KERNEL MODE THREATS AND PRACTICAL DEFENSES

Joe Desimone

Gabriel Landau

ENDGAME.

@dez_

Joe Desimone

Senior Malware Researcher

Interests include offensive security research, reverse engineering, threat intelligence, and development of endpoint protections.

@gabriellandau

Gabriel Landau

Principal Software Engineer

Past work includes product & DRM evaluation, malware RE, and offensive security research. Interests include Windows internals, with a focus development of endpoint protections.

ABOUT US

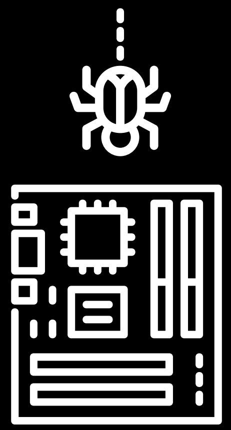
AGENDA

PART 1
Evolution of kernel mode threats and platform protections

PART 2
Offensive tradecraft to evade platform protections

PART 3
Augmenting OS defenses

WHY THE KERNEL?



Defense Evasion

- Hide processes, files, registry keys, network activity
- Entrenchment/Persistence
- Lack of visibility into kernel

Privilege Escalation

- Same privilege as security software

FIRST GENERATION KERNEL MALWARE

Rustock (~2007)
- Infect Windows drivers on disk
- Standard rootkit functionality

TDSS/TDL-1 (~2008)
- Reg/File/Process/Network hiding
- Infect driver

ZeroAccess (~2009)
- Overwrite random driver
- Hidden encrypted NTFS volume
- x86 only

NEW OS DEFENSES

EVOLUTION

PatchGuard

- Detect kernel patching/hooks → BSOD
- First on XP SP3 x64 (~2005)

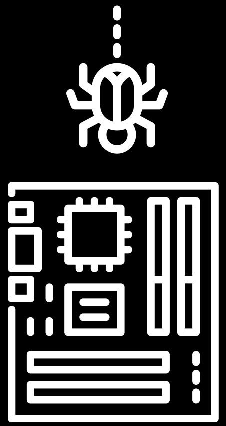
Driver Signature Enforcement (DSE)

- All drivers must be digitally signed
- First on Vista x64 (~2007)

Both defenses became more important as x64 market share grew

BOOTKITS

Replace MBR (or VBR), gain execution ***before*** OS.



EVOLUTION

EEye Bootroot (2005)

- First public POC

Mebroot *AKA Sinowal* (~2008)

- NDIS hook to evade FW

TLD4 (~2010)

- Replace kdcom.dll to gain early execution
- Modify Boot Config Data (BCD) to disable DSE

Xpaj (~2012)

- Set hooks before PG initialization

COUNTERING BOOTKITS

EVOLUTION

Secure Boot

- UEFI validates integrity of OS bootloader
- First support was Windows 8 (~2012)

Trusted Boot

- Each component of early windows boot process is verified by signature

Intel Boot Guard

- Root of trust in hardware (CPU)

Intel BIOS Guard

- Secure BIOS Updates

BRING YOUR OWN VULN

Bring a signed, ***vulnerable*** driver.
Use it to bootstrap into kernel.

Uroburos / Turla
- Exploit VBox driver
- Disable DSE by modifying g_CiEnabled
- Disable PatchGuard via RtlCaptureContext hook

Derusbi
- Exploit Novell driver
- Disable DSE by modifying CiOptions
- Also used stolen certificates

Slingshot
- Exploit Sandra driver
- Hide network traffic

EVOLUTION

DUQU 2.0

- **Main payload used 0day in win32k.sys for kernel execution (CVE-2015-2360)**
- **Hooked IAT of Kaspersky driver to spoof process information**
  - Allowed user mode component to become trusted ksp process
- **Separate driver used for persistence in DMZ**
  - Used stolen Foxconn certificate
  - Redirect traffic with NDIS filtering

DOUBLEPULSAR

- Volatile kernel mode implant
- Loaded via remote ring0 exploit (ex **ETERNALBLUE**)
- Evade PatchGuard by hooking srv!SrvTransactionNotImplemented pointer
- Injects DLLs into usermode via APCs

VIRTUALIZATION BASED SECURITY

EVOLUTION

- VTL1 – new Secure Kernel, trustlets
- VTL0 – normal Kernel, drivers
- Extended Page Tables (SLAT/EPT) to guard access
- IOMMU to protect from DMA access
- Hypervisor Code Integrity (HVCI)
  - All kernel code must be signed, (W^X)
- Credential Guard

EVOLUTION

Attacker
Initial Kernel Malware – Rustock, TDSS, ZeroAccess

Defender
First Kernel Defenses – Patchguard and Driver Signature Enforcement (DSE)

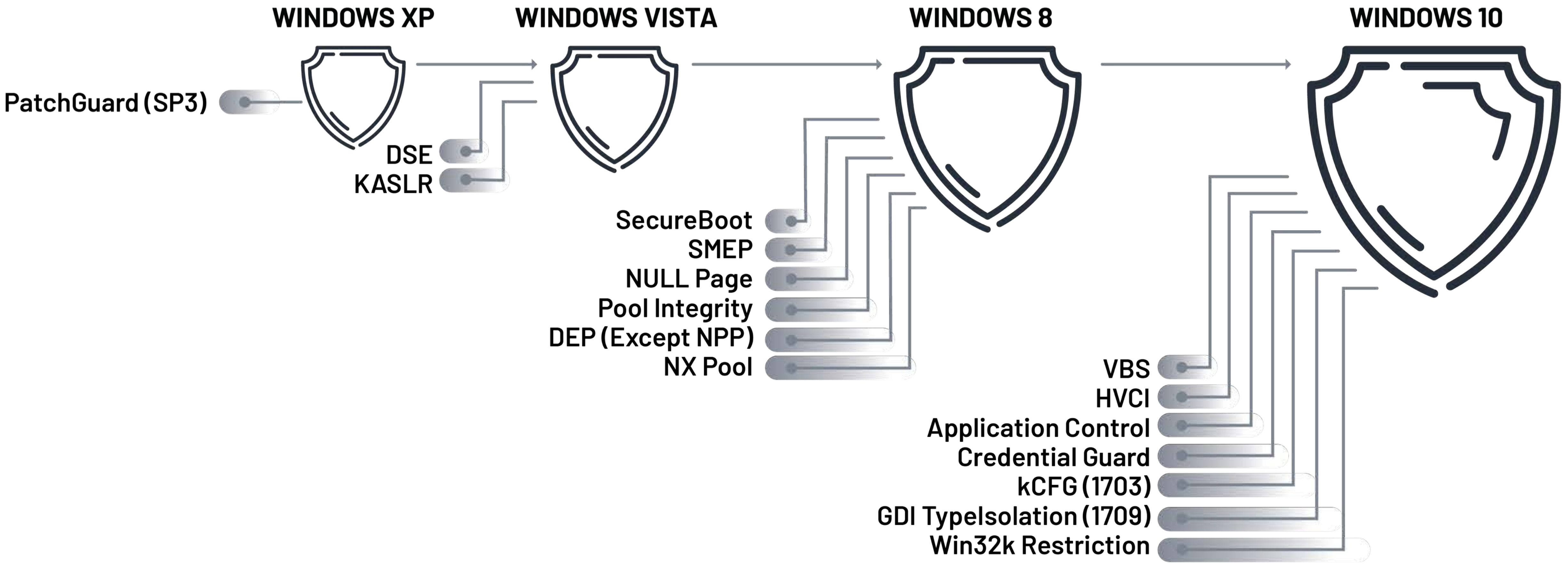
Attacker
BootKit Malware – Sinowal, TDL4, Xpaj

Defender
Countering Bootkits – SecureBoot, Trusted Boot, Boot Guard, etc.

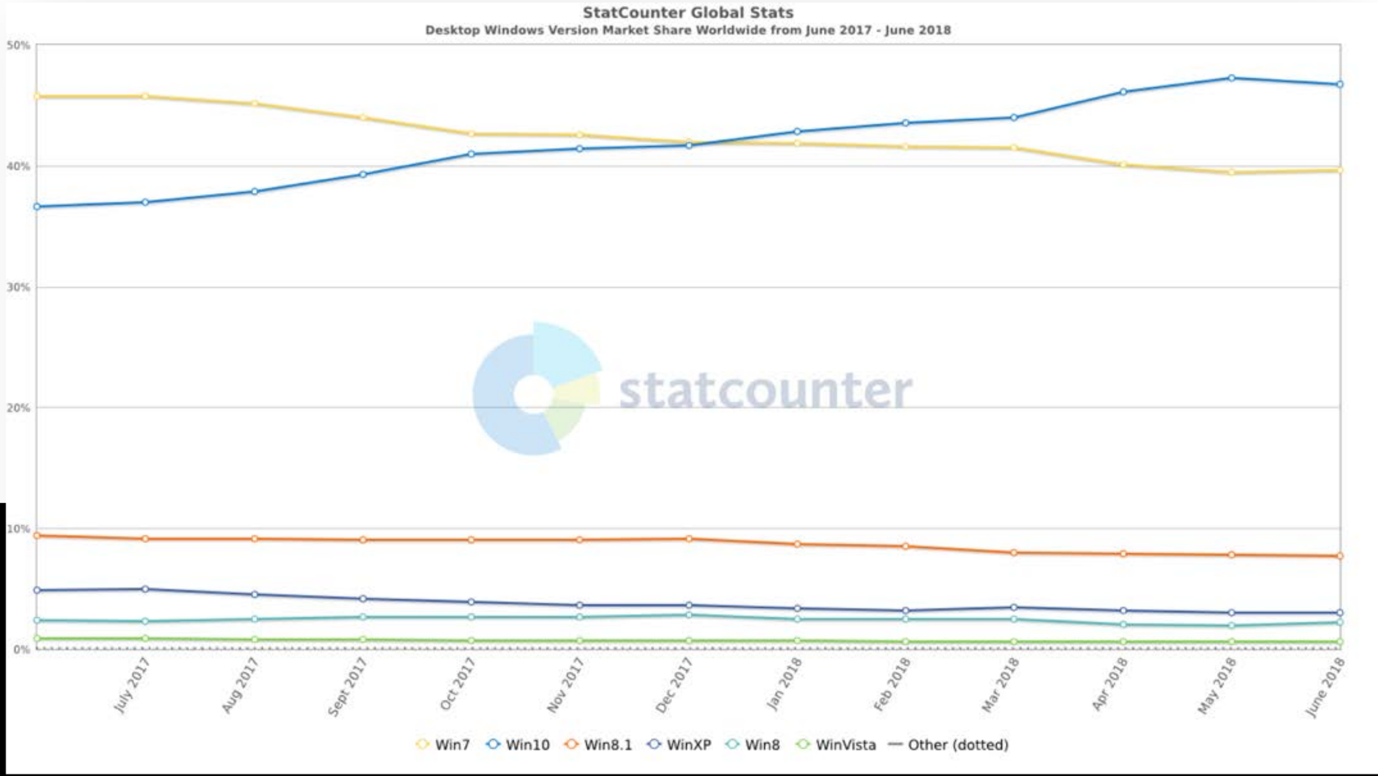
Attacker
Exploit To Load Driver – Uroburos, Duqu2, DoublePulsar

Defender
Virtualization Based Security (VBS)

KERNEL MITIGATIONS ACROSS WINDOWS VERSIONS



Adoption Rate



Windows 10 is less than half of worldwide installations. **How many are HVCI?**

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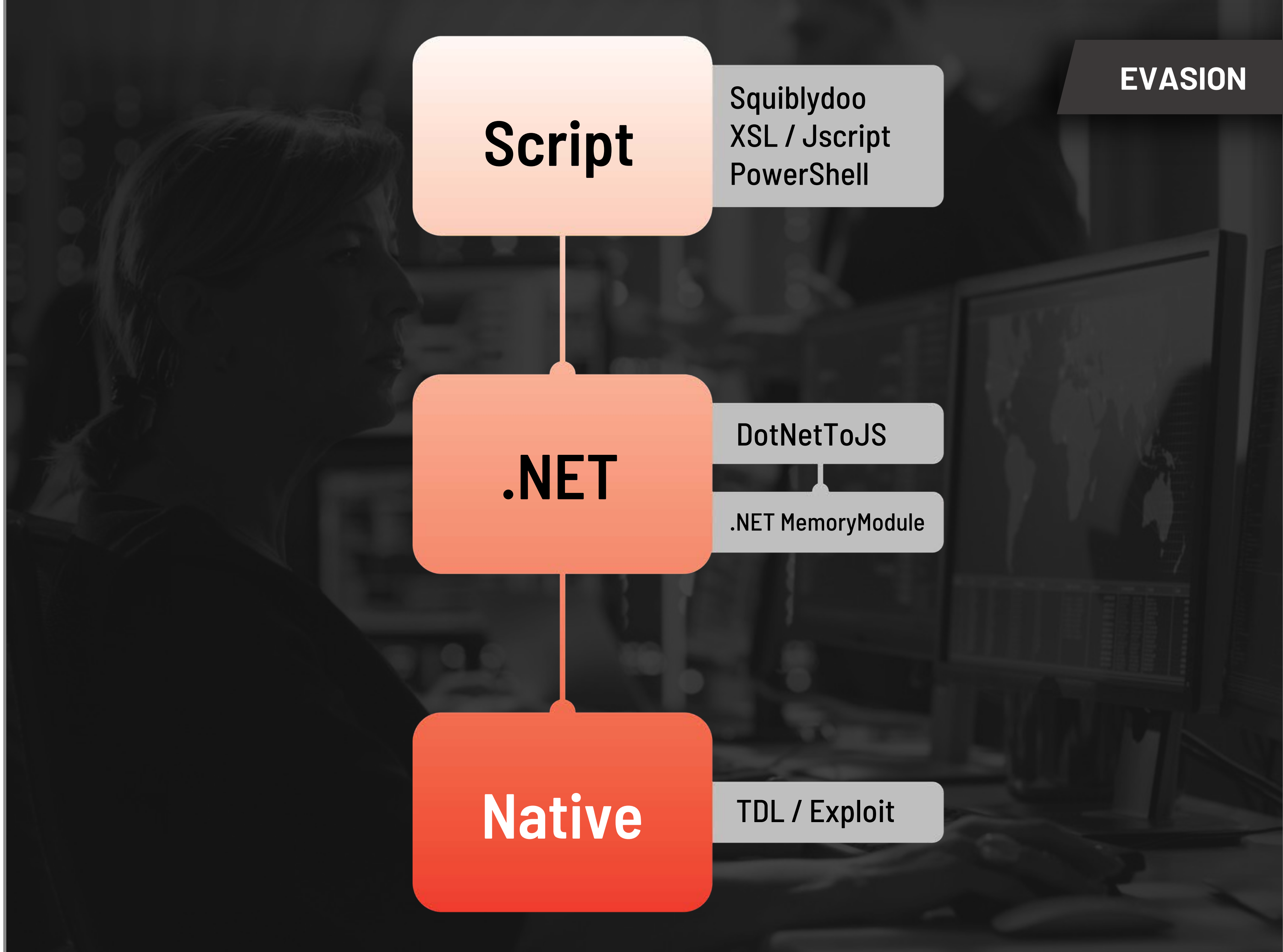
INTERNAL RvB
FILELESS KERNEL MODE IMPLANT

- Evade Blue Team by moving to the kernel
- Kernel dev environment
  - VS 2015, Windows Driver Kit (WDK) 10
  - Virtual KD / Windbg
- Turla Driver Loader (TDL)

IMPLANT DESIGN

- Kernel mode ONLY
- Winsock Kernel (WSK) for C2
- Triggerable (no beacons)
- Basic backdoor functionality

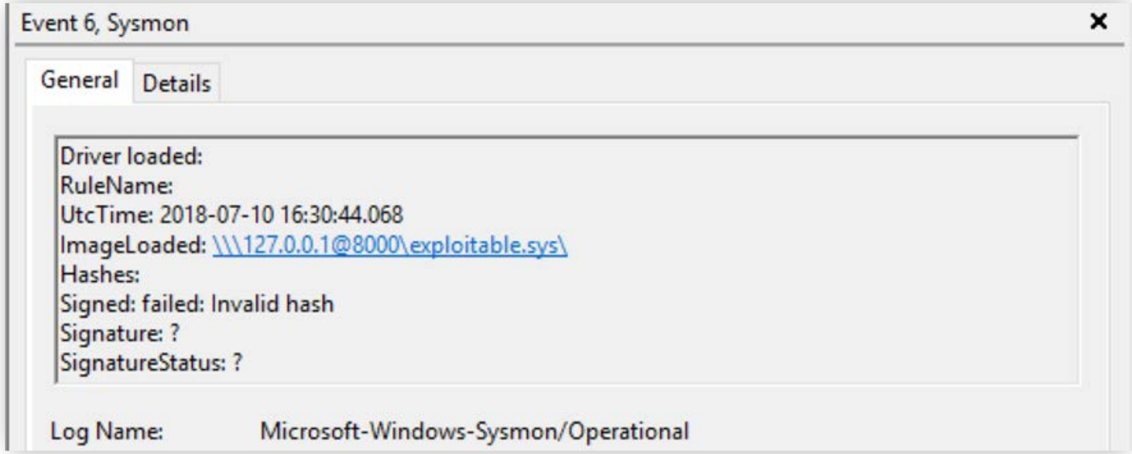
IMPLANT LOADER



EVASION

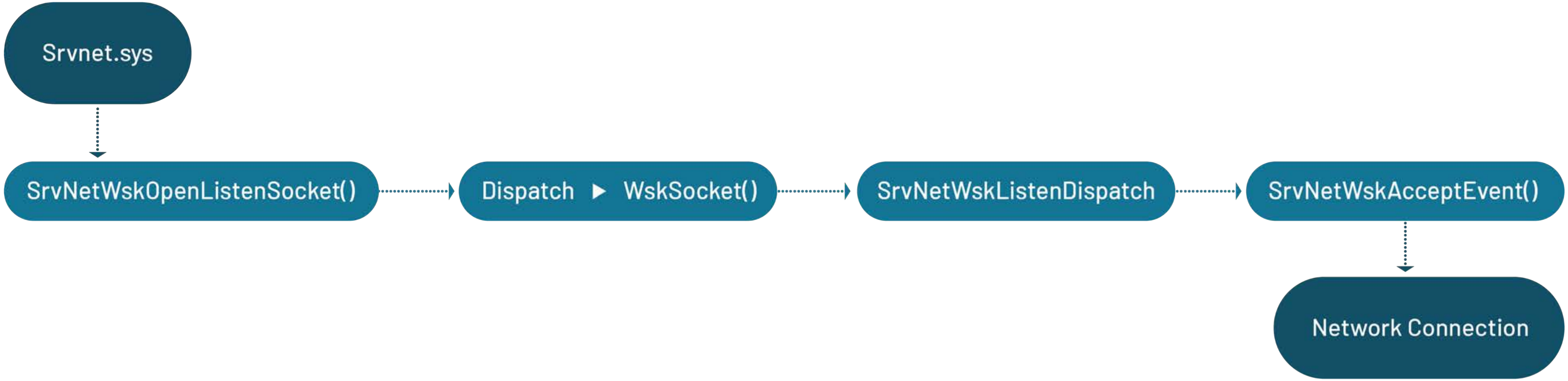
STAYING DISKLESS
NETWORK DRIVER LOAD

- Avoid dropping driver to disk by loading it with WebDAV:
  - ZwLoadDriver(\Device\WebDavRedirector\;\127.0.0.1@8000\exploitable.sys)
- Sysmon path conversion bug

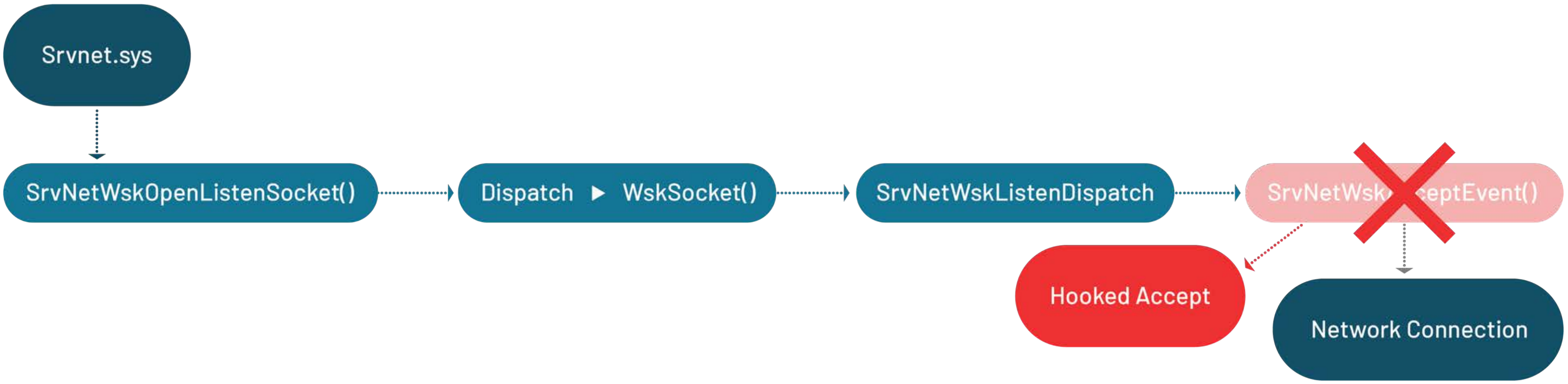


EVASION

STEALTHY NETWORK COMMS



STEALTHY NETWORK COMMS



DEMO

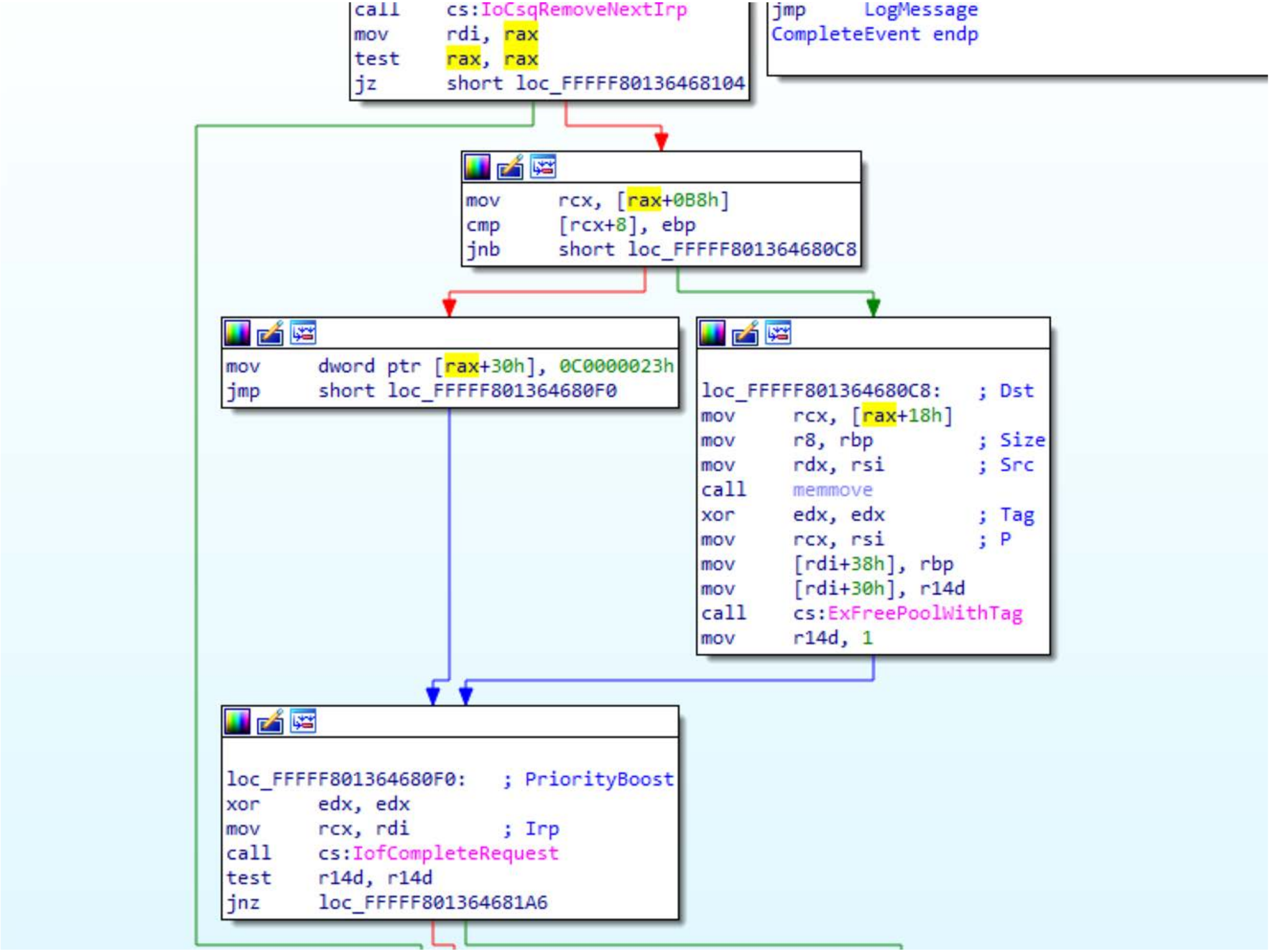
EVADING VBS / HVCI

- Virtual box driver vulnerability is a no-go, won't even load under HVCI
- Step one was to find a vulnerable driver which could load under HVCI. www.greyhathacker.net has tons of POCs (Parvez Anwar)
- BYOV – Bring your own vulnerability. Choose wisely!
  - Static 1-byte write vs
  - Write *what where

EVADING VBS / HVCI

DATA DRIVEN ATTACKS

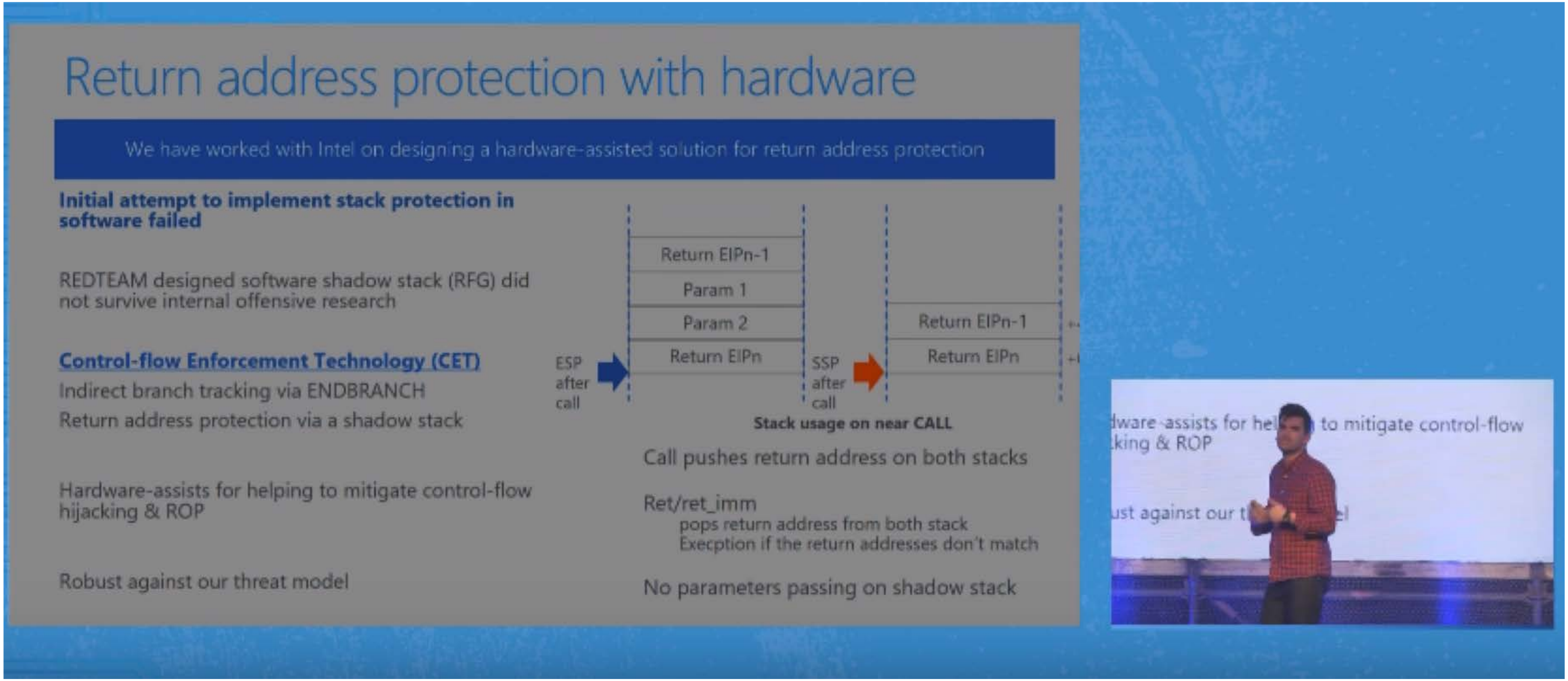
- Modification of kernel memory can significantly compromise the integrity of the system
- IAT patching
  - Even if IAT was protected by VBS, there are many other targets
- Disable EDR kernel-user communications
- Disable security focused kernel ETW providers
  - Microsoft-Windows-Threat-Intelligence
- Elevate Privileges – Token or Handle
- Data / Data Corruption



call cs:IoCsqRemoveNextIrp
mov rdi, rax
test rax, rax
jz short loc_FFFFF80136468104
jmp LogMessage
CompleteEvent endp
mov rcx, [rax+0B8h]
cmp [rcx+8], ebp
jnb short loc_FFFFF801364680C8
mov dword ptr [rax+30h], 0C0000023h
jmp short loc_FFFFF801364680F0
loc_FFFFF801364680C8: ; Dst
mov rcx, [rax+18h]
mov r8, rbp ; Size
mov rdx, rsi ; Src
call memmove
xor edx, edx ; Tag
mov rcx, rsi ; P
mov [rdi+38h], rbp
mov [rdi+30h], r14d
call cs:ExFreePoolWithTag
mov r14d, 1
loc_FFFFF801364680F0: ; PriorityBoost
xor edx, edx
mov rcx, rdi ; Irp
call cs:IofCompleteRequest
test r14d, r14d
jnz loc_FFFFF801364681A6

xrefs to EtwThreatIntProvRegHandle

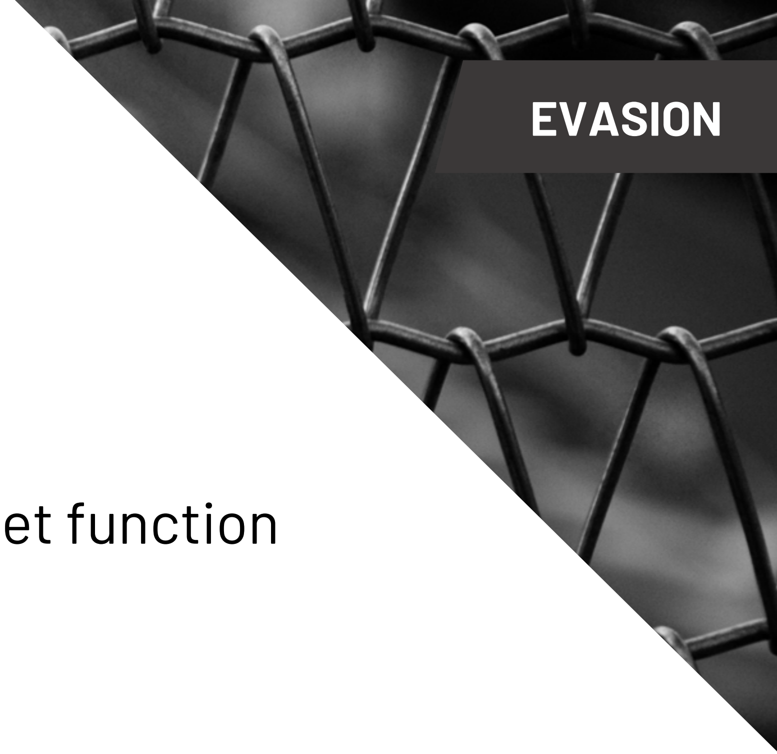
Direction	Typ	Address	Text
Do...	r	EtwTiLogAllocExecVm+19D	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogAllocExecVm+34	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogAllocExecVm+5C	mov r14, cs:EtwThreatIntProvRegHandle
Up	r	EtwTiLogMapExecView+19D	mov rcx, cs:EtwThreatIntProvRegHandle
Up	r	EtwTiLogMapExecView+34	mov rcx, cs:EtwThreatIntProvRegHandle
Up	r	EtwTiLogMapExecView+5C	mov r14, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogProtectExecVm+19D	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogProtectExecVm+34	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogProtectExecVm+5C	mov r14, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogQueueApcThread+2BC	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogQueueApcThread+57	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogQueueApcThread+8A	mov r15, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogQueueApcThread:loc_1405403F6	mov rsi, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogReadWriteVm+199	mov rcx, cs:EtwThreatIntProvRegHandle
	r	EtwTiLogReadWriteVm+4D	mov rbx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogSetContextThread+1AA	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogSetContextThread+221	mov rdi, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogSetContextThread+59	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogSetContextThread+8C	mov rdi, cs:EtwThreatIntProvRegHandle
Do...	r	EtwTiLogSetContextThread:loc_1405BD...	mov rcx, cs:EtwThreatIntProvRegHandle
Do...	o	EtwpInitialize+380	lea r9, EtwThreatIntProvRegHandle


Return address protection with hardware
We have worked with Intel on designing a hardware-assisted solution for return address protection
Initial attempt to implement stack protection in software failed
REDTEAM designed software shadow stack (RFG) did not survive internal offensive research
Control-flow Enforcement Technology (CET)
Indirect branch tracking via ENDBRANCH
Return address protection via a shadow stack
Hardware-assists for helping to mitigate control-flow hijacking & ROP
Robust against our threat model
Return EIPn-1
Param 1
Param 2
Return EIPn
ESP after call
SSP after call
Return EIPn-1
Return EIPn
Stack usage on near CALL
Call pushes return address on both stacks
Ret/ret_imm
pops return address from both stack
Execption if the return addresses don't match
No parameters passing on shadow stack

EVADING VBS / HVCI

CODE RE-USE

- Create a "surrogate" thread, put it to sleep
- Find location of stack [_ETHREAD]
- Build rop chain
- Hook stack -> overwrite NtWaitForSingleObject pointer with pivot gadget
- Resume thread (ReleaseMutex)



EVADING VBS / HVCI

CODE RE-USE

- Dynamically build chain based on number of arguments in target function
- We have 10 gadgets for full N-Argument function call
- Pivot (pop rsp, ret)
- Restore the 16 bytes overwritten on the stack
- Setup arguments in registers/stack
- Call target function
- Save return value (rax)
- Restore R14 (mutex object)
- Unpivot

EXAMPLE – WriteProcessMemory

```
NTSTATUS WPM(DWORD_PTR targetProcess, DWORD_PTR destAddress, void * pBuf, SIZE_T Size)
{
    SIZE_T Result;
    DWORD_PTR srcProcess = CallFunction("PsGetCurrentProcess");

    LONG ntStatus = CallFunction("MmCopyVirtualMemory", srcProcess,
        (DWORD_PTR)pBuf, targetProcess, destAddress, Size, KernelMode, (DWORD_PTR)&Result);

    return ntStatus;
}
```

DEMO

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DEFENSES

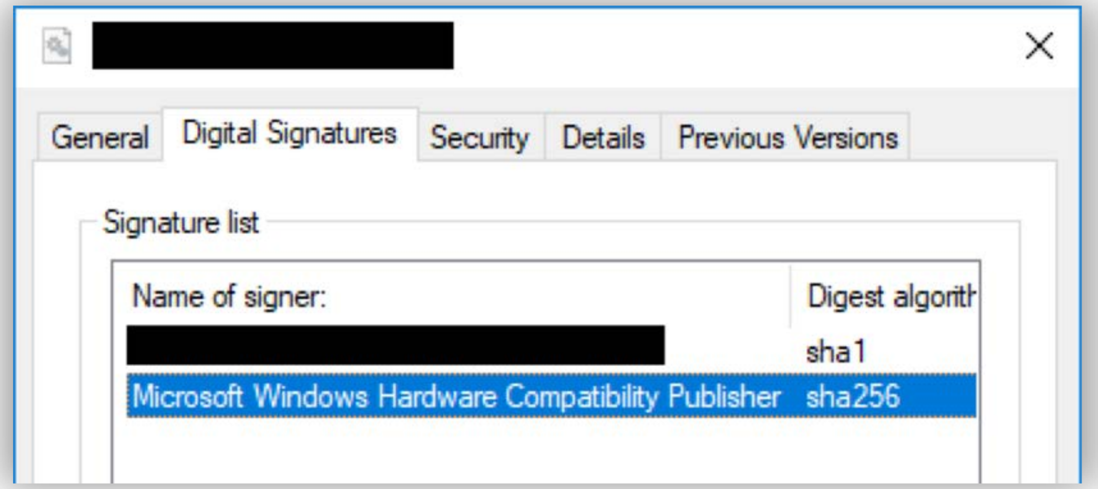
DRIVER EVENTING

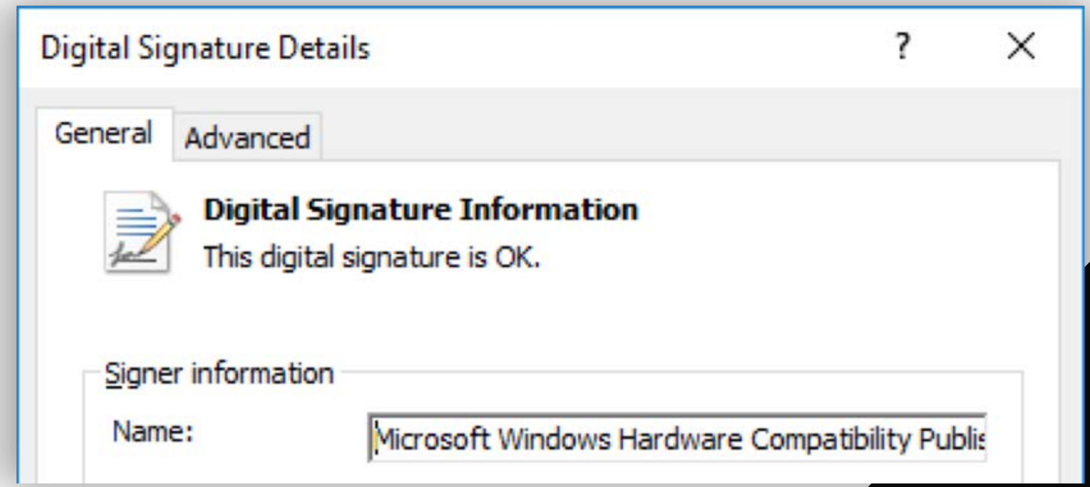
- You should very carefully monitor driver load events
- Look for low prevalence drivers
- Identify known-exploited drivers (blacklist)
- Free Instrumentation:
  - Sysmon Event ID 6: Driver loaded
  - Windows Defender Application Control (DG) Audit Mode

DEFENSES

REDUCING ATTACK SURFACE

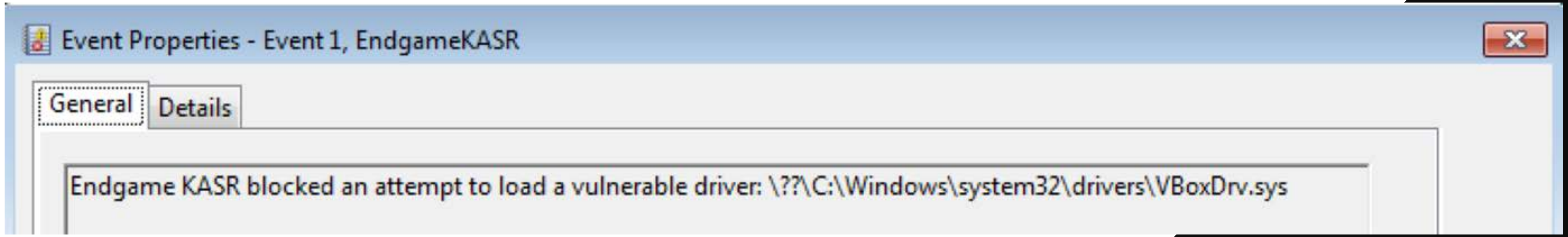
- Limit kernel drivers to WHQL





REDUCING ATTACK SURFACE

- Blacklisting Exploitable Drivers
  - Default in Win10 RS5 HVCI
- Endgame Kernel Attack Surface Reduction (KASR)
  - No configuration required
  - Free. Available at www.endgame.com



KERNEL MEMORY COLLECTION

Problem

Full memory acquisition and offline analysis does not scale

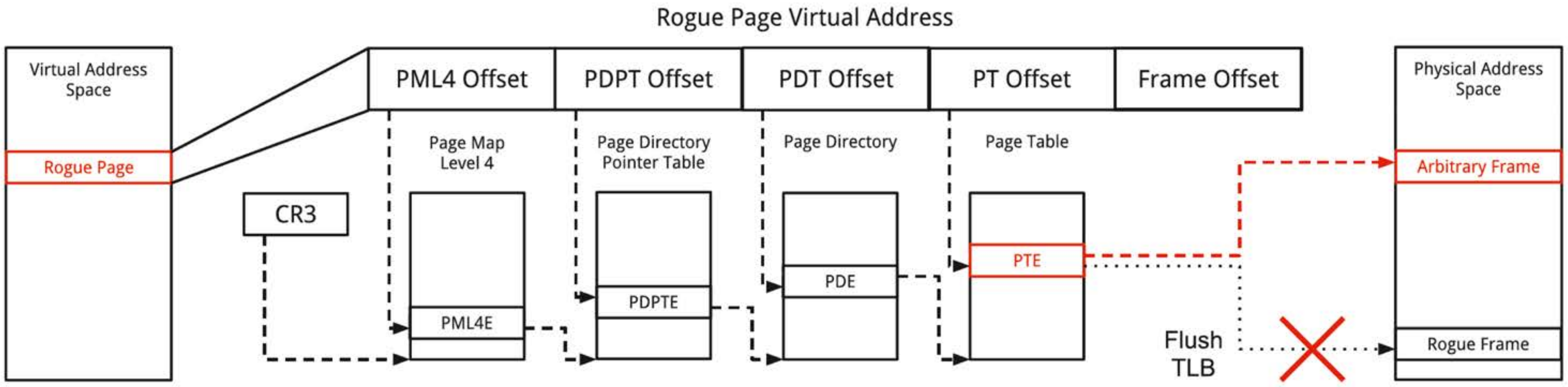
Solution

Leverage the same techniques to read kernel memory at the endpoint and perform analysis on the endpoint

- \Device\PhysicalMemory
- MmMapIoSpace
- MmMapMemoryDumpMdl
- Page Table Entry (PTE) Remapping

KERNEL MEMORY COLLECTION

- Page Table Entry (PTE) remapping
  - Invented by Stüttgen and Cohen
  - Most performant in testing
  - More resilient to tampering from rootkits (No API to hook)
  - Based on CPU architecture, so it is cross-OS-compatible
  - Modify the PTE of a controlled chunk of memory to point to where you want to read



FUNCTION POINTER INTEGRITY SCAN

- Generically detect function pointer hook
- Locate function pointers by walking relocation tables
- Endgame Marta
  - Free. Available at www.endgame.com

Consider a hit if...

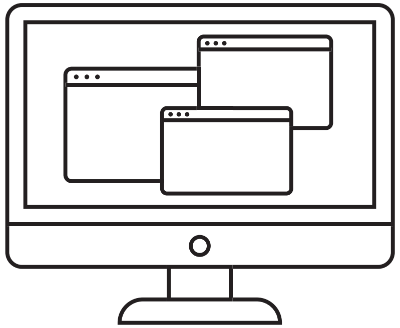
Originally pointed to +X section in on-disk copy of driver

Does not point to a loaded driver in memory

Points to executable memory

DEFENSES

REALTIME DETECTION OF UNBACKED KERNEL CODE



Performance Monitoring Unit (PMU)

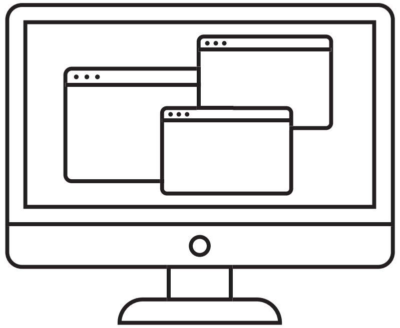
- Built into most CPUs in the last decade
- Programmable to count specific events
- Can generate an interrupt when a certain number of events occur

Detect unbacked kernel shellcode / unbacked drivers

- Program PMU to fire interrupts on some event likely to occur inside unbacked driver.
- When interrupt fires, validate IP belongs to a driver

DEMO

REALTIME DETECTION OF UNBACKED KERNEL CODE



Weaknesses

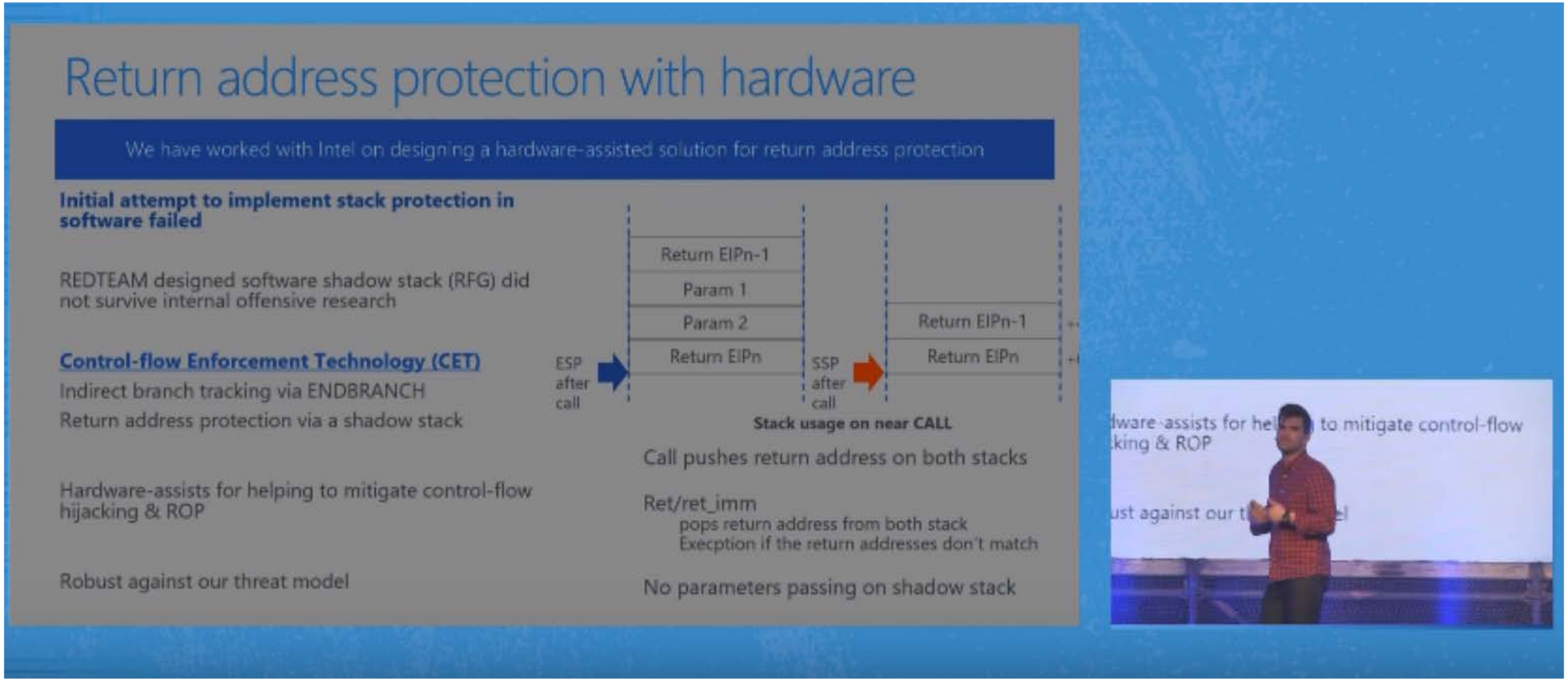
- FP from unbacked drivers (including PatchGuard)
- Vulnerable to PMU disablement via MSR
- Detection driver is susceptible to data attacks

HYPERVISOR APPROACHES

- MemoryMon
  - Leverage EPT to detected unbacked kernel code execution
- AllMemPro
  - Mitigates data attacks by isolating driver data with hypervisor
  - Based on same platform as MemoryMon
- SecVisor
  - CMU research from 2007
  - Early implementation of hypervisor enforced code integrity

DEFENSES

HARDENING THE WINDOWS KERNEL AGAINST ROP



HARDENING THE WINDOWS KERNEL AGAINST ROP

- CFG provides forward-edge CFI, but there is no reverse-edge CFI
  - RFG was cancelled
  - Intel CET requires future hardware

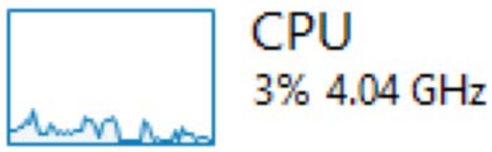
IDEA Provide reverse-edge kernel CFI using the PMU

DEFENSES

HARDENING THE WINDOWS KERNEL AGAINST ROP

ROP tends to generate lots of mispredictions

- Scan drivers to identify call/return sites
- Configure LBR to record CPL0 near returns
- Configure PMU fire PMI when BR_MISP_RETIRED counter overflows
- Validate every new LBR entry is call-preceded



Performance

- Protection tunable from deterministic to probabilistic
- JetStream benchmark on Intel Skylake 6700K: ~1.1% overhead

DEMO

HARDENING THE WINDOWS KERNEL AGAINST ROP

- Limitations
  - Vulnerable to malicious drivers. Hypervisor protection needed.
    - wrmsr IA32_PERF_GLOBAL_CTRL, 0
    - Data attack against policy bitmap
  - Requires available PMU and LBR
    - No VMware/Hyper-V support
  - Incompatible with obfuscated drivers
    - Windows ships with two: clipsp.sys and peauth.sys
- Something similar exists on Linux

CONCLUSION

- Windows platform security has gotten much better in the last decade. However, **kernel mode threats are still a big concern**
- Use Windows 10 with SecureBoot and HVCI
- Require EV/WHQL drivers via code integrity policy
- Monitor and hunt on driver load events

QUESTIONS?

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