Breaking Turtles All the Way Down:
An Exploitation Chain to Break out of VMware ESXi

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Abstract
VMware ESXi is an enterprise-class, bare-metal hypervisor dedicated to providing the state-of-the-art private-cloud infrastructures. Accordingly, the design and implementation of ESXi is of our community’s interest, yet lacking a thorough evaluation of its security internals. In this paper, we give a comprehensive analysis of the guest-to-host attack surfaces of ESXi and its recent security mitigation (i.e., the vSphere sandbox). In particular, we introduce an effective and reliable approach to chain multiple vulnerabilities for exploitation and demonstrate our approach by leveraging two new bugs (i.e., uninitialized stack usages), namely, CVE-2018-6981 and CVE-2018-6982. Our exploit chain is the first public demonstration of a virtual machine escape against VMware ESXi.

1 Introduction
Cloud computing has become the most popular choice for today’s online services. The foundation that enables cloud computing is virtualization technology, effectively allowing economy of scale. Some examples include QEMU-KVM, Xen, Hyper-V, and VMware Families, which are the basic building blocks of most public and private cloud infrastructures.

Unfortunately, its large and complicated code base of virtual machines inevitably includes software vulnerabilities such as memory corruptions. Moreover, unlike other software bugs, the bugs in virtualization infrastructures could lead to a break-in of the security boundary between guest and host; thus, the security of the entire cloud environment of the cloud provider might be subverted.

These unique propositions of cloud infrastructures make them an attractive target for attackers, but our communities lack, an in-depth analysis and evaluation of their security. Research communities have made several attempts to do this: one example that received considerable attention is a security bug of QEMU-KVM, called VENOM (known as CVE-2015-3456 [8]), which attempted to exploit a bug in a virtual, emulated floppy drive. Other vulnerabilities such as CVE-2015-5165 and CVE-2015-7504 have been disclosed and exploited in public PoC demonstrations [17]. However, most of them, as far as we know, rely on strict preconditions (e.g., supporting a decade-old floppy driver by the cloud provider), which fail to demonstrate exploitation under the default configuration of the underlying virtualization infrastructures. Admittedly, there have been a few public demonstrations against VMware Workstation in the Pwn2Own contest, but their approaches and details of exploitation have not been disclosed to the public.

The situation for enterprise-class, commercial hypervisors, such as VMware ESXi or Hyper-V, is even worse: they are much more attractive targets to attackers, but their internals still remain opaque to the security communities. Such security-by-obscurity approaches taken by commercial type-1 hypervisor require that many practical challenges be addressed. First, the complex internal design and machinery to implement a type-1 hypervisor is not trivial to understand in depth. Second, hypervisors are intensively protected by custom in-house protection schemes, limiting the capability for dynamic analysis. Lastly, non-trivial reverse engineering skills and efforts are required to understand and even navigate system binaries without proper source codes and symbols.

In this paper, we share the lessons learned from our in-depth, security analysis of ESXi. We first introduce the attack surfaces of ESXi by systematically evaluating attack scenarios. Second, we provide an exhaustive analysis of two previously unknown vulnerabilities we found in ESXi. Last, by leveraging these vulnerabilities, we elaborate a new exploit technique to bypass the deployed mitigation, the vSphere sandbox in ESXi. The constructed exploit is reliable and persistent; it dynamically adopts the version of ESXi and survives across the system reboot, causing persistent damage to cloud providers.

Overall, this paper makes the following contributions:

1. A systematic review of attack surfaces, mitigations, and vSphere sandbox of VMware ESXi.
2. An in-depth demonstration and analysis of the vulner-
abilities used in the first virtual machine escape of VMware ESXi.

3. State-of-the-art and reusable exploitation techniques for manipulating memory layout, constructing an arbitrary-address-write primitive, and achieving persistent exploitation in VMware ESXi.

Threat Model. In this research, we assume that an adversary can execute arbitrary codes in the user space and kernel space on the guest OS.

2 Background

2.1 The Architecture of the ESXi

As Figure 1 illustrates, VMware ESXi integrates its operating system (OS) called VMKernel, providing the functionalities of resource scheduling, I/O stacks, network stacks, storage stacks, and device drivers, and all processes are running on top of it. VMKernel also implements a simple in-memory file system to hold staged patches, configurations, and system logs.

To communicate with the hypervisor, the guest taps into the VM through VM-Exit in most circumstances. Notably, VMware also introduced another hypercall mechanism called backdoor. Interestingly, although it is named "backdoor," it is merely a communication channel between the guest and the hypervisor. Also, it has been widely applied to VMware products, e.g., some functionalities in open-vm-tools [18] such as drag-and-drop, copy-and-paste are implemented on top of the backdoor mechanism. As Figure 2 illustrates, the guest machine that runs in Ring-3 of a protected-mode OS executes the int or out instruction with a specific port, which raises a corresponding exception. Normally, this results in the crash of the process. However, in a VMware virtual machine, the hypervisor captures the fault and handles it, supporting the backdoor RPC mechanism.

Figure 1: The architecture of VMware ESXi [5]. VMKernel, a POSIX-like OS, is designed to multiplex the virtual machines and provides some core fundamentals such as resource scheduling, I/O stacks, file system (VMFS), and drivers. The guest machines can communicate with the host through hypercall, which includes normal hypercalls such as VM-Exit and special hypercalls such as backdoor and VMCI. The term "user world" refers to a process running in the VMKernel. A significant user world is "VMX," a Ring-3 process, because it contains RPC handlers and virtual hardwares. (Note that the VMX process and some other process sandboxed by the vSphere sandbox.) The virtual machine monitor (VMM) is a process that provides the execution environment for guest virtual machines.

Figure 2: The backdoor remote procedure call. Under default I/O privilege level, a Ring-3 program should not be able to issue I/O operations. As a result, the int or out instruction should cause the Ring-3 process to fault and crash. However, in this scene, the hypervisor captures the fault and handles it, supporting the backdoor RPC mechanism.

2.2 Virtual Machine Escape

VM escape is a process of breaking out of a virtual machine from a guest OS, so the guest VM can launch an arbitrary execution with the privilege of the host operating system [21]. Specifically, ESXi completely isolates the guest operating systems from each other by leveraging hardware virtualization technologies, such as Intel VT or AMD-V. Any privileged instructions from the guest operating systems will be captured...
1: Creating a new channel
2: asm(
4 "movl $0x564d5868, %eax\n\t" ; magic bytes: 'VMXh'
5 "movl $0xc9435052, %ebx\n\t" ; magic bytes for RPCI
6 "movl $0x564d5868, %edx\n\t" ; special I/O port
7 "out %eax, %edx\n\t" ; MESSAGE_TYPE_OPEN
8 "movl $0x5658, %edx\n\t" ; ret channel number (EDX(HI))
9 "movl $0xc9435052, %ebx\n\t" ; magic bytes: 'VMXh'
10 "movl $0x564d5868, %eax\n\t" ; MESSAGE_TYPE_SEND
11 "out %eax, %edx\n\t" ; special I/O port
12 "movl $0x5658, %edx\n\t" ; channel number (EDX(HI))
13 "movl $0xcb414141, %eax\n\t" ; 4 bytes to be sent
14 "movl $0x564d5868, %ecx\n\t" ; magic bytes: 'VMXh'
15 "movl $0x564d5868, %edx\n\t" ; MESSAGE_TYPE_SEND
16 "movl $0x5658, %edx\n\t" ; special I/O port
17 "out %eax, %edx\n\t" ; success or failure
18 "movl $0xcb414141, %eax\n\t" ; 4 bytes to be sent
19 "movl $0x564d5868, %ecx\n\t" ; magic bytes: 'VMXh'
20 "movl $0xcb414141, %edx\n\t" ; 4 bytes to be sent
21 "movl $0x5658, %edx\n\t" ; channel number (EDX(HI))
22 "movl $0xcb414141, %eax\n\t" ; 4 bytes to be sent
23 )

; Sending data through a specific channel
asm(
18 "movl $0x564d5868, %eax\n\t" ; magic bytes: 'VMXh'
19 "movl $0x564d5868, %edx\n\t" ; MESSAGE_TYPE_SEND
20 "out %eax, %edx\n\t" ; special I/O port
21 "movl $0x5658, %edx\n\t" ; channel number (EDX(HI))
22 "movl $0xcb414141, %eax\n\t" ; 4 bytes to be sent
23 "movl $0xcb414141, %edx\n\t" ; 4 bytes to be sent
24 "movl $0x564d5868, %ecx\n\t" ; magic bytes: 'VMXh'
25 "movl $0x564d5868, %edx\n\t" ; MESSAGE_TYPE_SEND
26 "movl $0x5658, %edx\n\t" ; special I/O port
27 "out %eax, %edx\n\t" ; success or failure
28 )

Figure 3: By using "RPCI," a sort of backdoor-based mechanism, guest machines can communicate with the host OS. By reading or writing a special I/O port (0x5658/ 0x5659), a process running in Ring-3 can invoke the RPC directly.

and sanitized by the hypervisor. In normal circumstances, the guest cannot execute codes or affect security-critical behaviors such as system configuration, and network connections of other guests or the host. By exploiting the vulnerabilities in the ESXi, the adversaries can cross the security boundary between the guest and the host, to execute arbitrary codes on the host operating system (i.e., virtual machine escape in the ESXi).

2.3 Security Analysis of the ESXi

Attack Surfaces. The virtualization layer is the most significant part of the lifetime of the guest operating system. Any interaction between the guest OS and the hypervisor is a potential attack vector that could be exploited by adversaries. Generally, the guest can communicate with the host of ESXi in several ways:

1. VMKernel and Core Virtualization Infrastructures: There are some fundamentals such as VM-Exit handlers, memory management, and memory virtualization infrastructures offered by the hypervisor running in the kernel space. An adversary who attacks the hypervisor successfully could take over the kernel of the host operating system directly.

2. Virtual Hardware: To support the I/O virtualization, VMware designed a batch of virtual hardware and devices. Most of them are integrated into the VMX process of ESXi [3, 15]. The guest OS can communicate with the virtual hardware through port I/O (P10) or memory-mapped I/O (MMIO). Table 1 shows some significant virtual hardware integrated in VMware ESXi. Most of them require that the root privilege be opened in the guest operating system.

3. RPC Channels: VMware developed some RPC protocols such as backdoor and VMware Virtual Machine Communication Interface (VMCI) to accelerate the communication between the guest OS and the host OS. It has been applied in VMware’s virtual machines for decades, because it does not rely on hardware virtualization extensions. Thus, it also results in some virtual machine escape attack surfaces. Some RPC handlers exist in the VMX process. By exploiting the bugs in these handlers, adversaries can escape from the guest OS.

Common Mitigations. The host maintains a POSIX-like operating system, and some Linux-like security mitigations are integrated into the host.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Category</th>
<th>Privilege</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVGA2D</td>
<td>Virtual Graphic</td>
<td>ROOT</td>
</tr>
<tr>
<td>SVGA3D</td>
<td>Virtual Graphic</td>
<td>ROOT</td>
</tr>
<tr>
<td>e1000</td>
<td>Virtual Ethernet</td>
<td>ROOT</td>
</tr>
<tr>
<td>e1000e</td>
<td>Virtual Ethernet</td>
<td>ROOT</td>
</tr>
<tr>
<td>VMXNET3</td>
<td>Virtual Ethernet</td>
<td>ROOT</td>
</tr>
<tr>
<td>xHCI</td>
<td>Virtual USB</td>
<td>ROOT</td>
</tr>
<tr>
<td>uHCI</td>
<td>Virtual USB</td>
<td>ROOT</td>
</tr>
<tr>
<td>aHCI</td>
<td>Virtual SATA</td>
<td>ROOT</td>
</tr>
<tr>
<td>LSilogic</td>
<td>Virtual SCSI</td>
<td>ROOT</td>
</tr>
<tr>
<td>Printer</td>
<td>Virtual COM Device</td>
<td>ROOT</td>
</tr>
</tbody>
</table>

Table 1: The virtual hardware has been demonstrated to affect the interaction of guest-to-host. The privilege field indicates the requirement to open the device in the guest OS.
### 3 VM Escape: Our Approach

#### Overview.

There are two uninitialized usages in vmxnet3 virtual ethernet card and a logical issue in the sandbox policy. CVE-2018-6982 is used for code pointer leak, and CVE-2018-6981 for arbitrary pointer free. Our technique is to chain both for an arbitrary write and, ultimately control-flow hijacking. Next, we bypass the vSphere sandbox and achieve virtual machine escape.

#### VMX program has fewer source codes, because VMware moved the data package operations into the VMkernel, enhancing the efficiency of ESXi. Meanwhile, it narrows the attack surfaces of VMX.

### Sandbox.

Since vSphere 6.5, VMware ESXi has introduced a mandatory access control (MAC), similar to Ubuntu’s AppArmor, to enforce the security policy of guest VMs. (VMware vSphere is a commercial name for the whole VMware Suite, and ESXi is the hypervisor server of vSphere.) The sandbox maintains some pre-defined policies that contain some white lists of allowed syscalls, sockets, and file permissions in the file system (VMFS). The main functionality of sandboxing is offered by VMKernel, dividing the target into several different restricted domains (app, ioFilter, pluginFramework, globalVM, plugin, tpm2emu). After the specific virtual machine starts, its behaviors are limited. It ensures the safety and security of VMs by running them in an operational sandbox with strict controls regarding hypervisor capabilities available to them [6]. Even if the adversaries have escaped from the guest operating system, they are still restricted by the vSphere sandbox; thus, it qualifies the impact of virtual machine escape attacks.

**Figure 4** shows a sample rule for global VMs. It grants what system calls a VMX process is allowed to call, what network connections a VMX process is allowed to establish, and what directories a VMX process is allowed to read or write.

```c
1 void _usercall vmxnet3_reg_cmd(vmxnet3_class *a1, int64 read_or_write, _DWORD *data, __int64 a4, __int64 a5)
2 ...
3 ...
4 ...
5 case 4: // VMXET3_CND_UPDATE_MAC_FILTERS
6 if ( a1->field_LA28 ) {
7    dma_memory_create(a1->driver_shared_addr + 8, 0x2B0ui64, 1, 1); 
8    vmxnet3_cmd_update_mac_filters(v6, &page, a5);
9    destruct_page_struct(page);
10   sub_1407CB30(v6);
11   }
12 break;
13 ...
14 ...
15 char __fastcall dma_memory_create(unsigned __int64 addr, unsigned __int64 size, int a3, int a4, page_struct *page)
16 {
17   unsigned __int64 v5;
18   ...
19   v5 = *(qword_140DAA810 + 12160);
20   // check the addr
21   if ( addr > v5 || size > v5 - addr + 1 )
22   return 6;
23   set_page_struct(addr, size, a3, a4, page);
24   return 1;
25 }
26 ...
27 ...

**Figure 5:** dma_memory_create() is responsible for creating a page struct used to read/write memory between guest and host. Inside the function, it checks the addr passed by users. If it is invalid, the function will return directly. However, it does not check whether the allocation is successful; thus, an uninitialized stack variable could be used in destruct_page_struct().

3 VM Escape: Our Approach

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3.1 Vulnerabilities

The vmxnet3 adapter is the recommended network adapter to use as default in VMware ESXi because it offers the best throughput of all the adapter options. As such, it’s likely in use on most virtual machines. In this section, we introduce two memory corruption bugs leveraged in our exploitation chain.

CVE-2018-6981. This bug is caused by an uninitialized use of stack memory in the vmxnet3 virtual Ethernet card. As Figure 5 shows, there is an interface (vmxnet3_reg_cmd()) that can execute commands in the MMIO memory of vmxnet3. In the command VMXNET3_CMD_UPDATE_MAC_FILTERS, the dma_memory_create() function creates a page structure used to read/write memory between guest and host. The destruct_page_struct() is responsible for releasing the memory of the page structure.

According to Figure 5, the page structure is allocated and initialized in the function set_page_struct(). At the beginning of the function, the dma_memory_create() function checks the validity of the physical address given by the guest. Unfortunately, if the guest provides an invalid physical address, the function will return immediately. However, after the dma_memory_create(), the VMXNET3_CMD_UPDATE_MAC_FILTERS handler fails to check whether the allocation of the page structure is successful, resulting in an uninitialized use in the destruct_page_struct() function.

Technically, this bug can also be turned into an information leakage bug. However, to improve the stability of the exploitation, we decided to chain a dependent information leakage bug into the exploitation.

CVE-2018-6982. This bug is also caused by an uninitialized stack variable in the memory of ESXi, and we utilized it to independently retrieve memory address information from the host. There is another command handler in vmxnet3_reg_cmd() called vmxnet3_cmd_get_coalesce() which represents the size.

Figure 6 depicts the core logic of it. The get_args() function is used to retrieve some data from a memory region of the VMX process. The sanity_check() function qualifies that the v19 must satisfy v19 \(\leq 16\). Also, the write_back_to_guest() function will write 16 bytes of data into the guest context. Unfortunately, only 8 bytes of them (v20) are initialized.

3.2 Exploitation

A significant challenge of exploiting uninitialized use bugs is how to control the uninitialized variable. In this section, we illustrate the entire process of turning the uninitialized use bug to arbitrary code execution and how we overcome the challenges.

1) Arbitrary address free primitive. As Figure 7 delineated, first, we leak some addresses to break ASLR through the information leakage bug. Next, in destruct_page_struct() function (Figure 8), the function frees a field of the uninitialized stack memory. Hence, after filling a pointer into the uninitialized memory, an arbitrary-address-free primitive could be constructed.

2) Arbitrary address write primitive. As Figure 11 illustrates, the metadata of Backdoor-RPC channel exists in the data segment. Therefore, we used this feature to construct an arbitrary-address-write primitive. First, we opened several Backdoor-RPC channels; thus, some metadata structures of the channel in the data segment will be activated. Second, we fake a glibc fast-bin chunk on it to do the House of Spirit Attack.

Specifically, after leaking the address of the data segment, we calculated the addresses of the metadata for the backdoor, and put them into the uninitialized stack memory using the function handle_port_iol(). For example, in Figure 9, when the size of the data is less than 0x800, it will put all of the data into the stack. Next, we use the arbitrary-address-free primitive to free the fake fast-bin chunk.

House of Spirit Attack. Because ESXi uses a variant of glibc to maintain Ring-3’s heap, we decide to fake a fast-bin chunk on the global metadata of Backdoor-RPC channels, i.e., House of Spirit Attack of glibc [1, 13, 22]. However, glibc has several integrity checks to mitigate memory corruption attacks. To bypass it, we need to construct the fake chunk and pick the size properly.

After investigating, as Figure 10 illustrates, we determine some constraints in the free() function of glibc that need to be satisfied:
1. The ISMMAP bit of the fake chunk is 0.
2. The fake chunk’s address is aligned.
3. The size of the fake chunk is 32 bytes to 128 bytes and aligned.

4. For the next chunk’s size $\theta$: $2 \times SIZE_SZ \leq \theta \leq \text{av} \to \text{system_mem}$. 

5. The first chunk in the fast-bin is not the fake chunk.

Then, we reallocate the fake chunk by leveraging other Backdoor-RPC channel operations, i.e., when a new channel is opened, the channel allocates a new buffer with a controllable length pointed by the data field in the metadata of the channel. This is a flexible and reusable trick to manipulate the heap of ESXi. Finally, we overwrite the next data pointer.
Figure 10: To fake a fast-bin chunk successfully, we need to bypass some constraints in glibc.

```c
void _int_free(mstate av, Void_t* mem)
{
    mchunkptr p;
    INTERNAL_SIZE_T size;
    mfastbinptr* fb;
    p = mem2chunk(mem);
    size = chunksize(p);
    fb = &(av->fastbins[fastbin_index(size)]);
    .....
    free(fb);
}
```

of the next channel and an arbitrary-address-write primitive can be constructed.

3) Code execution. To execute codes on the context of the host, we use the arbitrary-address-write primitive to corrupt the stack. First of all, we corrupt the global offset table and overwrite the qsort function into a stack pivot gadget. Next, a ROP chain will be put into the stack. Meanwhile, the control flow will be forwarded to the ROP chain on the pivoted stack. In particular, the ROP chain will invoke mmap syscall and enable the privilege to execute arbitrary shellcodes.

3.3 Circumventing the vSphere Sandbox

The logical bug in the sandbox policy. By scrutinizing the policies of the sandbox, we determine that there are some loopholes inside it. The sandbox grants the VMX process to read and write the /var/run directory of VMFS, and an internet server (inetd) configuration database exists in the /var/run/inetd.conf.

In this way, we can bind a shell on a specific port by overwriting the inetd.conf file. Note that files existing in the /var/run/* are not persistent and copied from the backup firmware in the /bootbank/* directory after rebooting.

**Forcing the process to restart.** To activate the configuration and spawn a shell, we need to force the inetd process to restart. However, we cannot simply restart the entire OS, because the inetd.conf file is not persistent. Files in the VMFS are copied from the bootbank after the host OS restart. Fortunately, there is a watchdog can help us to restart some processes. As a result, we use the kill() system call to terminate the inetd process. After that, the watchdog restarts the process, and a bind shell spawns.

### 3.4 Reliability

**Compatibility.** To improve the compatibility of our exploitation, we use some fingerprints retrieved from the host OS to manipulate the exploitation dynamically. As Figure 7 indicates, we first utilize the information leakage bug to retrieve some memory of .data segment, using it to determine the version of the running ESXi.

Next, we can dynamically construct some crucial payloads (e.g., shellcodes, address of fake chunk, etc.) in terms of the current version.

**Persistency.** As depicted in §3.3, after the host OS restarted, the entire VMFS is overwritten again, i.e., files in VMFS are overwritten by the backup firmware stored in /bootbank. In light of this, after getting the root privilege, we can overwrite the files under the /bootbank directory to achieve persistent exploitation.
4 Implementation

The exploit has been implemented in a kernel module with 450 LoC. The shellcodes embedded in the kernel module will spawn a bind shell on a specific port and a reverse shell connecting to our remote server. To launch the escape, we merely need to insert the module into the kernel of the guest OS.

Notably, all of the bugs depicted above have been reported to the vendor and patched appropriately. Now the exploit chain only affect the instances of VMware ESXi whose version is earlier than 6.7.0 with build number 10764712.

5 Evaluation

To examine the stability and compatibility of our exploit. We evaluate it on ESXi 6.7 with different versions.

Experimental Setup. We run the exploit on ESXi with different versions. The guest OS is Ubuntu 16.04.3 LTS, with 2 cores, and 4GB memory. The host machine has an i9-7980XE processor with a 64GB physical memory. For each guest OS, we run the exploit 30 times.

Results. Table 2 shows the results. The exploit chain has been demonstrated to affect ESXi 6.7, and ESXi 6.5. Also, the exploit can effectively adapt to the targeted environment. In particular, the maximum success rate of our proposed exploit chain is 93.33%.

6 Discussion

Evaluation results show that the success rate of our exploit is not 100%. In this section, we try to determine the reasons. By scrutinizing the memory status, we found two significant factors that qualified the success rate of the exploit.

1) Manipulating the uninitialized variables. In light of the fact that the arbitrary-address-free primitive requires valid addresses, we have to make sure the targeted address is legitimate before triggering the logic of free. However, the normal actions and executions in ESXi may pollute the stack, resulting in the “free” operation not going as expected.

2) The stability of heap. After releasing the targeted fake memory chunk, we need to reallocate it immediately. However, if ESXi allocates it before we do, the process will crash suddenly.

7 Related work

Virtual Machine Escape. Chaitin Security Research Lab has demonstrated an exploit of VMware Workstation with a single vulnerability in Backdoor-RPC [4]. However, in their tests, the stability is qualified by the Low Fragment Heap of the Windows 10 operating system, and the maximum success rate is 80%. Keen Security Lab has also demonstrated an exploit for VMware Workstation by using an information leakage bug in Backdoor-RPC and a memory corruption bug in xHCI [9]. For type-1 hypervisors, CVE-2015-7835 [2] has been demonstrated to achieve a virtual machine escape of the Xen hypervisor. Furthermore, Jordan Rabet has proposed an in-depth analysis of a successful virtual machine escape of Hyper-V [12].

Exploitation of Uninitialized Use. The leading part of the exploitation of uninitialized use is to control the uninitialized variables and turn them into other types vulnerabilities. Halvar Flake proposed an approach to determine all the paths that could be overlapped in the same stack frame [7]. Also, Kangjie Lu et al. proposed an automated approach using targeted stack spraying to facilitate the uninitialized uses of the kernel [10].

Mitigations for VM Escape. BitVisor [14] tried to enforce the security of I/O devices by minimizing the code size of hypervisors by allowing most of the I/O accesses from the guest OS to pass through the hypervisor. NoHype [16] presented a strategy to eliminate the hypervisor attack surface by enabling the guest VMs to run natively on the underlying hardware while maintaining the ability to run multiple VMs concurrently. Hypersafe [19] proposed an approach to apply the Control-Flow-Integrity to mitigate virtual machine escape attacks. Cloudvisor [23] introduced an approach that enforces the separation of resource management from security protection in the virtualization layer.
8 Conclusion

VMware ESXi is one of the most state-of-the-art enterprise class hypervisors. However, there has been no systematic security analysis or successful virtual machine escape until this research. We give a systematic overview of the architecture, attack surfaces, and exploitation approaches of ESXi. Furthermore, we proposed a flexible and reusable strategy that leverages the backdoor RPC to manipulate the memory layouts. Our exploitation chain contains three vulnerabilities. Evaluation results show that it is reliable (90% success rate on average).

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References


