Running Rootkits Like A Nation-State Hacker

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Introduction

What Is Driver Signing Enforcement (DSE)

- Code Integrity was first introduced over 15 years ago
- Kernel drivers must be digitally signed on x64-based Windows
  - Code signing certificate from cross-certificate supporting CA
  - From Win10 Redstone (August 2016) a 2nd signature from Microsoft is required
- Drivers are checked each time they are loaded into memory to be executed
- Allows to improve the security of the OS
  - No drivers from unknown\untrusted origin
  - No drivers that were modified post build, possibly by privileged malicious actor

Introduction

Code Integrity Internals

nt!Phase1Initialization

nt!SeInitSystem

nt!SepInitializeCodeIntegrity

nt!g_CiEnabled = TRUE

CI!CiInitialize(&nt!g_CiCallbacks)

CI!g_CiOptions |= DSE_ON
Callbacks = { CI!CiValidateImageHeader,
CI!CiValidateImageData,
CI!CiQueryInformation }

nt!MmLoadSystemImage

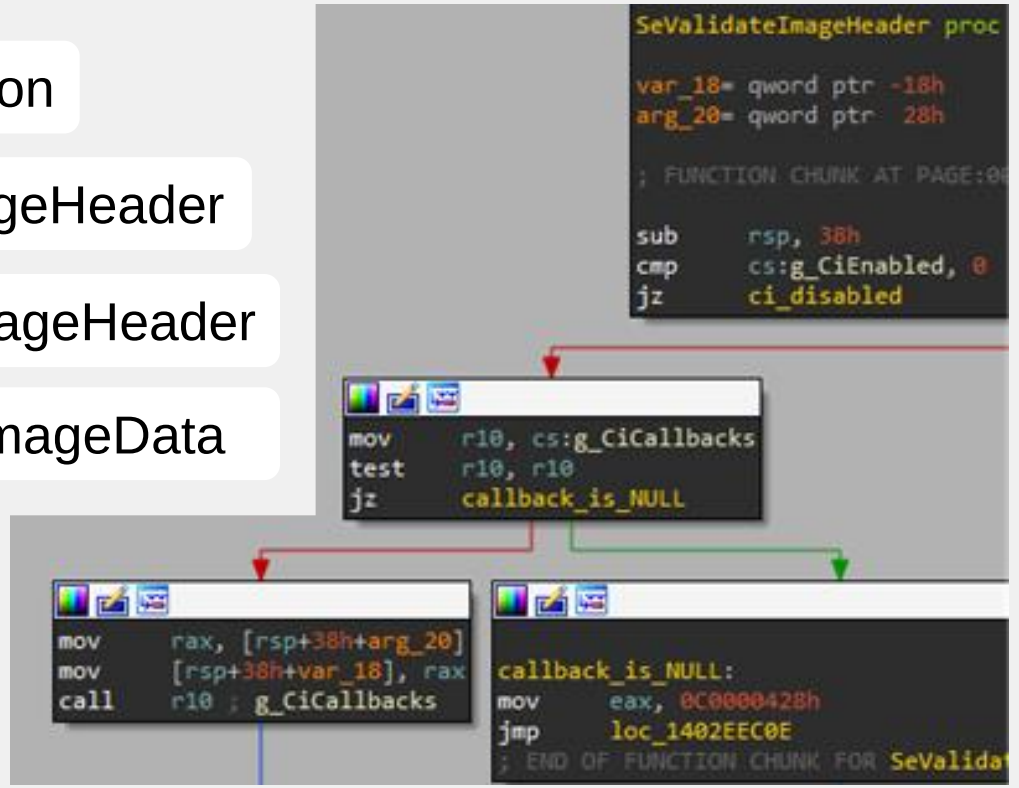
nt!...

nt!MmCreateSection

nt!MiValidateImageHeader

nt!SeValidateImageHeader

nt!SeValidateImageData



* Query info wrapper does not verify g_CiEnabled

Introduction

Code Integrity Internals Changes

- From Win8 nt!g_CiEnabled variable was removed
- The callbacks structure also changed
  - CI.dll provides more callbacks
  - Same important callbacks remain but their offsets changed
- Only validate image header is invoked when loading a driver
- From Win8.1 callbacks structure symbol changed to nt!SeCiCallbacks

Introduction

DSE Tampering in the Wild

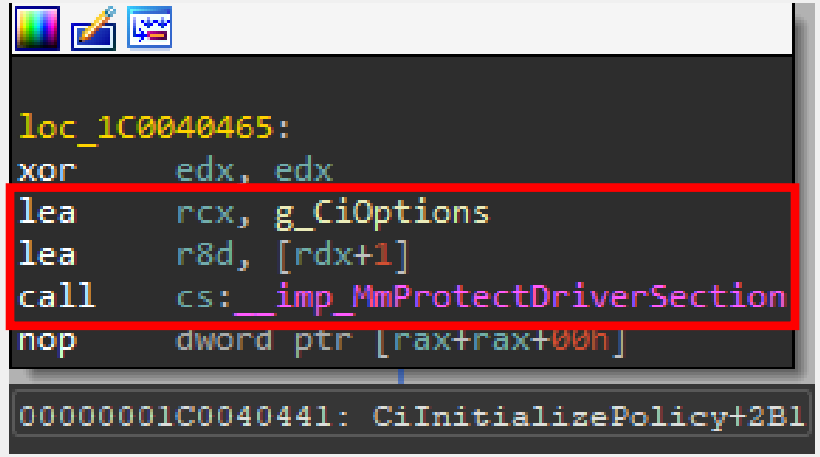
- Change CI!g_CiOptions or nt!g_CiEnabled in memory (“Flag Flipping”)
- Symbols are located by simple pattern matching
  - Minimal changes from between all Windows versions
- Overwrite and quickly proceed to load unsigned driver
- Once finished restore the flags back to their original state to avoid PatchGuard
- Bring Your Own Driver (BYOD) to gain kernel write primitive
  - With vulnerable or poorly written code that breaks security boundaries between user and kernel-mode
  - Pros: portable between OS versions, reusable after patching
  - Cons: Require administrative privileges, artifacts on disk

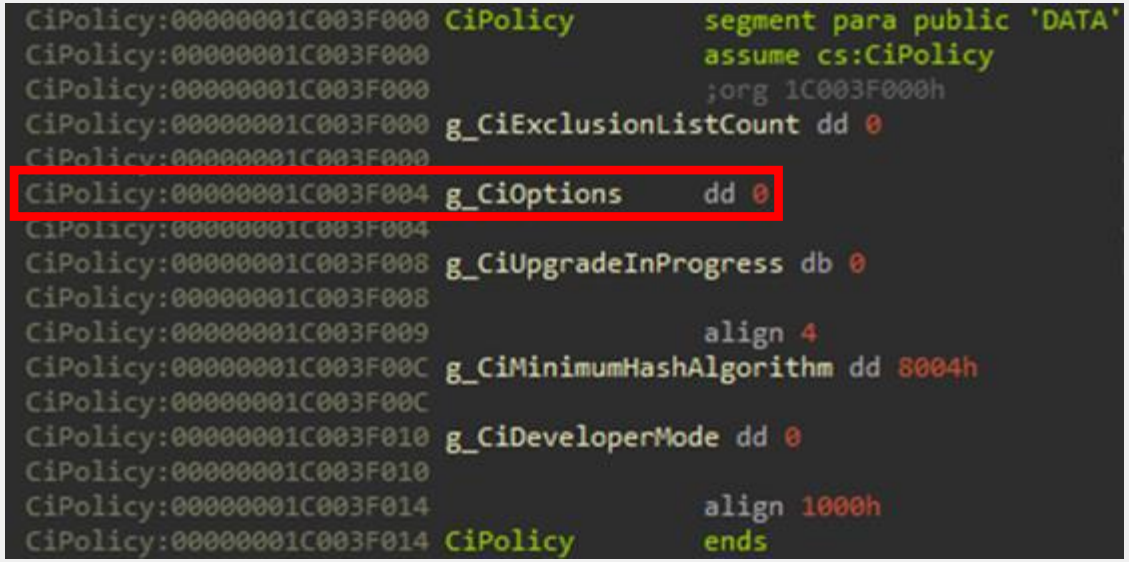
Protections

- Kernel Patch Protection (KPP, PatchGuard)
  - Callbacks structure in ntoskrnl.exe from Win8
  - CI!g_CiOptions from Win8.1
- Driver Blocklists
  - Enforced via Windows Defender Application Control (WDAC) or Secure Kernel (VTL1)
  - Reduce the attack vector – make it harder to gain a write primitive
  - The latest list can be found here
- Kernel Data Protection (KDP) introduced in Win10 20H1
  - Protect drivers in the Windows kernel against data-driven attacks
  - Reduce the attack surface – prevent changes to CI!g_CiOptions
  - Memory is marked by Secure Kernel (VTL1) as protected using the SLAT PTEs
  - Does not enforce how the GVA range mapping of a protected region is translated
    - Verifies only on a periodic basis that it translates to the appropriate GPAs

Protections

CI.dll With KDP





New Techniques

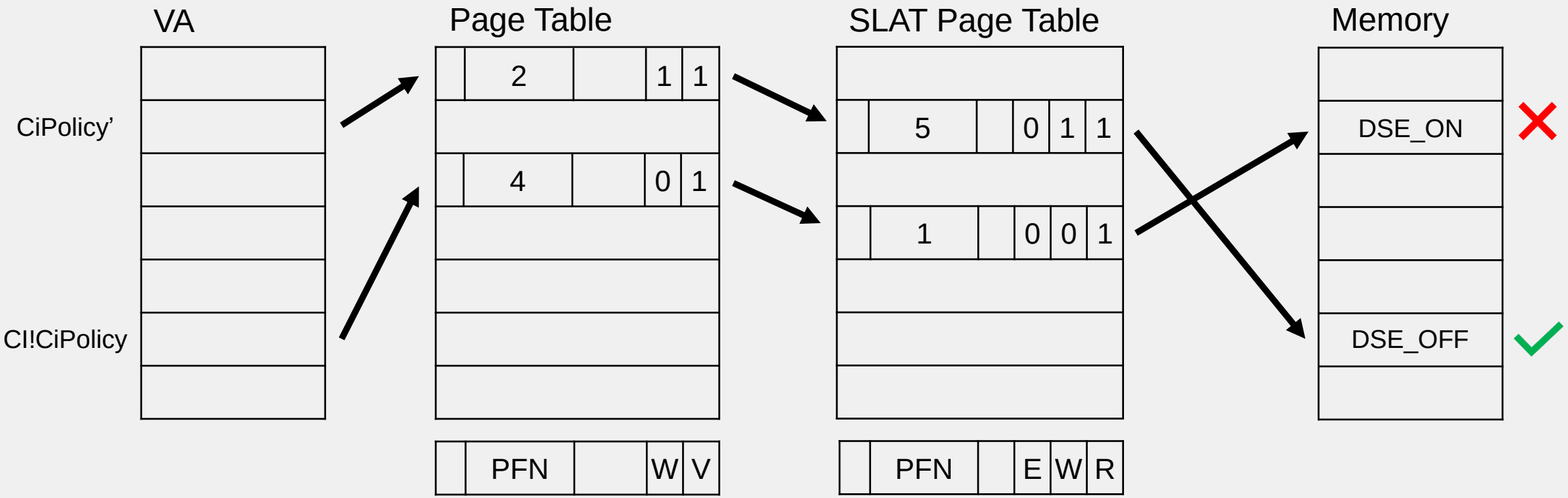
DSE Tampering Procedure

1. Locate
2. Overwrite
3. Load
4. Revert

New Techniques

Page Swapping

- Swap GPA (PFN in PTE) to a GPA we control
  - KDP doesn’t enforce PFN, only permissions



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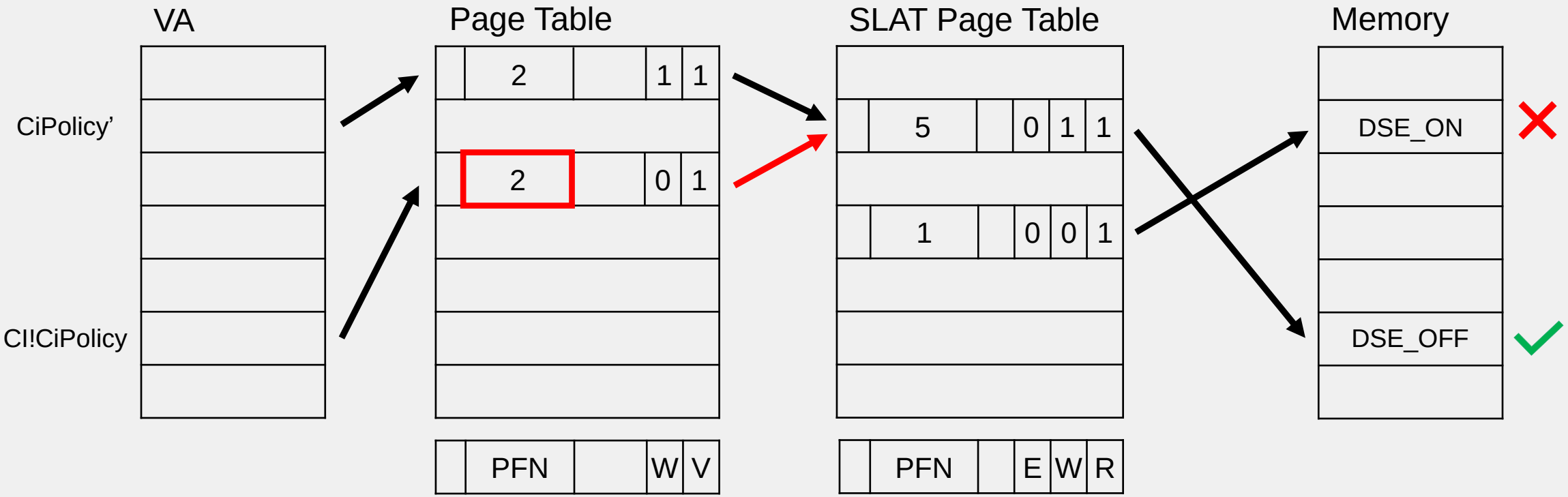


New Techniques

Page Swapping

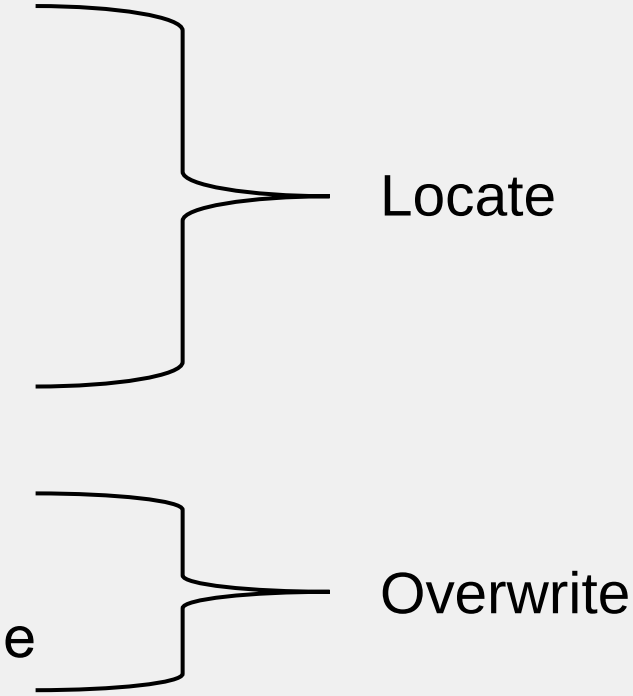
- Allocate a new, writable page
- Find CI!g_CiOptions (same as in the wild)
- Read PTE base
  - Randomized by KASLR from Win10 Redstone
  - Turning (Page) Tables, BSidesLV 2019 (slide 18)

```
; Exported entry 1438. MmGetVirtualForPhysical



; PVOID __stdcall MmGetVirtualForPhysical(PHYSI
public MmGetVirtualForPhysical
MmGetVirtualForPhysical proc near
mov     rax, rcx
shr     rax, 0Ch
lea     rdx, [rax+rax*2]
add     rdx, rdx
mov     rax, 0FFFFFA8000000008h
mov     rax, [rax+rdx*8]
shl     rax, 19h
mov     rdx, 0FFFFF68000000000h
shl     rdx, 19h
and     ecx, 0FFFh
sub     rax, rdx
sar     rax, 10h
add     rax, rcx
retn
MmGetVirtualForPhysical endp
```

New Techniques

Page Swapping

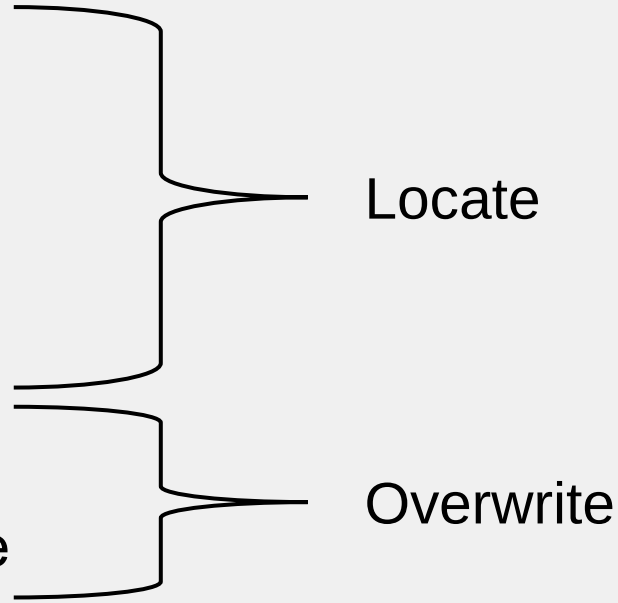
- Allocate a new, writable page
- Find CI!g_CiOptions (same as in the wild)
- Read PTE base
- Read PFN from PTE for CI!g_CiOptions' page
- Read PFN from PTE for our page
- Copy the entire page
- Modify our g_CiOptions
- Set our page's PFN in PTE for CI!g_CiOptions' page
- Load driver
- Restore original PFN



New Techniques

Page Swapping

- Allocate a new, writable user-space page
- Find CI!g_CiOptions
- Read PTE base
- Read PFN from PTE for CI!g_CiOptions' page
- Read PFN from PTE for our page
- Initialize our page with g_CiOptions as disabled
- Set our page's PFN in PTE for CI!g_CiOptions' page
- Load driver
- Restore the original PFN



Demo

New Techniques

Callback Swapping

- Replace CI.dll functions
  - Finding CI!g_CiOptions is not necessary

```
int nt!SeValidateImageHeader(pe)
{
  int status = 0;

  if (nt!g_CiEnabled)
  {
    if (nt!g_CiCallbacks.CiValidateImageHeader == NULL)
        status = STATUS_INVALID_SIGNATURE;
      else
        status = nt!g_CiCallbacks.CiValidateImageHeader(pe);
  }

    return (status);
}
```

```
int CI!CiValidateImageHeader(pe)
{
    int error;
    bool is_valid = validate_signature(pe, &error);

    if (is_valid)
        return (0);
    else
        return (ci_status_to_ret_value(error));
}
```

New Techniques

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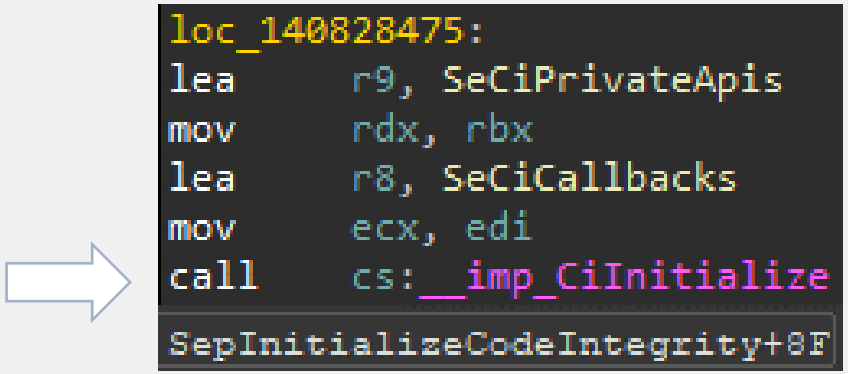
New Techniques

Callback Swapping

- Find the callbacks structure in ntoskrnl.exe
  - Find the call to CI!CiInitialize by reference to the Import Lookup Table (ILT) entry
  - Walk back to register assignment of a parameter pointing to uninitialized memory “.data" section



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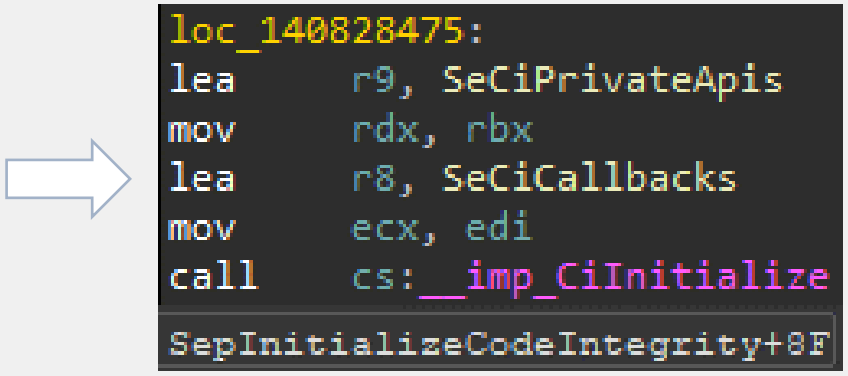
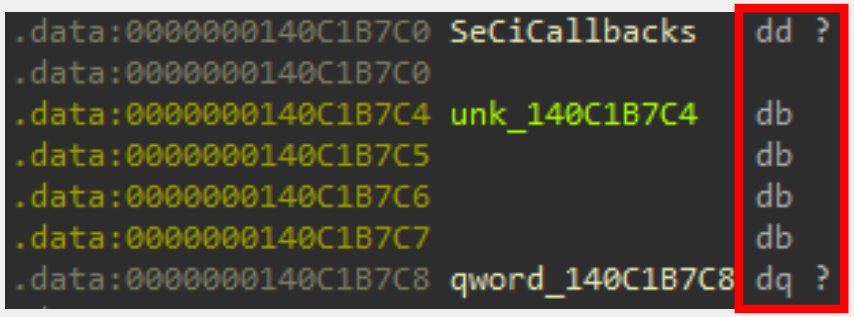




New Techniques

Callback Swapping

- Find the callbacks structure in ntoskrnl.exe
- Find a new callback
  - Exported functions in ntoskrnl.exe
  - Exported functions or gadgets in CI.dll

```
; Exported entry 390. FsRtlSyncVolumes


public xHalGetInterruptTranslator
xHalGetInterruptTranslator proc near
xor     eax, eax
retn
xHalGetInterruptTranslator endp
```

```
SIPolicySetOptions proc near
    mov     rax, [rcx+6Ch]
    mov     [rax+24h], edx
    mov     [rcx+2Ch], edx
    xor     eax, eax
    retn
SIPolicySetOptions endp

SIPolicySetOptions (Synchron
```

New Techniques

Callback Swapping

- Find the callbacks structure in ntoskrnl.exe
- Find a new callback
- Find the original callbacks
  - Search for the instructions setting the callbacks in the structure in CI!CipInitialize
  - Verify the addresses by traversing unwind information

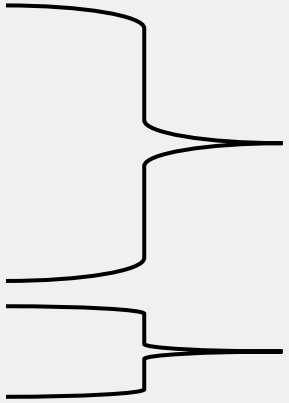
```
lea     rax, CiValidateImageHeader
mov     [rbx+20h], rax
lea     rax, CiValidateImageData
mov     [rbx+28h], rax
lea     rax, CiQueryInformation
mov     [rbx+18h], rax
lea     rax, CiSetFileCache
mov     [rbx+8], rax
lea     rax, CiGetFileCache
mov     [rbx+10h], rax
lea     rax, CiHashMemory
mov     [rbx+30h], rax
CipInitialize+23D (Synchronized wit
```

```
.pdata:00000001C00368B4 RUNTIME_FUNCTION <rva CiValidateImageHeader, rva algn_1C004FDA6,
.pdata:00000001C00368B4                  rva stru_1C002F894>
.pdata:00000001C00368C0 RUNTIME_FUNCTION <rva CiValidateImageData, rva byte_1C004FEA0, \
.pdata:00000001C00368C0                  rva stru_1C002EC38>
```

New Techniques

Callback Swapping

- Find the callbacks structure in ntoskrnl.exe
- Find a new callback
- Find the original callbacks
- Set the callback\s to the new function
- Load driver
- Restore the original callback\s



Demo

New Techniques

Comparison

	Flag Flipping	Page Swapping			Callback Swapping	
		Naïve	User Page	DSE Specific	Vista-Win7	Win8+
Read	0	Page + 3	Page + 3	3*	0	0
Alloc	0	Page	0	0	0	0
Write	1	Page + 1	1	1	2	1

* Assuming default values

Mitigation

- Confirm the state of DSE during driver loading
  - Why not find the internals variables the same way done for tampering?
- Capture the state
  - Copy the callbacks structure
  - Copy the flags
- Driver loading can be intercepted by
  - Hooking NtLoadDriver
  - Registry callbacks accessing the driver’s key
  - File system minifilter callback for IRP_MJ_ACQUIRE_FOR_SECTION_SYNCHRONIZATION
- Prevent by blocking the I\O request in callback or restore the variables

Summary

- Data-oriented mitigations are intricate to implement
  - “Robustly preventing this is non-trivial…” – Matt Miller, MSRC [BlueHatIL 2019]
- Defenders should adopt suggested mitigation as defense in-depth
- HVCI is the real solution for this case, enable it!
  - Introduced 7 years ago, with VBS, as Device Guard
  - Runs independently from KDP
  - Eliminate the attack surface – prevent any code from running in the kernel without being validated first in the Secure World (VTL1) by SKCI.DLL (Secure Kernel Code Integrity)
- Won’t be completely obsolete due to misconfigured and legacy systems
- https://www.fortinet.com/blog/threat-research/driver-signature-enforcement-tampering.html

Questions?

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