National University of Computer & Emerging Sciences

CS 3001 - COMPUTER NETWORKS

Lecture 21

Chapter 5

2nd November, 2023

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Office Hours: 02:30 pm till 06:00 pm (Every Tuesday & Thursday)

Network layer: “control plane” roadmap

- introduction
- routing protocols
- intra-ISP routing: OSPF
- routing among ISPs: BGP
- SDN control plane
- Internet Control Message Protocol

- network management, configuration
  - SNMP
  - NETCONF/YANG

Making routing scalable

our routing study thus far - idealized

- all routers identical
- network “flat”

… not true in practice

scale: billions of destinations:

- can’t store all destinations in routing tables!
- routing table exchange would swamp links!

administrative autonomy:

- Internet: a network of networks
- each network admin may want to control routing in its own network

Internet approach to scalable routing

aggregate routers into regions known as "autonomous systems" (AS) (a.k.a. "domains")

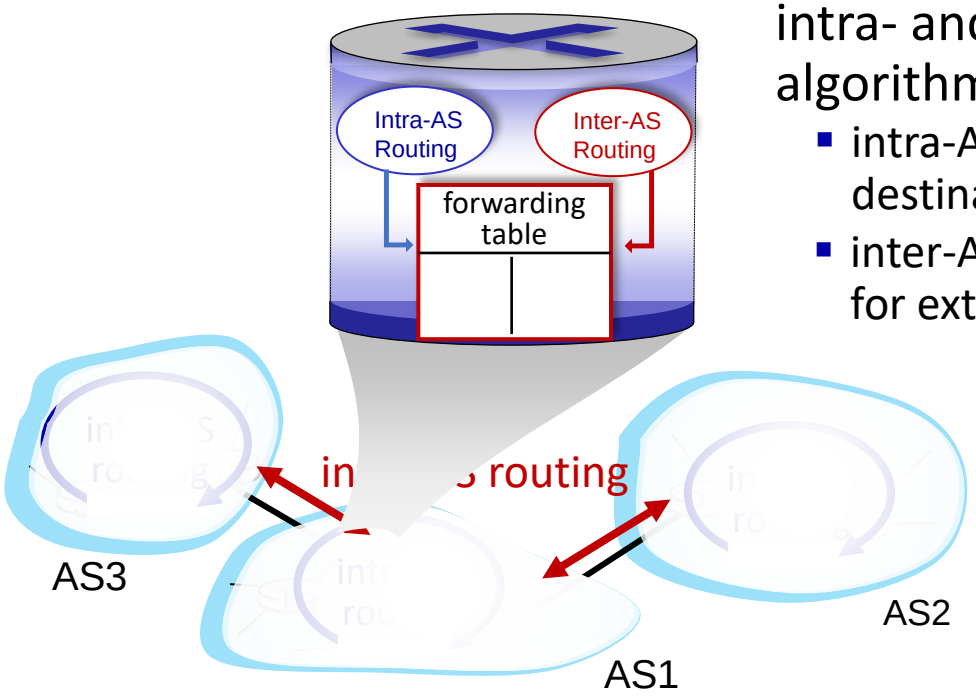
intra-AS (aka "intra-domain"):
routing among routers *within same AS ("network")*

- all routers in AS must run same intra-domain protocol
- routers in different AS can run different intra-domain routing protocols
- gateway router: at "edge" of its own AS, has link(s) to router(s) in other AS'es

inter-AS (aka "inter-domain"):
routing *among* AS'es

- gateways perform inter-domain routing (as well as intra-domain routing)

Interconnected ASes



forwarding table configured by intra- and inter-AS routing algorithms

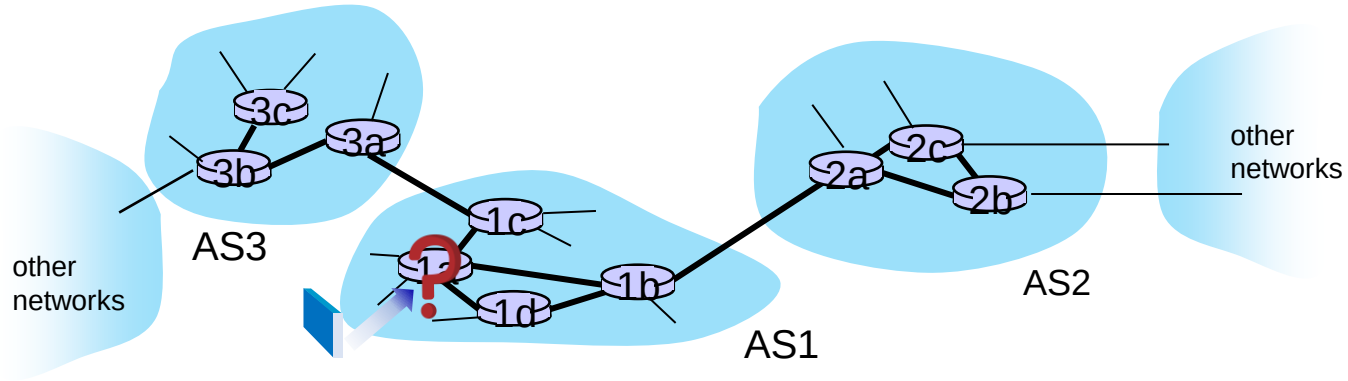
- intra-AS routing determine entries for destinations within AS
- inter-AS & intra-AS determine entries for external destinations

Inter-AS routing: a role in intradomain forwarding

- suppose router in AS1 receives datagram destined outside of AS1:
  - router should forward packet to gateway router in AS1, but which one?

AS1 inter-domain routing must:

1. learn which destinations reachable through AS2, which through AS3
2. propagate this reachability info to all routers in AS1



Intra-AS routing: routing within an AS (or Interior Gateway Protocols i.e. IGP)

most common intra-AS routing protocols:

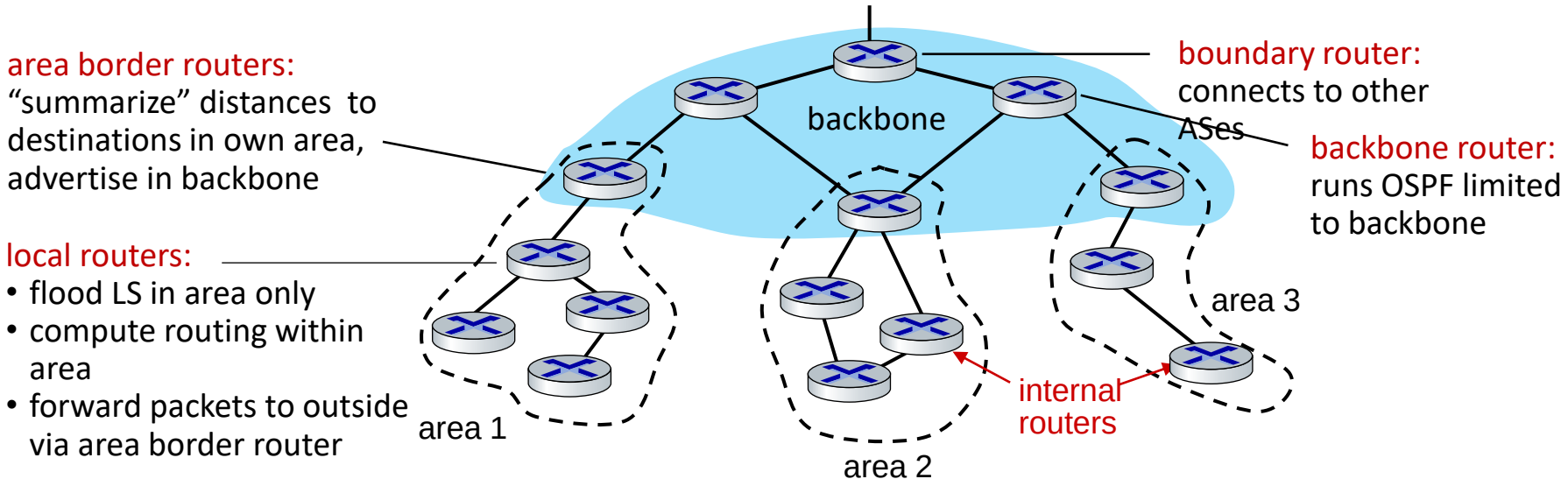
- RIP: Routing Information Protocol [RFC 1723]
  - classic DV: DVs exchanged every 30 secs
  - no longer widely used
- EIGRP: Enhanced Interior Gateway Routing Protocol
  - DV based
  - formerly Cisco-proprietary for decades (became open in 2013 [RFC 7868])
- OSPF: Open Shortest Path First [RFC 2328]
  - link-state routing
  - IS-IS protocol (ISO standard, not RFC standard) essentially same as OSPF

OSPF (Open Shortest Path First) routing

- "open": publicly available
- classic link-state
  - each router floods OSPF link-state advertisements every 30 minutes (directly over IP rather than using TCP/UDP upper layer field value = 89 for OSPF) to all other routers in entire AS
  - multiple link costs metrics possible: bandwidth, delay
  - each router has full topology, uses Dijkstra's algorithm to compute forwarding table
- *security:* all OSPF messages authenticated (to prevent malicious intrusion)

Hierarchical OSPF

- two-level hierarchy: local area, backbone.
  - link-state advertisements flooded only in area, or backbone
  - each node has detailed area topology; only knows direction to reach other destinations



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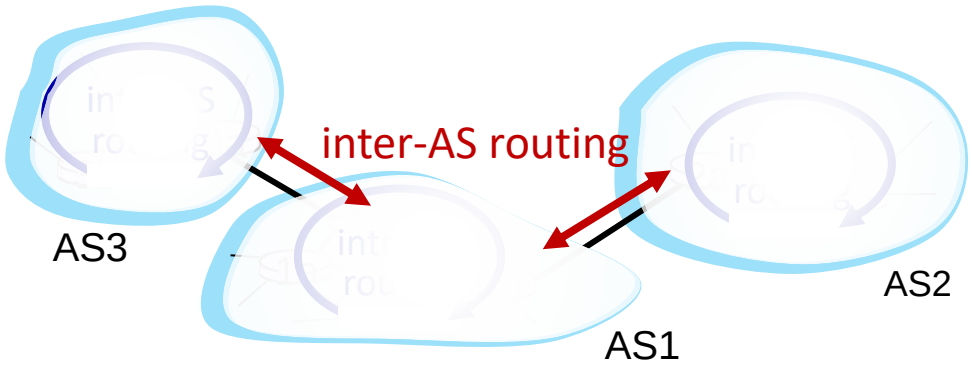
Interconnected ASes



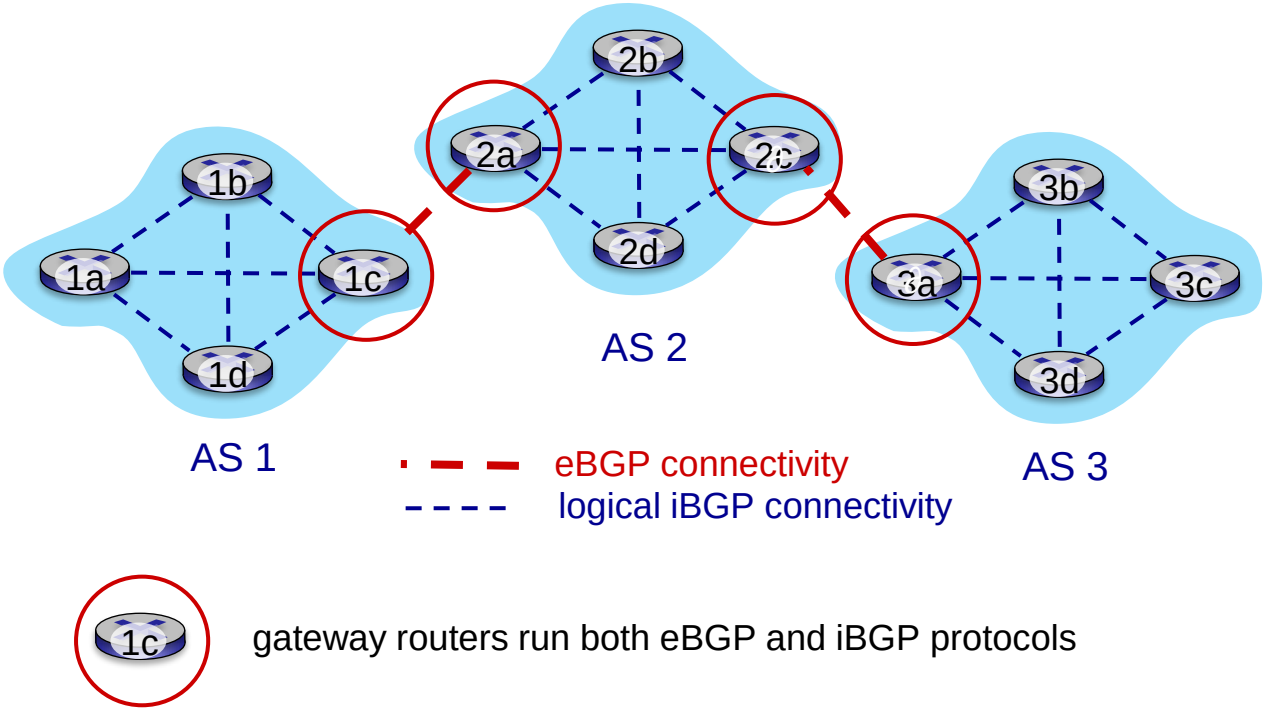
intra-AS (aka "intra-domain"): routing among routers *within same AS ("network")*

inter-AS (aka "inter-domain"): routing *among* AS'es

Internet inter-AS routing: BGP (The Three Napkin Protocol)

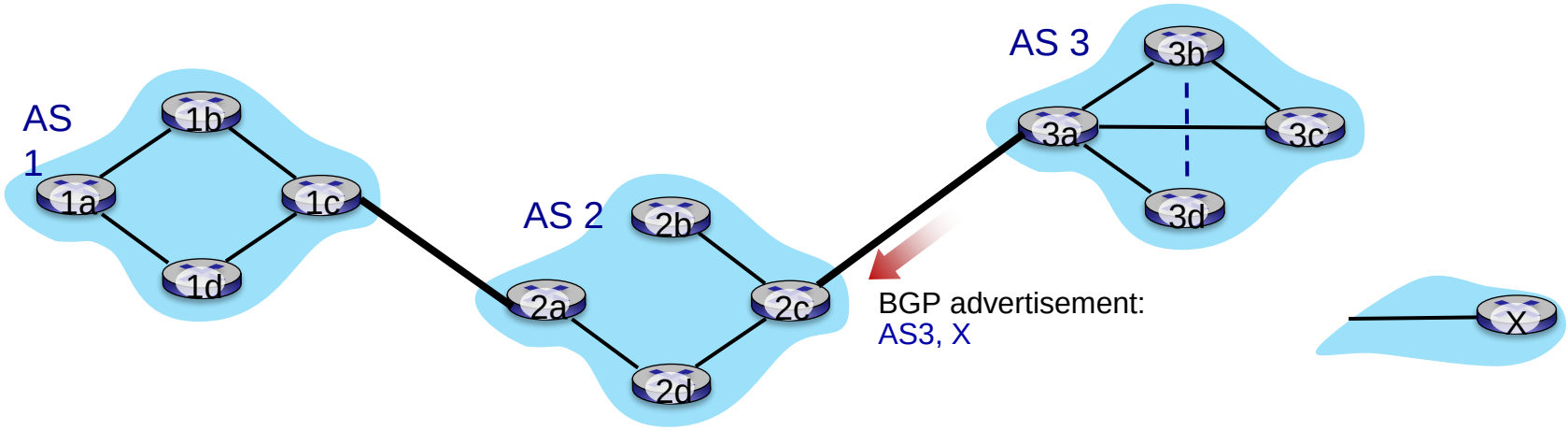
- BGP (Border Gateway Protocol): *the* de facto inter-domain routing protocol
  - "glue that holds the Internet together"
- allows subnet to advertise its existence, and the destinations it can reach, to rest of Internet: *"I am here, here is who I can reach, and how"*
- BGP provides each AS a means to:
  - obtain destination network reachability info from neighboring ASes (eBGP)
  - determine routes to other networks based on reachability information and *policy*
  - propagate reachability information to all AS-internal routers (iBGP)
  - advertise (to neighboring networks) destination reachability info

eBGP, iBGP connections



BGP basics

- BGP session: two BGP routers ("peers") exchange BGP messages over semi-permanent TCP connection (using port 179, semi-permanent means it is not permanently established i.e., it is changeable, but stay connected most of them time.):
  - advertising *paths* to different destination network prefixes (BGP is a "path vector" protocol: a path vector protocol is a network routing protocol which maintains the path information that gets updated dynamically)
- when AS3 gateway 3a advertises path AS3,X to AS2 gateway 2c:
  - AS3 *promises* to AS2 it will forward datagrams towards X



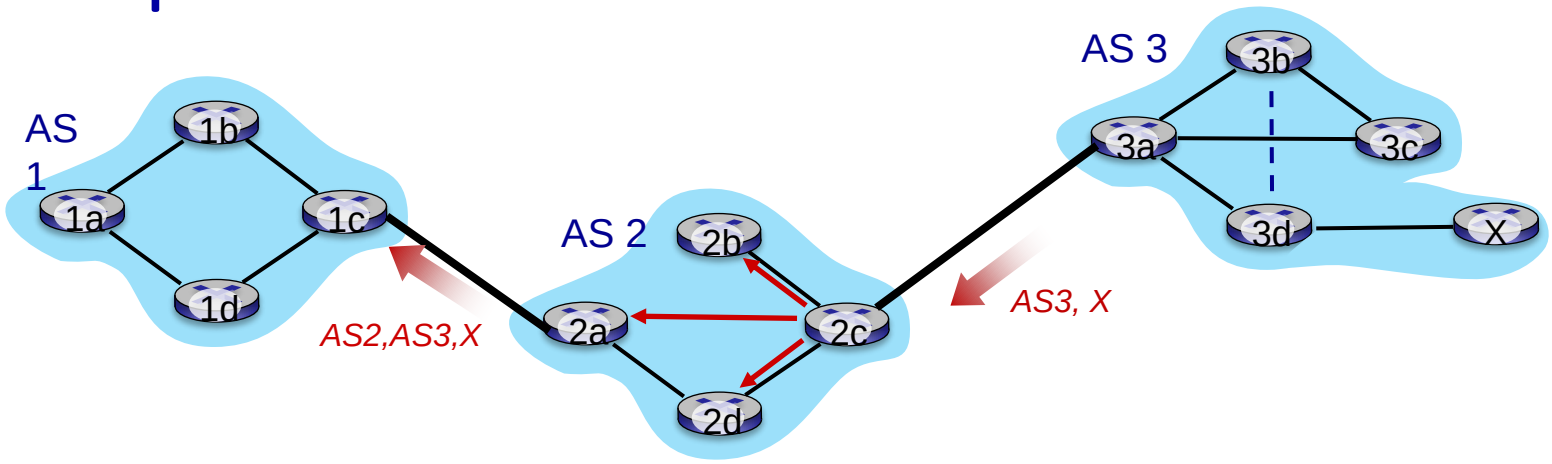
BGP protocol messages

- BGP messages exchanged between peers over TCP connection
- BGP messages [RFC 4371]:
  - 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

Path attributes and BGP routes

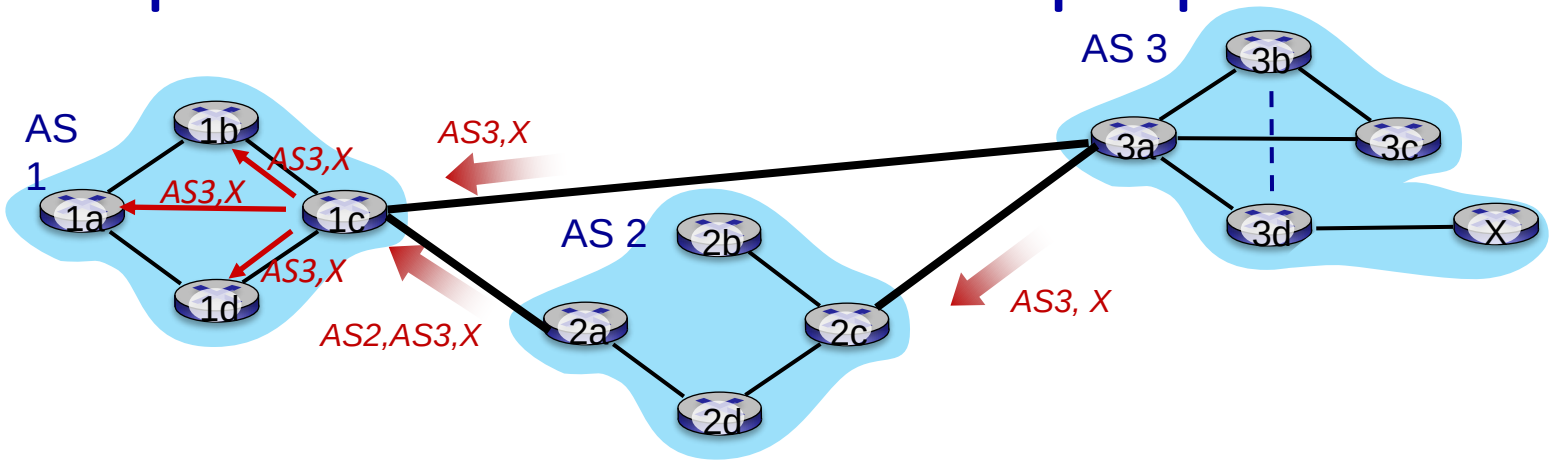
- BGP advertised route: prefix + attributes
  - prefix: destination being advertised
  - two important attributes:
    - AS-PATH: list of ASes through which prefix advertisement has passed
    - NEXT-HOP: indicates specific internal-AS router to next-hop AS
- policy-based routing:
  - gateway receiving 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

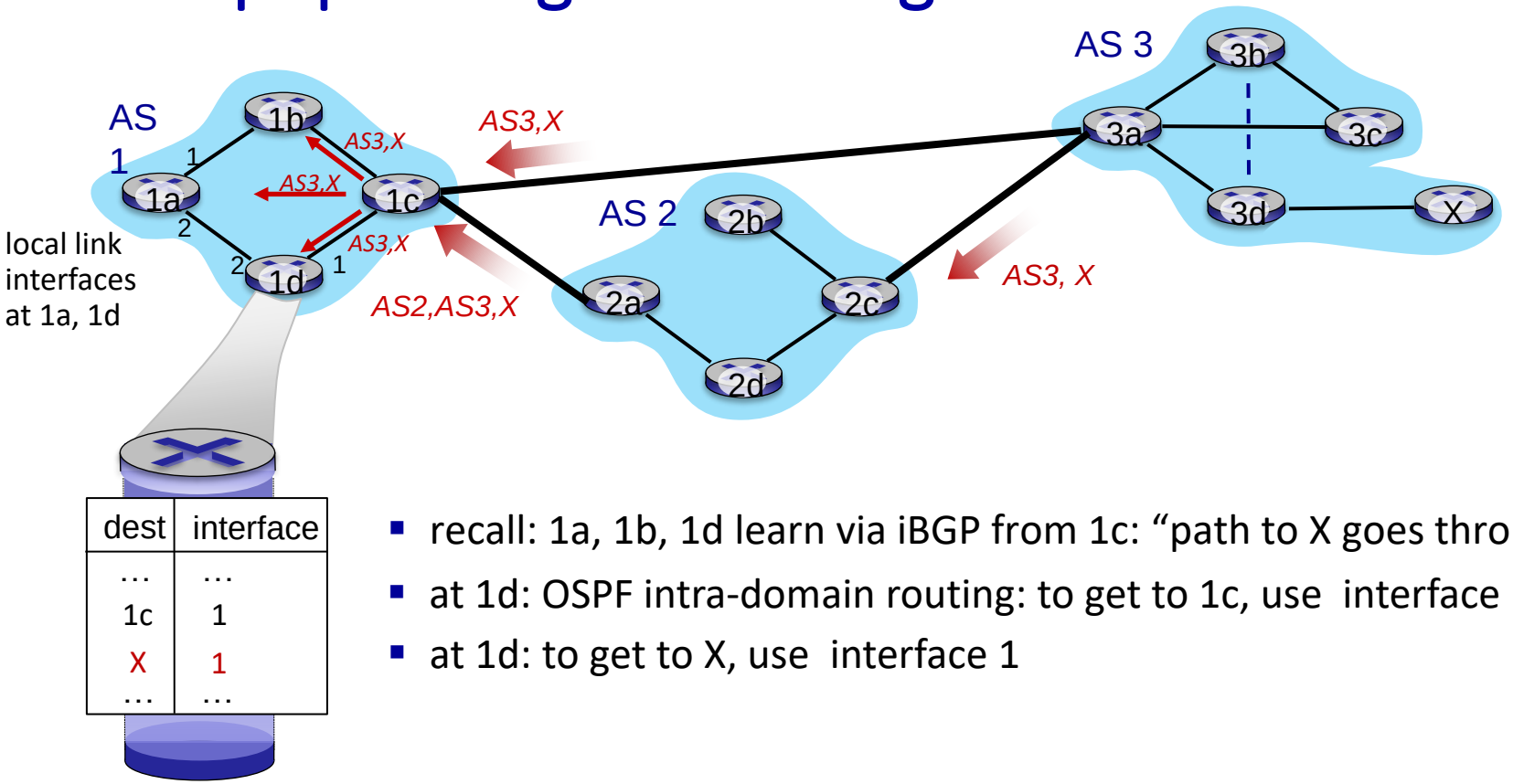
BGP path advertisement: multiple paths



gateway router may learn about multiple paths to destination:

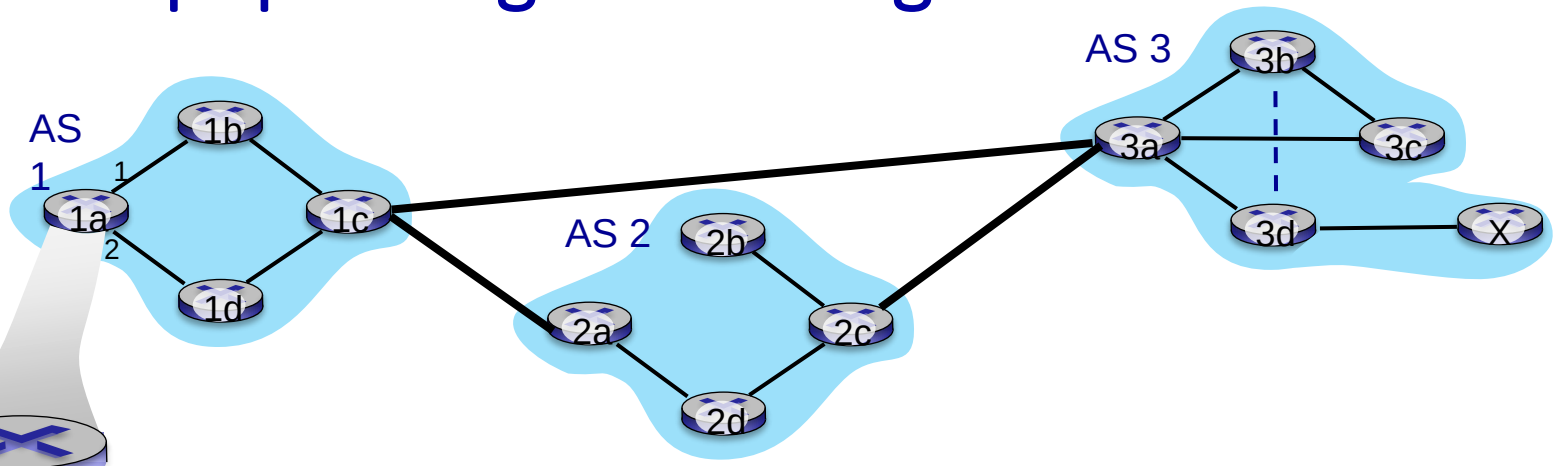
- AS1 gateway router 1c learns path *AS2,AS3,X* from 2a
- AS1 gateway router 1c learns path *AS3,X* from 3a
- based on *policy,* AS1 gateway router 1c chooses path *AS3,X* and advertises path within AS1 via iBGP

BGP: populating forwarding tables



- recall: 1a, 1b, 1d learn via iBGP from 1c: “path to X goes through 1c”
- at 1d: OSPF intra-domain routing: to get to 1c, use interface 1
- at 1d: to get to X, use interface 1

BGP: populating forwarding tables



dest	interface
…	…
1c	2
X	2
…	…

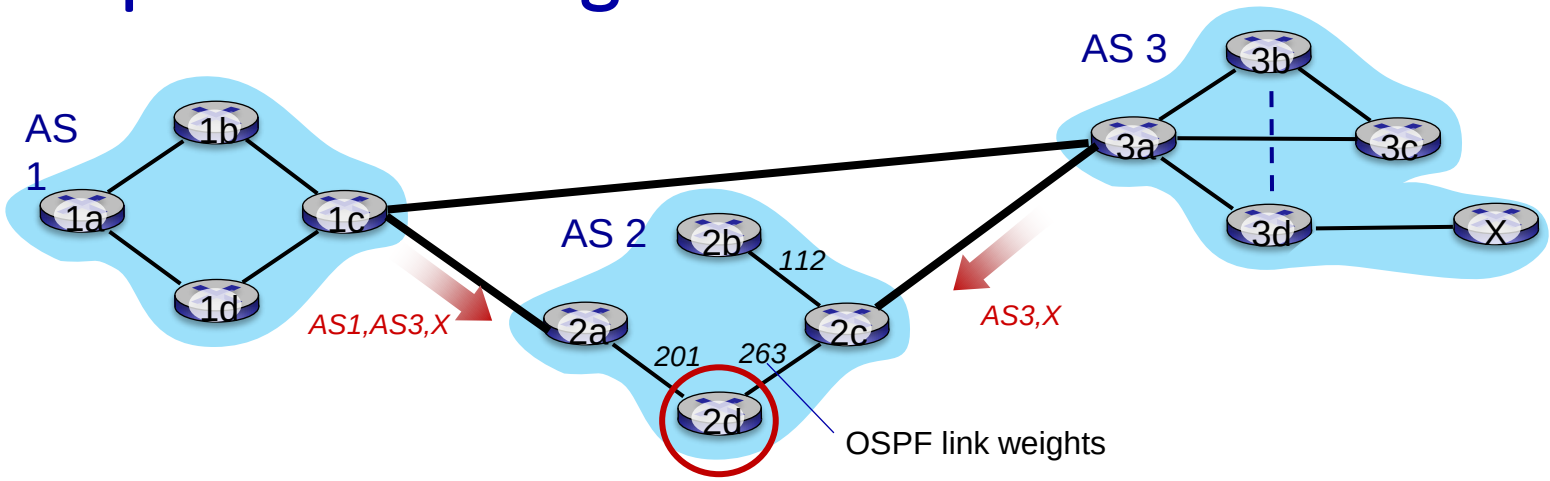
- recall: 1a, 1b, 1d learn via iBGP from 1c: “path to X goes through 1c”
- at 1d: OSPF intra-domain routing: to get to 1c, use interface 1
- at 1d: to get to X, use interface 1
- at 1a: OSPF intra-domain routing: to get to 1c, use interface 2
- at 1a: to get to X, use interface 2

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 (typically) to find best intra-AS route leading to best inter-AS route
   - Router identifies router port for that best route
3. Enter prefix-port entry in forwarding table

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!

Hot-Potato vs Cold-Potato Routing

- ***Hot-potato*** *routing is the practice of passing traffic off to another AS as quickly as possible (thus using their network for wide-area transit.)*
  - *normal behavior of most peering agreements. It has the effect that the network receiving the data bears the cost of carrying it between cities. When the traffic ratio (traffic in both directions between peers) is reasonably even, this is considered fair.*
- ***Cold-potato*** *routing is the opposite: where the source AS holds onto the packet until it is as near to the destination as possible.*
  - *This is more expensive to do, but keeps the traffic under the network administrator's control for longer, allowing operators of well-provisioned networks to offer a higher quality of service to their customers. It can also be preferred when connecting to content providers.*

Example

- *Consider the case of two ISPs, A & B, who both have global networks. Additionally, they have peering agreements in both Europe and in Asia, which allows them to exchange data packets destined for the other's network at either location.*
- *Suppose a European customer of ISP A wants to transmit a data packet to an Asian customer of ISP B. ISP A will receive the packet in Europe and has to decide where to send the packet next.*
- *The first option is to hand off the packet to ISP B in Europe, and let ISP B carry the packet to Asia to be delivered to its destination. This is hot-potato routing, since ISP A hands off the packet at the earliest opportunity.*
- *The second option is for ISP A to carry the packet to Asia on its own internal network, and hand off to ISP B in Asia. This is called cold-potato, since ISP A keeps the packet in its internal network for as long as possible.*

Source: Wikipedia

Assignement # 4 (Chapter – 4)

- *4th Assignment will be uploaded on Google Classroom on Thursday, 26th October, 2023, in the Stream - Announcement Section*

- *Due Date: Thursday, 2nd November, 2023 (Handwritten solutions to be submitted during the lecture)*

- *Please read all the instructions carefully in the uploaded Assignment document, follow & submit accordingly*

Quiz # 4 (Chapter – 4)

- *On: Thursday, 2nd November, 2023 (During the lecture)*

- *Quiz to be taken during own section class only*