CIS 551 / TCOM 401

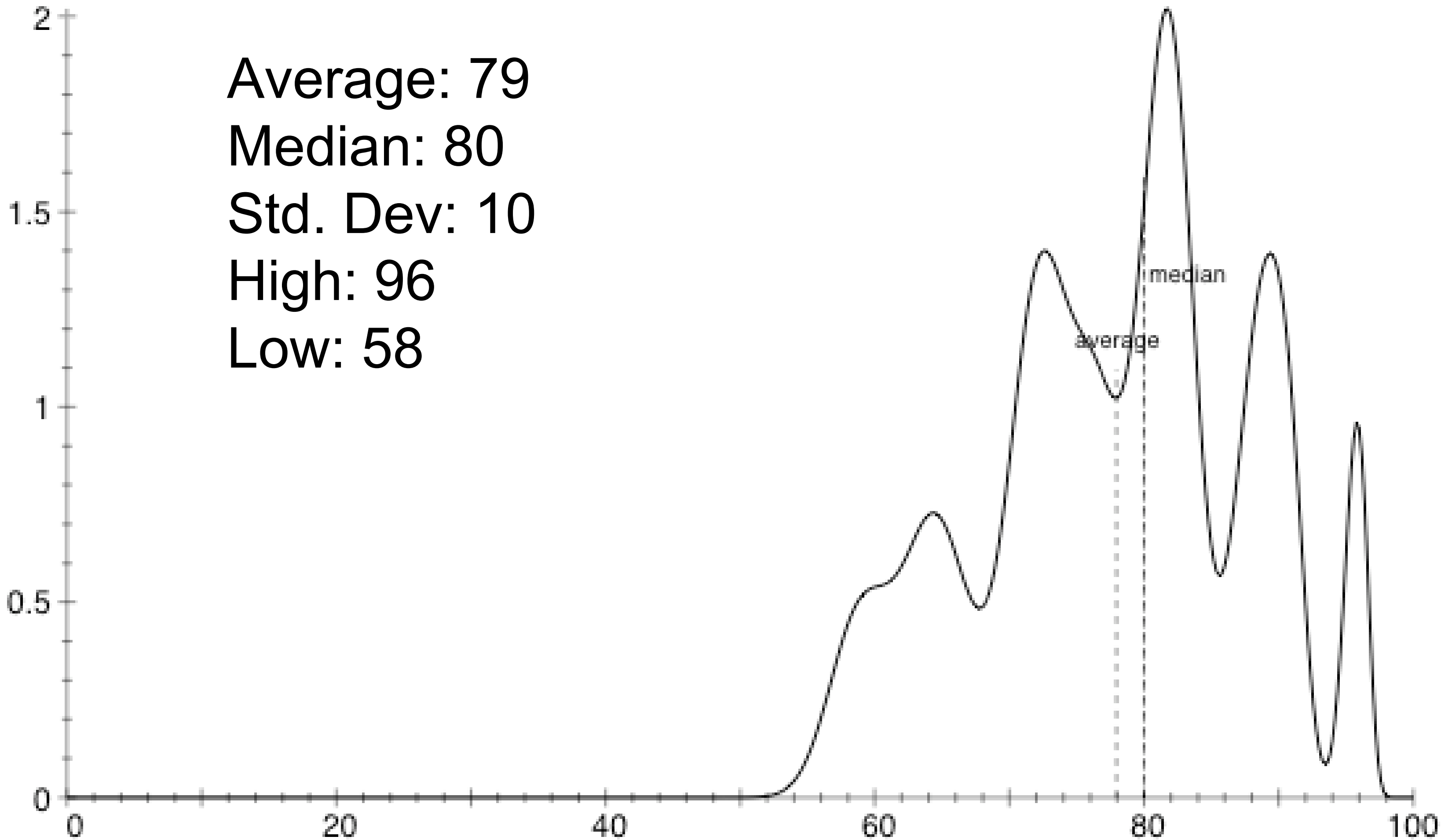
Computer and Network Security

Spring 2006

Lecture 20

Midterm II graded

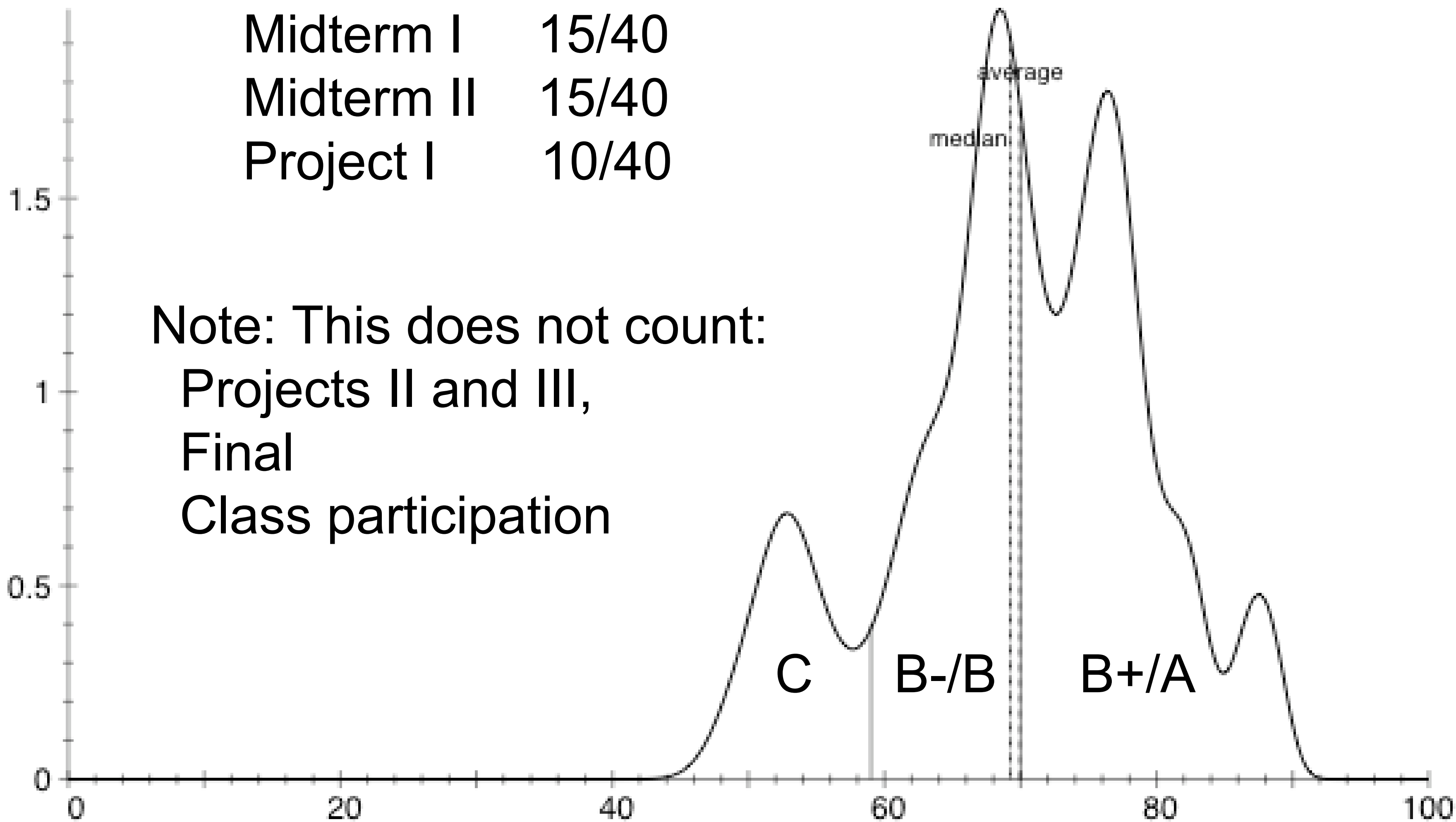
Average: 79
Median: 80
Std. Dev: 10
High: 96
Low: 58



Midpoint Grade Estimates

Midterm I 15/40
Midterm II 15/40
Project I 10/40

Note: This does not count:
- Projects II and III,
- Final
- Class participation



Worm Research Sources

- "Inside the Slammer Worm"
  - Moore, Paxson, Savage, Shannon, Staniford, and Weaver
- ☆ "How to 0wn the Internet in Your Spare Time"
  - Staniford, Paxson, and Weaver
- "The Top Speed of Flash Worms"
  - Staniford, Moore, Paxson, and Weaver
- ☆ "Internet Quarantine: Requirements for Containing Self-Propagating Code"
  - Moore, Shannon, Voelker, and Savage
- "Automated Worm Fingerprinting"
  - Singh, Estan, Varghese, and Savage

- Links on the course web pages.

Morris Internet Worm

- November 2, 1988
- Infected around 6,000 major Unix machines
- Cost of the damage at $10m - $100m
- Robert T. Morris Jr. unleashed Internet worm
  - Graduate student at Cornell University
  - Convicted in 1990 of violating Computer Fraud and Abuse Act
  - $10,000 fine, 3 yr. Suspended jail sentence, 400 hours of community service
  - Son of the chief scientist at the National Computer Security Center -- part of the National Security Agency
  - Today he's a professor at MIT

The Morris Worm Did Not:

- Alter or destroy files
- Save or transmit the passwords which it cracked
- Make special attempts to gain root or superuser access in a system (and didn't utilize the privileges if it managed to get them).
- Place copies of itself or other programs into memory to be executed at a later time. (Such programs are commonly referred to as timebombs.)
- Attack machines other than Sun 3 systems and VAX computers running 4 BSD Unix (or equivalent).
- Attack machines that were not attached to the internet.
- Travel from machine to machine via disk.
- Cause physical damage to computer systems.

Morris Worm Transmission

- Find user accounts on the target machine
  - Dictionary attack on /etc/passwd
  - If it found a match, it would log in and try the same username/password on other local machines
- Exploit bug in fingerd
  - Classic buffer overflow attack
- Exploit *trapdoor* in sendmail
  - Programmer left DEBUG mode in sendmail, which allowed sendmail to execute an arbitrary shell command string.

Morris Worm Infection

- Sent a small loader to target machine
  - 99 lines of C code
  - It was compiled on the remote platform (cross platform compatibility)
  - The loader program transferred the rest of the worm from the infected host to the new target.
  - Used authentication! To prevent sys admins from tampering with loaded code.
  - If there was a transmission error, the loader would erase its tracks and exit.

Morris Worm Stealth/DoS

- When loader obtained full code
  - It put into main memory and encrypted
  - Original copies were deleted from disk
  - (Even memory dump wouldn’t expose worm)
- Worm periodically changed its name and process ID
- Resource exhaustion
  - Denial of service
  - There was a bug in the loader program that caused many copies of the worm to be spawned per host
- System administrators cut their network connections
  - Couldn’t use internet to exchange fixes!

Code Red Worm (July 2001)

- Exploited buffer overflow vulnerability in IIS Indexing Service DLL

- Attack Sequence:
  - The victim host is scanned for TCP port 80.
  - The attacking host sends the exploit string to the victim.
  - The worm, now executing on the victim host, checks for the existence of c:\notworm. If found, the worm ceases execution.
  - If c:\notworm is not found, the worm begins spawning threads to scan random IP addresses for hosts listening on TCP port 80, exploiting any vulnerable hosts it finds.
  - If the victim host's default language is English, then after 100 scanning threads have started and a certain period of time has elapsed following infection, all web pages served by the victim host are defaced with the message,

Code Red Analysis

- http://www.caida.org/analysis/security/code-red/
- http://www.caida.org/analysis/security/code-red/newframes-small-log.gif
- In less than 14 hours, 359,104 hosts were compromised.
  - Doubled population in 37 minutes on average
- Attempted to launch a Denial of Service (DoS) attack against www1.whitehouse.gov,
  - Attacked the IP address of the server, rather than the domain name
  - Checked to make sure that port 80 was active before launching the denial of service phase of the attack.
  - These features made it trivially easy to disable the Denial of Service (phase 2) portion of the attack.
  - We cannot expect such weaknesses in the design of future attacks.

Code Red Worm

- The "Code Red" worm can be identified on victim machines by the presence of the following string in IIS log files:

/default.ida?NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNN%u9090%u6858%ucbd3%u7801%u9090%u6858%ucbd3%
u7801%u9090%u6858%ucbd3%u7801%u9090%u9090%u8190%u00c3%u0003%u8b00%u531
b%u53ff%u0078%u0000%u00=a

- Additionally, web pages on victim machines may be defaced with the following message:

HELLO! Welcome to http://www.worm.com!
Hacked By Chinese!

Slammer Worm

- Saturday, 25 Jan. 2003 around 05:30 UTC
- Exploited buffer overflow in Microsoft's SQL Server or MS SQL Desktop Engine (MSDE).
  - Port 1434 (not a very commonly used port)
- Infected > 75,000 hosts (likely more)
  - Less than 10 minutes!
  - Reached peak scanning rate (55 million scans/sec) in 3 minutes.
- No malicious payload
- Used a single UDP packet with buffer overflow code injection to spread.
- Bugs in the Slammer code slowed its growth
  - The author made mistakes in the random number generator

Internet Worm Trends

- Code Red, Code Red II, Nimda (TCP 80, Win IIS)
  - Code Red infected more than 350,000 on July 19, 2001 by several hours
  - Uniformly scans the entire IPv4 space
  - Code Red II (local scan), Nimda (multiple ways)
- SQL Slammer (UDP 1434, SQL server)
  - Infected more than 75,000 on Jan 25, 2003
  - Infected 90% of vulnerable hosts in 10 minutes.
- Blaster (TCP 135, Win RPC)
  - Sequential scan; infected 300,000 to more than 1 million hosts on August 11, 2003.

But it gets worse: Flash Worms

- Paper: "The Top Speed of Flash Worms"
- Idea: Don't do random search
  - Instead, partition the search space among instances of the worm
  - Permutation scanning
  - Or, keep a tailored "hit list" of vulnerable hosts and distribute this initial set to the first worms spawned
- Simulations suggest that such a worm could saturate 95% of 1,000,000 vulnerable hosts on the Internet in 510 milliseconds.
  - Using UDP
  - For TCP it would take 1.3 seconds

Analysis: Random Constant Spread Model

- IP address space = 2^{32}
- N = size of the total vulnerable population
- S(t) = susceptible/non-infected hosts at time t
- I(t) = infective/infected hosts at time t
- β = Contact likelihood
- s(t) = S(t)/N   proportion of susceptible population
- i(t) = I(t)/N   proportion of infected population

- Note: S(t) + I(t) = N

Infection rate over time

- Change in infection rate is expressed as:

$$\frac{dI}{dt} = I(t) * \beta * s(t)$$

$I(t)$: # of infected hosts

β: rate of contact

$s(t)$: likelihood that contacted hosts is susceptible

Rewrite to obtain:

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

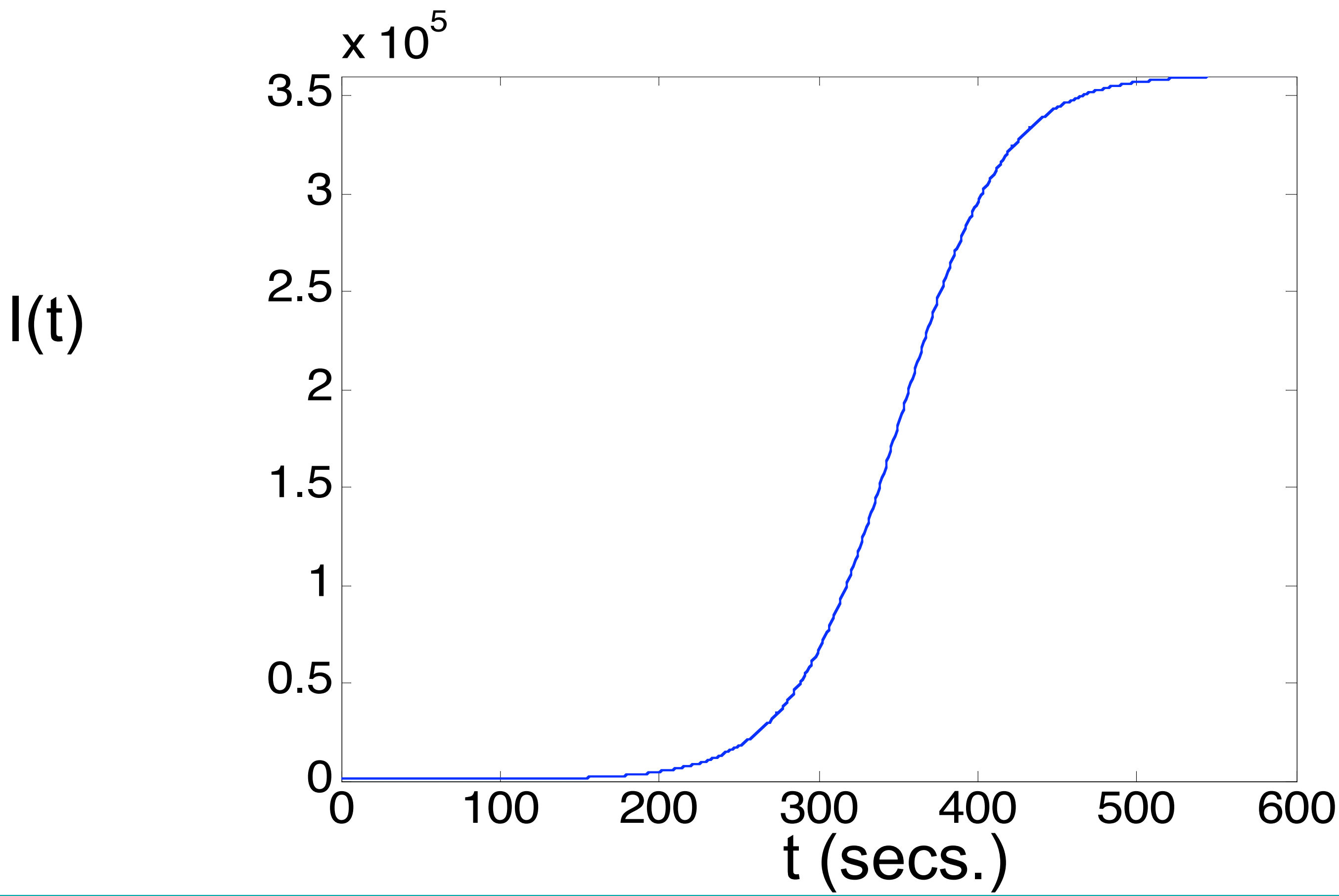
Integrate to get this closed form:

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

T = integration constant

Exponential growth, tapers off

- Example curve of I(t)   (which is i(t) * N)
- Here, N = 3.5×10^5 (β affects steepness of slope)



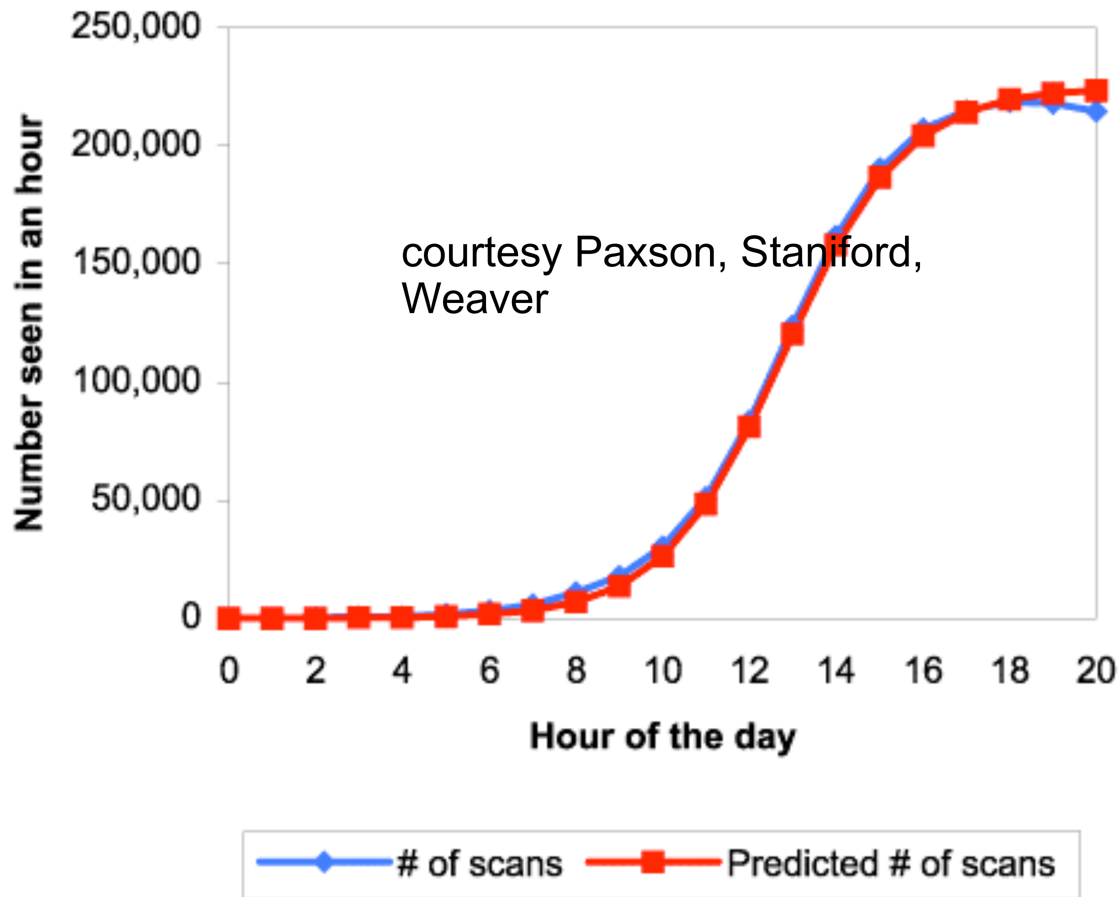
What about the constants?

- N = estimated # of hosts running vulnerable software
  - e.g. Apache or mail servers
  - In 2002 there were roughly 12.6M web servers on the internet
- Reasonable choice for β is $r * N / 2^{32}$
  - Where r = probing rate (per time unit)

- For Code Red I:
  - β was empirically measured at about 1.8 hosts/hour.
  - T was empirically measured at about 11.9 (= time at which half the vunerable hosts were infected)
- Code Red I was programmed to shut itself off at midnight UTC on July 19th
  - But incorrectly set clocks allowed it to live until August
  - Second outbreak had β of approximately 0.7 hosts/hour
  - Implies that about 1/2 of the vulnerable hosts had been patched

Predictions vs. Reality

- Port 80 scans due to Code Red I



What can be done?

- Reduce the number of infected hosts
  - **Treatment**, reduce I(t) while I(t) is still small
  - e.g. shut down/repair infected hosts
- Reduce the contact rate
  - **Containment**, reduce ß while I(t) is still small
  - e.g. filter traffic

}Reactive

- Reduce the number of susceptible hosts
  - **Prevention**, reduce S(0)
  - e.g. use type-safe languages

}Proactive

Treatment

- Reduce # of infected hosts

- Disinfect infected hosts
  - Detect infection in real-time
  - Develop specialized “vaccine” in real-time
  - Distribute “patch” more quickly than worm can spread
    - Anti-worm? (CRClean written)
    - Bandwidth interference…

Effects of "patching" infected hosts

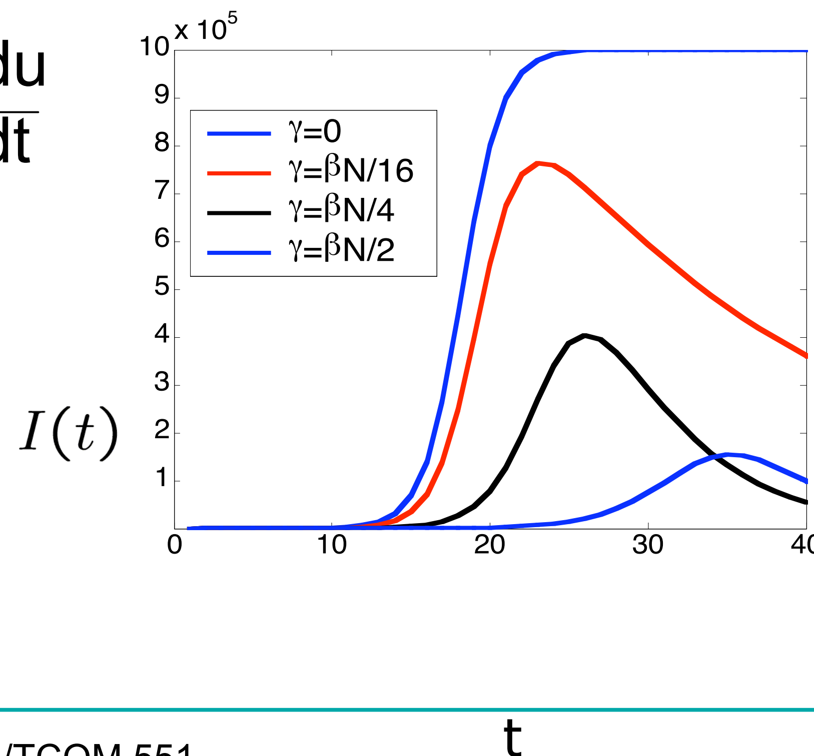
- Kermack-McKendrick Model
- State transition:

U(t) = # of removed from infectious population

γ = removal rate

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

$$\frac{du}{dt} = \gamma * i(t)$$



Containment

- Reduce contact rate β

- **Oblivious defense**
  - Consume limited worm resources
  - Throttle traffic to slow spread
  - Possibly important capability, but worm still spreads…

- **Targeted defense**
  - Detect and block worm

Design Space

- Design Issues for Reactive Defense
  [Moore et al 03]

- Any reactive defense is defined by:
  – ***Reaction time*** – **how long** to detect, propagate information, and activate response
  – ***Containment strategy*** – **how** malicious behavior is identified and stopped
  – ***Deployment scenario*** - **who** participates in the system

- Savage et al. evaluate the requirements for these parameters to build **any** effective system for worm propagation.

Methodology

- **Moore et al., "Internet Quarantine:…" paper**

- **Simulate spread of worm across Internet topology:**
  - infected hosts *attempt* to spread at a fixed rate (probes/sec)
  - target selection is uniformly random over IPv4 space

- **Simulation of defense:**
  - system detects infection within reaction time
  - subset of network nodes employ a containment strategy

- **Evaluation metric:**
  - % of vulnerable hosts infected in 24 hours
  - 100 runs of each set of parameters (95^{th} percentile taken)
    - Systems must plan for reasonable situations, **not** the average case

- **Source data:**
  - vulnerable hosts: 359,000 IP addresses of CodeRed v2 *victims*
  - Internet topology: AS routing topology derived from RouteViews

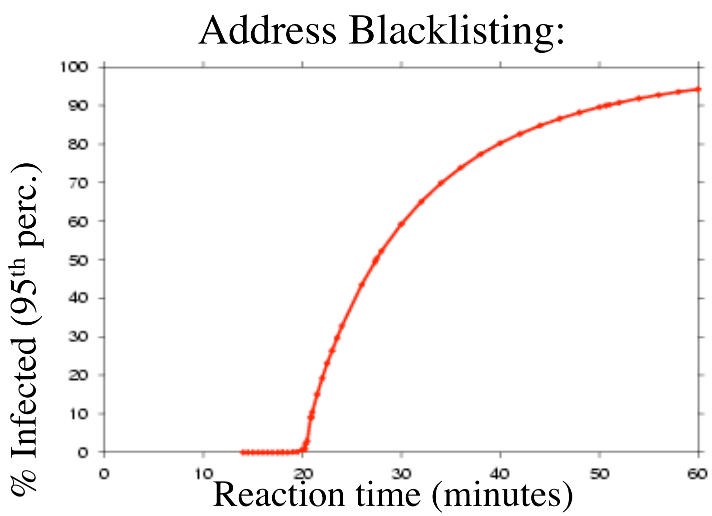
Initial Approach: Universal Deployment

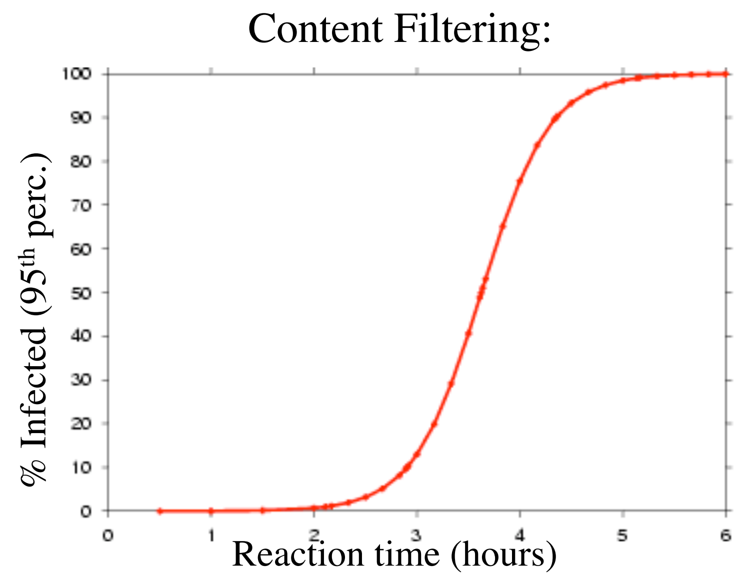
- Assume **every host** employs the containment strategy

- Two containment strategies they tested:
  - ***Address blacklisting:***
    - block traffic from malicious source IP addresses
    - reaction time is relative to each infected host
  - ***Content filtering:***
    - block traffic based on signature of content
    - reaction time is from first infection

- How quickly does each strategy need to react?
- How sensitive is reaction time to worm probe rate?

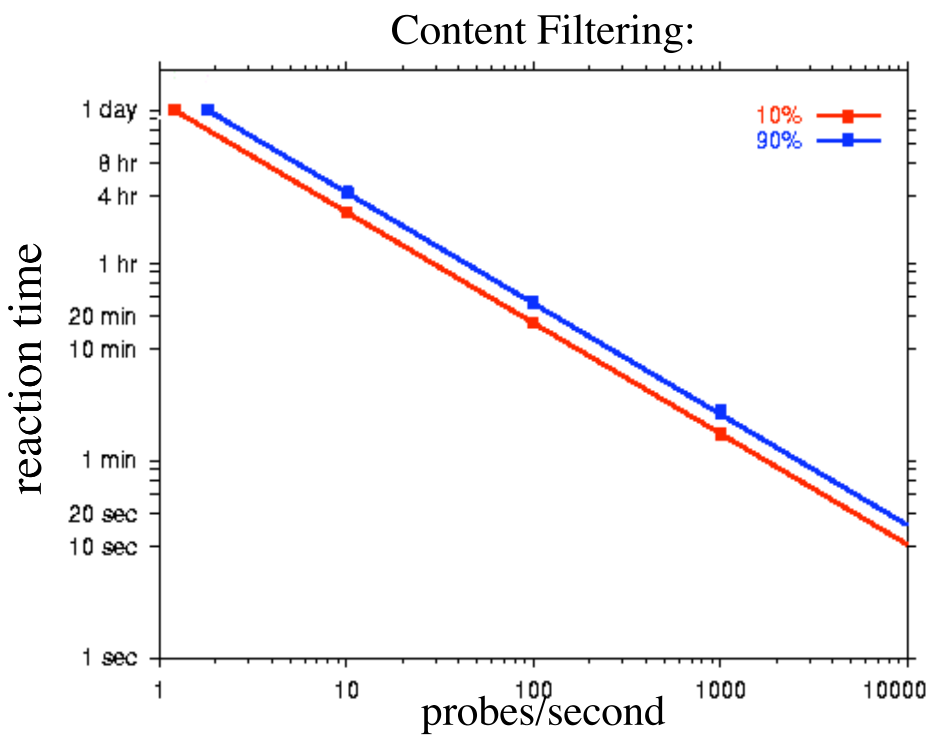
Reaction times?





- To contain worms to 10% of vulnerable hosts after 24 hours of spreading at 10 probes/sec (CodeRed):
  - Address blacklisting: reaction time must be < 25 minutes.
  - Content filtering: reaction time must be < 3 hours

Probe rate vs. Reaction Time



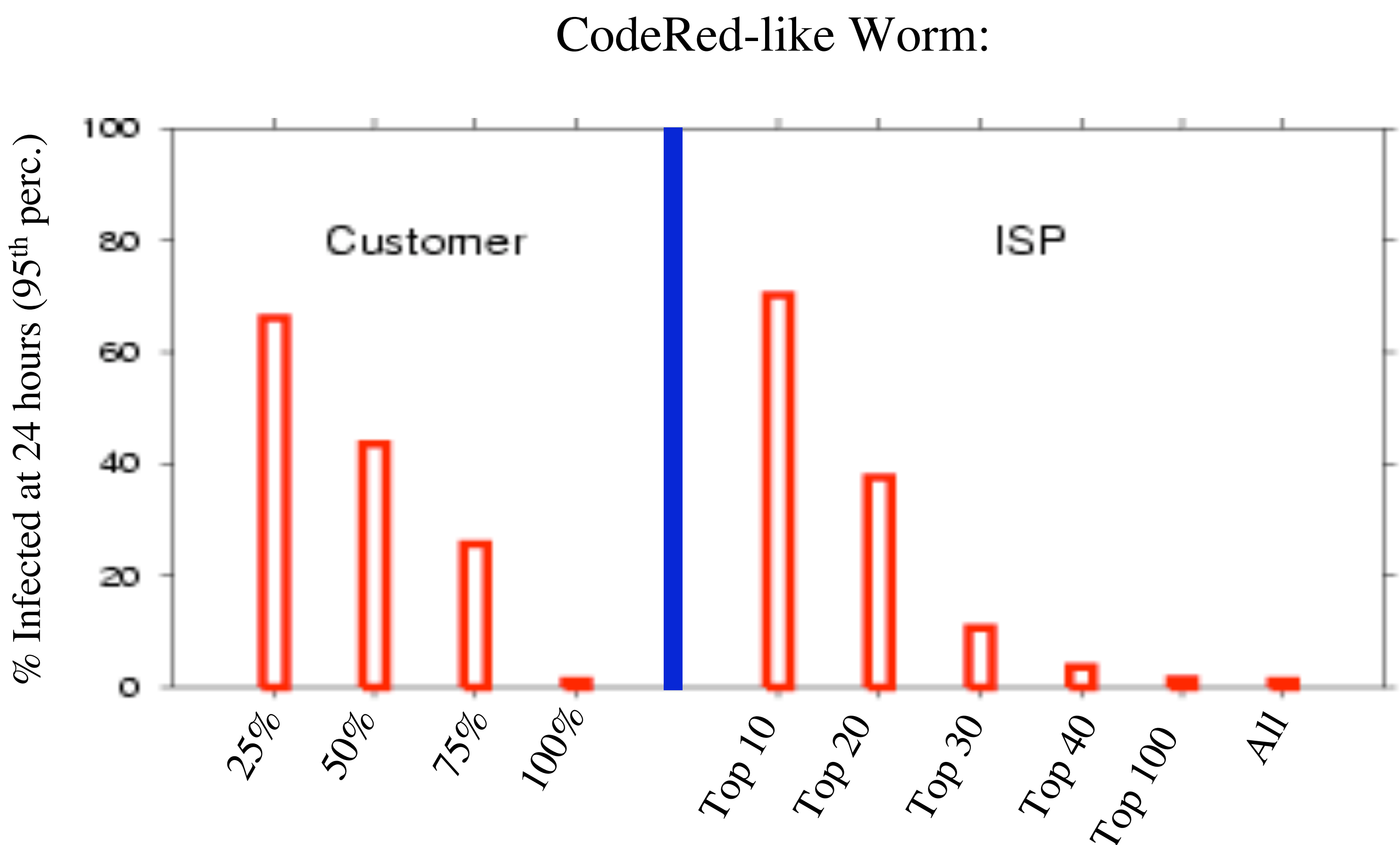
- Reaction times must be fast when probe rates get high:
  - 10 probes/sec: reaction time must be < 3 hours
  - 1000 probes/sec: reaction time must be < 2 minutes

Limited Network Deployment

- Depending on <u>every</u> **host** to implement containment is not feasible:
  - installation and administration costs
  - system communication overhead
- A more realistic scenario is <u>limited</u> deployment in the **network**:
  - Customer Network: firewall-like inbound filtering of traffic
  - ISP Network: traffic through border routers of large transit ISPs
- How effective are the deployment scenarios?
- How sensitive is reaction time to worm probe rate under limited network deployment?

Deployment Scenario Effectiveness?

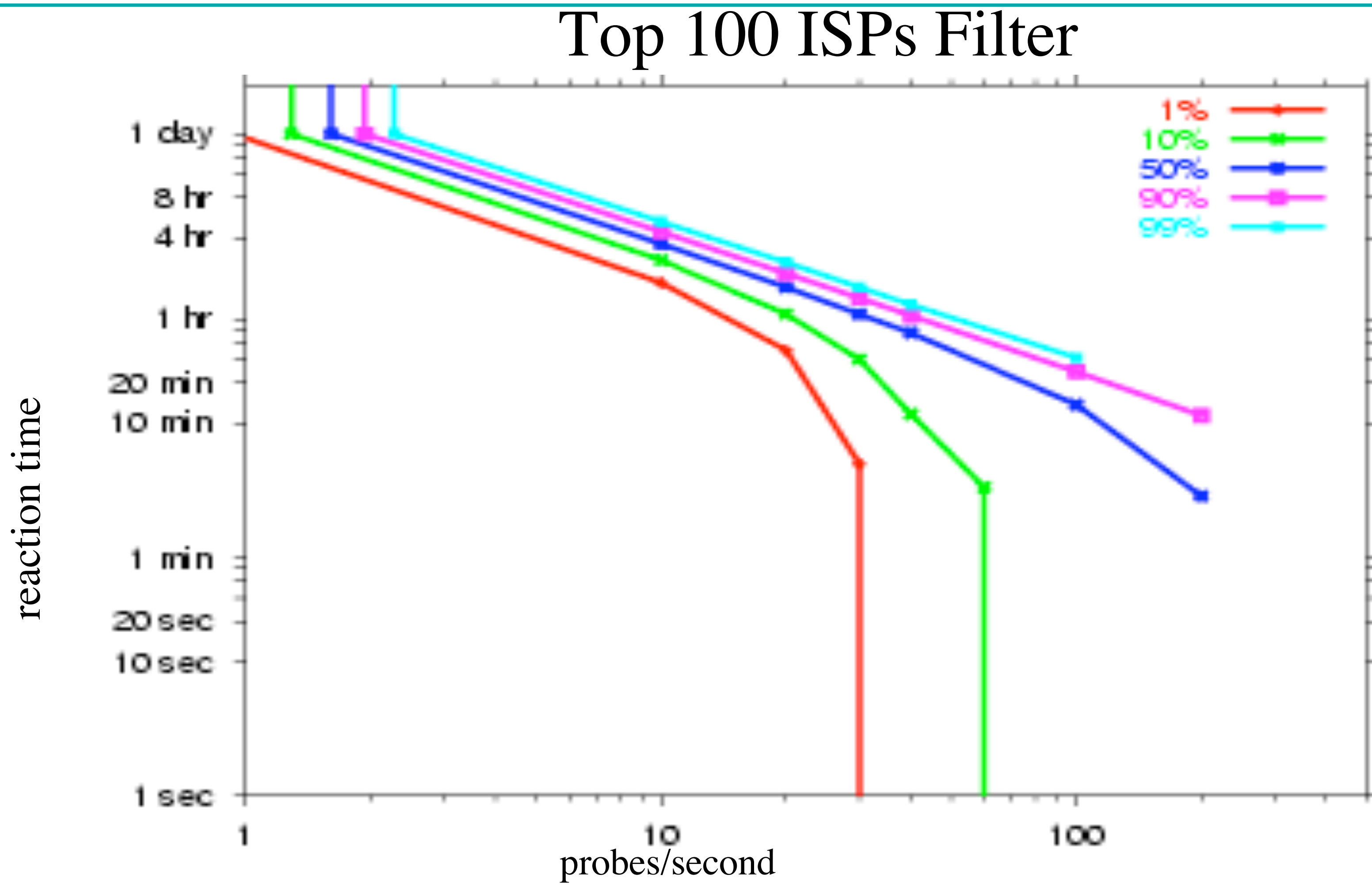
Reaction time = 2 hours



Content filtering firewalls at edge of customer nets.

Content filtering at exchange points in major ISPs.

Reaction Time vs. Probe Rate (II)



- Above 60 probes/sec, containment to 10% hosts within 24 hours is impossible even with *instantaneous* reaction.

Summary: Reactive Defense

- Reaction time:
  - required reaction times are a couple minutes or less (far less for bandwidth-limited scanners)
- Containment strategy:
  - content filtering is more effective than address blacklisting
- Deployment scenarios:
  - need nearly all customer networks to provide containment
  - need at least top 40 ISPs provide containment