



南开大学

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月异



恶意代码分析与防治技术

第9章 WinDBG内核调试

王志

zwang@nankai.edu.cn

南开大学 网络空间安全学院

2023/2024



允公允能 日新月异

知识点

- 系统内核与驱动

- 难点：设备（Device）、驱动（Driver）、物理设备（Physical Device）

- WinDbg

- Microsoft Symbols

- 内核调试实战

- Rootkits

- 难点：SSDT、IDT



南开大学
Nankai University



南开大学

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月异



系统内核与驱动

Windows内核会不会被计算机病毒感染？ 如果可以被感染，举例说明内核病毒有哪些行为。

作答



允公允能 日新月异

WinDbg vs. OllyDbg

- What is the difference between WinDbg and OllyDbg?
- Which type of malware we should use WinDbg for analysis?





允公允能 日新月异

WinDbg vs. OllyDbg

- OllyDbg is the most popular **user-mode** debugger for malware analysts
 - Ghidra NSA
 - BinaryNinja
- WinDbg can be used in either **user-mode** or **kernel-mode**
- This chapter explores ways to use WinDbg for **kernel** debugging and **rootkit** analysis



南开大学
Nankai University

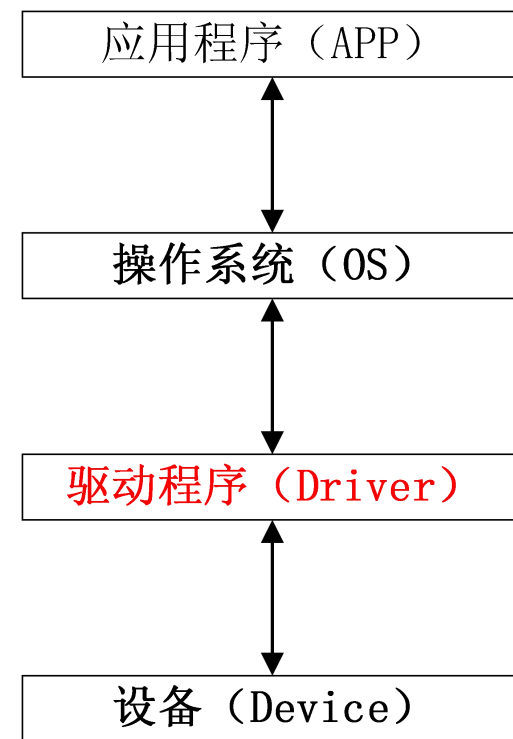
Windows内核中的代码是不是全是微软公司开发的？

- ☐ A 是
- ☐ B 不是

提交

驱动（Drivers）

- 驱动是一个软件组件（Software Component），实现操作系统与设备之间的通信。
 - 应用程序通过Windows API访问设备
 - Windows将访问请求转发给驱动程序，调用驱动程序提供的功能函数
 - 驱动程序由设备制造商开发，完成对设备硬件的访问。



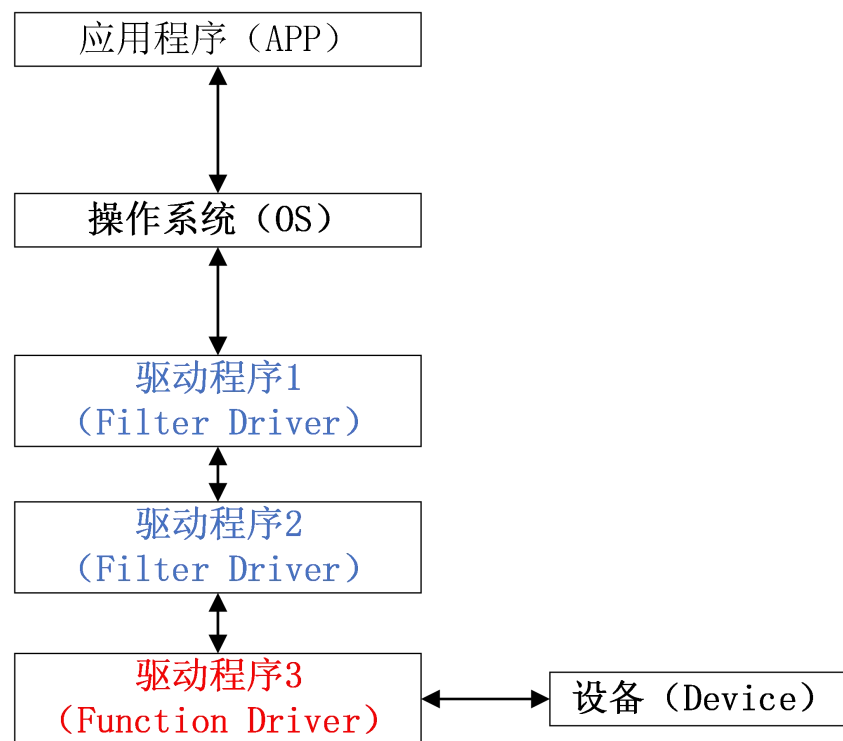
是不是所有的驱动都是由设备制造商提供的？

- ☐ A 是
- ☒ B 不是

提交

驱动栈（Driver Stack）

- 并不是所有的驱动都直接与设备进行通信
- 一次设备的访问过程通常会经过多个驱动
 - 驱动栈（Driver Stack）
 - 过滤驱动（Filter Driver）
 - 杀毒软件、防火墙、入侵检测等
 - 功能驱动（Function Driver）
 - 一个设备栈最多只有一个功能驱动



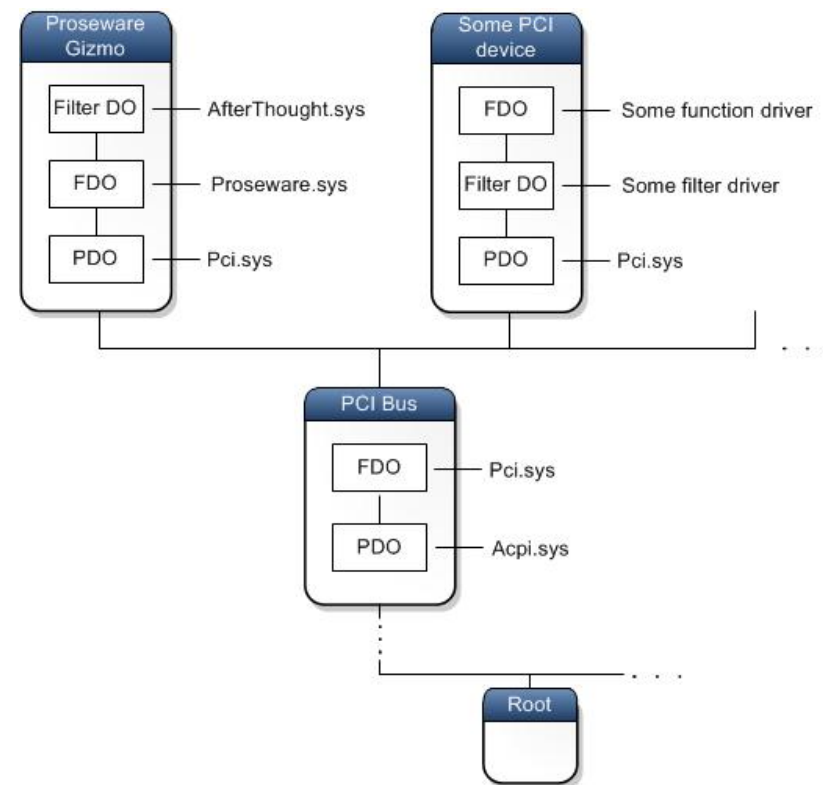
驱动栈中，过滤驱动一定在功能驱动的上面？

- ☐ A 正确
- ☒ B 错误

提交

过滤驱动

- 上层过滤驱动（Upper Filter Driver）
 - 在功能驱动之前的过滤驱动
- 下层过滤驱动（Lower Filter Driver）
 - 在功能驱动之后的过滤驱动



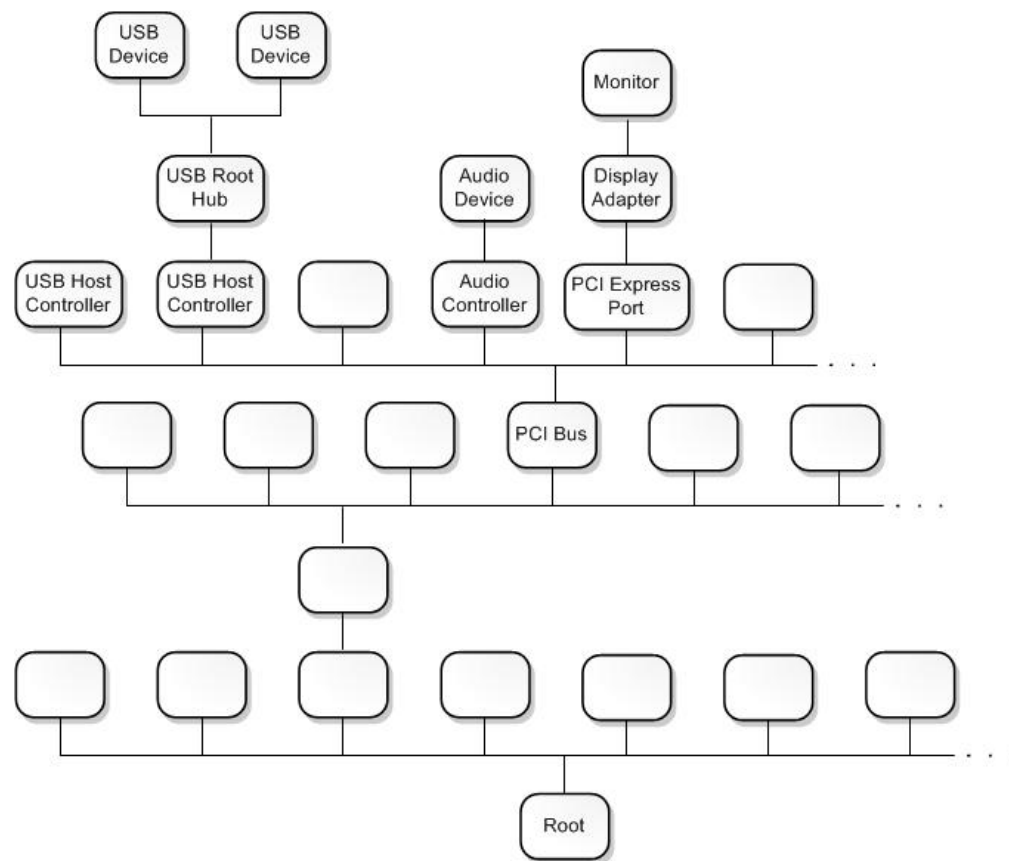
应用程序可以直接访问驱动程序吗？

- ☐ A 可以
- ☒ B 不可以

提交

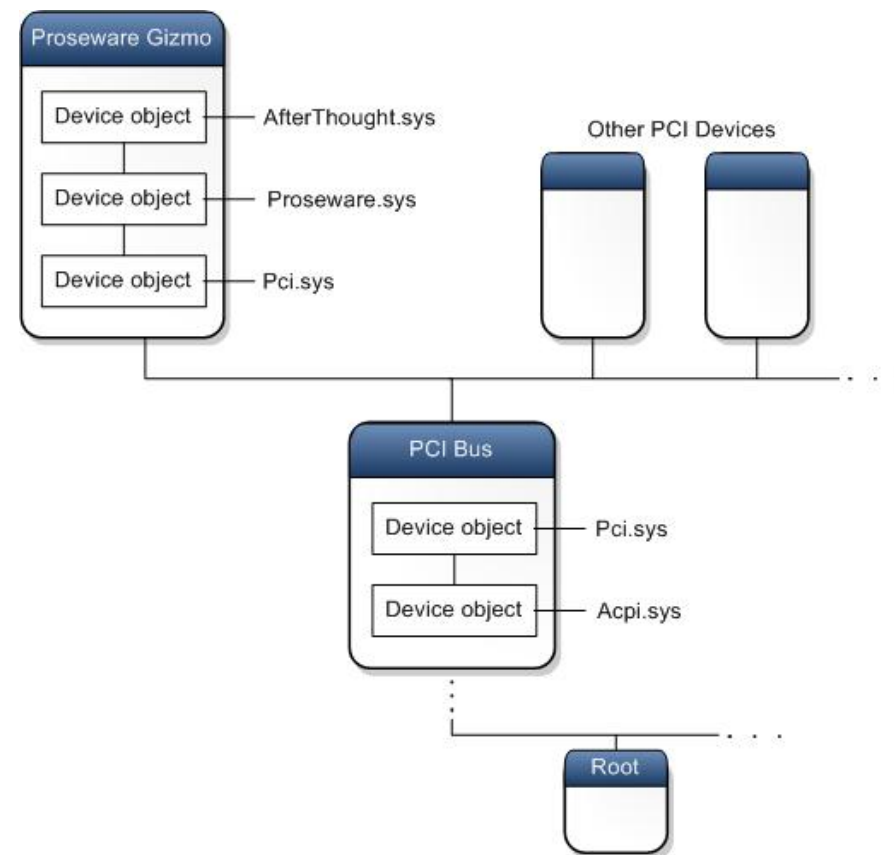
设备树

- Windows使用即插即用管理器(Plug and Play Manager), 创建设备树(Device Tree), 来管理系统中的设备
 - 设备节点 (Device Node)
 - 不是所有的设备节点都对应物理设备
 - 软件组件
 - 根设备节点 (Root Device Node)
 - 根节点在树的最下面
 - 继承关系(Parent/Child Relationships)
 - PCI总线-->USB Host Controller-->USB Root Hub -->USB Device



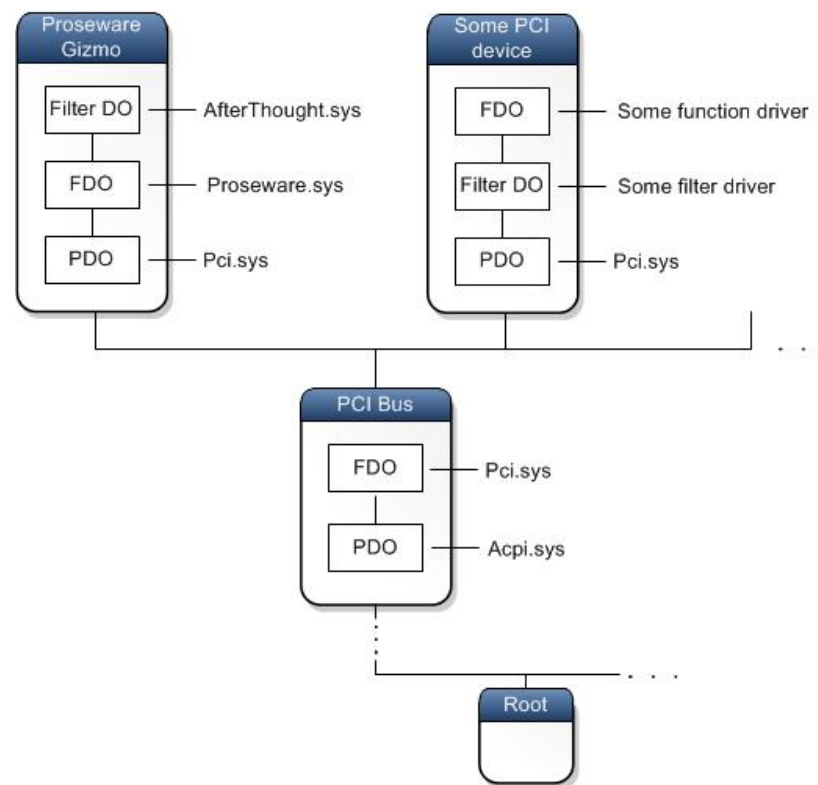
设备栈

- 每个设备节点是一个有序的设备对象列表
 - 每个设备对象关联一个驱动
 - <设备对象、驱动>
 - Proseware Gizmo设备栈中有3个设备对象
 - PCI Bus设备栈有2个设备对象



设备对象（Device Objects）

- PnP管理器控制总线驱动枚举挂在其上的设备
 - 发现的设备创建物理设备对象（Physical Device Object, PDO）
 - 遍历注册表，找到PDO对应的驱动，创建设备栈
 - PDO始终是设备栈的底部设备对象



<https://learn.microsoft.com/zh-cn/windows-hardware/drivers/kernel/introduction-to-device-objects>



允公允能 日新月异

USB Flash Drive

- User plugs in flash drive
- Windows creates the "**F: drive**" *device object*
- Applications can now make requests to the F: drive
 - They will be sent to the driver for USB flash drives



下面那个选项可以被用户空间的应用程序直接访问?

- ☐ A 物理设备 physical hardware
- ☐ B 设备驱动 device driver
- ☒ C 设备对象 device object
- ☐ D Windows 内核

提交

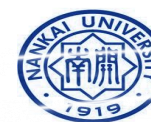




允公允能 日新月异

Loading Drivers

- Drivers must be loaded into the **kernel**
 - Just as DLLs are loaded into processes
- When a driver is first loaded, its **DriverEntry** procedure is called
 - Just like **DLLMain** for DLLs



南开大学
Nankai University



允公允能 日新月异

DriverEntry

- DLLs expose functionality through the **export table**
- Drivers must register the address for **callback functions**

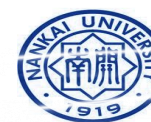




允公允能 日新月异

DriverEntry

- They will be called when a user-space software component requests a **service**
- DriverEntry performs this **registration**
 - Windows creates a **driver object** structure, passes it to DriverEntry which fills it with **callback functions**
 - DriverEntry then creates a **device object** that can be accessed from user-land



南开大学
Nankai University



允公允能 日新月异

Example: Normal Read

- Normal read request
 - User-mode application obtains a file **handle** to device
 - Calls **ReadFile** on that handle
 - Kernel processes ReadFile **request**
 - Invokes the driver's **callback function** handling I/O



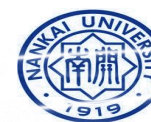
南开大学
Nankai University



允公允能 日新月异

Malicious Request

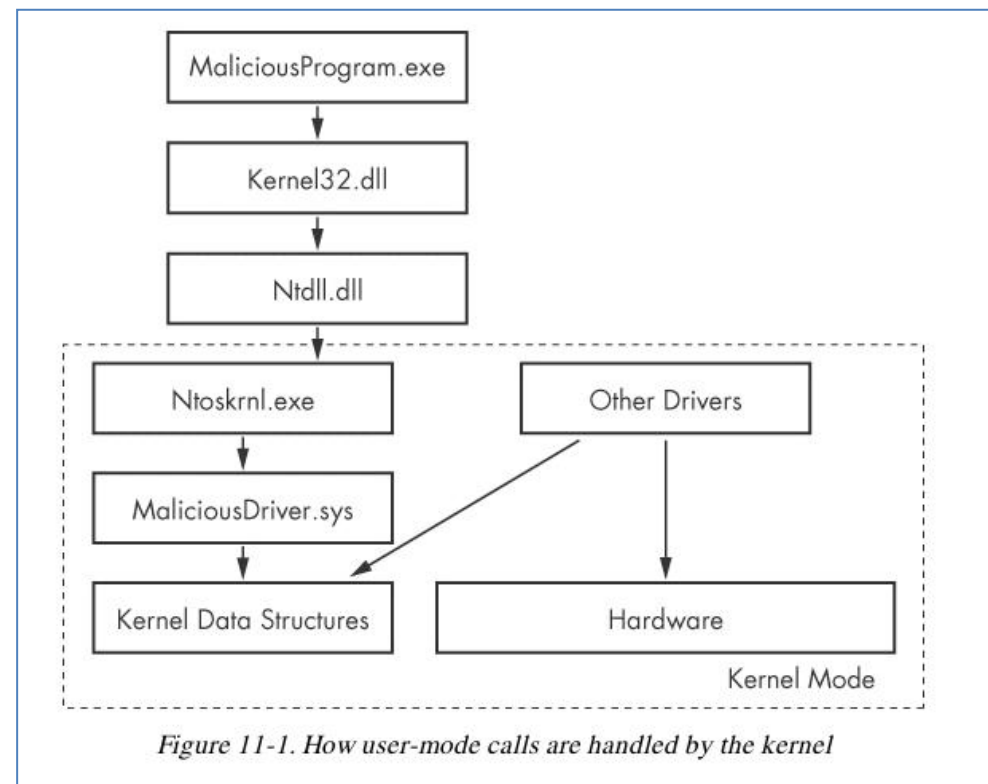
- Most common request from malware is **DeviceIoControl**
 - A generic request from a user-space module to a device managed by a driver
 - User-space program passes in an arbitrary-length buffer of **input** data
 - Received an arbitrary-length buffer of data as **output**



南开大学
Nankai University

Ntoskrnl.exe & Hal.dll

- Malicious drivers rarely control hardware
- They interact with *Ntoskrnl.exe* & *Hal.dll*
 - *Ntoskrnl.exe* has code for core OS functions
 - *Hal.dll* has code for interacting with main hardware components
- Malware will import functions from one or both of these files so it can manipulate the kernel



Which are supported by WinDbg?

- ☒ A user-mode debugging
- ☒ B kernel-mode debugging
- ☒ C rootkit debugging
- ☒ D application debugging

提交



Which statements are true for **driver**?

- ☒ A creates and destroys device objects
- ☒ B loaded into kernel
- ☐ C can be accessed from user space
- ☒ D has a DriverEntry procedure

Which statements are true for **DriverEntry**?

- ☒ A a procedure in driver
- ☒ B registers callback functions
- ☒ C creates device
- ☒ D initializes driver object structure

Which items are usually manipulated by malicious drivers?

- ☐ A kernel32.dll
- ☐ B hardware
- ☒ C ntoskrnl.exe
- ☒ D hal.dll



南开大学

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月异



WinDBG



允公允能 日新月异

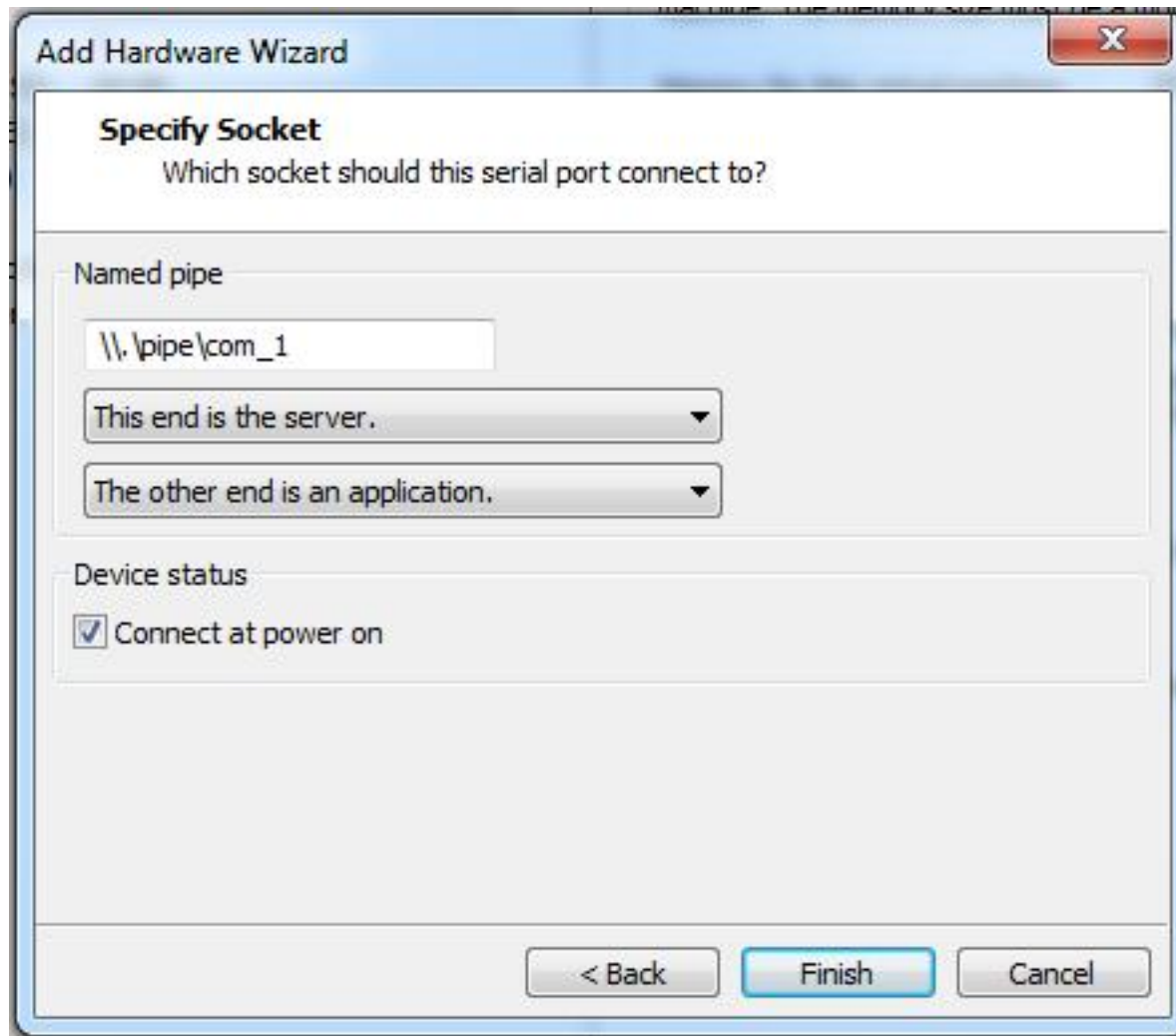
VMware

- In the virtual machine, **enable kernel debugging**
- Configure a virtual serial port between VM and host
- Configure WinDbg on the **host** machine



南开大学
Nankai University

Add a Virtual Serial Port



The screenshot shows the 'Add Hardware Wizard' window, specifically the 'Specify Socket' step. The window has a title bar with 'Add Hardware Wizard' and a close button. The main content area is titled 'Specify Socket' with the question 'Which socket should this serial port connect to?'. Below this, there is a section for 'Named pipe' with a text box containing '\\.\pipe\com_1'. There are two dropdown menus: 'This end is the server.' and 'The other end is an application.'. At the bottom, there is a 'Device status' section with a checked checkbox 'Connect at power on'. The bottom of the window has three buttons: '< Back', 'Finish', and 'Cancel'.

Add Hardware Wizard

Specify Socket
Which socket should this serial port connect to?

Named pipe

\\.\pipe\com_1

This end is the server.

The other end is an application.

Device status

☒ Connect at power on


< Back Finish Cancel

允公允能 日新月异

WinDBG 安装

- 下载 Windows SDK 安装程序 winsdksetup.exe
 - <https://developer.microsoft.com/en-us/windows/downloads/windows-sdk/>


Microsoft Ignite
Nov 14-17, 2023
Join us Nov 14-17, 2023 to explore the latest innovations, learn from experts, level up your skillset, and expand your network.
[Register >](#)

 **Microsoft** | **Developer** | [Learn](#) | [Documentation](#) | [Training](#) | [Q&A](#) | [Code Samples](#) | [Shows](#) | [Events](#)

Windows Dev Center | [Docs](#) | [Explore](#) | [Platforms](#) | [Resources & Support](#) | [Downloads](#)

Windows SDK

The Windows SDK (10.0.22621) for Windows 11, version 22H2 (updated Oct 2023) provides the latest headers, libraries, metadata, and tools for building Windows applications. Use this SDK to build Universal Windows Platform (UWP) and Win32 applications for Windows 11, version 22H2 and previous Windows releases.

 **Tip**
Windows App SDK
The Windows App SDK provides a unified set of APIs and tools that are decoupled from the OS and released to developers via NuGet packages. These APIs and tools can be used in a consistent way by any desktop app on Windows 11 and downlevel to Windows 10, version 1809.

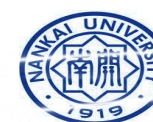
Getting started

You can get the Windows SDK in two ways: install it from this page by selecting the download link or by selecting "Windows 11 SDK (10.0.22621.0)" in the optional components of the Visual Studio 2022 Installer. Before you install this SDK:

- Review all [system requirements](#)
- Exit Visual Studio prior to installation.
- Review the [Release notes](#) and [Known Issues](#).

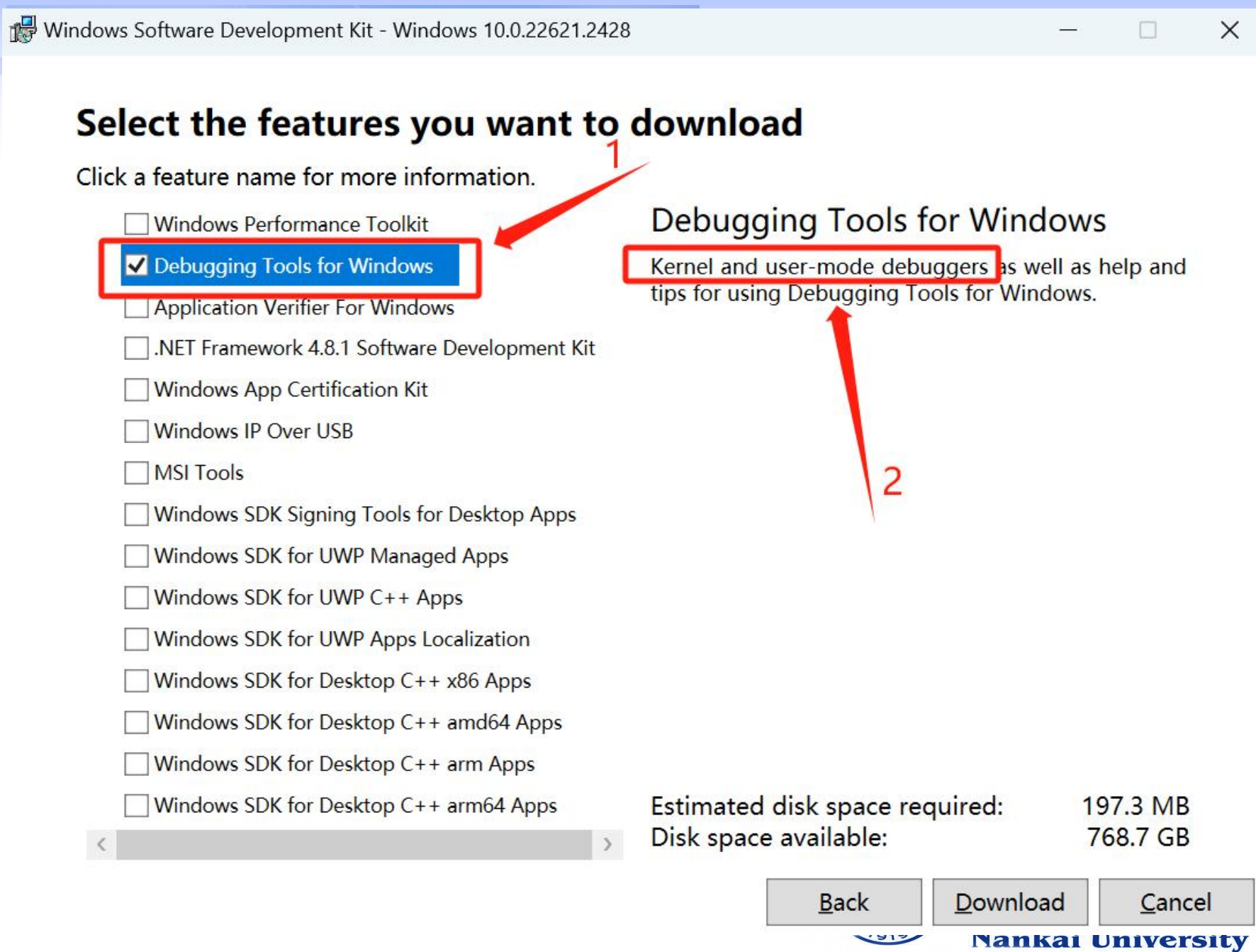
[Download the installer >](#)
[Download the .iso >](#)

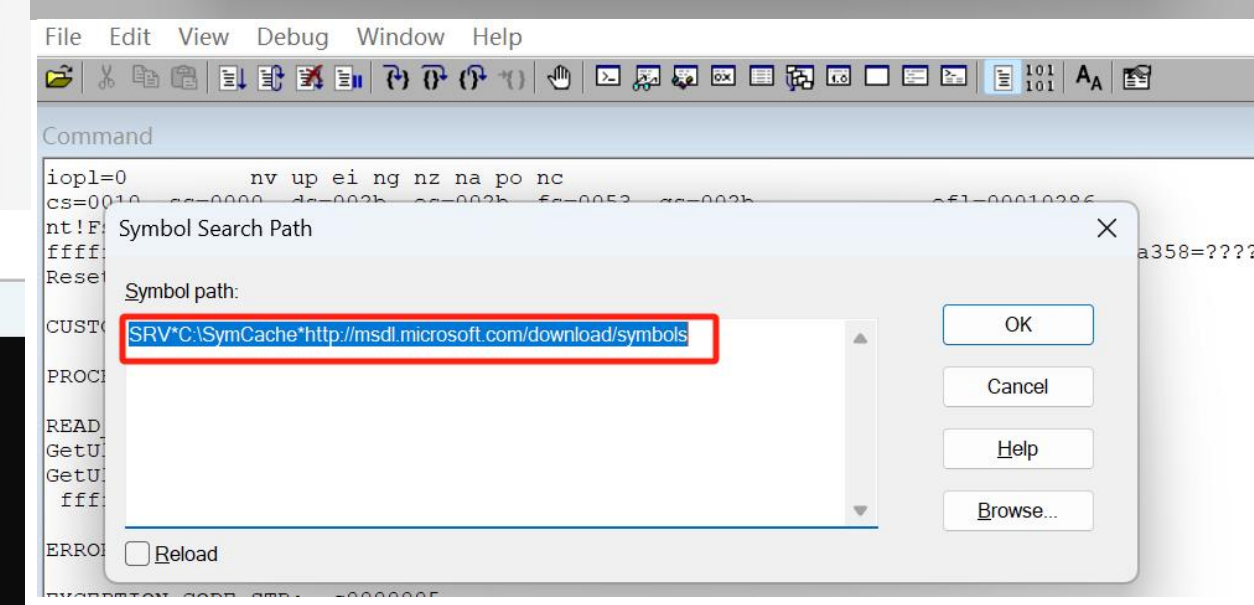
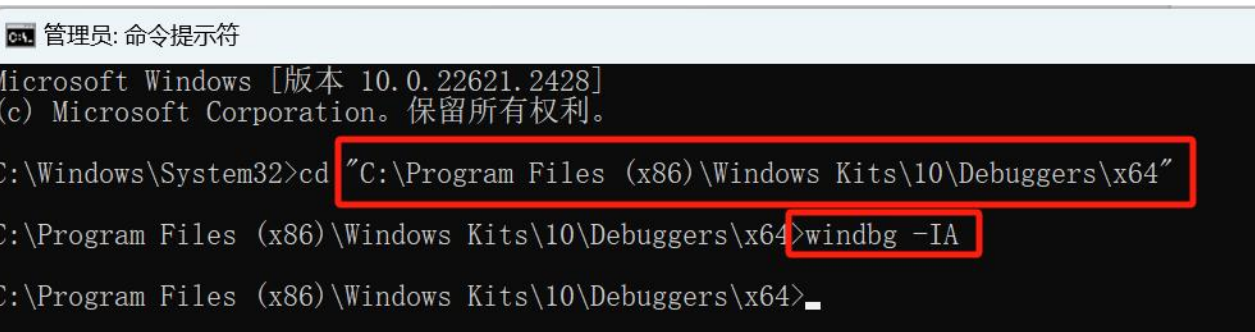
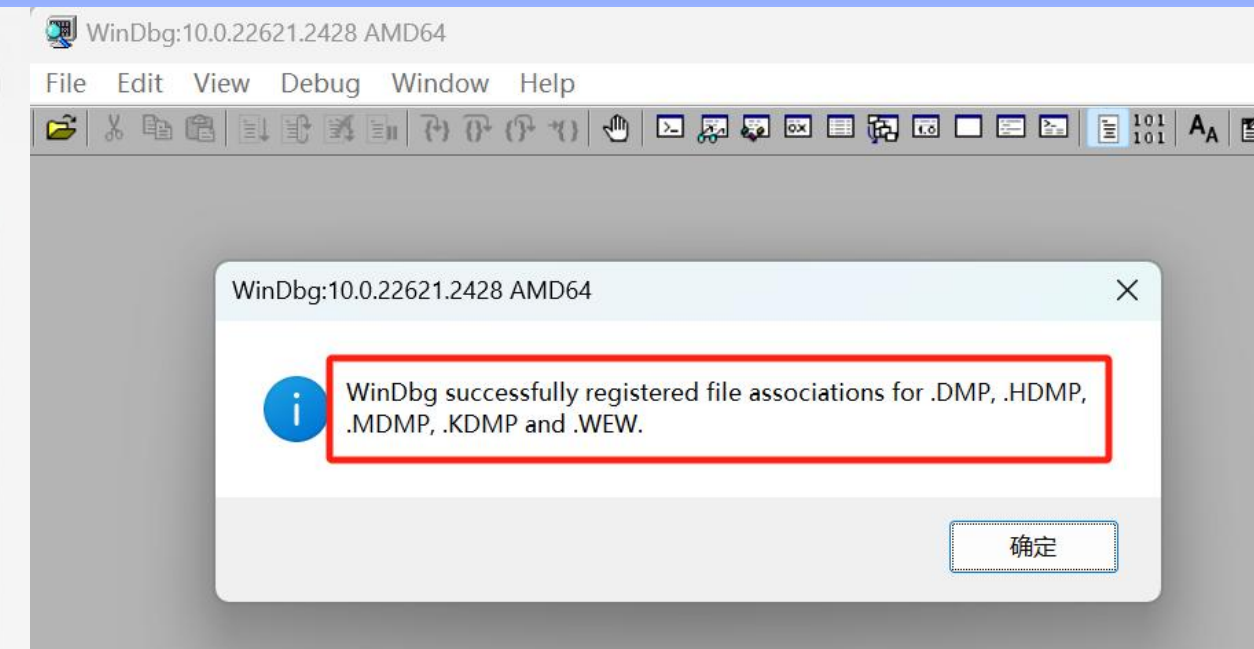
Last updated: October 2023



南开大学
Nankai University

- 运行winsdksetup.exe
- 安装Debugging Tool
sfor Windows
- Kernel and
user-mode debuggers





保存Windows符号路径: File > Save WorkSpace



允公允能 日新月异

WinDBG

```
. 386
.model flat, stdcall
option casemap :none

include \masm32\include\windows.inc
include \masm32\include\kernel32.inc
include \masm32\include\masm32.inc
includelib \masm32\lib\kernel32.lib
includelib \masm32\lib\masm32.lib

.data
    str_hello BYTE "Hello World!", 0

.code
start:
    invoke StdOut, addr str_hello
    invoke ExitProcess, 0
END start
```

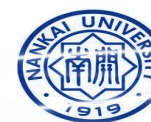
```
PS C:\masm32> .\bin\ml.exe /c /Zd /coff .\hello.asm
Microsoft (R) Macro Assembler Version 6.14.8444
Copyright (C) Microsoft Corp 1981-1997. All rights reserved.

Assembling: .\hello.asm

*****
ASCII build
*****

PS C:\masm32> .\bin\link.exe /SUBSYSTEM:CONSOLE .\hello.obj
Microsoft (R) Incremental Linker Version 5.12.8078
Copyright (C) Microsoft Corp 1992-1998. All rights reserved.

LINK : fatal error LNK1104: cannot open file "hello.exe"
PS C:\masm32>
```



南开大学
Nankai University

列出所有模块

- **lm** 列出当前内存空间装在的所有模块
 - 包括当前内存空间中装载的所有exe和dll程序
 - user-mode 只显示用户空间的模块信息
 - kernel-mode 显示所有的模块信息，包括内核、驱动、用户空间的exe和dll

```
0:000> lm
start      end        module name
00000000`00400000 00000000`00404000  hello (deferred)
00000000`77660000 00000000`77811000  ntdll32 (deferred)
00007ffb`4bbf0000 00007ffb`4bc06000  wow64con (deferred)
00007ffb`4cd00000 00007ffb`4cd8b000  wow64win (deferred)
00007ffb`4cf80000 00007ffb`4cfd7000  wow64 (deferred)
00007ffb`4cfe0000 00007ffb`4cfe9000  wow64base (deferred)
00007ffb`4de90000 00007ffb`4e0a7000  ntdll (pdb symbols)
```

查看模块的PE文件头信息

- !dh 查看指定模型的PE文件头

- !dh -a hello
- 入口点的RVA是1000
- image base是400000h
 - lm命令

```
0:000> !dh -a hello
```

```
File Type: EXECUTABLE IMAGE
```

```
FILE HEADER VALUES
```

```
14C machine (i386)
```

```
3 number of sections
```

```
65479C92 time date stamp Sun Nov 5 21:45:54 2023
```

```
0 file pointer to symbol table
```

```
0 number of symbols
```

```
E0 size of optional header
```

```
10F characteristics
```

```
Relocations stripped
```

```
Executable
```

```
Line numbers stripped
```

```
Symbols stripped
```

```
32 bit word machine
```

```
OPTIONAL HEADER VALUES
```

```
10B magic #
```

```
5.12 linker version
```

```
200 size of code
```

```
400 size of initialized data
```

```
0 size of uninitialized data
```

```
1000 address of entry point
```

```
1000 base of code
```

```
----- new -----
```

```
0000000000400000 image base
```

设置断点

- **bp**命令设置内存断点
 - bl命令查看断点列表
 - bc删除断点
 - bd禁用断点
 - be恢复禁用断点
- **g**命令恢复程序的执行，断点处中断程序执行
- **bp 401000**
 - 在hello.exe入口点设置断点

```

0:000> bp 00401000
*** WARNING: Unable to verify checksum for C:\masm32\hello.exe
0:000> g
ModLoad: 00000000`77650000 00000000`7765a000 C:\WINDOWS\System32\w
ModLoad: 00000000`76590000 00000000`76680000 C:\WINDOWS\SysWOW64\K
ModLoad: 00000000`76e40000 00000000`770b4000 C:\WINDOWS\SysWOW64\K
(274c.1e44): WOW64 breakpoint - code 4000001f (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.
ntdll32!LdrpDoDebuggerBreak+0x2b:
77718147 cc int 3
0:000:x86> g
SetContext failed, 0x80004005
Breakpoint 0 hit
hello+0x1000:
00401000 6800304000 push offset hello+0x3000 (00403000)
    
```



反汇编

- u命令显示当前地址的反汇编代码
 - u address 显示指定位置反汇编代码

```
0:000:x86> u
hello+0x1000:
00401000 6800304000    push    offset hello+0x3000 (00403000)
00401005 e80e000000    call    hello+0x1018 (00401018)
0040100a 6a00          push    0
0040100c e801000000    call    hello+0x1012 (00401012)
00401011 cc           int     3
00401012 ff2508204000 jmp     dword ptr [hello+0x2008 (00402008)]
00401018 55           push    ebp
00401019 8bec         mov     ebp, esp
```





读内存

- d* 显示内存内容
 - da命令以ASCII编码显示
 - du命令以Unicode编码显示
 - db命令以16进制和ASCII编码显示

```
0:000:x86> db 403000
00403000  48 65 6c 6c 6f 20 57 6f-72 6c 64 21 00 00 00 00  Hello World!....
00403010  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403020  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403030  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403040  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403050  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403060  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403070  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
0:000:x86> da 403000
00403000  "Hello World!"
```




写内存

- e* 将指定值输入到内存中
 - ea命令以ASCII编码写入
 - eu命令以Unicode编码写入
 - eb命令以16进制字节写入

```
0:000:x86> db 403000
00403000  48 65 6c 6c 6f 20 57 6f-72 6c 64 21 00 00 00 00  Hello World!....
00403010  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403020  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403030  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403040  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403050  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403060  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403070  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
0:000:x86> da 403000
00403000  "Hello World!"
0:000:x86> ea 403010 "Hello"
0:000:x86> db 403000
00403000  48 65 6c 6c 6f 20 57 6f-72 6c 64 21 00 00 00 00  Hello World!....
00403010  48 65 6c 6c 6f 00 00 00-00 00 00 00 00 00 00 00  Hello.....
00403020  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403030  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403040  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403050  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403060  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403070  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
0:000:x86> eb 403020 'H' 'e' 'l' 'l' 'o'
0:000:x86> db 403000
00403000  48 65 6c 6c 6f 20 57 6f-72 6c 64 21 00 00 00 00  Hello World!....
00403010  48 65 6c 6c 6f 00 00 00-00 00 00 00 00 00 00 00  Hello.....
00403020  48 65 6c 6c 6f 00 00 00-00 00 00 00 00 00 00 00  Hello.....
00403030  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403040  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403050  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403060  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403070  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
0:000:x86> eu 403030 "Hello"
0:000:x86> db 403000
00403000  48 65 6c 6c 6f 20 57 6f-72 6c 64 21 00 00 00 00  Hello World!....
00403010  48 65 6c 6c 6f 00 00 00-00 00 00 00 00 00 00 00  Hello.....
00403020  48 65 6c 6c 6f 00 00 00-00 00 00 00 00 00 00 00  Hello.....
00403030  48 00 65 00 6c 00 6c 00-6f 00 00 00 00 00 00 00  H.e.l.l.o.....
00403040  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403050  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403060  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
00403070  00 00 00 00 00 00 00 00-00 00 00 00 00 00 00 00  .....
```



单步执行

- p命令执行一条指令
 - pc执行到下一条call指令
 - pt执行到下一条ret指令
 - pct执行到下一条call或者ret指令

```
-----
0:000:x86> u
hello+0x1000:
00401000 6800304000    push    offset hello+0x3000 (00403000)
00401005 e80e000000    call   hello+0x1018 (00401018)
0040100a 6a00          push    0
0040100c e801000000    call   hello+0x1012 (00401012)
00401011 cc          int     3
00401012 ff2508204000  jmp     dword ptr [hello+0x2008 (00402008)]
00401018 55          push    ebp
00401019 8bec          mov     ebp,esp
0:000:x86> p
SetContext failed, 0x80004005
hello+0x1005:
00401005 e80e000000    call   hello+0x1018 (00401018)
0:000:x86> u
hello+0x1005:
00401005 e80e000000    call   hello+0x1018 (00401018)
0040100a 6a00          push    0
0040100c e801000000    call   hello+0x1012 (00401012)
00401011 cc          int     3
00401012 ff2508204000  jmp     dword ptr [hello+0x2008 (00402008)]
00401018 55          push    ebp
00401019 8bec          mov     ebp,esp
0040101b 83c4f4        add     esp,0FFFFFFF4h
```




栈信息

- dp显示指针指向的内存信息，esp指向栈顶
 - dp @esp, 显示栈信息
 - dpa @esp, 以字符串形式显示
 - dps @esp, 以符号形式显示
 - dps @esp L4, 显示4行

```
0:000:x86> dpa @esp L4
0019ff74 00403000 "Hello World!"
0019ff78 75d07ba9 "P.....u.....u^...t..."
0019ff7c 003bf000 ""
0019ff80 75d07b90 "..U..V....u..u.....0".u..P.....u.....u^...t..."
0:000:x86> dps @esp L4
0019ff74 00403000 hello+0x3000
0019ff78 75d07ba9 KERNEL32!BaseThreadInitThunk+0x19
0019ff7c 003bf000
0019ff80 75d07b90 KERNEL32!BaseThreadInitThunk
```



进程信息

- |命令显示当前进程ID和进程名
 - 进程ID 3fd0, 进程名 “C:\masm32\hello.exe”
- ~显示当前进程所有线程的状态
 - 1个线程, 线程ID 3fd0.4b88, 状态 Suspend, TEB地址 003c0000

```
0:000:x86> |  
. 0 id: 3fd0 create name: C:\masm32\hello.exe  
0:000:x86> ~  
. 0 Id: 3fd0.4b88 Suspend: 1 Teb: 003c0000 Unfrozen|
```



How to read a Unicode string starting at 0x00402000

- ☐ A da 0x00402000
- ☒ B du 0x00402000
- ☐ C ea 0x00402000
- ☐ D eu 0x00402000

提交



Which command could write a ASCII string into memory?

- ☐ A da
- ☒ B ea
- ☐ C du
- ☐ D lm

How to set a breakpoint at LoadLibrary?

- ☒ A bp LoadLibrary
- ☐ B ex LoadLibrary
- ☐ C lm LoadLibrary
- ☐ D da LoadLibray

提交



Which command could continue execution after breakpoint?

- ☒ A g
- ☐ B bp
- ☐ C da
- ☐ D eu



南開大學

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月異



Microsoft Symbols

病毒分析过程为什么需要Microsoft Symbols? Symbols有什么作用?

作答



允公允能 日新月异

对内存地址的符号化表示

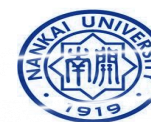
- Including symbols lets you use
 - **MmCreateProcessAddressSpace**
- instead of
 - **0x8050f1a2**





Searching for Symbols

- *moduleName!symbolName*
 - Can be used anywhere an **address** is expected
- *moduleName*
 - The EXE, DLL, or SYS filename (without extension)
- *symbolName*
 - Name associated with the **address**
- **ntoskrnl.exe** is an exception, and is named **nt**
 - Ex: **u nt!NtCreateProcess**
 - Unassembles that function (disassembly)





Deferred Breakpoints

- **bu *newModule!exportedFunction***
 - 设置未解析断点
 - Will set a breakpoint on *exportedFunction* **as soon as** a module named *newModule* is loaded
- **\$iment**
 - Function that finds the entry point of a module
- **bu \$iment(*driverName*)**
 - Breaks on the entry point of the driver before any of the driver's code runs



Searching with x

- You can search for functions or symbols using **wildcards**
- **x nt!*CreateProcess***
 - Displays exported functions & internal functions

```
0:003> x nt!*CreateProcess*
805c736a nt!NtCreateProcessEx = <no type information>
805c7420 nt!NtCreateProcess = <no type information>
805c6a8c nt!PspCreateProcess = <no type information>
804fe144 nt!ZwCreateProcess = <no type information>
804fe158 nt!ZwCreateProcessEx = <no type information>
8055a300 nt!PspCreateProcessNotifyRoutineCount = <no type information>
805c5e0a nt!PsSetCreateProcessNotifyRoutine = <no type information>
8050f1a2 nt!MmCreateProcessAddressSpace = <no type information>
8055a2e0 nt!PspCreateProcessNotifyRoutine = <no type information>
```



Listing Closest Symbol with ln

- Helps in figuring out where a call goes
- **ln *address***
 - First lines show **two closest** matches
 - Last line shows **exact match**

```
0:002> ln 805717aa
kd> ln ntreadfile
1 (805717aa)  nt!NtReadFile    | (80571d38)  nt!NtReadFileScatter
Exact matches:
2      nt!NtReadFile = <no type information>
```





Viewing Structure Information with dt

- Microsoft symbols include **type** information for many structures
 - Including undocumented internal types
 - They are often used by malware
- **dt *moduleName!symbolName***
- **dt *moduleName!symbolName address***
 - Shows structure with data from **address**



Example 11-2. Viewing type information for a structure

```
0:000> dt nt!_DRIVER_OBJECT
```

```
kd> dt nt!_DRIVER_OBJECT
```

+0x000	Type	: Int2B
+0x002	Size	: Int2B
+0x004	DeviceObject	: Ptr32 _DEVICE_OBJECT
+0x008	Flags	: Uint4B
1 +0x00c	DriverStart	: Ptr32 Void
+0x010	DriverSize	: Uint4B
+0x014	DriverSection	: Ptr32 Void
+0x018	DriverExtension	: Ptr32 _DRIVER_EXTENSION
+0x01c	DriverName	: _UNICODE_STRING
+0x024	HardwareDatabase	: Ptr32 _UNICODE_STRING
+0x028	FastIoDispatch	: Ptr32 _FAST_IO_DISPATCH
+0x02c	DriverInit	: Ptr32 long
+0x030	DriverStartIo	: Ptr32 void
+0x034	DriverUnload	: Ptr32 void
+0x038	MajorFunction	: [28] Ptr32 long





Example 11-3. Overlaying data onto a structure

```
kd> dt nt!_DRIVER_OBJECT 828b2648
+0x000 Type           : 4
+0x002 Size           : 168
+0x004 DeviceObject   : 0x828b0a30 _DEVICE_OBJECT
+0x008 Flags          : 0x12
+0x00c DriverStart    : 0xf7adb000
+0x010 DriverSize     : 0x1080
+0x014 DriverSection  : 0x82ad8d78
+0x018 DriverExtension : 0x828b26f0 _DRIVER_EXTENSION
+0x01c DriverName     : _UNICODE_STRING "\Driver\Beep"
+0x024 HardwareDatabase : 0x80670ae0 _UNICODE_STRING
"\REGISTRY\MACHINE\
HARDWARE\DESCRIPTION\SYSTEM"
+0x028 FastIoDispatch : (null)
+0x02c DriverInit     : 0xf7adb66c long Beep!DriverEntry+0
+0x030 DriverStartIo  : 0xf7adb51a void Beep!BeepStartIo+0
+0x034 DriverUnload   : 0xf7adb620 void Beep!BeepUnload+0
+0x038 MajorFunction  : [28] 0xf7adb46a long Beep!BeepOpen+0
```





允公允能 日新月异

Initialization Function

- The **DriverInit** function is called first when a driver is loaded
- Malware will sometimes place its entire malicious payload in this function

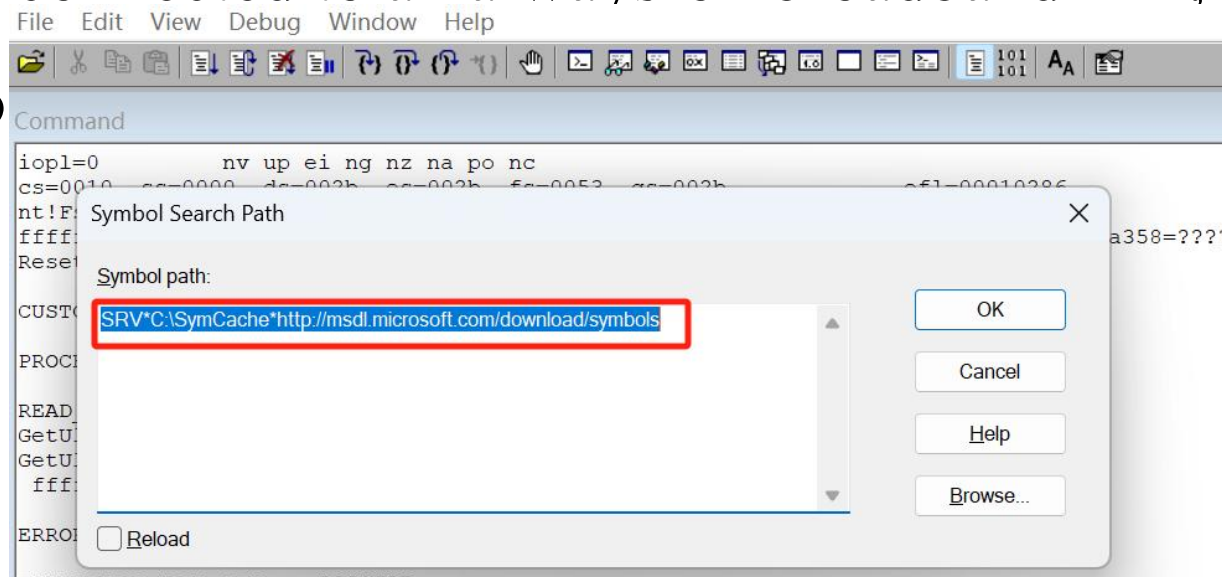


Configuring Windows Symbols

- If your debugging machine is connected to an always-on broadband link, you can configure WinDbg to Microsoft as needed

- They are cached locally

- **File, Symbol File Path**



- SRC*c:\websymbols*http://msdl.microsoft.com/download/symbols

Which module's name is nt in WinDbg?

- ☐ A kernel32.dll
- ☒ B ntoskrnl.exe
- ☐ C hal.dll
- ☐ D ntdll.dll

提交



How to list closest symbol at a specified address?

- ☒ A ln
- ☐ B lm
- ☐ C du
- ☐ D dt

提交



How to view a structure information at a specified memory address?

- ☒ A dt
- ☐ B da
- ☐ C du
- ☐ D dd

Which function is called first when a driver is loaded?

- ☒ A DriverInit
- ☐ B DriverEntry
- ☐ C DllMain
- ☐ D WinMain

提交





南开大学

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月异



内核调试实战

恶意代码的发展趋势

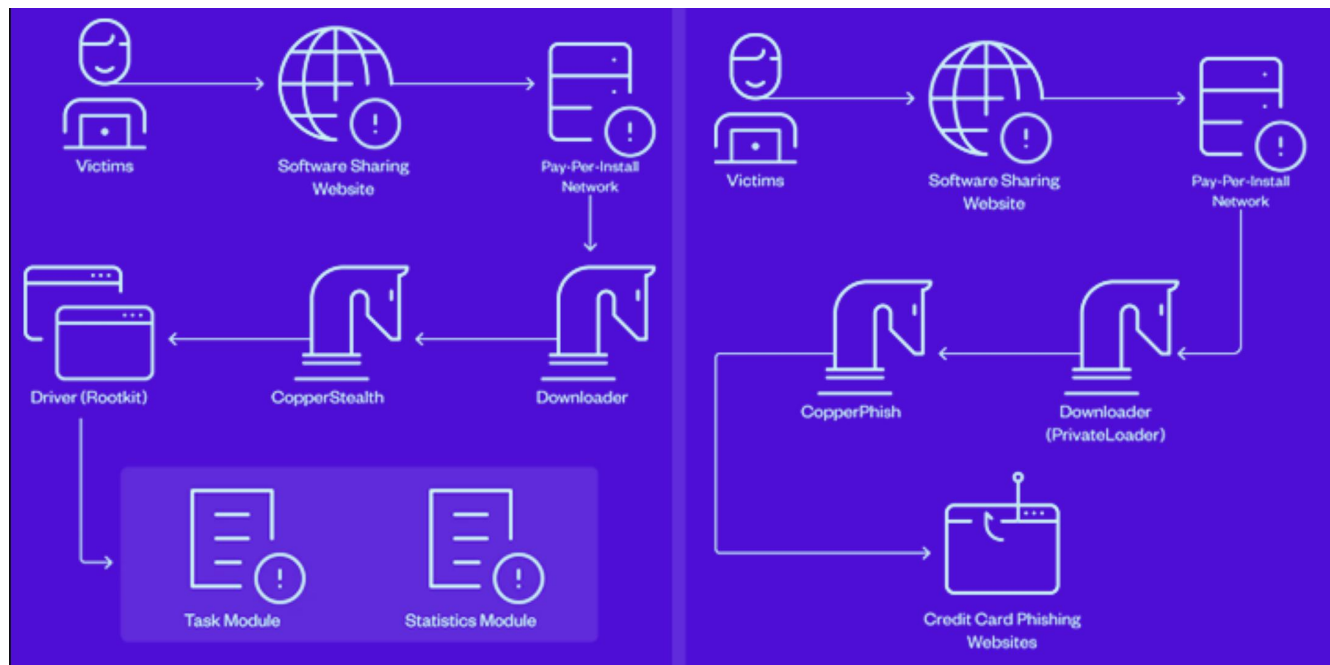
- “我们已进入与高级威胁对抗时代，需要通过**底层技术**对抗这类威胁”，“由已知恶意代码向高级恶意代码发展，包括**Rootkit、Bootkit等高级内核级攻击**”——朱颖（安芯网盾）
- 遇见2023网安行业发展新趋势

CopperStealer恶意软件使用新的Rootkit和网络钓鱼套件模块

日期：2023-05-22

标签：CopperStealer恶意软件

网络安全公司Trend Micro在2023年3月和4月发现CopperStealer恶意软件的威胁者重新出现，使用新负载CopperStealth和CopperPhish进行两个攻击活动。Trend Micro将这一以金钱为动机的组织命名为Water Orthrus。这个对手还负责另一个被称为Scranos的活动。Water Orthrus自2021年以来一直活跃，在使用“按装获利(PPI)”网络将被攻击者拦截的受害者重定向到破解软件下载站，在那里释放被称为CopperStealer的信息窃取软件的过程中拥有丰富的经验。最新的攻击活动使用了与前面攻击类似的技术，通过包装成中国软件共享网站的免费工具安装器来传播CopperStealth。CopperPhish恶意软件则通过PPI网络以类似的方式传播，利用网络钓鱼攻击窃取信用卡信息。这些攻击活动是威胁者策略演化的一部分，表明他们正在尝试添加新的工具来扩展其金融收益。



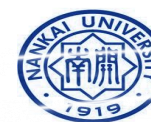
允公允能 日新月异

R77 Rootkit

The screenshot displays a Windows environment infected with the R77 Rootkit. The File Explorer shows a hidden folder named `$77hidden_folder` and a file named `$77myapp.exe`. The Task Manager shows a process named `$77-Example.exe` running. The Registry Editor shows a new registry value named `$77hidden-var` created under `Computer\HKEY_CURRENT_USER\SOFTWARE_my_key`. The TCPView shows a connection to the IP address `93.184.216.34`. The r77 Test Console shows a list of processes with columns for Process, PID, Platform, Integrity, User, Flags, Inject, Detach, and Hide by PID. The console also shows a message: `21:15:05 File Install.exe was executed.`

Process	PID	Platform	Integrity	User	Flags	Inject	Detach	Hide by PID
dllhost.exe	9556	64	System	SYSTEM		Inject		Unhide
dllhost.exe	9976	64	Medium	usr1		Inject		Hide
dwm.exe	1016	64	System	DWM-1		Inject	Detach	Hide
explorer.exe	4756	64	Medium	usr1		Inject	Detach	Hide
fontdrvhost.exe	796	64	Low	UMFD-0		Inject		Hide
fontdrvhost.exe	948	64	Low	UMFD-1		Inject		Hide
lsass.exe	676	64	System	SYSTEM		Inject	Detach	Hide
Memory Compression	1980	64	System	SYSTEM		Inject		Hide
MoUserCoreWorker.exe	7868	64	System	SYSTEM		Inject	Detach	Hide
MpCmdRun.exe	5220	64	System	NETWORK SERVICE		Inject	Detach	Hide
MpCmdRun.exe	5304	64	System	SYSTEM		Inject	Detach	Hide
MpSigStub.exe	9592	64	System	SYSTEM		Inject	Detach	Hide
msdtc.exe	4772	64	System	NETWORK SERVICE		Inject	Detach	Hide
MsMpEng.exe	3348	64	System	SYSTEM		Inject	Detach	Hide
OneDrive.exe	9648	64	Medium	usr1		Inject	Detach	Hide
Registry	92	64	System	SYSTEM		Inject	Detach	Hide
RuntimeBroker.exe	4000	64	Medium	usr1		Inject	Detach	Hide
RuntimeBroker.exe	6176	64	Medium	usr1		Inject	Detach	Hide
RuntimeBroker.exe	6568	64	Medium	usr1		Inject	Detach	Hide
RuntimeBroker.exe	8208	64	Medium	usr1		Inject	Detach	Hide
SearchApp.exe	6004	64	Low	usr1		Inject	Detach	Hide

<https://github.com/bytecode77/r77-rootkit>



南开大学
Nankai University



允公允能 日新月异

全民携手 共筑网络安全坚强防线



2023年国家网络安全宣传周的主题是什么？



2023 国家网络安全宣传周
CHINA CYBERSECURITY WEEK

网络安全为人民 网络安全靠人民

中国·福州 2023年9月

作答



允公允能 日新月异

国家网络安全宣传周

国家网络安全
宣传周
China Cybersecurity Week

网络安全为人民 网络安全靠人民

2023年国家网络安全宣传周

主办单位：
中央宣传部、中央网信办、教育部、工业和信息化部、公安部、
中国人民银行、国家广播电视总局、全国总工会、共青团中央、全国妇联



南开大学
Nankai University



允公允能 日新月异

Kernel Mode and User Mode Functions

- We'll examine a program that writes to files from kernel space
 - **Kernel** mode programs cannot call **user-mode** functions like **CreateFile** and **WriteFile**
 - Must use **NtCreateFile** and **NtWriteFile**



南开大学
Nankai University



允公允能 日新月异

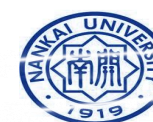
User-Space Code

Example 11-4. Creating a service to load a kernel driver

```
04001B3D  push    esi                ; lpPassword
04001B3E  push    esi                ; lpServiceStartName
04001B3F  push    esi                ; lpDependencies
04001B40  push    esi                ; lpdwTagId
04001B41  push    esi                ; lpLoadOrderGroup
04001B42  push    [ebp+lpBinaryPathName] ; lpBinaryPathName
04001B45  push    1                  ; dwErrorControl
04001B47  push    3                  ; dwStartType
04001B49  push    1                  ; dwServiceType
04001B4B  push    0F01FFh           ; dwDesiredAccess
04001B50  push    [ebp+lpDisplayName] ; lpDisplayName
04001B53  push    [ebp+lpDisplayName] ; lpServiceName
04001B56  push    [ebp+hSCManager]   ; hSCManager
04001B59  call    ds:__imp__CreateServiceA@52
```

Creates a service with the CreateService function

dwServiceType is 0x01 (**Kernel driver**)



南开大学
Nankai University

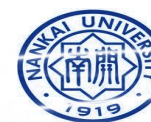


User-Space Code

Example 11-5. Obtaining a handle to a device object

```
04001893      xor     eax, eax
04001895      push    eax           ; hTemplateFile
04001896      push    80h           ; dwFlagsAndAttributes
0400189B      push    2            ; dwCreationDisposition
0400189D      push    eax           ; lpSecurityAttributes
0400189E      push    eax           ; dwShareMode
0400189F      push    ebx           ; dwDesiredAccess
040018A0      2push    edi           ; lpFileName
040018A1      1call    esi ; CreateFileA
```

- Not shown: edi being set to
 - `\\.\FileWriter\Device`





User-Space Code

Once the malware has a handle to the device, it uses the `DeviceIoControl` function at **1** to send data to the driver as shown in **Example 11-6**.

Example 11-6. Using `DeviceIoControl` to communicate from user space to kernel space

```
04001910  push    0                ; lpOverlapped
04001912  sub     eax, ecx
04001914  lea     ecx, [ebp+BytesReturned]
0400191A  push    ecx              ; lpBytesReturned
0400191B  push    64h              ; nOutBufferSize
0400191D  push    edi              ; lpOutBuffer
0400191E  inc     eax
0400191F  push    eax              ; nInBufferSize
04001920  push    esi              ; lpInBuffer
04001921  push    9C402408h        ; dwIoControlCode
04001926  push    [ebp+hObject]    ; hDevice
0400192C  call    ds:DeviceIoControl1
```



Kernel-Mode Code

- Set kernel-mode debugger to **Verbose** mode
- You'll see every kernel module that loads
- Kernel modules are not loaded or unloaded often
 - **Any loads are suspicious**
 - Except **Kmixer.sys** in VMware machines

In the following example, we see that the *FileWriter.sys* driver has been loaded in the kernel debugging window. Likely, this is the malicious driver.

```
ModLoad: f7b0d000 f7b0e780  FileWriter.sys
```





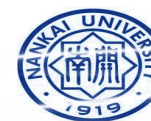
Kernel-Mode Code

- **!drvobj** command shows driver object

Example 11-7. Viewing a driver object for a loaded driver

```
kd> !drvobj FileWriter
Driver object (0827e3698) is for:
Loading symbols for f7b0d000  FileWriter.sys ->  FileWriter.sys
*** ERROR: Module load completed but symbols could not be loaded for
FileWriter.sys
\Driver\FileWriter
Driver Extension List: (id , addr)

Device Object list:
826eb030
```



Kernel-Mode Code

- **dt** command shows structure

Example 11-8. Viewing a device object in the kernel

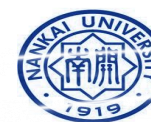
```
kd>dt nt!_DRIVER_OBJECT 0x827e3698
nt!_DRIVER_OBJECT
+0x000 Type           : 4
+0x002 Size           : 168
+0x004 DeviceObject    : 0x826eb030 _DEVICE_OBJECT
+0x008 Flags           : 0x12
+0x00c DriverStart     : 0xf7b0d000
+0x010 DriverSize      : 0x1780
+0x014 DriverSection   : 0x828006a8
+0x018 DriverExtension : 0x827e3740 _DRIVER_EXTENSION
+0x01c DriverName      : _UNICODE_STRING "\Driver\FileWriter"
+0x024 HardwareDatabase : 0x8066ecd8 _UNICODE_STRING
"\REGISTRY\MACHINE\
                        HARDWARE\DESCRIPTION\SYSTEM"
+0x028 FastIoDispatch  : (null)
+0x02c DriverInit       : 0xf7b0dfcd      long  +0
+0x030 DriverStartIo   : (null)
+0x034 DriverUnload     : 0xf7b0da2a      void  +0
+0x038 MajorFunction    : [28] 0xf7b0da06      long  +0
```



允公允能 日新月异

Kernel-Mode Filenames

- Tracing this function, it eventually creates this file
 - \DosDevices\C:\secretfile.txt
- This is a *fully qualified object name*
 - Identifies the root device, usually \DosDevices



南开大学
Nankai University



允公允能 日新月异

Finding Driver Objects

- Applications work with *devices*, not drivers
- Look at user-space application to identify the interesting *device object*
- Use *device object* in *User Mode* to find *driver object* in *Kernel Mode*
- Use **!devobj** to find out more about the *driver object*
- Use **!devhandles** to find application that use the driver



南开大学
Nankai University

Kernel mode programs [填空1] (can or cannot)
call user-mode functions

正常使用填空题需3.0以上版本雨课堂

作答





南開大學

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月異



Rootkits



允公允能 日新月异

Rootkit Basics

- Rootkits could modify the internal functionality of the OS to **conceal** themselves
 - Hide processes, files, network connections, drivers, services and other os components.
 - Reside at the user or kernel level in the operating system or lower, including **hypervisor**, **Master Boot Record**, or **System Firmware**.
 - Difficult for antivirus, administrators, and security analysts to discover their malicious activity



南开大学
Nankai University



允公允能 日新月异

Rootkit Basics

- Most rootkits modify the OS kernel
- Most popular method:
 - **System Service Descriptor Table (SSDT) hooking**



南开大学
Nankai University



允公允能 日新月异

System Service Descriptor Table (SSDT)

- Used **internally** by Microsoft
 - To look up function calls into the kernel
 - Not normally used by third-party applications or drivers



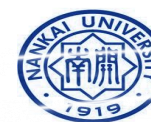
南开大学
Nankai University



允公允能 日新月异

SSDT

- Only three ways for user space to access kernel code
 - **SYSCALL**
 - **SYSENTER**
 - **INT 0x2E**

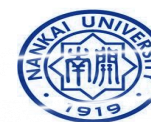




允公允能 日新月异

SYSENTER

- Used by modern versions of Windows
- **Function code** stored in EAX register





Example from ntdll.dll

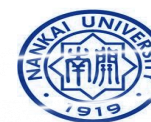
Example 11-11. Code for NtCreateFile function

```
7C90D682 1mov     eax, 25h          ; NtCreateFile
7C90D687  mov     edx, 7FFE0300h
7C90D68C  call    dword ptr [edx]
7C90D68E  retn    2Ch
```

The call to `dword ptr [edx]` will go to the following instructions:

```
7c90eb8b 8bd4  mov     edx, esp
7c90eb8d 0f34  sysenter
```

- EAX set to 0x25
- Stack pointer saved in EDX
- SYSENTER is called





SSDT Table Entries

Example 11-12. Several entries of the SSDT table showing NtCreateFile

```
SSDT[0x22] = 805b28bc (NtCreateaDirectoryObject)
SSDT[0x23] = 80603be0 (NtCreateEvent)
SSDT[0x24] = 8060be48 (NtCreateEventPair)
1 SSDT[0x25] = 8056d3ca (NtCreateFile)
SSDT[0x26] = 8056bc5c (NtCreateIoCompletion)
SSDT[0x27] = 805ca3ca (NtCreateJobObject)
```

- Rootkit changes the values in the SSDT so rootkit code is called instead of the intended function
- 0x25 would be changed to a malicious driver's function
- Hooking NtCreateFile



允公允能 日新月异

Rootkit Analysis in Practice

- Simplest way to detect SSDT hooking
 - Just look at the SSDT
 - Look for values that are **unreasonable**
 - In this case, *ntoskrnl.exe* starts at address 804d7000 and ends at 806cd580
 - *ntoskrnl.exe* is the Kernel!



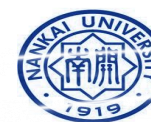
南开大学
Nankai University



允公允能 日新月异

Rootkit Analysis in Practice

- **lm m nt**
 - Lists modules matching "nt" (Kernel modules)
 - Shows the SSDT table



南开大学
Nankai University



SSDT Table

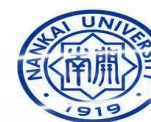
Example 11-13. A sample SSDT table with one entry overwritten by a rootkit

```
kd> lm m nt
```

...

8050122c	805c9928	805c98d8	8060aea6	805aa334
8050123c	8060a4be	8059cbbc	805a4786	805cb406
8050124c	804feed0	8060b5c4	8056ae64	805343f2
8050125c	80603b90	805b09c0	805e9694	80618a56
8050126c	805edb86	80598e34	80618caa	805986e6
8050127c	805401f0	80636c9c	805b28bc	80603be0
8050128c	8060be48	ff7ad94a4	8056bc5c	805ca3ca
8050129c	805ca102	80618e86	8056d4d8	8060c240
805012ac	8056d404	8059fba6	80599202	805c5f8e

- Marked entry is **hooked**
- To identify it, examine a clean system's SSDT





Finding the Malicious Driver

- **lm**
 - Lists open modules
 - In the kernel, they are all drivers

Example 11-14. Using the `lm` command to find which driver contains a particular address

```
kd>lm
```

```
...
```

```
f7ac7000 f7ac8580 intelide (deferred)
```

```
f7ac9000 f7aca700 dmload (deferred)
```

```
f7ad9000 f7ada680 Rootkit (deferred)
```

```
f7aed000 f7aee280 vmouse (deferred)
```

```
...
```



Example 11-16. Listing of the rootkit hook function

```

000104A4  mov     edi, edi
000104A6  push    ebp
000104A7  mov     ebp, esp
000104A9  push    [ebp+arg_8]
000104AC  call    1sub_10486
000104B1  test    eax, eax
000104B3  jz      short loc_104BB
000104B5  pop     ebp
000104B6  jmp     NtCreateFile
000104BB  -----
000104BB                ; CODE XREF: sub_104A4+F j
000104BB  mov     eax, 0C0000034h
000104C0  pop     ebp
000104C1  retn    2Ch
    
```


The hook function jumps to the original NtCreateFile function for some requests and returns to 0xC0000034 for others. The value 0xC0000034 corresponds to STATUS_OBJECT_NAME_NOT_FOUND. The call at **1** contains



Interrupts

- Interrupts allow **hardware to trigger software events**
- Driver calls `IoConnectInterrupt` to register a handler for an interrupt code
- Specifies an *Interrupt Service Routine (ISR)*
 - Will be called when the interrupt code is generated
- *Interrupt Descriptor Table (IDT)*
 - Stores the ISR information
 - **!idt** command shows the IDT





Example 11-17. A sample IDT

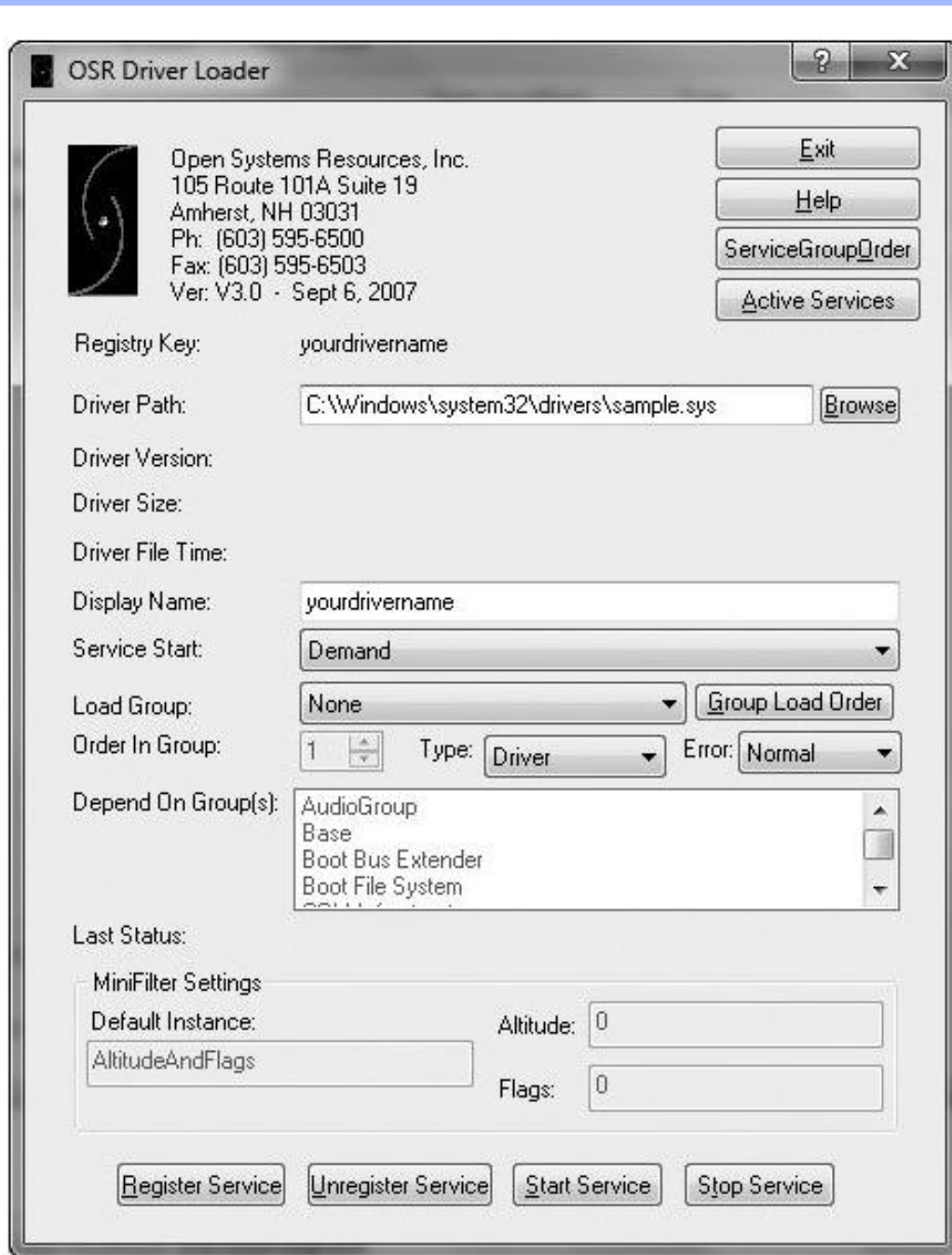
kd> !idt

```
37: 806cf728 hal!PicSpuriousService37
3d: 806d0b70 hal!HalpApcInterrupt
41: 806d09cc hal!HalpDispatchInterrupt
50: 806cf800 hal!HalpApicRebootService
62: 8298b7e4 atapi!IdePortInterrupt (KINTERRUPT 8298b7a8)
63: 826ef044 NDIS!ndisMIsr (KINTERRUPT 826ef008)
73: 826b9044 portcls!CKsShellRequestor::`vector deleting destructor'+0x26
    (KINTERRUPT 826b9008)
    USBPORT!USBPORT_InterruptService (KINTERRUPT 826df008)
82: 82970dd4 atapi!IdePortInterrupt (KINTERRUPT 82970d98)
83: 829e8044 SCSI!ScsiPortInterrupt (KINTERRUPT 829e8008)
93: 826c315c i8042prt!I8042KeyboardInterruptService (KINTERRUPT 826c3120)
a3: 826c2044 i8042prt!I8042MouseInterruptService (KINTERRUPT 826c2008)
b1: 829e5434 ACPI!ACPIInterruptServiceRoutine (KINTERRUPT 829e53f8)
b2: 826f115c serial!SerialCIsrSw (KINTERRUPT 826f1120)
c1: 806cf984 hal!HalpBroadcastCallService
d1: 806ced34 hal!HalpClockInterrupt
e1: 806cff0c hal!HalpIpiHandler
e3: 806cfc70 hal!HalpLocalApicErrorService
fd: 806d0464 hal!HalpProfileInterrupt
fe: 806d0604 hal!HalpPerfInterrupt
```

Interrupts going to unnamed, unsigned, or suspicious drivers could indicate a rootkit or other malicious software.

Loading Drivers

- If you want to load a driver to test it, you can download the OSR Driver Loader tool



The screenshot shows the OSR Driver Loader application window. It features a title bar with a question mark and a close button. The main area contains various input fields and buttons for configuring a driver service. The 'Registry Key' is set to 'yourdrivename'. The 'Driver Path' is 'C:\Windows\system32\drivers\sample.sys'. The 'Service Start' is set to 'Demand'. The 'Load Group' is 'None'. The 'Order In Group' is '1'. The 'Type' is 'Driver'. The 'Error' is 'Normal'. The 'Depend On Group(s)' list includes 'AudioGroup', 'Base', 'Boot Bus Extender', and 'Boot File System'. The 'Last Status' section includes 'MiniFilter Settings', 'Default Instance', 'Altitude', and 'Flags'. At the bottom, there are buttons for 'Register Service', 'Unregister Service', 'Start Service', and 'Stop Service'.

OSR Driver Loader

Open Systems Resources, Inc.
105 Route 101A Suite 19
Amherst, NH 03031
Ph: (603) 595-6500
Fax: (603) 595-6503
Ver: V3.0 - Sept 6, 2007

Exit
Help
ServiceGroupOrder
Active Services

Registry Key: yourdrivename

Driver Path: C:\Windows\system32\drivers\sample.sys Browse

Driver Version:

Driver Size:

Driver File Time:

Display Name: yourdrivename

Service Start: Demand

Load Group: None Group Load Order

Order In Group: 1 Type: Driver Error: Normal

Depend On Group(s): AudioGroup
Base
Boot Bus Extender
Boot File System

Last Status:

MiniFilter Settings

Default Instance: AltitudeAndFlags Altitude: 0

Flags: 0

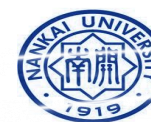
Register Service Unregister Service Start Service Stop Service



允公允能 日新月异

Driver Signing

- Enforced in all 64-bit versions of Windows starting with Vista
- Only digitally signed drivers will load
- Effective protection!



南开大学
Nankai University



允公允能 日新月异

R77 隐藏效果的验证实验

- 运行R77程序，实现对指定的进程、文件、注册表、网络连接的隐藏。
- 实验效果进行截图，完成实验报告
- R77使用了Windows的Detours机制。Detours机制的原理将在隐蔽执行章节介绍。



南开大学
Nankai University



南开大学

NANKAI UNIVERSITY, P.R. CHINA 1919

允公允能 日新月异



恶意代码分析与防治技术

第9章 WinDBG内核调试

王志

zwang@nankai.edu.cn

南开大学 网络空间安全学院

2023/2024



允公允能 日新月异

知识点

- 系统内核与驱动

- 难点：设备（Device）、驱动（Driver）、物理设备（Physical Device）

- WinDbg

- Microsoft Symbols

- 内核调试实战

- Rootkits

- 难点：SSDT、IDT



南开大学
Nankai University