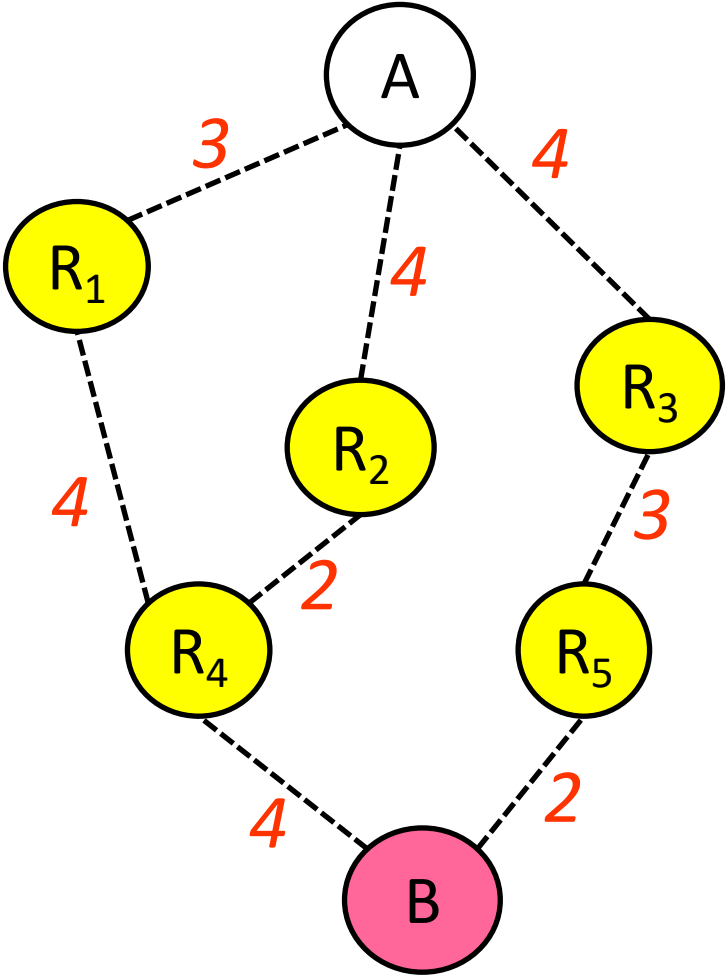
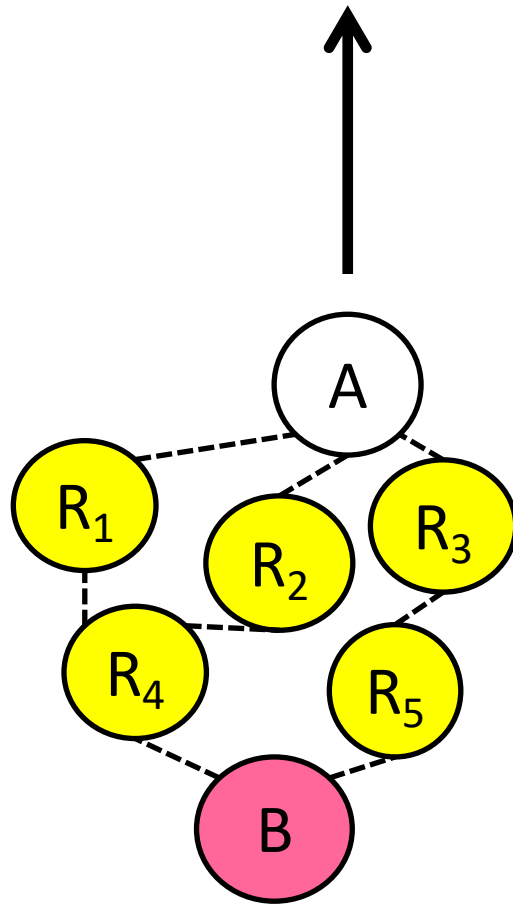
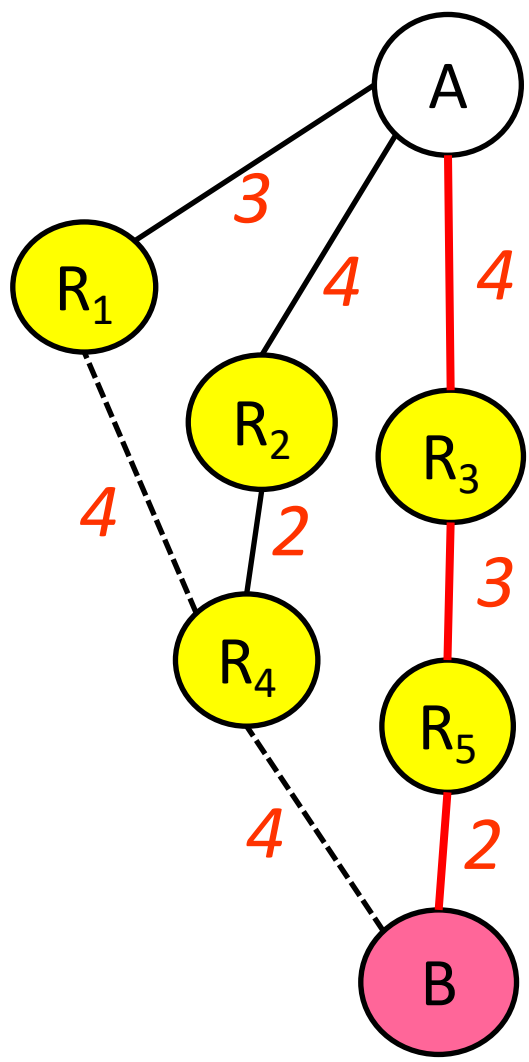


Another view of Dijkstra...

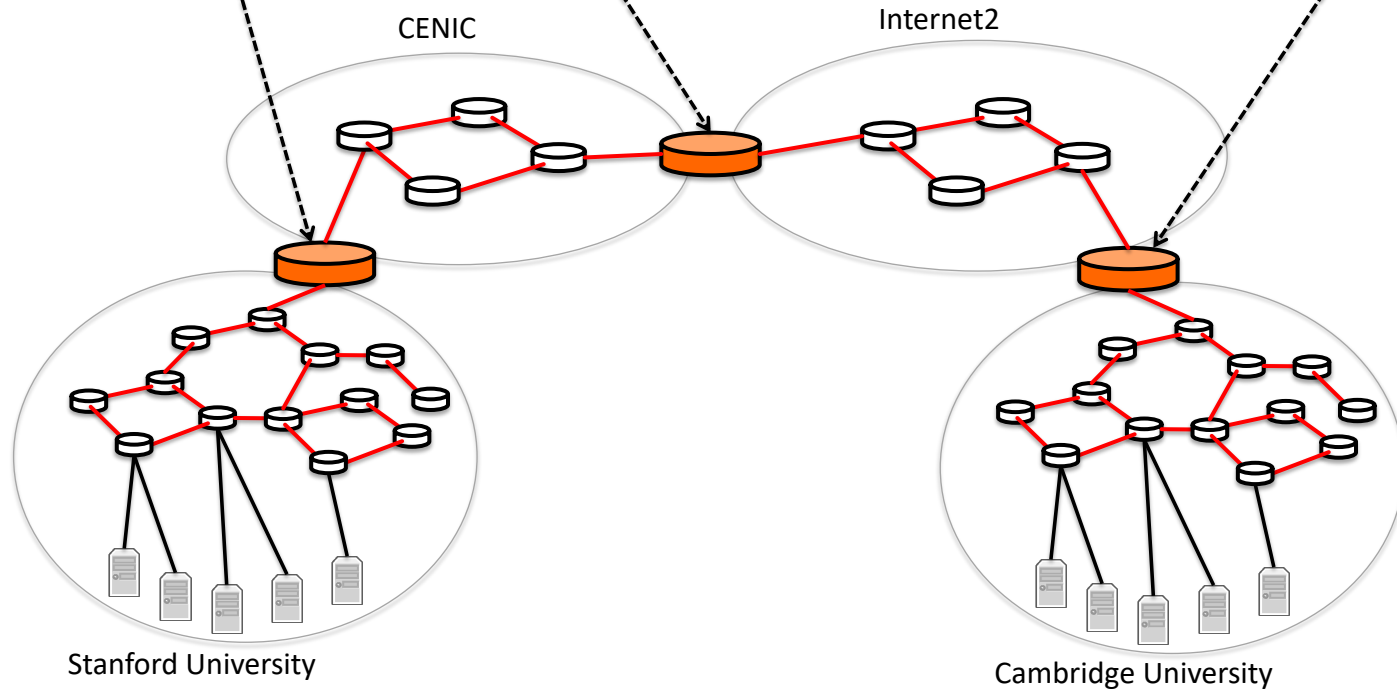






Internet routing is hierarchical

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-vl8.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- When a link/router fails, the path vector is “withdrawn”

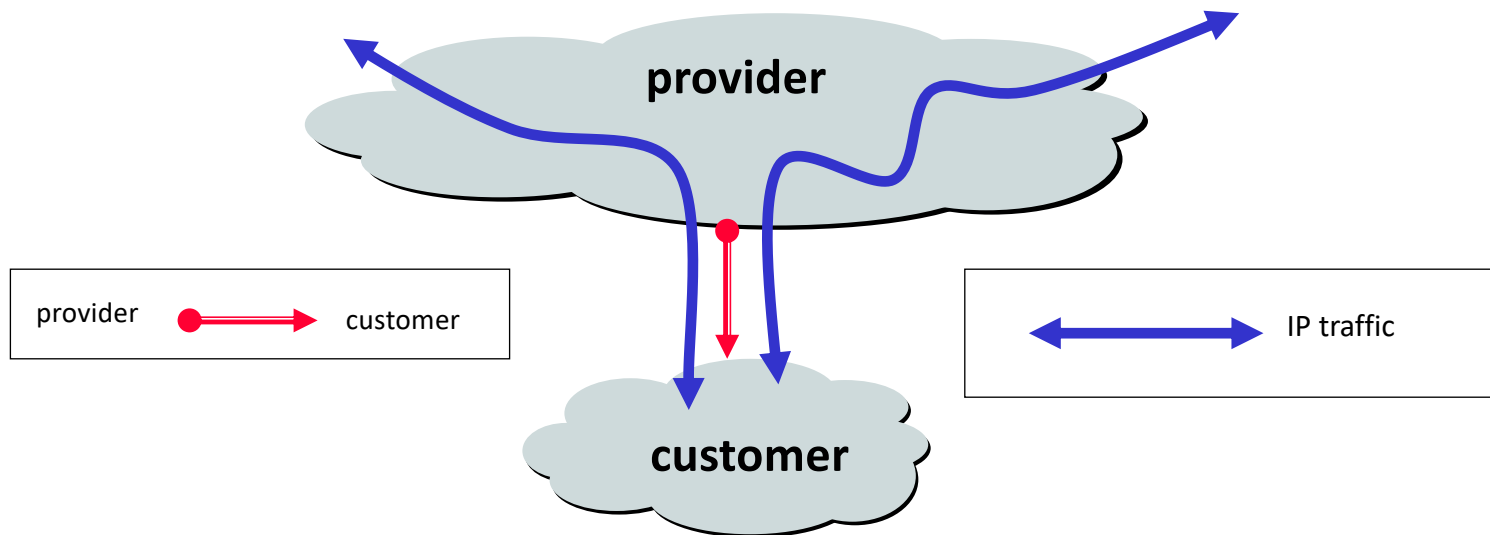
Border Gateway Protocol (BGP)

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

Paths with loops are detected locally and ignored.

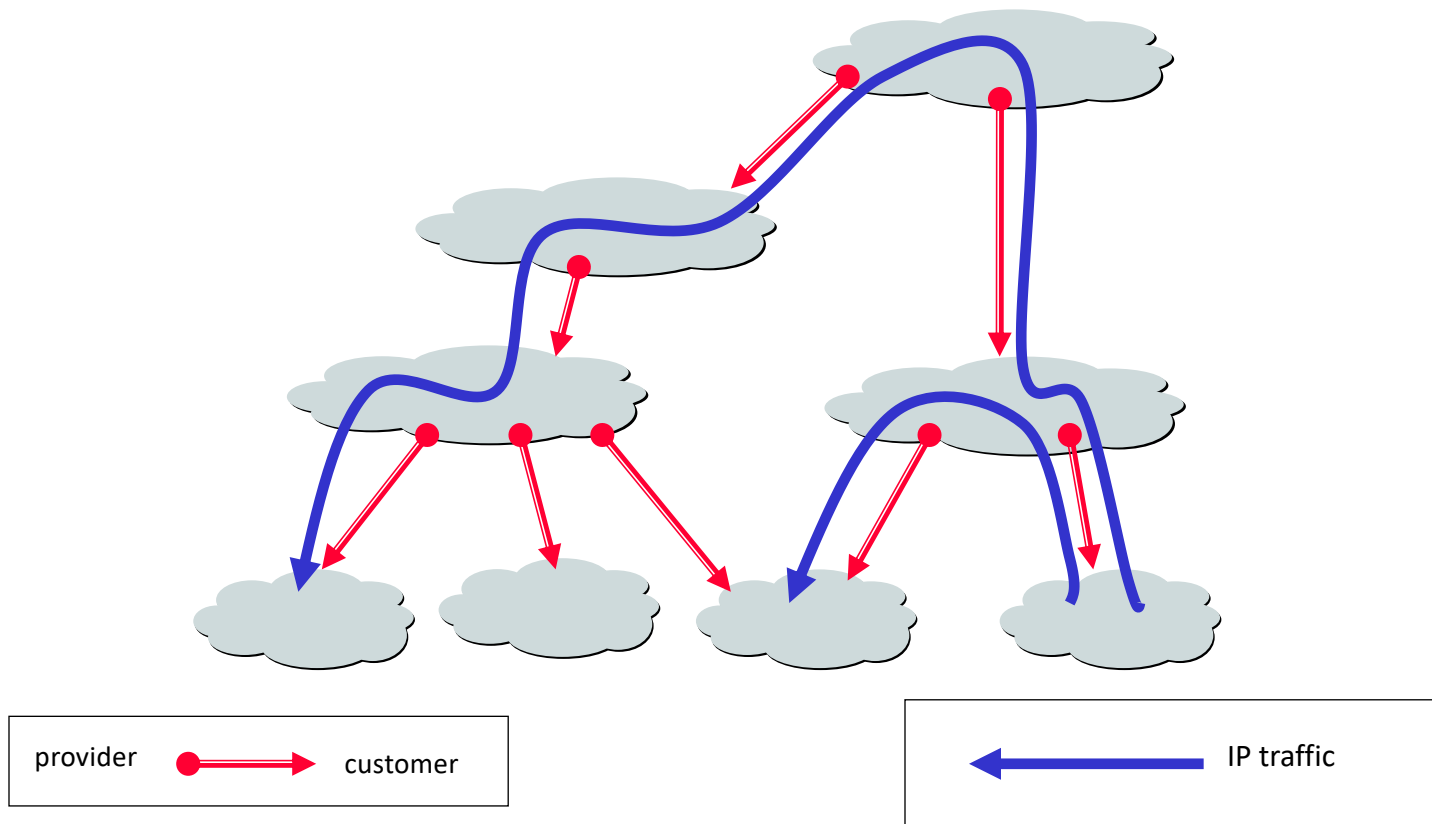
Local policies pick the preferred path among all advertised paths.

Customers and Providers

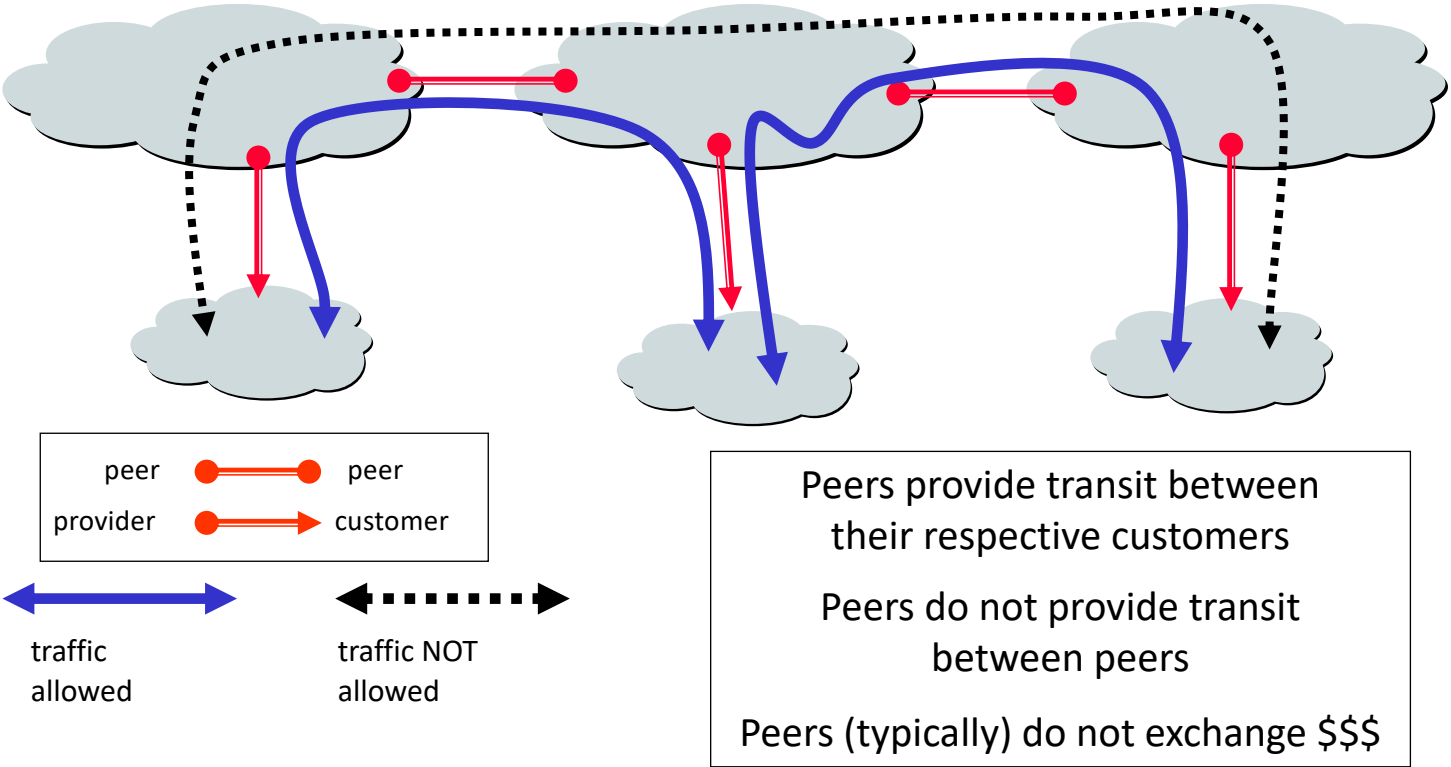


Customer pays provider to carry its packets.

Customer-Provider Hierarchy



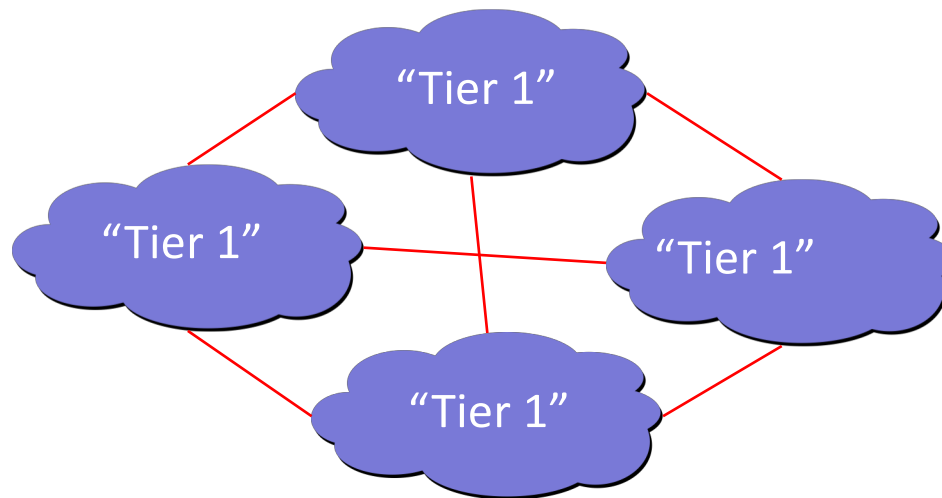
The Peering Relationship



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."

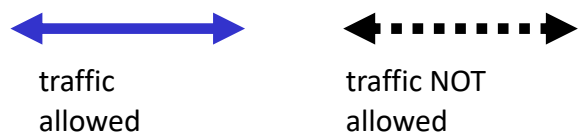
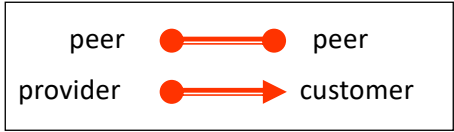
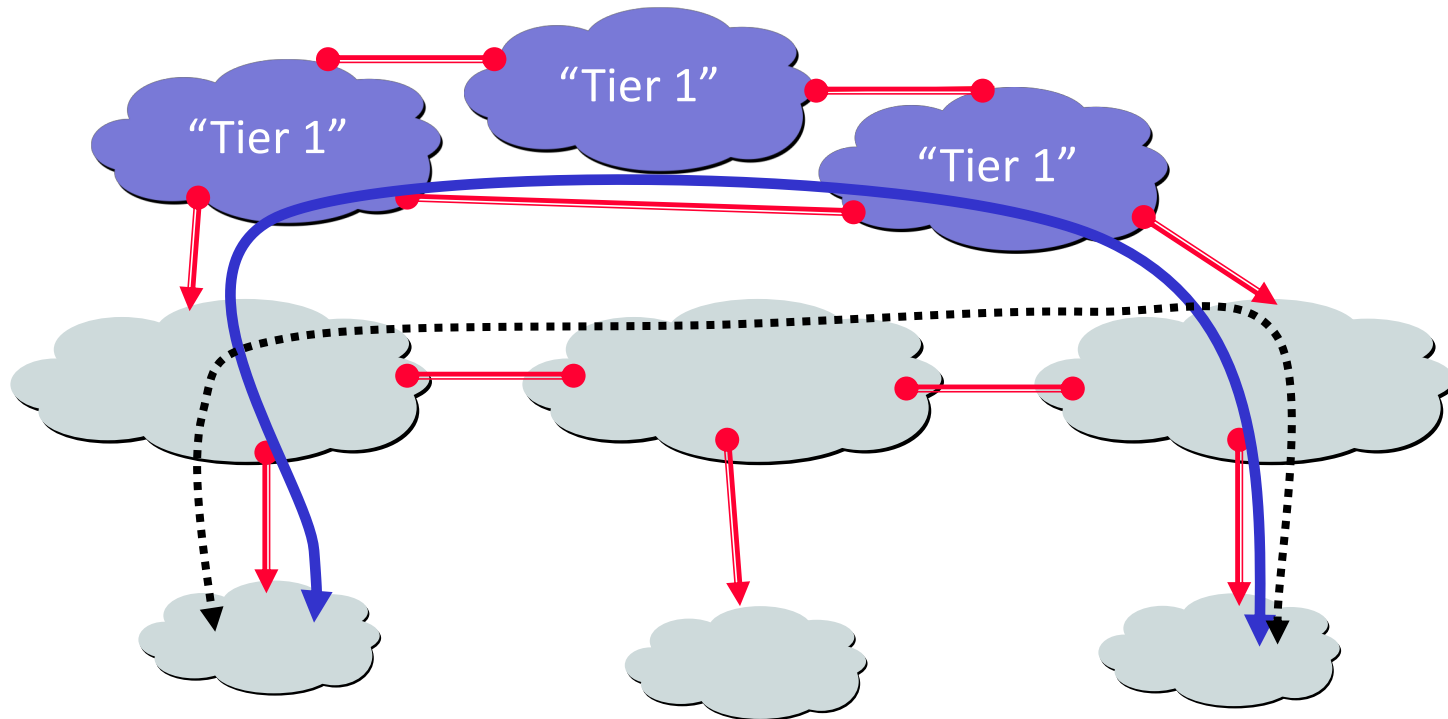
Tier 1 ISPs by country

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. IJ
5. Powered.com



Peers provide transit between their respective customers

Peers do not provide transit between peers

Peers (typically) do not exchange \$\$\$