

CNT 4704: Analysis of Computer Communication Networks

**The Network Layer:
Control Plane (Cont'd)**

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HOUSEKEEPING & ACKNOWLEDGEMENT



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being recorded

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- Original material can be found on:
https://gaia.cs.umass.edu/kurose_ross/ppt.htm

Network layer: “control plane” roadmap

- introduction
- routing protocols
 - link state
 - distance vector
- **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

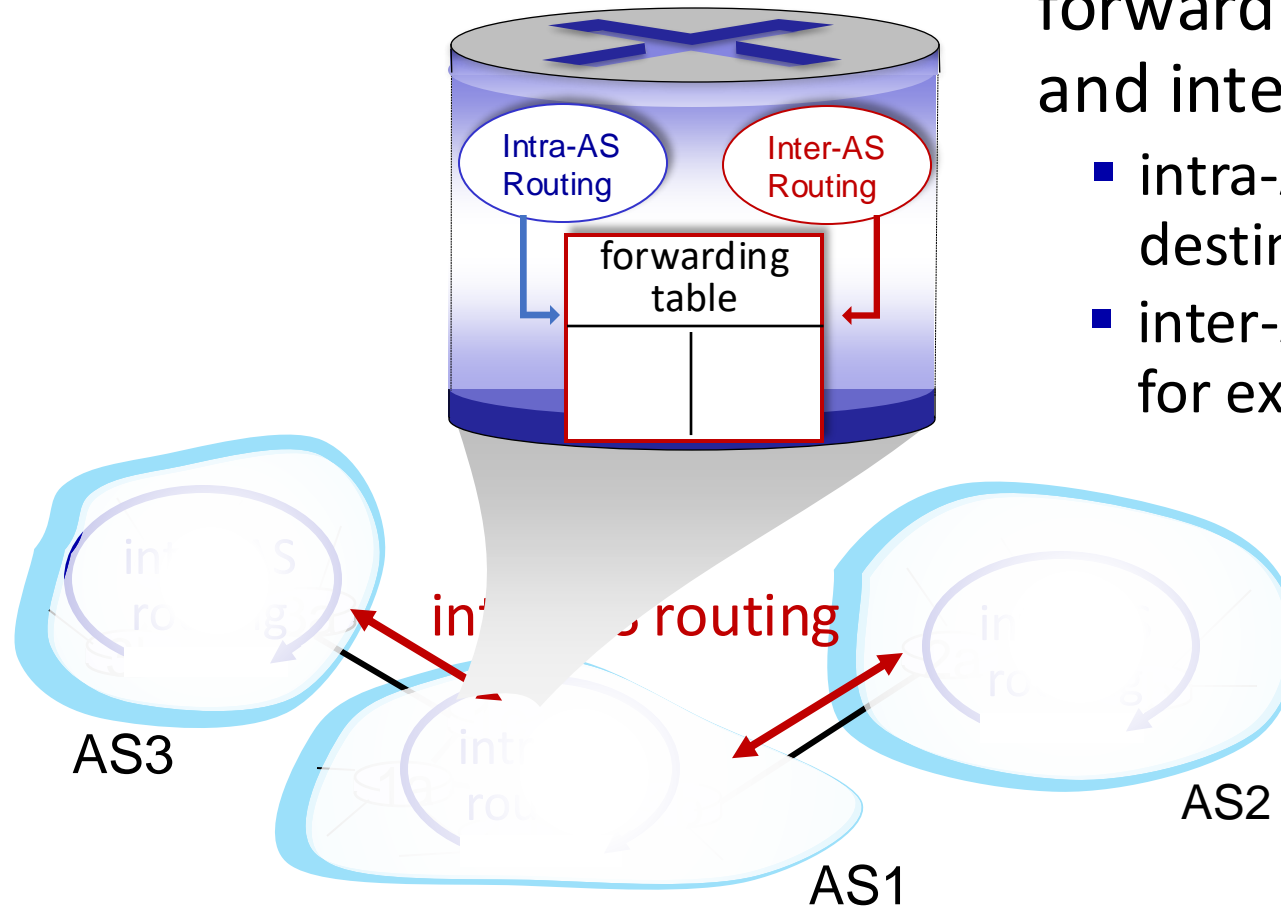
- gateways perform inter-domain routing (as well as intra-domain routing)

You can check:

<https://hackertarget.com/as-ip-lookup/>

Also, check other “asnlookup services”

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: routing within an AS

most common intra-AS routing protocols:

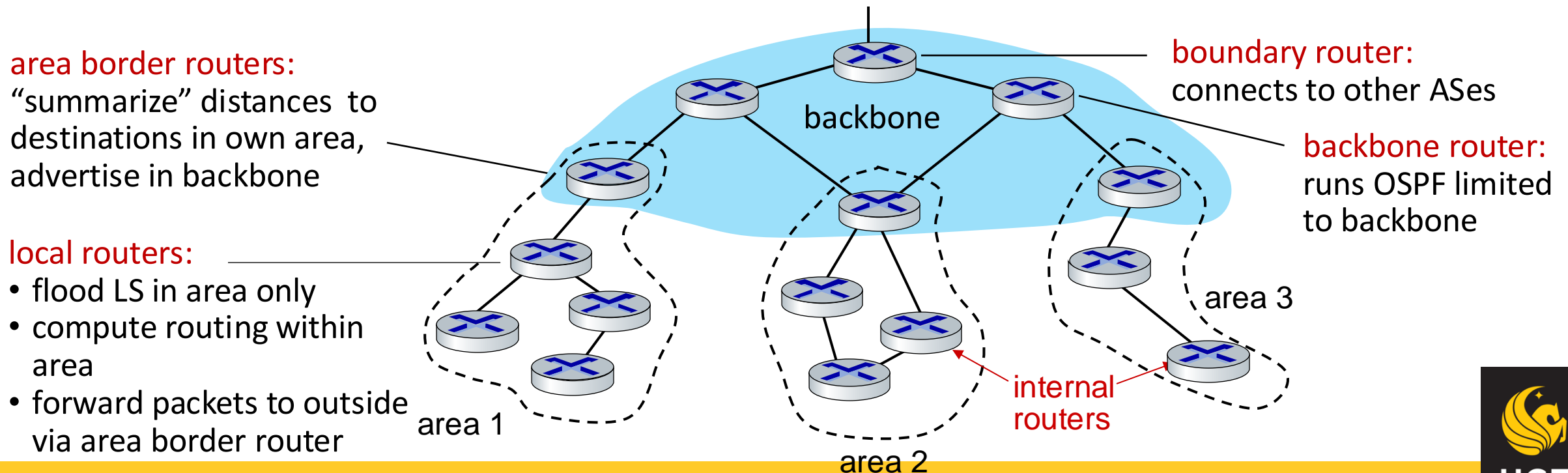
- **RIP: Routing Information Protocol** [RFC 1723]
 - classic DV: DVs exchanged every 30 secs
 - no longer widely used
- **OSPF: Open Shortest Path First** [RFC 2328]
 - link-state routing
 - IS-IS protocol (ISO standard, not RFC standard) essentially same as OSPF
- **EIGRP: Enhanced Interior Gateway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

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



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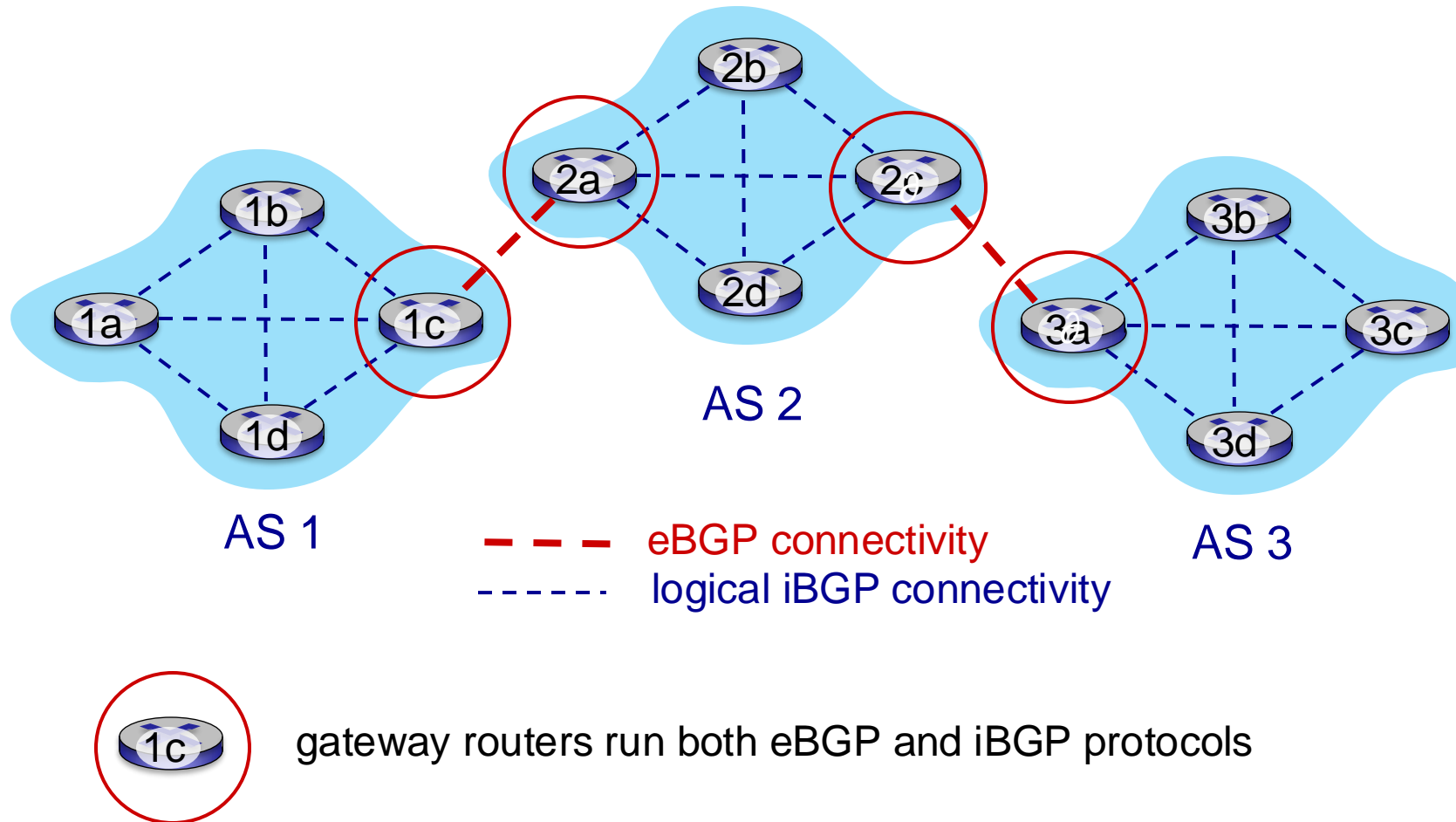


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Internet inter-AS routing: BGP

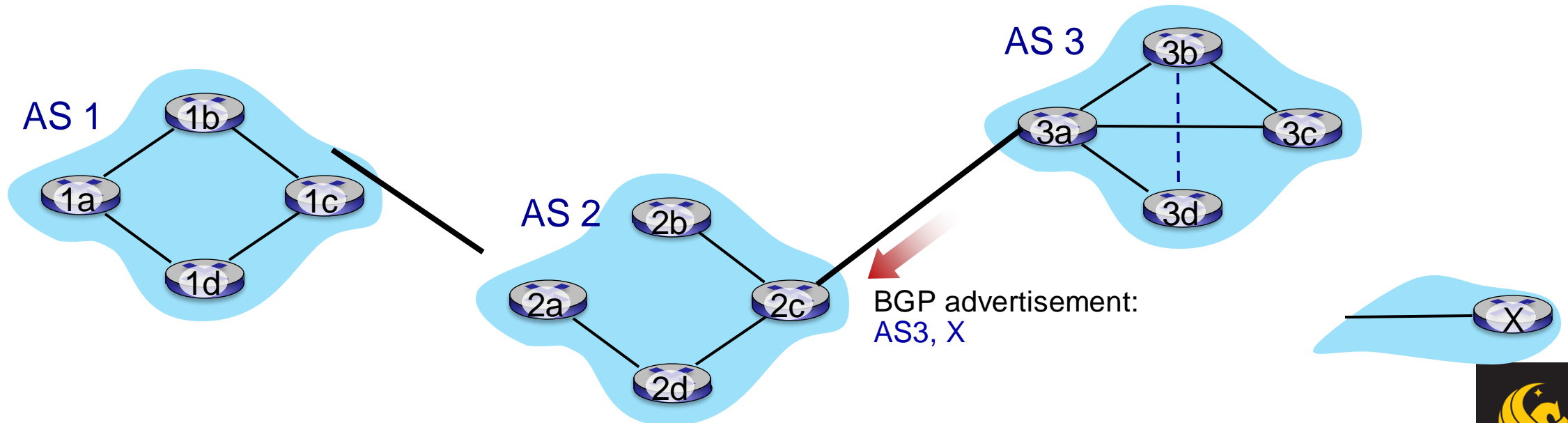
- **BGP (Border Gateway Protocol):** *the* de facto inter-domain routing protocol
 - “glue that holds the Internet together”
- allows subnet to advertise its existence, and the destinations it can reach, to rest of Internet: *“I am here, here is who I can reach, and how”*
- BGP provides each AS a means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



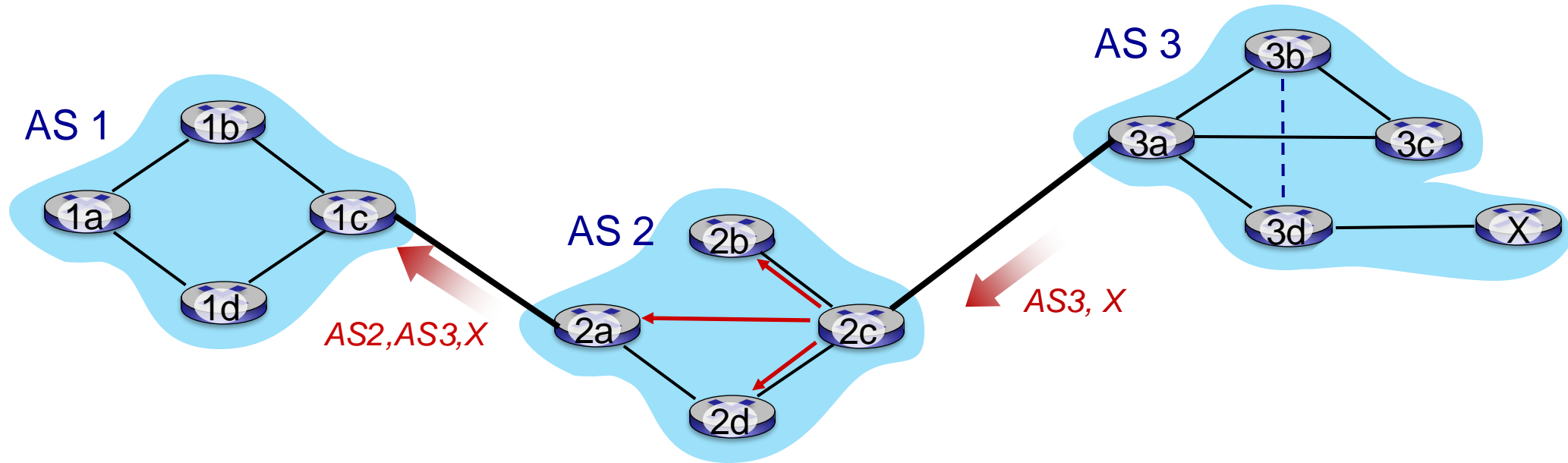
BGP messages

- 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

Path attributes and BGP routes

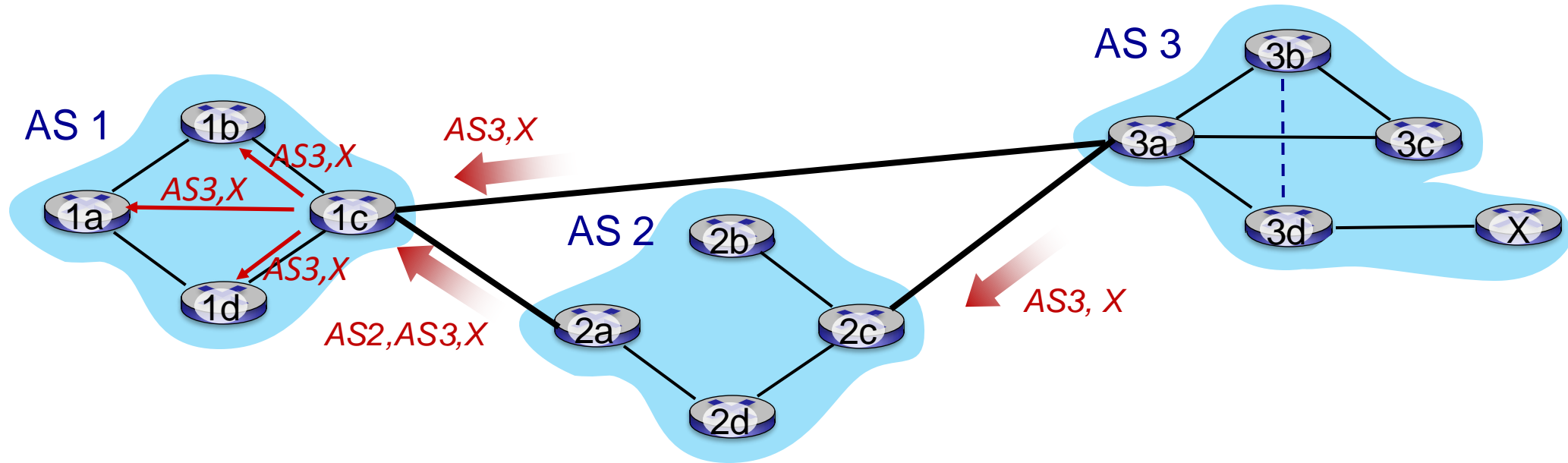
- BGP advertised route: prefix + attributes
 - prefix: destination being advertised
 - two important attributes:
 - **AS-PATH**: list of ASes through which prefix advertisement has passed
 - **NEXT-HOP**: indicates specific internal-AS router to next-hop AS
- **policy-based routing**:
 - gateway receiving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

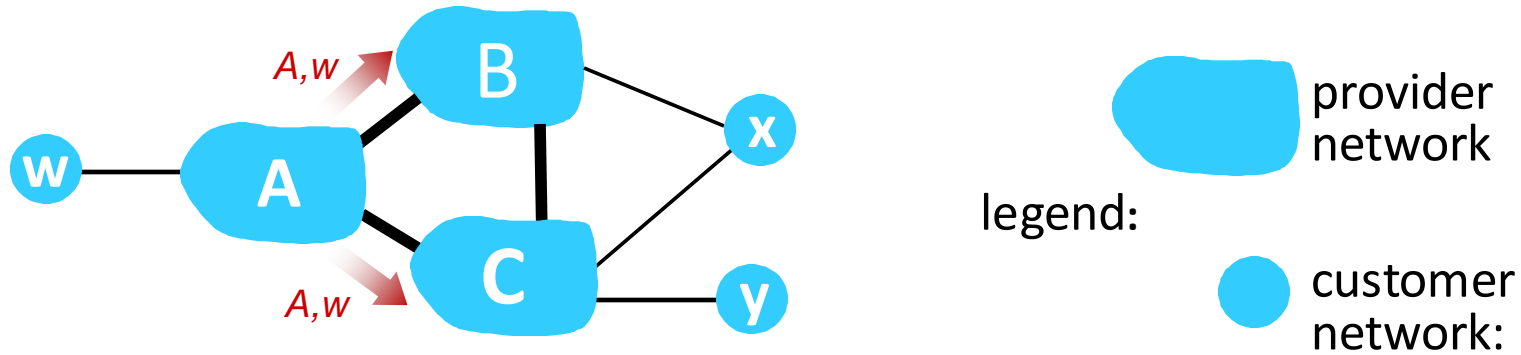
BGP path advertisement (multiple paths)



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

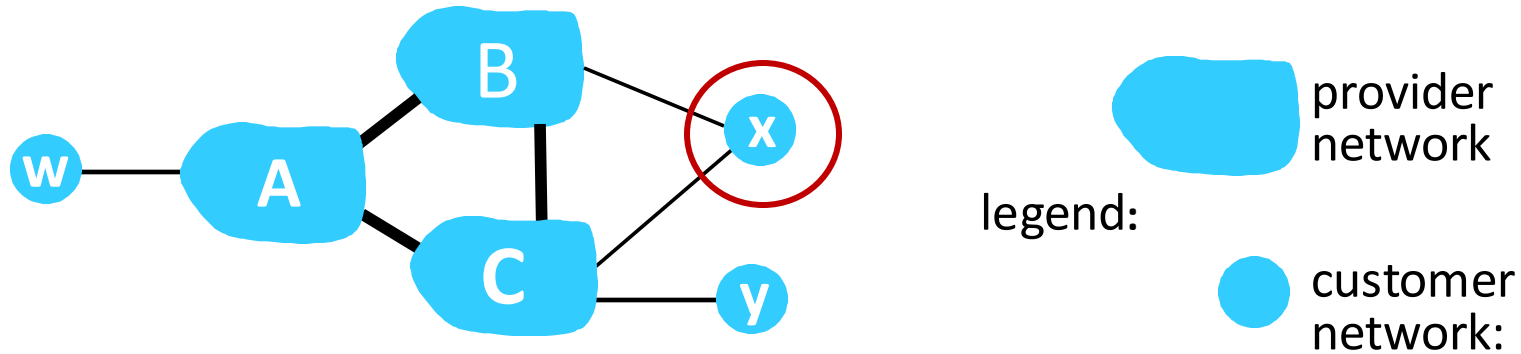
BGP: achieving policy via advertisements



ISP only wants to route traffic to/from its customer networks (does not want to carry transit traffic between other ISPs – a typical “real world” policy)

- 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

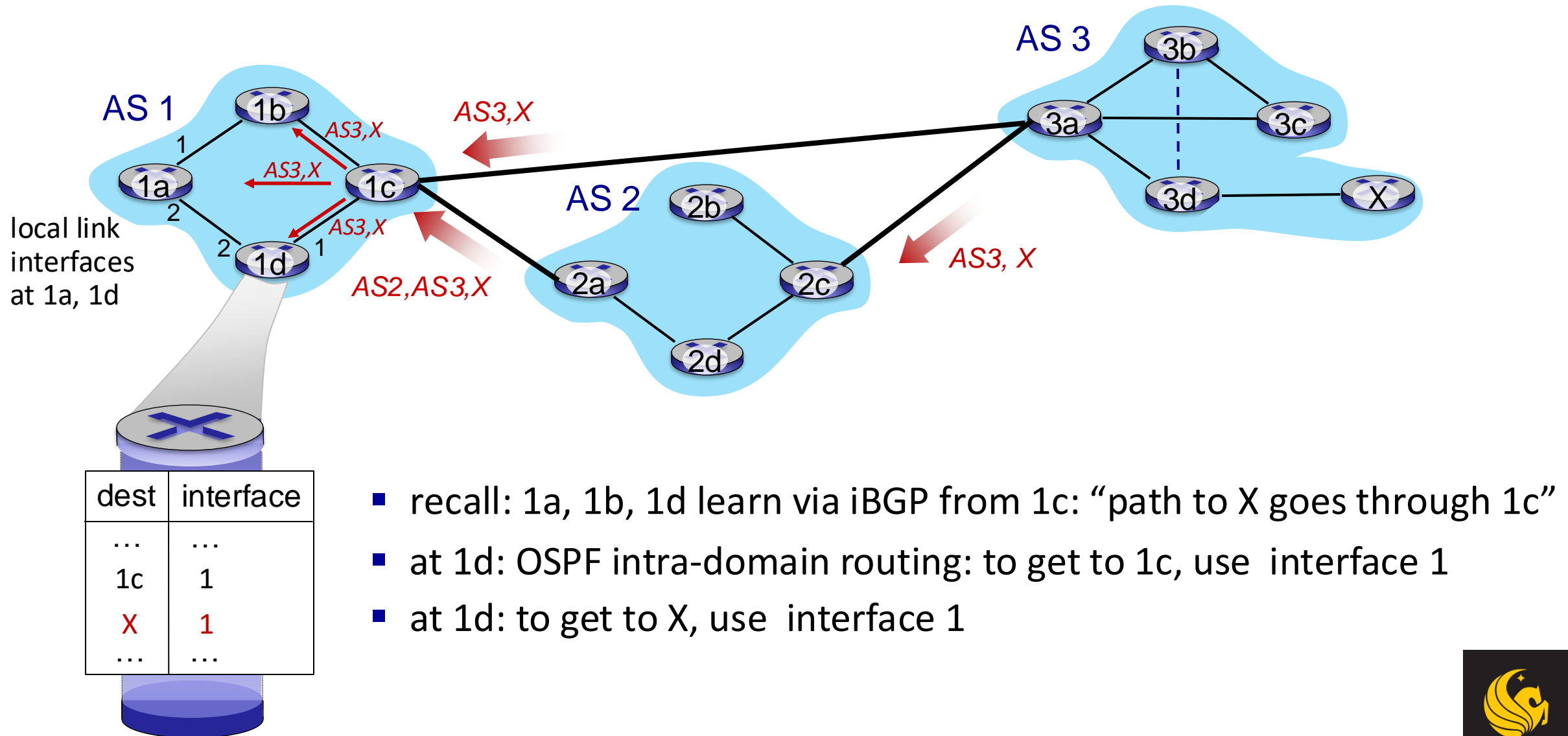
BGP: achieving policy via advertisements (more)



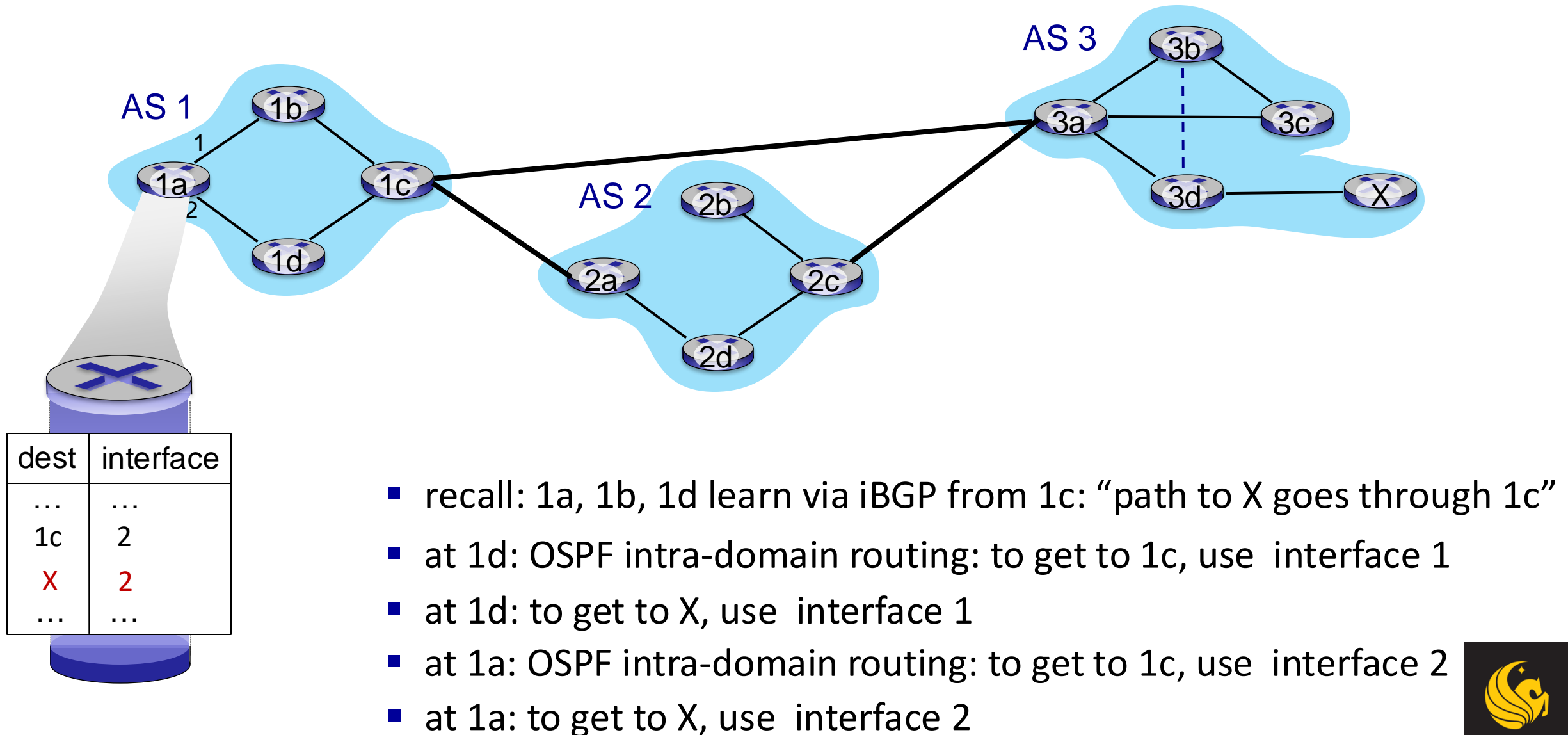
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- A,B,C are **provider networks**
- x,w,y are **customer** (of provider networks)
- x is **dual-homed**: attached to two networks
- **policy to enforce**: x does not want to route from B to C via x
 - .. so x will not advertise to B a route to C

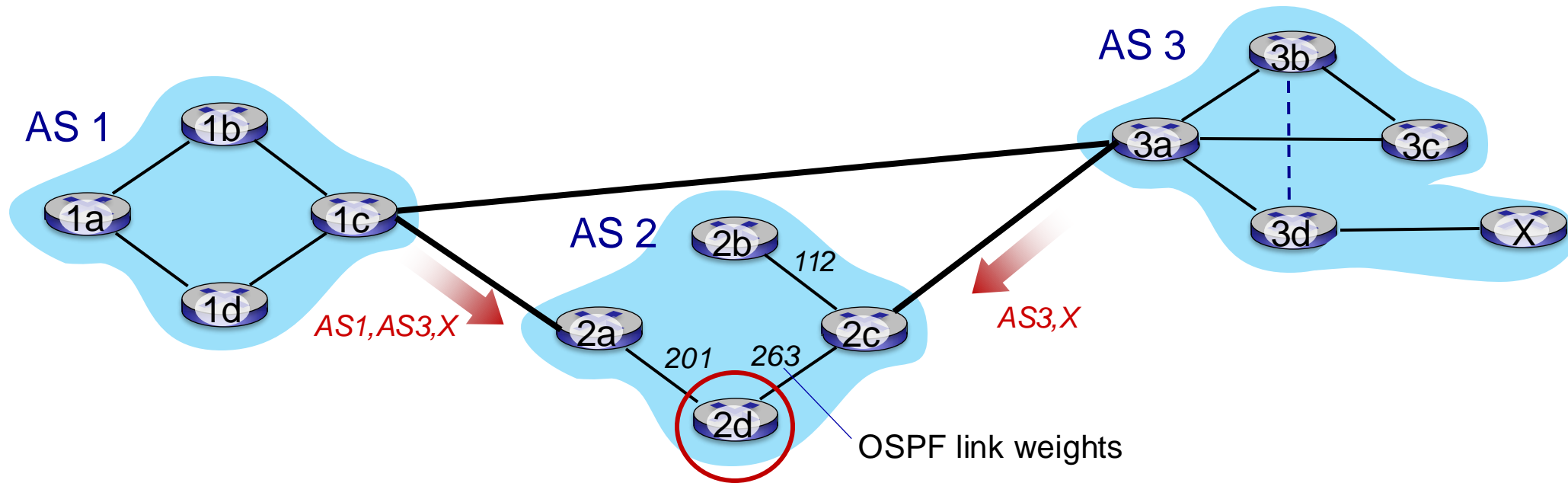
BGP: populating forwarding tables



BGP path advertisement



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!

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
- BGP routing to CIDRized destination networks (summarized routes)

performance:

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

Questions?

