Logistics

- Slides posted
  - Beginning of chapter ("preview")
  - After lecture (updated)
- HW4
- HW5 will be posted today – Chapter 5
- Evaluations are open: currently 49/300

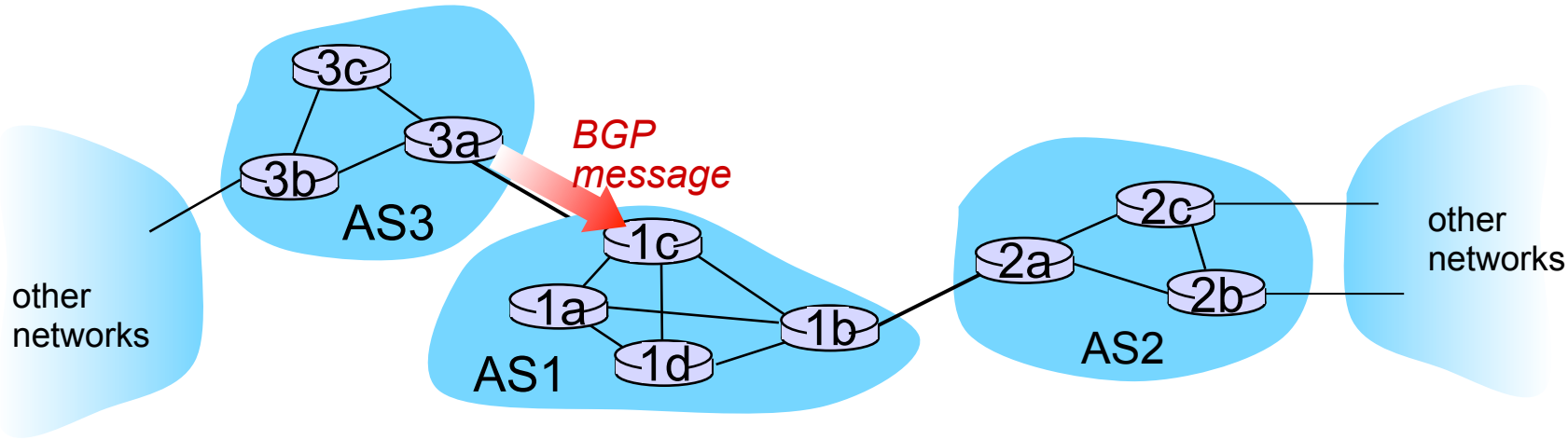
Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): *the* de facto inter-domain routing protocol
  - "glue that holds the Internet together"
- BGP provides each AS a means to:
  - eBGP: obtain subnet reachability information from neighboring ASs.
  - iBGP: propagate reachability information to all AS-internal routers.
  - determine "good" routes to other networks based on reachability information and policy.
- allows subnet to advertise its existence to rest of Internet: *"I am here"*

BGP basics

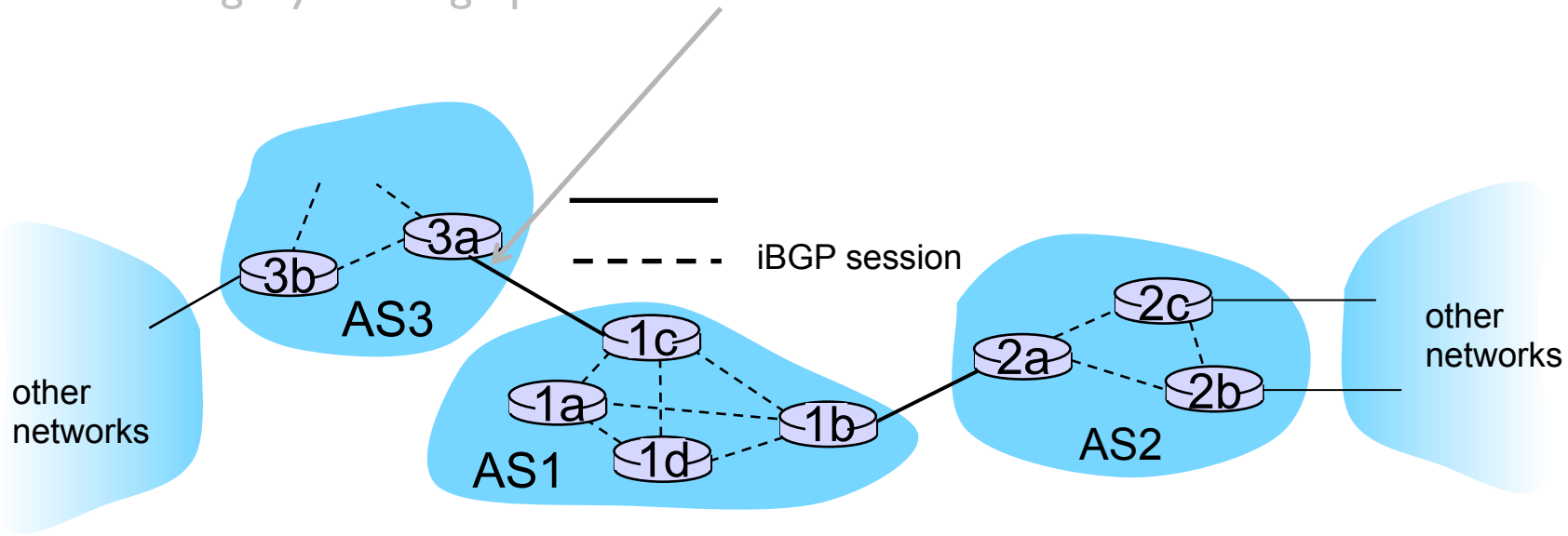
- BGP session: two BGP routers ("peers") exchange BGP messages:
  - advertising *paths* to different destination network prefixes ("path vector" protocol)
  - exchanged over semi-permanent TCP connections

- when AS3 advertises a prefix to AS1:
  - AS3 *promises* it will forward datagrams towards that prefix
  - AS3 can aggregate prefixes in its advertisement



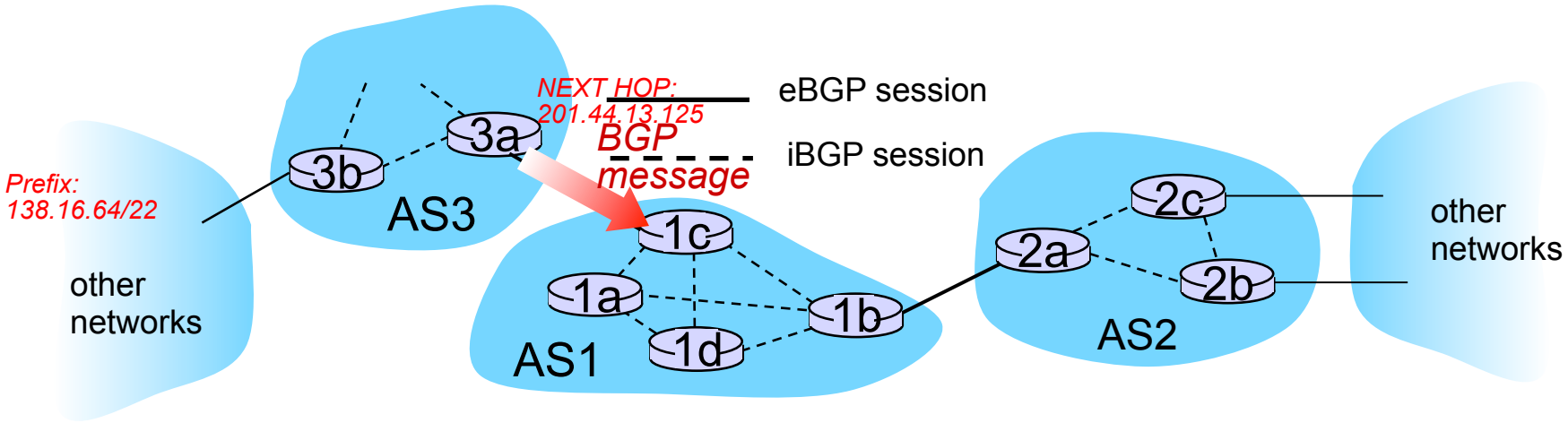
BGP basics: distributing path information

- using eBGP session between 3a and 1c, AS3 sends prefix reachability info to AS1.
  - 1c can then use iBGP to distribute new prefix info to all routers in AS1
  - 1b can then re-advertise new reachability info to AS2 over 1b-to-2a eBGP session
- when a router (e.g. 1d) learns of new prefix, it creates entry for prefix in its forwarding table
  - E.g. by looking up NEXT-HOP: 3a interface towards AS1



BGP basics: BGP Routes

- advertised prefix includes BGP attributes
  - prefix + attributes = "route"
  - Ex: Prefix:138.16.64/22; AS-PATH: AS3 AS131; NEXT-HOP: 201.44.13.125
- two important attributes:
  - AS-PATH: contains ASs through which prefix advertisement has passed: e.g., AS 67, AS 17
  - NEXT-HOP: indicates specific internal-AS router interface to next-hop AS.
    - The internal router interface to next hop AS (begins the AS path)
    - Link between inter-AS and intra-AS routing
    - E.g. NEXT-HOP for AS3 (advertised to 1a) is 3a interface towards AS1



BGP route selection

- gateway router receiving route advertisement uses import policy to accept/decline
  - e.g., never route through AS x
  - *policy-based* routing

- router may learn about more than 1 route to destination AS, selects route based on the following rules (applied sequentially):
  1. local preference value attribute: policy decision
  2. shortest AS-PATH
  3. closest NEXT-HOP router: hot potato routing
  4. additional criteria

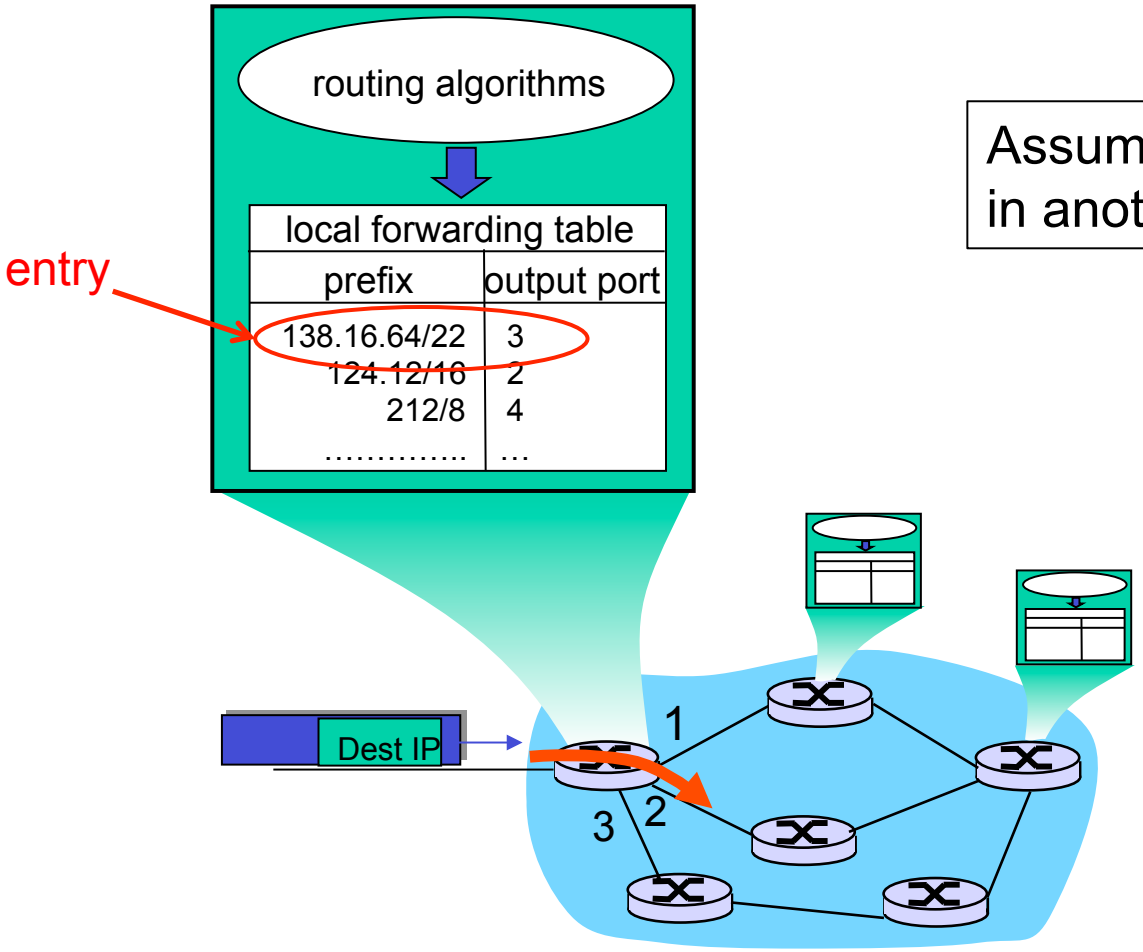
[BGP messages]

- BGP messages exchanged between peers over TCP connection
- 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

Putting it Altogether: *How Does an Entry Get Into a Router's Forwarding Table?*

- Ties together hierarchical routing (Section 4.5.3) with BGP (4.6.3) and OSPF (4.6.2).
- Provides review/overview of BGP!

How does entry get in forwarding table?



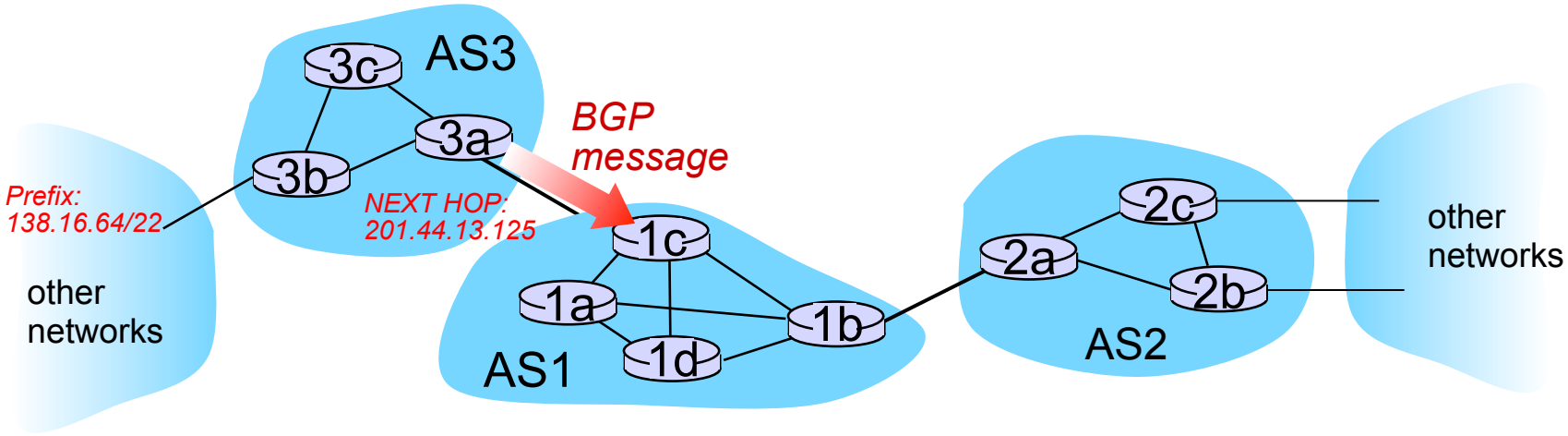
Assume prefix is in another AS.

How does entry get in forwarding table?

High-level overview

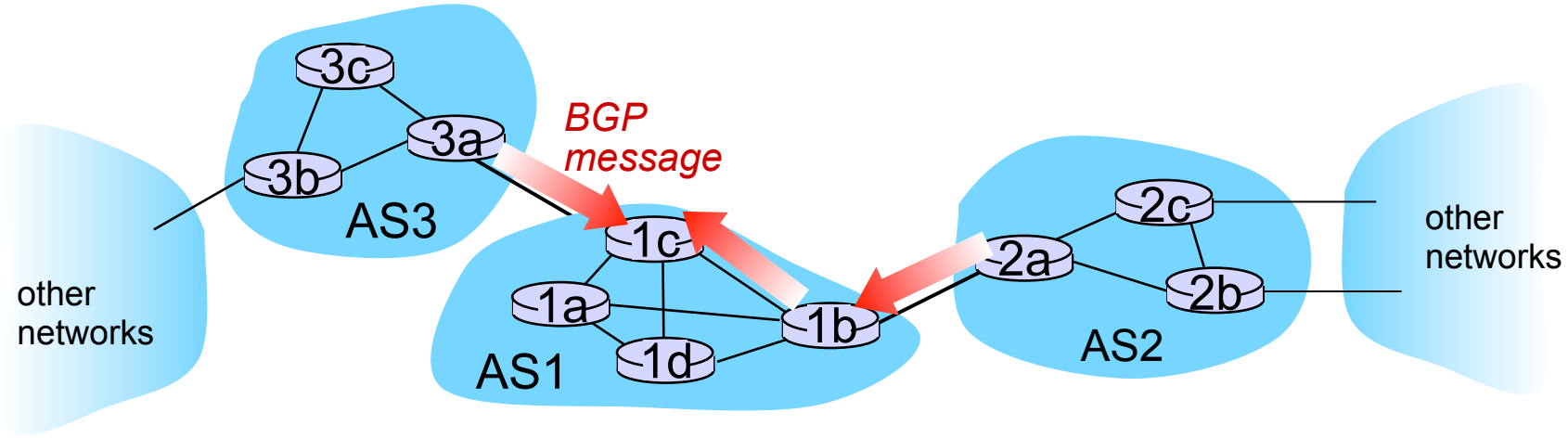
1. Router becomes aware of prefix
2. Router determines output port for prefix
3. Router enters prefix-port in forwarding table

Router becomes aware of prefix



- BGP message contains "routes"
- "route" is a prefix and attributes: AS-PATH, NEXT-HOP, …
- Example: route:
  - Prefix:138.16.64/22 ; AS-PATH: AS3 AS131 ; NEXT-HOP: 201.44.13.125

Router may receive multiple routes



- Router may receive multiple routes for same prefix
- Has to select one route

Select best BGP route to prefix

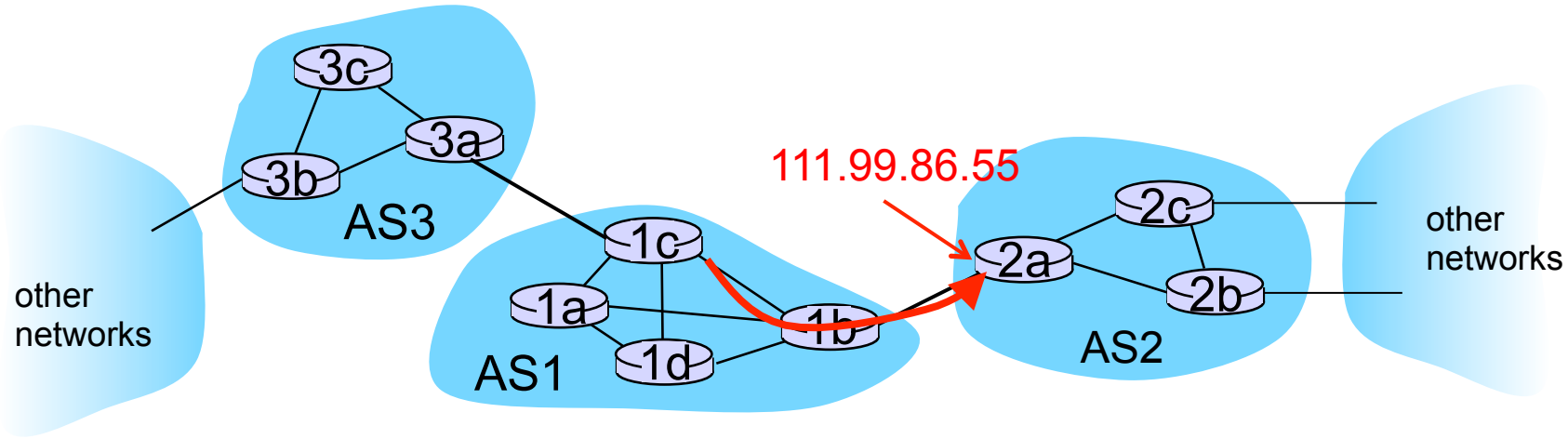
- Router selects route based on shortest AS-PATH

- Example:
  - AS2 AS17 to 138.16.64/22
  - AS3 AS131 AS201 to 138.16.64/22

- What if there is a tie? We'll come back to that!

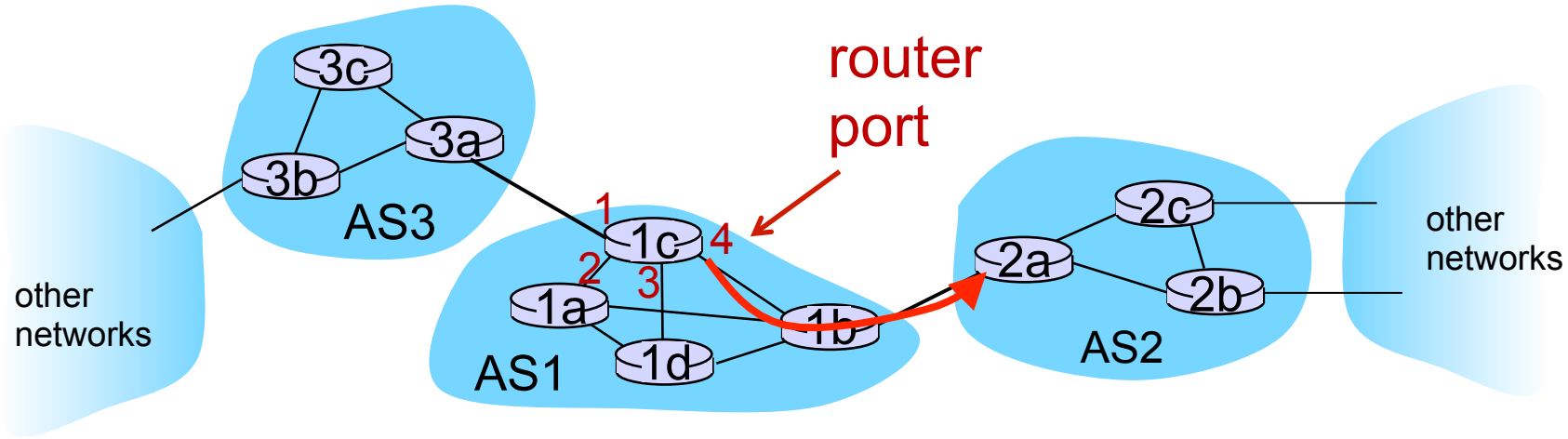
Find best intra-route to BGP route

- Use selected route's NEXT-HOP attribute
  - Route's NEXT-HOP attribute is the IP address of the router interface that begins the AS PATH.
- Example:
  - AS-PATH: AS2 AS17 ; NEXT-HOP: 111.99.86.55
- Router uses intra-domain routing (OSPF) to find shortest path from 1c to 111.99.86.55



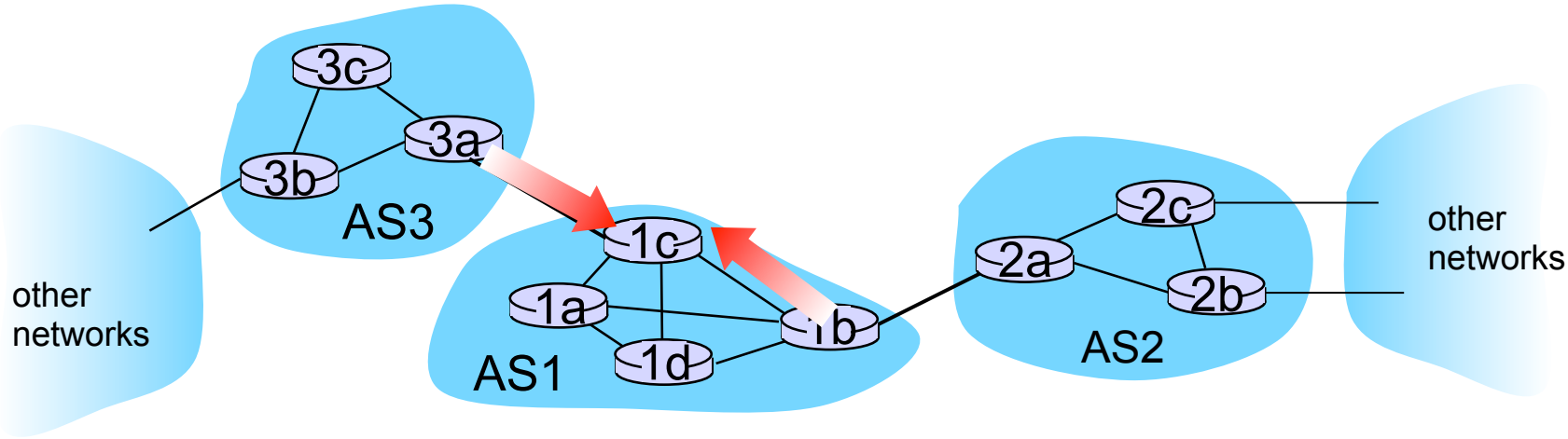
Router identifies port for route

- Identifies port along the OSPF shortest path
- Adds prefix-port entry to its forwarding table:
  - (138.16.64/22 , port 4)



Hot Potato Routing

- Suppose there are two or more best inter-routes.
- Then choose route with closest NEXT-HOP
  - Use intra-domain routing protocol (e.g. OSPF) to determine which gateway is closest
  - Q: From 1c, chose AS3 AS131 or AS2 AS17?
  - A: route AS3 AS131 since it is closer

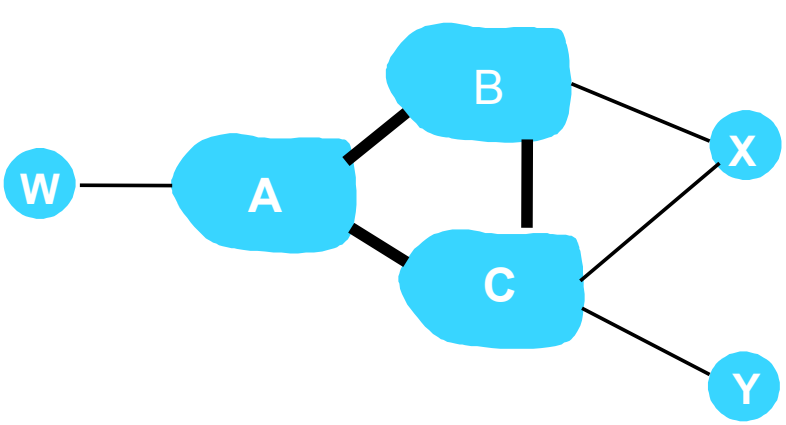


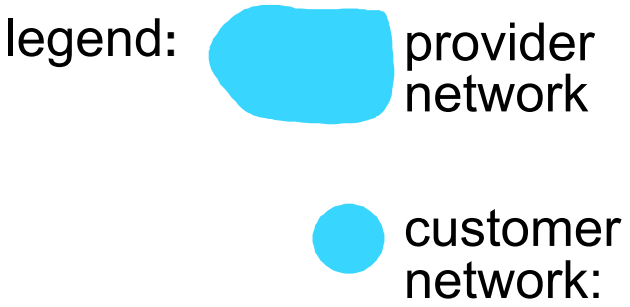
How does entry get in forwarding table?

Summary

1. Router becomes aware of prefix
   - via BGP route advertisements from other routers
2. Determine router output port for prefix
   - Use BGP route selection to find best inter-AS route
   - Use OSPF to find best intra-AS route leading to best inter-AS route (looking up NEXT-HOP of best route)
   - Router identifies router port for that best route
3. Enter prefix-port entry in forwarding table

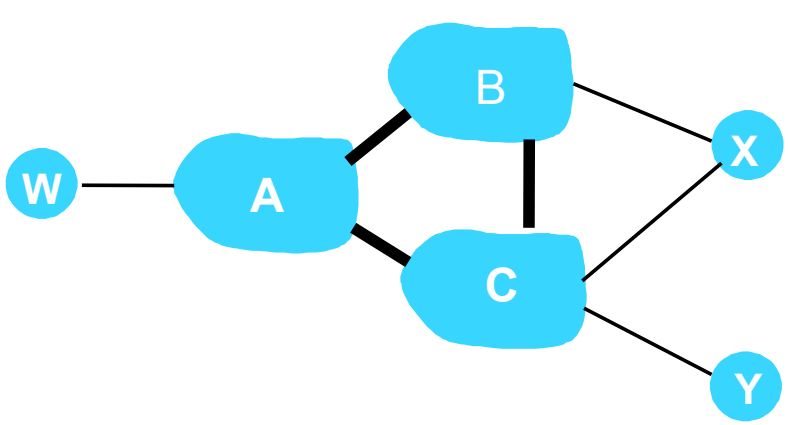
BGP routing policy (1)

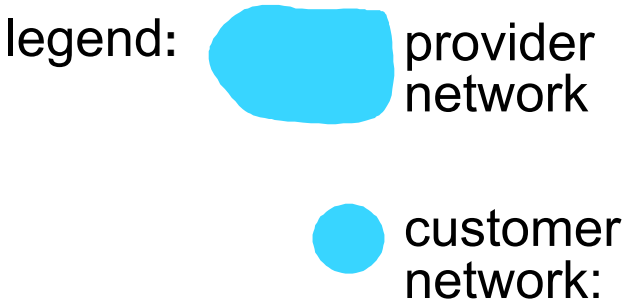




- A,B,C are *provider networks*
- X,W,Y are customer (of provider networks) or "stub networks"
- X is *dual-homed:* attached to two networks
  - X does not want to become "transit" network, e.g. route from B via X to C
  - .. so X will not advertise to B a route to C

BGP routing policy (2)





- A advertises path AW to B
- B advertises path BAW to X
- Should B advertise path BAW to C?
  - Probably not! 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!

Why different Intra-, 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