CSCE 465 Computer & Network Security

Instructor: Sungmin Kevin Hong

http://people.tamu.edu/~ghitsh/csce465/spring2019

Malware

Roadmap

- Malware basics
- Worms and examples
- Botnets and examples

Malicious Programs

- Needs host program
  - trap doors
  - logic bombs
  - Trojan horses
  - Viruses
  - Browser plugins, extensions, scripts

- Independent
  - Worms
  - bots

Trap doors

- A secret entry point to a program or system.

- Typically works by recognizing some special sequence of inputs or special user ID.

Logic bombs

- Embedded in some legitimate programs.

- Explode or perform malicious activities when certain condition are met.

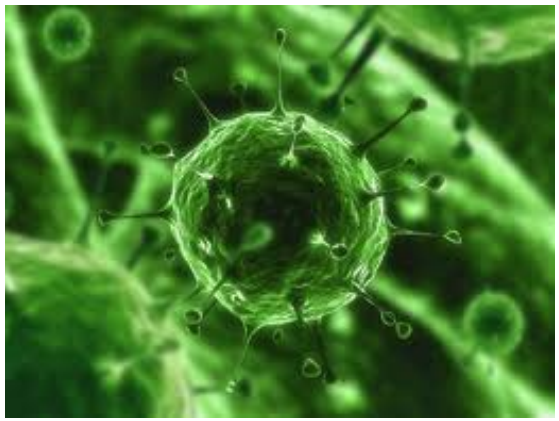
Trojan horses

- Hidden in an apparently useful host program

- Performs some unwanted/harmful function when the host program is executed.

Viruses

- "Infect" a program by **modifying** it
- Self-copied into other programs to spread
- Four stages:
  - dormant phase
  - propagation phase
    - E.g., attachment to email
  - triggering phase
  - execution phase



Host-required Malware quiz

Determine which category each of these belongs to:

( ) An email attachment that when being opened will send itself to all people in the user's address book.

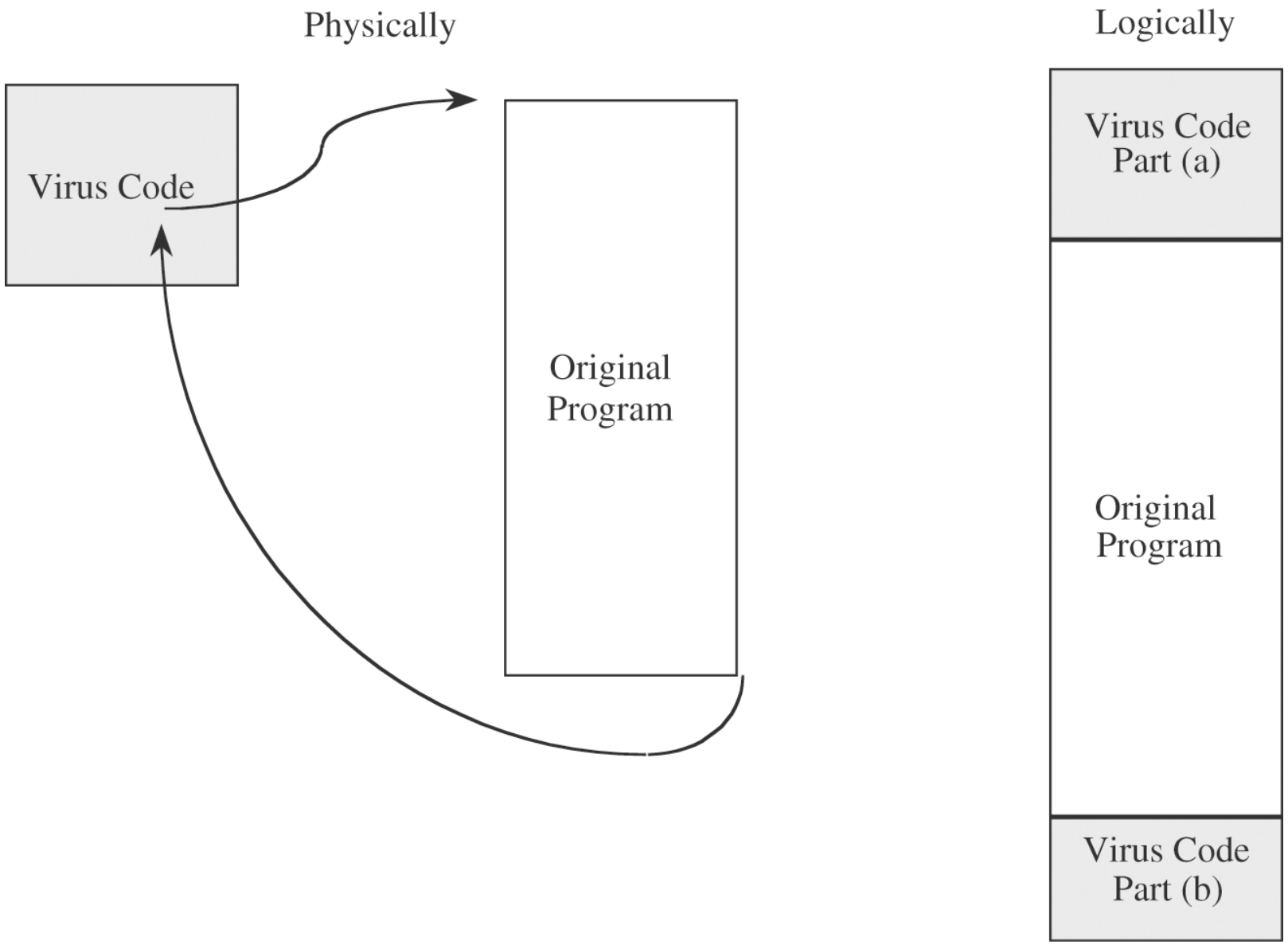
( ) A customized keyboard app that logs user input and sends it to a server on the Internet.

( ) Part of a program will only run if the computer is at the user's home, and it will upload all MS Word docs to a web site.

( ) A login program with an undocumented option (e.g., DEBUG) that would allow an attacker to supply any username and password to gain access to the computer.

T = trapdoor, L = logic bomb, H = trojan horse, V = virus

Virus Structure



Virus Structure

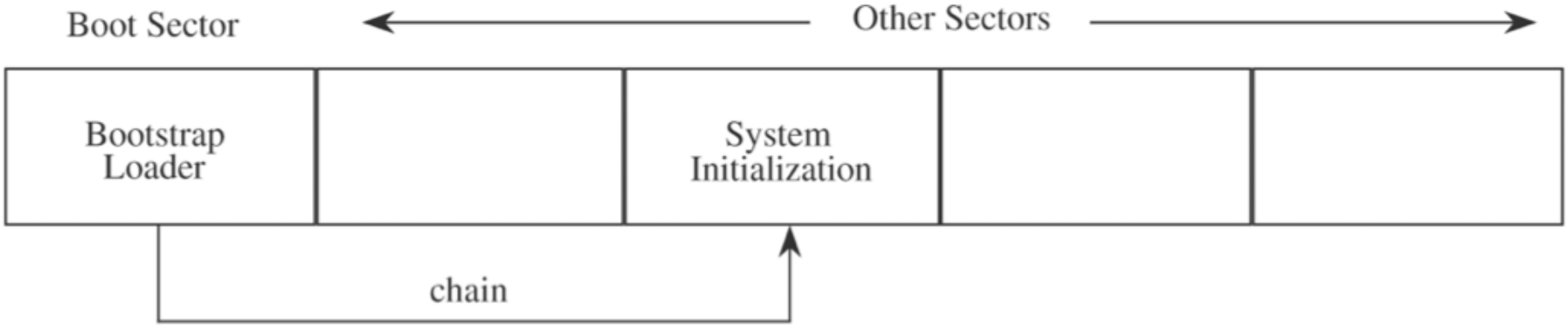
- First line: go to “main” of virus program
- Second line: a special mark (infected or not)
- Main:
  - find uninfected programs
    - infect and mark them
  - do something damaging to the system
  - now “go to” the first line of the original program
    - appear to do the normal work
- Avoid detection by looking at size of program:
  - compress/decompress the original program

Types of Viruses

- Parasitic virus
  - search and infect executable files
- Memory-resident virus
  - infect running programs
- Stealth virus
- Macro virus
  - embedded in documents, run/spread when opened
- Boot sector virus
  - spreads whenever the system is booted
- Polymorphic virus
  - encrypt part of the virus program using randomly generated key

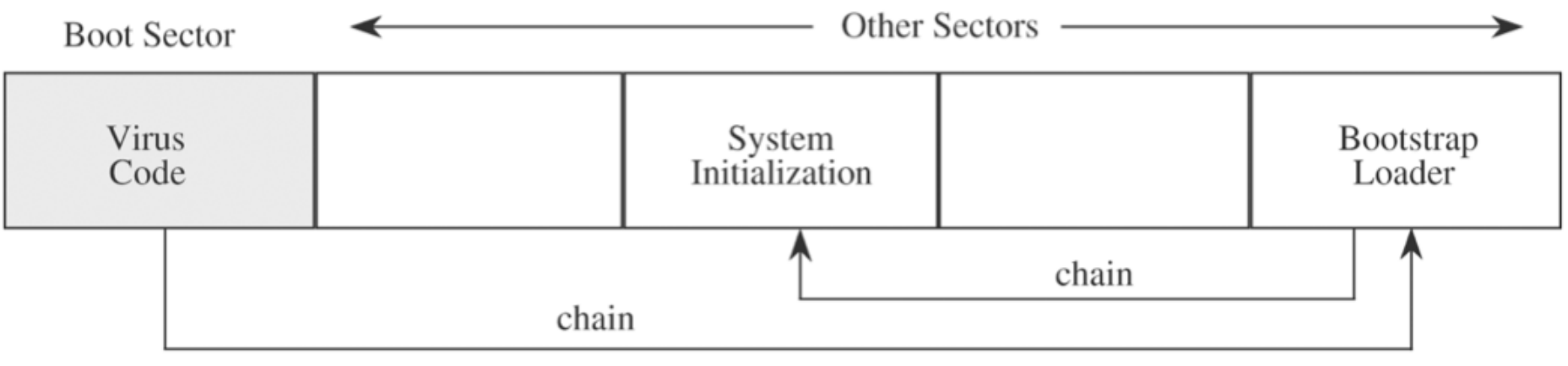
Boot Sector Virus

- Boot sector infectors
  - The boot sector is the part of a disk used to bootstrap the system.
  - Code in a boot sector is executed when the system “sees” the disk for the first time.



(a) Before infection

Boot Sector Virus



(b) After infection

1. Copy the old boot sector to alternative place;
2. Insert itself into the boot sector.

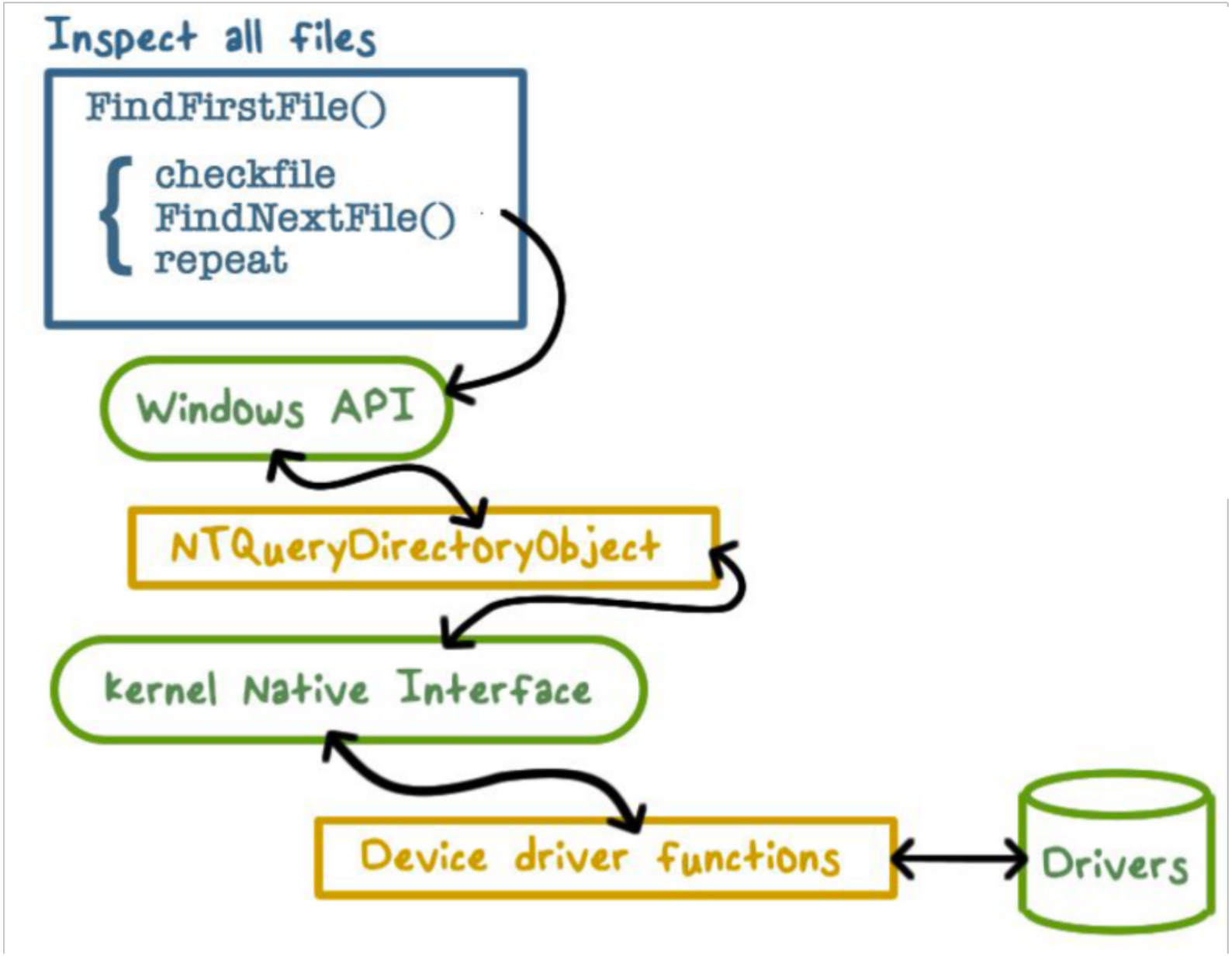
Macro Viruses

- Macro
  - an executable program (e.g., opening a file, starting an application) embedded in a word processing document, e.g. MS Word
- Common technique for spreading
  - A virus macro is attached to a Word document
  - Document is loaded and opened in the local system
  - When the macro executes, it copies itself to the global macro file
  - As a result, The global macro can be activated/spread when new documents are opened.

Rootkit

- Resides in operating systems
  - Modifies OS code and data structure
- Helps user-level malware
  - hide it from user (not listed in “ls” or “ps” command)

Rootkit


Inspect all files
FindFirstFile()
checkfile
FindNextFile()
repeat
Windows API
NTQueryDirectoryObject
kernel Native Interface
Device driver functions
Drivers

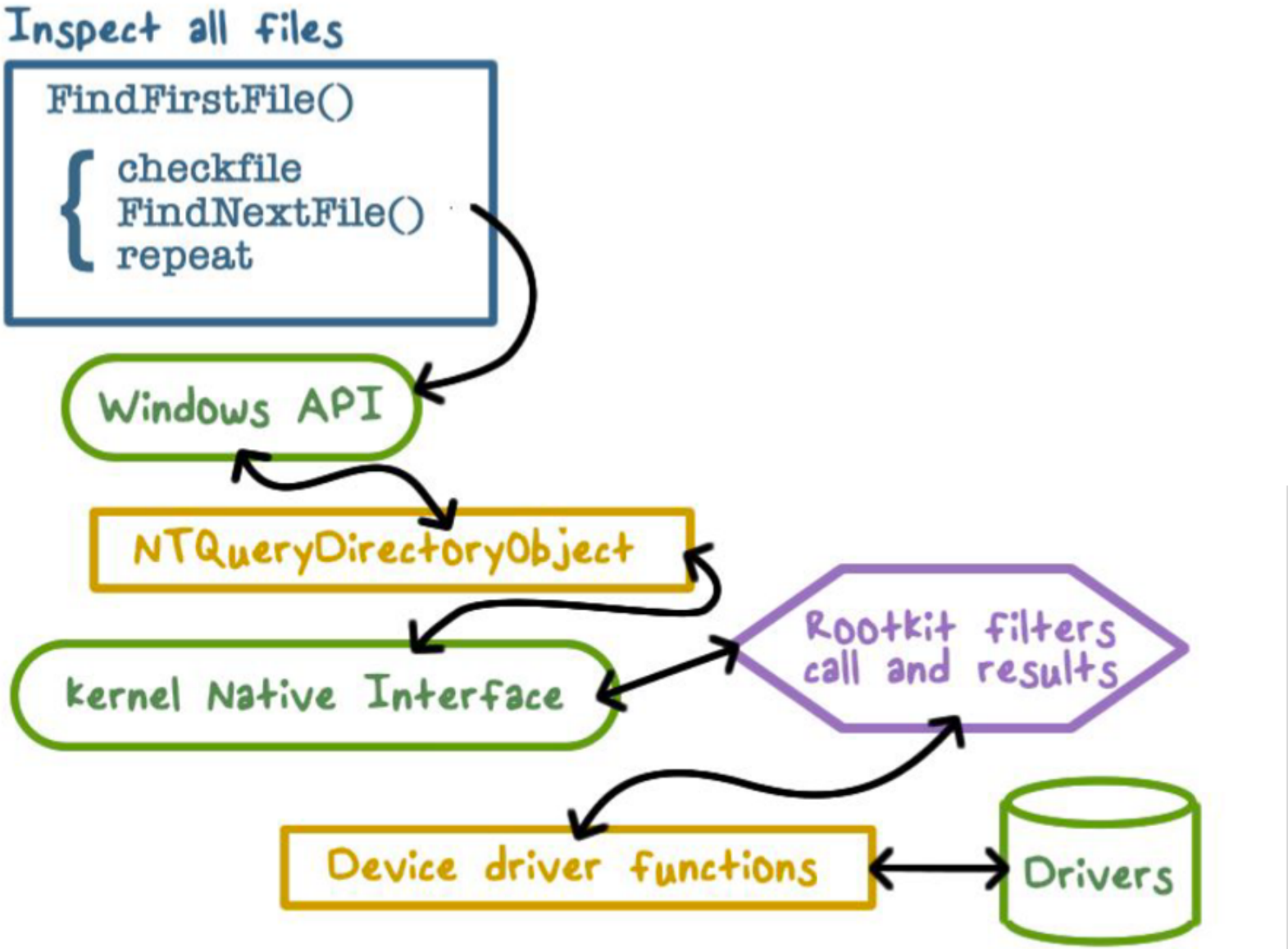
Rootkit

```
Volume in drive C has no label.
 Volume Serial Number is E4C5-A911

 Directory of C:\WINNT\APPS

01-09-10   13:34       <DIR>          .
01-09-10   13:34       <DIR>          ..
24-07-02   15:00            82,944 CLOCK.AVI
24-07-02   15:00            17,062 Coffee Bean.bmp
24-07-02   15:00                80 EXPLORER.SCF
24-07-08   15:00           256,192 mal_code.exe
22-08-04   01:00           373,744 PTDOS.EXE
21-02-04   01:00               766 PTDOS.ICO
19-06-03   15:05            73,488 regedit.exe
24-07-02   15:00            35,600 TASKMAN.EXE
14-10-02   17:23           126,976 UNINST32.EXE
               9 File(s)        966,852 bytes
               2 Dir(s) 13,852,132,800 bytes free
```

Rootkit


Inspect all files
FindFirstFile()
checkfile
FindNextFile()
repeat
Windows API
NTQueryDirectoryObject
kernel Native Interface
Rootkit filters
call and results
Device driver functions
Drivers

```
Volume in drive C has no label.
 Volume Serial Number is E4C5-A911

 Directory of C:\WINNT\APPS

01-09-10   13:29       <DIR>          .
01-09-10   13:29       <DIR>          ..
24-07-02   15:00            82,944 CLOCK.AVI
24-07-02   15:00            17,062 Coffee Bean.bmp
24-07-02   15:00                80 EXPLORER.SCF
22-08-04   01:00           373,744 PTDOS.EXE
21-02-04   01:00               766 PTDOS.ICO
19-06-03   15:05            73,488 regedit.exe
24-07-02   15:00            35,600 TASKMAN.EXE
14-10-02   17:23           126,976 UNINST32.EXE
               8 File(s)        710,660 bytes
               2 Dir(s) 13,853,472,768 bytes free
```

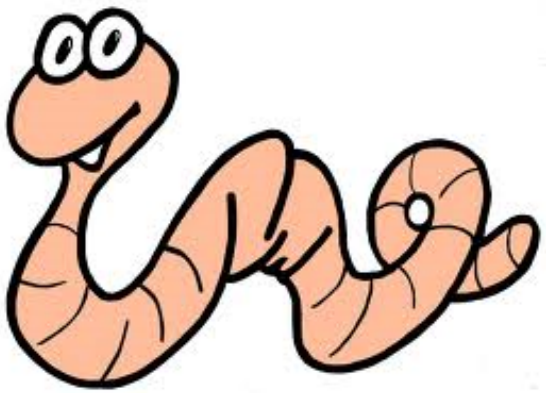
Truth and Myths about Viruses

- Can only infect Microsoft Windows
- Can modify hidden and read-only files
- Spread only on disks or in email
- Cannot remain in memory after reboot
- Cannot infect hardware
- Can be malevolent, benign, or benevolent

Antivirus Approach

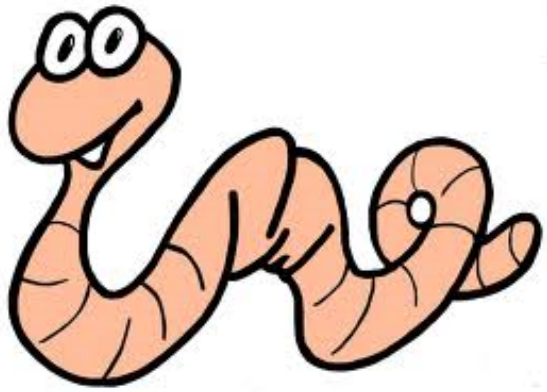
- Prevention
  - Limit contact to outside world
- Detection and identification
- Removal
- 4 generations of antivirus software
  - simple scanners
    - use “signatures” of known viruses
  - heuristic scanners
    - integrity checking: checksum, encrypted hash
  - activity traps
  - full-featured protection
    - Host-based, network-based, sandboxing-based

WORMS AND EXAMPLES



What is a Worm?

- Code that replicates and propagates across the network
  - Often carries a “payload”
- Usually spread via exploiting flaws in open services
  - “Viruses” require user action to spread
- **First worm:** Robert Morris, November 1988
  - 6-10% of all Internet hosts infected (!)



- Many more since, but none on that scale until July 2001

The Internet Worm

- What it did
  - Determine where it could spread
  - Spread its infection
  - Remain undiscovered and undiscoverable
- Effect
  - Resource exhaustion – repeated infection due to a programming bug
  - Servers are disconnected from the Internet by sys admin to stop infection

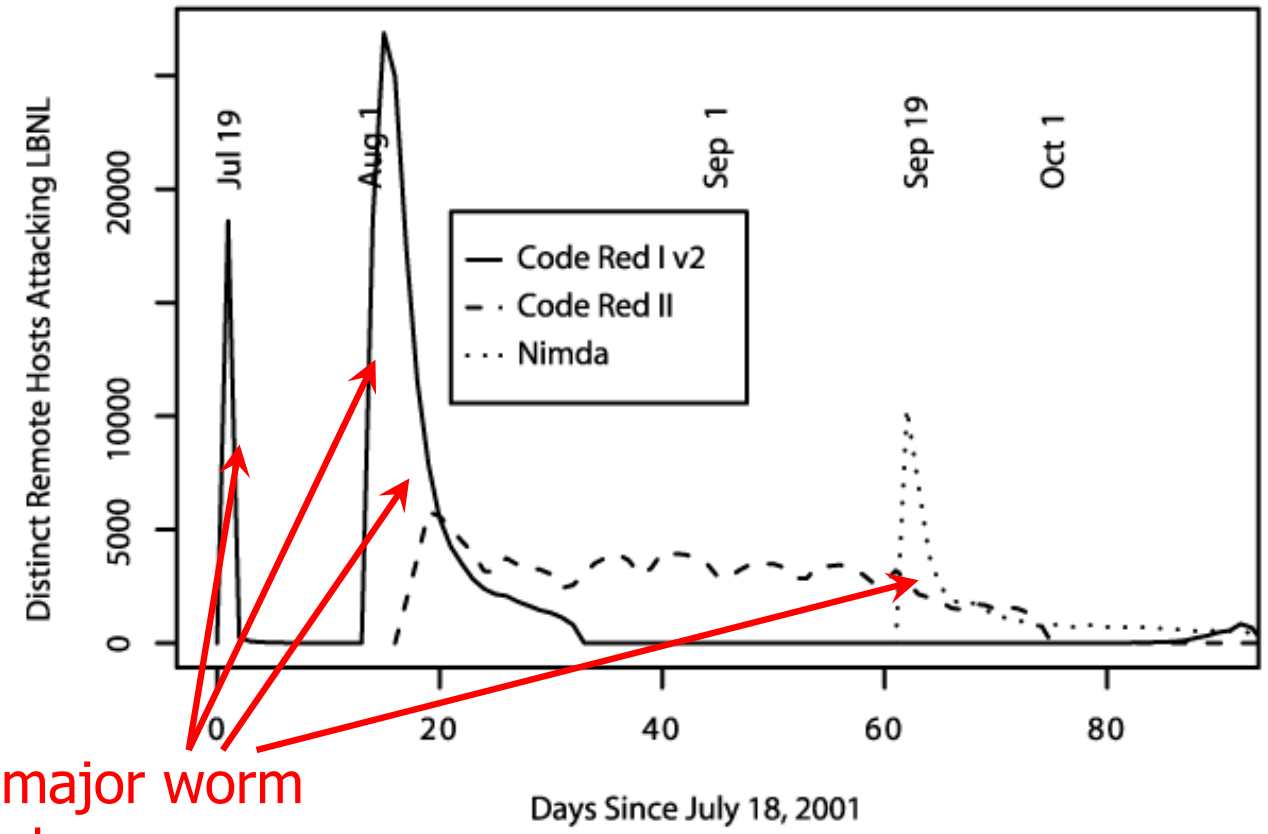
The Internet Worm

- How it worked
  - Where to spread
    - Exploit security flaws
      - Guess password (encrypted passwd file readable)
      - fingerd: buffer overflow
      - sendmail: trapdoor (accepts shell commands)
  - Spread
    - Bootstrap loader to target machine, then fetch rest of code (password authenticated)
  - Remain undiscoverable
    - Load code in memory, encrypt, remove file
    - Periodically changed name and process ID

Morris Worm, Redux

- 1988: No malicious payload, but bogged down infected machines by uncontrolled spawning
  - Infected 10% of all Internet hosts at the time
- Multiple propagation vectors
  - Remote execution using rsh and cracked passwords
    - Tried to crack passwords using small dictionary and publicly readable password file; targeted hosts from /etc/hosts.equiv
  - Buffer overflow in fingerd on VAX
    - Standard stack smashing exploit
  - DEBUG command in Sendmail
    - In early Sendmail versions, possible to execute a command on a remote machine by sending an SMTP (mail transfer) message

Summer of 2001



Three major worm outbreaks

Code Red I

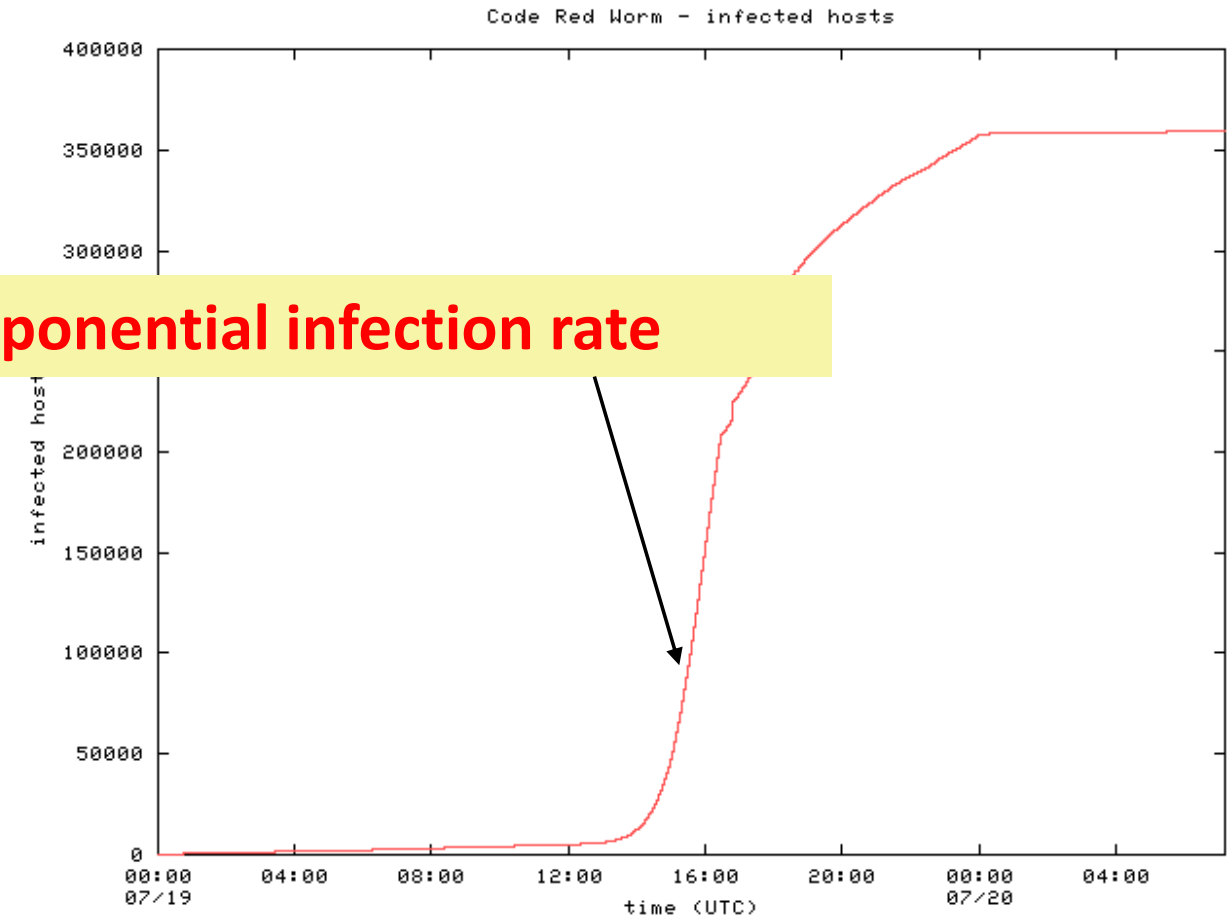
- July 13, 2001: First worm of the modern era
- Exploited buffer overflow in Microsoft's Internet Information Server (**IIS**)
- 1st through 20th of each month: spread
  - Find new targets by **random scan** of IP address space
    - Spawn 99 threads to generate addresses and look for IIS
  - Creator forgot to seed the random number generator, and every copy scanned the same set of addresses ☺
- 21st through the end of each month: attack
  - Deface websites to display "**HELLO! Welcome to http://www.worm.com! Hacked by Chinese!**"

Code Red I v2

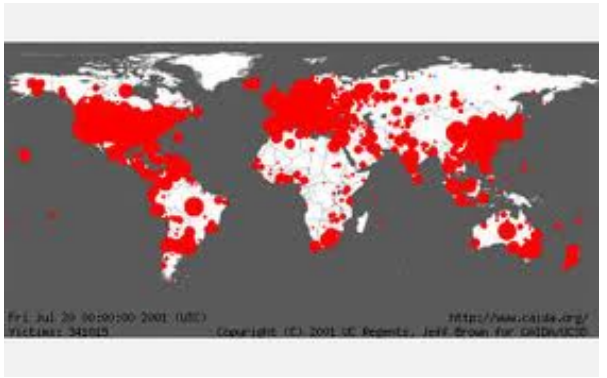
- July 19, 2001: Same codebase as Code Red I, but fixed the bug in random IP address generation
  - Compromised all vulnerable IIS servers on the Internet
  - Large vulnerable population meant fast worm spread
    - Scanned address space grew exponentially
    - 350,000 hosts infected in 14 hours!!
- Payload: distributed packet flooding (denial of service) attack against www.whitehouse.gov
  - Coding bug causes it to die on the 20th of each month… but if victim's clock is wrong, resurrects on the 1st

Code Red: Host Infection Rate

Measured using backscatter technique



Exponential infection rate



Designing Fast-Spreading Worms

- **Hit-list scanning**
  - Time to infect first 10k hosts dominates infection time
  - **Solution:** Reconnaissance (stealthy scans, etc.)

- **Permutation scanning**
  - **Observation:** Most scanning is redundant & potential for repeats and invalid addresses (random scanning)
  - **Idea:** Shared permutation of address space. Start scanning from own IP address. Re-randomize when another infected machine is found.

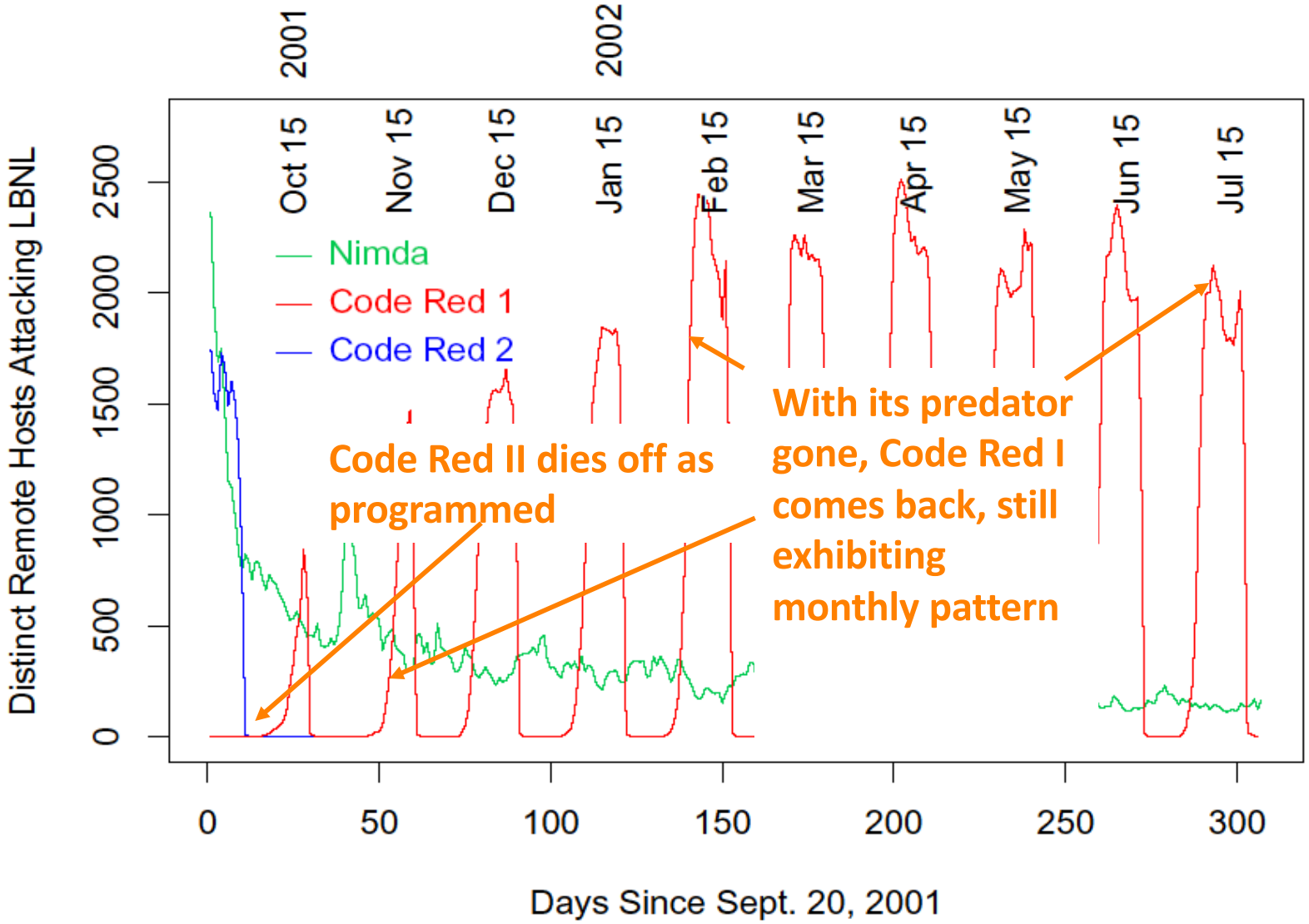
- **Internet-scale hit lists**
  - *Flash worm:* complete infection

    (saturate one million vulnerable hosts) under 30 seconds

Code Red II

- August 4, 2001: Same IIS vulnerability, completely different code, kills Code Red I
  - Known as "Code Red II" because of comment in code
  - Worked only on Windows 2000, crashed NT
- Scanning algorithm preferred nearby addresses
  - Chose addresses from same class A with probability ½, same class B with probability 3/8, and randomly from the entire Internet with probability 1/8
- Payload: installed root backdoor in IIS servers for unrestricted remote access
- Died by design on October 1, 2001

Code Red I and II (Paxson)



Nimda

- September 18, 2001: Multi-modal worm using several propagation vectors
  - Exploit same **IIS buffer overflow** as Code Red I and II
  - **Bulk-email** itself as an attachment to email addresses harvested from infected machines
  - Copy itself across open **network shares**
  - Add **exploit code to Web pages** on compromised sites to infect visiting browsers
  - Scan for **backdoors left by Code Red II**
- Payload: turned-off code deleting all data on hard drives of infected machines

Signature-Based Defenses Don't Help

- Nimda leaped firewalls
- Many firewalls passed mail untouched, relying on mail servers to filter out infections
  - Most filters simply scan attachments for signatures (code snippets) of known viruses and worms
- Nimda was a brand-new infection with unknown signature, and scanners could not detect it
- Big challenge: detection of zero-day attacks
  - When a worm first appears in the wild, signature is not extracted until minutes or hours later

Slammer (Sapphire) Worm

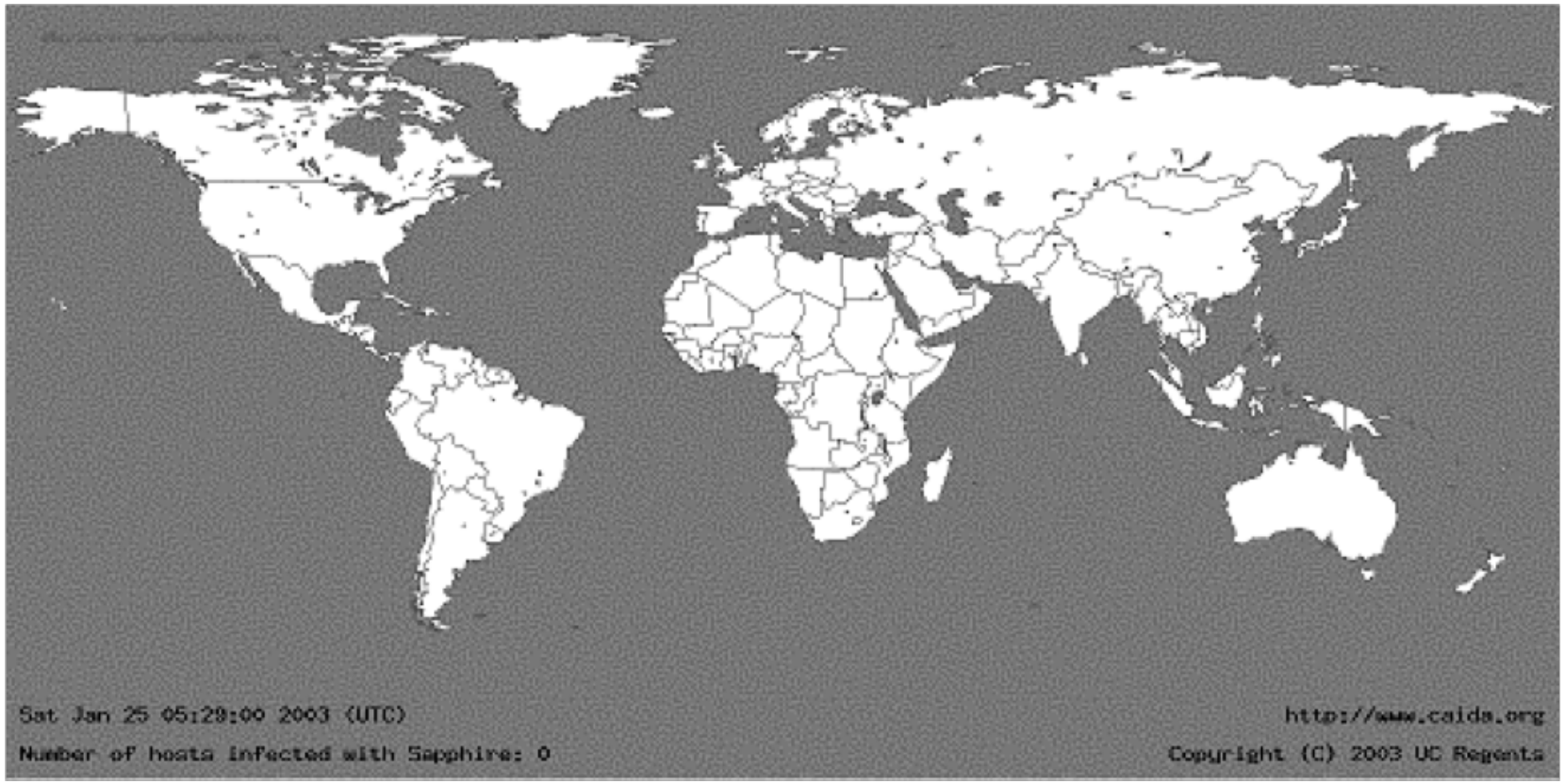
- January 24/25, 2003: **UDP** worm exploiting buffer overflow in **Microsoft's SQL Server**
  - Overflow was already known and patched by Microsoft… but not everybody installed the patch
- Entire code fits into a single 404-byte UDP packet
  - Worm binary followed by overflow pointer back to itself
- Classic buffer overflow combined with random scanning: once control is passed to worm code, it randomly generates IP addresses and attempts to send a copy of itself to port 1434
  - MS-SQL listens at port 1434

Slammer Propagation

- Scan rate of 55,000,000 addresses per second
  - Scan rate = rate at which worm generates IP addresses of potential targets
  - Up to 30,000 single-packet worm copies per second
- Initial infection was doubling in 8.5 seconds (!!)
  - Doubling time of Code Red was 37 minutes
- Worm-generated packets saturated carrying capacity of the Internet in 10 minutes
  - 75,000 SQL servers compromised
  - And that's in spite of broken pseudo-random number generator used for IP address generation

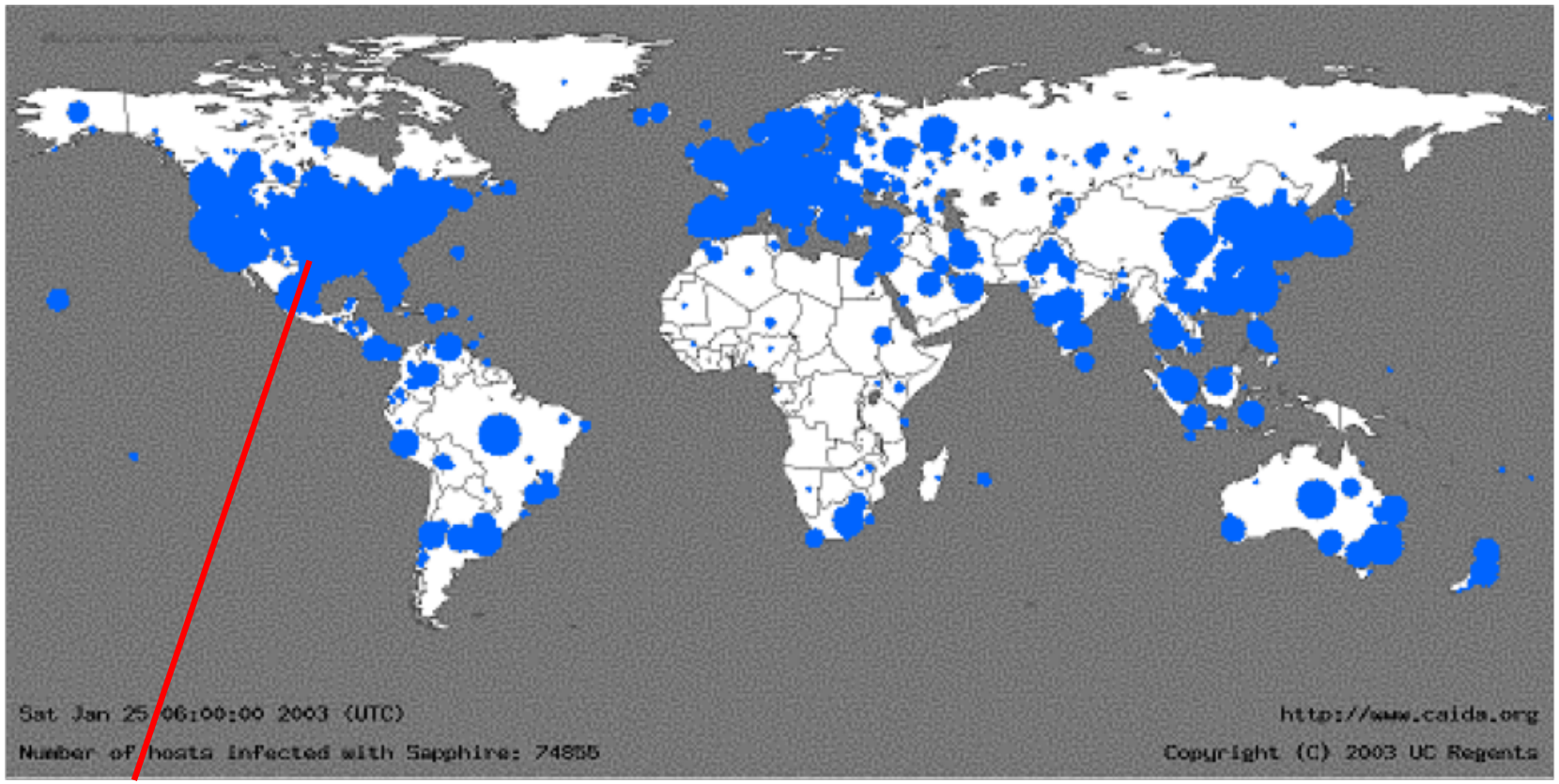
05:29:00 UTC, January 25, 2003

[from Moore et al. "The Spread of the Sapphire/Slammer Worm"]



30 Minutes Later

[from Moore et al. "The Spread of the Sapphire/Slammer Worm"]



Size of circles is **logarithmic** in the number of infected machines

Slammer Impact

- $1.25 Billion of damage
- Temporarily knocked out many elements of critical infrastructure
  - Bank of America ATM network
  - Entire cell phone network in South Korea
  - Five root DNS servers
  - Continental Airlines' ticket processing software
- The worm did not even have malicious payload… simply bandwidth exhaustion on the network and resource exhaustion on infected machines

Secret of Slammer's Speed

- Old-style worms (Code Red) spawn a new thread which tries to establish a **TCP** connection and, if successful, send a copy of itself over TCP
  - Limited by latency of the network
- Slammer was a connectionless **UDP** worm
  - No connection establishment, simply send 404-byte UDP packet to randomly generated IP addresses
  - Limited only by bandwidth of the network

"SLAMMER SHOWED US THAT IT'S HARD FOR EVERYONE TO KEEP UP WITH PATCHES, NO MATTER WHO YOU ARE."

- Mary-Ann Davidson, chief security officer, Oracle

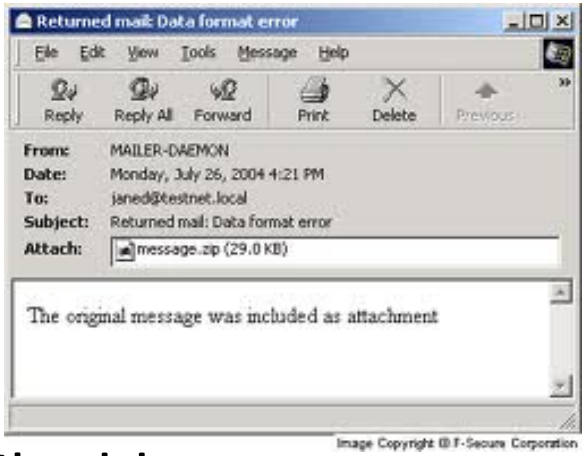
Blaster and Welchia/Nachia

- August 11, 2003: Scanning worm exploiting RPC service in Microsoft Windows XP and 2000
  - First address at random, then sequential upward scan
    - Easy to detect, yet propagated widely and leaped firewalls
- Payload: denial of service against MS Windows Update server + installing remotely accessible backdoor
- Welchia/Nachia was intended as a counter-worm
  - Random-start sequential scan, use ICMP to determine if address is live, then copy itself over, patch RPC vulnerability, remove Blaster if found
  - Did **more** damage by flooding networks with traffic

Search Worms

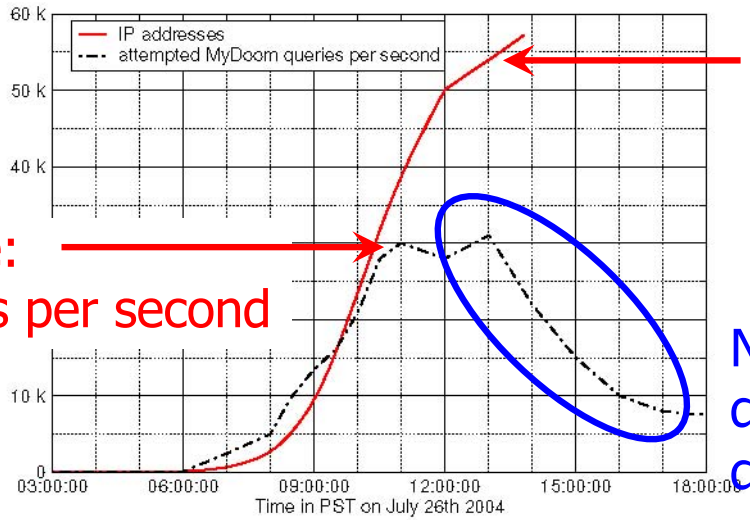
- Generate search query
  - Search for version numbers of vulnerable software to find exploitable targets (e.g., Santy)
  - Search for popular domains to harvest email addresses (e.g., MyDoom)
- Analyze search results
  - Remove duplicates, URLs belonging to search engine
- Infect identified targets
  - Reformat URLs to include the exploit
    - For example, append **exploit code instead of username**
  - Exploit code downloads the actual infection, joins the infected machine to a botnet, etc.

MyDoom



- Spreads by email
- MyDoom: searches local hard drive for email addresses
- MyDoom.O: uses domain names of email addresses to search for more email addresses through **Web search engines**
  - Queries split between Google (45%), Lycos (22.5%), Yahoo (20%) and Altavista (12.5%)

Google's view of MyDoom



Number of IP addresses generating queries (60,000 hosts infected in 8 hours)

Peak scan rate: 30,000 queries per second

Number of served queries drops as Google's anomaly detection kicks in

Santy

- Written in Perl, exploits a bug in **phpBB** bulletin board system (prior to version 2.0.11)
  - Allows injection of arbitrary code into Web server running phpBB
- Uses Google to find sites running phpBB
- Once injected, downloads actual worm code from a central site, asks **Google** for more targets and connects infected machine to an IRC botnet
- Multiple variants of the same worm
  - Polymorphism: actual Perl code **changes** from infection to infection, so filtering worm traffic is difficult!

Evading Anomaly Detection

- Google will refuse worm-generated queries using signature
- Different Santy variants generate different search terms or take them from an IRC botmaster

```
GET /search?q="View+previous+topic+::+View+next+topic"+8756+-modules&num=50&start=35
GET /search?q="vote+in+polls+in+this+forum"+7875+-modules&num=50&start=10
GET /search?q="reply+to+topics+in+this+forum"+5632+-modules&num=50&start=15
GET /search?q="Post+subject"+phpBB+6578+-modules&num=50&start=10
GET /search?q="delete+your+posts+in+this+forum"+9805+-modules&num=50&start=35
GET /search?q="post+new+topics+in+this+forum"+1906+-modules&num=100&start=30
```

- Google's solution: if an IP address generates a lot of "rare" queries, ask it to solve a CAPTCHA
- Do not return the result of a query if it contains (a) pages from many hosts, and (b) high percentage of them are tagged as vulnerable

Worm Detection and Defense

- Worm propagation modeling
- Automatic signature generation
  - E.g., Earlybird, Autograph
- Detection
  - Honeypot-based (e.g., HoneyStat)
  - Local information based (e.g., DSC)
  - Global information based (e.g., Kalman Filter)
- Mitigation and response
  - Inoculation, quarantine, treatment, etc.

CONFICKER WORM/*BOTNET*: ONE RECENT EXAMPLE

Conficker 2008-2010

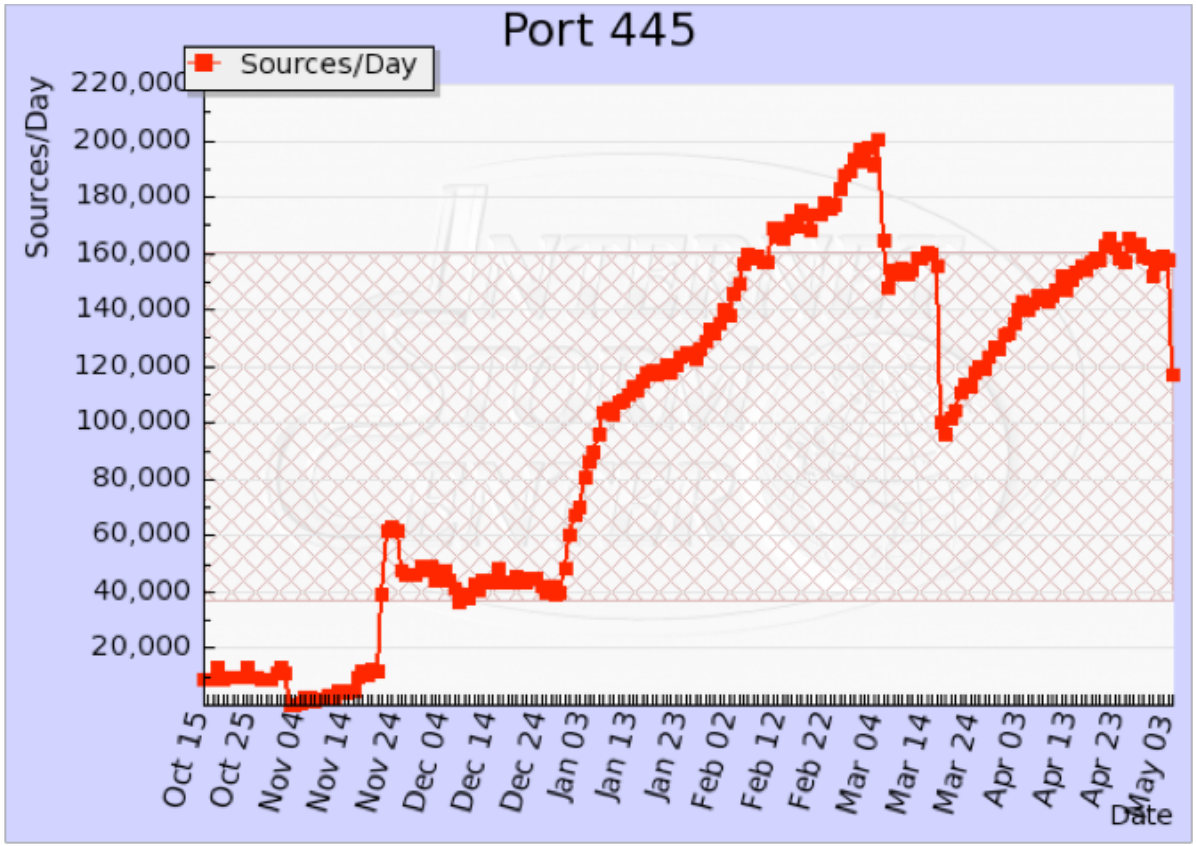
- Most important Worm since Slammer
- 4 years have passed..
- Vulnerability in Server Service
- 2000, XP, Vista, 2003, and 2008

Windows of Vulnerability

- Found in the wild
- Announced by MS 22 Oct 2008
- Out of band patch 26 Oct 2008
- Public Exploit 26 Oct 2008
- Conficker : Early november

Tech details

- Exploit buffer overflow in the RPC code
- Port 139 / 445

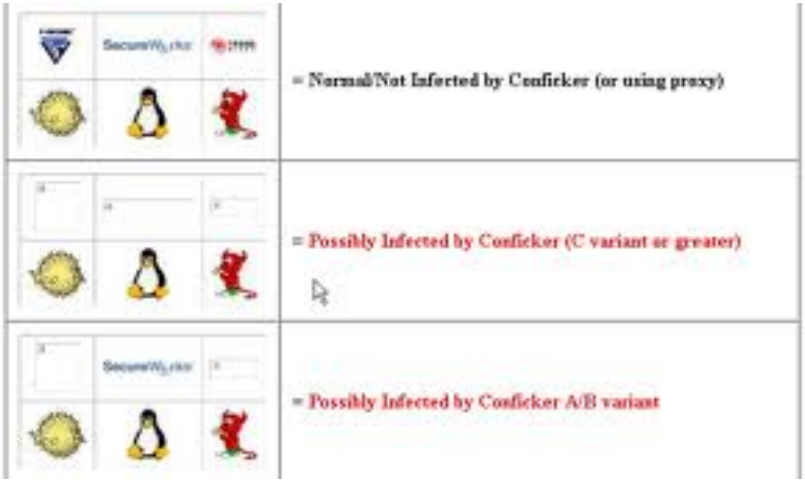


Conficker A 2008-11-21

- **Infection** : Netbios MS08-067
- **Update**: HTTP pull / 250 rand / 8 TLD
- **Self-defense** : N/A
- **End usage** : update to version B,C or D

Conficker B 2008-12-29

- **Infection** :
  - Netbios MS08-067
  - Removable Media (USB) via DLL
- **Update**
  - HTTP pull / 250 rand / 8 TLD
  - Netbios Push : patch for reinjection
- **Self-defense** :
  - Blocks DNS lookups
  - Disables AutoUpdate
- **End usage** : update to version C or D



Conficker C 2009-03-04

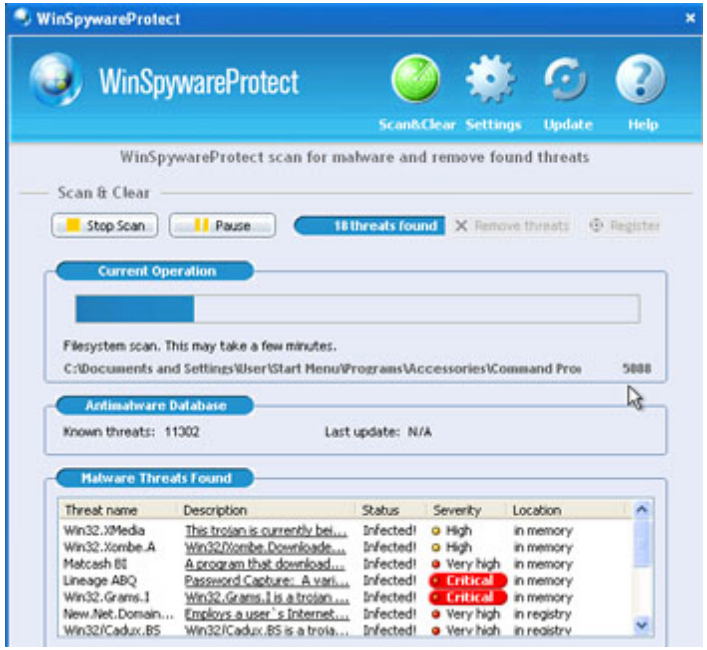
- **Infection** :
  - Netbios MS08-067
  - Removable Media via DLL
  - Dictionary attack on $Admin
- **Update**
  - HTTP pull / 250 rand / 8 TLD
  - Netbios Push : patch for reinjection, Create named pipe
- **Self-defense** :
  - Blocks DNS lookups
  - Disables AutoUpdate

Conficker D 2009-03-04

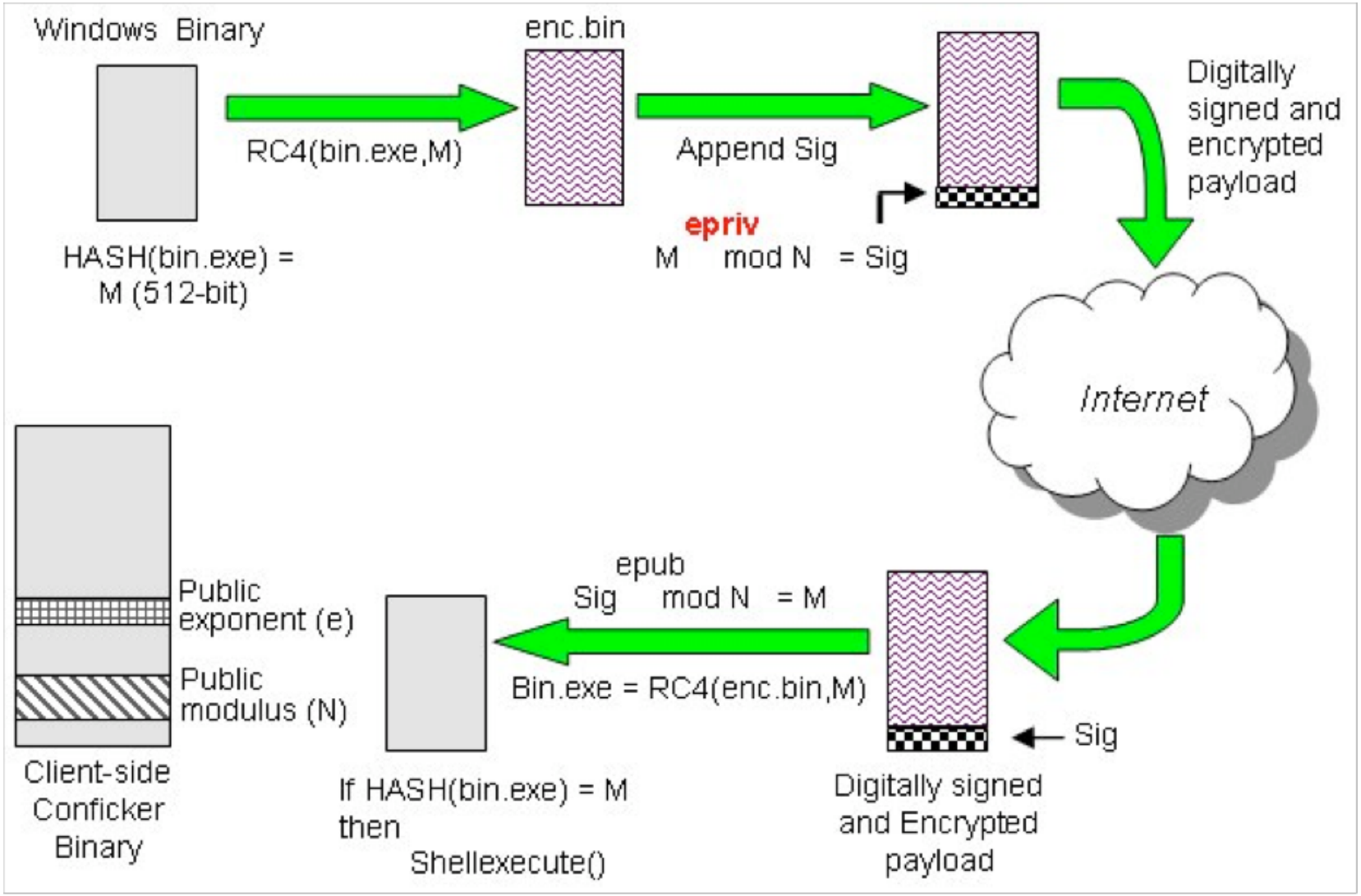
- **Update**
  - HTTP pull / 50 000 rand / 110 TLD
  - P2P push / pull custom protocol
- **Self-defense** :
  - Disables Safe Mode
  - Kills anti-malware
  - in-memory patch of DNSAPI.DLL to block lookups of anti-malware related web sites
- **End usage** : update to version E

Conficker E 2009-07-04

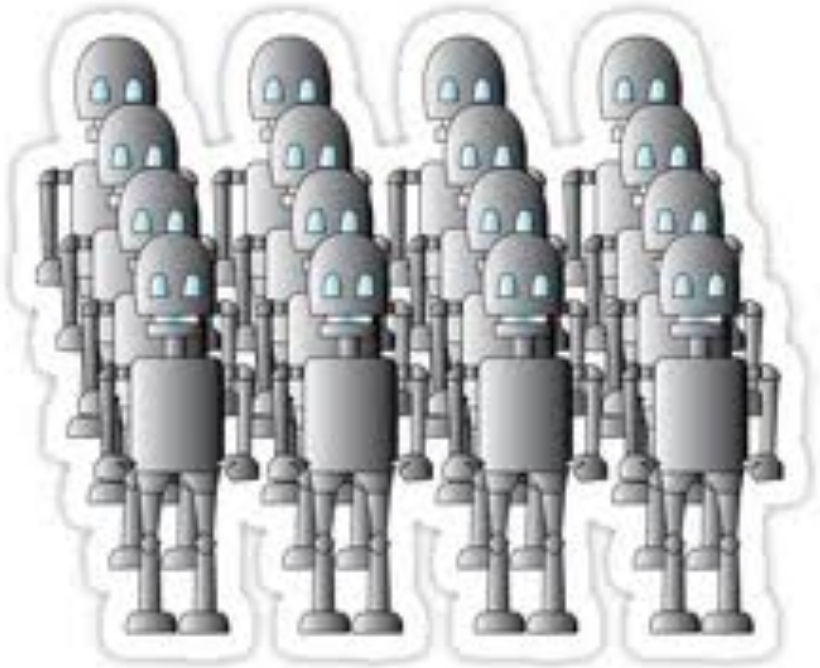
- **Downloads and installs additional malware:**
  - **Waledac spambot**
  - **SpyProtect 2009 scareware**
- **Removes self on 3 May 2009 (Does not remove accompanying copy of W32.Downadup.C) [37]**



Binary Security



BOTNET



Sea-Change in Internet Attacks

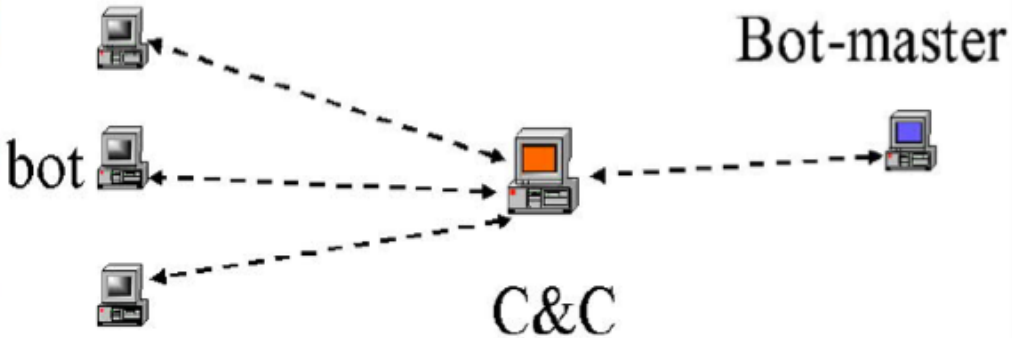
- Past Malware
  - In the past, often for "**fame**" and/or "**fun**"
    - E.g., defacing web pages
    - Fast and large-scale spreading
- Modern Malware
  - Now, often for **profit** and **political gains**
    - Technical sophistications on the latest technologies
      - Efficiency, robustness, and evasiveness

Bot

- Bot (Zombie)
  - A **compromised computer** under the control of an attacker
  - **Bot code (malware)** on the computer communicates with the attacker's server

Botnet

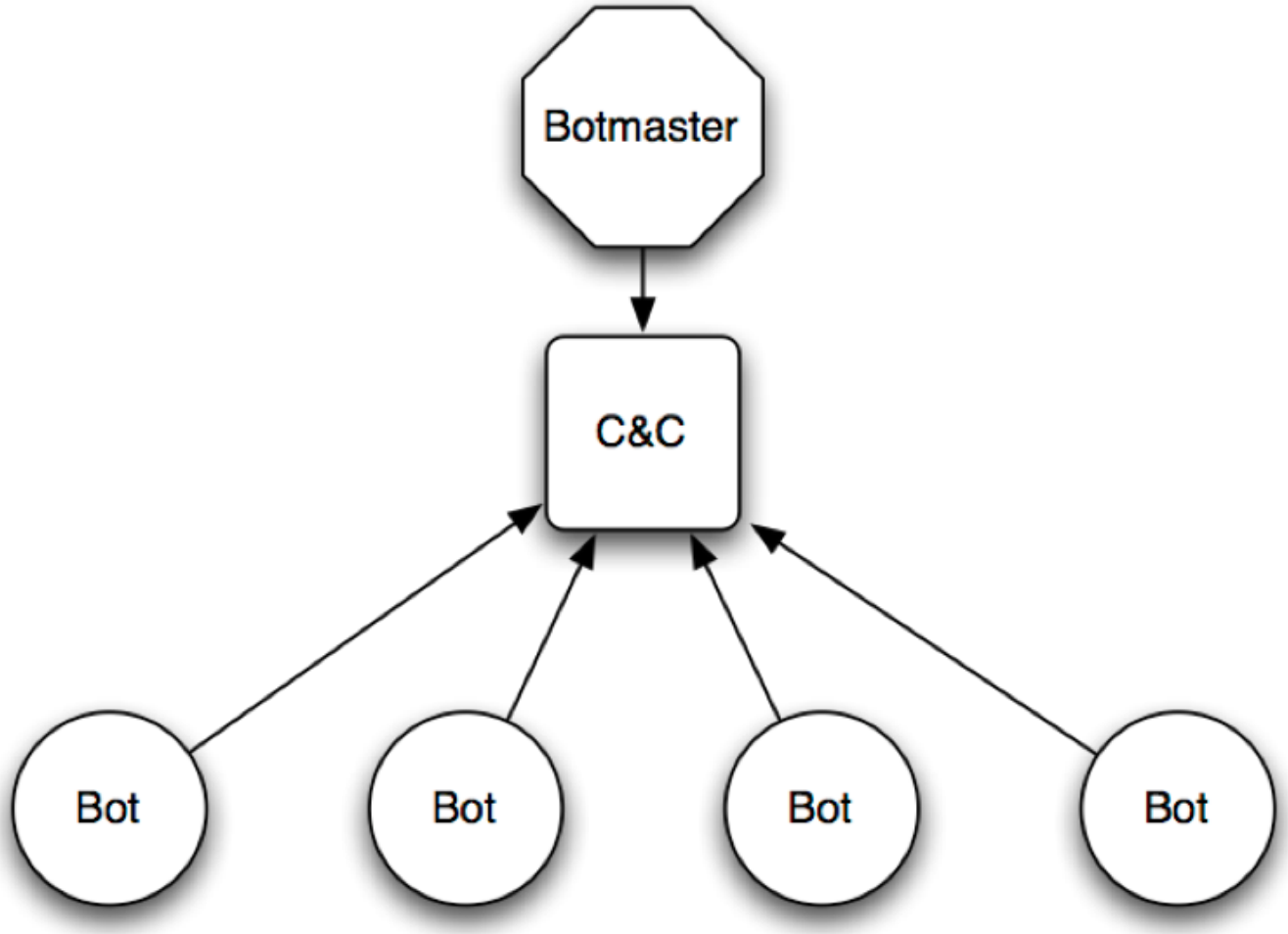
- Botnet
  - A **network of bots** controlled by an attacker to perform coordinated malicious activities
  - Definition: "A coordinated group of malware instances that are controlled via C&C (**C**ommand and **C**ontrol server) channels"
  - Architectures: Centralized (e.g., IRC, HTTP), Distributed (e.g., P2P)
  - Now, key platform for most Internet-based attacks and frauds



Botnet Epidemic

- More than 95% of all spam
- All distributed denial of service (DDoS) attacks
- Click fraud
- Phishing & Pharming attacks
- Key logging & Data/Identity Theft
- Key/Password cracking
- Anonymized terrorist & criminal communication
- Cheating in online games/polls
- Distributing other malware, e.g., spyware

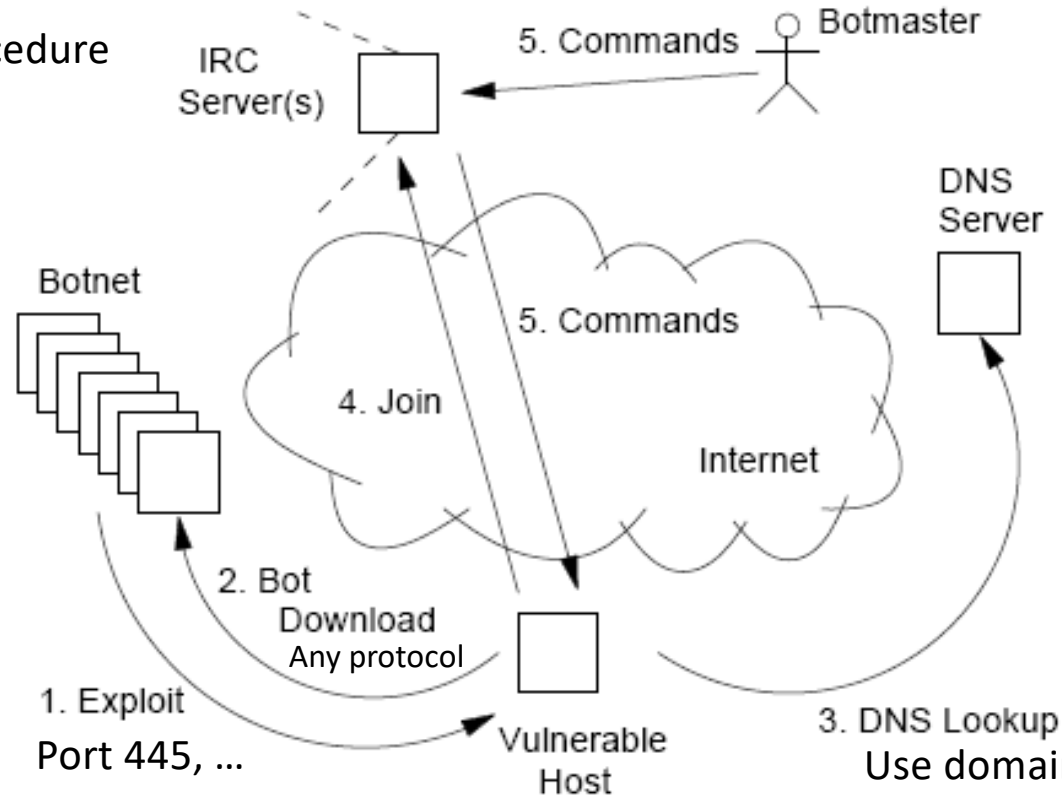
Centralized botnet



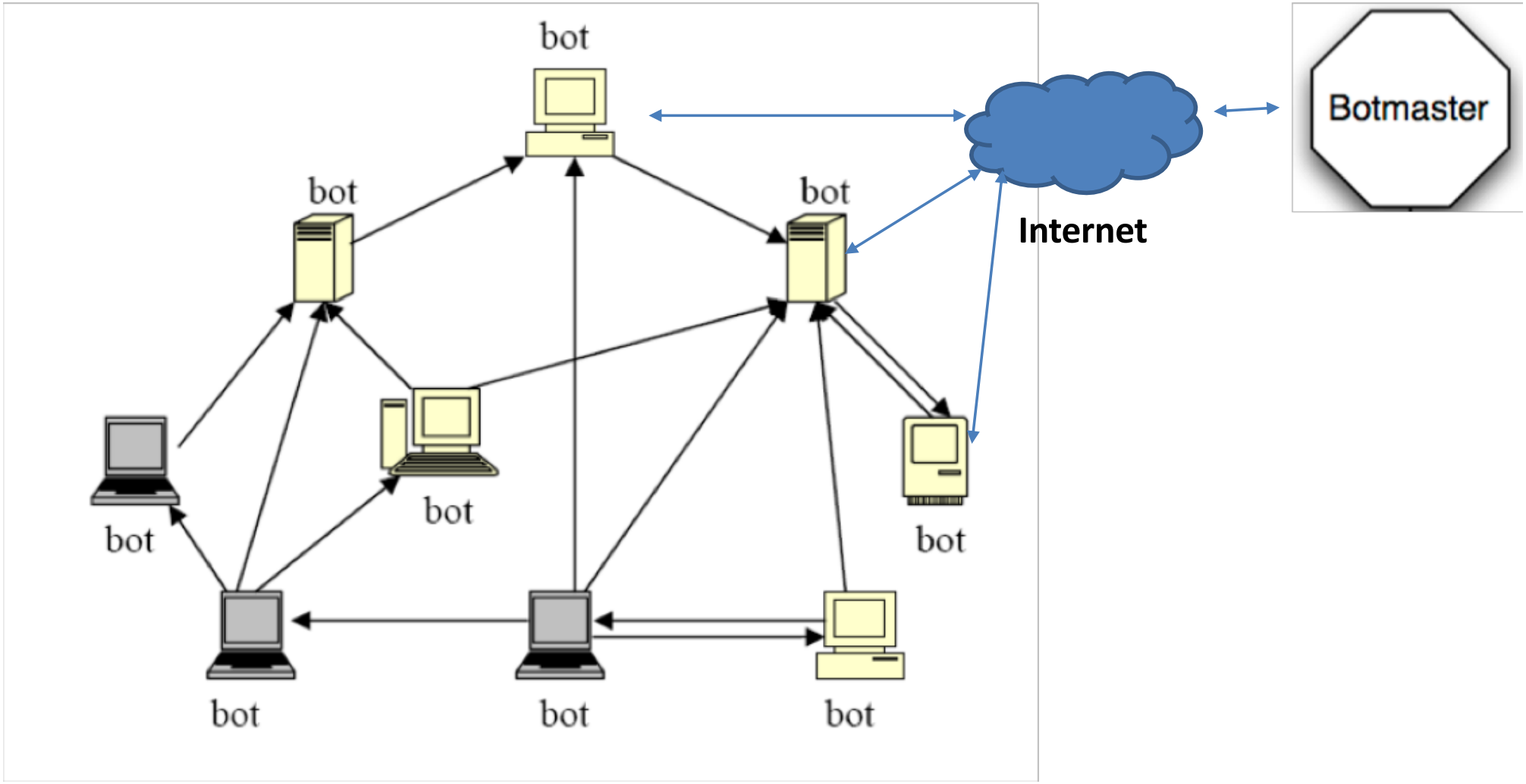
Centralized

Life-Cycle of an IRC-Based Botnet Infection

4. and 5. include authentication procedure



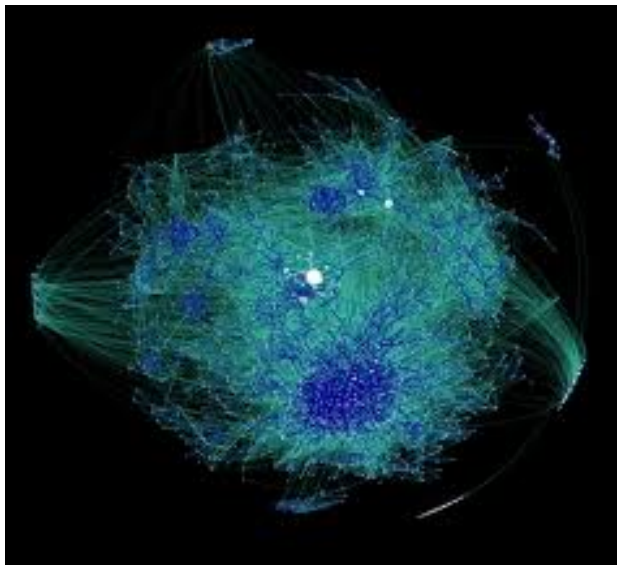
Distributed Botnet



Distributed via *P2P protocols*

Example: Storm

- Also known as W32/Peacomm Trojan
- Use P2P communication : kademlia
- Commands are stored into the DHT table
- Use advanced cryptography



Storm Worm / Peacomm (2007)

- Spreads by cleverly designed **spam** campaign
  - Arrives as an **email** with catchy subject
    - First instance: “230 dead as storm batters Europe”
    - Other examples: “Condoleeza Rice has kicked German Chancellor”, “Radical Muslim drinking enemies’s blood”, “Saddam Hussein alive!”, “Fidel Castro dead”, etc.
- Attachment or URL with malicious payload
  - FullVideo.exe, MoreHere.exe, ReadMore.exe, etc.
  - Also masquerades as flash postcards
- Once opened, installs **Trojan (wincom32) & rootkit**

Storm Worm Characteristics

- Infected machine joins **botnet**
  - Between 1 and 5 million machines infected (Sep 2007)
- Obfuscated **peer-to-peer** control structure
  - Not like Agobot, which uses simple IRC control channel
  - Interacts with peers via eDonkey protocol
- Obfuscated code, anti-debugging defenses
  - Goes into infinite loop if detects VMware or Virtual PC
  - Large number of spurious probes (evidence of external analysis) triggers distributed DoS attack

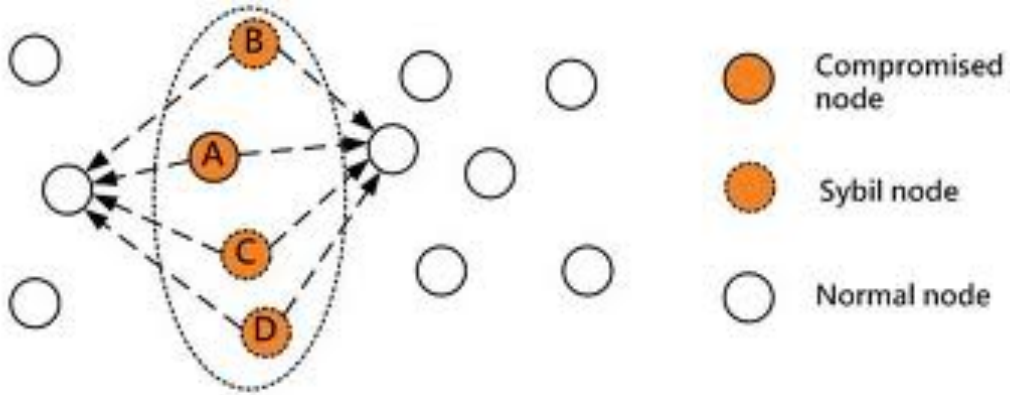
Storm Worm Outbreaks

- **Spambot binary used to spread** new infections in subsequent campaigns
  - Looks for email addresses and mailing lists in the files on the infected machines

Date	Spam Tactic
Jan 17, 2007	European Storm Spam
April 12, 2007	Worm Alert Spam
June 27, 2007	E-card (applet.exe)
July 4, 2007	231st B-day
Sept 2, 2007	Labor Day (labor.exe)
Sept 5, 2007	Tor Proxy
Sept 10, 2007	NFL Tracker
Sept 17, 2007	Arcade Games

Weakness

- Initial peer list
- sybil attack
  - create **fake identities** on various P2P networks either to gain a better reputation
  - eventually take control of the entire network
- Index poisoning
  - insert massive numbers of bogus records into the index (used for searching to find locations of desired titles)



Comparison

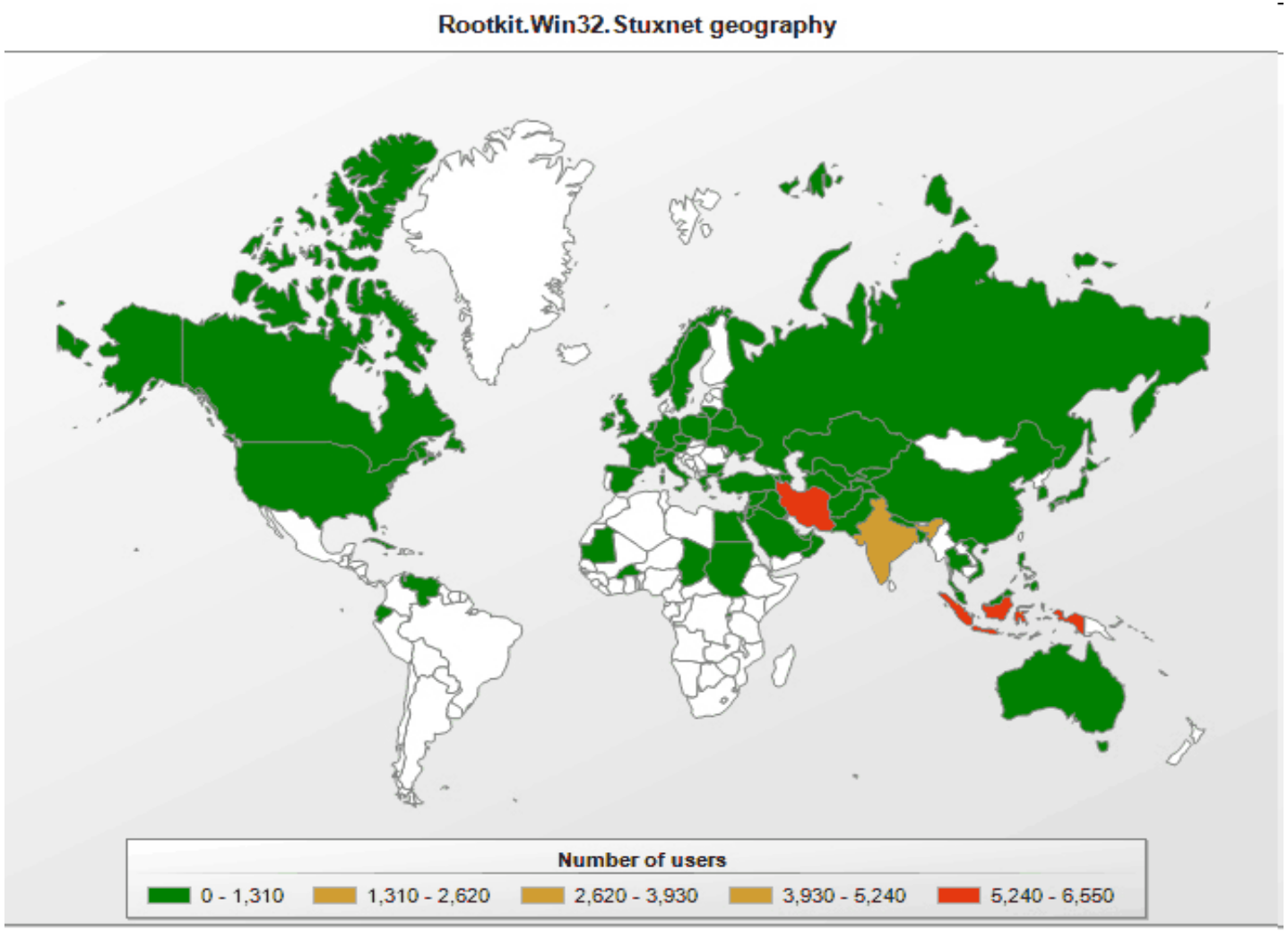
		Communication system		Security	
	Design complexity	Channel type	Message latency	Detectability	Resilience
Centralized	**Low**	**Bidirectionnal**	**Low**	High	Low
Distributed	High	Unidirectionnal	High	**Low**	**High**

STUXNET BOTNET: ANOTHER RECENT EXAMPLE

Stuxnet Worm/Botnet Overview

- Primary target: **industrial control systems**
  - Reprogram **Industrial Control Systems** (ICS)
  - On **Programmable Logic Controllers** (PLCs)
    - Specific Siemens Simatic (Step 7) PLC
- Code changes are hidden
- Vast array of components used:
  - **Zero-day exploits**
  - Windows rootkit
  - PLC rootkit (first ever)
  - Antivirus evasion
  - Peer-to-Peer updates
  - Signed driver with a valid certificate
- Command and control interface

Stuxnet Distribution



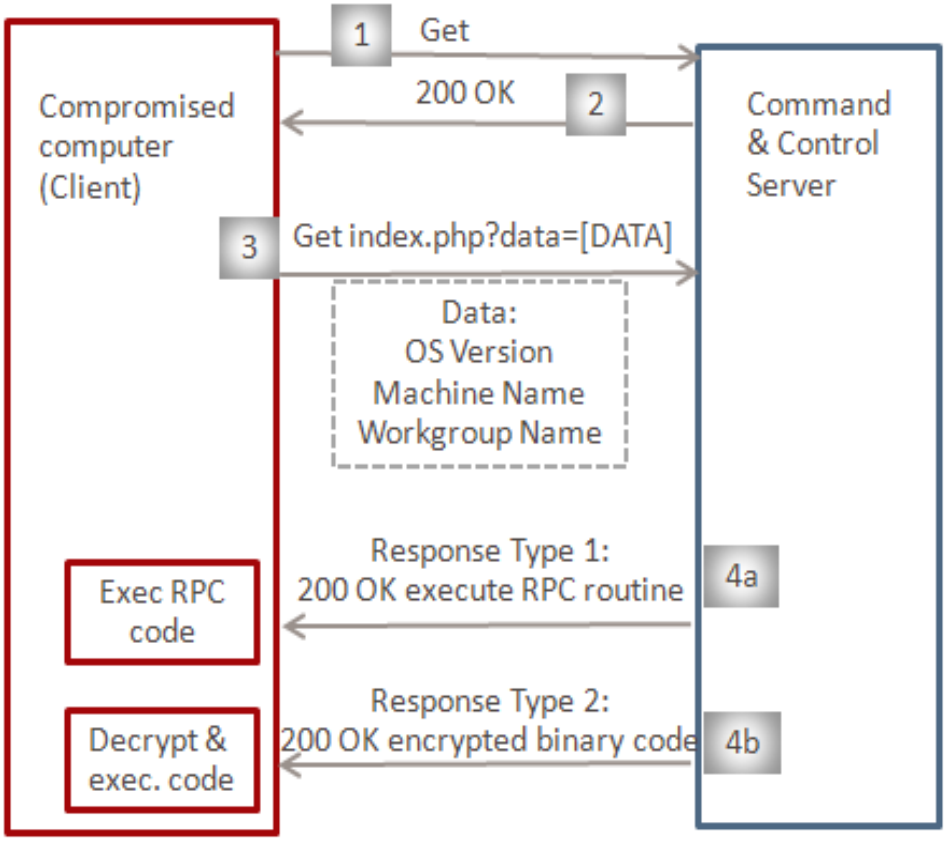
Propagation Methods

- Network
  - **Peer-to-peer** communication and updates
  - Infecting **WinCC machines** (Supervisory Control and Data Acquisition) via a hardcoded database server password
  - Propagating through **network shares**
  - Propagating through the MS10-061 Print Spooler **Zero-Day Vulnerability**
  - Propagating through the MS08-067 **Windows Server Service Vulnerability**
- USB

Command & Control (1)

- Stuxnet contacts the command and control server
  - Test if can connect to:
    - www.windowsupdate.com
    - www.msn.com
  - On port 80
  - Sends some basic information about the compromised computer to the attacker
  - **www.mypremierfutbol.com**
  - **www.todaysfutbol.com**
  - The two URLs above previously pointed to servers in Malaysia and Denmark

Command & Control (2)



1 & 2: Check internet connectivity
3: Send system information to C&C
4a: C&C response to execute RPC routine
4b: C&C response to execute encrypted binary code

Summary

- Stuxnet achieved many things in the malicious code realm
  - First to exploit 4 **zero-day vulnerabilities**
  - Compromised 2 digital certificates
  - Injected code into **industrial control systems** and hid the code from operators
  - …
- Many experts say it is the **most complex malicious software** created in the history of cyber security.
- Highlights that it is possible to attack **critical infrastructures** in places other than Hollywood movies.