Internet SIBILLA on Path-Stitching-Based Delay Prediction

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“Measurement Data”

- Internet performance measurement data useful to
  - Internet scientists, engineers or operators
  - Network application developers
  - End users

- Traditional active measurements:
  - Define estimation methodologies for delay, path, loss, etc.
  - Carefully construct an active probing strategy
  - Instrument end-systems to collect measurement

“Measurement Data” Retrieval

- ***Problem statements***

Given two arbitrary points x and y in the Internet,
We estimate Internet forwarding $path(x, y)$, and
retrieve queried measurement data on $path(x, y)$
without additional active measurements.

- Our vision is to offer measurements retrieval
  as “DNS-like” Internet service: Internet SIBILLA

Talk Outline

- Path Stitching algorithm
  - Constructing the path segment repository
  - Approximation and preference rules
  - Sources of errors
  - Evaluation
- Design considerations for Internet SIBILLA
  - Off-line storage
  - Interface

Part I. “Path Stitching”

A light-weight algorithm for Internet-wide path and delay estimation using existing measurements

“Path Stitching”

- Path and delay estimation between any pair of Internet hosts
- Key assumption:

  “Many good measurement data are available already.”

- Decoupling the data collection phase from the data analysis

Key ideas behind *path stitching*

Internet separates ***inter-*** and ***intra-domain*** routing;

To predict a new path, path stitching

» ***Splits*** paths into AS-path segments, and

» ***Stitches*** path segments together

» ***Using*** BGP routing information

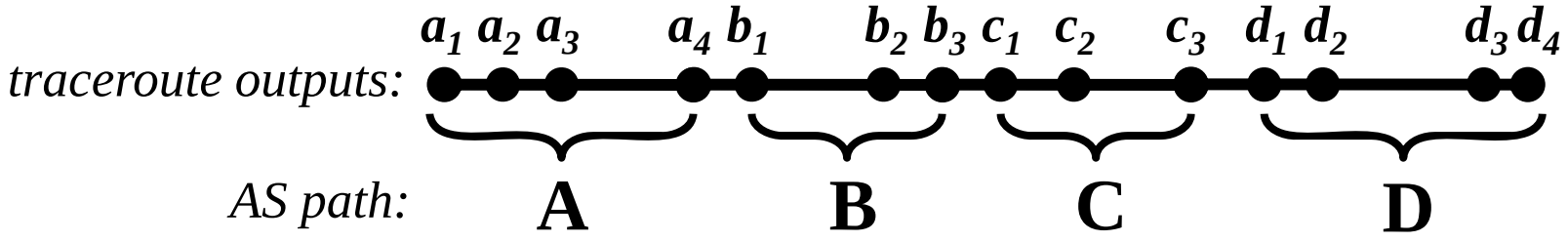
Data Sets

- *CAIDA **Ark**'s traceroutes*
  - One round of *traceroute* outputs from 18 sources to every /24 prefix
  - 14 millions of *traceroute* outputs

- BGP routing tables
  - University of Oregon, ***RouteViews***' BGP listener
  - ***RIPE RIS***' 14 monitoring points (rrc00 ~ rrc07, rrc10 ~ rrc15)

Path Segment Repository

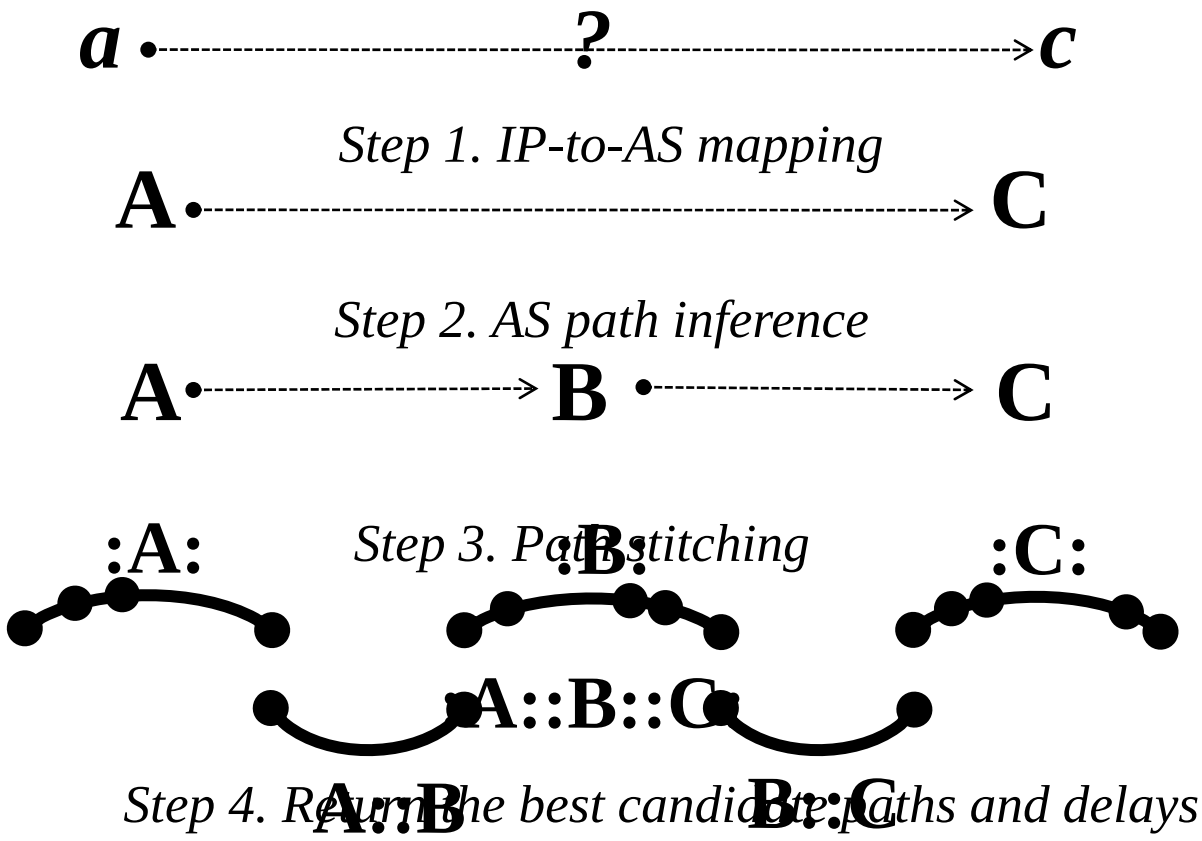
- In order to make a huge number of traceroute measurements ***searchable,***



  - **:A:** Intra-domain segments of **A** : $a_1\, a_2\, a_3\, a_4$
    :B: Intra-domain segments of **B** : $b_1 b_2\, b_3$
    A::B Inter-domain segments between **A** and **B** : $a_4\, b_1$
  - **:A: + A::B + :B:**
    = Router-level paths from **A** to **B** : $a_1\, a_2\, a_3 a_4\, b_1 b_2\, b_3$

Overview of "Path Stitching"

- What's the *router-level paths* and *latency estimates* between two arbitrary Internet hosts ***a*** and ***c?***

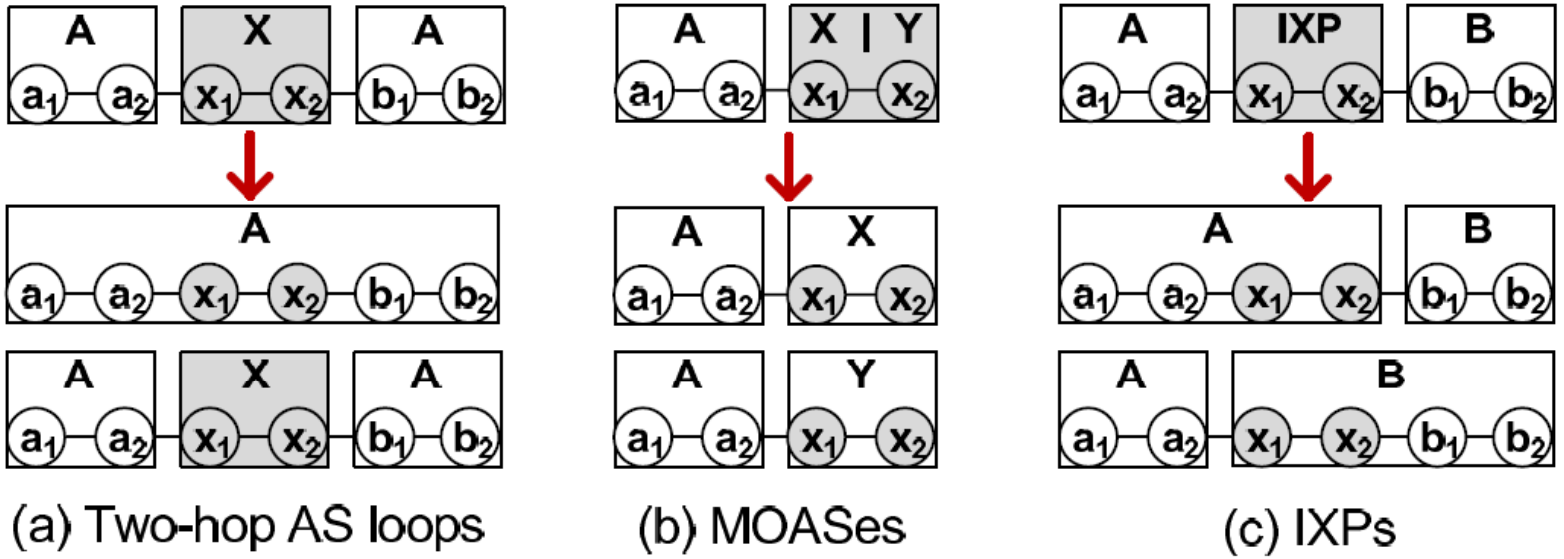


Addressing Sources of Error – (1)

- IP-to-AS Mapping
  - Single and multiple origin AS mismatches
  - Incorporate connectivity between ASes despite the mapping problem

IP-to-AS mapping errors

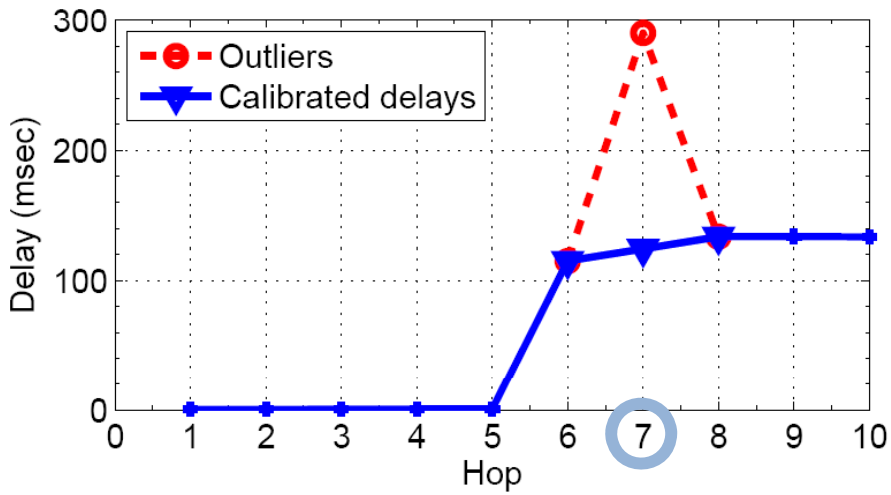
Build indexes for all possible combinations



Addressing Sources of Error – (2)

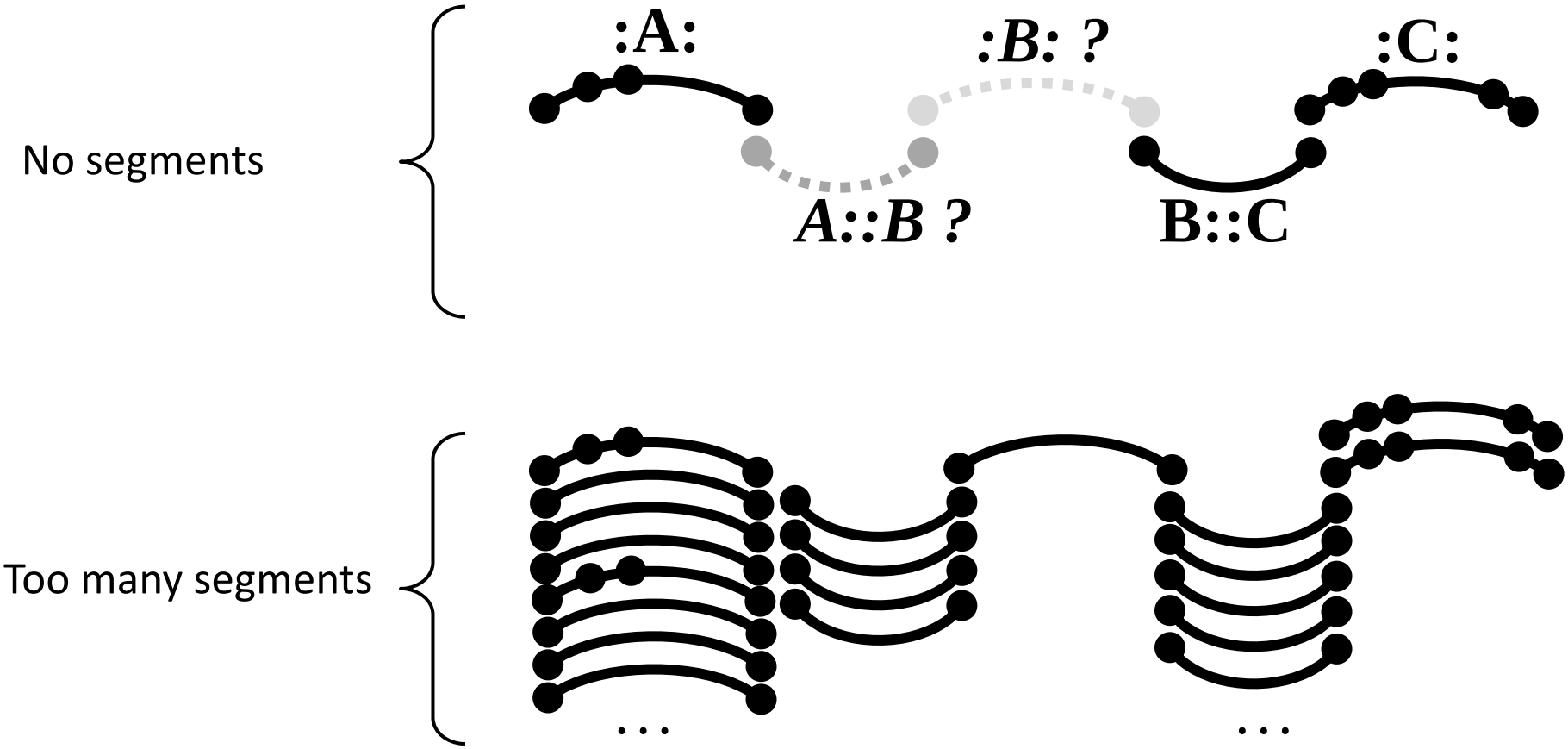
- AS Path Inference
  - Multi-homing is one of the main obstacles to the accurate AS path inference [Mao *et al.* SIGMETRICS 2005]
  - We extract ***first-hop information*** from the Ark traceroute data. (We garner first hop information for 5,387 ASes)

- Traceroutes
  - Internet dynamics captured by traceroute: provide both the ***median*** and ***the most recent*** measurements.
  - ***Nondecreasing delay principle*** ----------->



Too Few or Too Many Path Segments

- In Step 3 of our algorithm,



No Segments: Approximations

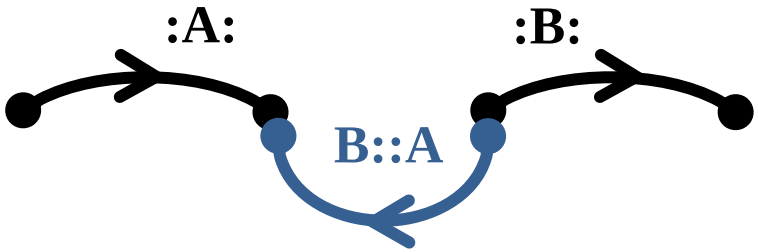
(i) Missing AS

» No solutions (other than collecting more measurements.)

(ii) Missing inter-domain segment

» Search for reverse path segments.

(i.e., if we cannot find **A::B**, use **B::A** instead)



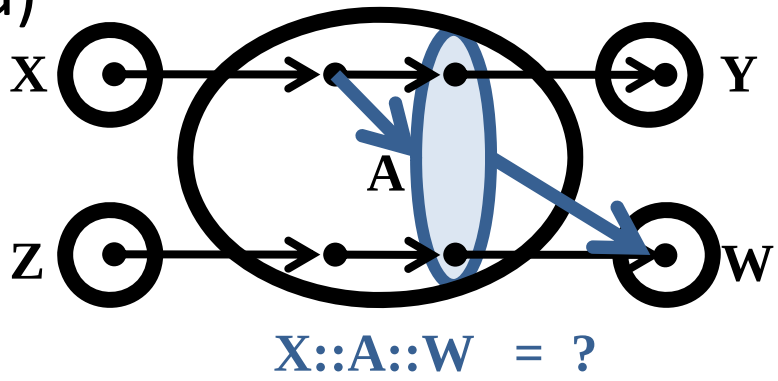
(iii) Path segments do not rendezvous at the same address

(i.e., the segment cannot be stitched)

» Use clustering heuristics:

Clustering by ***Router or PoP***

Clustering by the ***IP prefix***



Too Many Segments: Preference Rules

- Rule #1: Proximity

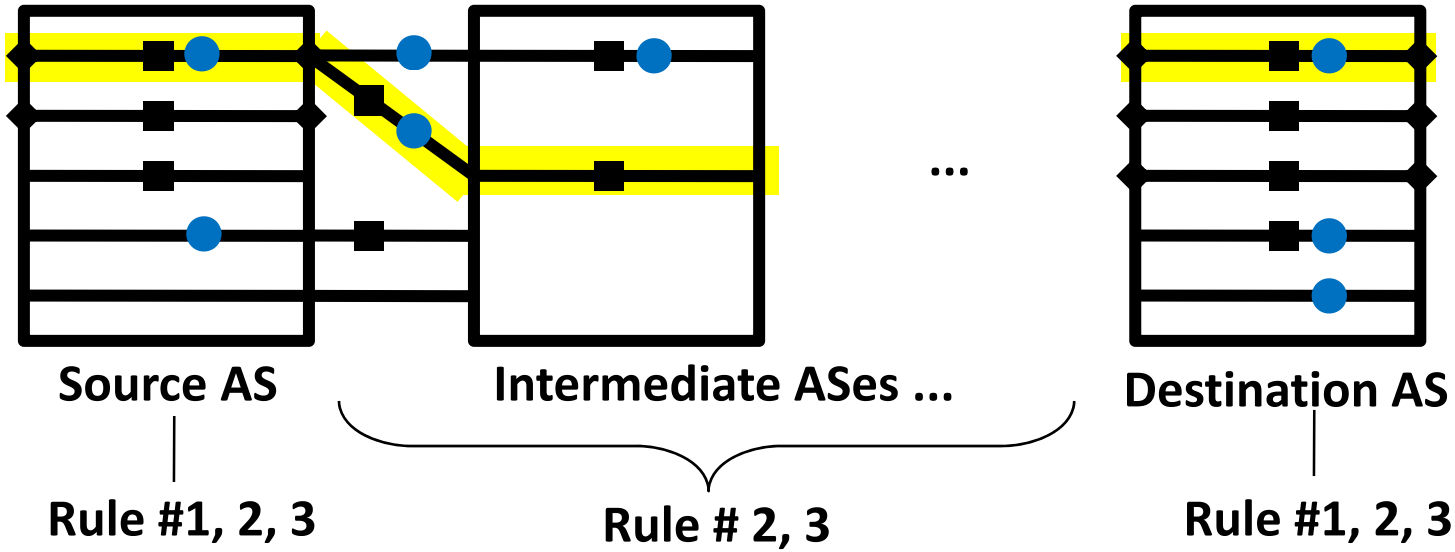
  Preference to the paths closest to the source and destination addresses of the query

- Rule #2: Destination-bound path segments

  Preference to the segments from traceroutes with the same destination prefix

- Rule #3: Most recent path segment

  Preference to the most recent path segment



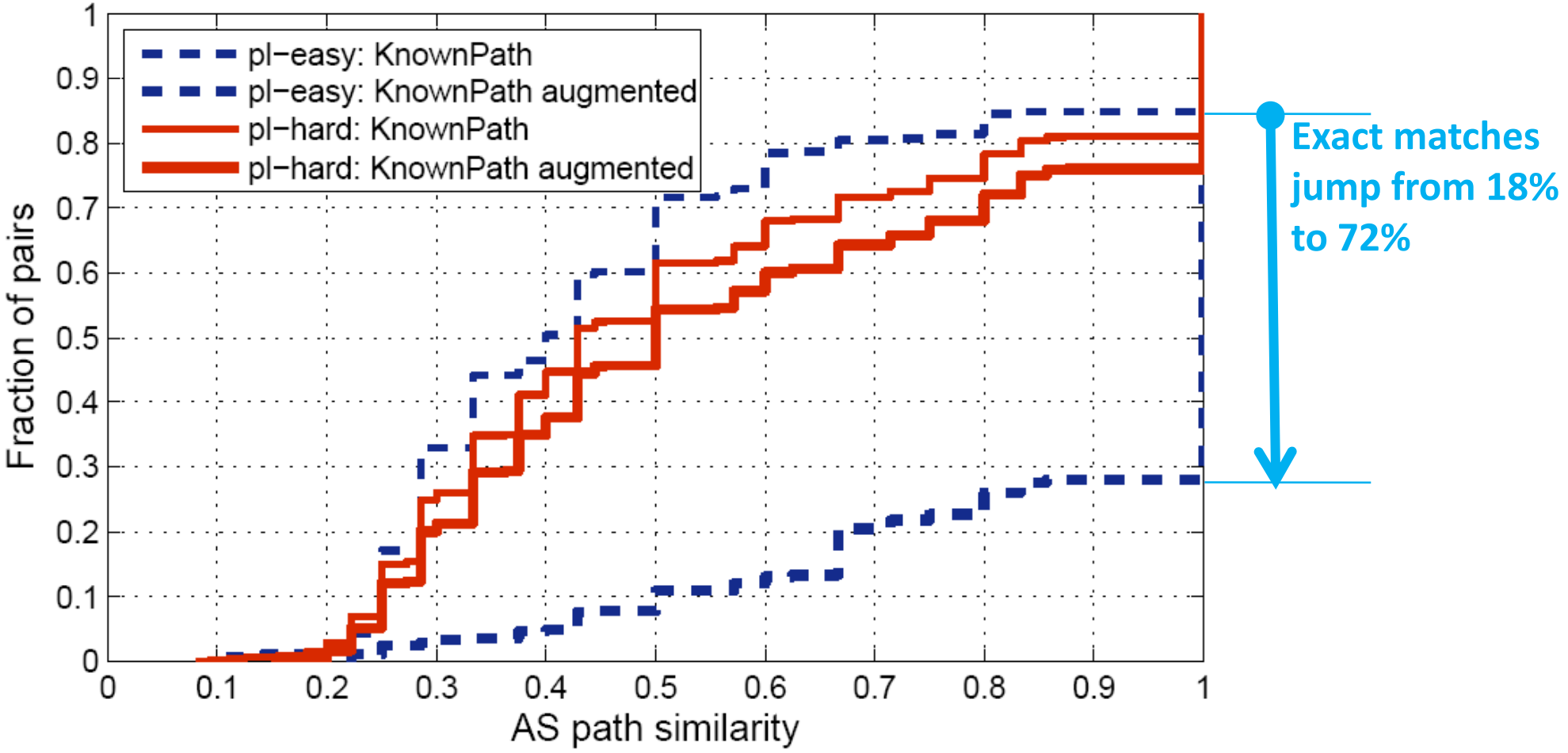
Evaluation

- Additional data set for comparison:
  - Perform traceroute 50 times a day between 184 PlanetLab nodes (real measurements)
  - **462 *pl-easy*** pairs and **10,077 *pl-hard*** pairs
  - For every pair, estimate path and delays using path stitching.

Source PL-nodes co-locate with Ark monitors (namely, *amw-us, cbg-uk, cjj-kr, dub-ie, gig-br*)

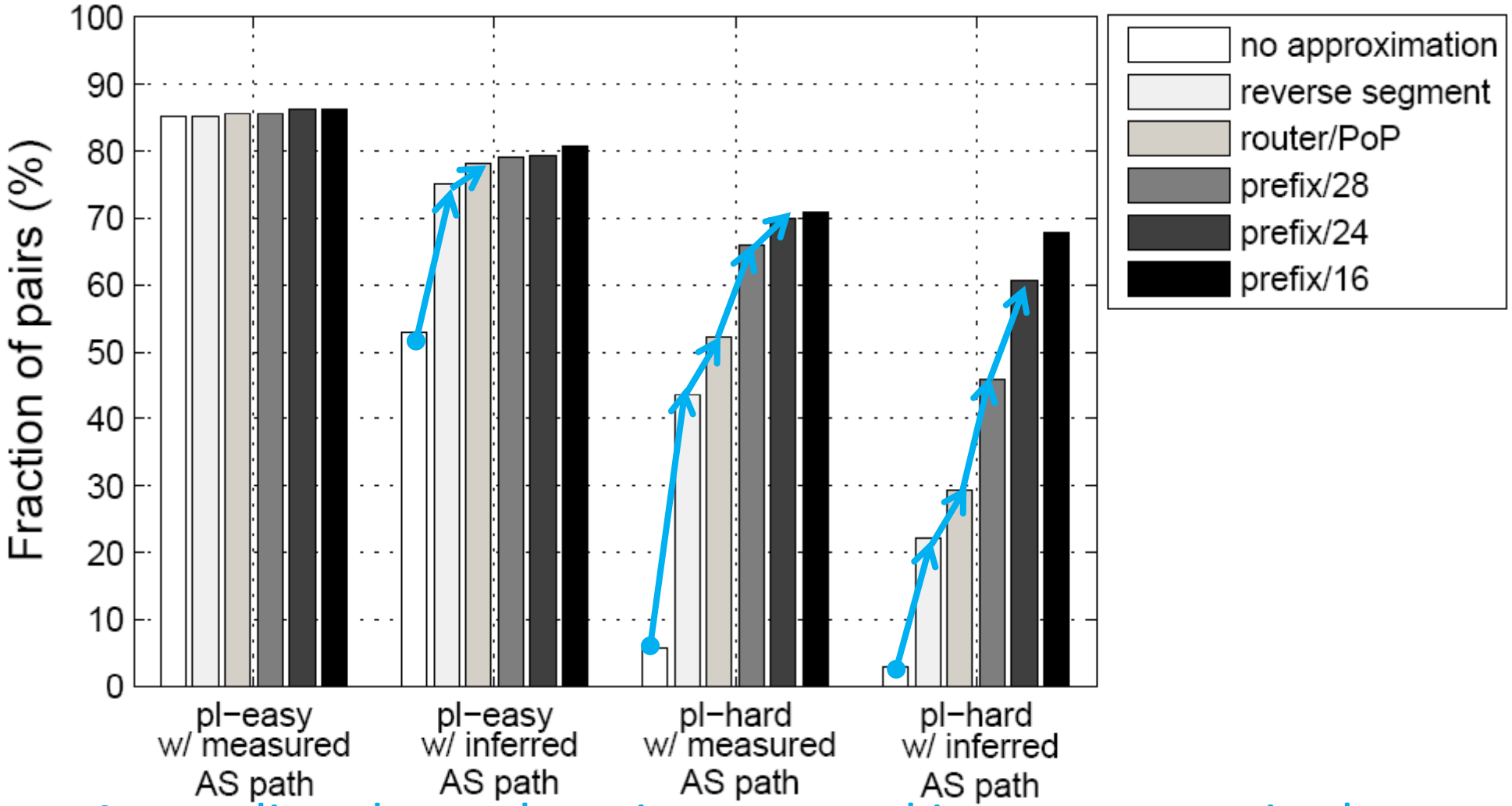
- Evaluation of
  - Quality of Inferred AS Path
  - Approximation methods
  - Preference rules
  - Accuracy in comparison with ***iPlane*** [Madhyastha *et al*, OSDI 2006]

AS Path Accuracy



Improvement in *pl-easy pairs* shows the potential value of the additional information

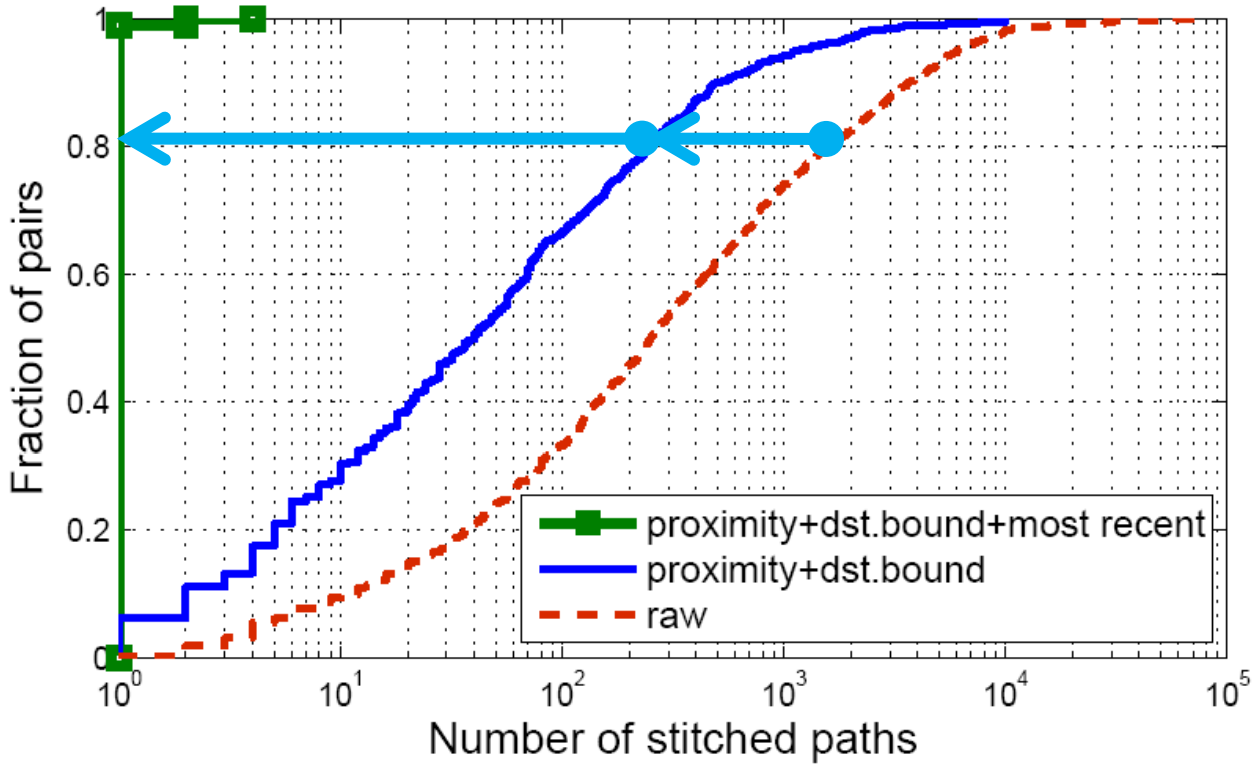
Approximations



As predicted, we show incremental improvement in the fraction of pairs with stitched paths

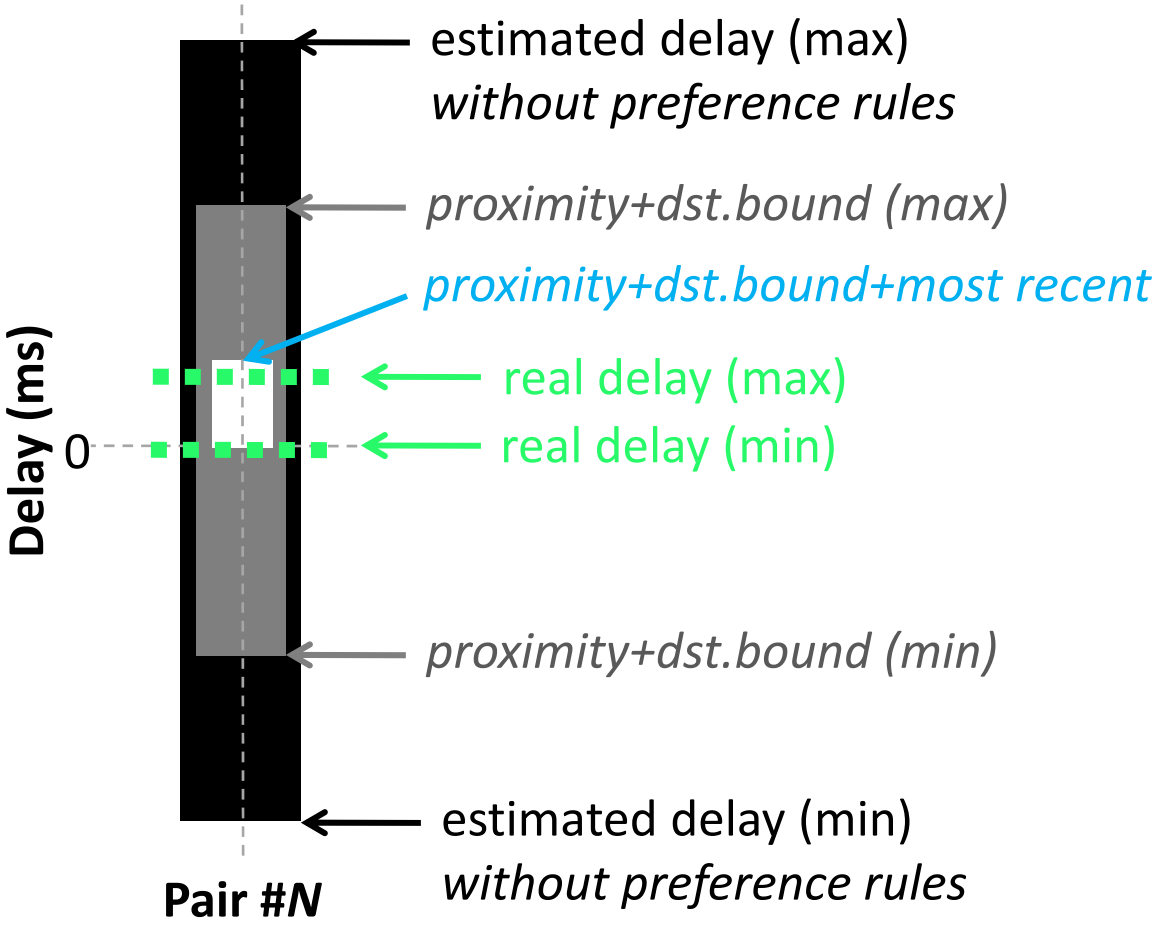
Preference Rules – (1)

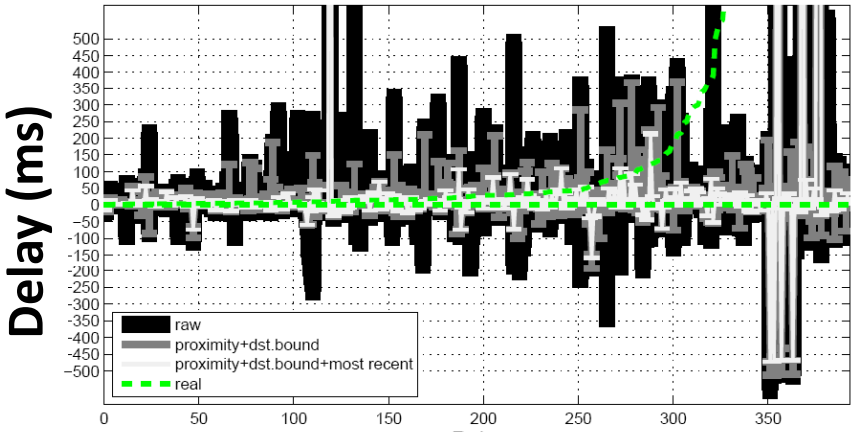
- We consider only *pl-easy* and *pl-hard* pairs that find stitched paths without any approximation method.



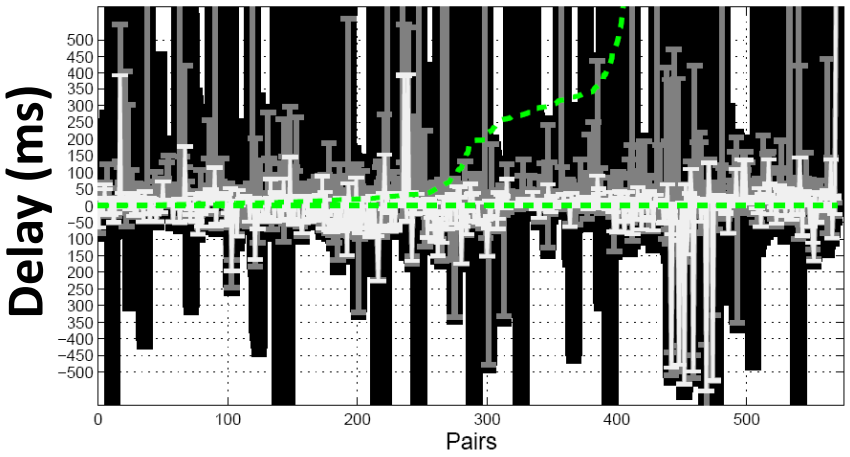
By applying preference rules, number of stitched paths decrease greatly.

Preference Rules – (2)





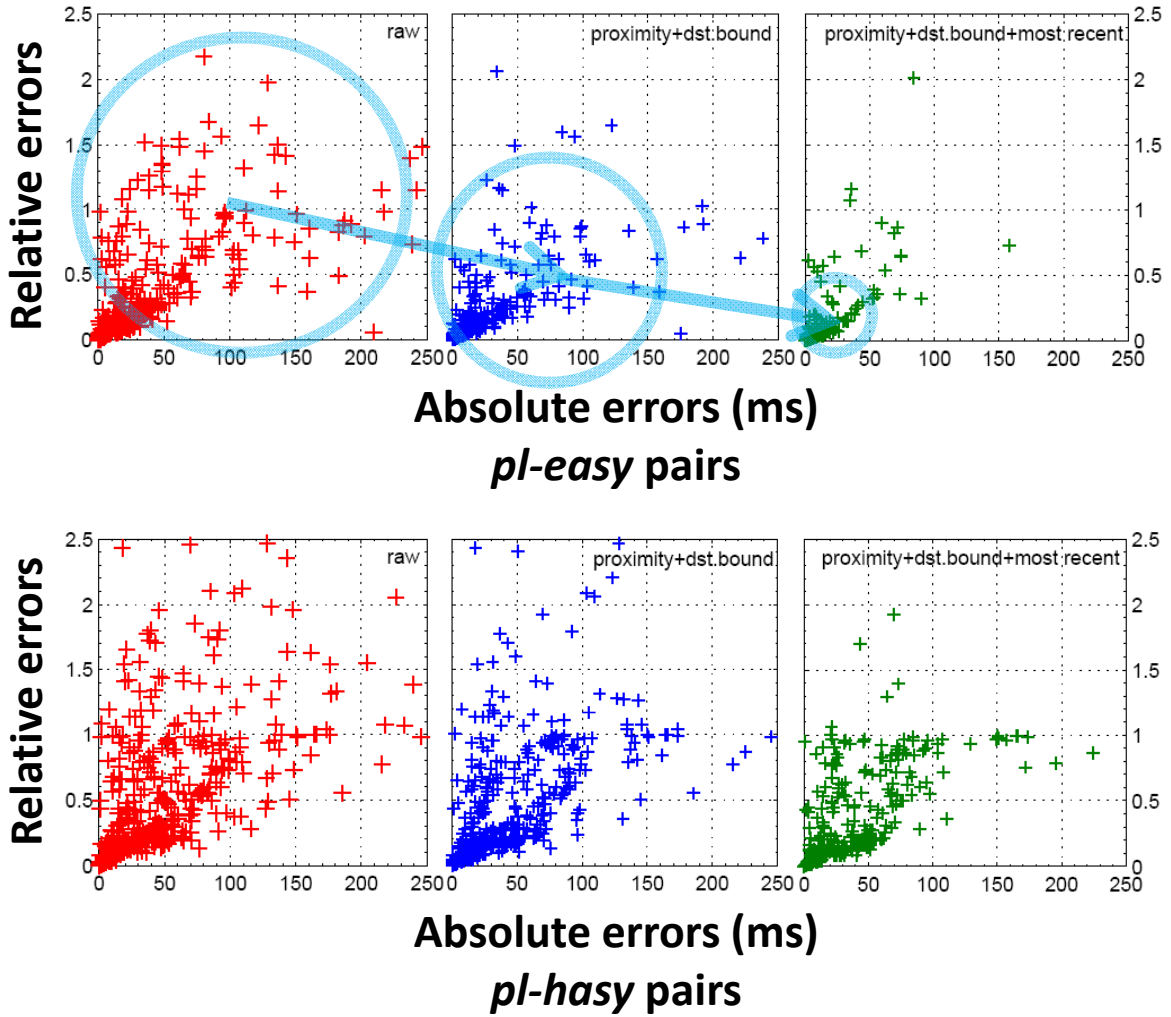
pl-easy pairs



pl-hard pairs

Preference Rules – (3)

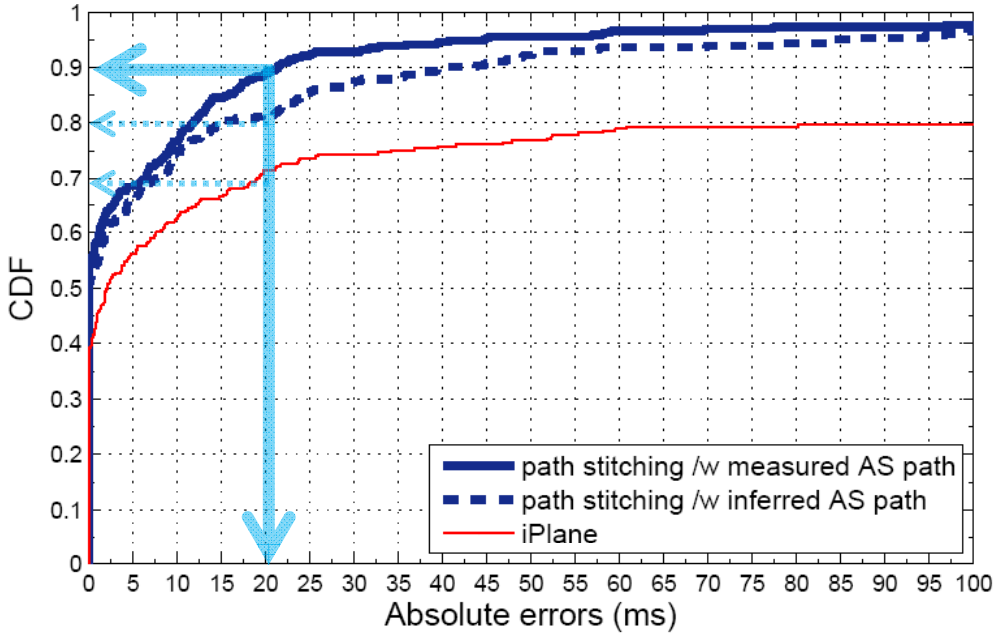
- Relative error vs. absolute error

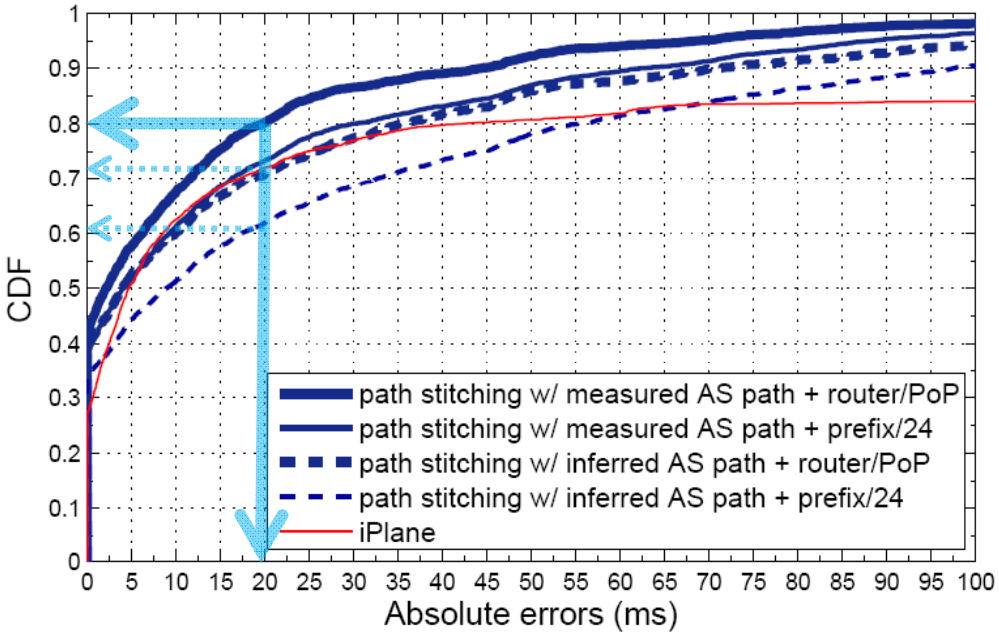


Improvements in ***absolute errors*** reflect similar improvements in ***relative errors***

Comparisons with iPlane

- CDF of absolute errors





We note that iPlane's performance observed in our results is comparable to the best cases reported in [Madhyastha *et al*, OSDI 2006]

With measured AS paths, errors <= **20ms for 90% of pl-easy** and for **80% of pl-hard** pairs
With inferred AS paths and approximation methods, accuracy degrades

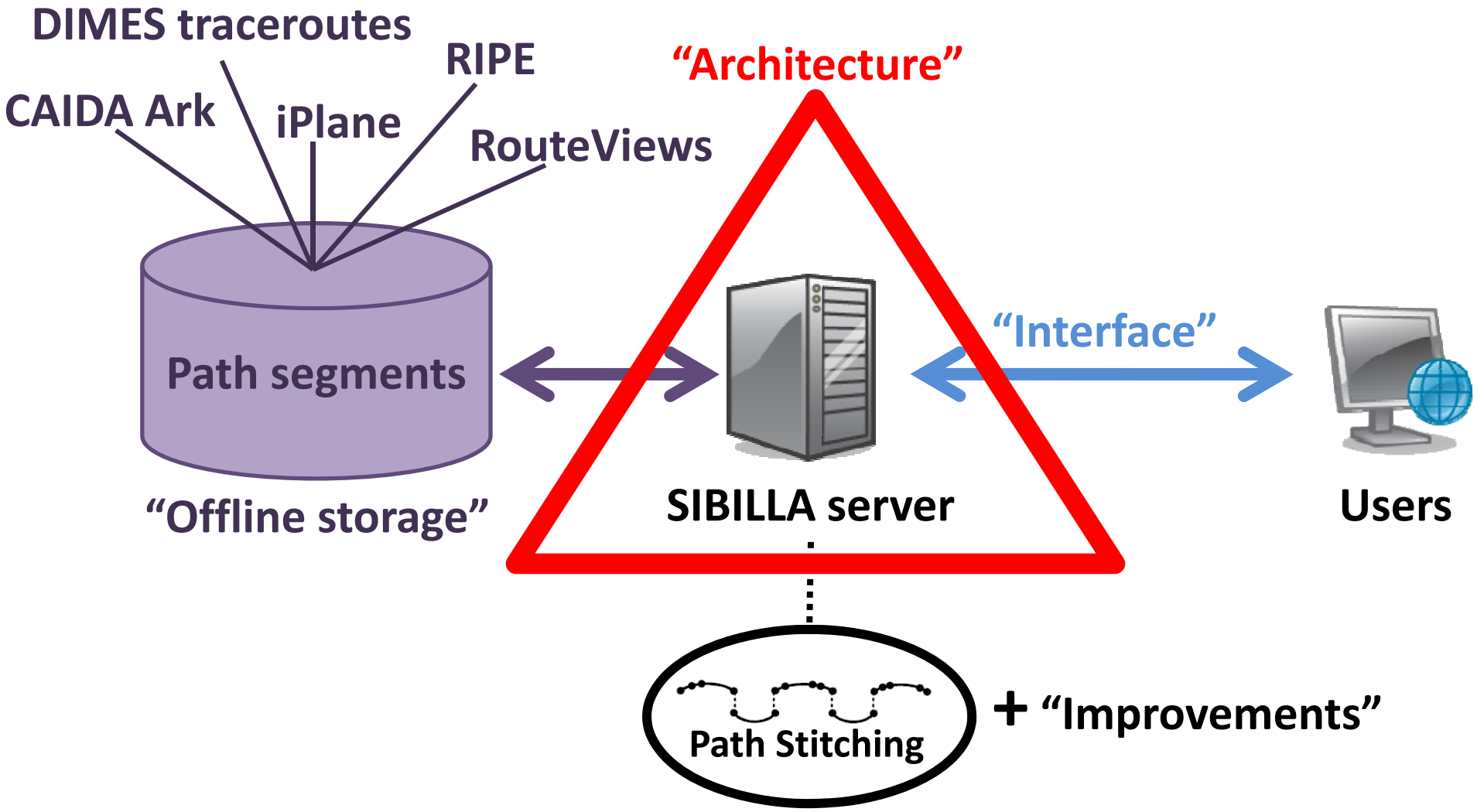
Conclusions

- "path stitching"
  - A new approach to improve the coverage of Internet-wide measurement infrastructures.
  - Fully *decouples* the data collection phases from the data analysis
  - *Enables the incremental integration of multiple data sets* in order to produce more accurate estimates
  - Achieves an accuracy similar or slightly better than previous solutions that require additional data collection

Part II. “Internet SIBILLA”

DNS-like Internet system that would allow users to issue queries about end-to-end path quality and performance

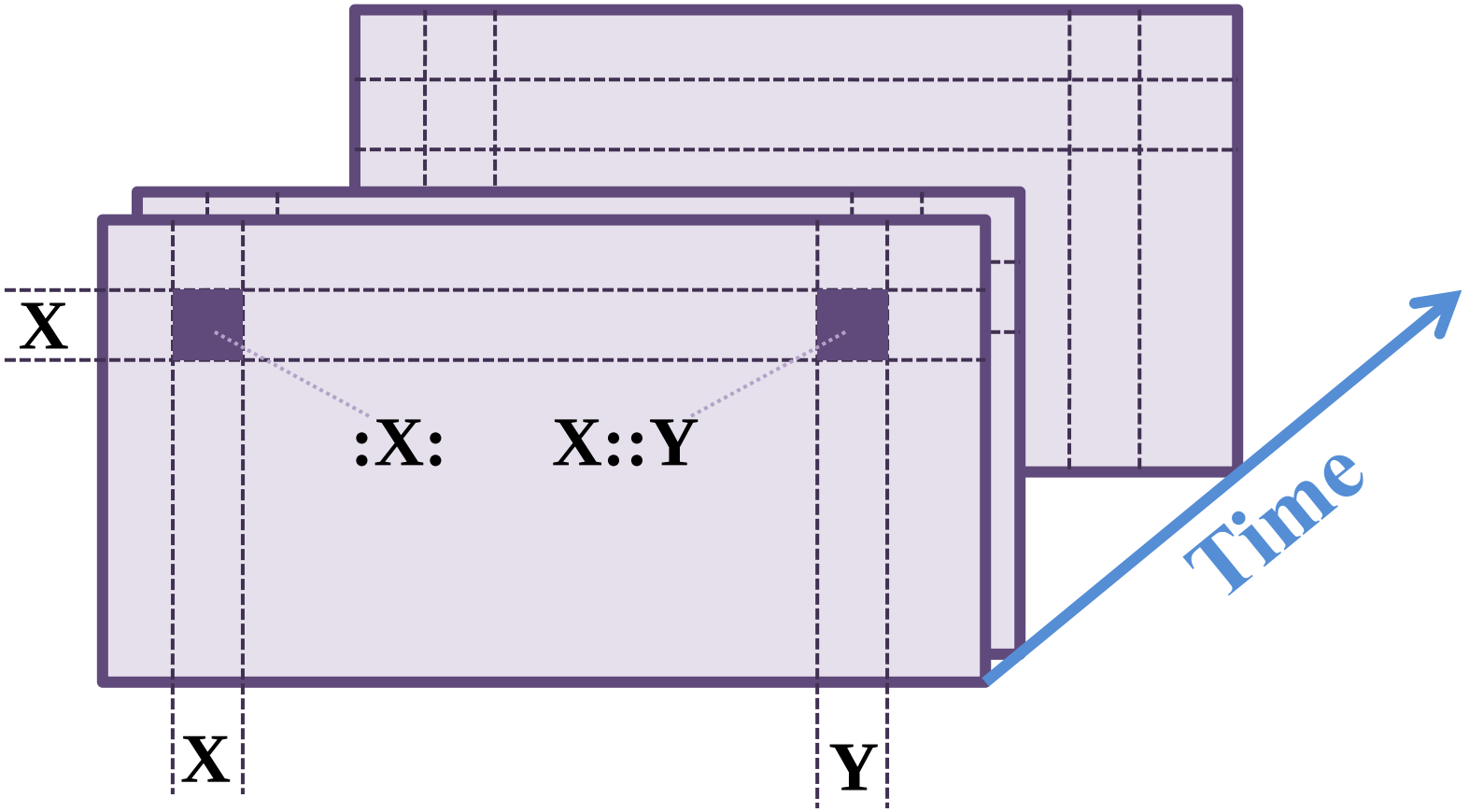
Beyond the “Path Stitching” algorithm



Storage Model: BigTable

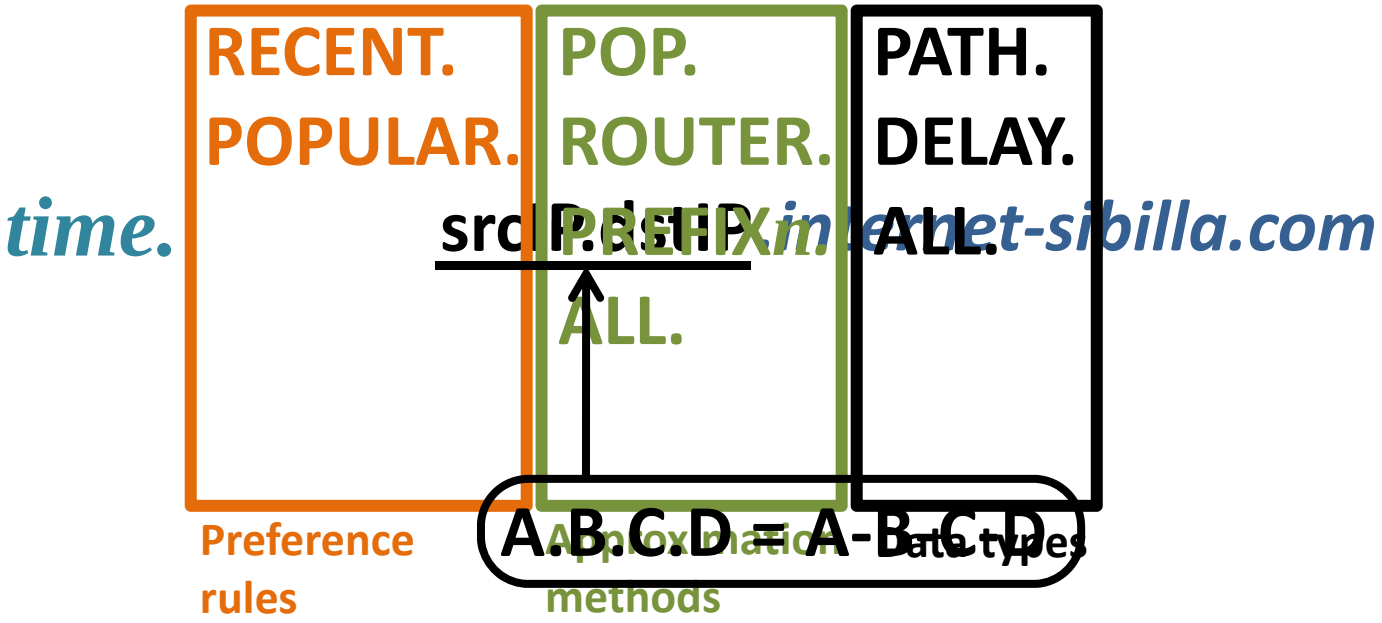
- Storage for massive amount of path segments

  (row: ASN, col: ASN, time: int64) → path segments



Query Interface – (1)

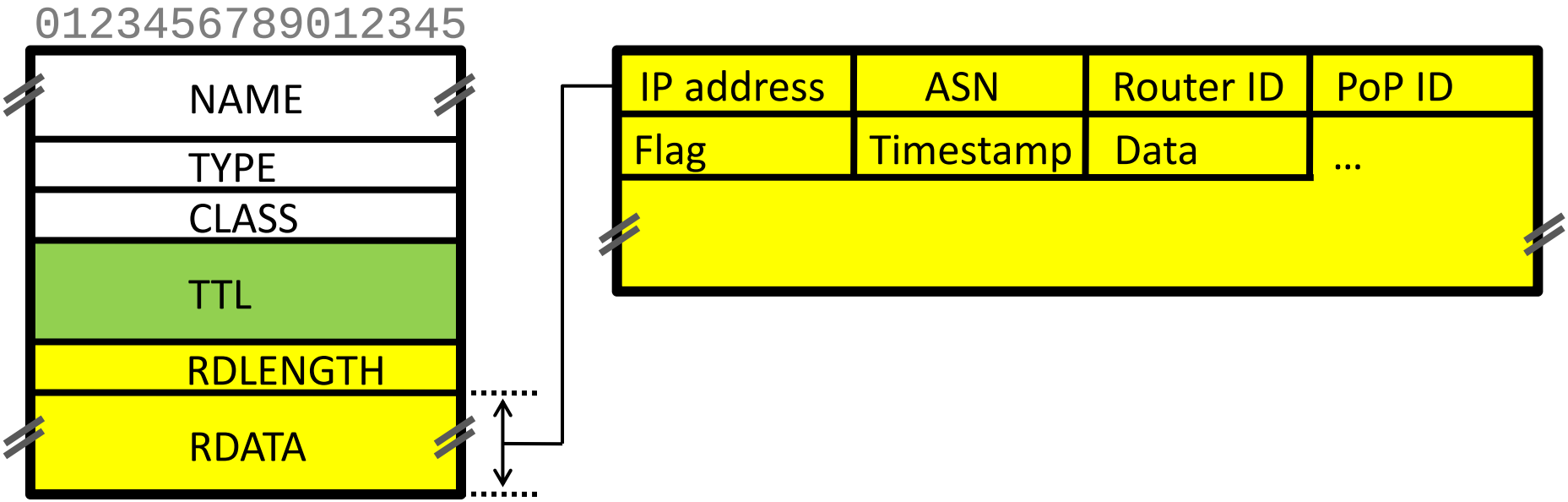
- **Queries (1) :**
  - *QNAME* (256 bytes)



  - *QTYPE*=A, *QCLASS*=IN

Query Interface – (2)

- **Responses:**
  - Exploit Resource records (RR, record type: A or AAAA)



  - We may define special record types: PATH or DELAY
  - *EDNS* for messages larger than 512 bytes. (RFC 2671)

Thank You!

- Internet SIBíLLA project

  http://an.kaist.ac.kr/sibilla/

- Any Question?

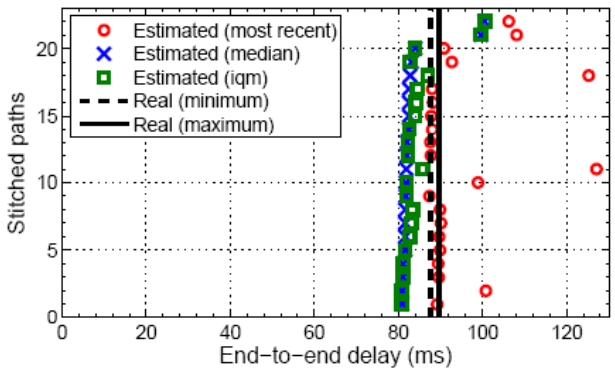
Appendix I. Backup Slides

“To get to the essence of things,
one has to work long and hard”

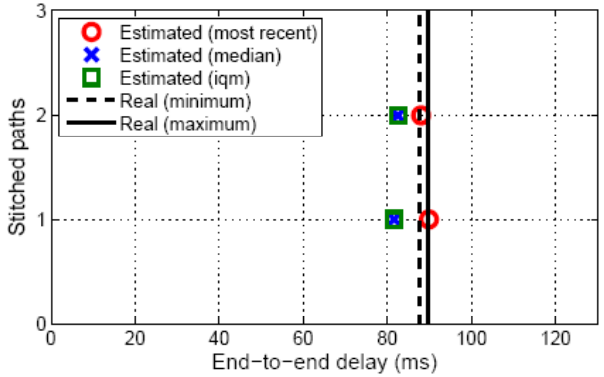
-- Vincent van Gogh

Finding Clues to Preference Rules

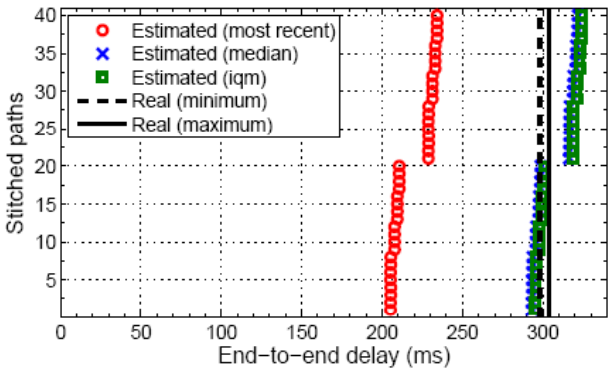
- Two examples to demonstrate differences between stitched paths



(a) planetlab1.csail.mit.edu → planet2.scs.stanford.edu



(b) filtering planetlab1.csail.mit.edu → planet2.scs.stanford.edu



(c) planetlab2.xeno.cl.cam.ac.uk → pl1-higashi.ics.es.osaka-u.ac.jp

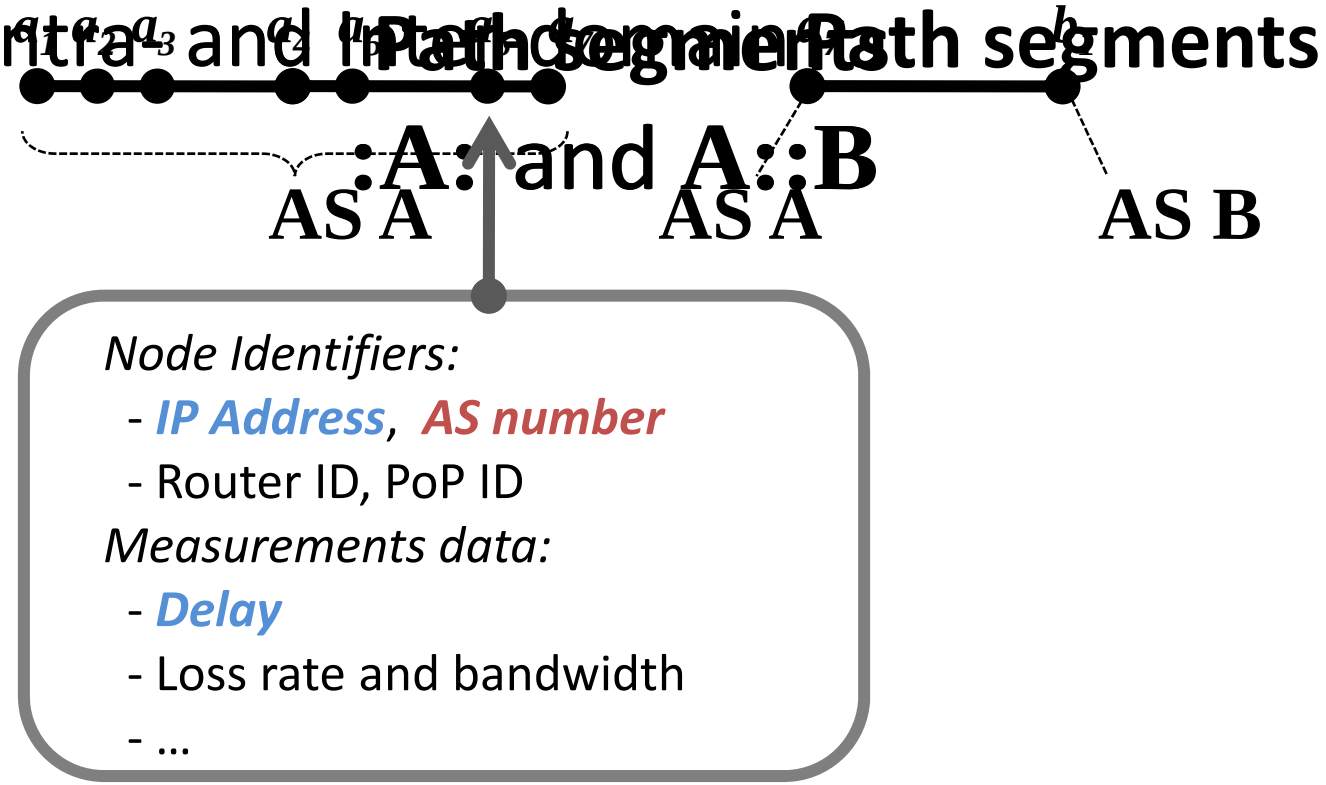
Prefixes with MOAS conflicts

IP Prefix	MOASes in the same country	%
205.189.33.0/24	6327 6509	26.18
134.75.20.0/24	1237 17579	25.41
207.231.241.0/24	293 14221 101	3.26
IP Prefix	MOASes caused by IXPs	%
80.81.192.0/23	12956 8365	10.90
198.32.176.0/24	701 2914 65517 4355 6461	7.72
198.32.160.0/24	6461 22691 12989	3.58
206.223.115.0/24	293 2914 1273	3.02
195.69.144.0/23	286 12956 1200 30132 31283	2.78
206.223.119.0/25	2914 293	2.33
IP Prefix	Other MOASes	%
69.28.128.0/18	22822 21318	4.85

Table 4: Prefixes with MOAS conflicts. The percentage refers to the portion of the total number of traceroutes that exhibit a MOAS conflict.

Path Segments: Unit of Data Storage

- Tradeoffs: information loss vs. size vs. efficiency

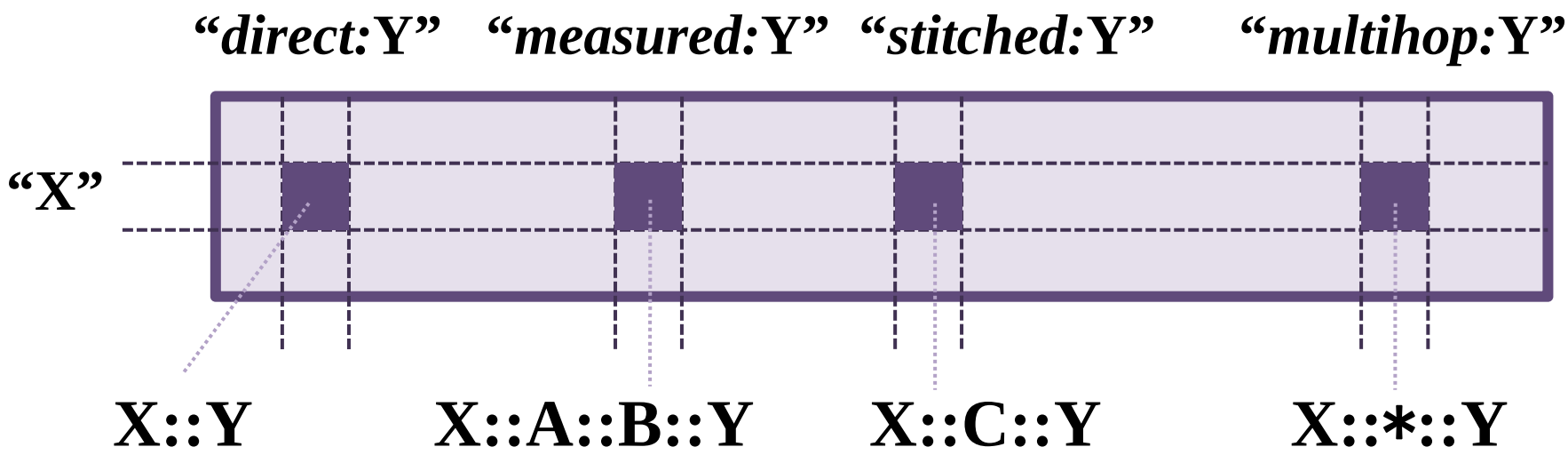


Big Table Clones

- ***HBase***
  - As a part of Apache Software Foundation's *Hadoop* project
  - Implemented in Java language
- ***Neptune*** by NHN
- ***HyperTable*** by Doug Judd
  - Implemented in C++, Open source project
  - Built on Hadoop file system
  - http://www.hypertable.org

Offline Storage – Open Issues

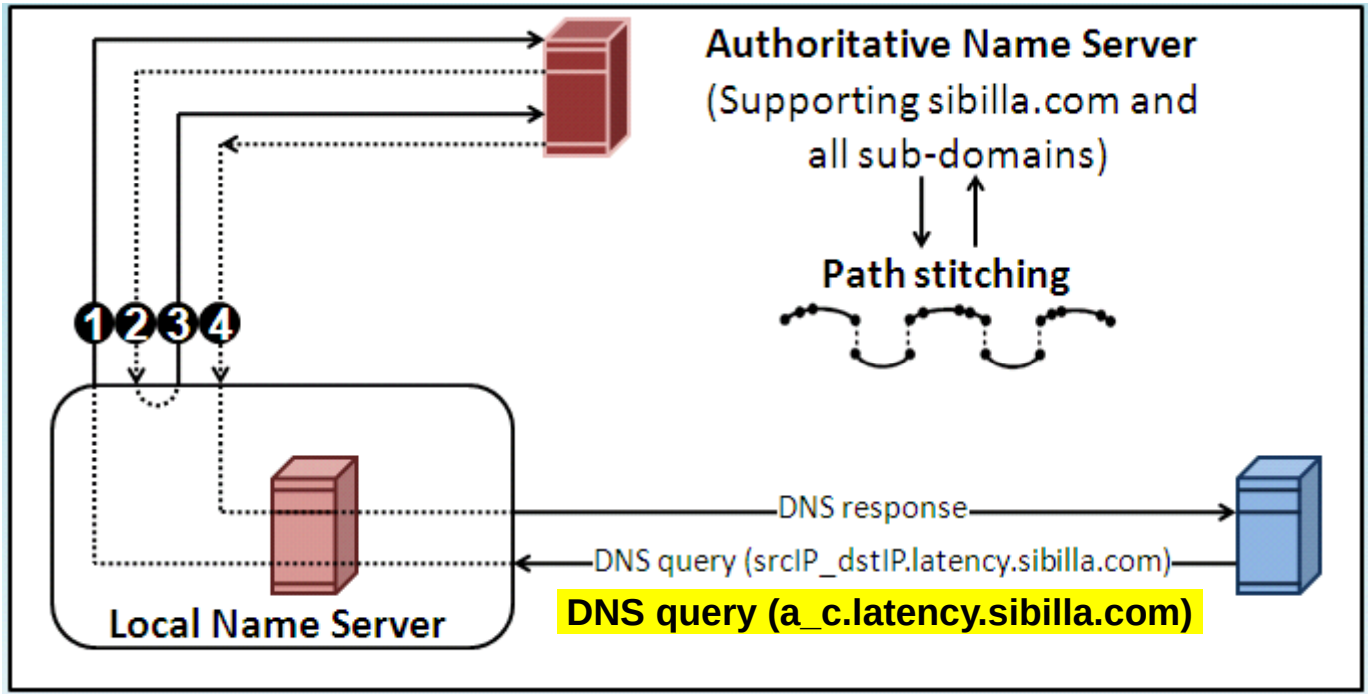
- Column families?



- Implementation (1 month)
- Performance evaluation

For the 100 % Response Rate

- When a client queries from *itself* to somewhere.



- When a client queries between two arbitrary hosts.
  - Additional data source is the solution.

Architecture

- To be *Peer-to-peer* or not to be?

- Advantages of P2P
  - Low budget requirement
  - Availability
  - Anonymity

- P2P is not appropriate for applications that need
  - lower latency
  - more than just distributed hash tables