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Kinneret College

Autonomous Systems, CIDR

25 January 2026
Lecture 13

Topics for Today

- Intra-network routing
- AS Types
- Classless Interdomain Routing (CIDR)

- Sources: PD 4.1.2, KR 4.6.3

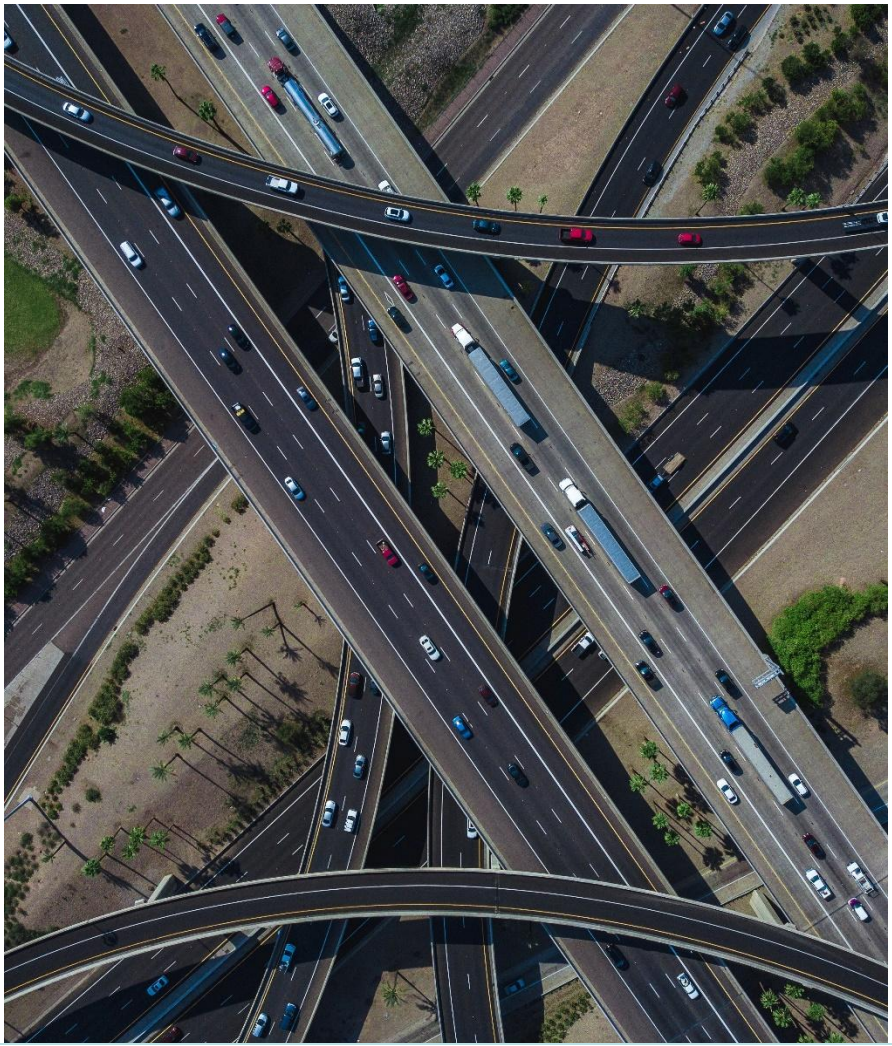
So Far

- Intra-network routing
- AS Types
- Classless Interdomain Routing (CIDR)

Intra-network Routing

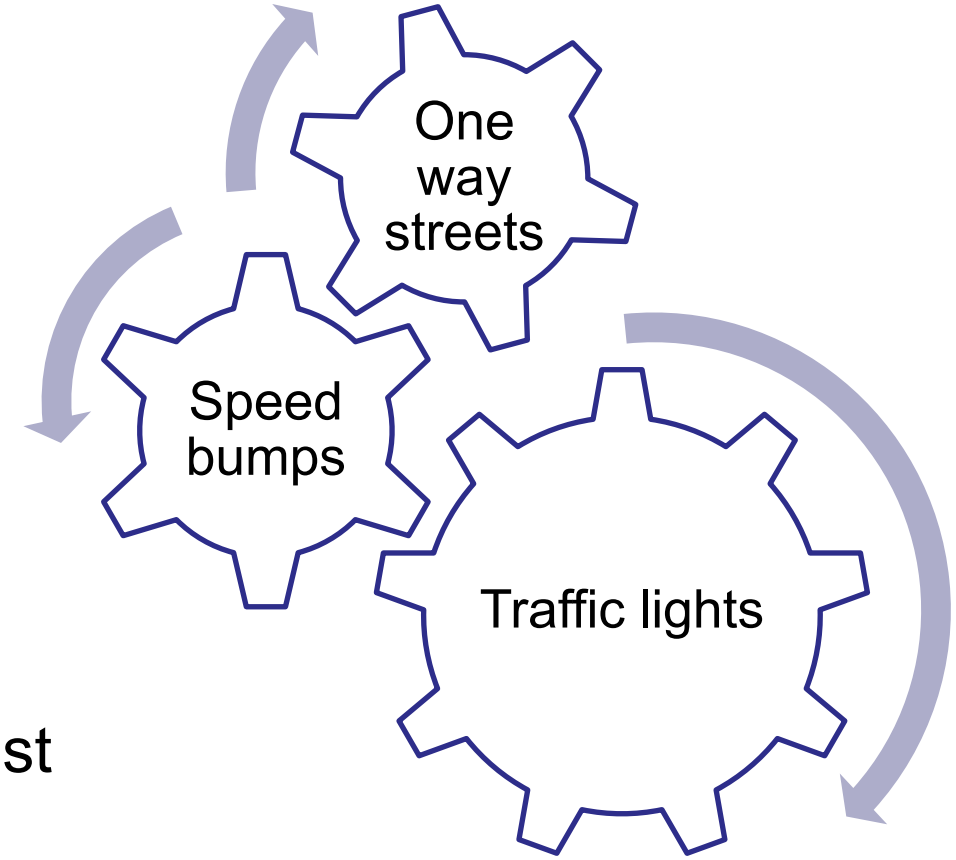
Photo by Andrea Cau on Unsplash

Inter-network Routing



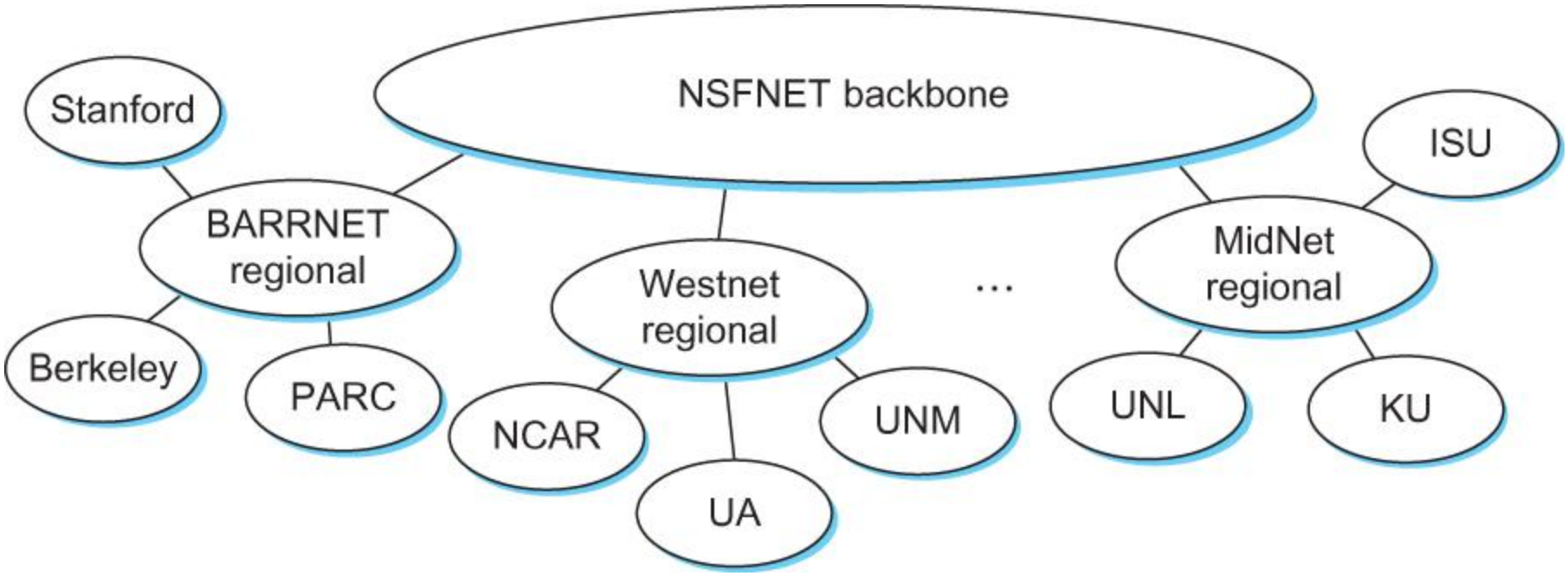
Inter- versus Intra-

- Different decisions:

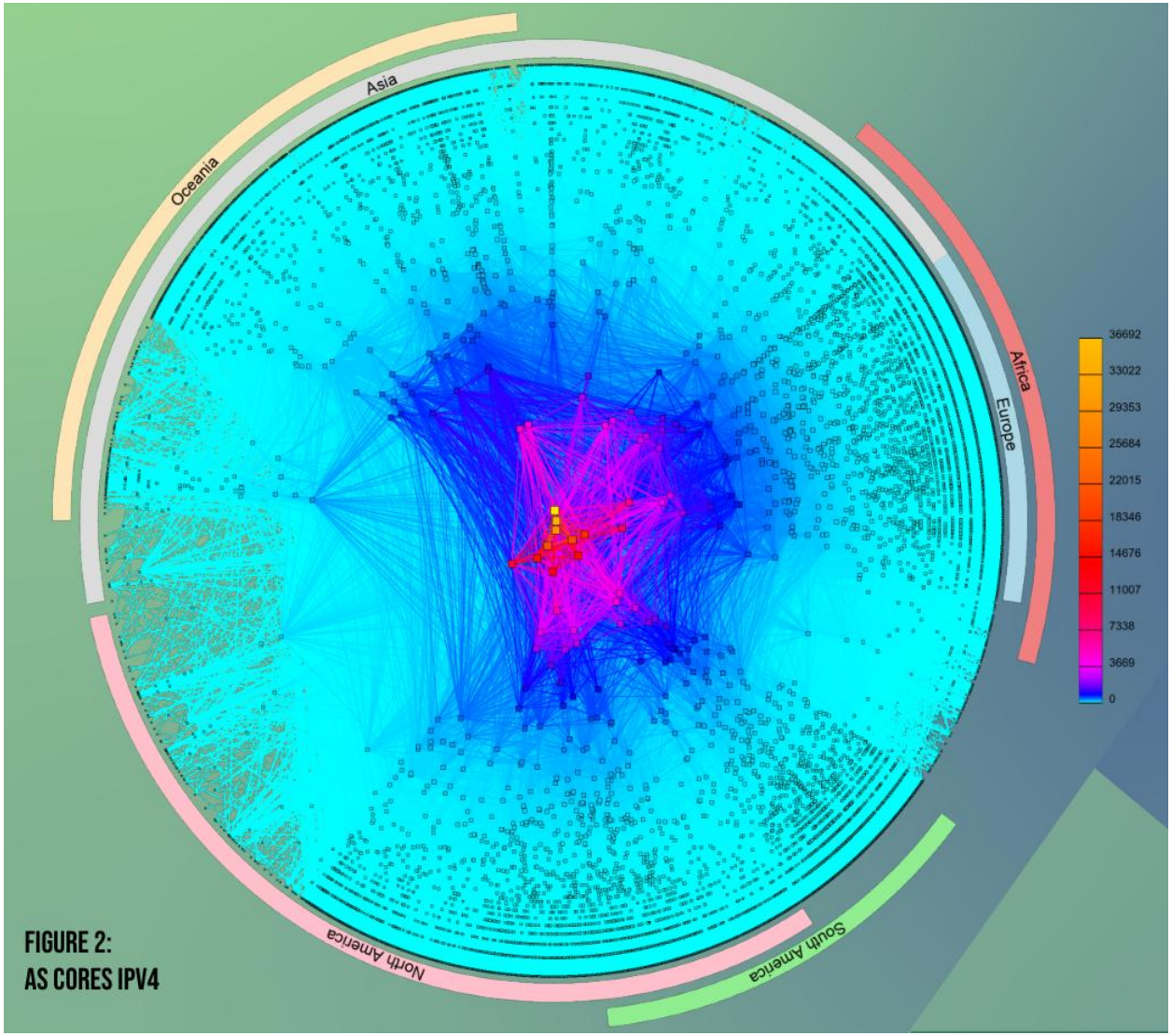


- Fastest versus Shortest
- What shape is the internet?

The old shape (1990s)



AS Core 2020


Asia
Oceania
Africa
Europe
North America
South America
36692
33022
29353
25684
22015
18346
14676
11007
7338
3669
0
FIGURE 2:
AS CORES IPV4

CAIDA's AS Core 2017 Internet Graph

http://www.caida.org/research/topology/as_core_network/

INTRODUCTION

The CAIDA AS Core visualization depicts the Internet's Autonomous Systems' (ASes) geographic locations, number of customers, and interconnections. Each AS approximately corresponds to an Internet Service Provider (ISP). The geographic location of the individual AS is inferred from the weighted centroid of its address space according to NetAcuity, a commercial geolocation service. The number of direct or indirect customers of an ASA is inferred using its *customer cone* (described below).

For this visualization we used the Feb 2017 Internet Topology Data Kit (ITDK). We obtained the raw IPv4 topology data for the ITDK by performing traceroutes to randomly-chosen destinations in each routed /24 BGP prefix using 121 Ark monitors located in 42 countries, on Jan 22 to Feb 7, 2017. The resulting IP topology contained almost 50 million IP addresses, 49 million inferred routers, and 36 million inferred links. We inferred the IP address to AS mappings using *bordermapit*, a tool for inferring router ownership (a collaboration between CAIDA and UPenn). The resulting AS topology contained 47,610 ASes and 148,455 links.

Each AS node is plotted in polar coordinates (radius, angle) on the circle, as formally defined in the equations below. The distance of each AS node from the center of the circle (the radial coordinate) is the inverse of each AS's customer cone size, (roughly) the number of the AS's direct or indirect customers. ASes at the outer edge of the circle have no customers and ASes at the center have the largest number of customers. The angular coordinate indicates the AS's geographic longitude.

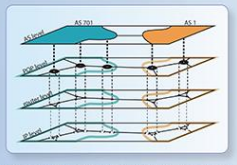
$$\text{radius} = 1 - \log\left(\frac{\text{transit degree(AS)} + 1}{\text{maximum transit degree} + 1}\right)$$

$$\text{angle} = \left(\text{longitude of the AS's BGP prefixes in Netacuity}\right)$$

The core of this topology, the set of ASes with the largest customer cones, is still dominated by U.S.-centric ASes.

INTERNET LAYERS

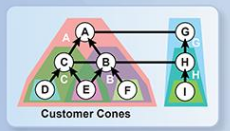
The Internet's network topology is often divided into four layers: AS, PoP, Router, and IP. The IP address uniquely identifies an attachment point (interface) of a device on the Internet. The router layer refers to the set of routers that transfer and route traffic. To support geophysically-aware topology analysis, we aggregate routers into Points of Presence (PoPs). To support interdomain (between networks) topology analysis, we aggregate routers by ownership into Autonomous Systems (ASes).

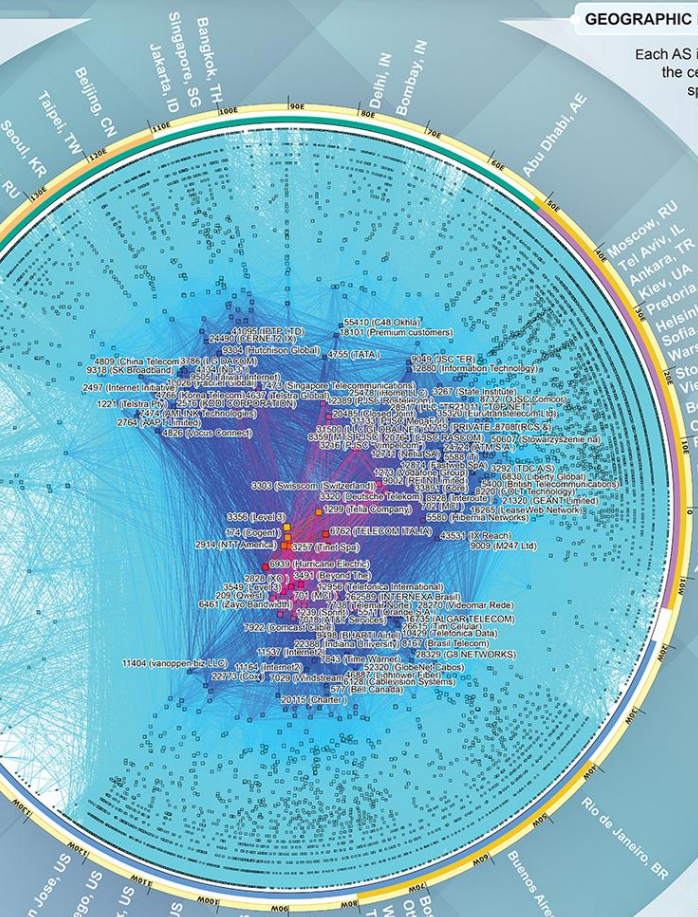


CUSTOMER CONE

The AS's customer cone is the set of ASes that directly or indirectly pay the AS to connect to the Internet. On the left, A has the largest cone with 6 ASes; H has two. An AS's customer cone contains the set of ASes we observe the AS announce to its peers or providers. This definition is more constrained than, but similar to, the set of ASes reachable through its customers.

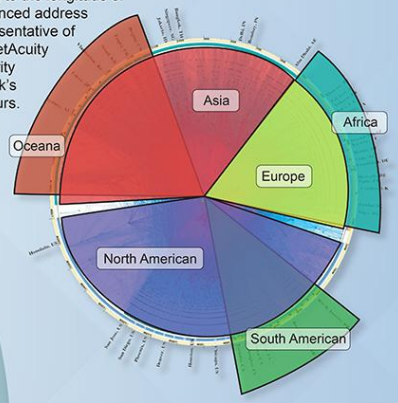
AS	Size
A	6
B	3
D	1





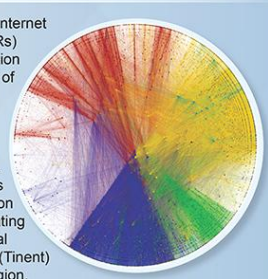
GEOGRAPHIC REGIONS

Each AS is placed according to the longitude of the centroid of its announced address space. This is representative of the area where NetAcuity inters the majority of this network's activity occurs.



REGIONAL INTERNET REGISTRIES

The Regional Internet Registries (RIRs) manage allocation and registration of Internet number resources, such as AS numbers, within a particular region of the world. Although most ASes geolocate to the region of the originally allocating RIR, some multinational networks, e.g., AS3257 (Tinent) geolocate outside their region.



American Registry for Internet Numbers (**ARIN**) for the United States, Canada, several part of the Caribbean region, and Antarctica.

Latin America and Caribbean Network Information Centre (**LACNIC**) for Latin America and parts of the Caribbean region

African Network Information Center (**AFRINIC**) for Africa

Reseaux IP Europeens Network Coordination Centre (**RIPE NCC**) for Europe, Russia, the Middle East, and Central Asia

Asia-Pacific Network Information Centre (**APNIC**) for Asia, Australia, New Zealand, and neighboring countries

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Acknowledgments

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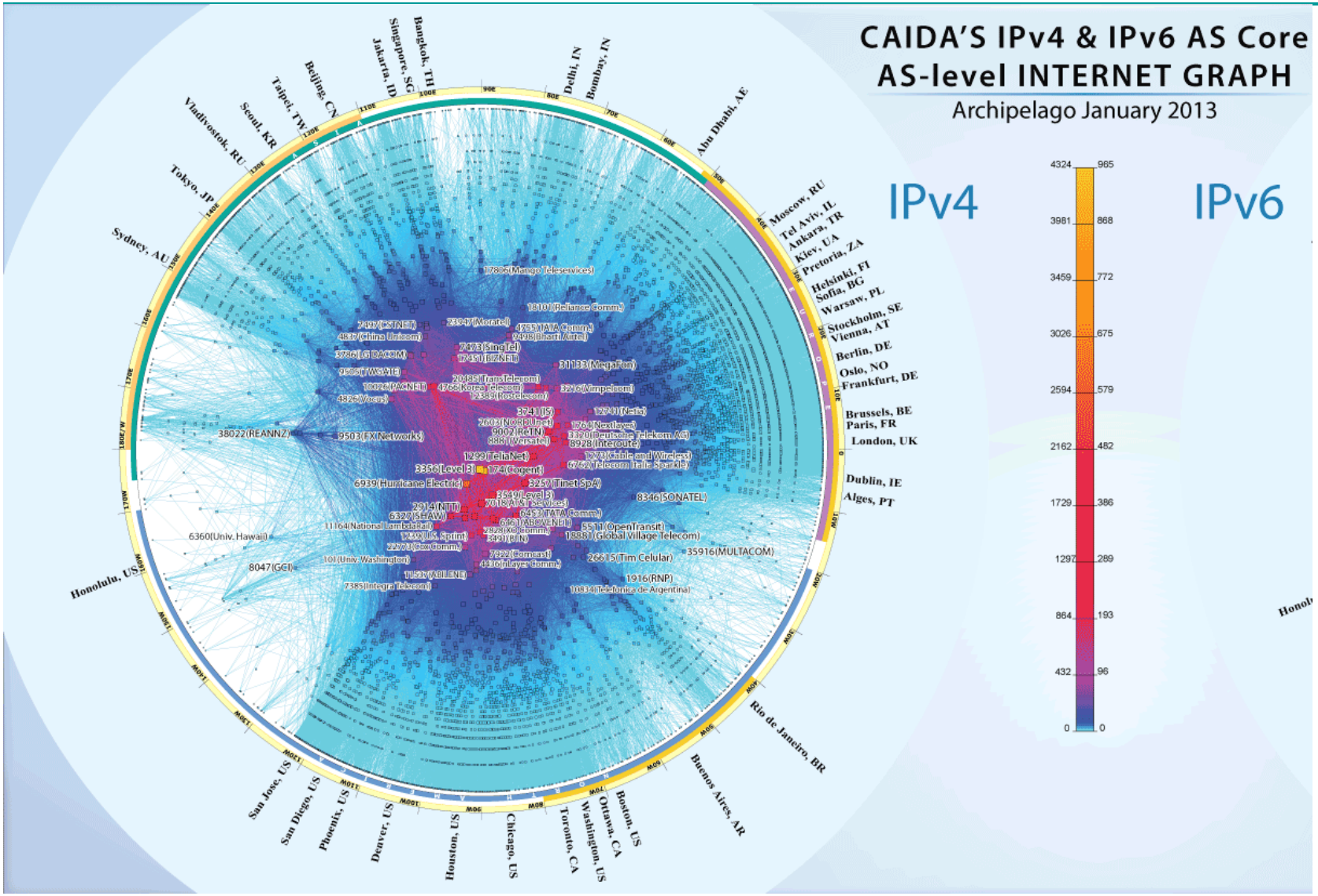
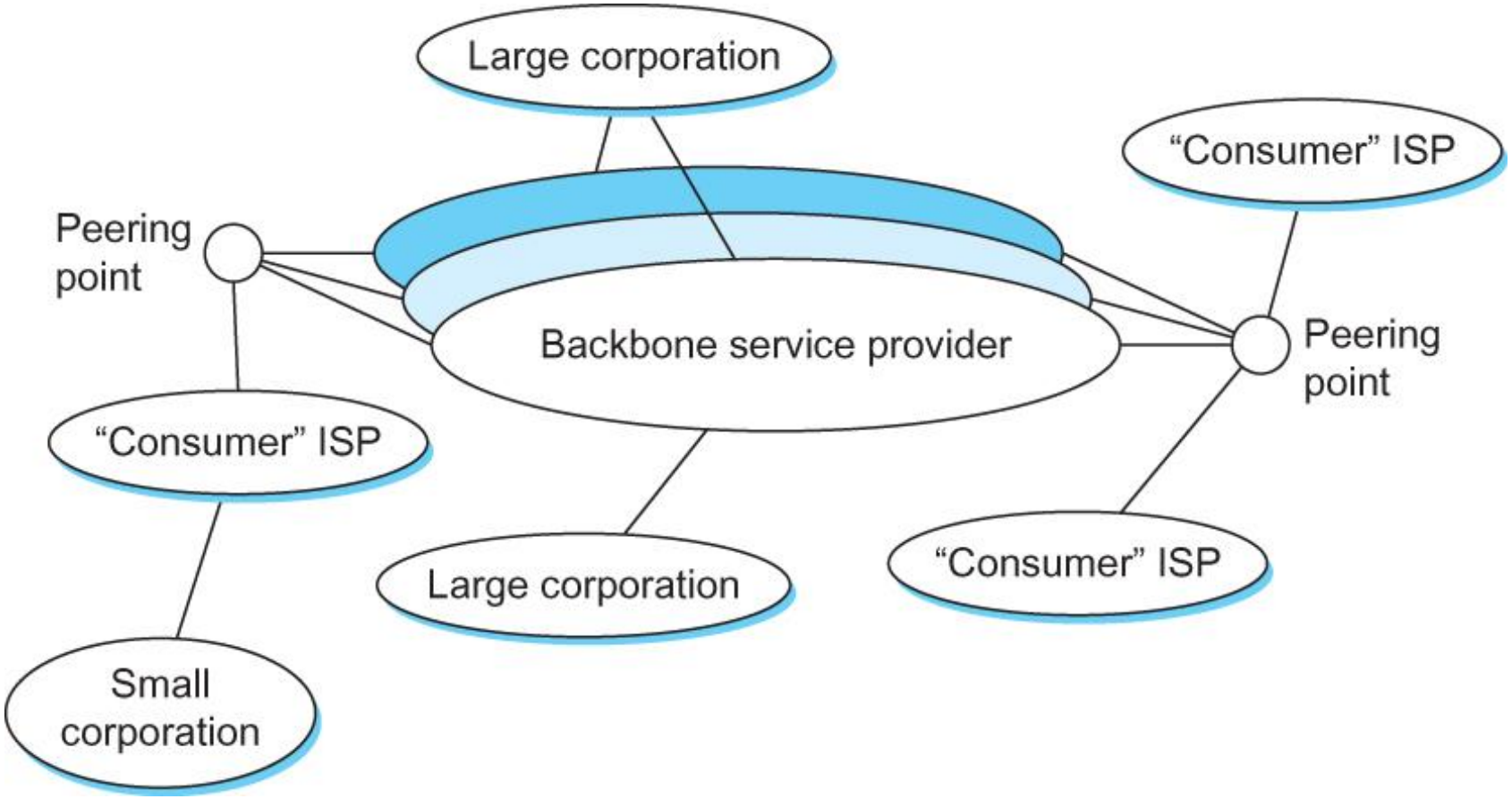
ARK Hosts: AARNet, AFRINIC, AMS-IX, APAN, ARIN, ASTI, Acreo, BDCOM Online Limited at BD-IX, CENIC, CNNIC, CNRST, Cablenet Communication Systems, Canarie, Carnegie Mellon University in Rwanda, Colorado State University, DCS1 Pte Ltd, DePaul University, Eötvös Loránd University (ELTE), Eurocom, Foundation for Research and Technology - Hellas (FORTH), Frankfurt CCI, Georgian College, HB Networks, IEANet, Hong Kong Polytechnic University, Hurricane Electric, IIJ, IX.br, Indonesian IXP Task Force, International Computer Science Institute (ICSI), Internet Systems Consortium, Iowa State University, Jacobs University Bremen, Jaguar Network, KREONet2, Kantonsschule Zug, Level 3 Communications, Liberty Global, NCAR, NIC Chile, NIC Mexico, NORDUnet, Nepal Research And Education Network, NetIX, Neterra Ltd, Northeastern University, Openmirrors.asia - at Equinix SG1, Ottawa Internet Exchange, Public University of Navarra, QCell, RIPE NCC, RNP, Rede ANSP / Projeto NARA, Registro.br, SURFnet, Simula Research Laboratory, Solido Networks ApS, Southern Methodist University, TKK, TWAREN, Technical University of Munich, Tinet, TorIX, UCAD, US Army Research Lab, Univ. Twente, Universitat Leipzig, Universitat Politecnica de Catalunya, University of Cambridge, University of Hawaii, University of Limerick, University of Melbourne, University of Napoli, University of Nevada at Reno, University of Oregon, University of Waikato, University of Washington, University of Zurich, VTR

From 2013

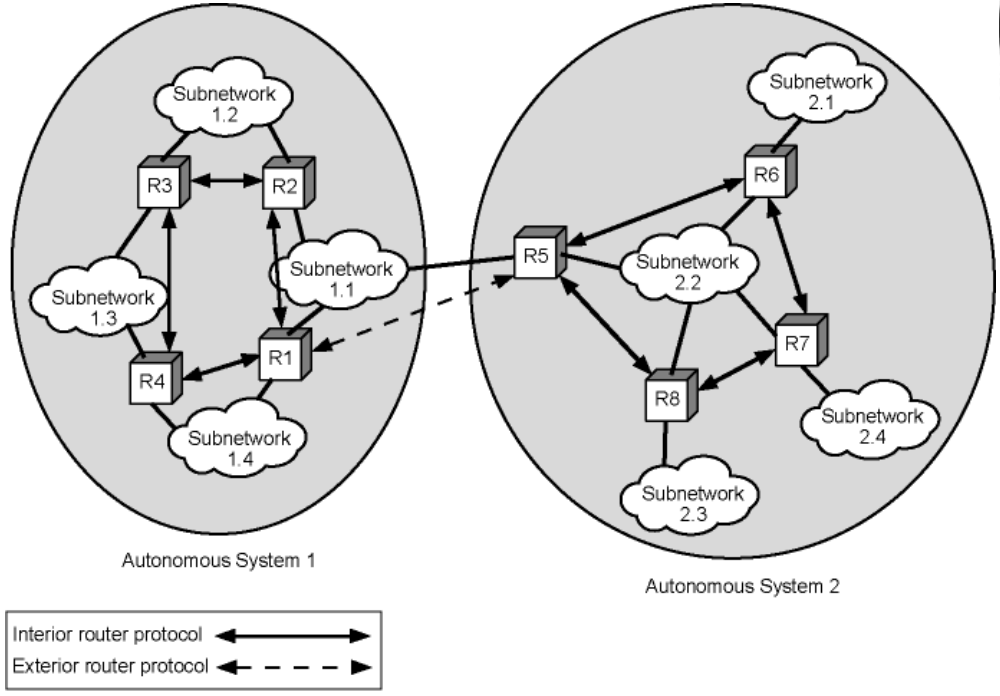

CAIDA'S IPv4 & IPv6 AS Core
AS-level INTERNET GRAPH
Archipelago January 2013
IPv4
IPv6
4324
3981
3459
3026
2594
2162
1729
1297
864
432
0
965
868
772
675
579
482
386
289
193
96
0
Singapore, SG
Jakarta, ID
Bangkok, TH
Delhi, IN
Bombay, IN
Abu Dhabi, AE
Moscow, RU
Tel Aviv, IL
Ankara, TR
Kiev, UA
Pretoria, ZA
Helsinki, FI
Sofia, BG
Warsaw, PL
Stockholm, SE
Vienna, AT
Berlin, DE
Oslo, NO
Frankfurt, DE
Brussels, BE
Paris, FR
London, UK
Dublin, IE
Alges, PT
Rio de Janeiro, BR
Buenos Aires, AR
Boston, US
Ottawa, CA
Washington, US
Toronto, CA
Chicago, US
Houston, US
Denver, US
Phoenix, US
San Diego, US
San Jose, US
Honolulu, US
Sydney, AU
Tokyo, JP
Vladivostok, RU
Seoul, KR
Taipei, TW
Beijing, CN
17838(Mango Teleservices)
18101 (Reliance Comm)
23947(Monatel)
4755(TATA Comm)
9498(Bharti Airtel)
7473(SingTel)
12541(BZNET)
31133(MegaFon)
20485(TransTelecom)
4766(Korea Telecom)
12389(Rostelecom)
3216(Vimpelcom)
4826(Vocus)
7449(BSTNET)
4837(China Unicom)
3786(GLOBAL)
9505(FWSRIE)
10026(PACNET)
3741(IS)
2603(NORDUnet)
9002(RETN)
8888(Versatel)
1299(TeliaNet)
3356(Level 3)
174(Cogent)
12713(Netia)
1764(Neuf aye)
3320(Deutsche Telekom AG)
8928(Interoute)
1273(Cable and Wireless)
6762(Telecom Italia Sparkle)
3257(Tinet SpA)
6939(Hurricane Electric)
38022(REANNZ)
9503(FX/Networks)
8346(SONATEL)
3549(Level 3)
7018(AT&T Services)
2914(NTT)
6320(SHAW)
6453(TATA Comm)
6461(ABOVENET)
11164(National Lambdarail)
2828(XO Comm)
8551(OpenTransit)
1239(Sprint)
3491(BTN)
18881(Global Village Telecom)
6360(Univ. Hawaii)
22773(Cox Comm)
7922(Comcast)
35916(MULTACOM)
101(Univ. Washington)
4230(Claro Comm)
26615(Tim Celular)
8047(GCI)
11537(ABILENE)
1916(RNP)
7385(Integra Telecom)
10834(Telefonica de Argentina)

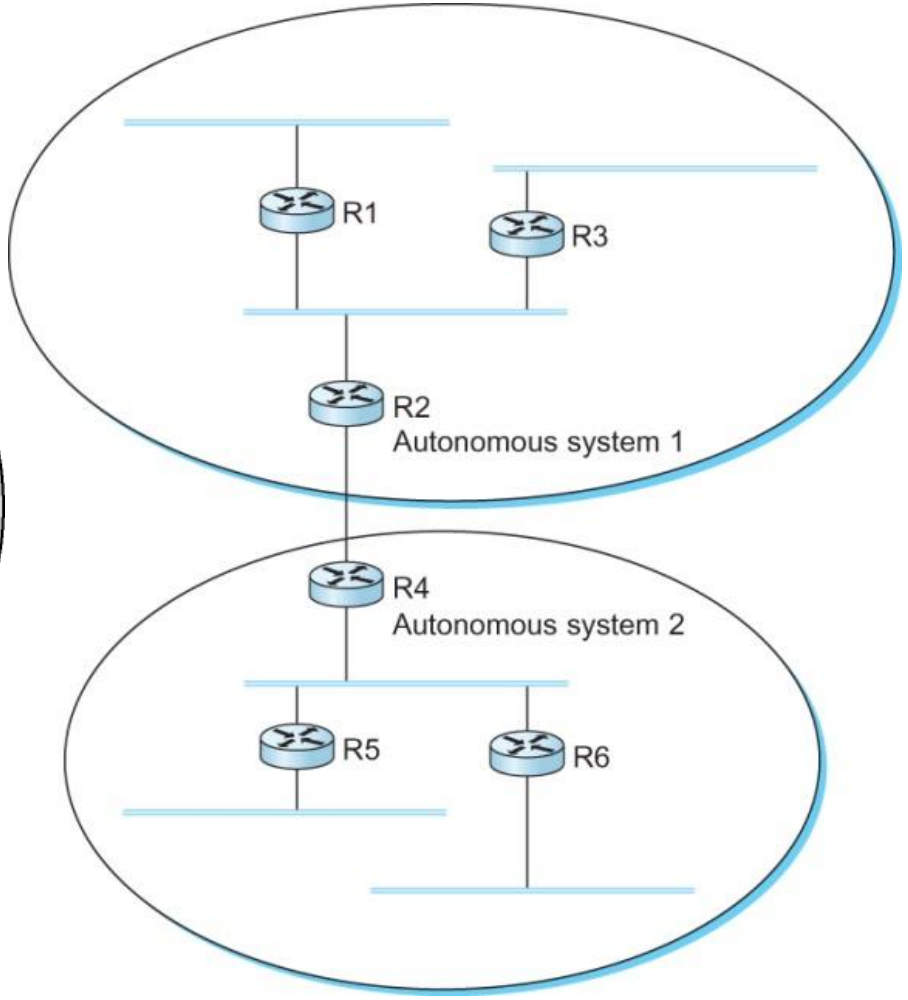
Organizations and Backbone



- Key Concept: Autonomous System (AS) (aka Routing Domain)

Organizations and Backbone

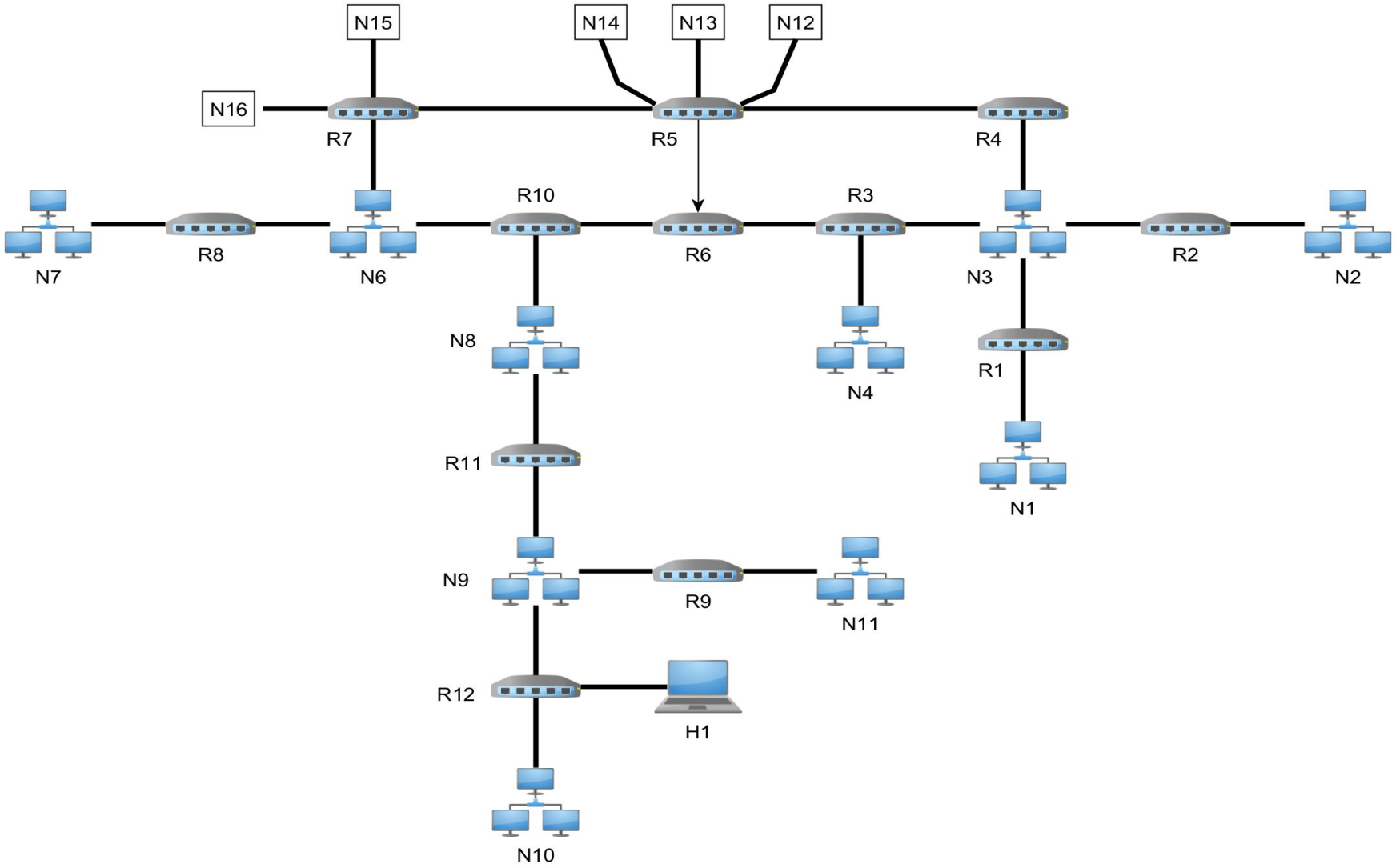




So Far

- Intra-network routing
- AS Types
- Classless Interdomain Routing (CIDR)

Sample AS Topology



AS Classes

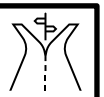
Stub AS

- Has only a single connection to one other AS
- Will only carry local traffic
- Ex. Consumer based Internet Service Provider, small corporation, small academic institution

Multihomed AS

- Has connections to 2+ AS', but refuses to carry transit traffic
- Ex. Large corporation, college, etc.
- Complicates routing and allocation (need provider independent address space, ASN, etc.)

Transit AS



- Has connections to 2+ AS', and is designed to carry both transit and local traffic
- Ex. Bezeq, Netvision, other international ISPs.

Network Types – Stub

Has only a single connection to one other AS

Will only carry local traffic

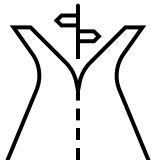
- Want to get data directed to them
- Want to send data to other places

Pay for bandwidth and connectivity

Examples:

- Consumer based Internet Service Provider
- Small corporation
- Small academic institution

Network Types - Transit



Networks that connect to other networks (ISPs, etc.)

- Has connections to 2+ AS', and is designed to carry both transit and local traffic

Move data from one place to another

Offer data transit services to customers for a fee

Examples

- Bezeq
- Netvision
- International ISPs.

Top 10 Transit ASes

AS Rank ▲	AS Number ▽	Organization		ASNs ▽
1	3356	Level 3 Parent, LLC		53761
2	1299	Arelion Sweden AB		42519
3	174	Cogent Communications		37338
4	3257	GTT Communications I...		33334
5	2914	NTT America, Inc.		26265
6	6762	Telecom Italia S.p.A.		21719
7	6939	Hurricane Electric LLC		21430
8	6461	Zayo Bandwidth		18381
9	6453	TATA COMMUNICATIO...		17240
10	62275	NHM - S.R.L.		11199

AS Rank: A ranking of the largest Autonomous Systems (AS) in the Internet. (caida.org)

Some Israeli Transit ASes

AS number	8551
AS name	BEZEQ-INTERNATIONAL-AS
organization	Bezeq International Ltd.
country	Israel
AS rank	277
customer cone	171 asn, 22643 prefix, 44916484 address
AS degree	305 global, 304 transit, 9 provider, 169 peer, 127 customer

AS number	12400
AS name	PARTNER-AS
organization	Partner Communications Ltd.
country	Israel
AS rank	374
customer cone	122 asn, 12700 prefix, 25850398 address
AS degree	263 global, 254 transit, 8 provider, 159 peer, 96 customer

AS number	1680
AS name	NV-ASN
organization	Cellcom Fixed Line Communication L.P
country	Israel
AS rank	299
customer cone	156 asn, 11465 prefix, 26590419 address
AS degree	324 global, 321 transit, 8 provider, 170 peer, 146 customer

Multihomed Stub

Owned by a single organization

Connected to more than one other AS

Only wants to send and receive data for itself

- Could offer transit services, but is not interested

About Multihomed Stub ASes

Image copyright: *Jay Hamburger/Park Record*
https://www.parkrecord.com/news/park-city-parked-cars-block-driveways-hydrants-buses-and-plows/

About Multihomed Stub ASes

Some Multihomed Stub ASes

AS number	27477
AS name	POLAR-PUBLIC-HUB-POP-ASN
organization	IBM
country	United States
AS rank	30749
customer cone	1 asn, 5 prefix, 1280 address
AS degree	6 global, 0 transit, 6 provider, 0 peer, 0 customer

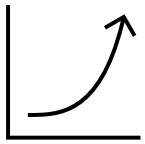
AS number	13445
AS name	13445
organization	Cisco Webex LLC
country	United States
AS rank	12046
customer cone	1 asn, 115 prefix, 326656 address
AS degree	149 global, 0 transit, 18 provider, 131 peer, 0 customer

AS number	204284
AS name	NESTLE
organization	Nestle Operational Services Worldwide SA
country	Switzerland
AS rank	20389
customer cone	1 asn, 3 prefix, 4608 address
AS degree	2 global, 0 transit, 2 provider, 0 peer, 0 customer

Challenges of inter-AS routing

Scale

- Things grow – stay efficient while growing

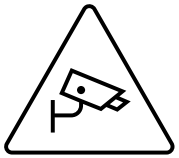


Load balancing

- Keep data moving when loads and traffic appear

Privacy

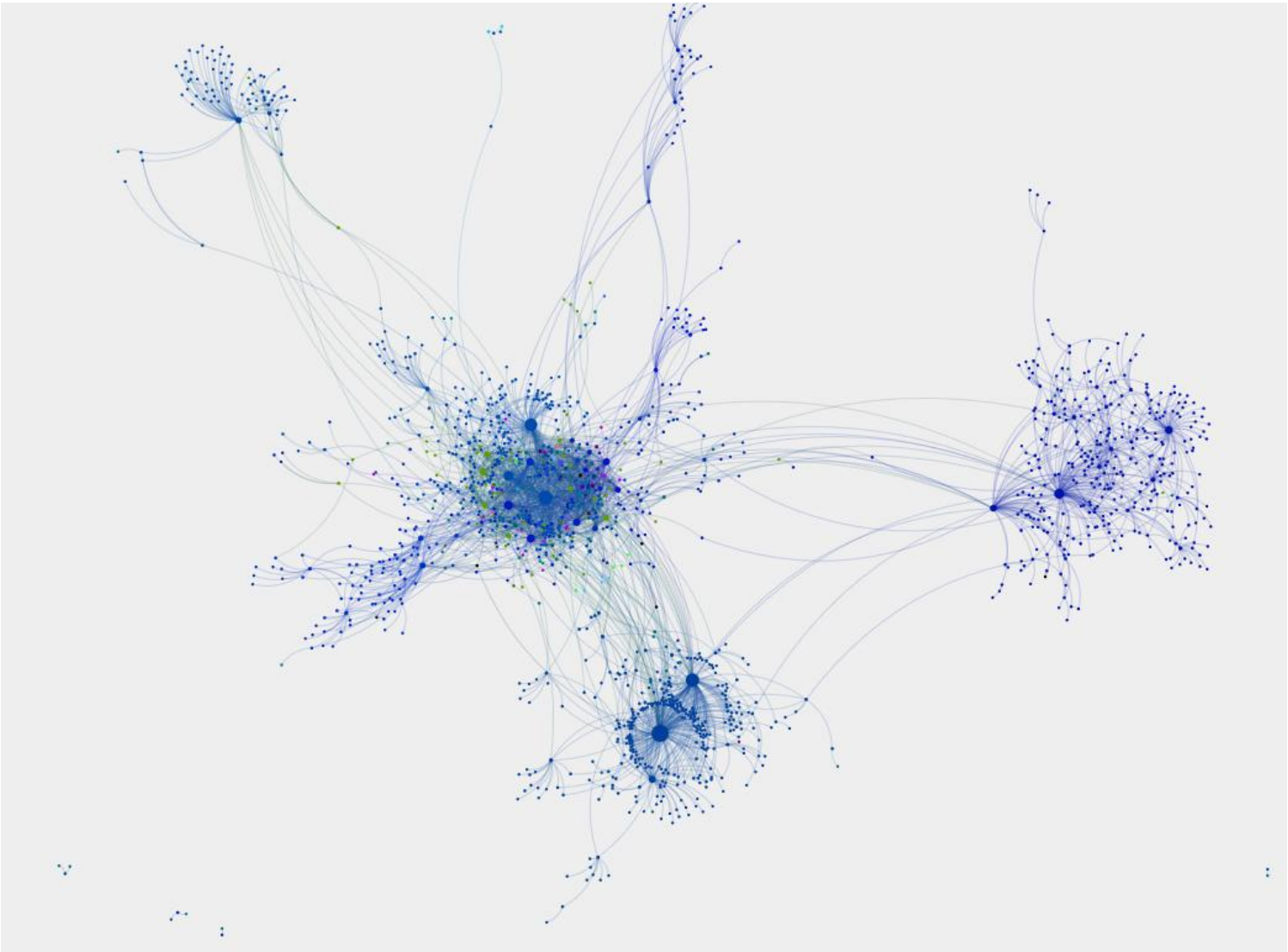
- Don’t let others see your internals



Policy

- Give priorities
- Prevent bad things
- Respond to changes

Visualizing It http://thyme.apnic.net/BGP/ME/



Some Numbers (London, 9 April 2024)

http://thyme.apnic.net/london/data-summary

```
Analysis Summary
----------------
BGP routing table entries examined:                              917478
       Prefixes after maximum aggregation (per Origin AS):      348263
Total ASes present in the Internet Routing Table:                 74273
       Prefixes per ASN:                                          12.35
Origin-only ASes present in the Internet Routing Table:           63779
Origin ASes announcing only one prefix:                           26255
Transit ASes present in the Internet Routing Table:               10494
Transit-only ASes present in the Internet Routing Table:          433
Average AS path length visible in the Internet Routing Table: 4.5
       Max AS path length visible:                                77
       Max AS path prepend of ASN ( 37447)                        75
Prefixes from unregistered ASNs in the Routing Table:             1075
       Number of instances of unregistered ASNs:                  1077
Number of bogon 32-bit ASNs visible in the Routing Table: 10
Prefixes being announced from unallocated address space:          579
Number of addresses announced to Internet:                        3,054,962,944
       Equivalent to 182 /8s, 23 /16s and 9 /24s
```

So Far

- Intra-network routing
- AS Types
- Classless Interdomain Routing (CIDR)

Running out of IP Addresses

Classical IP classes

- Class A: 16,777,214
- Class B: 65,534
- Class C: 254

Many orgs bought Class B network figuring they might go over 254

- Survey found over half of them had less than 50 hosts
- Millions of addresses have gone to waste
- Can’t recover them easily (already sold!)
- Some have been recycled so far

Running out of IP Addresses

14 Sept 2012: RIPE.net (European and Middle East ISP) announces it's on its last class A (/8) block

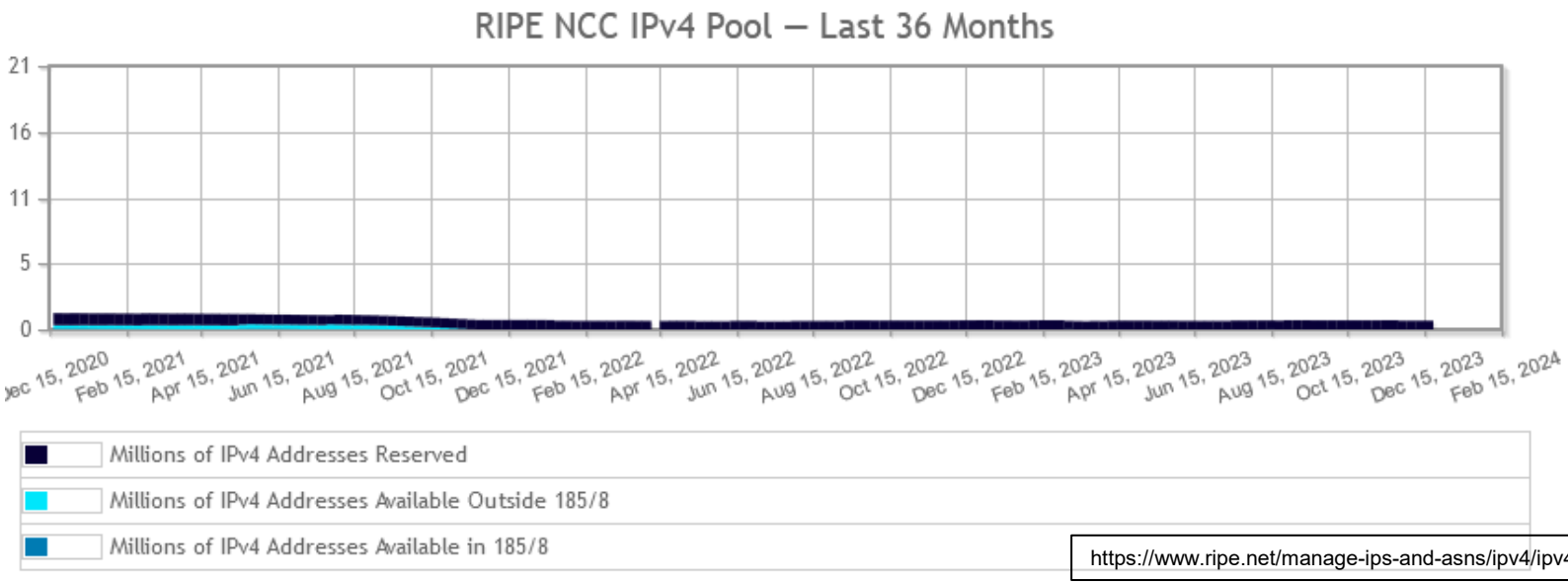
- No more IPv4 allocations to new customers
- Customers with IPv6 can only buy one more /22 (1,024 addresses) block
- 29 Feb 2016: 15.59 million addresses left in /8 block (93% of it)

- IANA has begun recovering IPv4 address blocks
  - 1 March 2016: RIPE.net received a recovered /15 block

RIPE NCC IPv4 Available Pool

Millions of IPv4 Addresses in the Pool	**0.70**
Millions of IPv4 Addresses Available	**0.00**
Millions of IPv4 Addresses Reserved	**0.70**

The graph below is interactive. You can zoom in by dragging a rectangle over any desired section. To reset the view, simply double-click anywhere inside the graph.



https://www.ripe.net/manage-ips-and-asns/ipv4/ipv4-available-pool

No More Classes

Stopgap measure: Stop using classes

Works only for newly granted networks

Give out addresses in chunks of Class C size

Network needs 4064 hosts?
Give 16 Class C networks

Creates a new problem: Routers designed for class based routing

An organization has 16 Class C networks assigned (4064 hosts)

Each router needs 16 lines for that organization

They all go to the same place!

Aggregate Routes

- The answer: *Aggregate Routes*
  - Very similar to Subnetting
  - Use addresses and masks
  - Requires us to allocate addresses contiguously
  - Technique: Classes Interdomain Routing

- If we give out 16 Class C networks: 192.4.16 – 192.4.31
  - 192.4.16: `11000000 00000100 00010000 00000000`
  - 192.4.31: `11000000 00000100 00011111 00000000`
  - The top 20 bits are the same
- We can write this: 192.4.16/20
  - Means the top 20 bits matter
  - Identical to using the subnet mask: 255.255.240.0
    - `11111111.11111111.11110000.00000000`

Conclusion

- Intra-network routing
- AS Types
- Classless Interdomain Routing (CIDR)