Seminar of Advanced Exploitation Techniques, WS 2006/2007

hacking in physically addressable memory

a proof of concept

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Table of Contents

Table of Contents

physical addressable memory

"hacking in physically addressable memory"

- Hacking: using a technique for something it has not been designed for
- Physically addressable memory: direct memory access, "DMA"

hacking

- I will show mostly attacks
- So actually I will be cracking a systems security
- Exploiting et al is not hacking by definition
- “to hack” is mostly misused by media

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DMA

- DMA = Direct Memory Access
- Basic requirement for introduced approach
- Known for a long time: attacker has DMA -> 0wn3d
  - 0wn3d by an iPod [1]
  - and others [2, 3]
- This is a proof of concept

Table of Contents

Methods

Many ways to gain access to memory:

- special PCI cards (forensic, remote management cards)
- special PCMCIA cards
- FireWire (IEEE1394) DMA feature
- anything with DMA
- `/dev/mem` (Linux)
- memory dumps
- Suspend2Disk images
- Virtual machines
- ...

Generic problems of DMA attacks

- Swapping
- Multiple accessors at any time
- Caching (?)

DMA hardware

Hardware we may use is

- expensive
- specially crafted
- selfmade (some)
- rare
- not hot-pluggable (depends)
- one exception: FireWire (IEEE1394)

FireWire overview

FireWire a.k.a. iLink a.k.a. IEEE1394

- Hot-pluggable
- Wide-spread (even among laptops)
- Expansion Bus (like PCI or PCMCIA)
- Has DMA (if enabled by driver)
- Guaranteed bandwith feature
- Used alot for media-crunching
- Most people are not aware of abuse-factor

FireWire DMA

- DMA only enabled if driver says so
    - Linux, BSD, MacOSX: by default (can be disabled)
    - Windows: only for devices that “deserve” it (more later)
- If DMA -> full access, no restrictions

Windows DMA

Devices that “deserve” DMA on Windows:
SBP2 (storage) devices, like

- external disks
- iPod (has a disk)

The iPod can run Linux. . .

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How to identify SBP2 devices

- Identify devices and features from their CSR config ROM
- Config ROM contains
  - GUID: 8 byte globally unique ID (like MAC address)
  - Identifier of driver
  - List of supported features
  - List of supported speeds
  - ...
- CSR config ROM can be faked (see [2])
- Copy config ROM from iPod and install it on any system (→`1394csrtool`)
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Joana Rutkowska will introduce methods to “Cheat Hardware Based RAM Forensics” on Black Hat DC in March (see http://theinvisiblethings.blogspot.com/2007/01/beyond-cpu-cheating-hardware-based-ram.html)

/dev/mem

- Gives access to physically addressed memory (in opposite to `/dev/kmem`)
- Often needed by X-server
- Shall be obsoleted in future (X shall use DRI)
- Only gives access to lower 896MB RAM (only these are mapped)

One interface to access them all

- One generic interface: `libphysical`
- Backends for anything...
- Implemented so far:
  - Filedescriptor (`/dev/mem`, memory dumps)
  - FireWire

Table of Contents

so what now?

- Once we got access. . . we can see a bunch of random memory
- How does OS manage memory?

Could parse kernel data-structures (if found). But they are different for different

- hardware architecture
- operating system
- OS version
- and may not be documented (Windows)

Or we could do something else…

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Virtual Address Spaces

- Multitasking Operating System
- System runs several processes “at once”
- Privilege separation required (see [5])
- Normally done in hardware

→ Each process has own virtual address space
→ Cannot access other processes memory or operating systems memory
→ Cannot circumvent protection mechanism

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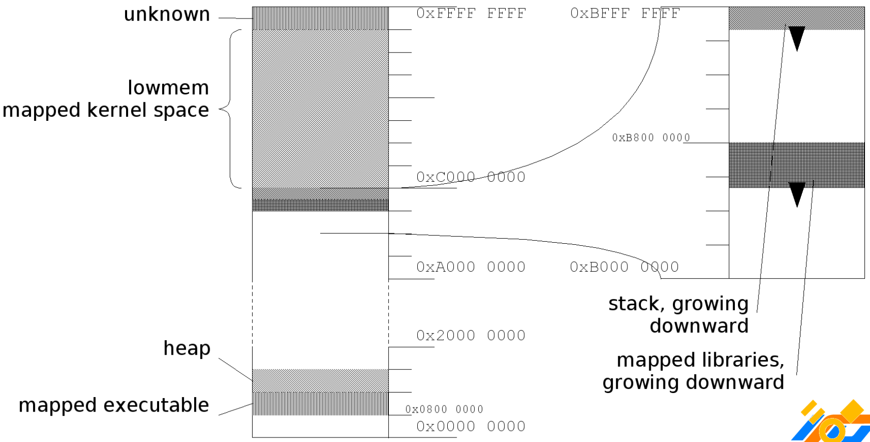
IA-32 Linux VM Layout



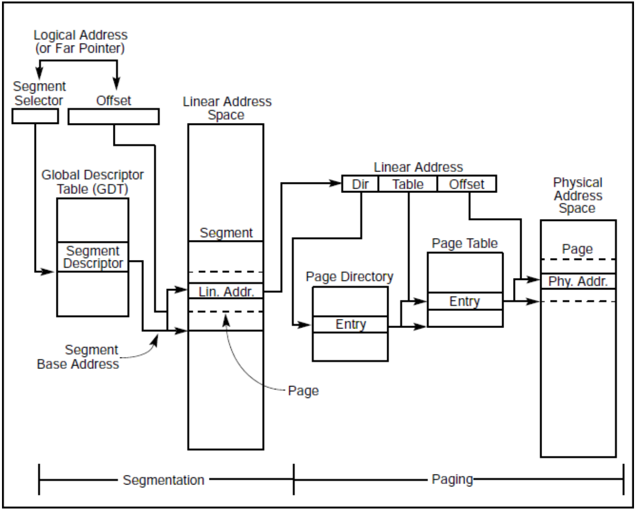
IA-32

IA-32 provides two techniques (that may be chained)

- Segmentation (required)
- Paging (optional)

Linux only uses paging, all segments span full 4GB of virtual memory

IA-32 virtual (“logical”) address translation



(from [6])

Done in hardware

- Translation done in hardware (by CPU)
- Hardware needs to know how to do it:
  - Global Descriptor Table (GDT)
  - Local Descriptor Table (LDT)
  - Page Directory (PD), Page Tables (PT)

Once we got these structures, we know which page belongs where in which address space

- Linux: GDT, LDT are irrelevant (flat segments)
- only PD is required
- PD references PTs
- PD may have recognisable patterns (has for Linux and Windows)
- one PD per process

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Finding ATTs

Address Translation Tables (including PDs)...

- depend on architecture
- depend on operating system
- may have recognisable patterns

→ create signature for (arch, OS). so far:

- (i386, Linux 2.4 and 2.6)
- (i386, Windows XP)

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Finding ATTs, details

1. Sieve all pages by simple, static pattern (e.g. 4 bytes)
2. For each possible do statistical analysis:
    - Normalized Compression Distance (NCD) to known true ATT
3. If possibility high enough, test integrity of data (for IA-32: try to load referenced PTs)
4. If ok, its (most probably) an ATT

Normalized Compression Distance

- Normalized Information Distance:
  - Minimal amount of changes required between two information
  - Uses Kolmogorov Complexity (KC) (size of minimal representation of information)
  - Incalculable
- KC can be approximated by compressor
  → Normalized Compression Distance:
  - Calculable
  - Very versatile
  - e.g. create relational trees of gene-sequences [4]

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Once a PD is found, we can do the translation by hand:

- Well-defined algorithm for architecture, e.g. for IA-32: [6]
- Implementation in software in `liblinear`. So far:
  - IA-32 Protected Mode, without PAE36
    (Linux with $\leq$ 4GB RAM)

Table of Contents

So far

- We can access physical memory sources in a generic way (`libphysical`)
- We can find and access virtual address spaces of processes (`liblinear`)

Now we want to identify processes we found.

```
#include <stdio.h>

int main(int argc, char**argv)
{
 printf("my name is %s\n", argv[0]);
 return 0;
}
```

- `argv`, `envv` are somewhere in the address space
- They are on the stack, on first mapped pages below page `0xc0000`
- NUL-separated vector with
  - Path of binary
  - Environment
  - Arguments

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```
# OLDPWD=/home/lostrace PWD=/home/lostrace/documents/rwth/SEAT \
  /attacks/userspace SHLVL=1 _=./victim  \
  ./victim --arg=foo bar --baz

0xbfc5ff70  00 00 00 00 2e 2f 76 69  |...../vi|    ARGV[]:
0xbfc5ff78  63 74 69 6d 00 2d 2d 61  |ctim.--a|      [0] = bfc5ff74
0xbfc5ff80  72 67 3d 66 6f 6f 00 62  |rg=foo.b|      [1] = bfc5ff7d
0xbfc5ff88  61 72 00 2d 2d 62 61 7a  |ar.--baz|      [2] = bfc5ff87
0xbfc5ff90  00 4f 4c 44 50 57 44 3d  |.OLDPWD=|      [3] = bfc5ff8b
0xbfc5ff98  2f 68 6f 6d 65 2f 6c 6f  |/home/lo|      [4] = NULL
0xbfc5ffa0  73 74 72 61 63 65 00 50  |strace.P|
0xbfc5ffa8  57 44 3d 2f 68 6f 6d 65  |WD=/home|
0xbfc5ffb0  2f 6c 6f 73 74 72 61 63  |/lostrac|
0xbfc5ffb8  65 2f 64 6f 63 75 6d 65  |e/docume|
0xbfc5ffc0  6e 74 73 2f 72 77 74 68  |nts/rwth|
0xbfc5ffc8  2f 53 45 41 54 2f 61 74  |/SEAT/at|
0xbfc5ffd0  74 61 63 6b 73 2f 75 73  |tacks/us|
0xbfc5ffd8  65 72 73 70 61 63 65 00  |erspace.|
0xbfc5ffe0  53 48 4c 56 4c 3d 31 00  |SHLVL=1.|
0xbfc5ffe8  5f 3d 2e 2f 76 69 63 74  |_=./vict|
0xbfc5fff0  69 6d 00 2e 2f 76 69 63  |im../vic|
0xbfc5fff8  74 69 6d 00 00 00 00 00  |tim.....|
```

Stack arguments

- Find page, parse structure back-to-front:
- Last 5 bytes are always `NUL`
- Previous string is always binary
- Problem: difference between argument and environment?
- Solution: find `argv[0]` on stack and use userspaces `argv[]`

Finding Specific Processes

1. Find all virtual address spaces
2. For each: look if binary matches searched binary, e.g.:
   - `/usr/lib/mozilla-firefox/firefox-bin`
   - `/usr/bin/gpg`
   - `/usr/bin/psi`
   - `/usr/bin/openssl`
   - `/usr/bin/ssh-agent`
3. If matches, steal a cookie or… a ssh-private key

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Stealing SSH private keys

Let's get dangerous!

Steal SSH private key from `ssh-agent`:

- agent keeps key decrypted, locked in memory
- has timeout-function to wipe keys from memory
- stalled in `read()`-syscall on socket
- no timer-signal to check for timeout
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finding SSH Private keys

- Where (in filesystem) do you keep your keys?
- `$HOME/.ssh/*`
- `comment` := path of key

```
[foo@bar:~]> ssh-add -l
1024 00:11:...:ee:ff /home/foo/.ssh/id_rsa (RSA
```

```
typedef struct identity {
    Key *key;
    char *comment;
    u_int death;
} Identity;

struct Key {
    int      type;
    int      flags;
    RSA     *rsa;
    DSA     *dsa;
};
```

finding SSH Private keys [2]

1. Find `comment`-string in heap
2. Find PTR to `comment` (`struct identity`) in heap
3. Follow `key`
4. Follow `key->RSA` and `key->DSA`
5. A lot of `BIGNUM`s (OpenSSL arbitrary precision integer implementation). Copy relevant, test integrity (see [7,8]).
6. 0wn3d

(yes, there are better methods to find the keys, but this is just a proof of concept)

Resume

- So far: only read memory.
- Works with memory dumps
- No time to prepare an attack?
- $\rightarrow$ Just dump memory and do it later

Table of Contents

Attacking by Writing

- No more sword to be feared than the learned pen.
- Even the virtual one.

Inject where?

- Cannot allocate extra memory
- Cannot overflow a buffer (no IO with process)
- Need to overwrite code, data or stack
- Data: where IS data? is data mapped into multiple processes?

Inject into code

- Shared objects, binaries: mapped into multiple processes
- → Affect multiple processes at same time
- Needs to be PIC[1] (mapped at different locations)
- Is there room to inject code?

[1] Position Independent Code

Inject into stack

- Stack is easy to find
- Affect one process at a time (one stack per thread)
- Inject into zero-padded pages containing ENV and ARG.
- Possibly overwrite these (if little space):
  - ENV, ARG are rarely parsed
  - typically only during init
- If overwrites ENV, ARG: possibly visible via
  - `/proc/$PID/environ`
  - `/proc/$PID/cmdline`

Executing injected code

Use program-flow:

- Typical process calls subroutines
- Stackframes on stack, including return-address

→ Overwrite return-addresses

Protection Mechanisms

- Stackoverflow protection checksums
  - Can manipulate checksum as well
- Page-level no-execute enforcements (Intels EXB, AMDs NX)
  - Manipulate Page Directory to allow execution of stack

Rootshell?

- Royal leage of code-injection: interactive (root-)shell

$\rightarrow$ Inject bindshell

- Network connection required
- Can be found simply:
  - `lsof -i -n`
  - Network sniffer
  - IDS, NIDS

Rootshell!

→ Inject Shellcode doing IEEE1394-stuff

- Big, complex payload (IEEE1394 handling)
- Attack via IEEE1394?

→ Inject Syscall-Proxy

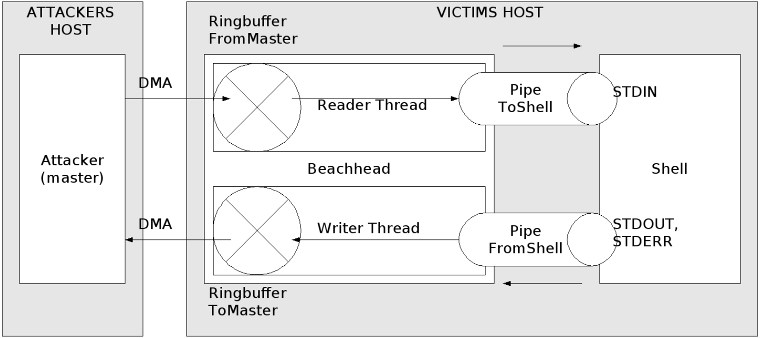
- Victim, self need to be same architecture, OS, syscall interface
- I attacked IA-32 from PPC…

DMA-Shell

- Only thing that is for sure: DMA

→ Communication via DMA

Special “Beachhead” Shellcode:



- Payload small (536 Bytes, yet big for shellcode)
- Independent of attackers arch, OS
- Only DMA required

Table of Contents

Prospects

- Kernelspace Modifications:
  - Shellcode that injects LKM?
  - `/dev/kmem` already emulated by `liblinear`
  - Live kernel patching?
- Bootstrapping custom operating systems

Conclusion

- DMA attacks are mature
- Access to memory $\rightarrow$ 0wn3d!
- Keep your firewire-ports secured
- Some of the tools (`libphysical`, `liblinear`) can also be used for forensics

Questions?

Thank you for your attention!

All tools will be released at
http://david.piegdon.de/products.html

Thanks...

- Maximillian Dornseif, Christian N. Klein and Michael Becher (basic idea)
- Lexi Pimenidis (supervisor)
- Timo Boettcher and Alexander Neumann (help)
- Swantje Staar (help with english)
- Chaos Computer Club Cologne (in general)

Thank you!

References (FireWire, DMA Attacks)

1 *Michael Becher, Maximillian Dornseif, and Christian N. Klein.* Firewire - all your memory are belong to us. 2005.

2 *Adam Boileau.* Hit by a bus: Physical access attacks with firewire. Ruxcon 2006.

3 *Mariusz Burdach.* Finding digital evidence in physical memory. 2006.

References

4 *Rudi Cilibrasi and Paul M. B. Vitányi.* Clustering by compression. IEEE transactions on information theory, vol. 51, 2005.

5 *Otto Spaniol et al.* Systemprogrammierung, Skript zur Vorlesung an der RWTH Aachen. Wissenschaftsverlag Mainz; Aachener Beitraege zur Informatik (ABI), 2002. ISBN 3-86073-470-9.

6 *Intel Corp.* Intel 64 and IA-32 Architectures Software Developer's Manual.

References

7 *Bruce Schneier.* Applied Cryptography (Second Edition). John Wiley & Sons, Inc, 1996. ISBN 0-471-11709-9.

8 *John Viega and Matt Messier and Pravir Chandra.* Network Security with OpenSSL. O'Reilly, 2002. ISBN 0-596-00270-X.