CSE 484 / CSE M 584: Computer Security and Privacy

Malware:
Viruses, Worms, Rootkits, Botnets

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Looking Ahead

- Today: Malware
- Next time(s): Mobile platform security and privacy
- Lab 2 due Wednesday, May 20 (5pm)

- Two guest lectures next week
  - **Wednesday:** Emily McReynolds (UW Tech Policy Lab)
    - Bring your law-related questions!
  - **Friday:** Peter Ney and Ian Smith on hacking tools etc.

- The following Monday is a holiday ☺

Malware

- Malicious code often masquerades as good software or attaches itself to good software
- Some malicious programs need host programs
  - Trojan horses (malicious code hidden in useful program)
- Others can exist and propagate independently
  - Worms, automated viruses
- Many infection vectors and propagation methods
- Modern malware often combines techniques

Viruses

- Virus propagates by infecting other programs
  - Automatically creates copies of itself, but to propagate, a human has to run an infected program
  - Self-propagating viruses are often called worms
- Many propagation methods
  - Insert a copy into every executable (.COM, .EXE)
  - Insert a copy into boot sectors of disks
    - PC era: "Stoned" virus infected PCs booted from infected floppies, stayed in memory, infected every inserted floppy
  - Infect common OS routines, stay in memory

First Virus: Creeper

- Written in 1971 at BBN
- Infected DEC PDP-10 machines running TENEX OS
- Jumped from machine to machine over ARPANET
  - Copied its state over, tried to delete old copy
- Payload: displayed a message
  "I'm the creeper, catch me if you can!"
- Later, Reaper was written to delete Creeper

http://history-computer.com/Internet/Maturing/Thomas.html

Virus Detection

- Simple anti-virus scanners
  - Look for signatures (fragments of known virus code)
  - Heuristics for recognizing code associated with viruses
    - Example: polymorphic viruses often use decryption loops
  - Integrity checking to detect file modifications
    - Keep track of file sizes, checksums, keyed HMACs of contents

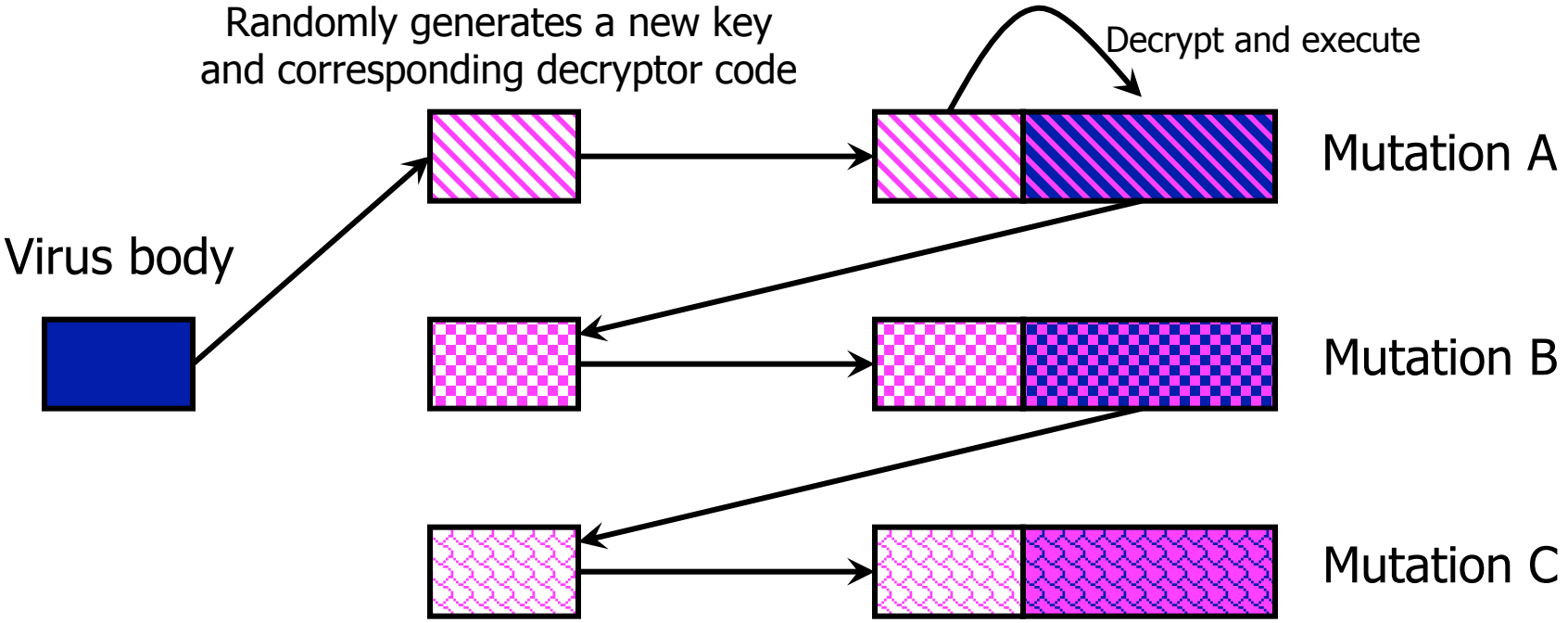
Arms Race: Polymorphic Viruses

- Encrypted viruses: constant decryptor followed by the encrypted virus body
- Polymorphic viruses: each copy creates a new random encryption of the same virus body
  - Decryptor code constant and can be detected
  - Historical note: "Crypto" virus decrypted its body by brute-force key search to avoid explicit decryptor code

Smarter Virus Detection?

- Generic decryption and emulation
  - Emulate CPU execution for a few hundred instructions, recognize known virus body after it has been decrypted
  - Does not work very well against viruses with mutating bodies and viruses not located near beginning of infected executable

Virus Detection By Emulation



To detect an unknown mutation  of a known virus  ,
emulate CPU execution of  until the current sequence of
instruction opcodes matches the known sequence for virus body 

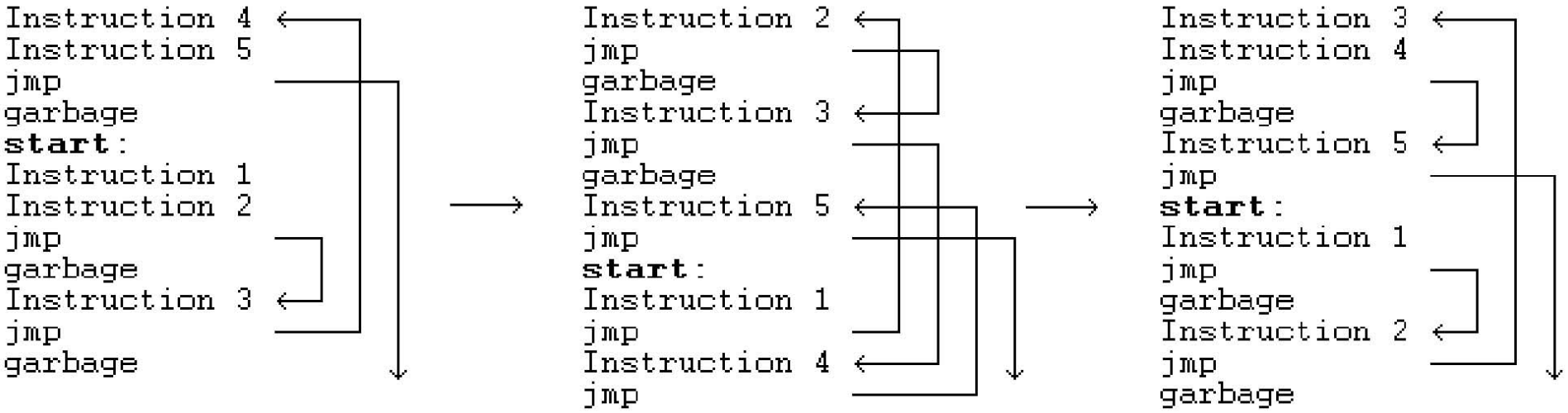
Arms Race: Metamorphic Viruses

- Obvious next step: mutate the virus body, too
- Apparition: an early Win32 metamorphic virus
  - Carries its source code (contains useless junk)
  - Looks for compiler on infected machine
  - Changes junk in its source and recompiles itself
  - New binary copy looks different!
- Mutation is common in macro and script viruses
  - A macro is an executable program embedded in a word processing document (MS Word) or spreadsheet (Excel)
  - Macros and scripts are usually interpreted, not compiled

Mutation Techniques

- Real Permutating Engine/RPME, ADMutate, etc.
- Large arsenal of obfuscation techniques
  - Instructions reordered, branch conditions reversed, different register names, different subroutine order
  - Jumps and NOPs inserted in random places
  - Garbage opcodes inserted in unreachable code areas
  - Instruction sequences replaced with other instructions that have the same effect, but different opcodes
    - Mutate SUB EAX, EAX into XOR EAX, EAX or MOV EBP, ESP into PUSH ESP; POP EBP
- There is no constant, recognizable virus body

Example of Zperm Mutation



[From Szor and Ferrie, "Hunting for Metamorphic"]

Obfuscation and Anti-Debugging

- Common in all kinds of malware
- Goal: prevent code analysis and signature-based detection, foil reverse-engineering
- Code obfuscation and mutation
  - Packed binaries, hard-to-analyze code structures
  - Different code in each copy of the virus
    - Effect of code execution is the same, but this is difficult to detect by passive/static analysis (undecidable problem)
- Detect debuggers and virtual machines, terminate execution

Drive-By Downloads

- Websites "push" malicious executables to user's browser with inline JavaScript or pop-up windows
  - Naïve user may click "Yes" in the dialog box
- Can install malicious software automatically by exploiting bugs in the user's browser
  - 1.5% of URLs - Moshchuk et al. study
  - 5.3% of URLs - "Ghost Turns Zombie"
  - 1.3% of Google queries - "All Your IFRAMEs Point to Us"
- Many infectious sites exist only for a short time, behave non-deterministically, change often

[Provos et al.]

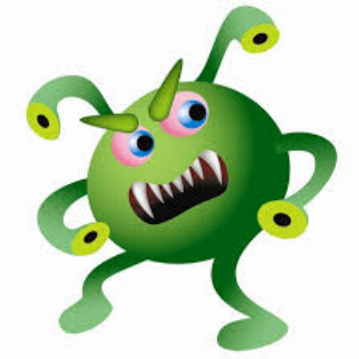
Obfuscated JavaScript

```
document.write(unescape("%3CHEAD%3E%0D%0A%3CSCRIPT%20
LANGUAGE%3D%22Javascript%22%3E%0D%0A%3C%21--%0D%0A
/*%20criptografado%20pelo%20Fal%20-%20Deboa%E7%E3o
%20gr%E1tis%20para%20seu%20site%20renda%20extra%0D
...
3C/SCRIPT%3E%0D%0A%3C/HEAD%3E%0D%0A%3CBODY%3E%0D%0A
%3C/BODY%3E%0D%0A%3C/HTML%3E%0D%0A"));
//-->
</SCRIPT>
```

Viruses vs. Worms

VIRUS

- Propagates by infecting other programs
- Usually inserted into host code (not a standalone program)



WORM

- Propagates automatically by copying itself to target systems
- A standalone program

1988 Morris Worm (Redux)

- 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 a 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, can execute a command on a remote machine by sending an SMTP (mail transfer) message

Dictionary attack

Memory corruption attack

Slammer (Sapphire) Worm

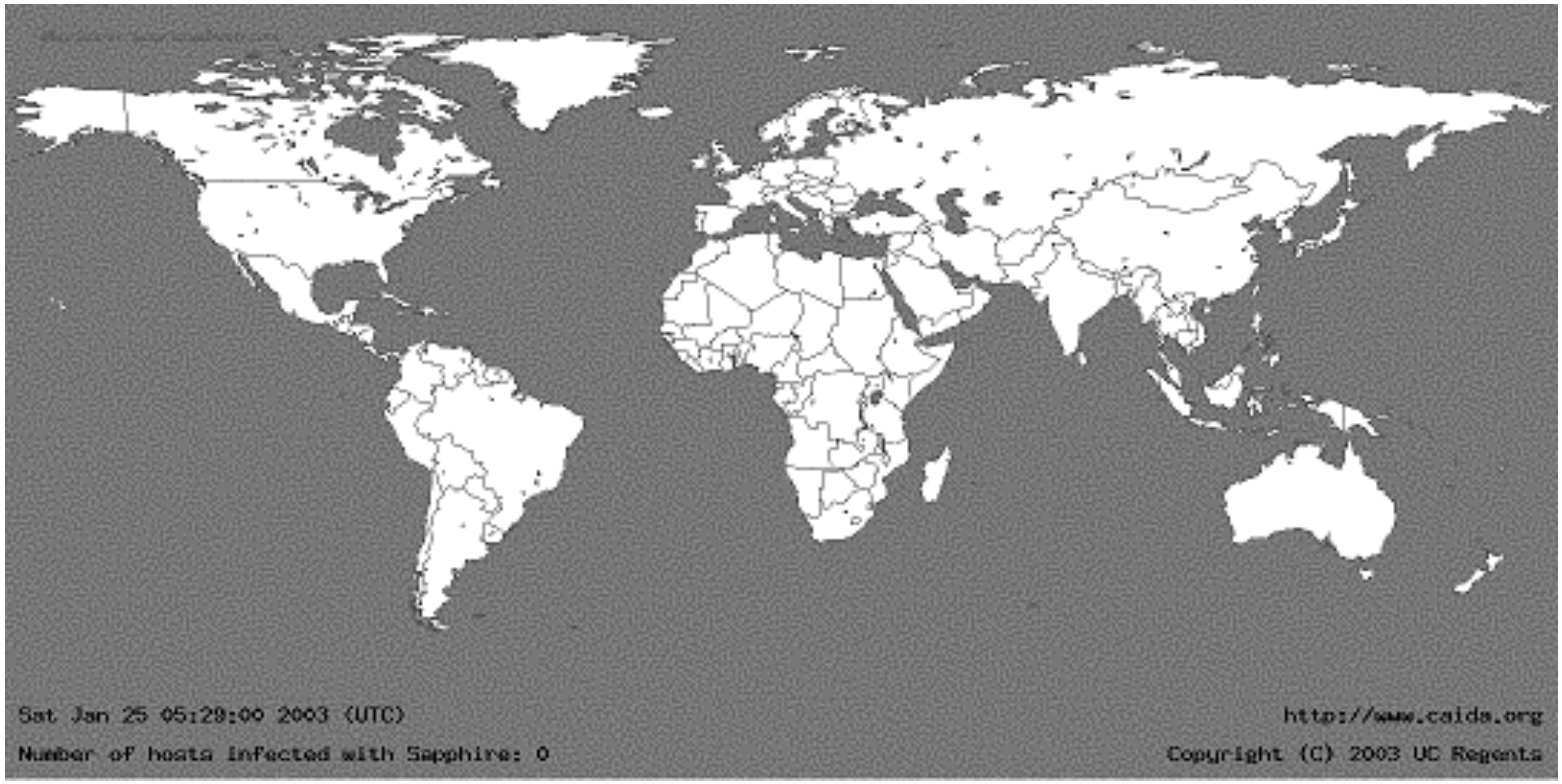
- January 24/25, 2003: UDP worm exploiting buffer overflow in Microsoft's SQL Server (port 1434)
  - Overflow was already known and patched by Microsoft… but not everybody installed the patch
- Entire code fits into a single 404-byte UDP packet
  - Worm binary followed by overflow pointer back to itself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

Slammer Propagation

- Scan rate of 55,000,000 addresses per second
  - Scan rate = the 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 (2001) was 37 minutes
- Worm-generated packets saturated carrying capacity of the Internet in 10 minutes
  - 75,000 SQL servers compromised
  - … in spite of the broken pseudo-random number generator used for IP address generation

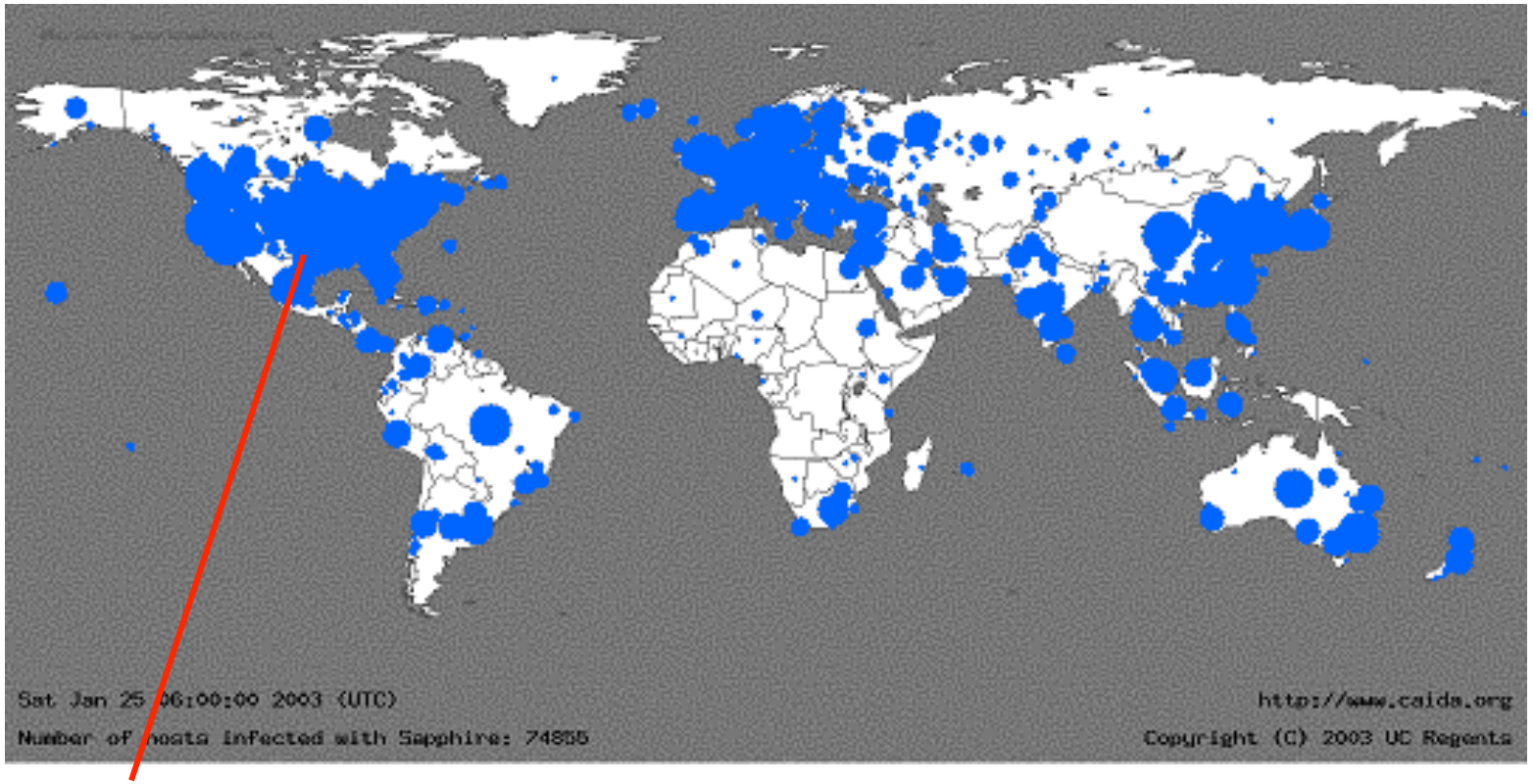
05:29:00 UTC, January 25, 2003

[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

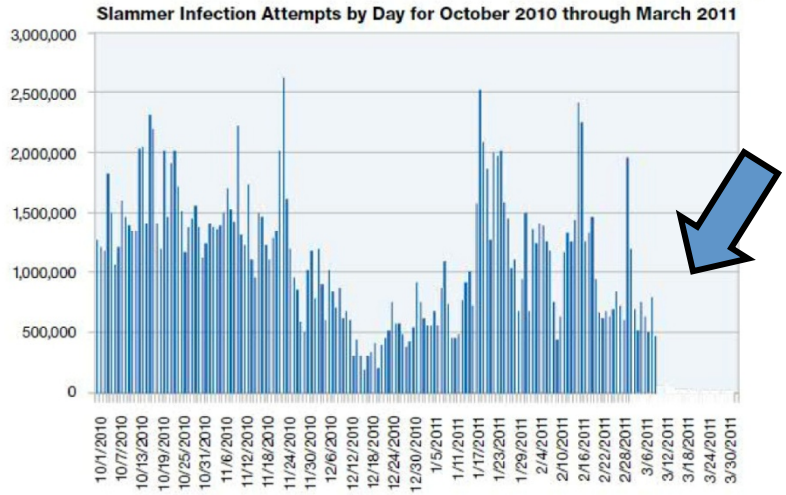
Impact of Slammer

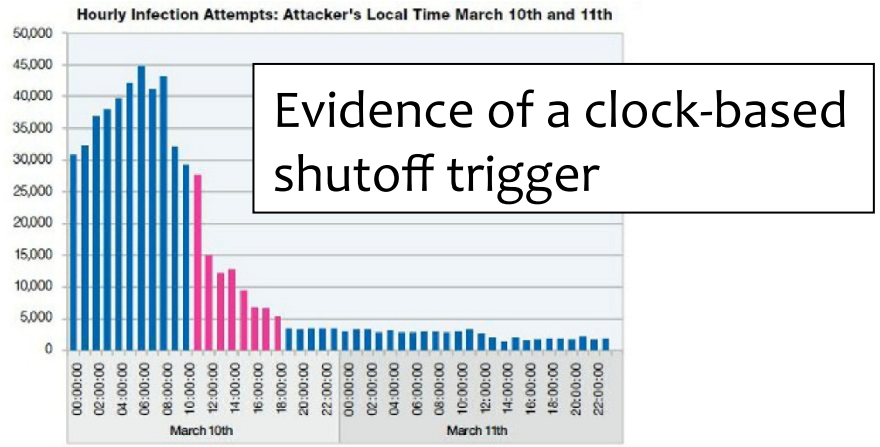
- $1.25 Billion of damage
- Temporarily knocked out many elements of critical infrastructure
  - Bank of America ATM network
  - Entire cell phone network in South Korea
  - Five root DNS servers
  - Continental Airlines' ticket processing software
- The worm did not even have malicious payload… simply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

[Cross and Valacek]

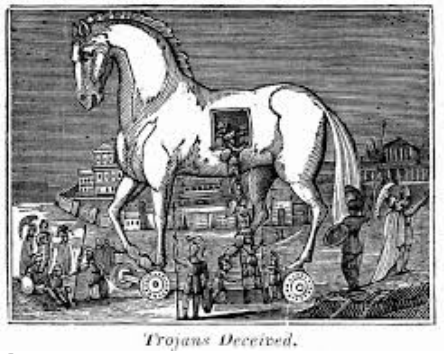
Slammer Aftermath

- Slammer packets were ubiquitous in the Internet for many years after 2003
  - Could be used as a test for Internet connectivity ☺
  - Packets provided a map of vulnerable machines
- Vanished on March 10-11, 2011





Rootkits


Trojans Deceived.

- Rootkit is a set of trojan system binaries
- Main characteristic: stealthiness
  - Create a hidden directory
    - /dev/.lib, /usr/src/.poop and similar
    - Often use invisible characters in directory name
  - Install hacked binaries for system programs such as netstat, ps, ls, du, login

Can't detect attacker's processes, files or network connections by running standard UNIX commands!

  - Modified binaries have same checksum as originals
    - Should use cryptographically secure hash function instead

Function Hooking

- Rootkit may "re-route" a legitimate system function to the address of malicious code
- Pointer hooking
  - Modify the pointer in OS's Global Offset Table, where function addresses are stored
- "Detour" or "inline" hooking
  - Insert a jump in first few bytes of a legitimate function
  - This requires subverting memory protection
- Modifications may be detectable by a clever rootkit detector

Example: Attack on RSA

- Successful attack on a big US security company
- Target: master keys for two-factor authentication
- Spear-phishing email messages
  - Subject line: "2011 Recruitment Plan"
  - Attachment: 2011 Recruitment plan.xls

- Spreadsheet exploits zero-day vulnerability in Adobe Flash to install Remote Administration Software (RAT)
  - Reverse-connect: pulls commands from C&C servers
  - Stolen data moved to compromised servers at a hosting provider, then pulled from there and traces erased

http://blogs.rsa.com/rivner/anatomy-of-an-attack/

Detecting a Rootkit

- Sad way to find out
  - Run out of physical disk space because of sniffer logs
  - Logs are invisible because du and ls have been hacked
- Manual confirmation
  - Reinstall clean ps and see what processes are running
- Automatic detection
  - Host-based intrusion detection can find rootkit files
    - … assuming an updated version of rootkit did not disable the intrusion detection system!

Botnets

- Botnet is a network of autonomous programs capable of acting on instructions
  - Typically a large (up to several hundred thousand) group of remotely controlled "zombie" systems
    - Machine owners are not aware they have been compromised
  - Controlled and upgraded from command-and-control (C&C) servers
- Used as a platform for various attacks
  - Distributed denial of service, Spam and click fraud
  - Launching pad for new exploits/worms

Bot History

- Eggdrop (1993): early IRC bot
- DDoS bots (late 90s): Trin00, TFN, Stacheldracht
- RATs / Remote Administration Trojans (late 90s):
  - Variants of Back Orifice, NetBus, SubSeven, Bionet
  - Include rootkit functionality
- IRC bots (mid-2000s)
  - Active spreading, multiple propagation vectors
  - Include worm and trojan functionality
  - Many mutations and morphs of the same codebase
- Stormbot and Conficker (2007-09)

Life Cycle of an IRC Bot

- Exploit a vulnerability to execute a short program (shellcode) on victim's machine
  - Buffer overflows, email viruses, etc.
- Shellcode downloads and installs the actual bot
- Bot disables firewall and antivirus software
- Bot locates IRC server, connects, joins channel
  - Typically need DNS to find out server's IP address
    - Especially if server's original IP address has been blacklisted
  - Password-based and crypto authentication
- Botmaster issues authenticated commands

Command and Control

```
(12:59:27pm) -- A9-pcgbdv (A9-pcgbdv@140.134.36.124) has
joined (#owned) Users : 1646

(12:59:27pm) (@Attacker) .ddos.synflood 216.209.82.62

(12:59:27pm) -- A6-bpxufrd (A6-bpxufrd@wp95-81.introweb.nl)
has joined (#owned) Users : 1647

(12:59:27pm) -- A9-nzmpah (A9-nzmpah@140.122.200.221) has
left IRC (Connection reset by peer)

(12:59:28pm) (@Attacker) .scan.enable DCOM

(12:59:28pm) -- A9-tzrkeasv (A9-tzrkeas@220.89.66.93) has
joined (#owned) Users : 1650
```

Detecting Botnet Activity

- Many bots are controlled via IRC and DNS
  - IRC used to issue commands to zombies
  - DNS used by zombies to find the master, and by the master to find if a zombie has been blacklisted
- IRC/DNS activity is very visible in the network
  - Look for hosts performing scans and for IRC channels with a high percentage of such hosts
  - Look for hosts who ask many DNS queries but receive few queries about themselves
- Easily evaded by using encryption and P2P ☹

What to Do With a Botnet?

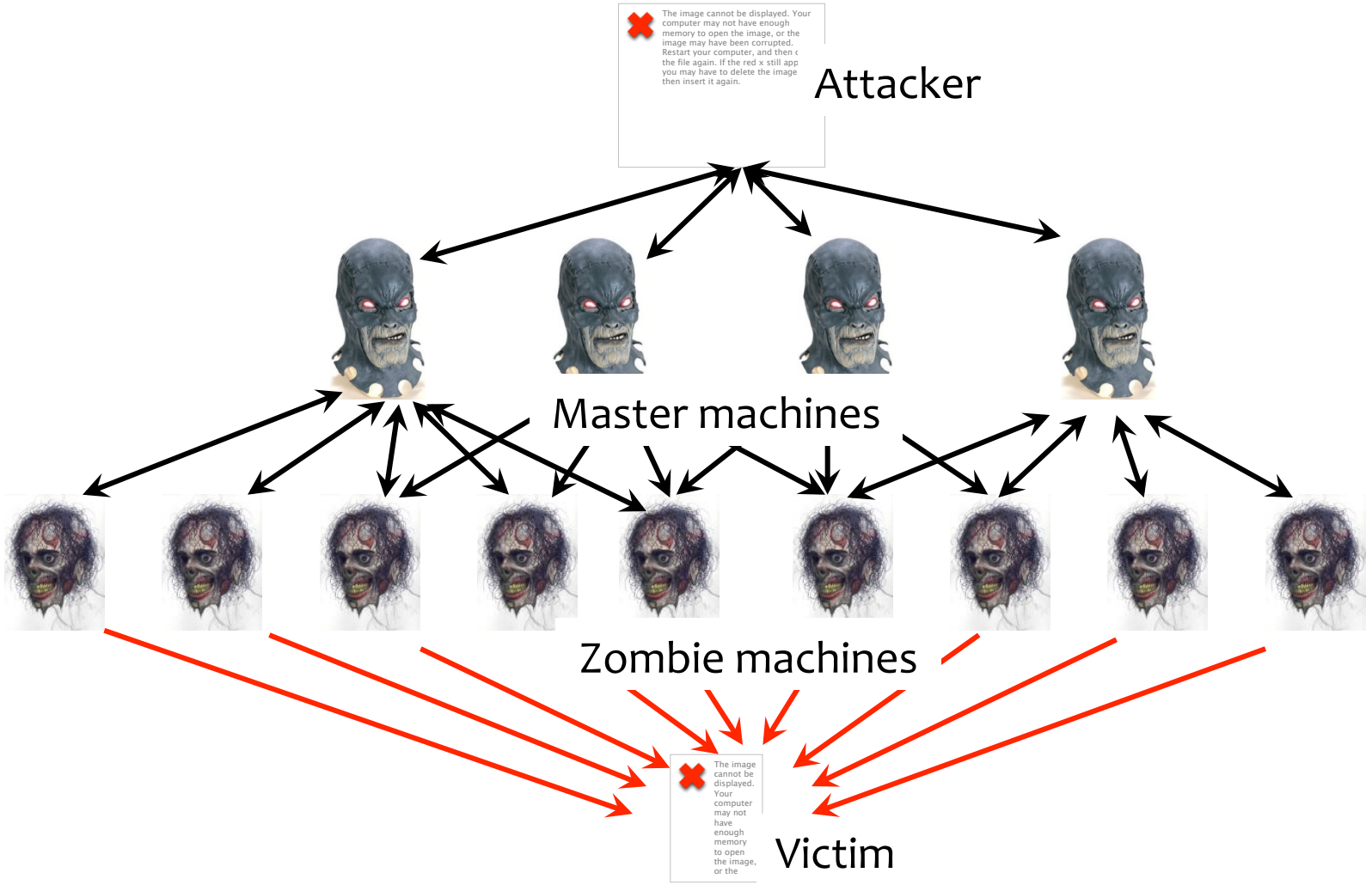
- Denial of service (including cyber-warfare)
- Spam
- Fake antivirus sales, Ransomware
- Advertising clickfraud
- Bitcoin mining
  - According to Symantec, one compromised machine yields 41 US cents a year…

CryptoLocker

Denial of Service (DoS)

- **Goal:** overwhelm victim machine and deny service to its legitimate clients
- DoS often exploits networking protocols
  - Smurf: ICMP echo request to broadcast address with spoofed victim's address as source
  - SYN flood: send lots of "open TCP connection" requests with spoofed source addresses
  - UDP flood: exhaust bandwidth by sending thousands of bogus UDP packets
  - HTTP request flood: flood server with legitimate-looking requests for Web content

Distributed Denial of Service (DDoS)



How to Protect Yourself?

- Nothing is perfect but…
  - Keep your software updated
  - Be vigilant for phishing attacks
  - Anti-virus
  - Firewalls
  - Intrusion detection systems