Advanced Network Security

Worms and Viruses

Amir Mahdi Sadeghzadeh, Ph.D.

Most slides have been adapted from Steven Bellovin, COMS W4180, Columbia University, 2006, and Mehdi Kharrazi, CE40-817, Sharif University of Technology, 2015

Worms and Viruses

- What are they?
- How do they spread?
- What can be done about them?

Viruses

- “Infected” program (or floppy)
- When program is executed, it performs its normal function
- It also infects some other programs
- It may carry an extra “payload” that performs other functions

Worms

- Similar to viruses, but they spread between machines
- Some are fully automatic; some require manual intervention to spread
- Some exploit bugs; others use social engineering

Classic Worms

Early Worms

- IBM Christmas Card "Virus", December 1987
- Morris Internet Worm, November 1988
- Most worms since then have emulated one or both of those

Christmas Card Virus

- Infected EARN, BITNET, and IBM's VNET
- (Old, pre-TCP/IP network for IBM mainframes)
- Spread by social engineering

What Users Saw

- The program arrives in an email with the subject line "Let this exec run and enjoy yourself!".

- A comment inside the Christmas Tree source code contains the comment:
  - Browsing this file is no fun at all. Just type Christmas.

```
             *
             *
            ***
           *****
          *******
         *********
       *************                 A
          *******
        ***********                 VERY
      ***************
    *******************             HAPPY
        ***********
      ***************             CHRISTMAS
    *******************
  ***********************            AND MY
      ***************
    *******************         BEST WISHES
  ***********************
***************************     FOR THE NEXT
          ******
          ******                    YEAR
          ******
```

What Happened

- A file transfer mechanism (not quite email, though it could have been) delivered a short script to users
- It was written in REXX, a shell script-like language for IBM's VM/CMS system
- When executed
  - Christmas Tree displays an ASCII Christmas tree.
  - It reads the files NAMES and NETLOG, files containing the addresses of communication partners, and mails itself to every email address in them.
  - It transmitted a copy of itself to any usernames it found
- People trusted it, because it was coming from a regular correspondent. . .

Essential Elements

- Self-replicating executable
- Apparently from a trusted source
- Request that the recipient execute the program
- Using the NETLOG file to find new victims

These characterize most current email worms

The Damage

- The worm itself wasn't malicious
- However, it had exponential growth patterns
- It clogged servers, communication paths, spool directories, etc.
- In other words, it was an unintentional denial of service attack

The Internet Worm

- Also known as the Morris worm
- Got much more mainstream publicity
- Estimated to have taken out 6000 hosts — 10% of the Internet
- Arguably, the first time the Internet made the evening news

Characteristics

- Much more sophisticated
- Exploited buggy code — spread without human intervention
- Exploited trust patterns among computers
- Multiple attack vectors
- Multiple architectures (Vax and Sun 3)
- Intended to demonstrate the insecurity of the Internet. . .

Attack Vectors

- Back door in sendmail
- Buffer overflow in fingerd
- Password-guessing
- Pre-authenticated login via rsh

Sendmail Back Door

- The author of sendmail wanted continued access to the production version installed at Berkeley
    - The system administrator wouldn't permit this
    - He put a deliberate back door into sendmail, to give himself continued access
    - Production systems shipped with this option enabled. . .

Buffer Overflow

- The finger daemon call gets(), a now-deprecated library routine
- Unlike fgets(), there was no buffer length parameter
- By sending a long-enough string over the network as input, the attacking program
  1. Injected some assembler-language code, and
  2. Overwrote the return address in the stack frame so that gets() branched to that code instead of back to the caller

Password Guessing

- It looked up a list of usernames in the password file
- It used easy transformations of the login name and the user's name, plus a dictionary of common passwords

Pre-Authenticated Login

- Exploit trust patterns: /etc/hosts.equiv and per-user .rhosts files list trusted machines
- If machine A trusts machine B (if only for a particular user), machine B usually trusts machine A
- This provided two things: an infection path and a list of other machines to attack

Spread Patterns

- It looked at a variety of sources to find other machines to attack:
  - rsh/rlogin trust sources
  - Machines listed in .forward files
  - Routers (in 1988, most routers were general-purpose computers)
  - Randomly-generated addresses on neighboring nets

Hiding

- The worm used a variety of techniques to hide
- It was named sh
- It forked frequently, to change processID
- Text strings were (lightly) encrypted

Essential Elements

- Self-spreading, via buggy code
- Self-spreading, via trust patterns
- Combination of directed and random targets for next attack
- Stealth characteristics

Modern Worms

Modern Worms

- Most resemble either the Christmas card worm or the Internet worm
- Today's email worms try to trick the user with tempting Subject: lines
  - million dollar award, software "updates", etc.
  - A notable one: "Osama bin Laden Captured", with an attached "video"
  - Some pose as anti-virus software updates. . .
- Can get through many firewalls

Stealthiness

- Deceptive filenames for the attachments
- Add a phony extension before the real one: Saddam_Capture.jpg.exe
- Hide in an encrypted .zip file, with the password in the body of the email
- Many strategies for hiding on hosts, including strange filenames, etc.

Trust Patterns

- Preferentially attack within the same network — may be on the inside of a firewall
- Exploit shared disks
- Mass-mailing worms rely on apparent trustworthy source

Spreading Via Buggy Code

- Exploit many different (Windows) bugs
- Can spread much more quickly
- Slammer spread about as far is it could in just 15 minutes, and clogged much of the Internet

The Slammer Worm

- Exploited a bug in Microsoft's SQL server
- Used UDP, not TCP — a single 376-byte packet to UDP port 1434 could infect a machine!
- Use of UDP instead of TCP let it spread much faster — one packet, from a forged source address, instead of a three-way handshake, payload transmission, and close() sequence
- No direct damage, but it clogged network links very quickly

The Welchi Worm

- Attempted to do good
- Used the same Microsoft RPC bug as the Nachi worm
- Removes certain other worm infections
- Installs Microsoft’s fix for the hole
- Deletes itself after January 1, 2004

Was it a Good Idea?

- No — unauthorized
- No — not well-tested
- No — generates a lot of network traffic, more than the worm it was trying to cure

Worm Effects

- Seriously clogged networks
- Slammer affected some ATM and air traffic control networks
- CSX Railroad's signaling network was affected

Sobig.F

- Launched in 2003
- Part of a family of worms
- High-quality code
- Primary purpose: spamming
- Turned infected machines into spambots
- Marked the turning point in worm design — now, it’s done for profit instead of fun

Updating and control

- Distributed control
  - Each worm has a list of other copies
  - Ability to create encrypted communication channels to spread info
  - Commands cryptographically signed by author.
  - Each worm copy, confirms signature, spreads to other copies and then executes the command
- Programmatic Updates
  - Operating systems allow dynamic code loading
  - New encrypted attack modules from Worm author

Worm Spread Patterns

How to 0wn the internet in your spare time [Staniford02]

Spread Patterns?

- The faster you spread, the less likely a defense could be put up against you
  - More hosts under your control
- Millions of hosts --> enormous damage
  - Distributed DOS
  - Access Sensitive Information
  - Create Confusion and Disruption

Code Red I

- Initial version released July 13, 2001.
- Exploited known bug in Microsoft IIS Web servers.
- But: failure to seed random number generator.
  - All worms attempted to compromise the same sequence of hosts.
- Linear spread, didn't get very far

Code Red I v2

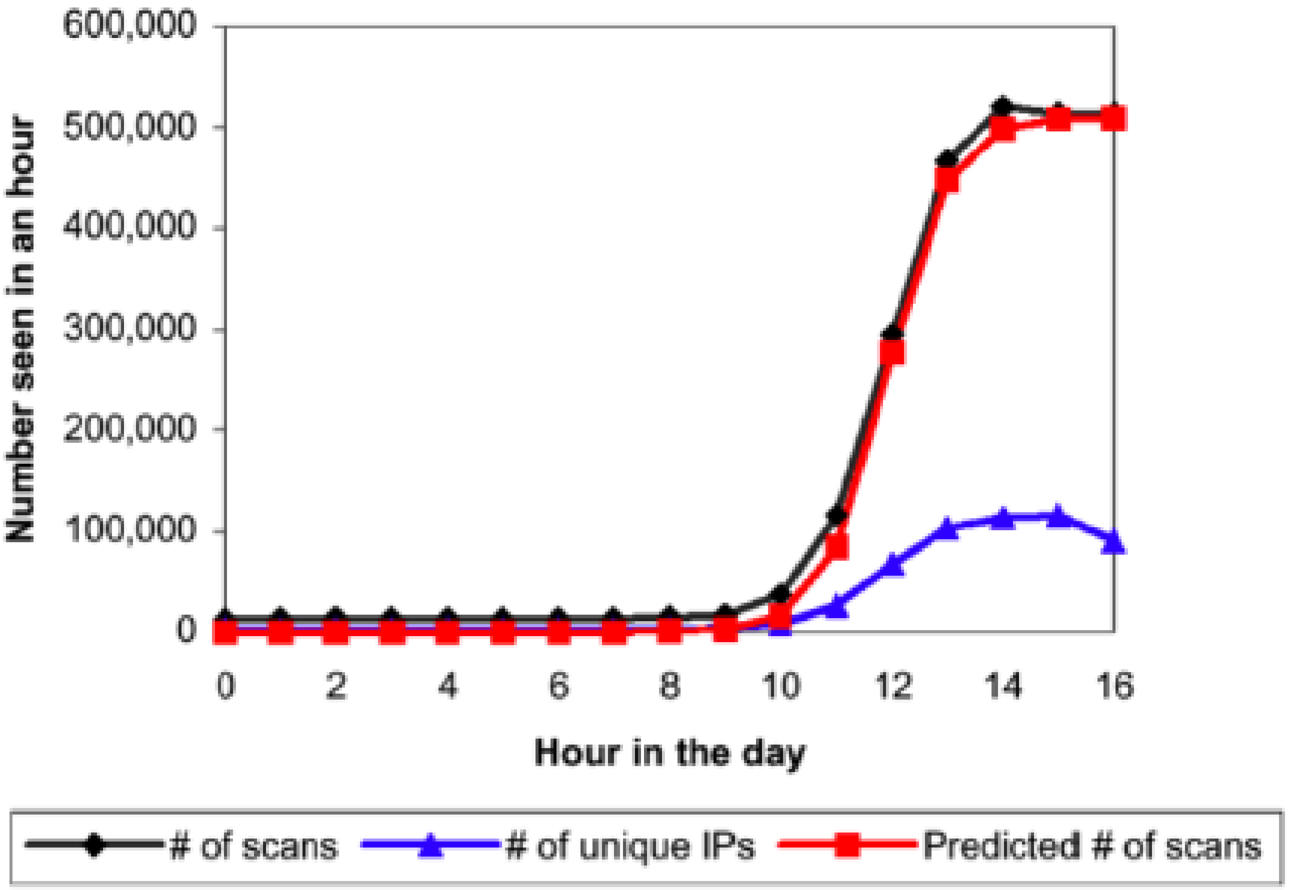
- Released July 19, 2001 (6 days later).
- Same code base but:
  - random number generator correctly seeded.
- DDoS payload targeting IP address of
  - www.whitehouse.gov
- That night, Code Red dies (except for hosts with inaccurate clocks!)

Random Constant Spread Model

- N: Total number of Vulnerable servers in Internet
- K: Initial Compromise Rate: Rate at which a infected host is able to infect new hosts at the start of the incident
- a: Proportion of machines already compromised
- Modeling --> Random Constant Spread (RCS)
  - Gives an exponential equation
  - Depends only on K, not N
- Good enough model (Works for Code Red I)

Hourly

- Hourly probe rate for inbound port 80 at CAS during initial outbreak
- # of unique IPs lags due to the time it takes from getting infected to starting scanning for other victims



Code Red II

- Released August 4, 2001.
- Comment in code: “Code Red II.” But in fact completely different code base.
- Payload: a root backdoor allowing unrestricted remote access
- Bug: crashes NT, only works right on Windows 2000.
- Used localized scanning strategy

Localized Scanning

- Attempt to infect addresses close to it
  - With probability 3/8 it chooses a random IP from with the class B (/16) address space of the infected machine
  - With probability ½ from class A (/8)
  - And with probability 1/8 from the whole internet

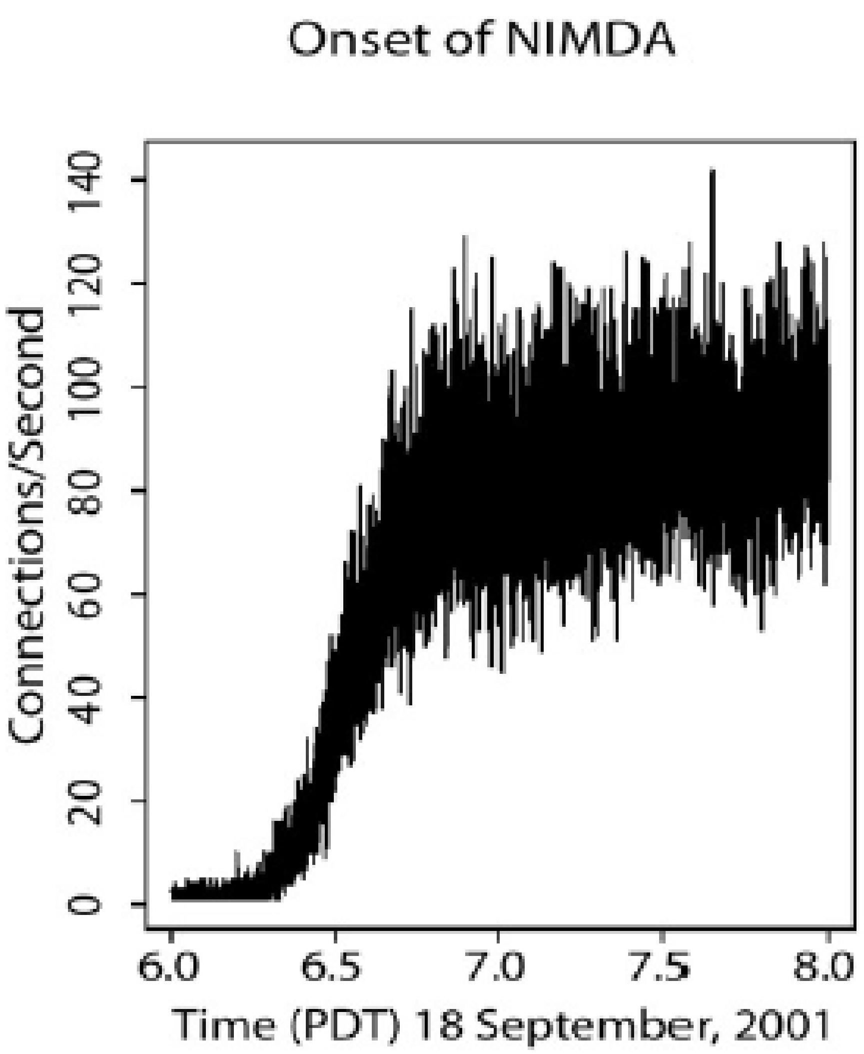
- Localized spreading works - hosts around it are often similar, topologically faster, spreads fast in internal network once it gets through the firewall

Nimda

- Released September 18, 2001.
- Multi-mode spreading:
  - attack IIS servers via infected clients.
  - email itself to address book as a virus
  - copy itself across open network shares
  - modifying Web pages on infected servers in order to infect clients
  - scanning for Code Red II and sadmind backdoors (!)

Onset

- Very rapid onset
- Mail based spread → very effective
- Full functionality → ?
- HTTP connections seen at the Lawrence Berkley National Laboratory



Ways of reducing spreading time

- Hit List scanning
- Permutation scanning
- Topological Scanning
- Internet scale hit-lists

Creating Better Worms

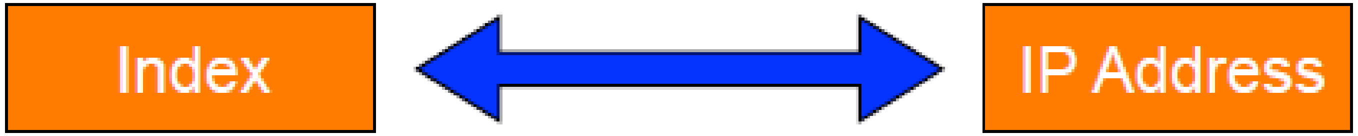
- Hit List Scanning
  - "getting off the ground" very fast
    - Say first 10,000 hosts
  - Pre-select 10,000-50,000 potentially vulnerable machines
  - First worm carries the entire hit list
  - Hit list split in half on each infection
  - Can establish itself in few seconds

Ways to get Hit list

- Distributed Scanning - use zombies
- Stealthy Scan - spread it over several months
- DNS searches - e. g., www.domain.com
- Spiders - ask the search engines
- Just Listening - P2P,
- or exploit existing worms

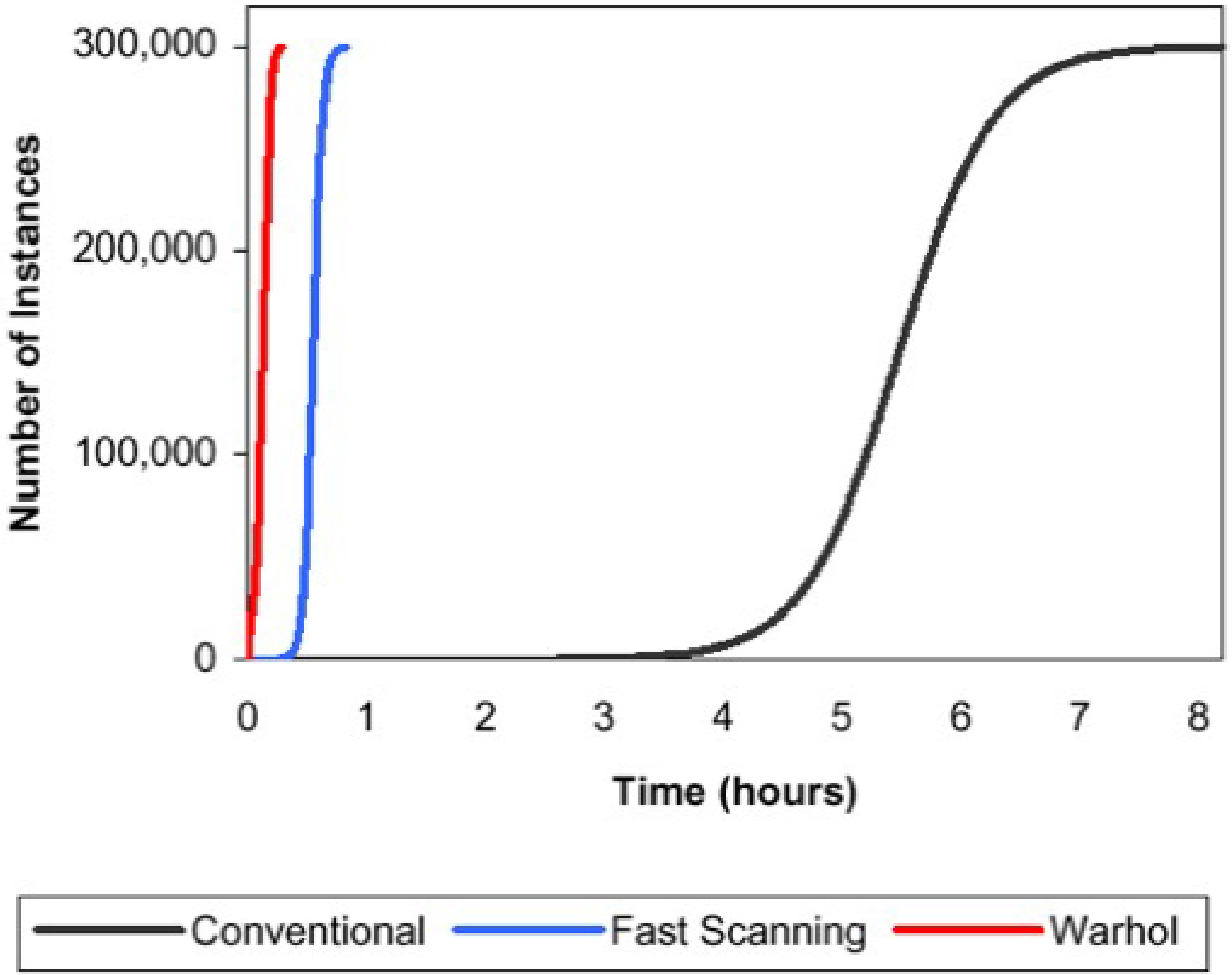
Permutation Scanning

- Random scanning inefficient --> lot of overlap
  - All worms share a common pseudo – random permutation



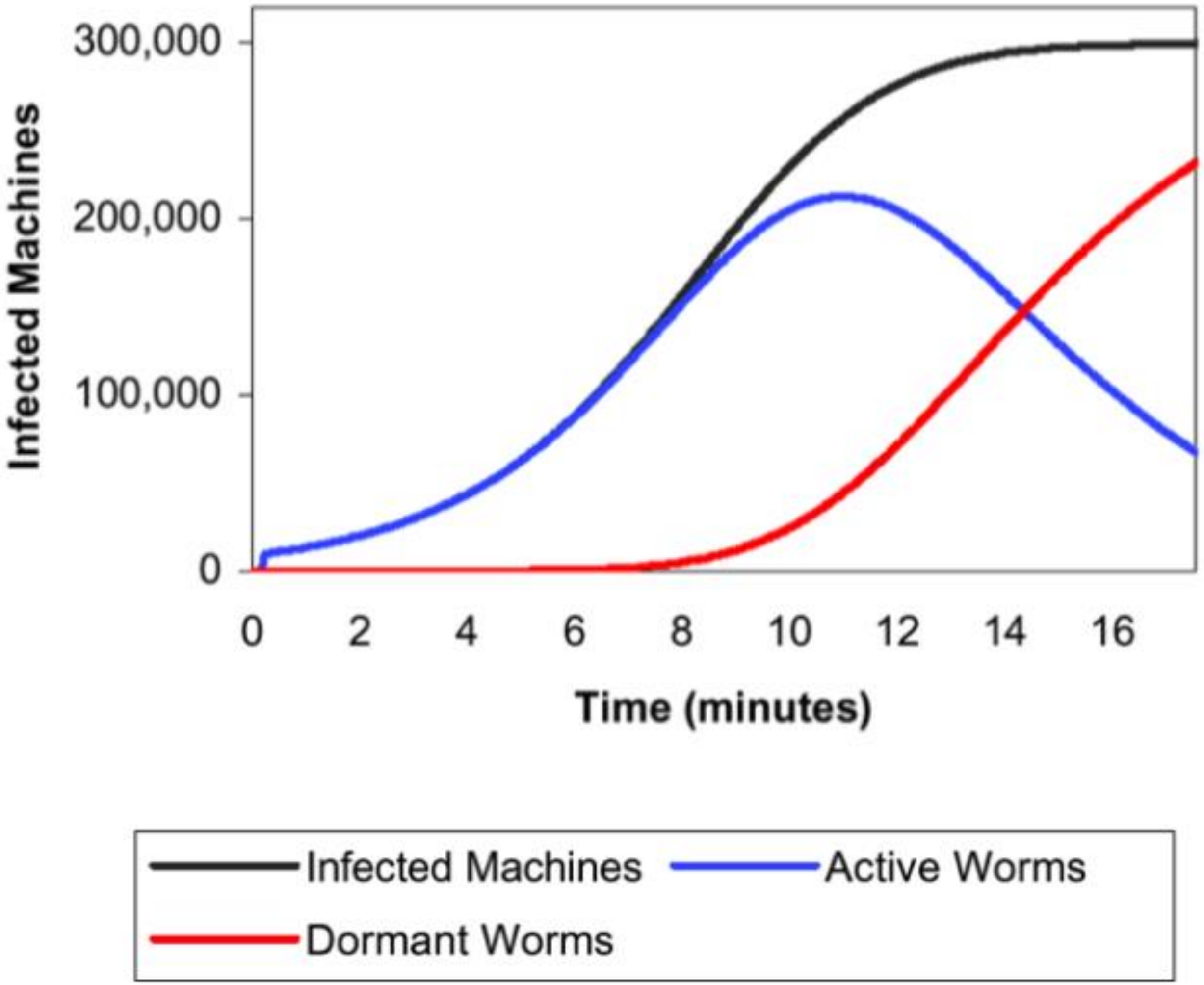
A Warhol Worm

- Combination of hit-list and permutation scanning
  - Can spread widely in less than 15 mins
- Simulation results
  - 300000 vulnerable machines
  - Conventional (code red) 10 scans/s
  - Fast scanning 100 scans/s
  - Warhol scanning 100 scans/s using 10000 hit-list



Warhol Worm

- Each worm stops when it finds two infected machined with out finding any new target
- Rapid growth initially as all worm are active
- As infection nears 100%, many worms go dormant concluding there are few vulnerable machines left



Topological Scanning

- Alternative to hit-list scanning
  - Use addresses available on victim's machines.
    - Email Lists
    - List of web servers from Bookmark

- Use this as a start point before using Permutation Scanning.
- Peer to peer systems are highly vulnerable to this kind of scanning

Faster Worms : Recap

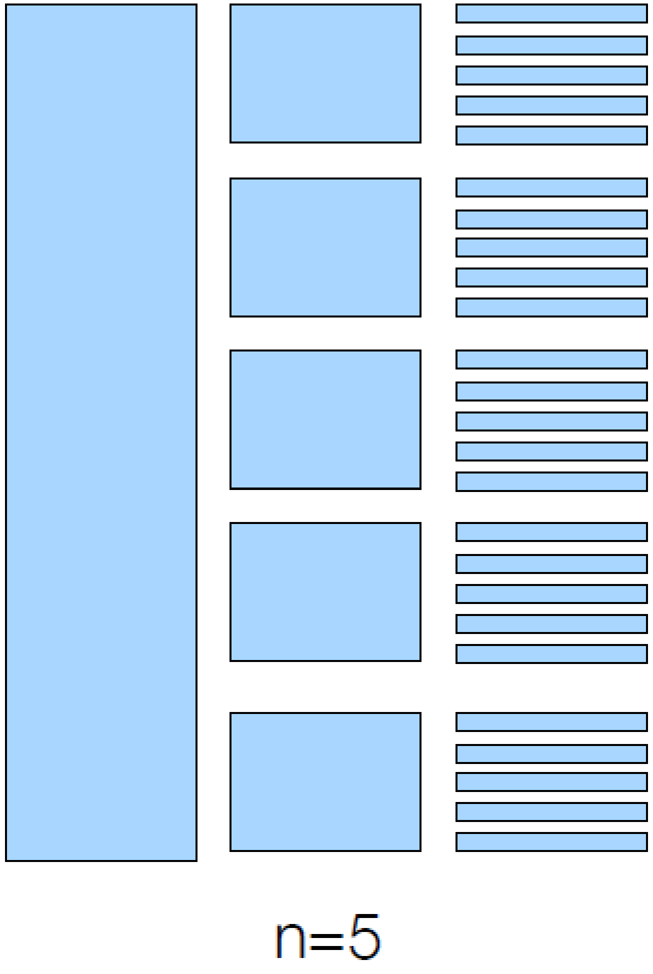
- Fast Startup --> Hit List Scanning
- Extremely Efficient --> Permutation scanning
- Combine the above --> Warhol worms
- Exploit local information --> Topological scanning

Flash Worms

- Fastest Method --> Entire internet in 10s of seconds
- Obtain hit-list of vulnerable servers in advance
  - 2 hours for entire IPv4 space on OC-12 link (622 mbps)
  - List would be big (~ 48 MB)
- Divide into n blocks
  - Infect first of each block and hand over the block to the new worm
  - Repeat for each block
- Alternative: Store pre-assigned chunks on a high BW server
- Two limitations
  - Large list size
  - Latency

Flash Worms

- For 3 million hosts, just 7 layers deep (n = 10)



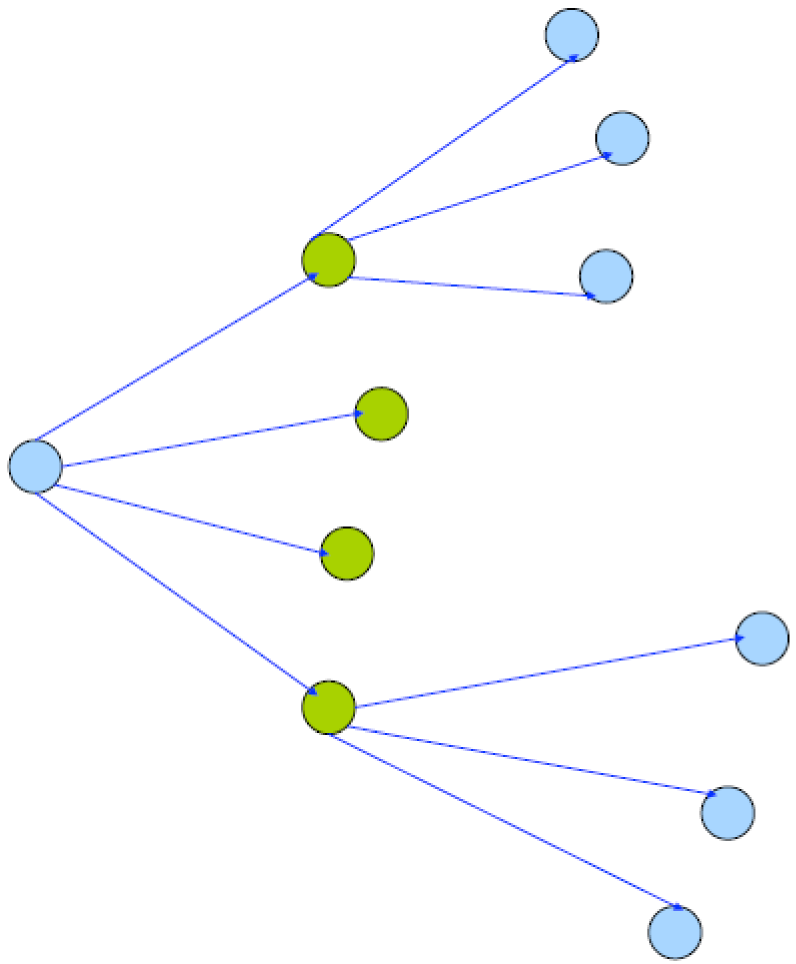
Still need better worms

- All those worms use singular communication patterns
- This forms the basis for automatic detection
- How can we remove that weakness from worms?

Contagion Worms

- Suppose you have two exploits:
  - Es : exploit in web server
  - Ec: exploit in client
- You infect a server (or client) with Es (Ec)
  - When vulnerable client arrives, infect it.
- As client happens to visit other vulnerable servers infects
- Clearly there are no unusual communication patterns to be observed (other than slightly larger- than- usual transfers)

Contagion Worms



Contagion Worms

- They become Dangerous with P2P systems because
  - Likely only need a single exploit, not a pair.
  - Often, peers running identical software.
  - Often used to transfer large files.

Contagion Worms

- KaZaA: 9 million distinct IP connections with university hosts (5800) in a single month
- If you 0wn'd a single university
  - then in November, 2001 you could have 0wn'd 9 million additional hosts.

References

- [Kapantaidakis] CS588, Giannis Kapantaidakis, University of Crete.
- [Gupta04] Network Security, Ashish Gupta, April 2004.
- [Staniford02]]How to 0wn the Internet in Your Spare Time, Stuart Staniford, Vern Paxson, and Nicholas Weaver, 11th USENIX Security Symposium (Security 02)
- Steven Bellovin, COMS W4180, Columbia University, 2006
- Mehdi Kharrazi, CE40-817, Sharif University of Technology, 2015
- Vitaly Shmatikov, CS 361S, UT Austin, 2014
- Vitaly Shmatikov, CS 5435, Cornell University, 2022