# Traffic: Monitoring, Estimation, and Engineering

Nick Feamster

CS 7260
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# Administrivia

- Syllabus redux
  - More time for traffic monitoring/engineering
  - Simulation vs. emulation pushed back (Feb. 21)

- Workshop deadlines (6-page papers)
  - Reducing unwanted traffic: April 17
  - Large scale attacks: April 21
  - Network management: April 26
  - *Include in your proposal whether you will aim for one of these.*

# End-to-End Routing *Behavior*

- **Prevalence:** Likelihood of seeing a route
  - Most paths dominated by a single prevalent route
- **Persistence:** Likelihood that a route stays same
  - Persistence of routes was variable
  - 2/3 of paths had routes persisting for days or weeks
- Observed doubling in pathologies over the course of a year.

# Method

- Centralized controller launches distributed traceroutes
- Pairwise traceroutes across sites
  - First dataset has interval of 1-2 days
  - Second dataset has some measurements in bursts
  - Second dataset has paired measurements
- (Mostly) poisson distribution of observations across paths
  - PASTA principle: fraction of *observations* implies fraction of overall *time*

# Arguing “Representativeness”

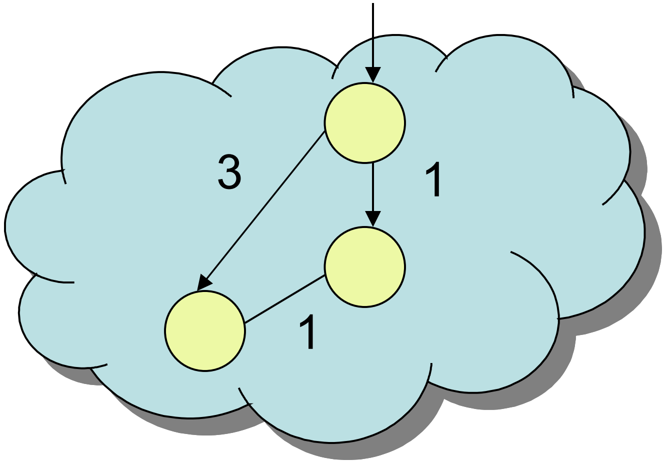
- Always tricky business…
- *This paper:* fraction of ASes traversed by the pairwise paths (8% “cross section”)
- D1: ~ 7k traceroutes; D2: ~38k traceroutes

## Limitations

- No explanation of *why* or *where*.
- Centralized controller limits flexibility
- Traceroute issues

# Routing Loops

- **Loops:** about 0.1% of all observations
  - Two modes: under three hours, more than 12 hours
  - Loops come in clusters
  - Loops can affect nearby routers
  - 5 observations of multiple AS loops (how can this happen? Examples…)



# Erroneous Routing

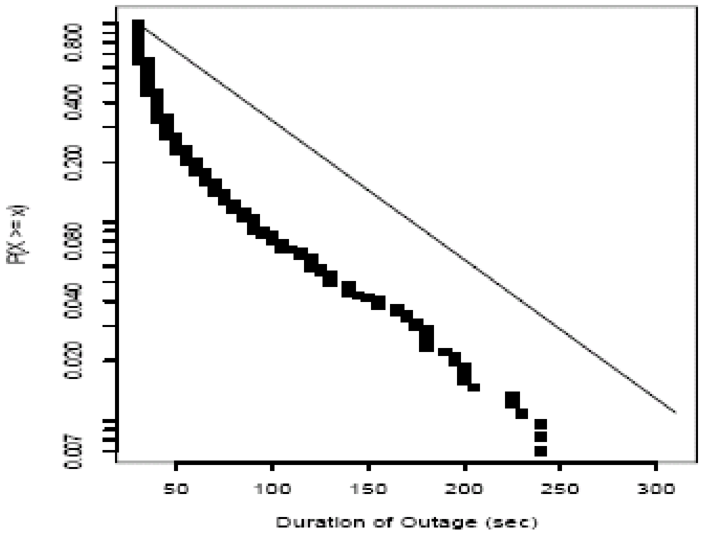
- Packets clearly taking wrong path (*e.g.*, through Israel)
- One example of erroneous routing

# Changing Paths

- Connectivity altered mid-stream
  - Between 0.16% and 0.44%
  - Recovery times bimodal
  - Cause
- Fluttering
  - Rapidly oscillating routing
    - Load balance/splitting
  - Distinct from fluttering caused by routing oscillations?

# Failures and Unreachability

- Availability rate of infrastructure about 99.5% - 99.8% (about 2.5 “nines”)
  - Assumes representative measurements
  - Assumes that other times paths were actually usable
  - Neglects times when infrastructure could not drive the measurement



- Most path lengths: about 15-16 hops
- Some diurnal patterns

# Routing Stability

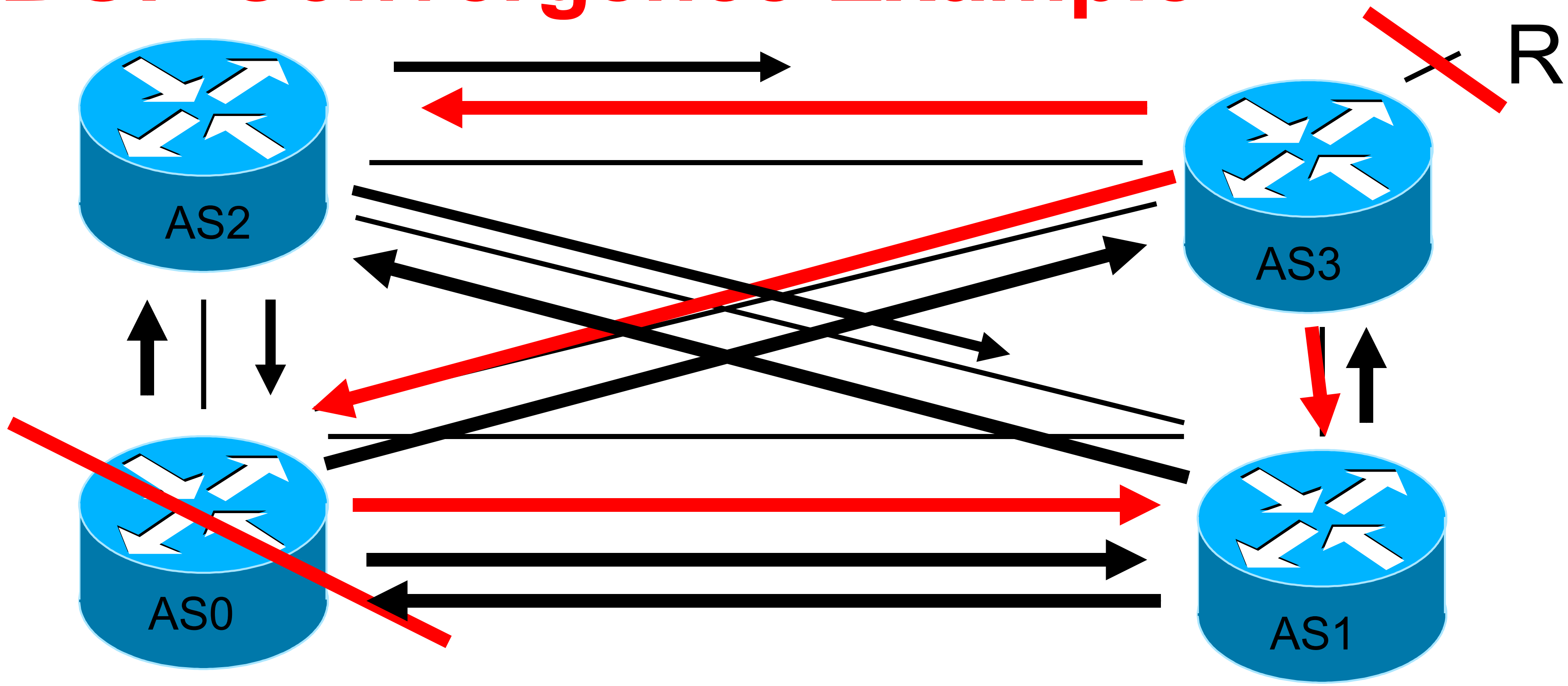
# Routing Symmetry

# Related Routing Pathology: Path Exploration

- **Routing pathologies:** Paxson’s paper from a few lectures ago: 3.3% of routes had “serious problems

- **Slow convergence:** BGP can take a long time to converge
  - Up to 30 minutes!
  - 10% of routes available < 95% of the time [Labovitz]

# BGP Convergence Example



~~*B R via AS3~~
~~*B R via AS1,AS3~~
~~B R via AS2.AS3~~

**AS0**

~~*B R via AS3~~
~~*B R via AS0,AS3~~
*B R via 203

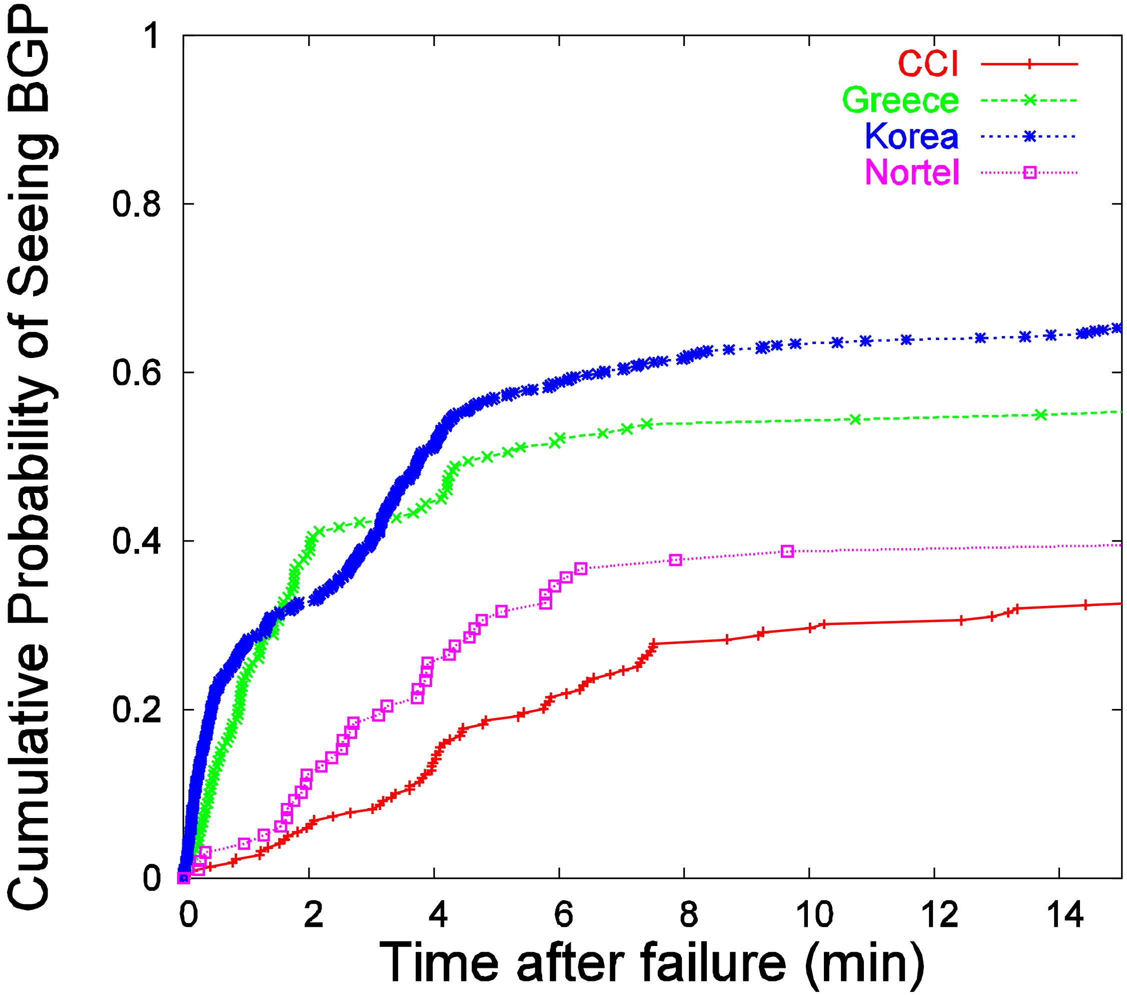
**AS1**

~~*B R via AS3~~
*B R via 013

**AS2**

# Slow Convergence in BGP

Given a failure, can take up to 15 minutes to see BGP.
*Sometimes, not at all.*

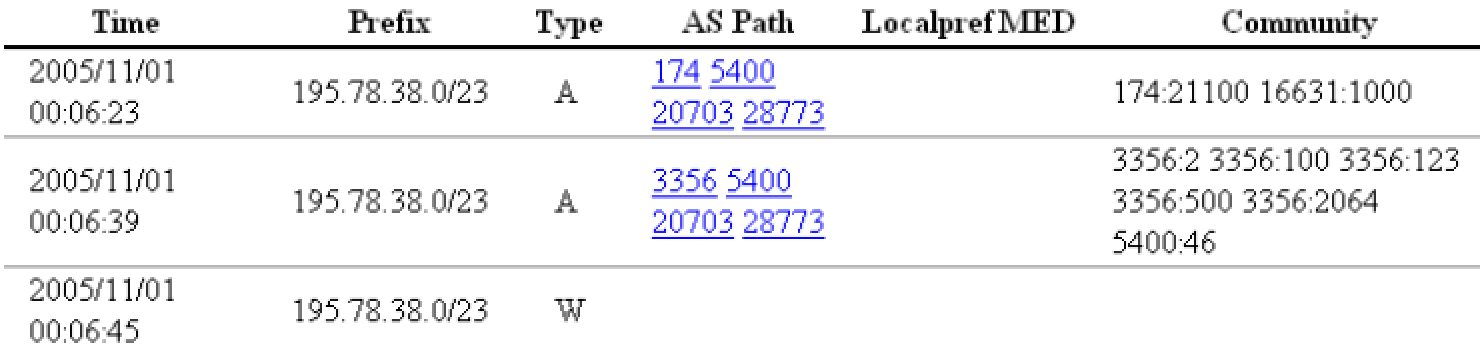


# Intuition for Delayed BGP Convergence

- There exists a message ordering for which BGP will explore all possible AS paths
  - Convergence is *O(N!)*, where N number of default-free BGP speakers in a complete graph
  - In practice, exploration can take 15-30 minutes
  - **Question:** What typically prevents this exploration from happening in practice?

- **Question:** Why can't BGP simply eliminate all paths containing a subpath when the subpath is withdrawn?

# Routing Convergence in Practice



| Time | Prefix | Type | AS Path | Localpref | MED | Community |
|---|---|---|---|---|---|---|
| 2005/11/01 00:06:23 | 195.78.38.0/23 | A | 174 5400 20703 28773 | | | 174:21100 16631:1000 |
| 2005/11/01 00:06:39 | 195.78.38.0/23 | A | 3356 5400 20703 28773 | | | 3356:2 3356:100 3356:123 3356:500 3356:2064 5400:46 |
| 2005/11/01 00:06:45 | 195.78.38.0/23 | W | | | | |

- Route withdrawn, but stub cycles through backup path…

# Passive Measurement

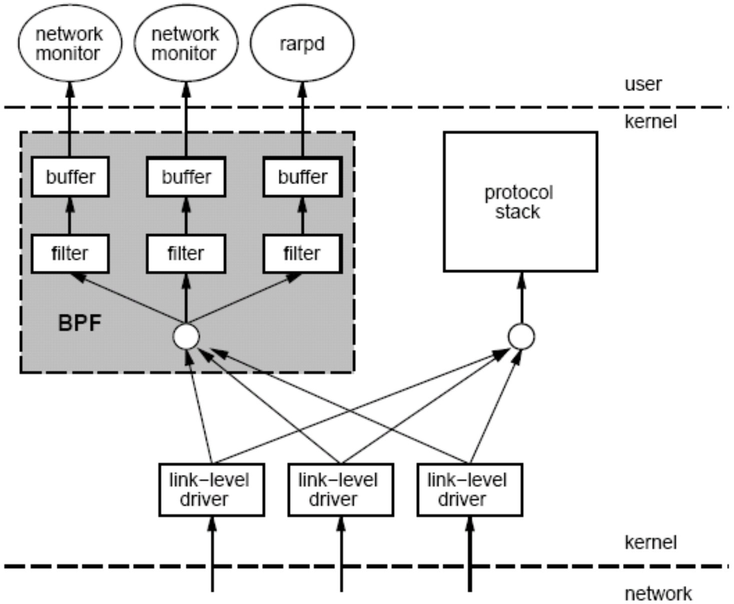
# Two Main Approaches

- Packet-level Monitoring
  - Keep packet-level statistics
  - Examine (and potentially, log) variety of packet-level statistics.  Essentially, anything in the packet.
  - **Timing**

- Flow-level Monitoring
  - Monitor packet-by-packet (though sometimes sampled)
  - Keep aggregate statistics on a flow

# Packet Capture: tcpdump/bpf

- Put interface in promiscuous mode
- Use bpf to extract packets of interest



## Accuracy Issues

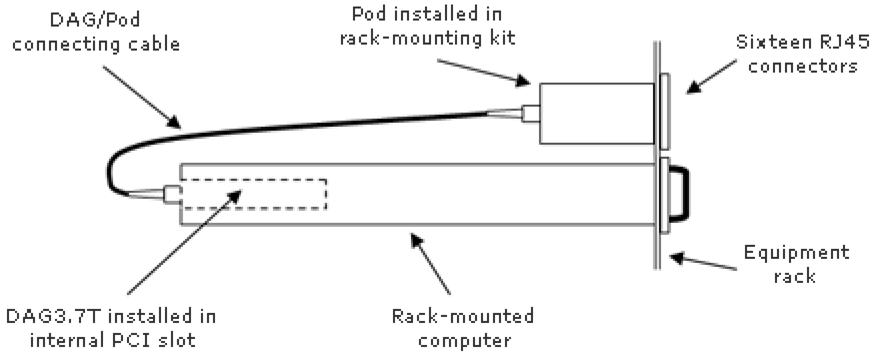
- Packets may be dropped by filter
  - Failure of tcpdump to keep up with filter
  - Failure of filter to keep up with dump speeds

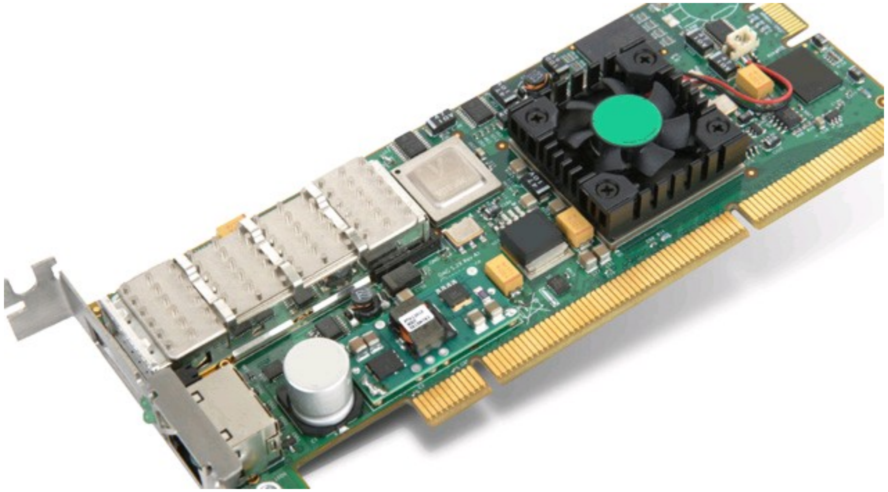
**Question:** How to recover lost information from packet drops?

# Packet Capture on High-Speed Links

**Example:** Georgia Tech “OC3Mon”

- Rack-mounted PC
- Optical splitter
- Data Acquisition and Generation (DAG) card





Source: endace.com

# Characteristics of Packet Capture

- Allows inpsection on every packet on 10G links

- Disadvantages
  - Costly
  - Requires splitting optical fibers
  - Must be able to filter/store data

# Traffic Flow Statistics

- *Flow monitoring* (*e.g*., Cisco Netflow)
  - Statistics about groups of related packets (*e.g.,* same IP/TCP headers and close in time)
  - Recording header information, counts, and time

- More detail than SNMP, less overhead than packet capture
  - Typically implemented directly on line card

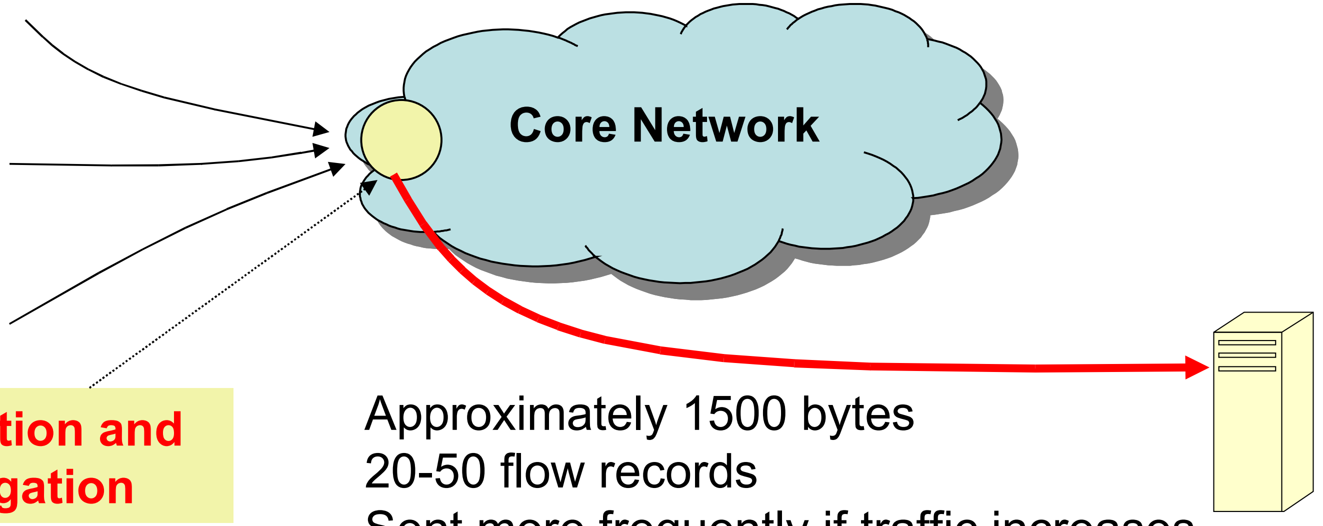
# What is a flow?

- **Source IP address**
- **Destination IP address**
- **Source port**
- **Destination port**
- **Layer 3 protocol type**
- TOS byte (DSCP)
- Input logical interface (ifIndex)

# Cisco Netflow

- Basic output: “Flow record”
  - Most common version is v5
  - Latest version is v10 (RFC 3917)

- Current version (10) is being standardized in the IETF (*template-based*)
  - More flexible record format
  - Much easier to add new flow record types



**Collection and Aggregation**

Approximately 1500 bytes
20-50 flow records
Sent more frequently if traffic increases

Collector
(PC)

# Flow Record Contents

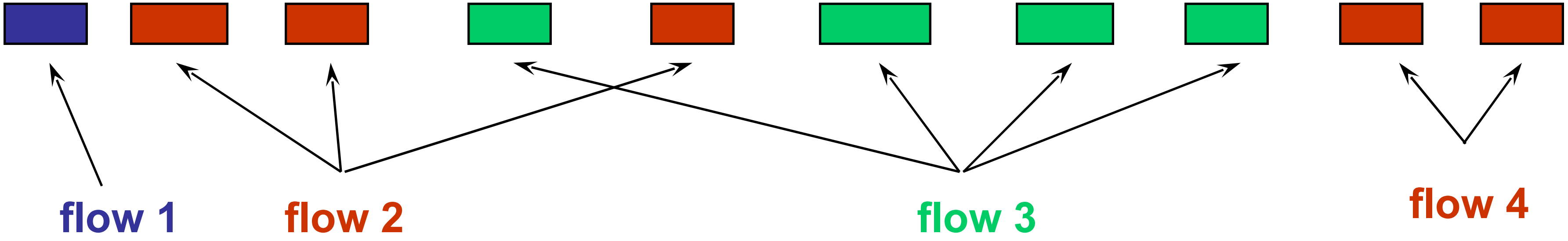
**Basic information about the flow…**

- Source and Destination, IP address and port
- Packet and byte counts
- Start and end times
- ToS, TCP flags

**…plus, information related to routing**

- Next-hop IP address
- Source and destination AS
- Source and destination prefix

# Aggregating Packets into Flows



- **Criteria 1:** Set of packets that "belong together"
  - Source/destination IP addresses and port numbers
  - Same protocol, ToS bits, …
  - Same input/output interfaces at a router (if known)

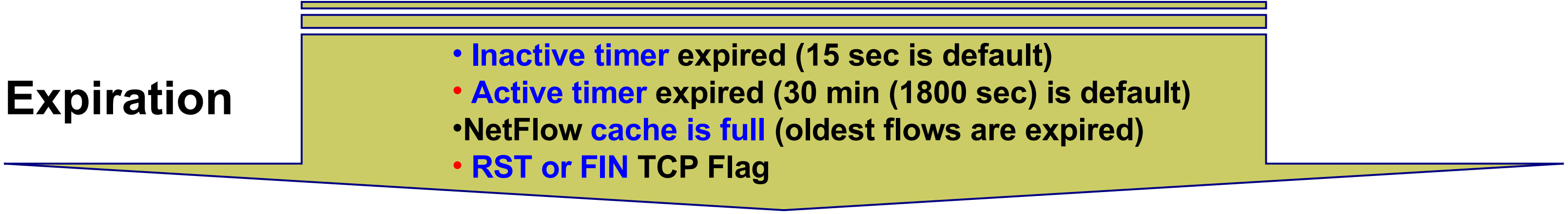
- **Criteria 2:** Packets that are "close" together in time
  - Maximum inter-packet spacing (e.g., 15 sec, 30 sec)
  - **Example:** flows 2 and 4 are different flows due to time

# Netflow Processing

## 1. Create and update flows in NetFlow Cache

| SrcIf | SrcIPadd | DstIf | DstIPadd | Protocol | TOS | Flgs | Pkts | SrcPort | SrcMsk | SrcAS | DstPort | DstMsk | DstAS | NextHop | Bytes/Pkt | Active | Idle |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fa1/0 | 173.100.21.2 | Fa0/0 | 10.0.227.12 | 11 | 80 | 10 | 11000 | 00A2 | /24 | 5 | 00A2 | /24 | 15 | 10.0.23.2 | 1528 | 1745 | 4 |
| Fa1/0 | 173.100.3.2 | Fa0/0 | 10.0.227.12 | 6 | 40 | 0 | 2491 | 15 | /26 | 196 | 15 | /24 | 15 | 10.0.23.2 | 740 | 41.5 | 1 |
| Fa1/0 | 173.100.20.2 | Fa0/0 | 10.0.227.12 | 11 | 80 | 10 | 10000 | 00A1 | /24 | 180 | 00A1 | /24 | 15 | 10.0.23.2 | 1428 | 1145.5 | 3 |
| Fa1/0 | 173.100.6.2 | Fa0/0 | 10.0.227.12 | 6 | 40 | 0 | 2210 | 19 | /30 | 180 | 19 | /24 | 15 | 10.0.23.2 | 1040 | 24.5 | 14 |

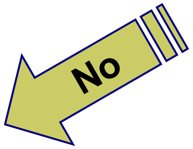
## 1. Expiration

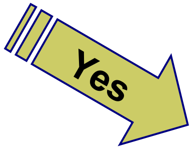


- **Inactive timer expired (15 sec is default)**
- **Active timer expired (30 min (1800 sec) is default)**
- **NetFlow cache is full (oldest flows are expired)**
- **RST or FIN TCP Flag**

| SrcIf | SrcIPadd | DstIf | DstIPadd | Protocol | TOS | Flgs | Pkts | SrcPort | SrcMsk | SrcAS | DstPort | DstMsk | DstAS | NextHop | Bytes/Pkt | Active | Idle |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fa1/0 | 173.100.21.2 | Fa0/0 | 10.0.227.12 | 11 | 80 | 10 | 11000 | 00A2 | /24 | 5 | 00A2 | /24 | 15 | 10.0.23.2 | 1528 | 1800 | 4 |

## 1. Aggregation?





e.g. Protocol-Port Aggregation Scheme becomes

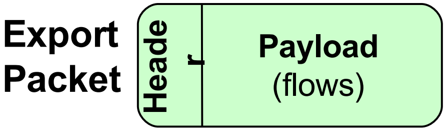
| Protocol | Pkts | SrcPort | DstPort | Bytes/Pkt |
|---|---|---|---|---|
| 11 | 11000 | 00A2 | 00A2 | 1528 |

## 1. Export Version

Non-Aggregated Flows – export **Version 5 or 9**

Aggregated Flows – export **Version 8 or 9**

## 1. Transport Protocol

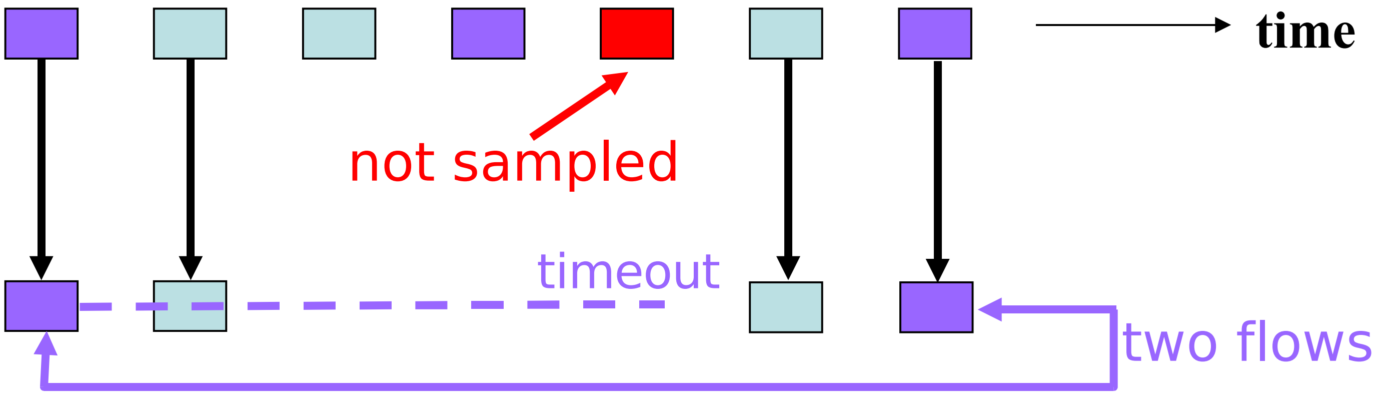


# Reducing Measurement Overhead

- **Filtering:** on interface
  - destination prefix for a customer
  - port number for an application (e.g., 80 for Web)
- **Sampling:** before insertion into flow cache
  - Random, deterministic, or hash-based sampling
  - 1-out-of-n or stratified based on packet/flow size
  - *Two types:* packet-level and flow-level
- **Aggregation:** after cache eviction
  - packets/flows with same next-hop AS
  - packets/flows destined to a particular service

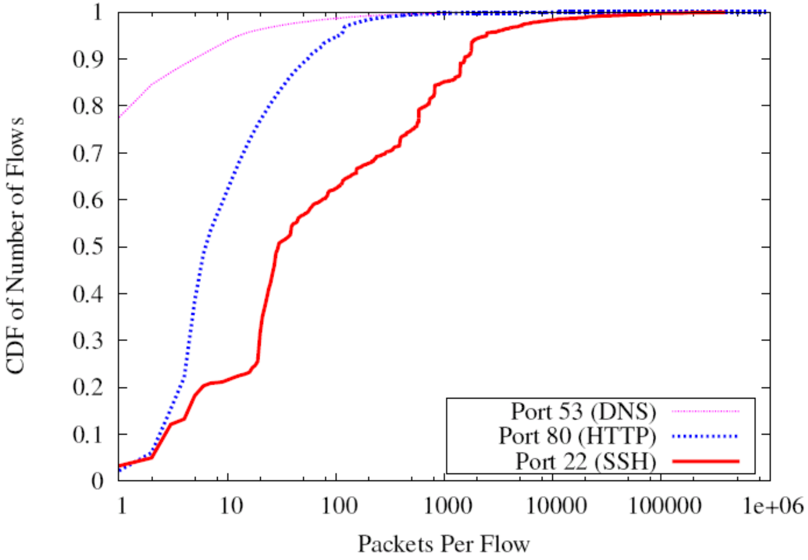
# Packet Sampling

- Packet sampling before flow creation (Sampled Netflow)
  - 1-out-of-m sampling of individual packets (*e.g.*, m=100)
  - Create of flow records over the sampled packets
- Reducing overhead
  - Avoid per-packet overhead on (m-1)/m packets
  - Avoid creating records for a large number of small flows
- Increasing overhead (in some cases)
  - May split some long transfers into multiple flow records
  - … due to larger time gaps between successive packets



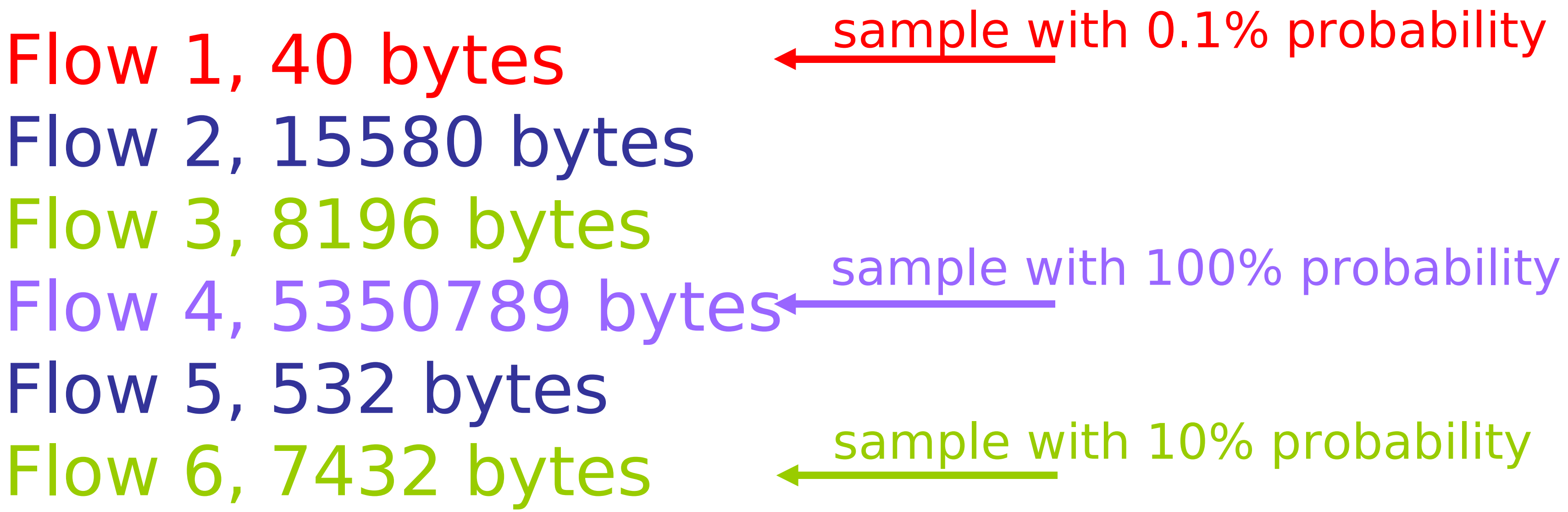
# Problems with Packet Sampling

- Determining size of original flows is tricky
  - For a flow originally of size *n*, the size of the *sampled* flow follows a binomial distribution
  - Extrapoliation can result in big errors
  - Much research in reducing such errors
    (upcoming lectures)
- Flow records can be lost
- Small flows may be eradicated entirely



# Sampling: Flow-Level Sampling

- Sampling of flow records evicted from flow cache
  - When evicting flows from table or when analyzing flows
- Stratified sampling to put weight on “heavy” flows
  - Select all long flows and sample the short flows
- Reduces the number of flow records
  - Still measures the vast majority of the traffic



Flow 1, 40 bytes

Flow 2, 15580 bytes

Flow 3, 8196 bytes

Flow 4, 5350789 bytes

Flow 5, 532 bytes

Flow 6, 7432 bytes

sample with 0.1% probability

sample with 100% probability

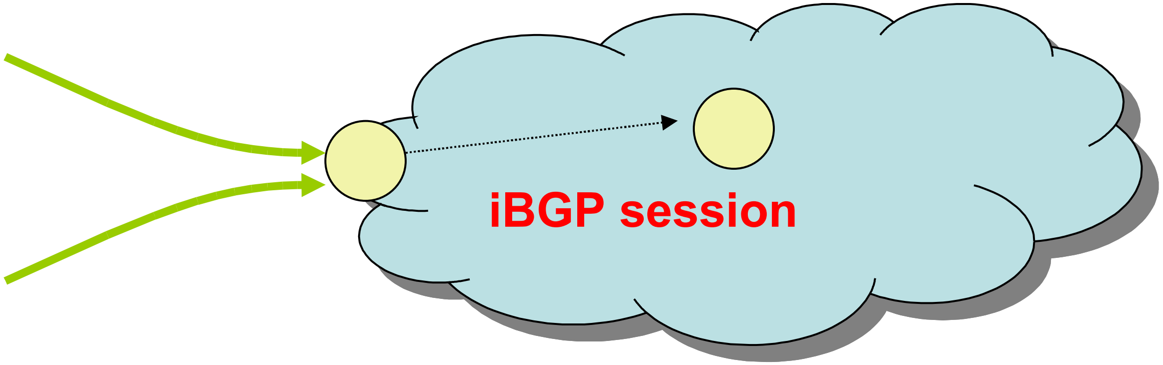
sample with 10% probability

# Accuracy Depends on Phenomenon

- Even naïve random sampling probably decent for capturing the *existence* of large flows

- Accurately measuring other features may require different approaches
  - Sizes of large flows
  - Distribution of flow sizes
  - Existence of small flows (coupon collection)
  - Size of small flows
  - Traffic “matrix”

# Routing Data



- IGP
- BGP
  - Collection methods
    - eBGP (typically “multihop”)
    - iBGP
  - Table dumps: Periodic, complete routing table state (direct dump from router)
  - Routing updates: Continuous, incremental, best route only

# Evaluation Strategies and Platforms

# Other Measurement Tools

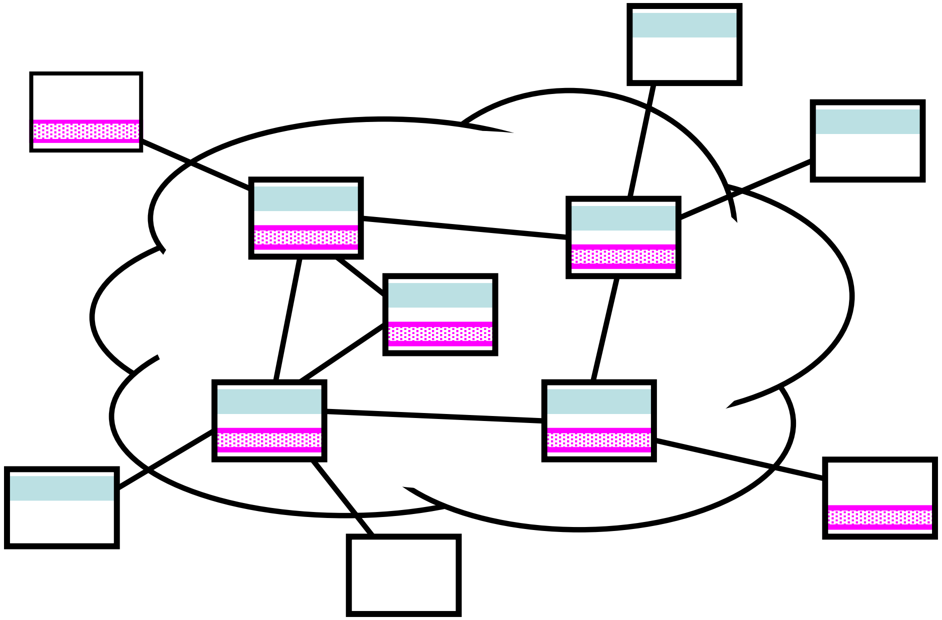
- Scriptroute (http://www.scriptroute.org/)
  - Write new probing tools/techniques, etc.
  - More on PS 2

# Evaluation Strategies

- **Simulation**
  - Ns2, SSFNet
  - Advantages: Control
- **Emulation**
  - Emulab
  - Advantages: Real software, more realistic conditions
- **Wide-area Deployment**
  - VINI
  - Simultaneous operation, sharing
  - Advantages: Ability to carry real traffic

**Next Lecture: Comparisons of these different evaluation strategies**

# PlanetLab: Distributed Services



**Key challenge: Isolation**

- **Slice:** Set of VMs are treated as a single entity (*distributed virtualization*)
- Isolation at system call level (vservers)
  - Shared filesystem, memory, etc.
- Network virtualization: safe raw sockets
  - Must be bound to a specific port

# Virtualization

- Advantages
  - Simultaneous access to shared physical resources
- Disadvantages
  - Requires scheduling
  - Not running on “raw” hardware. May not see similar performance as the “real” network/system

# PlanetLab for Network Measurement

- Nodes are largely at academic sites
  - Other alternatives: RON testbed (*disadvantage:* difficult to run long running measurements)
- Repeatability of network experiments is tricky
  - Proportional sharing
    - Minimum guarantees provided by limiting the number of outstanding shares
  - Work-conserving CPU scheduler means experiment could get *more* resources if there is less contention

# PlanetLab for Network Architecture

- New components must be virtualized
  - Interfaces
  - Links
- Support for forwarding traffic over virtual links
- Stock and custom routing software