Internet Topology: Part I

Internet Topology Discovery with Passive Measurements (BGP)

Prof. Georgios Smaragdakis, Ph.D.

Topologies at the Router Level
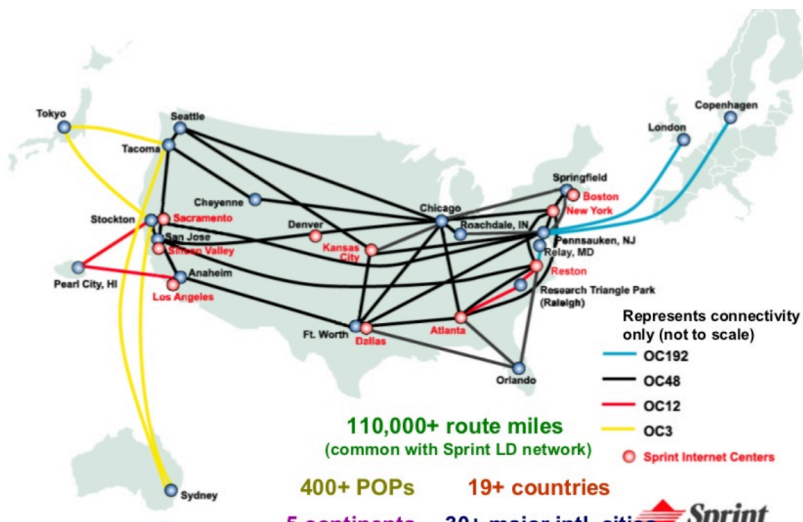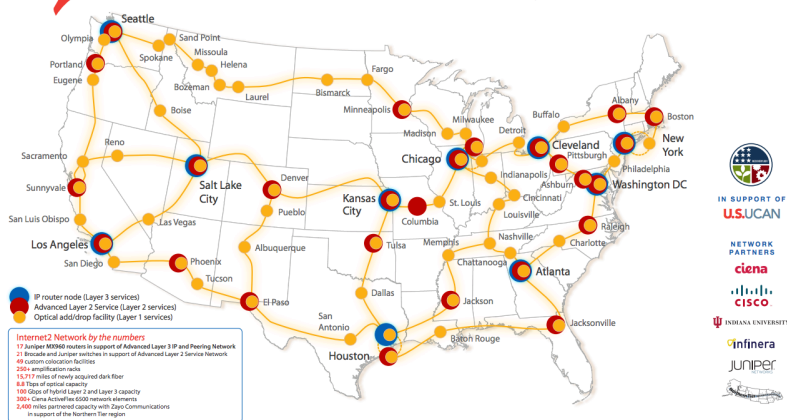
www.topology-zoo.org
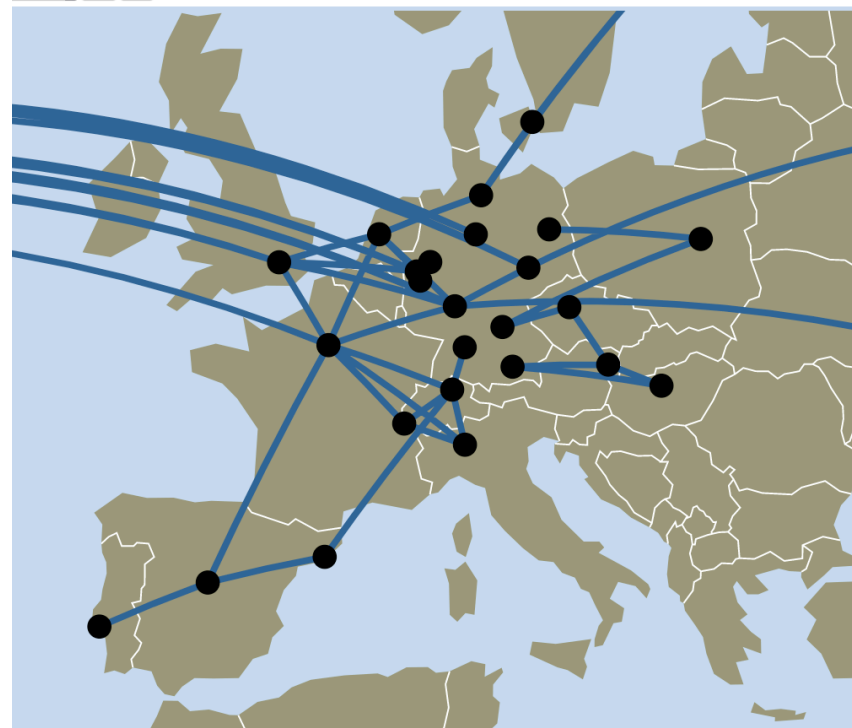
Topologies at the Physical Level (fiber)

Figure 1: Location of physical conduits for networks considered in the continental United States.

Figure 2: NationalAtlas roadway infrastructure locations.

Figure 3: NationalAtlas railway infrastructure locations.

"InterTubes: A Study of the US Long-haul Fiber-optic Infrastructure", SIGCOMM 2015

Topologies at the AS Level (logical level)

https://bgp.he.net
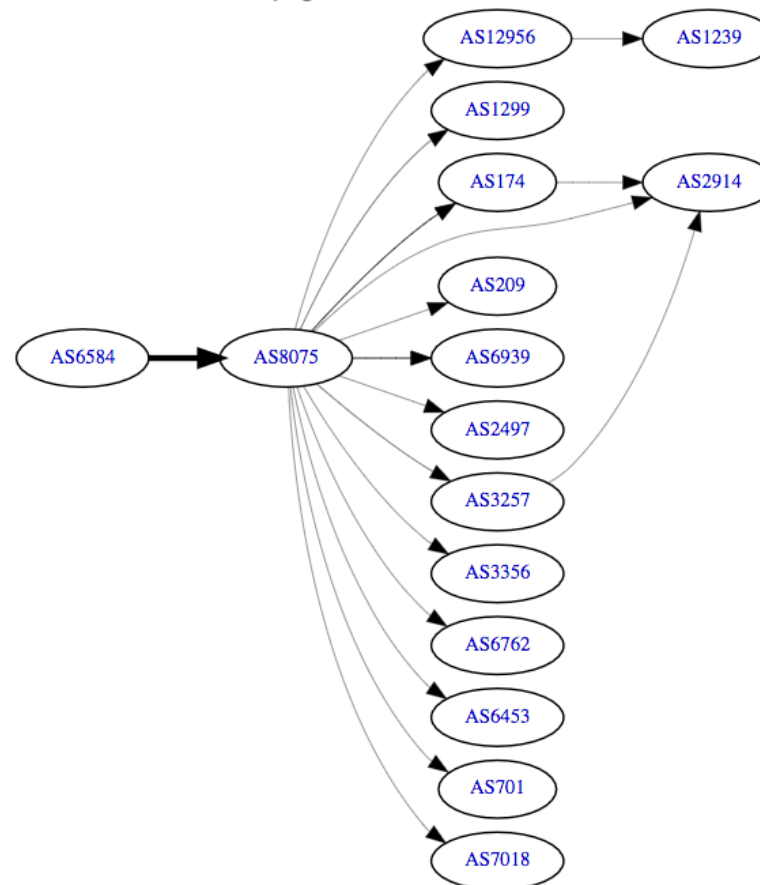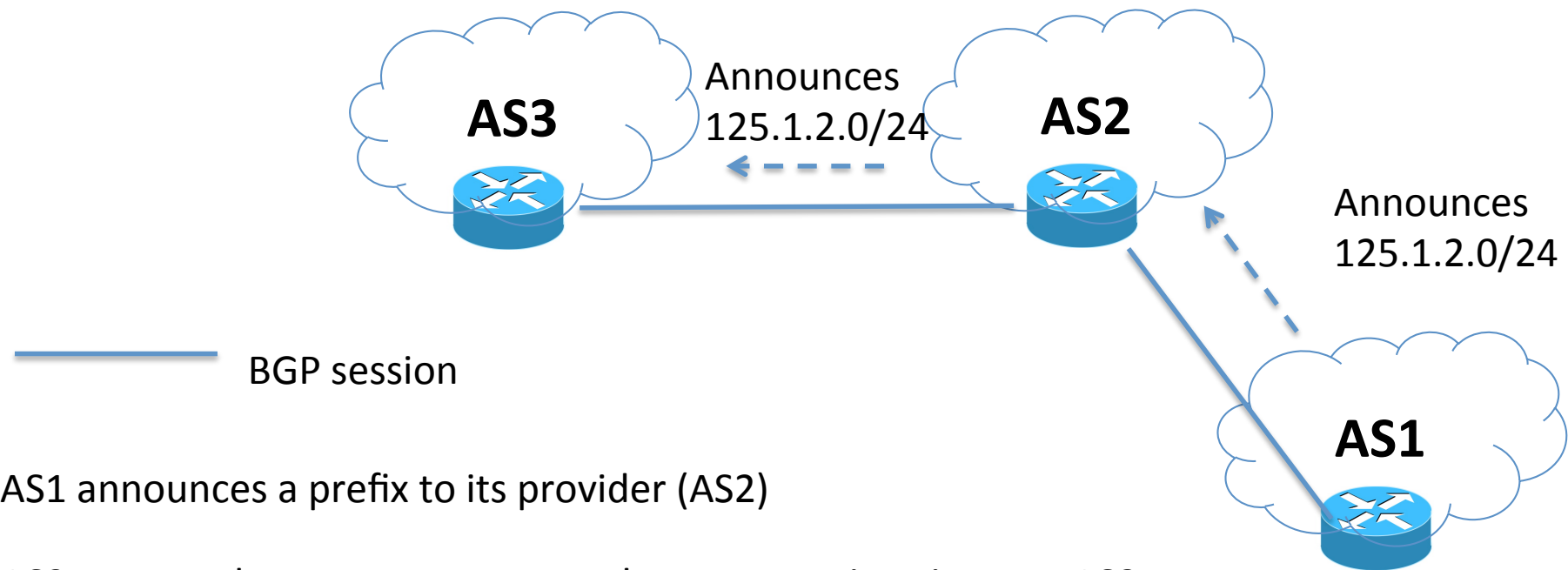
Constructing the Internet Topology using BGP

- AS-level Topology from Control Plane
  - How different networks interconnect
  - Architecture of the Internet
  - Business relationships

BGP Information

AS3

AS2

Announces
125.1.2.0/24

Announces
125.1.2.0/24

AS1

BGP session

AS1 announces a prefix to its provider (AS2)

AS2 accepts the announcement and propagates it to its peer AS3

AS Relationships

AS3   AS2 prefixes   AS2

AS3 prefixes

only AS1 prefixes

AS1

——————— BGP session
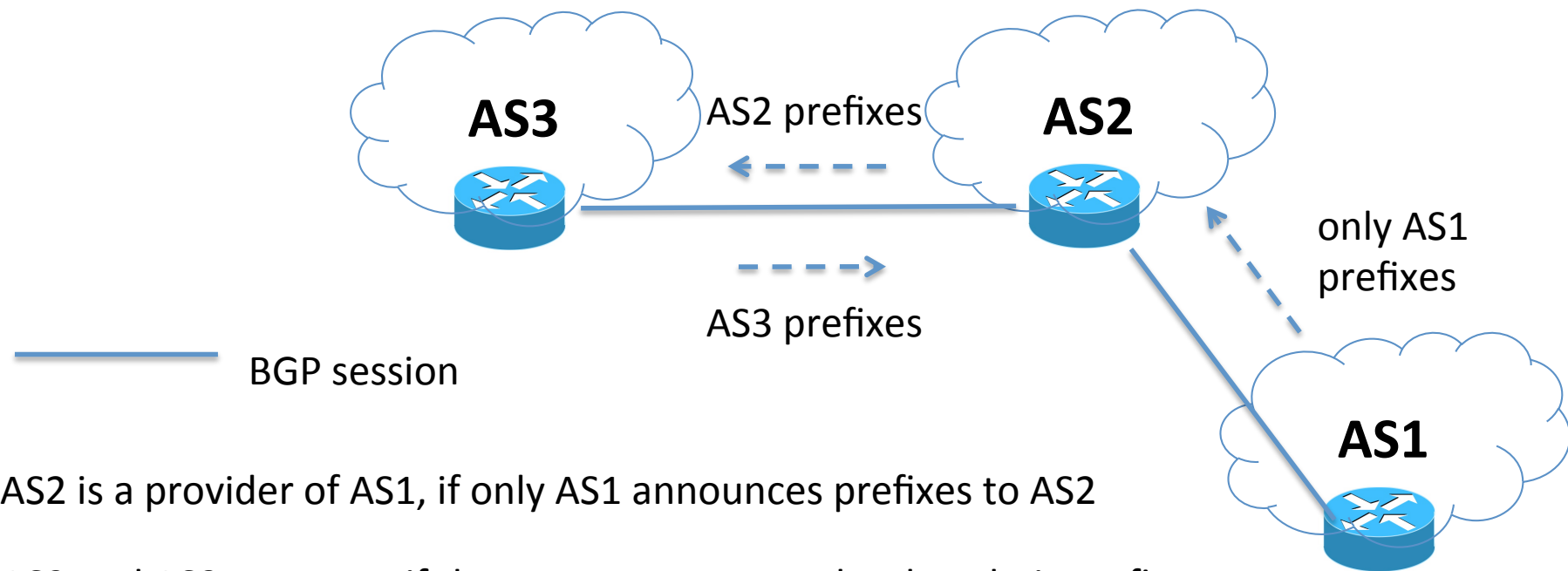
AS2 is a provider of AS1, if only AS1 announces prefixes to AS2

AS2 and AS3 are peers if they announces to each other their prefixes (typically, this is a relationship between networks that exchange same order of traffic volume)

BGP Collector

BGP Collector

AS3

AS2

Announces
125.1.2.0/24

Announces
125.1.2.0/24

Announces
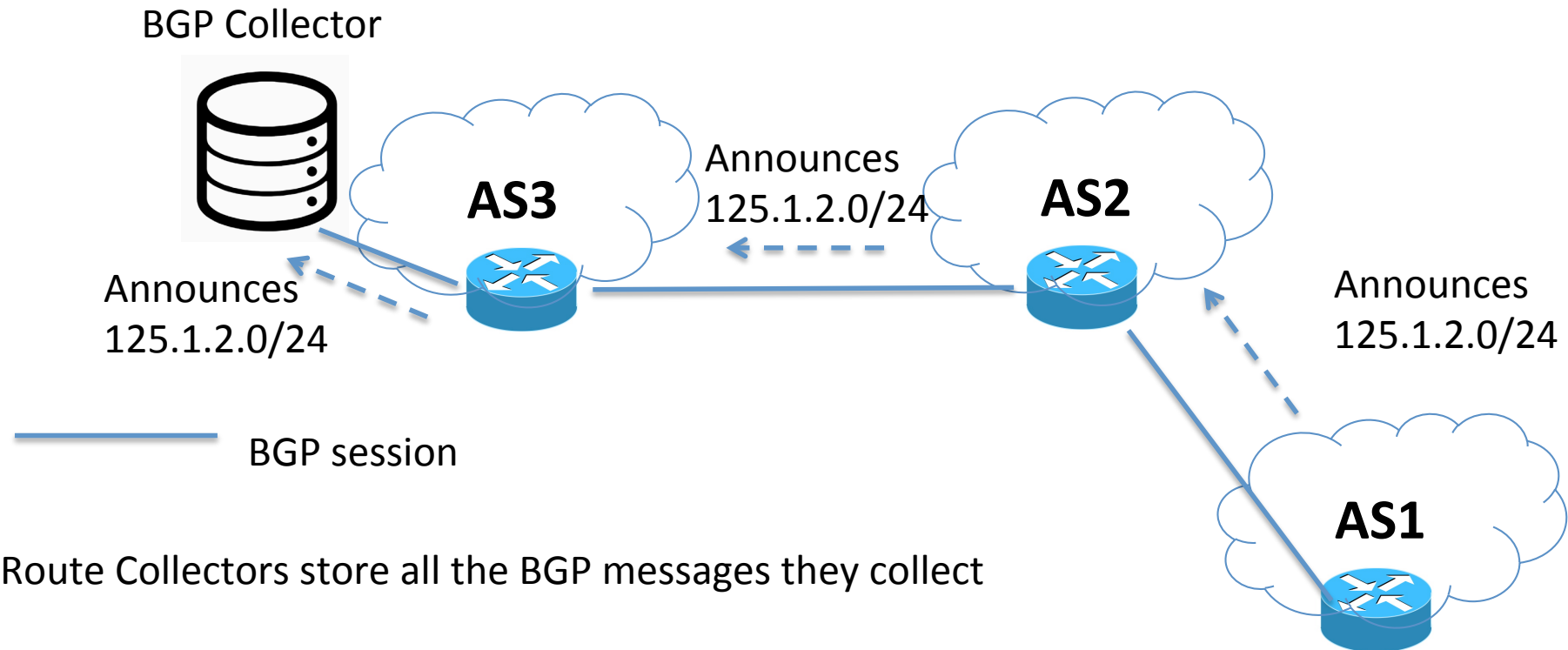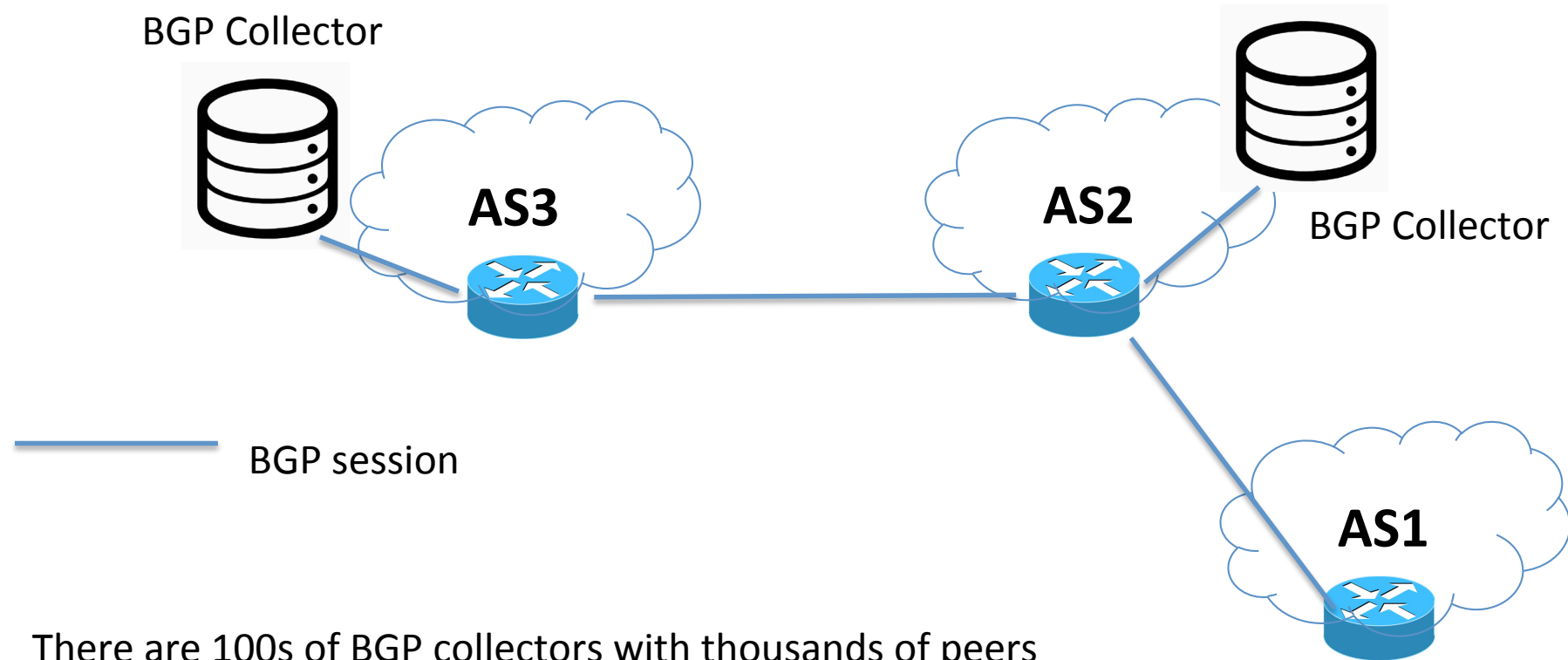125.1.2.0/24

AS1

BGP session

Route Collectors store all the BGP messages they collect

Time|IP-router3|AS3|125.1.2.0/24|AS3 AS2 AS1|···

AS1 is the origin of 125.1.2.0/24

BGP Collectors – Multiple Vantage Points

BGP Collector

AS3

AS2

BGP Collector

BGP session

AS1

There are 100s of BGP collectors with thousands of peers around the globe

RIPE: Raw BGP Data

Source:
https://www.ripe.net/analyse/internet-measurements/routing-information-service-ris/ris-raw-data

Routeviews : Raw BGP Data

University of Oregon Route Views Archive Project

- Please see www.routeviews.org for a description of the route views project, bibliography, and additional information.

- For asn.routeviews.org zone files click here or ftp from: ftp.routeviews.org/dnszones/

- Data Archives

  - MRT format RIBs and UPDATEs (quagga bgpd, from route-views2.oregon-ix.net)
    MRT format RIBs and UPDATEs (quagga bgpd, from route-views3 as of Aug 13, 2013)
    MRT format RIBs and UPDATEs (quagga bgpd, from route-views4.routeviews.org)
    v6 MRT format RIBs and UPDATEs (quagga bgpd, from route-views6.oregon-ix.net)
    MRT format RIBs and UPDATEs from Equinix Ashburn (quagga bgpd, from route-views.eqix.routeviews.org)
    MRT format RIBs and UPDATEs from ISC (PAIX) (quagga bgpd, from route-views.isc.routeviews.org)
    MRT format RIBs and UPDATEs from KIXP (quagga bgpd, from route-views.kixp.routeviews.org)
    MRT format RIBs and UPDATEs from JINX (quagga bgpd, from route-views.jinx.routeviews.org)
    MRT format RIBs and UPDATEs from LINX (quagga bgpd, from route-views.linx.routeviews.org)
    MRT format RIBs and UPDATEs from NAPAfrica (quagga bgpd, from route-views.napafrica.routeviews.org)
    MRT format RIBs and UPDATEs from NWAX (quagga bgpd, from route-views.nwax.routeviews.org)
    MRT format RIBs and UPDATEs from TELXATL (quagga bgpd, from route-views.telxatl.routeviews.org)
    MRT format RIBs and UPDATEs from DIXIE (WIDE) (quagga bgpd, from route-views.wide.routeviews.org)
    MRT format RIBs and UPDATEs from SYDNEY (quagga bgpd, from route-views.sydney.routeviews.org)
    MRT format RIBs and UPDATEs from SAOPAULO (quagga bgpd, from route-views.saopaulo.routeviews.org)
    MRT format RIBs and UPDATEs from SINGAPORE (quagga bgpd, from route-views.sg.routeviews.org)
    MRT format RIBs and UPDATEs from PERTH (quagga bgpd, from route-views.perth.routeviews.org)
    MRT format RIBs and UPDATEs from SFMIX (quagga bgpd, from route-views.sfmix.routeviews.org)
    MRT format RIBs and UPDATEs from SOXRS/Serbia (quagga bgpd, from route-views.soxrs.routeviews.org)
    ipv6 data split out from the above files (multiple collectors)

  - 'sh ip bgp' format RIBs from route-views.route-views.org (to now)
  - route dampening data from route-views.route-views.org (to March 2008)
  - 'sh ip bgp' format RIBs from route-views3.routeviews.org (to May 2012)

Source:
http://archive.routeviews.org/

PCH: Raw BGP Data

Source:
https://www.pch.net/resources/Raw_Routing_Data/

BGP Raw Data

- BGP Table Dump, a snapshot of the view of the router:

TIME: 04/08/18 00:00:00

TYPE: TABLE_DUMP_V2/IPV4_UNICAST

PREFIX: 1.1.1.0/24

SEQUENCE: 0

FROM: 111.91.233.1 AS45896

ORIGINATED: 04/04/18 02:03:00

ORIGIN: IGP

ASPATH: 45896 3356

NEXT_HOP: 111.91.233.1

COMMUNITY: 3356:3 3356:9 3356:575 3356:200

BGP Raw Data

- BGP Announcement, are updates from the last BGP dump:

TIME: 04/08/18 22:40:00

TYPE: BGP4MP/MESSAGE/Update

FROM: 12.0.1.63 AS7018

TO: 193.0.4.28 AS12654

ORIGIN: IGP

ASPATH: 7018 3356 3549 263165 52832

NEXT_HOP: 12.0.1.63

COMMUNITY: 7018:5000 7018:37232

ANNOUNCE

    177.53.180.0/22

BGP Raw Data

- BGP Withdrawal, are also updates from the last BGP dump:

TIME: 04/08/18 22:40:00

TYPE: BGP4MP/MESSAGE/Update

FROM: 79.143.241.12 AS29608

TO: 193.0.4.28 AS12654

WITHDRAW

205.108.244.0/22

BGP Compact Representation

- BGP Dump:

TABLE_DUMP2|1523145600|B|111.91.233.1|45896|1.1.1.0/24|45896
3356|IGP|111.91.233.1|0|0|3356:3 3356:9 3356:575 3356:2003|NAG||

- BGP Messages:
  - BGP4MP|1523227200|A|212.25.27.44|8758|44.136.224.0/24|8758
    6830 4637 1221|INCOMPLETE|212.25.27.44|0|0|6830:17000
    6830:17500 6830:23001 6830:34403 8758:110 8758:300|NAG||
  - BGP4MP|1523227200|W|79.143.241.12|29608|205.108.244.0/22

Constructing the Internet Topology using BGP (AS-level)

BGP|A|172.18.192.0/24

AS3

R3

R2

AS2

R1

AS1

BGP|A|90.18.1.0/24

AS4

BGP Collector

Routing Data (RIS)

- 18 BGP collectors and growing
- 600+ peers
- 150+ full-feed peers

Constructing the Internet Topology using BGP (AS-level)

AS3

R3

AS2

R2

BGP|A|172.18.192.0/24

BGP|A|172.18.192.0/24|AS2 AS3

AS4

R1

AS1

BGP|A|90.18.1.0/24

Routing Data (RIS)

- 18 BGP collectors and growing
- 600+ peers
- 150+ full-feed peers

BGP Collector

...

t1|R2|A|172.18.192.0/24|AS2 AS3
t2|R3|A|90.18.1.0/24|AS1
...

18
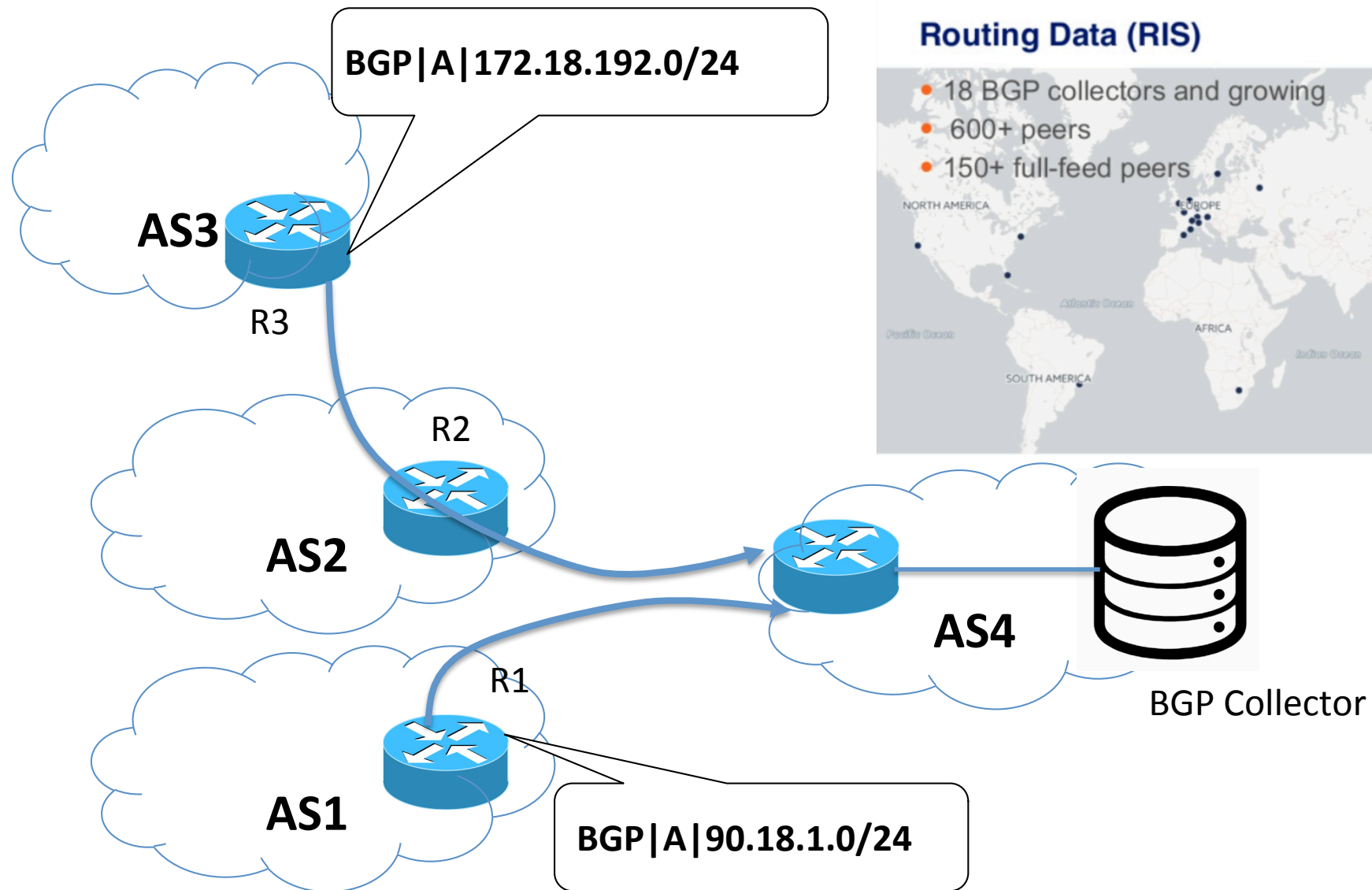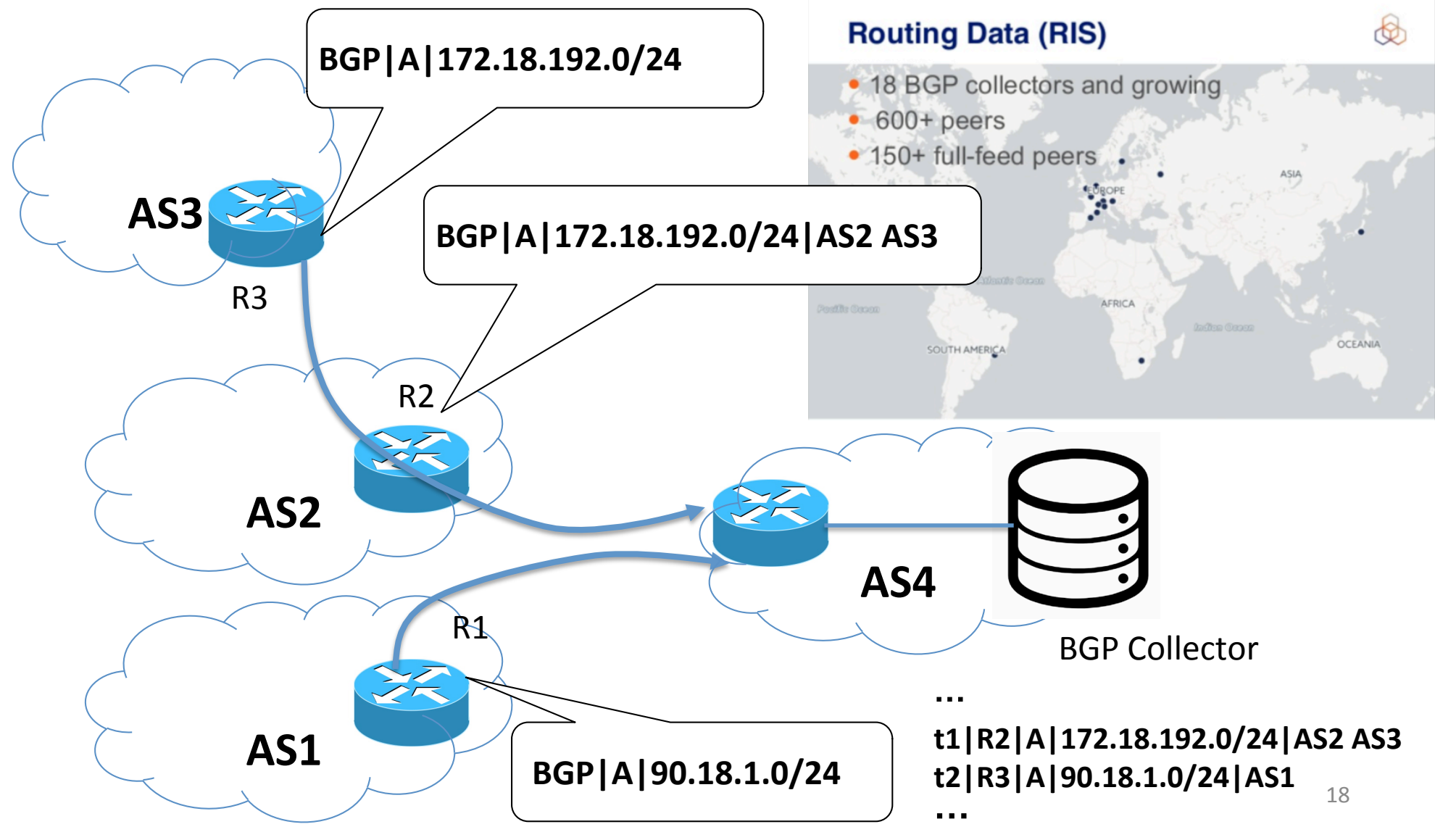
Connecting the Points

- AS3 AS2
- AS4 AS1
- AS3 AS2 AS1

AS-level Map: Connecting the Dots

- AS3 AS2
- AS4 AS1
- AS3 AS2 AS1
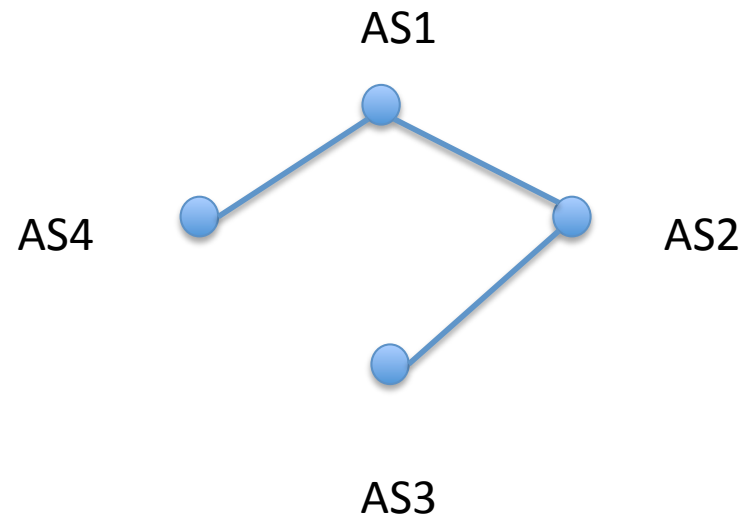
Internet-scale AS-level Map

To get the full view of the Internet connectivity for one day:

1. Download the first BGP dump from all the collectors at the beginning of the day

2. Find the AS-level topology

3. Update the AS-level topology using the announcements and withdrawals (updates)

Estimating the Number of AS-links

Year/Methodology	Est. # of customer-provider links in the Internet	Est. number of peering links in the Internet
2008 (BGP)*	~60,000	~15,000
2010 (BGP + traceroute)**	~90,000	~30,000
2012 (ground truth from a large IXP)***	~90,000	**>200,000**

Next Lectures

* Dhamdhere et al., , ACM IMC 2008, IEEE/ACM Trans on Networking 2011
** Augustin et al., ACM IMC 2009
** K. Chen et al., ACM CoNEXT 2009
*** Ager et al., SIGCOMM 2012

Courtesy of Walter Willinger

Core of the Internet

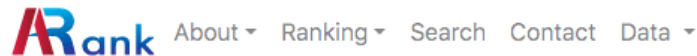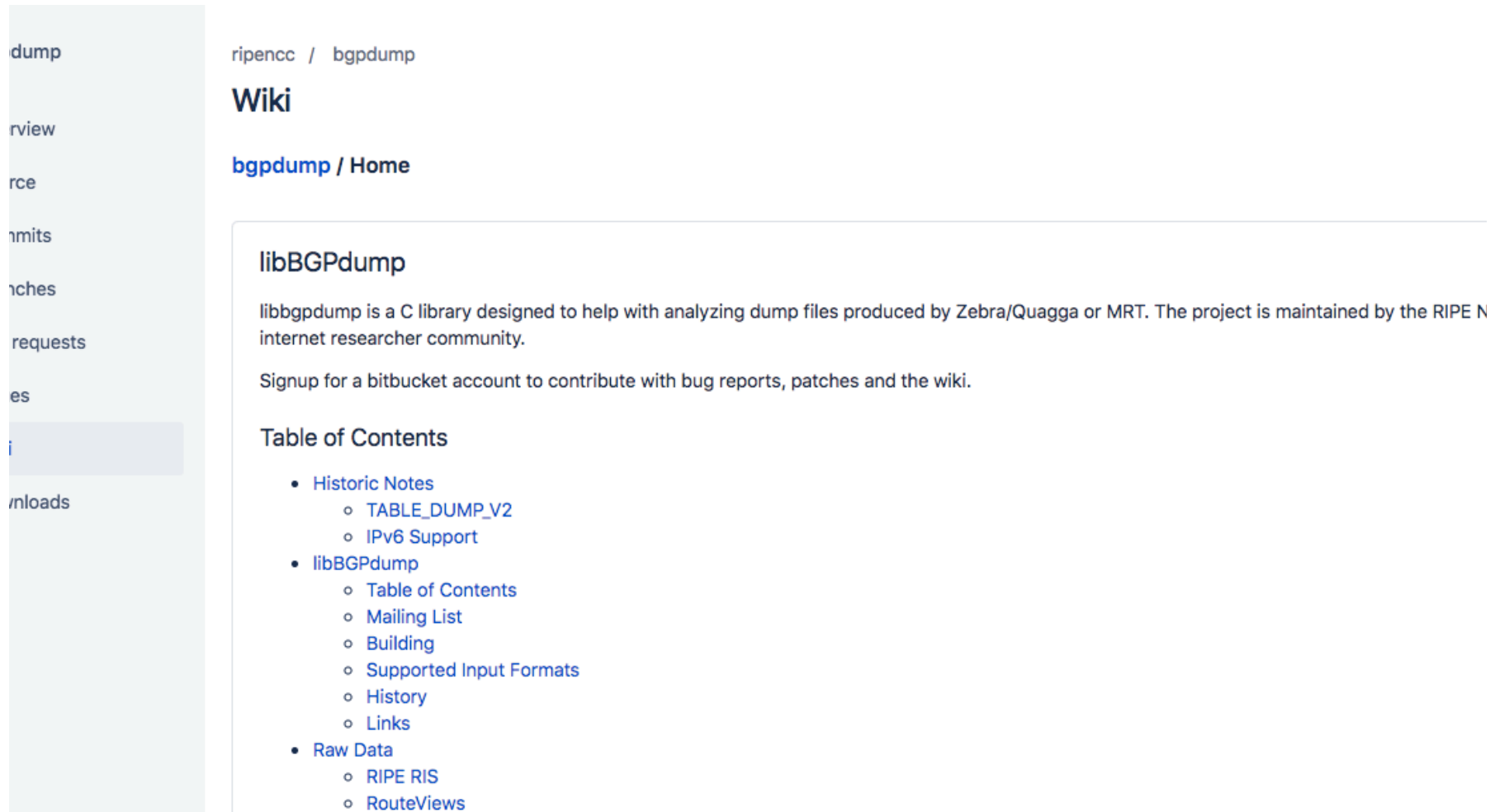| AS Rank ▲ | AS Number | Organization | | Customer Cone | | | | | | Transit |
| | | | | Number of | | | Percentages of All | | | |
				ASNs ▽	Prefixes ▽	Addresses ▽	ASNs	Prefixes	Addresses	ASN Degree ▽
1	3356	Level 3 Parent, LLC	🇺🇸	36019	516117	1293145968	40.02%	55.04%	45.77%	5177
2	1299	Telia Company AB	🇪🇺	28493	551873	1290079761	31.66%	58.85%	45.66%	1864
3	174	Cogent Communicatio...	🇺🇸	25947	486058	1207165764	28.83%	51.83%	42.73%	5761
4	2914	NTT America, Inc.	🇺🇸	24563	466401	992054726	27.29%	49.74%	35.12%	1769
5	3257	GTT Communications ...	🇩🇪	23367	439683	833095190	25.96%	46.89%	29.49%	1796
6	6762	TELECOM ITALIA SPA...	🇮🇹	15513	263025	447922042	17.24%	28.05%	15.86%	495
7	6939	Hurricane Electric LLC	🇺🇸	15344	308552	579488179	17.05%	32.9%	20.51%	7566
8	6453	TATA COMMUNICATIO...	🇺🇸	15189	383477	901968041	16.88%	40.89%	31.93%	740
9	3491	PCCW Global, Inc.	🇺🇸	10233	243645	409527793	11.37%	25.98%	14.5%	640
10	6461	Zayo Bandwidth	🇺🇸	7667	142021	357851577	8.52%	15.15%	12.67%	1896
11	1273	Vodafone Group PLC	🇪🇺	6676	132707	296777756	7.42%	14.15%	10.51%	328

23

BGPdump Tool

ripencc / bgpdump

Wiki

bgpdump / Home

libBGPdump

libbgpdump is a C library designed to help with analyzing dump files produced by Zebra/Quagga or MRT. The project is maintained by the RIPE N internet researcher community.

Signup for a bitbucket account to contribute with bug reports, patches and the wiki.

Table of Contents

- Historic Notes
    - TABLE_DUMP_V2
    - IPv6 Support
- libBGPdump
    - Table of Contents
    - Mailing List
    - Building
    - Supported Input Formats
    - History
    - Links
- Raw Data
    - RIPE RIS
    - RouteViews

Source:
https://bitbucket.org/ripencc/bgpdump/wiki/Home

Hands-on Exercise

Using BGPdump to analyze RIPE Raw BGP data
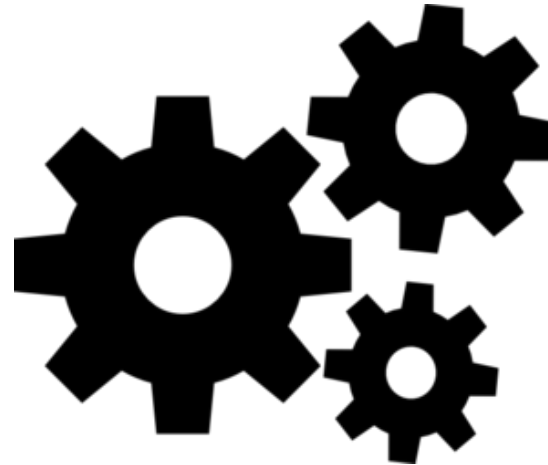
Analyzing the BGP data from one collector

- Go to:

https://www.ripe.net/analyse/internet-measurements/routing-information-service-ris/ris-raw-data

- Choose a collector,

 e.g., data.ris.ripe.net/rrc00

(rrc00 is in Amsterdam

And collects data since 1999)

Index of /rrc00

Name	Last modified	Size	Description
Parent Directory		-	
logs/	30-Aug-2016 12:55	-	
latest-update.gz	18-Apr-2019 05:20	1.1M	
latest-bview.gz	18-Apr-2019 00:39	219M	
invalid/	19-Sep-2018 18:47	-	
2019.04/	18-Apr-2019 05:25	-	
2019.03/	01-Apr-2019 00:00	-	
2019.02/	01-Mar-2019 00:00	-	

Analysis of rrc0/2019.04

Index of /rrc00/2019.04

Name	Last modified	Size	Description
Parent Directory		-	
updates.20190418.0620.gz	18-Apr-2019 06:25	1.1M	
updates.20190418.0615.gz	18-Apr-2019 06:20	1.1M	
bview.20190418.0000.gz	18-Apr-2019 00:39	219M	

bgpdump updates.20190418.0620.gz

TIME: 04/18/19 06:20:00
TYPE: BGP4MP/MESSAGE/Update
FROM: 72.22.223.9 AS11708
TO: 193.0.4.28 AS12654
ORIGIN: IGP
ASPATH: 11708 32097 6939 3356 19058
NEXT_HOP: 72.22.223.9
ANNOUNCE
  68.69.37.0/24
......

Update:
updates.20190418.0620.gz

BGP dump:
bview.20190418.0000.gz

Focusing on the AS paths

bgpdump updates.20190418.0620.gz | grep -e "ASPATH" | awk '{split($0,a,"ASPATH: "); print a[2]}'

11708 32097 6939 3356 19058
206479 34549 1299 16509
48821 205112 13030 9002 50923 44627 35564
206499 34549 1299 3356 20485 8427
202365 62240 6453 4761
202365 62240 2914 4761
202365 62240 2914 4761 38490
202365 206499 34549 1299 174 16509
202365 62240 2914 6453 4761 38490
202365 206499 34549 3320 12956 18881 263442
202365 206499 34549 13101 20485 8427 43812

....

Using a different representation

bgpdump -m updates.20190418.0620.gz

BGP4MP|1555568400|A|72.22.223.9|11708|68.69.37.0/24|11708 32097 6939 3356 19058|IGP|72.22.223.9|0|0||NAG||
BGP4MP|1555568400|A|185.120.22.16|206479|130.137.85.0/24|206479 34549 1299 16509|IGP|185.120.22.16|0|0|1299:30000 34549:100 34549:1299|NAG||
BGP4MP|1555568400|A|185.138.53.0|48821|80.242.50.0/24|48821 205112 13030 9002 50923 44627 35564|IGP|185.138.53.0|0|0|123:101 123:4901 13030:1 13030:4011 13030:7209 13030:50000 13030:51502 48821:3000 48821:3100|NAG||
BGP4MP|1555568400|A|185.215.214.1|206499|31.47.112.0/20|206499 34549 1299 3356 20485 8427|IGP|185.215.214.1|0|0|1299:25000 34549:100 34549:1299|NAG||
BGP4MP|1555568400|A|185.215.214.1|206499|212.21.0.0/19|206499 34549 1299 3356 20485 8427|IGP|185.215.214.1|0|0|1299:25000 34549:100 34549:1299|NAG||
……

Using a different representation

**bgpdump -m updates.20190418.0620.gz | awk '{split($0,a,"|");
print a[7]}'**

11708 32097 6939 3356 19058

206479 34549 1299 16509

48821 205112 13030 9002 50923 44627 35564

206499 34549 1299 3356 20485 8427

206499 34549 1299 3356 20485 8427

......

Has values only for announcements! Withdrawls do not have path information.

Find all the AS-level pairs (updates)

bgpdump -m updates.20190418.0620.gz | awk '{split($0,a,"|"); print a[7]}' | awk '{split($0, b, " "); for(i =1 ; i<length(b); i++){print b[i], b[i+1]}}'

11708 32097

32097 6939

6939 3356

3356 19058

206479 34549

34549 1299

1299 16509

48821 205112

…….

Find all the AS-level pairs
(BGP dump, file: bview.20190418.0000.gz)

bgpdump −m bview.20190418.0000.gz | awk '{split($0,a, "|"); print a[7]}' | awk '{split($0, b," "); for(i =1 ; i<length(b); i++){print b[i], b[i+1]}}'

395152 14007

205523 50673

11708 32097

32097 1299

7018 6453

6453 13335

174 13335

1836 13335

15562 2914

....

Directed and with duplications...

Find the *unique* AS level pairs
(BGP dump, file: bview.20190418.0000.gz)

Use lexicographic order!

Why we find different results?

bgpdump -m bview.20190418.0000.gz | awk '{split($0,a,"|"); print a[7]}' | awk '{split($0, b," "); for(i =1 ; i<length(b); i++){if(b[i]<=b[i+1]){print b[i], b[i+1]} else{print b[i+1], b[i]}}}' | sort | uniq | wc −l

-> 24577

bgpdump -m bview.20190418.0000.gz | awk '{split($0,a,"|"); print a[7]}' | awk '{split($0, b," "); for(i =1 ; i<length(b); i++){if(b[i]<b[i+1]){print b[i], b[i+1]} if(b[i]>b[i+1]){print b[i+1], b[i]}}}' | sort | uniq | wc −l

-> 22894
(removing the AS path prepending)
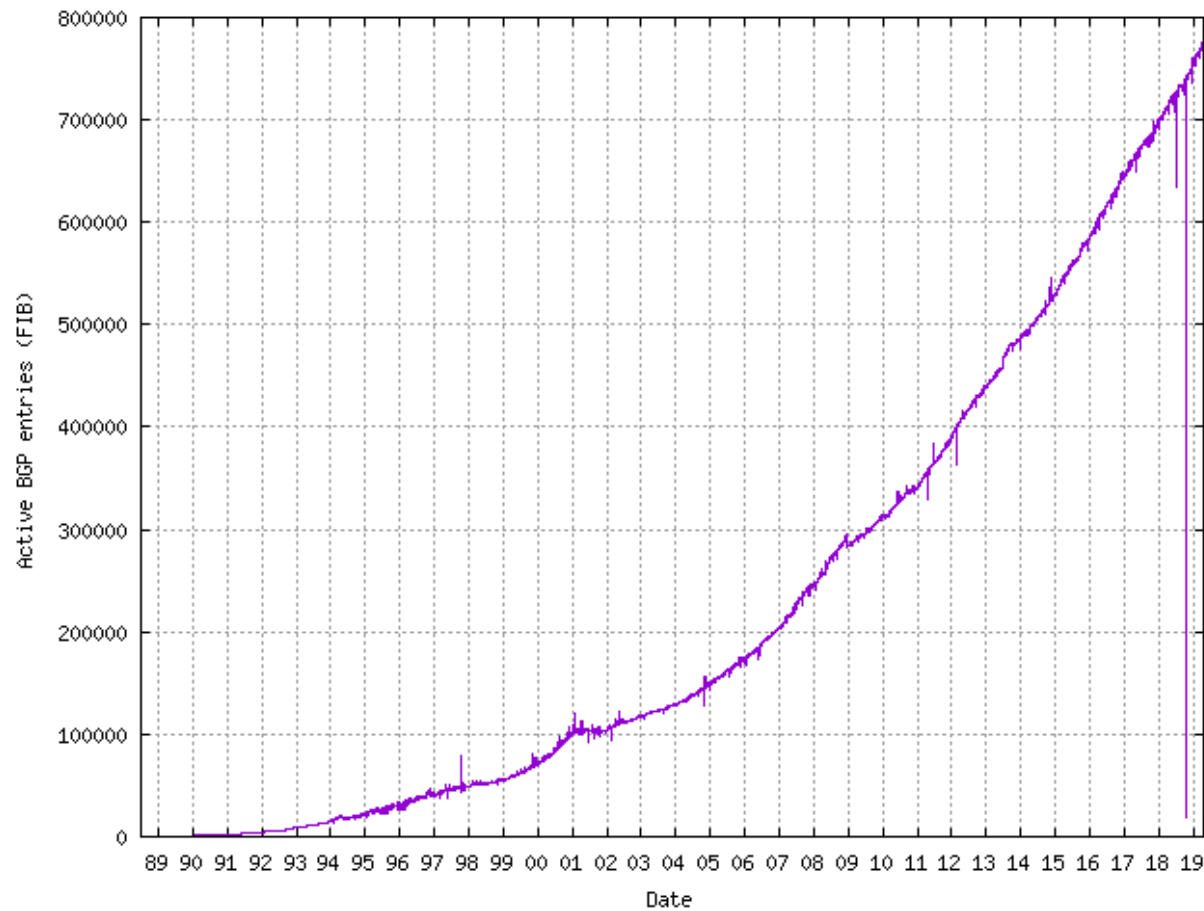
What Filters to Consider?

- For Prefixes?
  - More specific? Less specific?
  - Bogons
    - Prefixes that are private or reserved
    - Prefixes that have not been allocated to a regional registry by IANA
    - Allocated by not assigned by a regional registry
    - Hijack: prefixes that should not be announced by an ASN
    - Online lists, e.g.,
      http://team-cymru.com/bogon-reference-http.html
      http://data.caida.org/datasets/bogon
      https://www.cidr-report.org/as2.0/#Bogons

What Filters to Consider?

- For ASNs?
  - AS path prepending

    e.g., AS1 AS2 AS2 AS2 AS3 (AS2-AS2 appears as an AS-link)
  - AS path can be corrupted
  - Bogons
    - Including Private ASNs
    - Online lists, e.g.,

      http://team-cymru.com/bogon-reference-http.html

      http://data.caida.org/datasets/bogon

Route Table Increase (IPv4)

Active BGP entries (FIB)

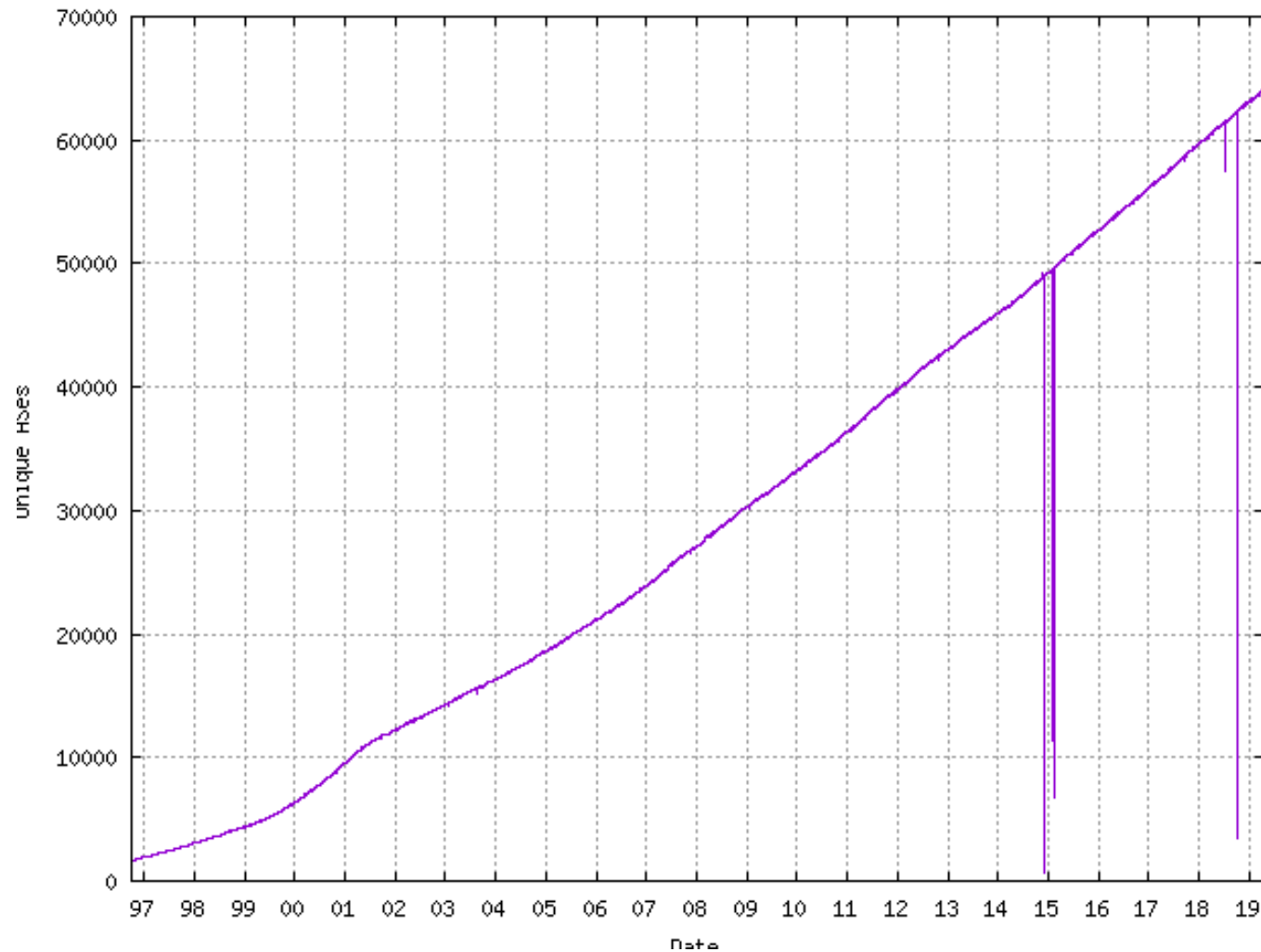Plot Range: 30-Jun-1988 1430 to 18-Apr-2019 0518

Source: CIDR report, https://www.cidr-report.org/as2.0/

Route Table Increase (IPv6)

Active% BGP% entries% %(FIB%)
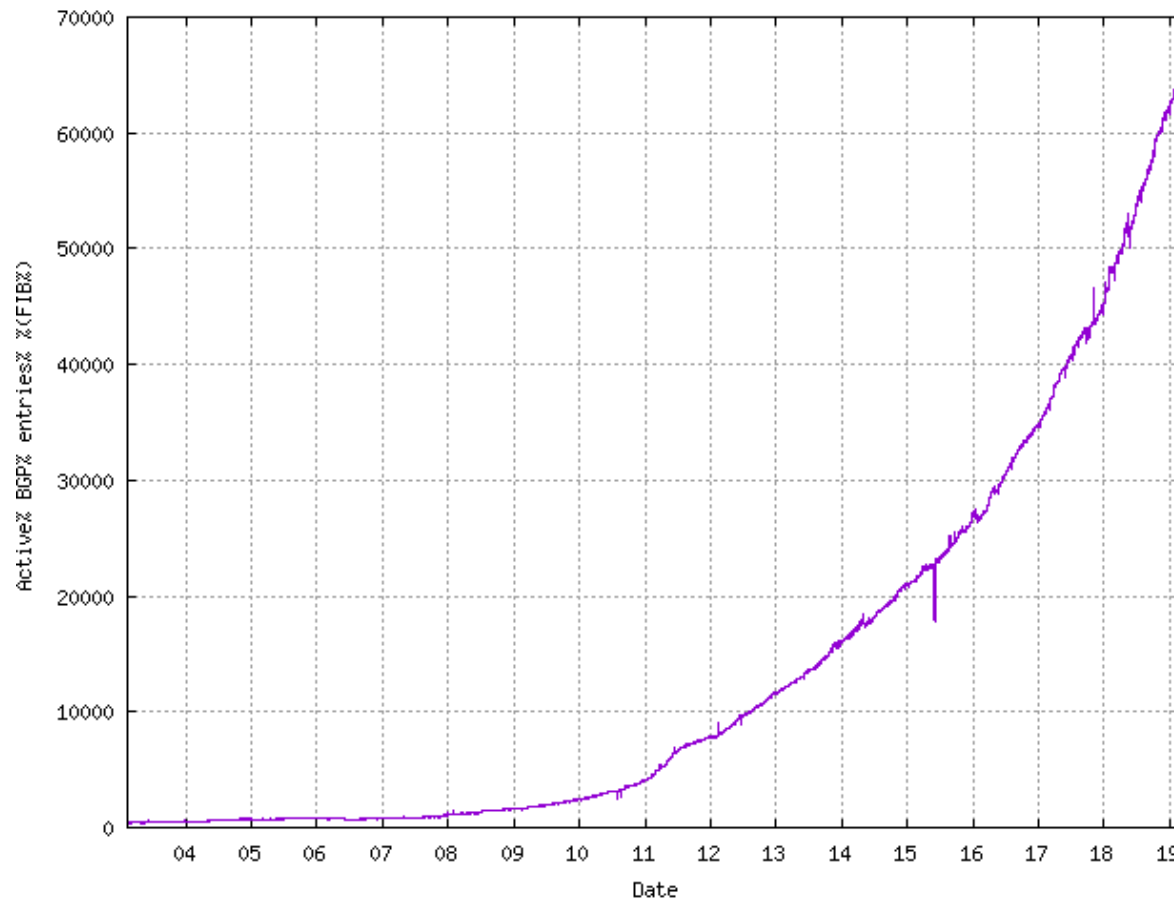
Plot Range: 10-Feb-2003 0910 to 18-Apr-2019 0518

Source: CIDR report, http://www.cidr-report.org/v6/as2.0/

Unique Ases (16-bit)

Reading

"In Search of the Elusive Ground Truth: Internet's AS-level Connectivity Structure",

R. Oliveira, D. Pei, W. Willinger, B. Zhang, and L Zhang, in the proceedings of SIGMETRICS 2018

[These slides cover sections 1, 2, and 3; we will cover the rest in the forthcoming lectures]