Who's Watching the Watchdog? Uncovering A Privilege Escalation Vulnerability in OEM Driver

Amit Rapaport, Microsoft

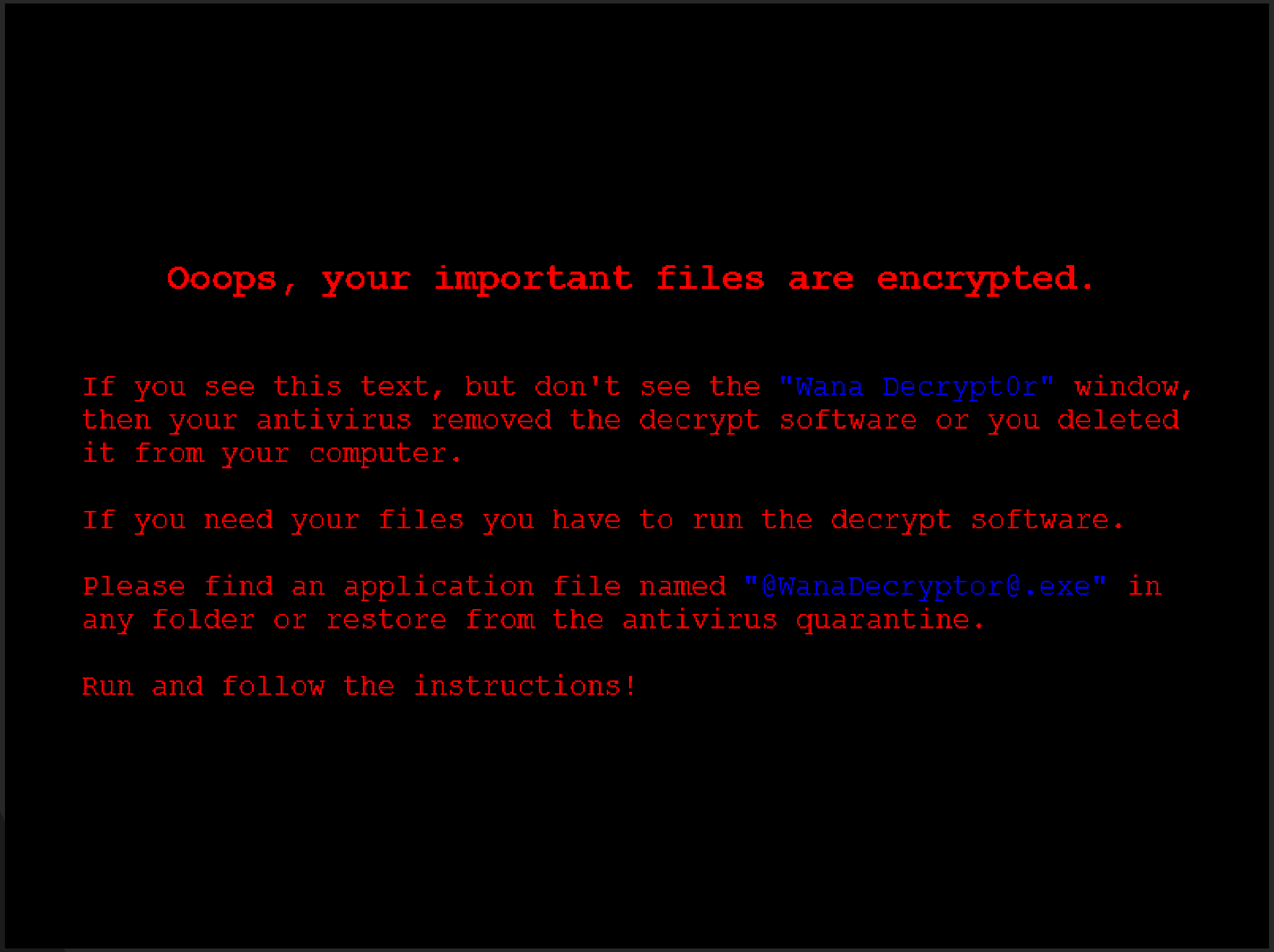
> whoami

- Amit Rapaport (@realAmitRap)
- Security researcher @ THRIL Team, Windows Defender ATP
- Born & raised on Windows OS
- Deeply interested in low-level, OS internals, reverse engineering and exploitation

Talk Scope

- The story of Windows Defender ATP alert -> zero-day discovery
  - CVE-2019-5241 & CVE-2019-5242
- Demo

Where Our Story Begins



WannaCry Ransomware

- Major outbreak during May 2017
- Demands 300-600 to recover encrypted files
- Infected more than 200k machines
- Propagates mainly through SMBv1 kernel exploit - *ETERNALBLUE*

WannaCry Ransomware - Infection

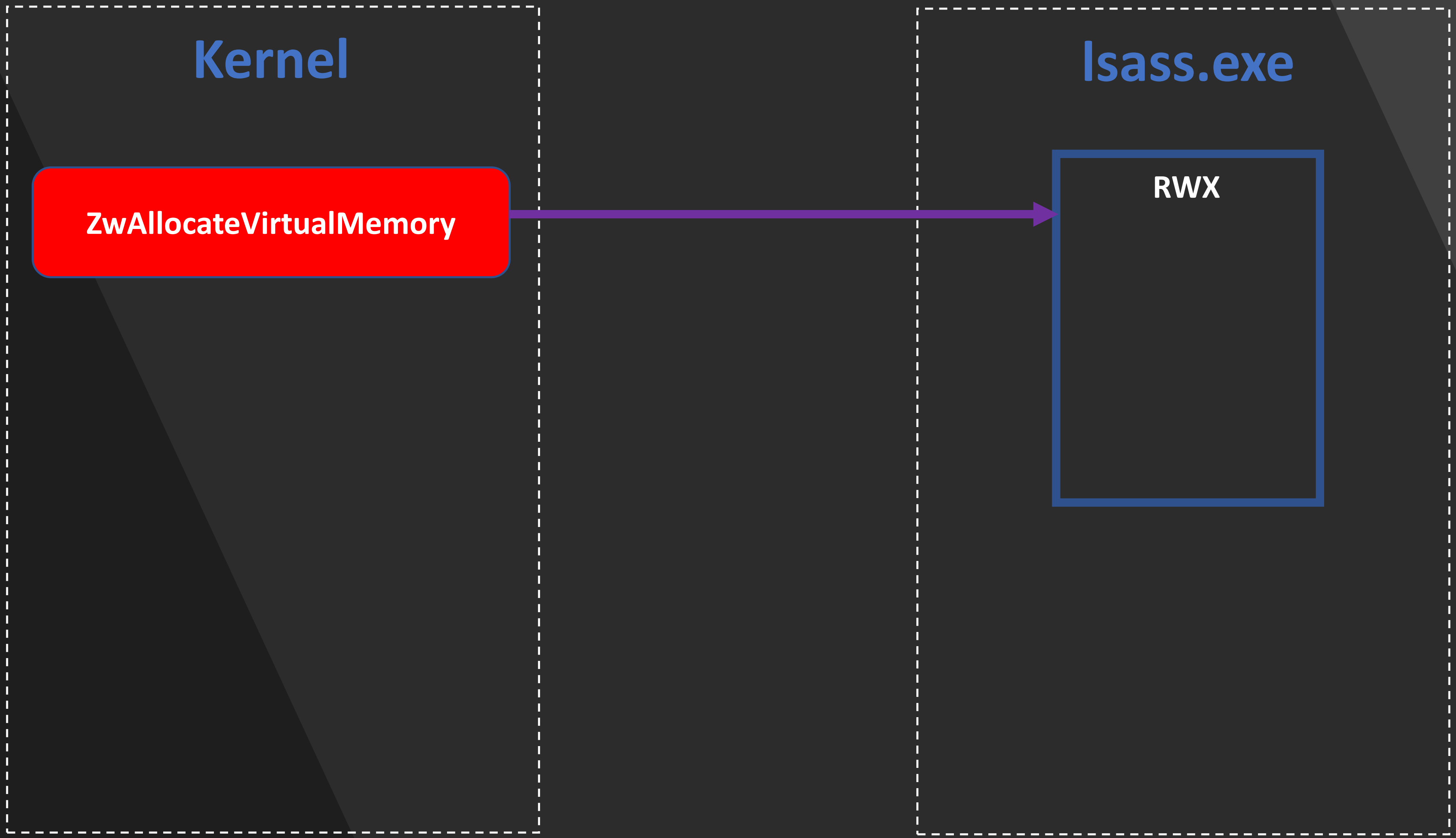
- Machine exploitation ends up loading a lightweight, non-persistent, kernel-mode backdoor – known as *DOUBLEPULSAR*
- *DOUBLEPULSAR* allows an attacker to inject a custom payload into user-mode
  - Victim process is *lsass.exe*
  - Used for the initial loading of WannaCry main payload

DOUBLEPULSAR Injection Technique

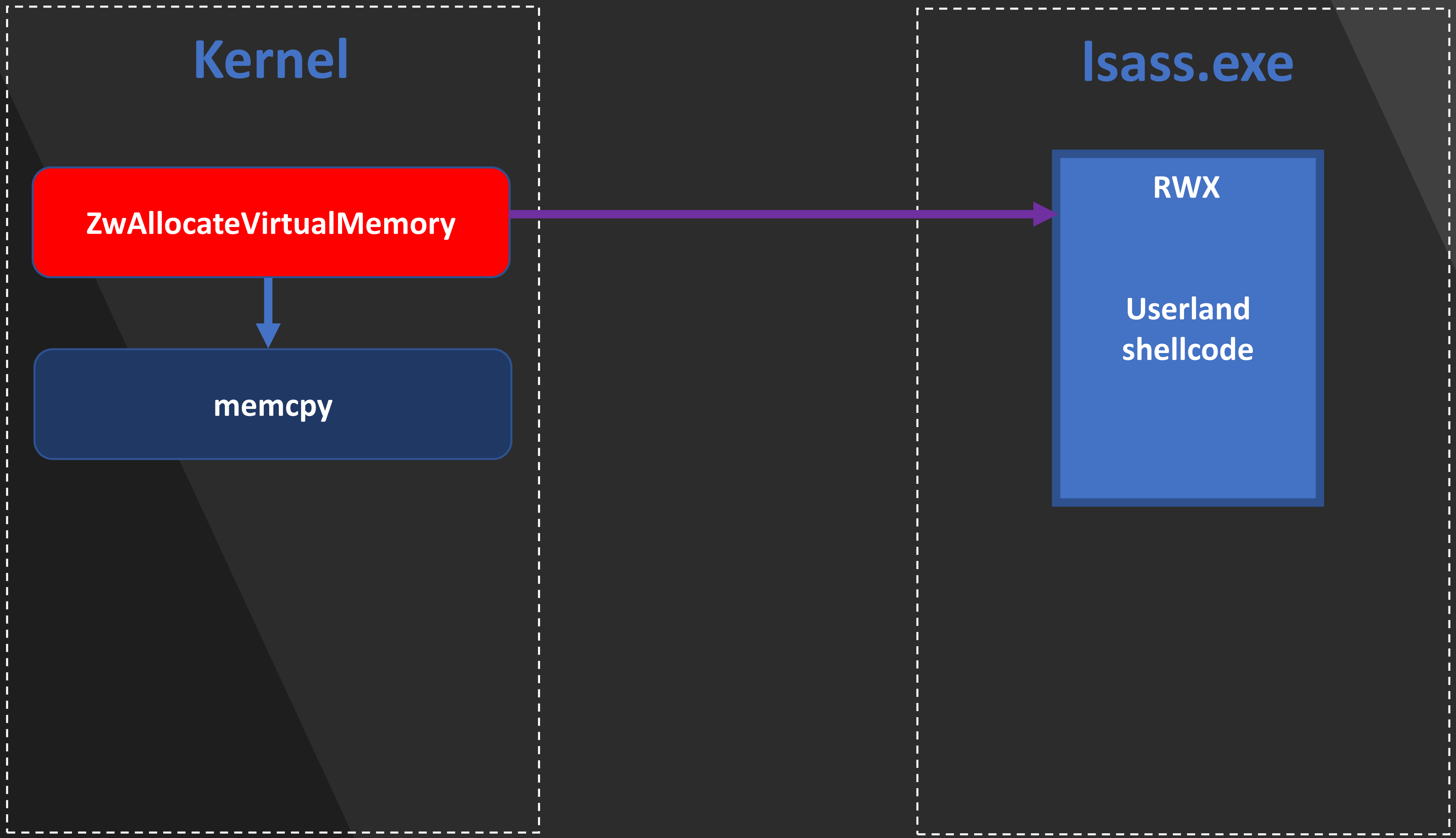
Kernel

lsass.exe

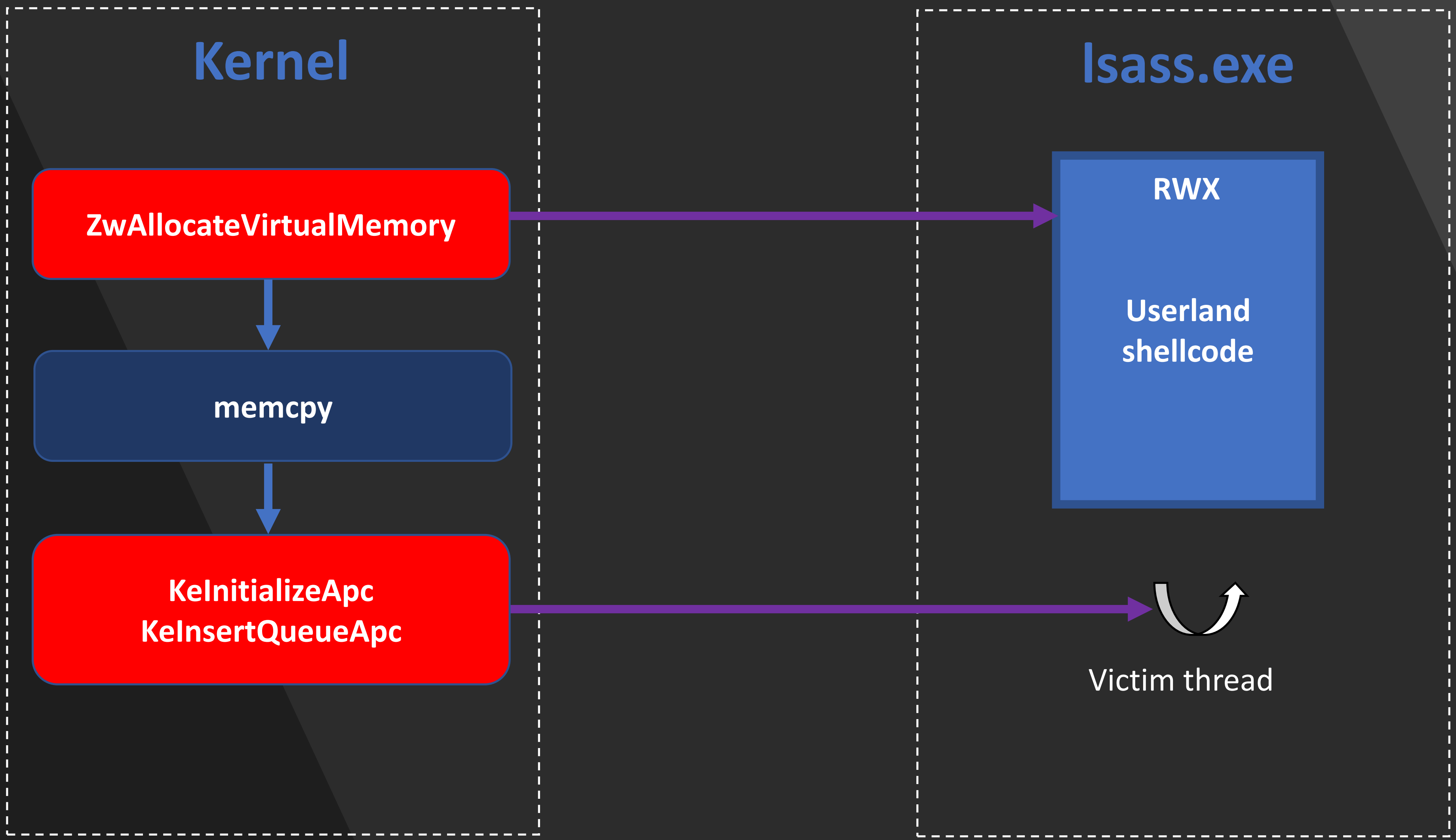
DOUBLEPULSAR Injection Technique



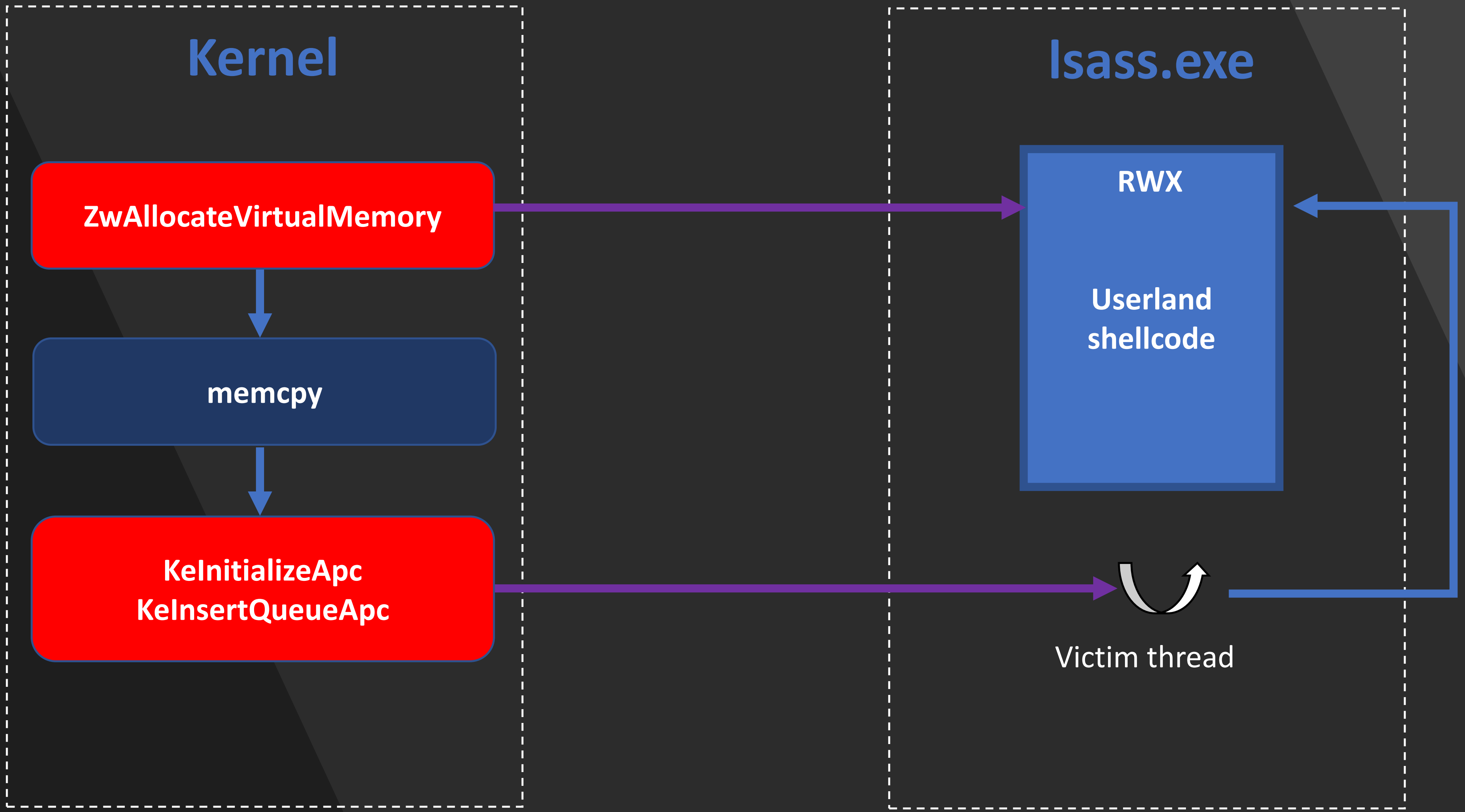
DOUBLEPULSAR Injection Technique



DOUBLEPULSAR Injection Technique

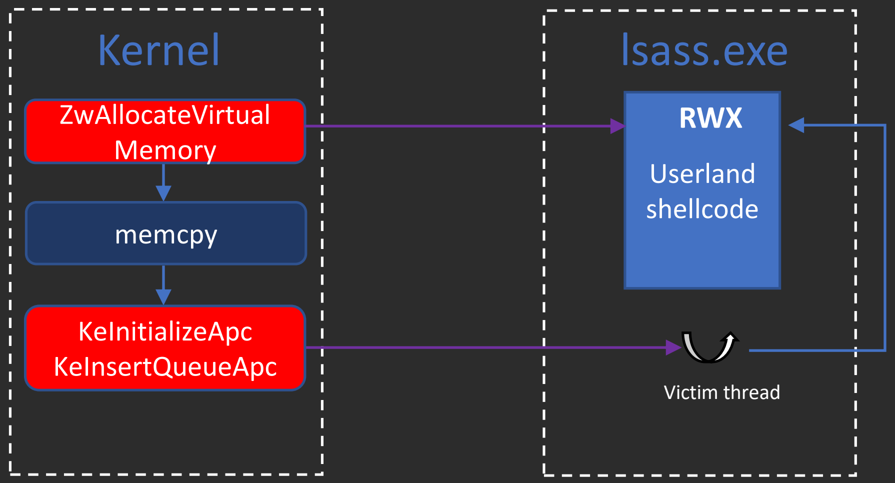


DOUBLEPULSAR Injection Technique



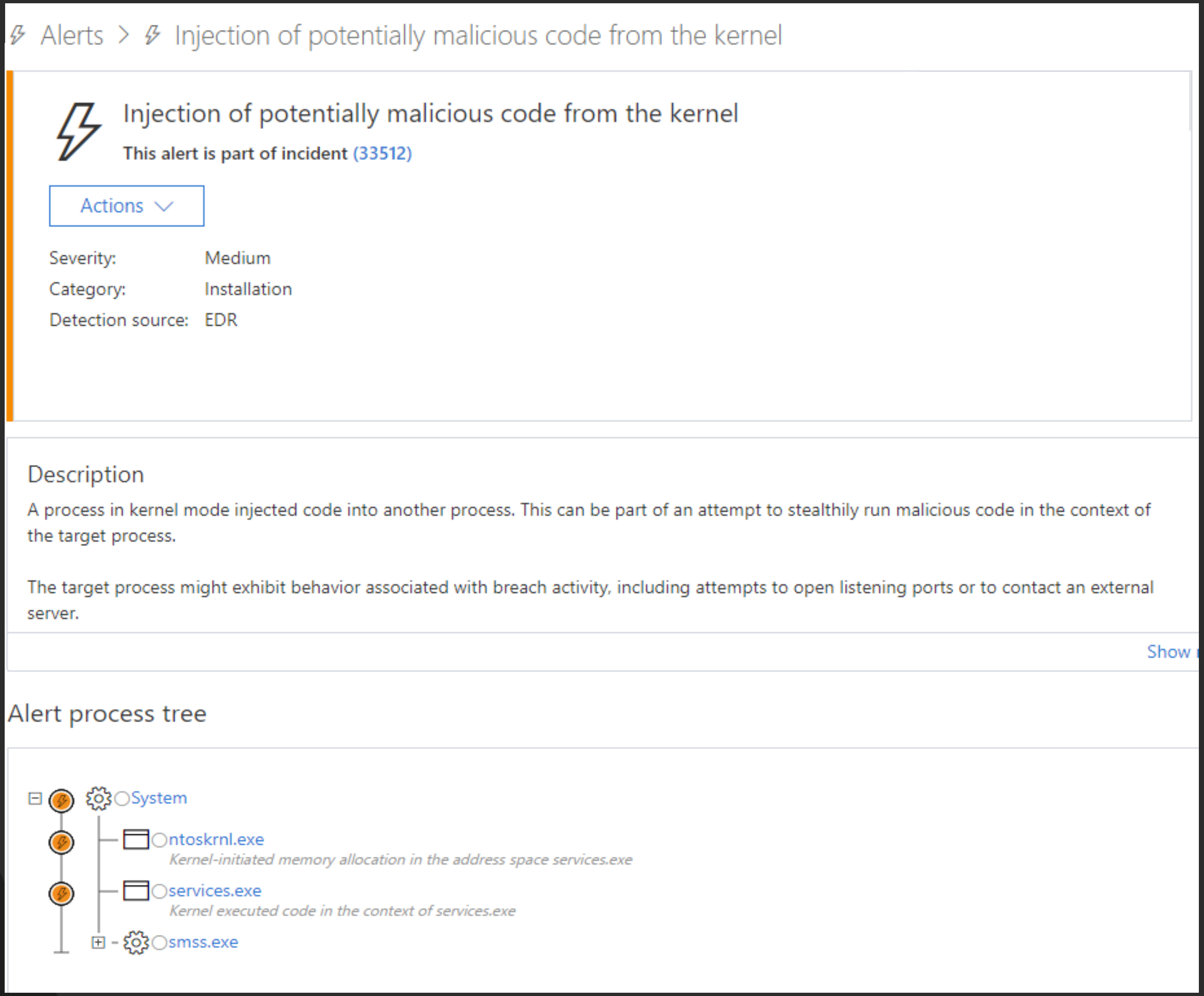
How to Detect Kernel->User APC Injection

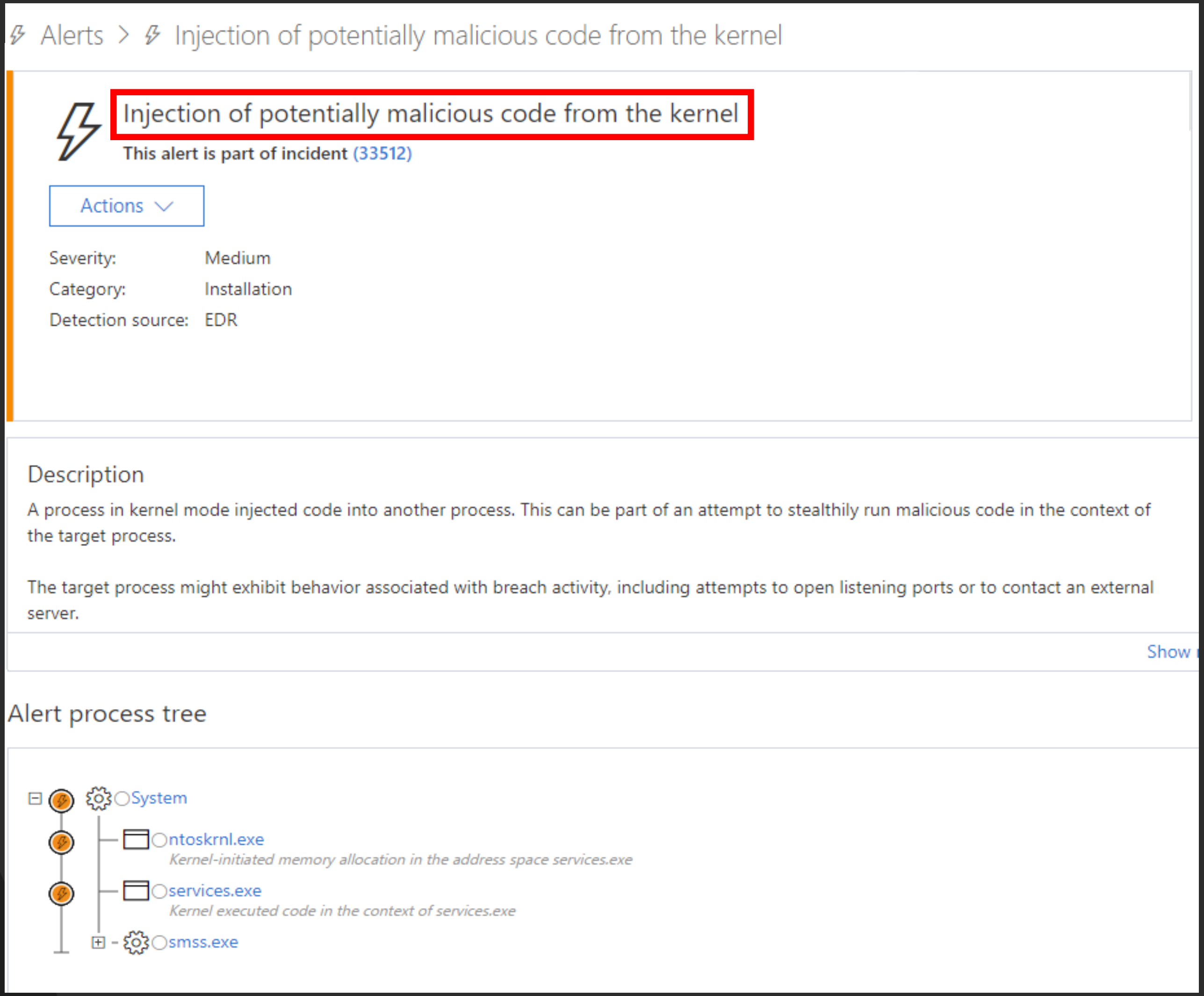
- No hooks are allowed
- No notify callback on Mm operations
- No notify callback on APC operations…



How to Detect Kernel->User APC Injection

- We instrumented *NTOSKRNL* in Windows 10 October 2018 update to trace kernel callers doing
  - Mm operations
  - APC insert operations
- Events are traced through *Microsoft-Windows-Threat-Intelligence* ETW provider


Alerts > Injection of potentially malicious code from the kernel
Injection of potentially malicious code from the kernel
This alert is part of incident (33512)
Actions
Severity: Medium
Category: Installation
Detection source: EDR
Description
A process in kernel mode injected code into another process. This can be part of an attempt to stealthily run malicious code in the context of the target process.
The target process might exhibit behavior associated with breach activity, including attempts to open listening ports or to contact an external server.
Alert process tree
System
ntoskrnl.exe
Kernel-initiated memory allocation in the address space services.exe
services.exe
Kernel executed code in the context of services.exe
smss.exe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Show
Alert process tree
System
ntoskrnl.exe
Kernel-initiated memory allocation in the address space services.exe
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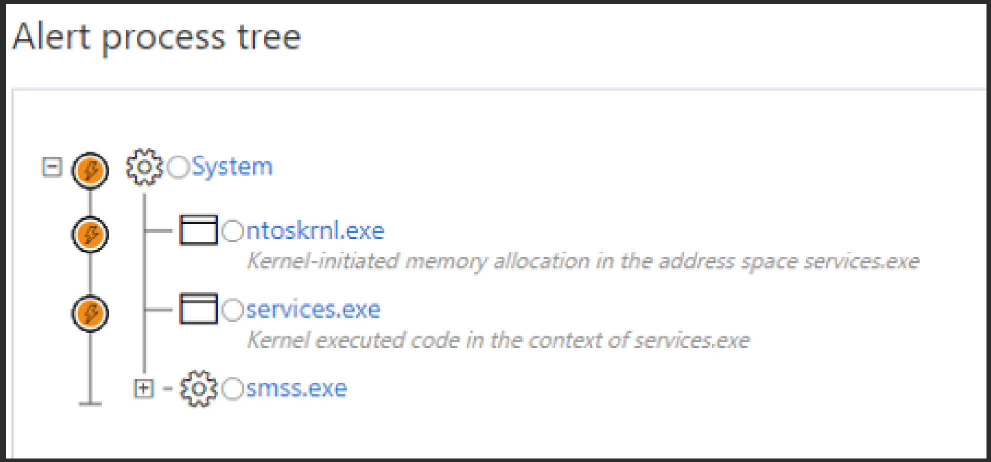
Kernel executed code in the context of services.exe
smss.exe

Collecting the Evidence

- Careful analysis of the alert showed that:
  - Kernel code allocated an executable region
  - Kernel code injected User APC targeting that region
  - *services.exe* – the only affected process on the machine
- Sounds familiar?



Hunting The Source

- Which kernel code triggered the injection?
  - Can become quite challenging…

Hunting The Source

- Which kernel code triggered the injection?
  - Can become quite challenging…

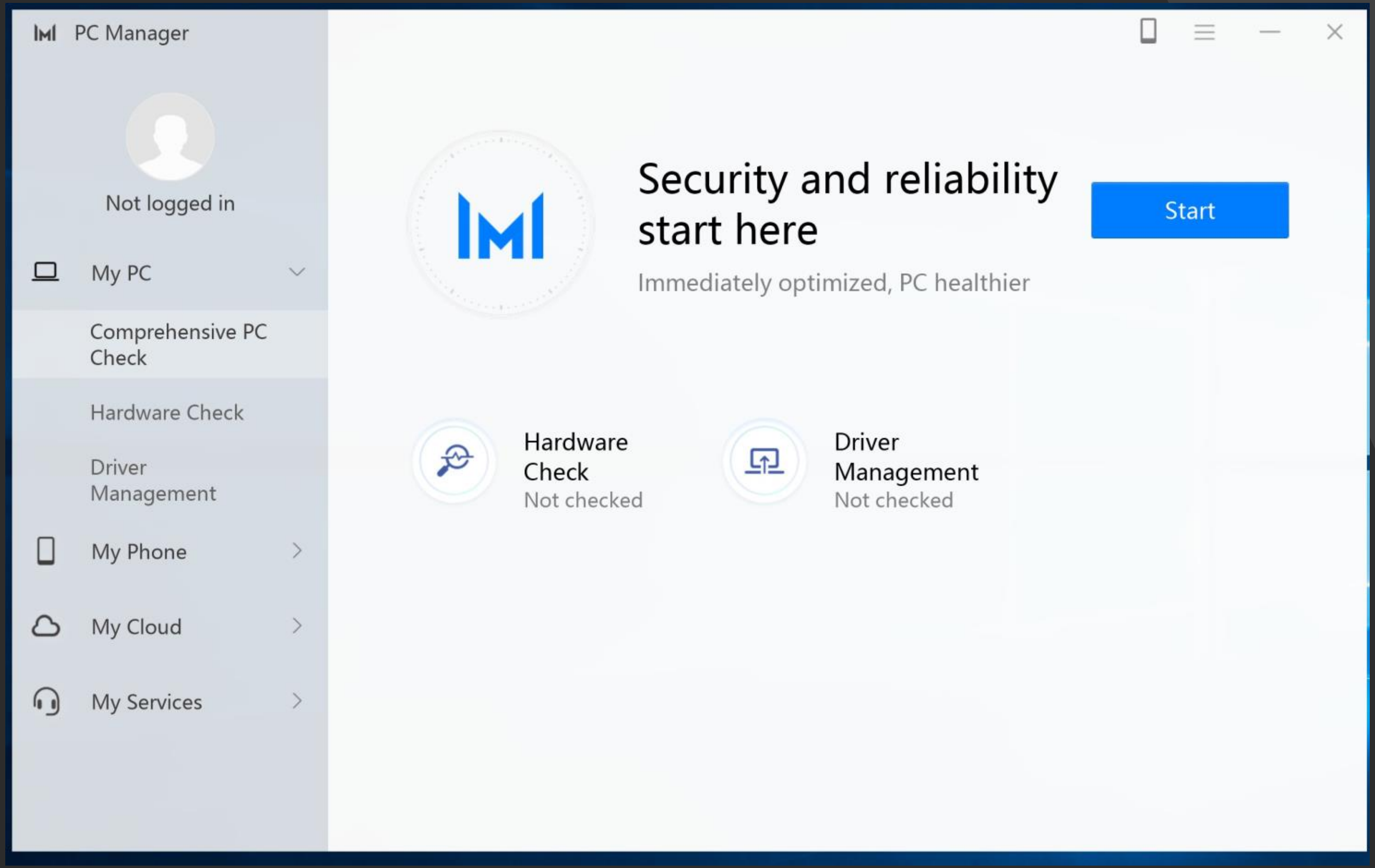
Let's dump driver-load events on that machine:

…

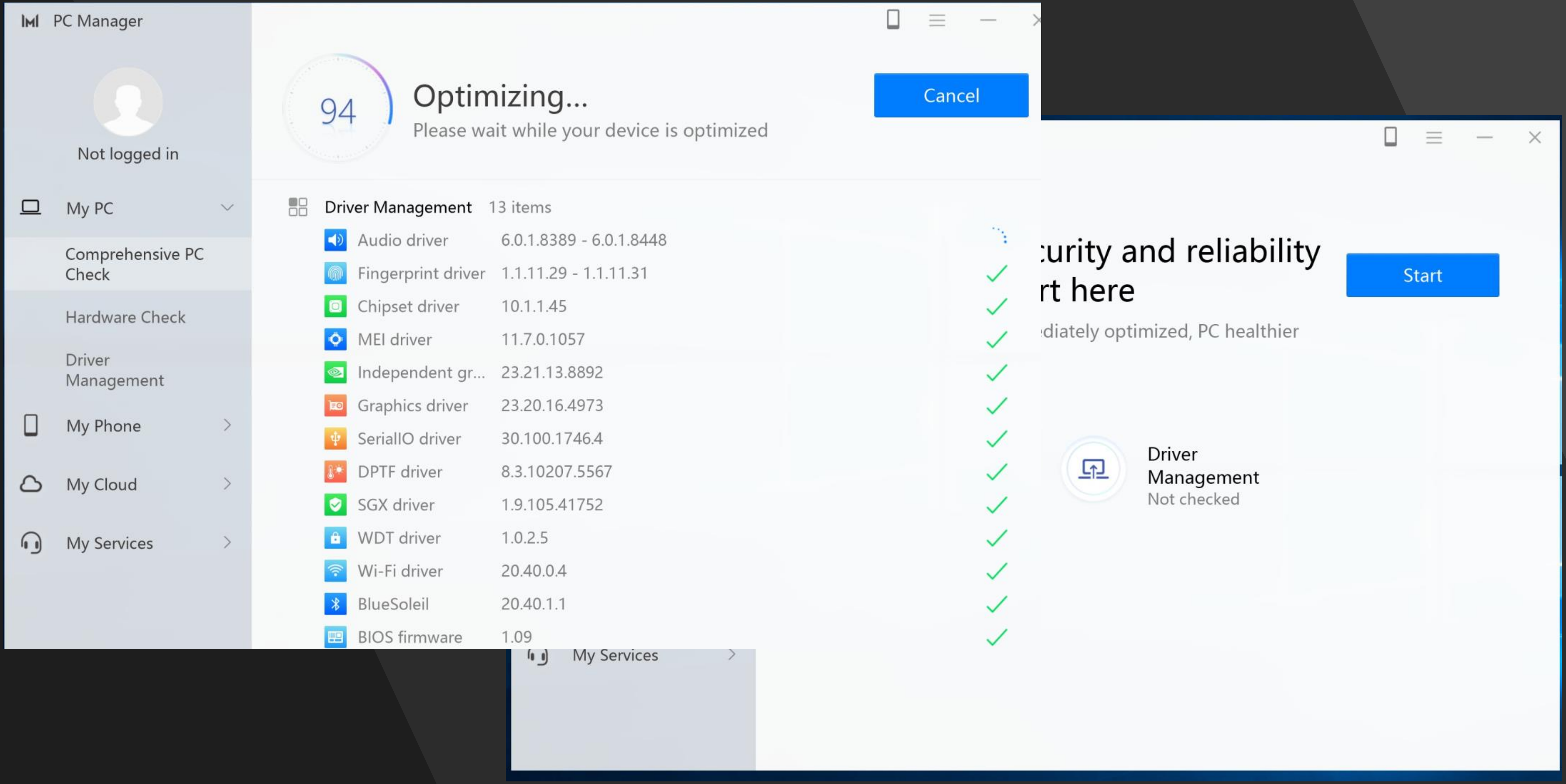
C:\Program Files\Huawei\PCManager\HwOs2Ec10x64.sys

…

PC Manager


PC Manager
Not logged in
My PC
Comprehensive PC Check
Hardware Check
Driver Management
My Phone
My Cloud
My Services
Security and reliability start here
Start
Immediately optimized, PC healthier
Hardware Check
Not checked
Driver Management
Not checked

PC Manager

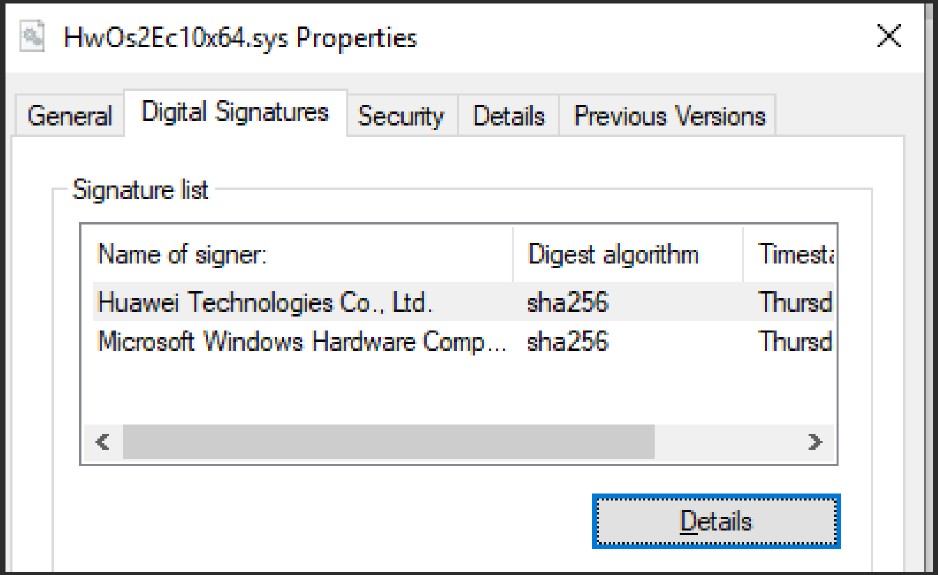

PC Manager
Not logged in
My PC
Comprehensive PC Check
Hardware Check
Driver Management
My Phone
My Cloud
My Services
94
Optimizing...
Please wait while your device is optimized
Cancel
Driver Management 13 items
Audio driver 6.0.1.8389 - 6.0.1.8448
Fingerprint driver 1.1.11.29 - 1.1.11.31
Chipset driver 10.1.1.45
MEI driver 11.7.0.1057
Independent gr... 23.21.13.8892
Graphics driver 23.20.16.4973
SerialIO driver 30.100.1746.4
DPTF driver 8.3.10207.5567
SGX driver 1.9.105.41752
WDT driver 1.0.2.5
Wi-Fi driver 20.40.0.4
BlueSoleil 20.40.1.1
BIOS firmware 1.09
curity and reliability
rt here
diately optimized, PC healthier
Start
Driver Management
Not checked
My Services

Hunting The Source

- Long shot, but let's analyze these drivers import section

```
C:\Program Files\Huawei\PCManager>dumpbin /imports:ntoskrnl.exe HwOs2Ec10x64.sys | findstr /i "ZwAllocateVirtualMemory KeInsertQueueApc"
                         93A ZwAllocateVirtualMemory
                         403 KeInsertQueueApc
```

- Looks promising!



Kernel->User Code Injector

```
*(_QWORD *)Length = 4096i64;
```

```
ntStatus = ZwAllocateVirtualMemory(TargetProcessHandle, &UserShellcodeAddress, 0i64, (PSIZE_T)Length, 0x3000u, 0x40u);
if ( (ntStatus & 0x80000000) != 0 )
  goto LABEL_13;
```

} **User mem alloc**

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User mem alloc

```
  if ( (unsigned int)GetExportedFunctionFromPeb(
                       TargetEProcessLocal,
                       L"Kernel32.dll",
                       (__int64)"CreateProcessW",
                       &CreateProcessWPtr)
    || (unsigned int)GetExportedFunctionFromPeb(
                       TargetEProcessLocal,
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                       &CloseHandlePtr) )
  {
LABEL_12:
    ntStatus = -1073741823;
    goto LABEL_13;
  }
```

Resolve user functions

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Resolve user functions

```
memcpy_s(UserShellcodeKernelAddress, 0x800u, UserApcRoutine, (char *)nullsub_1 - (char *)UserApcRoutine);
memset(UserShellcodeKernelAddress + 256, 0, 0x420u);
UserShellcodeKernelAddress[256] = CreateProcessWPtr;
UserShellcodeKernelAddress[257] = CloseHandlePtr;
memcpy_s(UserShellcodeKernelAddress + 258, 0x208u, ProcessCommandLine[1], *(unsigned __int16 *)ProcessCommandLine);
```

Copy user params

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```

Copy user params

```
NormalRoutine = (char *)UserShellcodeAddress;
Apc = ExAllocatePool(0, 0x58ui64);
if ( Apc )
{
  KeInitializeApc(Apc, Thread, 0i64, KernelRoutine, 0i64, NormalRoutine, 1, NormalRoutine + 2048, ApcMode);
  if ( (unsigned __int8)KeInsertQueueApc((__int64)Apc, 0i64, 0i64, 0i64) )
    return ntStatus;
```

Inject user APC

Kernel->User Code Injector

PCREATE_PROCESS_NOTIFY_ROUTINE

NotifyRoutine

```
*(_QWORD *)Length = 4096i64;
```

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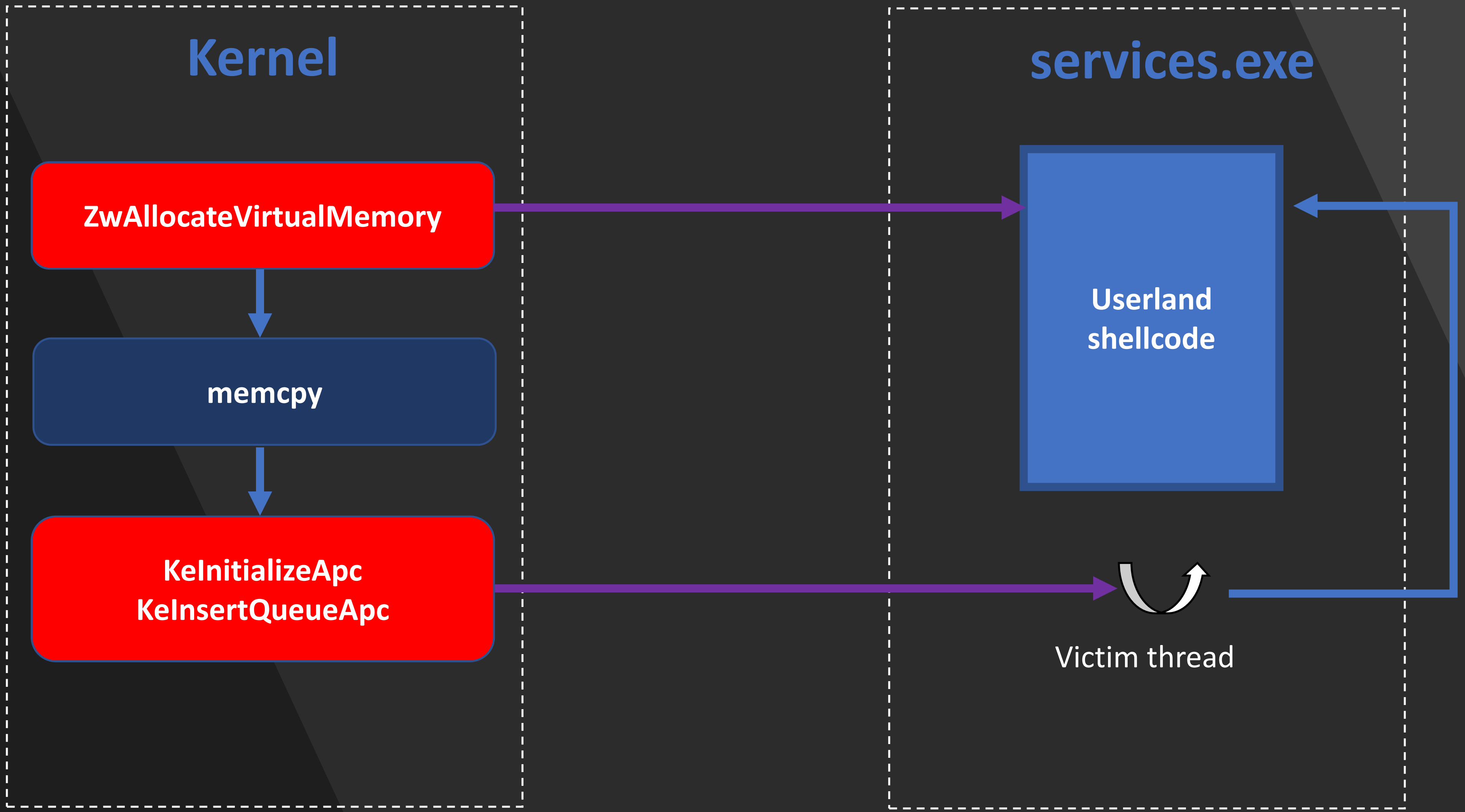
Inject user APC

Kernel->User Code Injector



The Shellcode

```
result = (ShellcodeParamLocal->CreateProcessPtr)(
           0i64,
           &ShellcodeParamLocal->CommandLinePtr,
           0i64,
           0i64,
           v2,
           v1,
           0i64,
           0i64,
           &v7,
           &v5);
if ( v6 )
  result = (ShellcodeParamLocal->CloseHandlePtr)(v6);
if ( v5 )
  result = (ShellcodeParamLocal->CloseHandlePtr)(v5);
return result;
```

What process gets created?

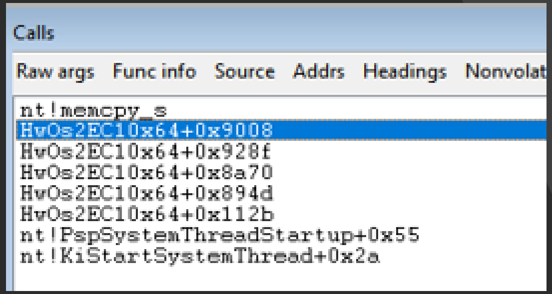
- Let’s set a breakpoint on the location where the parameter block is copied

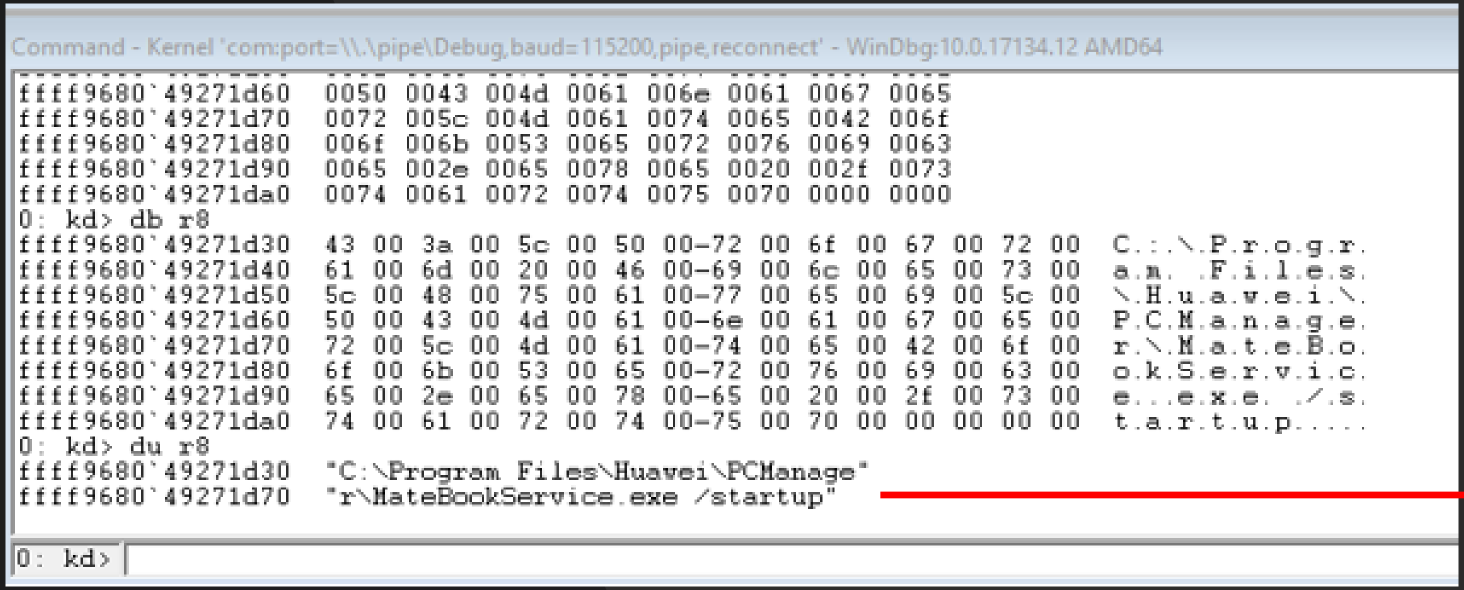
```
Calls
Raw args  Func info  Source  Addrs  Headings  Nonvolat
nt!memcpy_s
HvOs2EC10x64+0x9008
HvOs2EC10x64+0x928f
HvOs2EC10x64+0x8a70
HvOs2EC10x64+0x894d
HvOs2EC10x64+0x112b
nt!PspSystemThreadStartup+0x55
nt!KiStartSystemThread+0x2a
```

```
Command - Kernel 'com:port=\\.\pipe\Debug,baud=115200,pipe,reconnect' - WinDbg:10.0.17134.12 AMD64
ffff9680`49271d60  0050 0043 004d 0061 006e 0061 0067 0065
ffff9680`49271d70  0072 005c 004d 0061 0074 0065 0042 006f
ffff9680`49271d80  006f 006b 0053 0065 0072 0076 0069 0063
ffff9680`49271d90  0065 002e 0065 0078 0065 0020 002f 0073
ffff9680`49271da0  0074 0061 0072 0074 0075 0070 0000 0000
0: kd> db r8
ffff9680`49271d30  43 00 3a 00 5c 00 50 00-72 00 6f 00 67 00 72 00  C.:.\.P.r.o.g.r.
ffff9680`49271d40  61 00 6d 00 20 00 46 00-69 00 6c 00 65 00 73 00  a.m. .F.i.l.e.s.
ffff9680`49271d50  5c 00 48 00 75 00 61 00-77 00 65 00 69 00 5c 00  \.H.u.a.w.e.i.\.
ffff9680`49271d60  50 00 43 00 4d 00 61 00-6e 00 61 00 67 00 65 00  P.C.M.a.n.a.g.e.
ffff9680`49271d70  72 00 5c 00 4d 00 61 00-74 00 65 00 42 00 6f 00  r.\.M.a.t.e.B.o.
ffff9680`49271d80  6f 00 6b 00 53 00 65 00-72 00 76 00 69 00 63 00  o.k.S.e.r.v.i.c.
ffff9680`49271d90  65 00 2e 00 65 00 78 00-65 00 20 00 2f 00 73 00  e...e.x.e. ./.s.
ffff9680`49271da0  74 00 61 00 72 00 74 00-75 00 70 00 00 00 00 00  t.a.r.t.u.p.....
0: kd> du r8
ffff9680`49271d30  "C:\Program Files\Huawei\PCManage"
ffff9680`49271d70  "r\MateBookService.exe /startup"
0: kd>
```

What process gets created?

- Let’s set a breakpoint on the location where the parameter block is copied





“C:\Program Files\Huawei\PCManager\MateBookService.exe /startup”

MateBookService.exe Analysis

```
  if ( !wcsicmp(v1, L"/startup") )
  {
    v2 = sub_140013340();
    if ( v2 )
    {
```

```
__int64 sub_140013340()
{
  unsigned int v0; // ebx
  SC_HANDLE v1; // rax
  SC_HANDLE v2; // rdi
  SC_HANDLE v3; // rax
  SC_HANDLE v4; // rsi
  SC_HANDLE v5; // rcx
  struct _SERVICE_STATUS ServiceStatus; // [rsp+20h] [rbp-38h]

  v0 = 0;
  v1 = OpenSCManagerW(0i64, 0i64, 1u);
  v2 = v1;
  if ( v1 )
  {
    v3 = OpenServiceW(v1, L"MBAMainService", 0xF01FFu);
    v4 = v3;
    if ( v3 )
    {
      if ( QueryServiceStatus(v3, &ServiceStatus) && ServiceStatus.dwCurrentState == 1 && StartServiceW(v4, 0, 0i64) )
```

Watching out for MateBookService Termination

```
ZwQueryInformationProcess(Handle, 0i64, &ProcessPebPointer, 48i64, 0i64);
if ( ExtractCommandlineToExecute(
       &CurrentProcessCommandLine.Length,
       ProcessPebPointer,
       ProcessCommandLineToRunFromServices) >= 0 )
{
  RtlInitUnicodeString(&DestinationString, L"services.exe");
  InjectCreateProcessShellcodeToServices(&DestinationString, ProcessCommandLineToRunFromServices);
}
```

Watching out for MateBookService Termination

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ZwQueryInformationProcess(Handle, 0i64, &ProcessPebPointer, 48i64, 0i64);
if ( ExtractCommandlineToExecute(
       &CurrentProcessCommandLine.Length,
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{
  RtlInitUnicodeString(&DestinationString, L"services.exe");
  InjectCreateProcessShellcodeToServices(&DestinationString, ProcessCommandLineToRunFromServices);
}
```

```
v10 = ::IsProtectedProcess(*(v3 + 1), &IsProtectedProcess);
if ( (v10 & 0x80000000) != 0 )
  return 0xC0000001;
if ( !IsProtectedProcess )
  return 0xC0000225;
```

Watching out for MateBookService Termination

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ZwQueryInformationProcess(Handle, 0i64, &ProcessPebPointer, 48i64, 0i64);
if ( ExtractCommandlineToExecute(
       &CurrentProcessCommandLine.Length,
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```

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v10 = ::IsProtectedProcess(*(v3 + 1), &IsProtectedProcess);
if ( (v10 & 0x80000000) != 0 )
  return 0xC0000001;
if ( !IsProtectedProcess )
  return 0xC0000225;
```
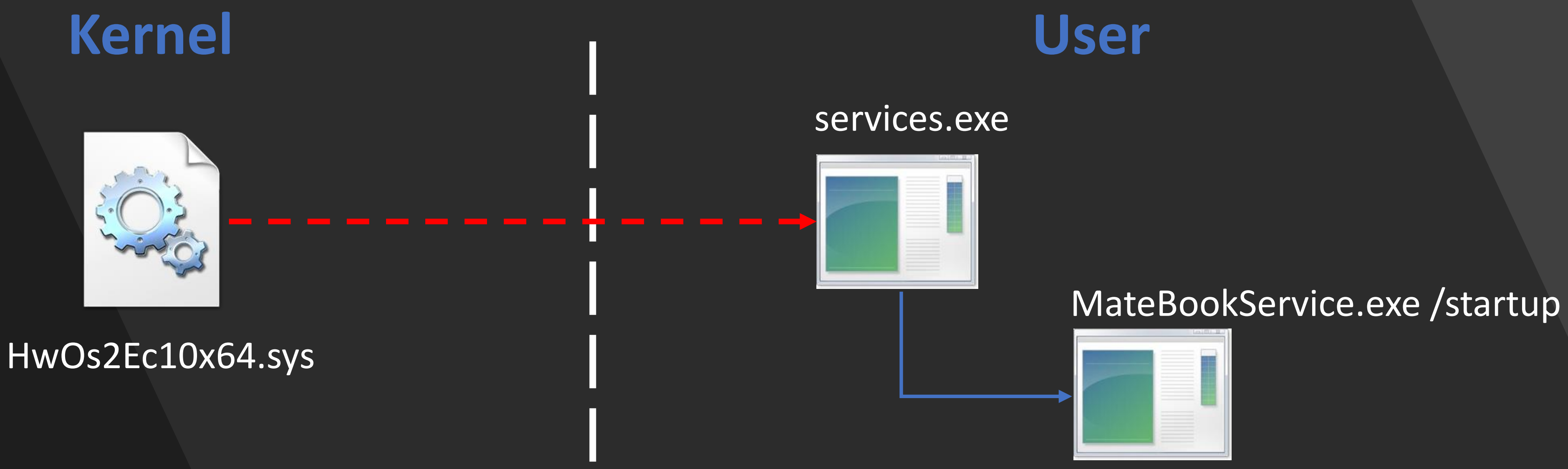

```
KeEnterCriticalRegion();
ExAcquireResourceSharedLite(&Resource, 1u);
for ( i = ProtectedProcessesAnchor; i != &ProtectedProcessesAnchor; i = *i )
{
  if ( !wcsnicmp(v3, i + 8, 0x104u) )
  {
    *v2 = 1;
    break;
  }
}
ExReleaseResourceLite(&Resource);
KeLeaveCriticalRegion();
```

Quick Recap

- MateBookService.exe process terminates -> Revived by the driver
- Watched processes are held in a driver's global list variable



I Wonder….

- If that’s a list, then there might be a way to extend it
- How does the watched processes list get extended?

I Wonder….

- If that’s a list, then there might be a way to extend it
- How does the watched processes list get extended?

-> There’s a designated IOCTL handler exactly for that purpose!

  - No validation checks on the executable directory
  - Just need to get a valid handle to the device object

Obtaining a Device Handle

- Finding #1: The device is created with DACL granting **Everyone** RW access

```
DeviceObject = 0i64;
DeviceName.Buffer = L"\\Device\\HwOs2EcDevX64";
*&DeviceName.Length = 2883626;
SymbolicLinkName.Buffer = L"\\DosDevices\\HwOs2EcX64";
*&SymbolicLinkName.Length = 3014700;
result = IoCreateDevice(a1, 8u, &DeviceName, 0x22u, 0, 0, &DeviceObject);
if ( result >= 0 )
{
  v2 = IoCreateSymbolicLink(&SymbolicLinkName, &DeviceName);
```

Obtaining a Device Handle

- Finding #2: the caller process is validated by its main executable path
  - Must belong to a whitelist

```
__int64 __fastcall IrpMjCreateDispatchRoutine(__int64 a1, struct _IRP *Irp)
{
  struct _IRP *CurrentIrp; // rdi
  PEPROCESS CurrentProcess; // rax
  NTSTATUS v4; // ebx

  Irp->IoStatus.Information = 0i64;
  CurrentIrp = Irp;
  CurrentProcess = IoGetCurrentProcess();
  v4 = VerifyCallingProcessByPath(CurrentProcess);
  if ( v4 < 0 )
    v4 = -1073740767;
  CurrentIrp->IoStatus.Status = v4;
  IofCompleteRequest(CurrentIrp, 0);
  return v4;
}
```

Obtaining a Device Handle

- BUT there’s no guarantee on integrity of the caller process!

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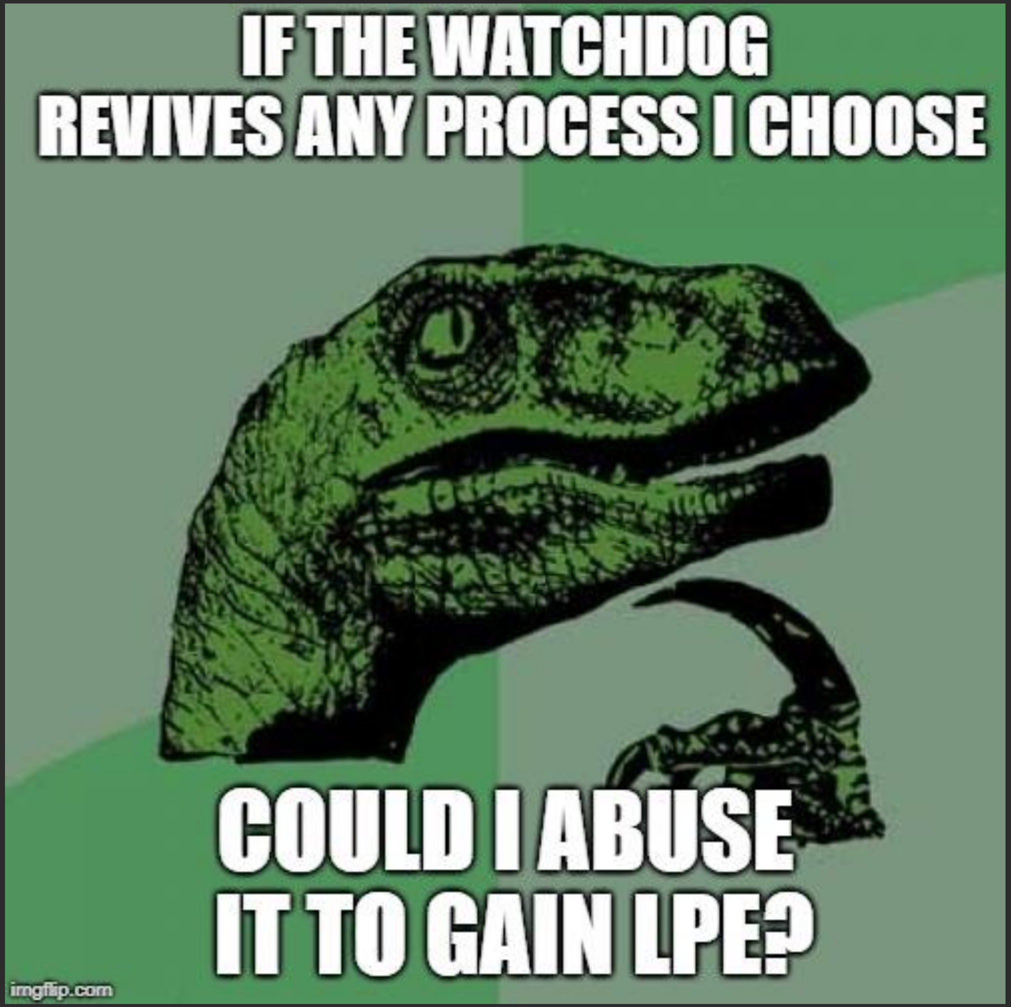
- Malicious MateBookService.exe process might bypass this integrity check

Obtaining a Device Handle

- BUT there’s no guarantee on integrity of the caller process!
- Malicious MateBookService.exe process might bypass this integrity check
- Infecting our own MateBookService.exe process can be done by a low-privilege process
  - Thanks to the fact a parent process has PROCESS_ALL_ACCESS permissions over its children


IF THE WATCHDOG
REVIVES ANY PROCESS I CHOOSE
COULD I ABUSE
IT TO GAIN LPE?
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Abusing the Watchdog to Gain LPE

Create & inject malicious code into a MateBookService.exe process → Craft special IOCTL to register LPE_POC.exe → Run LPE_POC.exe which exits immediately → The watchdog revives LPE_POC.exe as child of services.exe

Create & inject malicious code into a MateBookService.exe process	Craft special IOCTL to register LPE_POC.exe	Run LPE_POC.exe which exits immediately	The watchdog revives LPE_POC.exe as child of services.exe
Standard User	Standard User	Standard User	NT AUTHORITY\SYSTEM

Abusing the Watchdog to Gain LPE

Create & inject malicious code into a MateBookService.exe process → Craft special IOCTL to register LPE_POC.exe → Run LPE_POC.exe which exits immediately → The watchdog revives LPE_POC.exe as child of services.exe

Standard User | Standard User | Standard User | NT AUTHORITY\SYSTEM

CVE-2019-5241


DEMO TIME
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Wrap up

- EDR alert -> investigation -> vulnerability find
- Reversing isn’t always the entry point
- OEM drivers – low hanging fruits for attackers
- Software devs – use OS supplied mechanisms

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References

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