CSE 410/565 Computer Security
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Lecture 17: Malware

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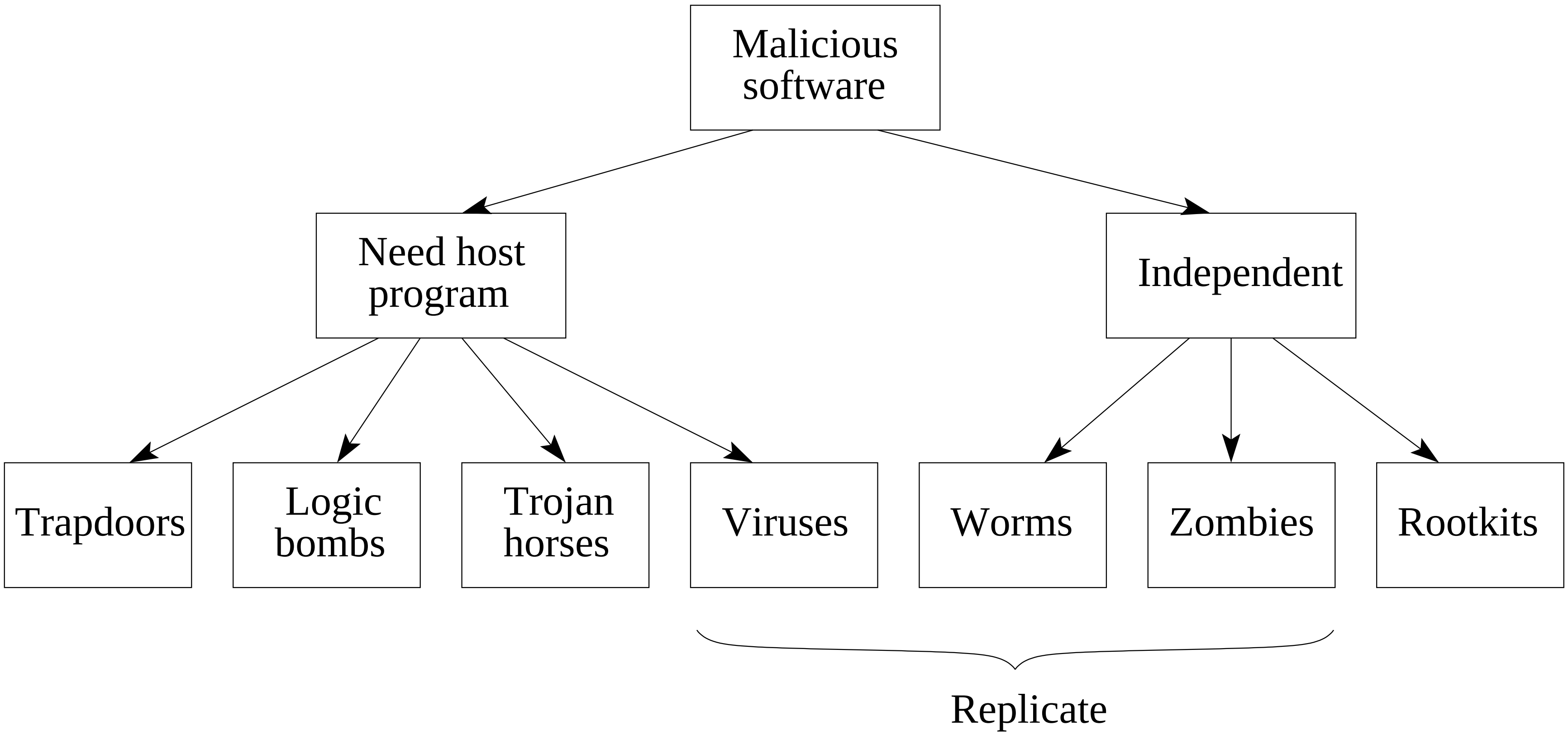
Malicious Software

- 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

Malicious Software Types

- 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
  - the program recognizes a special user ID or a combination of events and grants the user special privileges
  - programmers can easily gain access to the program for debugging purposes or in case something goes wrong
- Trapdoors have been used to gain unauthorized access to systems

Malicious Software Types

- 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

Malicious Software Types

- 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

Malicious Software Types

- 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

Malicious Software Types

- 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

- A virus contains an infection mechanism 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
- 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

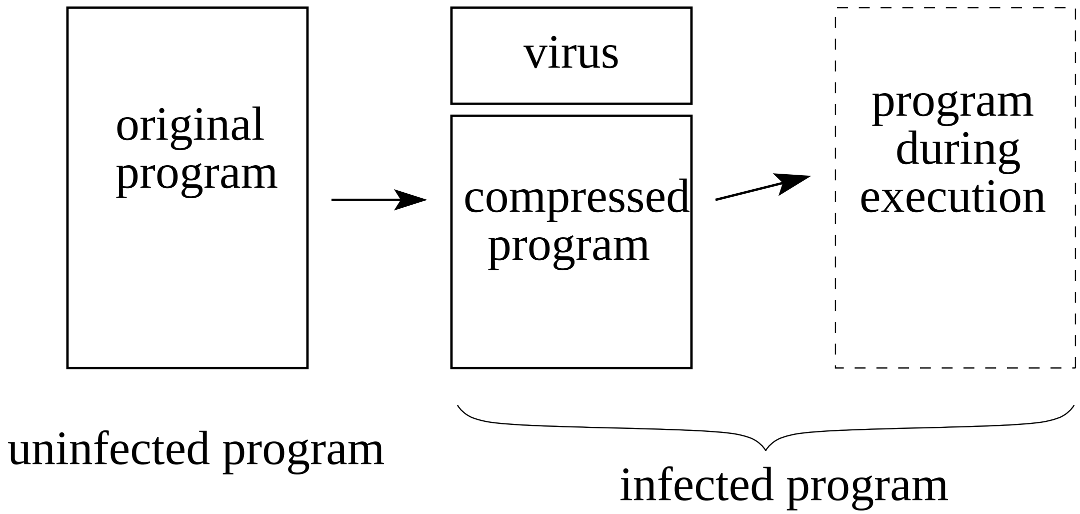
- Viruses can be classified in many different ways
- Virus types based on the target of infection
  - boot sector viruses
    - how do we ensure that virus carrier get executed?
    - solution: place the code in boot sector of disk
    - the code is run on each boot and propagates by altering boot disk 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

- 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

- Encryption
  - part of the virus creates an encryption key and encrypts the rest of the virus with it
  - the key is stored with the virus and is used to decrypt it when necessary
  - each copy of the virus uses a different randomly chosen key
  - virus scanners no longer can look for a specific signature
- Polymorphism
  - the virus mutates with each infection by introducing differences in the virus code
  - virus scanners cannot look for a specific signature

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

Viruses

- Types of antivirus software
  - activity monitors (cont.)
    - intervene when such actions are performed
  - combination of the above techniques
  - 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)
- 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

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, ...

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 not 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

- Code Red
  - initial version was released on July 13, 2001
  - the worm sends its code as an HTTP requests and exploits buffer overflow in MS Internet Information Server (IIS)
  - when it is executed
    - first checks whether the machine is already infected
    - 1st–20th of each month: spreads via random scan of 32-bit IP address space
    - 20th–end of each month: performs a flooding attack against 198.137.240.91 (`www.whitehouse.gov`)
  - 1st release had an error in seeding PRNG and had a linear growth
  - 2nd release (July 19, 2001) infected almost 360K servers in 14 hours

Worms

- Witty worm
  - released on March 19, 2004
  - exploited buffer overflow in firewall (ISS) products
  - first widely propagated worm with destructive payload
    - corrupted hard disk
  - shortest interval between vulnerability disclosure and worm release
    - 1 day
  - demonstrated that security devices can open doors to attacks
    - other examples include antivirus software and IDS

Worms

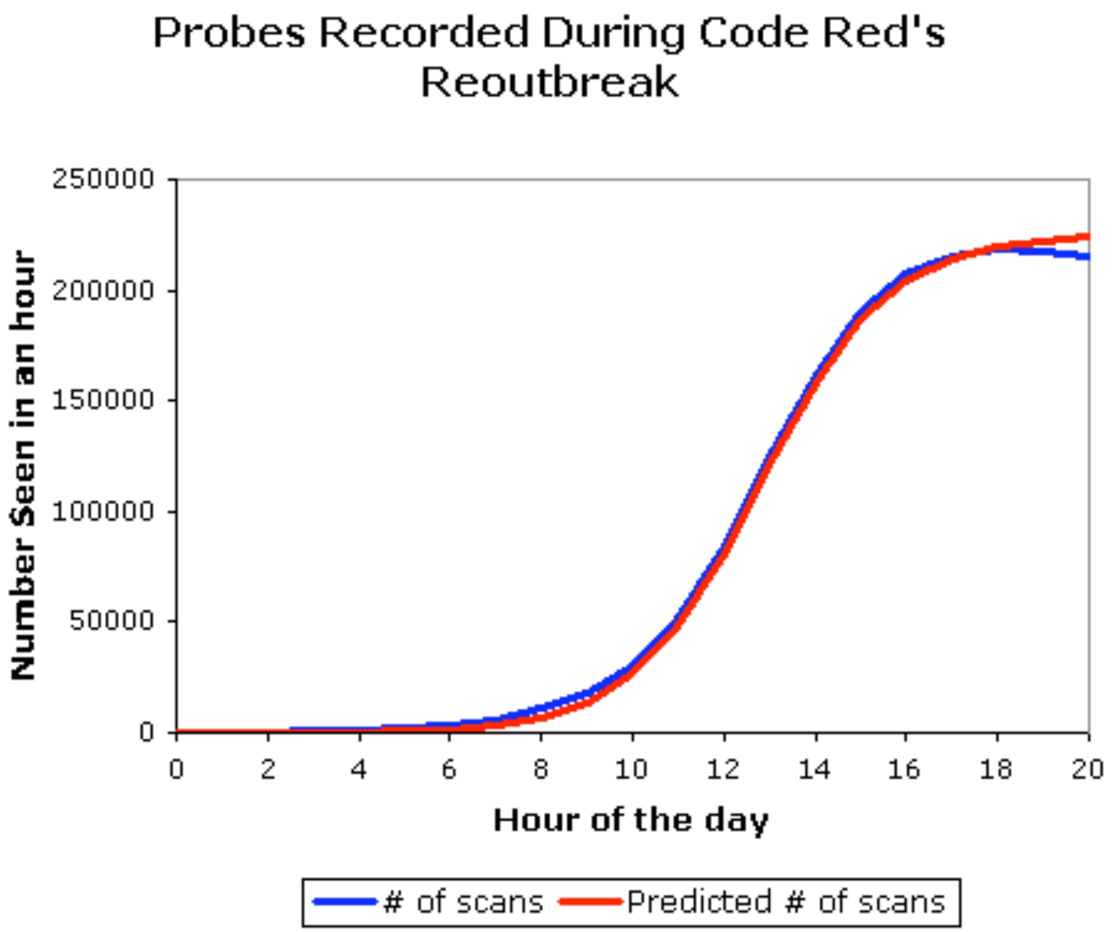
- Stuxnet worm
  - was detected in 2010, but has been spreading quietly for some time
  - deliberately restricted the rate to reduce detection
  - targeted industrial control systems (Iranian nuclear program)
  - supported a range of propagation mechanisms
- WannaCry ransomware
  - released in May 2017
  - quickly spread infecting hundreds of thousands of machines
  - organizations in 150 coutries were affected
  - encrypted files and demanded payment

Worms

- How do worms propagate?
  - scanning worms
    - worm chooses random address
    - model propagation as infectious epidemic
  - coordinated scanning
    - different worm instances scan different addresses
  - flash worms
    - assemble a tree of vulnerable hosts in advance, propagate along the tree
  - topological worms
    - use information from infected hosts (web server logs, email address books, config files, SSH known hosts, etc.)

Worm Propagation

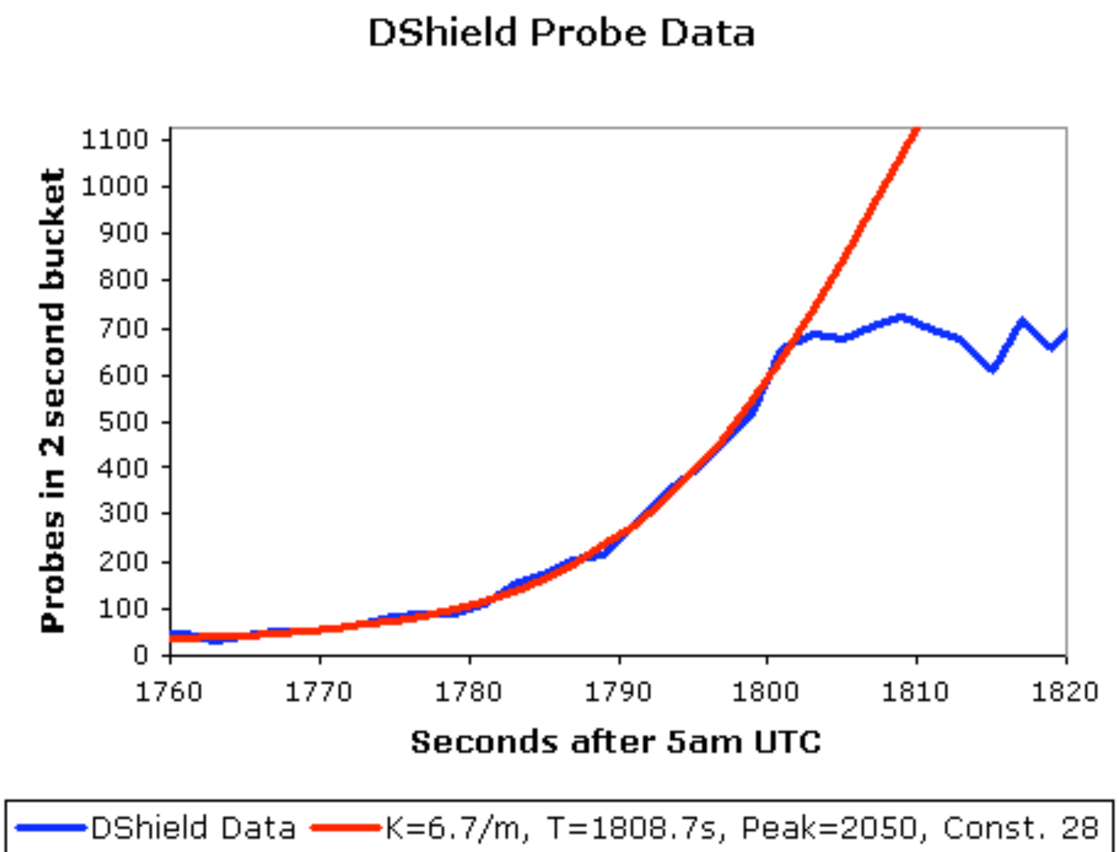
- Code red: theory meets practice (based on number of scans)



Data from CAIDA

Worm Propagation

- SQL Slammer (2003): infects 90% vulnerable machines in 10 minutes, reaches network saturation



Data from CAIDA

Worms

- For more information, see
  - “How to 0wn the Internet in Your Spare Time”, USENIX Security Symposium, 2002
  - “The Spread of the Sapphire/Slammer Worm”, http://www.caida.org/publications/papers/2003/sapphire/sapphire.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

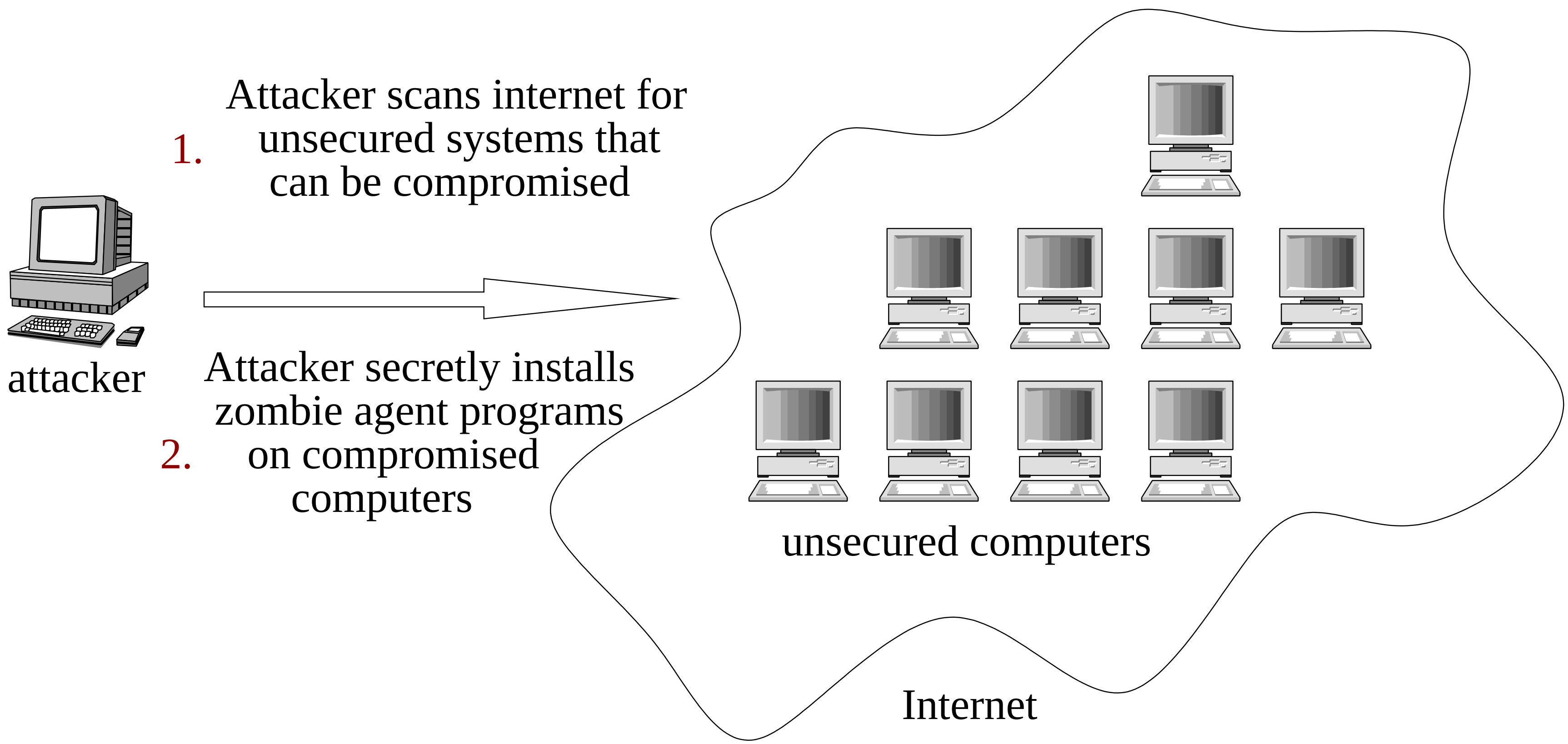
- Worm detection and defense by traffic monitoring
  - approach 2: identify worm patterns (cont.)
    - content-sifting by detecting the same bitstring pattern
      - main observation: strings of (say) 40 bytes repeat rarely in normally generated traffic
      - disadvantages: large computation and 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

- Bot (or zombie)
  - 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)
- A collection of bots often acts in a coordinated manner and forms a botnet

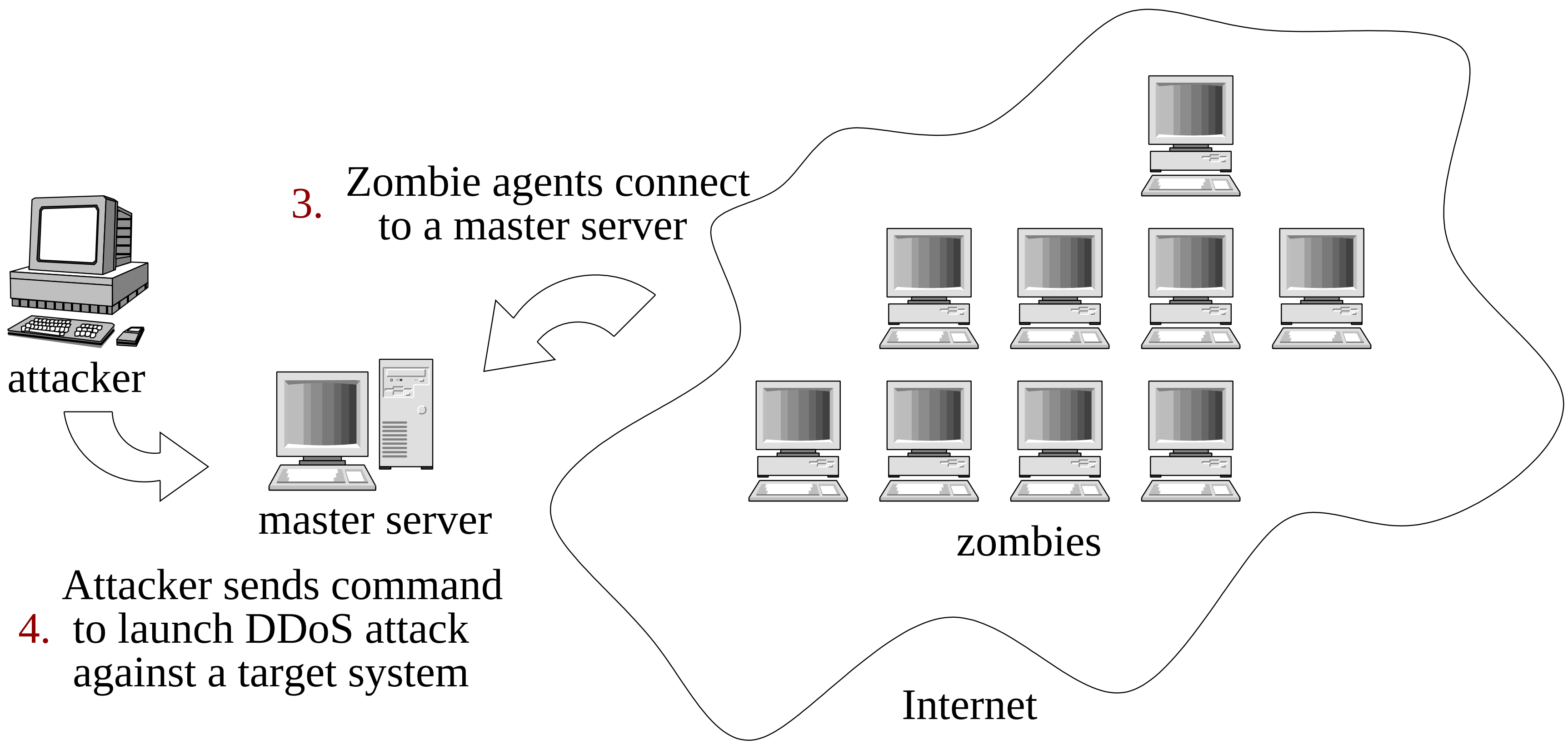
Botnets

- Construction and operation of botnets (steps 1 and 2)



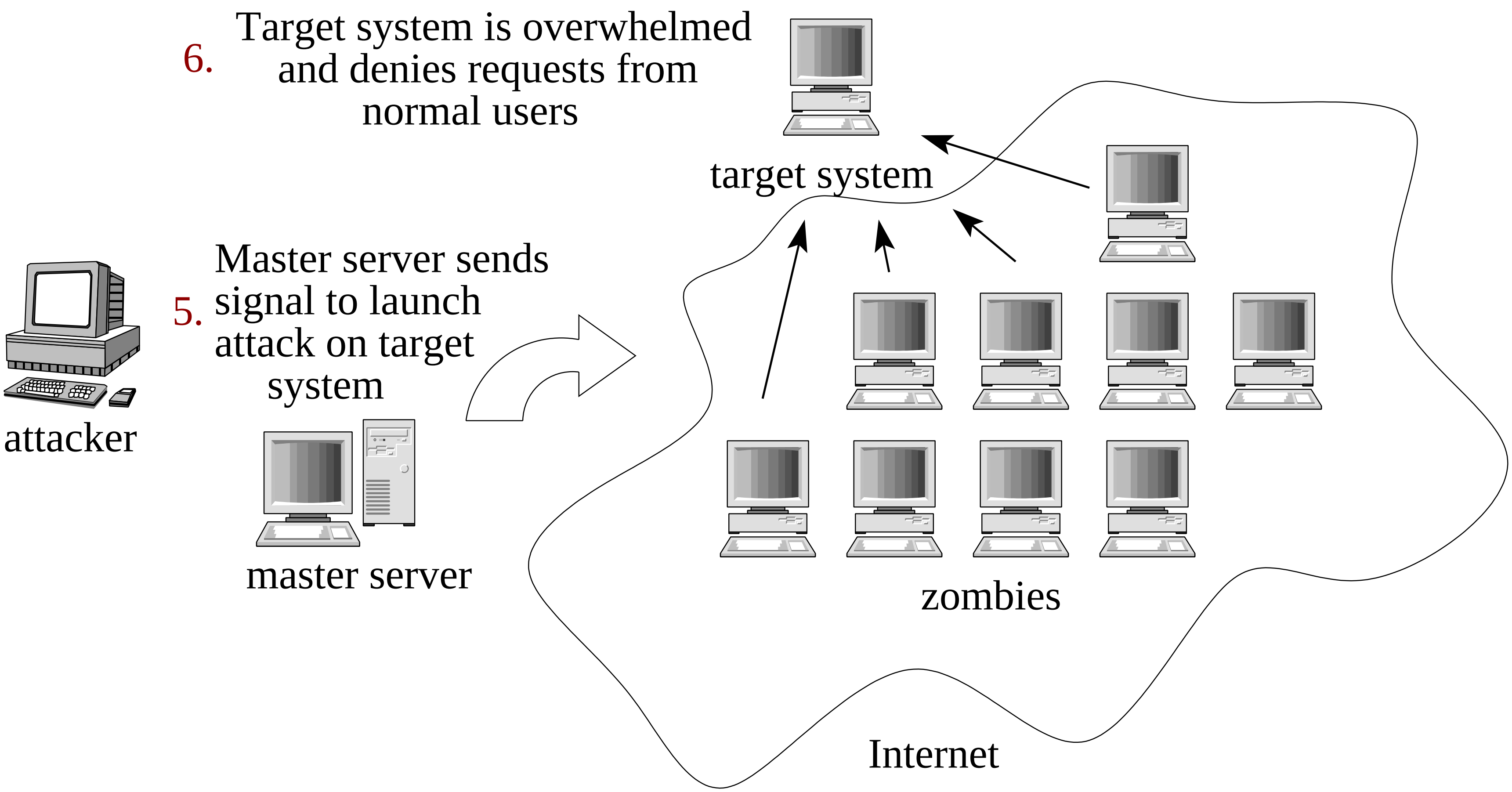
Botnets

- Construction and operation of botnets (steps 3 and 4)



Botnets

- Construction and operation of botnets (steps 5 and 6)



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

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
- Rootkits are independent of the way of gaining root privileges
  - any mechanism suffices (Trojan horse program, password guessing, system vulnerability, malware, etc.)

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 frutile

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