Worms: Attacks and Defense

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Some slides by John Mitchell

Review

- **So far, talked about basics**
  - **Different types of vulnerabilities**
  - **Principles & best practices**
- **From now on, more advanced topics**
  - **Many of the problems we don't know how to solve yet**
  - **We'll see some latest research results as state-of-the-art**

Outline

- **Worm propagation**
  - **Worm examples**
  - **Propagation models**
- **Detection & defense**
  - **Traffic patterns: EarlyBird**
  - **Semantic-based: TaintCheck and Sting**

Worm

- **A worm is self-replicating software designed to spread through the network**
  - **Typically exploit security flaws in widely used services**
  - **Can cause enormous damage**
    - » **Launch DDOS attacks, install bot networks**
    - » **Access sensitive information**
    - » **Cause confusion by corrupting the sensitive information**
- **Worm vs Virus vs Trojan horse**
  - **A virus is code embedded in a file or program**
  - **Viruses and Trojan horses rely on human intervention**
  - **Worms are self-contained and may spread autonomously**

Some historical worms of note

Worm	Date	Distinction
Morris	**11/88**	**Used multiple vulnerabilities, propagate to "nearby" sys**
ADM	**5/98**	**Random scanning of IP address space**
Ramen	**1/01**	**Exploited three vulnerabilities**
Lion	**3/01**	**Stealthy, rootkit worm**
Cheese	**6/01**	**Vigilante worm that secured vulnerable systems**
Code Red	**7/01**	**First sig Windows worm; Completely memory resident**
Walk	**8/01**	**Recompiled source code locally**
Nimda	**9/01**	**Windows worm: client-to-server, c-to-c, s-to-s, …**
Scalper	**6/02**	**11 days after announcement of vulnerability; peer-to-peer network of compromised systems**
Slammer	**1/03**	**Used a single UDP packet for explosive growth**

Kienzle and Elder

Cost of worm attacks

- **Morris worm, 1988**
  - **Infected approximately 6,000 machines**
    - » **10% of computers connected to the Internet**
  - **cost ~ $10 million in downtime and cleanup**
- **Code Red worm, July 16 2001**
  - **Direct descendant of Morris' worm**
  - **Infected more than 500,000 servers**
    - » **Programmed to go into infinite sleep mode July 28**
  - **Caused ~ $2.6 Billion in damages,**
- **Love Bug worm: $8.75 billion**

Statistics: Computer Economics Inc., Carlsbad, California

Aggregate statistics

Financial Impact of Virus Attacks 1995—2005

Worldwide Impact (US $)	
2005	$14.2 Billion
2004	17.5 Billion
2003	13.0 Billion
2002	11.1 Billion
2001	13.2 Billion
2000	17.1 Billion
1999	13.0 Billion
1998	6.1 Billion
1997	3.3 Billion
1996	1.8 Billion
1995	500 Million

Source: Computer Economics, 2006 *Figure 1*

Internet Worm (First major attack)

- **Released November 1988**
  - **Program spread through Digital, Sun workstations**
  - **Exploited Unix security vulnerabilities**
    - » **VAX computers and SUN-3 workstations running versions 4.2 and 4.3 Berkeley UNIX code**
- **Consequences**
  - **No immediate damage from program itself**
  - **Replication and threat of damage**
    - » **Load on network, systems used in attack**
    - » **Many systems shut down to prevent further attack**

Three ways the worm spread

- **Sendmail**
  - **Exploit debug option in sendmail to allow shell access**
- **Fingerd**
  - **Exploit a buffer overflow in the fgets function**
  - **Apparently, this was the most successful attack**
- **Rsh**
  - **Exploit trusted hosts**
  - **Password cracking**

The worm itself

- Program is called 'sh'
  - Clobbers argv array so a 'ps' will not show its name
  - Opens its files, then unlinks (deletes) them so can't be found
    - Since files are open, worm can still access their contents
- Tries to infect as many other hosts as possible
  - When worm successfully connects, forks a child to continue the infection while the parent keeps trying new hosts
- Worm did not:
  - Delete system's files, modify existing files, install trojan horses, record or transmit decrypted passwords, capture superuser privileges, propagate over UUCP, X.25, DECNET, or BITNET

Stopping the worm

- System admins busy for several days
  - Devised, distributed, installed modifications
- Perpetrator
  - Student at Cornell; discovered quickly and charged
  - Sentence: community service and $10,000 fine
    - Program did not cause deliberate damage
    - Tried (failed) to control # of processes on host machines
- Lessons?
  - Security vulnerabilities come from system flaws
  - Diversity is useful for resisting attack
  - “Experiments” can be dangerous
- More Info
  - Eugene H. Spafford, The Internet Worm: Crisis and Aftermath, CACM 32(6) 678-687, June 1989
  - Page, Bob, "A Report on the Internet Worm", http://www.ee.ryerson.ca:8080/~elf/hack/iworm.html

Code Red

- Initial version released July 13, 2001
  - Sends its code as an HTTP request
  - HTTP request exploits buffer overflow
  - Malicious code is not stored in a file
    - Placed in memory and then run
- When executed,
  - Worm checks for the file C:\Notworm
    - If file exists, the worm thread goes into infinite sleep state
  - Creates new threads
    - If the date is before the 20th of the month, the next 99 threads attempt to exploit more computers by targeting random IP addresses

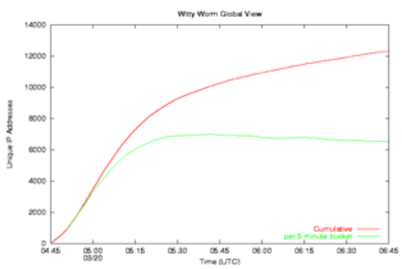
Code Red of July 13 and July 19

- **Initial release of July 13**
  - **1st through 20th month: Spread**
    - **» via random scan of 32-bit IP addr space**
  - **20th through end of each month: attack.**
    - **» Flooding attack against 198.137.240.91 (*www.whitehouse.gov)***
  - **Failure to seed random number generator ⇒ *linear growth***
- **Revision released July 19, 2001.**
  - **White House responds to threat of flooding attack by <u>changing the address</u> of *www.whitehouse.gov***
  - **Causes Code Red to <u>die</u> for date ≥ 20th of the month.**
  - **But: this time random number generator correctly seeded**

Slides: Vern Paxson

Witty Worm (I)

- **March 19, 2004, exploiting buffer overflow in firewall (ISS) products**
- **Infected 12,000 machines in 45 mins**



Witty Worm (II)

- **First widely propagated worm w. destructive payload**
  - **Corrupted hard disk**
- **Seeded with more ground-zero hosts**
  - **110 infected machines in first 10 seconds**
- **Shortest interval btw vulnerability disclosure & worm release**
  - **1 day**
- **Demonstrate worms effective for niche too**
- **Security devices can open doors to attacks**
  - **Other examples: Anti-virus software, IDS**

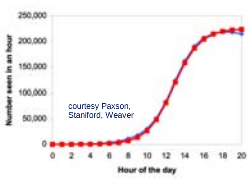
How do worms propagate?

- Scanning worms
  - Worm chooses “random” address
- Coordinated scanning
  - Different worm instances scan different addresses
- Flash worms
  - Assemble tree of vulnerable hosts in advance, propagate along tree
- Meta-server worm
  - Ask server for hosts to infect (e.g., Google for “powered by phpbb”)
- Topological worm:
  - Use information from infected hosts (web server logs, email address books, config files, SSH “known hosts”)
- Contagion worm
  - Propagate parasitically along with normally initiated communication

How fast are scanning worms?

- Model propagation as infectious epidemic
  - Simplest version: Homogeneous random contacts

N: population size
S(t): susceptible hosts at time t
I(t): infected hosts at time t
ß: contact rate
i(t): I(t)/N, s(t): S(t)/N



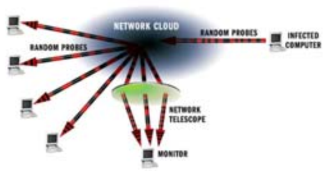
$$\frac{dI}{dt} = \beta \frac{IS}{N}$$
$$\frac{dS}{dt} = -\beta \frac{IS}{N}$$

$$\frac{di}{dt} = \beta i(1-i)$$

$$i(t) = \frac{e^{\beta(t-T)}}{1+e^{\beta(t-T)}}$$

How to Measure Worm Scale?

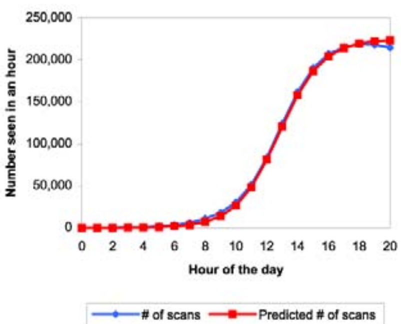
Measuring activity: network telescope



- Monitor cross-section of Internet address space, measure traffic
  - "Backscatter" from DOS floods
  - Attackers probing blindly
  - Random scanning from worms
- LBNL's cross-section: 1/32,768 of Internet
- UCSD, UWisc's cross-section: 1/256.

Code Red I Propagation: Theory Meets Practice

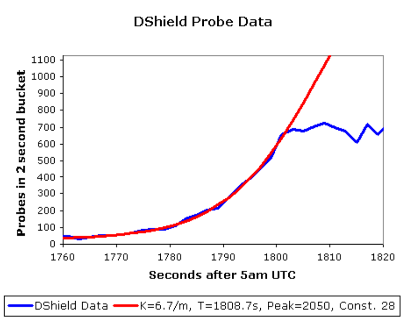
- Hard to count number of infected hosts
  - Count scans by them instead
- Theory matches observed



How to Own the Internet in Your Spare Time in Proceedings of the 11th USENIX Security Symposium (Security '02)

Slammer: The Story Is More Complicated

- Observed Slammer worm behavior doesn't match theory
  - Fast propagating worms encounter links' BW and latency constraints
  - Non-universal connectivity



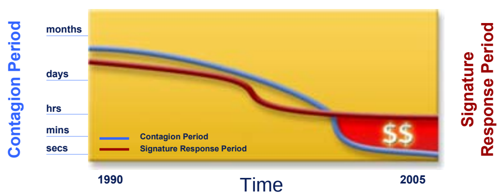
The Spread of the Sapphire/Slammer Worm, http://www.caida.org/publications/papers/2003/sapphire/sapphire.html

Challenges for Worm Defense

- **Short interval btw vulnerability disclosure & worm release**
  - Witty worm: 1 day
  - Zero-day exploits
- **Fast**
  - Slammer: 10 mins infected 90% vulnerable hosts
  - How fast can it be?
    - » Flashworm: seconds [Staniford et. al., WORM04]
- **Large scale**
  - Slammer: 75,000 machines
  - CodeRed: 500,000 machines

Need for automation

- Current threats can spread faster than defenses can reaction
- Manual capture/analyze/signature/rollout model too slow



Slide: Carey Nachenberg, Symantec

Administravia

- Milestone #2 due Apr 23 (instead of Apr 21)
- HW4 out

Worm Detection and Defense by Traffic Monitoring

- **Detection via *honeyfarms*: collections of "honeypots" fed by a network telescope.**
  - **Any outbound connection from honeyfarm = worm.**
    (at least, that's the theory)
  - **If telescope covers N addresses, expect detection when worm has infected 1/N of population**
- **Detecting superspreaders**
  - **Hosts that make failed connection attempts to too many other hosts**
  - **Defense: throttling/rate limiting**
    - **Limiting the number of failed connections by a host**