Example: LBL Forensics

i dont think this looks good:

Sep 20 00:30:37 *<local-addr>* **/USR/SBIN/CRON[24948]:**

(root) CMD (/usr/share/hCtQEFtTsNlb.p2/.p-2.4a i &> /dev/null)

the ".p-2.4a" is one of the Phalanx backdoor signatures.

> .... checking logs, looks like the problems started after a reboot around 2:30 PM on the sixteenth. So, maybe have been something "dormant" waiting for a reboot well in advance of the *<elided>* **account.**

Can you pull the disks? I'll pick them up from you for imaging.

>> **Its fairly strange that multiple computers, when ssh'd by** *ATTACKER.uk* **respond back with a connection back to an unspecified high port (if it was ident, that would be understandable) - note that** *<VICTIM1>* **is doing that, but also** *<VICTIM2>,* **and** *<VICTIM3>* **- other hosts that** *ATTACKER.uk* **probed** *[4 hostnames elided]* **are former compromised hosts...**

- **Given the ~500 msec delay between the two and the consistently short data volume on the SSH connection, this very likely is the attacker issuing a single command via SSH to back-connect to their machine. The telltale is that the second connection lasts a number of seconds and transfers a good amount of data. It might be the transfer part of an scp, say.**

  That then suggests that any machine responding in this fashion is compromised, because the attacker was able to run a command on it.

- *<IP-address-2>* **is exhibiting the same behavior as** *<IP-address-1>* **- a backchannel return response to an inbound ssh - suggest looking for connections to/from that IP as well.**

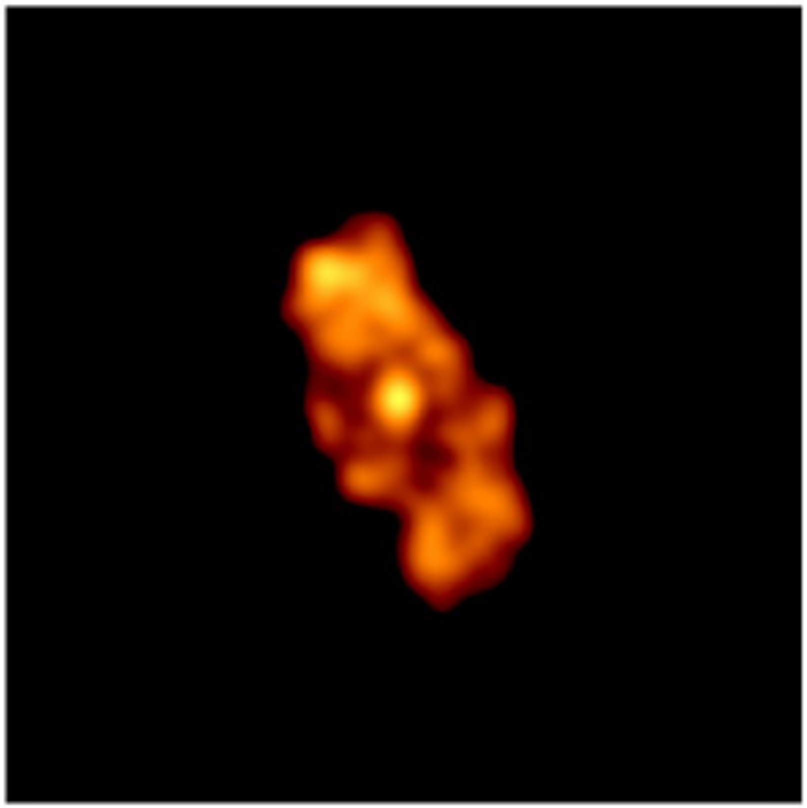
- **For both** *<victim-1>* **and** *<victim-2>*, **the /usr/share/LecPuokMdTSR.p2 directory was used for the rootkit - might be a good idea to check for the existence of that directory - if it exists, please, please, PLEASE, don't access it, as that could affect timestamps, but just report.**

Exploiting Underlying Structure for Detailed Reconstruction of an Internet-scale Event

Abhishek Kumar (Georgia Tech / Google)
Vern Paxson (ICSI)
Nicholas Weaver (ICSI)

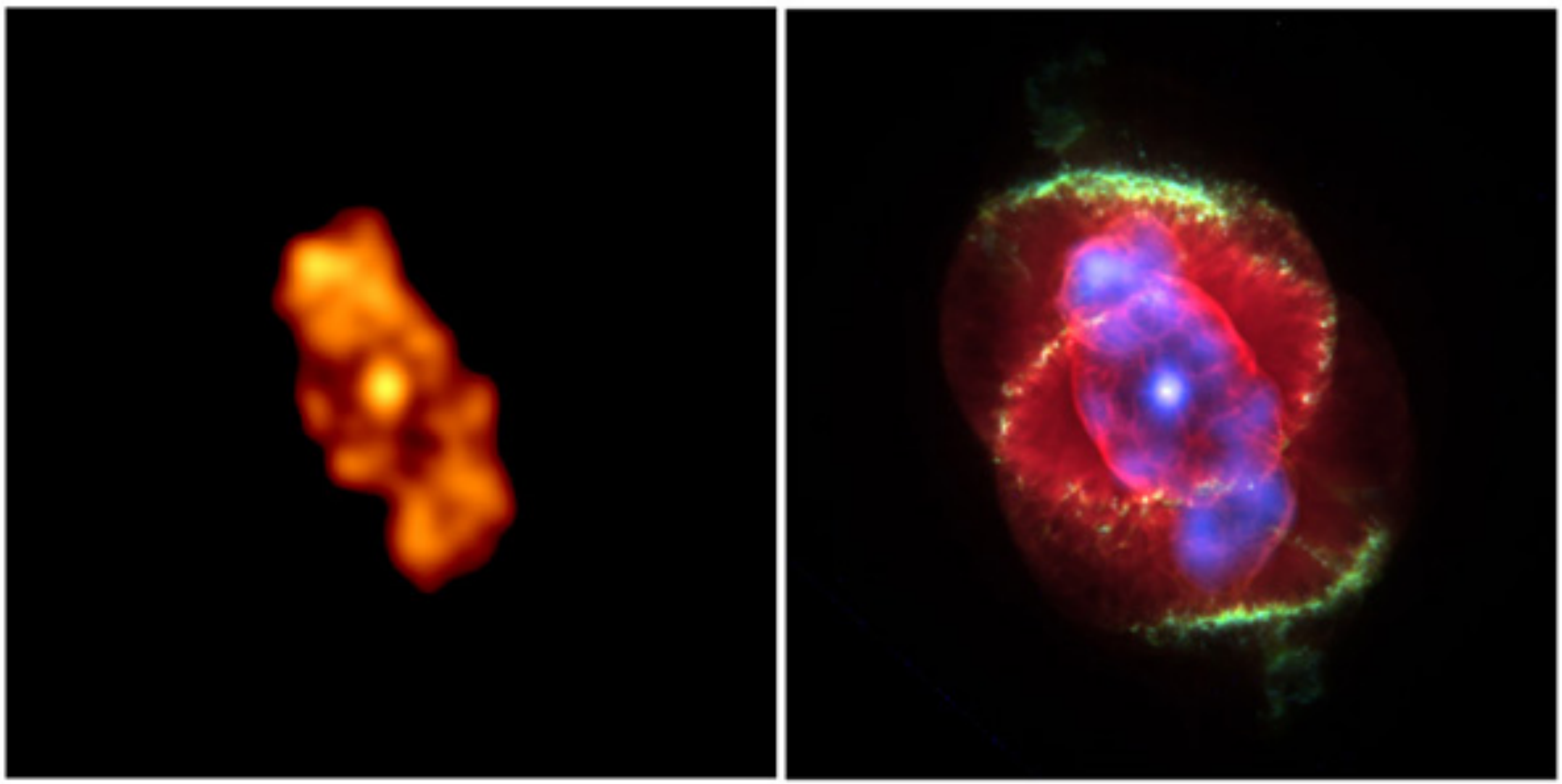
Proc. ACM Internet Measurement Conference 2005

Enhancing Telescope Imagery



NGC6543: Chandra X-ray Observatory Center (http://chandra.harvard.edu)

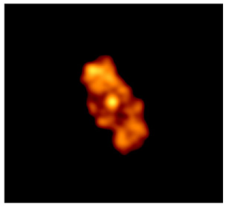
Enhancing Telescope Imagery



NGC6543: Chandra X-ray Observatory Center (http://chandra.harvard.edu)

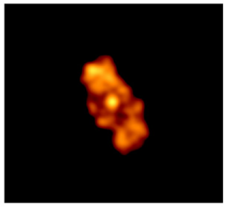
The "Witty" Worm

- Released March 19, 2004.
- Exploited flaw in the *passive analysis* of Internet Security Systems products
- Worm fit in a *single* Internet packet
  - ***Stateless***: When scanning, worm could "fire and forget"
- Vulnerable pop. (12K) attained in 75 minutes.
- Payload: *slowly corrupt random disk blocks*.
- Flaw had been announced the *previous day*.
- Written by a Pro.

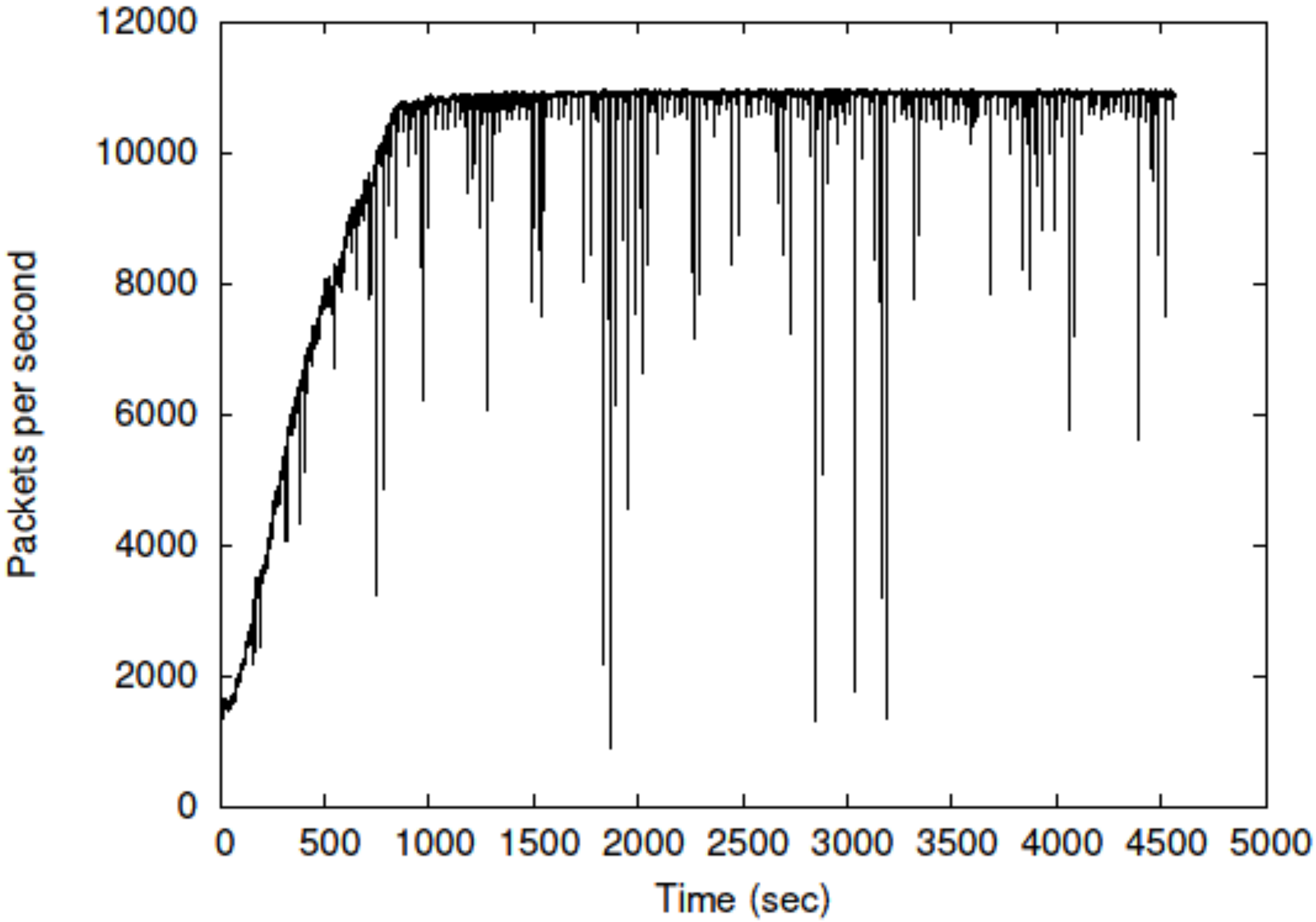


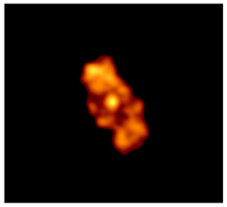
Witty Telescope Data

- UCSD telescope recorded every Witty packet seen on /8 (2^{24} addresses).
  - *But with significant, unknown losses*



Extensive Telescope Measurement Loss





Witty Telescope Data

- UCSD telescope recorded every Witty packet seen on /8 (2^{24} addresses).
  - *But with significant, unknown losses*

- In the **best case**, we see ≈ 4 of every 1,000 packets sent by each Witty infectee.

? What can we figure out about the worm?

What Exactly Does Witty Do?

1. Seed the PRNG using system uptime.
2. Send 20,000 copies of self to randomly selected destinations.
3. Open physical disk chosen randomly between 0 .. 7.
4. If success:
5. Overwrite a randomly chosen block on this disk.
6. Goto line 1.
7. Else:
8. Goto line 2.

Generating (Pseudo-)Random Numbers

- *Linear Congruential Generator* (LCG) proposed by Lehmer, 1948:

  $X_{i+1} = X_i{*}A + B \mod M$

- Picking A, B takes care, e.g.:

  $A = 214{,}013$

  $B = 2{,}531{,}011$

  $M = 2^{32}$

- Theorem: the *orbit* generated by these is a complete permutation of $0 .. 2^{32}-1$
- Another theorem: we can invert this generator

srand(*seed*) { X ← *seed* }

rand() { X ← X*214013 + 2531011; return X }

main()

1. **srand**(get_tick_count());

2. for(i=0;i<20,000;i++)

3. *dest_ip* ← **rand**()$_{[0..15]}$ || **rand**()$_{[0..15]}$

4. *dest_port* ← **rand**()$_{[0..15]}$

5. *packetsize* ← 768 + **rand**()$_{[0..8]}$

6. *packetcontents* ← *top-of-stack*

7. sendto()

8. if(open_physical_disk(**rand**()$_{[13..15]}$))

9. write(**rand**()$_{[0..14]}$ || 0x4e20)

10. goto 1

11. else goto 2

What Can We Do Seeing Just 4 Packets Per Thousand?

- Each packet contains bits from 4 consecutive PRNGs:

  3.dest_ip ← **rand**()$_{[0..15]}$ || **rand**()$_{[0..15]}$

  4.dest_port ← **rand**()$_{[0..15]}$

  5.packetsize ← 768 + **rand**()$_{[0..8]}$
- If first call to **rand**() returns X_i :

  3.dest_ip ← $(X_i)_{[0..15]}$ || $(X_{I+1})_{[0..15]}$

  4.dest_port ← $(X_{I+2})_{[0..15]}$
- Given top 16 bits of X_i, now *brute force* all possible lower 16 bits to find which yield consistent top 16 bits for X_{I+1} & X_{I+2}

⇒ **Single** Witty packet suffices to extract infectee's *complete* PRNG state! Think of this as a **sequence number**.

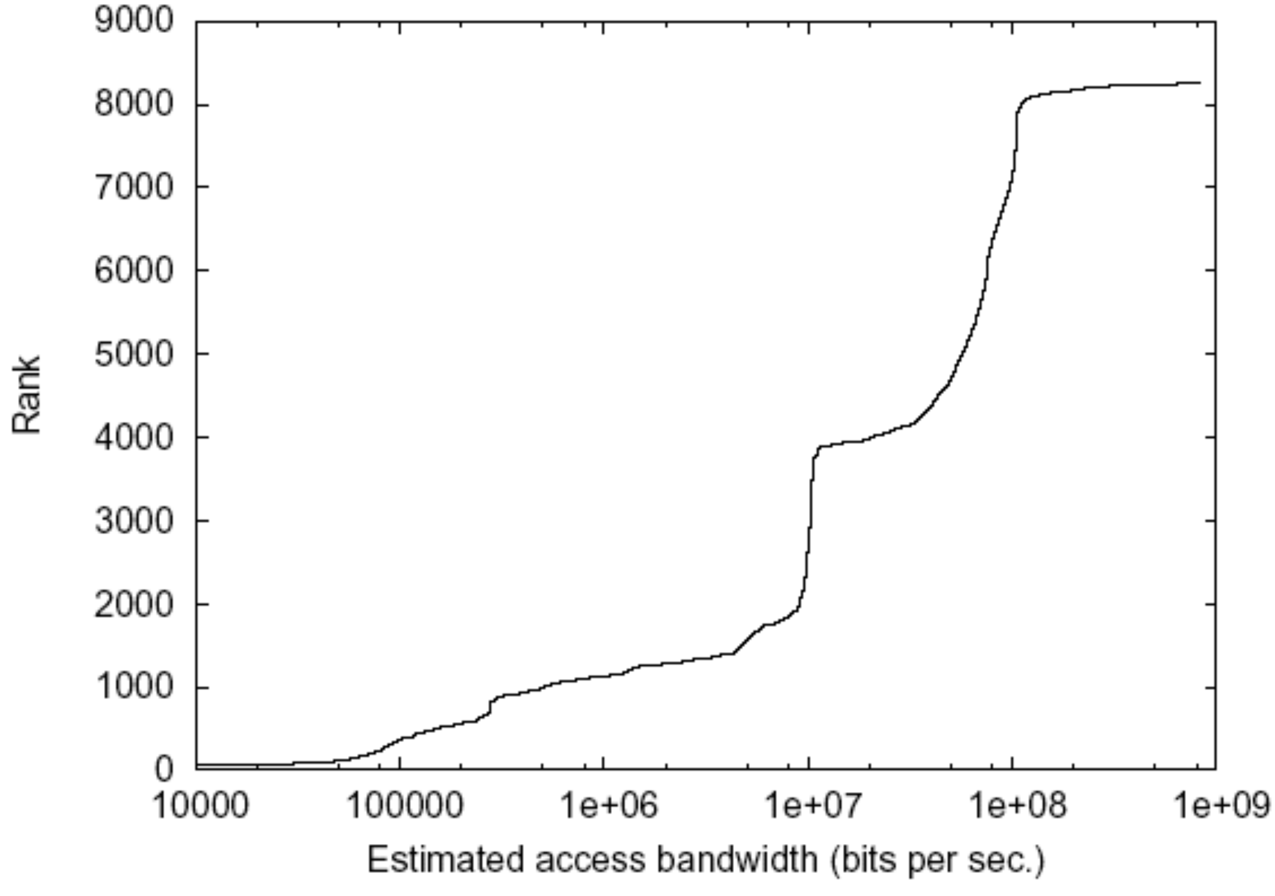
How Can We Confirm Such an Inference?

- Consider inference of *individual attached B/W*
  - Suppose two consecutively-observed packets from source ***S*** arrive with states X_i and X_j
  - Compute *j-i* by counting # of cranks forward from X_i to reach X_j
  - # packets sent between the two observed = *(j-i)/4*
  - **sendto** call in Windows is *blocking*
  - Ergo, attached bandwidth of that infectee should be

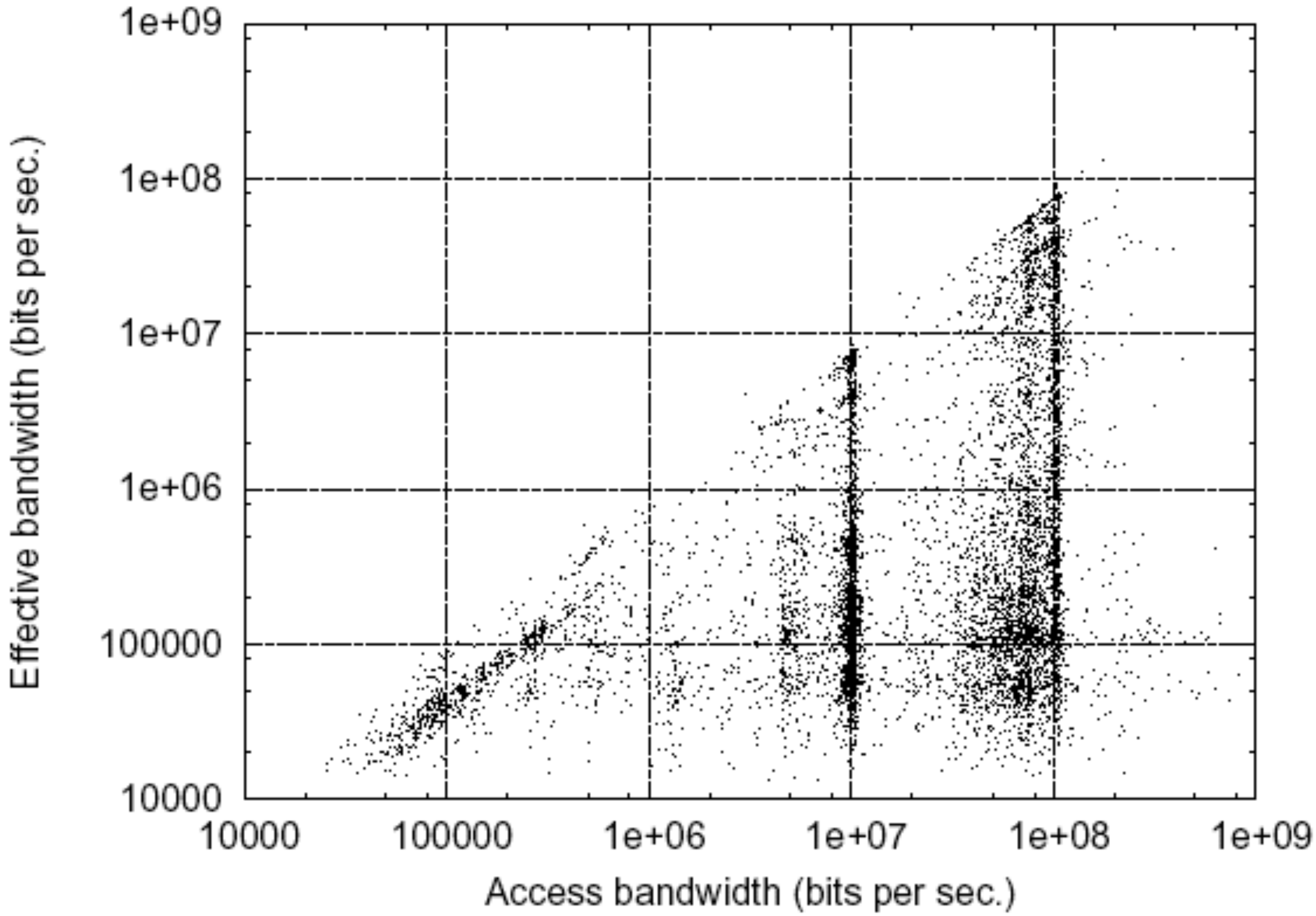
    *(j-i)/4 * size-of-those-packets* / ΔT

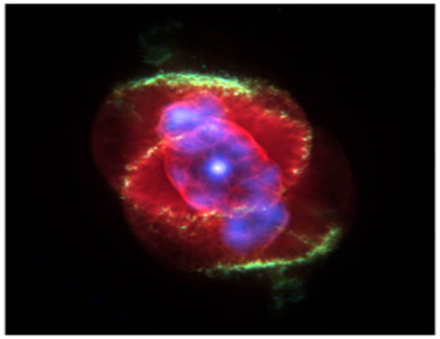
  - Note: should work even in the presence of <u>very heavy</u> packet loss

Inferred Attached Bandwidth of Individual Witty Infectees



Precise Bandwidth Estimation vs. Rates Measured by Telescope





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main()

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4. *dest_port* ← **rand**()$_{[0..15]}$

5. *packetsize* ← 768 + **rand**()$_{[0..8]}$

4 calls to **rand()** per loop

6. *packetcontents* ← *top-of-stack*

7. sendto()

8. if(open_physical_disk(**rand**()$_{[13..15]}$))

Plus one more every 20,000 packets, ***if*** disk open fails …

9. write(**rand**()$_{[0..14]}$ || 0x4e20)

10. goto 1

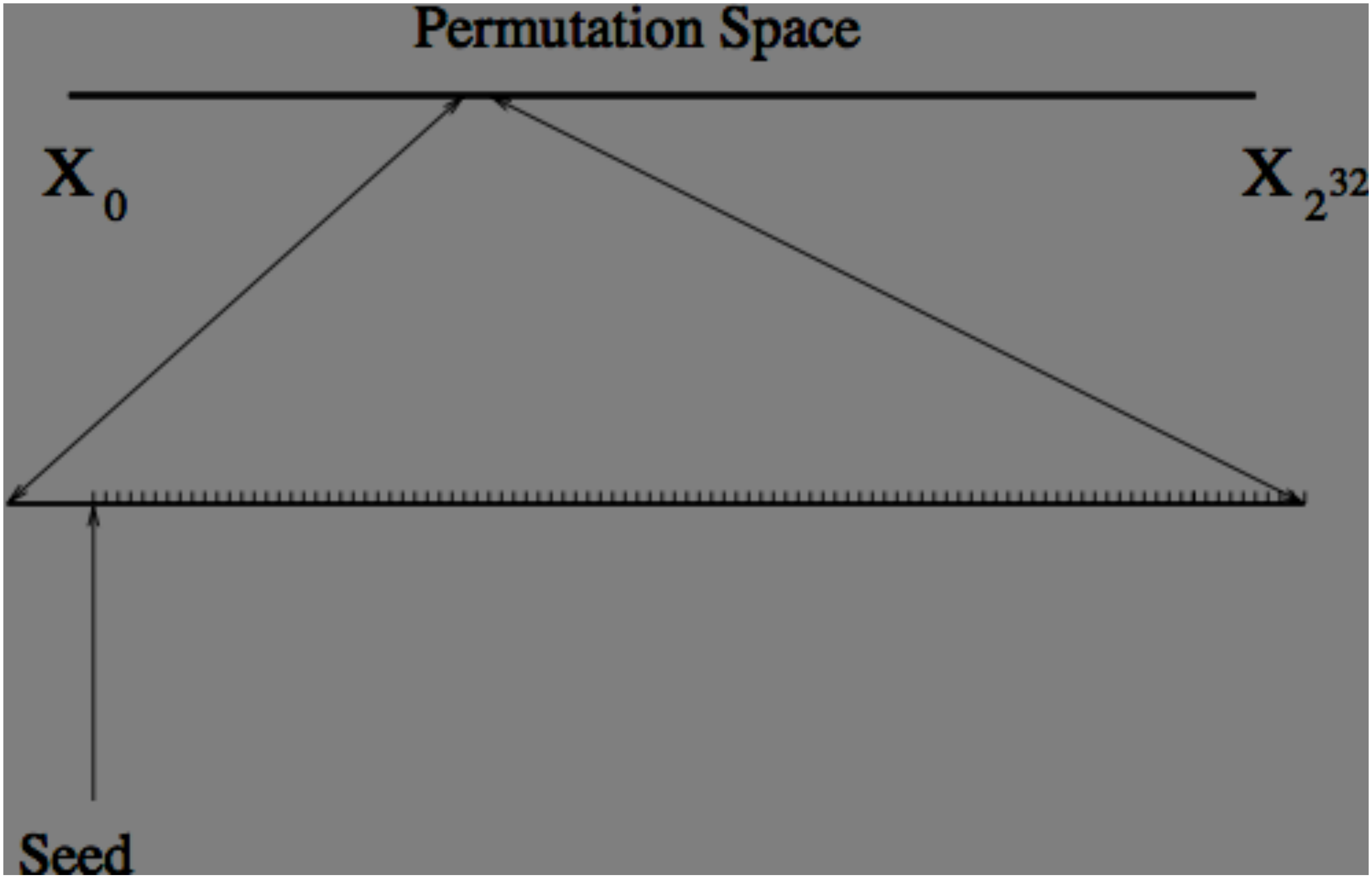
… Or complete reseeding if not

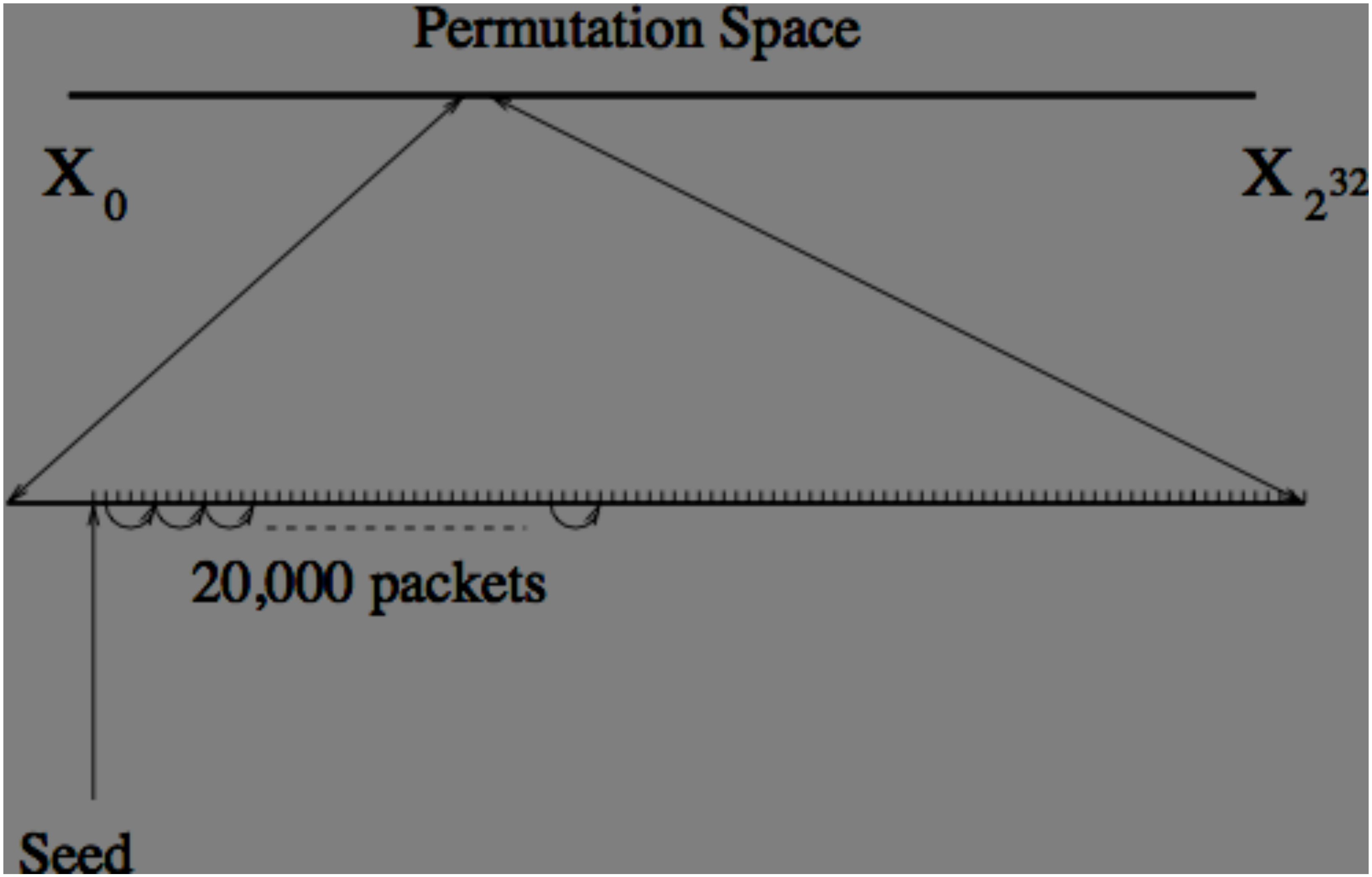
11. else goto 2

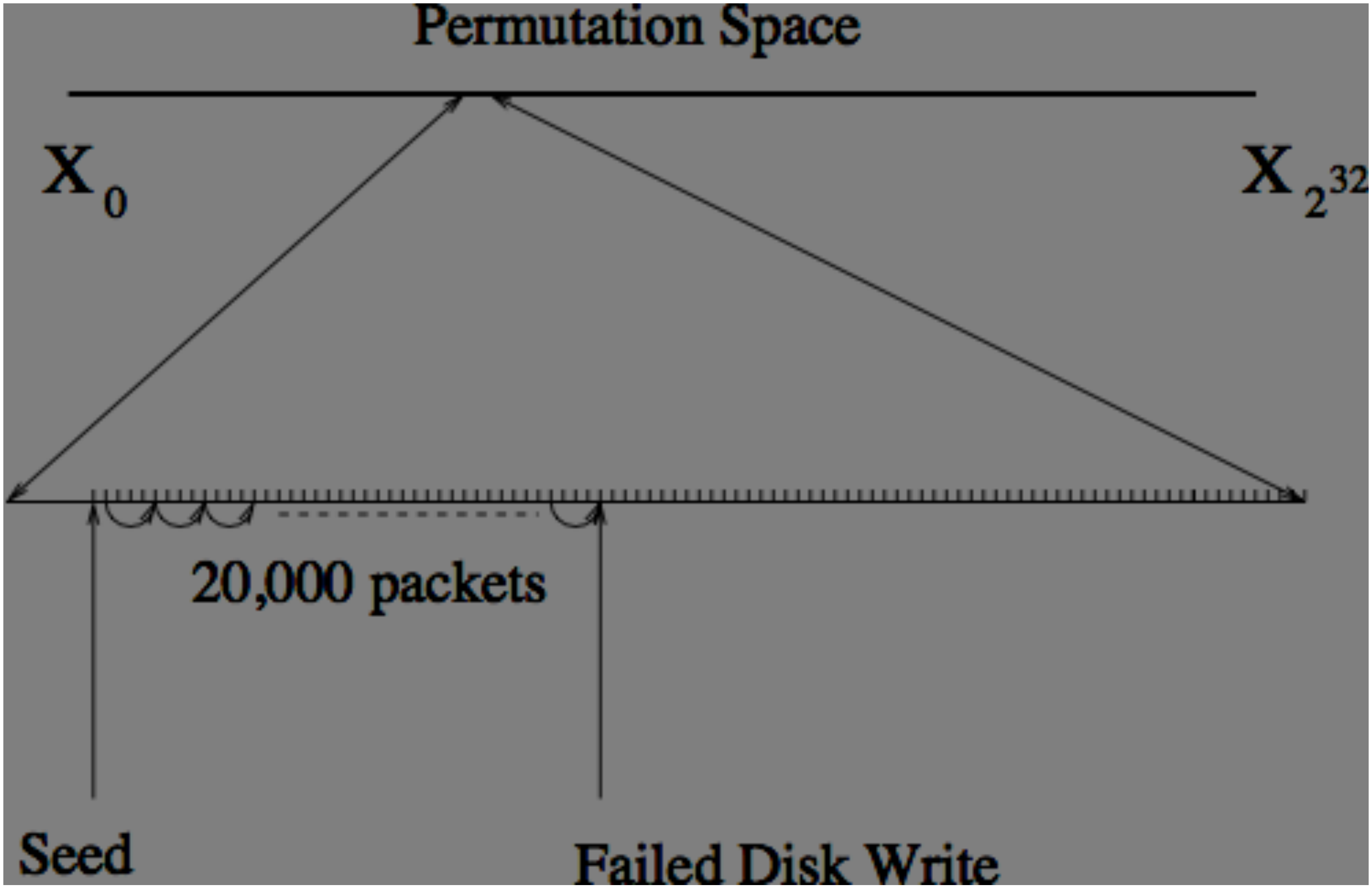
Witty Infectee Reseeding Events

- For packets with state X_i and X_j:
  - If from the same batch of 20,000 then
    - $j - i = 0 \mod 4$
  - If from separate but adjacent batches, for which Witty did not reseed, then
    - $j - i = 1 \mod 4$

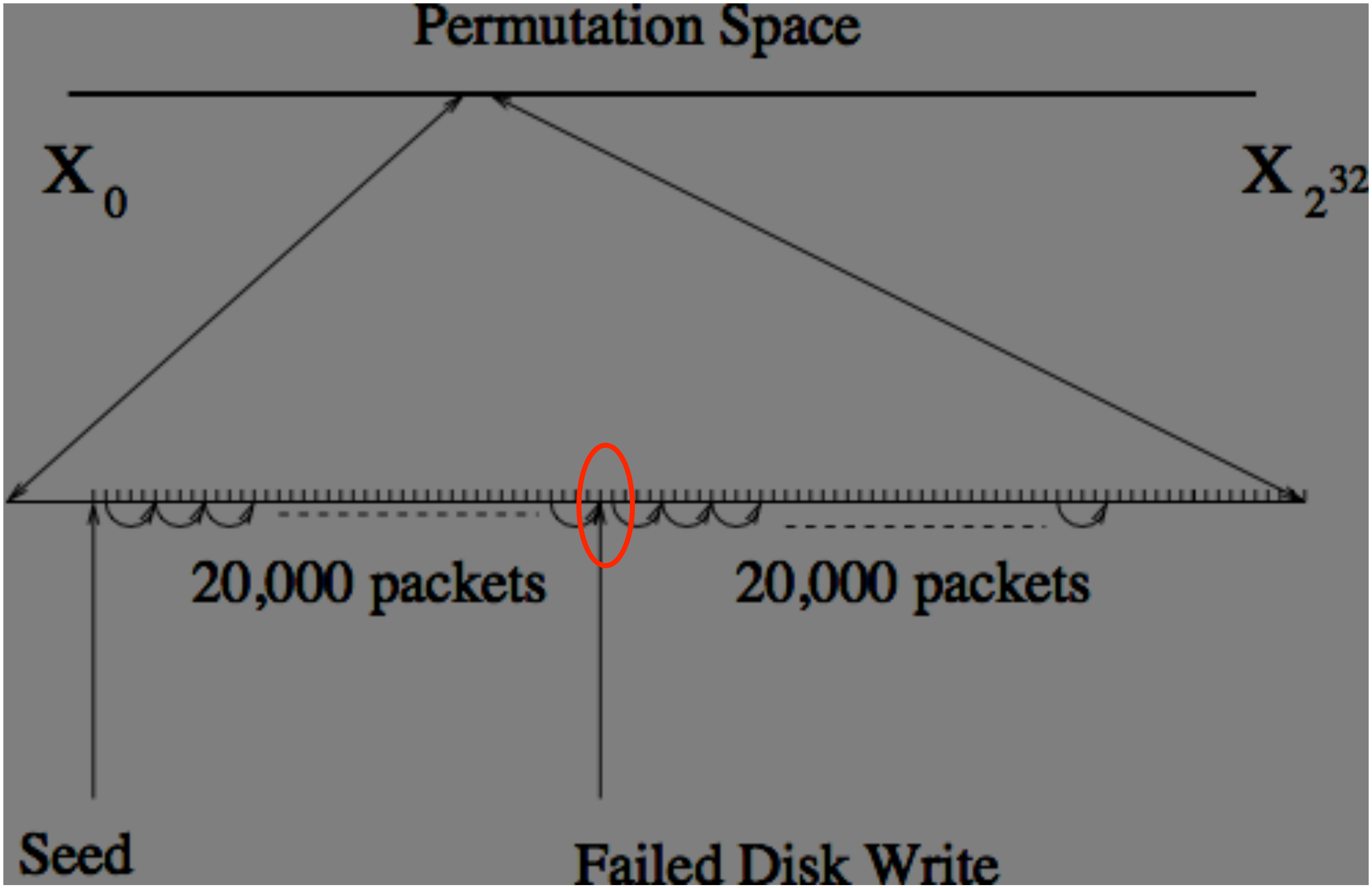
      (but which of the 100s/1000s of intervening packets marked the phase shift?)
  - If from batches across which Witty reseeded, then no apparent relationship.

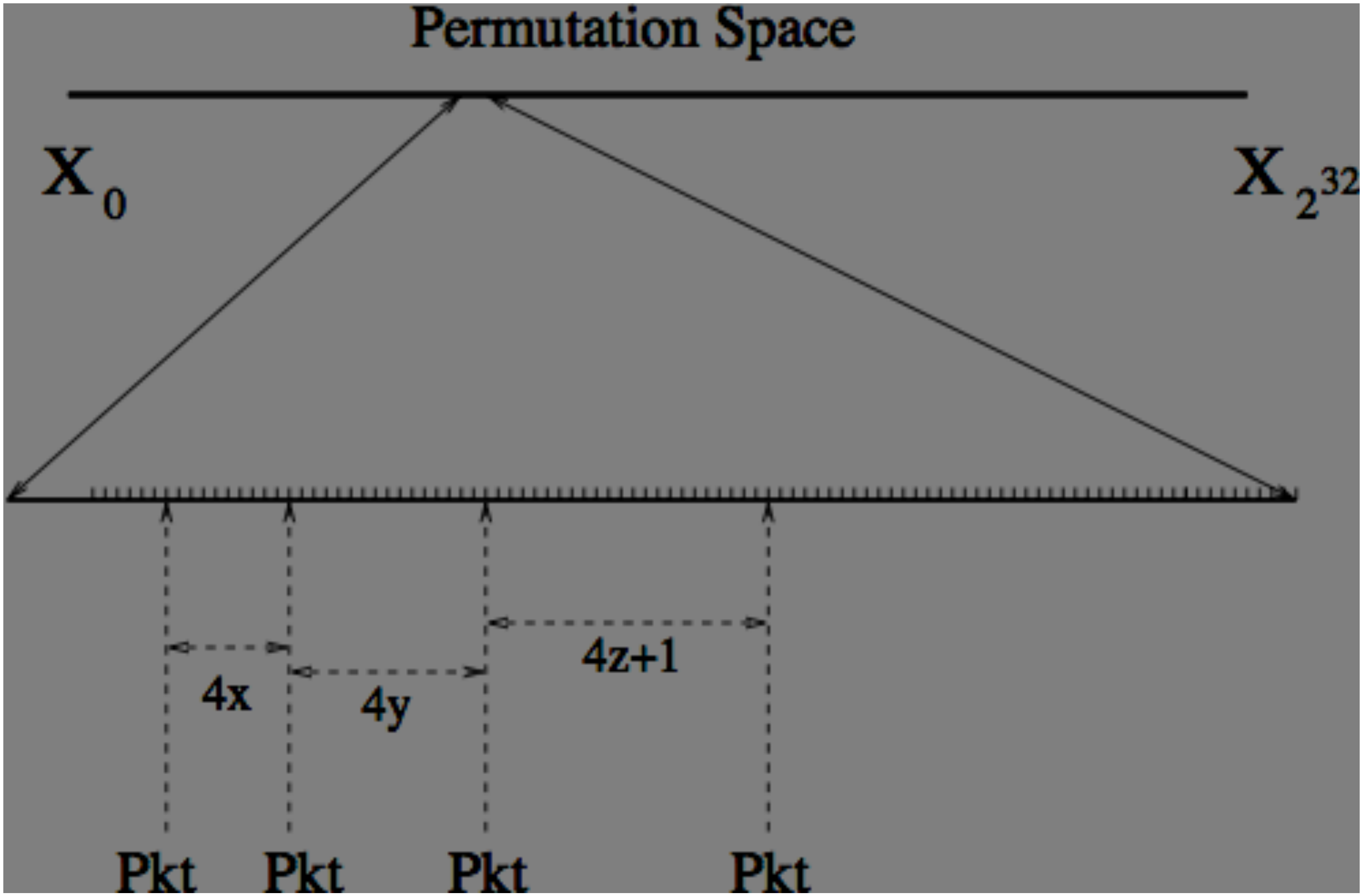

Permutation Space
X_0
$X_{2^{32}}$
Seed

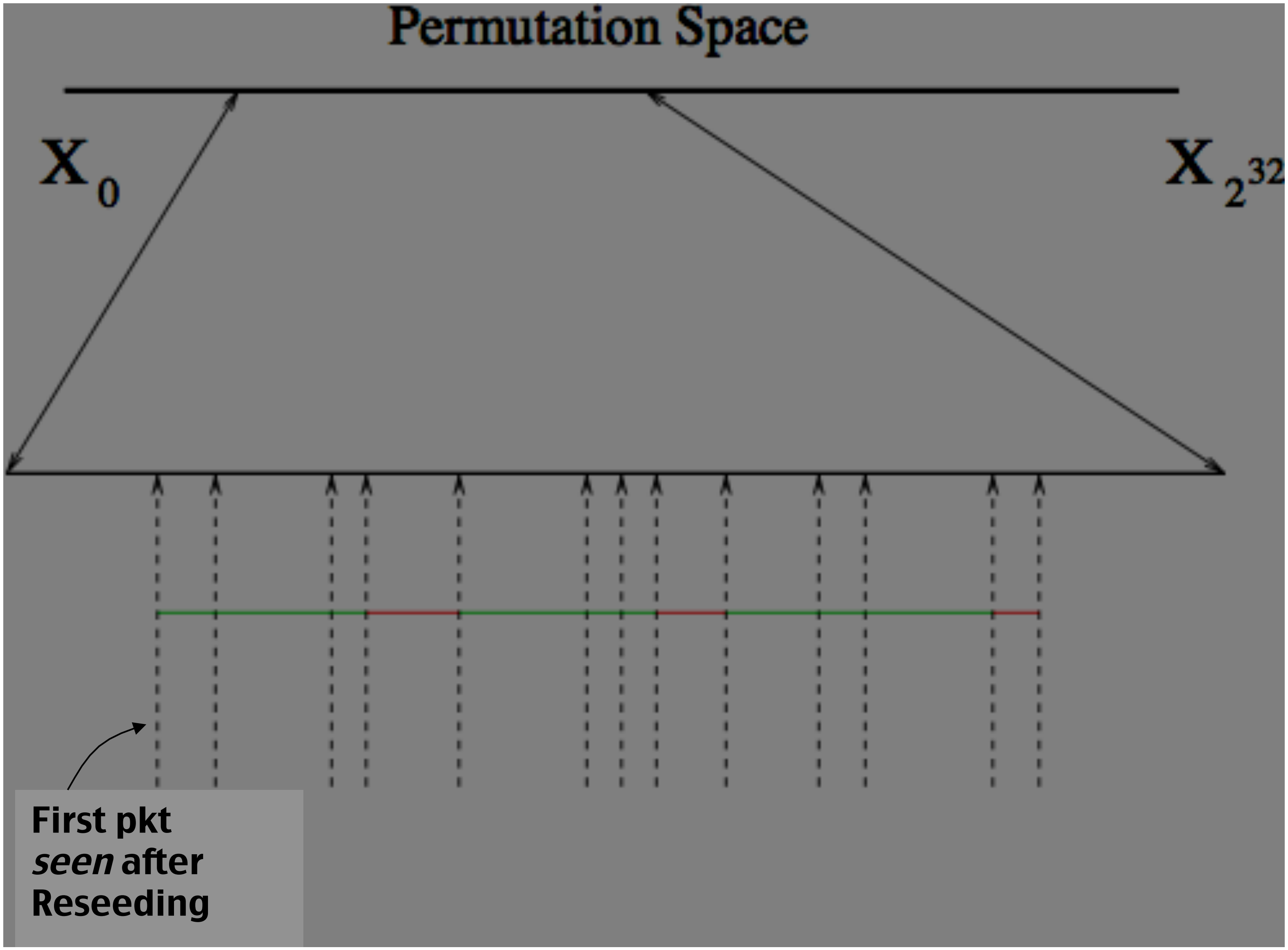

Permutation Space
X_0
$X_{2^{32}}$
20,000 packets
Seed

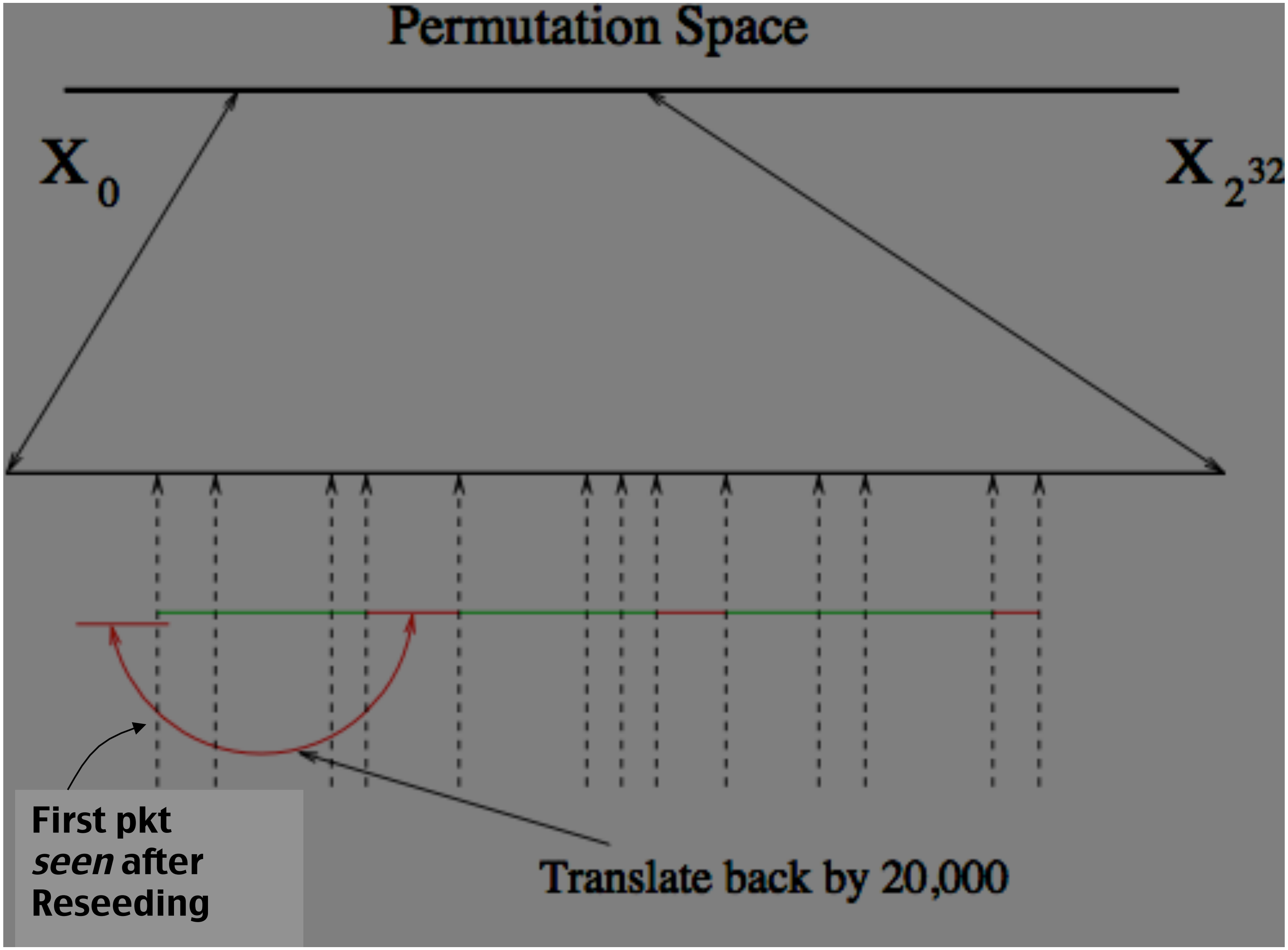


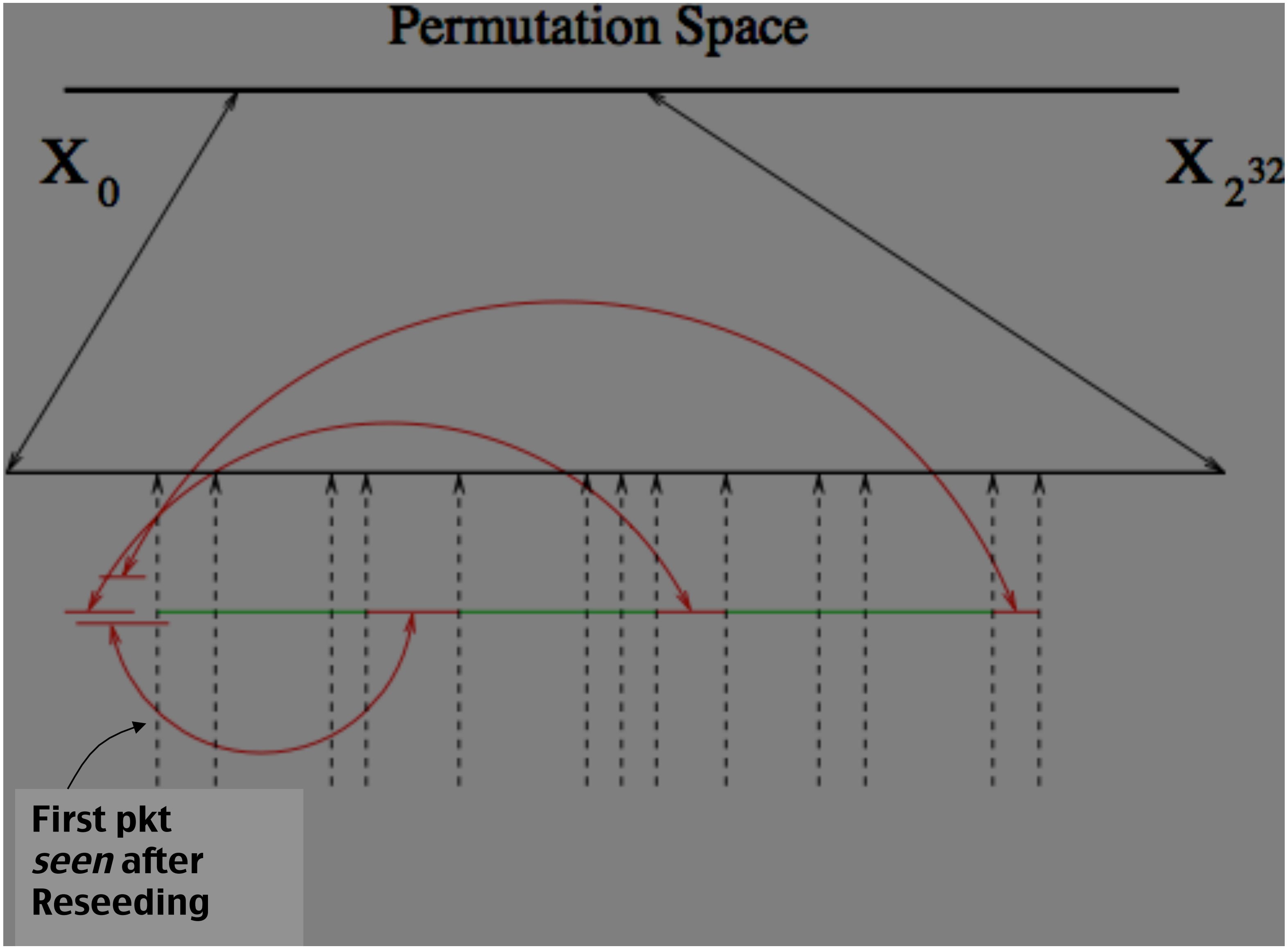
Permutation Space
X_0
$X_{2^{32}}$
20,000 packets
Seed
Failed Disk Write

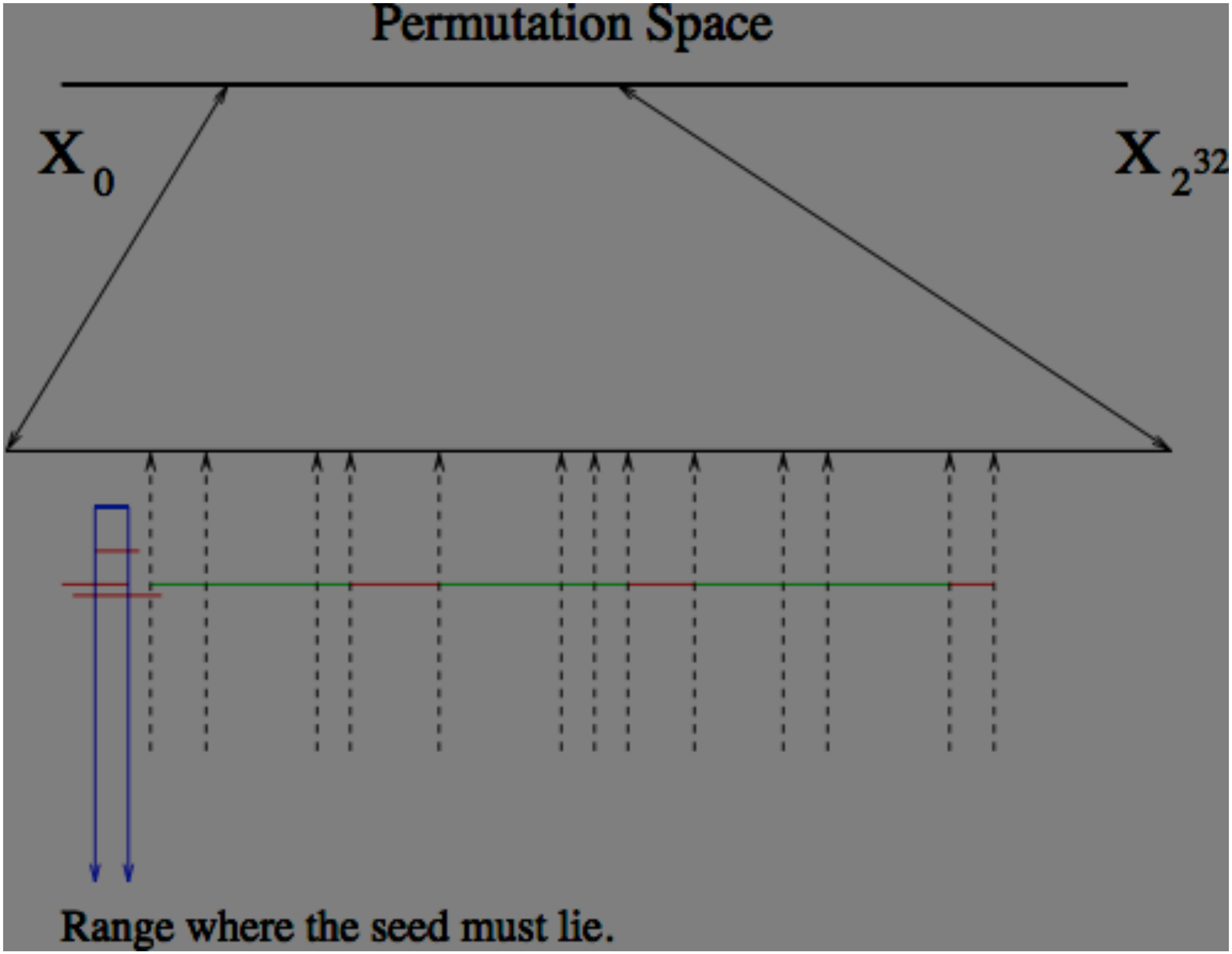

Permutation Space
X 0
X 2^32
20,000 packets
20,000 packets
Seed
Failed Disk Write

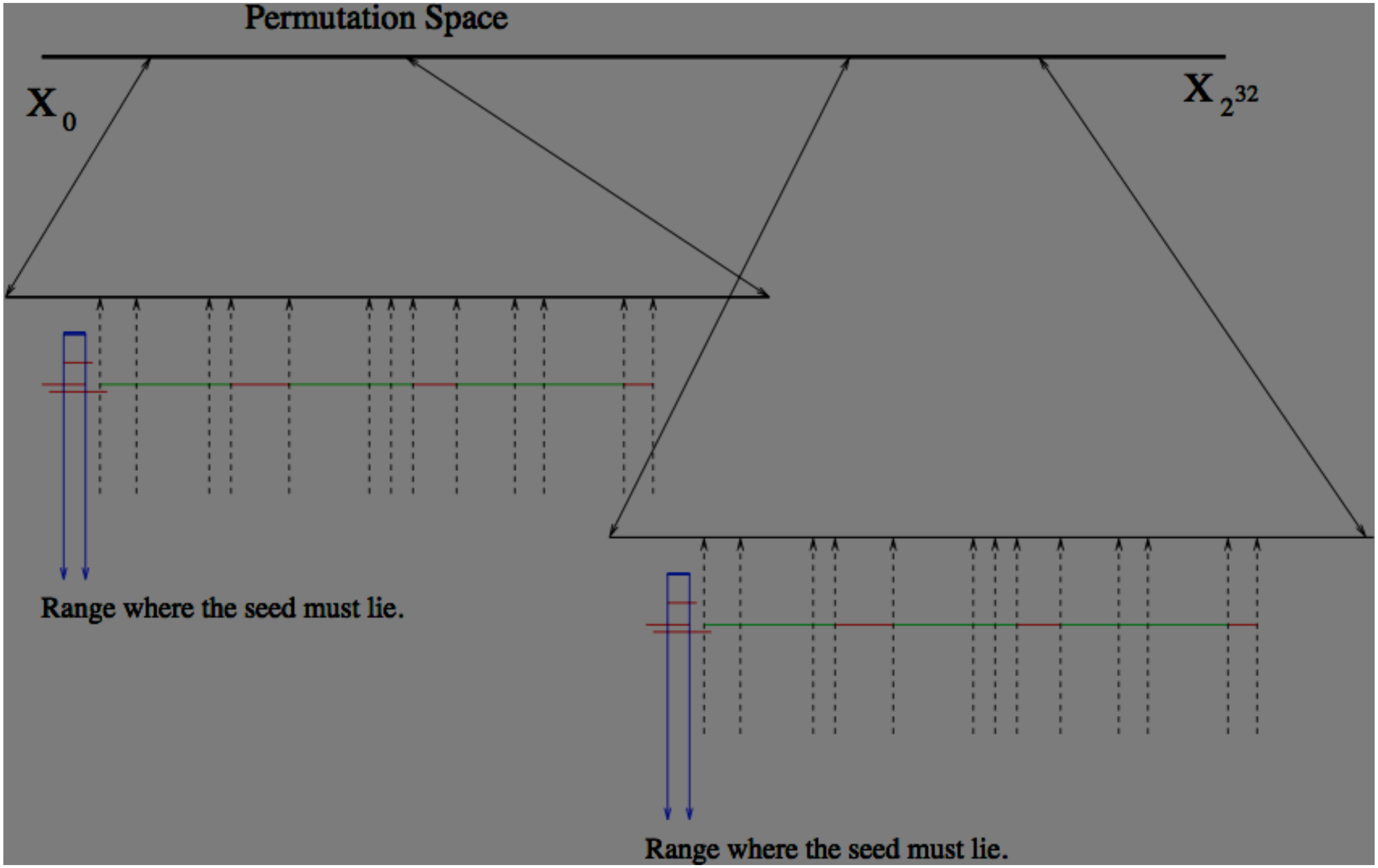

Permutation Space
X_0
$X_{2^{32}}$
4x
4y
4z+1
Pkt
Pkt
Pkt
Pkt

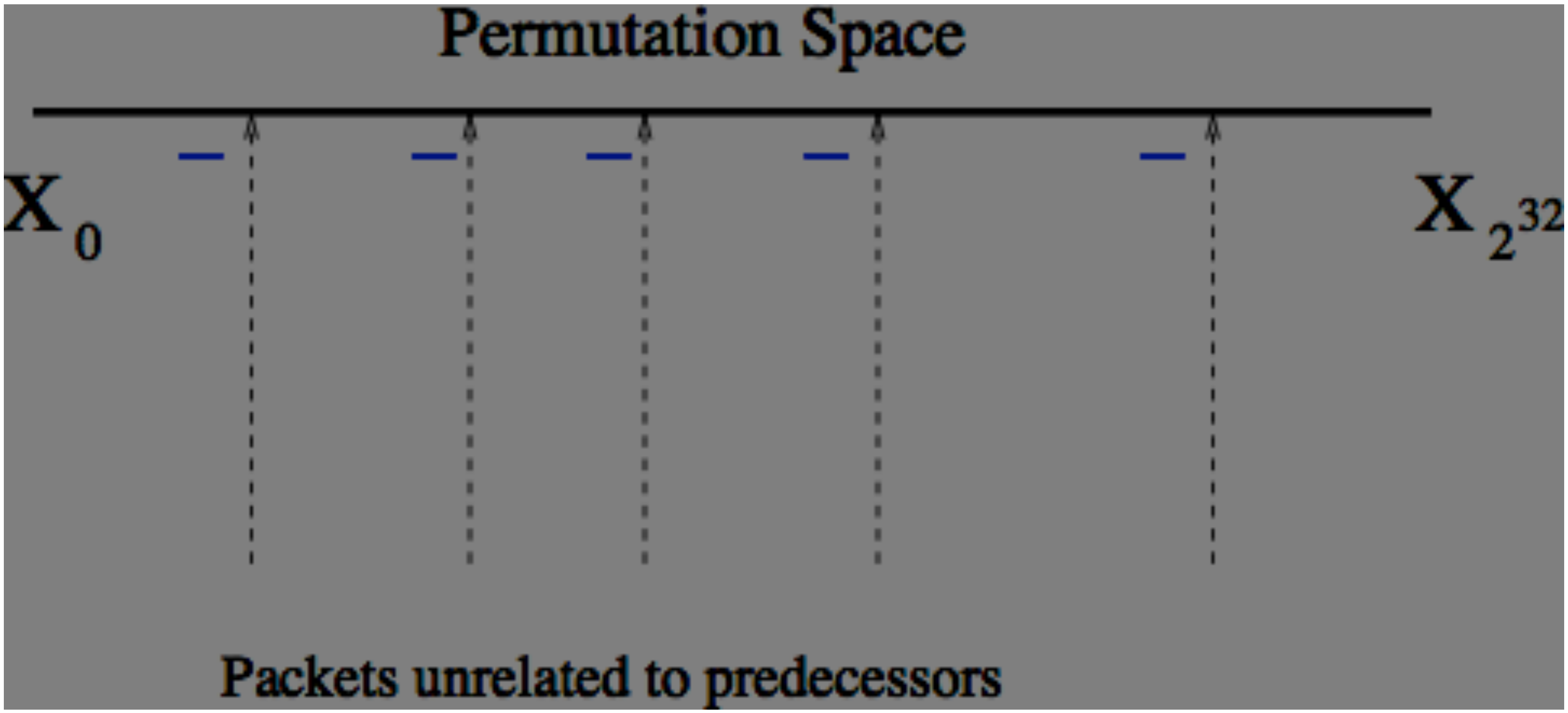

Permutation Space
X_0
$X_{2^{32}}$
First pkt
seen after
Reseeding

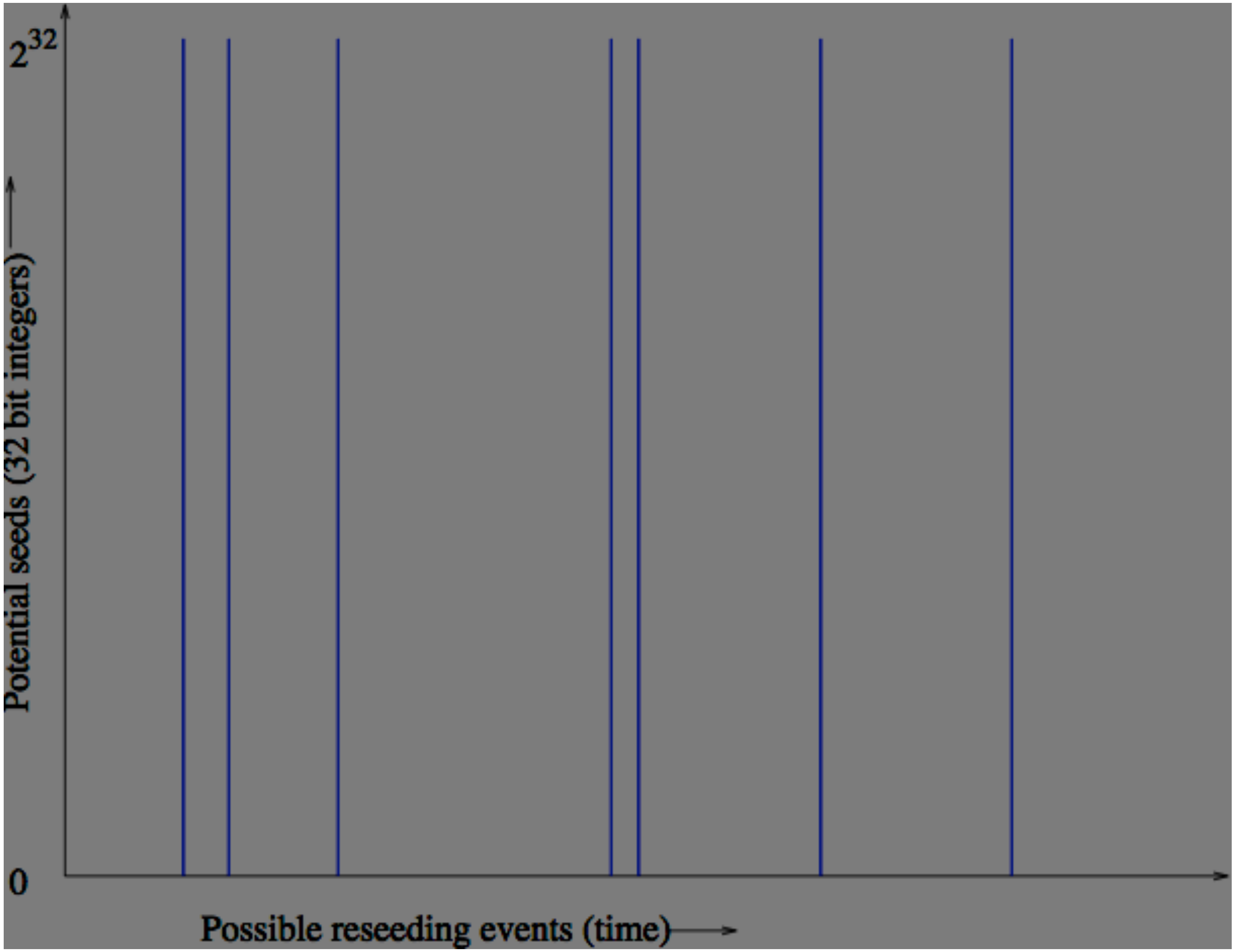

Permutation Space
X_0
$X_{2^{32}}$
First pkt
seen after
Reseeding
Translate back by 20,000


Permutation Space
X_0
$X_{2^{32}}$
First pkt
seen after
Reseeding

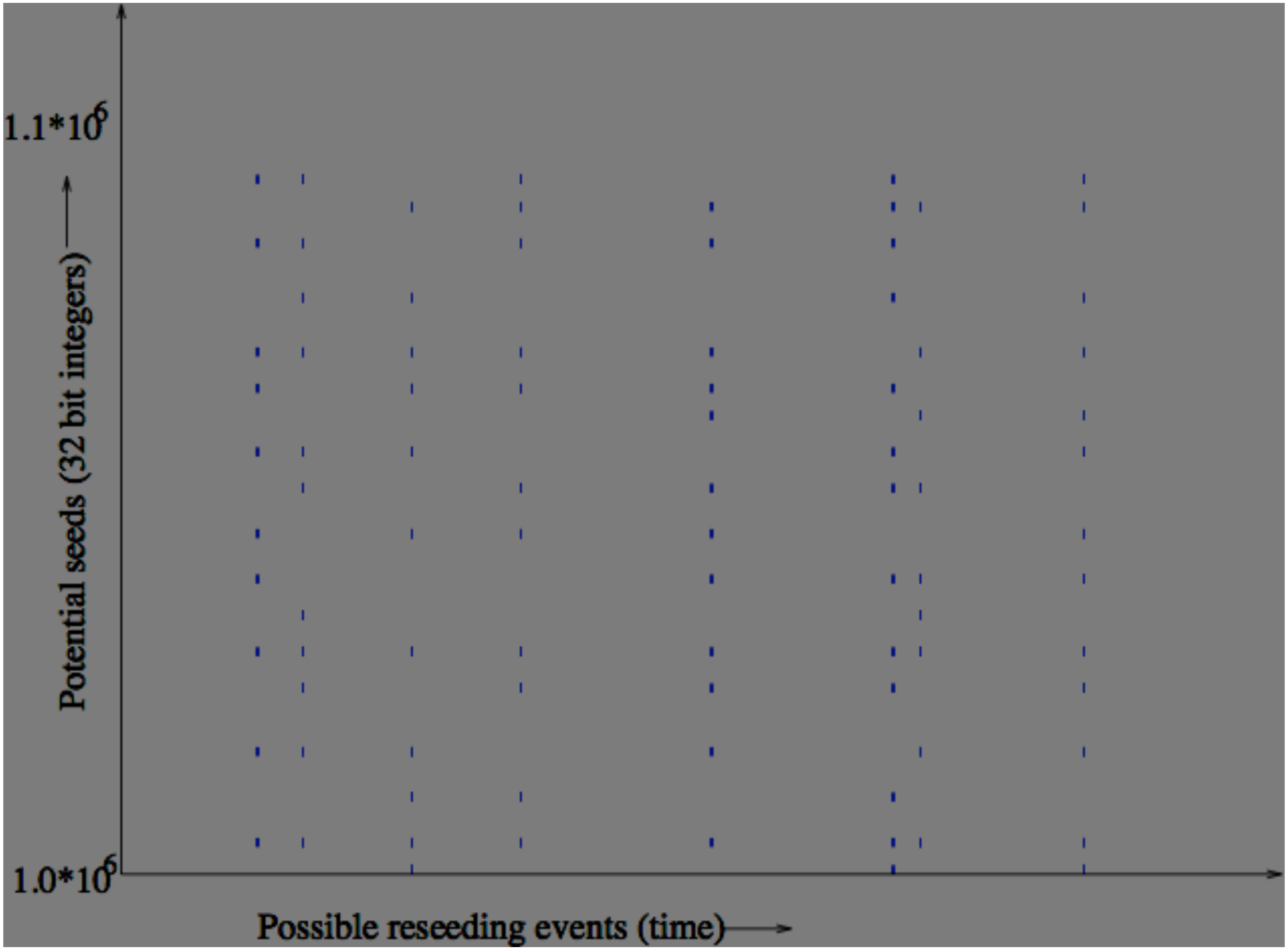

Permutation Space
X 0
X 2 32
Range where the seed must lie.


Permutation Space
X_0
$X_{2^{32}}$
Range where the seed must lie.
Range where the seed must lie.


Permutation Space
X_0
$X_{2^{32}}$
Packets unrelated to predecessors



2^{32}
0
Potential seeds (32 bit integers)
Possible reseeding events (time)


1.1*10^6
Potential seeds (32 bit integers)
1.0*10^6
Possible reseeding events (time)

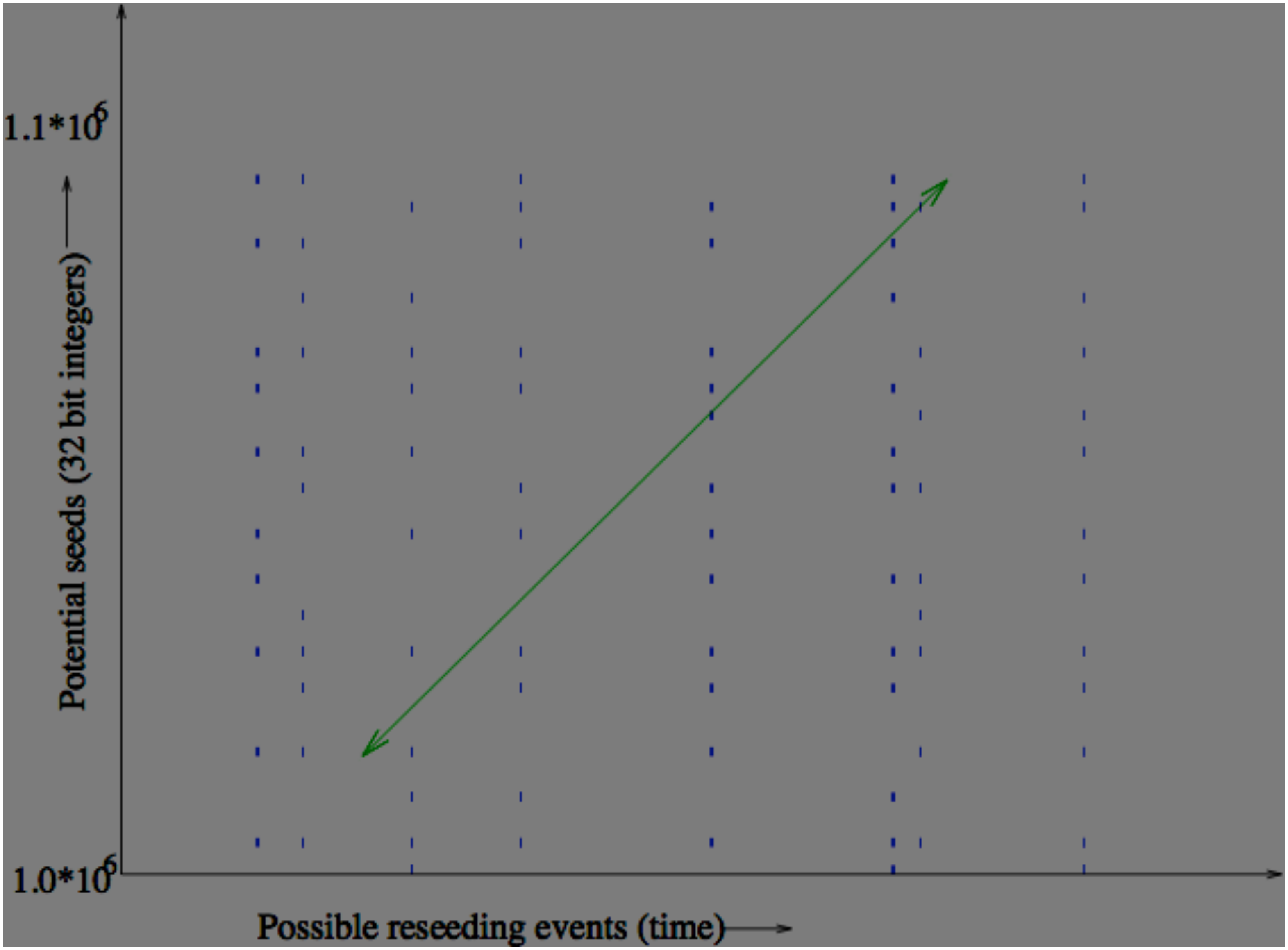
We Know Intervals in Which Each *First-Seed* Packet Occurs ….

- … but which among the 1,000s of candidates are the actual seeds?
- Entropy isn't all that easy to come by …
- Consider

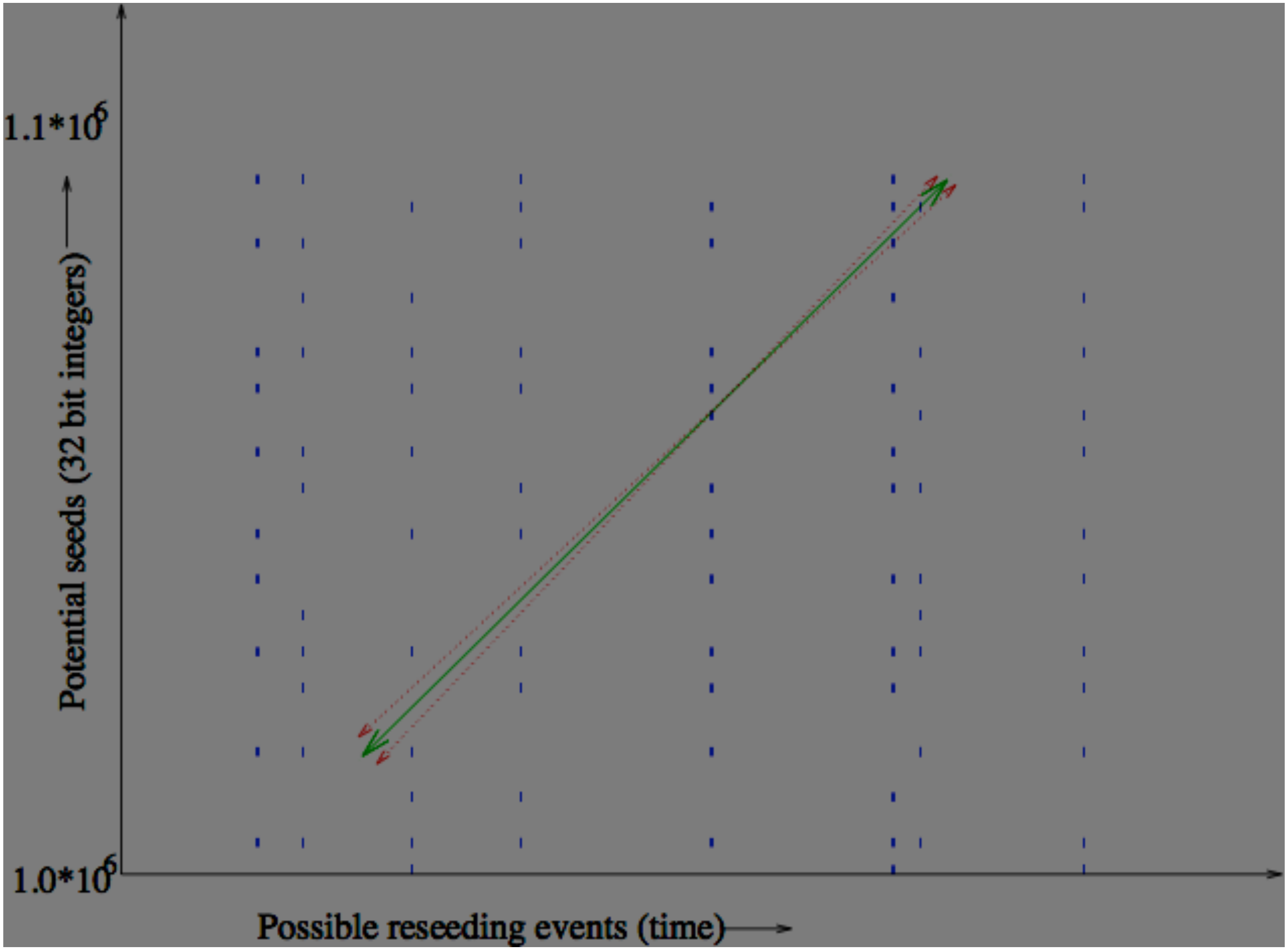
  srand(get_tick_count())

  i.e., uptime in msec

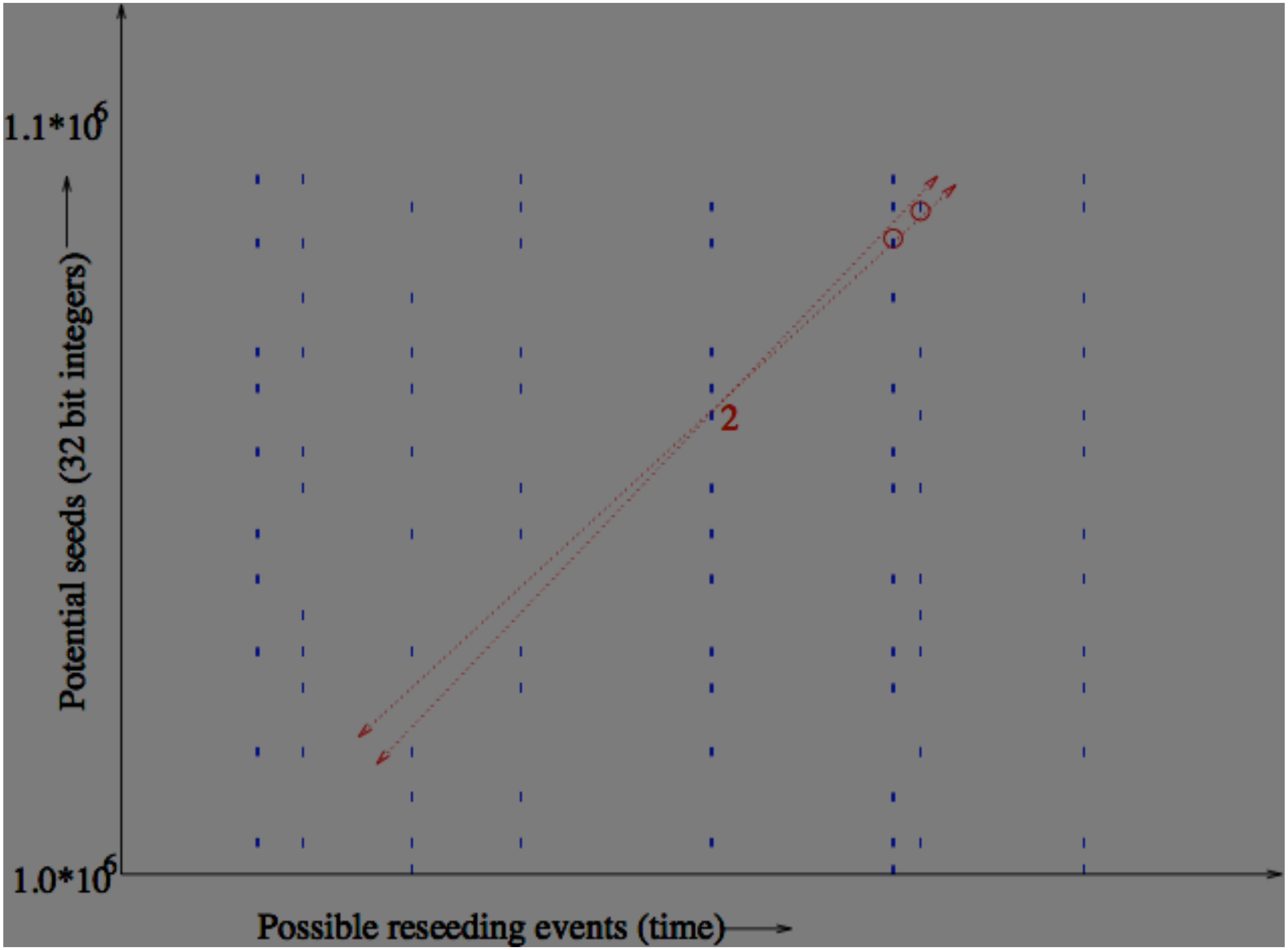
- The values used in repeated calls increase linearly with time

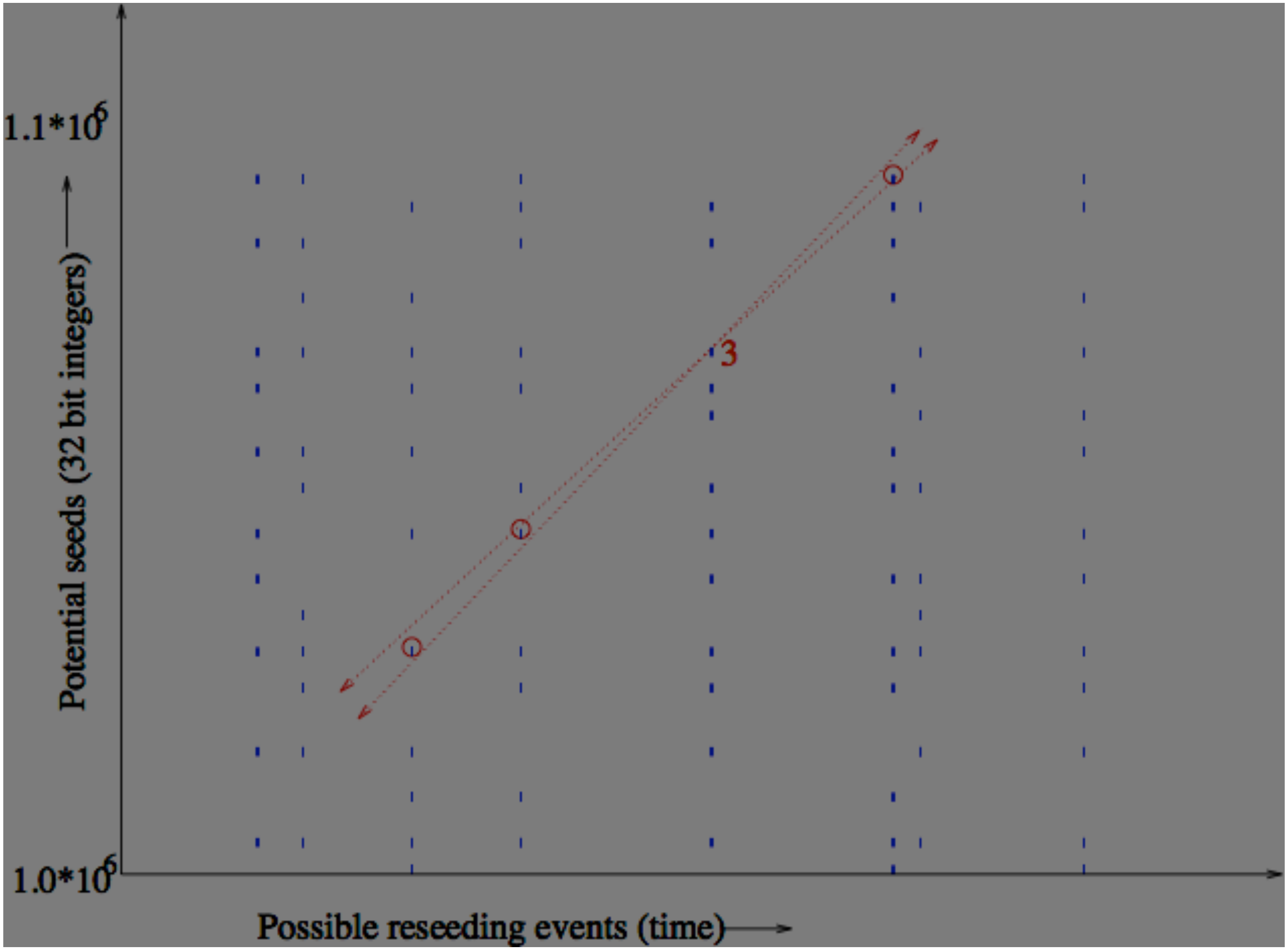


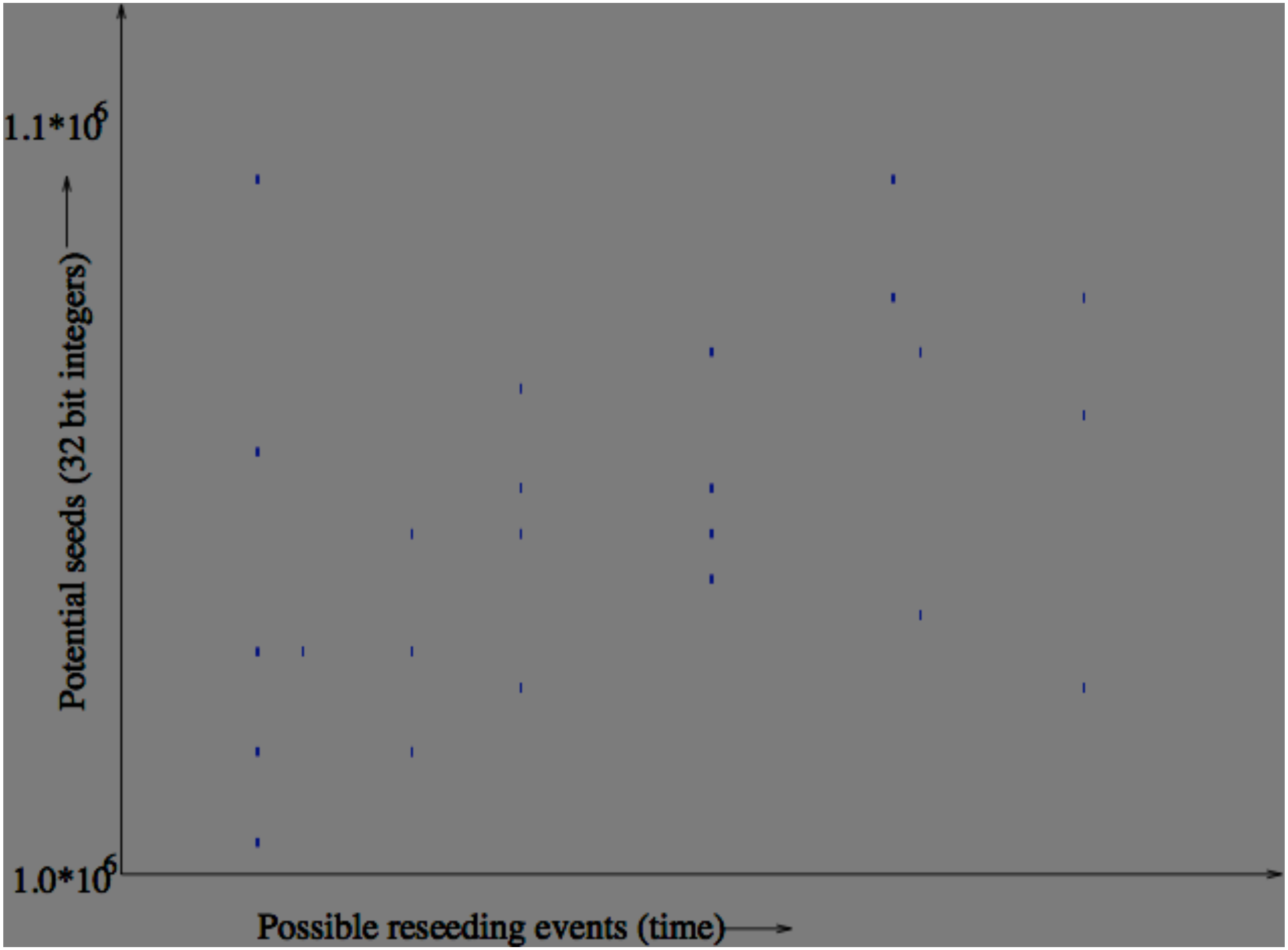
1.1*10^6
Potential seeds (32 bit integers)
1.0*10^6
Possible reseeding events (time)

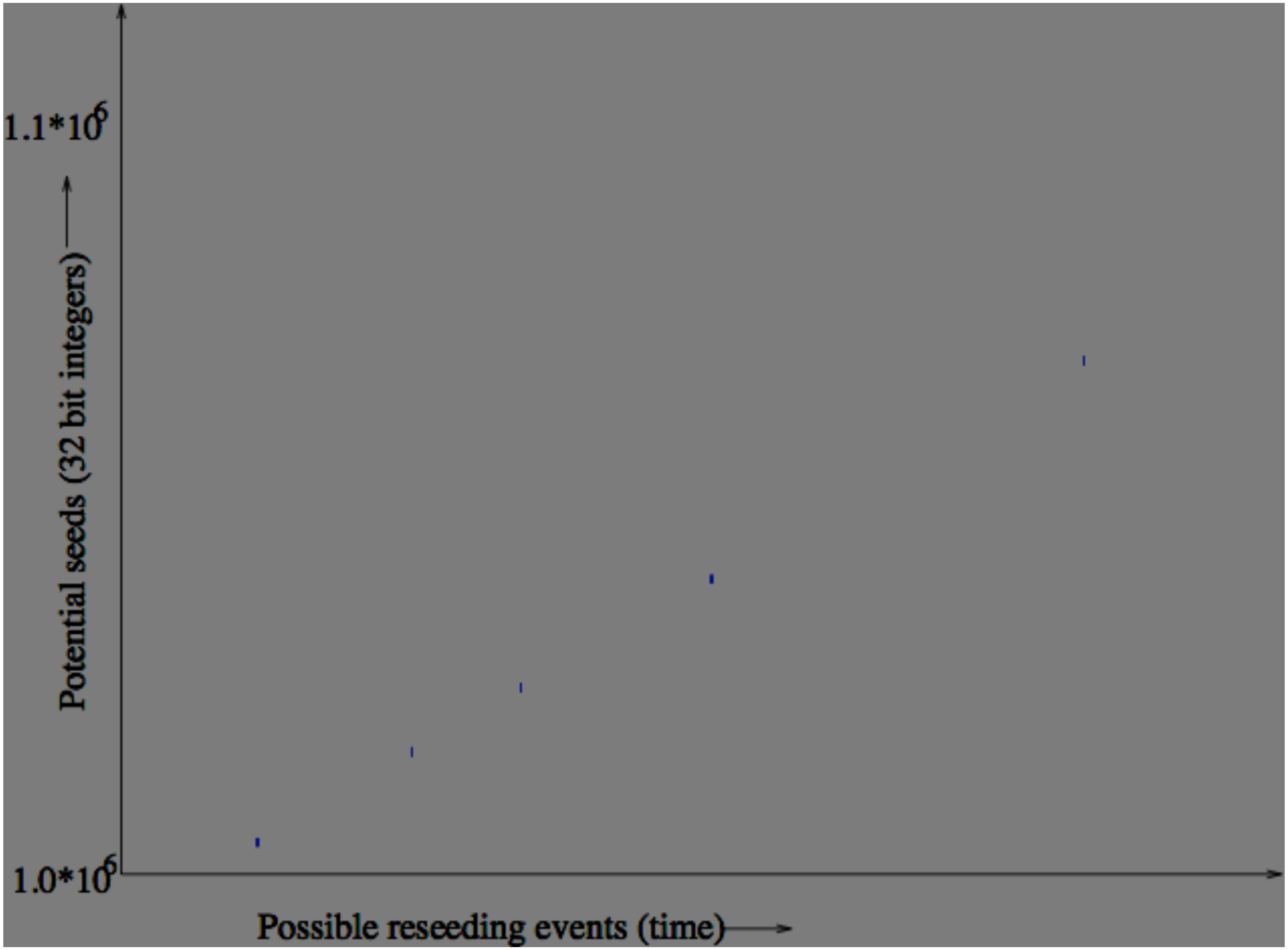


1.1*10^6
1.0*10^6
Potential seeds (32 bit integers)
Possible reseeding events (time)


1.1*10^6
1.0*10^6
Potential seeds (32 bit integers)
Possible reseeding events (time)
2


1.1*10^6
1.0*10^6
Potential seeds (32 bit integers)
Possible reseeding events (time)
3


1.1*10^6
Potential seeds (32 bit integers)
1.0*10^6
Possible reseeding events (time)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Potential seeds (32 bit integers)
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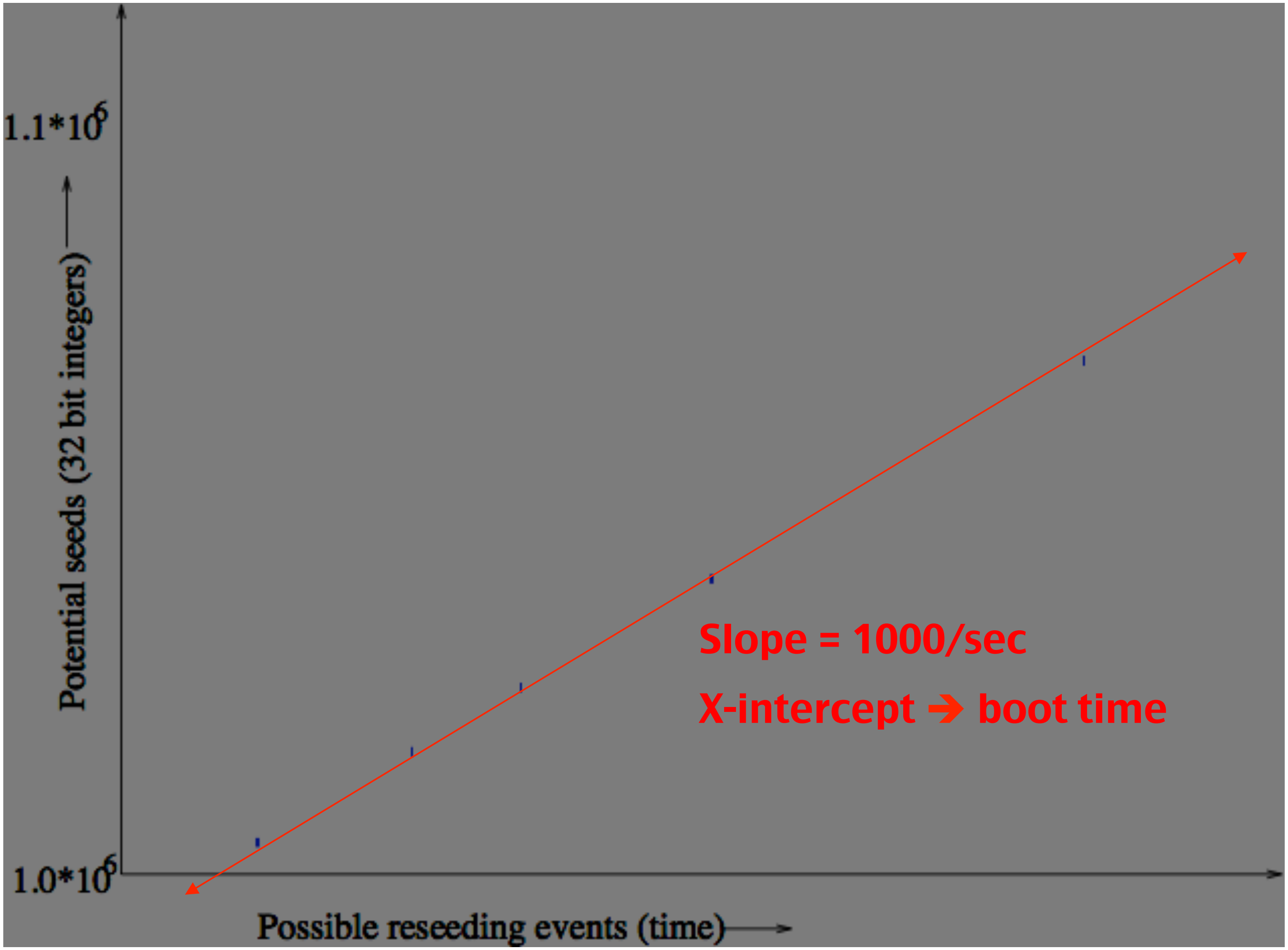
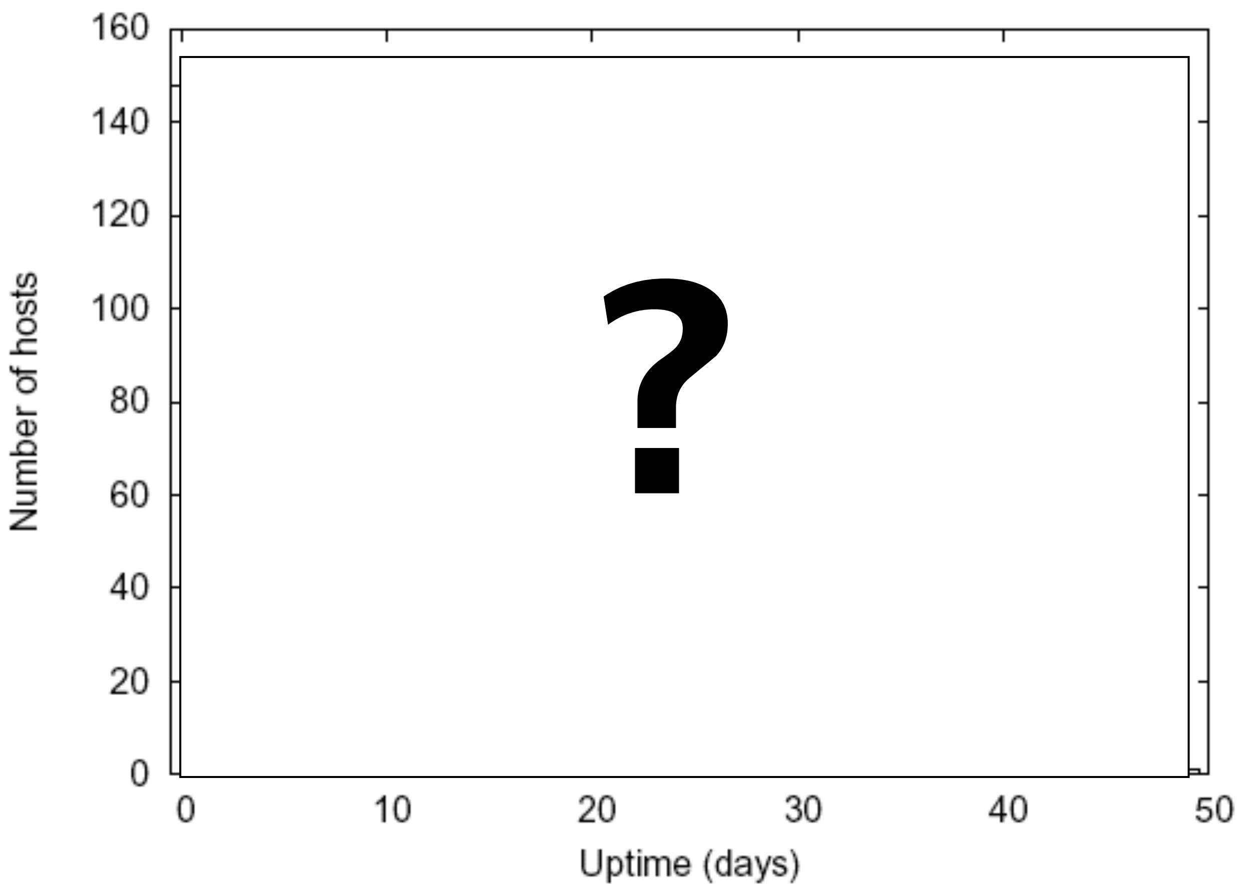
Possible reseeding events (time)

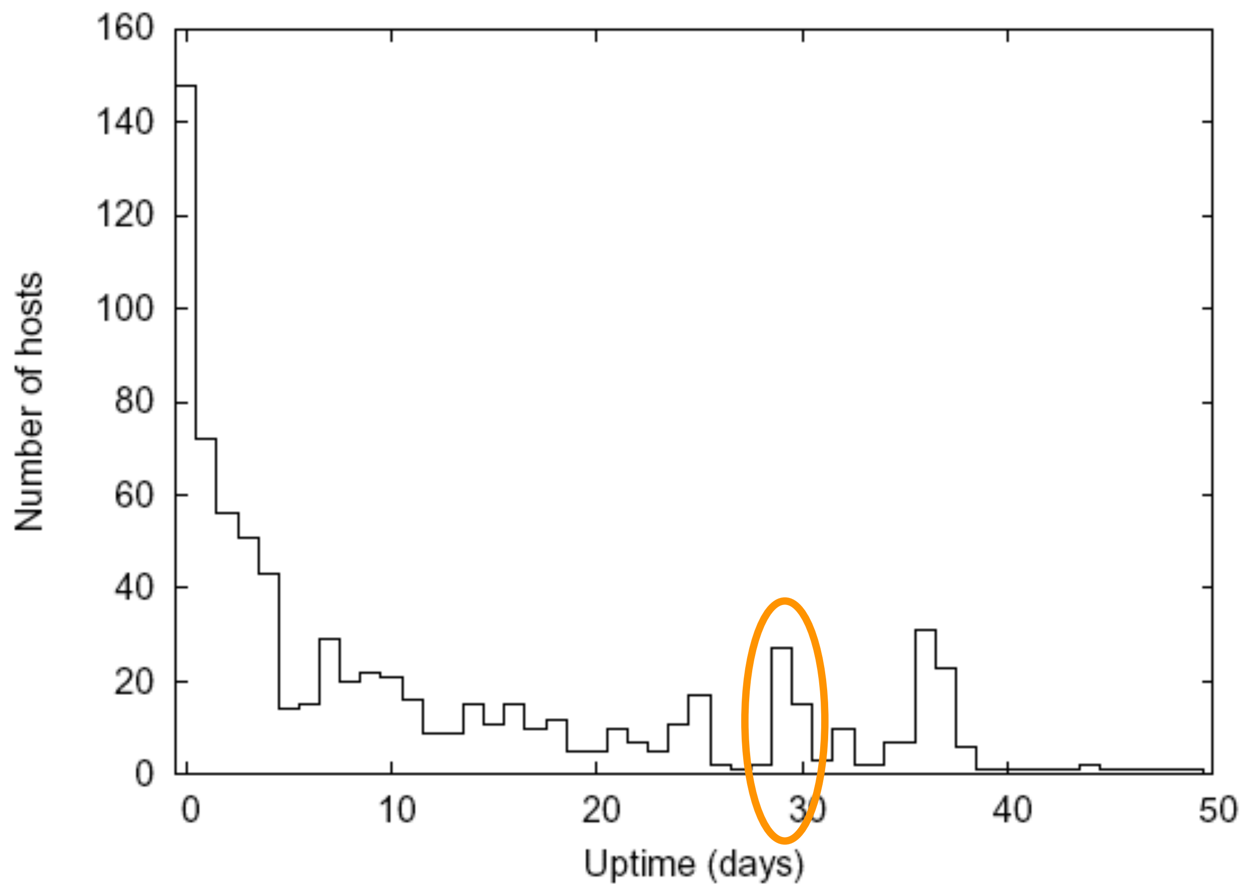


1.1*10^6
1.0*10^6
Potential seeds (32 bit integers)
Possible reseeding events (time)
Slope = 1000/sec
X-intercept → boot time

Uptime of 750 Witty Infectees



Uptime of 750 Witty Infectees



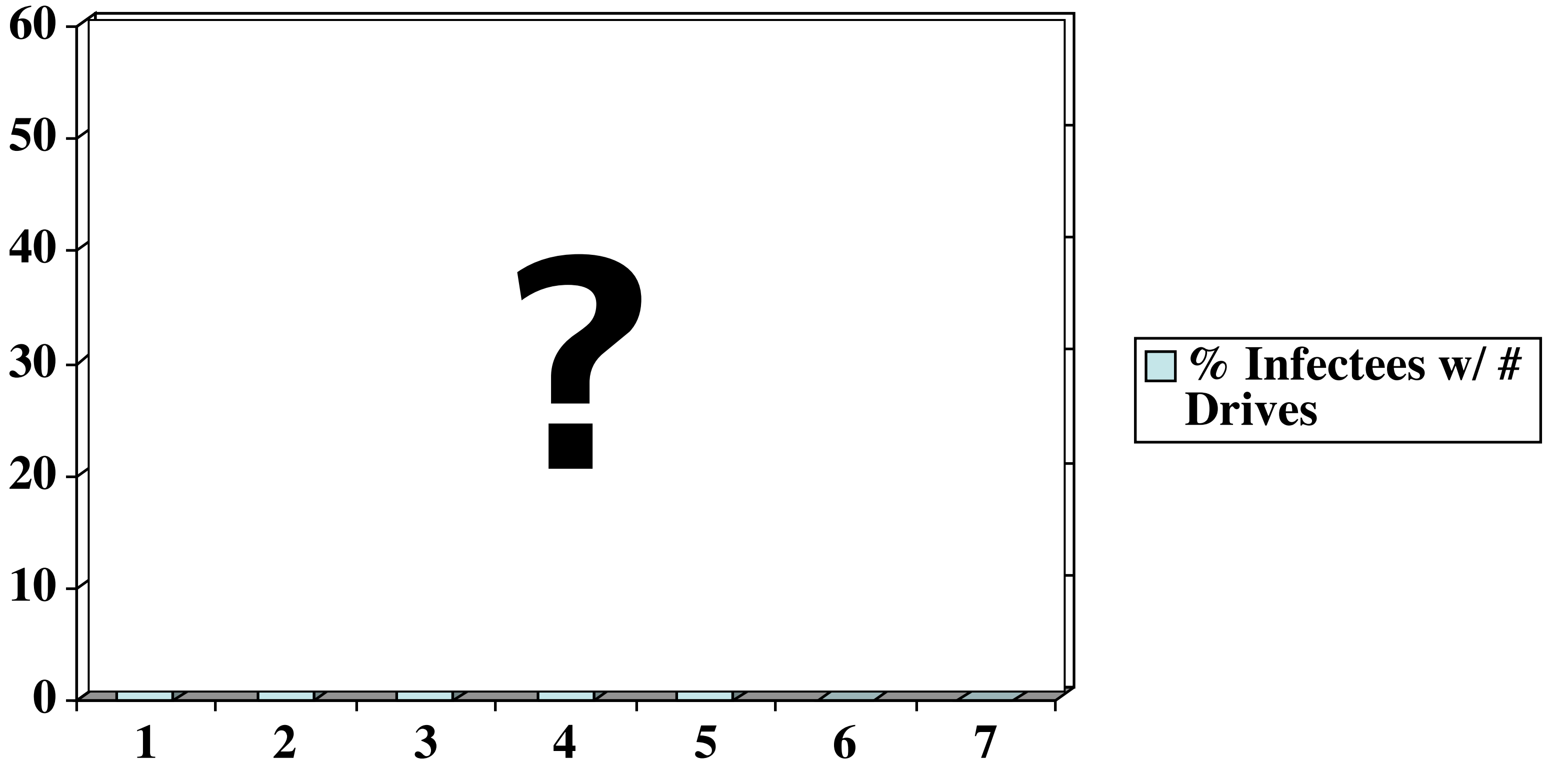
Given Exact Values of Seeds Used for Reseeding …

- … we know exact random # used at each subsequent disk-wipe test:

    if(open_physical_disk(**rand**()$_{[13..15]}$)

- … and its success, or failure, i.e., number of drives attached to each infectee …

Disk Drives Per Witty Infectee



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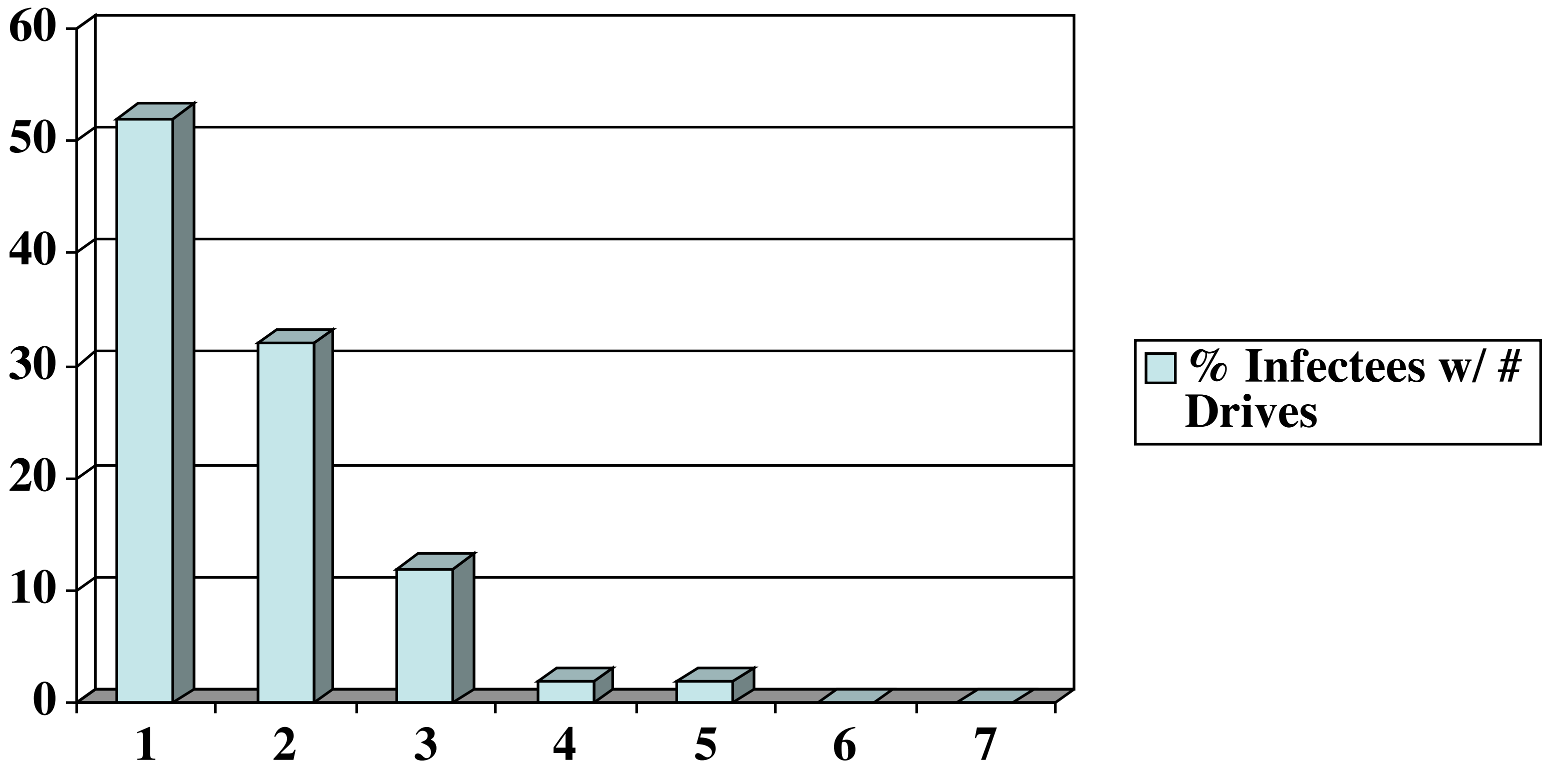


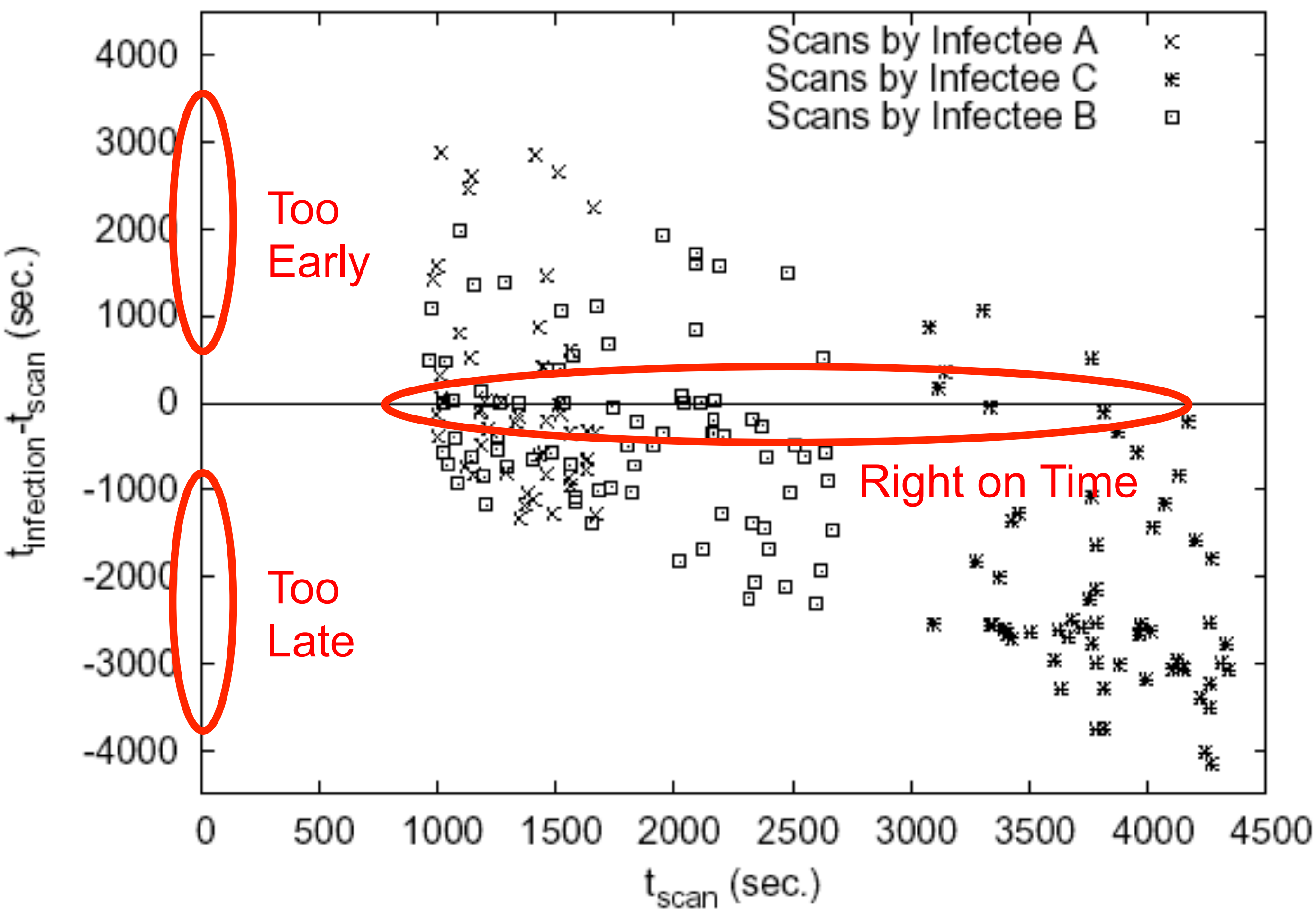
Given Exact Values of Seeds Used for Reseeding …

- … we know exact random # used at each subsequent disk-wipe test:

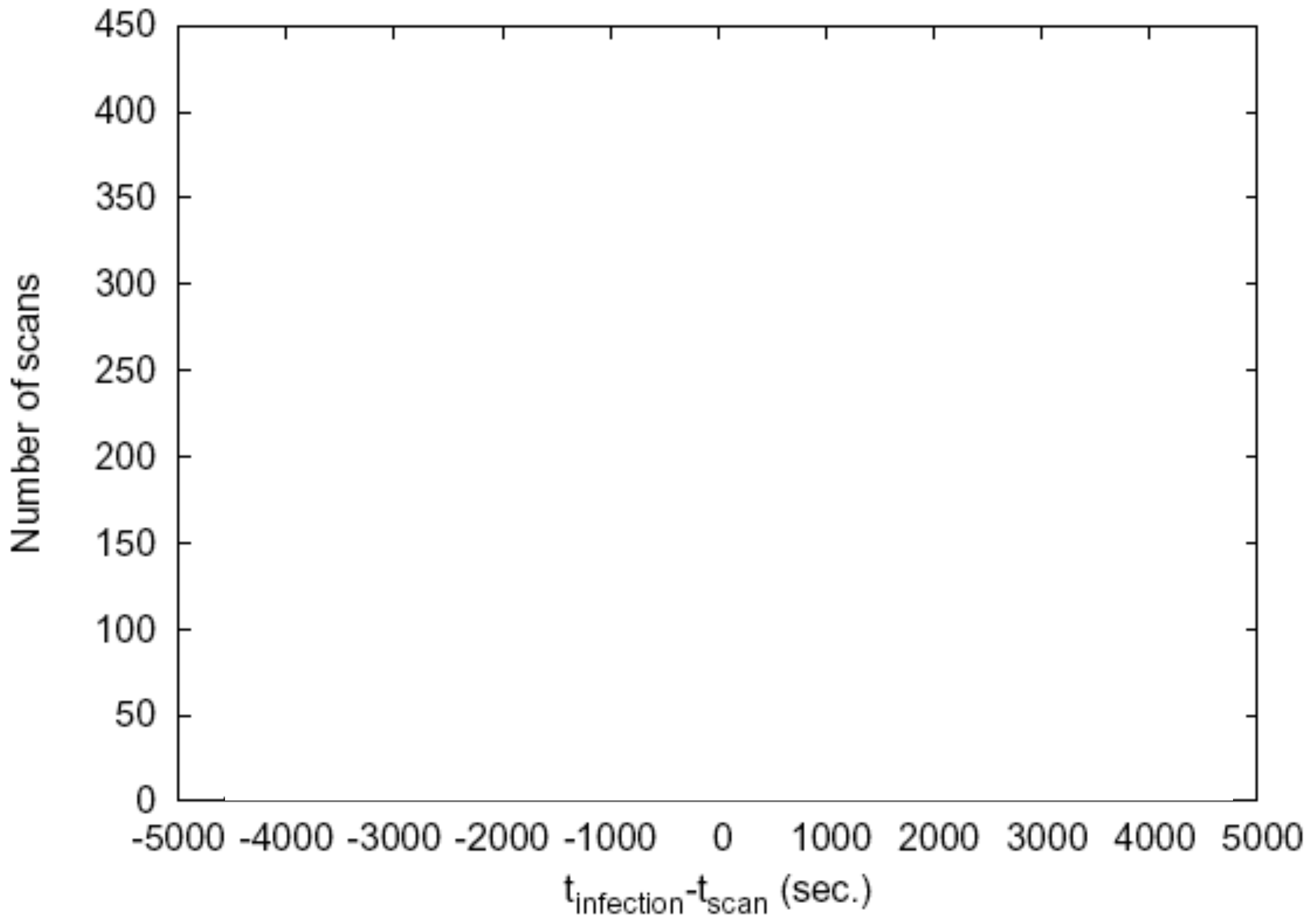
  if(open_physical_disk(**rand**()$_{[13..15]}$)

- … and its success, or failure, i.e., number of drives attached to each infectee …
- … and, more, generally, *every packet each infectee sent*
  - Can compare this to when new infectees show up
  - i.e., *Who-Infected-Whom*

Time Between Scan by Known Infectee and New Source Arrival At Telescope



Infection Attempts That Were Too Early, Too Late, or *Just Right*



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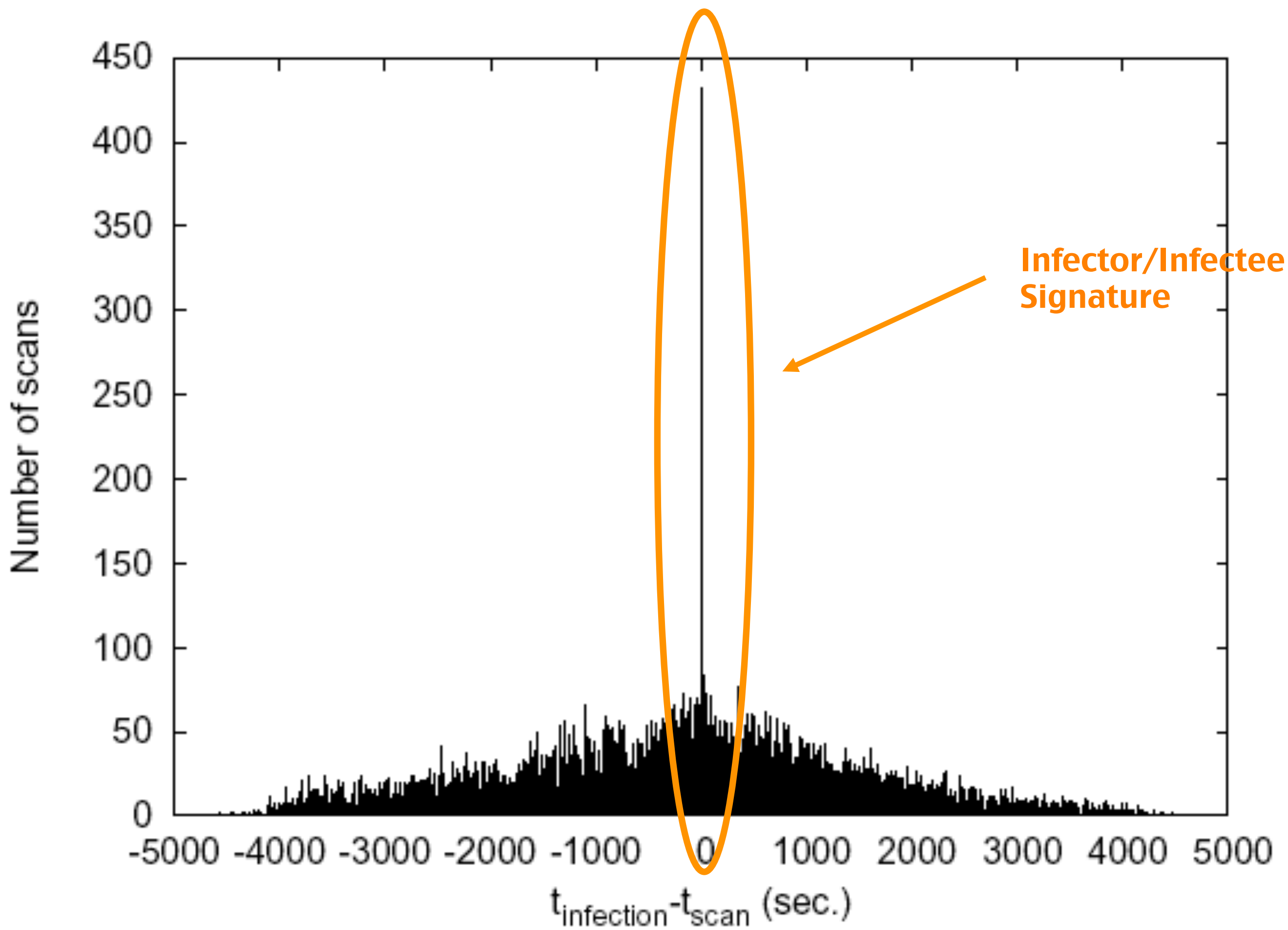
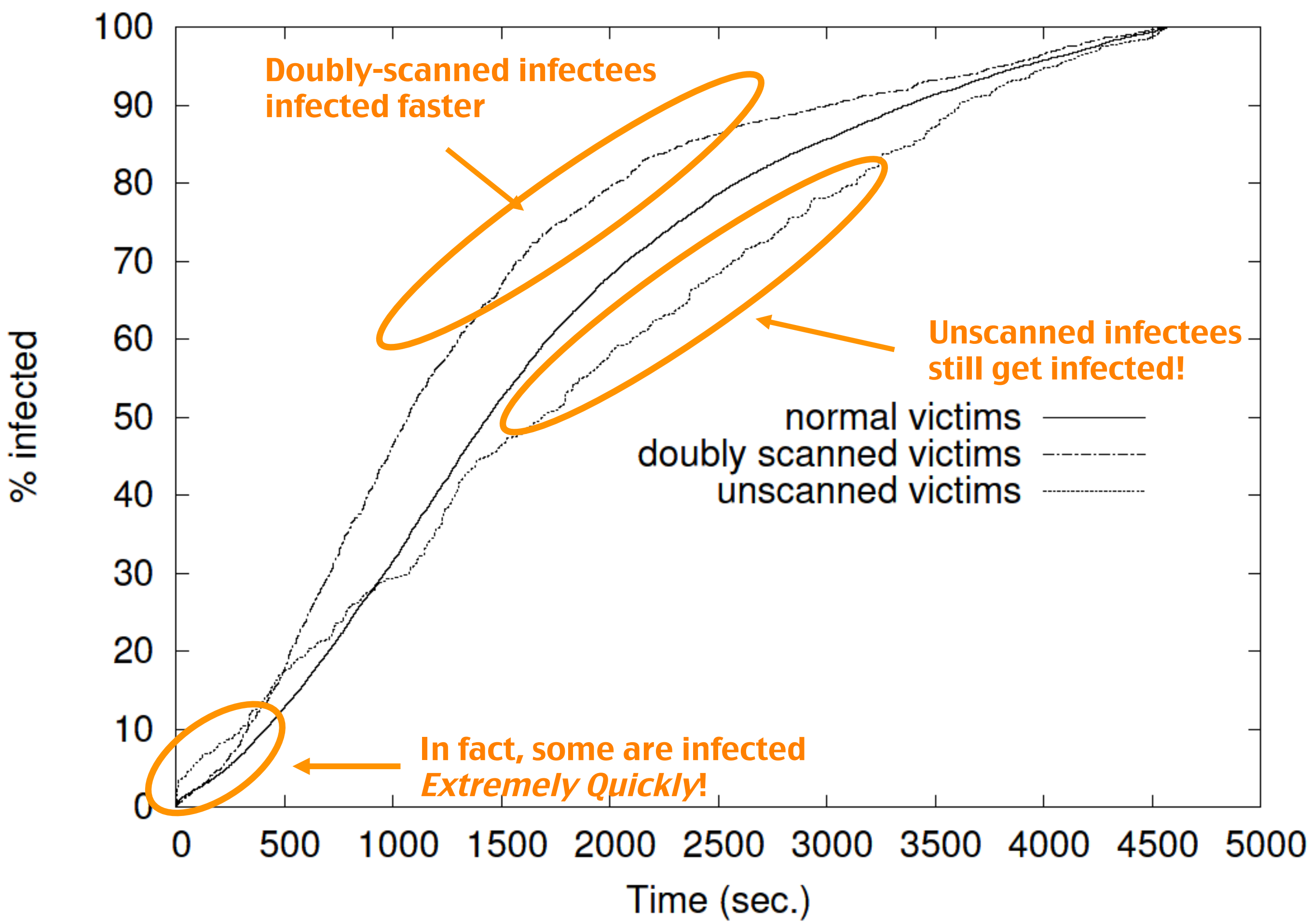


Witty is Incomplete

- Recall that LCG PRNG generates a complete orbit over a permutation of $0..2^{32}-1$.
- **But**: Witty author didn't use all 32 bits of single PRNG value
  - *dest_ip* $\leftarrow (X_i)_{[0..15]} \,||\, (X_{I+1})_{[0..15]}$
  - Knuth recommends top bits as having better pseudo-random properties
- **But²**: This does *not* generate a complete orbit!
  - Misses 10% of the address space
  - Visits 10% of the addresses (exactly) twice
- So: were 10% of the potential infectees protected?

Time When Infectees Seen At Telescope

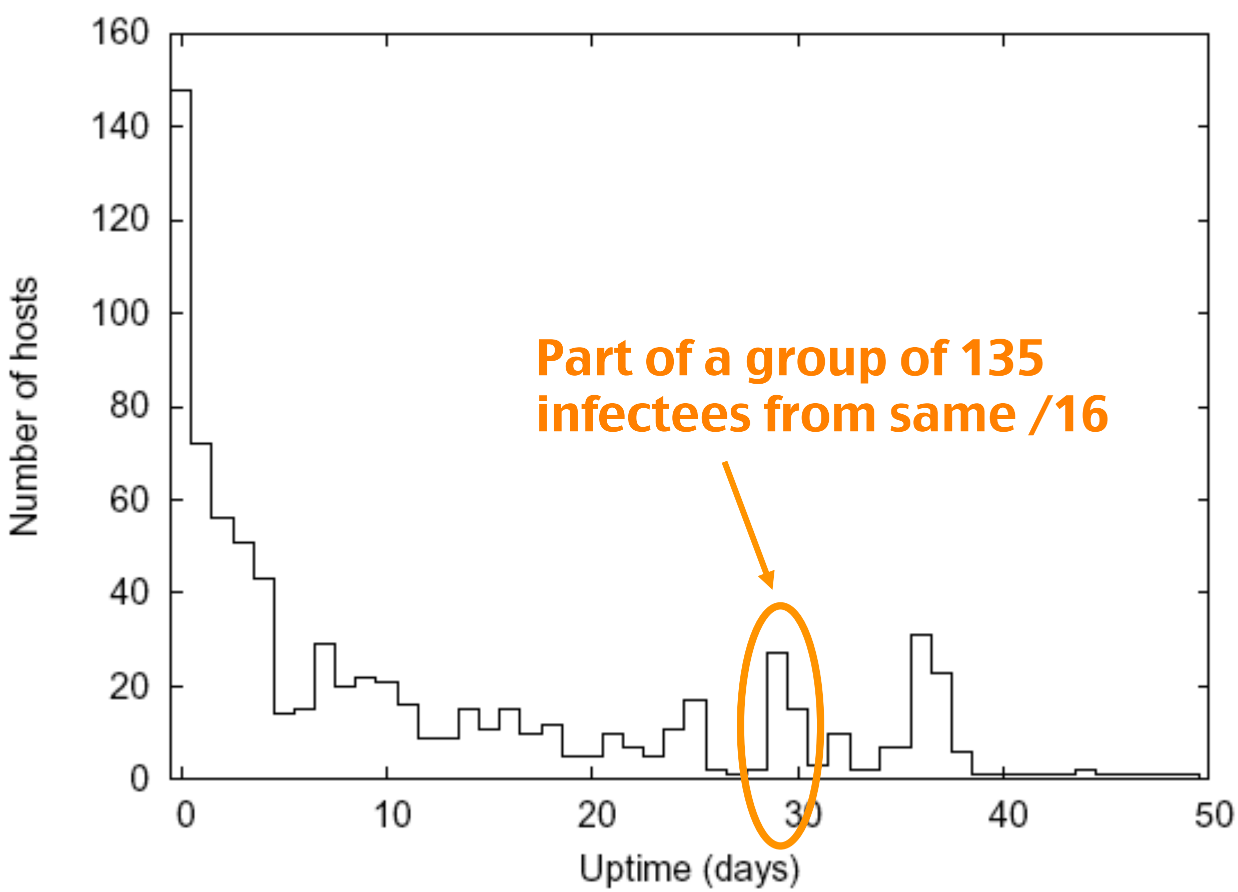


How Can an Unscanned Infectee Become Infected?

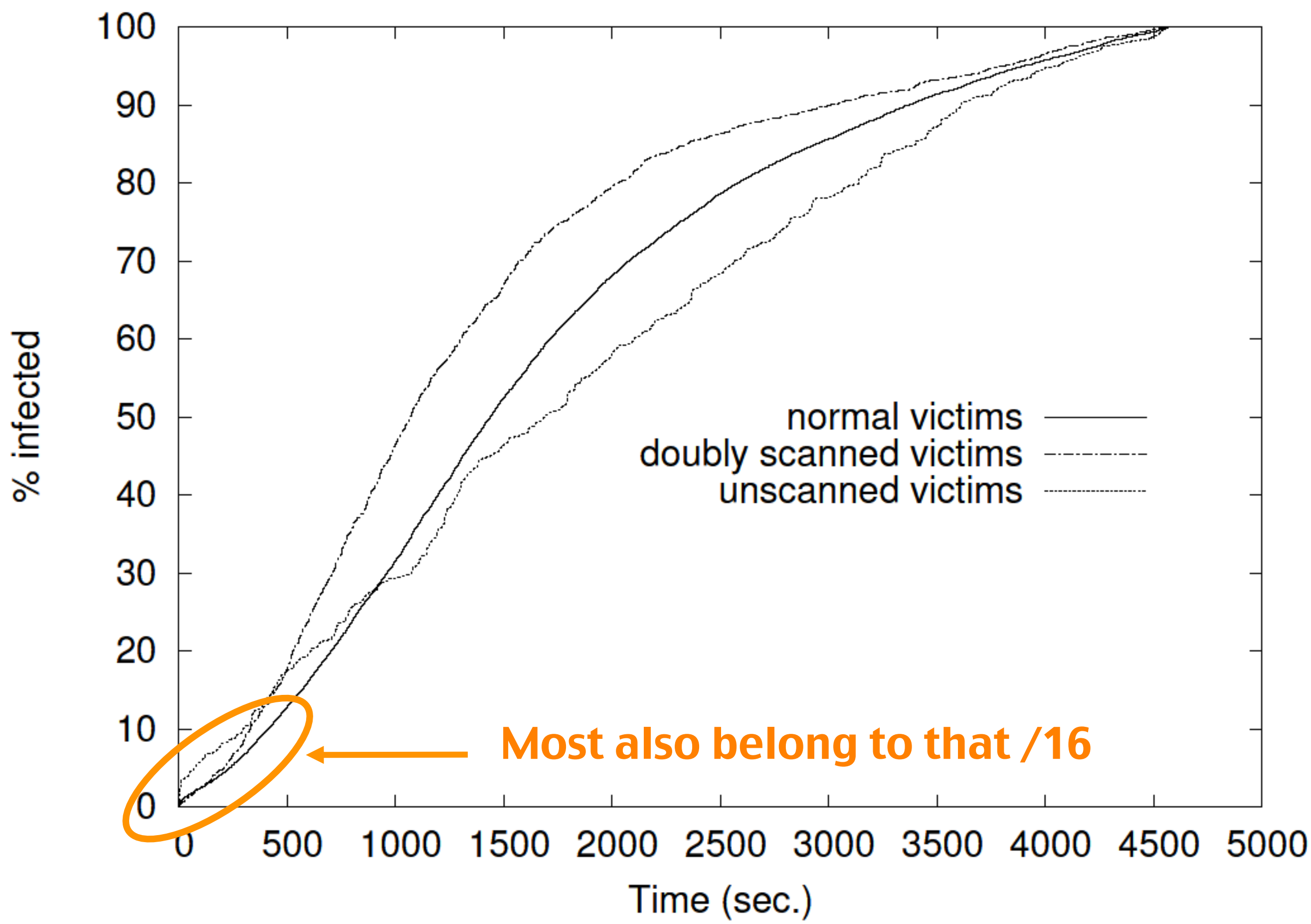
- Multihomed host infected via another address
  - Might show up with normal speed, but not *early*
- DHCP or NAT aliasing
  - Would show up *late*, certainly not *early*

- Could they have been *passively infected* extra quickly because they had large cross-sections?
- Just what are those hosts, anyway?

Uptime of 750 Witty Infectees



Time When Infectees Seen At Telescope



Did Witty Start With A "Hit List"?

- …Unlikely infection was due to passive monitoring: would require huge deployment
- Prevalent /16 = U.S. military base
- Attacker knew of ISS security software installation at military site ⇒ ***ISS insider*** (or *ex-insider*)
- Fits with very rapid development of worm after public vulnerability disclosure

Are All The Worms In Fact Executing Witty?

- Answer: No
- There is *one* “infectee” that probes addresses **not on the orbit.**
- Each probe contains Witty contagion, but lacks randomized payload size.
- Shows up very near beginning of trace.

⇒ *Patient Zero* - machine attacker used to launch Witty. (Really, *Patient Negative One*.)

  - European retail ISP
  - Information passed along to Law Enforcement

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- Fits with very rapid development of worm after public vulnerability disclosure
- Postscript, Mar 2014:
  – It was indeed a huge deployment!

Summary of Witty Telescope Forensics

- Understanding a measurement's underlying structure adds enormous analytic power
- Cuts both ways: makes *anonymization* much harder than one would think
- With enough effort, worm "attribution" can be possible
  - But: a *lot* of work
  - And: no guarantee of success