Exploiting Live Virtual Machine Migration

Jon Oberheide
University of Michigan

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Game Plan

• Introduction to VM migration
• Live migration security
• Exploiting live migration
• Future attacks and wrap-up
Live VM Migration

- Transfer of a VM from one physical machine to another with little or no service downtime

**High Availability**

**Enhanced Mobility**

**Dynamic Load Balancing**
Live Migration Methodology

- Minimize service downtime
- Minimize migration duration
- Migration Types:
  - Stop-and-copy (S-C)
  - Demand-migration (D-M)
  - Iterative precopy (I-P)
Stop and Copy

- Stop source VM
- Copy all pages over the network
- Start destination VM

Stop and Copy

Longest Service Downtime

Shortest Migration Duration
Demand Migration

- Copy over critical OS structures
- Start destination VM
- Page faults trigger network copy

**Demand Migration**

- Shortest Service Downtime
- Longest Migration Duration
Iterative Precopy

- Iteratively copy pages over network
- Keep copying dirtied pages until threshold
- At threshold, stop source VM, copy remaining pages, start destination VM

Iterative Precopy

Balances Service Downtime and Migration Duration

- Method used by VMware/Xen
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A Trip Down Memory Lane

- Physical machines
  - Machine state protected by MMU/hardware
  - Physical attacks (firewire device DMA)

- Virtual Machines
  - VM state protected by VMM/hypervisor
  - Software attacks (weak VMM isolation)

Can we break any more isolation boundaries?
A Trip Down Memory Lane

Of course! Functionality always usurps security!

- Migration-enabled VMs
  - Full VM state exposed to network
  - Trades off security for management capabilities
  - Authentication, confidentiality, isolation concerns
VM Migration Security

- Migration data plane
  - Network transit path over which migration occurs
- Security of data plane
  - Unauthenticated, insecure migration data plane
- Full access granted to VM state
  - OS/kernel memory
  - Application state
  - Sensitive data, passwords, keys, etc
- VMware and Xen migrations vulnerable
Breach of data plane means game over
  - Entire virtual machine may be compromised
  - Kernel, userspace applications, data

Requirement for breach
  - Manipulate traffic along migration path between source and destination VMM

Need to perform MITM attack
  - ARP/DHCP spoofing
  - DNS spoofing/poisoning
  - IP/route hijacking
Breaching the Data Plane

- **Passive Attacks**
  - Snarf sensitive data, passwords, keys in memory

- **Active Attacks**
  - Manipulate authentication services
    - sshd, /bin/login, pam, etc
  - Manipulate kernel structures
    - slip rootkits into memory
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Exploiting VM Migration

- Xensploit
  - Non-weapons-grade proof-of-concept tool
  - Works against Xen and VMware migrations

- Attack classes
  - VM application/userland exploits
  - OS/kernel exploits
  - VMM subversion
VM Application Exploits

- sshd authentication bypass
  - Identify pubkey authentication routines
  - Manipulate to allow unrestricted root access
  - Access wide-open after migration completes

- Cron daemon shellcode injection
  - Privileged, inconspicuous daemon
  - Inject HTTP GET + execve shellcode
  - Payload fetch/exec on next find_jobs invocation
Exploitation Example

sshd authentication bypass

- Before migration:
  - attacker denied access to VM
- During migration
  - Xensploit manipulates the in-memory object code of sshd as it crosses the wire
- After migration
  - attacker achieves unrestricted root access to VM
Before Migration

- Attacker attempts to gain root access to the target virtual machine via ssh

```
jonojono@jonojono ~ $ ssh root@vm-test
Password:
Password:
Password:
Permission denied (keyboard-interactive).
jonojono@jonojono ~ $
```

- Attacker is denied access to the VM
sshda Authentication Code

- Source code from OpenSSH's auth2-pubkey.c:

```c
if (key != NULL)
    key_free(key);
xfree(pkalg);
xfree(pkblob);
#ifdef HAVE_CYGWIN
    if (check_nt_auth(0, authctxt->pw) == 0)
        authenticated = 0;
#endif
    return authenticated;

/* return 1 if user allows given key */
static int
user_key_allowed2(struct passwd *pw, Key *key, char *file)
{
    char line[SSH_MAX_PUBKEY_BYTES];
    int found_key = 0;
    FILE *f;
    u_long linenum = 0;
    struct stat st;
    Key *found;
    char *fp;

    /* Temporarily use the user's uid. */
    temporarily_use_uid(pw);
    debug("trying public key file \%s", file);

    /* Fail quietly if file does not exist */
    if (stat(file, &st) < 0) {
```
During Migration

- Xensploit manipulates the object code of sshd's authentication routines as it crosses the wire.

```
805da77: 0f 84 23 fd ff ff   je 805d7a0 <user_key_allowed2+0x80>
805da7d: 89 3c 24   mov %edi,%esp
805da80: e8 37 e5 fe ff   call 804bfc <fclose@plt>
805da85: 8d 65 8c df ff ff   lea 0xffffdf8c(%ebp),%eax
805da8b: 89 44 24 04   mov %eax,0x4(%esp)
805da8f: c7 04 24 15 0e 08 08   movl $0x8080e15,%esp
805da96: e8 d5 28 01 00   call 8070370 <logit>
805da9c: e8 20 0d 01 00   call 80797c0 <restore_uid>
805daa0: 81 c4 9c 20 00 00   add $0x209c,%esp
805daa6: 31 c0   xor %eax,%eax
805daa8: 5b   pop %ebx
805daa9: 5e   pop %esi
805daaa: 5f   pop %edi
805dab: 5d   pop %ebp
805dacc: c3   ret
805daad: 68 76 00   lea 0x0(%esi),%esi
```

- Xensploit injects a `mov $0x1,%eax` instruction into user_key_allowed2, returning 1 (true).
After Migration

- Attacker again attempts to gain root access via ssh on the target virtual machine

```
jonojono@jonojono ~ $ ssh root@vm-test
Last login: Thu Oct 18 15:18:37 2007 from jonojono.eecs.umich.edu
fjbox1 ~ # id
uid=0(root) gid=0(root) groups=0(root),1(bin),2(daemon),3(sys),4(adm),6(disk),10(wheel),11(floppy),20(dialout),25(at),26(tape),27(video),1006(vmware)
fjbox1 ~ #
```

- No authentication is necessary as sshd's routines have been manipulated by Xensploit
- Root access is granted to the attacker
VM Kernel Exploits

- Kernel manipulation
  - Direct access to in-memory kernel image
  - More complexity but more power
  - Leverage all your DMA attack payloads

- Stealthy backdoor drop
  - network/syscall/ioctl trigger

- Full-blown VMBR hoisting
VMBR Hoisting

- Virtual Machine-Based Rootkits
  - Slip in extra virt layer a la SubVirt/Blue Pill/Vitriol
Subverting the VMM

- Mangle migration payload
  - Exploit a vulnerability and subvert VMM
- Leverage Xen dom0 vulns
  - Present in Xen daemon migration routines
  - <= 3.1.0 release vulnerable
  - Undoubtedly more...
- Instantly own all hosted VMs
  - And all future migrated VMs!
Subverting the VMM

- Xen's libxc/xc_domain_restore.c:

```c
unsigned long region_pfn_type[MAX_BATCH_SIZE];
...
for (; ; )
{
    int j, nr_mfns = 0;
    ...
    if (!read_exact(io_fd, &j, sizeof(int)) )
    if ( j == -1 )
    if ( j == -2 )
    if ( j == 0 )
    ...
    if ( j > MAX_BATCH_SIZE )
    if ( !read_exact(io_fd, region_pfn_type, j*sizeof(unsigned long)) )

- No check for signed integer j < 0
- Stack overflow of region_pfn_type in Xen VMM
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Additional Attacks

- Fraudulent migration requests
  - Owned VMMs snarfing up VMs
- False resource advertising
  - Migration-enabled load balancing
- Future attacks inevitable
  - Increased functionality
  - Increased complexity
  - Increased security risk

Lots more juice in the migration orange!
Just Encrypt It, Stupid!

- Encryption goes a long way!
- Fingerprinting migrations
  - Reconnaissance / targeting
  - Enabled by iterative-precopy method
  - Similar to VBR attacks
- Increased complexity
  - Full PKI adds considerable deployment complexity
- Not currently implemented!
Vendor Response

- VMware
  - Use separate network for migration paths
  - Use hardware-based crypto cards
  - VMotion/Virtual Infrastructure 3 vulnerable

- XenSource
  - Consult vendor/distribution for security fixes
  - Latest open-source release still at risk
  - Unsure of migration status in XenServer4

- Microsoft Hyper-V
  - Will they get it right?
The Big Picture

- VM migration paradigm
  - VERY useful functionality
  - Awareness of security risk necessary
  - Better isolation, access control, authentication

- Until then...
  - Severe weaknesses exist in extensively deployed systems
  - Valuable weapon for pentester/attacker
QUESTIONS?

- Contact info:
  - Jon Oberheide <jonojono@umich.edu>
  - PhD student, University of Michigan
  - Advisor: Farnam Jahanian
  - Research Group: http://www.eecs.umich.edu/fjgroup/