CIS 551 / TCOM 401

Computer and Network Security

Spring 2008

Lecture 13

Announcements

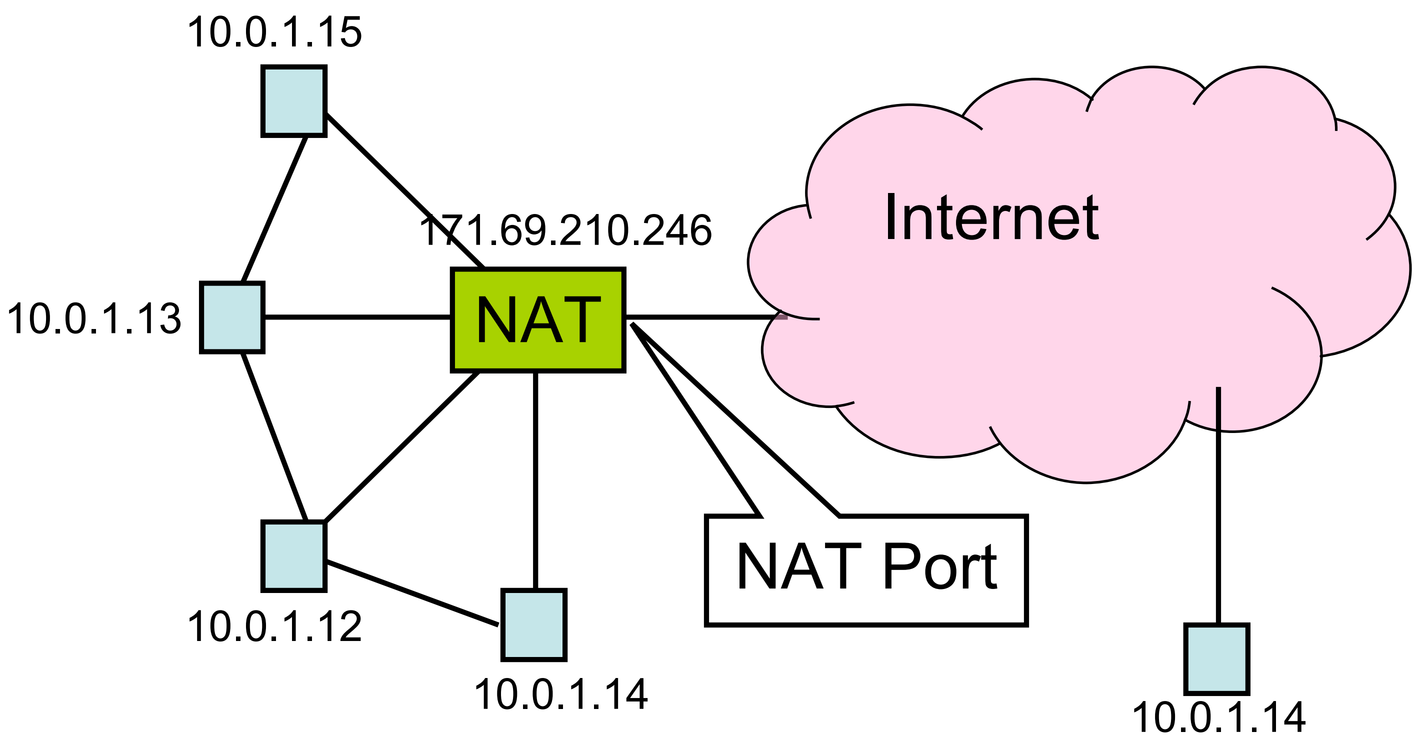
- Reminder:
  – Project 2 is due Friday, March 7th at 11:59 pm

Kinds of Firewalls

- Personal firewalls
  - Run at the end hosts
  - e.g. Norton, Windows, etc.
  - Benefit: has more application/user specific information
- Network Address Translators
  - Rewrites packet address information
- Filter Based
  - Operates by filtering based on packet headers
- Proxy based
  - Operates at the level of the application
  - e.g. HTTP web proxy

Network Address Translation

- Idea: Break the invariant that IP addresses are globally unique



NAT Behavior

- NAT maintains a table of the form:

  <client IP> <client port> <NAT ID>

- Outgoing packets (on non-NAT port):
  - Look for client IP address, client port in the mapping table
  - If found, replace client port with previously allocated NAT ID (same size as PORT #)
  - If not found, allocate a new unique NAT ID and replace source port with NAT ID
  - Replace source address with NAT address

NAT Behavior

- Incoming Packets (on NAT port)
  - Look up destination port number as NAT ID in port mapping table
  - If found, replace destination address and port with client entries from the mapping table
  - If not found, the packet is not for us and should be rejected

- Table entries expire after 2-3 minutes to allow them to be garbage collected

- "Private" IP addresses:
  - 192.168.x.x
  - 172.16.x.x
  - 172.31.x.x
  - 10.x.x.x

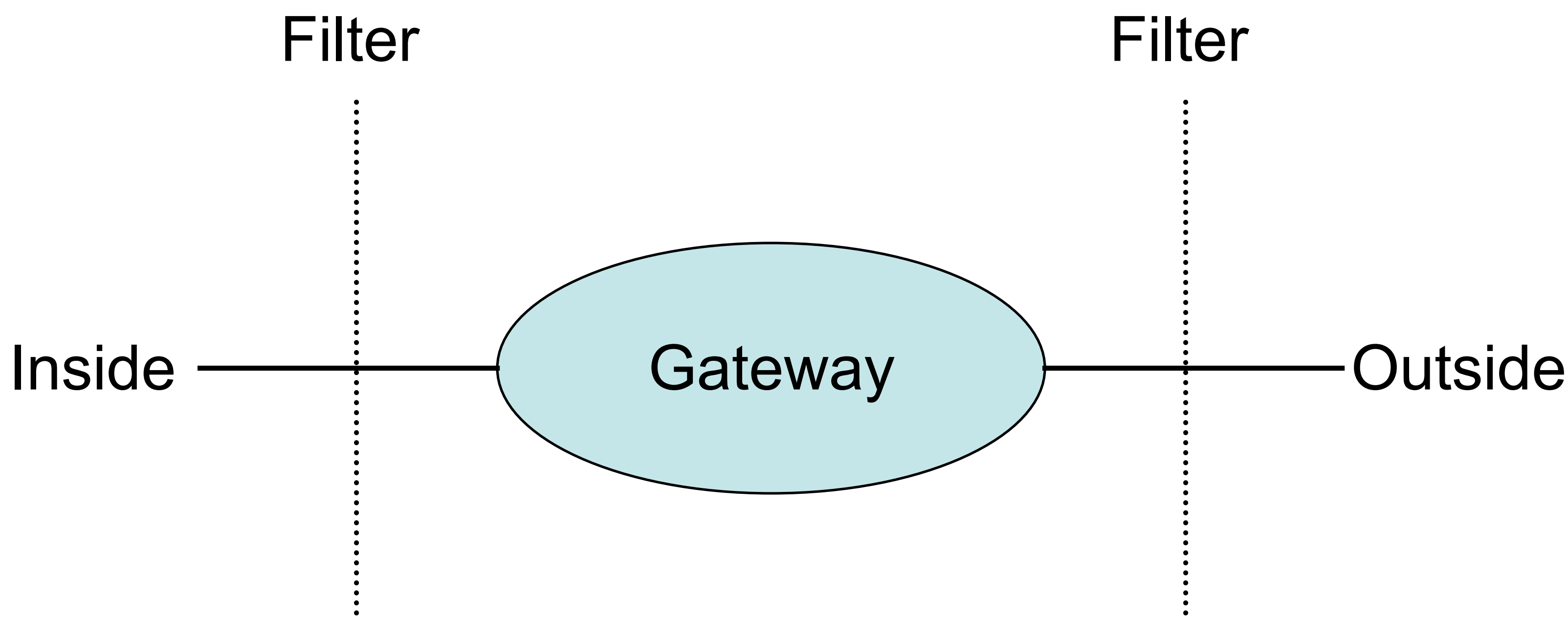
Benefits of NAT

- Only allows connections to the outside that are established from *inside.*
  - Hosts from outside can only contact internal hosts that appear in the mapping table, and they're only added when they establish the connection
  - Some NATs support firewall-like configurability
- Can simplify network administration
  - Divide network into smaller chunks
  - Consolidate configuration data
- Traffic logging
- Load balancing
- Robust failover

Drawbacks of NAT

- Rewriting IP addresses isn't so easy:
  - Must also look for IP addresses in other locations and rewrite them (may have to be protocol-aware)
  - Potentially changes sequence number information
  - Must validate/recalculate checksums
- Hinder throughput
- May not work with all protocols
  - Clients may have to be aware that NAT translation is going on
- Slow the adoption of IPv6?
- Limited filtering of packets / change packet semantics
  - For example, NATs may not work well with encryption schemes that include IP address information

Firewalls



- Filters protect against “bad” packets.
- Protect services offered internally from outside access.
- Provide outside services to hosts located inside.

Filtering Firewalls

- Filtering can take advantage of the following information from network and transport layer headers:
  - Source
  - Destination
  - Source Port
  - Destination Port
  - Flags (e.g. ACK)
  - Protocol type (e.g. UDP vs. TCP)
- Some firewalls keep state about open TCP connections
  - Allows conditional filtering rules of the form “if internal machine has established the TCP connection, permit inbound reply packets”

Filter Example

Action	ourhost	port	theirhost	port	comment
block	*	*	BAD	*	untrusted host
allow	GW	25	*	*	allow our SMTP port

Apply rules from top to bottom with assumed *default* entry:

Action	ourhost	port	theirhost	port	comment
block	*	*	*	*	default

Bad entry intended to allow connections to SMTP from inside:

Action	ourhost	port	theirhost	port	comment
allow	*	*	*	25	connect to their SMTP

This allows all connections from port 25, but an outside machine can run *anything* on its port 25!

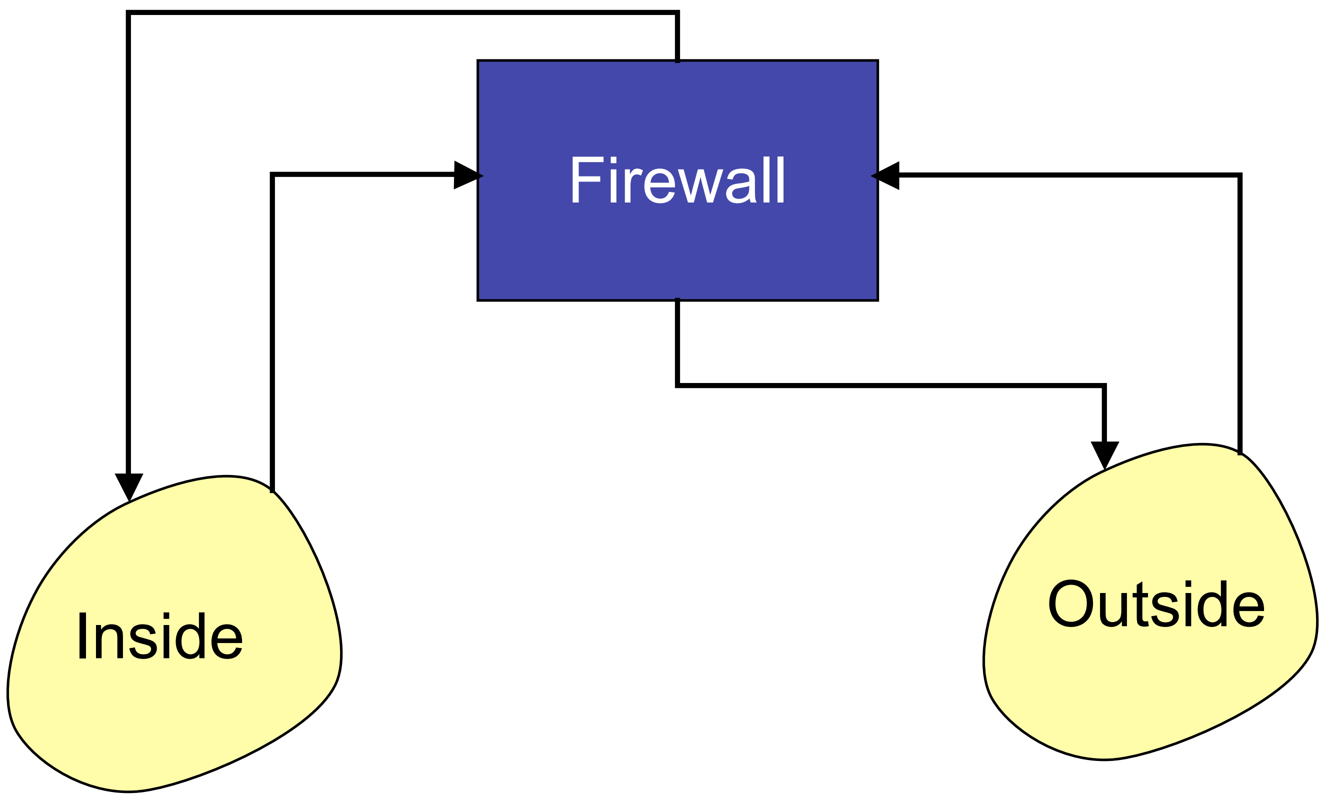
Filter Example Continued

Permit *outgoing* calls to port 25.

Action	src	port	dest	port	flags	comment
allow	123.45.6.*	*	*	25	*	their SMTP
allow	*	25	*	*	ACK	their replies

This filter doesn’t protect against IP address spoofing. The bad hosts can “pretend” to be one of the hosts with addresses 123.45.6.* .

When to Filter?



On Input or Output?

- Filtering on *output* can be more efficient since it can be combined with table lookup of the route.
- However, some information is lost at the output stage
  - e.g. the physical input port on which the packet arrived.
  - Can be useful information to prevent address spoofing.
- Filtering on *input* can protect the router itself.

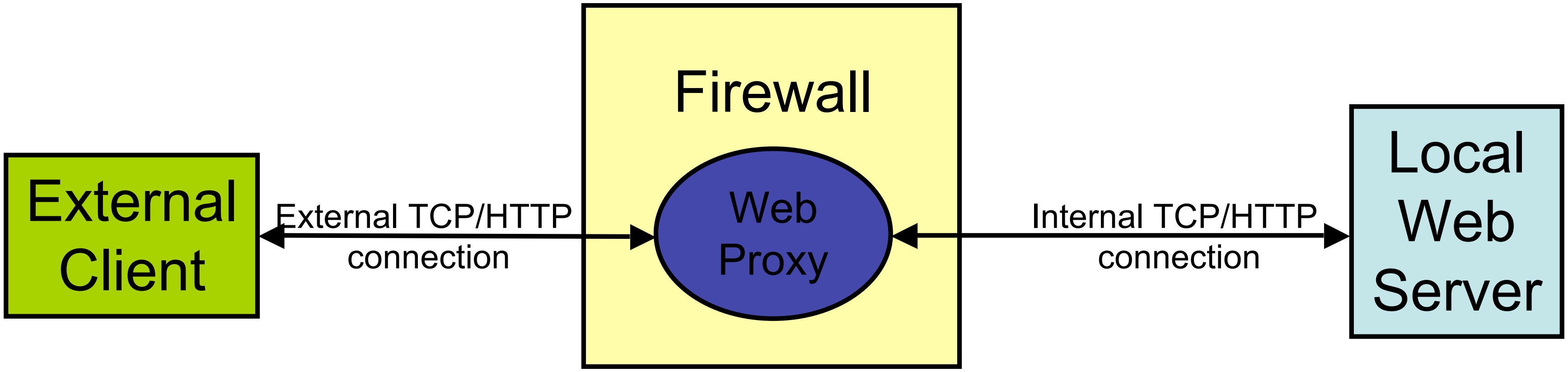
Principles for Firewall Configuration

- General principal: Filter as early as possible
- Least Privileges:
  - Turn off everything that is unnecessary (e.g. Web Servers should disable SMTP port 25)
- Failsafe Defaults:
  - By default should reject
  - (Note that this could cause usability problems…)
- Egress Filtering:
  - Filter outgoing packets too!
  - You know the valid IP addresses for machines internal to the network, so drop those that aren’t valid.
  - This can help prevent DoS attacks in the Internet.

Example “real” firewall config script

```
############
# FreeBSD Firewall configuration.
# Single-machine custom firewall setup. Protects somewhat
# against the outside world.
############

# Set this to your ip address.
ip="192.100.666.1"
setup_loopback

# Allow anything outbound from this address.
${fwcmd} add allow all from ${ip} to any out

# Deny anything outbound from other addresses.
${fwcmd} add deny log all from any to any out

# Allow inbound ftp, ssh, email, tcp-dns, http, https, imap, imaps,
# pop3, pop3s.
${fwcmd} add allow tcp from any to ${ip} 21 setup
${fwcmd} add allow tcp from any to ${ip} 22 setup
${fwcmd} add allow tcp from any to ${ip} 25 setup
${fwcmd} add allow tcp from any to ${ip} 53 setup
${fwcmd} add allow tcp from any to ${ip} 80 setup
${fwcmd} add allow tcp from any to ${ip} 443 setup
…
```

Proxy-based Firewalls



- Proxy acts like *both* a client and a server.
- Able to filter using application-level info
  - For example, permit some URLs to be visible outside and prevent others from being visible.
- Proxies can provide other services too
  - Caching, load balancing, etc.
  - FTP and Telnet proxies are common too

Benefits of Firewalls

- Increased security for internal hosts.
- Reduced amount of effort required to counter break ins.
- Possible added convenience of operation within firewall (with some risk).
- Reduced legal and other costs associated with hacker activities.

Drawbacks of Firewalls

- Costs:
  - Hardware purchase and maintenance
  - Software development or purchase, and update costs
  - Administrative setup and training, and ongoing administrative costs and trouble-shooting
  - Lost business or inconvenience from broken gateway
  - Loss of some services that an open connection would supply.
- False sense of security
  - Firewalls don't protect against viruses…

Snort

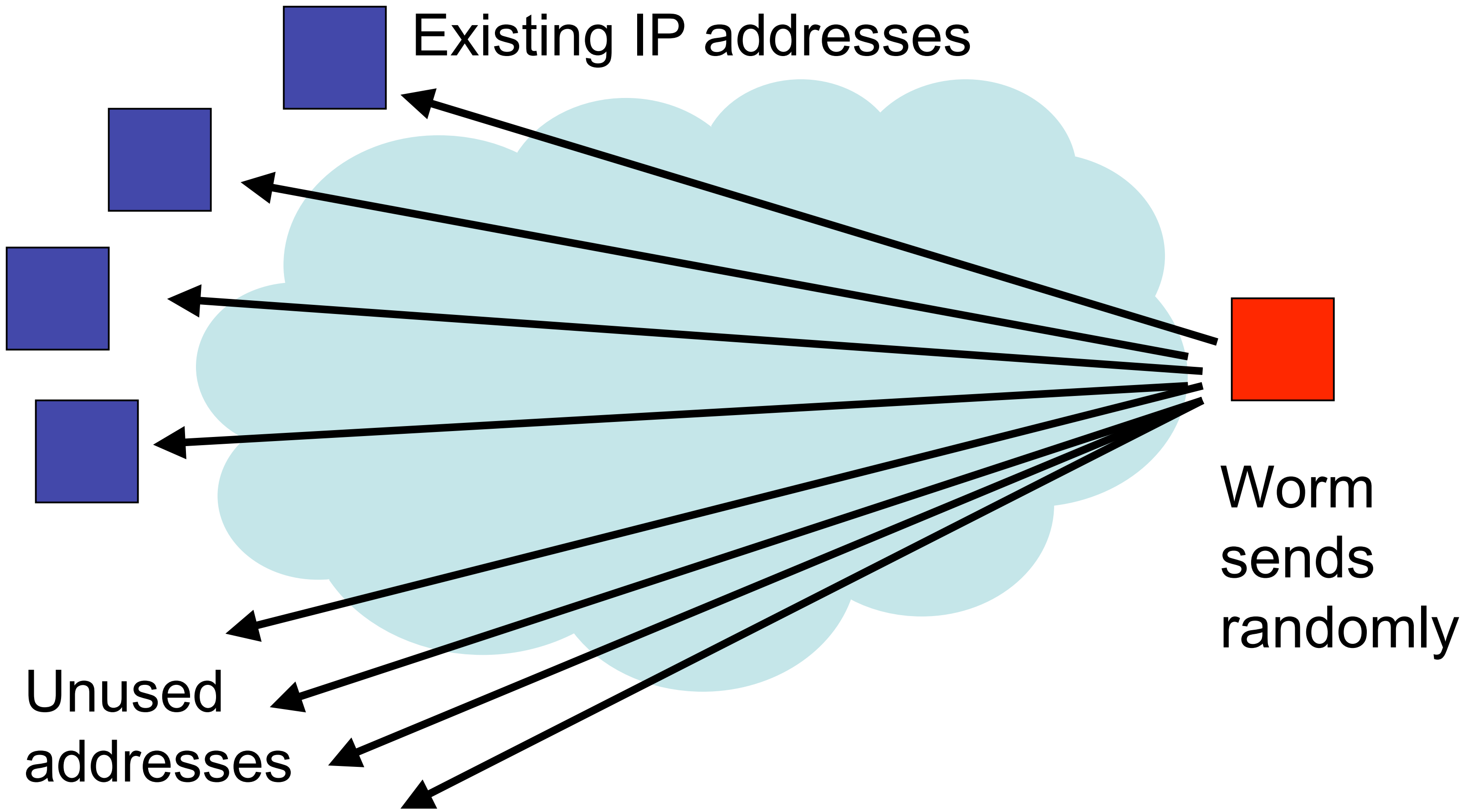
- Snort is a lightweight intrusion detection system:
  – Real-time traffic analysis
  – Packet logging (of IP networks)
- Rules based logging to perform content pattern matching to detect a variety of attacks and probes:
  – such as buffer overflows, stealth port scans, CGI attacks, SMB probes, etc.
- Example Rule:

```
alert tcp any any -> 192.168.1.0/24 143 (content:"|E8C0 FFFF
FF|/bin/sh"; msg:"New IMAP Buffer Overflow detected!";)
```

  – Generates an alert on all inbound traffic for port 143 with contents containing the specified attack signature.
- The Snort web site:
  – http://www.snort.org/docs/
- Question: How do you come up with the filter rules?

Internet Telescopes

- Can be used to detect large-scale, wide-spread attacks on the internet.



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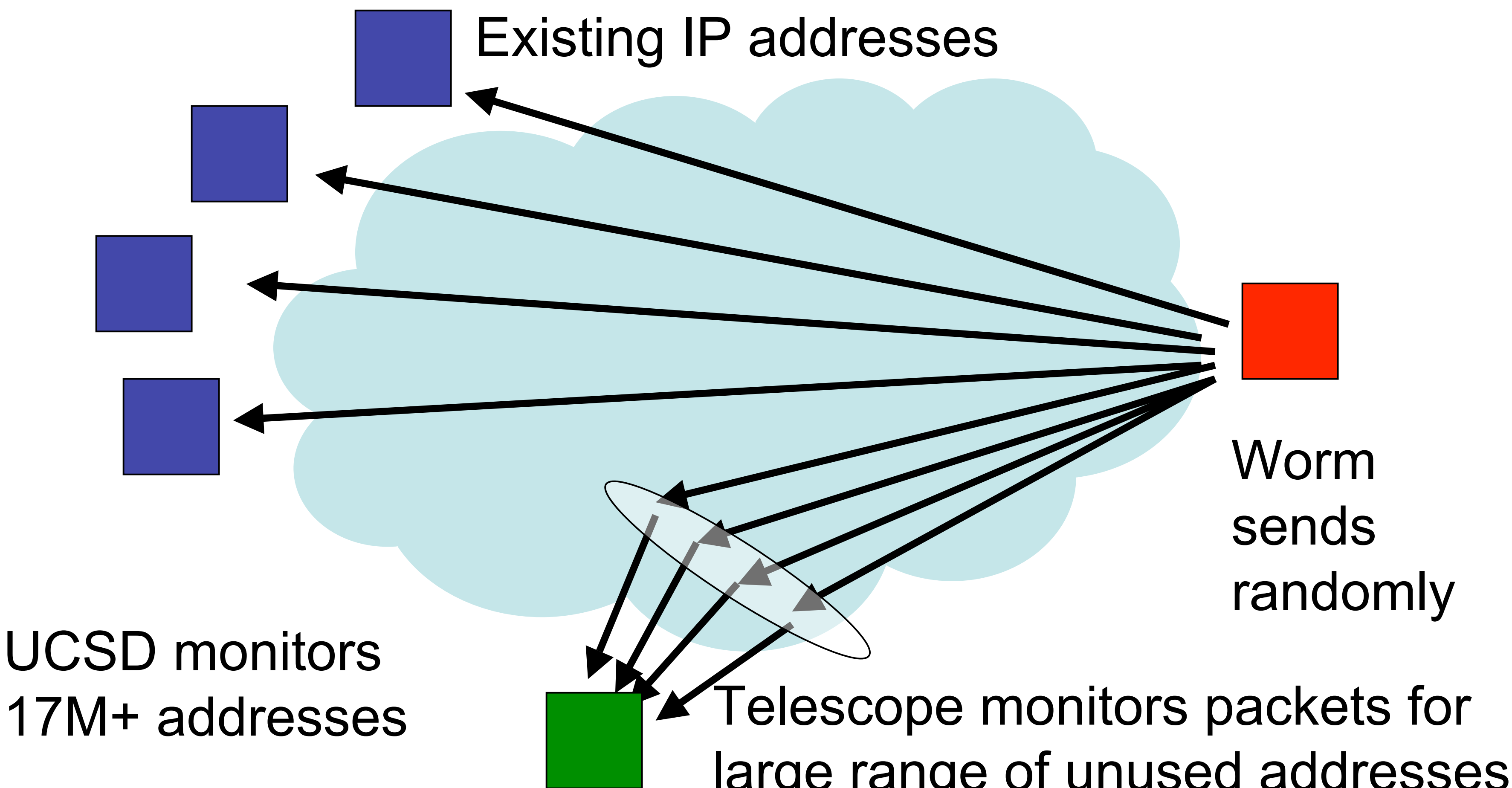
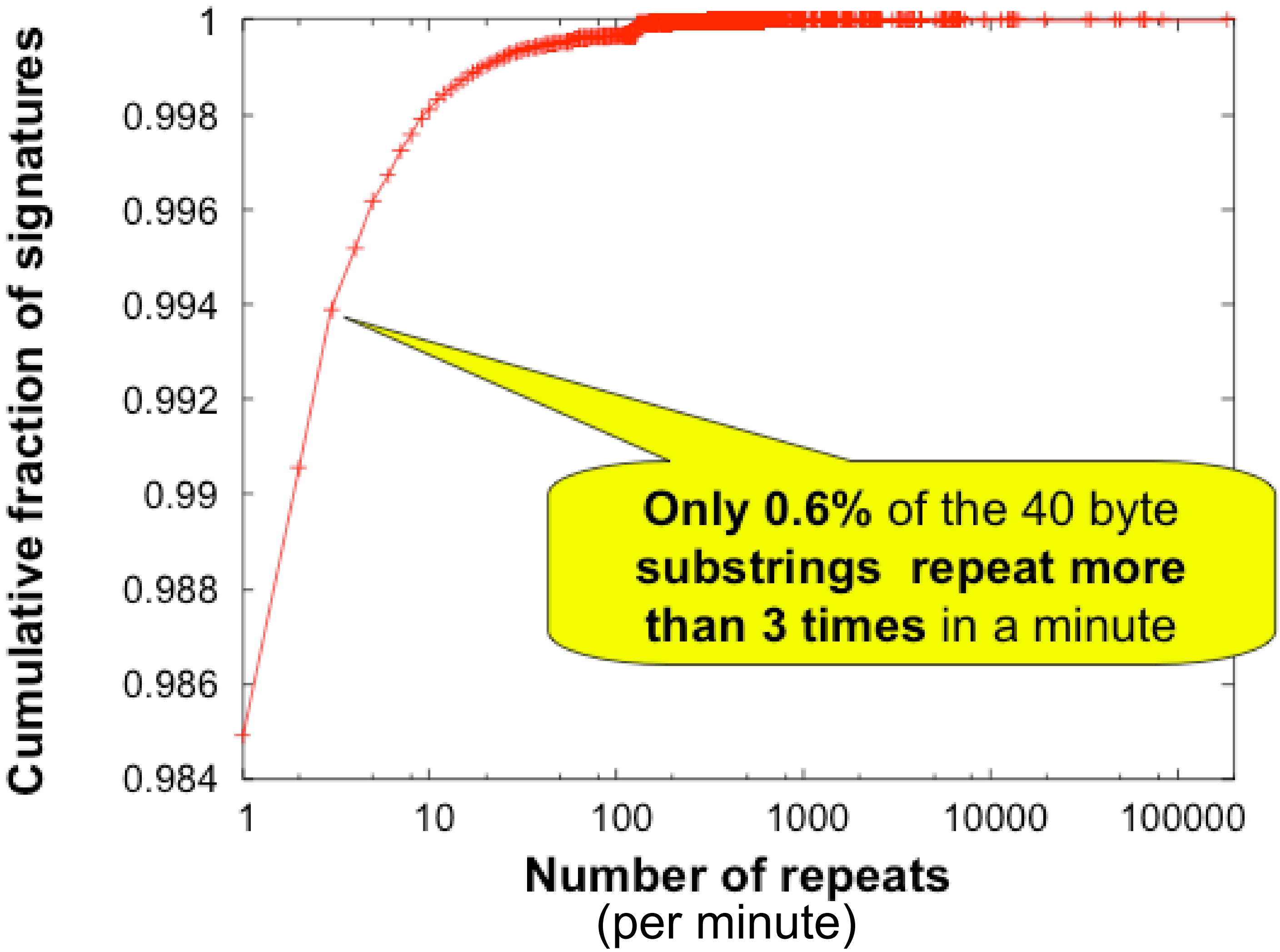


Automated Worm Fingerprinting

- Paper by Singh, Estan, Varghese, and Savage

- Assumptions:
  - All worms have invariant content
  - Invariant packets will appear frequently on the network
    - Worms are trying to propagate, after all
  - Packet sources and destinations will show high variability
    - Sources: over time number of distinct infected hosts will grow
    - Destinations: worms scan randomly
    - Distribution will be roughly uniform (unlike regular traffic that tends to be clustered)

High-prevalence strings are rare



Naïve Content Sifting

- ProcessTraffic(packet, srcIP, dstIP) {

```
  count[packet]++;
  Insert(srcIP, dispersion[packet].sources);
  Insert(dstIP, dispersion[packet].dests);
  if (count[packet] > countThresh
     && size(dispersion[packet].sources) > srcThresh
     && size(dispersion[packet].dests) > dstThresh) {
       Alarm(packet)
  }
}
```

- Tables count and dispersion are indexed by entire packet content.

Problems with Naïve approach

- Frequency count is inaccurate:
  - Misses common substrings
  - Misses shifted content
  - Ideally, would index count and dispersion by all substrings of packet content (of some length)
- Counting every source and destination is expensive.
- Too much data to process every packet.
  - Most packets are going to be uninteresting.
  - Tables count and dispersion will be huge!

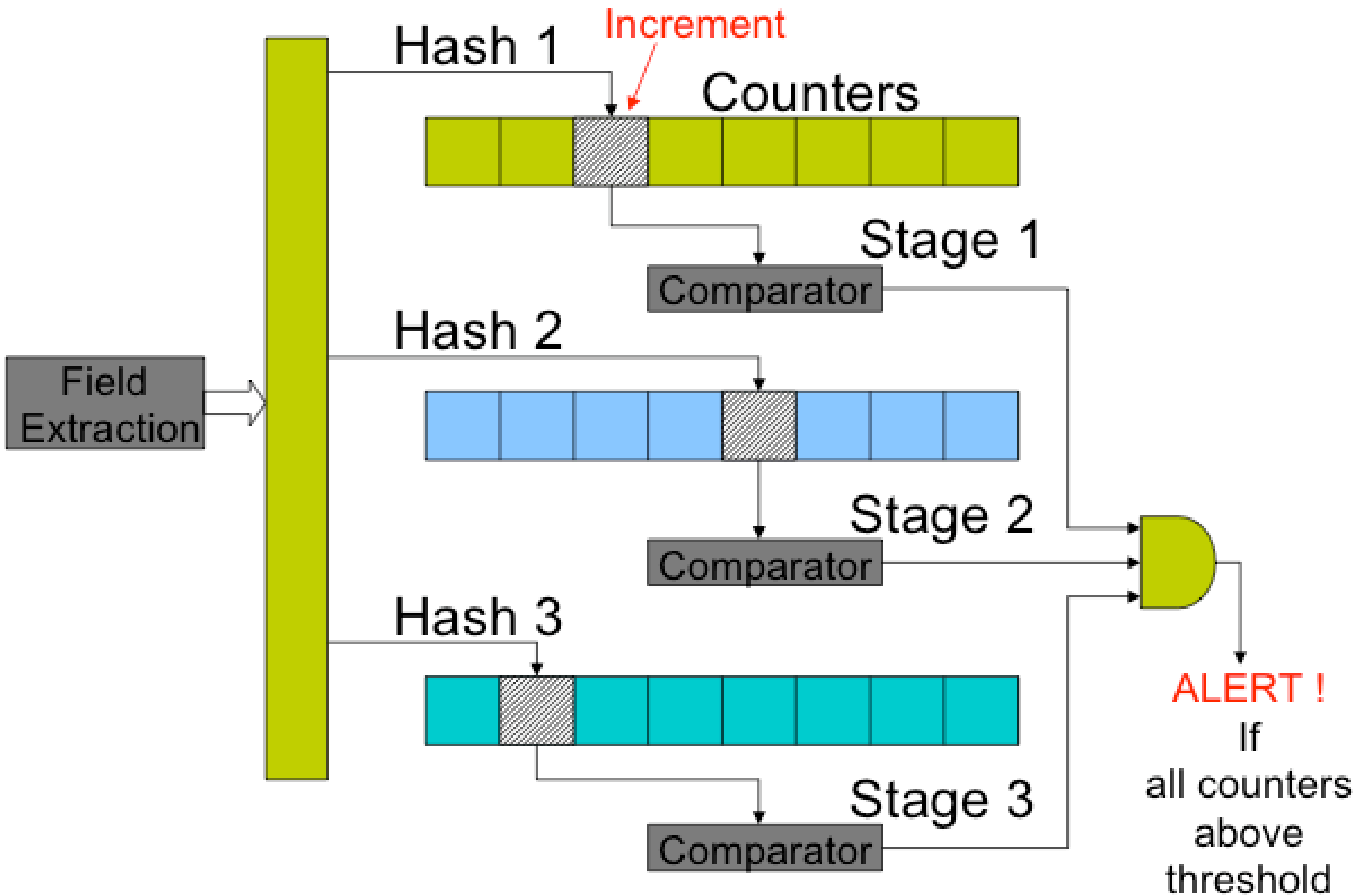
Engineering Challenges

- To support 1Gbps line rate have 12us to process each packet.
- Naïve implementation can easily use 100MB/sec for tables.
- Don't want to just do naïve sampling
  - E.g. don't want to just look at 1/N of the packets because detecting the worm will take N times as long

Practical Content Sifting

- Reduce size of count table by:
  - Hashing the packet content to a fixed size (*not* cryptographic hashes)
  - Hash collisions may lead to false positives
  - So, do multiple different hashes (say 3) -- worm content is flagged only if counts along all hashes exceed a threshold
- Include the destination port in the hash of the packet content
  - Current worms target specific vulnerabilities, so they usually aim for a particular port.
- To check for substring matches they propose to use a Rabin fingerprint
  - Probabilistic, incrementally computable hash of substrings of a fixed length.

Multistage Filters, Pictorially



Tracking Address Dispersion

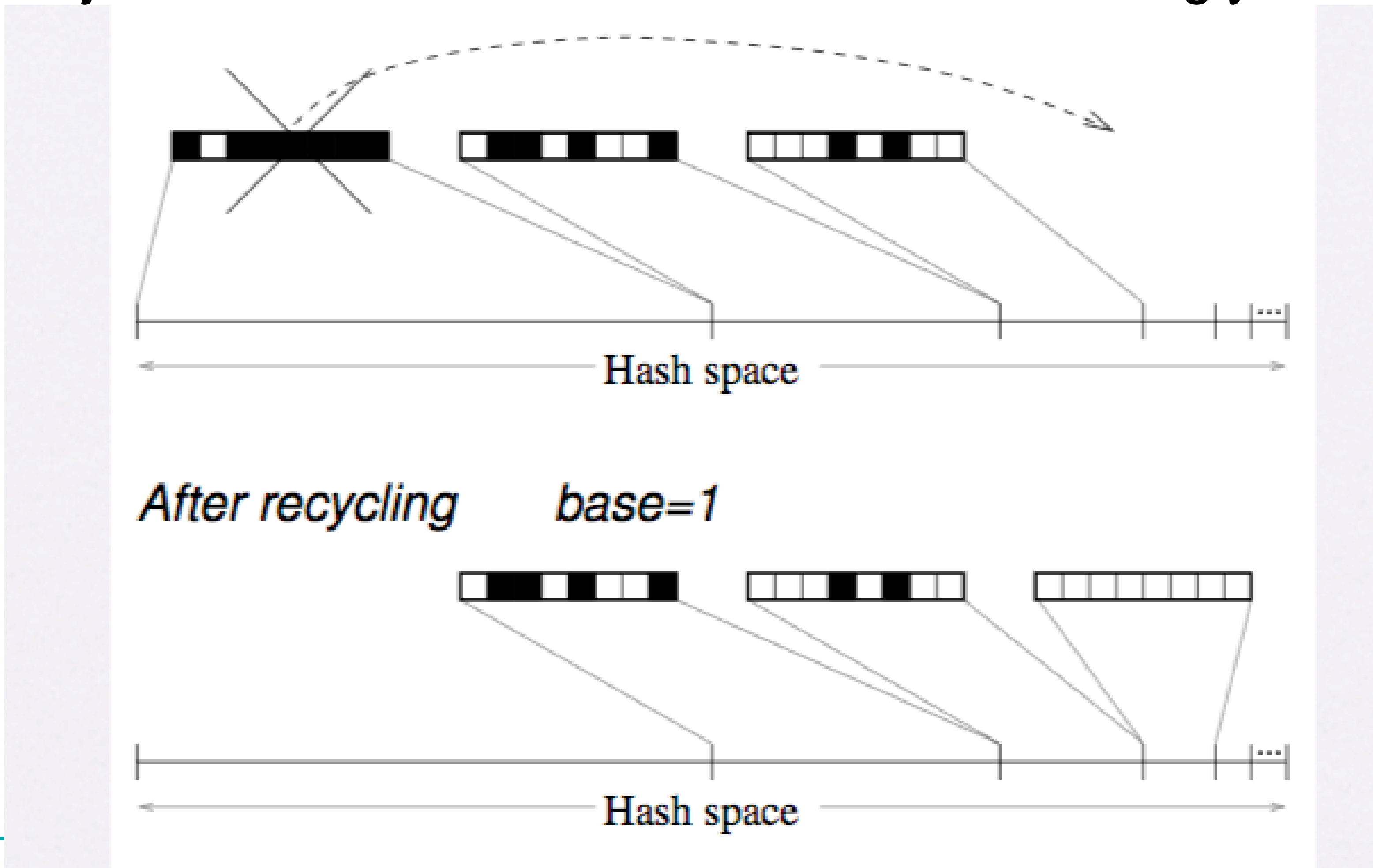
- In this case, we care about the number of distinct source (or destination) addresses in packets that contain suspected worm data.
- Could easily keep an exact count by using a hash table, but that becomes too time and memory intensive.
  - In the limit, need one bit per address to mark whether it has been seen or not.
- Instead: Keep an *approximate* count
- Scalable bitmap counters
  - Reduce memory requirements by 5x

Scalable Bitmap Counters

- Suppose there are 64 possible addresses and you want to use only 32 bits to keep track of them.
- High-level idea:
  - Hash the address into a value between 0 and 63
  - Use only the lower 5 bits (yielding 32)
  - To estimate actual number of addresses, multiply the number of bits set in the bitmap by 2.

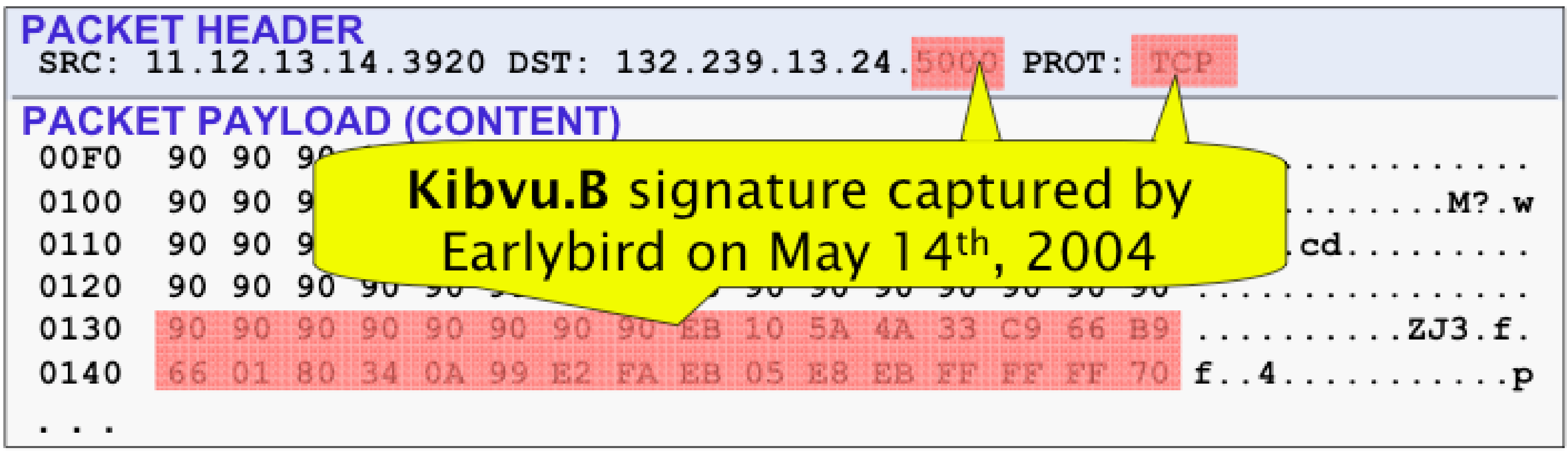
Multiple Bitmaps, Pictorially

- Recycle bitmaps after they fill up
- Adjust the scale factors on the counts accordingly



Results

- Earlybird successfully detects and extracts virus signatures from every known recent worm (CodeRed, MyDoom, Sasser, Kibvu.B,…)
- Tool generates content filter rules suitable for use with Snort



Analysis

- False Positives:
  - SPAM
  - BitTorrent
  - Common protocol headers
    - HTTP and SMTP
    - Some P2P system headers
  - Solution: whitelist by hand
- False Negatives:
  - Hard (impossible?) to prove absence of worms
  - Over 8 months Earlybird detected all worm outbreaks reported on security mailing lists