Detecting Internet Worms

David Moore

University of California, San Diego

Research Exam – March 17, 2005

Motivation for Worm Defense

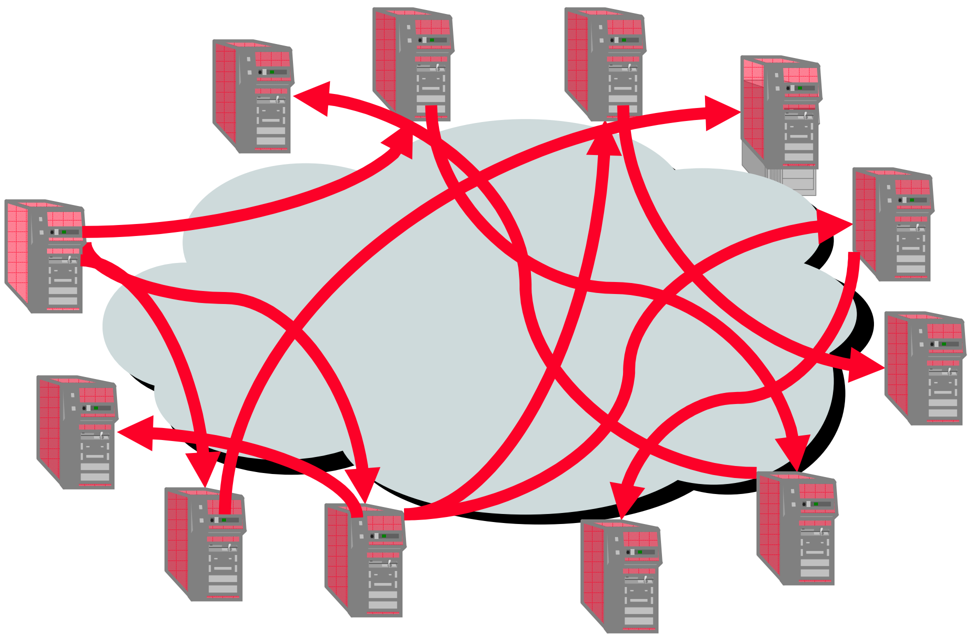
- **Speed** - Slammer spread in 10 minutes
- **Virulence** - Blaster infected millions of hosts
- **Malice** - Witty destroyed hard drive data
- **Opportunity** - 1000s of vulnerabilities yearly

Outline

- Motivation
- **Background**
- Detection schemes
- Tying things together

What is a Network Worm?

- Self-propagating self-replicating network program
  - Exploits some vulnerability to infect remote machines
    - No human intervention necessary
  - Infected machines continue propagating infection



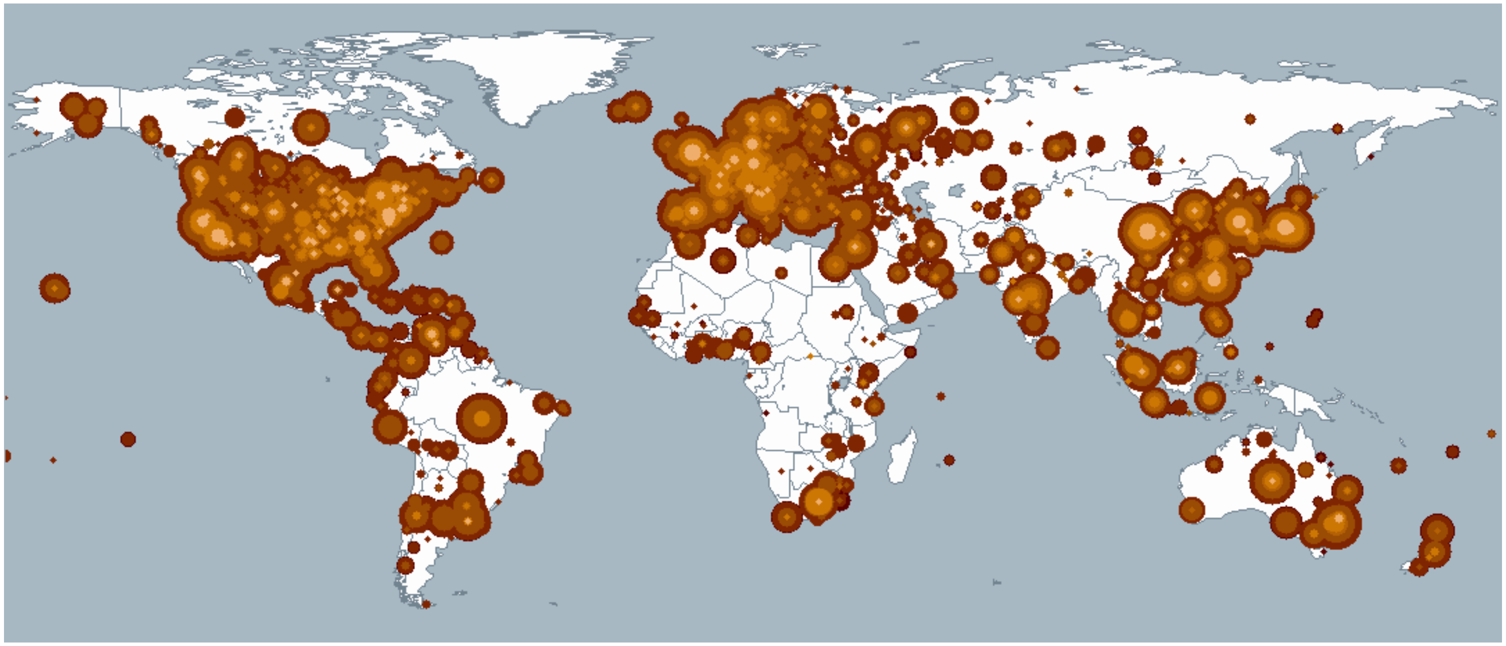
A Brief History…

- Brunner describes “tapeworm” program in novel “Shockwave Rider” (1972)
- Shoch&Hupp co-opt idea; coin term “worm” (1982)
  - Key idea: programs that self-propagate through network to accomplish some task
  - Benign; didn’t replicate
- Fred Cohen demonstrates power and threat of self-replicating viruses (1984)
- Morris worm exploits buffer overflow vulnerabilities & infects a few thousand hosts (1988)

Mostly a hiatus for 13 years…

Wake-Up Call: Code-Red

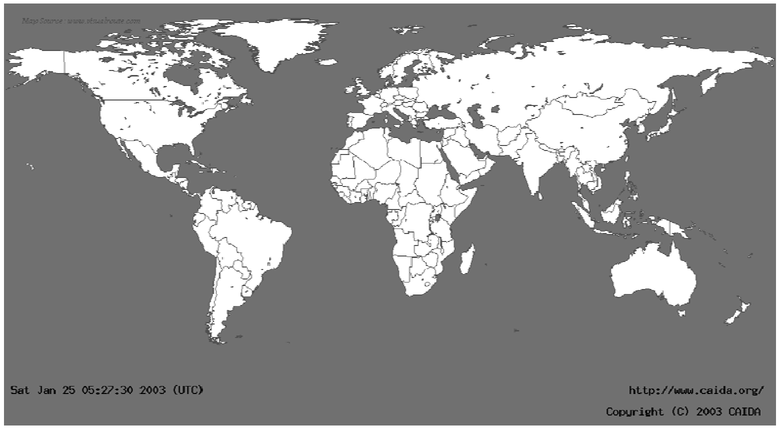
(July 19, 2001) [MSB02]



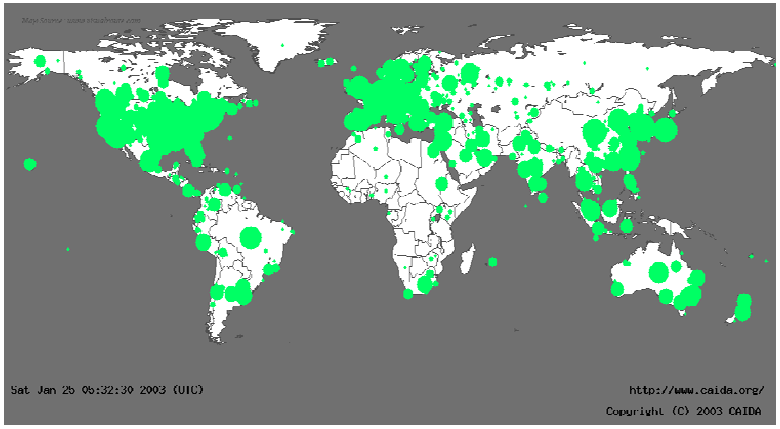
- 360,000 hosts infected in *ten hours*
- No effective patching response
- More than $1.2 billion in economic damage in the first ten days
- Collateral damage: printers, routers, network traffic

Surprising Speed: SQL Slammer

(aka Sapphire) – January 24, 2003 [MPSSW03]



Before 9:30PM (PST)



After 9:40PM (PST)

- >100,000 hosts infected in *ten* ***minutes***
- Sent more than 55 million probes per second world wide
- Collateral damage: Bank of America ATMs, 911 disruptions, Continental Airlines cancelled flights
- Unstoppable; relatively benign to hosts

Huge Population: MSBlast

August 11, 2003 [L04]

- Microsoft estimates 8-16 <u>million</u> hosts infected
- Note: this count includes hosts behind NATs, firewalls, and internal networks
- Designed to launch a denial-of-service (DoS) attack against Microsoft

More Novelty: Witty

March 19, 2004 [SM04]

- First wide-spread Internet worm with destructive payload
  - writes 64k blocks to disk at random location, repeatedly
- Launched from a large set of ground-zero hosts
  - >100 hosts
- Shortest interval from vulnerability disclosure to worm release
  - 1 day
- Witty infected firewall/security software
  - i.e. proactive user base
- Spread quickly even with a small population
  - ~12,000 total hosts, 45 minutes to peak of infection

Ability to Defend: Who vs. What

- There are two primary methods of blocking malicious traffic
  - Hosts sending the traffic (who)
  - Content of the traffic (what)
- Advantage of knowing who
  - Anything sent by a malicious host is suspect
- Advantage of knowing what
  - Able to prevent the malicious activity from any host

Monitor Placement of Detection System

- Directly on an end-host:
  - Greatest ability to know a compromise has occurred
  - Least ability to see what other hosts are doing
- On a backbone link:
  - Difficult to know if traffic is malicious or legitimate
  - High visibility of traffic from many distributed hosts
- Between:
  - Sharp transition of knowledge of compromise events
  - Gradual transition of visibility of multiple hosts

A Worm's Raison d'Être

- As a collective whole a worm wishes to infect as many vulnerable machines as possible

- To achieve this goal, instances of the worm must:
  - Spread - find other vulnerable hosts
  - Replicate - create new instances on those hosts

Exploiting a Worm's Fundamental Behaviors

- To spread, a worm instance needs to:
  - Chose potential targets
  - Send network packets to the target

  Detection strategy: Find hosts which are unexpectedly connecting to many other hosts

- To replicate, a worm instance sends data to:
  - Exploit the vulnerability
  - Transfer the worm code

  Detection strategy: Find a ***signature***, a portion of worm payload, which identifies the malicious traffic but does not match legitimate network traffic

General Detection Guidelines

Detection results must:

- have few false-positives, to avoid affecting legitimate traffic
- have few false-negatives, to avoid continued worm spread
- be generated rapidly, to contain fast worms [MSVS03]
- be simple enough to check against traffic in near real-time
- be readily distributable in a trustworthy manner

Outline

- Motivation
- Background
- **Detection schemes:**
  - **Content Signature - Network**
  - Content Signature – Host/Honeypot
  - Scanning Activity
  - Population Dynamics
- Tying things together

Content Signature - Network

- To replicate, worm must send data to:
  - Exploit the vulnerability
  - Transfer the worm code
- Successful worm $\Rightarrow$ lots of copies of data
  - Assumption that even with polymorphism, some portion of the data will not change
- $\Rightarrow$ look for frequently occurring substrings
- However, do not match common legitimate strings
  - **“`GET / HTTP/1.0`”** or **“`@ucsd.edu`”**

Content Signature - Network

- Autograph [KK04] and Earlybird [SEVS04] both look for frequently occurring substrings in packet payloads

- Primary differences:
  – Which substrings are sampled and checked
  – Heuristics to minimize generating signatures for legitimate traffic
  – Speed of basic algorithm (online vs. batch)

Outline

- Motivation
- Background
- **Detection schemes:**
  – Content Signature - Network
  – **Content Signature – Host/Honeypot**
  – Scanning Activity
  – Population Dynamics
- Tying things together

Content Signature – Host/Honeypot

- A ***honeypot*** [Spitzner] is a special host dedicated for the purpose of being attacked, compromised or infected

- Honeypot approaches:
  - Normal host running a normal software distribution
  - Virtualized host
  - Specialized light-weight responder software emulating portions of other services

Content Signature – Host/Honeypot

- Since a honeypot has no legitimate users, its behavior is determined by its setup and the influence of unsolicited network traffic

- Steps to generating a signature:
  – Detect that the honeypot has been compromised
  – Determine which network packets were responsible
  – Generate a content signature from packet data

- Honeycomb [KC03] is an example system to create intrusion signatures from the *honeyd* honeypot

Content Signature – Host/Honeypot

- Patching problems:
  - Bugs often understood before a patch can be made
  - Testing patches is time consuming
  - Miscreants reverse-engineer patches to discover bugs
- The Shield [WGSZ04] project:
  - Proactively protect hosts before patches are available
  - Use vulnerability signatures
- Vulnerability signature:
  - sufficient information to check that traffic does not exploit a bug

Content Signature – Host/Honeypot

- Vulnerability signatures can require a large amount of state to emulate protocols, libraries and applications

- Vulnerability signatures are generally specific to an exact set of software installed on a machine
  - The union of all vulnerability signatures might match a large fraction of legitimate traffic

- $\Rightarrow$ best suited for use directly on hosts

Content Signature – Host/Honeypot

- Hosts running shield can act similarly to honeypots
  - When traffic arrives which is deemed an exploit, generate a content signature from the data in those packets
  - While the vulnerability signature is host specific, the resultant content signature is shareable
  - Note, the content signature can not exist until there is an actual, observed exploit

Outline

- Motivation
- Background
- **Detection schemes:**
  - Content Signature - Network
  - Content Signature – Host/Honeypot
  - **Scanning Activity**
  - Population Dynamics
- Tying things together

Scanning Activity

- To spread, a worm instance needs to:
  - Chose potential targets
  - Send network packets to the target

- Successful worm ⇒ talks to many distinct hosts
  - For a random scan worm, many connections are to addresses with no actual host

- ⇒ look for hosts with large “outdegree”

- However, do not match legitimate servers
  - **`“www.cs.ucsd.edu”`** or **`“ns0.ucsd.edu”`**

Scanning Activity: Connection Tracking

- Measure successful/unsuccessful communication attempts over time
  - Note: judging success generally requires being near the host

- The Williamson algorithm [W02] uses a leaky-bucket approach to limit the *rate* of connections to hosts not recently seen

- Sequential hypothesis testing [SJB04,WSP04] makes a Bayesian decision by comparing the observed sequence with a random walk

Scanning Activity: Large Outdegree

- Examine hosts which communicate with a large number of other hosts (ignoring success)
- Can be deployed deeper in the network and requires less state than connection tracking techniques
- Other non-worm activity can look similar:
  - Flash crowd to normally quiet web server (legitimate)
  - Port scanning source (malicious)
  - Port scanning victim (legitimate response to malicious traffic)
  - Backscatter from DDoS (legitimate response to malicious traffic)

Scanning Activity: Large Outdegree

- Superspreader algorithm [VSGB05]
  - Designed specifically to solve this problem
  - Can immediately report hosts which cross a threshold

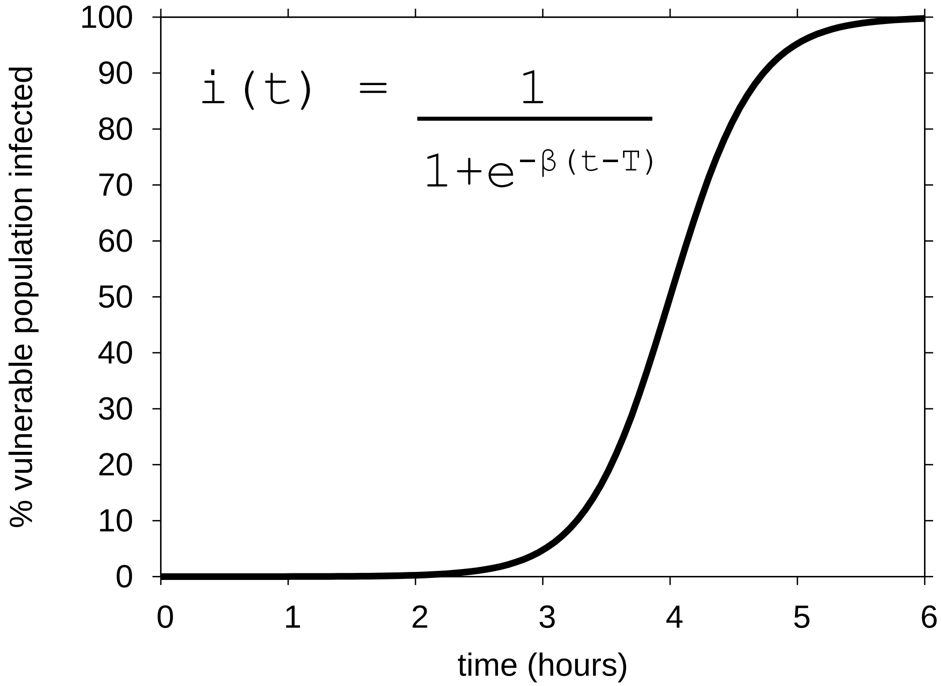
- Traffic summaries [KME05]
  - Large degree report one of many “heavy-hitter” reports
  - Designed to generate reports at fixed time intervals

Outline

- Motivation
- Background
- **Detection schemes:**
  - Content Signature - Network
  - Content Signature – Host/Honeypot
  - Scanning Activity
  - **Population Dynamics**
- Tying things together

Population Dynamics

- Random scan worms:
  - Pick targets randomly
  - Common in practice
  - Characteristic infection curve
- Look for traffic matching this growth pattern [ZGGT03]



Outline

- Motivation
- Background
- Detection schemes:
  - Content Signature - Network
  - Content Signature – Host/Honeypot
  - Scanning Activity
  - Population Dynamics
- **Tying things together**

Tying Things Together

- Lots of progress on “basic” detection algorithms
  - Efficient, fairly effective, combinable
- Many depend on wide or random scanning
  - Including the content signature algorithms
- Recent work in worm design avoids random scans
  - Can we use the existing building blocks to solve?
  - What new techniques are needed?
- Combinations of host- and network-based detectors could provide best of both worlds

Questions?