MALWARE: WORMS

GRAD SEC

OCT 12 2017

TODAY'S PAPERS


How to Own the Internet in Your Spare Time

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Abstract

The ability of attackers to rapidly gain control of vast numbers of Internet hosts poses an immense risk to the overall security of the Internet. Once subverted, these hosts can not only be used to launch massive denial of service floods, but also to steal or corrupt great quantities of sensitive information, and confuse and disrupt use of the network in more subtle ways.

We present an analysis of the magnitude of the threat. We begin with a mathematical model derived from empirical data of the spread of Code Red I in July, 2001. We discuss techniques subsequently employed for achieving greater virulence by Code Red II and Nimda. In this context, we develop and evaluate several new, highly virulent possible techniques: hit-list scanning (which creates a *Warhol* worm), permutation scanning (which enables self-coordinating scanning), and use of Internet-sized hit-lists (which creates a *flash* worm).

We then turn to the threat of *surreptitious* worms that spread more slowly but in a much harder to detect "contagion" fashion. We demonstrate that such a worm today could arguably subvert upwards of 10,000,000 Internet hosts. We also consider robust mechanisms by which attackers can control and update deployed worms.

In conclusion, we argue for the pressing need to develop a "Center for Disease Control" analog for virus- and worm-based threats to national cybersecurity, and sketch some of the components that would go into such a Center.

1 Introduction

If you can control a million hosts on the Internet, you can do enormous damage. First, you can launch distributed denial of service (DDOS) attacks so immensely diffuse that mitigating them is well beyond the state-of-the-art for DDOS traceback and protection technologies. Such attacks could readily bring down e-commerce sites, news outlets, command and coordination infrastructure, specific routers, or the root name servers.

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Third, not only can you access this information, but you can sow confusion and disruption by corrupting the information, or sending out false or confidential information directly from a user's desktop.

In short, if you could control a million Internet hosts, the potential damage is truly immense: on a scale where such an attack could play a significant role in warfare between nations or in the service of terrorism.

Unfortunately it is reasonable for an attacker to gain control of a million Internet hosts, or perhaps even ten million. The highway to such control lies in the exploitation of *worms*: programs that self-propagate across the Internet by exploiting security flaws in widely-used services.[1] Internet-scale worms are not a new phenomenon [Sp89, ER89], but the severity of their threat has rapidly grown with (i) the increasing degree to which the In-

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[1] We distinguish between the worms discussed in this paper—*active worms*—and *viruses* (or *email worms*) in that the latter require some sort of user action to abet their propagation. As such, they tend to propagate more slowly. From an attacker's perspective, they also suffer from the presence of a large anti-virus industry that actively seeks to identify and control their spread.

Inside the Slammer Worm

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For more on how we tracked Slammer, see the "Network telescope operations" sidebar.

How Slammer chooses its victims

The worm's spreading strategy uses random scanning—it randomly selects IP addresses, eventually finding and infecting all susceptible hosts. Random-scanning worms initially spread exponentially, but their rapid new-host

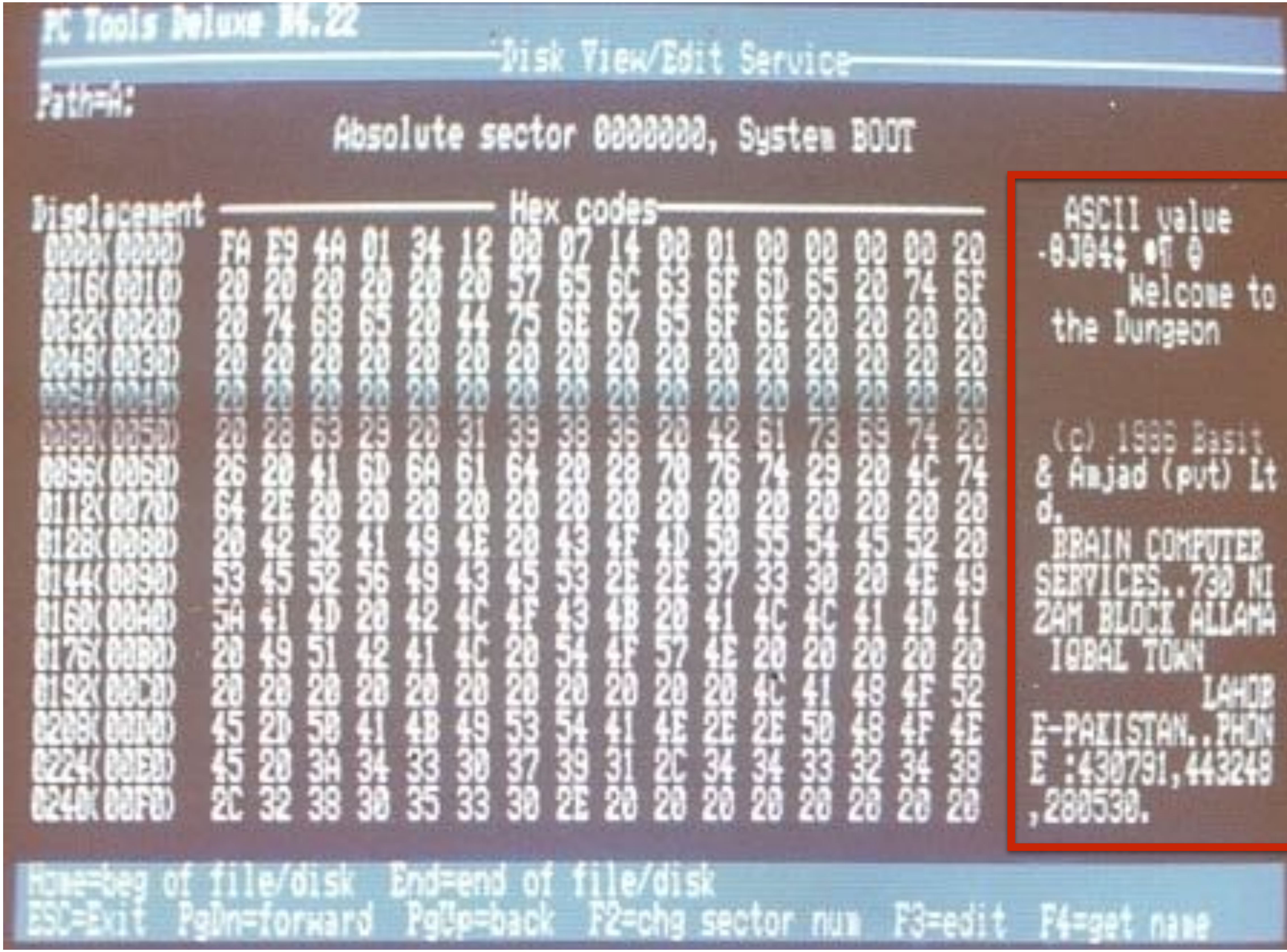
VIRUS
CASE STUDIES

BRAIN

First IBM PC virus (1987)

- Propagation method
  - Copies itself into the boot sector
  - Tells the OS that all of the boot sector is “faulty” (so that it won’t list contents to the user)
    - Thus also one of the first examples of a **stealth** virus
  - Intercepts disk read requests for 5.25” floppy drives
    - Sees if the 5th and 6th bytes of the boot sector are 0x1234
    - If so, then it’s already infected, otherwise, infect it

- Payload:
  - Nothing really; goal was just to spread (to show off?)
  - However, it served as the template for future viruses


PC Tools Deluxe R4.22
Disk View/Edit Service
Path=A:
Absolute sector 0000000, System BOOT
Displacement
Hex codes
ASCII value
0000(0000) FA E9 4A 01 34 12 00 07 14 00 01 00 00 00 00 20
0016(0010) 20 20 20 20 20 20 57 65 6C 63 6F 6D 65 20 74 6F
0032(0020) 20 74 68 65 20 44 75 6E 67 65 6F 6E 20 20 20 20
0048(0030) 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0064(0040) 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0080(0050) 20 28 63 29 20 31 39 38 36 20 42 61 73 69 74 20
0096(0060) 26 20 41 6D 6A 61 64 20 28 70 76 74 29 20 4C 74
0112(0070) 64 2E 20 20 20 20 20 20 20 20 20 20 20 20 20 20
0128(0080) 20 42 52 41 49 4E 20 43 4F 4D 50 55 54 45 52 20
0144(0090) 53 45 52 56 49 43 45 53 2E 2E 37 33 30 20 4E 49
0160(00A0) 5A 41 4D 20 42 4C 4F 43 4B 20 41 4C 4C 41 4D 41
0176(00B0) 20 49 51 42 41 4C 20 54 4F 57 4E 20 20 20 20 20
0192(00C0) 20 20 20 20 20 20 20 20 20 20 20 4C 41 48 4F 52
0208(00D0) 45 2D 50 41 4B 49 53 54 41 4E 2E 2E 50 48 4F 4E
0224(00E0) 45 20 3A 34 33 30 37 39 31 2C 34 34 33 32 34 38
0240(00F0) 2C 32 38 30 35 33 30 2E 20 20 20 20 20 20 20 20
Welcome to the Dungeon
(c) 1986 Basit & Amjad (pvt) Ltd.
BRAIN COMPUTER SERVICES..730 NIZAM BLOCK ALLAMA IQBAL TOWN
LAHORE-PAKISTAN..PHONE :430791,443248,280530.
Home=beg of file/disk End=end of file/disk
ESC=Exit PgDn=forward PgUp=back F2=chg sector num F3=edit F4=get name

ROOTKITS

Malicious code that hides from discovery

- Ways to hide:
  - By intercepting system calls, patching the kernel, etc.
  - Often effectively done by a man in the middle attack
- Rootkit revealer: analyzes the disk offline and through the online system calls, and compares
- Mark Russinovich ran a rootkit revealer and found a rootkit in 2005…

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  - Loaded thanks to autorun.exe on the CD
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- How it messed up
  - Morally: violated trust
  - Technically: Hid ***all files*** that started with "sys"
  - Seriously?: The uninstaller did not check the integrity of the code it downloaded, and would not delete it afterwords.

STUXNET

June 2010

- Virus in that it initially spread by infected USB stick
  - Once inside a network, it acted as a worm, spreading quickly
- Exploited **four** zero-day exploits
  - Zero-day: Known to only the attacker until the attack
  - Typically, one zero-day is enough to profit
  - Four was unprecedented
    - Immense cost and sophistication on behalf of the attacker
- Rootkit: installed *signed* device drivers
  - Thereby avoiding user alert when installing
  - Signed with certificates stolen from two Taiwanese CAs

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    - .. then drop back to normal range

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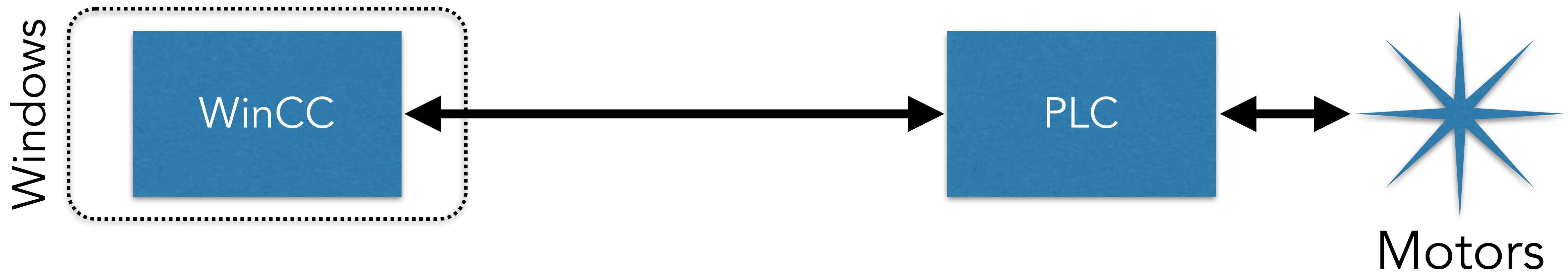
- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



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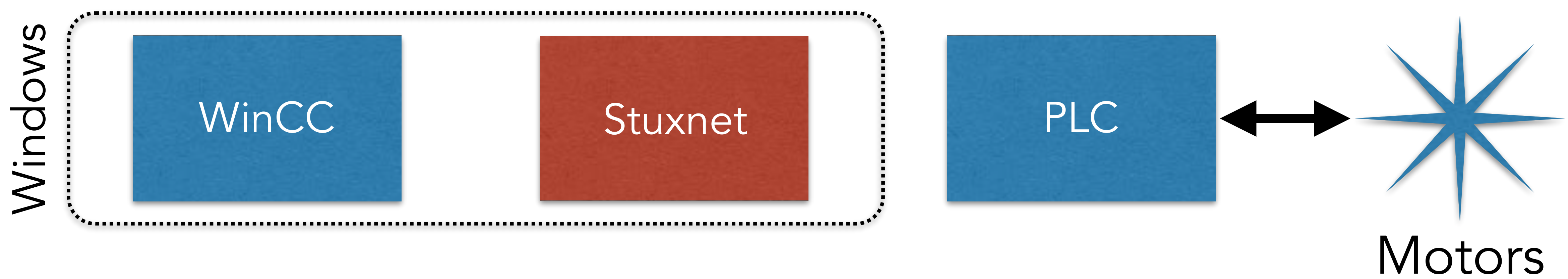

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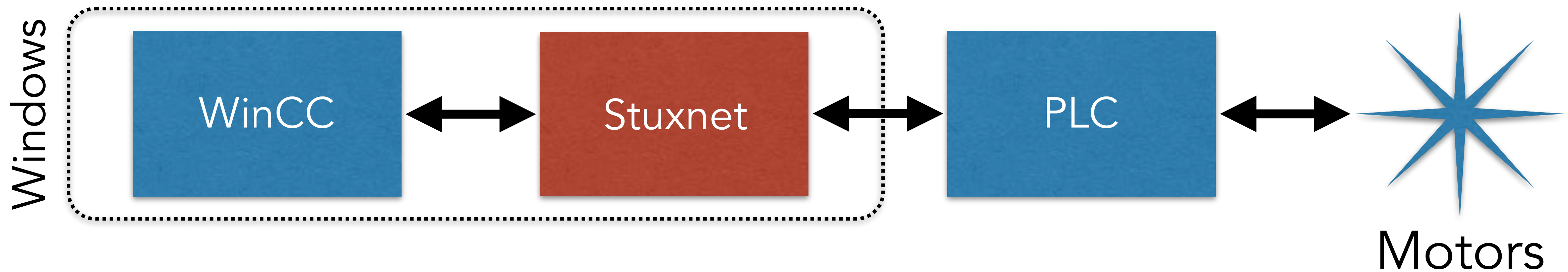

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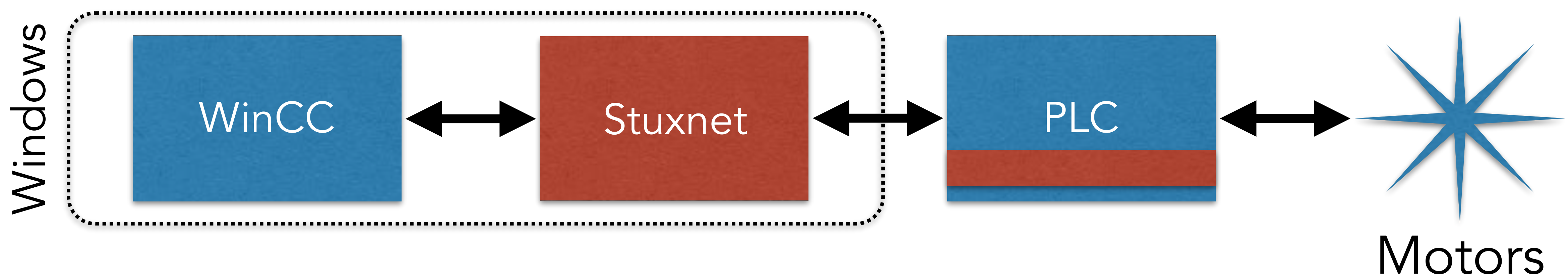

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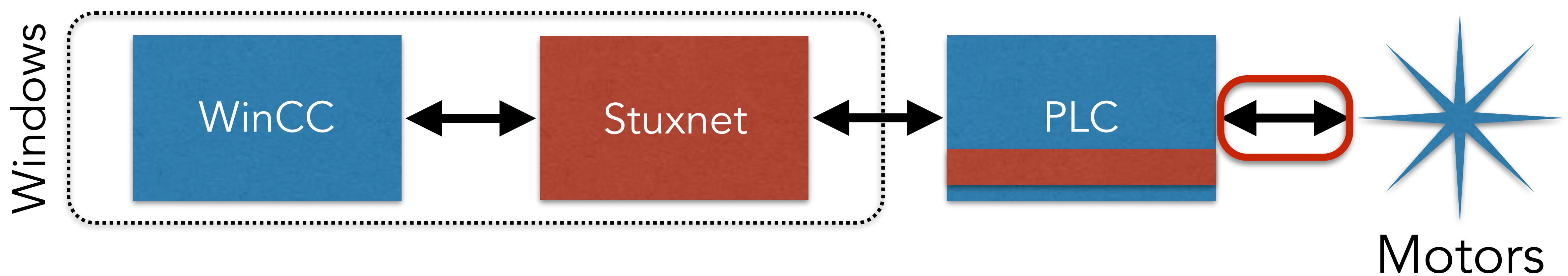

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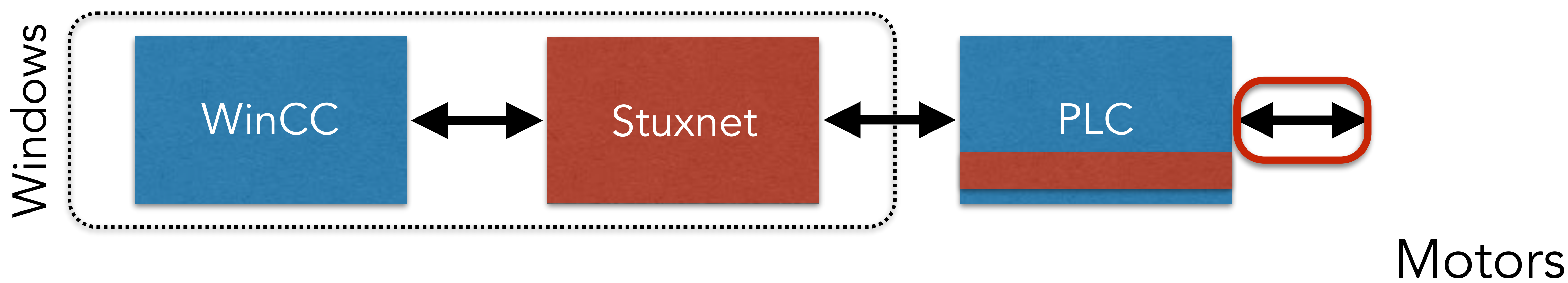

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STUXNET FALLOUT

- Iran denied they had been hit by Stuxnet
- Then claimed they were, but had contained it
- Understood now that it took out 1k of Iran’s 5k centrifuges
- Security experts believe the U.S. did it (possibly along with Israel) due to its sophistication and cost
- **Legitimized cyber warfare**

VIRUSES: SUMMARY

- Technological arms race between those who wish to detect and those who wish to evade detection
- Started off innocuously, capable by only a few very clever people
- But viruses have become commoditized; any scriptkiddy can launch one (creation remains hard)
- No longer purely of academic interest
  - Economic pursuits (zero-day markets)
  - Cyber warfare

OTHER WORK

- Detecting malware in the Android app store
- Lots of drive-by-download work
- Malware distribution networks: use enterprise-wide network traces to detect malware downloads
- Side-channel defenses: Measure, e.g., power consumption of benign vs. malicious code
- Metamorphic arms race

10/10 Malware

- **Hunting For Metamorphic**, Péter Ször, Peter Ferrie
- **The Ghost In The Browser Analysis of Web-based Malware**, Niels Provos, Dean McNamee, Panayiotis Mavrommatis, Ke Wang, Nagendra Modadugu

- Dissecting Android Malware: Characterization and Evolution, Yajin Zhou, Xuxian Jiang
- Hey, you, Get Off of My Market: Detecting Malicious Apps in Official and Alternative Android Markets, Yajin Zhou, Zhi Wang, Wu Zhou, Xuxian Jiang
- All Your iFrames Point to Us, Niels Provos, Panayiotis Mavrommatis, Moheeb Abu Rajab, Fabian Monrose
- Android Permissions Demystified, Adrienne Porter Felt, Erika Chin, Steve Hanna, Dawn Song, David Wagner
- Prudent Practices for Designing Malware Experiments: Status Quo and Outlook, Christian Rossow, Christian J. Dietrich, Chris Grier, Christian Kreibich, Vern Paxson, Norbert Pohlmann, Herbert Bos, Maarten van Steen
- Detection and Analysis of Drive-by-Download Attacks and Malicious JavaScript Code, Marco Cova, Christopher Kruegel, Giovanni Vigna
- Towards Automatic Generation of Vulnerability-Based Signatures, David Brumley, James Newsome, Dawn Song, Hao Wang, Somesh Jha
- Nazca: Detecting Malware Distribution in Large-Scale Networks, Luca Invernizzi, Stanislav Miskovic, Ruben Torres, Sabyasachi Saha, Sung-Ju Lee, Marco Mellia, Christopher Kruegel, Giovanni Vigna
- WattsUpDoc: Power Side Channels to Nonintrusively Discover Untargeted Malware on Embedded Medical Devices, Shane S. Clark, Benjamin Ransford, Amir Rahmati, Shane Guineau, Jacob Sorber, Kevin Fu, Wenyuan Xu
- Sony's DRM Rootkit: The Real Story, Bruce Schneier
- Lessons from the Sony CD DRM Episode, J. Alex Halderman, Edward W. Felten

DETECTING METAMORPHIC VIRUSES

New idea: side-channel metamorphic detection

- Measure some effect of the system
  - Power consumption
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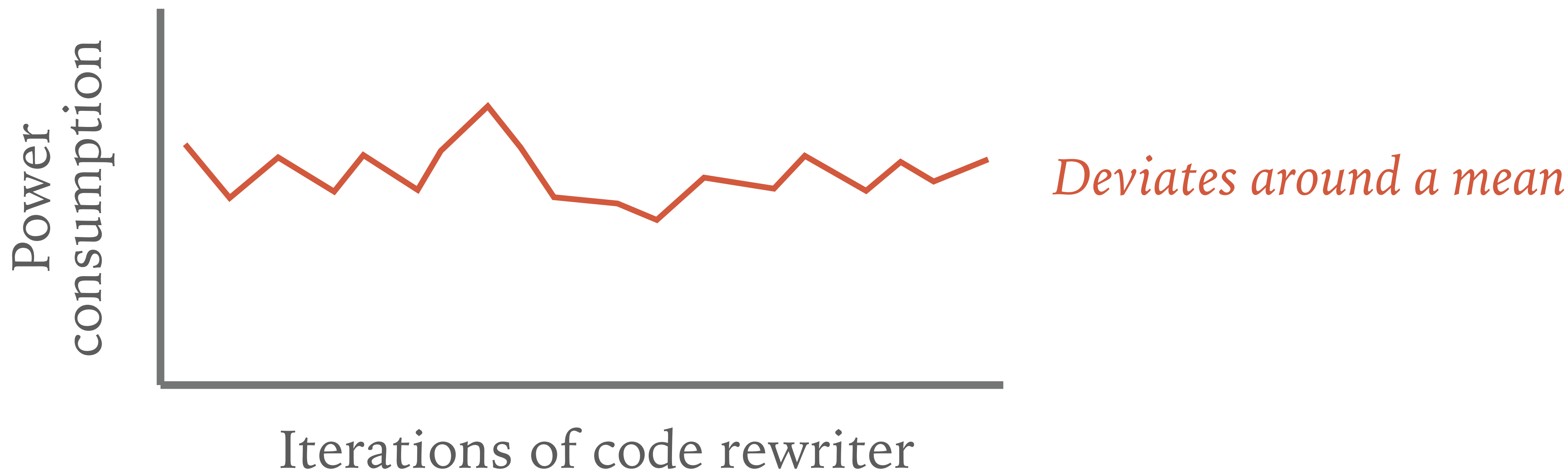

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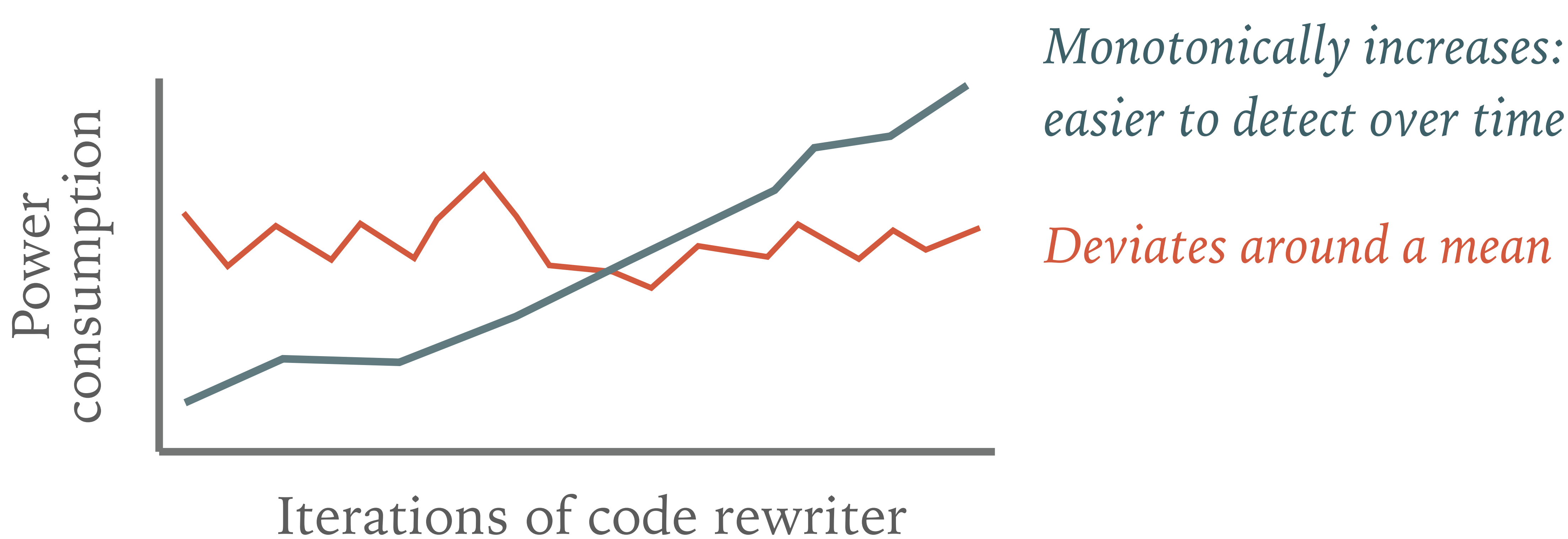

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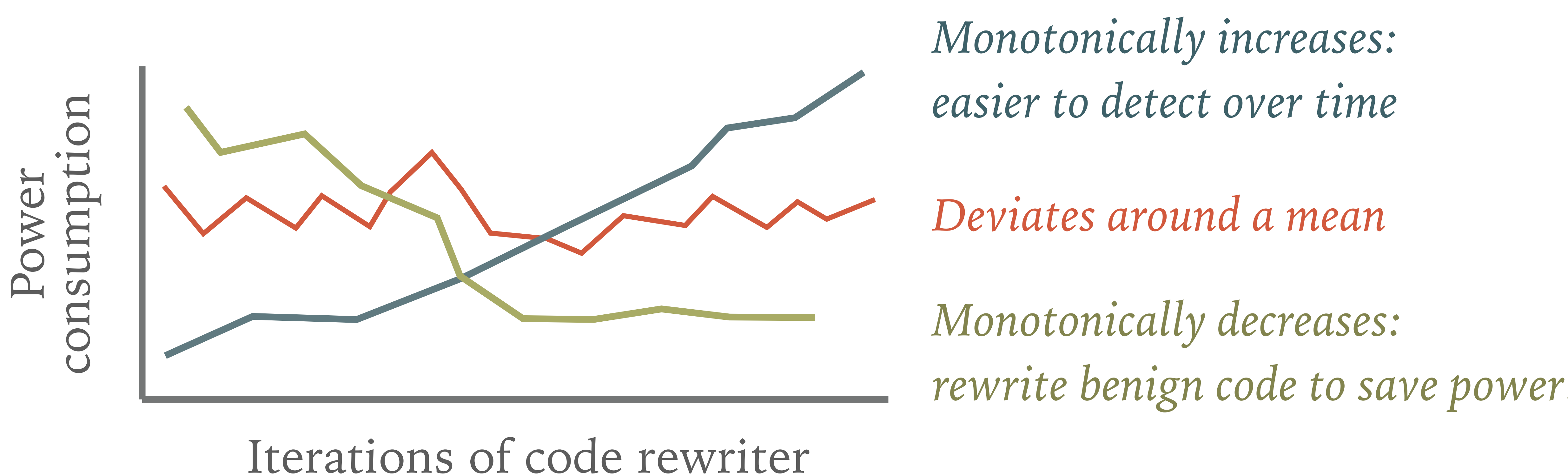

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WORM PROPAGATION

CONTROLLING MILLIONS OF HOSTS: WHY?

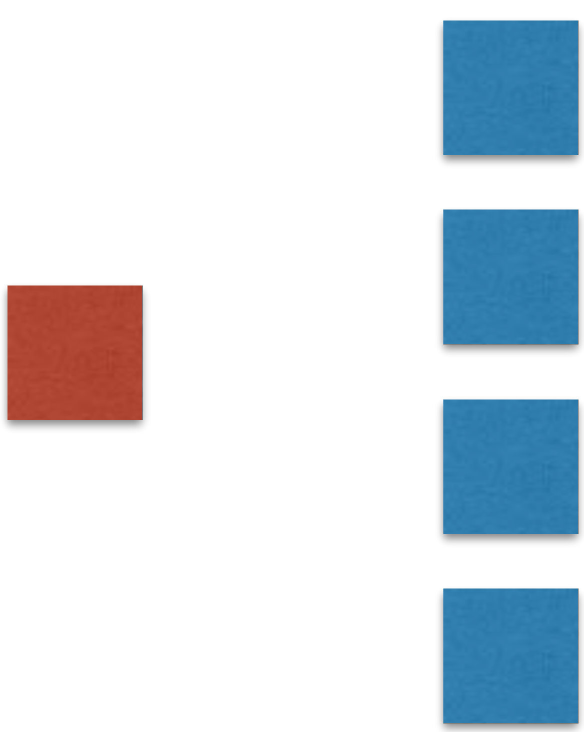
- Distributed Denial of Service (DDoS)
  - Generate network traffic from many sources..
  - .. to a single destination
  - .. with the intention of overloading their network
    - Consume too many resources for legitimate users to also use
- Steal sensitive information from millions of others
  - Even a small fraction of unprotected people ⇒ $
- Confuse and disrupt

CONTROLLING MILLIONS OF HOSTS: HOW?

- Worm: *self*-propagates by arranging to have itself *immediately* executed
  - At which point it creates a new, additional instance of itself
- Typically infects by altering *running* code
  - No user intervention required
- Like viruses, propagation and payload are orthogonal

SELF PROPAGATION

- The goal is to spread as quickly as possible
- The key is ***parallelization***
    - Ditto for viruses, but they require human interaction to trigger each propagation



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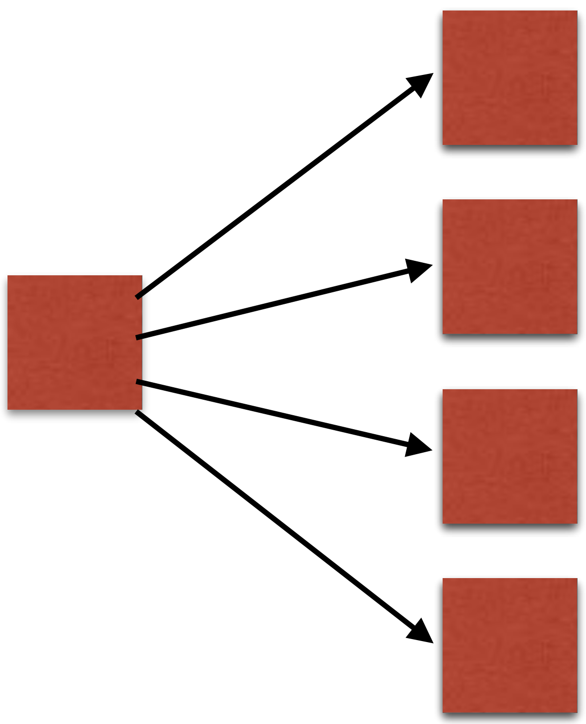

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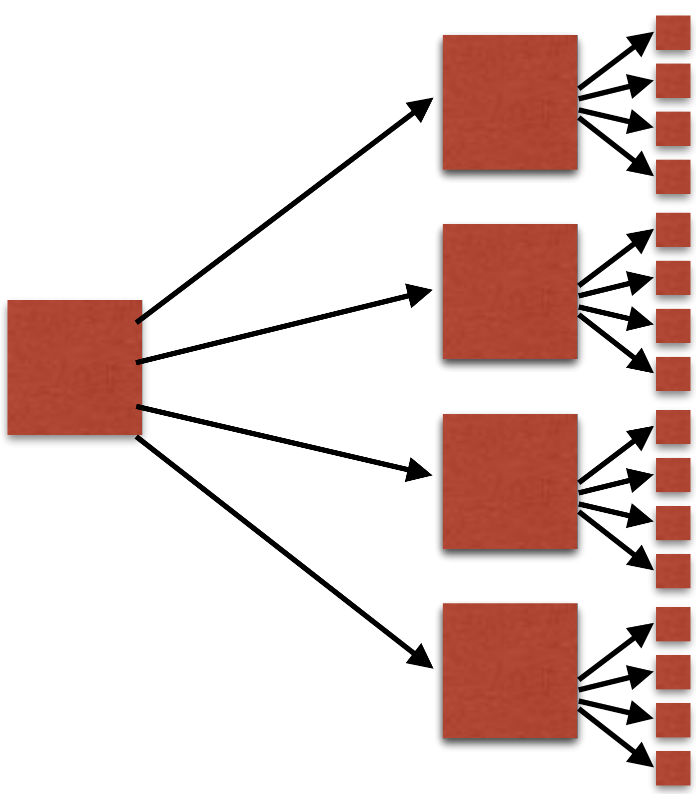

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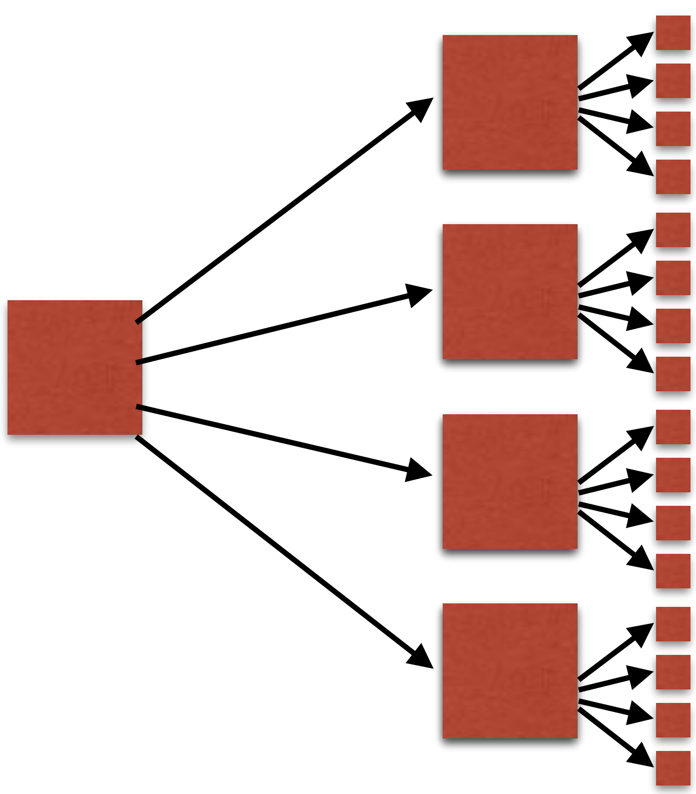

Propagation

(1) Targeting: how does the worm **find new prospective victims**?

(2) Exploit: how does the worm get code to **automatically run**?

WORMS: A BRIEF HISTORY

First arrival

1988 | 1999 | 2000 | 2001 | 2002 | 2003

- Morris worm
  - Propagated across machines (too aggressively, thanks to a bug)
  - One way it propagated was a **buffer overflow attack** against a vulnerable version of fingerd on VAXes
    - Sent a special string to the finger daemon, which caused it to execute code that created a new worm copy
    - Didn’t check OS: caused Suns running BSD to crash
  - End result: $10-100M in damages, probation, community service

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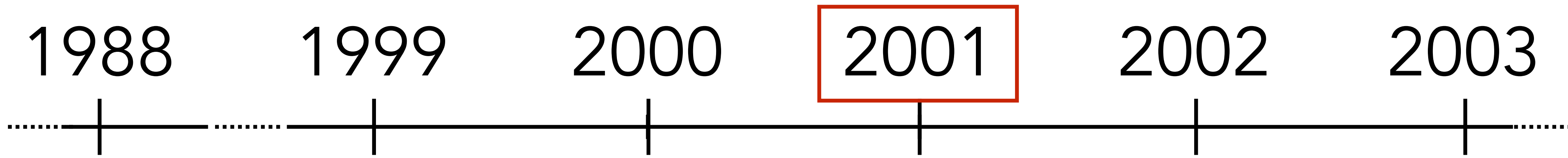
Robert Morris is now a professor at MIT

WORMS: A BRIEF HISTORY

Introduction of "modern day" worms



- CodeRed
  - Propagation: Exploited an overflow in the MS-IIS server
  - Payload 1: website defacement
    - HELLO! Welcome to http://www.worm.com
      Hacked By Chinese!
  - Payload 2: time bomb
    - Day of month 1-20: **Spread**
    - Day of month 20+: **Attack** (flood 198.137.240.91 = whitehouse.gov)
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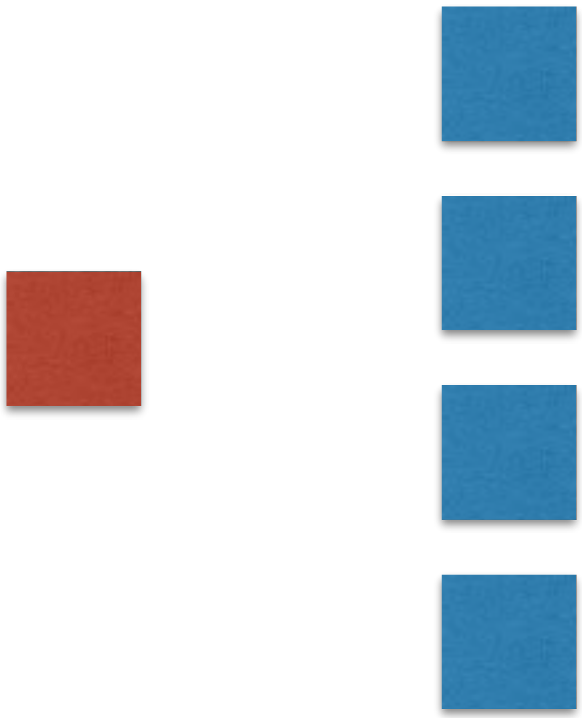

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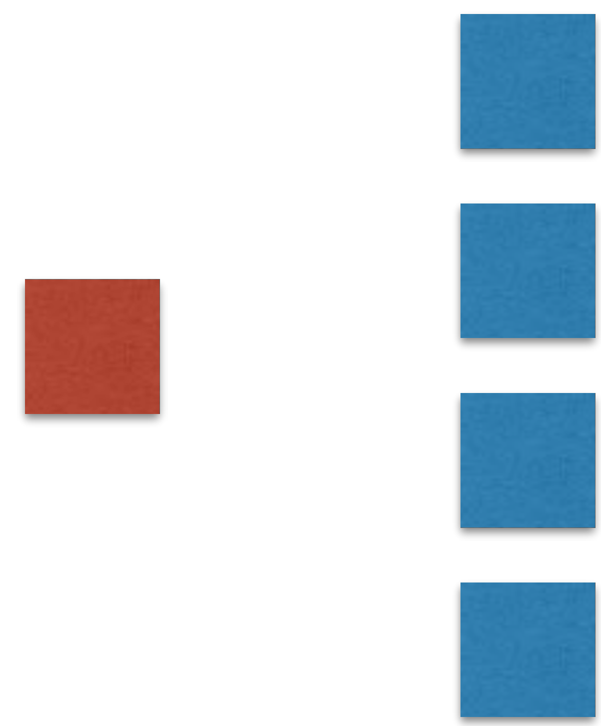

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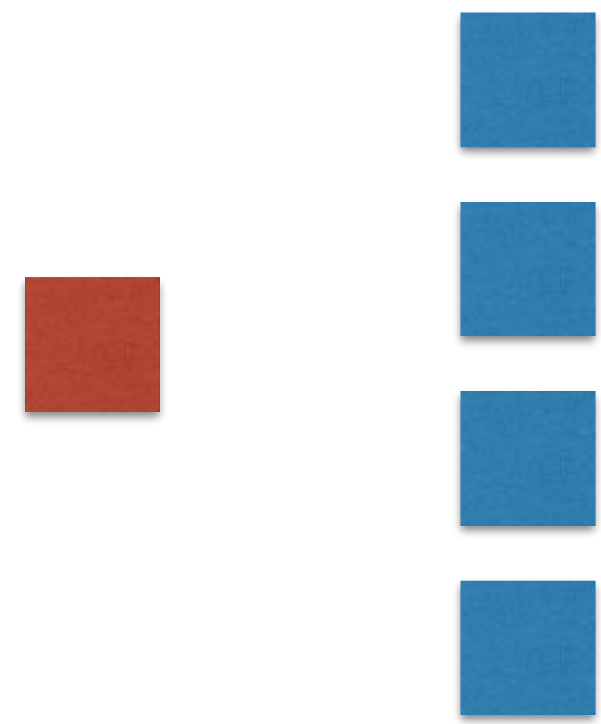

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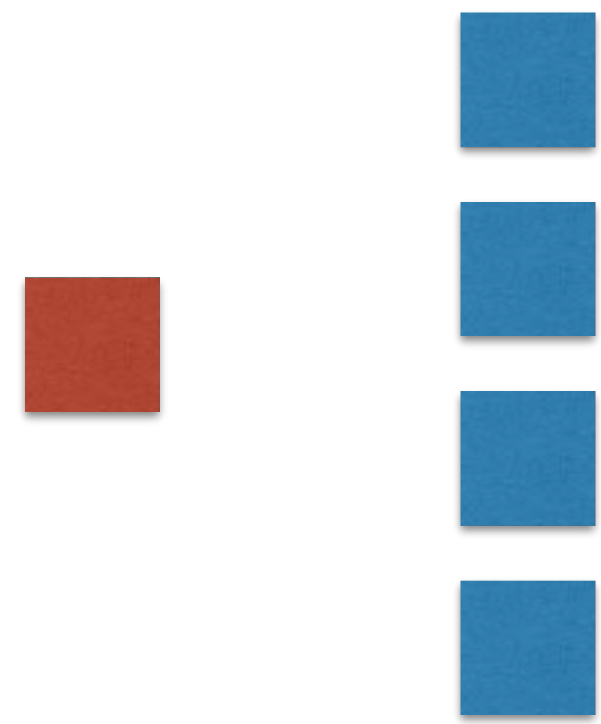

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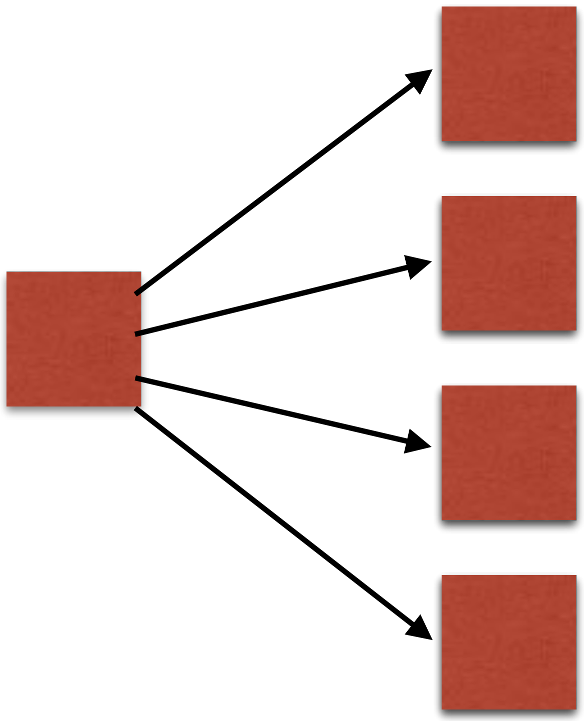

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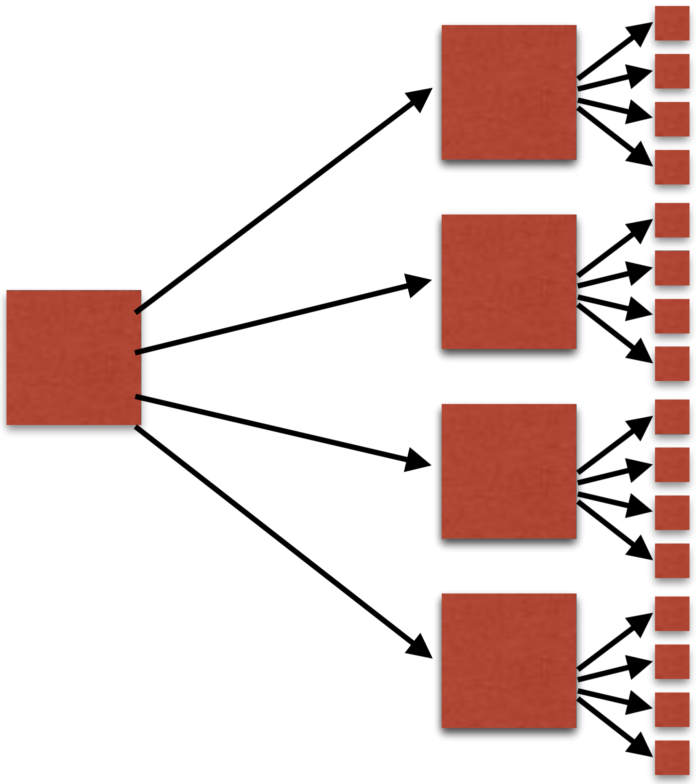

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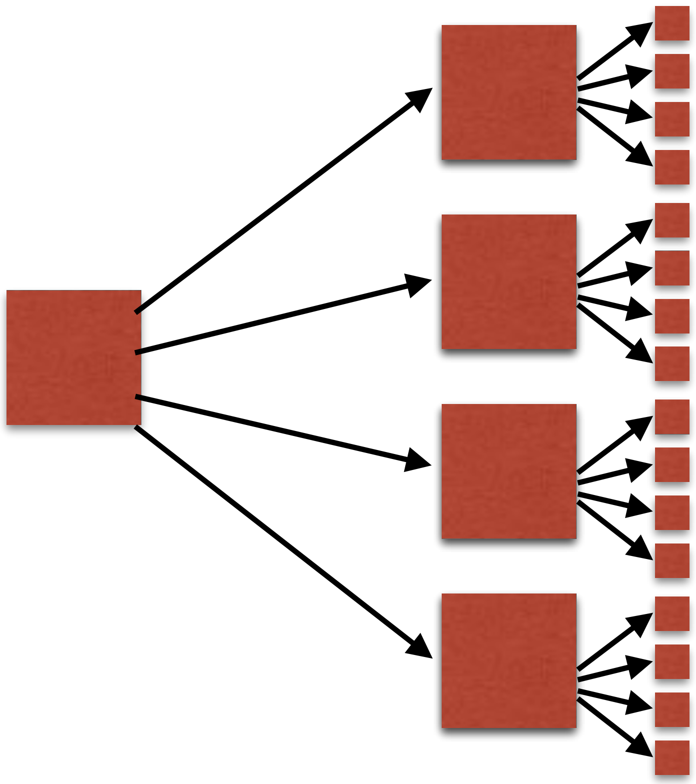
- Question: What IP addresses do you choose? What do your "children" choose?



CODERED'S PROPAGATION: V.1

- Spread by randomly scanning the entire 32-bit IP address space
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What would the growth over time be? *Linear*

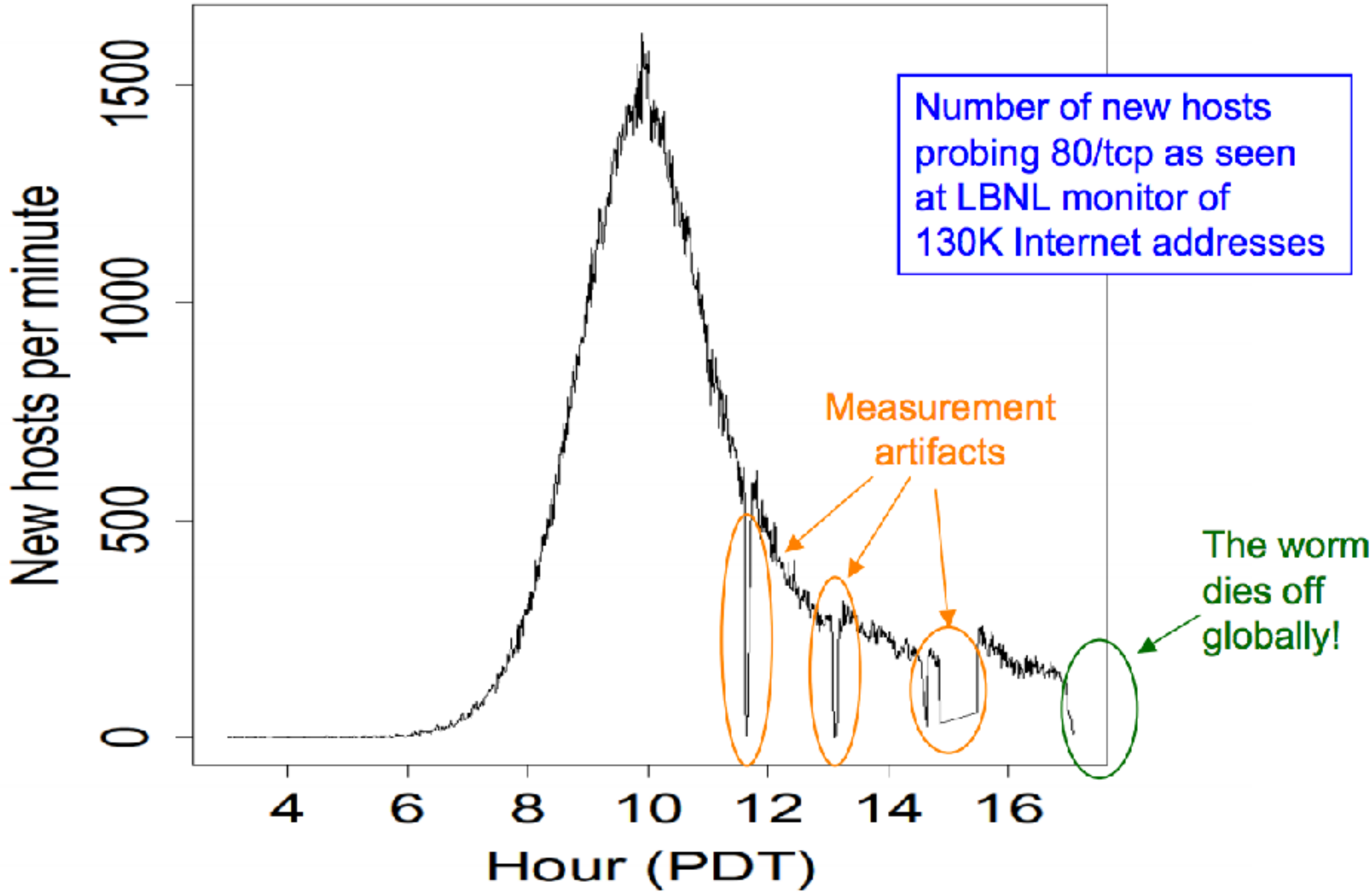
CODERED'S PROPAGATION: V.2

- Revision released one week later (July 19, 2001)

- Whitehouse.gov **changed** its IP address
  - This caused CodeRed to **die** for date ≥20th of the month
  - .. Author didn't test the code: it was ***buggy***!

- But with this revision, the random number generator was **seeded** properly!

CODERED'S GROWTH



MODELING WORM SPREAD

- Worm spread is well described as *infectious epidemic*
  - Classic "SI" model (Susceptible-Infectible)

- Model parameters:
  - N: Population size
  - S(t): # Susceptible hosts at time t
  - I(t): # Infected hosts at time t
  - β: contact rate
    - How many population members each infected host communicates with per unit time
    - E.g., if each infected host scans 10 IP addresses per unit time, and 2% of all IP addresses run a vulnerable server, then β = 0.2

$$N = S(t) + I(t)$$
$$S(0) = I(0) = N/2$$

$$i(t) = I(t) / N = \text{fraction of hosts infected}$$

COMPUTING HOW AN EPIDEMIC PROGRESSES

$$\frac{dI}{dt} = \beta \cdot I \cdot \frac{S}{N}$$

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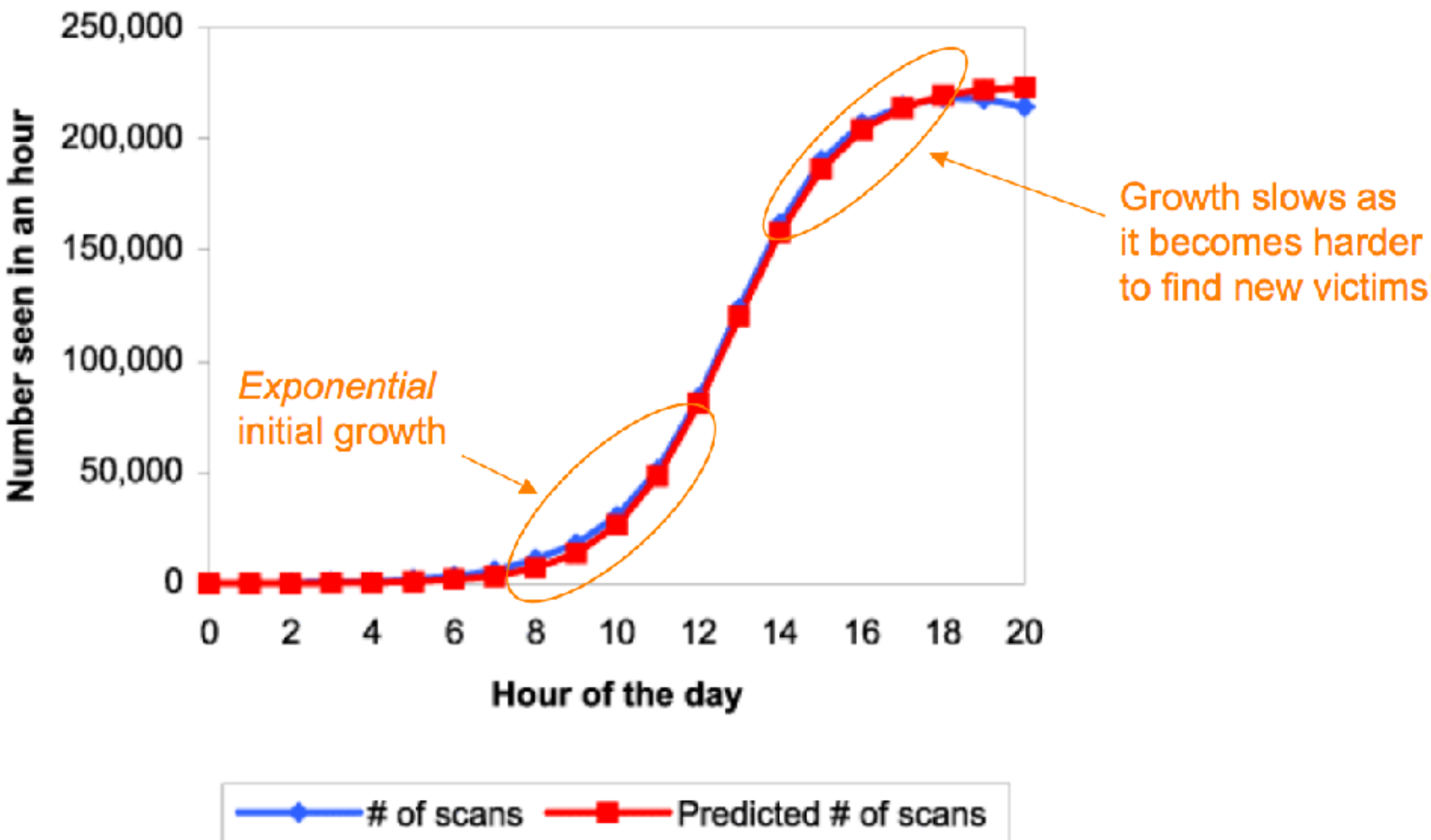
Fraction infected grows as a *logistic*

FITTING THE MODEL TO CODERED



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- That night (the 20th) the worm died due to bug
- Successfully managed to restart itself Aug 1
  - … and each successive month for years to come

BETTER WORMS

Key challenge:

Coordinating action across distributed hosts

This is a distributed systems problem!

BETTER WORMS

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Localized scanning:

Preferentially hosts with similar IP addresses

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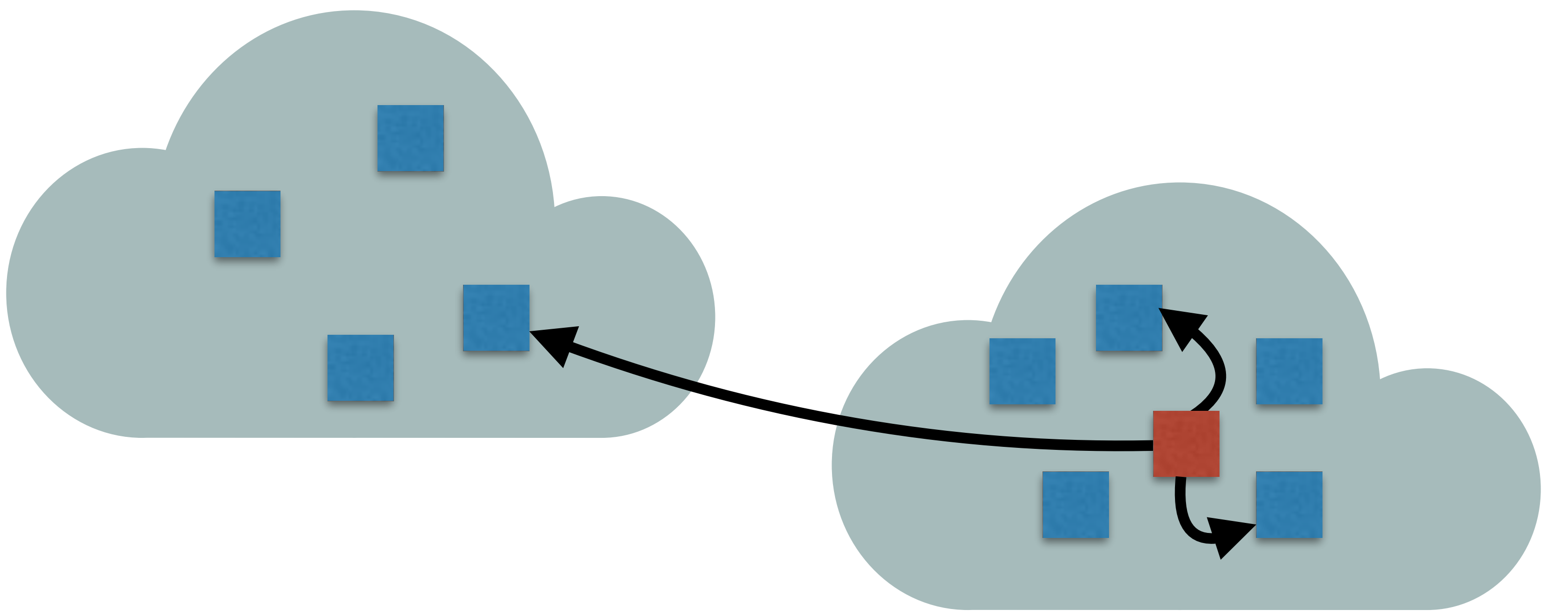

Pr = 3/8	Random IP address in same /16
Pr = 4/8	Random IP address in same /8
Pr = 1/8	Random IP address

BETTER WORMS

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Hit-list scanning

Start with a list of likely-successful targets

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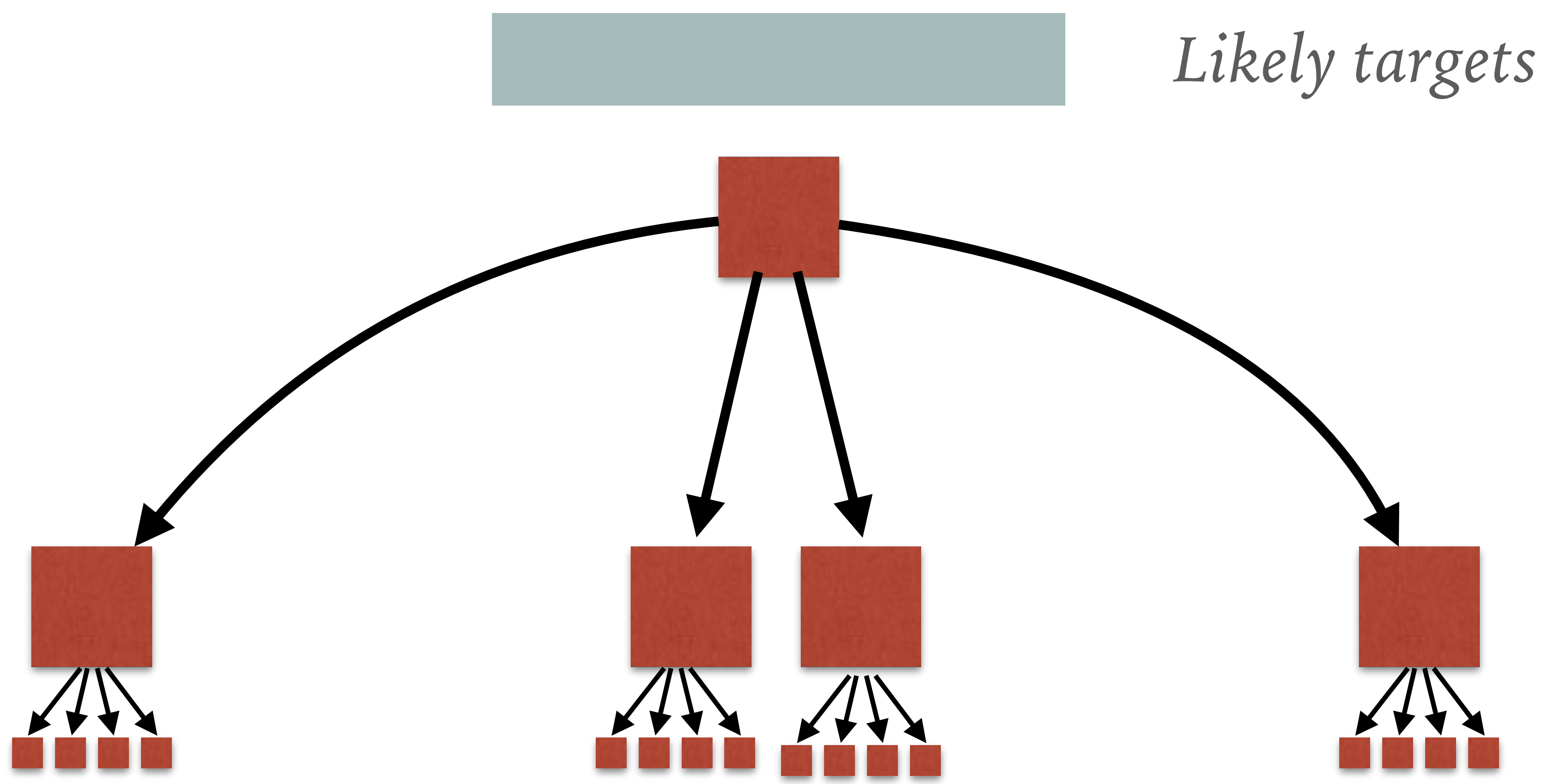

Quickly build an initial set of bots to “get off the ground”

BETTER WORMS

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Permutation scanning

Break up the work deterministically

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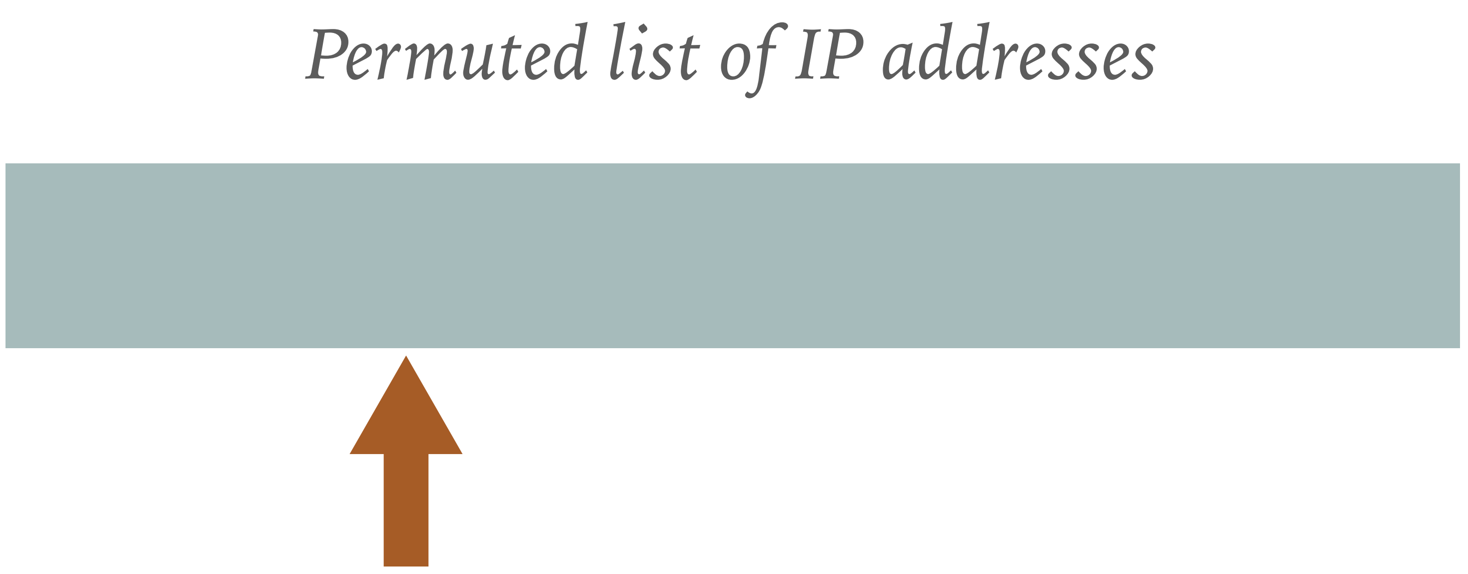
Break up the work deterministically



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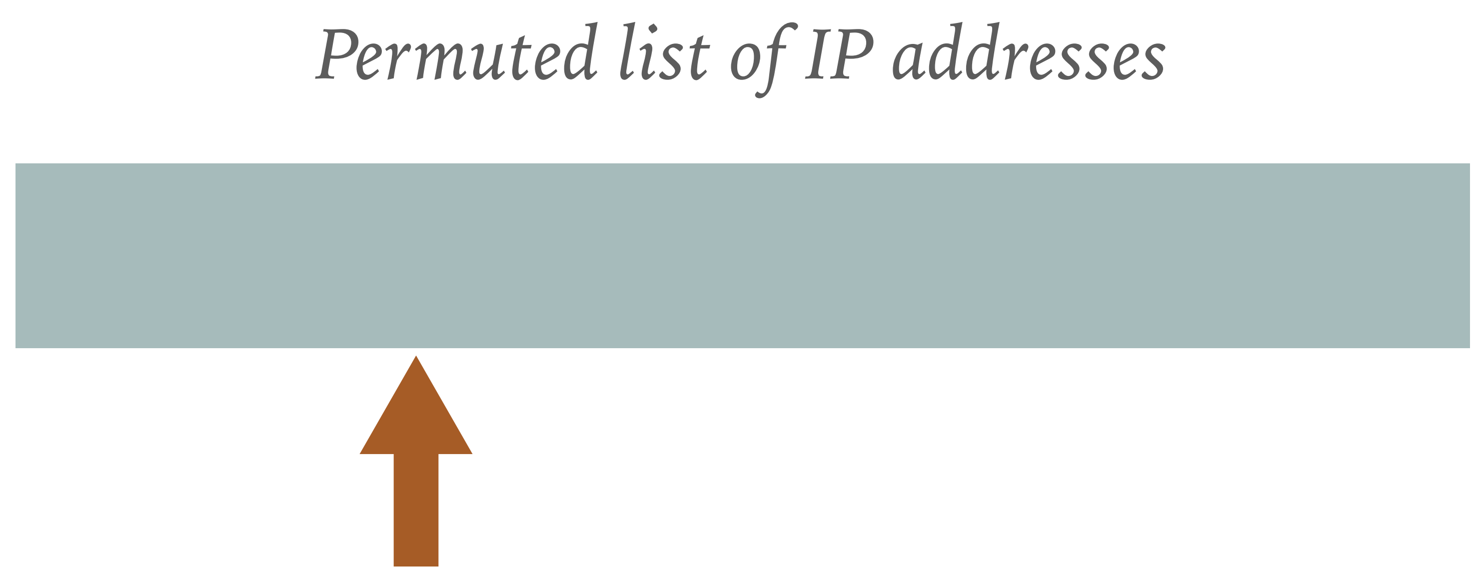

Start at a random seed; iteratively attack

BETTER WORMS

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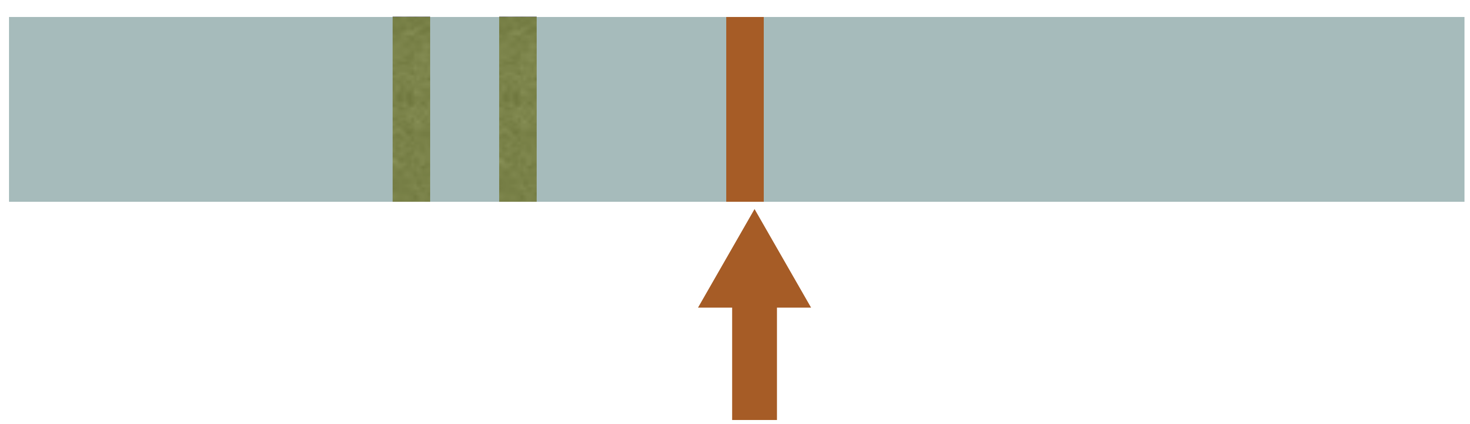
Permuted list of IP addresses



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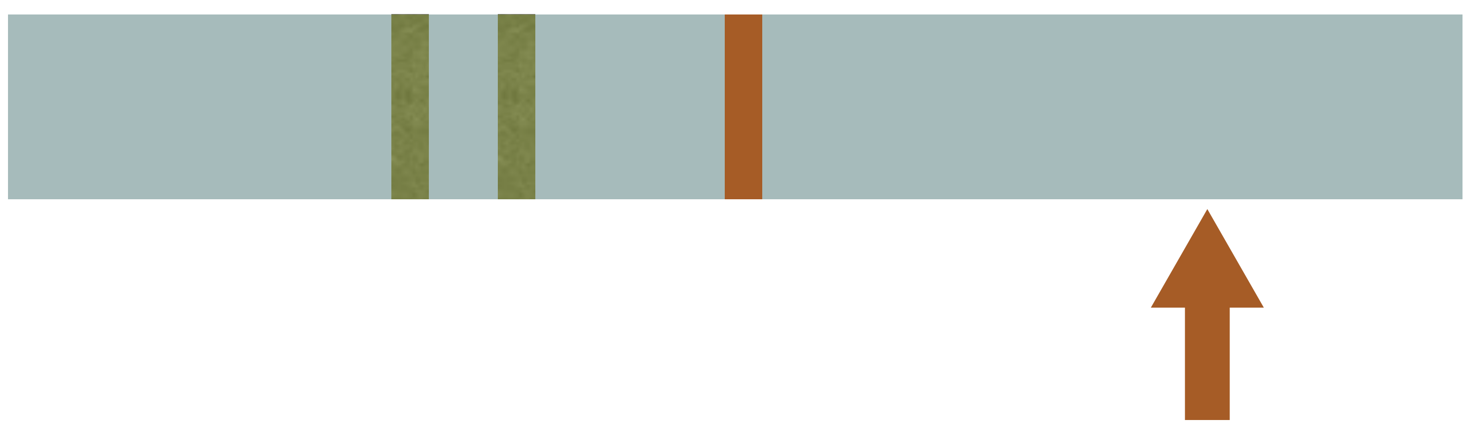

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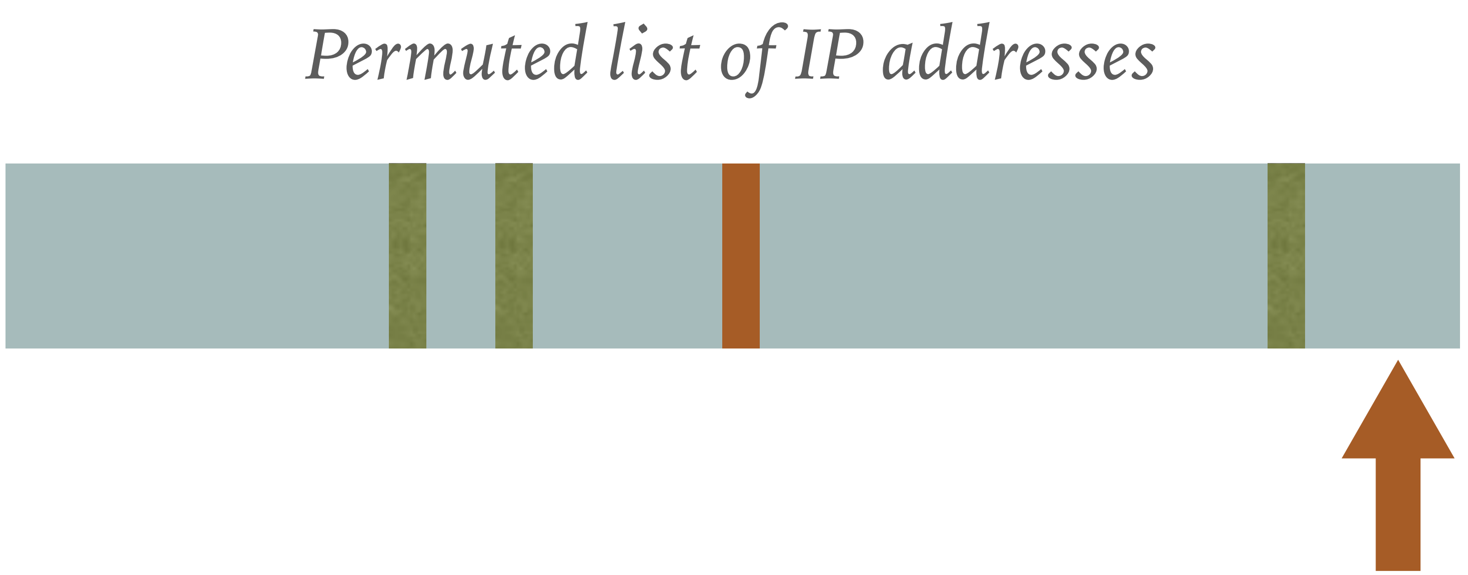

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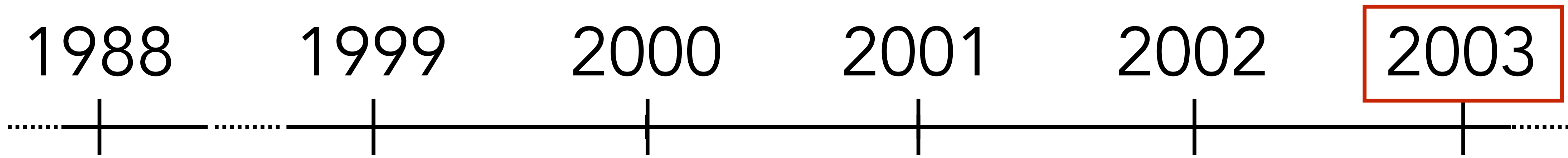
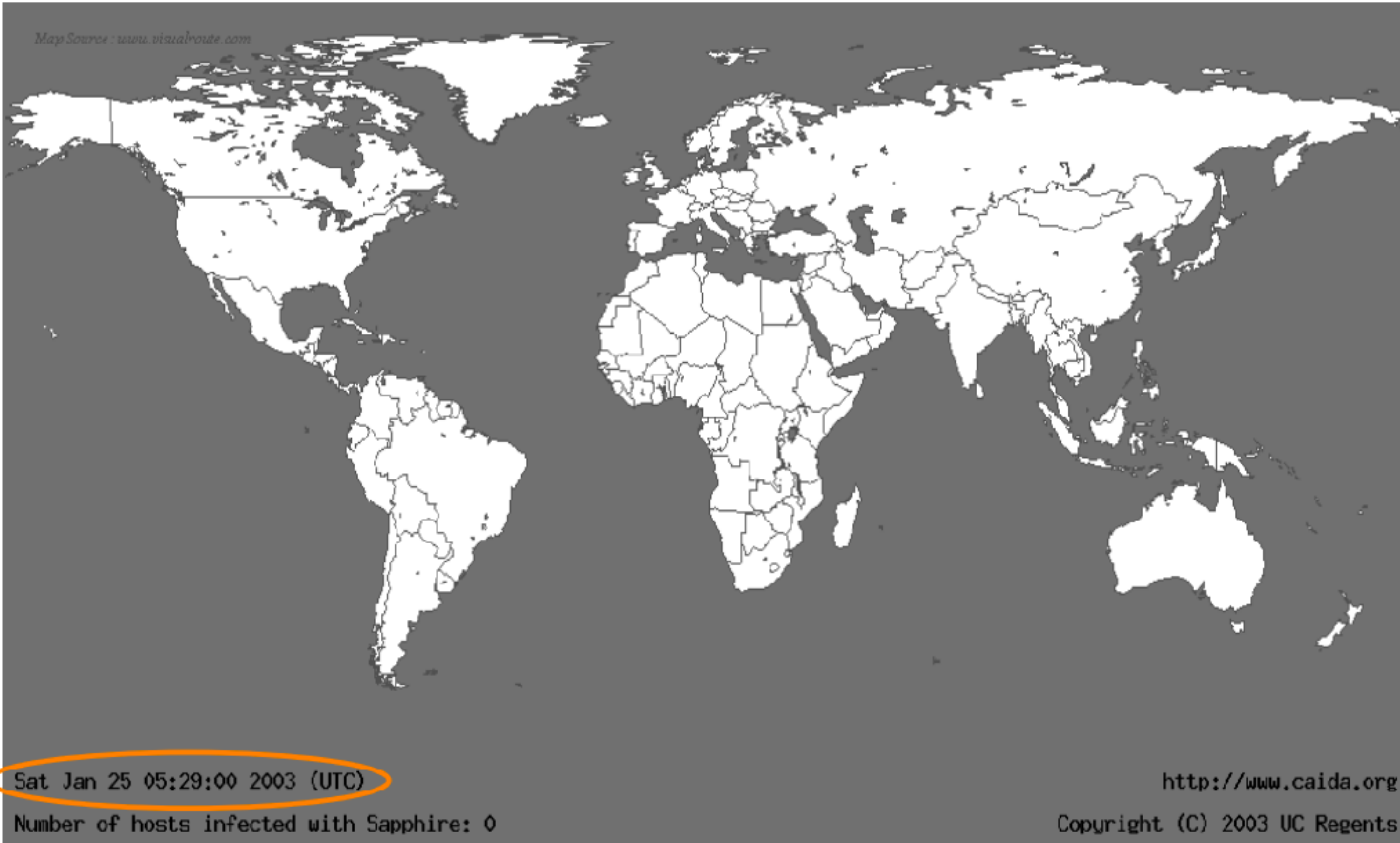
WORMS: A BRIEF HISTORY

The harm can be substantial



- SQL Slammer
  - Exploited an overflow in the MS-SQL server
  - 75,000 machines infected in 10 *minutes*

LIFE BEFORE SLAMMER



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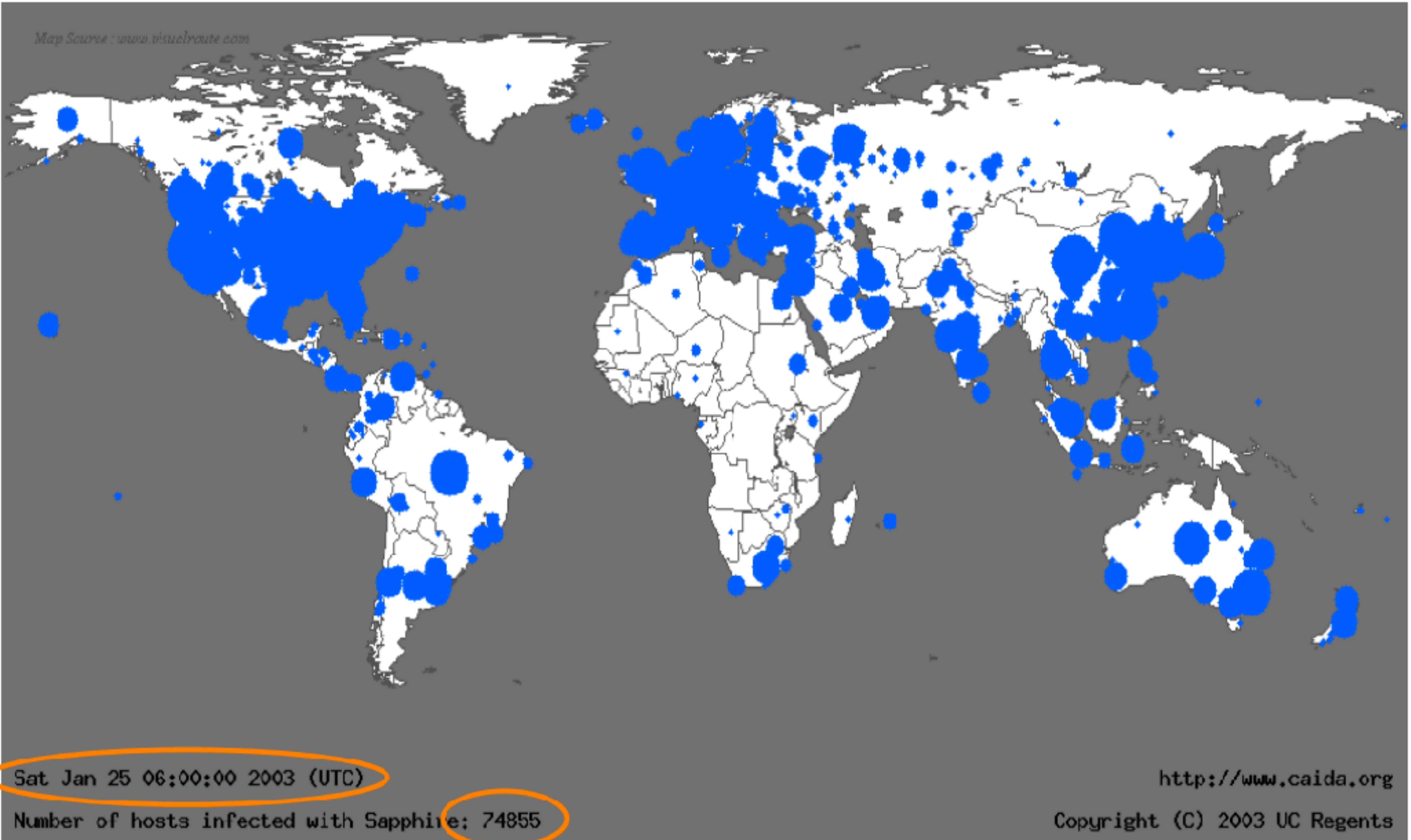

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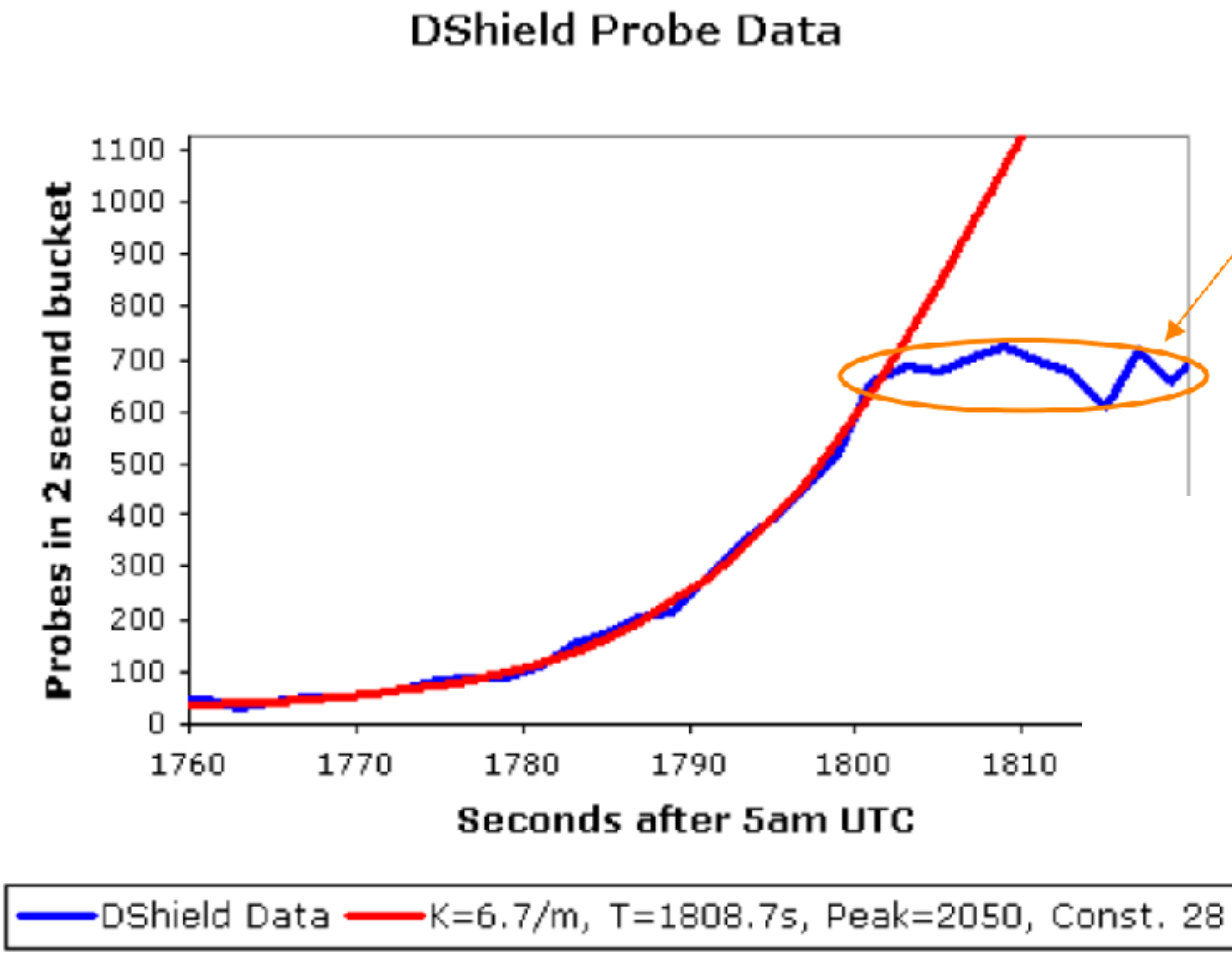
SLAMMER PROPAGATION

- Slammer exploited connectionless UDP service rather than connection-oriented TCP
- Entire worm fit in a single packet!
- When scanning, the worm could “fire and forget”
  - Stateless!
- Infected 75k+ hosts in < 10 minutes
- At its peak, doubled ever <u>8.5 seconds</u>

SLAMMER'S GROWTH



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Hint: at this point the worm is generating *55,000,000 scans/sec*

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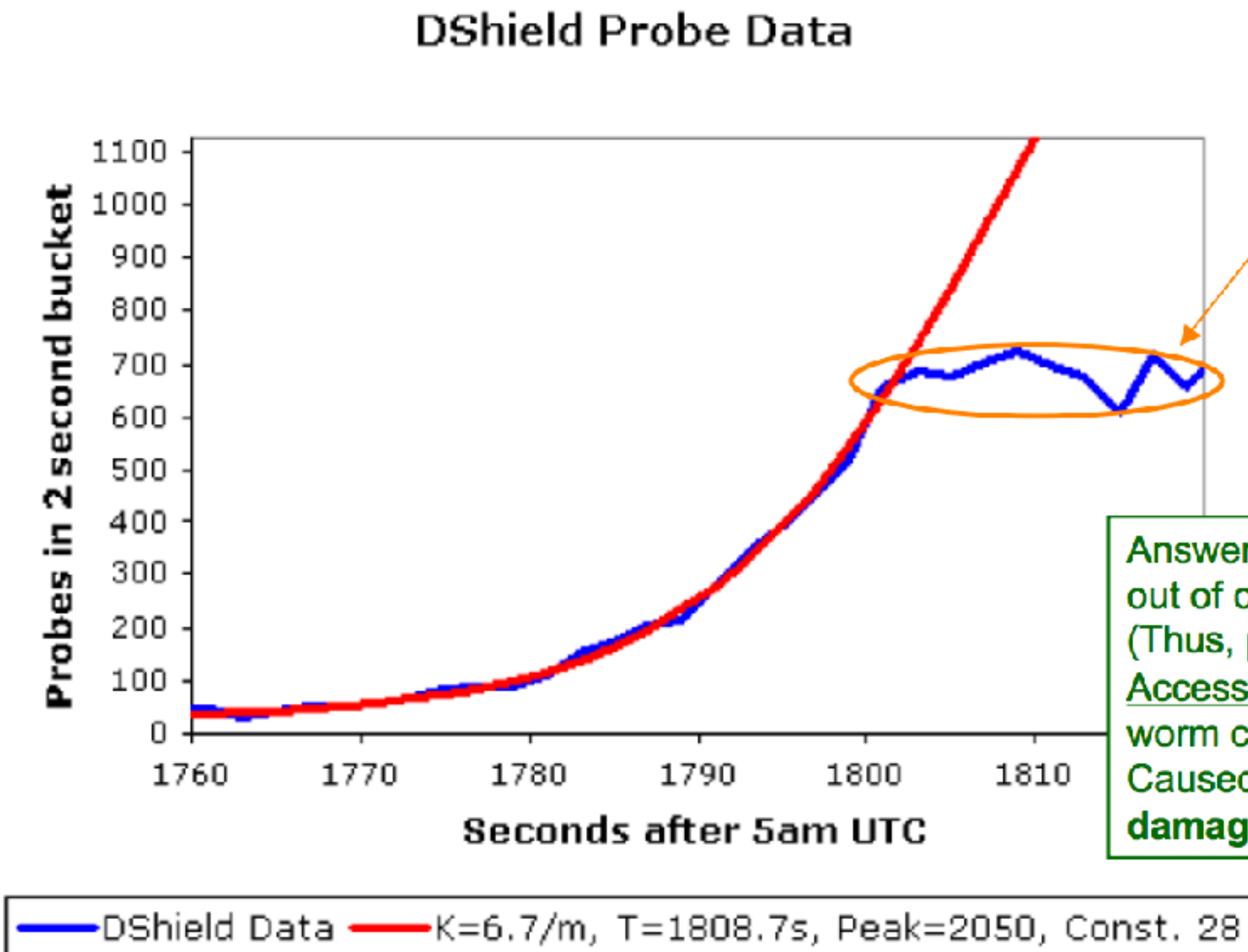

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Hint: at this point the worm is generating *55,000,000 scans/sec*

Answer: the Internet ran out of carrying capacity! (Thus, β decreased.) Access links used by worm completely clogged. Caused **major collateral damage**.

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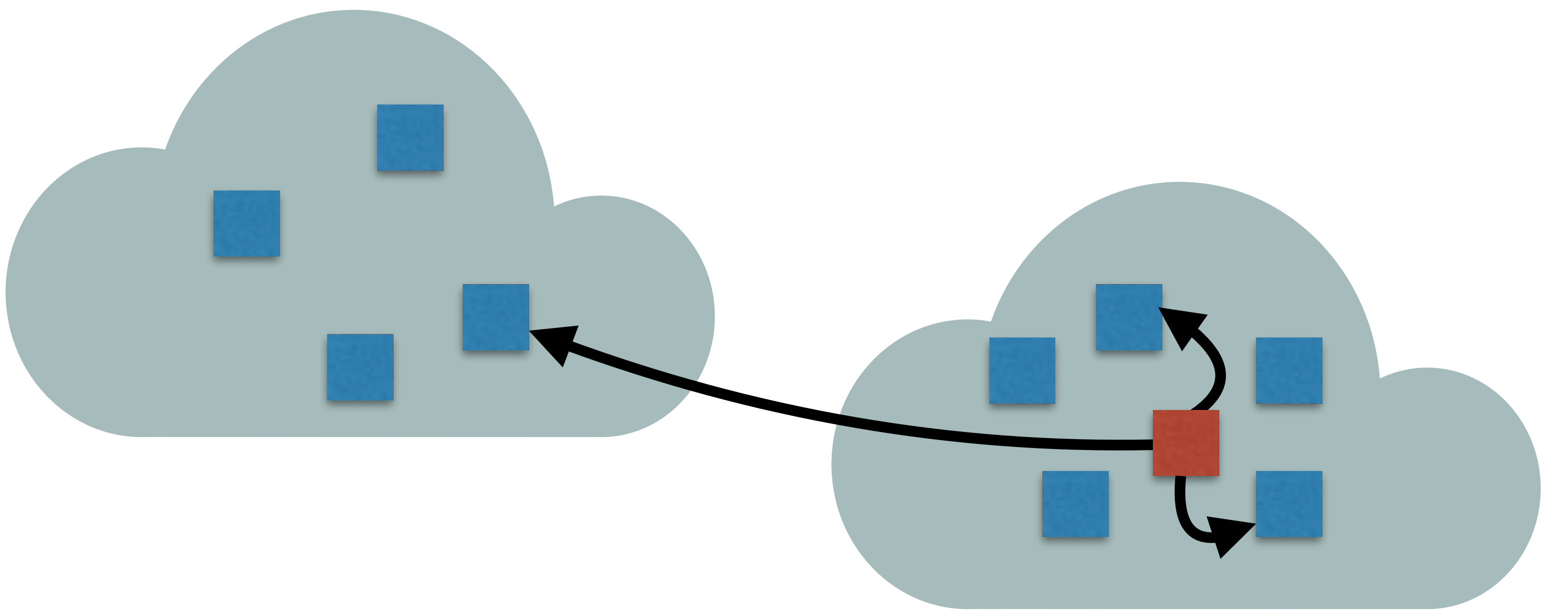
HOW CAN YOU MEASURE WORM ACTIVITY AT SCALE?

Idea: Exploit the fact that worms indiscriminately scan



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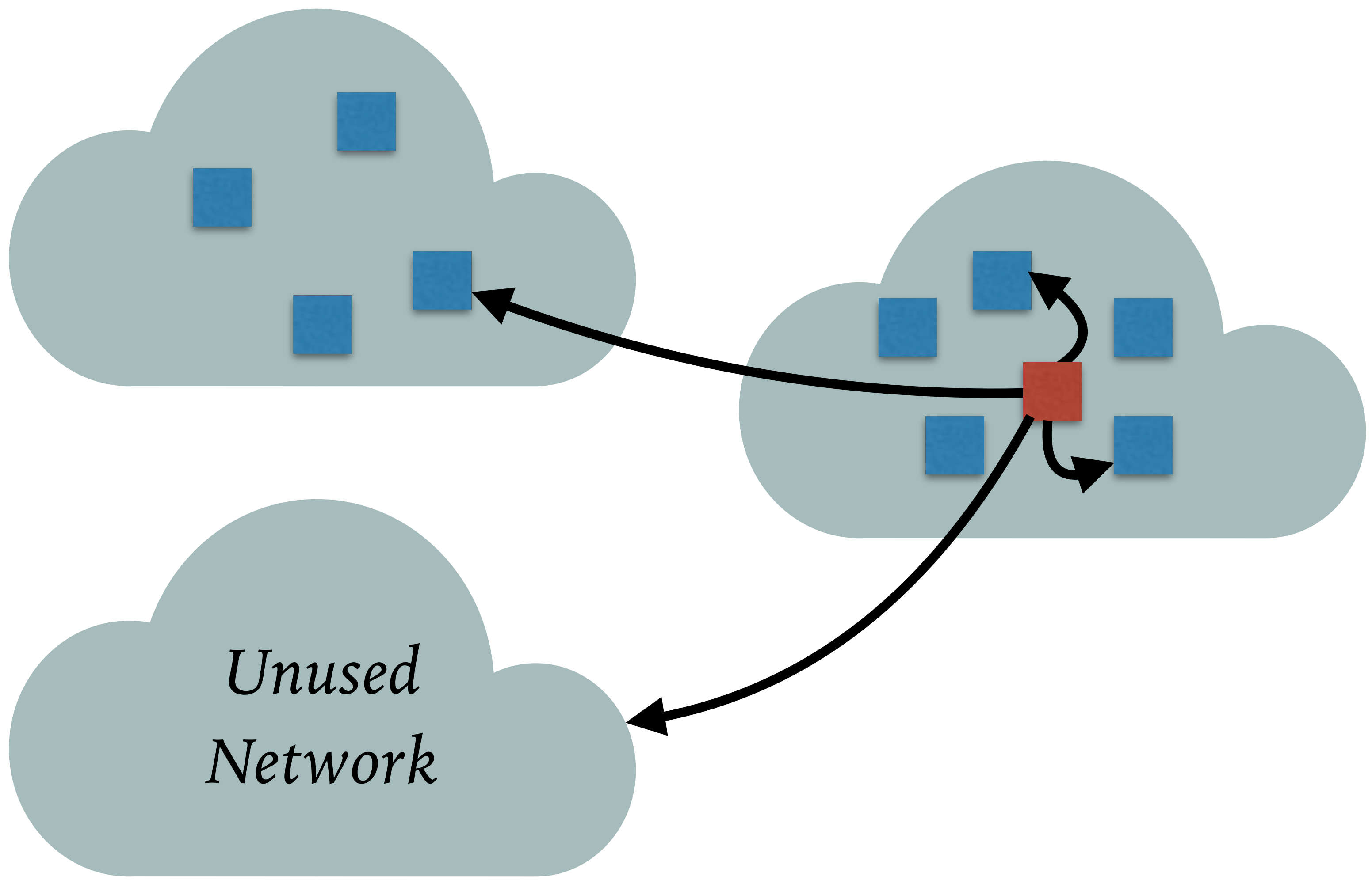

No-one *should* be hitting this network

INTERNET BACKGROUND RADIATION

Traffic sent to unused IP addresses

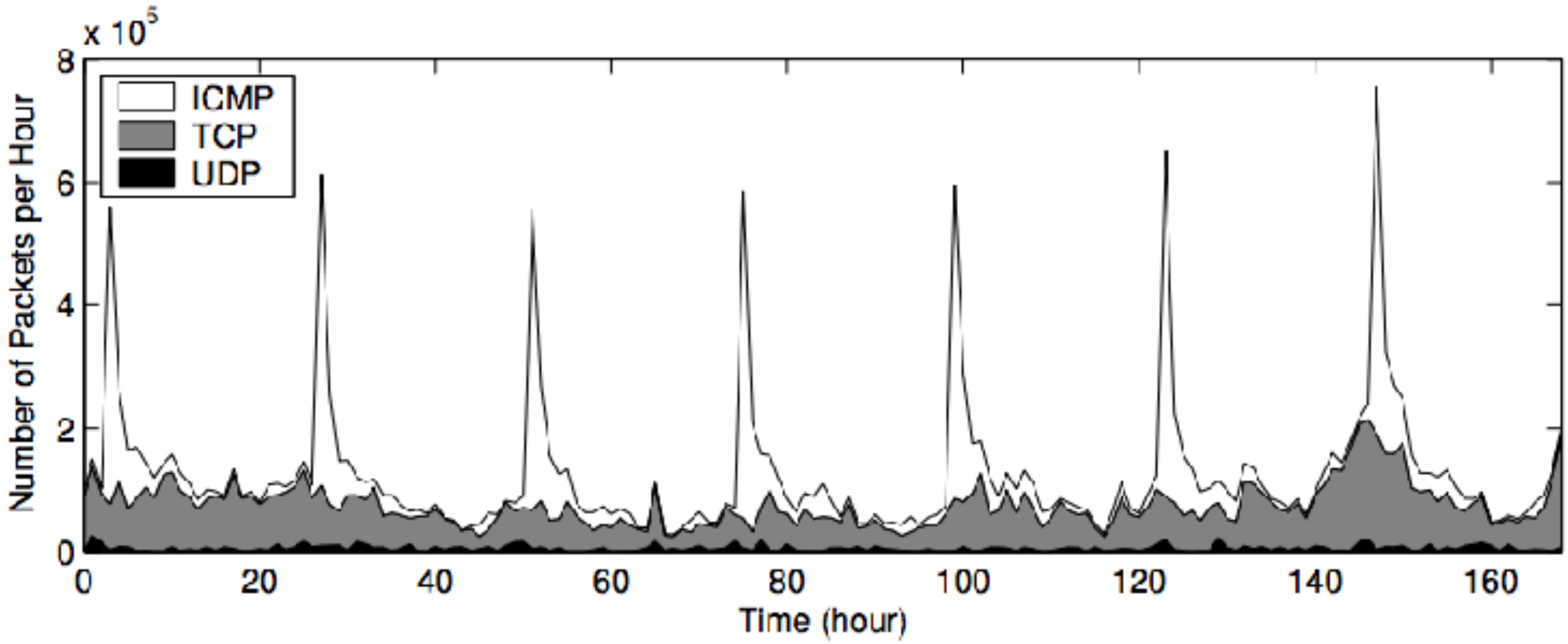

Figure 6: Number of background radiation packets per hour seen at LBL

WHAT CAN WE LEARN FROM BACKGROUND RADIATION?

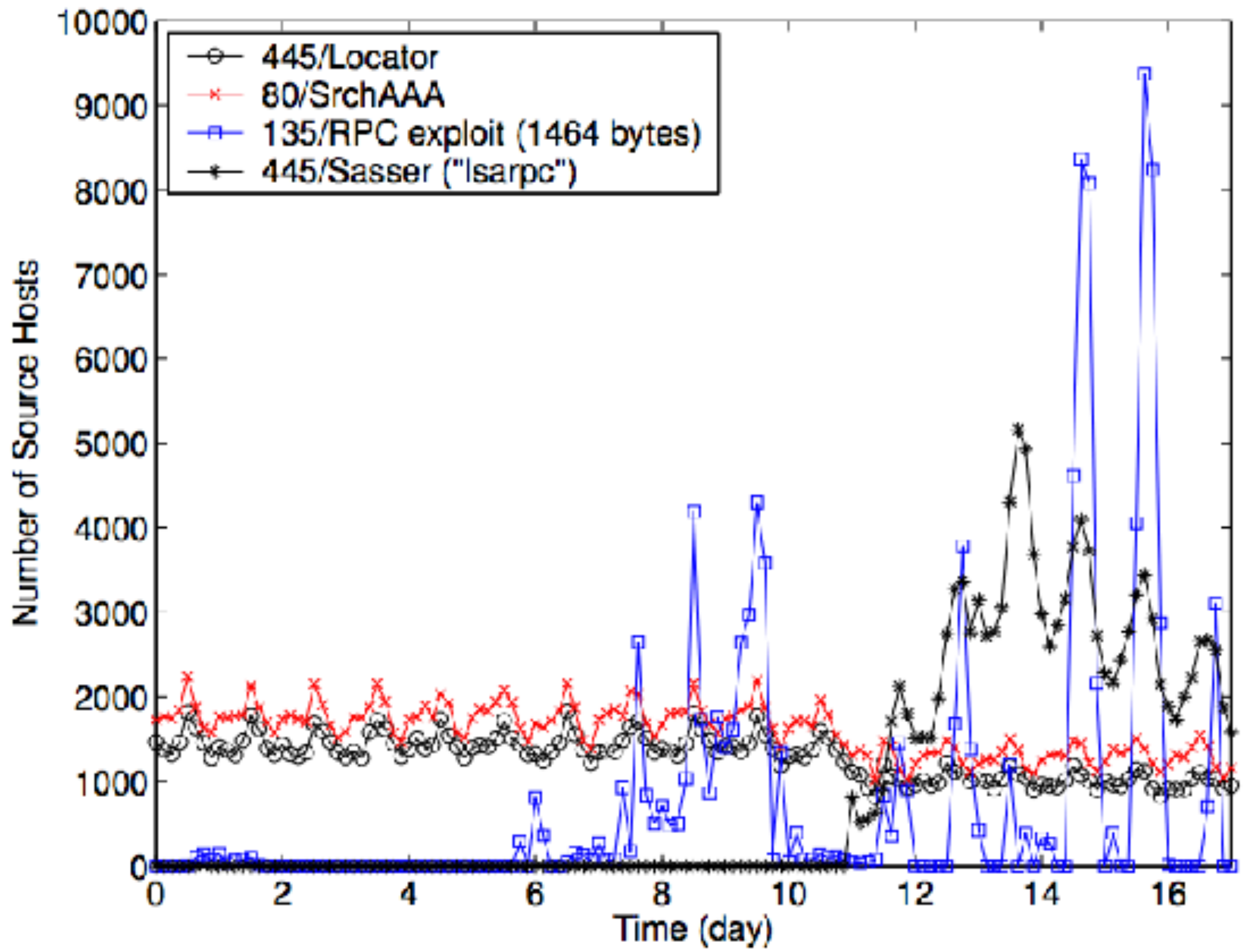

Figure 11: The Big Exploits (Apr 20 to May 7, 2004), as observed on 5 /C networks at LBL. The source hosts are counted every three hours.