Network Layer II

EECS 122: Lecture 12

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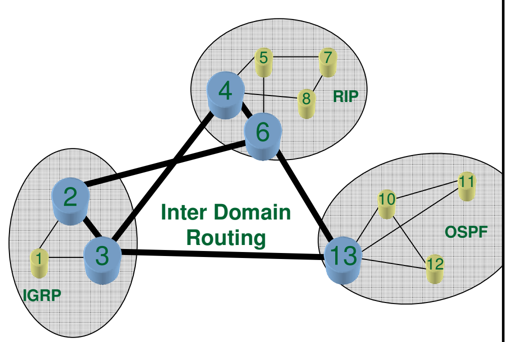
Hierarchical Routing

- Is a natural way for routing to scale
  - Size
  - Network Administration
  - Governance
- Exploits address aggregation and allocation
- Allows multiple metrics at different levels of the hierarchy



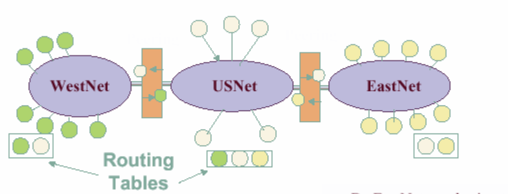
Two ways to interconnect IP Networks…

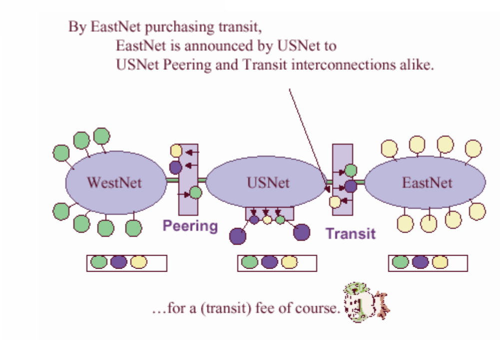
- Peering
  - The business relationship whereby ISPs reciprocally provide to each other connectivity to each others' transit customers
- Transit
  - The business relationship whereby one ISP provides (usually sells) access to all destinations in it's routing table

William B. Norton, "Internet Service Providers and Peering"

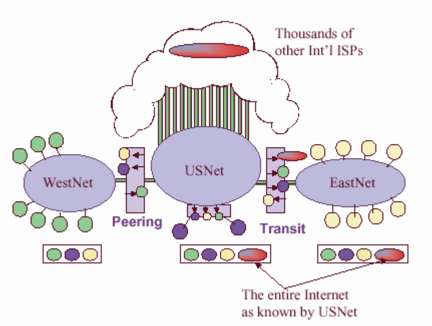
Peering and Transit

Figures from William B. Norton, "Internet Service Providers and Peering"





Benefits of Transit v/s Peering



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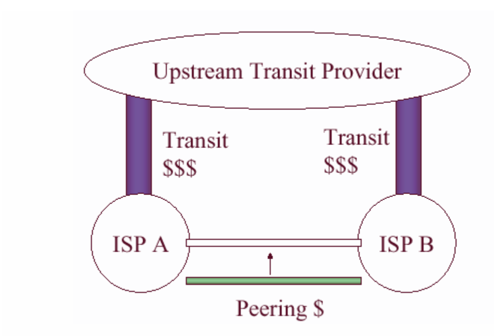
Moving from Transit to Peering



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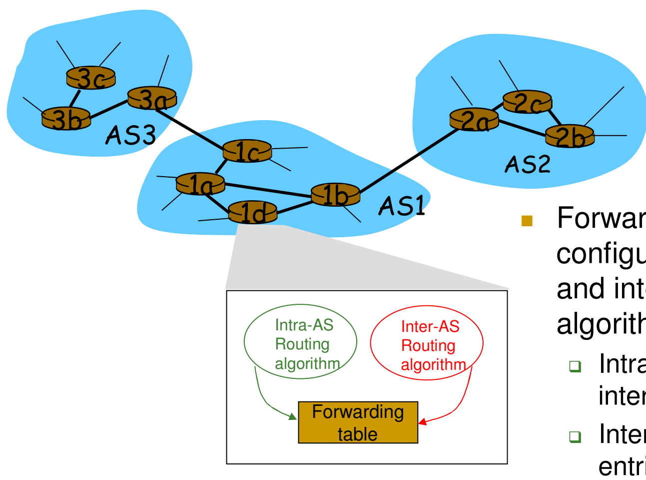
Interconnected ASes



- Forwarding table is configured by both intra- and inter-AS routing algorithm
  - Intra-AS sets entries for internal dests
  - Inter-AS & Intra-As sets entries for external dests

Inter-AS tasks

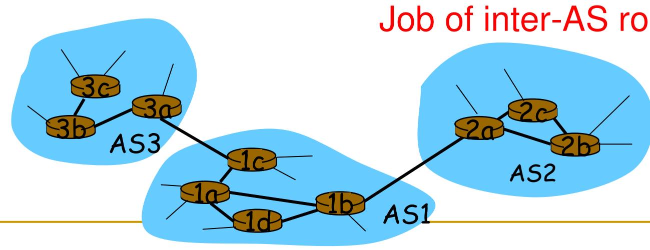
- Suppose router in AS1 receives datagram for which dest is outsid
  - Router shoul packet towar the gateway routers, but which one?

Q: With 200M hosts how is each host going to know which AS a host address belongs to?

AS1 needs:

1. to learn which dests are reachable through AS2 and through AS3
2. agate this ability info to all routers in AS1

Job of inter-AS routing!

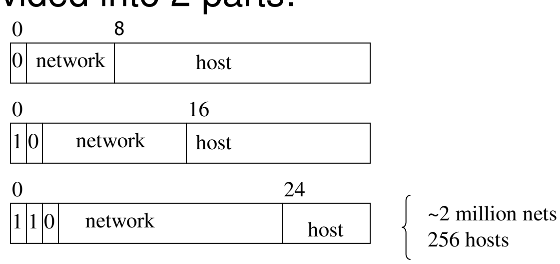


Addressing

- Every router must be able to forward based on *any* destination IP address
  - One strategy: Have a row for each address
    - There would be 10^8 rows!
  - Better strategy: Have a row for a range of addresses
    - If addresses are assigned at random that wouldn't work too well
      - MAC addresses
    - Addresses allocation is a big deal.

Class-base Addressing

- Addressing reflects internet hierarchy
  - 32 bits divided into 2 parts:
  - Class A
  - Class B
  - Class C



Class-based addresses did not scale well

Example: an organization initially needs 100 addresses

- Allocate it a class C address
- Organization grows to need 300 addresses
- Class B address is allocated. (~64K hosts)
- That's overkill -a huge waste
- Only about 8200 class B addresses!
- Artificial Address crises

IP addressing: CIDR

CIDR: Classless InterDomain Routing

- net portion of address of arbitrary length: subnet
- address format: a.b.c.d/x, where x is # bits in subnet portion of address

subnet part | host part

11001000 00010111 00010000 00000000

200.23.16.0/23

CIDR: Example

Suppose fifty computers in a network are assigned IP addresses 128.23.9.0 - 128.23.9.49

- They share the **prefix** 128.23.9
- Is this the **longest** prefix?
  - Range is 01111111 00001111 00001001 00000000 to
    01111111 00001111 00001001 00110001
  - How to write 01111111 00001111 00001001 00X?
  - Convention: 128.23.9/26
    - /26 is called the subnet mask
  - There are 32-26=6 bits for the 50 computers
    - $2^6 = 64$ addresses

CIDR: Example

- Example 128.5.10/23
  - Common prefix is 23 bits: 01000000 00000101 0000101
  - Number of addresses: $2^9 = 512$
- Prefix aggregation
  - Combine two address ranges
  - 128.5.10/24 and 128.5.11/24:
  - 01000000 00000101 00001010
    01000000 00000101 00001011

  gives 128.5.10/23
- Routers match to longest prefix

Assigning IP address (Ideally)

- A host gets its IP address from the IP address block of its organization
- An organization gets an IP address block from its ISP's address block
- An ISP gets its address block from its own provider OR from one of the 3 routing registries:
  - ARIN: American Registry for Internet Numbers
  - RIPE: Reseaux IP Europeens
  - APNIC: Asia Pacific Network Information Center
- Each Autonomous System (AS) is assigned a 16-bit number (65536 total)
  - Currently 10,000 AS's in use

Address Assignment: Example

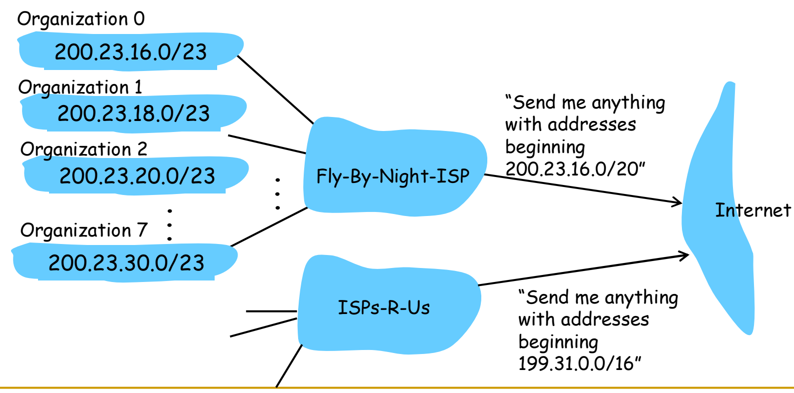
Q: How does *network* get subnet part of IP addr?

A: gets allocated portion of its provider ISP's address space

ISP's block	11001000 00010111 00010000	00000000	200.23.16.0/20
Organization 0	11001000 00010111 00010000	00000000	200.23.16.0/23
Organization 1	11001000 00010111 00010010	00000000	200.23.18.0/23
Organization 2	11001000 00010111 00010100	00000000	200.23.20.0/23
...	.....	....	....
Organization 7	11001000 00010111 00011110	00000000	200.23.30.0/23

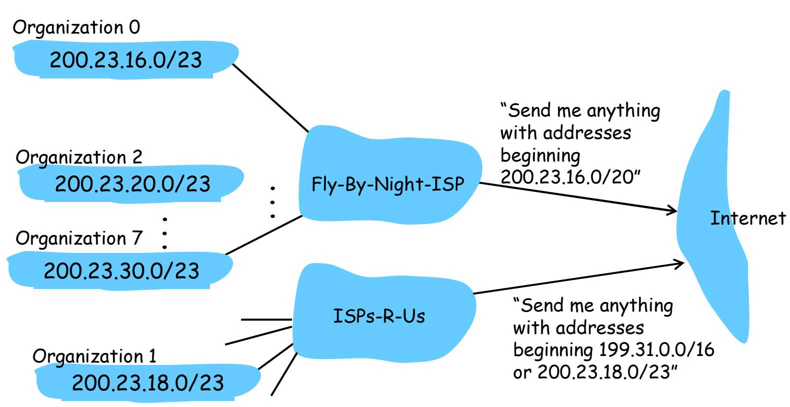
Hierarchical addressing: route aggregation

Hierarchical addressing allows efficient advertisement of routing information:



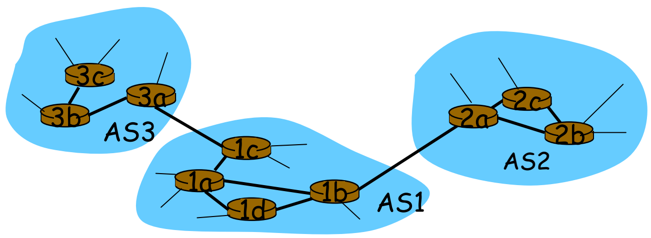
Hierarchical addressing: more specific routes

ISPs-R-Us has a more specific route to Organization 1



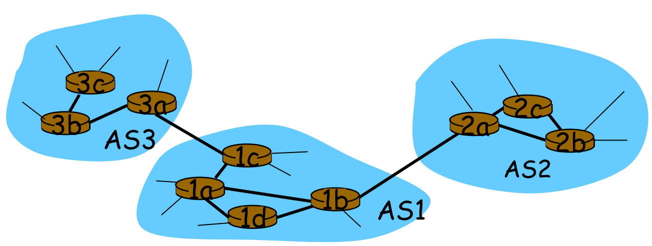
Example: Setting forwarding table in router 1d

- Suppose AS1 learns (via inter-AS protocol) that subnet *x* is reachable via AS3 (gateway 1c) but not via AS2.
- Inter-AS protocol propagates reachability info to all internal routers.
- Router 1d determines from intra-AS routing info that its interface *I* is on the least cost path to 1c.
- Puts in forwarding table entry *(x,I)*.



Example: Choosing among multiple ASes

- Now suppose AS1 learns from the inter-AS protocol that subnet *x* is reachable from AS3 *and* from AS2.
- To configure forwarding table, router 1d must determine towards which gateway it should forward packets for dest x.
- This is also the job of inter-AS routing protocol!



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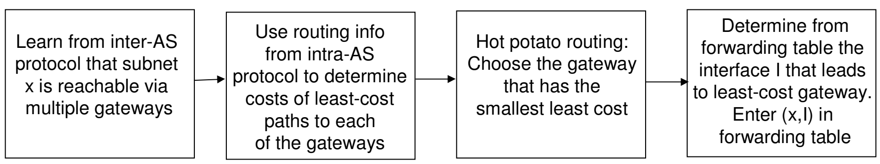
Hot potato routing: send packet towards closest of two routers.



Name of the Game: Reachability

- Interdomain routing is about implementing policies of reachabilty
  - Routing efficiency and performance is important, but not essential
- ISPs could be competitors and do not want to share internal network statistics such as load and topology
- Use Border Gateway Protocol (BGP)
  - Border routers communicate over TCP port 179
  - A Path Vector Protocol
    - Communicate entire paths: Route Advertisements
  - A Router Can be involved multiple BGP sessions

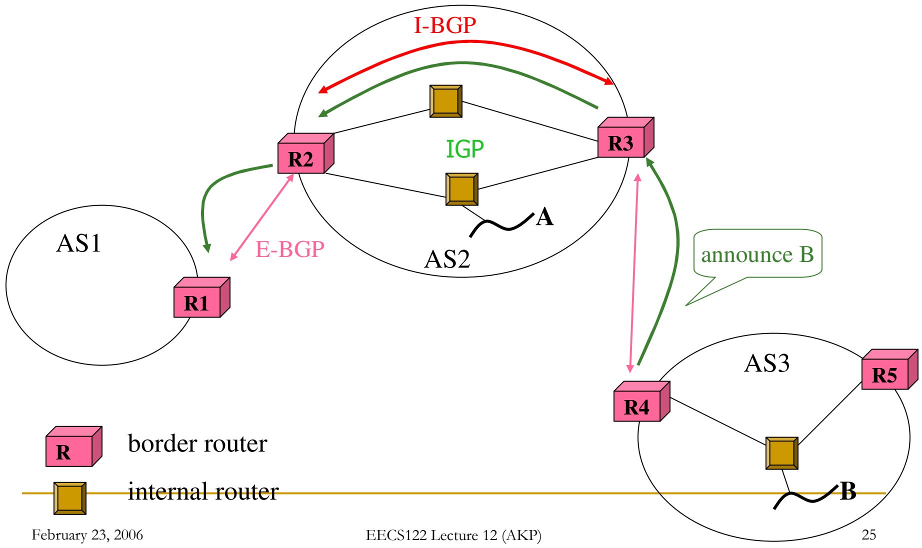
Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): *the* de facto standard
- BGP provides each AS a means to:
  1. Obtain subnet reachability information from neighboring ASs.
  2. Propagate reachability information to all AS-internal routers.
  3. Determine "good" routes to subnets based on reachability information and policy.
- allows subnet to advertise its existence to rest of Internet: *"I am here"*

BGP

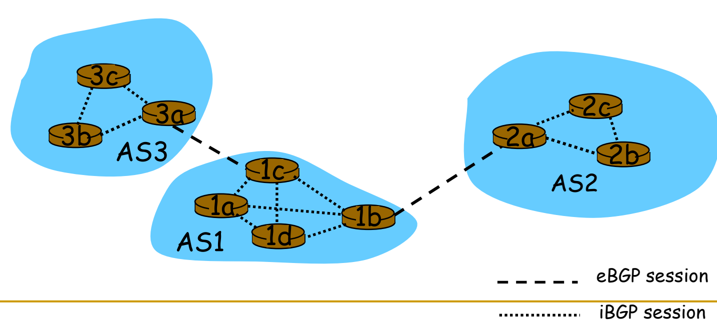
- Border Routers
  - from the same AS speak IBGP
  - from different AS's speak EBGP
- EBGP and IBGP are essentially the same protocol
  - IBGP can only propagate routes it has learned directly from its EBGP neighbors
  - All routers in the same AS form an IBGP mesh
  - Important to keep IBGP and EBGP in sync

I-BGP and E-BGP



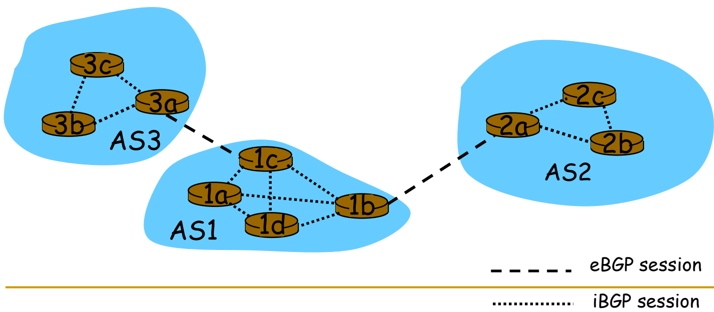
BGP basics

- Pairs of routers (BGP peers) exchange routing info over semi-permanent TCP connections: BGP sessions
  - BGP sessions need not correspond to physical links.
- When AS2 advertises a prefix to AS1, AS2 is *promising* it will forward any datagrams destined to that prefix towards the prefix.
  - AS2 can aggregate prefixes in its advertisement



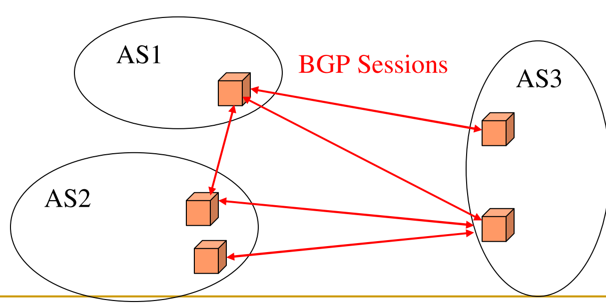
Distributing reachability info

- With eBGP session between 3a and 1c, AS3 sends prefix reachability info to AS1.
- 1c can then use iBGP to distribute this new prefix reach info to all routers in AS1
- 1b can then re-advertise new reachability info to AS2 over 1b-to-2a eBGP session
- When router learns of new prefix, creates entry for prefix in its forwarding table.



Sharing routes

- One router can participate in many BGP sessions.
- *Initially* … node advertises ALL routes it wants neighbor to know (could be > 50K routes)
- *Ongoing* … only inform neighbor of changes



BGP messages

- BGP messages exchanged using TCP.
- BGP messages:
  - OPEN: opens TCP connection to peer and authenticates sender
  - UPDATE: advertises new path (or withdraws old)
  - KEEPALIVE keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - NOTIFICATION: reports errors in previous msg; also used to close connection

Path attributes & BGP routes

- When advertising a prefix, advert includes BGP attributes.
  - prefix + attributes = “route”
- Two important attributes:
  - AS-PATH: contains ASs through which prefix advertisement has passed: AS 67 AS 17
  - NEXT-HOP: Indicates specific internal-AS router to next-hop AS. (There may be multiple links from current AS to next-hop-AS.)
- When gateway router receives route advertisement, uses import policy to accept/decline.

BGP: A Path-vector protocol

```
ner-routes>show ip bgp
BGP table version is 6128791, local router ID is 4.2.34.165
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal
Origin codes: i - IGP, e - EGP, ? - incomplete
   Network          Next Hop            Metric LocPrf Weight Path
* i3.0.0.0          4.0.6.142             1000     50      0 701 80 i
* i4.0.0.0          4.24.1.35                0    100      0 i
* i12.3.21.0/23     192.205.32.153           0     50      0 7018 4264 6468 ?
* e128.32.0.0/16    192.205.32.153           0     50      0 7018 4264 6468 25 e
```

- Every route advertisement contains the entire AS path
  - Generalization of distance vector
- Can implement policies for choosing best route
- Can detect loops at an AS level

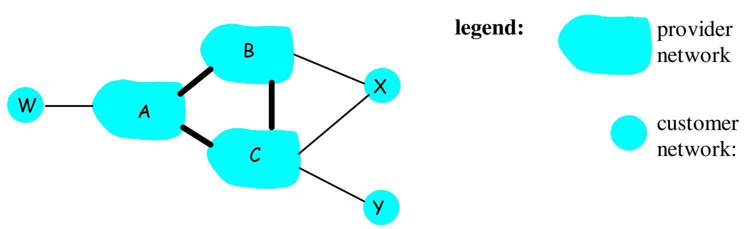
BGP Update Message

- Contains information about
  - New Routes
  - Withdrawn Routes: No longer valid
  - Path Attributes:
    - Path Weights
    - Multple Exit Discriminators
    - Local Preferences
    - Etc.
- Attribute information allows policies to be implemented

BGP route selection

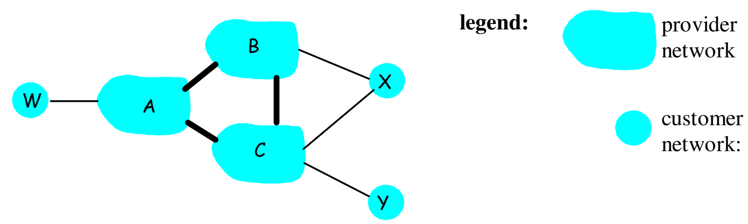
- Router may learn about more than 1 route to some prefix. Router must select route.
- Elimination rules:
  1. Local preference value attribute: policy decision
  2. Shortest AS-PATH
  3. Closest NEXT-HOP router: hot potato routing
  4. Additional criteria

BGP routing policy



- A,B,C are provider networks
- X,W,Y are customer (of provider networks)
- X is dual-homed: attached to two networks
  - X does not want to route from B via X to C
  - .. so X will not advertise to B a route to C

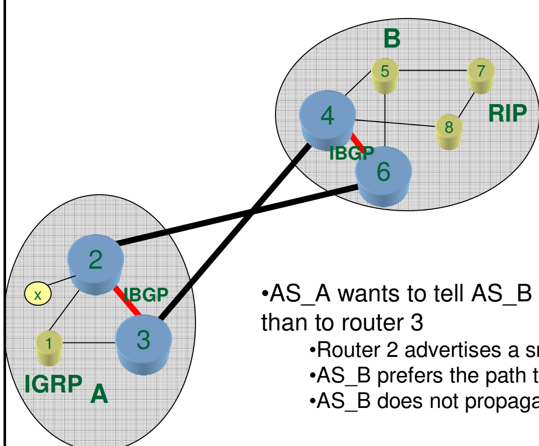
BGP routing policy (2)



- A advertises to B the path AW
- B advertises to X the path BAW
- Should B advertise to C the path BAW?
  - No way! B gets no "revenue" for routing CBAW since neither W nor C are B's customers
  - B wants to force C to route to w via A
  - B wants to route *only* to/from its customers!

Multiexit Discriminators (MEDs)

One AS influences the decisions of a neighboring AS

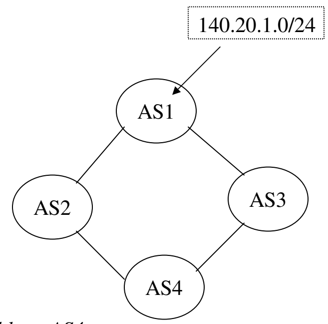


•AS_A wants to tell AS_B that network **x** is closer to router 2 than to router 3

- •Router 2 advertises a smaller MED value for **x** than Router 3
- •AS_B prefers the path to **x** that does not go through 6 and 3
- •AS_B does not propagate MEDS from AS_A any further

Attribute: Local Preference

- Used to indicate preference among multiple paths for the same prefix *anywhere* in the Internet.
- The higher the value the more preferred
- Exchanged between IBGP peers only. Local to the AS.
- Often used to select a specific exit point for a particular destination



BGP table at AS4:

Destination	AS Path	Local Pref
140.20.1.0/24	**AS3 AS1**	**300**
140.20.1.0/24	**AS2 AS1**	**100**

BGP Policies

- Multiple ways to implement a "policy"
  - Decide not propagate advertisements
    - I'm not carrying your traffic
  - Decide not to consider MEDs but use shortest hop
    - Hot potato routing
  - Prepend own AS# multiple times to fool BGP into not thinking AS further away
  - Many others…

BGP and Performance

- BGP isn't designed for policy routing not performance
  - Hot Potato routing is most common but suboptimal
  - Performance isn't the greatest
- 20% of internet paths inflated by at least 5 router hops
- Very susceptible to router misconfiguration
  - Blackholes: announce a route you cannot reach
    - October 1997 one router brought down the internet for 2 hours
  - Flood update messages (don't store routes, but keep asking your neighbors to clue you in). 3-5 million useless withdrawals!
- In principle, BGP could diverge
  - Various solutions proposed to limit the set of allowable policies
  - Focuses on avoiding "policy cycles"

Why different Intra- and Inter-AS routing ?

Policy:

- Inter-AS: admin wants control over how its traffic routed, who routes through its net.
- Intra-AS: single admin, so no policy decisions needed

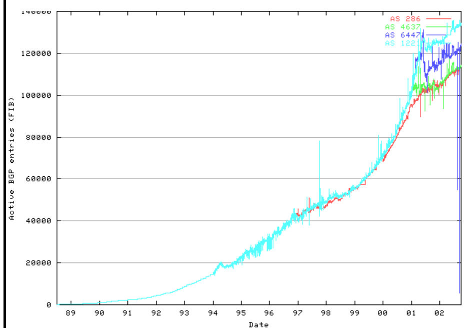
Scale:

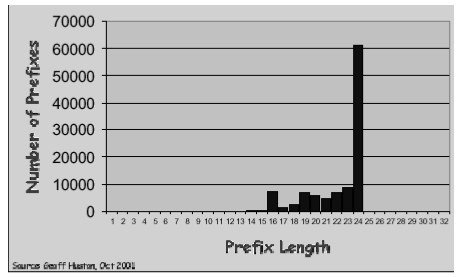
- hierarchical routing saves table size, reduced update traffic

Performance:

- Intra-AS: can focus on performance
- Inter-AS: policy may dominate over performance

BGP Routing Table Scaling





- Many small networks