CAIDA's AS-rank: measuring the influence of ASes on Internet Routing

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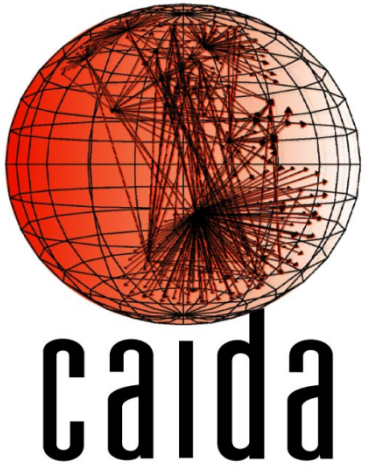


http://as-rank.caida.org/

Overview

1. Inferring **AS relationships** using publicly available BGP paths
   - views of ~400 ASes at Route Views and RIPE RIS
2. Inferring the **influence of ASes** based on their "customer cone"
   - Traffic in your customer cone stays on-net and is the most profitable (when it reaches you)

http://as-rank.caida.org/

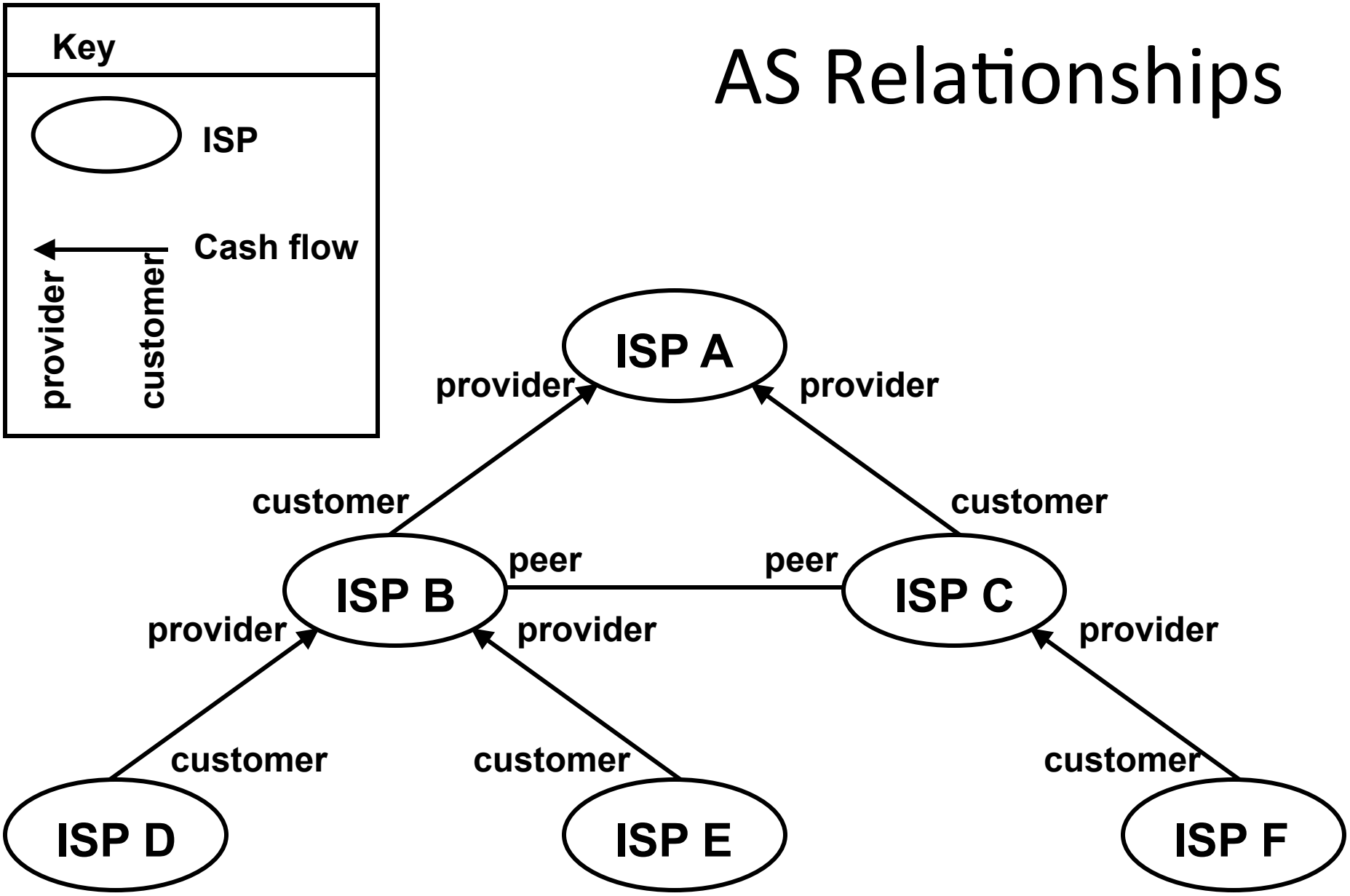
Roadmap

- Objectives
- Methodology
  - Definitions, assumptions, and caveats
  - Algorithm
  - Illustration
- Results
- Open Problems
  - How NANOG can help!

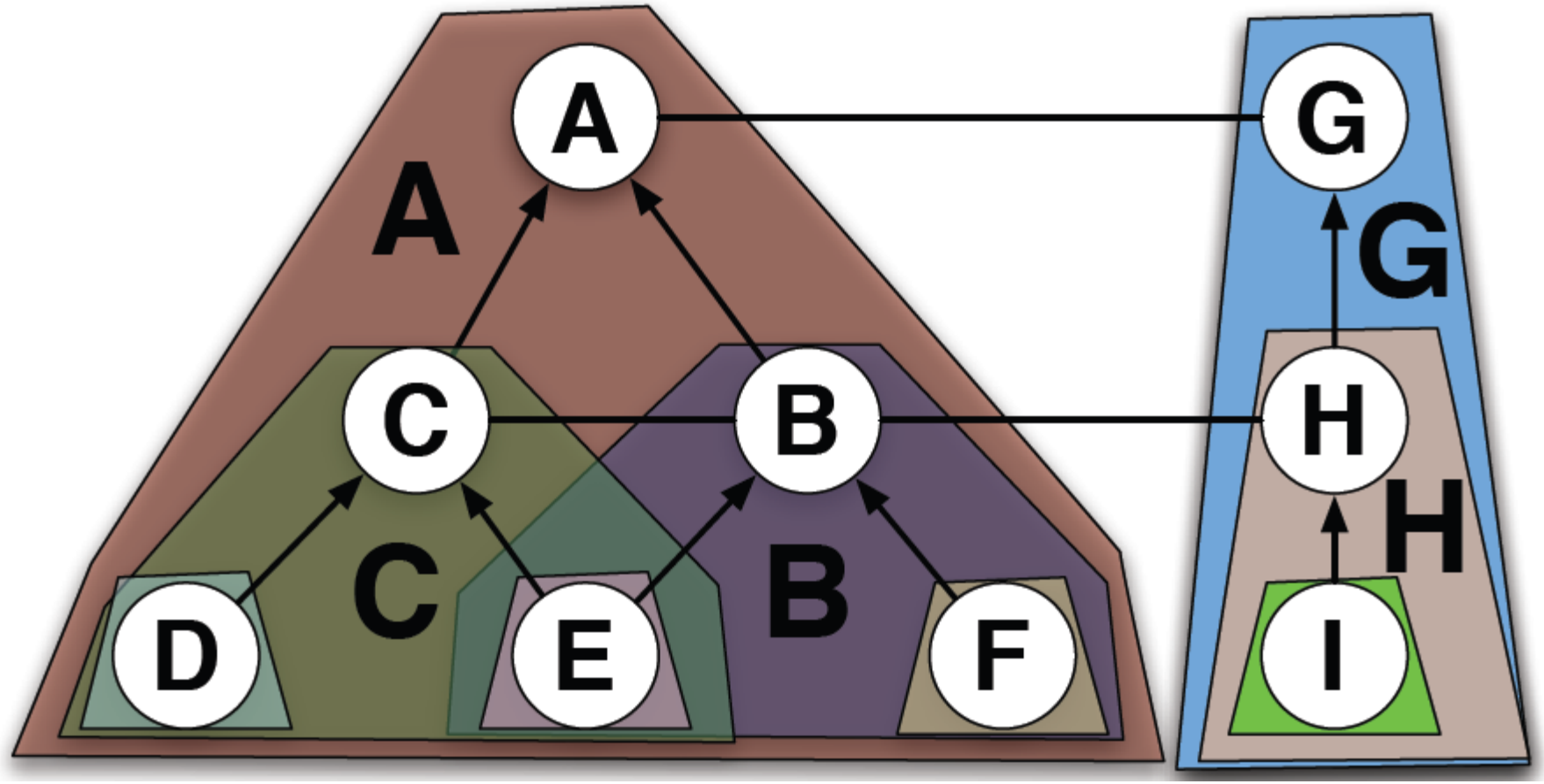
Objectives

- AS relationships determine how traffic flows through the Internet
- Having accurate AS relationships supports:
  - Modeling infrastructure **security and stability**
  - Analysis of **BGP mis-configuration**
  - Analysis of the **influence of ASes** on Internet routing using "customer cone"
    - What is the absolute number of ASes a provider could charge traffic for?

AS Relationships



Definition – Customer Cones



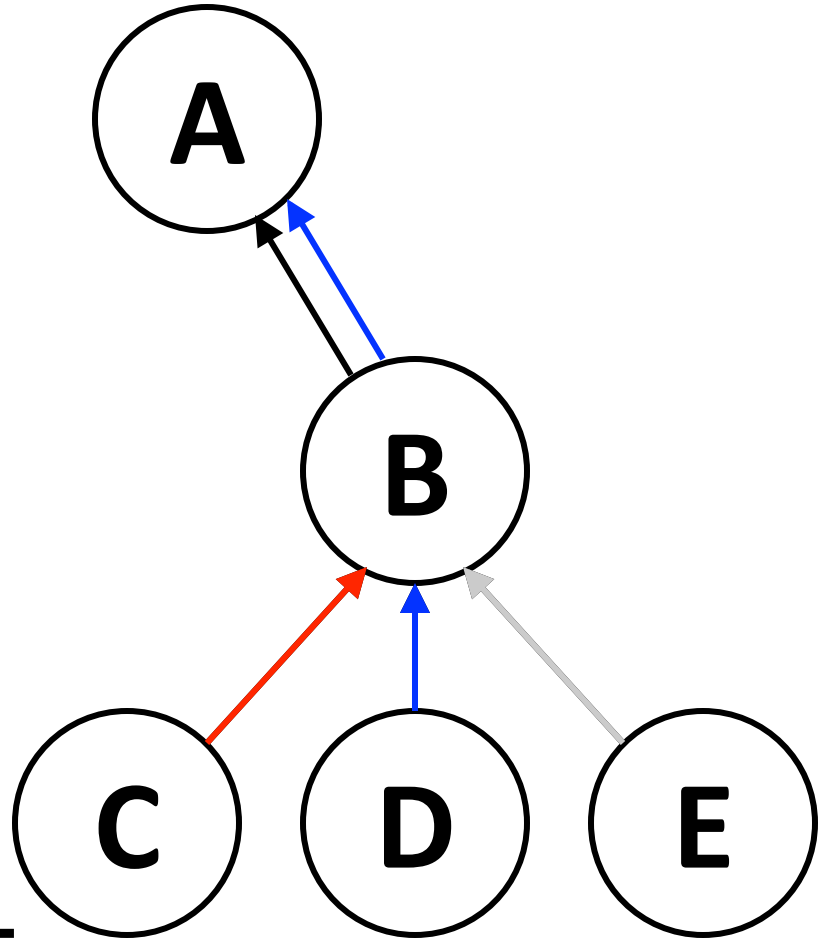
A's customer cone: A, B, C, D, E, F

B's customer cone: B, F

C's customer cone: C, D

Customer Cone Computation (1)

BGP Paths
A B C
A B D
B E

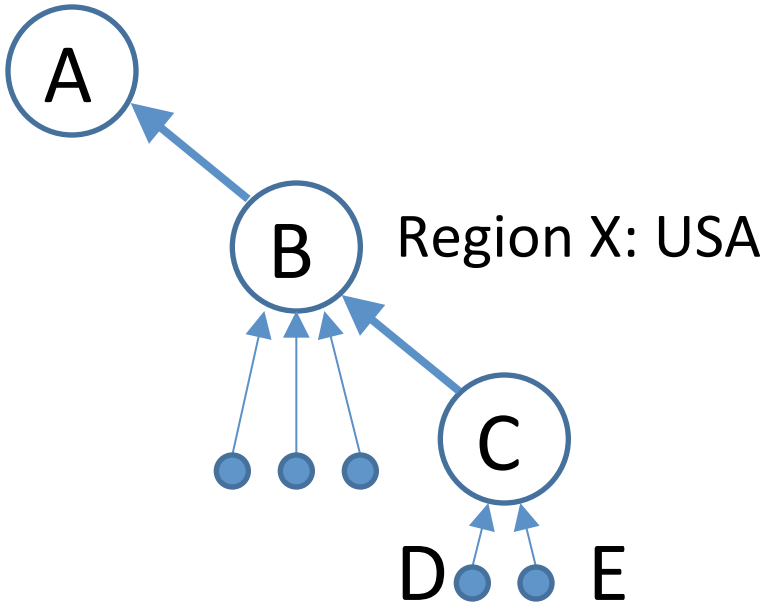


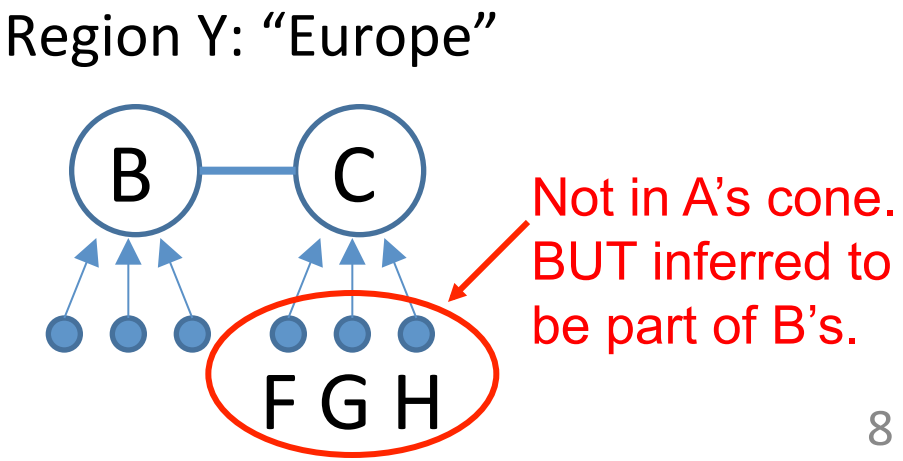
Customer cones for A:

- **Recursive (5): A, B, C, D, E**
- **Observed (4): A, B, C, D**

Customer Cone Computation (2)

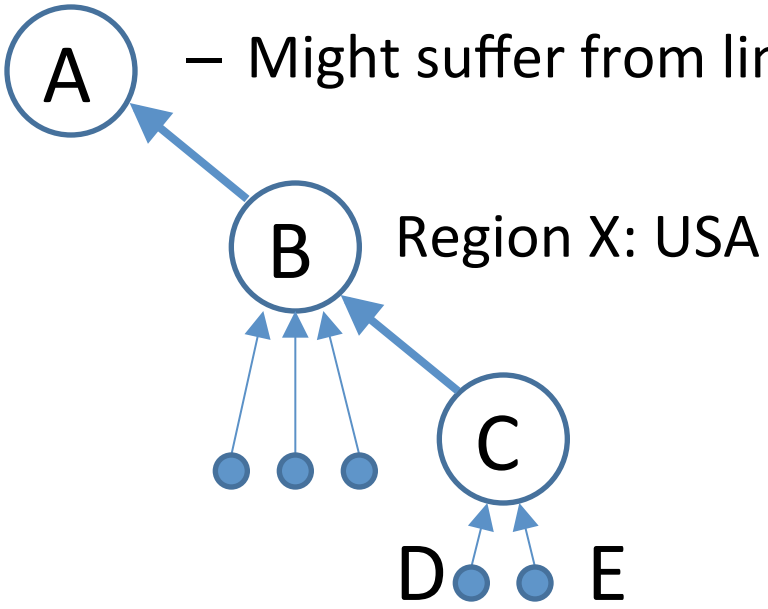
- AS relationships are complex: two ASes may have a c2p relationship in one location, but p2p elsewhere
- Use observed BGP paths to limit damage
  - B-C is inferred to be p2c, and B's customer cone contains all of C's customers (D, E, F, G, H)
  - A will only contain C's customers it learns from B (D+E).

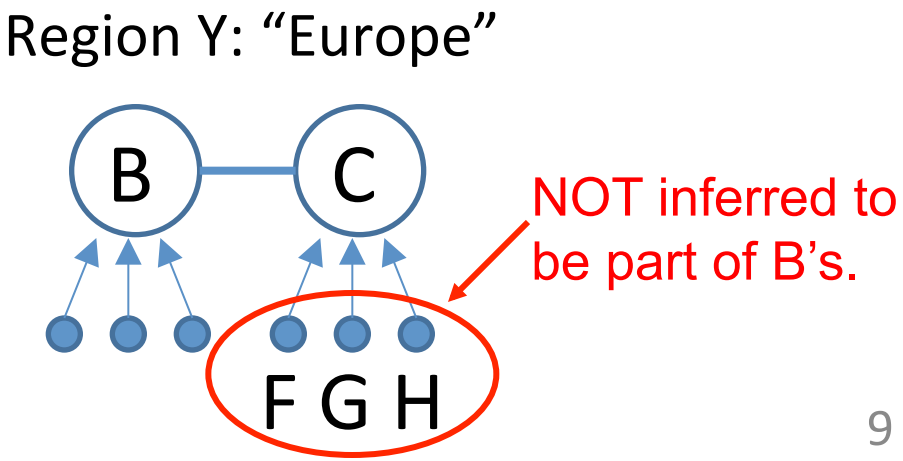




Customer Cone Computation (3)

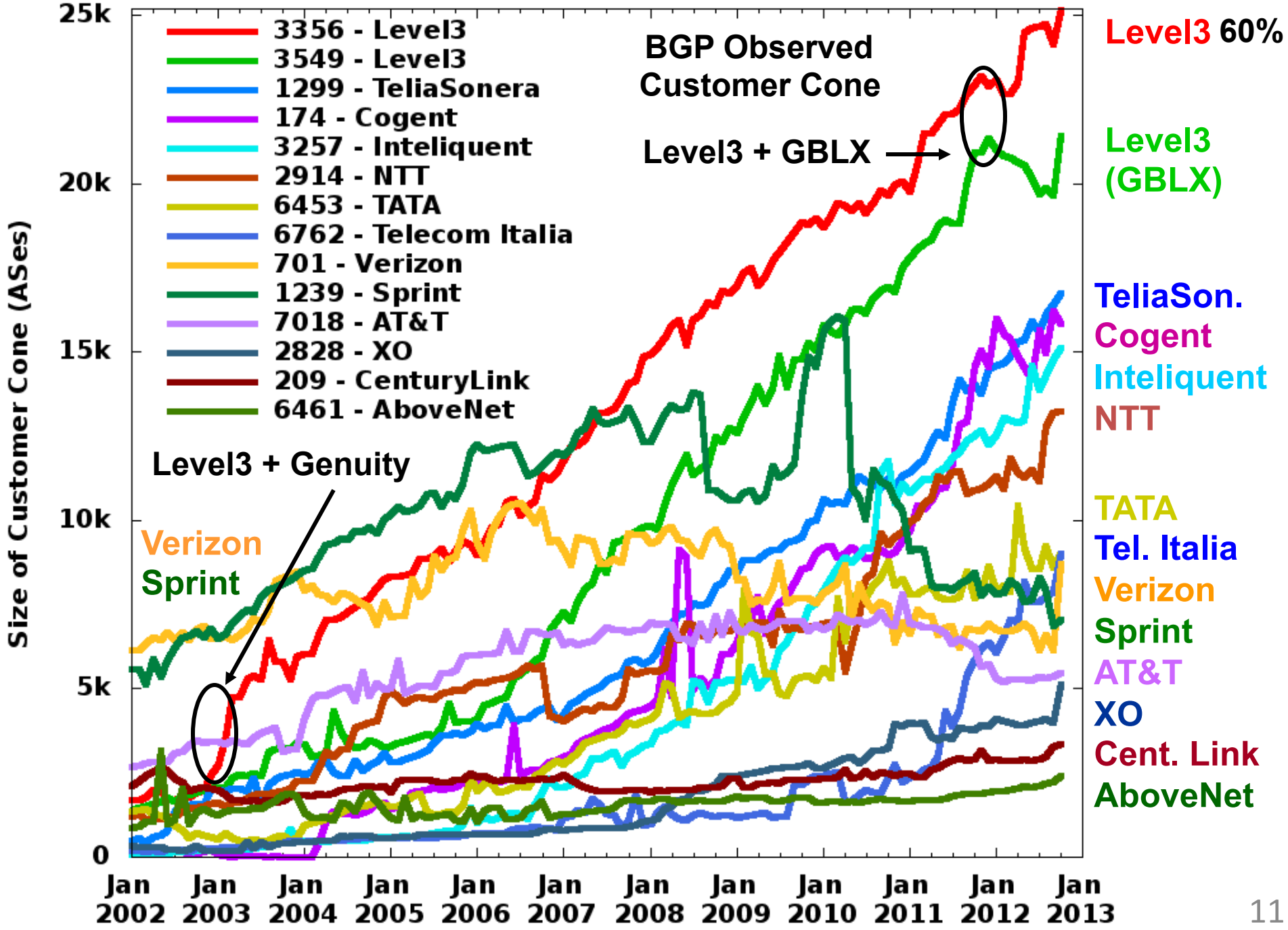
- AS relationships are complex: two ASes may have a c2p relationship in one location, but p2p elsewhere
- Define customer cone based on provider/peer observed view of an AS
  - A sees D and E as indirect customers via B, so B's customer cone only includes D, E from C.
  - Might suffer from limited visibility

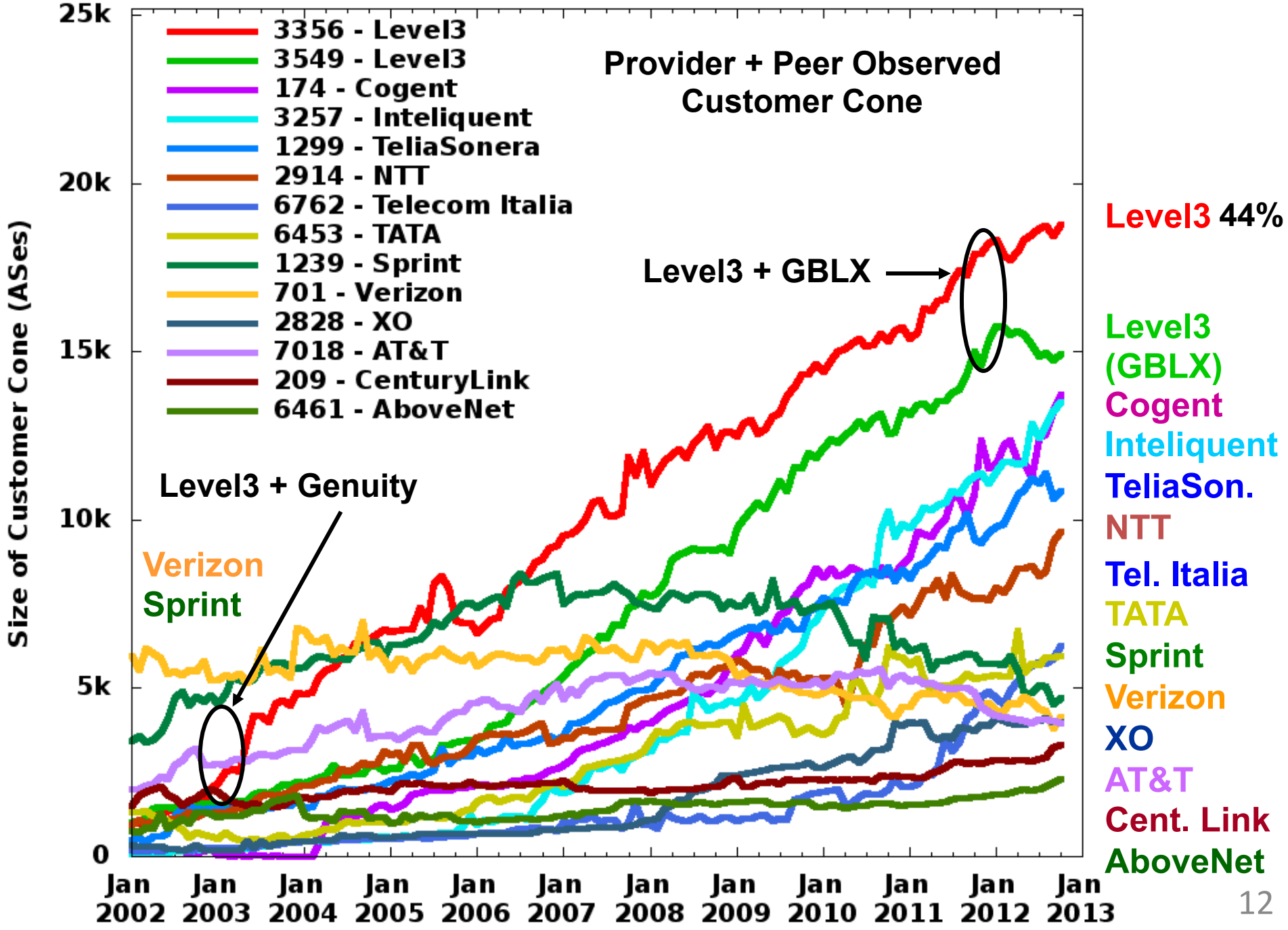




Caveats

- AS Relationship ecosystem is complex
  - Different relationships in different **regions**
  - Can't differentiate between **paid-peers** and **settlement-free peers** (financial difference, not routing)
- Don't know about **traffic**
- Don't have much **visibility into peering**
- BGP paths are **messy** (poisoning, leaking)
- NOT a clear metric of market power


BGP Observed
Customer Cone
Level3 + GBLX
Level3 + Genuity
Verizon
Sprint
3356 - Level3
3549 - Level3
1299 - TeliaSonera
174 - Cogent
3257 - Inteliquent
2914 - NTT
6453 - TATA
6762 - Telecom Italia
701 - Verizon
1239 - Sprint
7018 - AT&T
2828 - XO
209 - CenturyLink
6461 - AboveNet
Size of Customer Cone (ASes)
25k
20k
15k
10k
5k
0
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006
Jan 2007
Jan 2008
Jan 2009
Jan 2010
Jan 2011
Jan 2012
Jan 2013
Level3 60%
Level3 (GBLX)
TeliaSon.
Cogent
Inteliquent
NTT
TATA
Tel. Italia
Verizon
Sprint
AT&T
XO
Cent. Link
AboveNet


Provider + Peer Observed
Customer Cone
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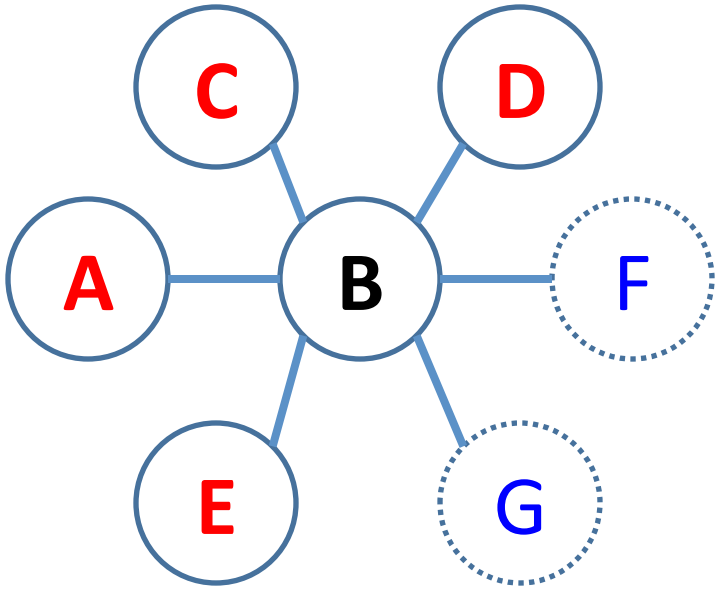
Level3 + GBLX
Level3 + Genuity
Verizon
Sprint
Level3 44%
Level3 (GBLX)
Cogent
Inteliquent
TeliaSon.
NTT
Tel. Italia
TATA
Sprint
Verizon
XO
AT&T
Cent. Link
AboveNet

Existing AS-relationship algorithms do not match ground truth very well.

So we developed a new one.

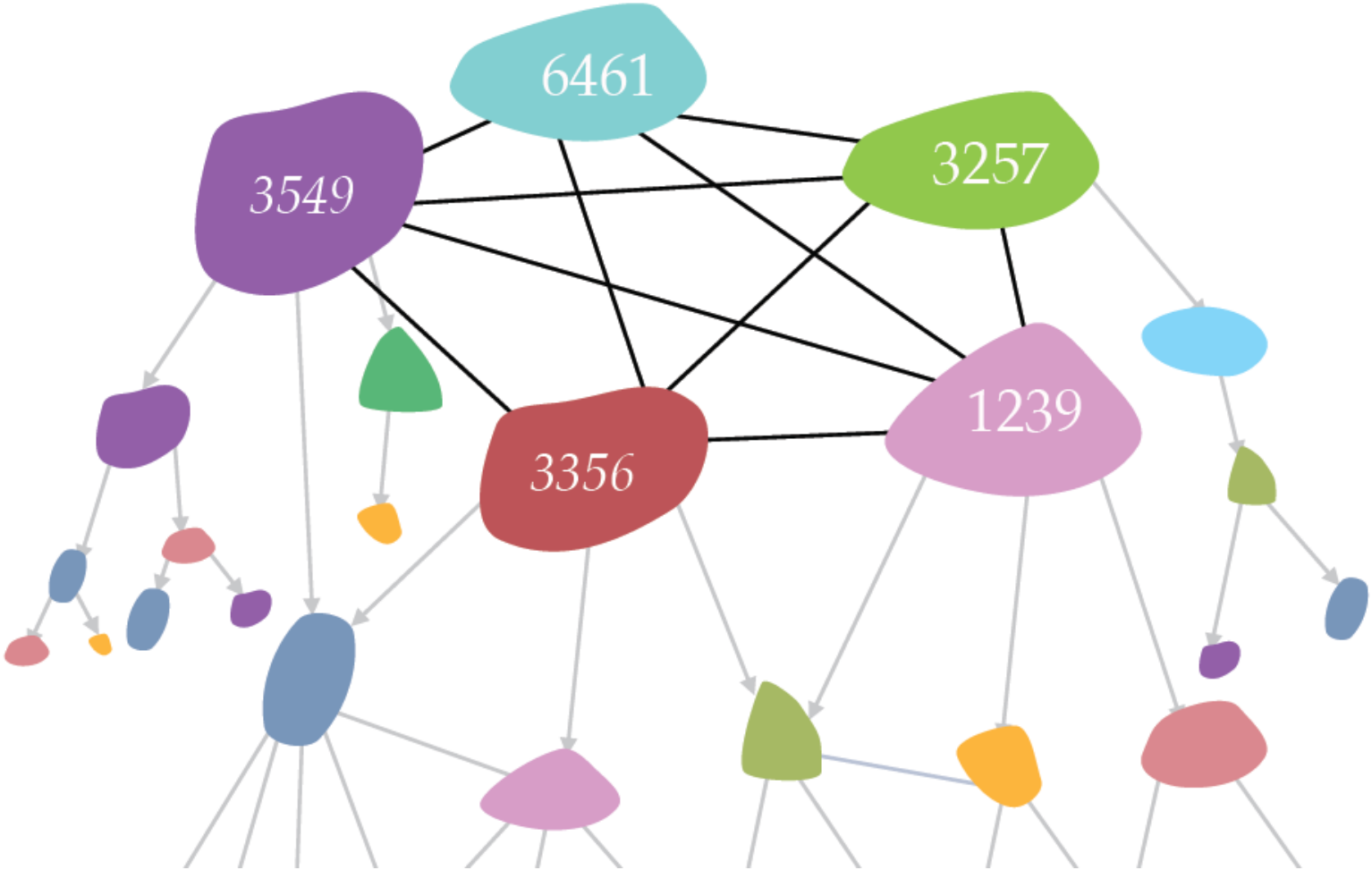
Definition – Transit Degree

- **Transit Degree (TD)** : given set of BGP paths, the **number of ASes for which an AS provides transit**
  - A B C
  - A B D
  - A B E
  - B F
  - B G



- Useful first-pass for ranking ASes:
  - B **transits traffic** for 4 ASes (A, C, D, E) : TD of 4.
  - B's **node degree** is 4 + 2 = 6

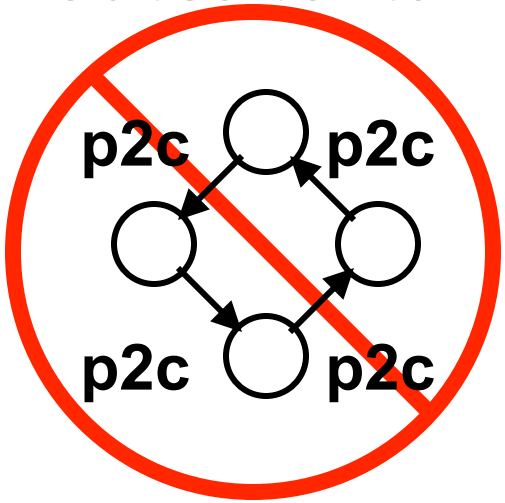
Assumption – Clique of ASes



Clique: Tier-1 ASes and their (possibly paid) peers in a full mesh. We cannot distinguish paid and settlement free peers.

Assumptions

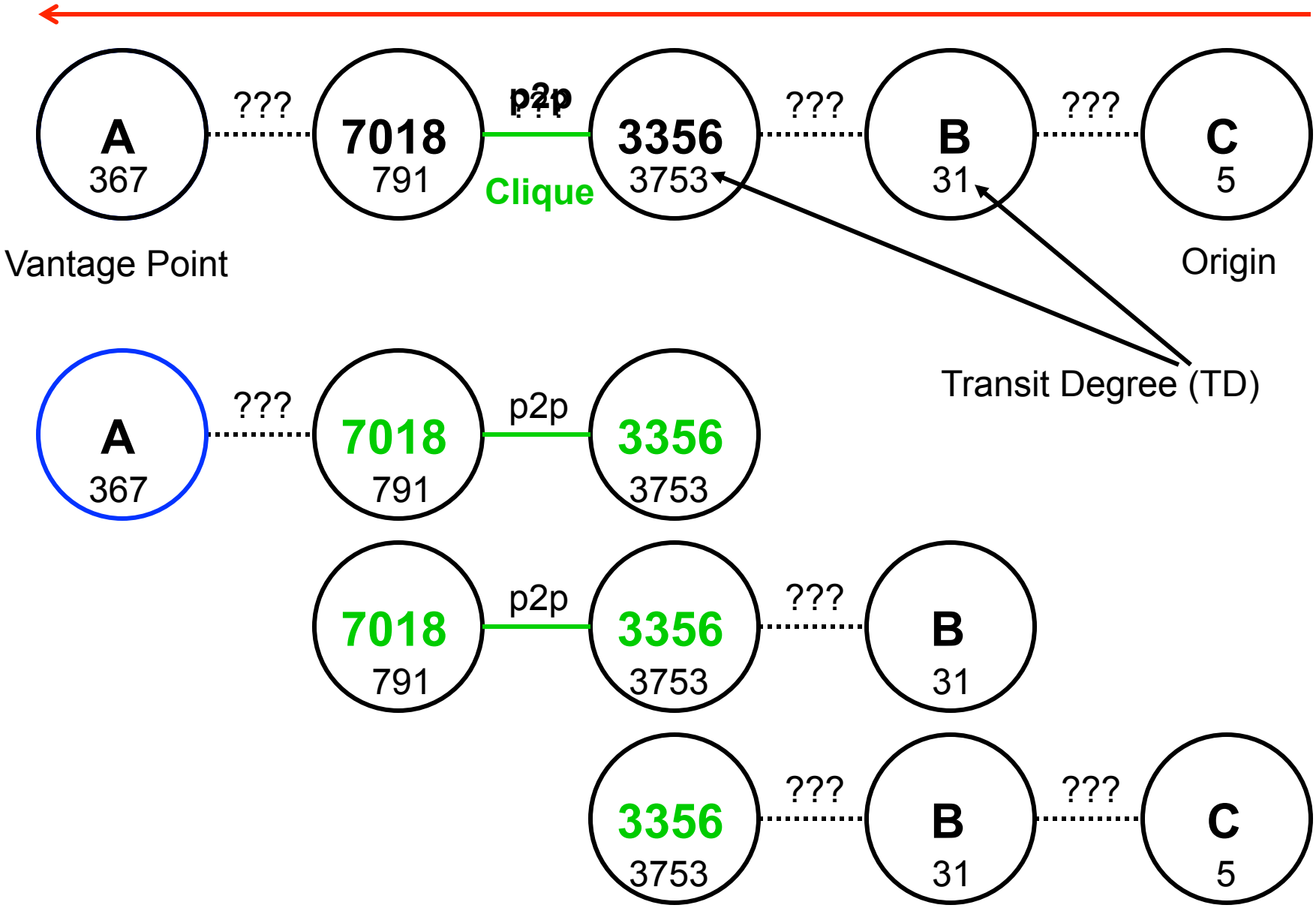
1. Full p2p mesh (clique) at top of hierarchy
   - **Otherwise Internet topology partitioned**
2. A provider announces customer routes to its providers
   - **Main point of paying a provider**
3. $TD_{provider} > TD_{customer}$ (mostly)
   - Supported by our **ground truth**
4. AS topology graph is acyclic: no p2c cycle
   - Supported by our **ground truth**



High-level Algorithm

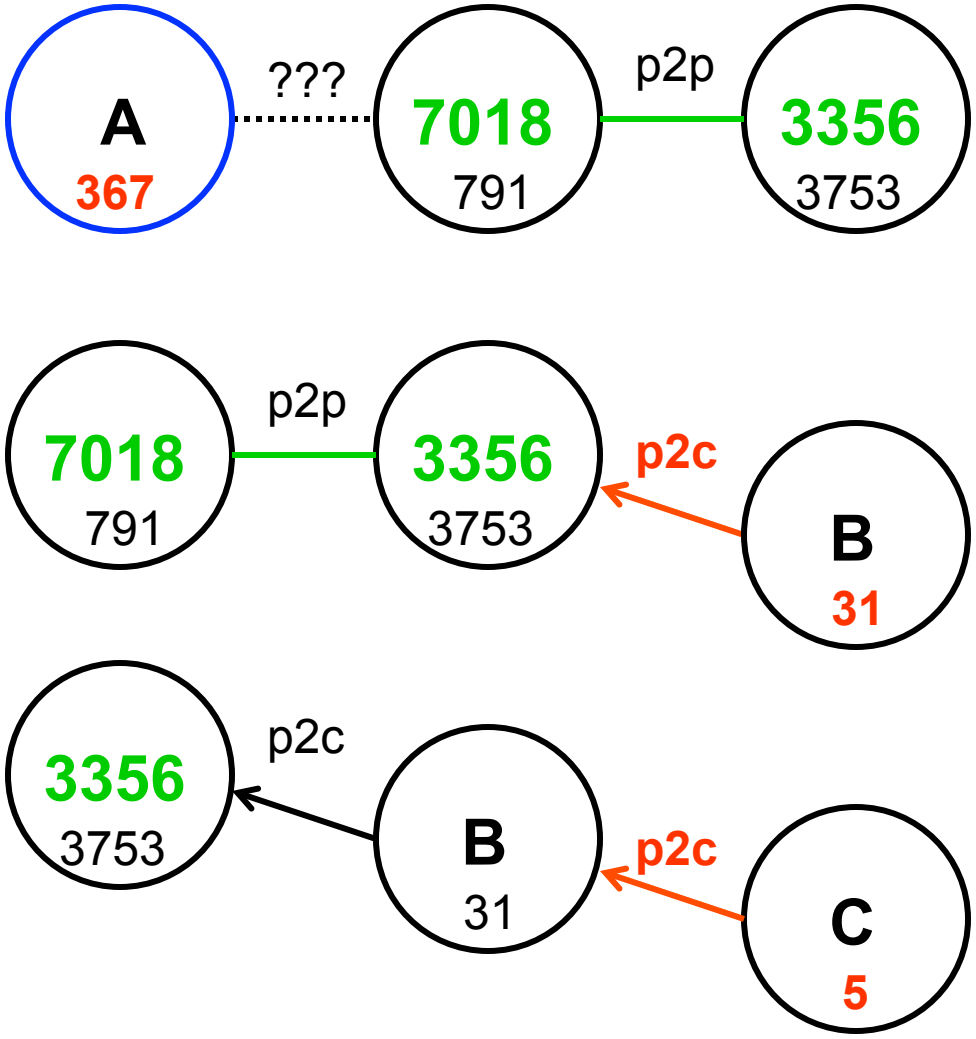
- **Infer clique** and resulting p2p mesh
- Filter BGP paths (reserved ASes, **poisoning**)
- Break paths into **AS triplets**
- Visit ASes in order by largest **transit degree**
  - Infer c2p if
    - **neighbour passes route to a provider**, or
    - **neighbour is in clique** and passes route to another clique AS
  - 56.6% of graph / 99.8% PPV
  - Additional steps in algorithm (next slides)
- All other links in graph are p2p
  - 36.9% of graph / 98.5% PPV

Inferring Relationships



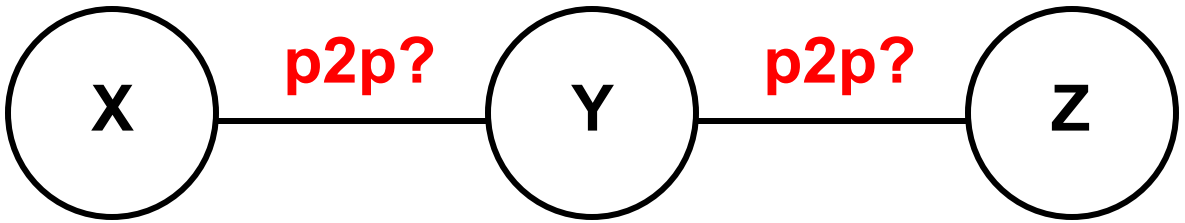
Inferring Relationships from Triplets

Visit ASes in order of highest transit degree



Special Cases (6.5%)

1. VPs with no provider routes
2. Providers with smaller transit degree than customer
3. Customers for ASes with no providers (e.g. TransitRail)
4. Collapsing sequences of p2p links



Ground Truth Summary

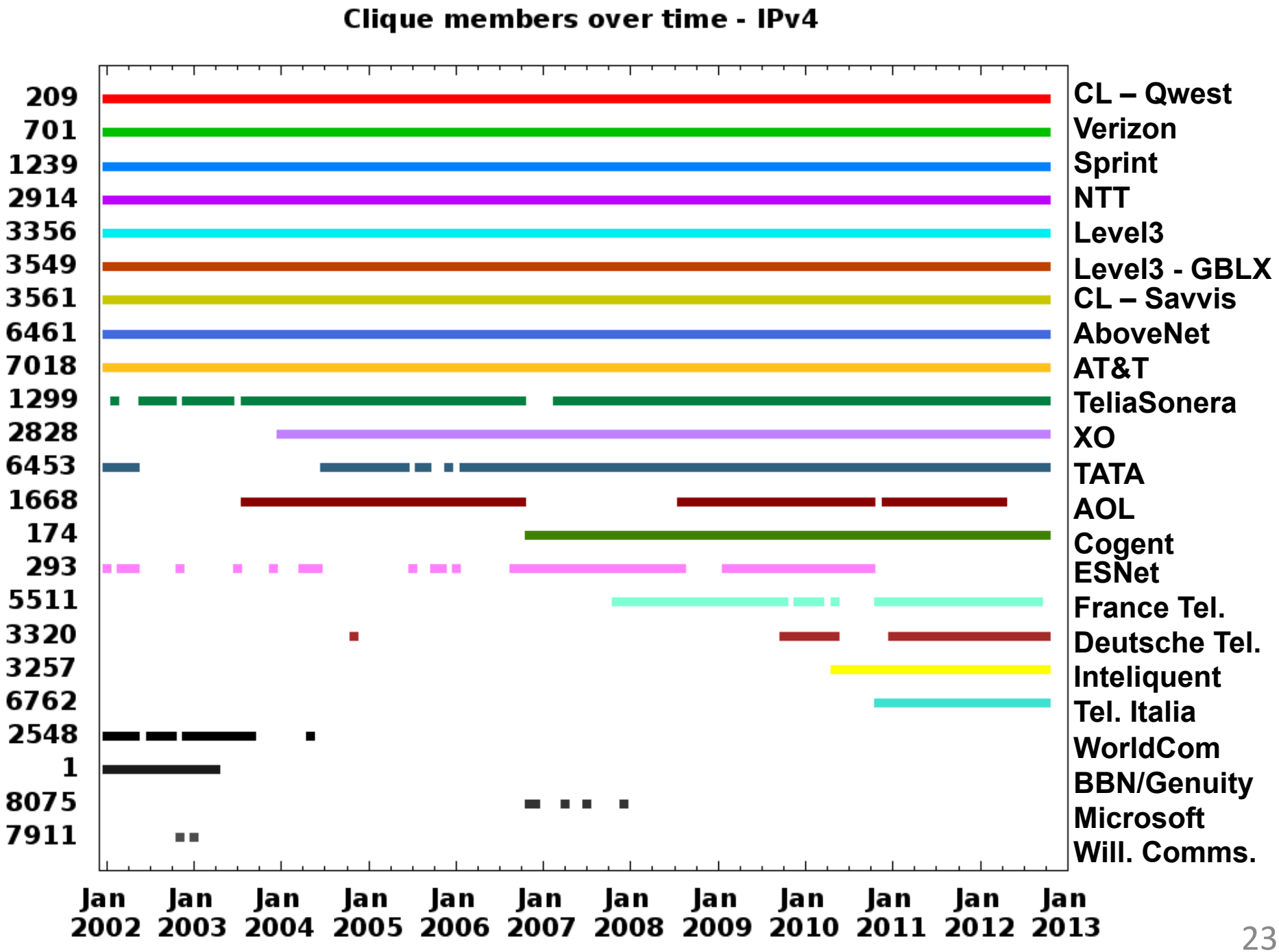
- **CAIDA**: **2,370**
  - 2010 – 2012 83% p2p
  - Most submitted via web form, some via email
- **RPSL**: **6,065**
  - April 2012 100% p2c
  - RIPE whois database, two-way handshake
- **BGP Communities**: **39,838**
  - April 2012 59% p2c
  - Dictionary of operator-published community meanings assembled by Vasileios Giotsas (UCL)

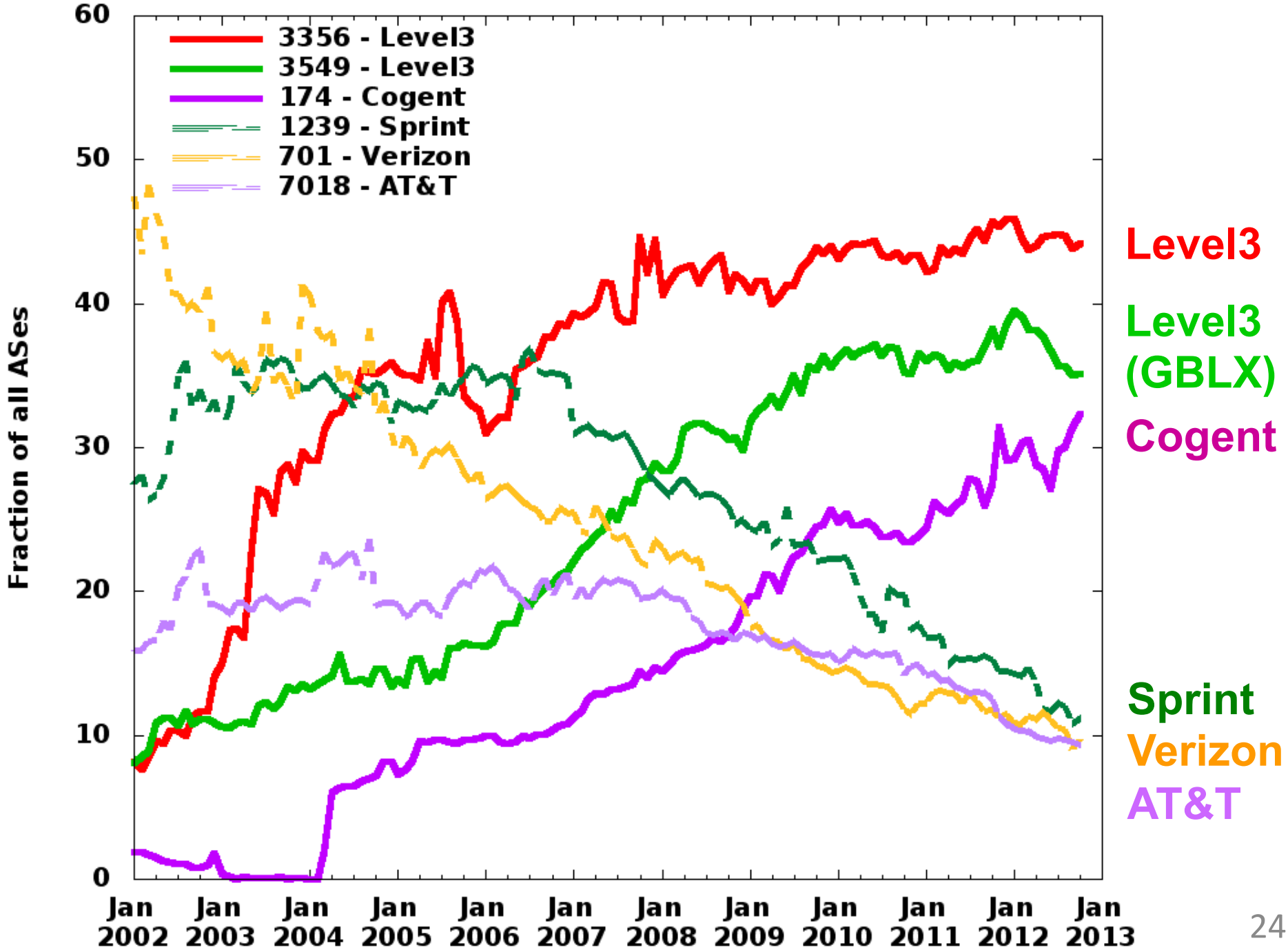
- Overall: 47,881 GT relationships, 63% p2c, 37% p2p
  - **~38% of the publicly available graph.**

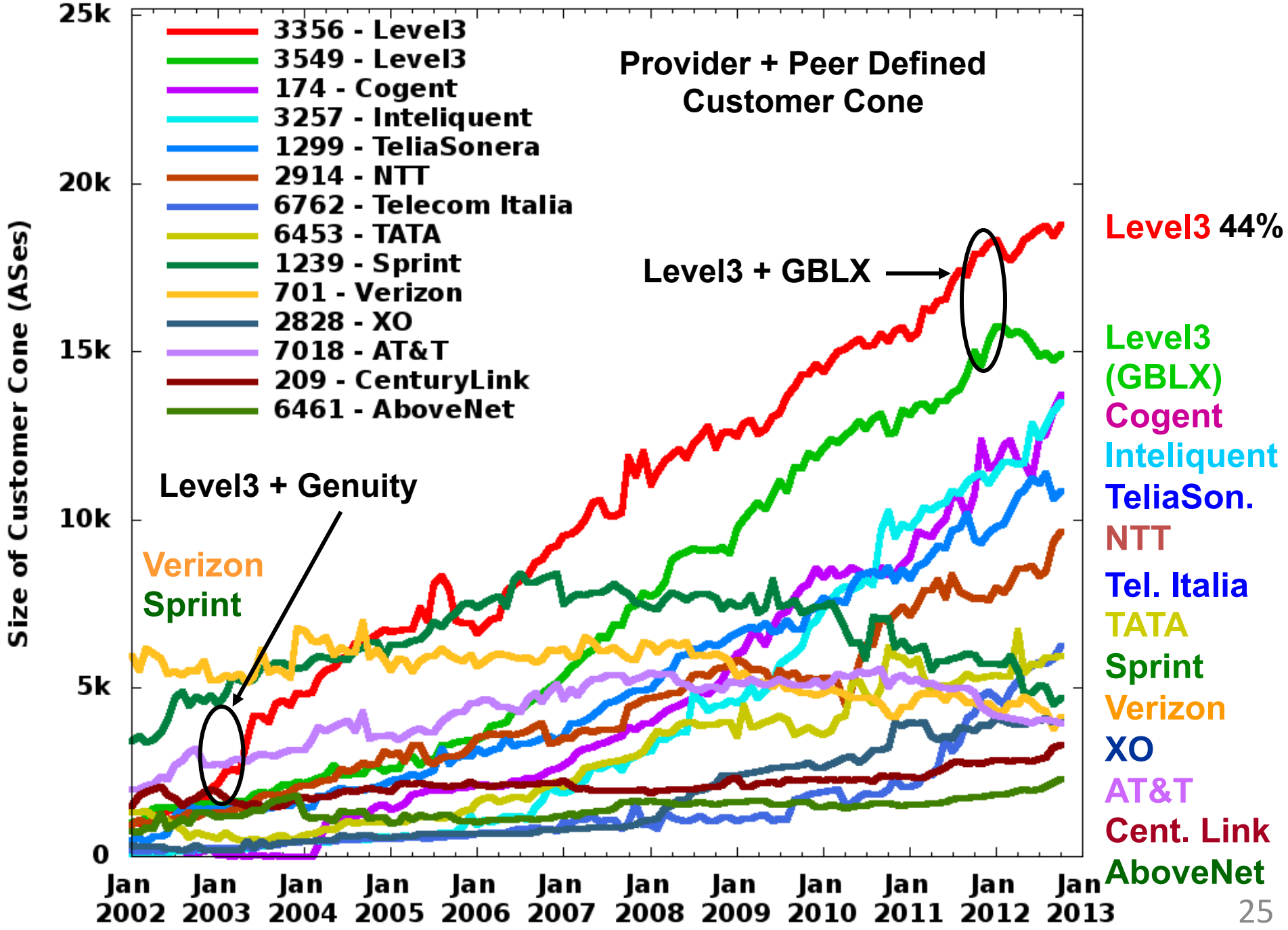
Validation (AS Relationships)

	p2c	p2p
CAIDA	99.6%	98.4%
UCLA	99.0%	90.9%
Gao	84.7%	99.5%

Percentages are Positive Predictive Value (PPV).
Take home: difficult to be accurate at inferring both types of relationships


Clique members over time - IPv4
209
701
1239
2914
3356
3549
3561
6461
7018
1299
2828
6453
1668
174
293
5511
3320
3257
6762
2548
1
8075
7911
CL – Qwest
Verizon
Sprint
NTT
Level3
Level3 - GBLX
CL – Savvis
AboveNet
AT&T
TeliaSonera
XO
TATA
AOL
Cogent
ESNet
France Tel.
Deutsche Tel.
Inteliquent
Tel. Italia
WorldCom
BBN/Genuity
Microsoft
Will. Comms.
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006
Jan 2007
Jan 2008
Jan 2009
Jan 2010
Jan 2011
Jan 2012
Jan 2013


3356 - Level3
3549 - Level3
174 - Cogent
1239 - Sprint
701 - Verizon
7018 - AT&T
Fraction of all ASes
0
10
20
30
40
50
60
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006
Jan 2007
Jan 2008
Jan 2009
Jan 2010
Jan 2011
Jan 2012
Jan 2013
Level3
Level3 (GBLX)
Cogent
Sprint
Verizon
AT&T


Provider + Peer Defined
Customer Cone
3356 - Level3
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Level3 + GBLX
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Verizon
Sprint
Size of Customer Cone (ASes)
25k
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Level3 44%
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Cogent
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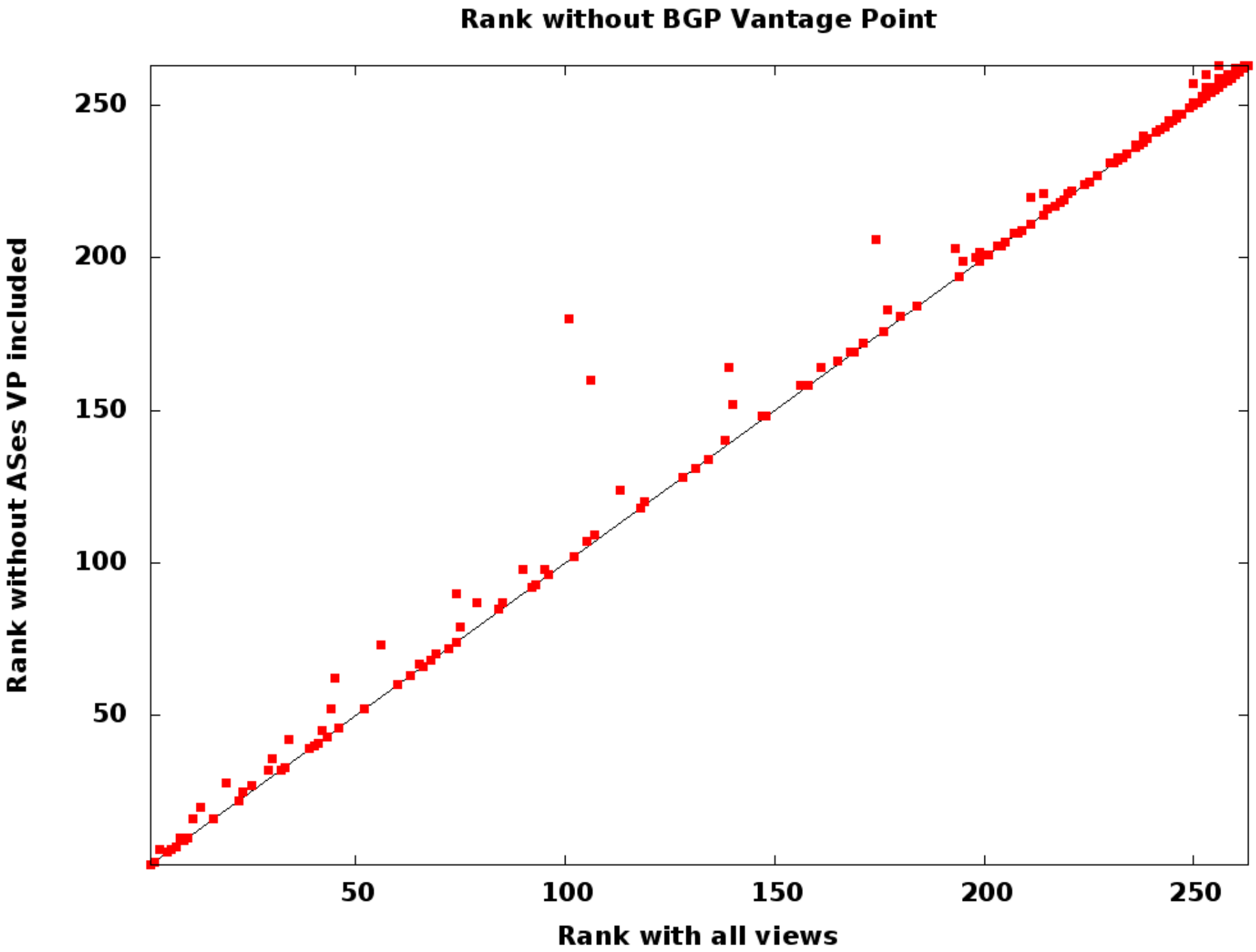
TeliaSon.
NTT
Tel. Italia
TATA
Sprint
Verizon
XO
AT&T
Cent. Link
AboveNet

Help Wanted from NANOG

- What have we not thought of?
- How prevalent is **paid-peering**?
  - Is there any routing differences between a paid peer and a settlement-free peer?
  - Related: in what situations might a customer not be announced to its provider's providers?
- How prevalent are **complex relationships**?
  - What **granularity** is used for routing policies?
    - Region?
    - Prefix?

- More vantage points at Route Views and RIPE RIS
- Additional ground truth -- ideally submitted through http://as-rank.caida.org/

Backup Slides Follow


Rank without BGP Vantage Point
Rank without ASes VP included
Rank with all views
250
200
150
100
50
50
100
150
200
250

Algorithm Details – Preparing BGP paths for input

- Filter paths with
  - Reserved ASNs (23456, 61440-65534, etc) 0.1%
  - AS Loops (<0.1%)
  - If any two Clique ASes are separated by another
    - Assume leak or poisoning (0.01%)
  - More than 5 ASes in the path (14.7% of paths)
- Remove IXP ASNs from paths
  - Manually defined list of 25 ASes

AS Rank: AS Ranking - CAIDA : http://as-rank.caida.org - Mozilla Firefox

File Edit View History Bookmarks Tools Help

AS Rank: AS Ranking - CAIDA : http://as-ra...

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Google

The top ASes ranked by customer cone size are displayed below.

Dataset: 2012.06.01

For information about a specific AS, enter its AS name, its AS number, or the name of the Org of which the AS is a member.

Look up an AS by number or name | Search

Table **shows** 10 of 41203 ASes, **sorted by** number of ASes in customer cone | update view

AS rank	AS number	AS name	Org name	customer cone						AS degree
				Number of			Percentages of all			
				ASes	IPv4 Prefixes	IPv4 Addresses	ASes	IPv4 Prefixes	IPv4 Addresses	
1	3356	LEVEL3	Level 3 Communications	24,632	273,357	1,557,093,299	59%	65%	60%	3331
2	3549	LVLT-3549	Level 3 Communications	20,747	238,941	1,029,028,043	50%	57%	40%	1519
3	1299	TELIANET	TeliaNet Global Network	16,021	174,713	749,588,007	38%	41%	29%	683
4	3257	TINET-BACK...	Tinet SpA	14,594	179,792	794,176,517	35%	43%	31%	884
5	174	COGENT-174	Cogent/PSI	14,058	164,072	667,755,471	34%	39%	26%	3537
6	2914	NTT-COMMUN...	NTT America, Inc.	11,690	160,779	757,127,906	28%	38%	29%	814
7	6453	AS6453	TATA Communications	8,265	126,544	509,082,235	20%	30%	19%	573
8	1239	SPRINTLINK	Sprint	7,791	126,000	958,565,637	18%	30%	37%	972
9	6762	SEABONE-NET	TELECOM ITALIA SPARKLE S.p.A.	7,567	105,985	379,857,433	18%	25%	14%	263
10	701	UUNET	MCI Communications Services, Inc. d/b/a Verizon Business	5,468	83,096	607,375,447	13%	19%	23%	1812

data sources

geolocation	database	2012.06.25	netacuity
organization	whois	0000.00.00	JPNIC, KRNIC, LACNIC
		2012.06.29	AFRINIC, APNIC, ARIN, LACNIC, RIPE
topology	BGP	2012.06.01, 2012.06.02, 2012.06.03, 2012.06.04, 2012.06.05	ripe rrc00, rrc01, rrc03, rrc04, rrc05, rrc06, rrc07, rrc10, rrc11, rrc12, rrc13, rrc14, rrc15
			routeviews eqix, isc, linx, routeviews2, saoppaulo, sydney

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AS Rank: Org Ranking - CAIDA : http://as-rank.caida.org - Mozilla Firefox

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AS Rank: Org Ranking - CAIDA : http://as-r...

as-rank.caida.org/?mode0=org-ranking

The top Organizations ranked by customer cone size are displayed below.

Dataset: 2012.06.01

For information about a specific Org, enter its name:

Look up an Org by name Search

Table **shows** 10 of 43174 Orgs, **sorted by** number of ASes in customer cone update view

Org rank	Org name	Num. ASes	customer cone						AS degree	Org degree
			Number of			Percentages of all				
			ASes	IPv4 prefixes	IPv4 addresses	ASes	IPv4 Prefixes	IPv4 Addresses		
1	Level 3 Communications	18	31,141	330,943	1,770,445,516	75%	79%	69%	4,375	3,872
2	TeliaNet Global Network	5	16,073	175,312	759,252,039	39%	41%	29%	742	662
3	Tinet SpA	2	14,595	179,793	794,176,773	35%	43%	31%	884	798
4	Cogent/PSI	3	14,060	164,075	667,755,727	34%	39%	26%	3,535	3,267
5	NTT America, Inc.	7	11,697	160,793	757,129,442	28%	38%	29%	809	703
6	TATA Communications	6	8,528	131,962	518,890,651	20%	31%	20%	842	777
7	Sprint	16	7,844	129,977	965,836,541	19%	31%	37%	1,023	906
8	TELECOM ITALIA SPARKLE S.p.A.	3	7,569	105,987	379,857,945	18%	25%	14%	262	236
9	Qwest Communications Company, LLC	11	7,253	122,871	759,408,992	17%	29%	29%	1,754	1,596
10	Init7 Global Backbone	424	6,744	72,220	395,631,197	16%	17%	15%	2,564	2,305

data sources

geolocation	database	2012.06.25	netacuity
organization	whois	0000.00.00	JPNIC, KRNIC, LACNIC
		2012.06.29	AFRINIC, APNIC, ARIN, LACNIC, RIPE
topology	BGP	2012.06.01, 2012.06.02, 2012.06.03, 2012.06.04, 2012.06.05	ripe rrc00, rrc01, rrc03, rrc04, rrc05, rrc06, rrc07, rrc10, rrc11, rrc12, rrc13, rrc14, rrc15
			routeviews eqix, isc, linx, routeviews2, saoppaulo, sydney

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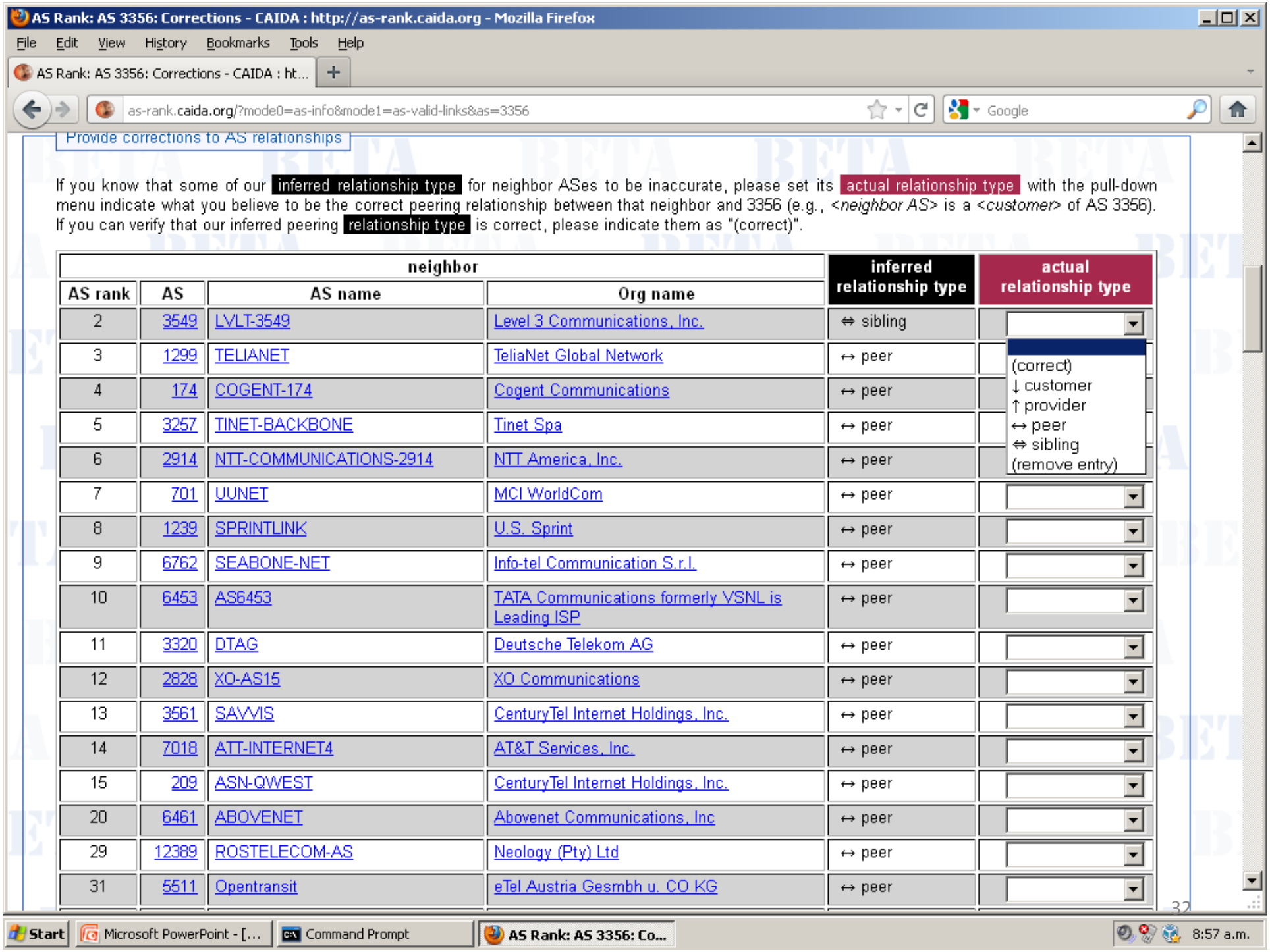
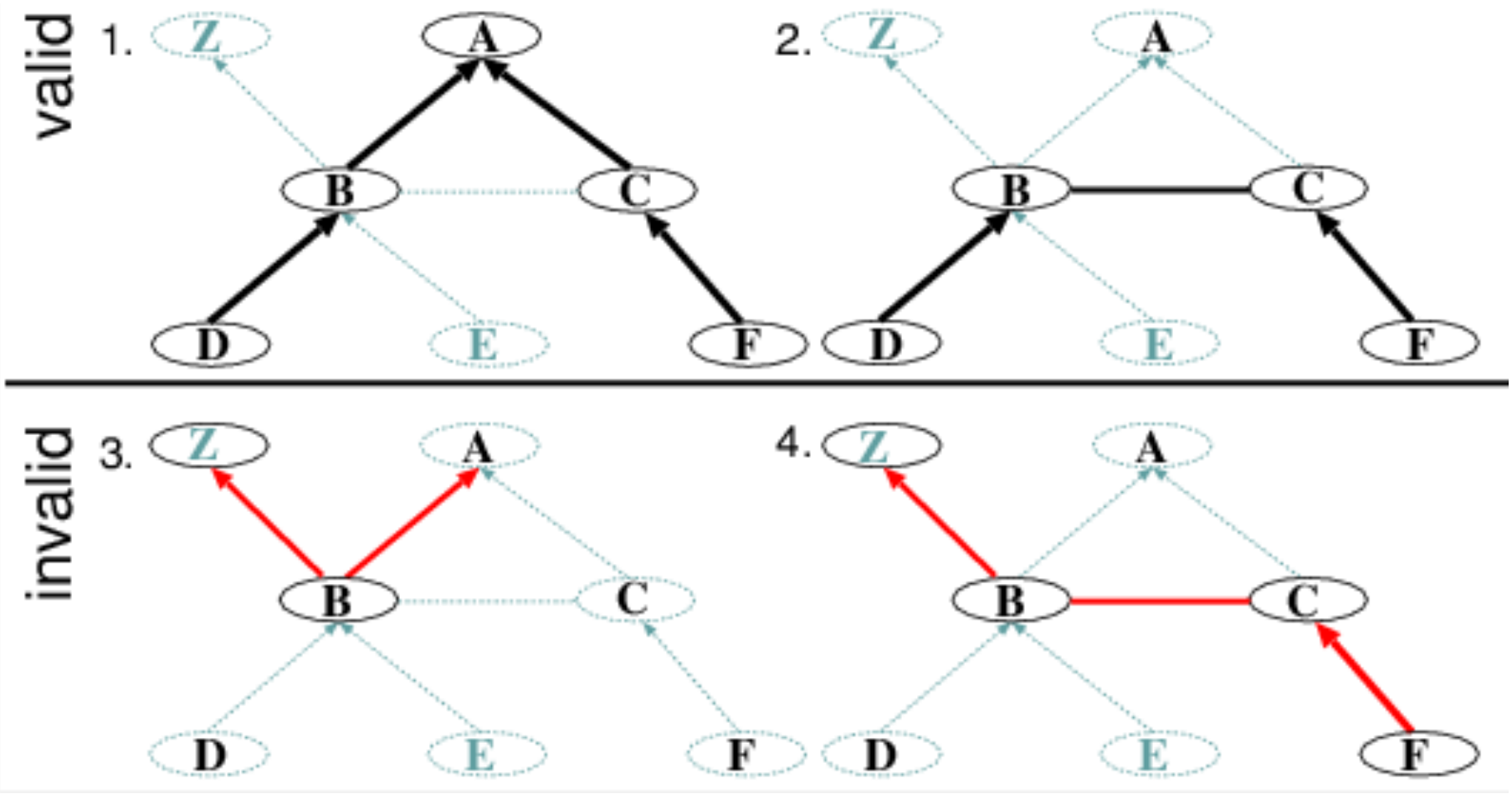
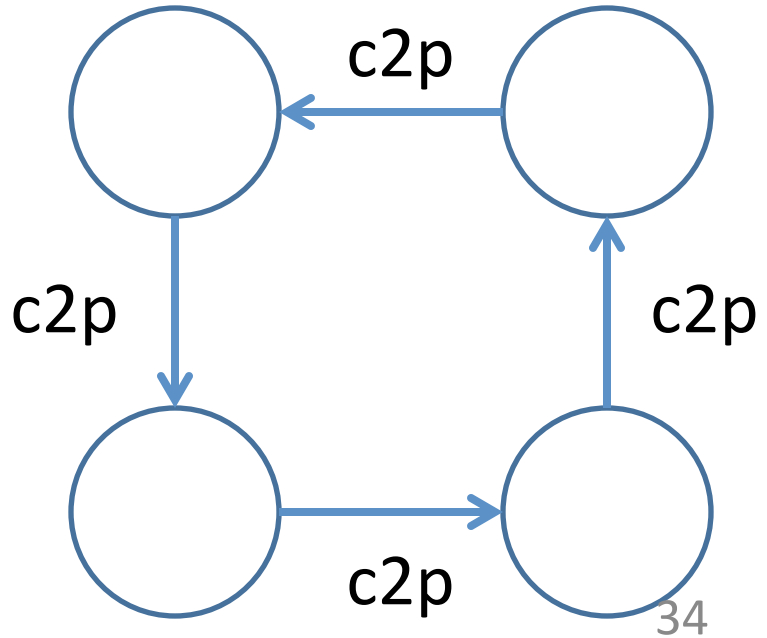

AS Rank: AS 3356: Corrections - CAIDA : http://as-rank.caida.org - Mozilla Firefox
File Edit View History Bookmarks Tools Help
AS Rank: AS 3356: Corrections - CAIDA : ht...
as-rank.caida.org/?mode0=as-info&mode1=as-valid-links&as=3356
Google
Provide corrections to AS relationships
If you know that some of our inferred relationship type for neighbor ASes to be inaccurate, please set its actual relationship type with the pull-down menu indicate what you believe to be the correct peering relationship between that neighbor and 3356 (e.g., <neighbor AS> is a <customer> of AS 3356). If you can verify that our inferred peering relationship type is correct, please indicate them as "(correct)".
neighbor
AS rank
AS
AS name
Org name
inferred relationship type
actual relationship type
2 3549 LVLT-3549 Level 3 Communications, Inc. ⇔ sibling
3 1299 TELIANET TeliaNet Global Network ↔ peer
4 174 COGENT-174 Cogent Communications ↔ peer
5 3257 TINET-BACKBONE Tinet Spa ↔ peer
6 2914 NTT-COMMUNICATIONS-2914 NTT America, Inc. ↔ peer
7 701 UUNET MCI WorldCom ↔ peer
8 1239 SPRINTLINK U.S. Sprint ↔ peer
9 6762 SEABONE-NET Info-tel Communication S.r.l. ↔ peer
10 6453 AS6453 TATA Communications formerly VSNL is Leading ISP ↔ peer
11 3320 DTAG Deutsche Telekom AG ↔ peer
12 2828 XO-AS15 XO Communications ↔ peer
13 3561 SAVVIS CenturyTel Internet Holdings, Inc. ↔ peer
14 7018 ATT-INTERNET4 AT&T Services, Inc. ↔ peer
15 209 ASN-QWEST CenturyTel Internet Holdings, Inc. ↔ peer
20 6461 ABOVENET Abovenet Communications, Inc ↔ peer
29 12389 ROSTELECOM-AS Neology (Pty) Ltd ↔ peer
31 5511 Opentransit eTel Austria Gesmbh u. CO KG ↔ peer
(correct)
↓ customer
↑ provider
↔ peer
⇔ sibling
(remove entry)
Start
Microsoft PowerPoint - [...
Command Prompt
AS Rank: AS 3356: Co...
8:57 a.m.

Background – Valid paths



Definition – Strongly Connected Components

- Assumption: AS topology is hierarchical
  - Therefore AS graph is a DAG
- Avoid creating a "Strongly Connected Component" of c2p links between ASes



Inferring Clique

- Infer clique of ASes which includes Tier-1 ASes
  1. Apply Bron/Kerbosch 1973 algorithm to top 10 ASes by transit degree.
  2. Do not admit an AS to the clique if it appears to receive transit from other members of the clique
  - Add additional ASes to the clique provided they do not break these rules
  - Infer p2p between all members of the clique