# Internet expansion
## refinement and churn

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# Overview

- Data description and caveats
- Taxonomy of prefixes (definitions)
- Size measures & proportions
- Topology changes
- Prefix set changes
- More specifics
- Multihoming
- Routing updates

Acknowledgement: inspired by Jeff Huston's analysis

# Data analysis: BGP peer and prefix selection

- Select only full-size tables from RouteViews peers
  - full: > 104K prefixes
  - filtered: 89-97K prefixes

Prefix selection:

- globally routed prefixes (those common to all tables)
- semiglobal (found in the majority of backbone tables)
  - prefixes dropped by one (few) peers still observed
  - prefixes seen only locally won't get into table
  - more robust than either full or global prefix set
- We use only semiglobal prefixes

# Caveats:

- many metrics are sensitive to prefix/peer choice
- important when trends are small and/or undecided
- instant and  daily influx or loss of prefixes
- Table sizes differ noticeably (few %) by day

# Data sources

## UOregon ANTC RouteViews BGP tables

- Data on or around the 1st of each month
- Nov. 1, 2000 (18 tables)
- Nov. 1, 2001 (26 tables)
- Feb. 1, 2002 (26 tables)

unless otherwise specified

Sampling for prefix analysis:

- from 1 year (1997-2001)
- to 2 hours (data from the end of 2001.)

# Prefix taxonomy

Prefix types:

- standalone -- no subsets/supersets in the table
- root -- a least specific route, has subsets in the table
- more specific -- a subset of some other prefix

In addition: top prefixes = standalone + roots

Caveats:

- depends on the prefix set
- not an inherent property of a prefix

# Bulk and relative measures

## Short term (3 month) trends, Feb.2002

- Semiglobal prefixes: 104K, stable
- Prefix table size is constant for 4 months (-1k)

- Smallest blocks (/24s): 55.8%, down
- More specifics: 50.3%, down
- Trends of 1990s reverted

- ASes: 12570, up
- Transit ASes: 2050, up
- Transit ASes: 16%, stable

# Bulk and relative measures (cont'd)

- AS links in BGP graph: 26046, up
- AS links/ASes 2.06, stable/down
- AS paths/ASes (1 tb.) 1.25, stable 4 years

- Path system very rigid
- Less paths than the graph allows
- Due to policy constraints & shortest paths

# Bulk and relative measures (cont'd)

- ASes with one prefix: 40%
- Prefixes originated by such ASes: 5%
- very small contribution

- ASes with over 100 prefixes: 1% <---"large ASes"
- Prefixes originated by such ASes: 32%

# Growth in prefixes, ASes, and degree

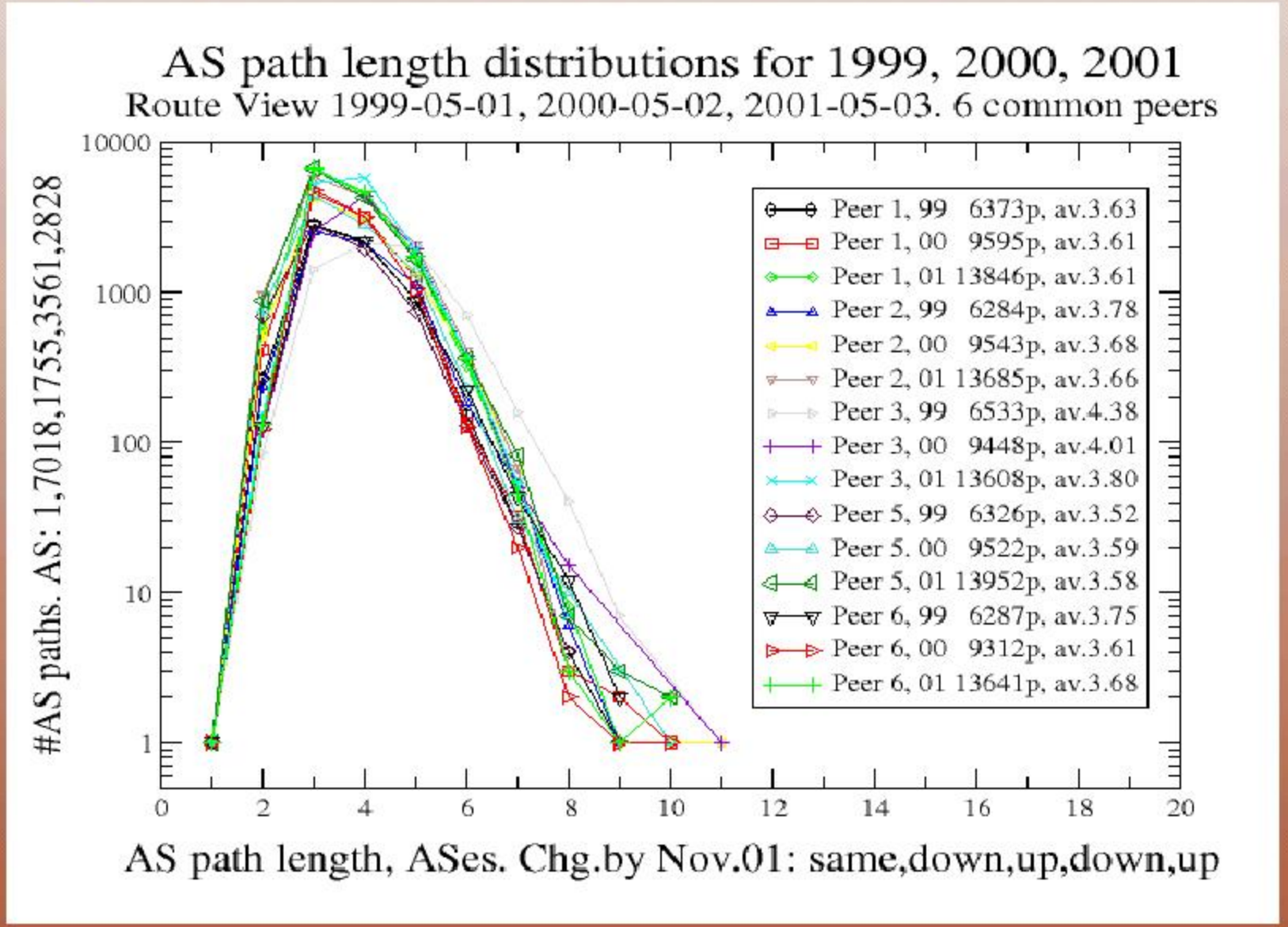
| | 1999 | 2000 | | 2001 | |
|---|---|---|---|---|---|
| Semiglobal prefixes | 64769 | 88714 | (+37%) | 102394 | (+15%) |
| ASes | 6107 | 9116 | (+50%) | 12399 | (+36%) |
| AS links/nodes (avg in/outdegree) | 1.97 | 2.00 | | 2.07 | |

- prefix and AS growth slowed in 2001
- prefix growth is close to 2/3 of AS growth
- link/node ratio grows slowly, almost invariant

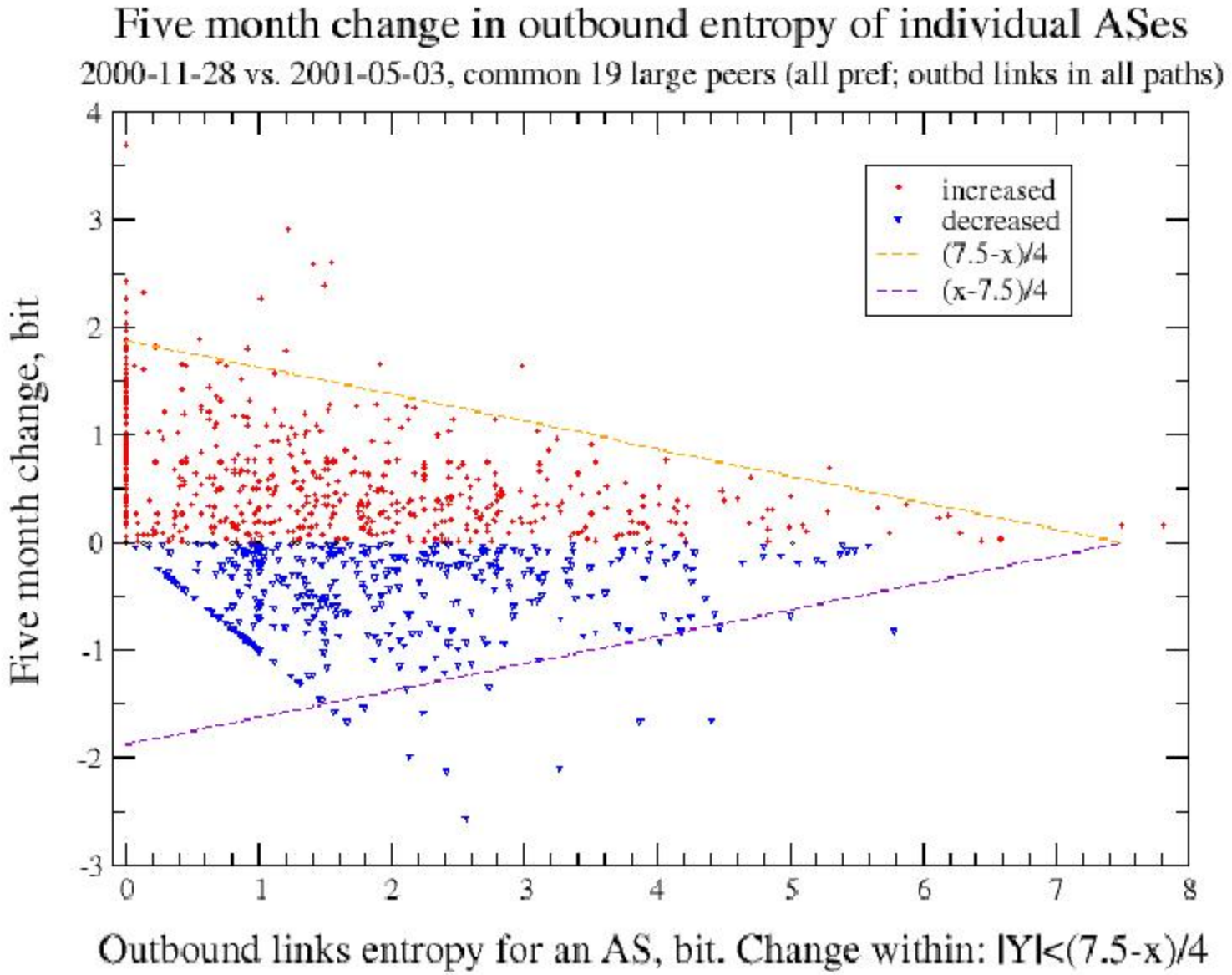
peering richness, and navigation complexity of BGP AS graph did not significantly change between Nov 2000 and May 2001, although there were a lot of changes for individual ASes

# Is average AS path length decreasing?

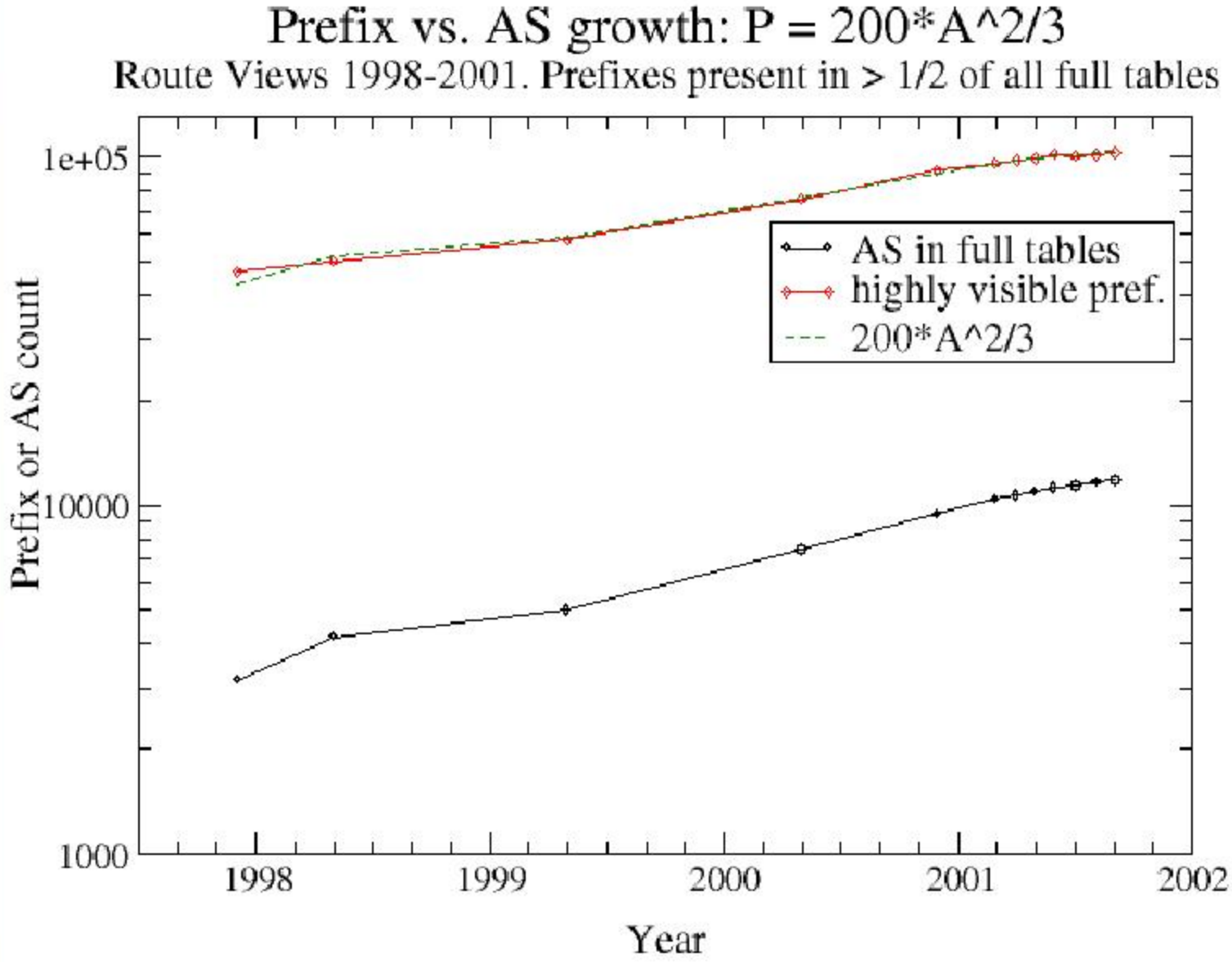
- Since 1999, many AS paths changed either way
- Change in the average AS path length is insignificant



# Peering richness: changes per AS, not on average



# AS refinement formula: P = 200 A^(2/3)



# Super-refinement

## Refinement formula worked for 3 years

- Current prediction: 107140 (formula overestimates)
- Prefix growth stopped (last few months)
- AS refinement faster than predicted by formula
- Average prefixes per AS:  8.3, down 4 years
- Will eventually have less than one prefix per AS
- Already have ASes with 0 announced prefixes
- (85 transit-only ASes for Nov 01, 2001, up from 55 a few months ago)

# Prefix distribution: findings

- Changes in global routing not captured by bulk measures such as number of prefixes in a table
- Net change is a sum total of commensurable contributions of opposite sign, so...
- Total variation is not the difference, but rather the sum of their magnitudes.
- Most measures of routing system complexity demonstrate slow growth, dynamic equilibrium and/or decrease for May-Dec. 2001.

# Prefix distribution

- /24 prefixes are the smallest globally routable
- Q: Is proportion of /24s in backbone tables growing?
  A: No
  - Since 1998, the share of /24s has stayed between 57% and 58.5%
  - Has decreased since then by 0.6%-0.9% in all non-filtered tables
- About 1/2 of all prefixes are more specifics (subsets).
  - 1999 50%
  - 2000 55%
  - 2001 52%
  - 2002 50.3%

# Prefix distribution: refinement of prefix trees

Prefix type breakdown
(semiglobal prefixes in 26 tables, Nov.01,2001)

| | | |
|---|---|---|
| standalone | 44264 | 42.75% |
| root | 5601 | 5.41% |
| more specifics | 53686 | 51.84% |
| total prefixes | 103551 | 100.00% |

Percentage of root prefixes grows slowly

- 1999 4.64
- 2000 4.86
- 2001 5.41

Another refinement phenomenon:

- growing share of the table is roots
- constant or decreasing share of more specifics
- average number of subblocks of a root is decreasing

# Prefix set churn

Churn (emergence and disappearance of prefixes in the table) was much higher than growth rate.

- highest for more specifics
- lowest for standalone blocks
- net change in table size sometimes < 0

semiglobal prefixes in following data uses all available RouteViews backbone tables, including filtered tables, for 3 sample points: May 3, August 1, and November 1, 2001 (33, 42, and 39 tables, respectively)

# Changes in prefix status from May->Aug 2001

- transitions are from columns to rows
  - from May to August 2001
  - equal number of prefixes moved from standalones to roots/m.s.'s
  - more prefixes changed from m.s. to standalone than v.v.
  - "Vacuum" counts prefixes which appeared or disappeared

| | St.al | Root | M.sp | Vac | Sum | Out |
|---|---|---|---|---|---|---|
| St.al | 38676 | 544 | 576 | 2450 | 42246 | 8.45 |
| Root | 377 | 4374 | 40 | 307 | 5098 | 14.20 |
| M.sp | 917 | 41 | 42188 | 8746 | 51892 | 18.70 |
| Vac | 4232 | 420 | 9206 | 0 | 13858 | 100.00 |
| In | 13.08 | 19.71 | 18.93 | 83.01 | 99236r | |
| Sum | 44202 | 5379 | 52010 | 11503 | 101591c | |

# Changes in prefix status from Aug->Nov 2001

- transitions are from columns to rows
  - from August to November 2001
  - Root prefixes coming mostly from standalone (607 vs. 433 new)
  - more prefixes changed from standalone to m.s. than v.v. (reversal of May-Aug trend)

| | standal. | root | more spec | vac | sum | out |
|---|---|---|---|---|---|---|
| St.al | 39530 | 607 | 1460 | 2605 | 44202 | 10.57 |
| Root | 396 | 4532 | 146 | 305 | 5379 | 15.75 |
| M.sp | 604 | 33 | 41835 | 9538 | 52010 | 19.56 |
| Vac | 3738 | 433 | 10178 | 0 | 14349 | 100.00 |
| In | 10.72 | 19.95 | 22.66 | 86.75 | 101591r | |
| Sum | 44268 | 5605 | 53619 | 12448 | 103492c | |

# Prefix set churn, cont.

May-Aug 2001 (33 (May) and 42 (Aug) RouteViews peers):

| | % standalone | % of root | % more spec. |
|---|---|---|---|
| Out | 8.45 | 14.20 | 18.70 |
| In | 13.08 | 19.71 | 18.93 |
| Net | 4.63 | 5.51 | 0.23 |

No growth for more specifics in May-Aug 2001

Aug-Nov 2001 (42 (Aug) and 39 (Nov) RouteViews peers):

| | % standalone | % of root | % more spec. |
|---|---|---|---|
| Out | 10.57 | 15.75 | 19.56 |
| In | 10.72 | 19.95 | 22.66 |
| Net | 0.15 | 4.20 | 3.09 |

No growth for standalones in Aug-Nov 2001

("In" and "Out" include transitions when existing prefix changes its type, e.g., from standalone to more specific)

# Growth of non-transit ASes

- Transit and non-transit ASes contribute about equal numbers of prefixes despite the fact that there are 5 times as many non-transit ASes as transit ASes.
- Transit ASes announce over 1/2 prefixes (53%)
- For 1999-2000-2001:
  - Fraction of nontransit ASes: 81%, 83%, 84%
  - Announcements from nontransit ASes (percentage of semiglobal): 42%, 43%, 46%

# Growth of non-transit ASes, cont.

Q: Does the Internet grow mostly at the periphery?
A: Most likely, although BGP graph may not have enough coverage at network edge to answer

- may show transit ASes as nontransit
- may undercount indegree (multi-homing)
- captures only downstream, not lateral, connectivity
  - 18%, 17%, 16% transit ASes in 1999, 2000, 2001
  - absolute number grows but proportion shrinks
  - bidirectional part of the graph (core): 3.13%, 2.24%, 2.09%
- compare to skitter (traceroute-based) AS graph:
  - 32% transit ASes, twice as many as BGP graph
  - 28% ASes in combinatorial core (BGP: 2%)

# Multihomed ASes

Definitions: AS with indegree > 1 in BGP AS graph is called multihomed
AS with outdegree > 0 in BGP AS graph is called transit

BGP gives only a lower bound on multi-homing, although a consistent one

- (26 vs. 39 tables differ by 0.3% in multi-homed ASes)

For Nov 01, 2001 RouteViews data, multihomed networks originated

- 76% of all prefixes
- 74% of all more specific (subset) prefixes
- includes transit & non-transit
- multihomed nets originate a proper fraction of more specifics
- Non-transit multihomed ASes contribute less prefixes than their fair share:

| Year | %AS | %prefixes |
|---|---|---|
| 1999 | 43.65 | 27.46 |
| 2000 | 45.84 | 29.37 |
| 2001 | 48.75 | 29.74 |

- Fraction of non-transit multihomed ASes grew in 1999-2001
- Fraction of prefixes grew in 1999-2000, was constant in 2000-2001

# Transit AS prefixes by type (Nov.01 2001, 26 tables)

Prefixes from transit multihomed ASes:

| | | | |
|---|---|---|---|
| standalone | 23801 | 49.28% | |
| root | 3723 | 7.71% | |
| more specific | 20777 | 43.02% | |
| total | 48301 | 100.00% | --> 46.64% of all prefixes |

Prefixes from transit singlehomed ASes:

| | | | |
|---|---|---|---|
| standalone | 2608 | 37.74% | |
| root | 344 | 4.98% | |
| more specific | 3958 | 57.28% | |
| total | 6910 | 100.00% | --> 6.67% of all prefixes |

# Non-transit AS prefixes by type

Prefixes from non-transit multihomed ASes:

| | | | |
|---|---|---|---|
| standalone | 10715 | 34.80% | |
| root | 999 | 3.24% | |
| more specifics | 19080 | 61.96% | |
| total | 30794 | 100.00% | --> 29.74% of all prefixes |

Prefixes from non-transit singlehomed ASes:

| | | | |
|---|---|---|---|
| standalone | 6507 | 39.51% | |
| root | 452 | 2.74% | |
| more specifics | 9509 | 57.74% | |
| total | 16468 | 100.00% | --> 15.90% of all prefixes |

# New top prefixes

- New address space announcements and deaggregation of existing prefixes were two major sources of new root and standalone prefixes between Nov 2000-May 2001.

# Multihomed ASes and traffic engineering

Q: Are extra routes introduced for traffic engineering?
A: Yes, but only a minority

- Multihomed ASes originating on one link
  - Nov.01, 2001, 26 tables; multiorigin prefixes are excluded
  - 22.2% of all prefixes
  - 15.8% of all top prefixes
  - 28.6% of all more specifics
  - more specifics are announced on one link more frequently
  - 6-12% more specifics may be traffic engineered splinter blocks
- Majority of semiglobal prefixes are announced on all available connections
- Largest groups:
  - On 1 connection for singly homed AS, 22.6%
  - On 2 connections for doubly homed AS, 15.8%
  - On 3 connections for triply homed AS, 31.1%
  - On 2 connections for triply homed AS, 7.3%
    - (triply homed = indegree >= 3)

# More specifics and traffic engineering

- traffic engineering would imply the more specific announced on only one connection
- some more specifics are involved in traffic engineering, but most of them aren't

# Routing changes: Oct -Nov 2001

Semiglobal prefixes, 26 full size backbone tables

104555 prefixes on Oct 01
103815 prefixes on Nov 30
Union: 137374

There are lots of

- flips (withdrawals and reannouncements)
- transients (initial announcements and final withdrawals)

# Flips (reannouncements after withdrawals)

| | number | % of total | % of Oct01 |
|---|---|---|---|
| Long-lived: | 93127 | 67.79% | 89.07% |
| Apparently emerged: | 32819 | 23.89% | 31.39% |
| Apparently disapp.: | 33559 | 24.43% | 32.10% |
| Transients (came&went): | 22131 | 16.11% | 21.17% |
| Entries w.a flip: | 31007 | 22.57% | |
| Long-lived entries w.a flip: | 20951 | 15.25% | |
| Long-lived entries' flips: | 35591 | 60.06% (of flips) | |
| Transient entries w.a flip: | 3743 | 2.72% | |
| Transient entries' flips: | 9285 | 15.67% (of flips) | |

long-lived + emerged + disappeared - transients = total observed = 137K

# Flips (/24's flip more frequently; /21-24's most transients)

| Pf.len | prefxs | flp.pf | flips | trans | %all | %flp.pfs | %flips | %trans |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 1 | 0 | 0 | 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 28 | 8 | 264 | 11 | 0.02 | 0.03 | 0.45 | 0.05 |
| 9 | 5 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 9 | 0 | 0 | 1 | 0.01 | 0.00 | 0.00 | 0.00 |
| 11 | 12 | 1 | 2 | 0 | 0.01 | 0.00 | 0.00 | 0.00 |
| 12 | 39 | 8 | 12 | 1 | 0.03 | 0.03 | 0.02 | 0.00 |
| 13 | 95 | 13 | 21 | 0 | 0.07 | 0.04 | 0.04 | 0.00 |
| 14 | 236 | 27 | 43 | 5 | 0.17 | 0.09 | 0.07 | 0.02 |
| 15 | 410 | 55 | 81 | 5 | 0.30 | 0.18 | 0.14 | 0.02 |
| 16 | 7387 | 1256 | 1966 | 115 | 5.38 | 4.05 | 3.32 | 0.52 |
| 17 | 1452 | 203 | 302 | 62 | 1.06 | 0.65 | 0.51 | 0.28 |
| 18 | 2605 | 401 | 581 | 115 | 1.90 | 1.29 | 0.98 | 0.52 |
| 19 | 7450 | 1213 | 1792 | 203 | 5.42 | 3.91 | 3.02 | 0.92 |
| 20 | 6852 | 1737 | 3981 | 356 | 4.99 | 5.60 | 6.72 | 1.61 |
| 21 | 7176 | 1193 | 1866 | 2009 | 5.22 | 3.85 | 3.15 | 9.08 |
| 22 | 8803 | 1792 | 3367 | 1169 | 6.41 | 5.78 | 5.68 | 5.28 |
| 23 | 11636 | 2600 | 4503 | 2028 | 8.47 | 8.39 | 7.60 | 9.16 |
| 24 | 83177 | 20500 | 40480 | 16049 | 60.55 | 66.11 | 68.31 | 72.52 |
| Total | 137374 | 31007 | 59261 | 22131 | 100.00 | 100.00 | 100.00 | 100.00 |

- The fraction of flips in /24 range is larger than fair share
- But not overwhelmingly large

# Flips in /24s per class (A,B,C)

Statistics of /24s

| Class | /24s | flp.pfs | flips | %/24s | %fpg/24s | %allfp | P{fp\|cl} |
|---|---|---|---|---|---|---|---|
| A | 11266 | 1890 | 3338 | 13.54 | 9.22 | 8.25 | 16.78 |
| B | 6666 | 2034 | 4587 | 8.01 | 9.92 | 11.33 | 30.51 |
| C | 65245 | 16576 | 32555 | 78.44 | 80.86 | 80.42 | 25.41 |
| Total | 83177 | 20500 | 40480 | 100.00 | 100.00 | 100.00 | 24.65 |

# Flips per lifetime of a prefix

| #) AS | Av.#pf | Flips | Fp/Kupt | Fp/Klft | Pc.fp | Acc.pc | NewAnn | TmpW/drw | Reann | FinW/hdr |
|---|---|---|---|---|---|---|---|---|---|---|
| 1) 4323 | 421.72 | 1466 | 4.89 | 4.59 | 2.47 | 2.47 | 34 | 52 | 51 | 16 |
| 2) 752 | 3.60 | 1444 | 564.72 | 335.58 | 2.44 | 4.91 | 1 | 659 | 658 | 2 |
| 3) 701 | 2196.94 | 1379 | 0.88 | 0.82 | 2.33 | 7.24 | 101 | 351 | 350 | 91 |
| 4) 702 | 956.48 | 924 | 1.36 | 1.32 | 1.56 | 8.80 | 68 | 373 | 346 | 45 |
| 5) 3908 | 652.29 | 921 | 1.99 | 1.79 | 1.55 | 10.35 | 63 | 105 | 109 | 43 |
| 6) 705 | 397.04 | 661 | 2.34 | 2.18 | 1.12 | 11.47 | 62 | 162 | 165 | 46 |
| 7) 1580 | 180.75 | 613 | 4.77 | 4.36 | 1.03 | 12.50 | 5 | 147 | 144 | 7 |
| 8) 3475 | 28.91 | 540 | 26.27 | 21.79 | 0.91 | 13.41 | 23 | 237 | 238 | 22 |
| 9) 4755 | 308.19 | 510 | 2.33 | 2.20 | 0.86 | 14.27 | 31 | 195 | 180 | 31 |
| 10) 8708 | 161.29 | 497 | 4.33 | 4.14 | 0.84 | 15.11 | 21 | 52 | 59 | 19 |
| 18) 8112 | 48.03 | 378 | 11.07 | 8.71 | 0.64 | 20.58 | 7 | 7 | 7 | 4 |
| 27) 724 | 244.60 | 278 | 1.60 | 1.56 | 0.47 | 25.14 | 12 | 76 | 81 | 11 |
| 39) 1239 | 692.89 | 190 | 0.39 | 0.38 | 0.32 | 30.21 | 55 | 94 | 90 | 33 |
| 56) 13609 | 109.98 | 150 | 1.92 | 1.90 | 0.25 | 35.03 | 14 | 40 | 40 | 4 |
| 80) 18618 | 64.45 | 114 | 2.49 | 2.45 | 0.19 | 40.17 | 1 | 10 | 9 | 2 |
| 110) 7629 | 21.04 | 83 | 5.55 | 5.40 | 0.14 | 45.10 | 7 | 22 | 23 | 6 |
| 150) 11623 | 6.90 | 66 | 13.46 | 13.26 | 0.11 | 50.01 | 0 | 12 | 12 | 0 |
| 201) 9800 | 104.11 | 52 | 0.70 | 0.70 | 0.09 | 55.07 | 6 | 18 | 17 | 2 |
| 266) 11554 | 18.78 | 39 | 2.92 | 2.90 | 0.07 | 60.01 | 0 | 3 | 3 | 1 |
| 356) 17625 | 6.84 | 29 | 5.97 | 4.97 | 0.05 | 65.05 | 4 | 7 | 9 | 3 |
| 399) 10223 | 42.14 | 25 | 0.83 | 0.83 | 0.04 | 67.01 | 1 | 10 | 10 | 2 |
| 478) 600 | 89.94 | 20 | 0.31 | 0.31 | 0.03 | 70.01 | 1 | 17 | 17 | 1 |
| 654) 6539 | 239.63 | 15 | 0.09 | 0.09 | 0.03 | 75.02 | 6 | 10 | 10 | 3 |
| 902) 224 | 14.94 | 10 | 0.94 | 0.94 | 0.02 | 80.00 | 0 | 10 | 10 | 1 |
| 1262) 2508 | 1.16 | 7 | 8.47 | 4.92 | 0.01 | 85.01 | 0 | 7 | 7 | 0 |

Total origins of flips: 5259 AS. Sum of temp. w/draw AS events: 22657. Reannouncement: 22816
All AS initiating temp. withrawals: 5259. Reannouncing AS: 5259
Note: when a prefix changes origin, an interval of AS lifetime sum is lost

# Several origin ASes over time

| #) | #or.AS | # Prefixes |
|---|---|---|
| 1) | 1 | 130786 |
| 2) | 2 | 4901 |
| 3) | 3 | 1500 |
| 4) | 4 | 96 |
| 5) | 5 | 50 |
| 6) | 6 | 16 |
| 7) | 7 | 17 |
| 8) | 8 | 5 |
| 9) | 9 | 1 |
| 10) | 11 | 1 |
| 11) | 12 | 1 |
| Total | | 137374 |

- 6588 prefixes changed hands (origin or some of origins)
- 4220 prefixes were multiorigin (at least once)
- 3861 ( 91.49% of above) multiorigin prefixes also changed hands

multi-origin prefixes are highly dynamic, some may be artifacts of convergence to a new origin at snapshot time

# BGP table change contributors (summary)

- ASes with new and/or (temporarily) lost prefixes
  - sum total of all changes in prefix status
- 50% of (all) changes from 127 most "dynamic" ASes
- Sorted by total lost+found prefix occurrences
- for Oct-Nov 2001 (61 days, 2 hour int, 711 tables)

# BGP table change: top 10 contributors

| | type | ASN | Av.#pf | ap+ds | a+d /Kupt | a+d /Klft | %a+d | cum %a+d | 2-hour intervals with changes: new app | tmp disp | reapp | final disp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bac | 701 | 2196.94 | 6790 | 4.35 | 4.04 | 3.67 | 3.67 | 101 | 351 | 350 | 91 |
| 2 | Bac | 3908 | 652.29 | 5915 | 12.75 | 11.49 | 3.20 | 6.87 | 63 | 105 | 109 | 43 |
| 3 | AOL | 4323 | 421.72 | 3236 | 10.79 | 10.14 | 1.75 | 8.62 | 34 | 52 | 51 | 16 |
| 4 | Bac | 1239 | 692.89 | 3199 | 6.49 | 6.47 | 1.73 | 10.35 | 55 | 94 | 90 | 33 |
| 5 | Res | 752 | 3.60 | 2893 | 1131.4 | 672.32 | 1.56 | 11.92 | 1 | 659 | 658 | 2 |
| 6 | Bac | 702 | 956.48 | 2883 | 4.24 | 4.12 | 1.56 | 13.48 | 68 | 373 | 346 | 45 |
| 7 | Tech | 71 | 46.22 | 2589 | 78.79 | 77.60 | 1.40 | 14.88 | 3 | 10 | 10 | 6 |
| 8 | Bac | 705 | 397.04 | 2409 | 8.53 | 7.94 | 1.30 | 16.18 | 62 | 162 | 165 | 46 |
| 9 | Bac | 4999 | 21.64 | 1493 | 97.02 | 28.93 | 0.81 | 16.99 | 6 | 2 | 2 | 6 |
| 10 | Mil | 1580 | 180.75 | 1448 | 11.27 | 10.30 | 0.78 | 17.77 | 5 | 147 | 144 | 7 |

(ap = appeared, ds = disappeared)

- Both background noise and storm-like events are present

# BGP table change contributors: prefix flips (reannouncements after withdrawals)

- 50% flips from 150 ASes (3% of 5259 flipping ASes)
- 75% flips from 12.4% ASes
- #events for AOL larger than for other ASes
  - not just background noise

| | type | ASN | Av.#pf | Flips | Fp/Kupt | Fp/Klft | %fps | Cum %fps | newap | tmpdisp | re-app | finaldisp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | AOL | 4323 | 421.72 | 1466 | 4.89 | 4.59 | 2.47 | 2.47 | 34 | 52 | 51 | 16 |
| 2 | Res | 752 | 3.60 | 1444 | 564.72 | 335.58 | 2.44 | 4.91 | 1 | 659 | 658 | 2 |
| 3 | Bac | 701 | 2196.94 | 1379 | 0.88 | 0.82 | 2.33 | 7.24 | 101 | 351 | 350 | 91 |
| 4 | Bac | 702 | 956.48 | 924 | 1.36 | 1.32 | 1.56 | 8.80 | 68 | 373 | 346 | 45 |
| 5 | Bac | 3908 | 652.29 | 921 | 1.99 | 1.79 | 1.55 | 10.35 | 63 | 105 | 109 | 43 |
| 6 | Bac | 705 | 397.04 | 661 | 2.34 | 2.18 | 1.12 | 11.47 | 62 | 162 | 165 | 46 |
| 7 | Mil | 1580 | 180.75 | 613 | 4.77 | 4.36 | 1.03 | 12.50 | 5 | 147 | 144 | 7 |
| 8 | Mil | 3475 | 28.91 | 540 | 26.27 | 21.79 | 0.91 | 13.41 | 23 | 237 | 238 | 22 |
| 9 | Dev | 4755 | 308.19 | 510 | 2.33 | 2.20 | 0.86 | 14.27 | 31 | 195 | 180 | 31 |
| 10 | Dev | 8708 | 161.29 | 497 | 4.33 | 4.14 | 0.84 | 15.11 | 21 | 52 | 59 | 19 |

- Under best conditions, a prefix flips once in 3 months
- Aside: global (all-peer) prefixes have twice as much flux as semiglobal (flux estimates depend on the prefix set)

# analysis of BGP updates

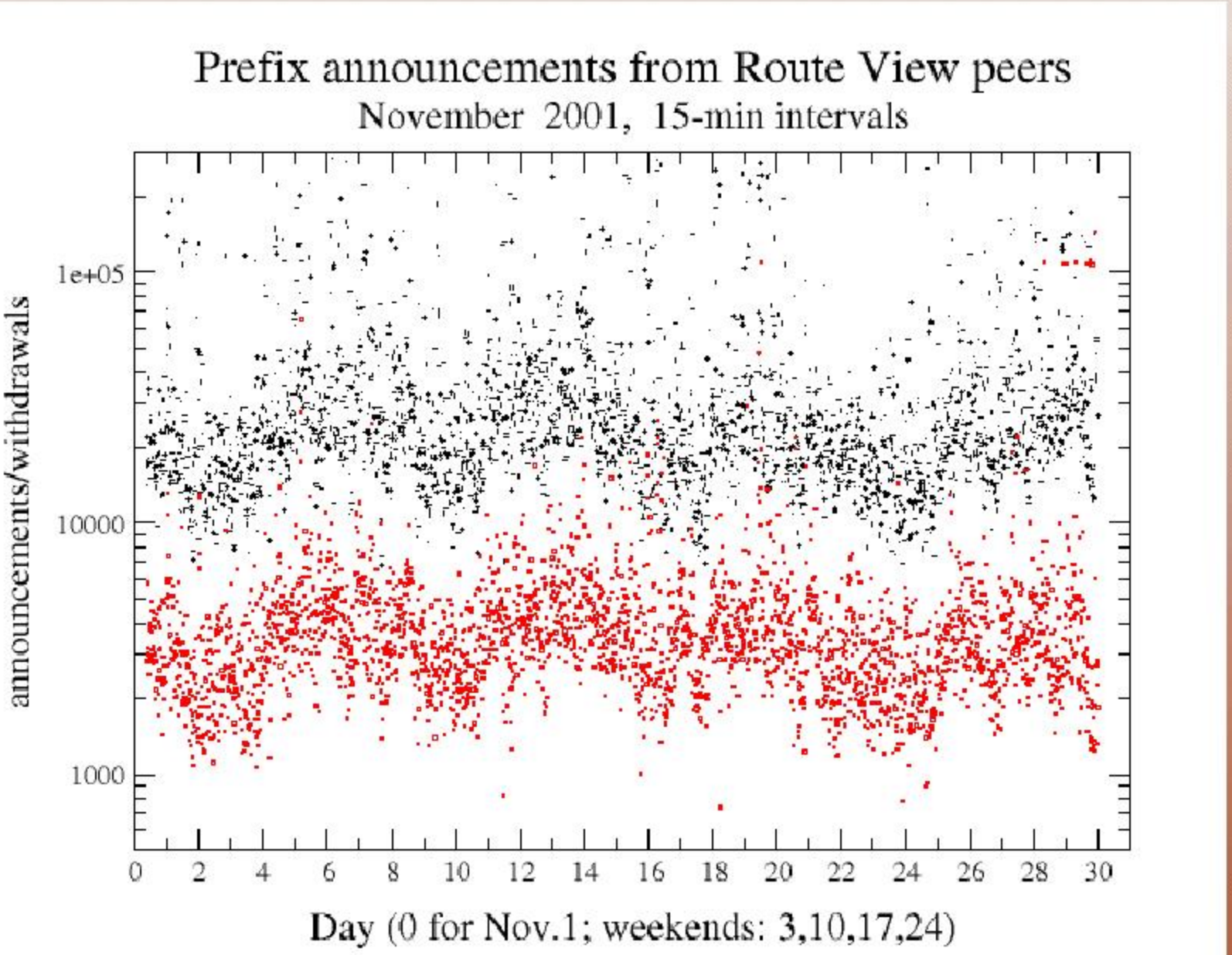
- now we look at granularity of individual BGP updates
- RouteViews started archiving October 2001
- we analyze BGP updates over one month (Nov 2001)
  - 15 min updates per file, 22 peers contribute
  - Contribution sizes span an order of magnitude
  - use 50K cutoff to avoid events like full-table transmission
  - leaves about 90% of all time intervals (2434 out of 2711)
  - and about 2/3 of all packets

## Results:

- Announcements more frequent than withdrawals
- Many whole table transmissions, O(100K) prefixes
- Weekly and diurnal variations clearly visible
- Match traffic pattern on the 'Net
- Traffic load translates into path fluctuations
  - Is it human intervention or automatic tools output?

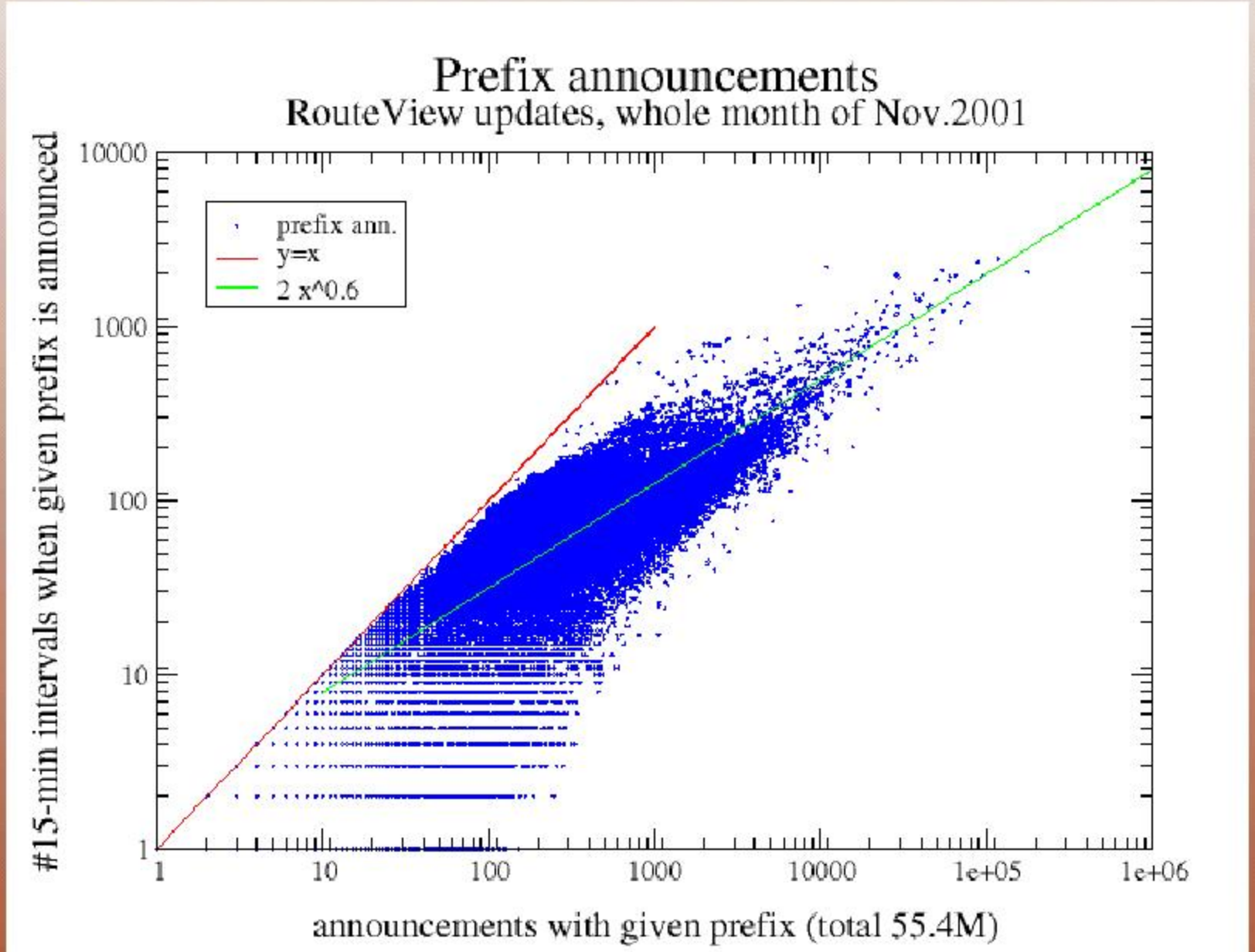
# BGP updates over one month

- withdrawal vs announcemts (and some full table updates)



# BGP prefix announcements

- ann/prefix related to counts of 15-min.int, esp. at the cusp



# BGP prefix announcements/withdrawals

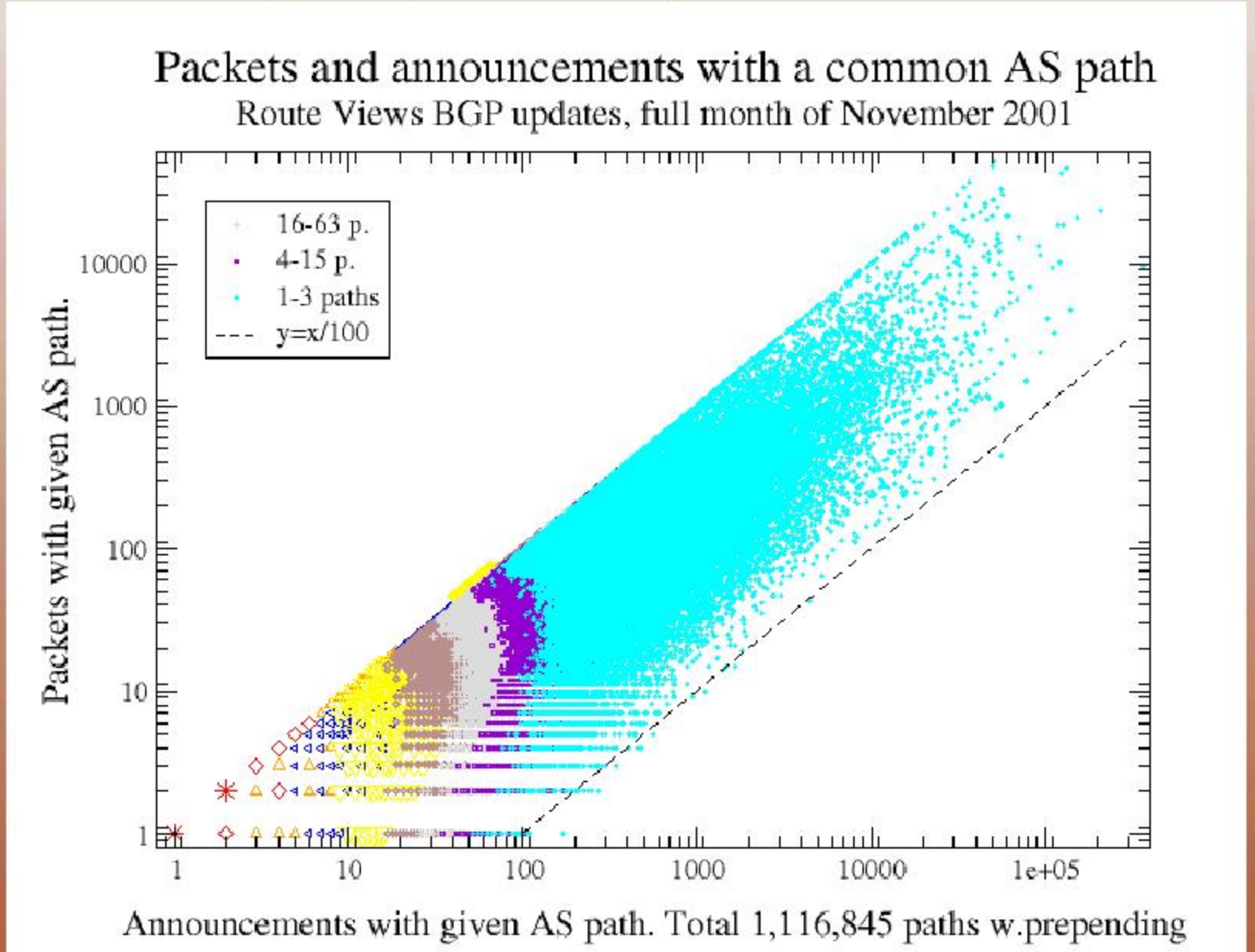
- Nov 2001 RouteViews
- 2711 files (no cutoff for #announcements per file)

| | |
|---|---|
| total packets: | 30M |
| packets with announcements | 28.2M |
| packets with withdrawals | 1,955,188 |
| packets with both | 127,429 |
| total announcements | 83.5M |
| total withdrawals | 11.7M |
| average announcements/packet | 2.7736 |
| average withdrawals/packet | 0.3874 |
| average withdrawals/wd.packet | 5.9615 |

- 15X as many announcement as withdraws
- 15X as many withdraws as ann.&withdraw
- withdrawals packed at prefixes/AS path ratio of ~6.5

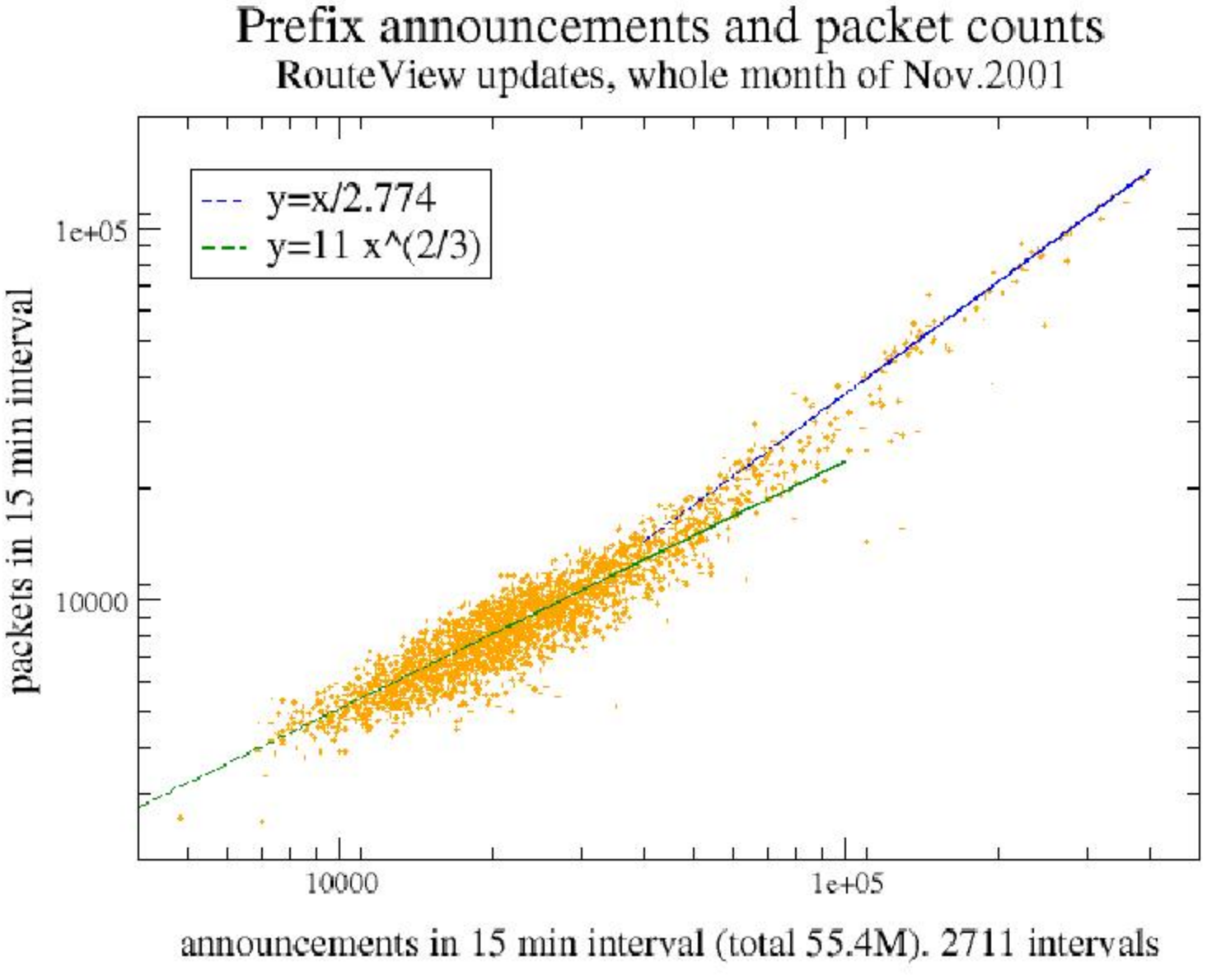
# Dependence between packets seen & bgp announcements

- some AS paths update 100s of prefixes at once



# packing of prefixes into announcements

- two regions: full tables (blue) and incremental updates (green)



# BGP updates contributors

Q: Are small ASes major contributors of BGP updates?

A: The bulk of BGP announcements comes from ISPs who announce many (tens to hundreds) prefixes:

- backbone providers
- government networks
- ISPs in developing nations
- ISPs in Canada and US

Large batches of announcements often contain deaggregated intervals of IP space (as in "avoiding a small block" scenario)

# Top 10 announcers, Nov 2001

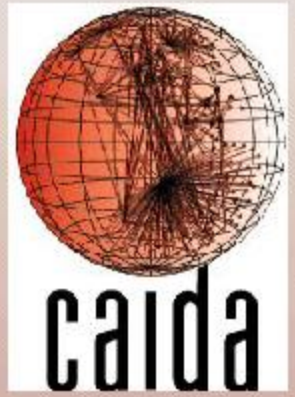
| | type | ASN | #Anns | %ann | cum% | /15mi |
|---|---|---|---|---|---|---|
| 1 | ISP Can | 852 | 777540 | 1.40 | 1.40 | 732 |
| 2 | Dev Eu | 12302 | 578932 | 1.05 | 2.45 | 681 |
| 3 | Mil | 6595 | 564201 | 1.02 | 3.47 | 1622 |
| 4 | Bac | 577 | 508675 | 0.92 | 4.39 | 1085 |
| 5 | Dev Asia | 4755 | 471458 | 0.85 | 5.24 | 1985 |
| 6 | Bac | 702 | 436282 | 0.79 | 6.02 | 2421 |
| 7 | Dev SAm | 20043 | 412334 | 0.74 | 6.77 | 749 |
| 8 | Gov ZA | 2018 | 370335 | 0.67 | 7.44 | 337 |
| 9 | Gov | 2572 | 365096 | 0.66 | 8.10 | 592 |
| 10 | Bac | 6453 | 346551 | 0.63 | 8.72 | 2442 |

- top 2 announce 538 and 102 prefixes, resp. (backbones up to 2K)
- announcements are spread across time, not just storms
- reminder: only 1% of ASes announce >100 prefixes

# Conclusions

- Internet undergoes refinement process
- Some bulk measures are stable
- Others change slowly
- Opposite trends cancel each other
- More churn than bulk measures suggest
- Internet churn comes from everywhere
  - mostly from large ISPs, .gov/.mil, and developing nation telecoms
- Small ASes generate little churn and table growth
- Invariant or almost invariant relations do exist
  - e.g. AS paths/AS ratio

still a lot left to analyze...

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