A Hypervisor IPS based on Hardware Assisted Virtualization Technology

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Presentation Outline

1. Review of subversive techniques in kernel space
2. Review of Virtualization Technology
3. Viton, Hypervisor IPS
4. Conclusion

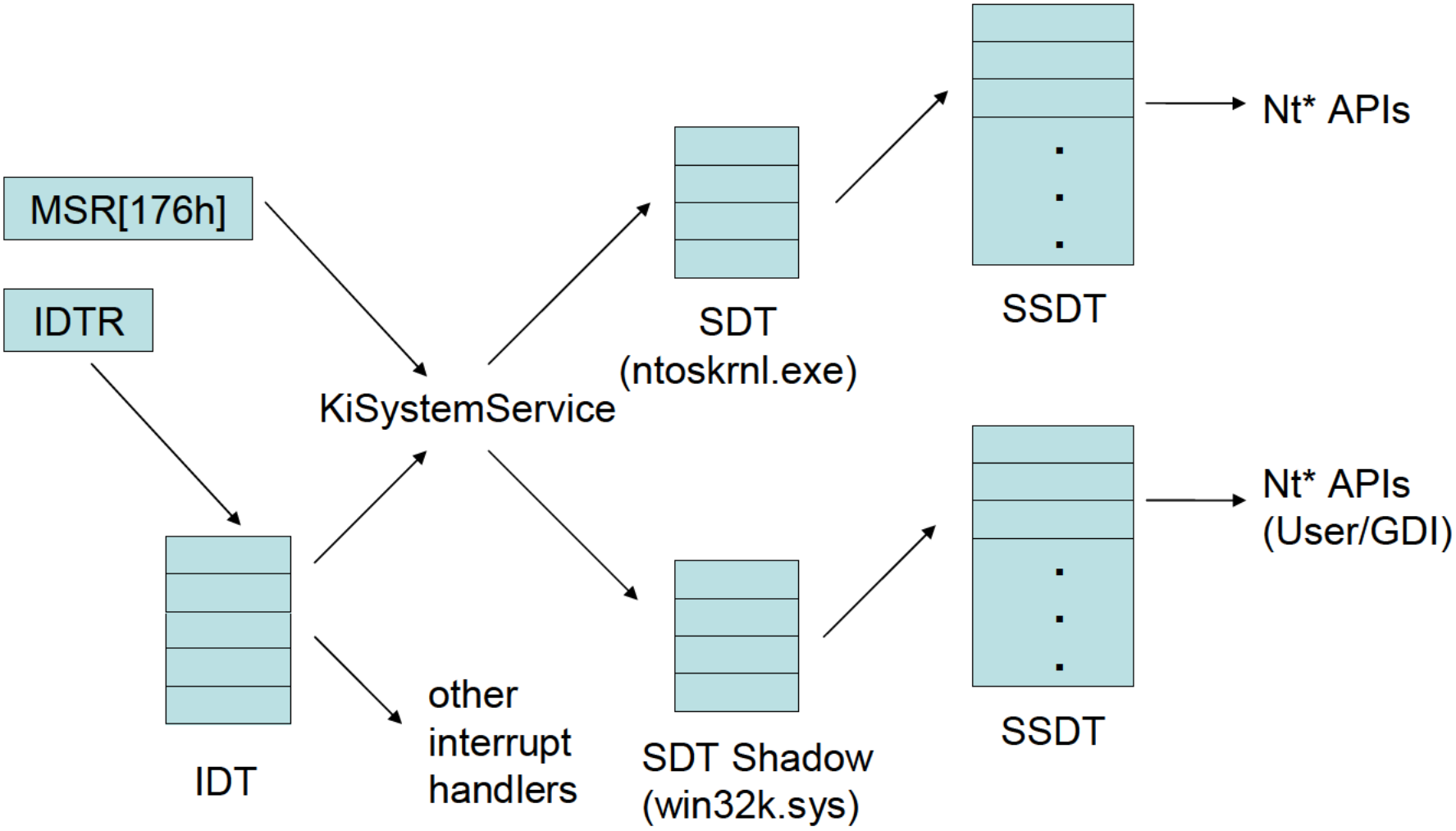
- 1. Review of subversive techniques in kernel space

Remember Joanna's classification

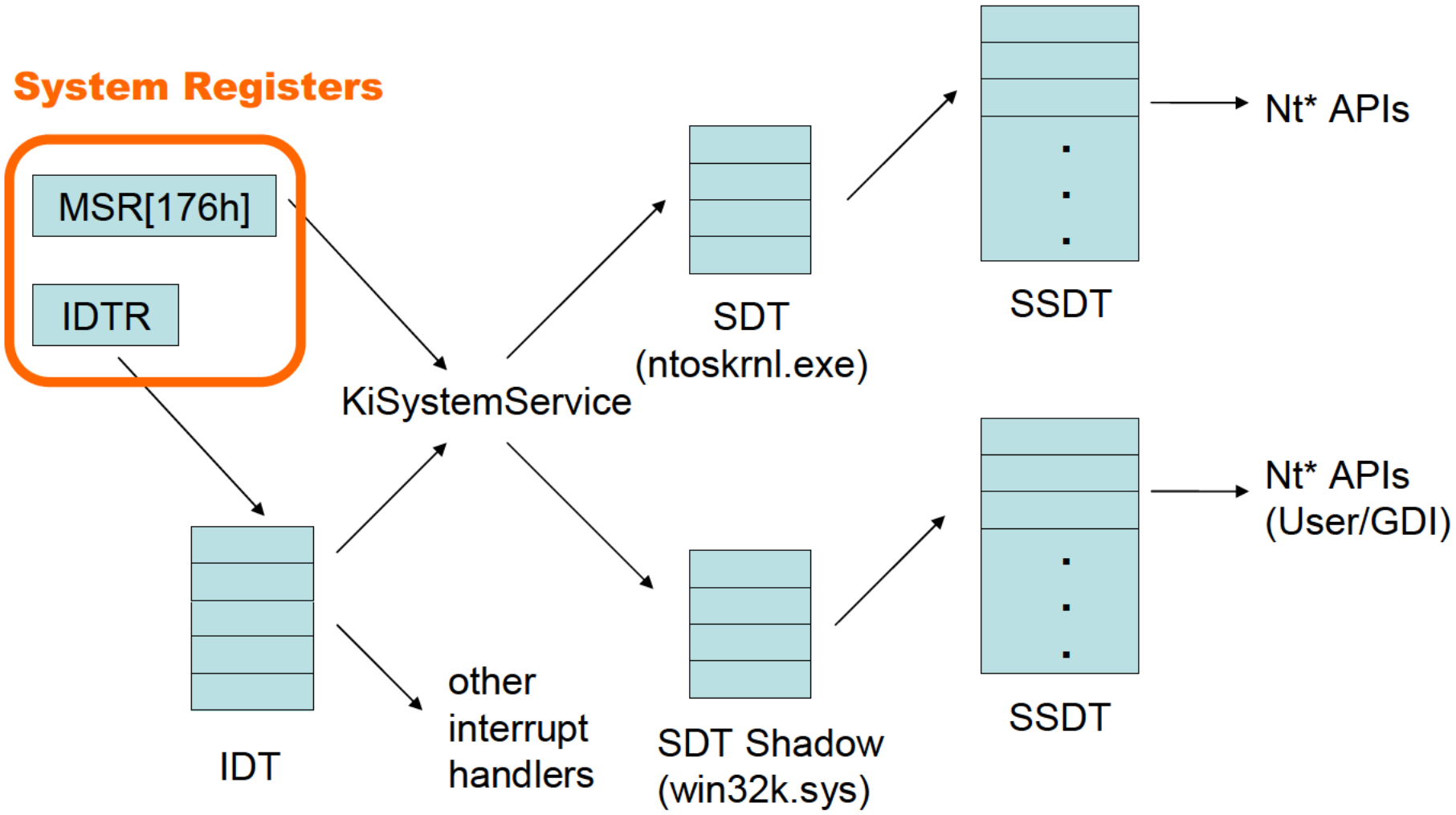
- Joanna Rutkowska proposed stealth malware taxonomy in November, 2006.
  http://invisiblethings.org/papers/malware-taxonomy.pdf

- Type 0
  - standalone malware, which never changes any system resources
- Type I
  - changes the persistent system resources
- Type II
  - changes the non-persistent system resources
- Type III
  - malware runs outside the system

Type I: Overview of Hooking Points

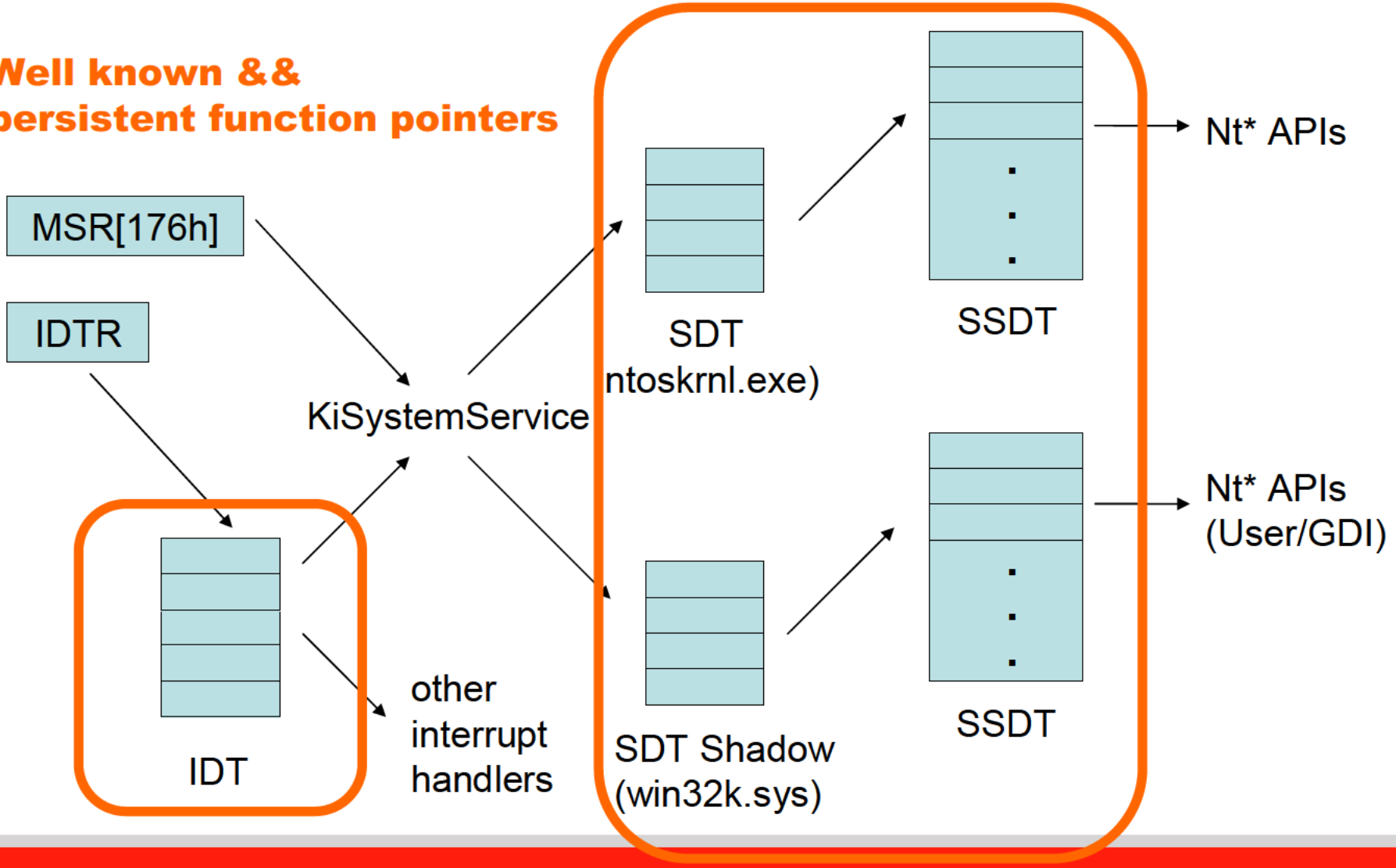


Type I: Overview of Hooking Points



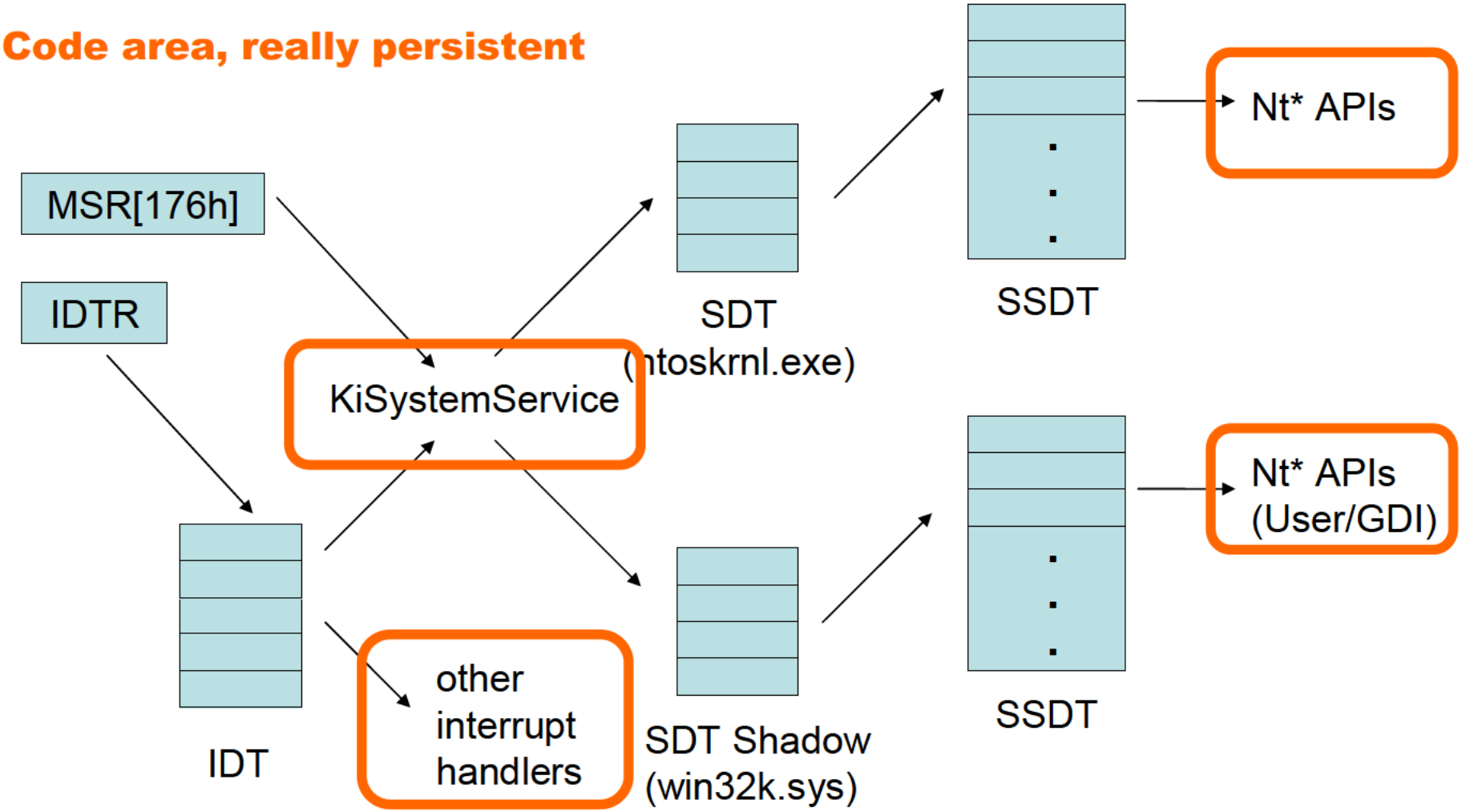
Type I: Overview of Hooking Points

Well known &&
persistent function pointers



Type I: Overview of Hooking Points

Code area, really persistent



Type I

- It is easy to detect
- PatchGuard in Vista(x64) is a countermeasure for this type
- Many rootkit detectors have been released for this type

Type II

- Malware changes the non-persistent system resources
- Hooking point might be modified by the regular execution path

- DKOM(Direct Kernel Object Manipulation)
  - by http://www.blackhat.com/presentations/win-usa-04/bh-win-04-butler.pdf

- KOH(Kernel Object Hooking)
  - by Greg Hoglund in Jan, 2006
    http://www.rootkit.com/newsread.php?newsid=501

DKOM(Direct Kernel Object Manipulation)

- Malware manipulates the process list, tokens and other kernel objects directly

- For example:
  - Unlink target process from process list
  - Add/remove priviledges to tokens

- DKOM's possibilities are limited
  - Whether information hiding can be done depends on the implementation of process that deals with the data

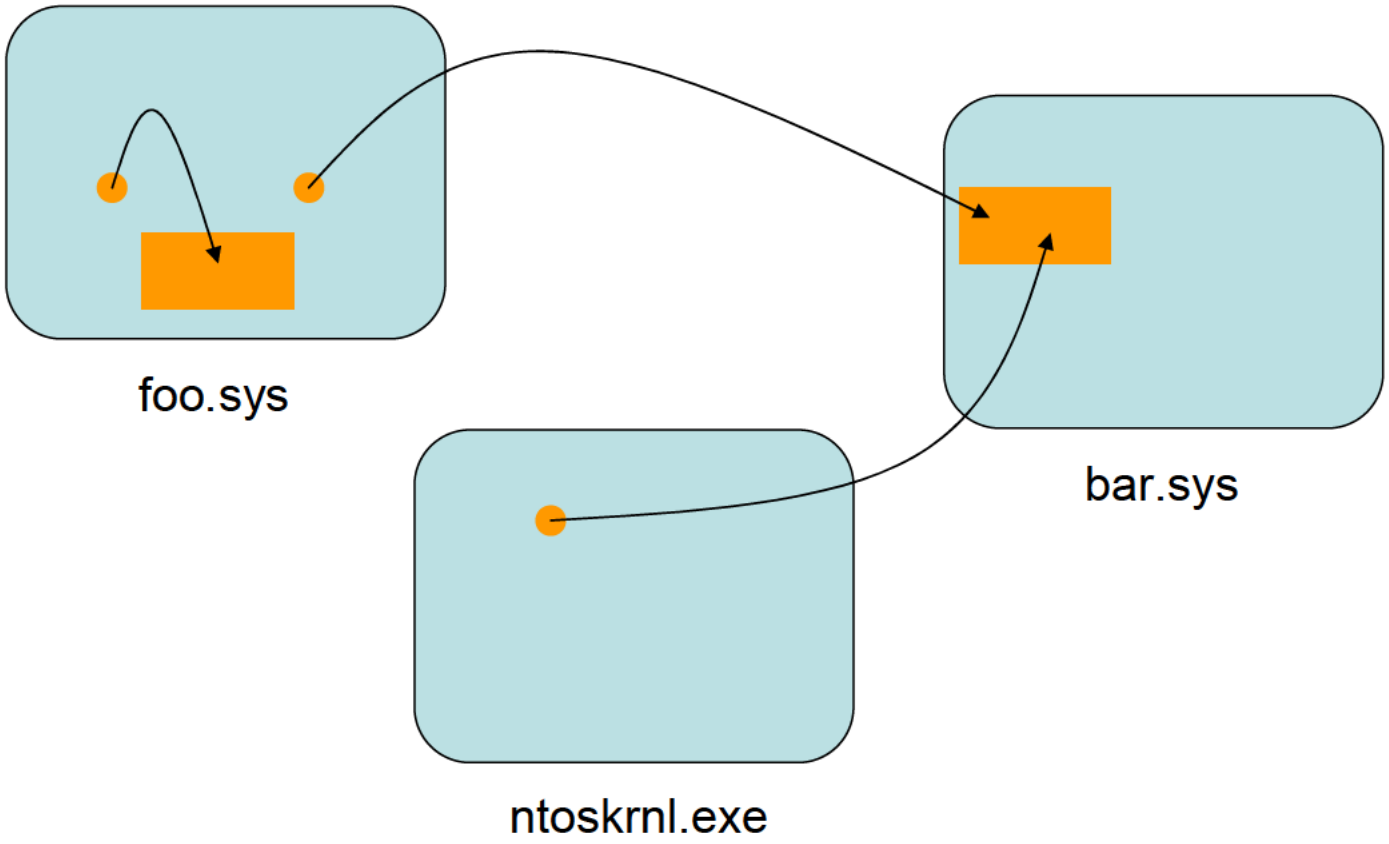
KOH(Kernel Object Hooking)

- Remember the SDT, SSDT and other well known && persistent function pointers?

- Do you know how many such patching points are there in kernel space?
  - They might or might not be persistent
  - It depends on each kernel object

- Detector has to understand all function pointers
- is_within_own_memory_range(PVOID Address) is useful, but not enough

is_within_own_memory_range(PVOID Addr)



Type III

- No malware exists in the system(guest)
- Malware (ab)uses Virtualization Technology
- SMM Rootkit and Firmware Rootkit might also fall into this category (a problem of taxonomy that is not important for our cause)

- BluePill
  - Original BP was presented by Joanna Rutkowska in BH-US-2006.
  - (Current) New BP supports both Intel VT and AMD-v technologies, and is also capable of on the fly loading and unloading
  - BP doesn't modify any system resources on the guest
    - From a technical view, BP patches the guest's PTE to hide its loaded virtual memory from the guest
    - However this doesn't really help detecting it

Type III (cont.)

- Vitriol
  - Presented by Dino Dai Zovi, Black Hat US 2006
  - VT-x rootkit, closed source

- VMM Rootkit Framework
  - Posted by Shawn Embleton, Aug, 2007
    http://www.rootkit.com/newsread.php?newsid=758
  - This is really good start point for learning for how to create VMM

Case Study: Storm Worm

- The Storm Worm first appeared in Fall, 2006
- Some variants have rootkit functions to hide from AV products
- As of Jan 2008 we can see "Happy New Year 2008" variants
- When a user clicks onto the executable,

Storm Worm

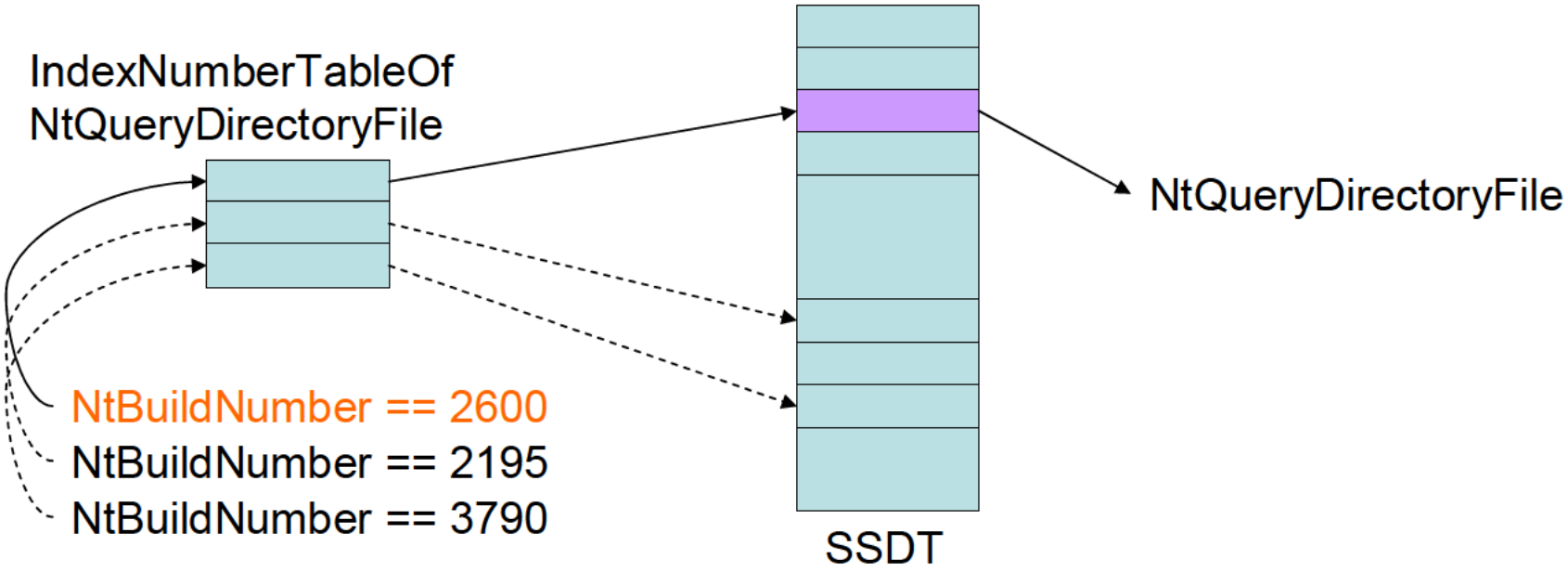
1. Executable drops the system driver (.sys), and loads it into the kernel using Service Control Manager (SCM)

2. Driver has two functions shown below
   - Rootkit functions
     Hide files, registry entries and connections using SSDT and IRP hooking
   - Code Injection function
     Inject malicious code (not DLL) into process context of services.exe and execute it

3. Injected code starts P2P communication

Rootkit functions

- Storm Worm hooks three Native APIs
  - NtQueryDirectoryFile, NtEnumerateKey, NtEnumerateValueKey
- API Index of SSDT is different for each NtBuildNumber
- Storm Worm has index number tables for build 2195(2k), 2600(XP) and 3790(2k3)



Rootkit functions (cont.)

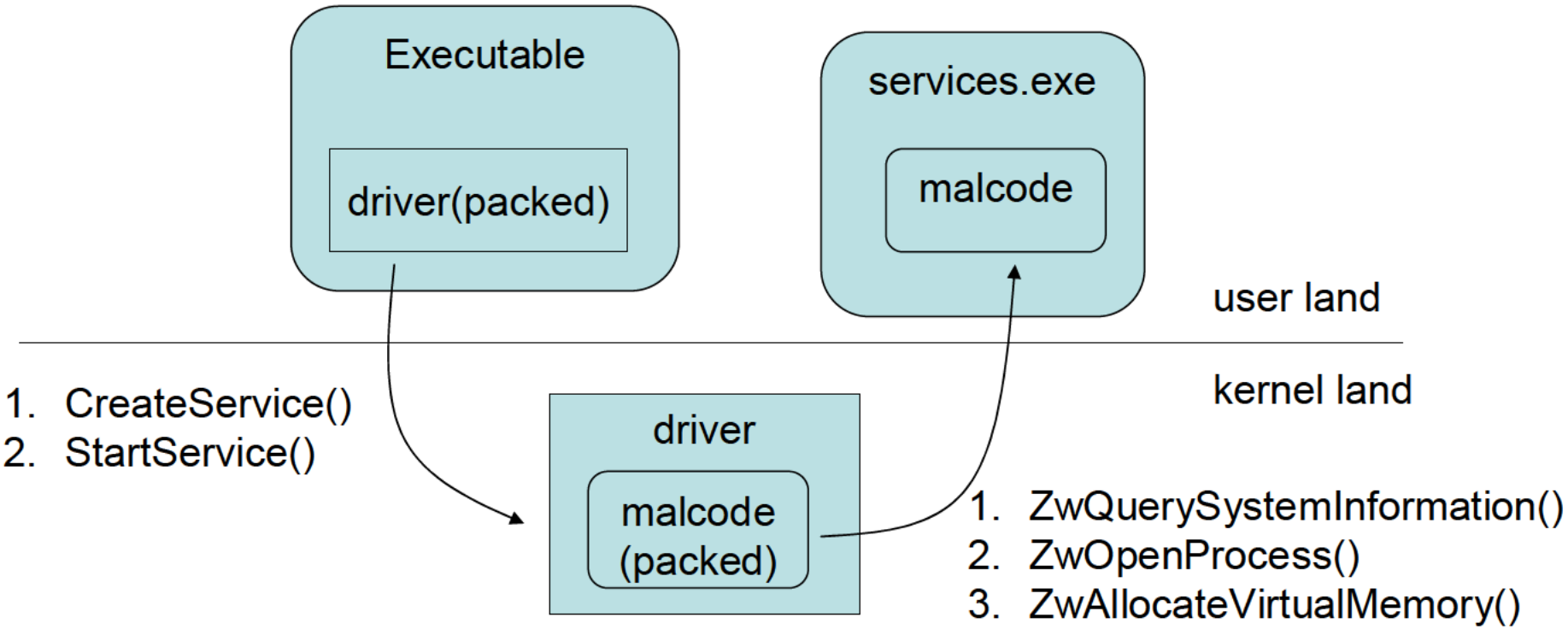
- It hooks the IRP_DEVICE_CONTROL routine by patching the TCP DriverObject's IRP table (″¥¥Device¥¥Tcp″)
- Hide connections from netstat

But is this KOH?

YES: It modifies the IRP Table contained within the DriverObject

NO: Many people know about the existence of IRP tables

Code injection function



2. Review of subversive techniques in kernel space

What we have to consider "Virtualization"

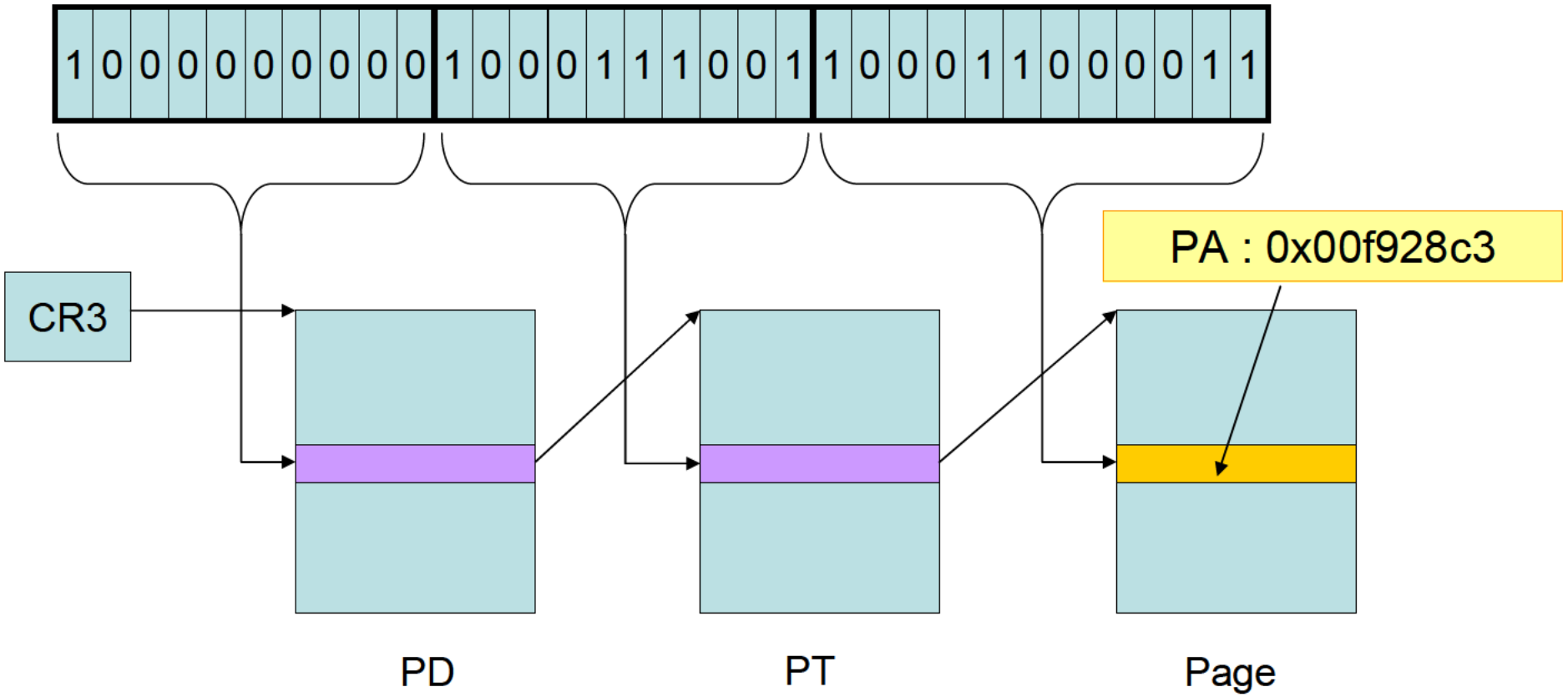
- CPU Virtualization
  - Some registers should be reserved for VMM and each VM.
    GDTR, LDTR, IDTR, CR0-4, DR0-7, MSR, Segment Register, etc
  - Exceptions

- Memory Virtualization
  - should separate VMM memory space and each VM's memory space

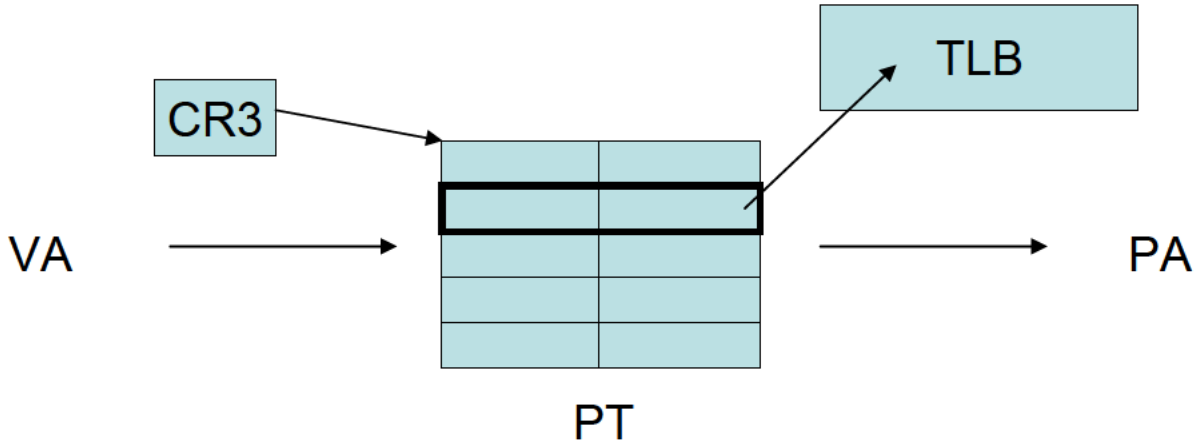
- Device Virtualization
  - Interrupt, I/O instructions, MMIO, DMA access

Virtual Address to Physical Address

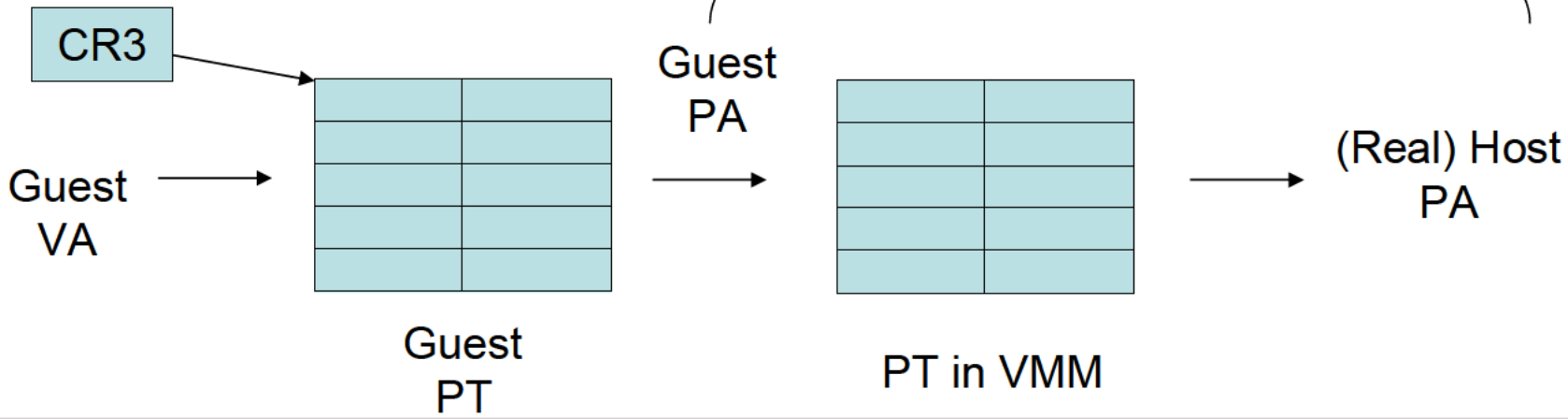
VA : 0x802398c3



To simplify...



Who translates this?



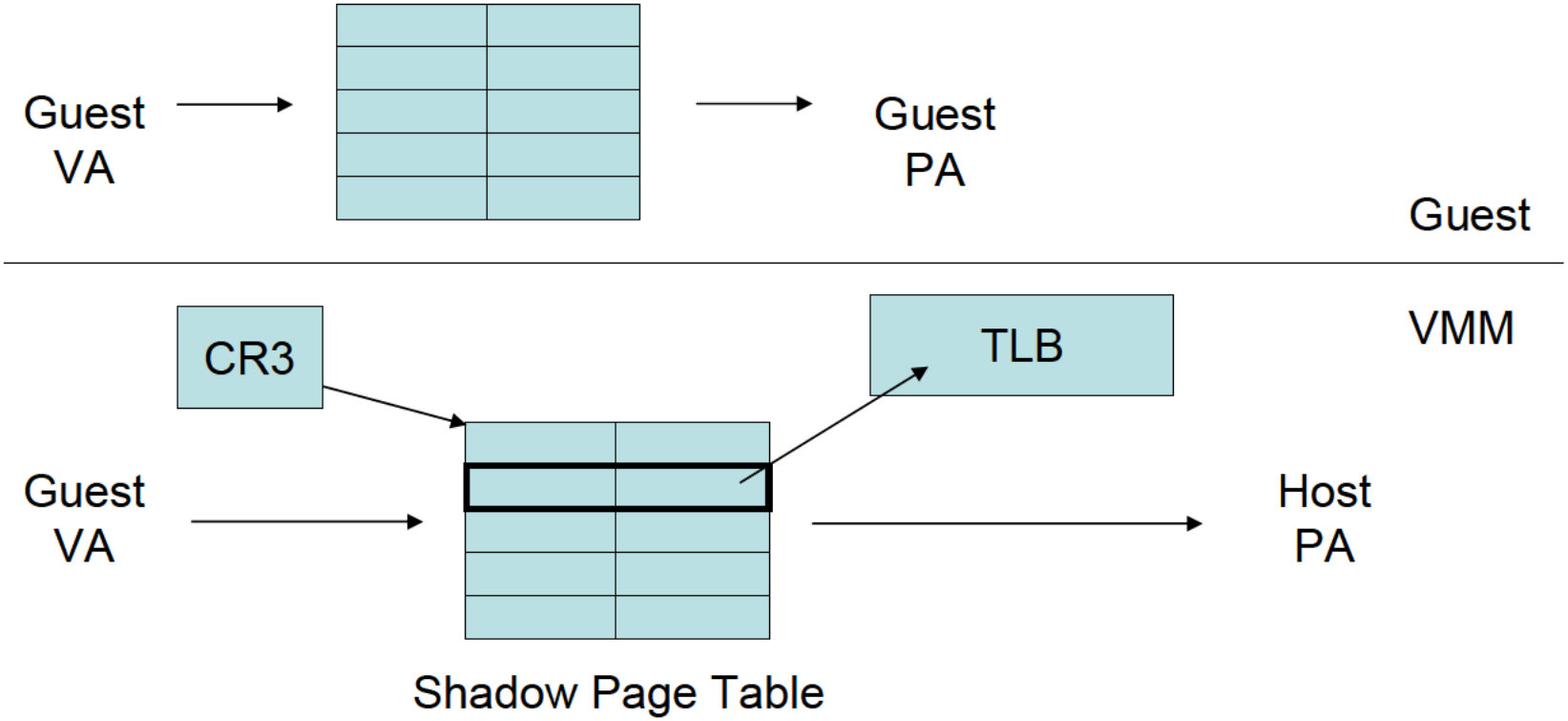
Memory virtualization

- If the processor supports EPT (Extended Page Table), this 2-stages translation is automatically done by the MMU
  - EPT is not implemented yet

- VMM should implement this translation as software using Shadow Paging

Shadow Paging

- VMM updates SPT on #PF in the guest
  - and also emulates TLB flush caused by MOV to CR3 and INVLPG

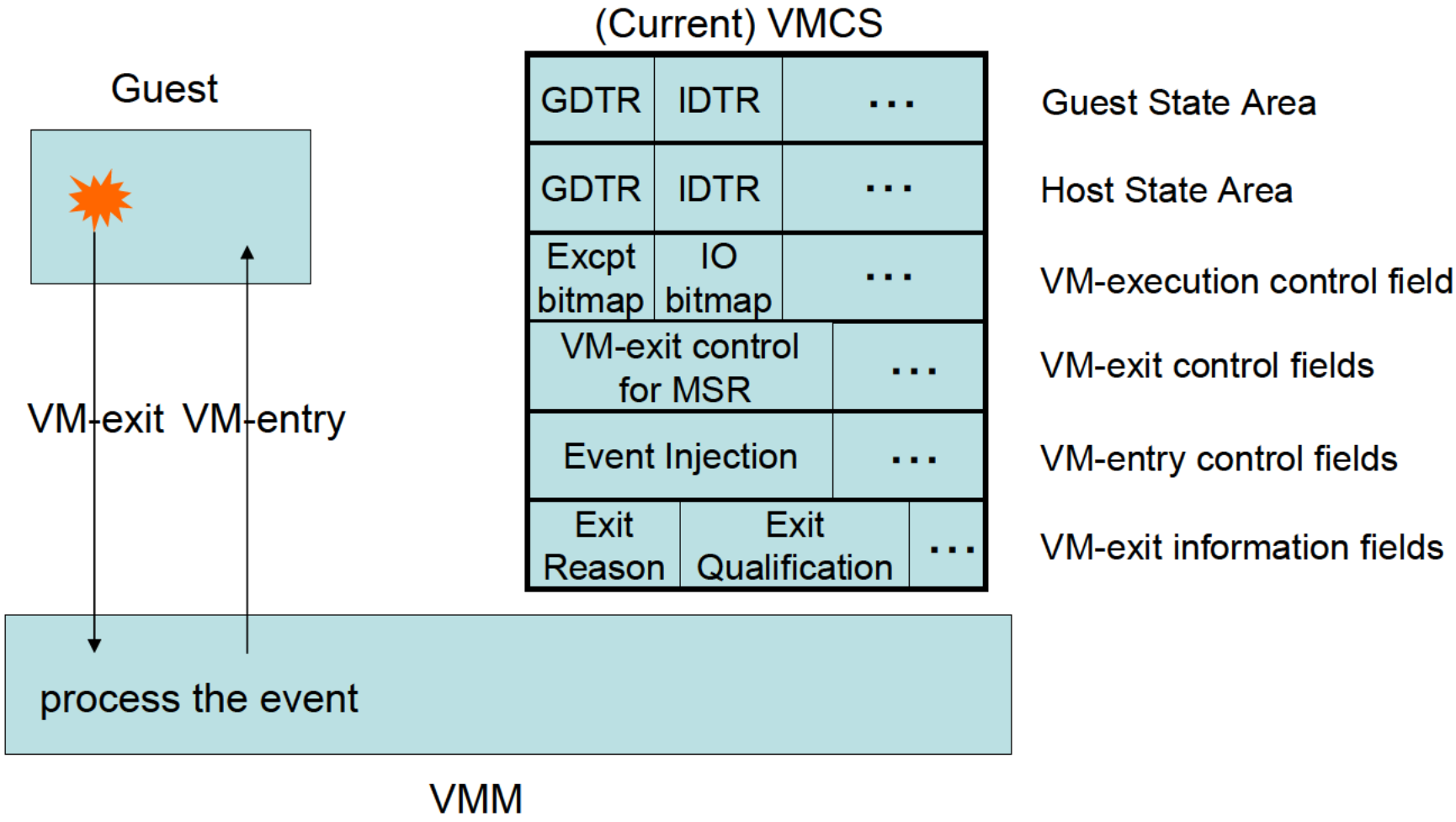


Intel VT

- Intel VT is the Intel VT-* family's generic name
  - VT-x, virtualization for x86/64
  - VT-d, virtualization for device (Directed I/O)
  - VT-i, virtualization for Itanium

- Key factors
  - VMX mode
    - VMX root-operations(ring0-3)
    - VMX non-root-operations(ring0-3)
  - VMCS (Virtual Machine Control Structure)
  - VMX Instructions set
    - VMXON, VMXOFF, VMLAUNCH, VMRESUME, VMCALL, VMWRITE, VMREAD, VMCLEAR, VMPTRLD, VMPTRST

How Intel VT works:



enum EXIT_REASON {

- Specific instructions
  - CPUID, INVD, INVLPG, RDTSC, RDPMC, HLT, etc.
  - All VMX Instructions
- I/O Instructions
  - IN, OUT, etc.
- Exceptions
- Access to CR0–CR4, DR0–DR7, MSR
- etc.

};

Steps to launch the VMM and VM

- Confirm that the processor supports VMX operations
  - CPUID
- Confirm that VMX operations are not disabled in the BIOS
  - MSR_IA32_FEATURE_CONTROL
- Set the CR4.VMXE bit
- Allocate and Initialize VMXON region
  - Write lower 32 bits value of VMX_BASIC_MSR to VMXON region
- Execute VMXON
  - CR0.PE, CR0.PG, and CR4.VME must be set.

Steps to launch the VM and VMM (cont.)

- Allocate VMCS regions
- Execute VMPTRLD to set Current VMCS
- Initialize Current VMCS using VMREAD and VMWRITE
  - VMCS contains the EP of VMM, and Guest IP after VMLAUNCH
- Execute VMLAUNCH
  - Continue to execute the guest from IP is contained in VMCS
- When VM-exit occurred, IP and other registers are switched to VMM ones.

3. Viton, Hypervisor IPS

Viton

- IPS, which runs outside the guest
- Just a PoC, tested on Windows XP SP2 only

- Force immutability to persistent system resources
- Observe control/system registers modification,
  and VMX instructions are raised in the guest
- Offer the extensibility for monitoring the guest activity

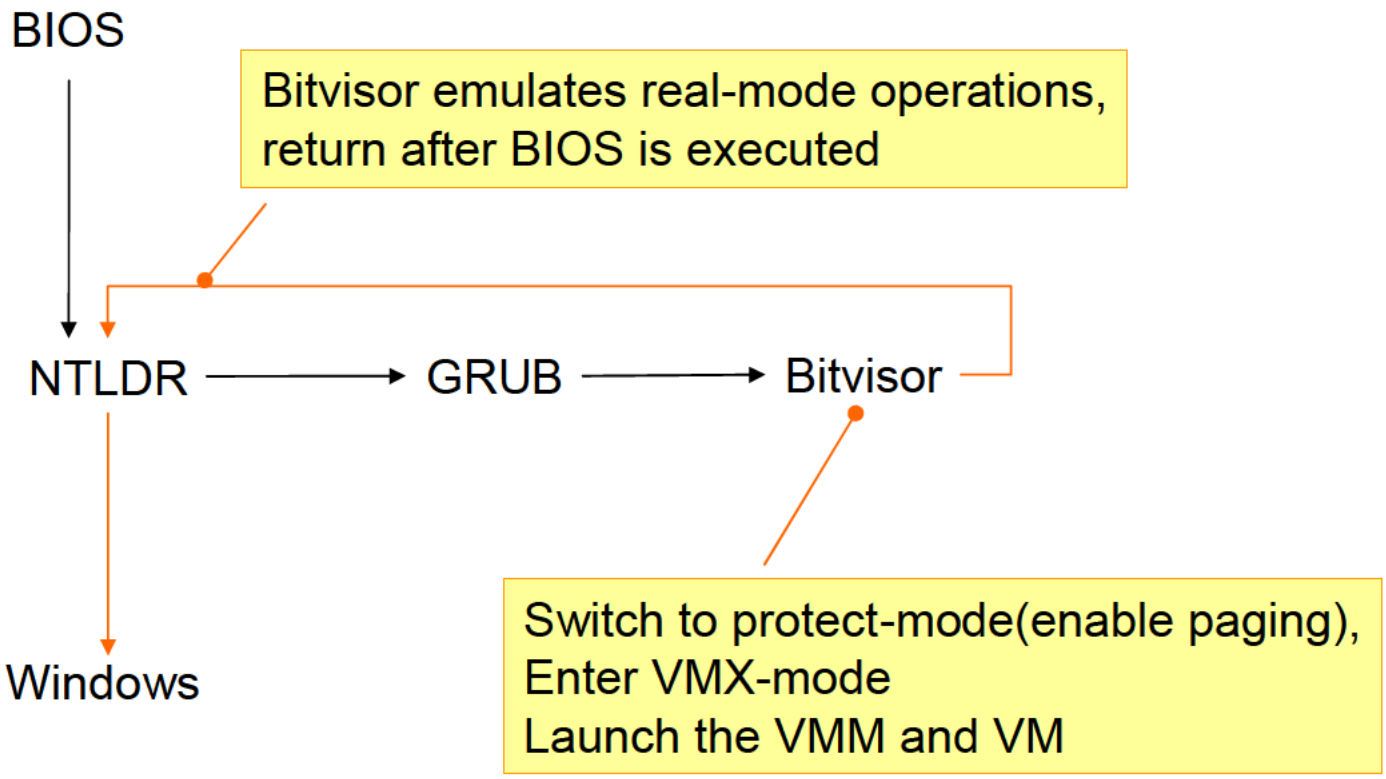
- It is based on Bitvisor

Bitvisor – http://www.securevm.org

- The Bitvisor VMM software is developed by the Secure VM project centered around Tsukuba Univ. in Japan

- Features:
  - Open source, BSD License
  - Semi-path through model
  - Type I VMM (Hypervisor model, like Xen)
  - Full scratched, pure domestic production
  - Support for 32/64 bits architecture in VMM
  - Support for Multi-core/processor in VMM and Guest
  - Can run Windows XP/Vista as Guests without modification
  - Support for PAE in the Guest
  - Support for Real-mode emulation

How Bitvisor works: Launch process

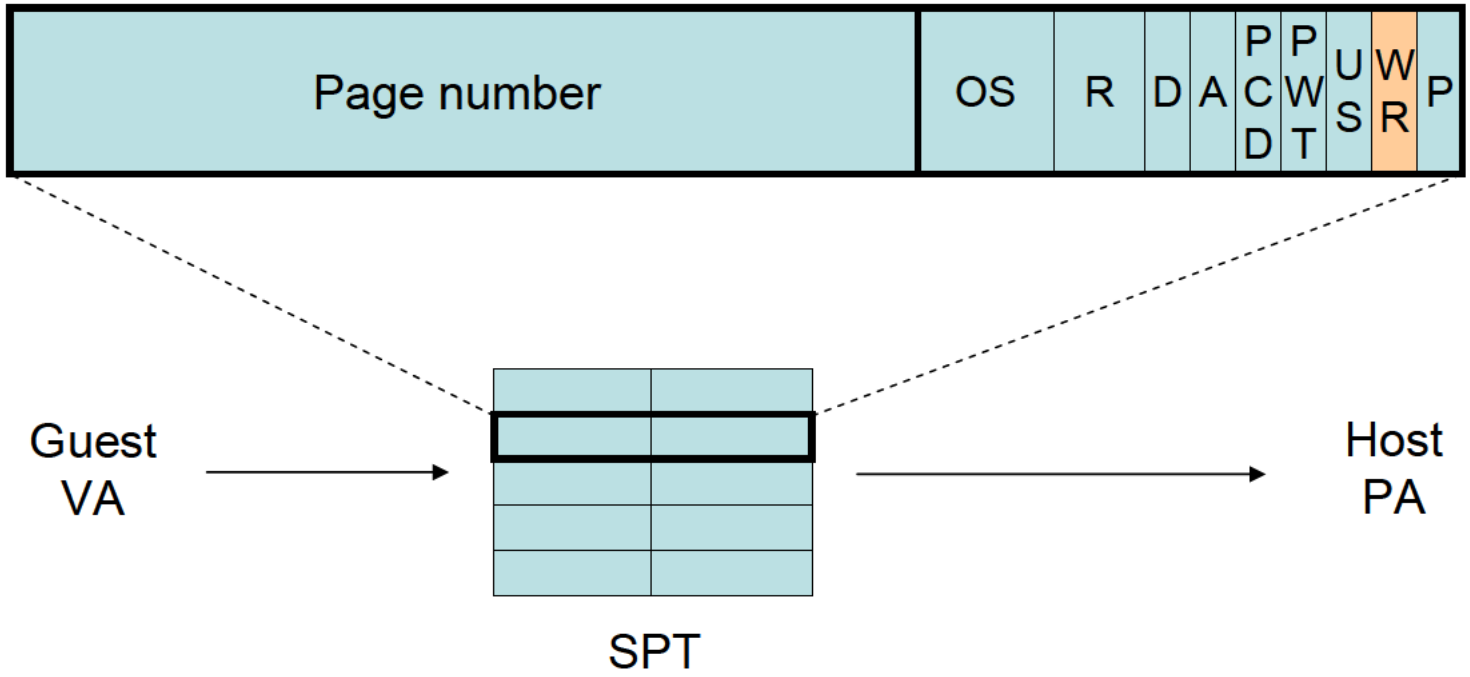


What Viton protects/detects:

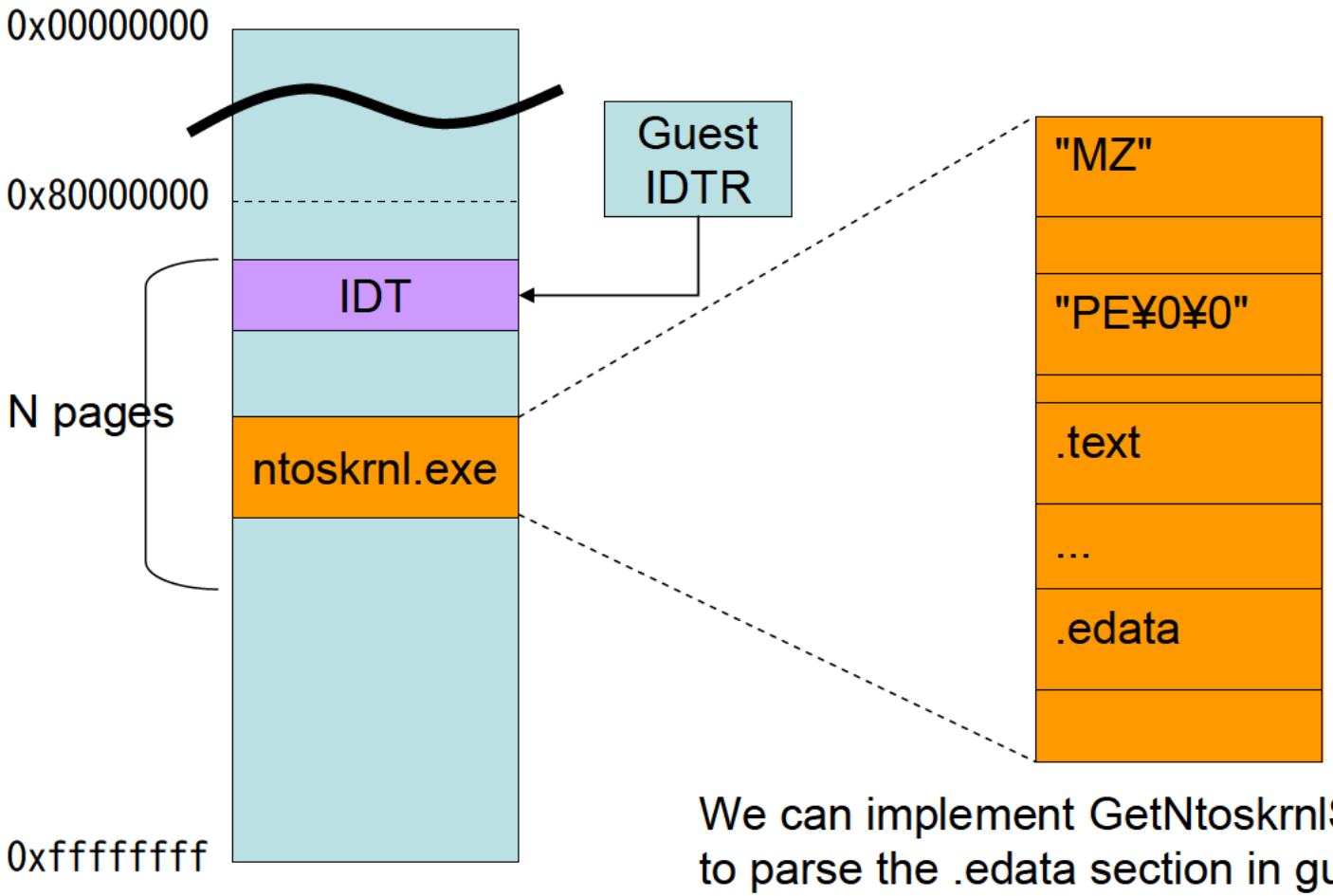
- Instructions
  - Detect and block all VMX Instructions
- Registers
  - Watchdog for IDTR
  - Locking the MSR[SYSTENR_EIP]
  - Locking the CR0.WP Bit
- Memory
  - Protect from modification
    - All code sections (R-X) in ntoskrnl.exe
    - IDT
    - SDT
    - SDT.ST (SSDT)

How to protect the guest memory modification

- Viton clears the WR bit in a SPT entry
  - If CR0.WP is set, even the kernel cannot modify the page



How to recognize the guest memory layout



We can implement GetNtoskrnlSymbolAddr()
to parse the .edata section in guest VA space.

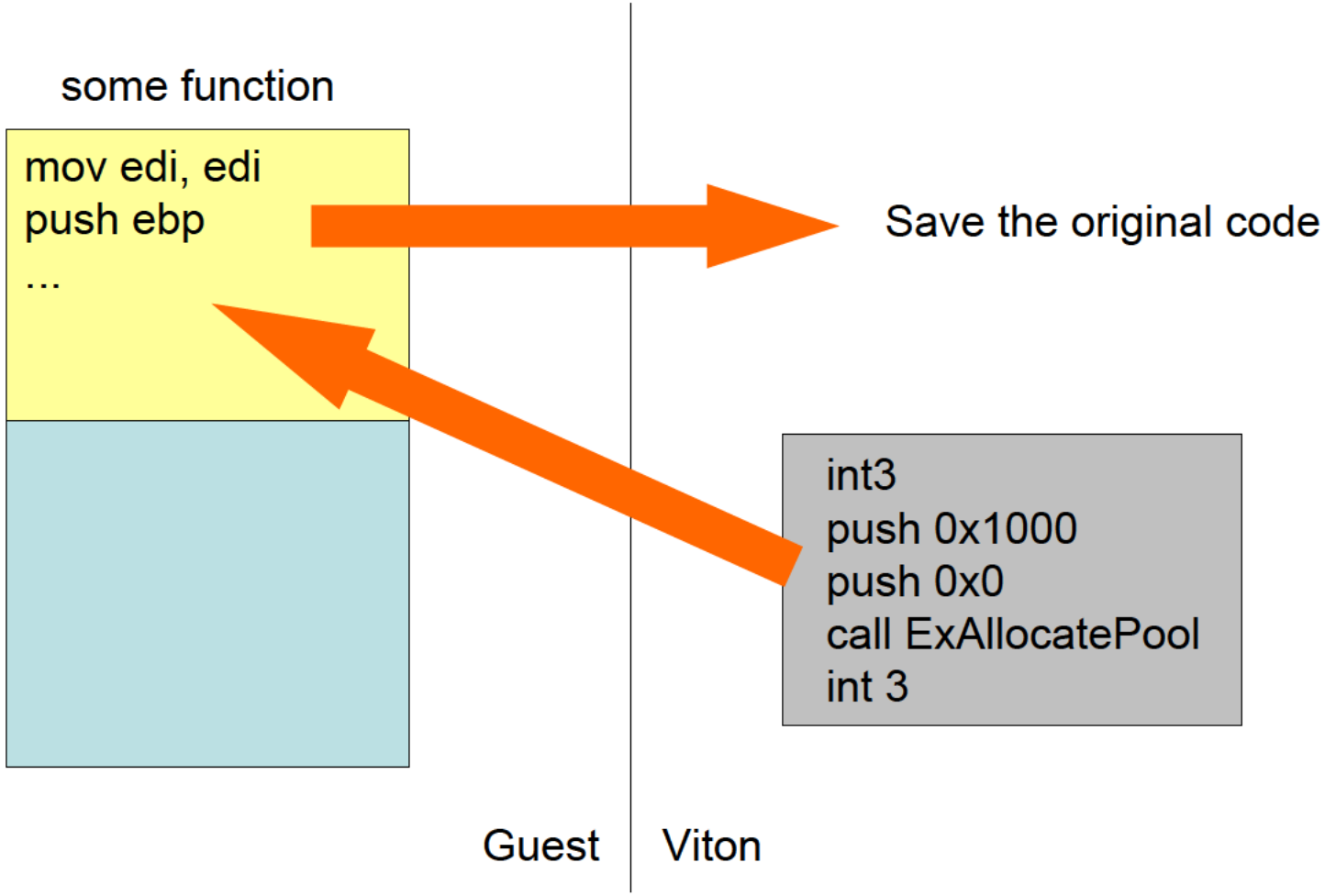
Guest activity monitoring

- When we use the Viton, no one can modify the kernel code, excluding the Viton.

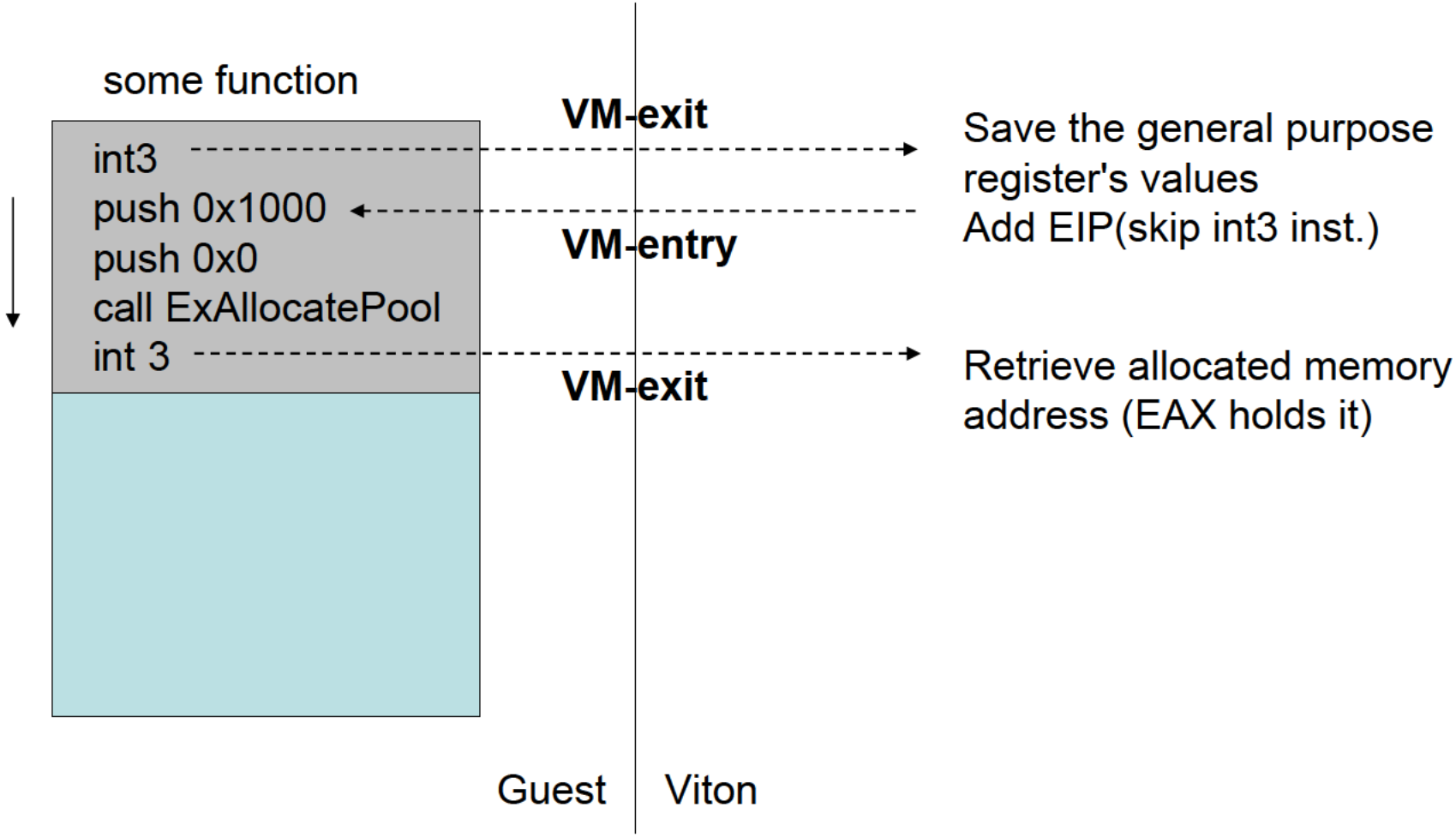
- Viton can monitor the guest's activity by hooking the code

  1. Allocate memory for detours in the guest VA space
  2. Setup the detours buffer
  3. Hook the target function

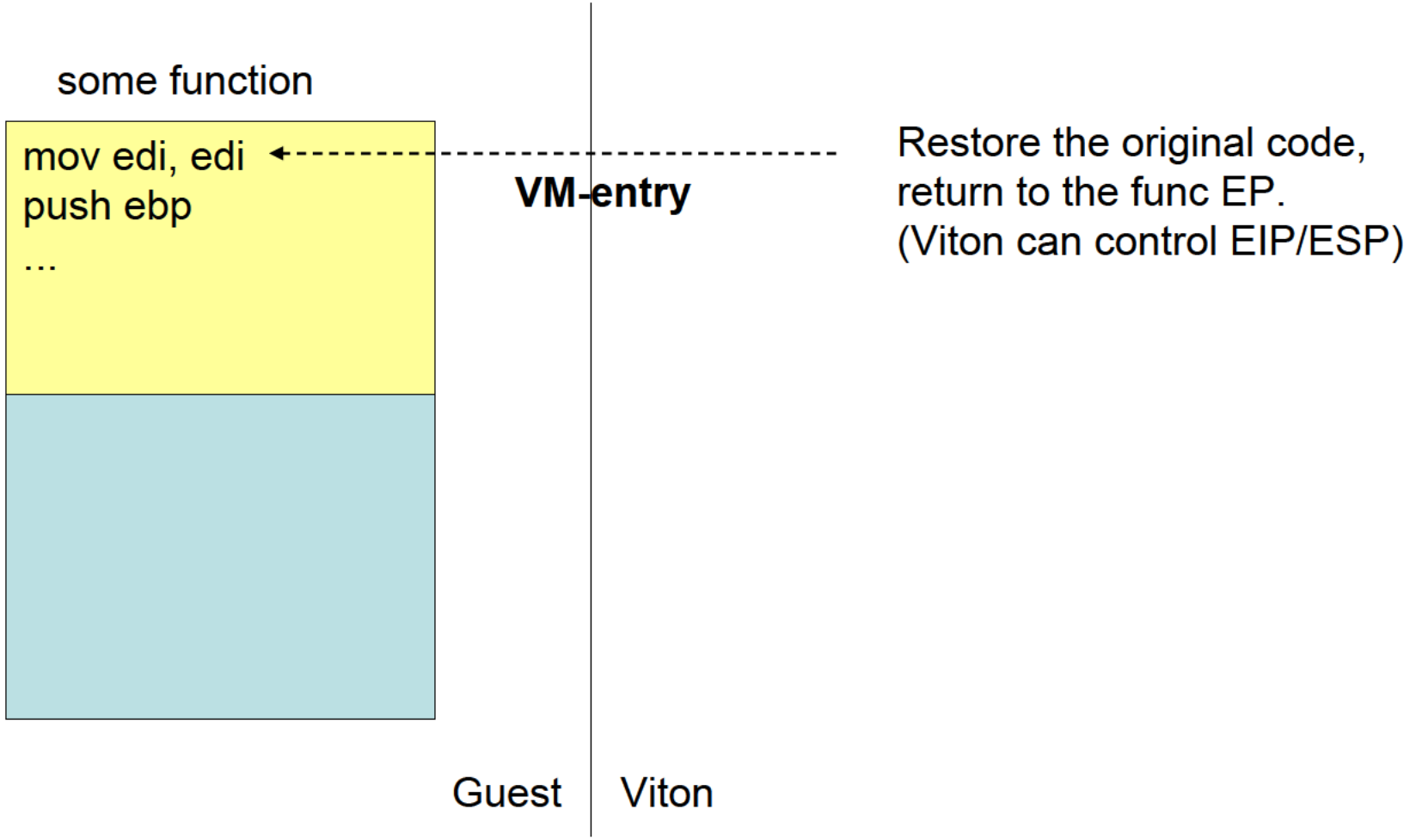
How to allocate memory in guest VA space



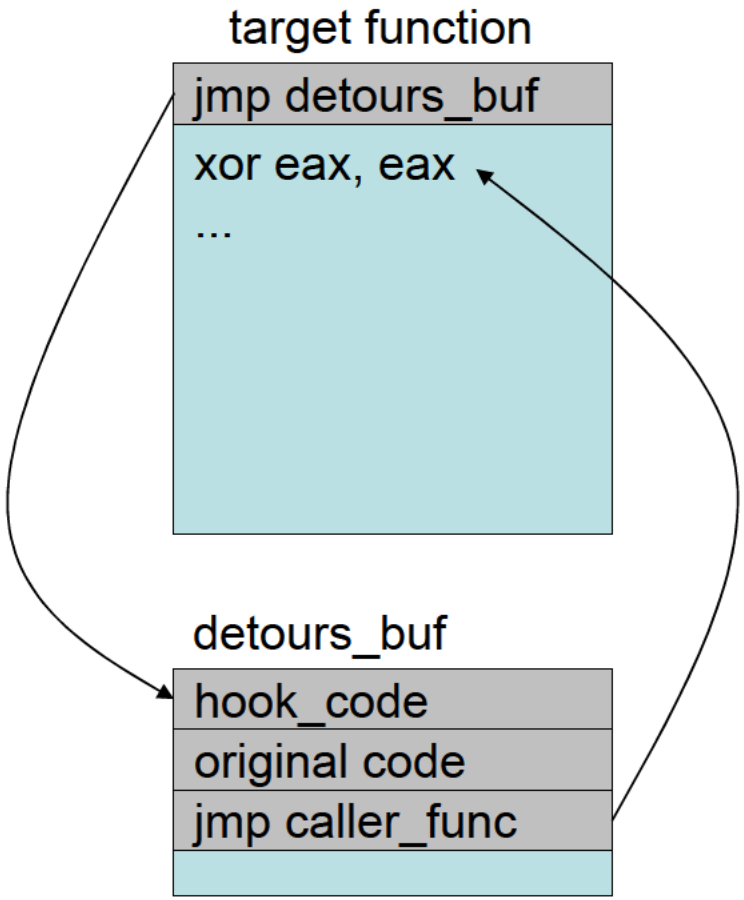
How to allocate memory in guest VA space



How to allocate memory in guest VA space



How to hook the guest code



When the target function is called,

1. jump to the detours_buf
2. Execute our hook_code
3. Execute original code which is overwritten by "jmp detours_buf"
4. jump to the next code of overwritten one

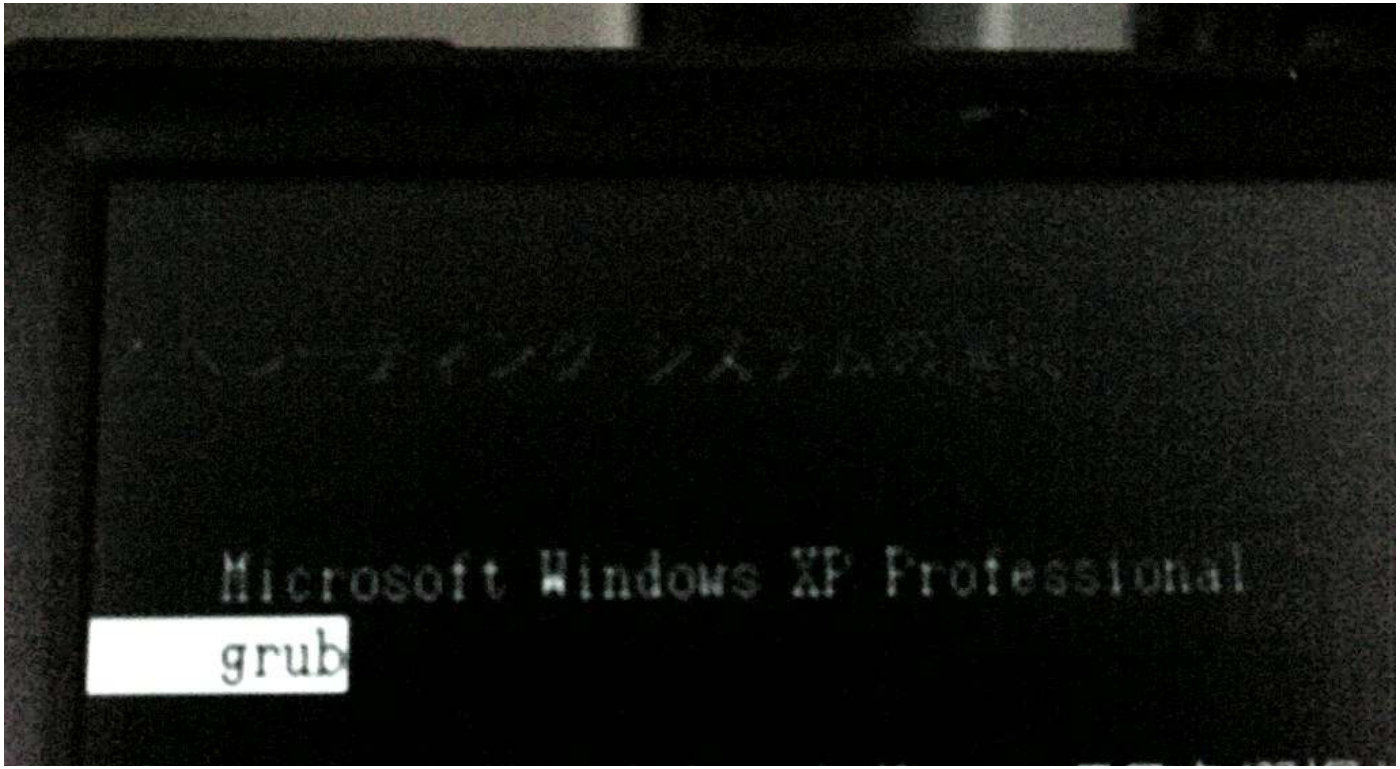
What can Viton do hooking the guest code ?

- Viton can retrieve the guest information in hook_code
  - int3 and other inst. that cause VM-exit are useful

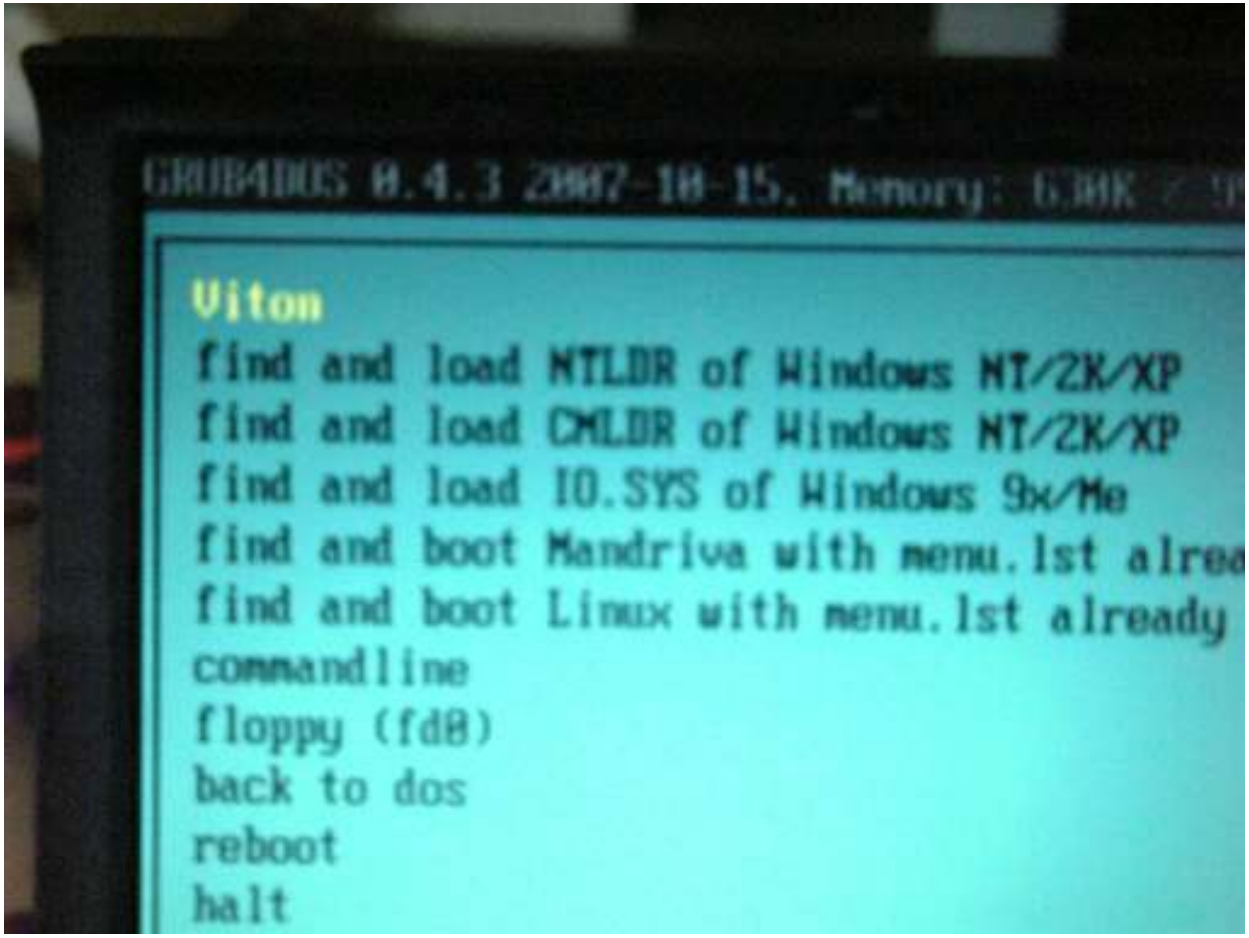
- So, Wouldn't you hook below functions ?
  - ZwCreateProcess/ZwTerminateProcess
  - ZwLoadDriver

- Then, Viton understands process, driver and other guest system resource information.

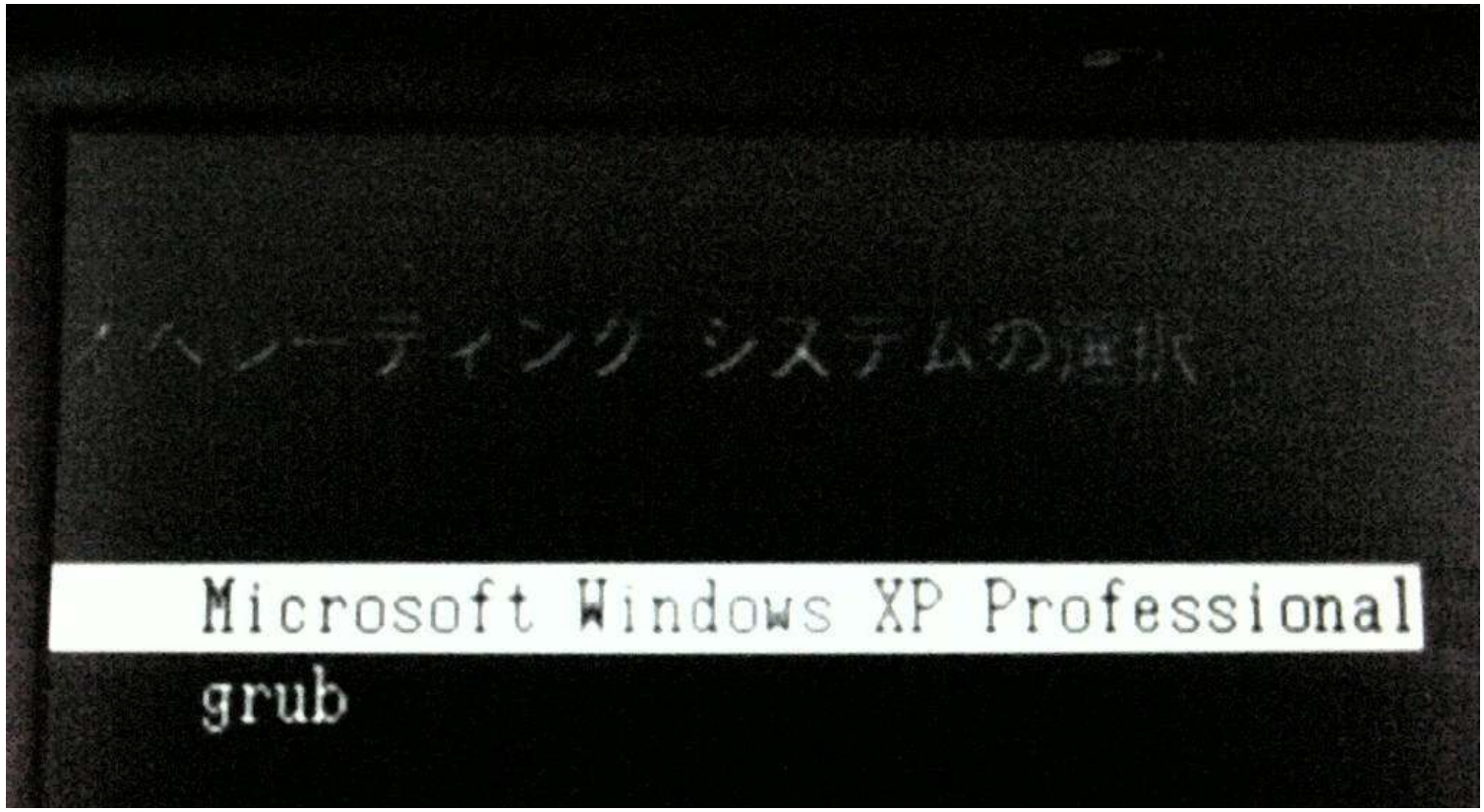
Demo



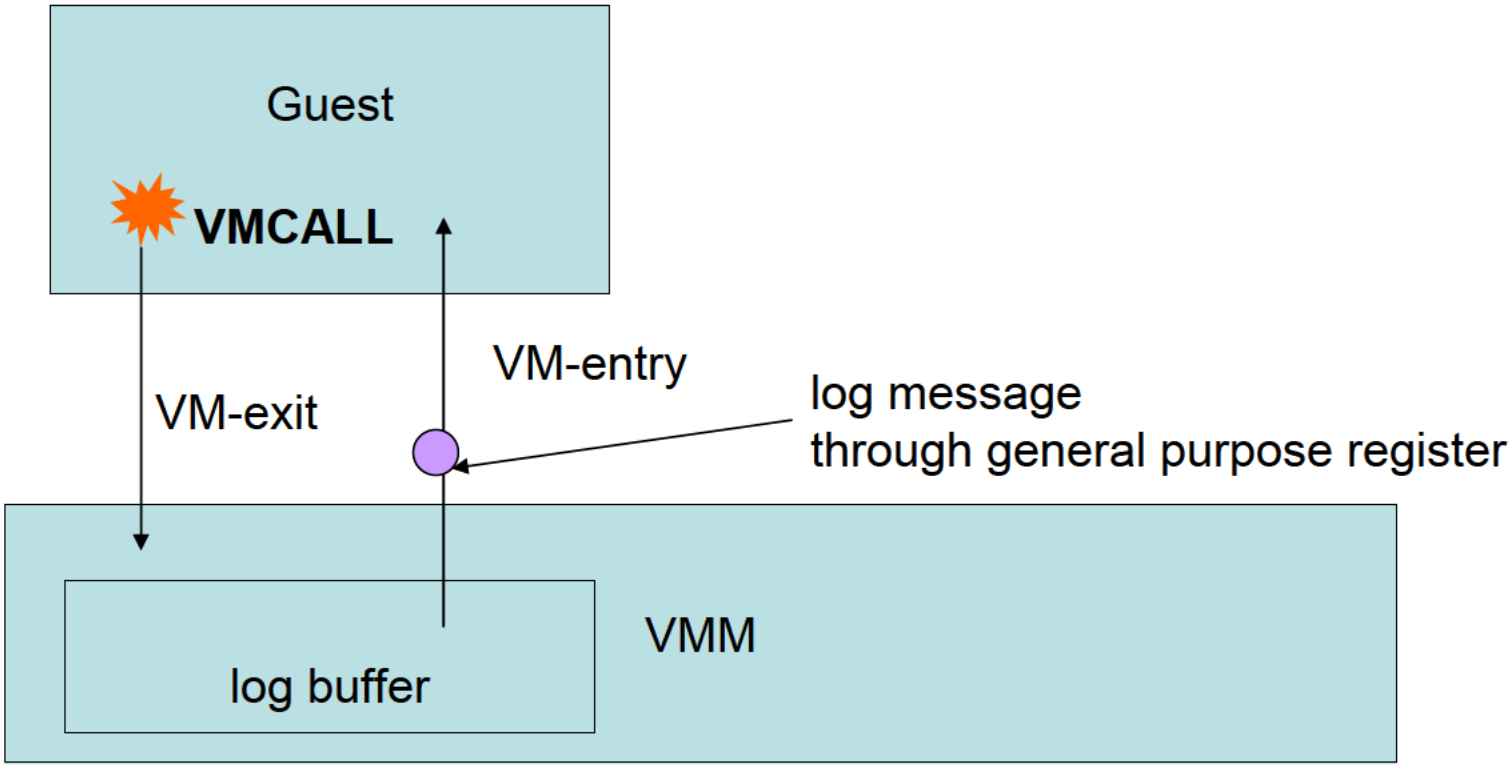
Demo


Viton
find and load NTLDR of Windows NT/2K/XP
find and load CMLDR of Windows NT/2K/XP
find and load IO.SYS of Windows 9x/Me
find and boot Mandriva with menu.lst alrea
find and boot Linux with menu.lst already
commandline
floppy (fd0)
back to dos
reboot
halt

Demo



dbgsh (Bitvisor's debuging function)



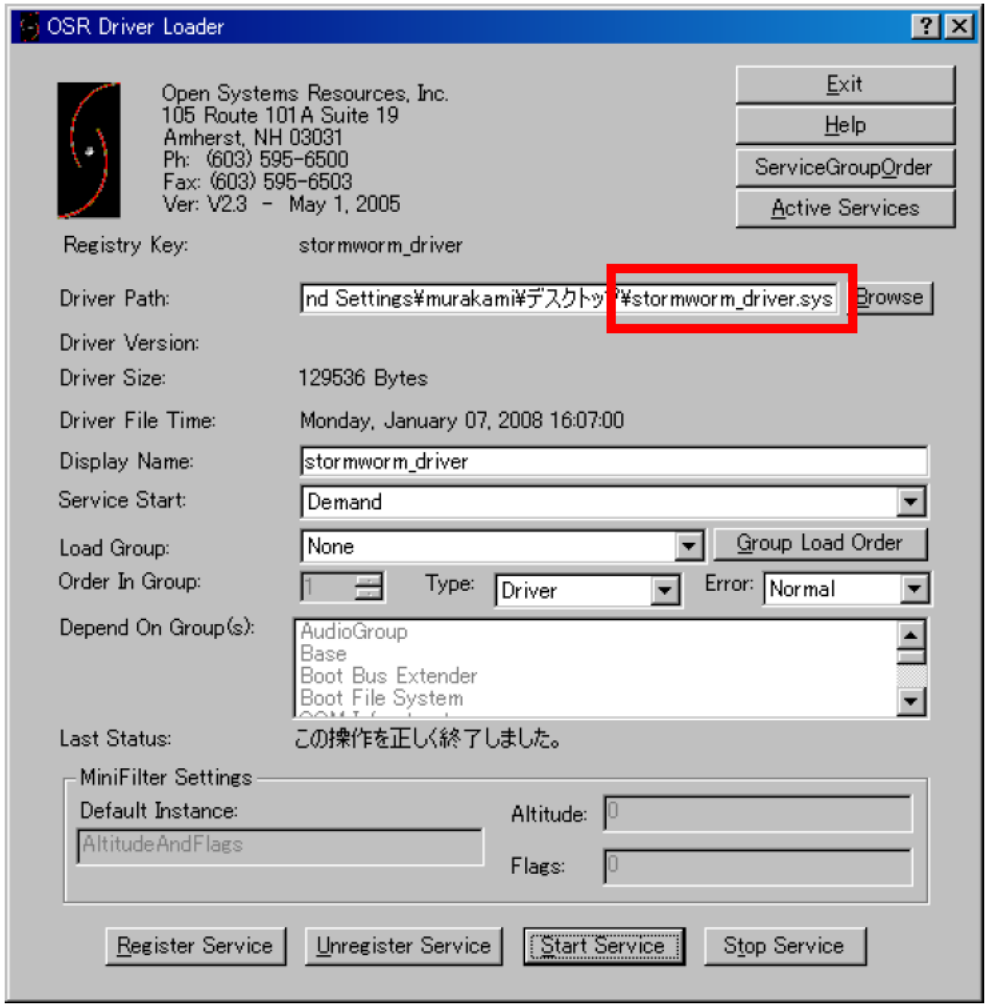
Demo

C:¥Documents and Settings¥murakami¥デスクトップ¥dbgsh.exe

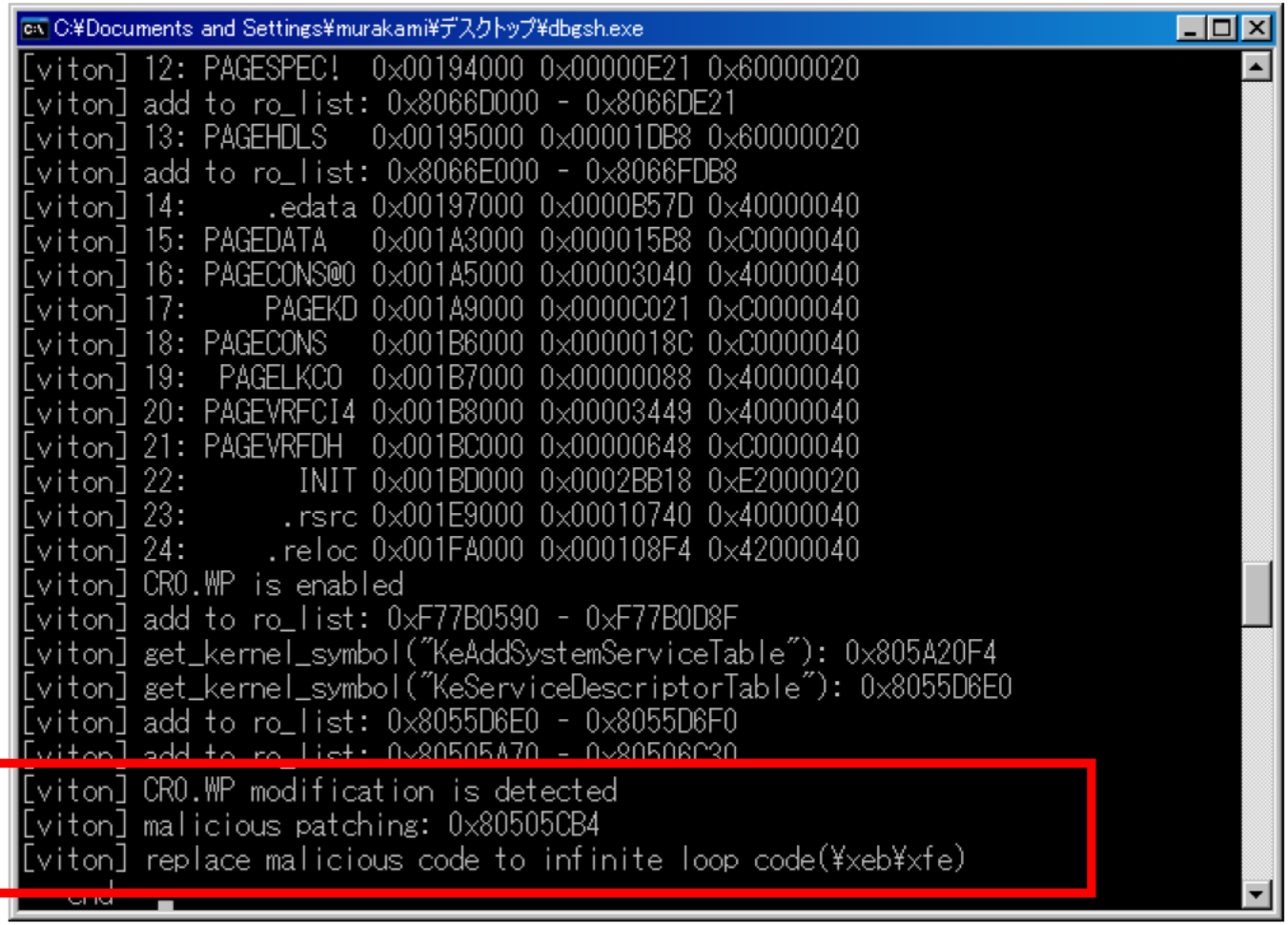
```
[viton] CR0.WP is enabled
[viton] VMCS_GUEST_IDTR_BASE: 0x8003F400
[viton] Guest IDT[0x2E].handler: 0x80542000
[viton] Start address for searching kernel base: 0x80442000
[viton] Kernel base: 0x804D9000
[viton] 0:      .text 0x00001000 0x0006E46C 0x68000020
[viton] add to ro_list: 0x804DA168 - 0x8054846C
[viton] 1:     POOLMI 0x00070000 0x000011F9 0x68000020
[viton] add to ro_list: 0x80549000 - 0x8054A1F9
[viton] 2: MISYSPTE   0x00072000 0x000006CB 0x68000020
[viton] add to ro_list: 0x8054B000 - 0x8054B6CB
[viton] 3: POOLCODE   0x00073000 0x000012AE 0x68000020
[viton] add to ro_list: 0x8054C000 - 0x8054D2AE
[viton] 4:      .data 0x00075000 0x00018CE8 0xC8000040
[viton] 5:  INITDATA8 0x0008E000 0x00000038 0xC8000040
[viton] 6: INITCONSe  0x0008F000 0x00001A65 0x48000040
[viton] 7:       PAGE 0x00091000 0x000DECDF 0x60000020
[viton] add to ro_list: 0x8056A000 - 0x80648CDF
[viton] 8:     PAGELK 0x00170000 0x0000E520 0x60000020
[viton] add to ro_list: 0x80649000 - 0x80657520
[viton] 9: PAGEVRFY   0x0017F000 0x0000EAA6 0x60000020
[viton] add to ro_list: 0x80658000 - 0x80666AA6
[viton] 10:    PAGEWMI 0x0018E000 0x00001703 0x60000020
[viton] add to ro_list: 0x80667000 - 0x80668703
[viton] 11:     PAGEKD 0x00190000 0x00003D93 0x60000020
```

ro_list: read only list

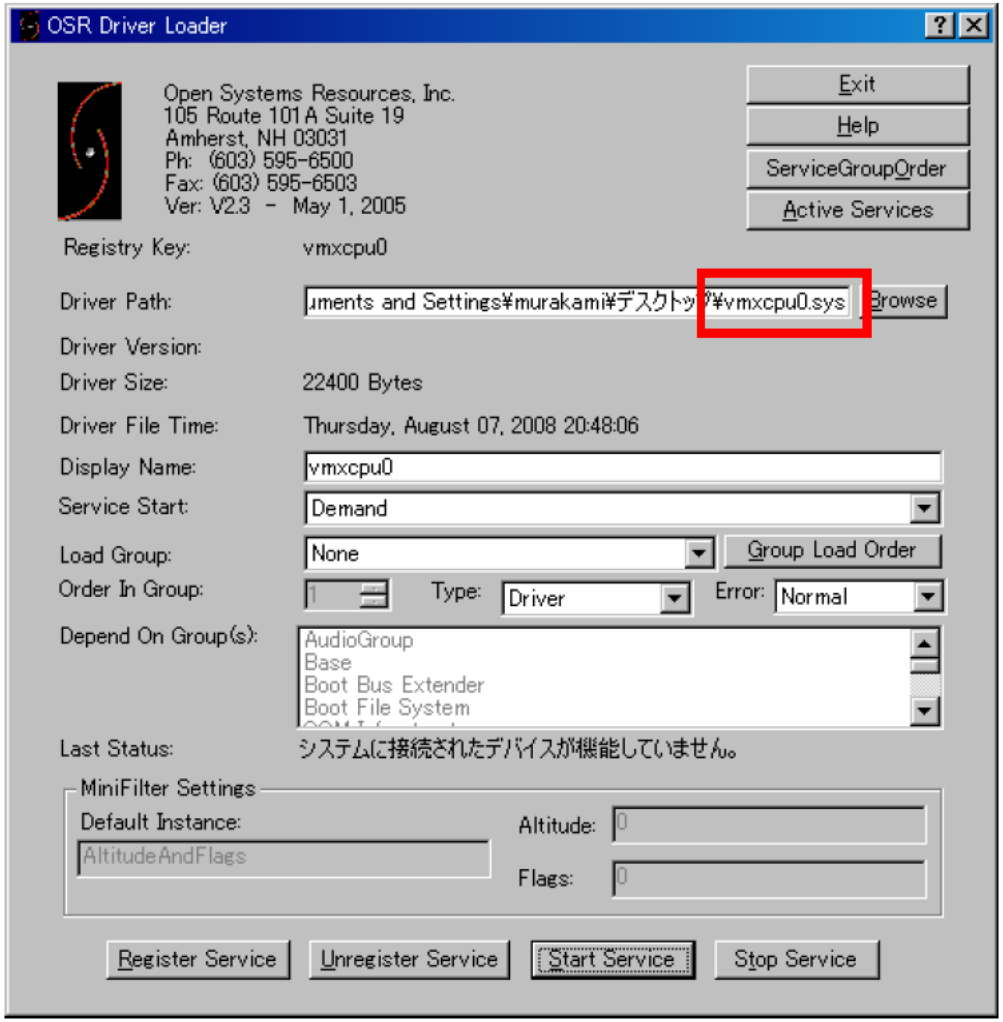
Demo


OSR Driver Loader
Open Systems Resources, Inc.
105 Route 101A Suite 19
Amherst, NH 03031
Ph: (603) 595-6500
Fax: (603) 595-6503
Ver: V2.3 - May 1, 2005
Exit
Help
ServiceGroupOrder
Active Services
Registry Key:
stormworm_driver
Driver Path:
nd Settings¥murakami¥デスクトップ¥stormworm_driver.sys
Browse
Driver Version:
Driver Size:
129536 Bytes
Driver File Time:
Monday, January 07, 2008 16:07:00
Display Name:
stormworm_driver
Service Start:
Demand
Load Group:
None
Group Load Order
Order In Group:
Type:
Driver
Error:
Normal
Depend On Group(s):
AudioGroup
Base
Boot Bus Extender
Boot File System
Last Status:
この操作を正しく終了しました。
MiniFilter Settings
Default Instance:
AltitudeAndFlags
Altitude:
Flags:
Register Service
Unregister Service
Start Service
Stop Service

Demo


C:¥Documents and Settings¥murakami¥デスクトップ¥dbgsh.exe
[viton] 12: PAGESPEC! 0x00194000 0x00000E21 0x60000020
[viton] add to ro_list: 0x8066D000 - 0x8066DE21
[viton] 13: PAGEHDLS   0x00195000 0x00001DB8 0x60000020
[viton] add to ro_list: 0x8066E000 - 0x8066FDB8
[viton] 14:   .edata 0x00197000 0x0000B57D 0x40000040
[viton] 15: PAGEDATA   0x001A3000 0x000015B8 0xC0000040
[viton] 16: PAGECONS@0 0x001A5000 0x00003040 0x40000040
[viton] 17:   PAGEKD 0x001A9000 0x0000C021 0xC0000040
[viton] 18: PAGECONS   0x001B6000 0x0000018C 0xC0000040
[viton] 19: PAGELKCO 0x001B7000 0x00000088 0x40000040
[viton] 20: PAGEVRFCI4 0x001B8000 0x00003449 0x40000040
[viton] 21: PAGEVRFDH 0x001BC000 0x00000648 0xC0000040
[viton] 22:   INIT 0x001BD000 0x0002BB18 0xE2000020
[viton] 23:   .rsrc 0x001E9000 0x00010740 0x40000040
[viton] 24:   .reloc 0x001FA000 0x000108F4 0x42000040
[viton] CR0.WP is enabled
[viton] add to ro_list: 0xF77B0590 - 0xF77B0D8F
[viton] get_kernel_symbol("KeAddSystemServiceTable"): 0x805A20F4
[viton] get_kernel_symbol("KeServiceDescriptorTable"): 0x8055D6E0
[viton] add to ro_list: 0x8055D6E0 - 0x8055D6F0
[viton] CR0.WP modification is detected
[viton] malicious patching: 0x80505CB4
[viton] replace malicious code to infinite loop code(¥xeb¥xfe)

Demo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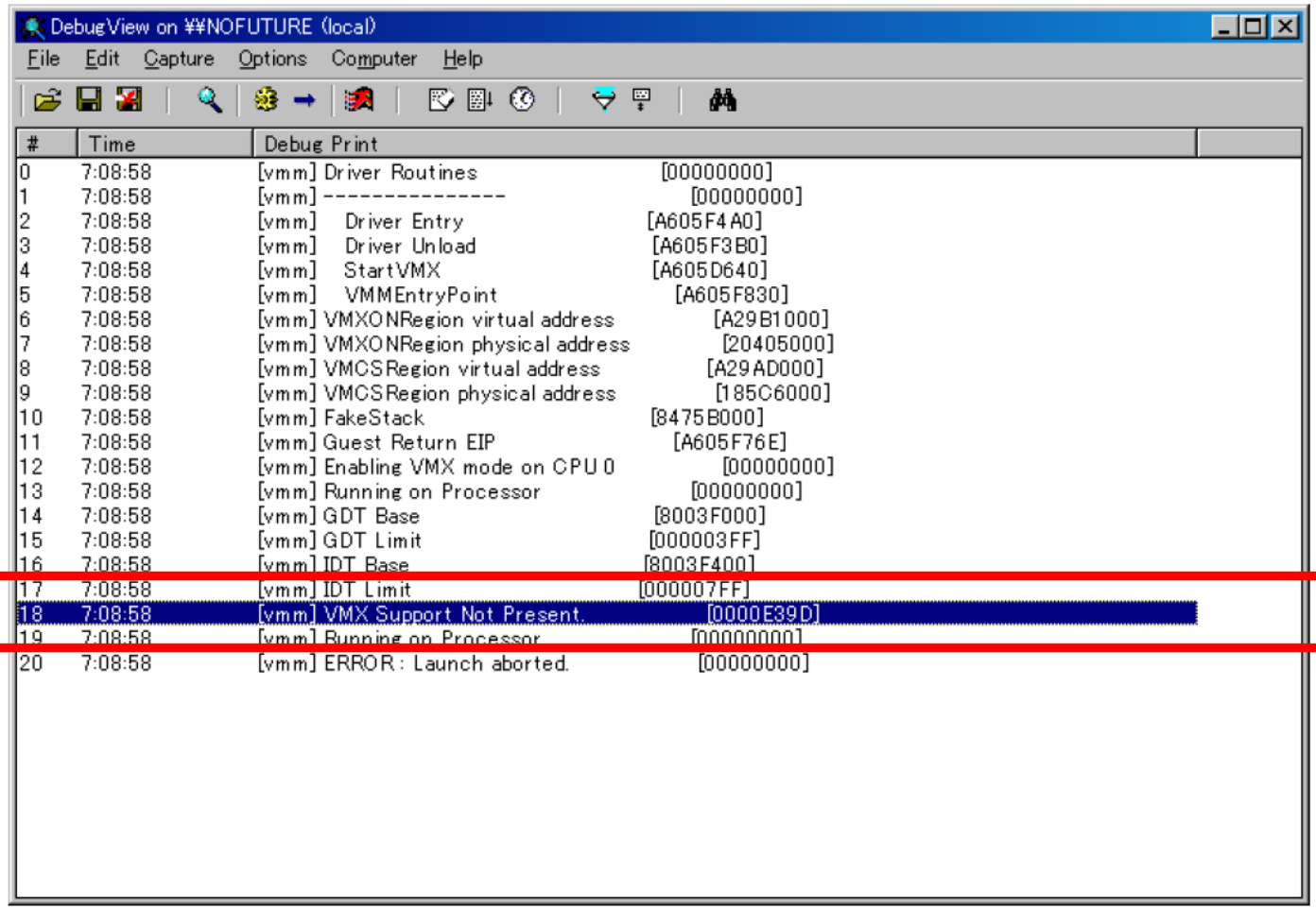
Ver: V2.3 - May 1, 2005
Exit
Help
ServiceGroupOrder
Active Services
Registry Key:
vmxcpu0
Driver Path:
uments and Settings¥murakami¥デスクトップ¥vmxcpu0.sys
Browse
Driver Version:
Driver Size:
22400 Bytes
Driver File Time:
Thursday, August 07, 2008 20:48:06
Display Name:
vmxcpu0
Service Start:
Demand
Load Group:
None
Group Load Order
Order In Group:
Type:
Driver
Error:
Normal
Depend On Group(s):
AudioGroup
Base
Boot Bus Extender
Boot File System
Last Status:
システムに接続されたデバイスが機能していません。
MiniFilter Settings
Default Instance:
AltitudeAndFlags
Altitude:
Flags:
Register Service
Unregister Service
Start Service
Stop Service

Demo


DebugView on ¥¥NOFUTURE (local)
File Edit Capture Options Computer Help
Time Debug Print
0 7:08:58 [vmm] Driver Routines [00000000]
1 7:08:58 [vmm] --------------- [00000000]
2 7:08:58 [vmm] Driver Entry [A605F4A0]
3 7:08:58 [vmm] Driver Unload [A605F3B0]
4 7:08:58 [vmm] StartVMX [A605D640]
5 7:08:58 [vmm] VMMEntryPoint [A605F830]
6 7:08:58 [vmm] VMXONRegion virtual address [A29B1000]
7 7:08:58 [vmm] VMXONRegion physical address [20405000]
8 7:08:58 [vmm] VMCSRegion virtual address [A29AD000]
9 7:08:58 [vmm] VMCSRegion physical address [185C6000]
10 7:08:58 [vmm] FakeStack [8475B000]
11 7:08:58 [vmm] Guest Return EIP [A605F76E]
12 7:08:58 [vmm] Enabling VMX mode on CPU 0 [00000000]
13 7:08:58 [vmm] Running on Processor [00000000]
14 7:08:58 [vmm] GDT Base [8003F000]
15 7:08:58 [vmm] GDT Limit [000003FF]
16 7:08:58 [vmm] IDT Base [8003F400]
17 7:08:58 [vmm] IDT Limit [000007FF]
18 7:08:58 [vmm] VMX Support Not Present. [0000E39D]
19 7:08:58 [vmm] Running on Processor [00000000]
20 7:08:58 [vmm] ERROR: Launch aborted. [00000000]

Viton vs.

- Type I
  - Easy
- Type II
  - DKOM: Difficult, but possible
  - KOH: Difficult, we need more research, and breakthrough
- Type III
  - Easy (First come, first served)

4. Conclusions

- Virtualization Technology becomes a help to protect the kernel

- However, it is not a silver bullet
  - Foundation for existing security solutions

Thank you!

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