Subverting Vista™ Kernel For Fun And Profit

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About this presentation

- This presentation is based on the research done exclusively for COSEINC Research (Advanced Malware Labs)
- This presentation has been first presented at SyScan’06 conference in Singapore, on July 21st, 2006
Part I

- Loading unsigned code into Vista Beta 2 kernel (x64) without reboot

Part II

- Blue Pill – creating undetectable malware on x64 using Pacifica technology
Part I – getting into the kernel
Signed Drivers in Vista x64

- All kernel mode drivers must be signed
- Vista allows to load only signed code into kernel
- Even administrator cannot load unsigned module!
- This is to prevent kernel malware and anti-DRM
- Mechanism can be deactivated by:
  - attaching Kernel Debugger (reboot required)
  - Using F8 during boot (reboot required)
  - using BCDEdit (reboot required, will not be available in later Vista versions)
- This protection has been for the first time implemented in Vista Beta 2 build 5384.
How to bypass?

- Vista allows usermode app to get raw access to disk (provided they run with admin privileges of course)
  - `CreateFile(\\.\C:)`
  - `CreateFile(\\.\PHYSICALDRIVE0)`
- This allows us to read and write disk sectors which are occupied by the *pagefile*
- So, we can modify the contents of the pagefile, which may contain the code and data of the paged kernel drivers!
- No undocumented functionality required – all documented in SDK :)

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Challenges

- How to make sure that the specific kernel code is paged out to the pagefile?
- How to find that code inside pagefile?
- How to cause the code (now modified) to be loaded into kernel again?
- How to make sure this new code is executed by kernel?
How to force drivers to be paged?

- Allocate *lots of* memory for a process (e.g. using `VirtualAlloc()`)
- The system will try to do its best to back up this memory with the actual physical pages
- At some point there will be no more physical pages available, so the system will try to page out some unused code…
- Guess what is going to paged now… some unused drivers :)

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Eating memory...
What could be paged?

- Pageable sections of kernel drivers (recognized by the section name starting with ‘PAGE’ string)
- Driver’s data allocated from a Paged pool (e.g. ExAllocatePool())
Finding a target

- We need to find some rarely used driver, which has some of its code sections marked as pageable…
- How about NULL.SYS?
- After quick look at the code we see that its dispatch routine is located inside a PAGE section – one could not ask for more :)  
- It should be noted that there are more drivers which could be used instead of NULL – finding them all is left as an exercise to the audience ;)
Locating paged code inside pagefile

- This is easy – we just do a pattern search
  - if we take a sufficiently long binary string (a few tens of bytes) it’s very unlikely that it will appear more than once in a page file
- Once we find a pattern we just replace the first bytes of the dispatch function with our shellcode
- The next slide demonstrates how to use disk editor to do that
How to make sure our shellcode gets executed?

- We need to ask kernel to be kind enough and execute our driver’s routine (whose code we have just replaced in pagefile)
- In case of replacing driver’s dispatch routine it’s just enough to call `CreateFile()` specifying the target driver’s object to be opened
- This will cause the driver’s paged section to be loaded into memory and then executed!
Putting it all together

- Allocate lots of memory to cause unused drivers code to be paged
- Replace the paged out code (inside pagefile) with some shellcode
- Ask kernel to call the driver code which was just replaced
The above attack has been implemented in a form of a ‘1-click tool’

Special heuristics has been used to automatically find out how much memory should be allocated, before ‘knocking the driver’

The shellcode used in the demo disables signature checking, thus allowing any unsigned driver to be subsequently loaded
Creating useful shellcodes

- We can create a shellcode which would disable signature checking...

- … or we can create a small shellcode which would allocate some memory (via `ExAllocatePool`) and then “download” the rest of the malware from ring 3…
Possible solutions (1/3)

- Solution #1: Forbid raw disk access from usermode.
- This would probably break lots of programs:
  - diskeditors/undeleters
  - some AV programs?
  - some data bases?
- Besides, access would still be possible from kernel mode
- So we can expect that lots of legal apps would provide their own drivers for raw disk access
- Those drivers would be signed of course, but could be used by attacker as well (no bug is required!).
Possible solutions (2/3)

- Solution #2: Encrypt pagefile!
- Generate encryption key while system starts and keep it in kernel non-paged memory. Do not write it to disk nor to the registry!
- Big (?) performance impact
- Encrypt only those pages which were paged from ring0, keep ring3 pages unencrypted
- Sounds better, still introduces some performance impact (not sure how much though)
- You can actually enable PF encryption in a registry in Vista! (performance impact unknown)
Solution #3: Disable kernel memory paging!

Disadvantage: wasting precious physical memory…

On the other hand:

- is RAM really so precious these days?
- BTW, you can manually disable kernel memory paging in registry!
- But it can be enabled again (reboot required), so it’s not a good solution.
Bottom line

- The presented attack does not rely on any implementation bug nor on any undocumented functionality.
- MS did a good thing towards securing kernel by implementing signature check mechanism.
- The fact that this mechanism was bypassed does not mean that Vista is completely insecure (it’s just not that secure as it’s advertised).
- It’s very difficult to implement a 100% efficient kernel protection in a general purpose operating system.
Part II – Blue Pill
Invisibility by Obscurity

- Current malware is based on a concept...
- e.g. *FU* unlinks EPROCESS from the list of active processes in the system
- e.g. *deepdoor* modifies some function pointers inside NDIS data structures
- … etc…
- Once you know the *concept* you can write a detector!
- This is boring!
Imagine a malware...

- …which does not rely on a concept to remain undetected…
- …which can not be detected, even though its algorithm (concept) is publicly known!
- …which can not be detected, even though it’s code is publicly known!

- Does this reminds you a modern crypto?
Blue Pill Idea

- Exploit AMD64 SVM extensions to move the operating system into the virtual machine (do it ‘on-the-fly’)
- Provide thin hypervisor to control the OS
- Hypervisor is responsible for controlling “interesting” events inside guest OS
AMD64 & SVM

- Secure Virtual Machine (AMD SVM) Extensions (AKA Pacifica)
- May 23rd, 2006 – AMD releases Athlon 64 processors based on socket AM2 (revision F)
- AM2 based processors are the first to support SVM extensions
- AM2 based hardware is available in shops for end users as of June 2006
SVM

- SVM is a set of instructions which can be used to implement Secure Virtual Machines on AMD64
- MSR EFER register: bit 12 (SVME) controls whether SVM mode is enabled or not
- EFER.SVME must be set to 1 before execution of any SVM instruction.

Reference:
The heart of SVM: VMRUN instruction
Blue Pill Idea (simplified)

- CALL bluepill
  - Native Operating System

PROC bluepill
- enable SVM
- prepare VMCB

VMRUN
- check VMCB.exitcode

VMCB
- RIP

Blue Pill Hypervisor
- only during first call

RET

Native Operating System continues to execute, but inside Virtual Machine this time…

RET from bluepill PROC, never reached in host mode, only executed once in guest mode
BP installs itself ON THE FLY!

- The main idea behind BP is that it installs itself on the fly.
- Thus, no modifications to BIOS, boot sector or system files are necessary.
- BP, by default, does not survive system reboot.
- But this is not a problem:
  - servers are rarely restarted
  - In Vista the ‘Power Off’ button does not shut down the system – it only puts it into stand by mode!
- And also we can intercept (this has not been yet implemented):
  - restart events (hypervisor survives the reboot)
  - shutdown events (emulated shutdown)
SubVirt Rootkit

- SubVirt has been created a few months ago by researchers at MS Research and University of Michigan
- SubVirt uses commercial VMM (Virtual PC or VMWare) to run the original OS inside a VM
SubVirt vs. Blue Pill

- SV is permanent! SV has to take control before the original OS during the boot phase. SV can be detected off line.

- SV runs on x86, which does not allow for full virtualization (e.g. SxDT attack)
- SV is based on a commercial VMM, which creates and emulates virtual hardware. This allows for easy detection

- Blue Pill can be installed on the fly – no reboot nor any modifications in BIOS or boot sectors are necessary. BP can not be detected off line.

- BP relies on AMD SVM technology which promises full virtualization
- BP uses ultra thin hypervisor and all the hardware is natively accessible without performance penalty
Matrix inside another Matrix

What happens when you install Blue Pill inside a system which is already bluepilled?

If nested virtualization is not handled correctly this will allow for trivial detection – all the detector would have to do was to try creating a test VM using a VMRUN instruction.

Of course we can cheat the guest OS that the processor does not support SVM (because we control MSR registers from hypervisor), but this wouldn’t cheat more inquisitive users ;)

So, we need to handle nested VMs…
Nested VMs

- Hypervisor
- VM 1
- VM 2

VMCB1 → VMRUN → VMCB2

Creating new VM on behalf of the VM1

VMCB1 → VMRUN

Allow VM1 to handle VM2's events

intercepted event

time
Detection via timing analysis

We can assume that some of the instructions are always intercepted by the hypervisor

- VMMCALL
- RDMSR – to cheat about the value of EFER.SVME bit

So, not surprisingly, the time needed to execute RDMSR to read the value of EFER would be different (longer) when running from guest

Detector can execute such instructions a few millions of times and measure the time.
The first problem is that detector (usually) does not have a base line to compare the results with…

But even if it had (e.g. when testing access to physical pages and while one of them being backed up by disk) still we can cheat it!

SVM offers a way to fool the guest’s time stamp counter (obtained using RDTSC).

All we have to do is to adjust VMCB.TSC_OFFSET accordingly before executing VMRUN (which resumes the guest)
Time dilatation for guest

Hypervisor → VMRUN → VMRUN

VM

Intercepted Event, e.g. RDMSR

(tx = extra time)

Set VMCB.TSC_OFFSET = -tx

Next instruction in guest after the one which caused interception, e.g. RDTSC
Getting the real time...
Now imagine that you need to check 1000 computers in your company using the “external” stopwatch…

Now imagine that you need to do this a couple of times every day…

Time dilatation should make it impossible to write a self-sufficient detector based on timing analysis!

The challenge: we need a good ‘calibrating’ mechanism so that we know how much time to subtract.
Blue Pill based malware

- Blue Pill is just a way of silently moving the running OS into Matrix on the fly
- BP technology can be exploited in many various ways in order to create stealth malware
- Basically ‘sky is the limit’ here :) 
- On the next slides we present some simple example:
Delusion Backdoor

- Simple Blue Pill based network backdoor
- Uses two DB registers to hook:
  - ReceiveNetBufferListsHandler
  - SendNetBufferListsComplete
- Blue Pill takes care about:
  - handling #DB exception (no need for IDT[1] hooking inside guest)
  - protecting debug registers, so that guest can not realize they are used for hooking
- Not even a single byte is modified in the NDIS data structures nor code!
- Delusion comes with its own TCP/IP stack based on lwIP
Delusion Demo (Blue Pill powered)

Attacker connecting to Delusion backdoor

Internet

Delusion/Blue Pill installed

serial connection (null modem)

Blue Pill debugging/tracing
Blue Pill detection

- Two level of stealth:
  - level 1: can not be detected even though the concept is publicly known (BPL1)
  - level 2: can not be detected even if the code is publicly known (BPL2)
- Level 1 does not requite BP’s pages protection
- Level 2 is about avoiding signature based detection
- Level 2 is not needed in targeted attacks
- BPL2 has not been implemented yet!
Generic BP detection

- If we could come up with a generic program which would detect SVM virtual mode then…
- it would mean that SVM/Pacifica design/implementation does not support full virtualization!
- To be fair: AMD does not claim full virtualization in SVM documentation – it only says it is ‘Secure VM’… However it’s commonly believed that SVM == full virtualization…
Blue Pill detection

- We currently research some theoretical generic attacks against BPL1.
- It seems that the attack would only allow for crashing the system if its bluepilled.
- It seems that the only attack against BPL2 would be based on timing analysis (or crashing when some special conditions will be met, like e.g. user removing SATA disk in a specific moment during tests).
Pacifica vs. Vanderpool

- Pacifica (SVM) and Vanderpool (VT-x) are not binary compatible
- However they seem to be very similar
- XEN even implements a common abstraction layer for both technologies
- It seems possible to port BP to Intel VT-x
Blue Pill Prevention

- Disable it in BIOS
  - Its better not to buy SVM capable processor at all!
- Hypervisor built into OS
  - What would be the criteria to allow 3\textsuperscript{rd} party VMM (e.g. VMWare or some AV product) to load or not?
  - Or should we stuck with “The Only Justifiable VMM”, provided by our OS vendor? ;)
- Not allowing to move underlying OS \textit{on the fly} into virtual machine
  - would not solve the problem of permanent, “classic” VM based malware
- or maybe another hardware solution…”
Hardware Red Pill?

- How about creating a new instruction – `SVMCHECK`:
  
  ```
  mov rax, <password>
  svmcheck
  cmp rax, 0
  jnz inside_vm
  ```

- Password should be different for every processor
- Password is necessary so that it would be impossible to write a *generic* program which would behave differently inside VM and on a native machine.
- Users would get the passwords on certificates when they buy a new processor or computer
- Password would have to be entered to the AV program during its installation.
Future work

- Implement nested VMs
- Implement time dilatation for guest
- Intercept restart and shutdown events (controlled restart, emulated shutdown)
- Support for multi-core processors
- Implement BPL1 using Intel VT-x
- Implement Blue Pill Level 2 (BPL2)
Bottom line

- Arbitrary code can be injected into Vista x64 kernel (provided attacker gained administrative rights)
- This could be abused to create Blue Pill based malware on processors supporting virtualization
- BP installs itself on the fly and does not introduce any modifications to BIOS nor hard disk
- BP can be used in many different ways to create the actual malware – Delusion was just one example
- BP should be undetectable in any practical way (when fully implemented)
- Blocking BP based attacks on software level will also prevent ISVs from providing their own VMMs and security products based on SVM technology
- Changes in hardware (processor) could allow for easy BP detection
References

- Dino Dai Zovi, *Hardware Virtualization Rootkits*, Black Hat USA 2006 (very similar work to Blue Pill but for Intel VT-x, developed independently)

- MS Research and University of Michigan, *SubVirt: Implementing malware with virtual machines* (non-hardware virtualization malware)
Credits

- Neil Clift for interesting discussions about Windows kernel
- Edgar Barbosa for preparing shellcode for the kernel strike attack
  - Edgar joined COSEINC AML at the end of June!
- Alexander Tereshkin AKA 90210 for thrilling discussions about Blue Pill detection
  - Alex is going to join COSEINC AML in August!
- Brandon Baker for interesting discussions about Virtualization
Thank you!

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check out http://coseinc.com/
for information about available trainings!