CS 4910: Intro to Computer Security

Malicious Software

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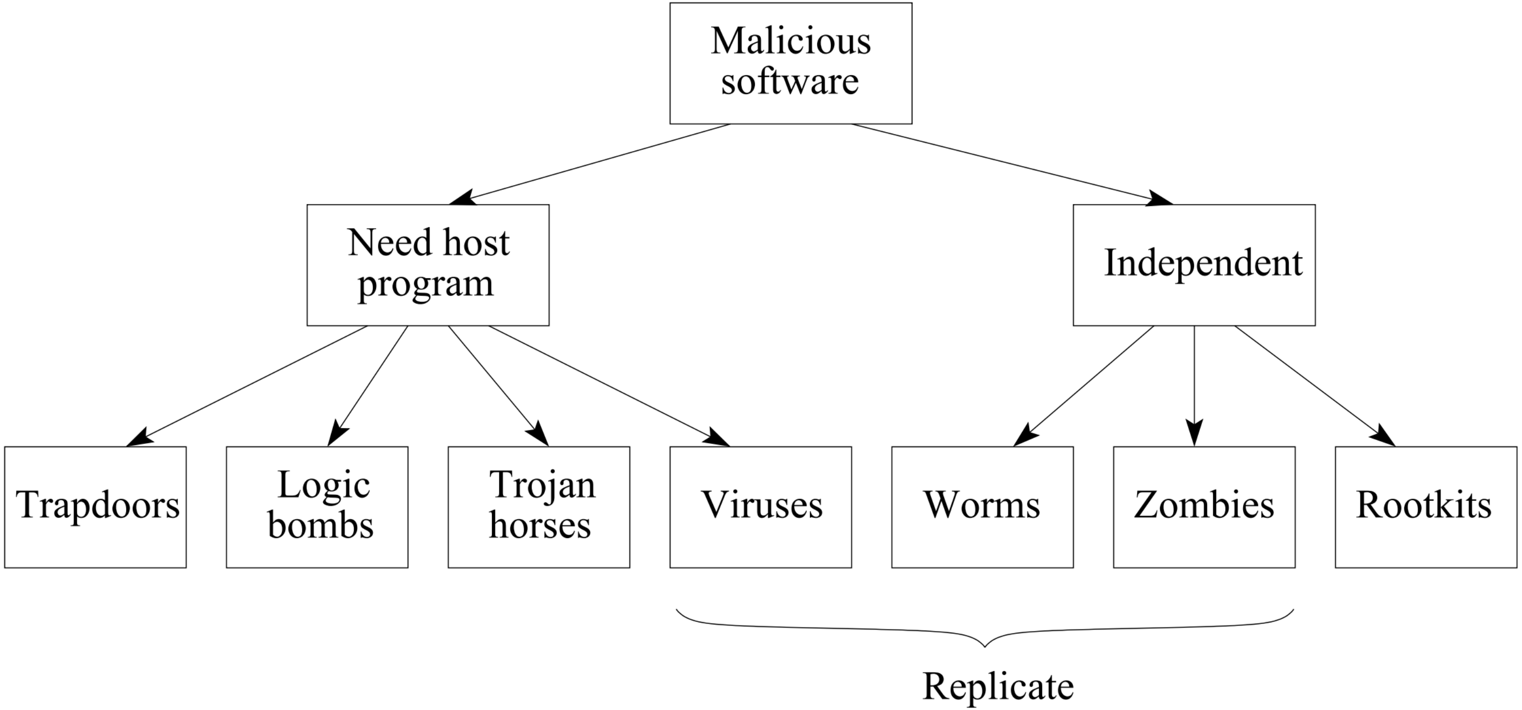
Malicious Software

- There are many types of security problems in software
  - often such holes are exploited by malicious software or malware
- There are many types of malware
  - backdoors
  - logic bombs
  - Trojan horses
  - viruses
  - worms
  - bots
  - rootkits
  - . . .

Malicious Software

- Taxonomy of malicious software



Malicious Software

- Another way to classify malicious software
  - Propagation
    - infected content: viruses
    - vulnerable exploit: worms
    - social engineering: spam email, trojans
  - Payload
    - system corruption: ransomware, logic bomb
    - attack agent: zombie, bots
    - information theft: keyloggers, phishing, spyware
    - stealthing: backdoors, rootkits

Insider Attacks

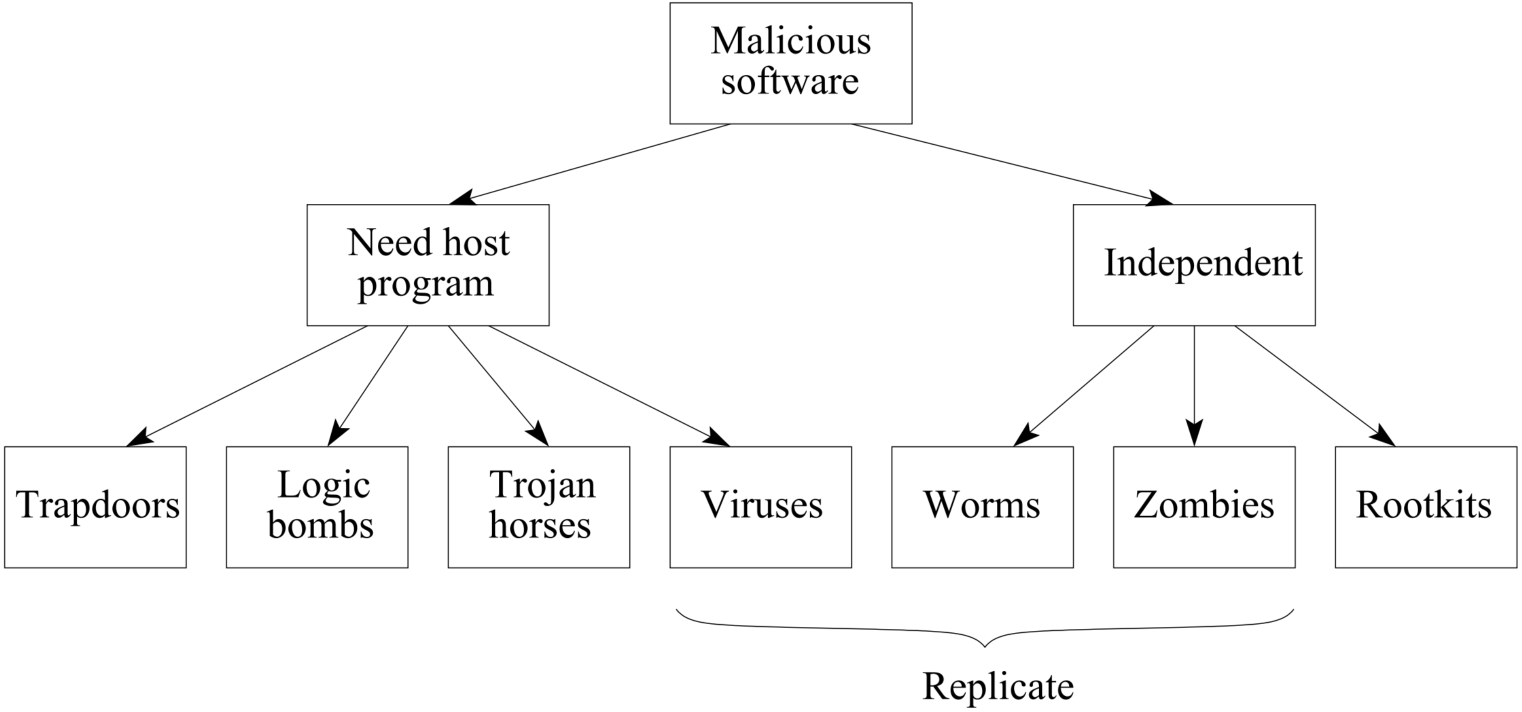
- An **insider attack** is a security breach that is caused or facilitated by someone who is a part of the organization that controls or builds the asset that should be protected.
- In the case of malware, an insider attack refers to a security hole that is created in a software system by one of its programmers.

Defenses against Insider Attacks

- Avoid single points of failure.
- Use code walk-throughs.
- Use archiving and reporting tools.
- Limit authority and permissions.
- Physically secure critical systems.
- Monitor employee behaviors.
- Control software installations.

Malicious Software

- Taxonomy of malicious software



Backdoors

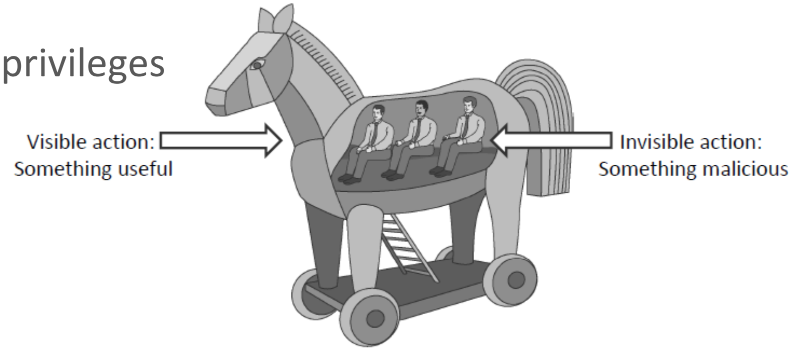
- Trapdoor (or backdoor)
  - a secret point entry into a program
  - it allows one who knows of the trapdoor existence to get around the normal security access procedures and gain access
- Trapdoors were commonly used by developers to debug and test programs
  - When used in a normal way, this program performs completely as expected and advertised.
  - But if the hidden feature is activated, the program does something unexpected, often in violation of security policies, such as performing a privilege escalation.
- Trapdoors have been used to gain unauthorized access to systems

Logic Bombs

- Logic bomb
    - code embedded in a **legitimate** program
    - the code is set to activate when certain **conditions** are met
    - example conditions
        - presence or absence of particular files
        - particular date or time
        - particular user
- when a logic bomb is triggered, it typically damages the system
    - modify/delete data, files, or even disks
    - cause the system to halt

Trojan horse

- Trojan horse
  - a program with overt (expected) and covert function
    - the overt functionality appears normal and useful
    - when invoked, covert functionality violates security policy
  - user is tricked into executing Trojan horse
    - user sees overt behavior
    - covert function is performed with user’s privileges



Trojan horse

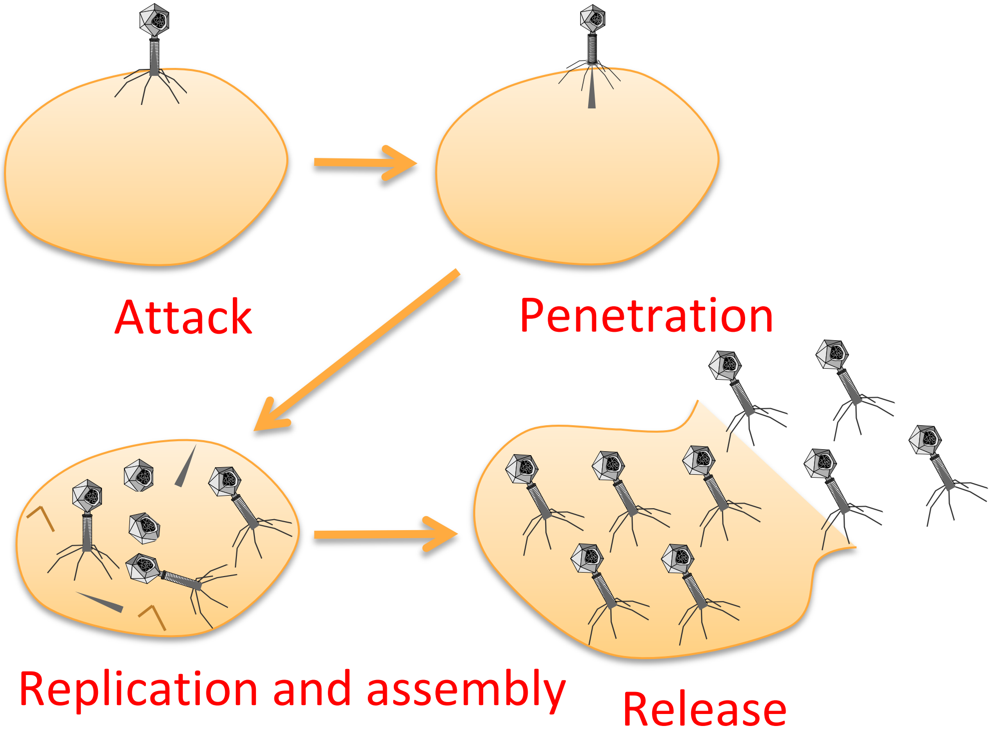
- Examples of Trojan horses
  - accomplishing a task an authorized user could not perform
    - Trojan directory listing program ls lists files and makes them world readable
    - login program stores passwords and sends them to a specific address
    - compiler inserts extra code into programs
  - performing data destruction
    - listing directory contents and then removing the files
    - reporting the weather and quietly deleting files
- Covert functionality can be related or unrelated to the overt functionality

Viruses

- Viruses
  - a **self-replicating** code that attaches itself to a host program
  - the virus contained in an “infected” program will have the ability to **infect** other programs
  - there is no overt action, it generally tries to remain undetected
- A virus is activated when the host program is executed
  - often the virus attaches itself in the beginning of the program
  - i.e., first virus code is executed and then the original program is run

Viruses

- Computer viruses share some properties with Biological viruses



Viruses

- A virus contains an infection mechanism, trigger and payload
  - the **infection** mechanism is code responsible for virus replication
  - the **payload** is other functionality the virus has, including any damage and benign activity
  - the **trigger** is an event or condition that determines when the payload is activated or delivered
- Example operation of an infected program

```
if (spread condition) then
    for target files
        if not infected, then alter to include virus
if (activate payload) then
    perform malicious action (payload)
execute the host program
```

Viruses

- Virus lifetime phases
  - the virus can be dormant while the spread condition is false
  - then it enters the propagation phase and infects other programs or system areas
  - when the payload is activated, it performs its main function
  - propagation and execution phases can be activated based on any event
    - date, system utilization, presence/absence of some object, etc.
- Often virus's code starts with a specific label that indicates that a program has already been infected
  - the virus checks for the presence of this label before infecting

Viruses

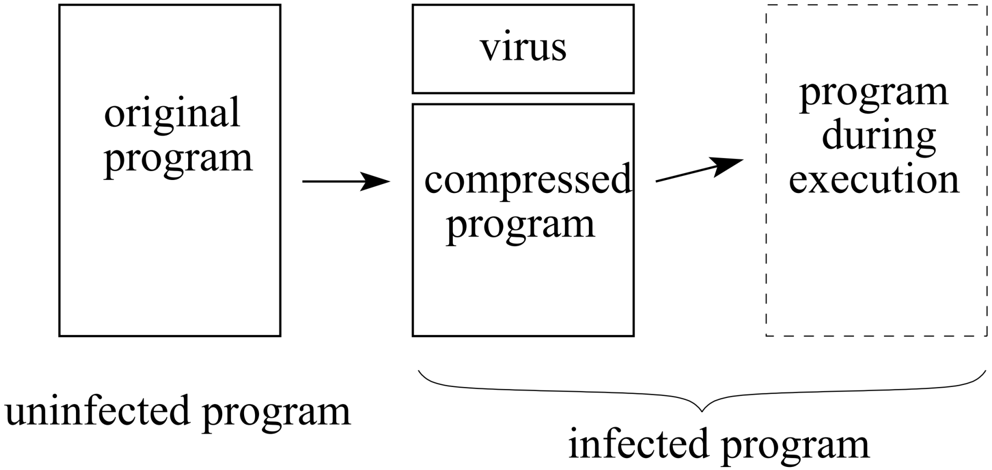
- Viruses can be classified in many different ways
- Virus types based on the target of infection
  - boot sector viruses
    - how do we ensure that virus carrier get executed?
    - solution: place the code in boot sector of disk
    - the code is run on each boot and propagates by altering boot disk creation
  - executable infectors
    - malicious code is placed at beginning of a legitimate program
    - the code is run when the program is executed, followed by the normal program execution

Viruses

- Virus types based on the target (cont.)
  - macro viruses
    - non-executable files with macro code are infected
    - the code is interpreted by the application that opens the file
    - example: Microsoft Office documents that can carry macros
- There is a constant battle between virus writers and antivirus software writers
  - both viruses and antivirus software are getting increasingly sophisticated
- Viruses can employ a number of strategies to **conceal** their presence

Viruses Concealment

- Compression
  - goal: avoid detection based on increased length of the host program
  - solution: store main program in compressed form
    - when the virus is added to the program, the rest of it is compressed
    - when the program is executed, the virus code uncompresses the program and runs it



Viruses Concealment

- Encrypted virus
  - Decryption engine + encrypted body
  - Randomly generate encryption key
  - Detection looks for decryption engine
- Polymorphic virus
  - Encrypted virus with random variations of the decryption engine (e.g., padding code)
  - Detection using CPU emulator
- Metamorphic virus
  - Different virus bodies
  - Approaches include code permutation and instruction replacement
  - Challenging to detect

Viruses

- Virus evolution
  - boot sector and executables
    - early systems had poor access control protection mechanisms
  - macro viruses
    - became prevalent in 1990s
    - now MS Office applications have greater protection
  - email viruses
    - prevalent today and allow for faster spreading speeds
    - email virus sends infected contents to all email addresses found on the infected machine
    - first opening infected attachment was necessary to get infected, now simply opening the email could be sufficient

Viruses

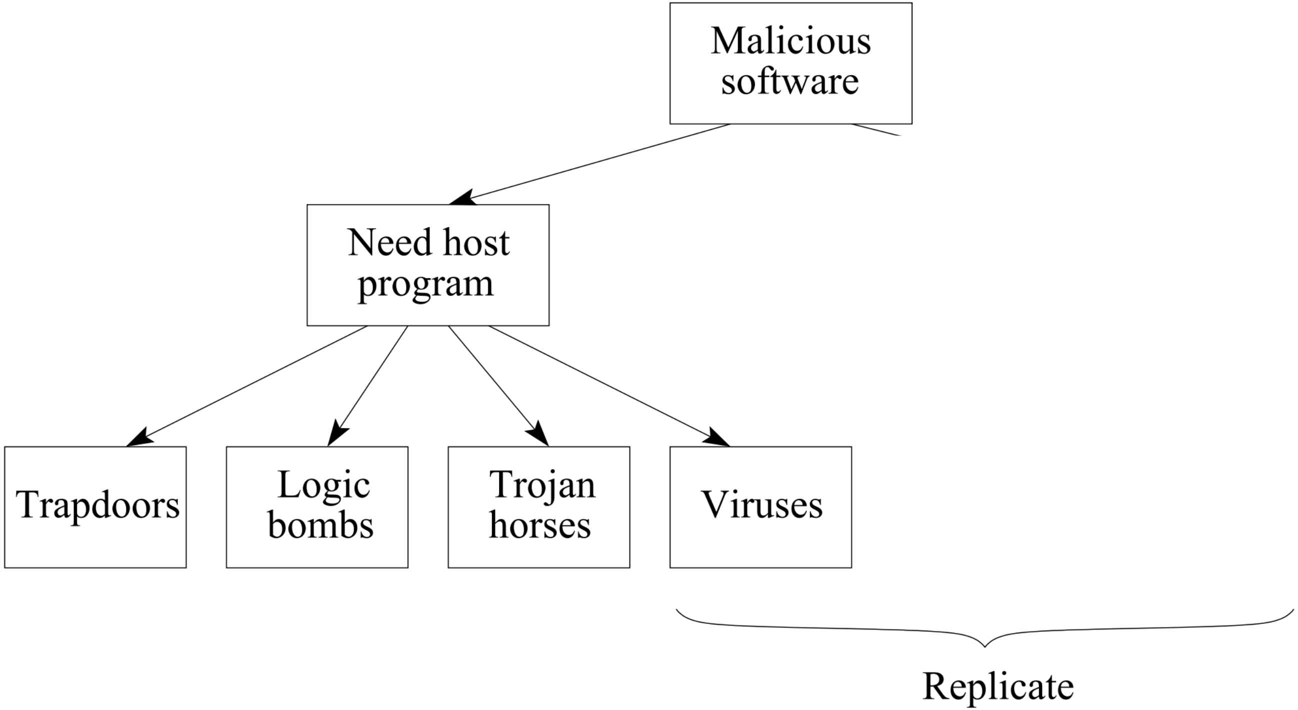
- Types of antivirus software
  - first generation: simple scanners
    - the simplest technique is to identify a virus “signature”
    - antivirus software then searches for this specific bit pattern
  - heuristic scanners
    - identify common behavior of a virus
    - look for traces of such behavior
    - examples: viruses that use encryption, integrity checking of executables
  - activity monitors
    - identify a set of actions that indicate that infection is attempted
    - intervene when such actions are performed
  - combination of the above techniques

Viruses

- Types of antivirus software
  - advanced detection through program simulation
    - an executable file is run on a CPU emulator in controlled environment
    - code scanning is performed to detect a virus (which could be stored encrypted, but is decrypted during execution)
  - combine with ML, DL
- Antivirus software can have the ability to communicate information about new viruses to a central server
  - allows for timely dissemination of new information to all clients

Malicious Software

- So far …



Worms

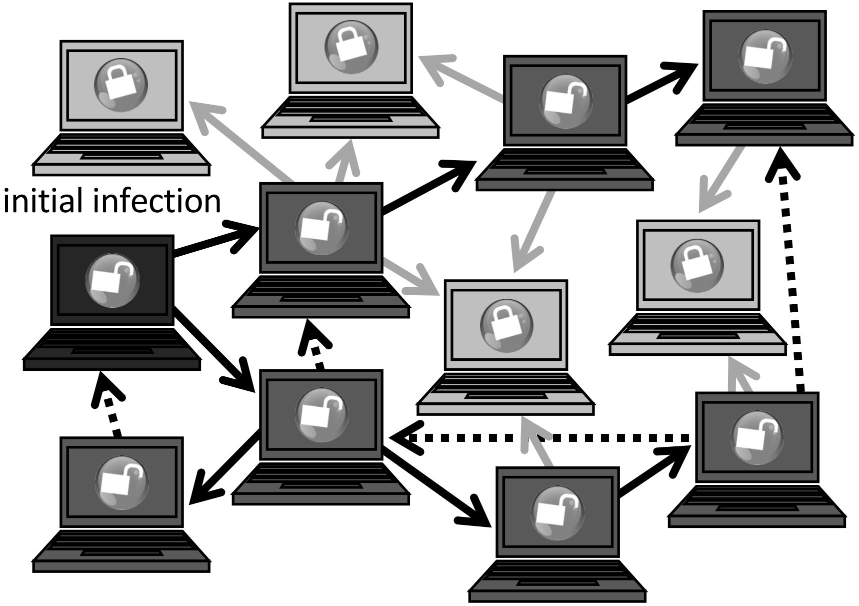
- Worm
  - a program that **self-replicates**, but runs independently
  - it propagates by **copying** itself to other machines through network connection
  - like viruses, it carries a payload for performing hidden tasks
    - e.g., backdoors, spam relays, DDoS agents, etc.
- A worm can use any network-based mechanism for propagation
  - e.g., through email, remote exploits, remote logins
  - often a worm is programmed to use more than one propagation method

Worms

- Worm lifetime has similar phases to that of a virus
    - probing: search for potential hosts to infect by inspecting host tables and other files
    - exploitation: find a way to gain access to a remote host
    - replication: copy itself to the remote host and cause it to run
    - payload execution: payload can be executed immediately or triggered by some event
- The first well-known worm is Morris worm which was released in 1988
- Many other large-scale worms appeared afterwards
    - Code Red and Nimda worm in 2001, SQL Slammer in 2003, . . .

Worm Propagation

- Worms propagate by **finding** and **infecting** vulnerable hosts.
  - They need a way to tell if a host is vulnerable
  - They need a way to tell if a host is already infected.



Worms

- Cost of worm attacks
  - Morris worm (1988)
    - infected approx. 6,000 machines (10% of computers connected to the internet)
    - cost approx. $10 million in downtime and cleanup
  - Code Red worm (2001)
    - infected more than 500,000 servers
    - caused approx. $2.6 billion in damages
  - Love Bug worm (2000)
    - cost approx. $8.75 billion

Worms

- Morris worm (1988) – first major attack
  - exploited Unix security vulnerabilities, as well as tried password cracking
  - no immediate damage from the program itself
    - most of the code was to ensure spread of the worm (find other machines, attempt to gain access)
    - another part was to copy the worm, compile, and activate on a new machine
  - replication and threat of damage
    - load on network and systems used in attack
    - many systems shut down to prevent further attack

Worms

- Morris worm propagation mechanisms
  - buffer overflow problem in `fingerd` (Unix finger daemon)
    - `fingerd` is written in C and runs continuously
    - the worm exploited `fgets` through a buffer boundary attack
    - somehow this was the most successful propagation mechanism
  - trapdoor in the debug option of `sendmail` (e-mail distribution program)
    - this option allowed the worm to obtain shell access
  - remote logins through `rsh`
    - trusted logins found in `.rhosts`
    - cracking of weak passwords (using `/etc/passwd` and its own database of about 400 common passwords)

Worms

- More on Morris worm
  - the program was called ‘sh’ to remain undetected
  - the program opens its files and unlinks (deletes) them so that they cannot be found
  - it tried to infect as many hosts as possible
    - when worm successfully connects, it forks a child to continue infection while the parent process keeps trying other hosts
  - the worm **did no**t modify or delete existing files, install Trojan horses, capture superuser privileges, etc.
  - the author was quickly found and charged
  - system admins were busy for several days
    - machines got reinfected and overloaded

Worms

- Lessons learned from Morris worm?
  - security vulnerabilities come from system flaws
  - diversity is useful for resisting attack
  - “experiments” can be dangerous
- More resources
  - E. Spafford, “The Internet Worm: Crisis and Aftermath,” CACM 32(6), pp. 678–687, 1989
  - B. Page, “A Report on the Internet Worm,”

    `http://www.ee.ryerson.ca/˜~elf/hack/iworm.html`

Worms

- Challenges in defending against worms
  - small interval between vulnerability disclosure and worm release
    - Witty worm: 1 day; zero-day exploits
  - ultrafast spreading
    - Slammer: 10 minutes, Flashworm: seconds
  - large scale
    - Slammer: 75,000 machines, Code Red: 500,000 machines
- Need for automation
  - current threats can spread faster than defenses can react
  - manual capture/analysis/signature generation/rollout model is slow

Worms

- Worm detection and defense by traffic monitoring
  - observe all traffic between your network and the internet
  - approach 1: apply throttling/rate limiting
    - detect superspreaders by finding hosts that make failed connected attempts to too many other hosts
    - limit the number of connections and/or number of hosts scanned
  - approach 2: identify worm patterns
    - look for strings common to traffic with worm-like behavior in monitored traffic
    - signature-based approach

Worms

- Worm detection and defense by traffic monitoring
  - approach 2: identify worm patterns (cont.)
    - content-sifting by detecting the same bitstring pattern
      - main observation: strings of (say) 40 bytes repeat rarely in normally generated traffic
      - disadvantages: large computation and memory requirements, false positives and negatives
- Worm defenses can also be semantic-based
  - focus on the root cause (vulnerability)
  - detect exploits, diagnose, generate antibodies

Botnets

- Botnet: a “network” of infected machines
  - Infected machines are “bots”
    - a program that secretly runs on a networked computer
    - it uses the machine to launch attacks that don’t trace back to the creator of the bot
    - each infected machine receives and executes remote commands
- Worm vs. bot
  - a worm propagates itself and executes itself
  - a bot is controlled by a **central** server (or servers)

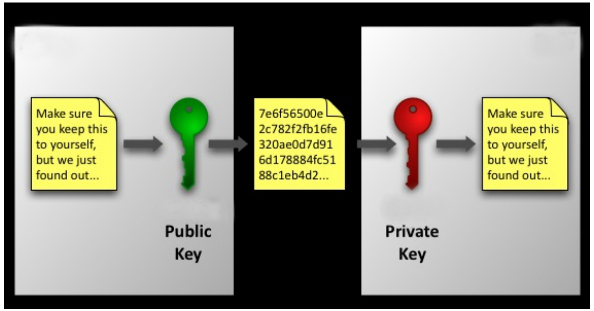
Botnets

Botnets

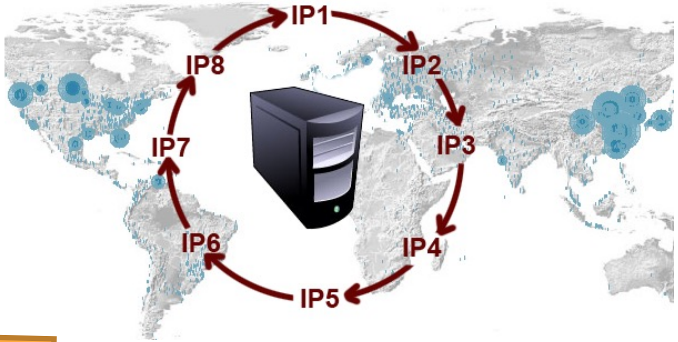
- How bots are used
  - launch attacks that are hard to trace to the originator
    - DDoS
    - phishing, spamming
    - traffic sniffing or keylogging, stealing data
    - spreading new malware
- IRC servers were popular as the master server
  - bots join a specific chat channel and wait for commands
  - distributed control mechanisms can be used to minimize failure
- The main objective in defending against botnets is to detect and disable it at construction phase

How do They Hide?

Encryption

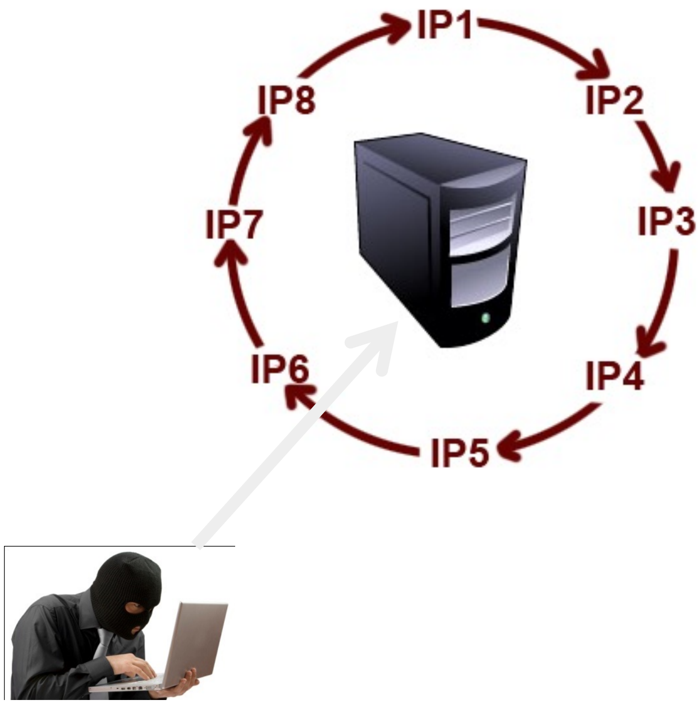


Fast Flux



Rootkit

Fast Flux



IP addresses that are rotated in seconds against the same domain.

For example:

[QUESTION] Website name:

www.lijg.ru

[ANSWER] IP Addresses:

www.lijg.ru → 68.124.161.76
www.lijg.ru → 69.14.27.151
www.lijg.ru → 70.251.45.186
www.lijg.ru → 71.12.89.105
www.lijg.ru → 71.235.251.99
www.lijg.ru → 75.11.10.101
www.lijg.ru → 75.75.104.133
www.lijg.ru → 97.104.40.246
www.lijg.ru → 173.16.99.131
…………………

Rootkits

- Rootkit is software used on a compromised machine to maintain superuser access
    - it is used to hide attacker’s presence
    - it also provides a reentry mechanism into the system

- Since attacker has full access to the system, a rootkit might
    - add/change programs, files, and system utilities
    - monitor processes and network traffic
    - modify the kernel
    - install backdoors for reentry
    - carry any type of malicious payload

Rootkits

- Types of rootkits
  - user mode
    - modifies results returned by various programs to hide its presence
  - kernel mode
    - patches the kernel to modify results returned by native APIs and/or hide some running processes
  - rootkits can also be persistent (survive reboot) or memory-based
    - persistent rootkit stores code in a persistent store and finds a way to execute it after reboot
  - virtual machine based
    - installs a lightweight virtual machine monitor and then runs the operating system in a virtual machine above it

Rootkits

- Reentry can be performed through any mechanism that works
    - modified login program, accepting connections on a specific port, etc.
- Rootkit’s payload can include running sniffers, mounting attacks, compromising other machines, etc.

- Rootkits are often difficult to detect
    - since we cannot rely on system’s tools for rootkit detection, other mechanisms must be used
    - can combine network-based monitoring with host-based view
    - the only reliable way to recover from a kernel-based rootkit is to reinstall the OS

Ransomware

- Ransomware is a relatively new term
- It refers to software that encrypts victim’s data and demands payment to regain access to it
  - payment in cryptocurrencies is requested in exchange for the decryption key

- A number of devastating ransomware attacks took place in recent years
  - WannaCry ransomware affected railroads, hospitals, etc. in May 2017
  - NotPetya froze many companies and government agencies around the world in 2018
    - it irreversibly encrypted computers’ master boot sectors and payment efforts were futile

Malware Countermeasure Approaches

Ideal solution to the threat of malware is prevention

- Four main elements of prevention:
  - Policy
  - Awareness
  - Vulnerability mitigation
  - Threat mitigation
- If prevention fails, technical mechanisms can be used to support the following threat mitigation options:
  - Detection
  - Identification
  - Removal

Conclusions

- A large number of malicious software types exist
  - Trojan horses, viruses, worms, bots, keyloggers, etc.
- Malware results in large losses
- Malware evolves as better countermeasures become available
- Effective defenses often require substantial efforts and must adopt to constantly changing malware techniques