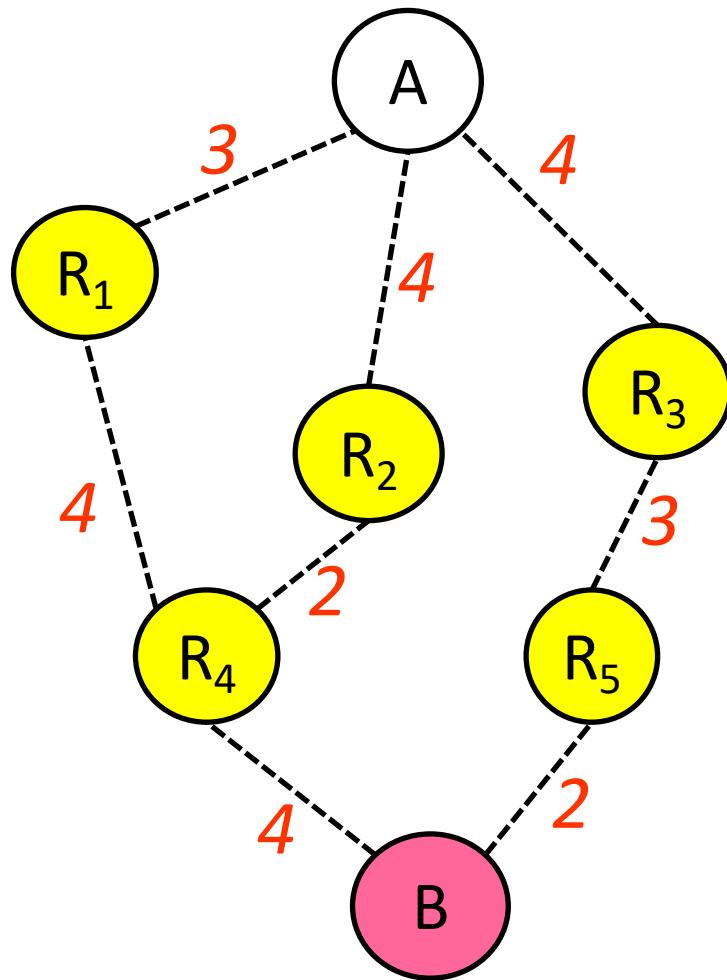
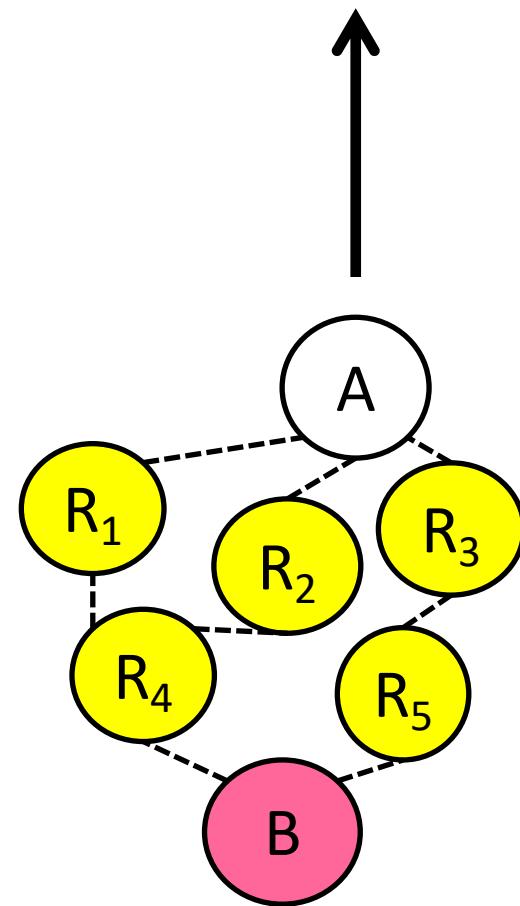
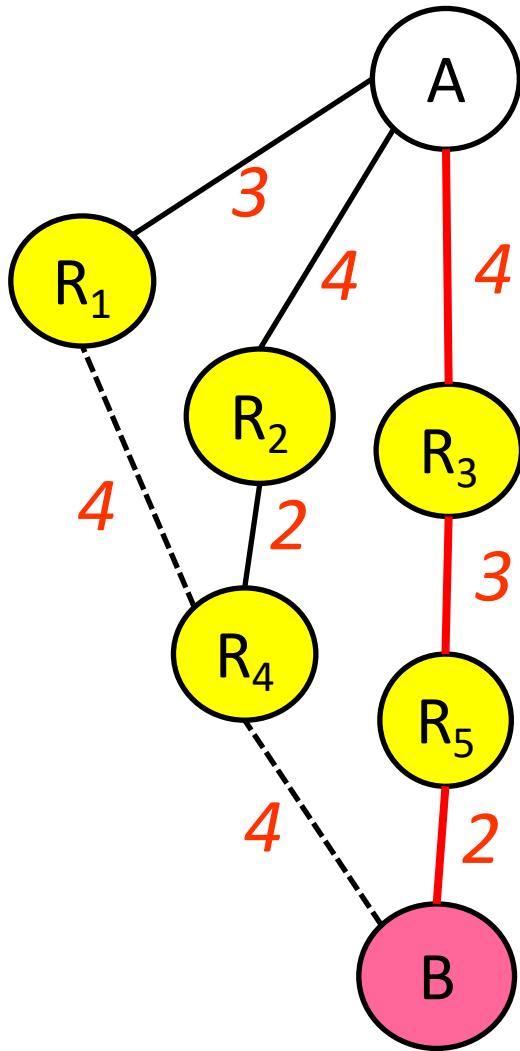


Another view of Dijkstra...

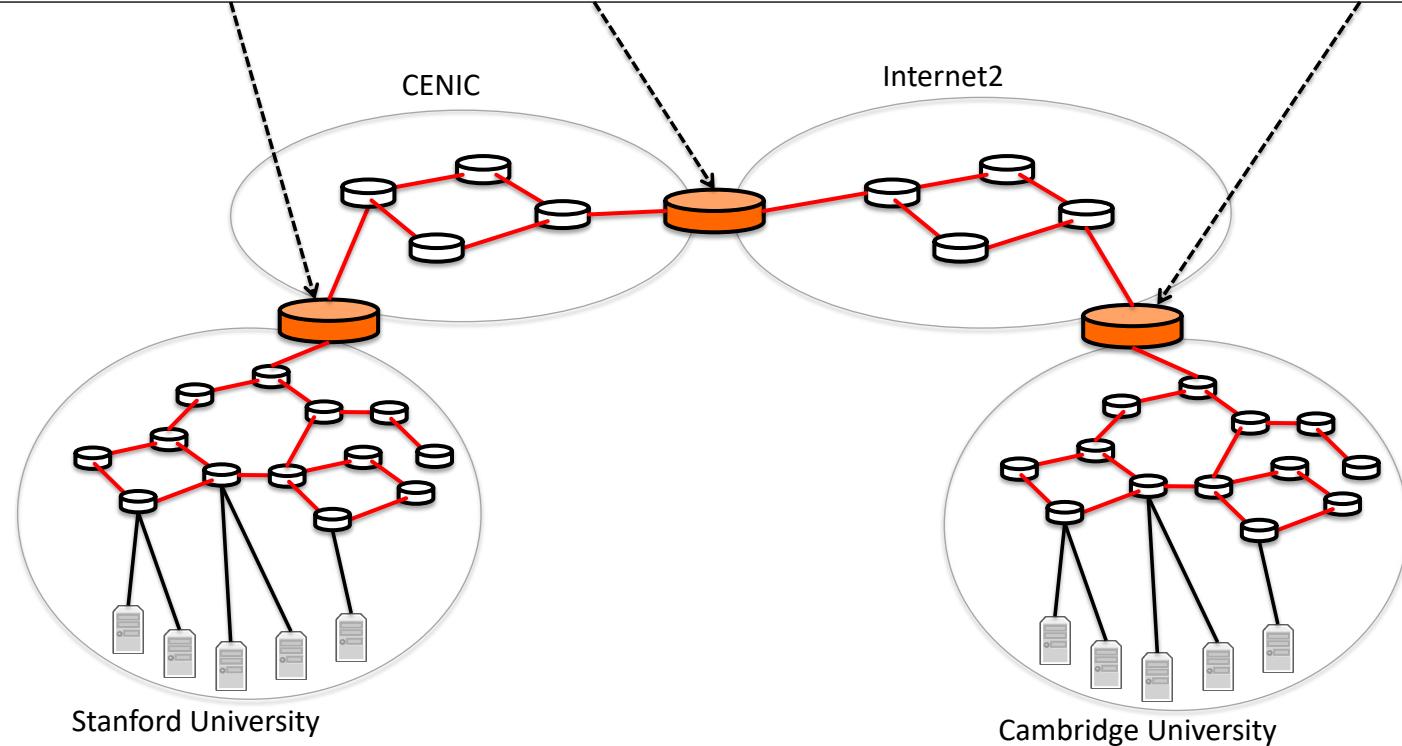






Internet routing is hierarchical

All organizations (Autonomous Systems) use the same algorithm to talk to each other



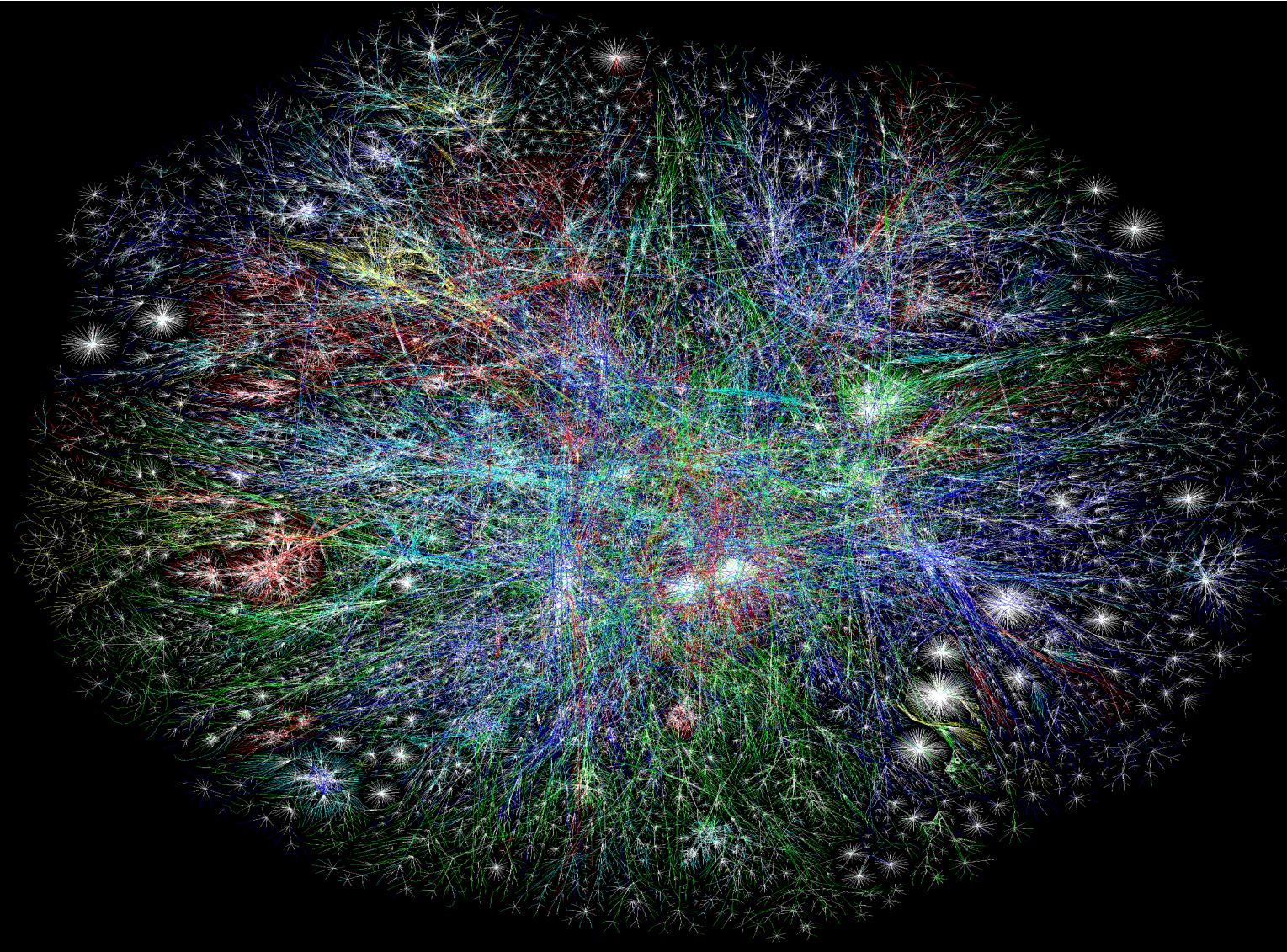
AS (Autonomous System) numbers

```
nickm> traceroute -q1 www.cam.ac.uk
```

```
traceroute to www.cam.ac.uk (131.111.150.25),
 30 hops max, 40 byte packets
 1 csmx-west-rtr.SUNet (171.64.74.2)  8.567 ms
 2 dc-svl-rtr-v18.SUNet (171.64.255.204)  0.334 ms
 3 dc-svl-agg4--stanford-100ge.cenic.net
    (137.164.23.144)  1.041 ms
...
 7 et-4-0-0.4079.sdn-sw.lasv.net.internet2.edu
    (162.252.70.28)  14.320 ms
...
14 internet2.mx1.lon.uk.geant.net
  (62.40.124.44)  144.085 ms
15 janet-gw.mx1.lon.uk.geant.net
  (62.40.124.198)  144.552 ms
...
24 primary.admin.cam.ac.uk (131.111.150.25)  150.353
  ms
```

```
nickm> whois -h whois.cymru.com 62.40.124.198
```

```
[Querying whois.cymru.com]
[whois.cymru.com]
AS      | IP                  | AS Name
20965  | 62.40.124.198       | GEANT The GEANT IP Service, GB
21320  | 62.40.124.198       | GEANT_IAS_VRF, EU
```



Border Gateway Protocol (BGP)

- BGP neighbors (“peers”) establish a TCP connection.
- BGP is not a link-state or a distance-vector routing protocol.
- Instead, BGP uses what is called a “Path vector”.

- For each prefix, a BGP router advertises a path of AS’s to reach it.
 - This is the “path vector”
 - Example of path vector advertisement:
“The network 171.64/16 can be reached via the path {AS1, AS5, AS13}”
- When a link/router fails, the path vector is “withdrawn”

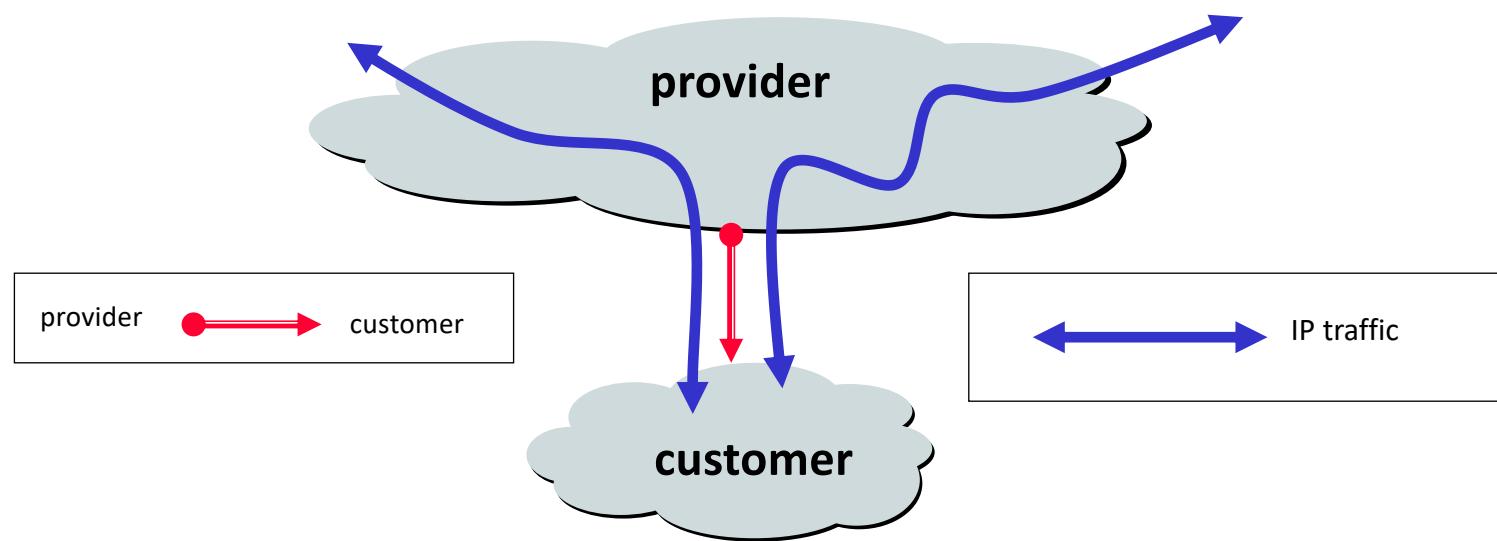
Border Gateway Protocol (BGP)

“The network 171.64/16 can be reached via the path {AS1, AS5, AS13}”

Paths with loops are detected locally and ignored.

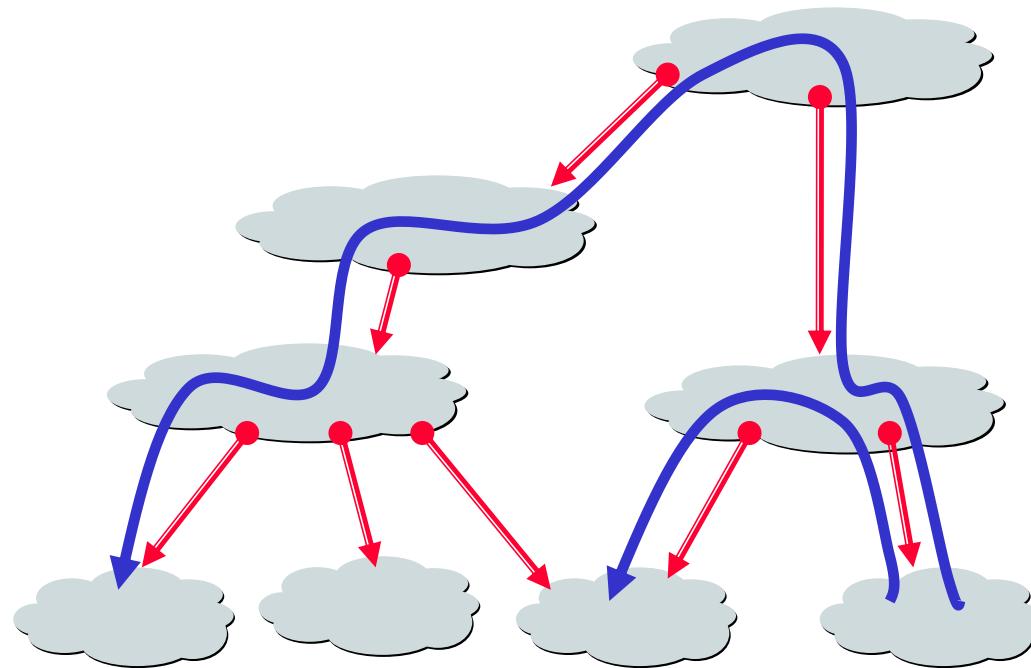
Local policies pick the preferred path among all advertised paths.

Customers and Providers



Customer pays provider to carry its packets.

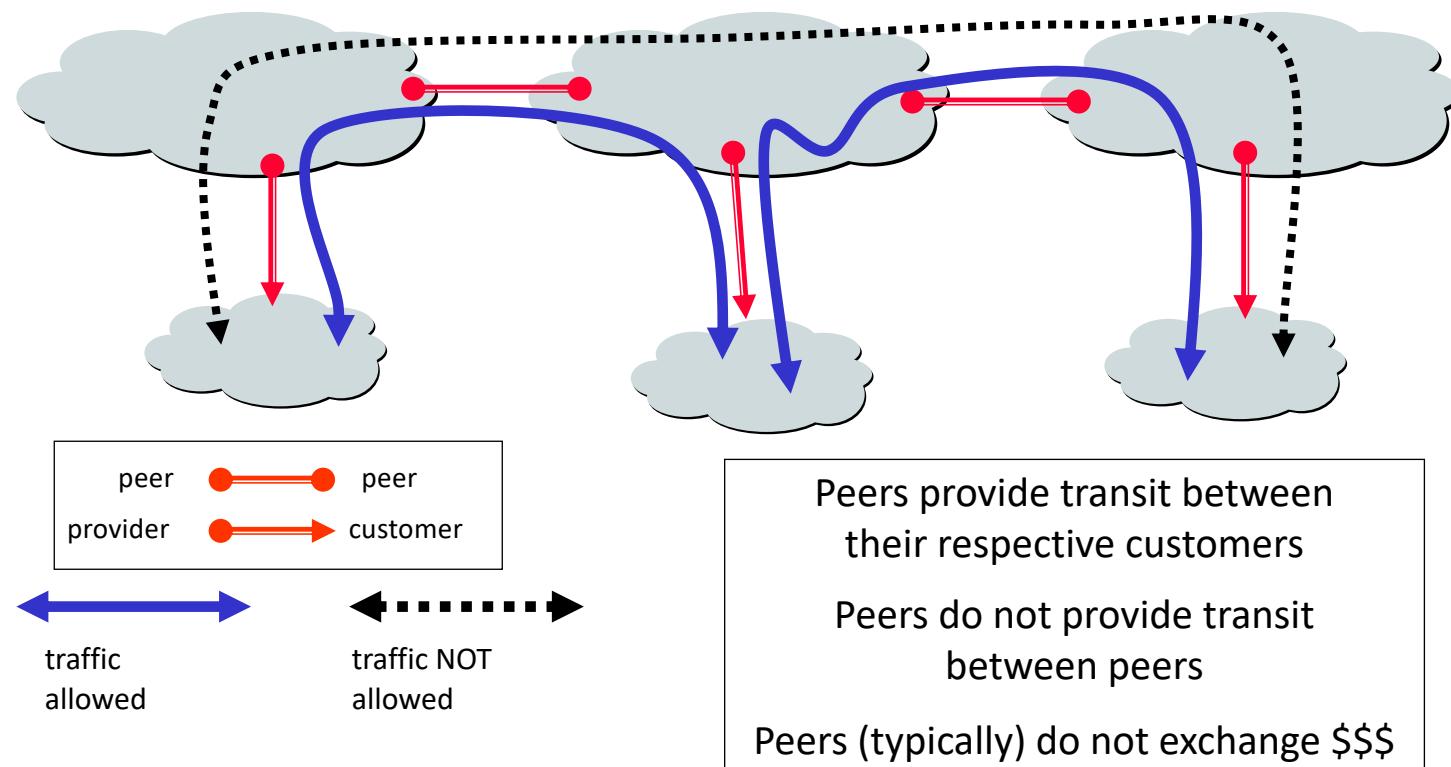
Customer-Provider Hierarchy



provider → customer

← IP traffic

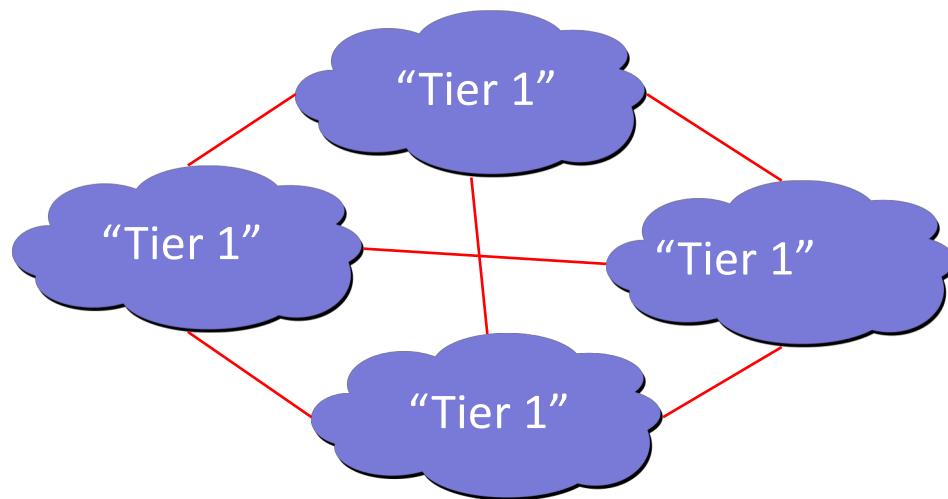
The Peering Relationship



So how does traffic from the left side reach the right side?

“Tier 1” Providers

A tier 1 network is a transit-free network that peers with every other tier 1 network



Tier 1 ISPs

Definition: A *Tier 1 ISP* has access to the entire *Internet Region* solely via its free and reciprocal peering agreements.

Definition: An *Internet Region* is a portion of the Internet network typically bounded by a country's geographical boundaries.

Each Internet Region has its own set of "Tier 1 ISPs."

The litmus test:

"*Does an ISP pay anyone to reach any destination in the Internet Region?*"

If the answer is "No" then it is a "Tier 1 ISP", and

If the answer is "Yes" then it is a "Tier 2 ISP."

Tier 1 ISPs by country

The U.S. Internet Region Tier 1 ISPs

1. AT&T
2. Verizon
3. Sprint (Softbank Broadband)
4. Century Link (Qwest)
5. Level 3 (with Global Crossing now)
6. NTT/Verio
7. Cogent

The Japan Internet Region Tier 1 ISPs

1. NTT
2. Japan Telecom (Softbank)
3. KDDI
4. IIJ
5. Powered.com

