

Chapter 5

Network Layer: Control Plane

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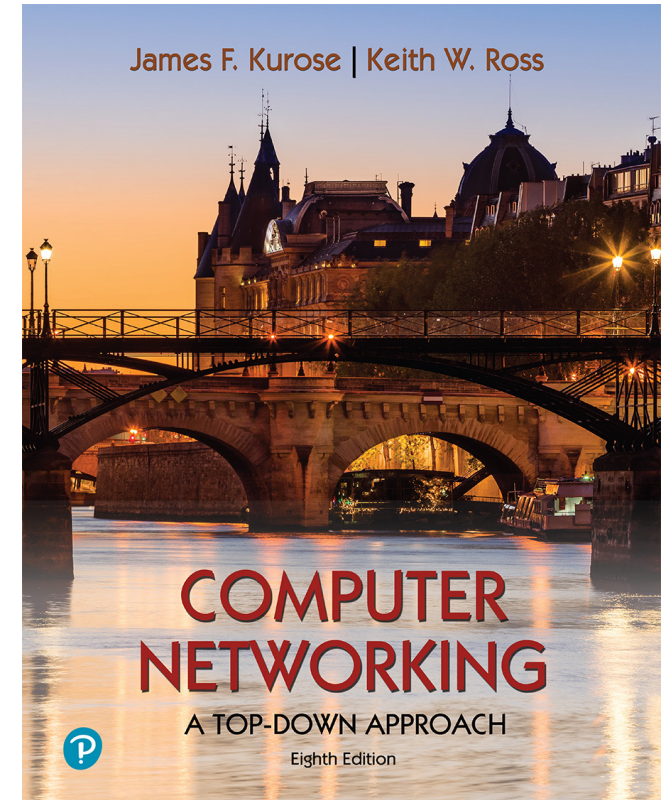
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*Computer Networking: A
Top-Down Approach*

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

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 *within same AS* (“*network*”)

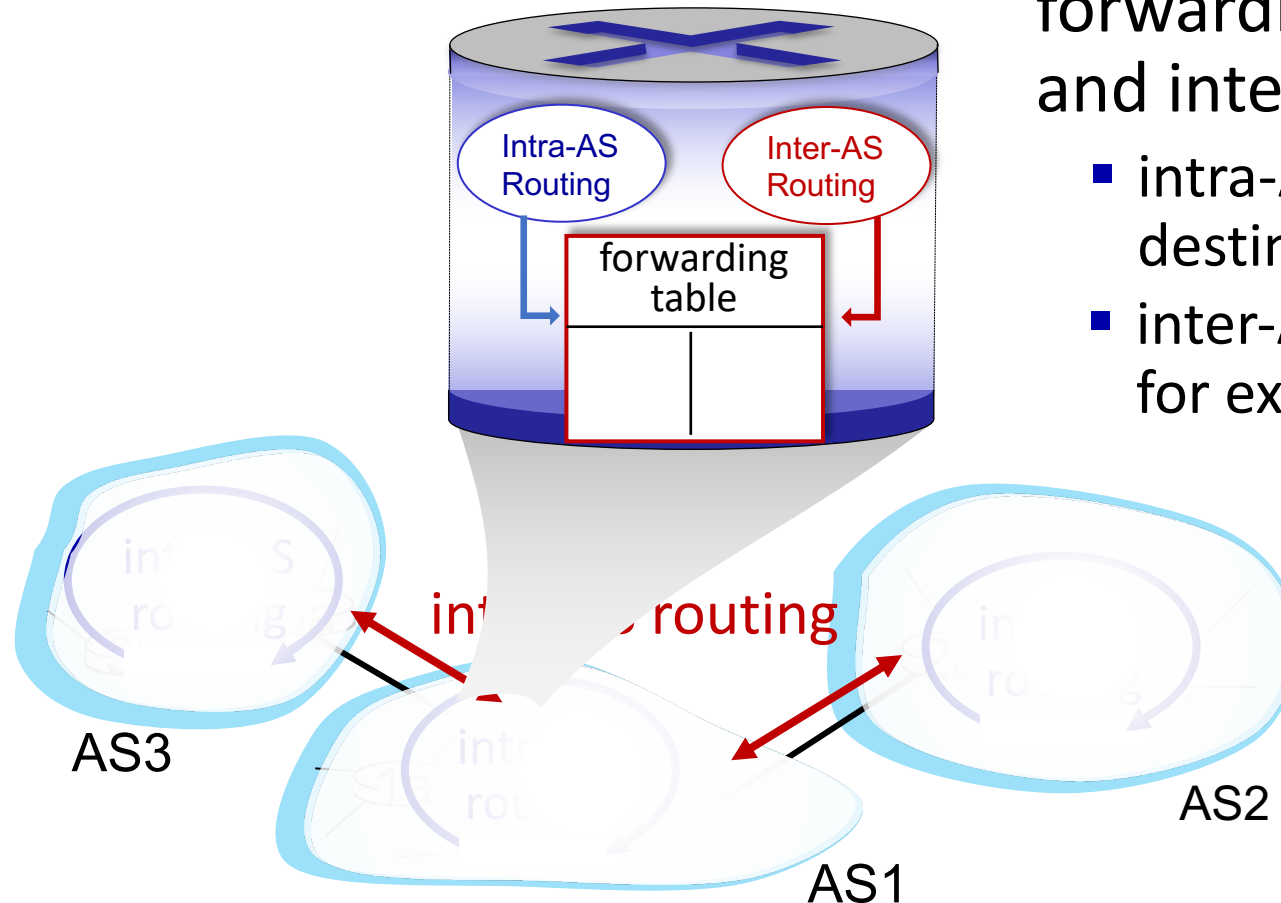
- all routers in AS must run same intra-domain protocol
- routers in different AS can run different intra-domain routing protocols
- **gateway router**: at “edge” of its own AS, has link(s) to router(s) in other AS'es

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

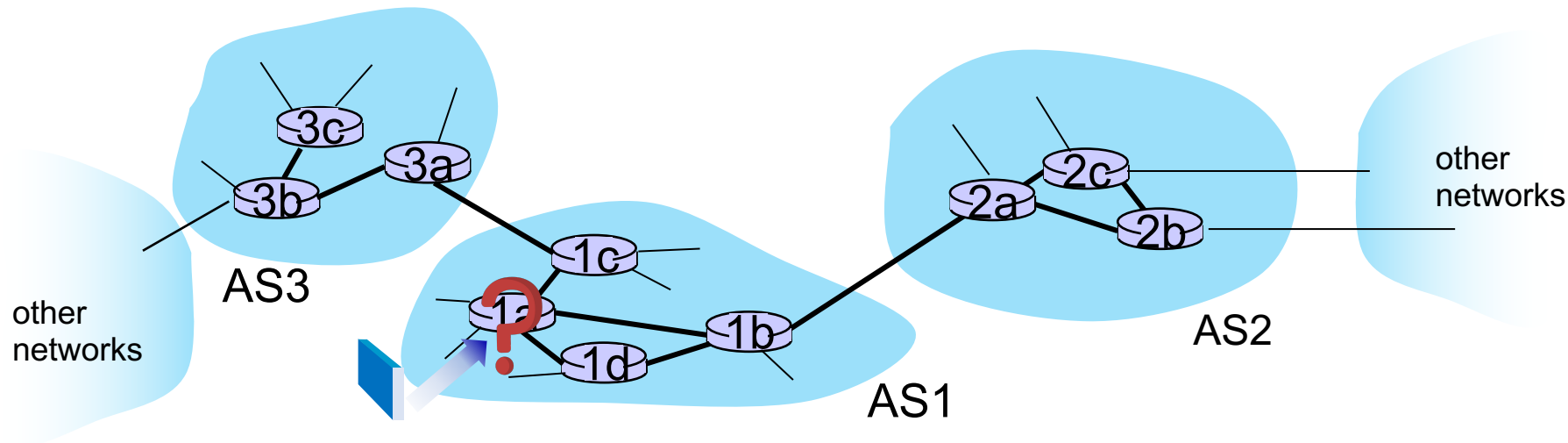
Inter-AS routing: a role in intradomain forwarding

- 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



Inter-AS routing: routing within an AS

most common intra-AS routing protocols:

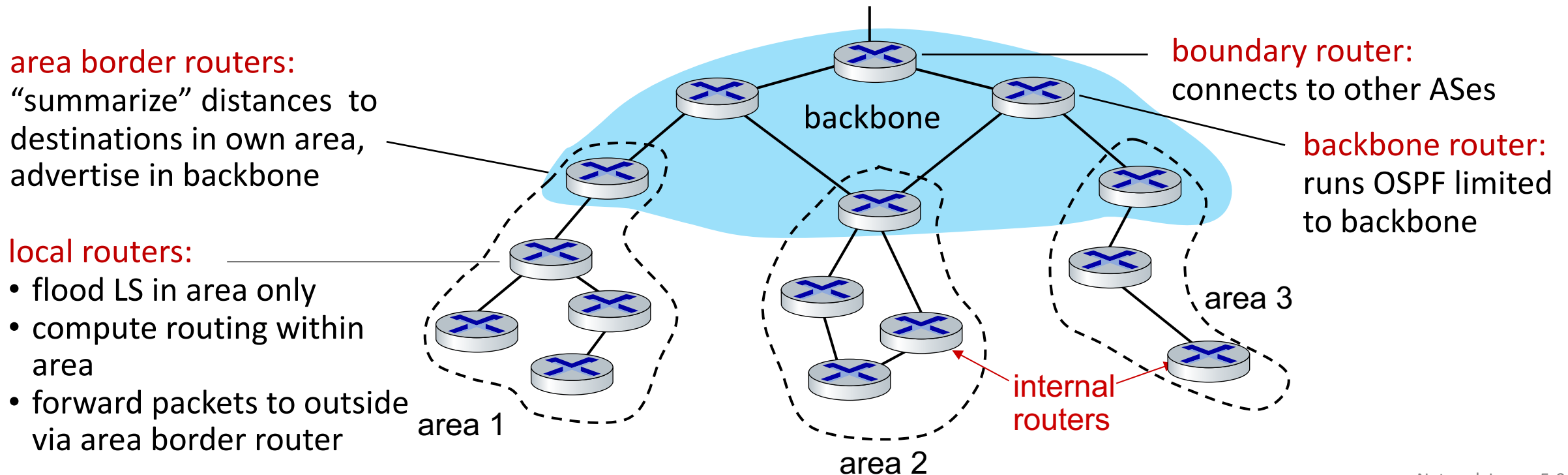
- **RIP: Routing Information Protocol** [RFC 1723]
 - classic DV: DVs exchanged every 30 secs
 - no longer widely used
- **EIGRP: Enhanced Interior Gateway Routing Protocol**
 - DV based
 - formerly Cisco-proprietary for decades (became open in 2013 [RFC 7868])
- **OSPF: Open Shortest Path First** [RFC 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 (directly over IP rather than using TCP/UDP) 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)

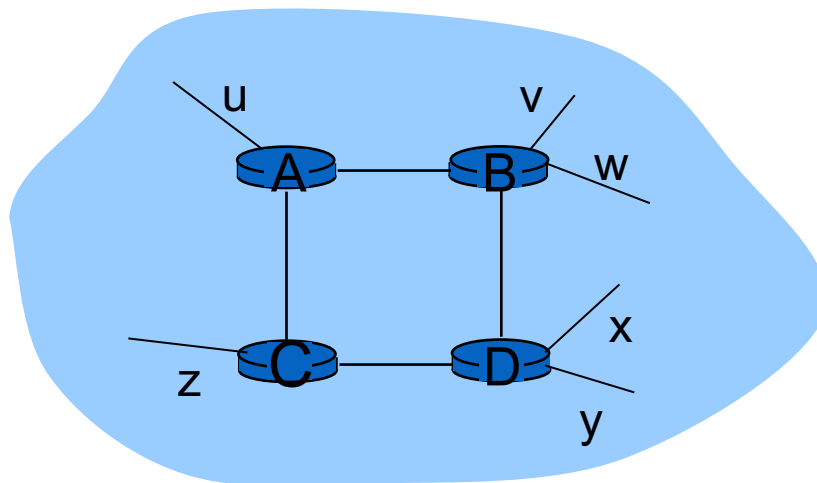
Hierarchical OSPF

- **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



RIP (Routing Information Protocol)

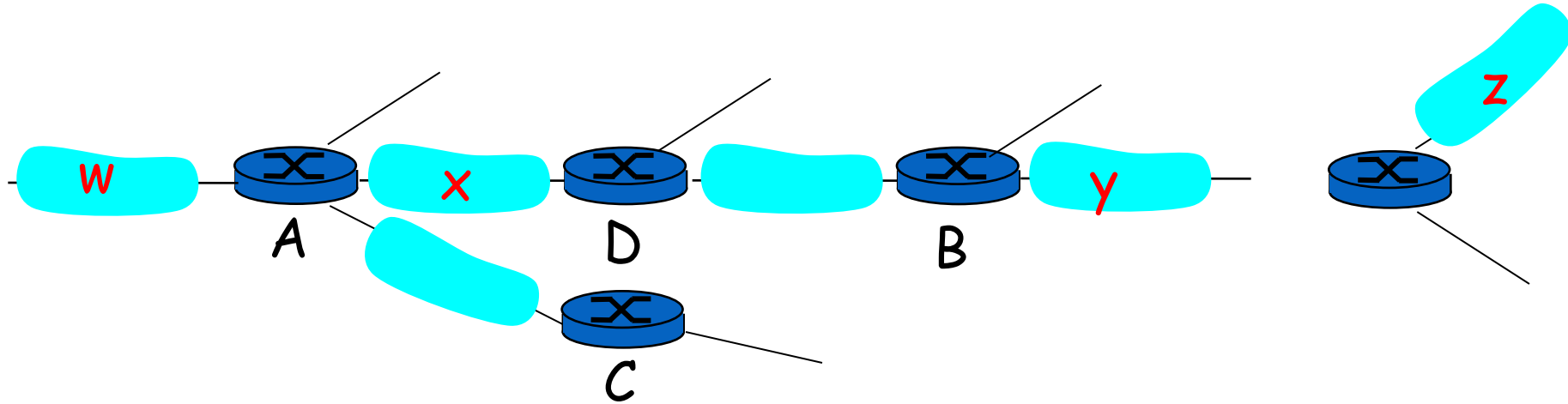
- included in BSD-UNIX distribution in 1982
- distance vector algorithm
 - distance metric: # hops (max = 15 hops), each link has cost 1
 - DVs exchanged with neighbors every 30 sec in response message (aka **advertisement**)
 - each advertisement: list of up to 25 destination **subnets** (*in IP addressing sense*)



from router A to destination **subnets**:

<u>subnet</u>	<u>hops</u>
u	1
v	2
w	2
x	3
y	3
z	2

RIP: Example



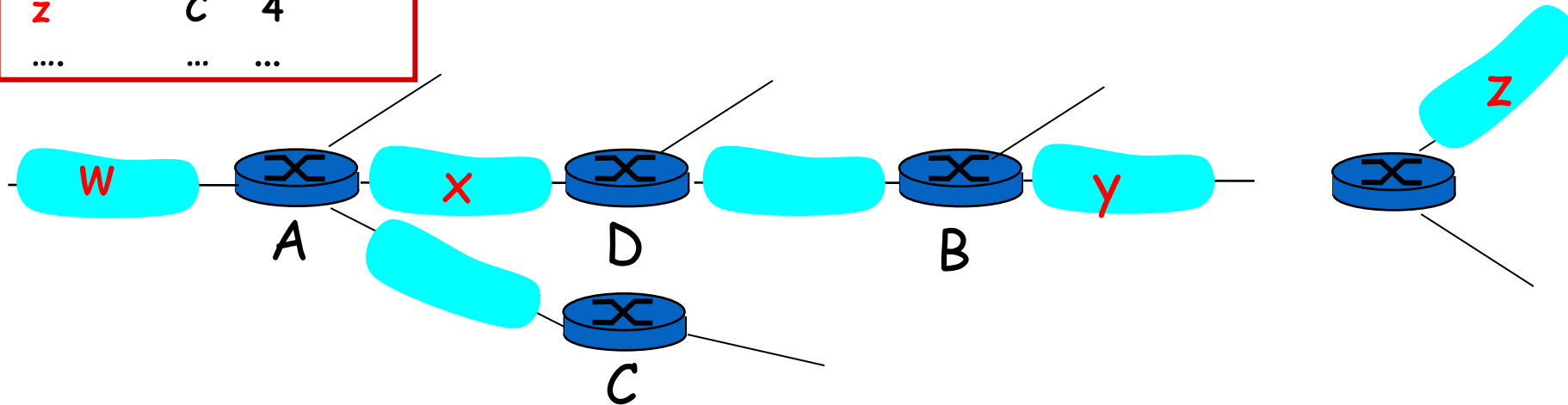
Destination Network	Next Router	Num. of hops to dest.
W	A	2
Y	B	2
Z	B	7
X	--	1
....

Routing/Forwarding table in D

RIP: Example

Dest	Next	hops
w	-	1
x	-	1
z	C	4
....

Advertisement
from A to D



Destination Network	Next Router	Num. of hops to dest.
w	A	2
y	B	2
z	B A	7 5
x	--	1
....

Routing/Forwarding table in D

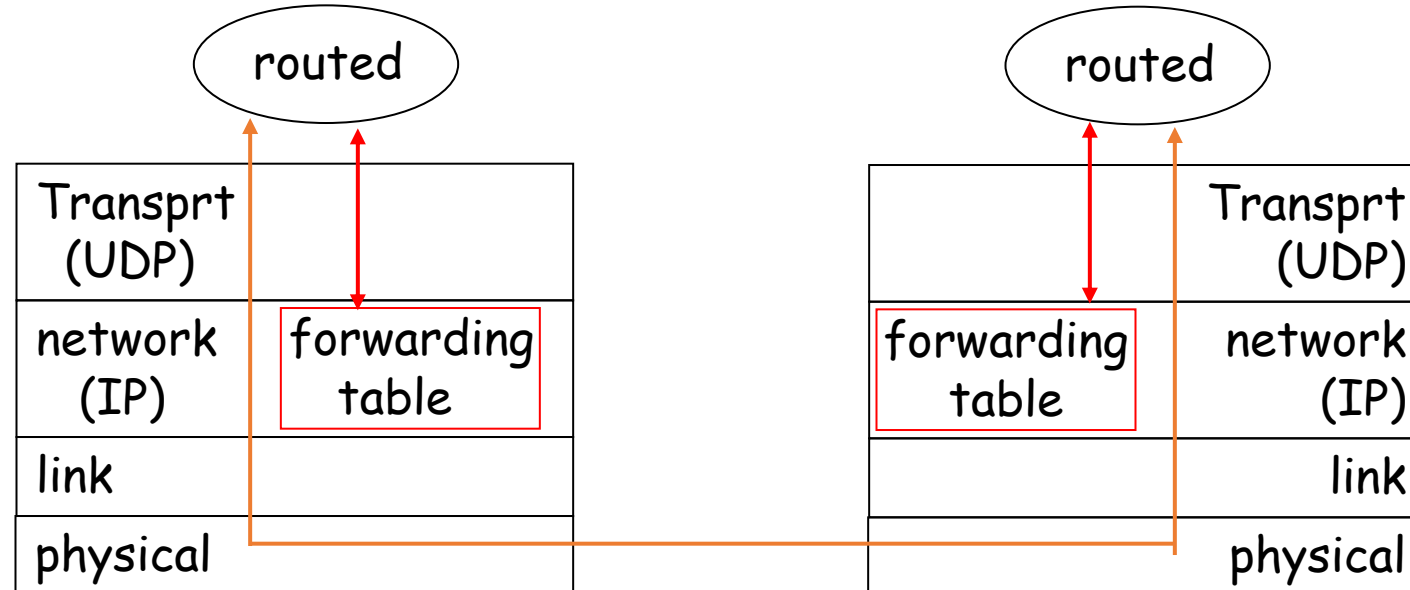
RIP: Link Failure and Recovery

If no advertisement heard after 180 sec --> neighbor/link declared dead

- routes via neighbor invalidated
- new advertisements sent to neighbors
- neighbors in turn send out new advertisements (if tables changed)
- link failure info quickly (?) propagates to entire net
- *poison reverse* used to prevent ping-pong loops (infinite distance = 16 hops)

RIP Table processing

- RIP routing tables managed by **application-level** process called route-d (daemon)
- advertisements sent in UDP packets, periodically repeated



Network layer: “control plane” roadmap

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- **routing among ISPs: BGP**
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- Internet Control Message Protocol

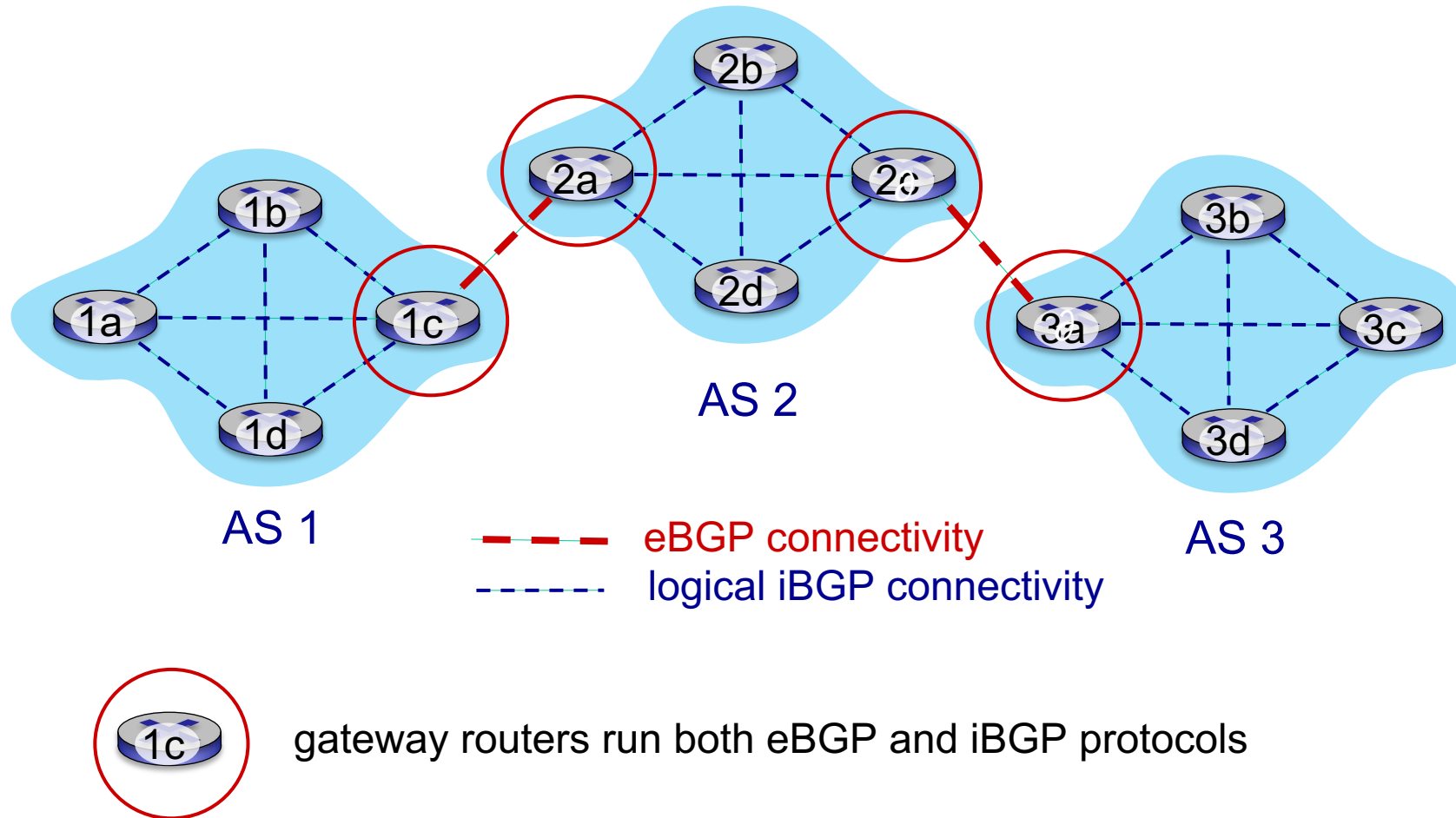


- network management, configuration
 - SNMP
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Internet inter-AS routing: BGP

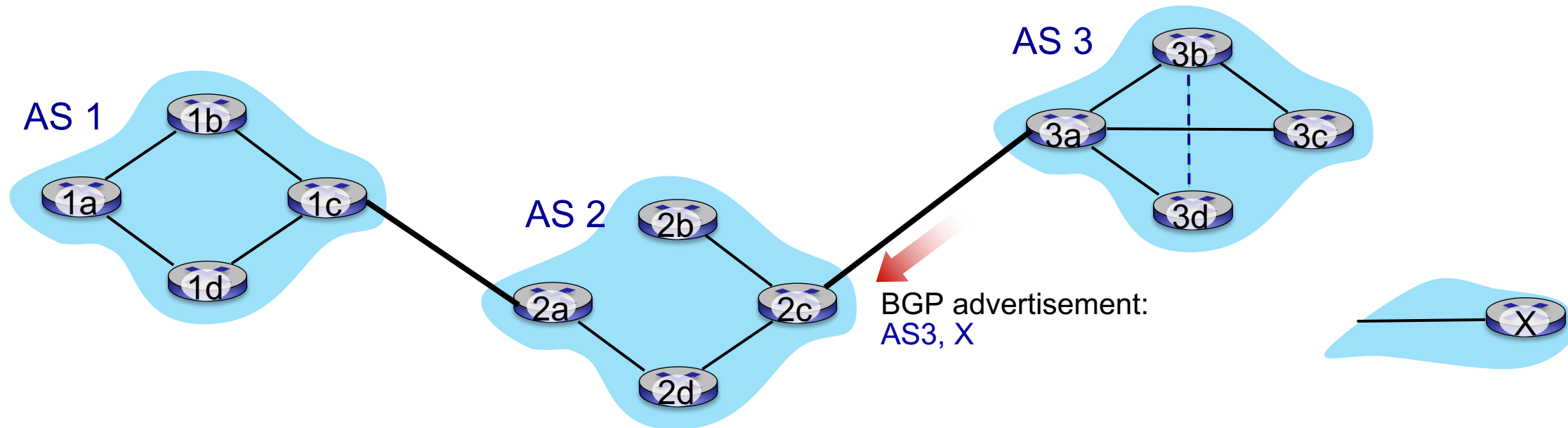
- **BGP (Border Gateway Protocol):** *the* de facto inter-domain routing protocol
 - “glue that holds the Internet together”
- allows subnet to advertise its existence, and the destinations it can reach, to rest of Internet: *“I am here, here is who I can reach, and how”*
- BGP provides each AS a means to:
 - **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*

eBGP, iBGP connections

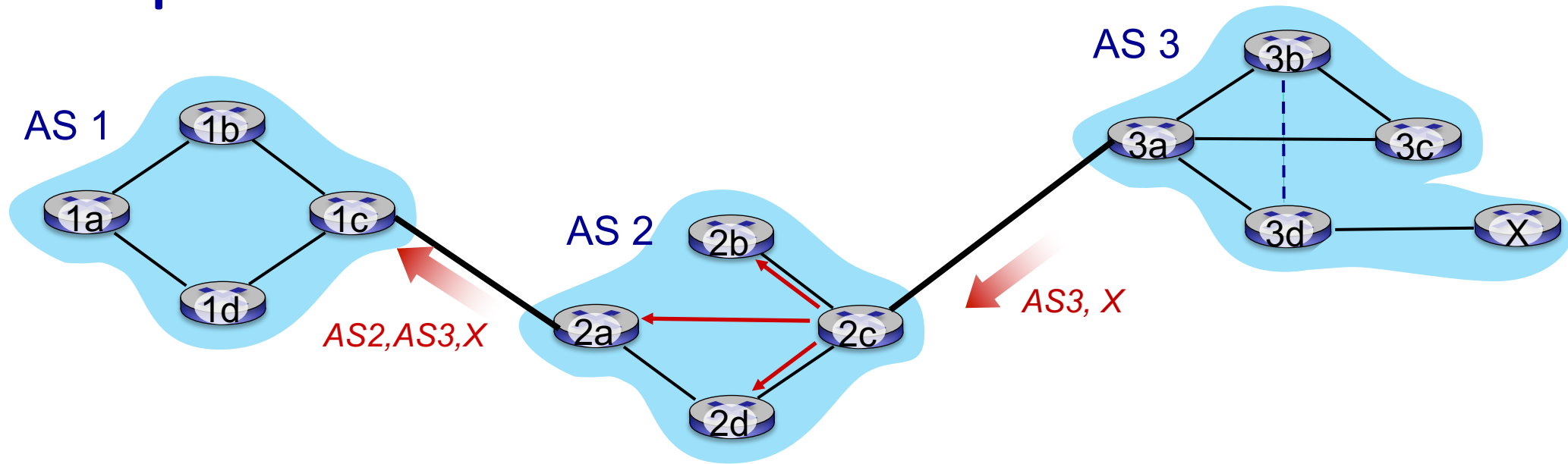


BGP basics

- **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 3a advertises *path AS3,X* to AS2 gateway 2c:
 - AS3 *promises* to AS2 it will forward datagrams towards X

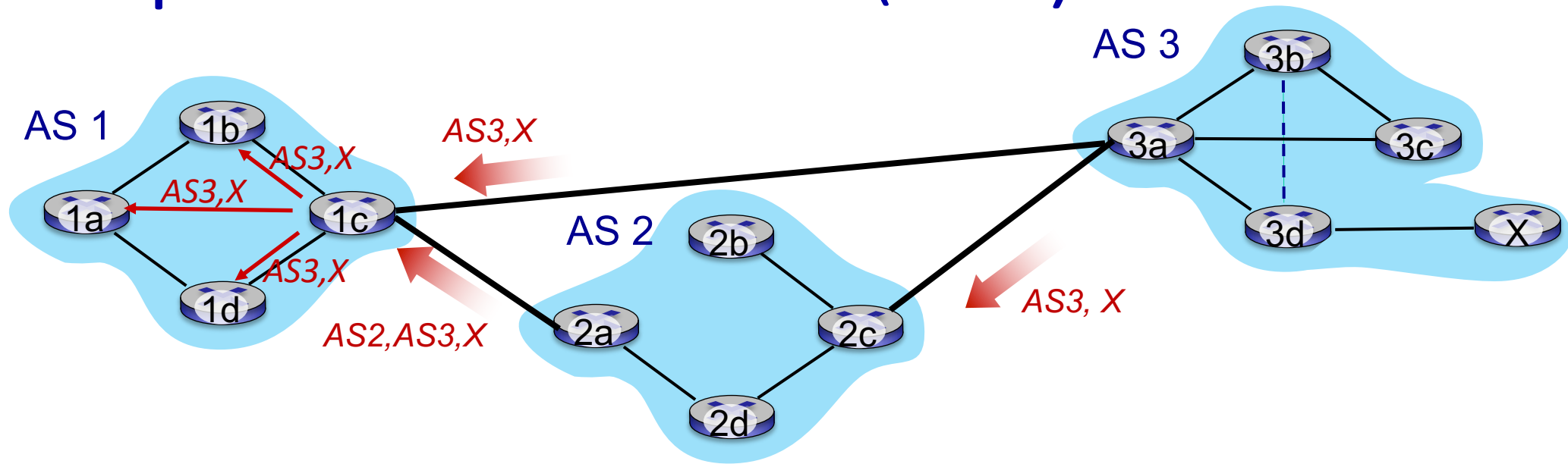


BGP path advertisement



- 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

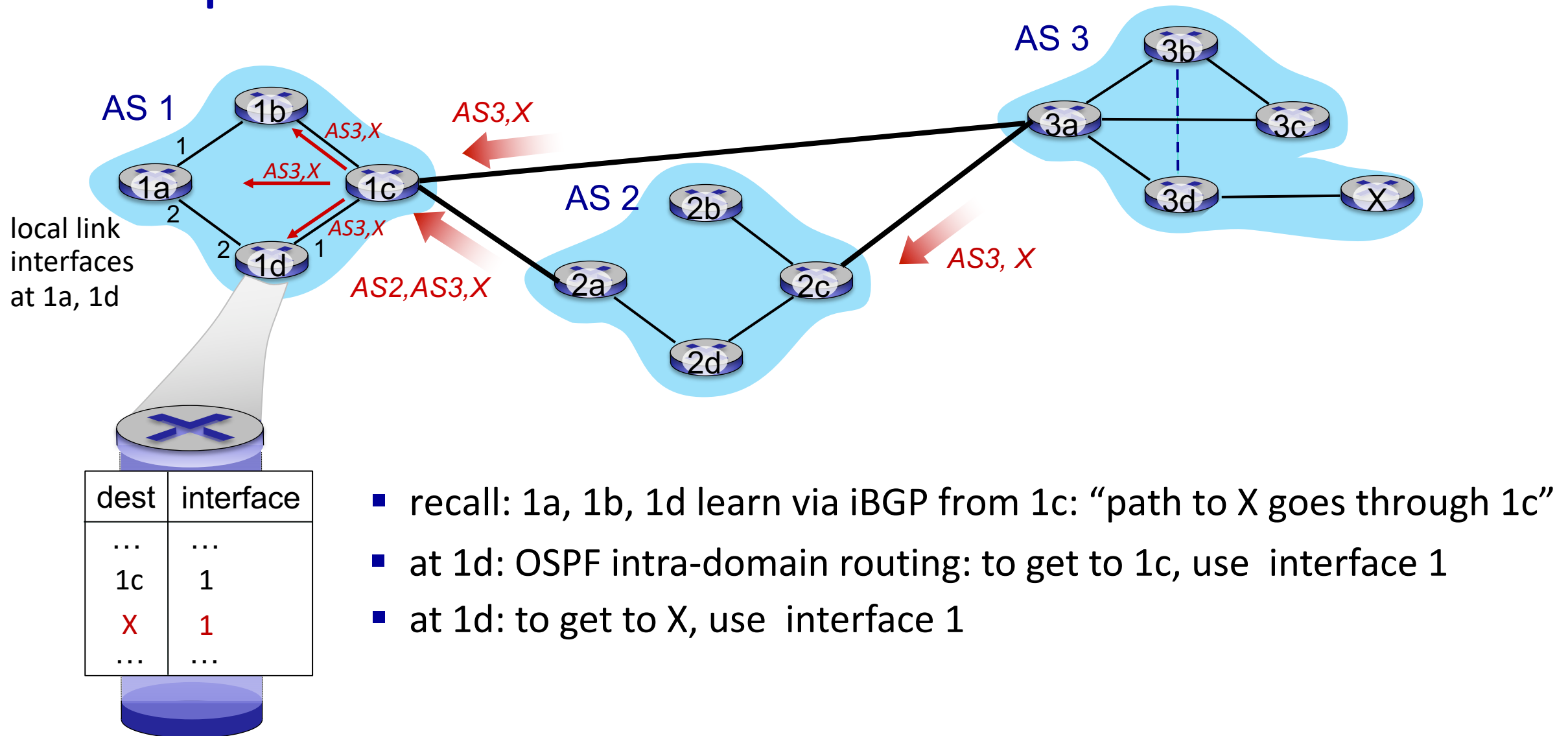
BGP path advertisement (more)



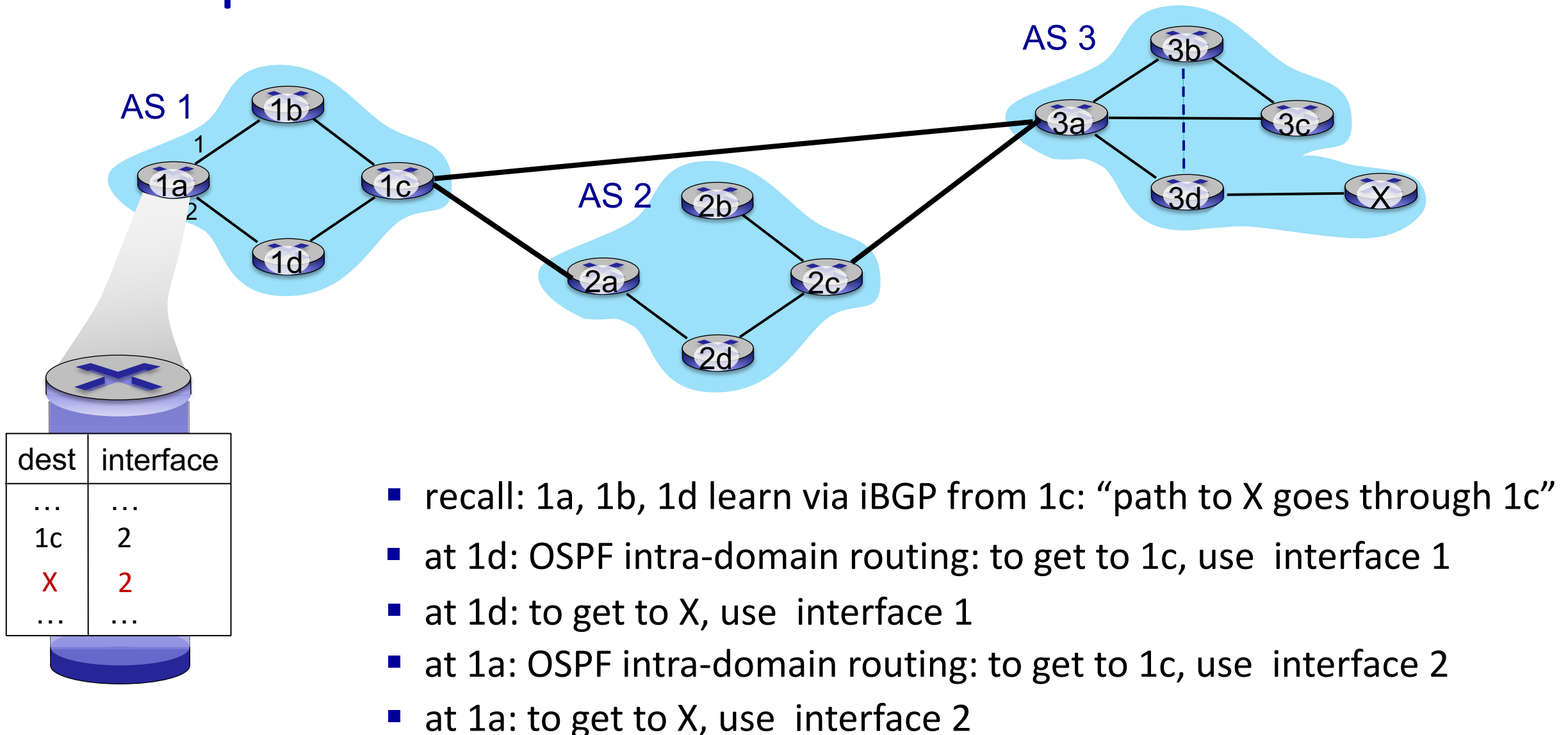
gateway router may learn about **multiple** paths to destination:

- 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 path advertisement



BGP path advertisement



Why different Intra-, Inter-AS routing ?

policy:

- inter-AS: admin wants control over how its traffic routed, who routes through its network
- intra-AS: single admin, so policy less of an issue

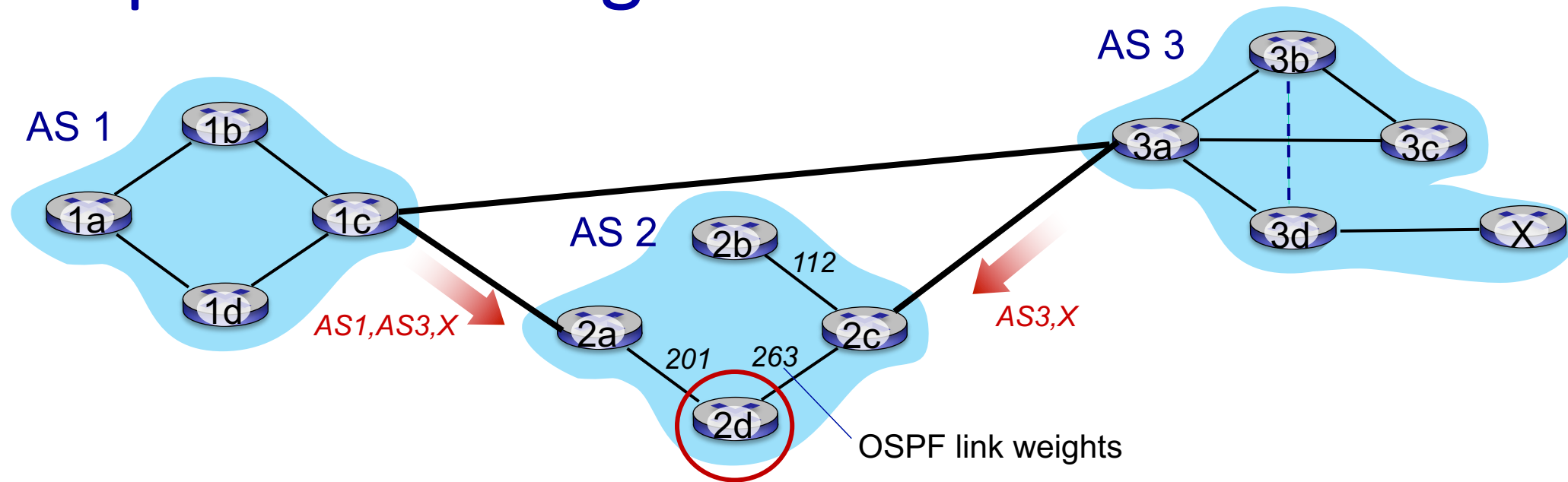
scale:

- hierarchical routing saves table size, reduced update traffic

performance:

- intra-AS: can focus on performance
- inter-AS: policy dominates over performance

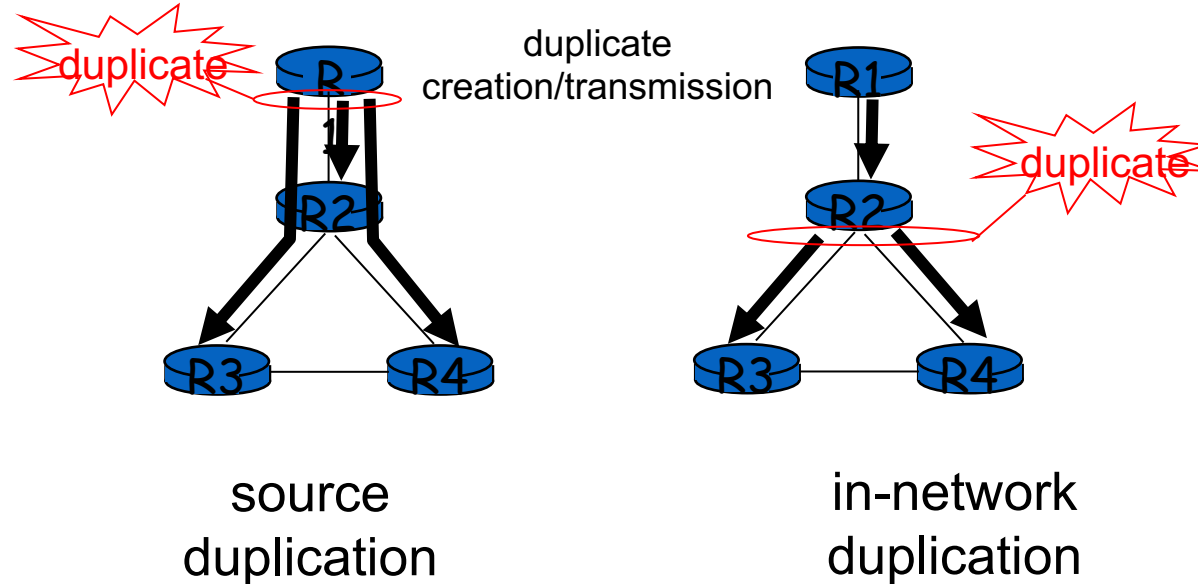
Hot potato routing



- 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!

Broadcast routing

- deliver packets from source to all other nodes
- source duplication is inefficient:



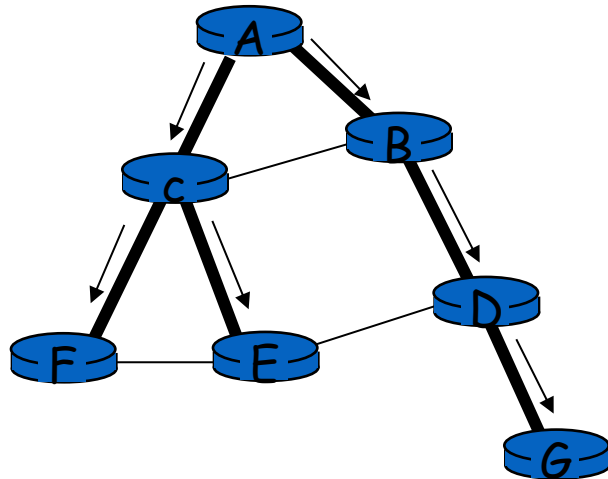
- source duplication: how does source determine recipient addresses?

In-network duplication

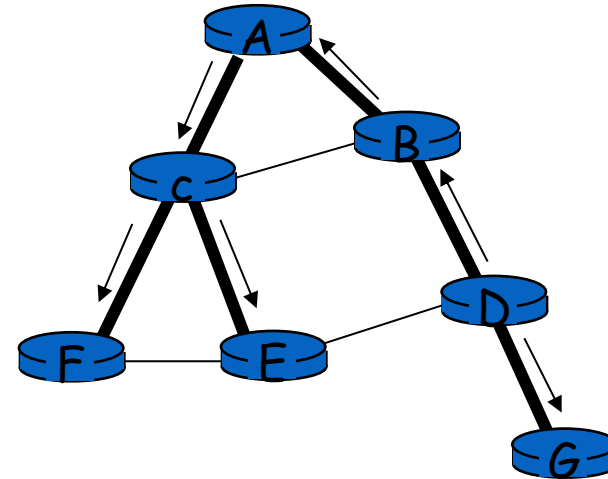
- flooding: when node receives brdcst pkt, sends copy to all neighbors
 - Problems: cycles & broadcast storm
- controlled flooding: node only brdcsts pkt if it hasn't brdcst same packet before
 - Node keeps track of pkt ids already brdcsted
 - Or reverse path forwarding (RPF): only forward pkt if it arrived on shortest path between node and source
- spanning tree
 - No redundant packets received by any node

Spanning Tree

- First construct a spanning tree
- Nodes forward copies only along spanning tree



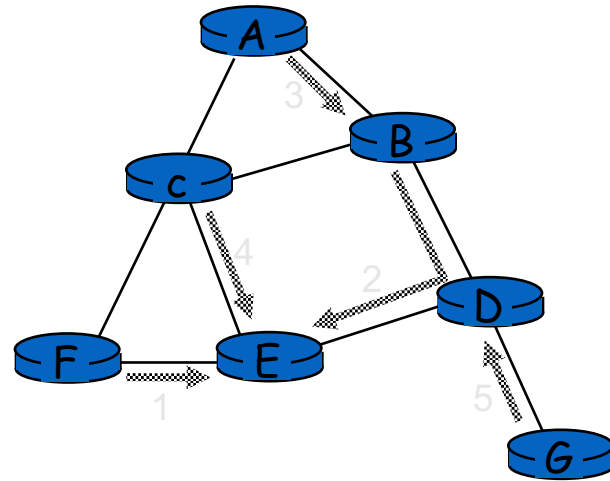
(a) Broadcast initiated at A



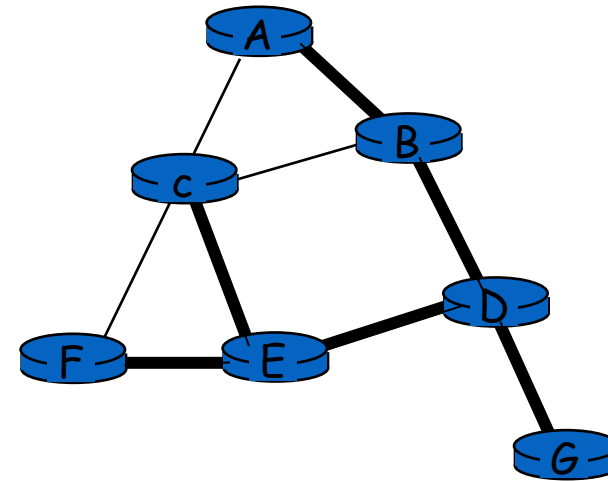
(b) Broadcast initiated at D

Spanning Tree: Creation

- Center node
- Each node sends unicast join message to center node
 - Message forwarded until it arrives at a node already belonging to spanning tree



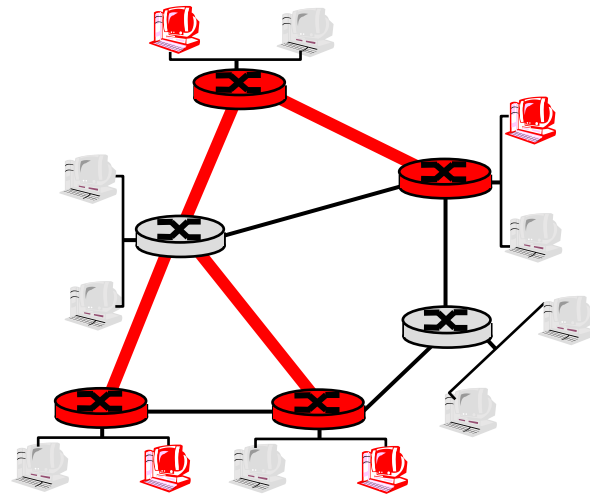
(a) Stepwise construction of spanning tree



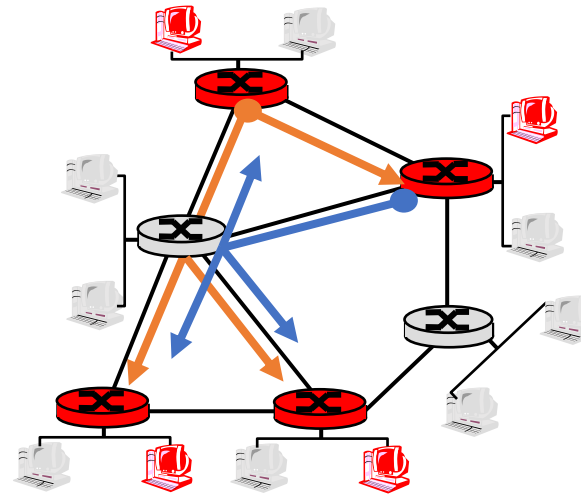
(b) Constructed spanning tree

Multicast Routing: Problem Statement

- **Goal:** find a tree (or trees) connecting routers having local mcast group members
 - tree: not all paths between routers used
 - source-based: different tree from each sender to rcvrs
 - shared-tree: same tree used by all group members



Shared tree



Source-based trees