

# Chapter 5: outline

5.1 introduction

5.2 routing protocols

- link state
- distance vector

5.3 intra-AS routing in the Internet: OSPF

5.4 routing among the ISPs:  
BGP

5.5 The SDN control plane

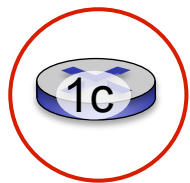
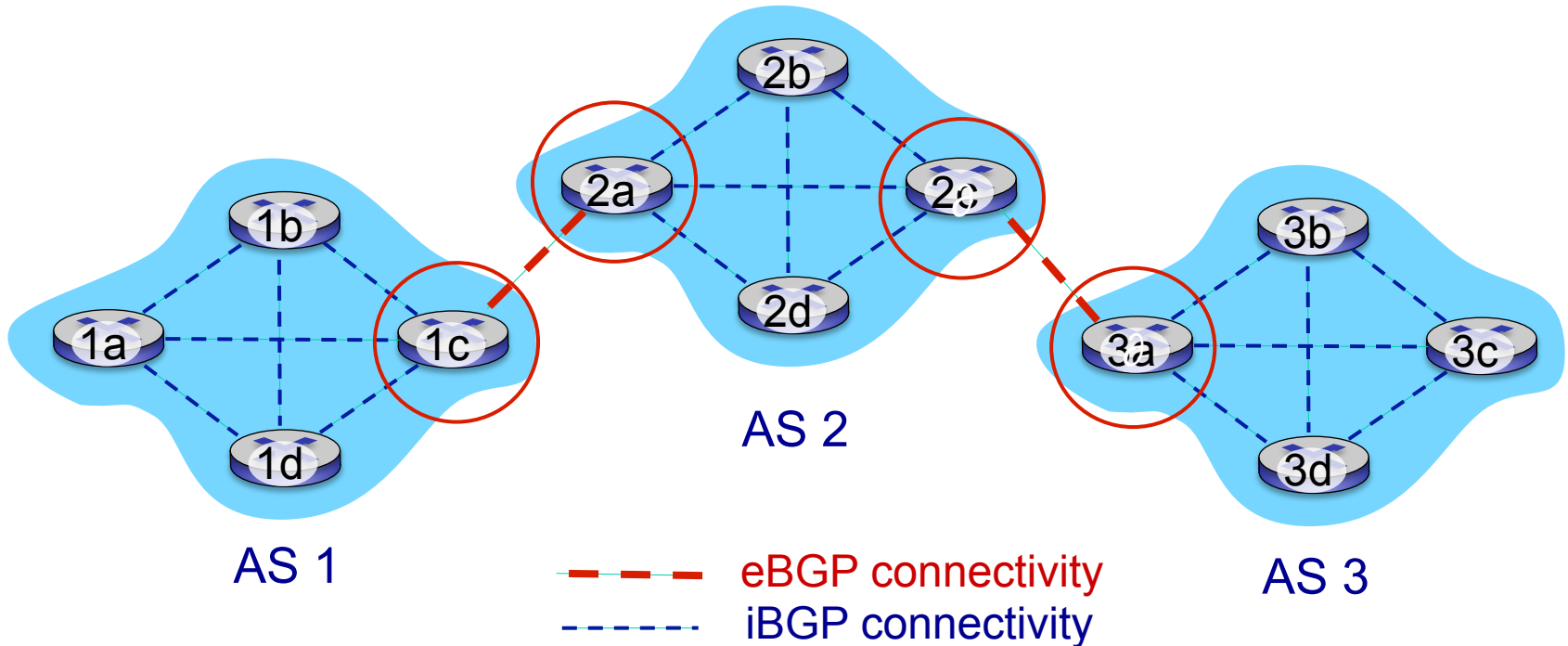
5.6 ICMP: The Internet  
Control Message  
Protocol

5.7 Network management  
and SNMP

# 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 ASes
  - **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”*

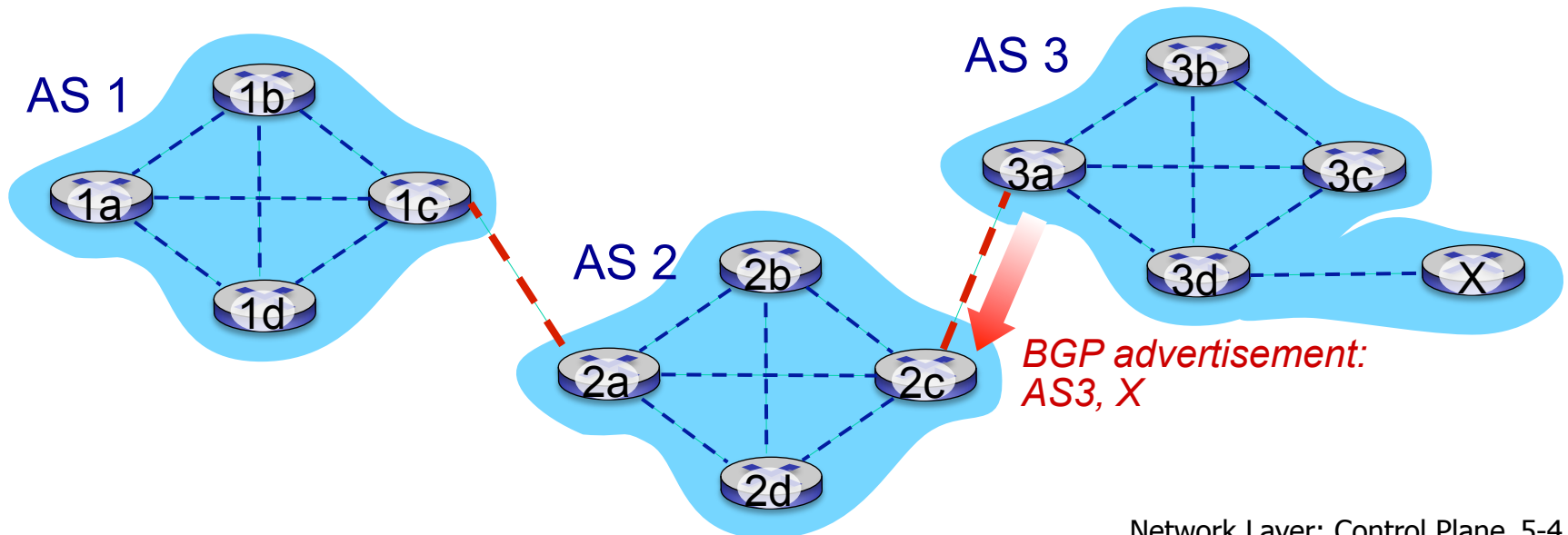
# eBGP, iBGP connections



gateway routers run both eBGP and iBGP protocols

# BGP basics

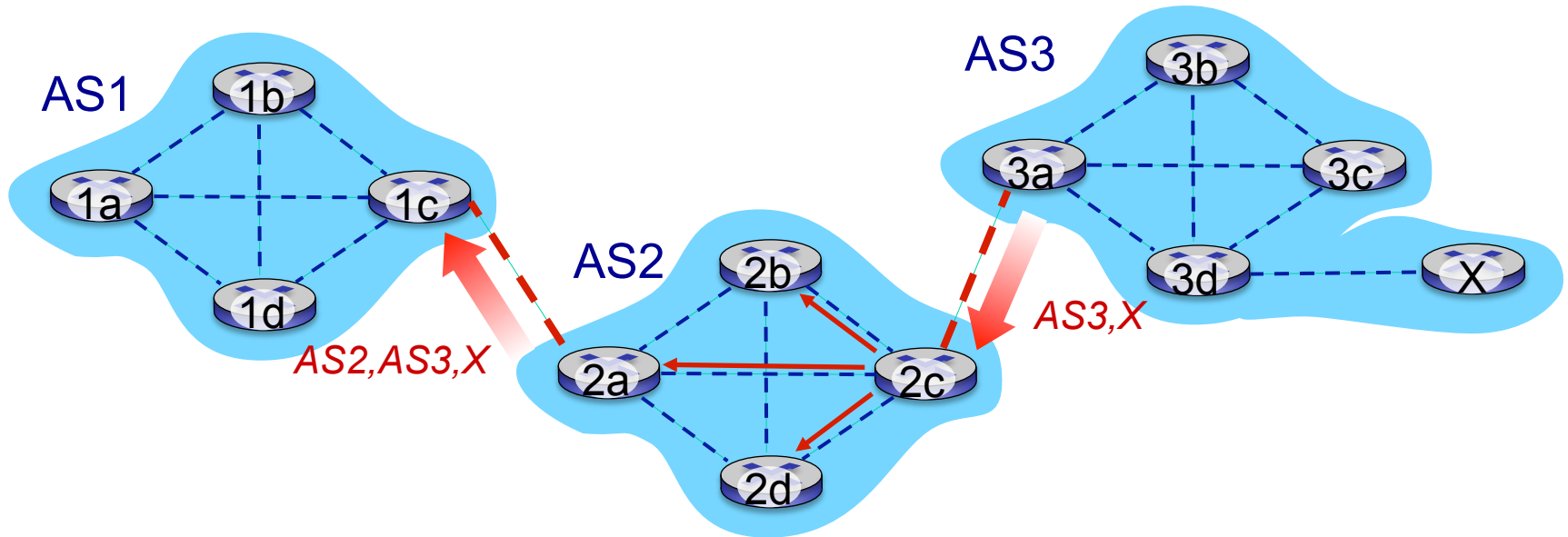
- **BGP session:** two BGP routers (“peers”) exchange BGP messages over semi-permanent TCP connection:
  - advertising *paths* to different destination network prefixes (BGP is a “path vector” protocol)
- when AS3 gateway router 3a advertises path **AS3,X** to AS2 gateway router 2c:
  - AS3 *promises* to AS2 it will forward datagrams towards X



# Path attributes and BGP routes

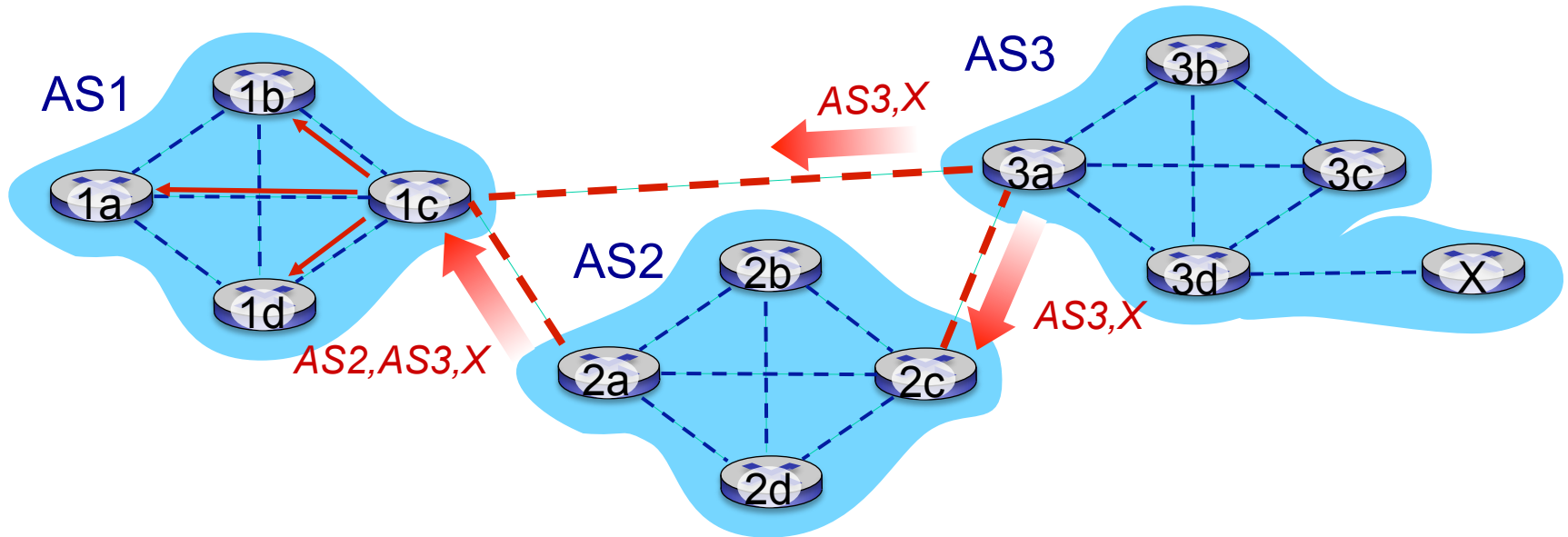
- advertised prefix includes BGP attributes
  - prefix + attributes = “route”
- two important attributes:
  - **AS-PATH**: list of ASes through which prefix advertisement has passed
  - **NEXT-HOP**: indicates specific internal-AS router to next-hop AS
- *Policy-based routing*:
  - gateway receiving route advertisement uses *import policy* to accept/decline path (e.g., never route through AS Y).
  - AS policy also determines whether to *advertise* path to other other neighboring ASes

# BGP path advertisement



- AS2 router 2c receives path advertisement **AS3,X** (via eBGP) from AS3 router 3a
- Based on AS2 policy, AS2 router 2c accepts path AS3,X, propagates (via iBGP) to all AS2 routers
- Based on AS2 policy, AS2 router 2a advertises (via eBGP) path **AS2, AS3, X** to AS1 router 1c

# BGP path advertisement



gateway router may learn about **multiple** paths to destination:

- AS1 gateway router 1c learns path *AS2,AS3,X* from 2a
- AS1 gateway router 1c learns path *AS3,X* from 3a
- Based on policy, AS1 gateway router 1c chooses path *AS3,X*, and *advertises path within AS1 via iBGP*

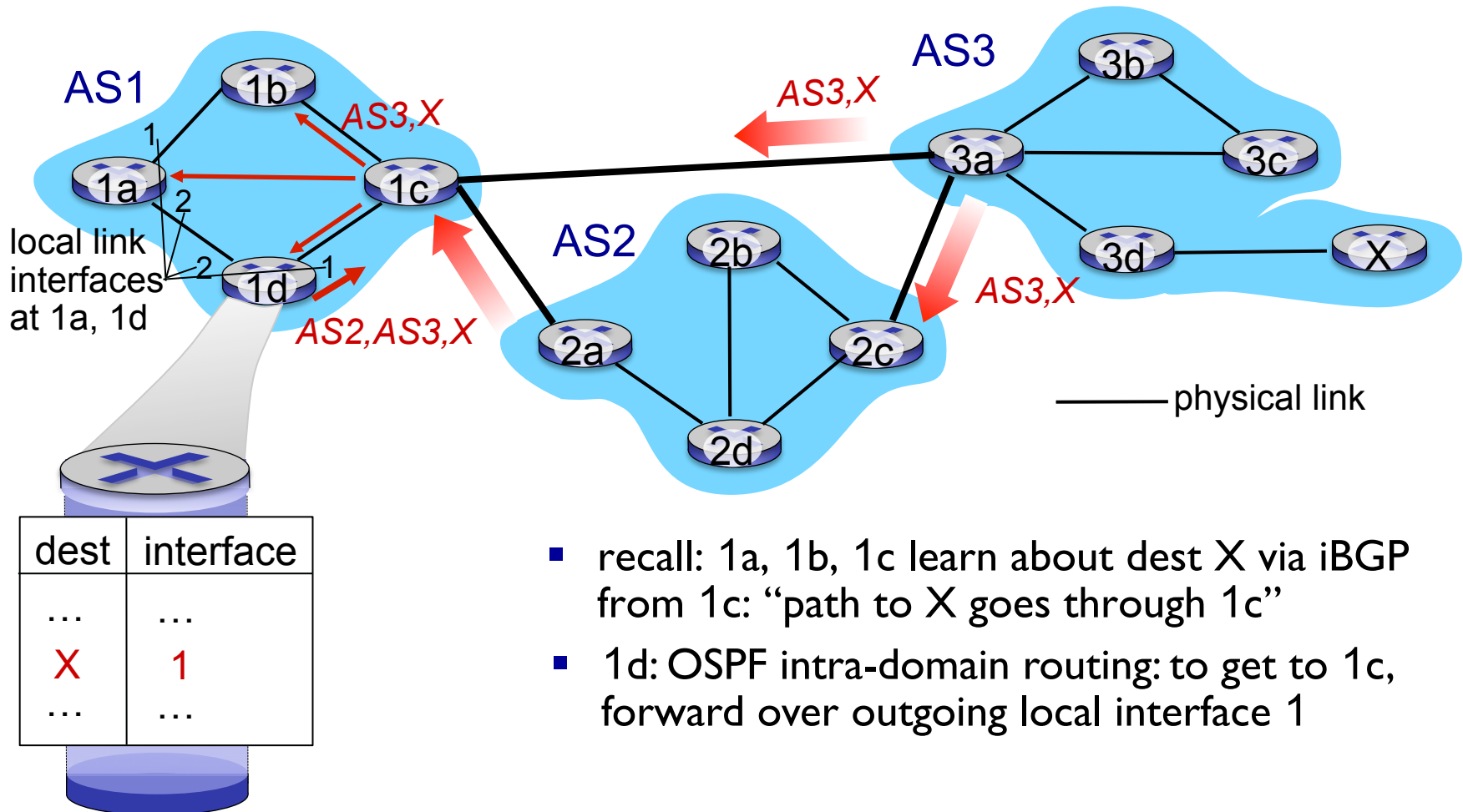
# BGP messages

- BGP messages exchanged between peers over TCP connection
- BGP messages:
  - **OPEN:** opens TCP connection to remote BGP peer and authenticates sending BGP peer
  - **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



# BGP, OSPF, forwarding table entries

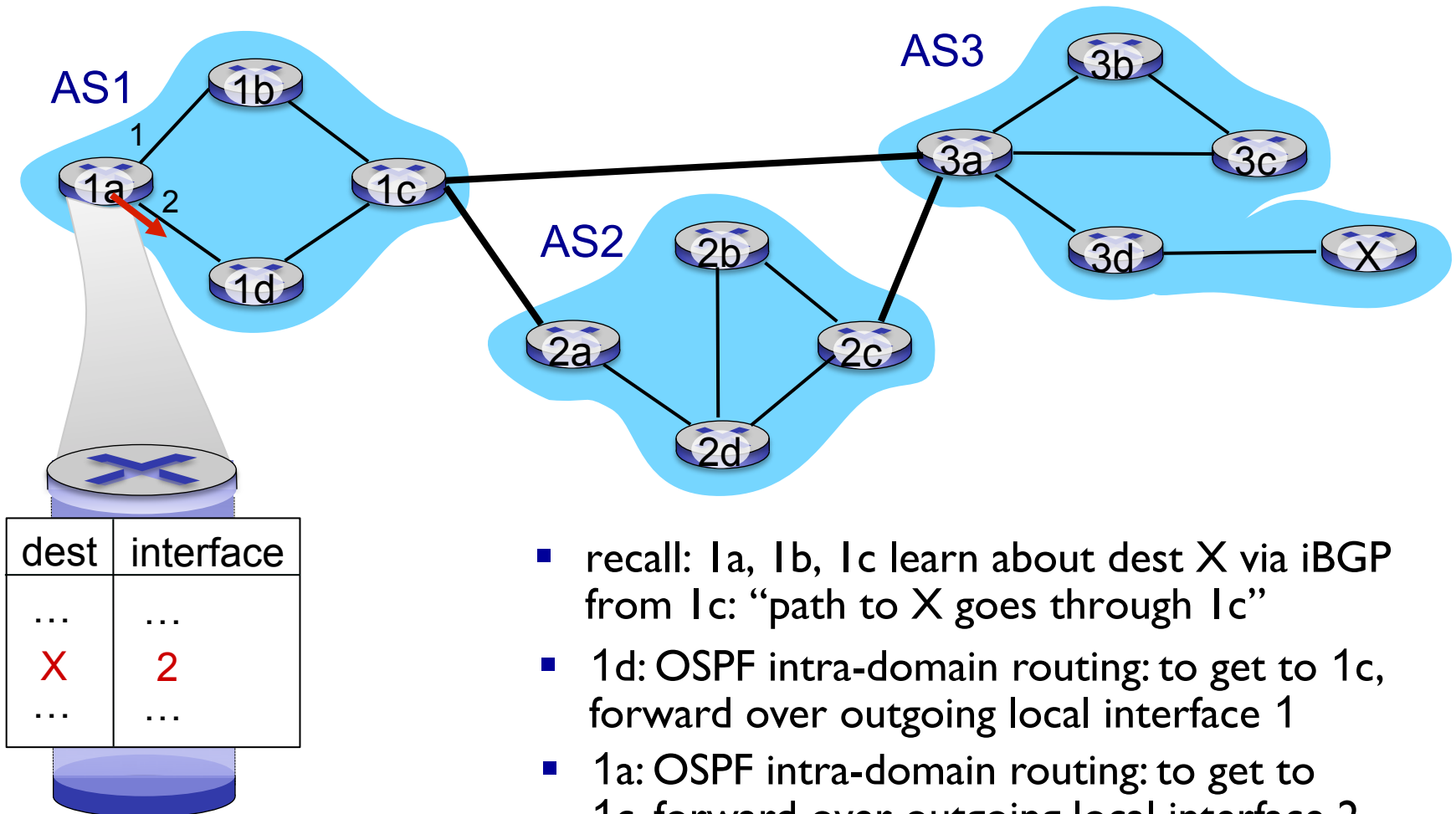
Q: how does router set forwarding table entry to distant prefix?



- recall: 1a, 1b, 1c learn about dest X via iBGP from 1c: “path to X goes through 1c”
- 1d: OSPF intra-domain routing: to get to 1c, forward over outgoing local interface 1

# BGP, OSPF, forwarding table entries

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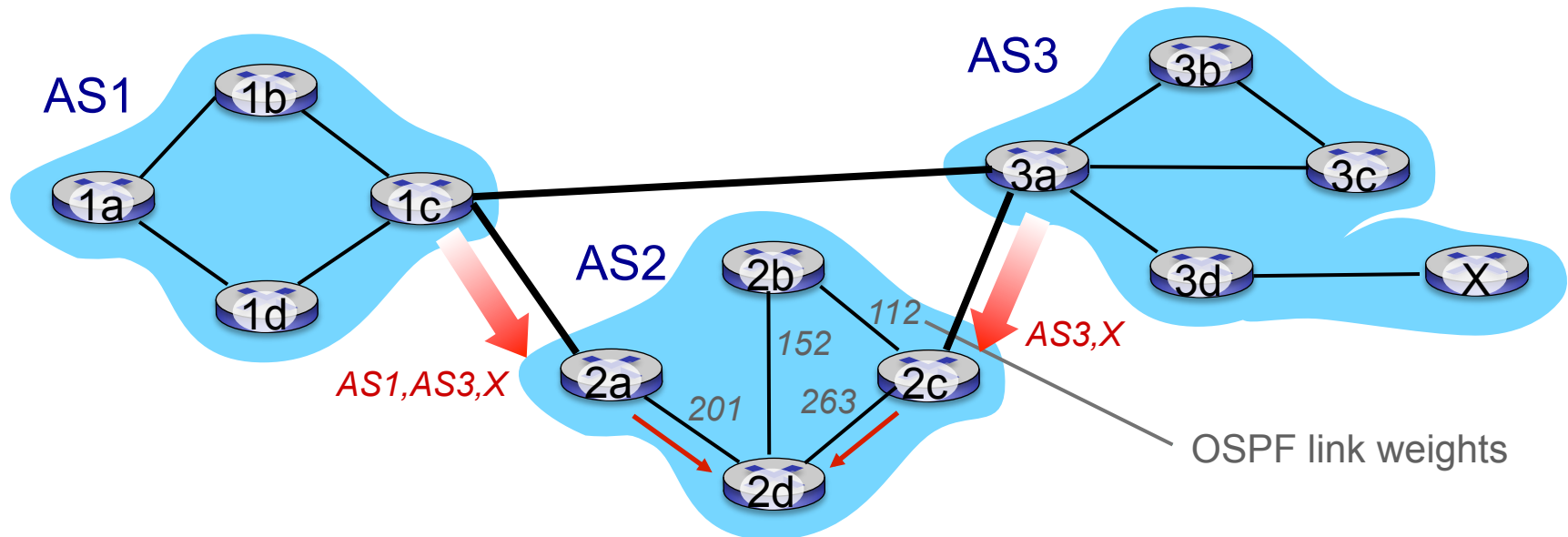


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- 1d: OSPF intra-domain routing: to get to 1c, forward over outgoing local interface 1
- 1a: OSPF intra-domain routing: to get to 1c, forward over outgoing local interface 2

# BGP route selection

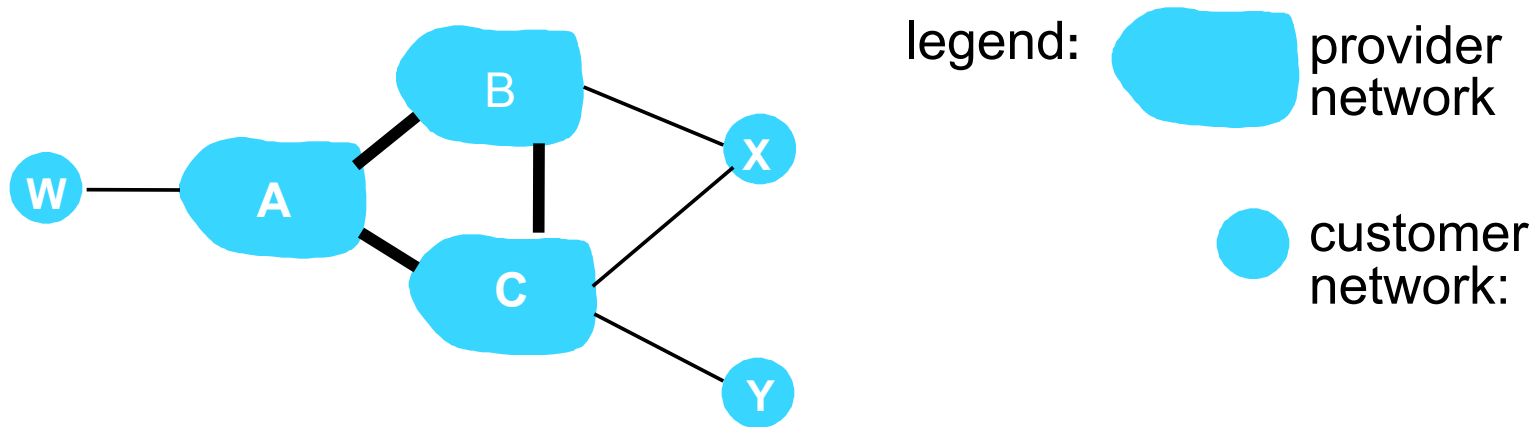
- router may learn about more than one route to destination AS, selects route based on:
  1. local preference value attribute: policy decision
  2. shortest AS-PATH
  3. closest NEXT-HOP router: hot potato routing
  4. additional criteria

# Hot Potato Routing



- 2d learns (via iBGP) it can route to X via 2a or 2c
- *hot potato routing*: choose local gateway that has least intra-domain cost (e.g., 2d chooses 2a, even though more AS hops to X): don't worry about inter-domain cost!

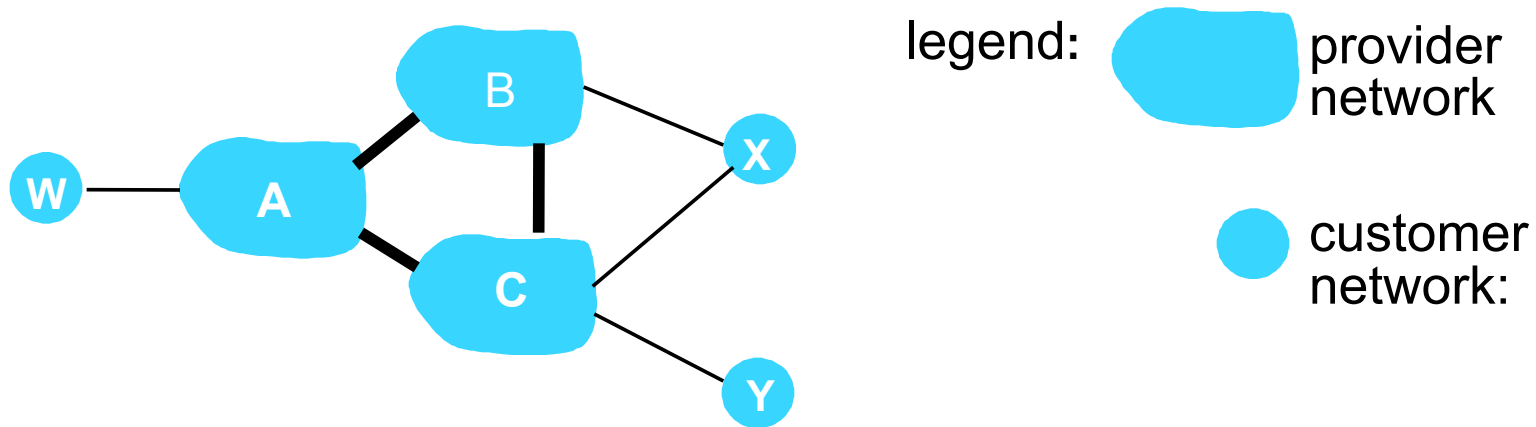
# BGP: achieving policy via advertisements



Suppose an ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs)

- A advertises path Aw to B and to C
- B *chooses not to advertise* BAw to C:
  - B gets no “revenue” for routing CBAw, since none of C,A,w are B’s customers
  - C does not learn about CBAw path
- C will route CAw (not using B) to get to w

# BGP: achieving policy via advertisements



Suppose an ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs)

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

# 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

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