORIGINAL (CLEAR) - Static Data

OBFUSCATED (CONSTANT UNFOLDING) - Executable Code

3. WHAT THIS TECHNIQUE ACHIEVES (THE GOAL)

DEFEATS SIMPLE PATTERN MATCHING: Standard antivirus signatures or tools like the strings command looking for specific hex values will fail to find them.

COMPLICATES STATIC ANALYSIS: An analyst looking at disassembled code cannot immediately see critical values; they see only generic math instructions.

FORCES DYNAMIC ANALYSIS: To determine the hidden value, an analyst must typically run the code in a debugger or use advanced symbolic execution engines, increasing the time and effort required for reverse engineering.

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CONSTANT UNFOLDING (OR VALUE SPLITTING)

Replicating Assembly Behavior in Python

32-BIT REGISTER BEHAVIOR

PYTHON IMPLEMENTATION WITH MASKING

```python
# mov eax, 5991B898h
# Initialize eax
eax = 0x5991B898
print(f"Initial: 0x{eax:08X}")

# xor eax, 39765675h
# We must mask after subtraction to handle potential underflow (negative results)
eax = (eax ^ 0x39765675) & MASK_32
print(f"After XOR: 0x{eax:08X}")

# add eax, 0B900DCA2FD0Bh
# Bitwise operations between two 32-bit numbers usually stay within 32 bits,
# but masking guarantees consistency.
eax = (eax + 0x0DCA2FD0B) & MASK_32
print(f"After ADD: 0x{eax:08X}")

# xor eax, 7F464A46h
# We must mask after addition to handle potential overflow
eax = (eax ^ 0x7F464A46) & MASK_32
print(f"After XOR: 0x{eax:08X}")

# add eax, 0BD335F42h
eax = (eax + 0x0BD335F42) & MASK_32
print(f"After ADD: 0x{eax:08X}")
```

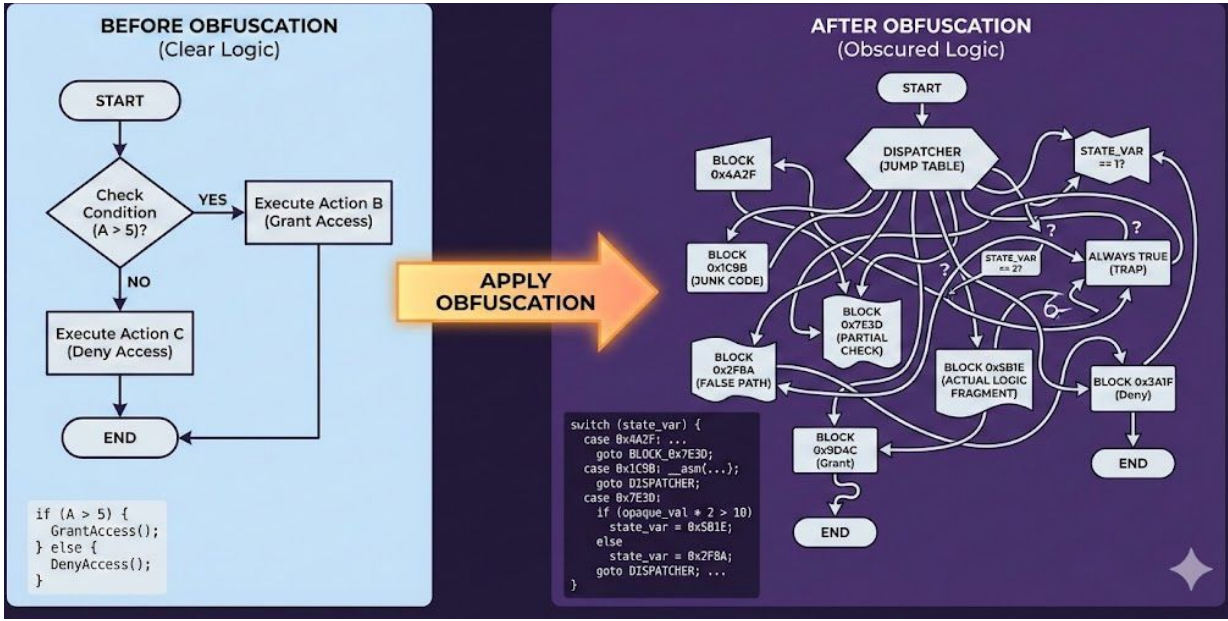
Constant Unfolding (or Value Splitting)

```
debug750:121C14C9 test    bl, al
debug750:121C14CB cmp     bh, ch
debug750:121C14CD mov     ebp, esp
debug750:121C14CF sub     esp, 2B4B200h
debug750:121C14D5 add     esp, 2B4AF00h
debug750:121C14DB push    ebp
debug750:121C14DC mov     ebp, esp
debug750:121C14DE mov     ecx, 0CC4599Ah
debug750:121C14E3 xor     ecx, 8B49813Ch
debug750:121C14E9 xor     ecx, 295CA7C4h
debug750:121C14EF xor     ecx, 0AED17F7Ah; ECX=0x18
```

Guloader **stage2shellcode** entry point

Control Flow Obfuscation

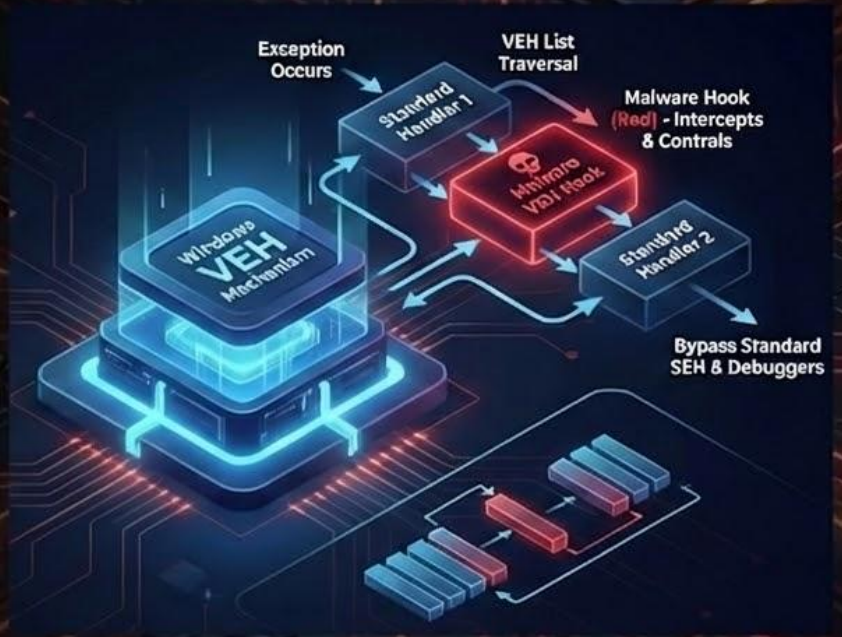
- Control Flow Obfuscation intentionally confuses the code's logic.
- It makes the logical flow difficult for human analysts to follow.
- This technique uses nonsensical if-else statements and/or goto jumps and/or privilege instructions (e.g. Int 3)
- Its purpose is to increase time and effort for reverse engineering.
- Control flow obfuscation can include the use of **Vectored Exception Handlers**.



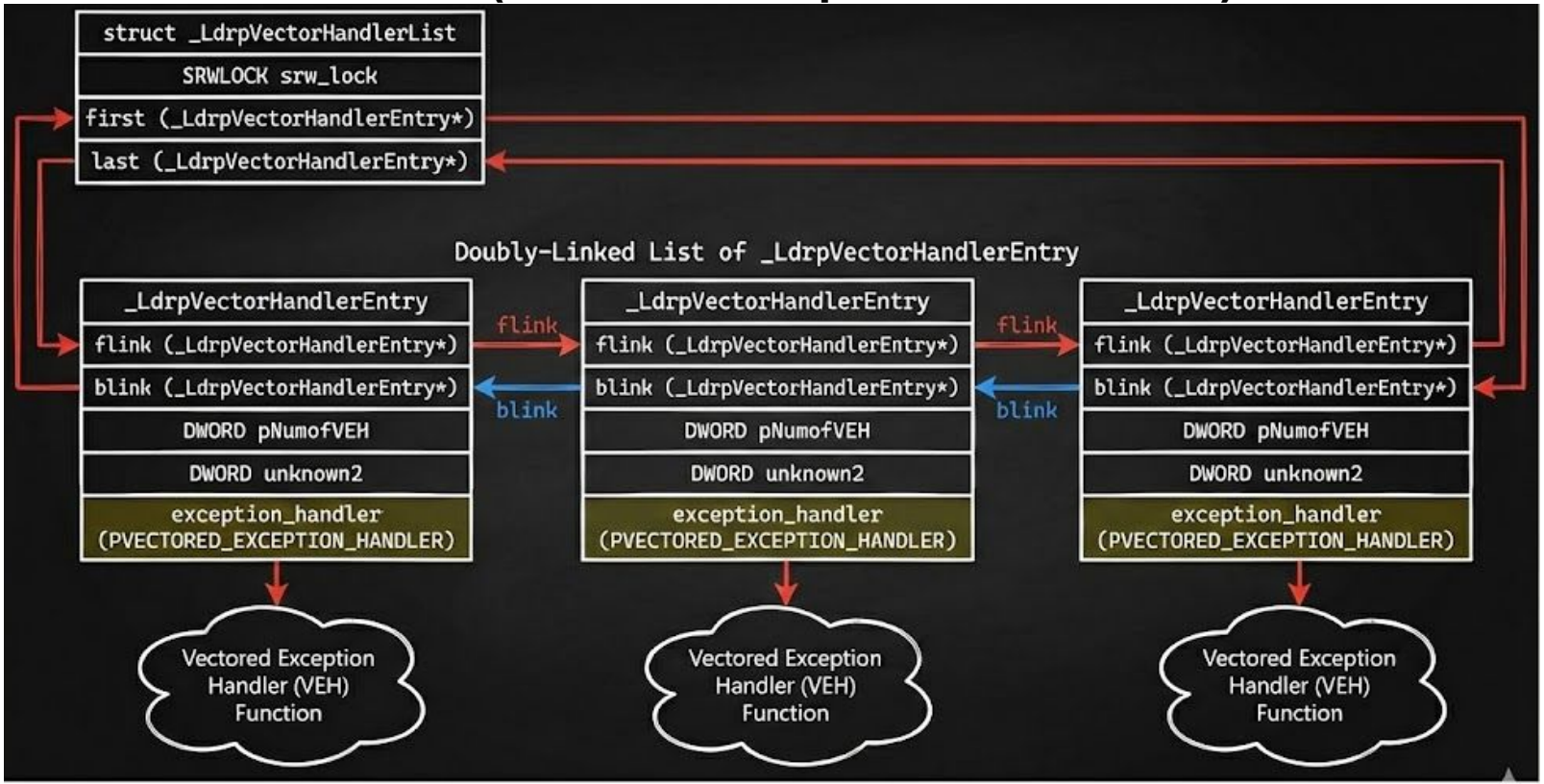
AI generated diagram not actual malware

Control Flow Obfuscation (Vectored Exception Handler VEH)

- Vectored Exception Handling (VEH) is a global mechanism in Windows.
- VEH handlers are called before any standard Structured Exception Handling (SEH).
- This mechanism does not require modifying the stack frame, enhancing stealth.
- Malware uses VEH to gain early, global control and bypass simple debuggers.
- Locating the VEH requires walking internal NTDLL.dll structures.



Control Flow Obfuscation (Vectored Exception Handler VEH)



Visualization of Windows VEH structures in memory.

Control Flow Obfuscation (Vectored Exception Handler VEH)

Context & Exception Record Structures (x86 & x64)
When an exception actually occurs, Windows bundles the crash details into these structures and passes them to your handler.

_EXCEPTION_POINTERS This is the "master" structure passed to your handler. It contains pointers to the two most critical pieces of info.

```
typedef struct _EXCEPTION_POINTERS {
  PEXCEPTION_RECORD ExceptionRecord; // The "What" (Error code, address)
  PCONTEXT          ContextRecord;   // The "Where" (Register state: EIP, ESP, EAX...)
} EXCEPTION_POINTERS, *PEXCEPTION_POINTERS;
_EXCEPTION_RECORD Describes the error itself.

typedef struct _EXCEPTION_RECORD {
  DWORD                    ExceptionCode;    // e.g., 0xC0000005 (Access Violation)
  DWORD                    ExceptionFlags;   // 0 = Continuable, 1 = Non-continuable
  struct _EXCEPTION_RECORD *ExceptionRecord; // Nested exception (usually NULL)
  PVOID                    ExceptionAddress; // Address where the crash happened
  DWORD                    NumberParameters; // Number of items in ExceptionInformation
  ULONG_PTR                ExceptionInformation[EXCEPTION_MAXIMUM_PARAMETERS]; // Extra details (e.g., read vs write)
} EXCEPTION_RECORD;
```

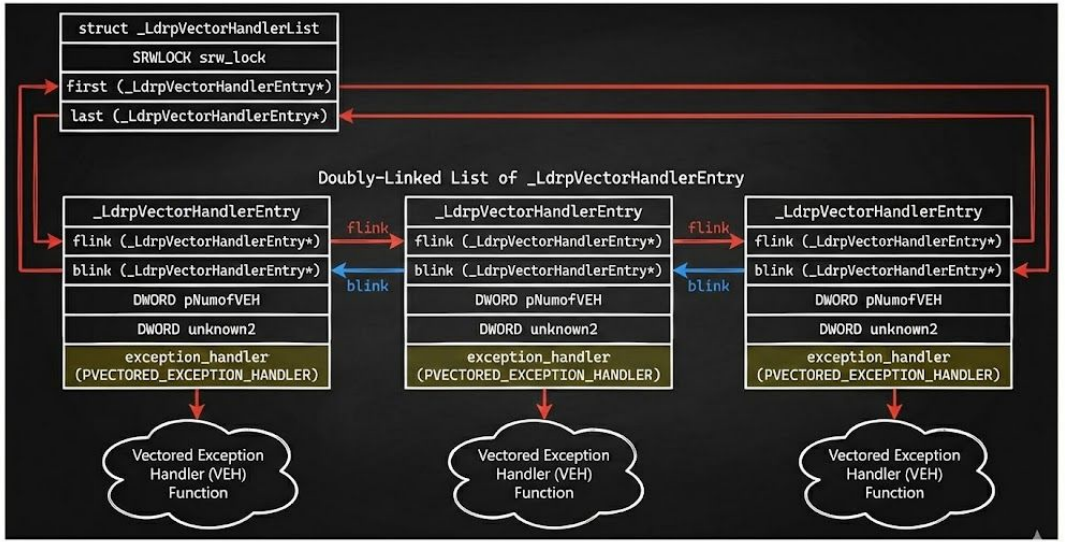
_CONTEXT (Architecture Dependent) This is a snapshot of the CPU registers at the exact moment of the crash.
x86 (32-bit): Contains Eax, Ebx, Ecx, Edx, Esi, Edi, Ebp, Esp, Eip, EFlags, Dr0-Dr7 (Debug Registers).
x64 (64-bit): Contains Rax, Rbx, ... R15, Rip, Rsp, Xmm0-Xmm15, etc.

Malware Trick: You can modify this structure in your exception handler to change the CPU registers and redirect execution flow (Context Manipulation).

Control Flow Obfuscation (Vectored Exception Handler VEH)

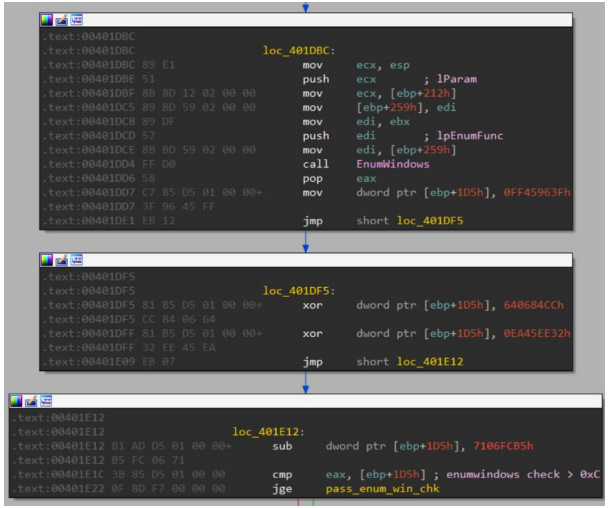
VEH Handler analysis

1. Locate the VEH handler by walking the NTDLL.dll structures
2. Determine how VEH handles the various types of exceptions ?
3. Determine how VEH decides how many junk bytes to skip ? (offset)
4. Determine how VEH updates the EIP?
5. List all the anti analysis techniques used (dynamic and static)



Visualization of Windows VEH structures in memory.

Control Flow Obfuscation (Vectored Exception Handler VEH)



APPLY OBFUSCATION

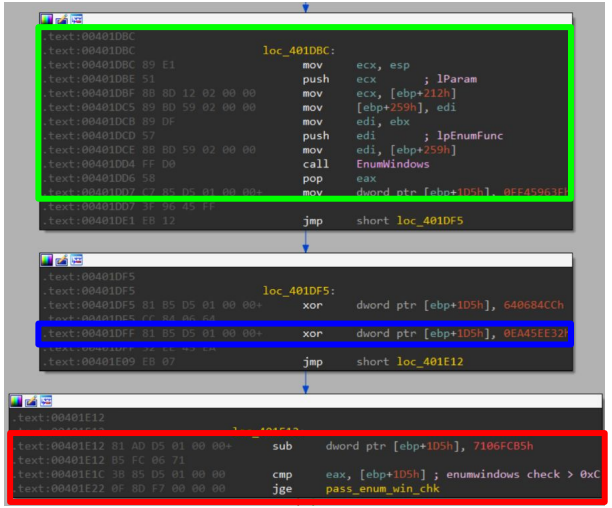
```
mov     ecx, esp
push    ecx
mov     ecx, [ebp+212h]
mov     [ebp+259h], edi
mov     edi, ebx
push    edi
mov     edi, [ebp+259h]
call    eax
pop     eax
mov     dword ptr [ebp+1D5h], 0FF45963Fh
int     3                               ; Trap to Debugger
mov     ebp, 47215F19h
out     dx, eax
push    64h ; 'd'
sub     [ebp-27016C12h], ebp
pop     eax
jo      short near ptr loc_401E1C+1
cmpsd
cmp     al, ds:byte_1D5B5[ecx]
add     ah, cl
test    [esi], al
xor     dword ptr fs:[ebp+1D5h], 0EA45EE32h
int     3                               ; Trap to Debugger
mov     al, ds:1C28DDCFh
in      eax, 13h
;
db  80h
;
sub     dword ptr [ebp+1D5h], 7106FCB5h

loc_401E1C:                             ; CODE XREF: ...
cmp     eax, [ebp+1D5h]
jge     loc_401F1F
```

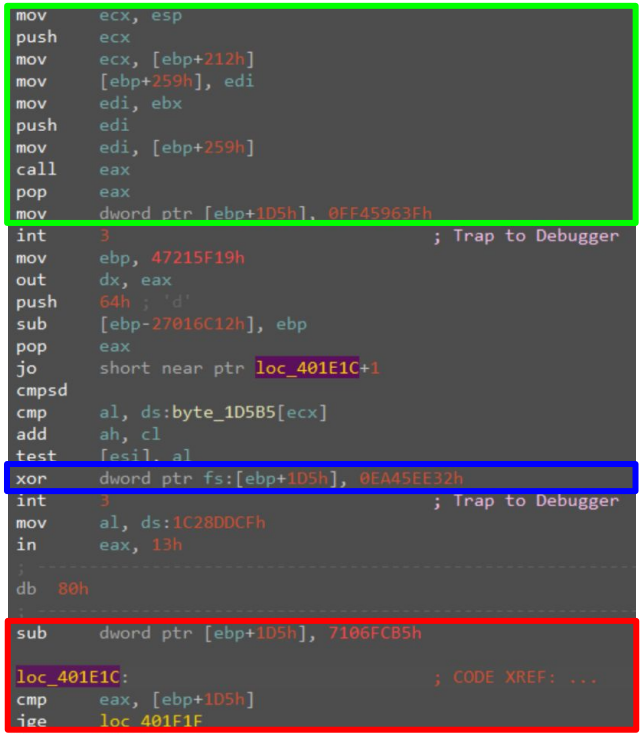
Guloader **without** obfuscation

Guloader **with** obfuscation

Control Flow Obfuscation (Vectored Exception Handler VEH)



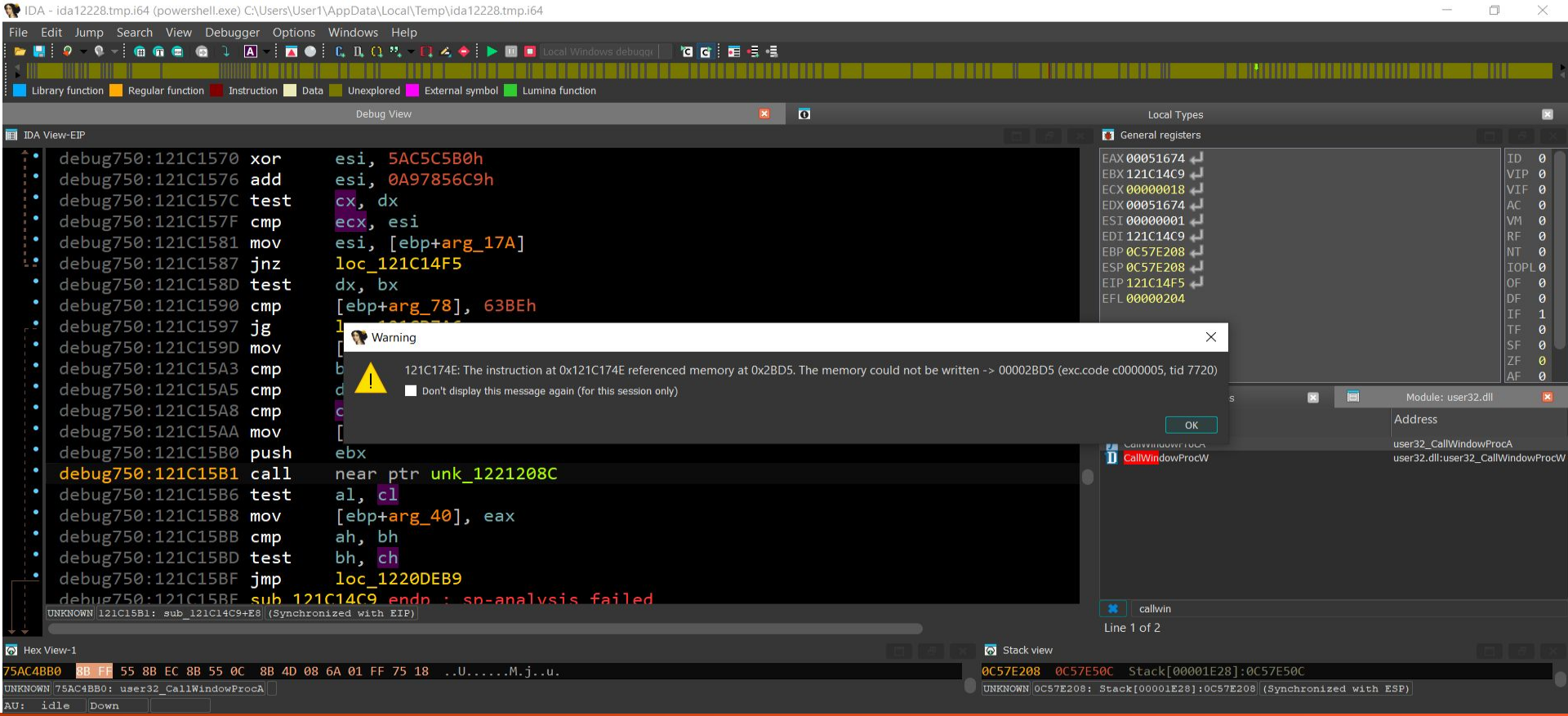
APPLY OBFUSCATION



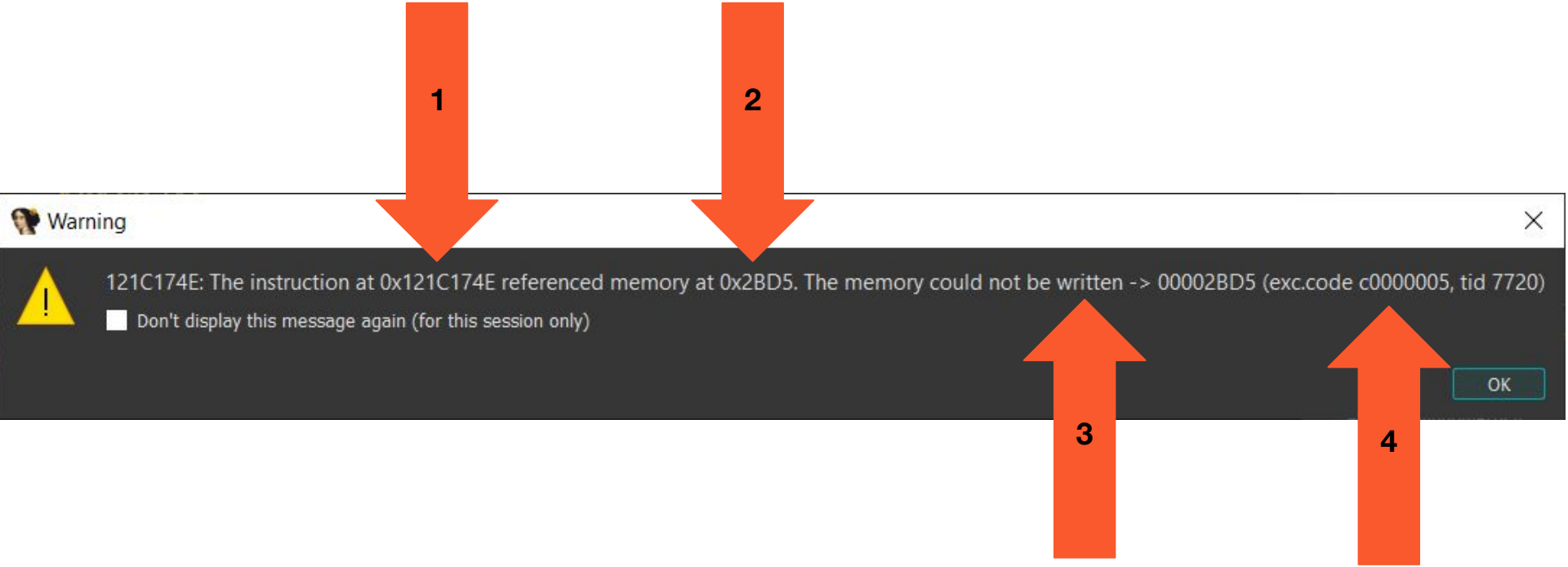
Guloader **without** obfuscation

Guloader **with** obfuscation

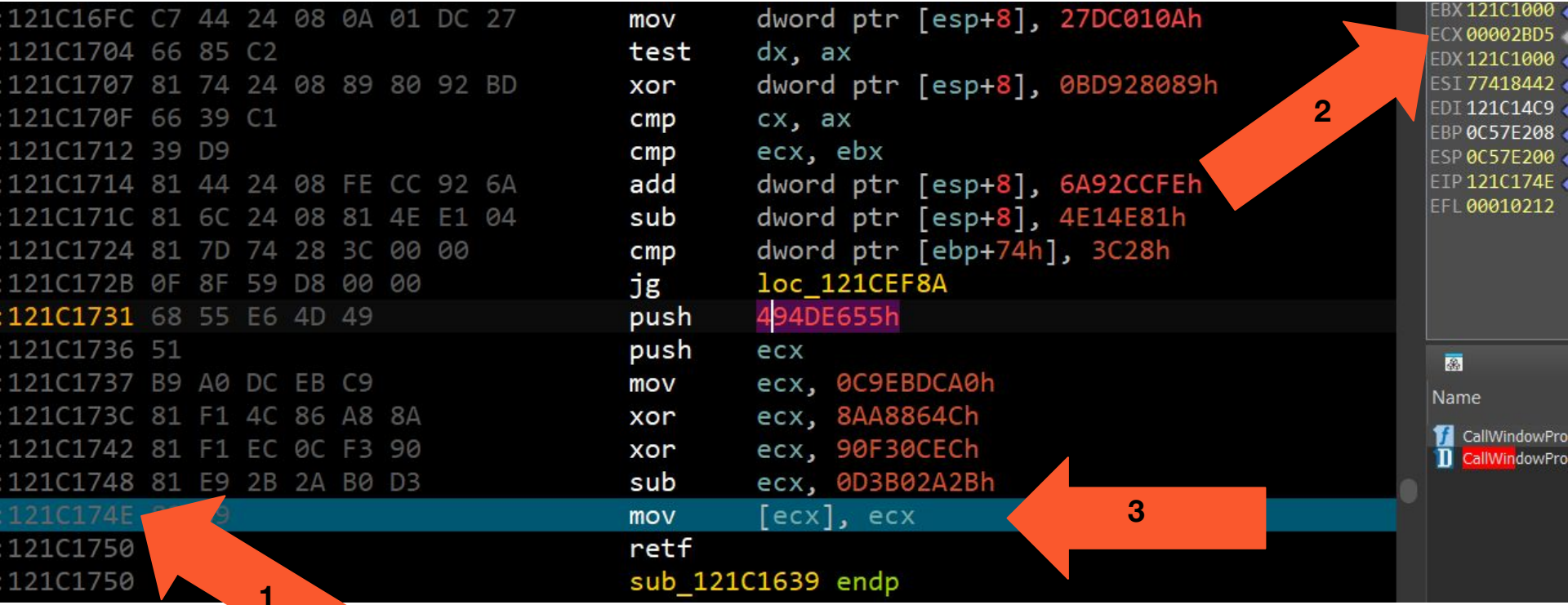
Control Flow Obfuscation (Vectored Exception Handler VEH)



Control Flow Obfuscation (Vectored Exception Handler VEH)



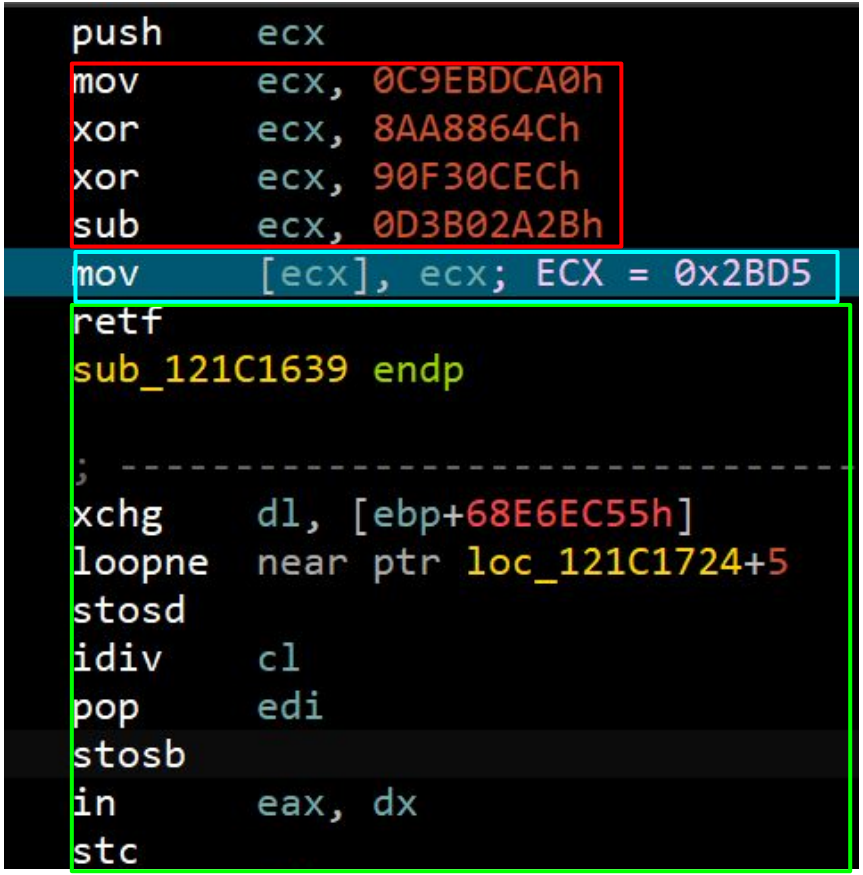
Control Flow Obfuscation (Vectored Exception Handler VEH)



First instruction in Guloader stage 2 shellcode that will be handled by the Vector Exception Handler function

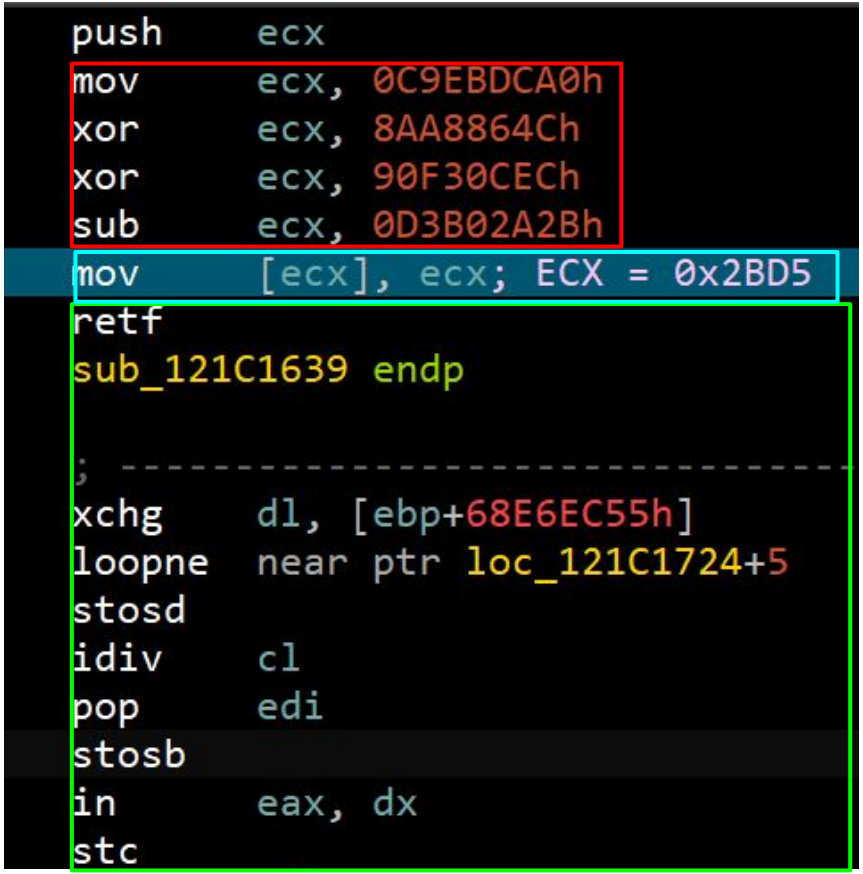
Control Flow Obfuscation (Vectored Exception Handler VEH)

- What does the instructions in the **red** box do ?
  Does it look familiar ?
- What does the instruction in **blue** do ?
- Does the instructions in the **green** box makes sense ?



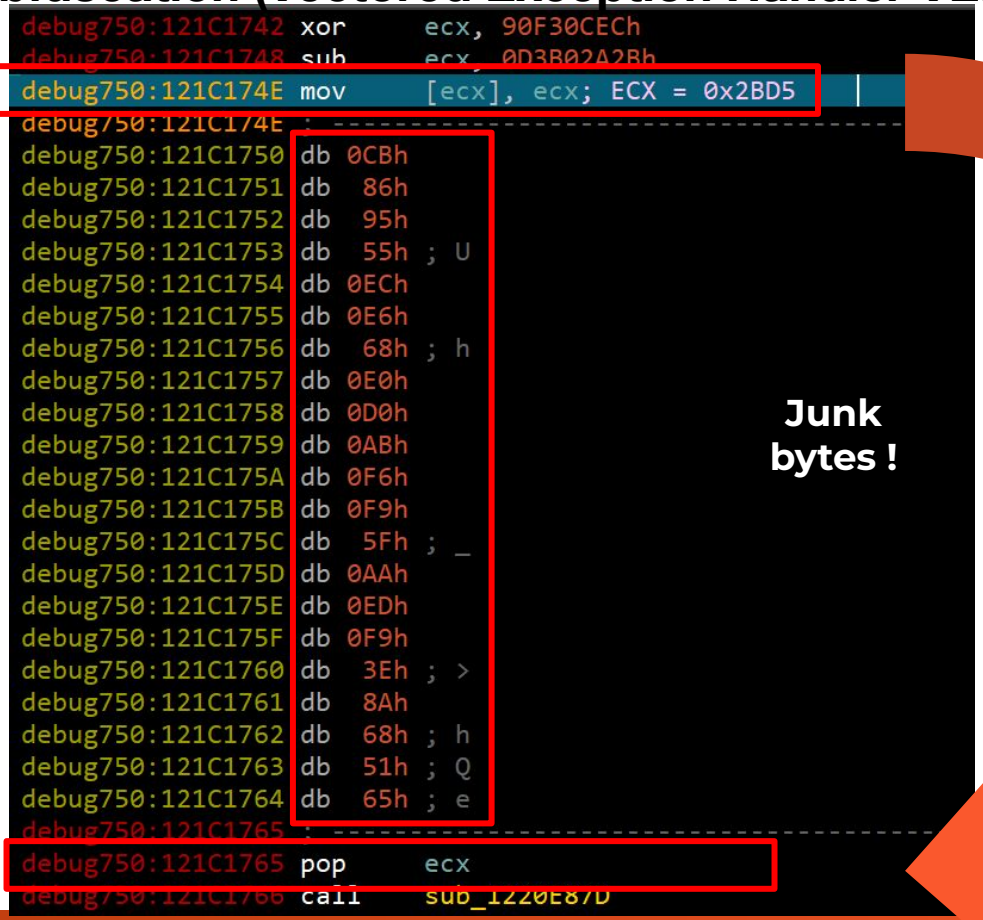
Control Flow Obfuscation (Vectored Exception Handler VEH)

- **Constant unfolding** to ‘hide’ the ecx = 0x2BD5
- Write into the address ‘0x2BD5’
  Triggers
  EXCEPTION_ACCESS_VIOLATION
- Instructions in the **green** box is not ‘correctly’ disassembled



Control Flow Obfuscation (Vectored Exception Handler VEH)

Trigger Exception!



Junk bytes !

Updated EIP

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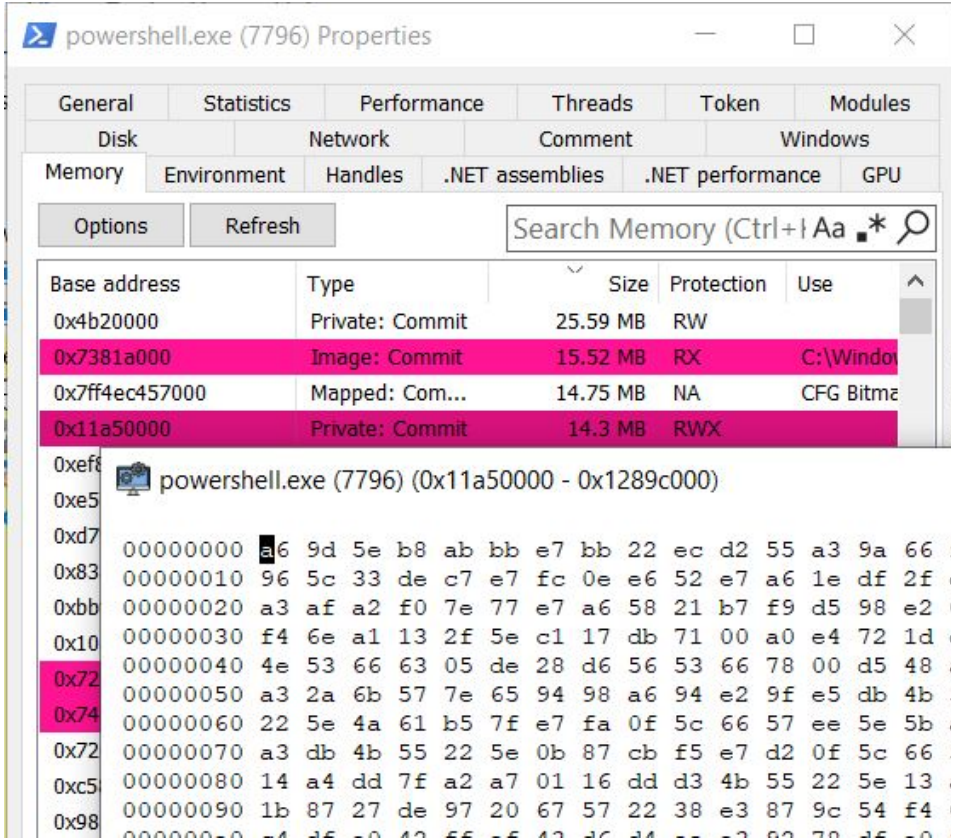
Control Flow Obfuscation (Vectored Exception Handler VEH)

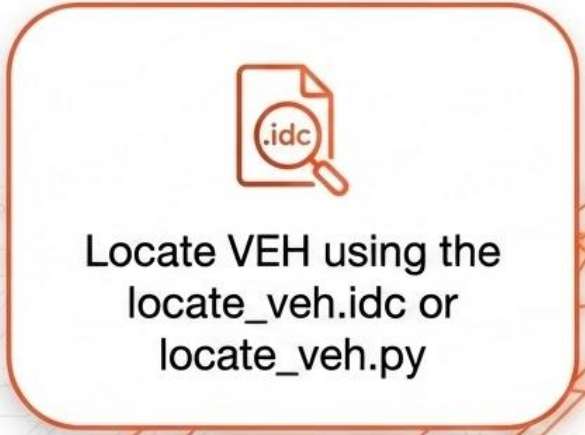
Memory Dump steps (after locating VEH)

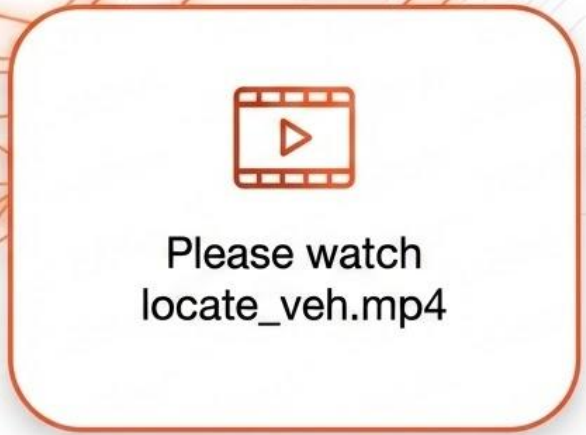
1. Use System Informer (a.k.a. Process Hacker)
2. VBS -> Ps1 -> powershell.exe (32bit)
3. Look for powershell.exe after Guloader is injected
4. Locate the RWX memory pages (about 14.3 MB) that contained **Secondstageshellcode**
5. Dump the memory pages



Control Flow Obfuscation (Vectored Exception Handler VEH)

- Locate VEH using the locate_veh.idc or locate_veh.py



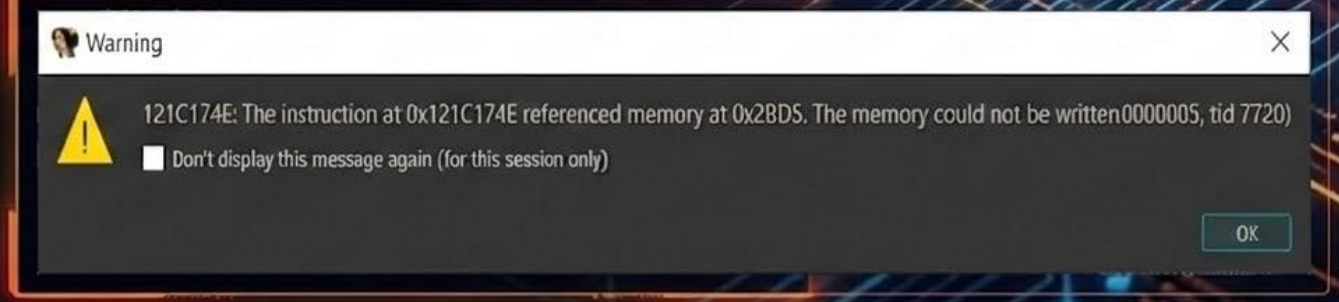


Exercise 4

- Locate the handler function using the **locate_veh.idc** script (make sure Windows symbols are already loaded)
- Analyse secondstageshellcode using the memory dump
- How did the secondstageshellcode **handles** exceptions ?
- What types of exceptions were handled ?
- How did secondstageshellcode know how many junk bytes to jump over ?
- Take note of the anti-analysis in the handler function.

Goal:

- Explain what caused the following exception and how was it handled in details?



Exercise 4 (Bonus)

- How did secondstageshellcode install the VEH function? (Which API was used to do it?)
- What anti-analysis checks were done by the malware just before the VEH was installed ?
- What does the sample do if the anti-analysis checks failed ?

Exercise 4

Walk-through and Demo

Guided analysis and live demonstration of the techniques.

Exercise 4

```
8B 44 24 04           mov     eax, [esp+arg_0]
66 85 C9              test    cx, cx
8B 10                 mov     edx, [eax]
38 EE                 cmp     dh, ch
8B 12                 mov     edx, [edx]
39 D8                 cmp     eax, ebx
38 F5                 cmp     ch, dh
B9 BB E2 04 F2        mov     ecx, 0F204E2BBh
81 C1 59 1C 9C D8     add     ecx, 0D89C1C59h
85 C1                 test    ecx, eax
81 F1 86 94 B8 A1     xor     ecx, 0A1B89486h
66 39 C2              cmp     dx, ax
81 F1 97 6B 18 AB     xor     ecx, 0AB186B97h
38 FE                 cmp     dh, bh
39 CA                 cmp     edx, ecx
0F 84 B7 00 00 00     jz      loc_1C4B1D9A
B9 12 41 A7 FD        mov     ecx, 0FDA74112h
66 F7 C1 A0 0B        test    cx, 0BA0h
81 E9 72 DB 85 F3     sub     ecx, 0F385DB72h
81 C1 A5 EE 61 07     add     ecx, 761EEA5h
81 F1 58 54 83 D1     xor     ecx, 0D1835458h
66 85 DA              test    dx, bx
39 CA                 cmp     edx, ecx
0F 84 D8 00 00 00     jz      loc_1C4B1DE2
39 D3                 cmp     ebx, edx
B9 89 E6 D0 AF        mov     ecx, 0AFD0E689h
84 CB                 test    bl, cl
81 F1 06 98 E6 6D     xor     ecx, 6DE69806h
38 D1                 cmp     cl, dl
81 C1 D5 DA 0D F6     add     ecx, 0F60DDAD5h
81 F1 F2 59 44 78     xor     ecx, 784459F2h
```

Entry point of the Vector Exception Handler function in the Guloader stage 2 shellcode

Control Flow Obfuscation (Vectored Exception Handler VEH)

```
1  int __stdcall FN_VEH(PEXCEPTION_POINTERS ExceptionInfo)
2  {
3    DWORD ExceptionCode;
4
5    ExceptionCode = ExceptionInfo->ExceptionRecord->ExceptionCode;
6    if ( ExceptionCode != EXCEPTION_ACCESS_VIOLATION )
7    {
8      if ( ExceptionCode != EXCEPTION_ILLEGAL_INSTRUCTION
9        && ExceptionCode != EXCEPTION_PRIV_INSTRUCTION
10       && ExceptionCode != EXCEPTION_SINGLE_STEP
11       && ExceptionCode != EXCEPTION_BREAKPOINT )
12     {
13       return 0;                                  // exception NOT handled
14     }
15 FN_VEH_handles_exception:
16     FN_Get_Offset_Decode_key(ExceptionInfo);
17     FN_Get_Offset_Update_EIP();
18     return -1;                                   // exception handled
19   }
```

Decompiled output of the VEH function

Control Flow Obfuscation (Vectored Exception Handler VEH)

```
pop     eax
xor     dword ptr [ebx], 0D62B9FCCh
int     3                       ; EXCEPTION_BREAKPOINT triggered!
-------------------------------------------------------------------
db 3,13h,19h,15h,'2',12h,0AFh,'IMp|',0E9h,4Dh,4Dh ; junk bytes
-------------------------------------------------------------------
add     dword ptr [ebx], 3FA3DA06h
```

EXCEPTION_BREAKPOINT

EXCEPTION_ACCESS_VIOLATION

```
mov     esi, 0D37212A5h
add     esi, 4C655390h
xor     esi, 1FD76635h          ; esi=0
mov     [esi], esi              ; EXCEPTION_ACCESS_VIOLATION
-------------------------------------------------------------------
db 1Ch,0C5h,74h,0C3h,4Ch,0F6h,8Fh,0FBh,0FAh,'36',92h,0Eh,0 ; junk bytes
-------------------------------------------------------------------
pop     esi
```

```
adc     byte ptr [ebx-781E6E5Ah], 3Ch ; '<'
test    [ebx-76655A7Bh], edx
;
db  65h ; e                         ; exception triggeered!
a4s db '4s',0FDh,0A0h,'%~',12h,'f9',0C8h,5Fh,85h,0CBh,5Ah,5,'N'
db 0C5h,0E5h,1Fh,0F3h,0CCh,0FBh,12h,0Dh,';',0EEh,0E4h,89h,0DCh,
```

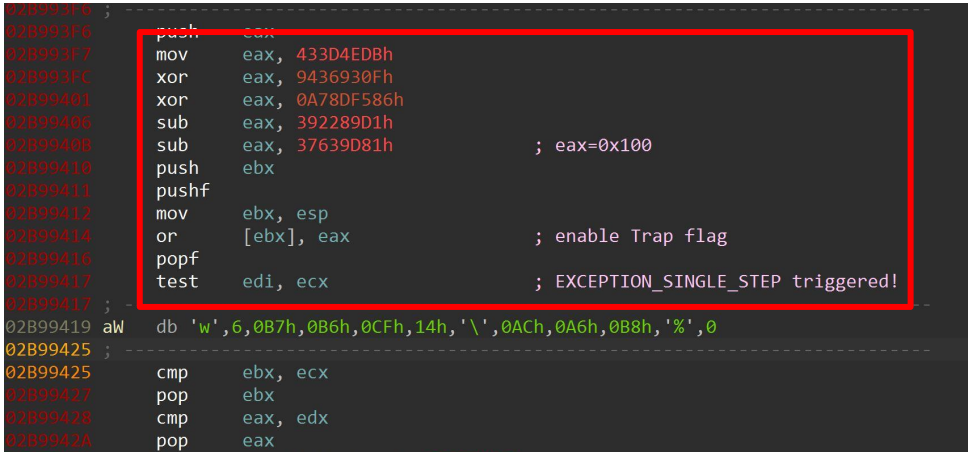
EXCEPTION_ILLEGAL_INSTRUCTION

EXCEPTION_PRIV_INSTRUCTION

```
mov     dword ptr [ebx], 0ACDB2BA7h
add     dword ptr [ebx], 9B37543h
xor     dword ptr [ebx], 80317A66h
sub     dword ptr [ebx], 36BFDA32h
sysret                          ; trigger exception!
;
aHz db 'Hz',0,0,0,0,0,0,0,0,0F7h,9Bh,19h,0D7h,'{',13h,1Ch,0A8h
;
```

Control Flow Obfuscation (Vectored Exception Handler VEH)

EXCEPTION_SINGLE_STEP



Control Flow Obfuscation (Vectored Exception Handler VEH)

```
1   int __stdcall FN_VEH(PEXCEPTION_POINTERS ExceptionInfo)
2   {
3     DWORD ExceptionCode;
4
5     ExceptionCode = ExceptionInfo->ExceptionRecord->ExceptionCode;
6     if ( ExceptionCode != EXCEPTION_ACCESS_VIOLATION )
7     {
8       if ( ExceptionCode != EXCEPTION_ILLEGAL_INSTRUCTION
9         && ExceptionCode != EXCEPTION_PRIV_INSTRUCTION
10        && ExceptionCode != EXCEPTION_SINGLE_STEP
11        && ExceptionCode != EXCEPTION_BREAKPOINT )
12      {
13        return 0;                                   // exception NOT handled
14      }
15  FN_VEH_handles_exception:
16      FN_Get_Offset_Decode_key(ExceptionInfo);
17      FN_Get_Offset_Update_EIP();
18      return -1;                                    // exception handled
19    }
```

Decompiled output of the VEH function

Control Flow Obfuscation (Vectored Exception Handler VEH)

```
1  int __usercall FN_Get_Offset_Decode_key@<ecx>(_EXCEPTION_POINTERS *a1@<eax>)
2  {
3    PCONTEXT ContextRecord; // eax
4    int result; // ecx
5    int count; // edx
6
7    ContextRecord = a1->ContextRecord;
8    result = 0x18;
9    count = 0;
10   while ( 1 )
11   {
12     count += 4;
13     if ( *(DWORD *)((char *)&ContextRecord->ContextFlags + count) )// check all HW BP registers are zero
14       break;
15     if ( count == 0x18 )
16       return 0xE1;                          // return offset decode key
17   }
18   return result;
19 }
```

Control Flow Obfuscation (Vectored Exception Handler VEH)

```
call    FN_Get_Offset_Decode_key
test    cl, cl
cmp     edx, ebx
mov     edx, 63C7099Ch
xor     edx, 6649E730h
test    ch, bh
add     edx, 1691B385h
cmp     ah, ch
add     edx, 0E3DF5E87h          ; 0xB8
cmp     dx, 4070h
add     eax, edx                 ; _Context.EIP = _CONTEXT+0xB8
test    dl, cl
mov     edx, [eax]
add     edx, 0Ch                 ; Get enc offset*
cmp     dl, bl
call    FN_Get_Offset_Update_EIP
```

Locate the encrypted offset which is 0xC bytes away from the trigger

Control Flow Obfuscation (Vectored Exception Handler VEH)

```
1  _DWORD *__usercall FN_Get_Offset_Update_EIP@<eax>(
2          _DWORD *offset@<eax>,
3          unsigned __int8 *enc_offset@<edx>,
4          int offset_key@<ecx>)
5  {
6    *offset += offset_key ^ *enc_offset;
7    return offset;
8  }
```

Offset decode key XOR with encrypted offset byte

Control Flow Obfuscation (Vectored Exception Handler VEH)

Trigger Exception!

0xC

Encrypted offset

```
debug750:121C1742 xor     ecx, 90F30CECh
debug750:121C1748 sub     ecx, 0D3B02A2Bh
debug750:121C174E mov     [ecx], ecx; ECX = 0x2BD5
debug750:121C174E ; ---------------------------------------
debug750:121C1750 db 0CBh
debug750:121C1751 db  86h
debug750:121C1752 db  95h
debug750:121C1753 db  55h ; U
debug750:121C1754 db 0ECh
debug750:121C1755 db 0E6h
debug750:121C1756 db  68h ; h
debug750:121C1757 db 0E0h
debug750:121C1758 db 0D0h
debug750:121C1759 db 0ABh
debug750:121C175A db 0F6h
debug750:121C175B db 0F9h
debug750:121C175C db  5Fh ; _
debug750:121C175D db 0AAh
debug750:121C175E db 0EDh
debug750:121C175F db 0F9h
debug750:121C1760 db  3Eh ; >
debug750:121C1761 db  8Ah
debug750:121C1762 db  68h ; h
debug750:121C1763 db  51h ; Q
debug750:121C1764 db  65h ; e
debug750:121C1765 ; ---------------------------------------
debug750:121C1765 pop     ecx
debug750:121C1766 call    sub_1220E87D
```

0xE1 ^ 0xF6 = offset

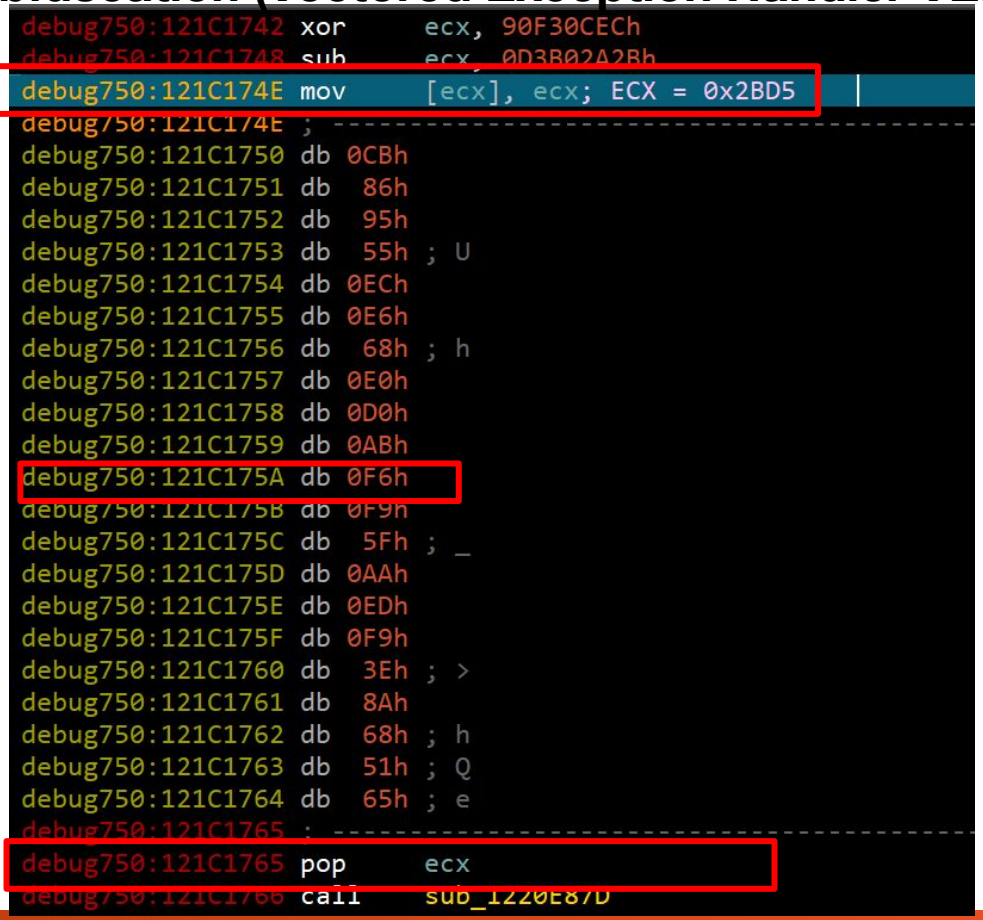
Control Flow Obfuscation (Vectored Exception Handler VEH)

Trigger Exception!

0xC

Encrypted offset

Updated EIP



target_address.idc
Or
target_addres .py

paloalto NETWORKS

Phase V: Guloader the downloader Malware Configuration Extraction (MCE)

Guloader

What are malware configurations?

CONCEPT & UNIQUENESS

- Similar to **‘settings’** or **‘preferences’** in software

- Malware configuration defines the uniqueness of each instance

CONFIGURATION CONTENT

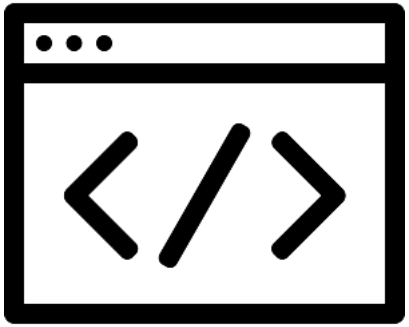
- C&C addresses
- encryption keys
- attack parameters
- other IOCs

EXTRACTION CHALLENGE

- **‘Tough’** to obtain statically

- But can be extracted from process memory.

Decrypting Malware Configuration



Encryption routine

Encryption key

Ciphertext

Decrypting Malware Configuration

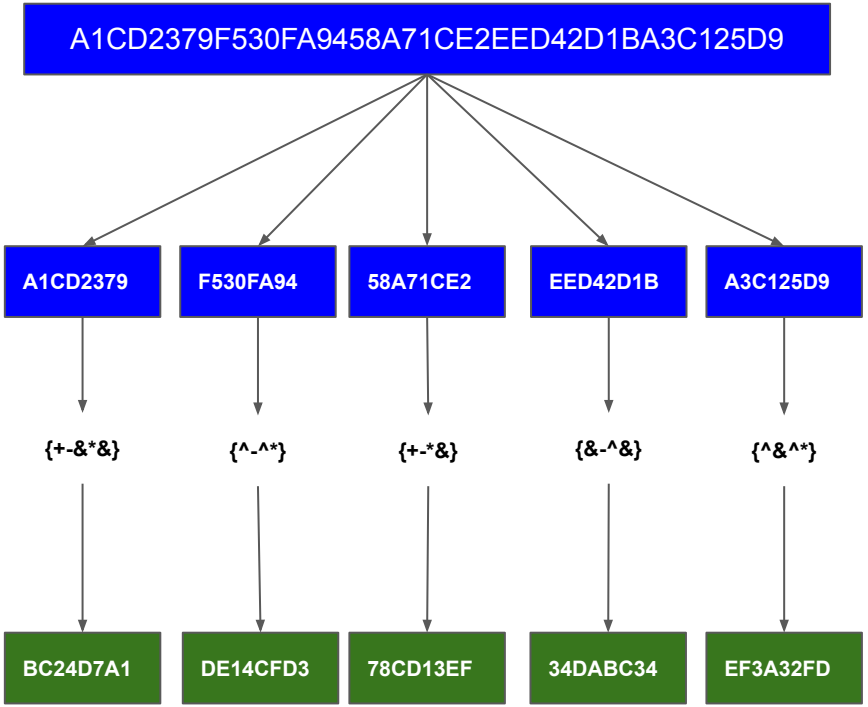
Simple
XOR

Predictable location of
encryption key

???

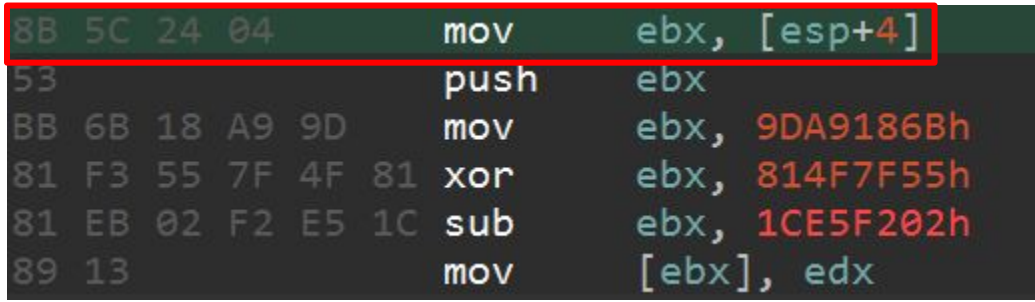
Ciphertext Splitting

1. Ciphertext splitted into multiple DWORD
2. Each DWORD is encoded with different arithmetic operations
3. Stored as local variables in functions



Ciphertext Splitting

- Function starts with loading of address of variable that would the encrypted cipher text
- The function’s purpose is to ‘construct’ the encrypted cipher text
- The completed encrypted cipher text would be stored in the variable



Ciphertext Splitting

- First DWORD constructed by the function is the length of the ciphertext!

```
1   MASK_32 = 0xFFFFFFFF
2   eax = 0xE3A8C688
3   eax = (eax ^ 0x8378D243) & MASK_32
4   eax = (eax - 0x504C6F4F) & MASK_32
5   eax = (eax ^ 0x1083A54F) & MASK_32
6   print(f"Final eax Value: 0x{eax:08X}")
Final eax Value: 0x00000033
```

```
mov     ebx, [esp+4]                    ; Encrypted_C2
push    ebx
mov     ebx, 9DA9186Bh
xor     ebx, 814F7F55h
sub     ebx, 1CE5F202h
mov     [ebx], edx                      ; EBX = 0
;---------------------------------------------------------
db 0BAh, 0D9h, 0FDh, 45h, 0E3h, 5Dh, 0C1h, 0C3h, 76h,
db 0C8h, 60h, 0F2h, 97h, 7Fh, 53h, 4Bh, 5Dh, 83h, 0D2h
db 5Eh, 0A2h, 0F7h, 75h, 69h, 33h, 0E9h, 60h, 0D6h, 0A
db 86h, 34h, 0C1h, 80h, 60h
;---------------------------------------------------------
pop     ebx
ltr     di
;---------------------------------------------------------
db 57h, 8 dup(0), 0FFh, 95h, 3Ah, 0E2h, 14h, 0DBh, 81h
db 93h, 0B2h, 0F6h, 0DDh, 0C3h, 15h, 0C3h
;---------------------------------------------------------
mov     dword ptr [ebx], 0E3A8C688h
xor     dword ptr [ebx], 8378D243h
int     3
;---------------------------------------------------------
db 8Bh, 7Ch, 40h, 82h, 78h, 8Dh, 83h, 55h, 5Fh, 6Bh, 3
db 4Ch, 50h, 0F7h, 40h, 3Bh, 15h, 49h, 2Ch, 82h, 0FCh,
;---------------------------------------------------------
sub     dword ptr [ebx], 504C6F4Fh
xor     dword ptr [ebx], 1083A54Fh      ; EBX = 0x33
```

Decrypting Malware Configuration

Simple
XOR

Predictable location of
encryption key

???

Unicorn CPU emulator

- https://github.com/unicorn-engine/unicorn
- lightweight multi-platform
- multi-architecture
- CPU emulator framework
- Has python bindings

EXERCISE 5

GIVEN:

- Encryption key
- Address of the function containing the cipher text
- Address of the end of the function...
- Encryption algorithm used
- Memory dump from exercise 4

GOAL:

Write a Malware Configuration Extractor (MCE) to get C2 URL...

Extend the MCE to dump other strings in the sample

Extend the MCE to work for other similar Guloader samples

Exercise 5

```
python emulate_config_dmp.py

INFO:__main__:String found = %Idigbo% -w 1 $Mycoprotein=(Get-ItemProperty -Path 'HKCU:\Oversanselig\').Penta;%Idigbo% ($Mycoprotein)            @@@@@@@@            0x780256
INFO:__main__:String found = %Idigbo% -w 1 $Trustor=(Get-ItemProperty -Path 'HKCU:\Oversanselig\').Penta;%Idigbo% ($Trustor)              @@@@@@@@            0x781444
INFO:__main__:String found = Oversanselig\              @@@@@@@@            0x782507
INFO:__main__:String found = Penta              @@@@@@@@            0x782672
INFO:__main__:String found = c:\windows\system32\WindowsPowerShell\v1.0\powershell.exe            @@@@@@@@            0x782736
INFO:__main__:String found = c:\windows\SysWOW64\WindowsPowerShell\v1.0\powershell.exe            @@@@@@@@            0x783252
INFO:__main__:String found = Idigbo             @@@@@@@@            0x783AC7
INFO:__main__:String found = Environment            @@@@@@@@            0x783BB2
INFO:__main__:String found = \Microsoft.NET\Framework\\msbuild.exe            @@@@@@@@            0x78BA05
INFO:__main__:String found = psapi.dll              @@@@@@@@            0x79ABE2
INFO:__main__:String found = wininet.dll            @@@@@@@@            0x79CF24
INFO:__main__:String found = Msi.dll            @@@@@@@@            0x79D9EE
INFO:__main__:String found = KERNELBASE.DLL             @@@@@@@@            0x79E87A
INFO:__main__:String found = shell32            @@@@@@@@            0x79F7CF
INFO:__main__:String found = windir=            @@@@@@@@            0x7A00A1
INFO:__main__:String found = SYSTEM\ControlSet001\Enum\ACPI\PNP0C0C            @@@@@@@@            0x7A08D6
INFO:__main__:String found = TEMP=              @@@@@@@@            0x7A188D
INFO:__main__:String found = CONOUT$            @@@@@@@@            0x7A40B5
INFO:__main__:String found = mshtml.dll             @@@@@@@@            0x7A4C61
INFO:__main__:String found = LinjsSmesoftiq.ro/event/update/mCNQZhDQboPBW61.bin            @@@@@@@@            0x7A54BF
INFO:__main__:C2 url = https://softiq.ro/event/update/mCNQZhDQboPBW61.bin enc config addr = 0x7A54BF
```

Exercise 5

Walk-through and Demo

Contact me.

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