12. Malicious Software

Computer Security Courses @ POLIMI

Prof. Carminati & Prof. Zanero

What is “malware”?

- A *portmanteau* of “malicious software”
  - Meaning: **code that is intentionally written to violate a security policy.**
- Several "categories", or "features":
  - **Viruses:** code that **self-propagate** by infecting other files, usually executables (but also documents with macros, boot loader). They are not standalone programs (i.e.,executables).
  - **Worms:** programs that **self-propagate**, even remotely, often by exploiting host vulnerabilities, or by social engineering (e.g., mail worms).
  - **Trojan horses:** apparently benign program that hide a malicious functionality and allow remote control.

A Brief History of Malware...Viruses

1971 – **Creeper** is first self-replicating program on PDP-10

1981 – First outbreak of **Elk Cloner** on Apple II floppy disks

1983 – The first documented experimental virus (Fred Cohen‘s pioneering work; name coined by Len Adleman)

1987 – **Christmas worm** (mass mailer) hit IBM Mainframes (500,000 replications/hour) -> paralyze many networks

1988 – **Internet worm** (November 2, 1988): created by Robert **Morris** Jr. - birth of CERT

1995 – Concept virus, the **first macro virus**

1998 – Back Orifice, the **trojan** for the IRC masses -> to demonstrate the lack of security in MS systems

1999 – **Melissa** virus (large-scale email macro-virus)

…Turning Into an History of Worms

1999 – First DDoS attacks via trojaned machines (zombies)

1999 – Kernel Rootkits become public (Knark, modification of system call table)

2000 – ILOVEYOU (large-scale email worm) - Social Engineering

2001 – **Code Red** (large-scale, exploit-based worm)

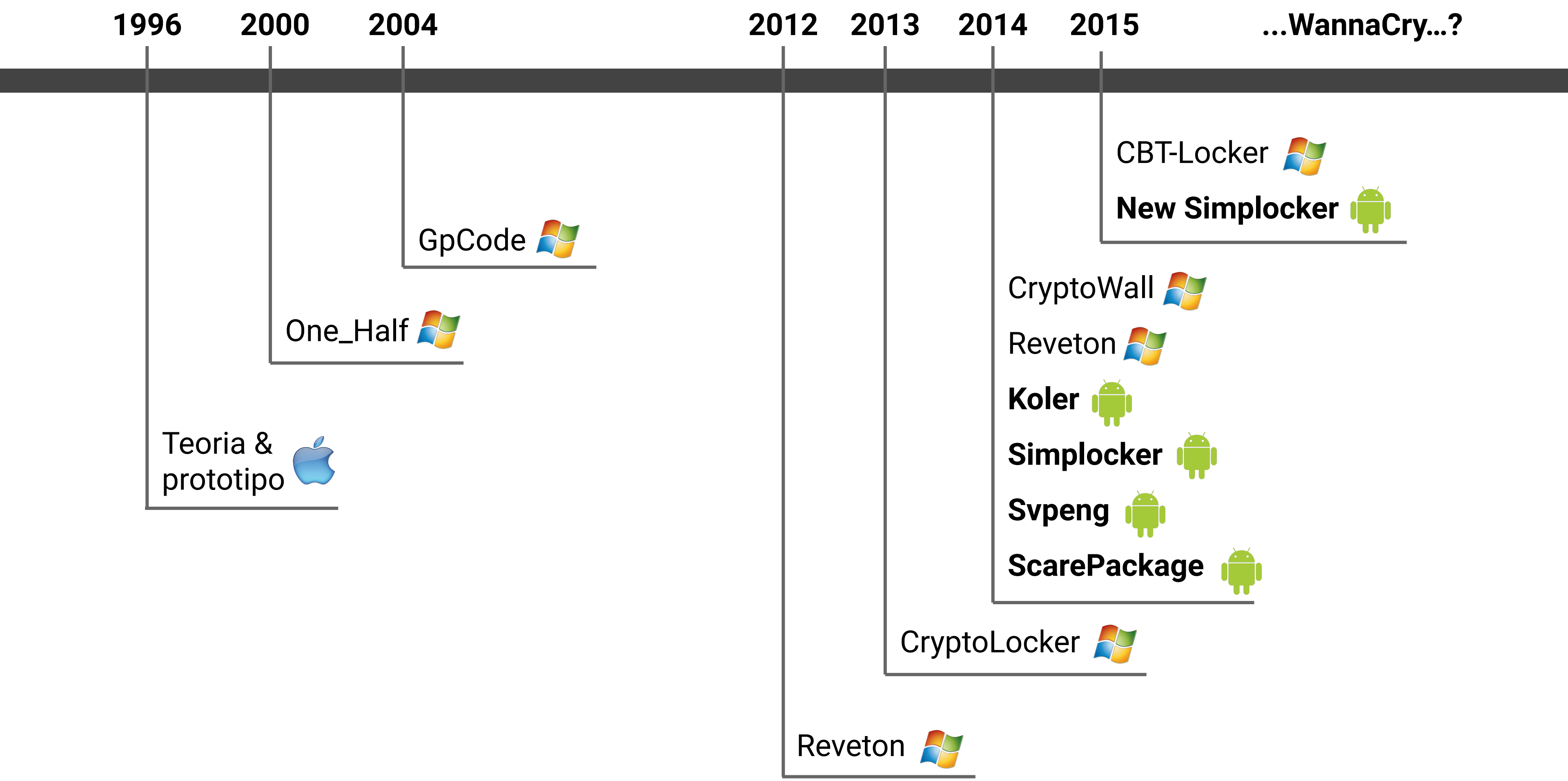
2003 – **SQL Slammer** worm (extremely fast propagation through UDP)

2004+ **– Malware that create botnet infrastructures**

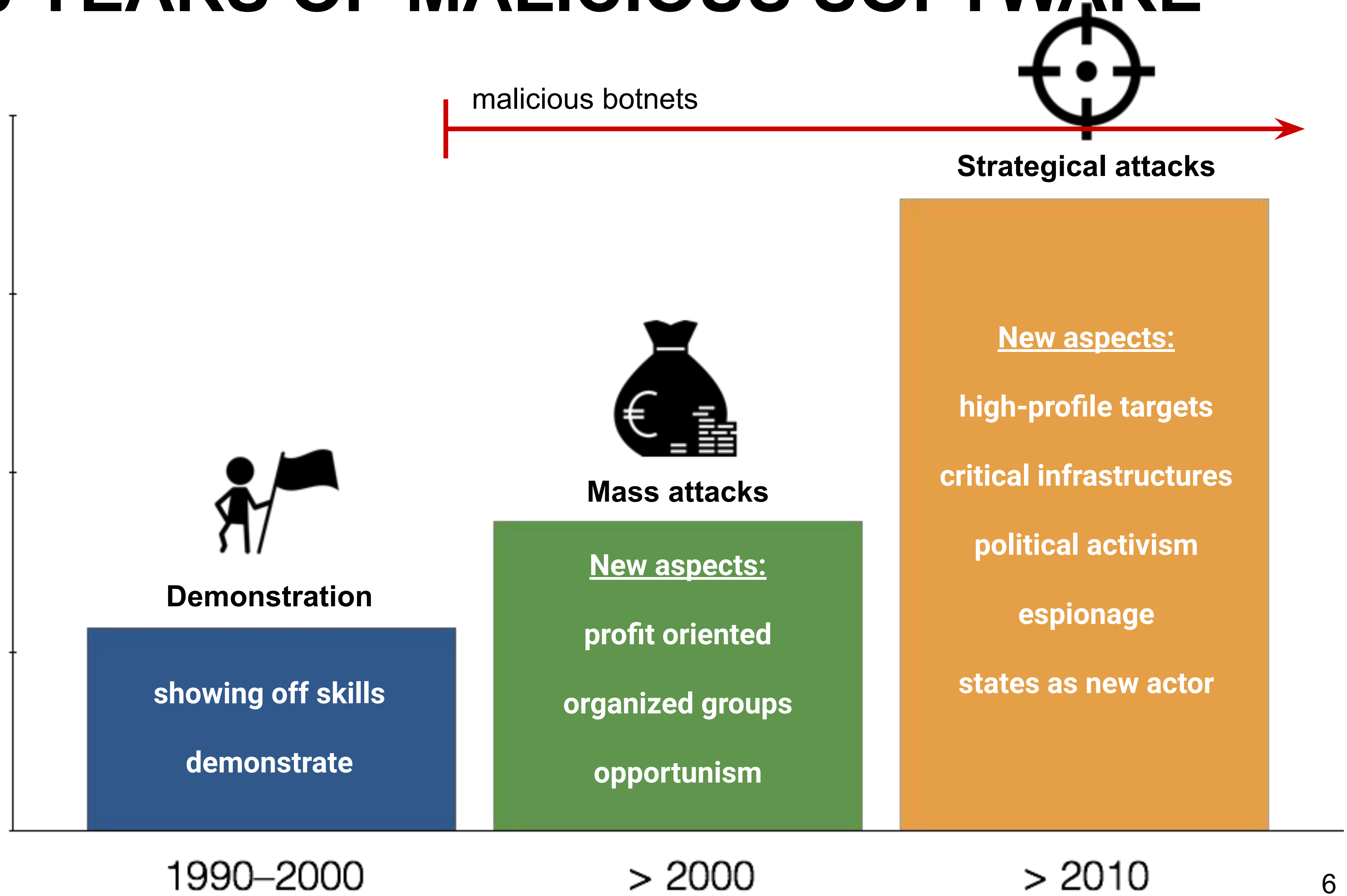
(e.g., Storm Worm, Torpig, Koobface, Conficker, Stuxnet)

2010+ – Scareware, Ransomware and State-sponsored malware

BRIEF HISTORY OF RANSOMWARE



30 YEARS OF MALICIOUS SOFTWARE



Theory of Computer Viruses

- Fred Cohen ('83), theorized the existence and produced the first examples of viruses
    - From a theoretical computer science point of view, interesting concept of **self modifying** and **self propagating code**.
    - Soon, the security challenges were understood.
- It is **impossible** to build the **perfect virus detector** (i.e., propagation detector)
    - Let **P** be a perfect detection program
    - Let **V** be a virus that calls **P** on itself:
        - if **P**(**V**) = True ~> **V** halt (does not spread) -> **V** is not a virus
        - if **P**(**V**) = False ~> **V** spread -> **V** is a virus

The Malicious Code Lifecycle

Reproduce, infect, stay hidden, run **payload**

Reproduction and Infection phase

- Balance **infection versus detection** possibility
- Need to identify a suitable **propagation vector** (may be social engineering, vulnerability exploits)
  - Need to infect files (viruses only) and propagate to other machines
- **Note:** most modern malware does not self-propagate at all (most bots and trojans).

Variety of techniques to stay hidden.

Payload: sometimes harmful.

https://www.youtube.com/watch?v=v1-jNkzBx_M

https://youtu.be/966O0sXubxw

https://www.youtube.com/watch?v=gN7JKHOVnJ0

https://youtu.be/LSgk7ctw1HY --- https://www.youtube.com/watch?v=HajECunjYjM&t=448s

Infection Techniques

- **Boot viruses**
  - Master Boot Record (MBR) of hard disk (first sector on disk) or boot sector of partitions
    - e.g., Brain, nowadays Mebroot/Torpig
  - Rather old, but interest is growing again
    - diskless workstations, virtual machines (SubVirt)
- **File infectors**
  - <u>simple overwrite virus</u> (damages original program)
  - <u>parasitic virus</u>
    - append code and modify program entry point
  - <u>(multi)cavity virus</u>
    - inject code in unused region(s) of program code

“Macro” Viruses

- Data files traditionally safe from viruses
- Macro functionality blurs the line between data and code
- **Example:** spreadsheet macros can
  - Modify a spreadsheet
  - Modify other spreadsheets
  - Access address book
  - Send email
  - ...
- *Successful example*: the Melissa virus.
- Difficult to remove

Worms

- How 99 lines of code brought down the Internet (ARPANET actually) in Nov. 1988
- Robert Morris Jr. (at the time a Ph.D student at Cornell), wrote a program that could:
  - Connect to another computer, and find and use one of several vulnerabilities (e.g., buffer overflow in fingerd, password cracking) to copy itself to that second computer.
  - Begin to run the copy of itself at the new location.
  - Both the original code and the copy would then repeat these actions in an infinite loop to other computers on the ARPANET (**mistake**!)

Mass-mailers: Rebirth of the Worms

- Email software started allowing attached files, including:
  - Executables (dancing bears)
  - Executables masquerading as data
    - E.g. "LOVE-LETTER-FOR-YOU.txt.vbs"
- Spread by emailing itself to others
  - Use address book to look more trustworthy
- Modern variations include social networks to spread (e.g., ever received a suspicious-looking Twitter message/ facebook post from a friend?)

Modern Worms: Mass Scanners

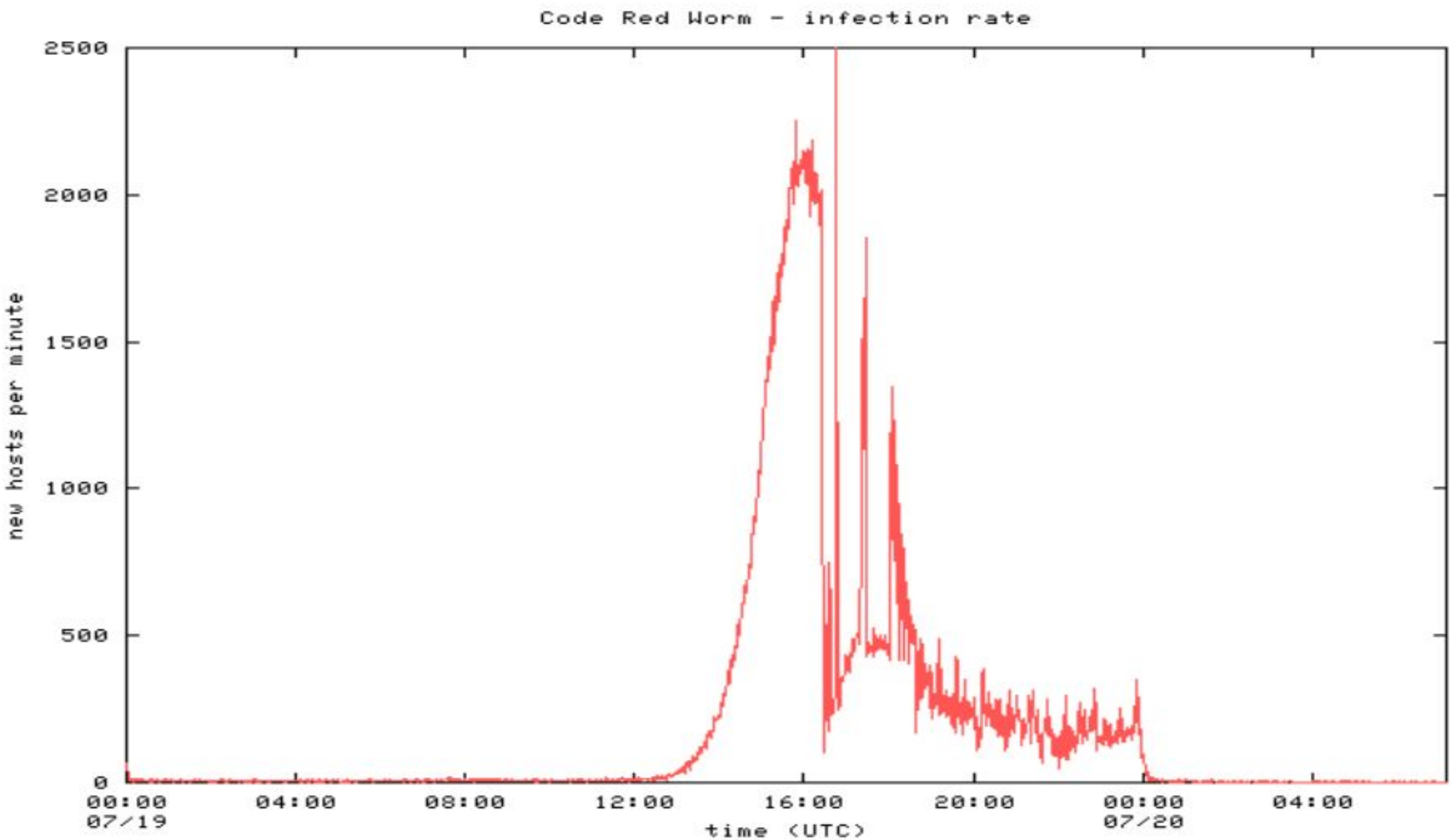
- Basic pattern the same:
  - Infect a computer and seek out new targets.
- Faster spread (minutes), larger scale (hundreds of thousands of hosts)
- Scanning
  - Select random address
  - Local preference: more scans towards local network
  - Permutation scanning (divide up IP address space)
  - Hit list scanning
  - Warhol worm: Hit list + permutation

Paper "How to 0wn the Internet in your spare time", http://www.icir.org/vern/papers/cdc-usenix-sec02/)

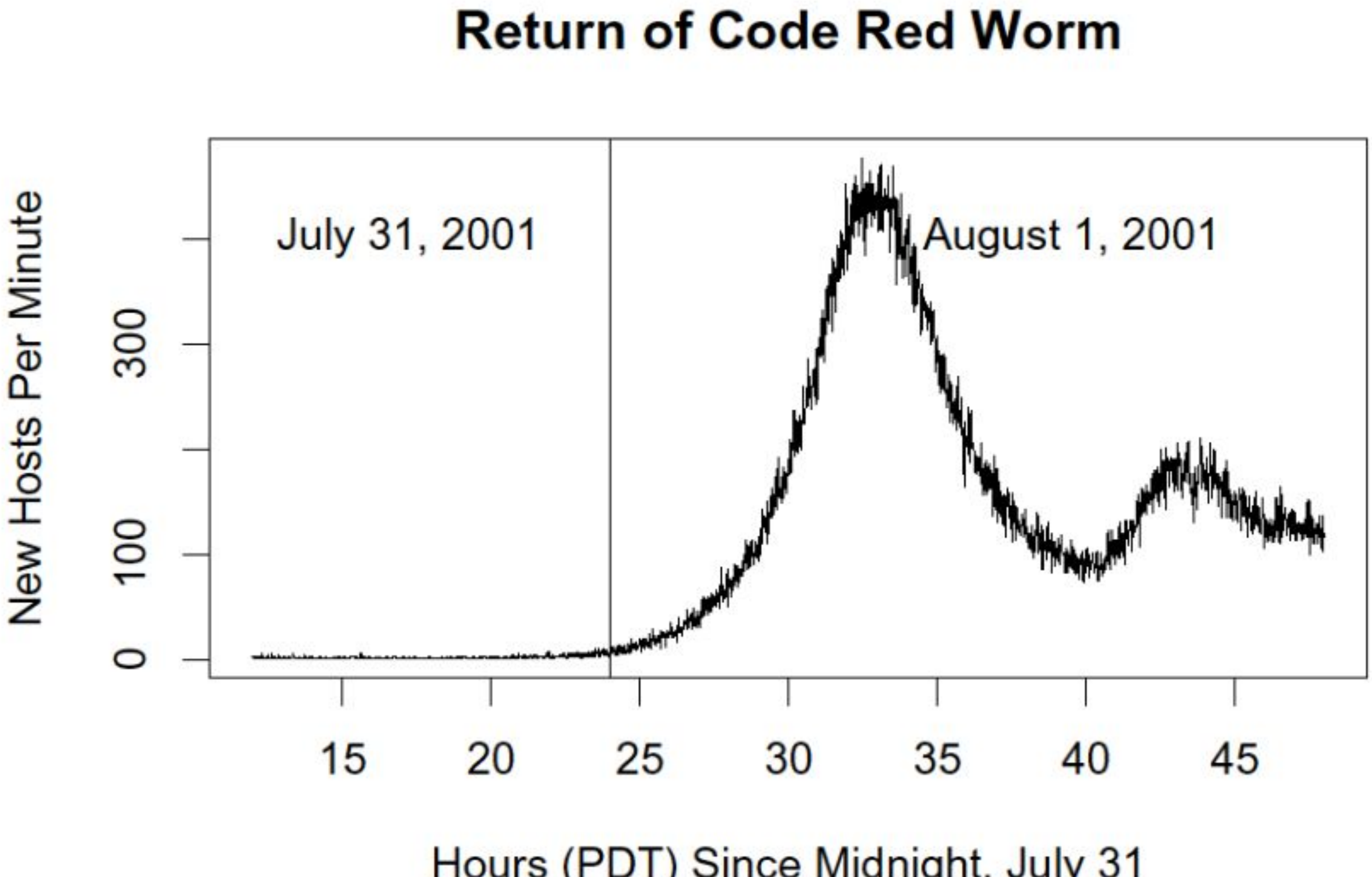
Worm history

Worm	Date	Distinction
Morris	11/88	Used multiple vulnerabilities, first one :)
ADM	5/98	Random scanning of IP address space
Lion	3/01	Stealthy, rootkit worm
Cheese	6/01	Vigilante worm that secured vulnerable systems
Code Red	7/01	Completely memory resident
Walk	8/01	Recompiled source code locally
Nimda	9/01	Windows worm: client-to-server, c-to-c, s-to-s
Scalper	6/02	11 days after announcement of vulnerability; peer-to-peer network of compromised systems
Slammer	1/03	Used a single UDP packet for explosive growth

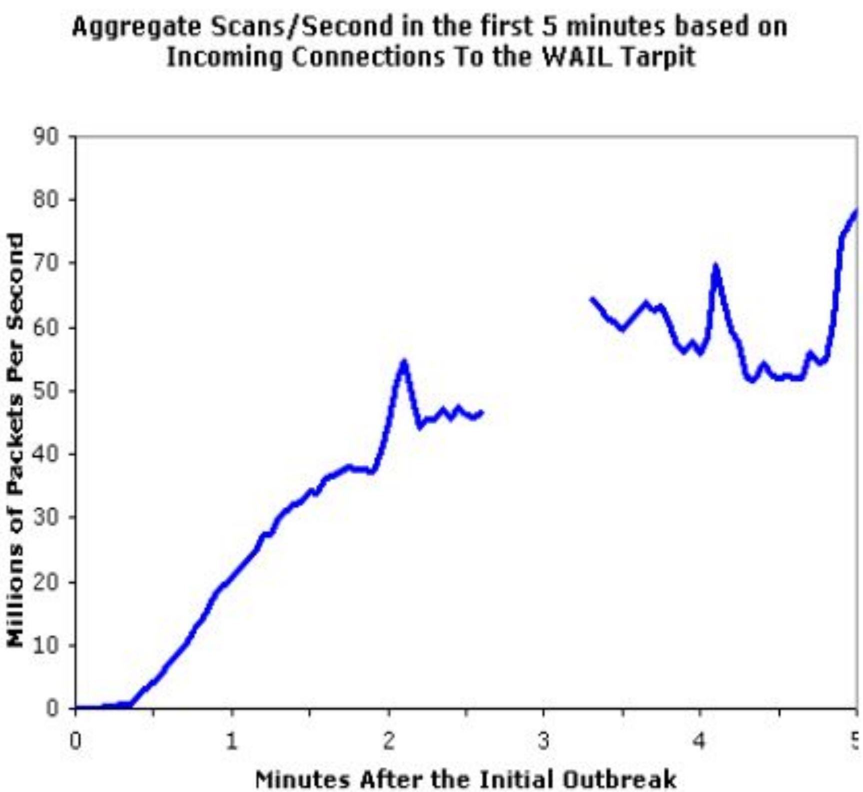
Code Red: Propagation

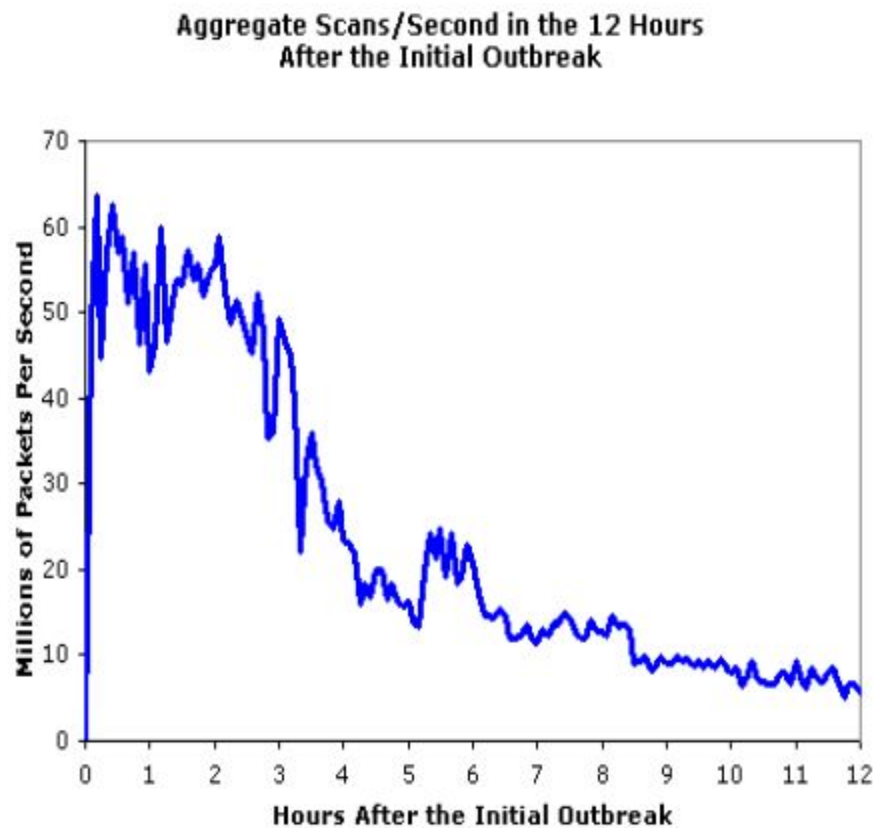


Code Red: Reactivation



Slammer: UDP Propagation Disaster





Silence on the Wires

- We all thought that the Internet would get "wormier"
- Since 2004, "silence on the wires". No new "major" worm outbreaks
    - Weaponizable vulnerabilities were there, we even collectively braced for impact a couple of times :-)

Where did the worm writers disappear?

Similar Questions…

- Why no worm has ever targeted the Internet infrastructure?
  - Traditional worm for propagation + specialized payload for infrastructure damage
- Windows of opportunity were there:
  - June 2003: MS03-026, RPC-DCOM Vulnerability (Blaster) + Cisco IOS Interface Blocked by IPv4 pkts
  - April 2004: MS04-011, LSASS Vulnerability (Sasser) + TCP resets on multiple Cisco IOS products
- So why **`/bin/laden`** did not strike?

Similar Questions…

- Why no worm has ever targeted the Internet infrastructure?
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- So why `/bin/laden` did not strike?
  - Answer: **lack of motivation, attackers need the infrastructure to be up to do their stuff.**

…similar answer!

- The attackers are now interested in **monetizing** their malware
- **Direct** monetization (e.g., abuse of credit cards, connection to premium numbers)
- **Indirect** monetization
  - Information gathering
  - abuse of computing resources
  - rent or sell botnet infrastructures

All of this created a growing **underground** (black) **economy.**

The Cybercrime Ecosystem

- Organized groups
- Various "activities"
  - exploit development and procurement
  - site infection
  - victim monitoring
  - selling "exploit kits"
  - ...they also offer support to their clients.
- Further reading

  "Manufacturing Compromise: The Emergence of Exploit-as-a-Service"

  http://cseweb.ucsd.edu/~voelker/pubs/eaas-ccs12.pdf

Introducing Bots!

The Jargon File, version 4.4.7:

bot: n [common on IRC, MUD and among gamers; from "robot"]

1. An IRC or MUD user who is actually a program. On IRC, typically the robot provides some useful service.Examples are NickServ, which tries to prevent random users from adopting nicks already claimed by others, and MsgServ, which allows one to send asynchronous messages to be delivered when the recipient signs on.

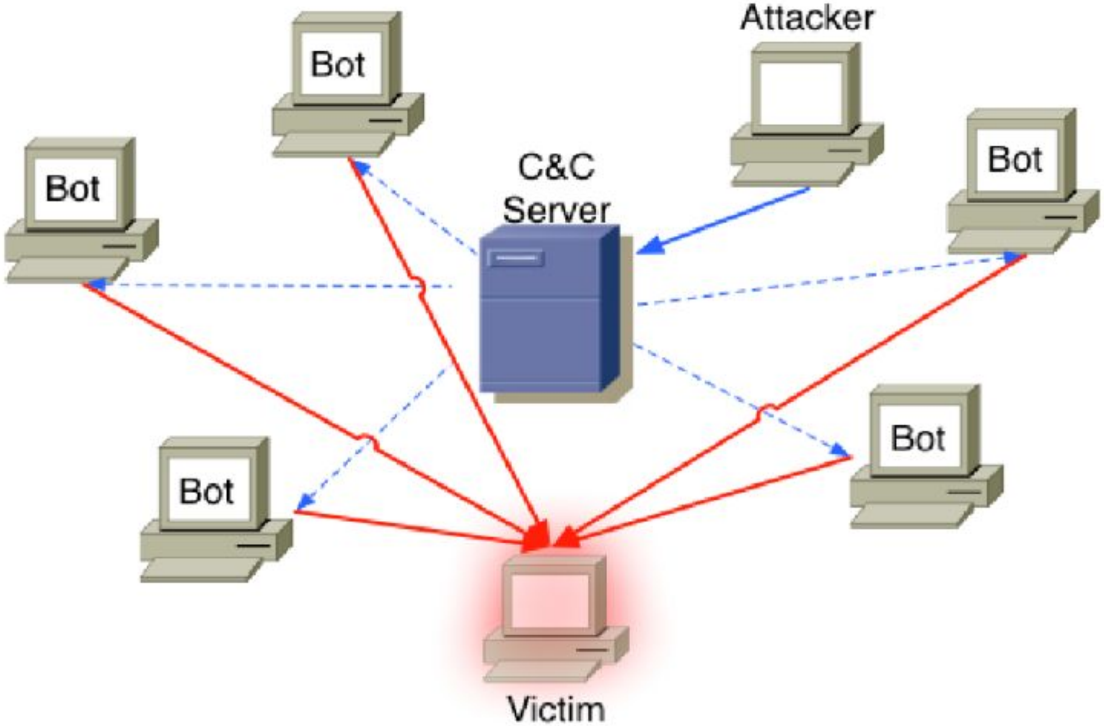
[...]

Rise of the Bots

- Abuse of IRC bots (IRCwars):
  - IRCwars: one of the first documented DDoS attacks
- 1999: trinoo "DDoS attack tool"
  - originally ran on Solaris (later ported to Windows)
  - setup of the botnet was mostly manual
  - August 1999: DDoS attack against a server at University of Minnesota using at least 227 bots (http://staff.washington.edu/dittrich/misc/trinoo.analysis)
- 2000s: DDoS attacks against high profile websites (Amazon, CNN, eBay) got huge media coverage

Botnets

A **botnet** is a network that consists of several malicious bots that are controlled by a commander, commonly known as botmaster (botherder).



Examples of commands: Phatbot

- harvest email addresses from host
- log all keypresses
- sniff network traffic
- take screenshots
- start an http server that allows to browse C:
- kill a hard-coded list of processes
  - AV programs
  - rival malware
- steal windows CD keys
  - also keys to popular games
- Socks proxy
  - sets up a proxy to be used as a "stepping stone" for SPAM
- download file at an url
- run a shell command
- Update
  - allows to change the available commands!

Threats posed by bot(net)s

- **For the infected host**: information harvesting
    - Identity data
    - Financial data
    - Private data
    - E-mail address books
    - Any other type of data that may be present on the host of the victim.
- **For the rest of the Internet**
    - Spamming
    - DDoS
    - Propagation (network or email worm)
    - Support infrastructure for illegal internet activity (the botnet itself, phishing sites, drive-by-download sites)

Further Reading

To read more on botnets, C&C strategies and botnet tracking or takedowns

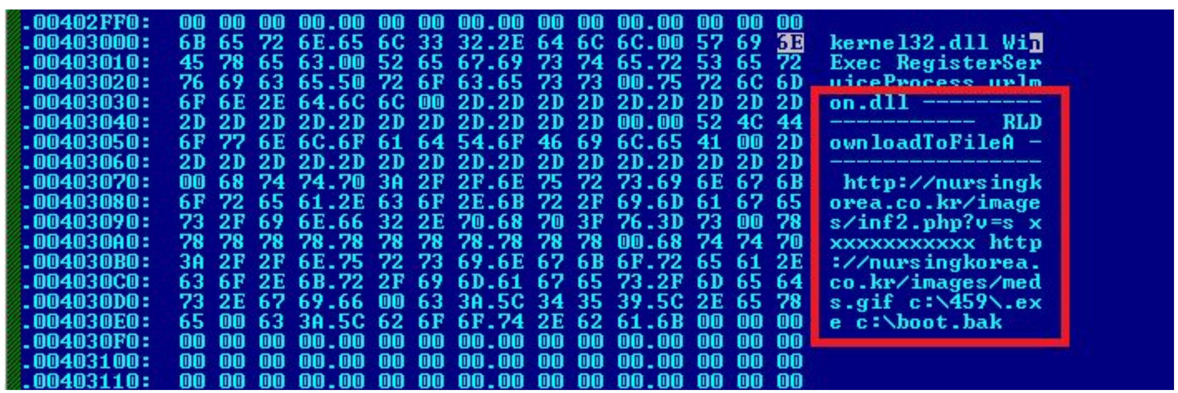
- Your botnet is my botnet: taking over the Torpig botnet https://seclab.cs.ucsb.edu/academic/projects/projects/your-botnet-my-botnet/
- Tracking and Characterizing Botnets Using Automatically Generated Domains (Stefano Schiavoni, Federico Maggi, Lorenzo Cavallaro, Stefano Zanero) http://arxiv.org/abs/1311.5612
- If you're interested, we have research thesis projects on these topics.

Defending Against Malware

- **Patches**
  - Most worms exploit known vulnerabilities
  - Useless against zero-day worms
- **Signatures**
  - Must be developed automatically
  - Worms operate too quickly for human response
- **Intrusion** or **anomaly detection**
  - Notice fast spreading, suspicious activity.
  - Can be a driver to automated signature generation

Antivirus and Anti-malware

- Basic strategy: **signature-based detection**
  - database of byte-level or instruction-level signatures that match known malware
  - wildcards can be used, regular expressions common



Virus Name	*String Pattern (Signature)*
Accom.1280	89C3 B440 8A2E 2004 8A0E 2104 BA00 05CD 21E8 D500 BF50 04CD
Die.448	B440 B9E8 0133 D2CD 2172 1126 8955 15B4 40B9 0500 BA5A 01CD
Xany.979	8B96 0906 B000 E85C FF8B D5B9 D303 E864 FFC6 8602 0401 F8C3

Antivirus and Anti-malware

- Basic strategy: **signature-based detection**
  - database of byte-level or instruction-level signatures that match <u>known</u> malware
  - wildcards can be used, regular expressions common
- **Heuristics** (check for signs of infection)
  - code execution starts in last section
  - incorrect header size in PE header
  - suspicious code section name
  - patched import address table
- **Behavioral Detection**
  - detect signs (behavior) of known malware
  - detect “common behaviors” of malware

A Note on Malicious Behaviors

Summary:

Description	Risk
Changes security settings of Internet Explorer: This system alteration could seriously affect safety surfing the World Wide Web.	
Creates files in the Windows system directory: Malware often keeps copies of itself in the Windows directory to stay undetected by users.	
Performs File Modification and Destruction: The executable modifies and destructs files which are not temporary.	
Spawns Processes: The executable produces processes during the execution.	
Performs Registry Activities: The executable reads and modifies registry values. It may also create and monitor registry keys.	

Table of Contents

expand all collapse all

- General information
- sample.exe
  - services.exe
  - i1ru74n4.exe
    - Explorer.EXE
      - i1ru74n4.exe

Recognizing Interesting Behaviors

M.Polino, A. Scorti, F. Maggi, S. Zanero, *Jackdaw: Towards Automatic Reverse Engineering of Large Datasets of Binaries*, DIMVA 2015

Paper PDF

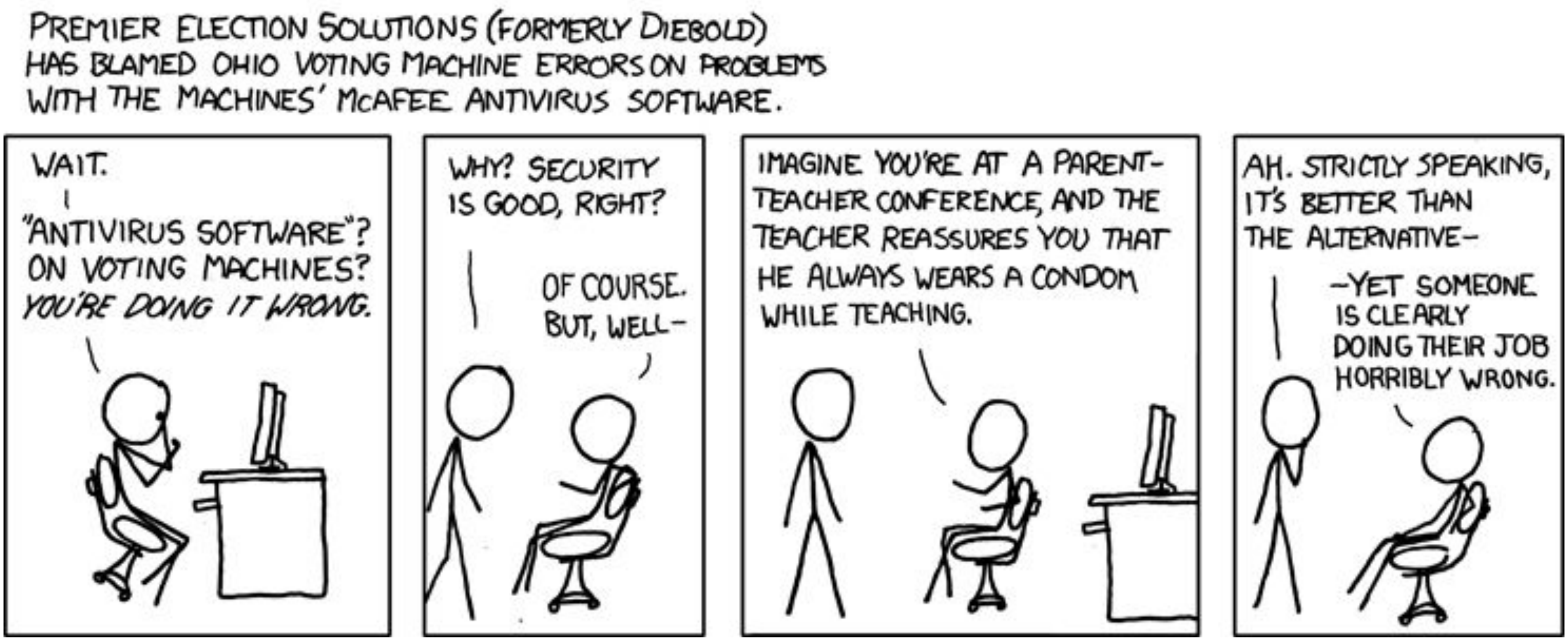
Slides: PDF

```
<dataflow_dependency id="19">
    <call api_function="RegOpenKeyExW"
        caller_address="0x0065006e,0x00b0df8f" id="1"
        objects="ObjectAttributes='hku\s-1-5-21-842925246-1425521274-308236825-500\software
                    \microsoft\internet explorer\privacy',
        SubKey='software\microsoft\internet explorer\privacy'"/>

    <call api_function="RegQueryValueExW"
        caller_address="0x0065006e,0x00b1cb90" id="2"
        objects="ValueName='cleancookies'"/>

    <call api_function="RegOpenKeyExW"
        caller_address="0x0065006e,0x00b0dfb5,0x00b1ca3a" id="3"
        objects="ObjectAttributes='hku\s-1-5-21-842925246-1425521274-308236825-500\software
                    \microsoft\internet explorer\privacy',
        SubKey='software\microsoft\internet explorer\privacy'"/>

    <call api_function="GetProcAddress"
                caller_address="0x0065006e,0x00b0dfb5,0x00b1ca3a">

    <function_boundaries begin="0x00b0de6f" blocks="0x00b0dfb5,0x00b0df8f" end="0x00b0e06f"
        function_name="sub_B0DE6F"/>
    <function_boundaries begin="0x00b1cb7d" blocks="0x00b1cb90" end="0x00b1cba6"
        function_name="sub_B1CB7D"/>
    <function_boundaries begin="0x00b1ca1c" blocks="0x00b1ca3a" end="0x00b1ca6f"
        function_name="sub_B1CA1C"/>
     <path begin="0x00b0de6f" end="0x00b0e06f" function_name="sub_B0DE6F">
</dataflow_dependency>
```

Data-flow propagation

Name normalization

Not everything needs an antivirus



Virus Stealth Techniques

Virus scanners quickly discover viruses by searching around entry point

- **Entry Point Obfuscation**
  - Multicavity viruses
  - virus **hijacks control later** (after program is launched)
    - overwrite import table addresses (e.g., libraries)
    - overwrite function call instructions

Virus and Worm Stealth Techniques (Obfuscation)

- **Polymorphism**
  - change layout (shape) with each infection
  - payload is encrypted (~ packing) using different key for each infection:
    - makes static string analysis practically impossible
    - of course, AV could detect encryption routine

- **Metamorphism**
  - create different “versions” of code that look different but have the same semantics (i.e., do the same)

Metamorphism: dead code insertion

5B 00 00 00 00	pop ebx
8D 4B 42	lea ecx, [ebx + 42h]
51	push ecx
50	push eax
50	push eax
0F 01 4C 24 FE	sidt [esp - 02h]
5B	pop ebx
83 C3 1C	add ebx, 1Ch
FA	cli
8B 2B	mov ebp, [ebx]

5B 00 00 00 00 8D 4B 42 51 50 50 0F 01 4C 24 FE 5B 83 C3 1C FA 8B 2B

Metamorphism: dead code insertion

5B 00 00 00 00	pop ebx
8D 4B 42	lea ecx, [ebx + 42h]
51	push ecx
50	push eax
90	**nop**
50	push eax
40	**inc eax**
0F 01 4C 24 FE	sidt [esp - 02h]
48	**dec eax**
5B	pop ebx
83 C3 1C	add ebx, 1Ch
FA	cli
8B 2B	mov ebp, [ebx]

5B 00 00 00 00 8D 4B 42 51 50 90 50 40 0F 01 4C 24 FE 48 5B 83 C3 1C FA 8B 2B

Metamorphism: instruction reorder

5B 00 00 00 00 EB 09	pop ebx jmp <S1>	1
	S2:	
50 0F 01 4C 24 FE 5B EB 07	push eax sidt [esp - 02h] pop ebx jmp <S3>	3
	S1:	
8D 4B 42 51 50 EB F0	lea ecx, [ebx + 42h] push ecx push eax jmp <S2>	2
	S3:	

83 C3 1C
FA
8B 2B
	add ebx, 1Ch
	cli
	mov ebp, [ebx]
		4

```
5B 00 00 00 00 EB 09 1 | 50 0F 01 4C 24 FE 5B EB 07 3 | 8D
4B 42 51 50 EB F0 2 | 83 C3 1C FA 8B 2B 4
```

Malware general stealth techniques

- **Dormant period**
  - During which no malicious behavior is exhibited
    - "Identifying Dormant Functionality in Malware Programs"
- **Event-triggered payload**
  - Often: C&C channel
- **Anti-virtualization techniques**
- **Encryption / Packing**
  - Similar to polymorphism but more advanced techniques are available in more complex malware
- **Rootkit techniques**

Anti-virtualization techniques

- If a program is not run natively on a machine, chances are high that it
  - is being analyzed (in a security lab)
  - scanned (inside a sandbox of an Antivirus product)
  - debugged (by a security specialist)
- Modern malware detect <u>execution environment</u> to complicate analysis
  - <u>virtual machine</u>: very easy (timing, environment detection)
  - <u>hardware supported virtual machine</u>: adjusted techniques, still easy (timing, environment detection)
  - <u>Emulator</u>: theoretically undetectable, practically also easy to detect (timing attack, incomplete specs -> different emulator implementations)

Packing

- **Encrypt** malicious content
- Use small a **encryption/decryption routine** changing the key at each execution
- Typical functions:
  - Compress/Decompress
  - Encrypt/Decrypt
  - Metamorphic components
  - **Anti-debugging techniques**
  - **Anti-VM techniques**
  - Virtualization

Further Readings

Tal Garfinkel, Keith Adams, Andrew Warfield, Jason Franklin, *“Compatibility is Not Transparency: VMM Detection Myths and Realities”*

http://static.usenix.org/legacy/events/hotos07/tech/full_papers/garfinkel/garfinkel_html/

"Lines of Malicious Code:

Insights Into the Malicious Software Industry"

https://www.acsac.org/2012/openconf/modules/request.php?module=oc_program&action=view.php&a=&id=205&type=4

Counteracting Malware: Malware Analysis Overview

Ex-post workflow

1. suspicious executable reported by "someone"
2. automatically analyzed
3. manually analyzed
4. antivirus signature developed

Static analysis

- Parse the executable code
- Pros and Cons
  - + code coverage, dormant code
  - - obfuscation (metamorphism, encryption, packing, ...)

Dynamic analysis

- Observe the runtime behavior of the executable
- Pros and Cons
  - - code coverage, dormant code
  - + obfuscation (metamorphism, encryption, packing, ...)

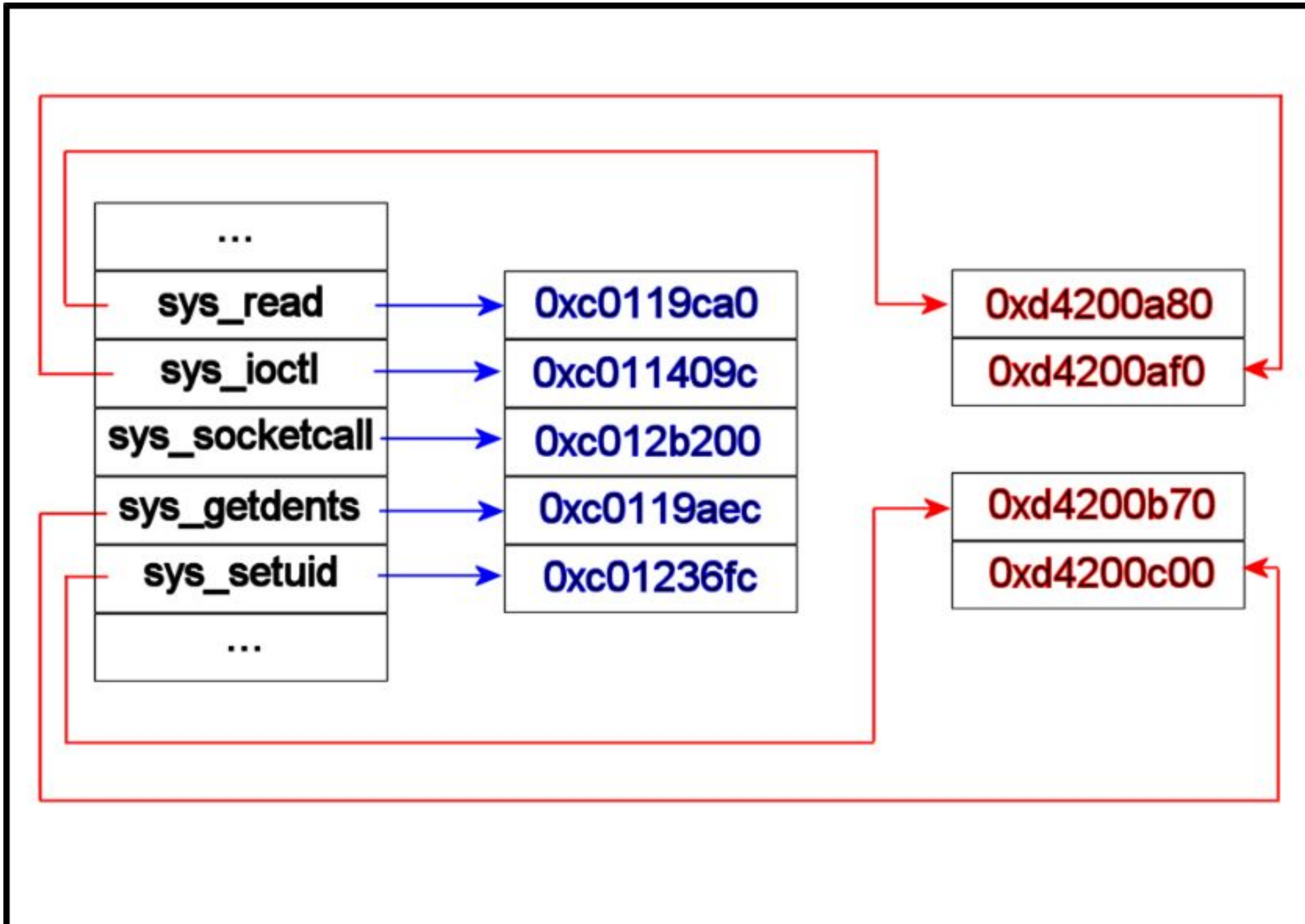
What are Rootkits?

- History: you become **root** on a machine, and you planted your **kit** to remain root
  - Make files, processes, user and directories disappear
  - Make the attacker **invisible**
- Can be either **userland** or **kernel-space**
  - Linux userland rootkit example:
    - Backdoored login, sshd, passwd
    - Trojanized utilities to hide: ps, netstat, ls, find, du, who, w, finger, ifconfig.
  - Windows userland rootkit targets:
    - Task Manager, Process Explorer, Netstat, ipconfig.

From Userland to Kernel Space

- Userland rootkit
  - “easier” to build, but often incomplete
  - easier to detect (cross layer examination, use of non-trojaned tools)
- Kernel space
  - More difficult to build, but can hide artifacts completely
  - Can only be detected via post-mortem analysis
  - Concept was born on 1997, Phrack 50, HalfLife “Abuse of the Linux Kernel for Fun and Profit”
    - First implementation of syscall hijacking
  - 1998, plaguez, “Weakening the Linux Kernel”, first complete LKM rootkit

Syscall hijacking

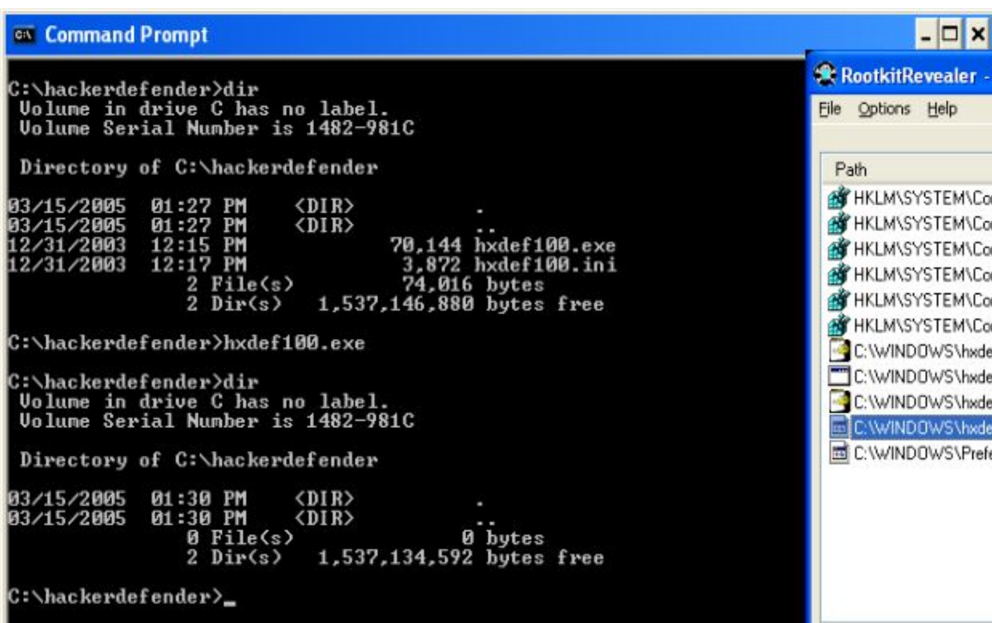


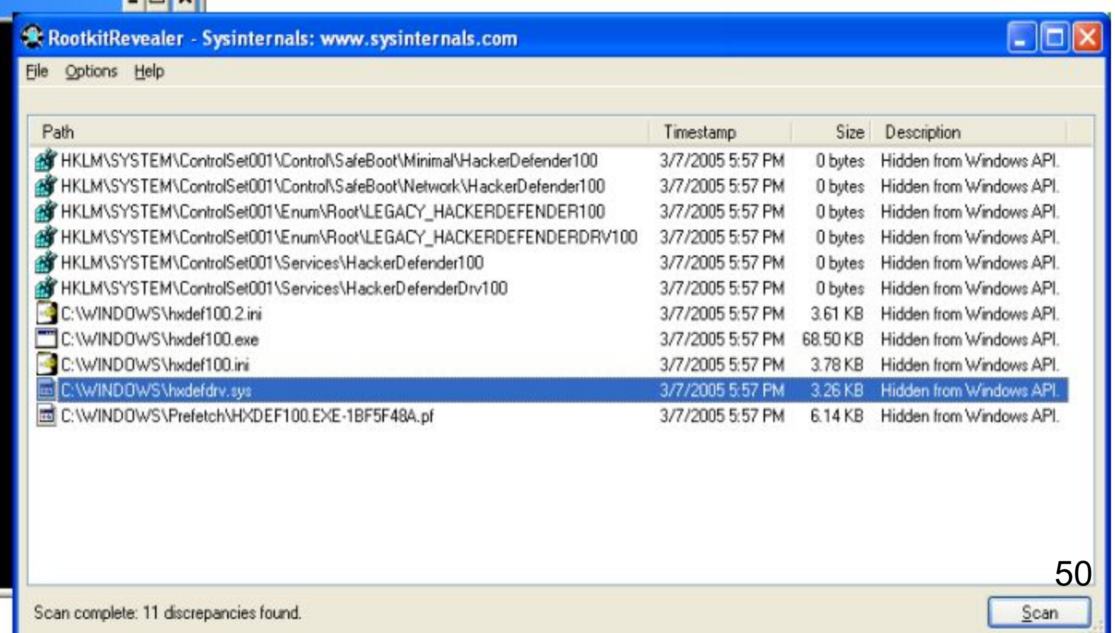
Methods for Hijacking Those Calls

- Methods
  - Hook SYS_CALL Table, Interrupt Descriptor Table, o Global Descriptor Table
    - After in kernel 2.6 SYS_CALL table was hidden, scanning the IDT looking for a FAR JMP *0x<syscall table address>[eax]
  - Detour Patching
  - Directly patch through /dev/mem or /dev/kmem (Silvio Cesare showed it possible even with monolithic kernel)
- Exercise or self-research: How to detect?

Methods for Recognizing Rootkits

- Intuition (“Hmmmm…that’s funny…”)
- Post-mortem on different system
- Trusted computing base / tripwire / etc.
- Cross-layer examination





It can get even more complex

- **Rootkit in BIOS**
  - In ACPI, John Heasman
  - CMOS, eEye bootloader
  - Bootkit which is not even in the BIOS (Brossard)
- **Rootkit on firmware** of NIC or Video Card
- **Rootkits in virtualization systems** (how do you recognize a rootkit which acts as an hypervisor?)