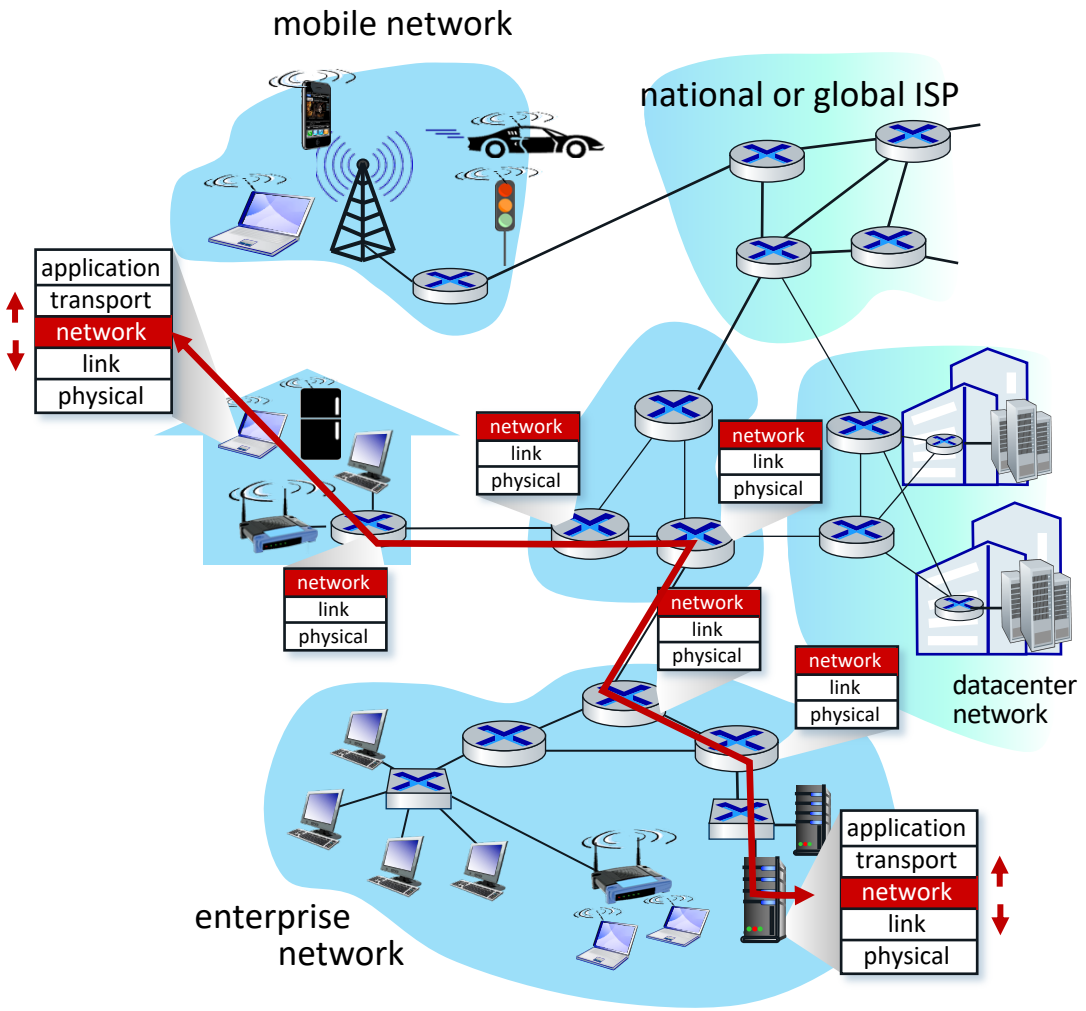
Network Layer Introduction

Network Layer Services and Protocols

- transport segment from sending to receiving host
  - sender: encapsulates segments into datagrams, passes to link layer
  - receiver: delivers segments to transport layer protocol
- network layer protocols in *every Internet device*: hosts, routers
- routers:
  - examines header fields in all IP datagrams passing through it
  - moves datagrams from input ports to output ports to transfer datagrams along end-end path



Network Layer: Two Key Functions

network-layer functions:

forwarding: move packets from a router's input link to appropriate router output link

- *routing:* determine route taken by packets from source to destination
  - *routing algorithms*

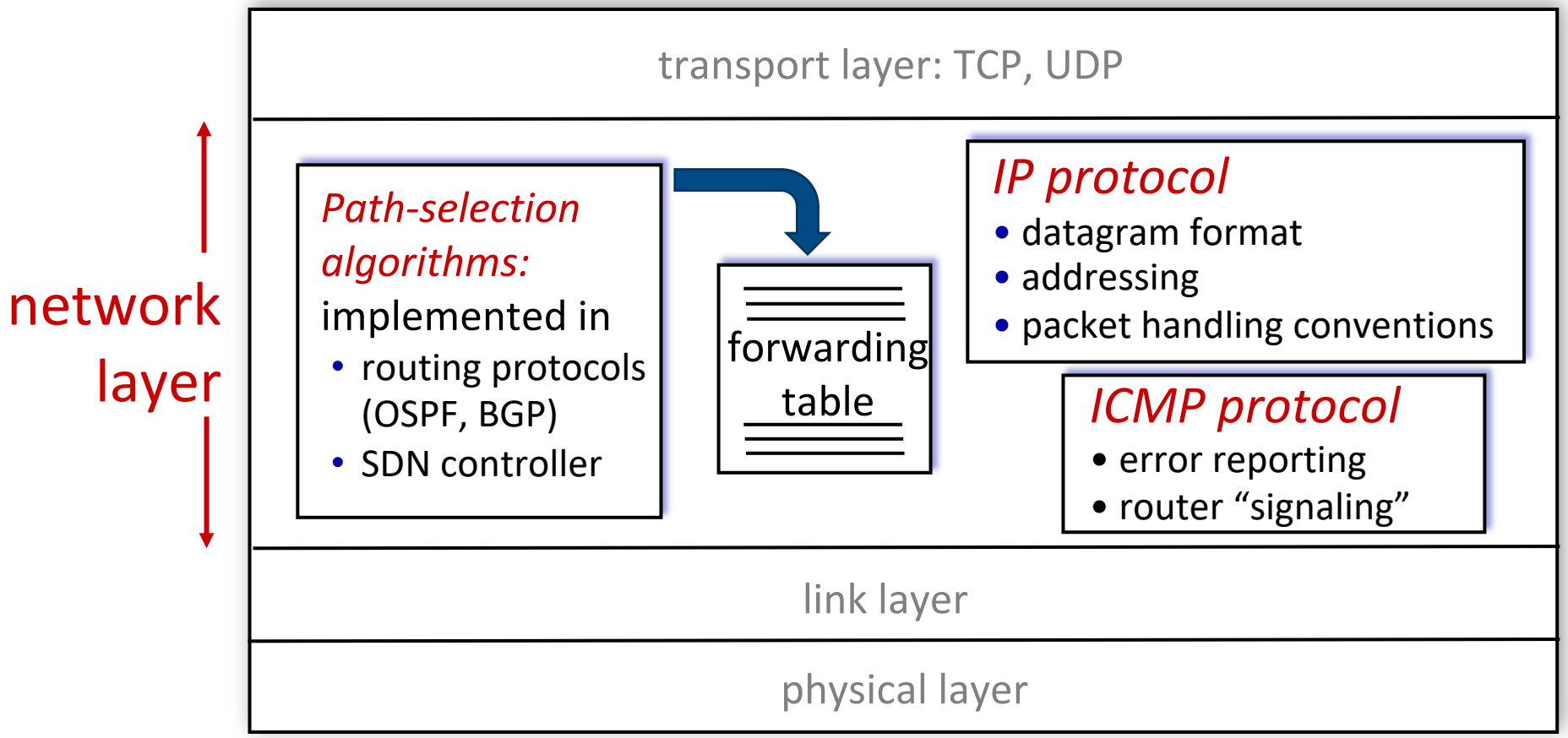
analogy: taking a trip

- *forwarding:* process of getting through single interchange
- *routing:* process of planning trip from source to destination

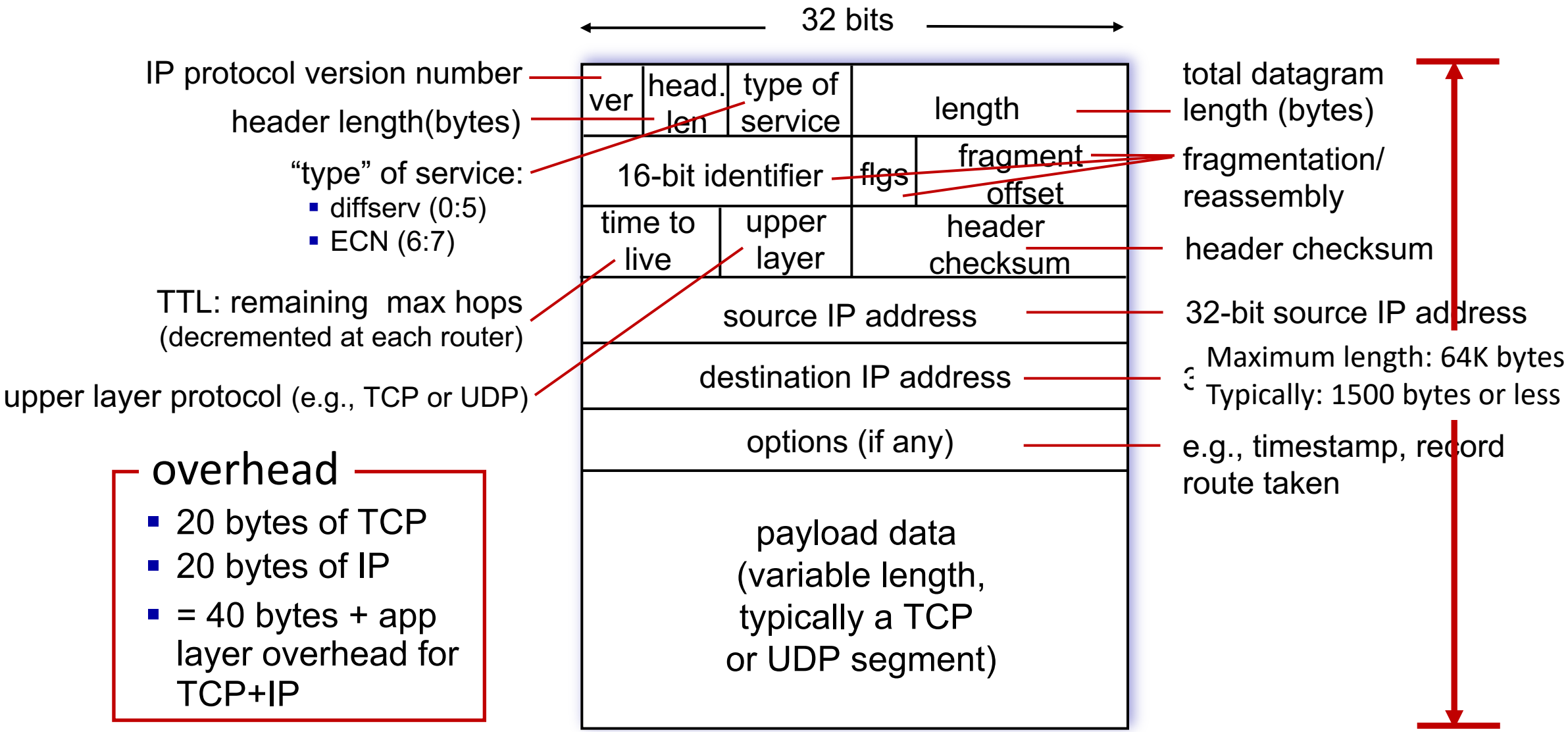
forwarding

routing

Network Layer: Where is it?



Network Layer Services and Protocols



overhead

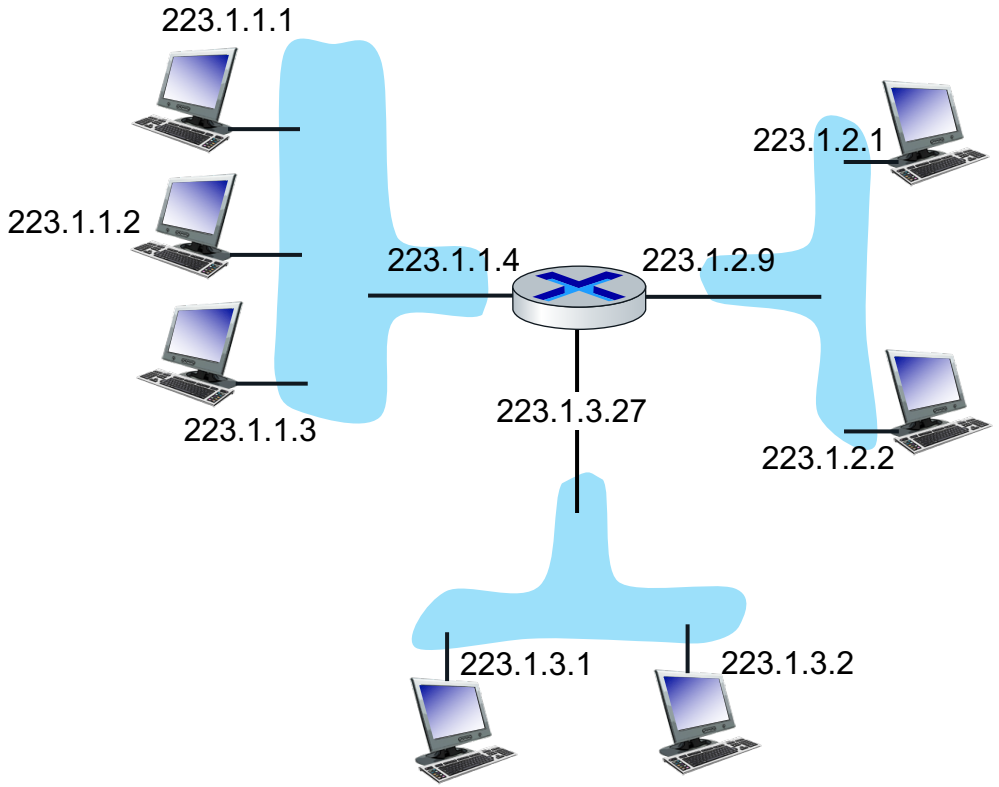
- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes + app layer overhead for TCP+IP

IP Addressing: Introduction

IP address: 32-bit identifier associated with each host or router *interface*

interface: connection between host/router and physical link

- router's typically have multiple interfaces
- host typically has one or two interfaces (e.g., wired Ethernet, wireless 802.11)



dotted-decimal IP address notation:

223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

IP Addressing: Introduction

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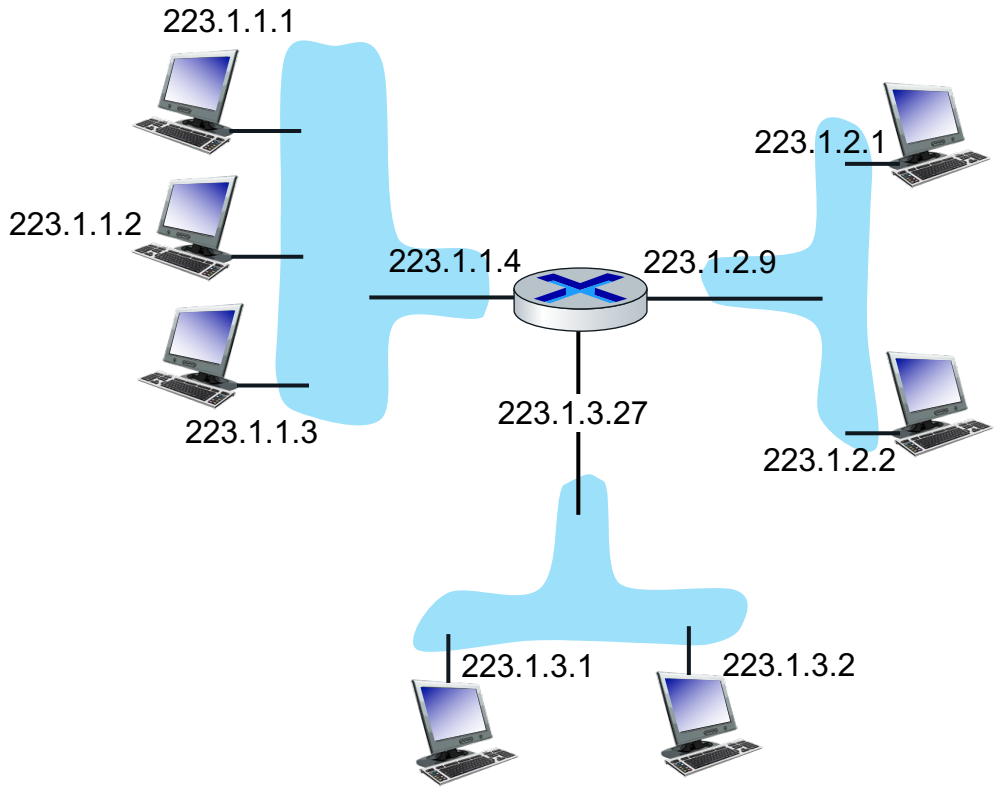


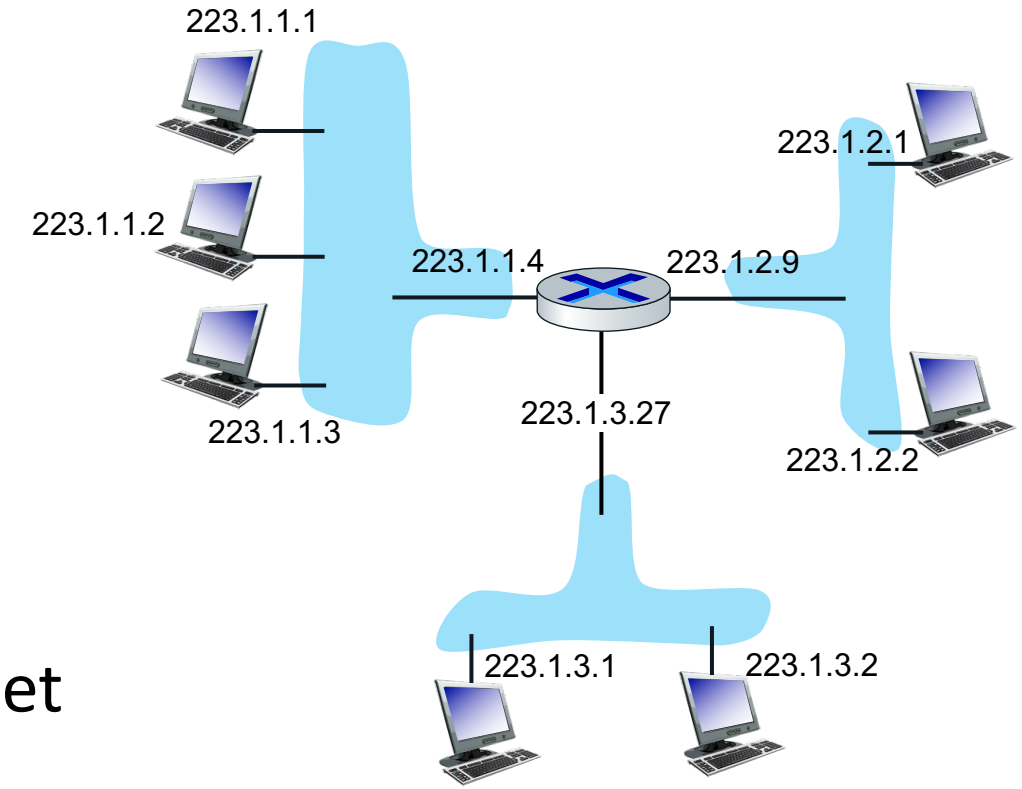
dotted-decimal IP address notation:

223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

Subnets

- *What's a subnet ?*
  - device interfaces that can physically reach each other without passing through an intervening router
- IP addresses have structure:
  - subnet part: devices in same subnet have common high order bits
  - host part: remaining low order bits

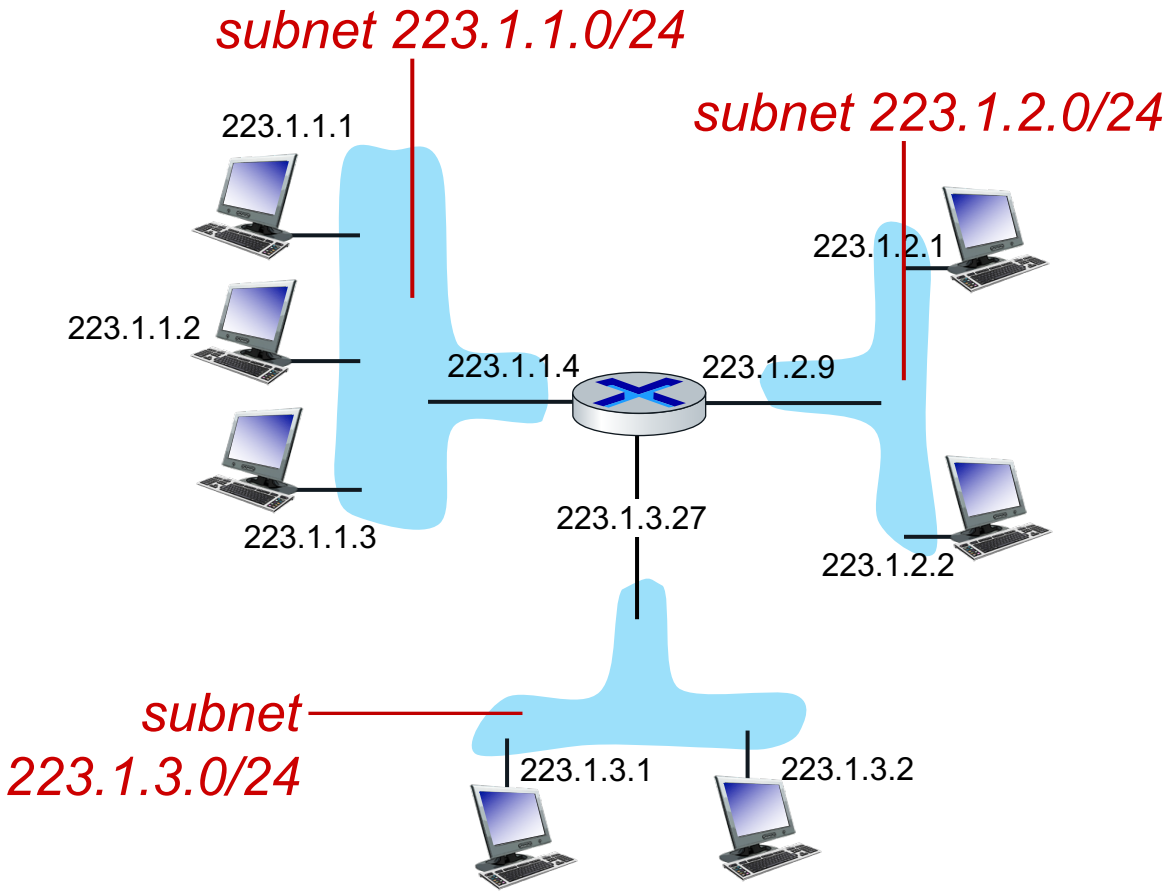


network consisting of 3 subnets

Subnets

Recipe for defining subnets:

- detach each interface from its host or router, creating "islands" of isolated networks
- each isolated network is called a *subnet*

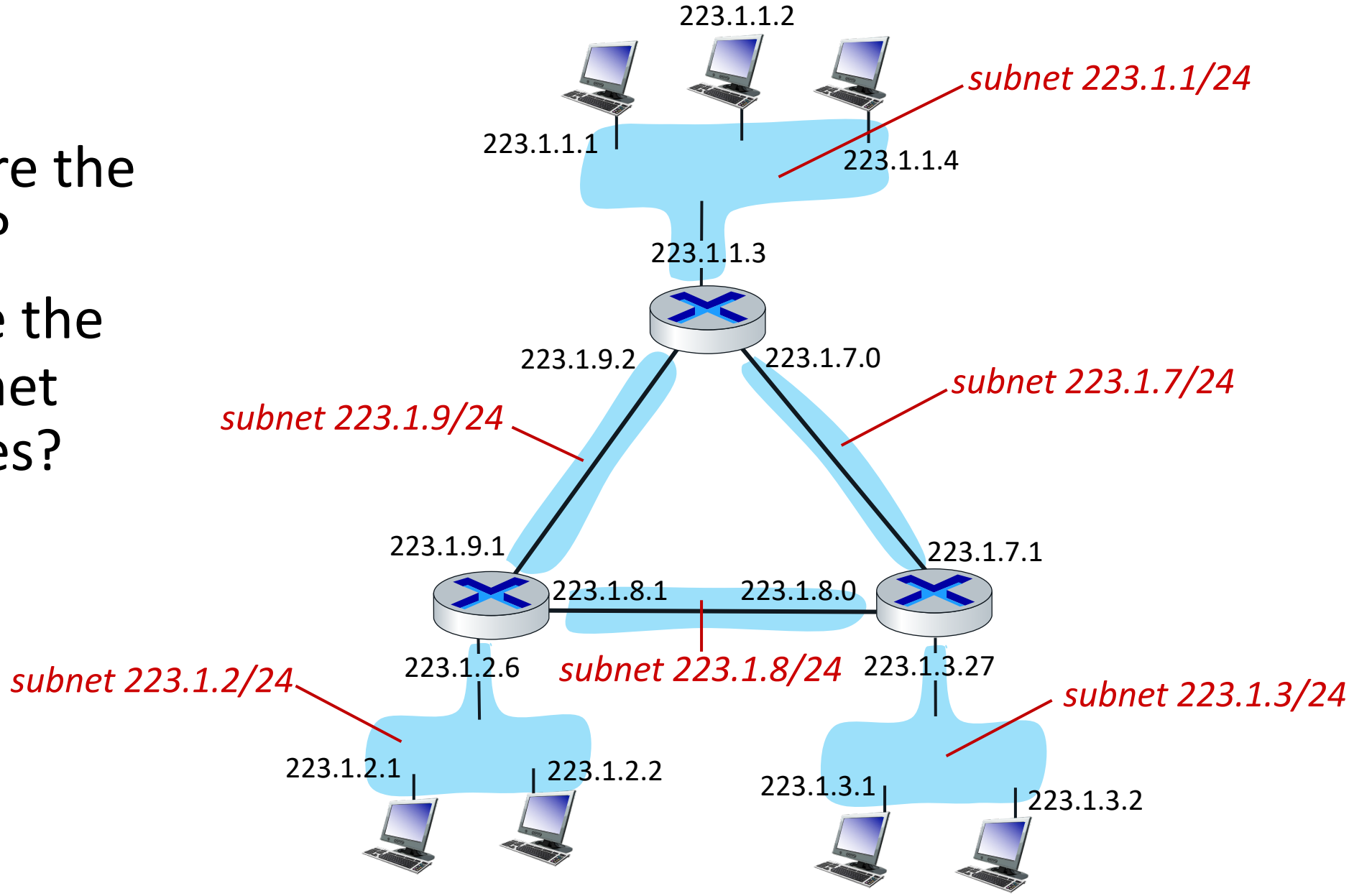


subnet mask: /24

(high-order 24 bits: subnet part of IP address)

Subnets

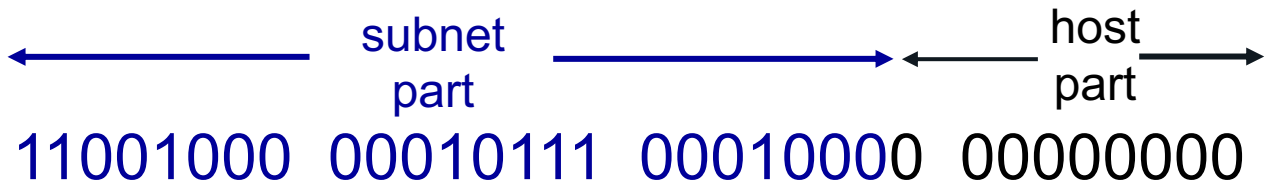
- where are the subnets?
- what are the /24 subnet addresses?



IP Addressing: CIDR

CIDR: Classless InterDomain Routing (pronounced “cider”)

- subnet portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in subnet portion of address



200.23.16.0/23

IP Addressing: Example

How is the subnet mask used to determine the network ID?

Computers determine the network ID by doing a logical AND operation between its IP address and subnet mask. A logical AND is an operation between two binary values. AND operations can have the following results:

0 AND 0 = 0

1 AND 0 = 0

0 AND 1 = 0

1 AND 1 = 1

IP Addressing: Example

Finding the subnet mask:

The logical AND operation between a computer's IP address and subnet mask looks like this: e.g. 172.31.100.0/16

10101100.00011111.01100100.00000110 (binary for 172.31.100.6)

AND

11111111.11111111.00000000.00000000 (binary for 255.255.0.0)

10101100.00011111.00000000.00000000 (binary for 172.31.0.0)

IP Addressing: How to get one?

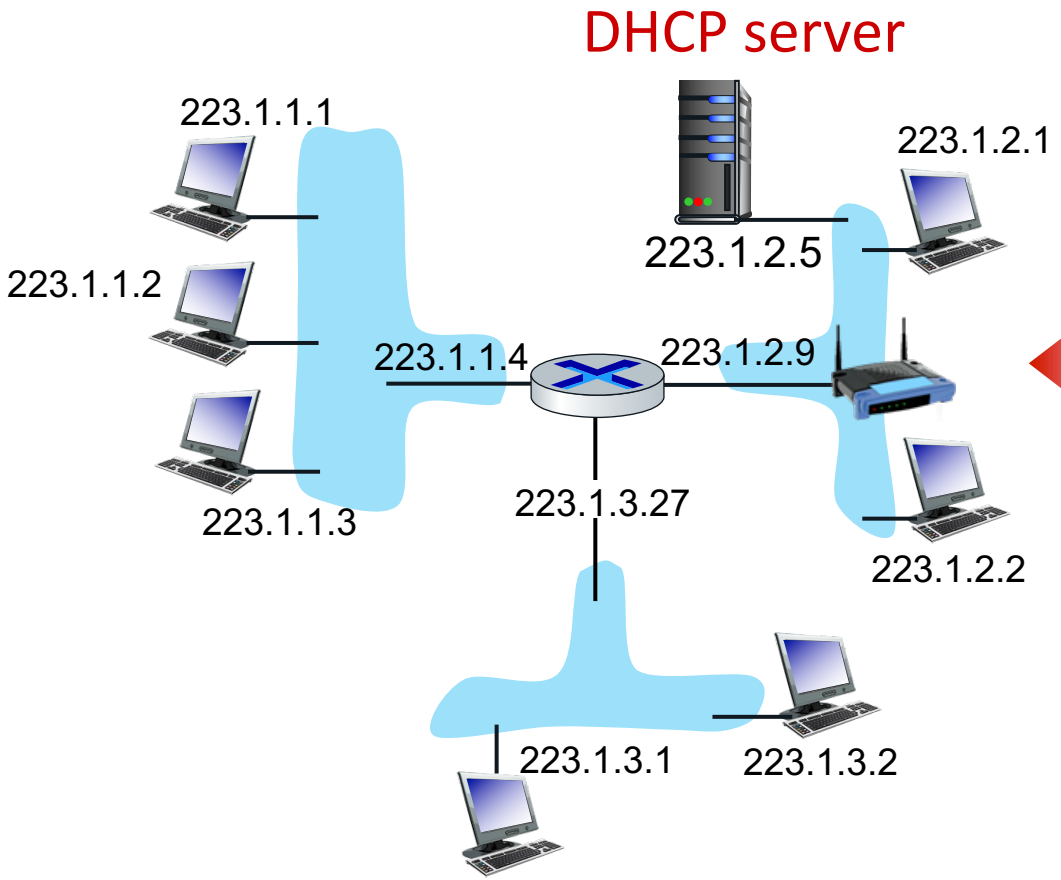
That's actually two questions:

1. Q: How does a *host* get IP address within its network (host part of address)?
2. Q: How does a *network* get IP address for itself (network part of address)

How does *host* get IP address?

- hard-coded by sysadmin in config file (e.g., /etc/rc.config in UNIX)
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - "plug-and-play"

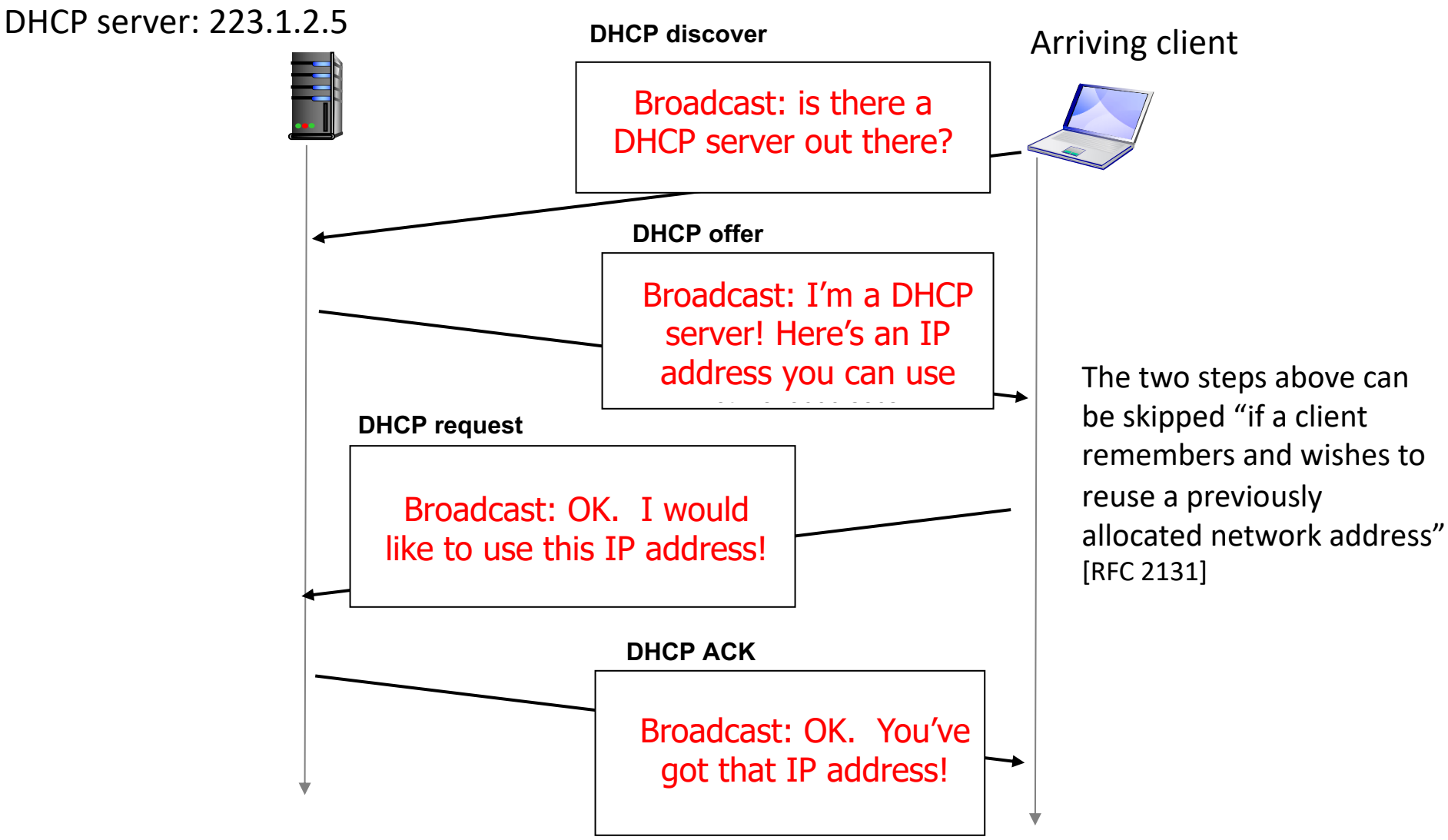
DHCP: Client-Server Scenario



Typically, DHCP server will be co-located in router, serving all subnets to which router is attached

arriving DHCP client needs address in this network

DHCP: Client-Server Scenario



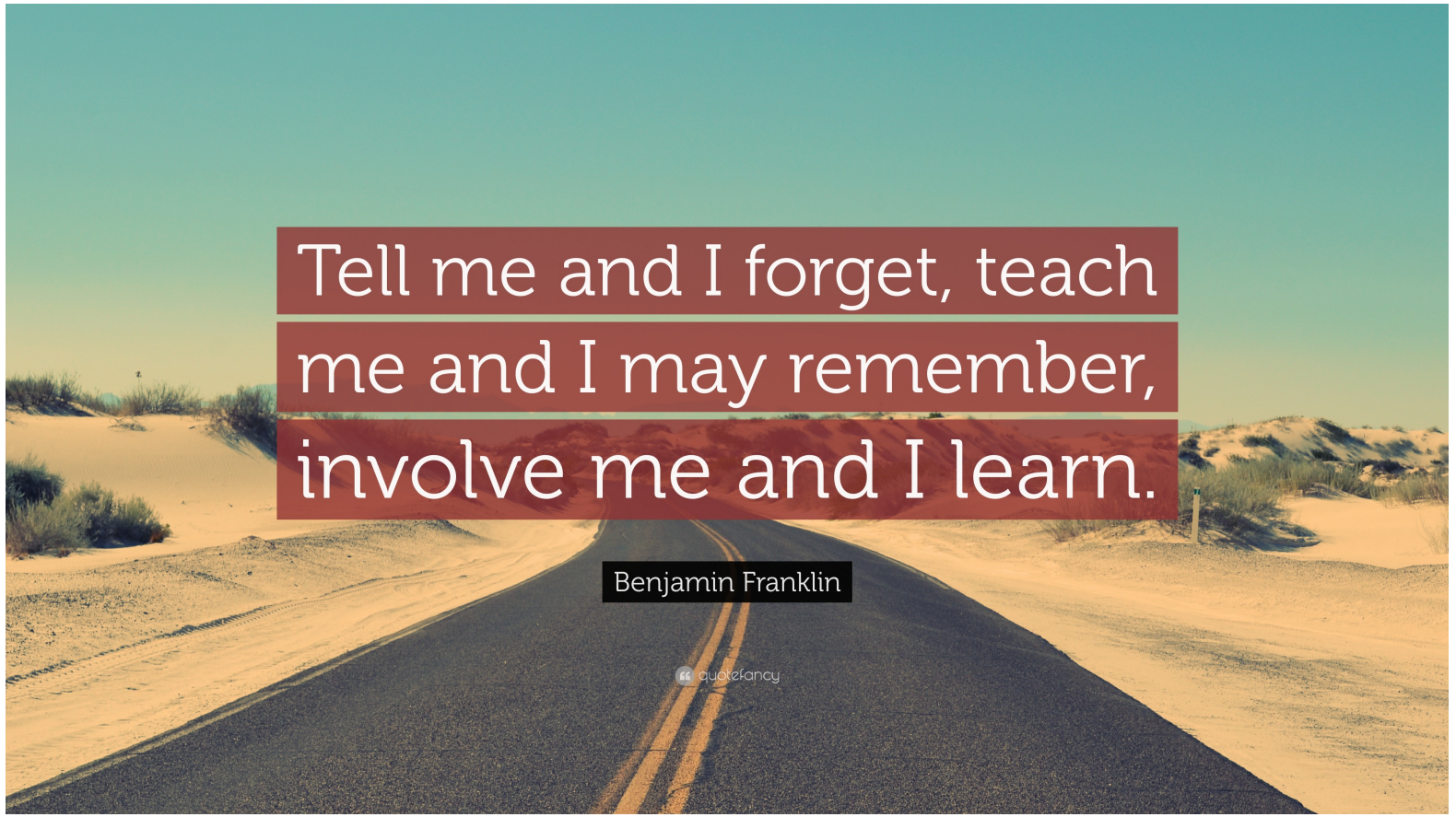
The two steps above can be skipped "if a client remembers and wishes to reuse a previously allocated network address" [RFC 2131]

DHCP: More than IP Address

DHCP can return more than just allocated IP address on subnet:

- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

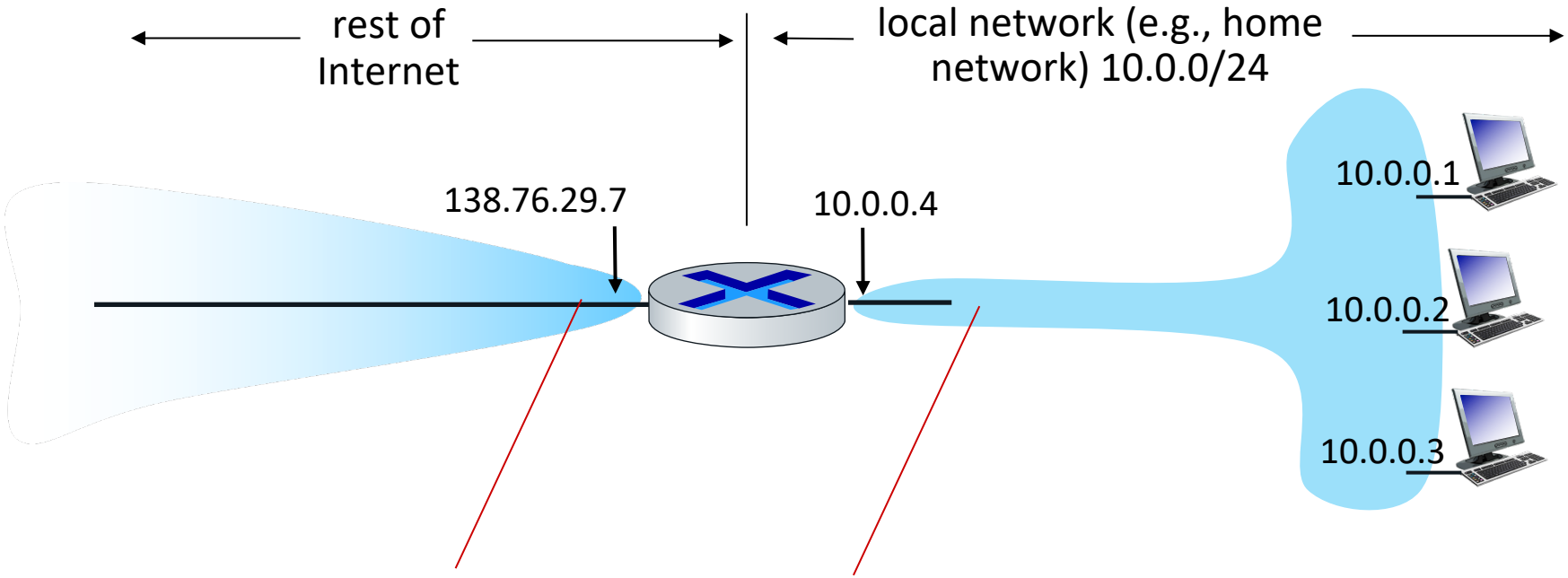
Thank You!


Tell me and I forget, teach
me and I may remember,
involve me and I learn.
Benjamin Franklin
quotefancy

NAT and IPV6

NAT: Network Address Translation

NAT: all devices in local network share just one IPv4 address as far as outside world is concerned



all datagrams *leaving* local network have *same* source NAT IP address: 138.76.29.7, but *different* source port numbers

datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: Network Address Translation

- all devices in local network have 32-bit addresses in a “private” IP address space (10/8, 172.16/12, 192.168/16 prefixes) that can only be used in local network
- advantages:
  - just one IP address needed from provider ISP for *all* devices
  - can change addresses of host in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - security: devices inside local net not directly addressable, visible by outside world

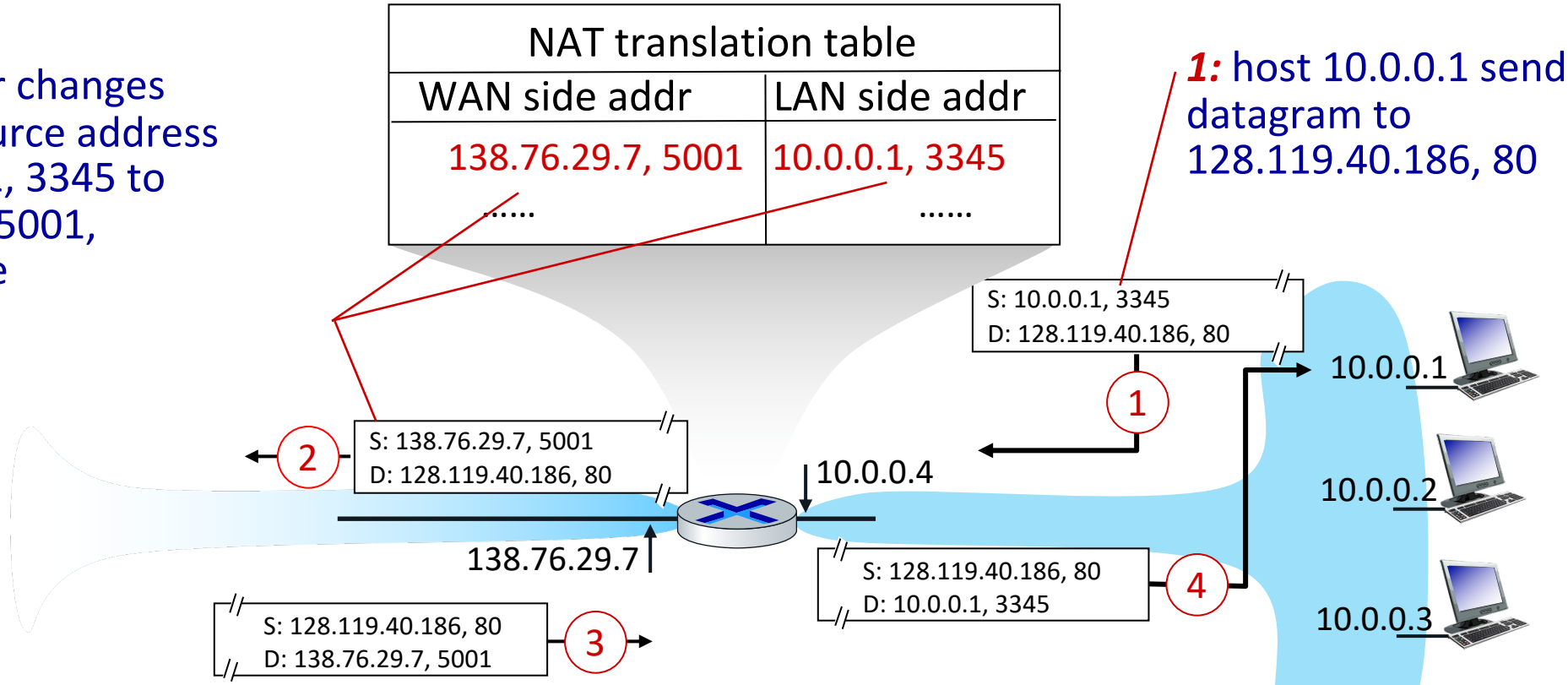
NAT: Network Address Translation

implementation: NAT router must (transparently):

- outgoing datagrams: replace (source IP address, port #) of every outgoing datagram to (NAT IP address, new port #)
  - remote clients/servers will respond using (NAT IP address, new port #) as destination address
- remember (in NAT translation table) every (source IP address, port #) to (NAT IP address, new port #) translation pair
- incoming datagrams: replace (NAT IP address, new port #) in destination fields of every incoming datagram with corresponding (source IP address, port #) stored in NAT table

NAT: Network Address Translation

2: NAT router changes datagram source address from 10.0.0.1, 3345 to 138.76.29.7, 5001, updates table



1: host 10.0.0.1 sends datagram to 128.119.40.186, 80

3: reply arrives, destination address: 138.76.29.7, 5001

NAT: Network Address Translation

- NAT has been controversial:
  - routers “should” only process up to layer 3
  - address “shortage” should be solved by IPv6
  - violates end-to-end argument (port # manipulation by network-layer device)
  - NAT traversal: what if client wants to connect to server behind NAT?
- but NAT is here to stay:
  - extensively used in home and institutional nets, 4G/5G cellular nets

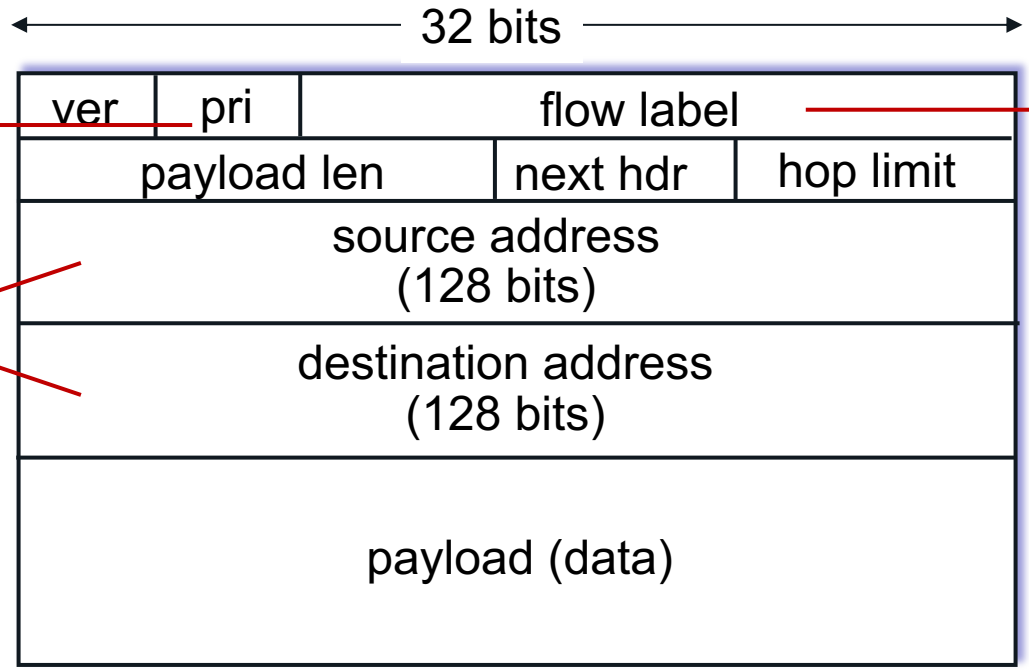
IPv6: Motivation

- initial motivation: 32-bit IPv4 address space would be completely allocated
- additional motivation:
  - speed processing/forwarding: 40-byte fixed length header
  - enable different network-layer treatment of “flows”

IPv6: Datagram Format

priority: identify priority among datagrams in flow

128-bit IPv6 addresses



flow label: identify datagrams in same "flow." (concept of "flow" not well defined).

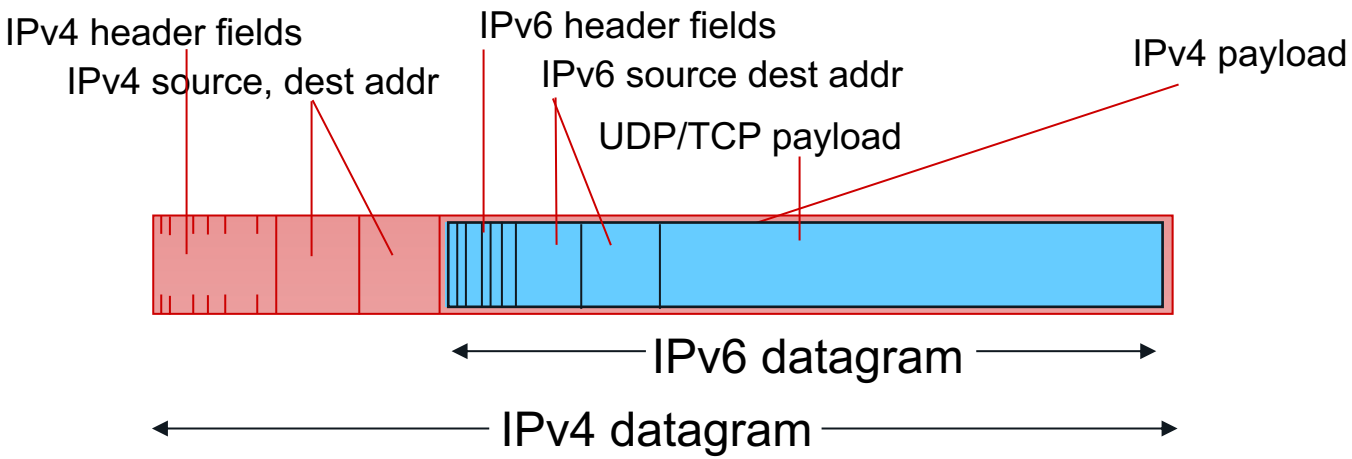
What's missing (compared with IPv4):

- no checksum (to speed processing at routers)
- no fragmentation/reassembly
- no options (available as upper-layer, next-header protocol at router)

Transition from IPv4 to IPv6

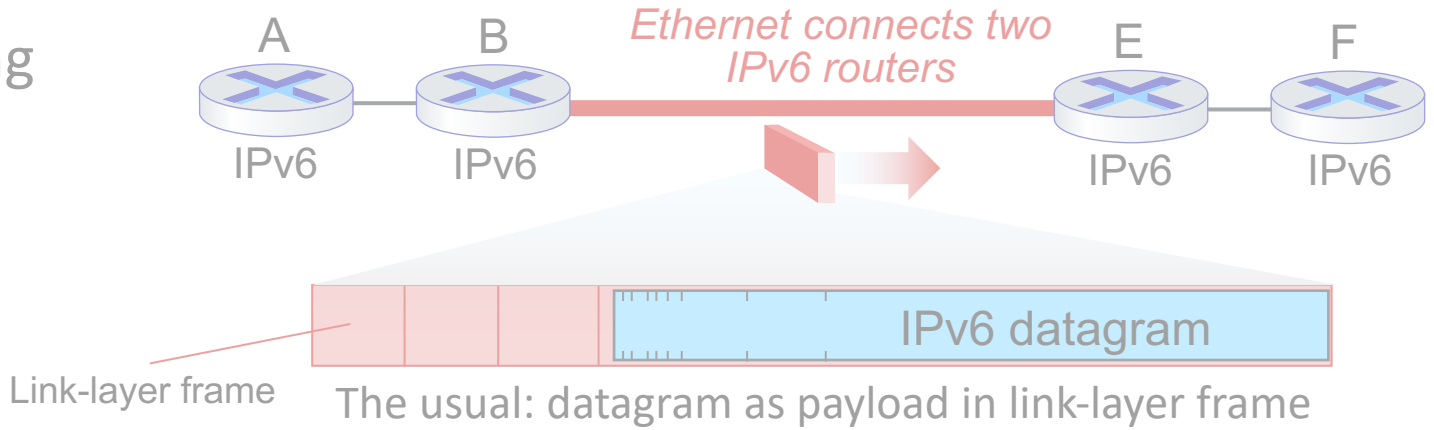
not all routers can be upgraded simultaneously
- no “flag days”
- how will network operate with mixed IPv4 and IPv6 routers?

- tunneling: IPv6 datagram carried as *payload* in IPv4 datagram among IPv4 routers (“packet within a packet”)
  - tunneling used extensively in other contexts (4G/5G)

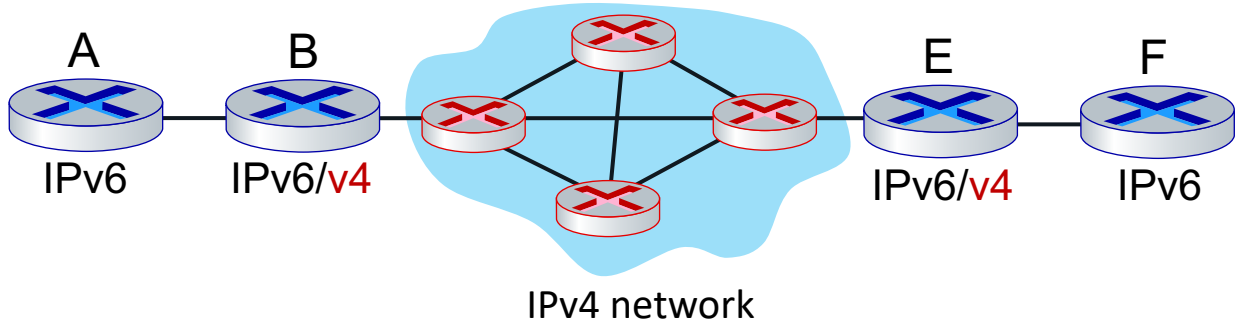


Tunning and Encapsulation

Ethernet connecting two IPv6 routers:



IPv4 network connecting two IPv6 routers



Tunning and Encapsulation

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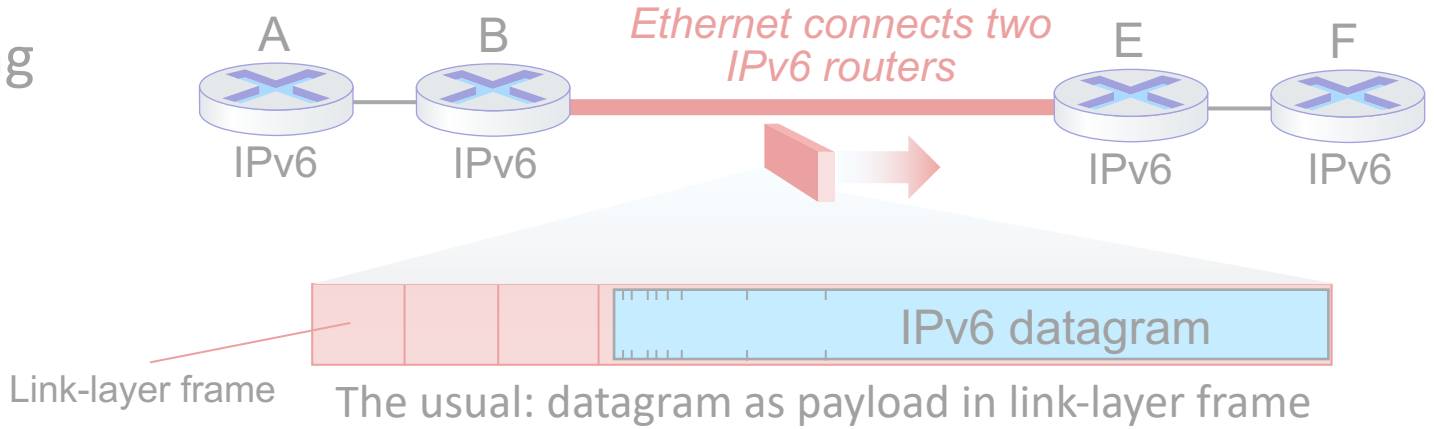
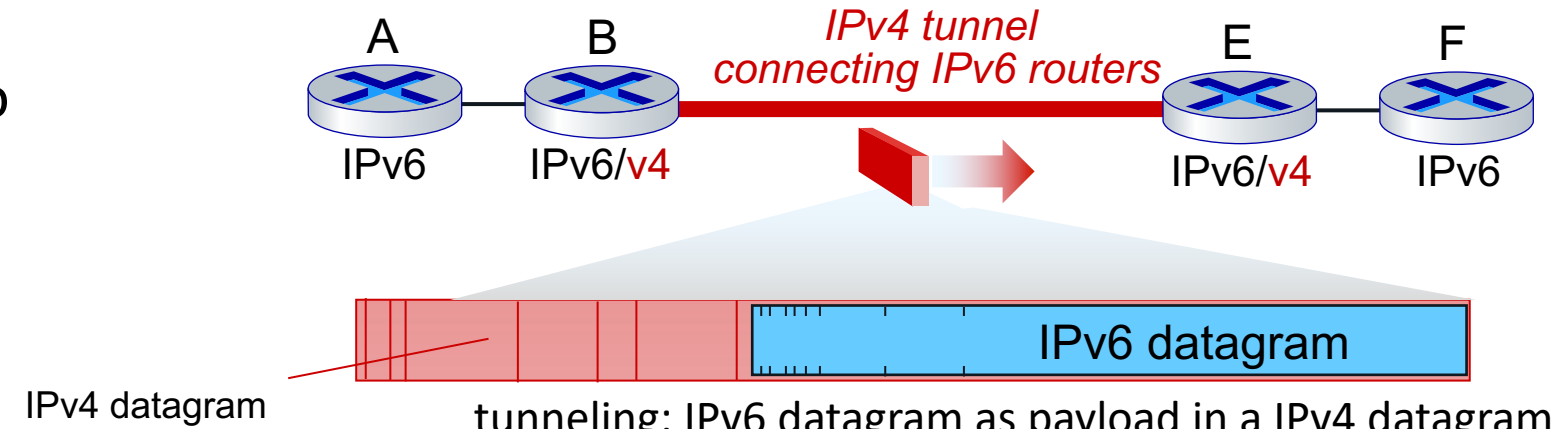


The usual: datagram as payload in link-layer frame

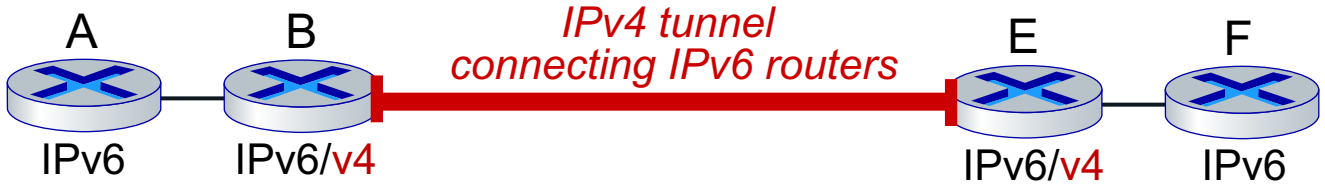
IPv4 tunnel connecting two IPv6 routers



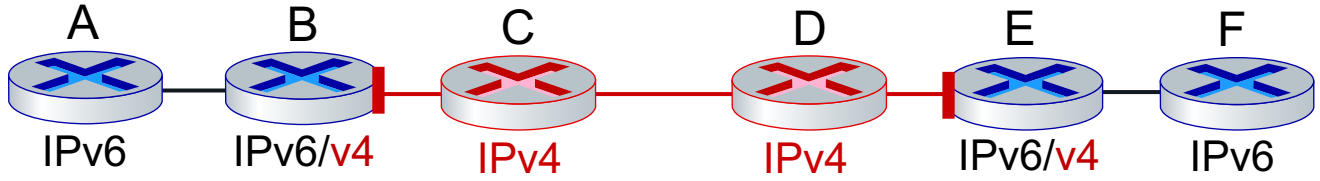
tunneling: IPv6 datagram as payload in a IPv4 datagram

Tunning

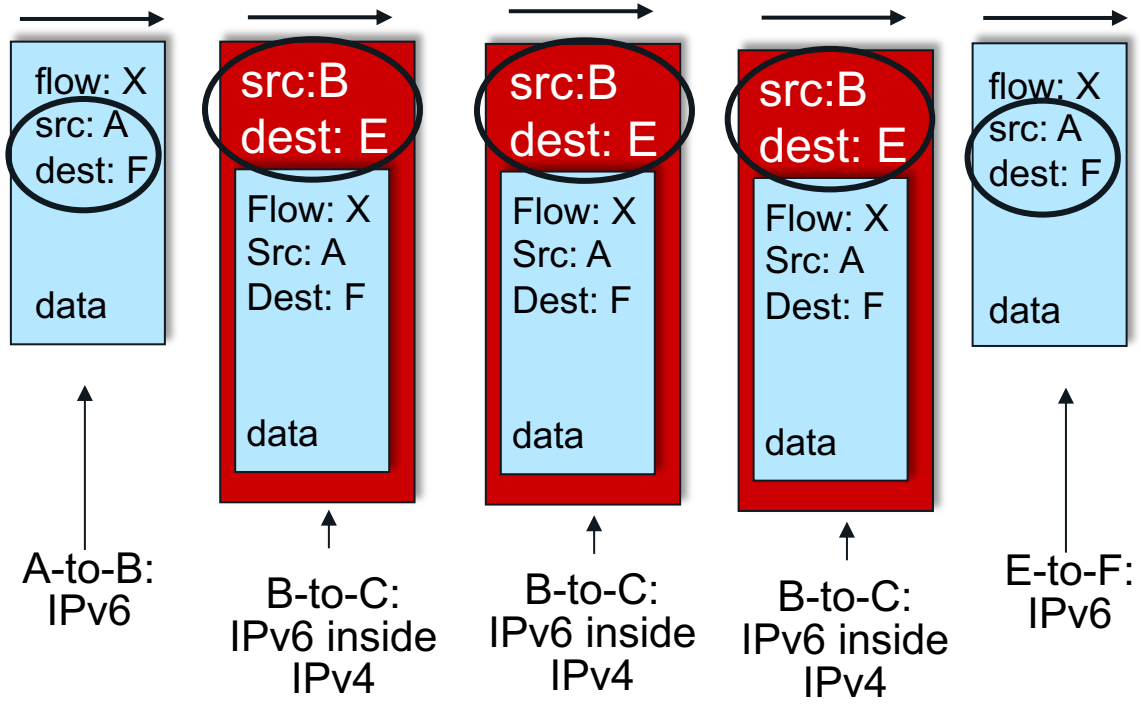
logical view:



physical view:



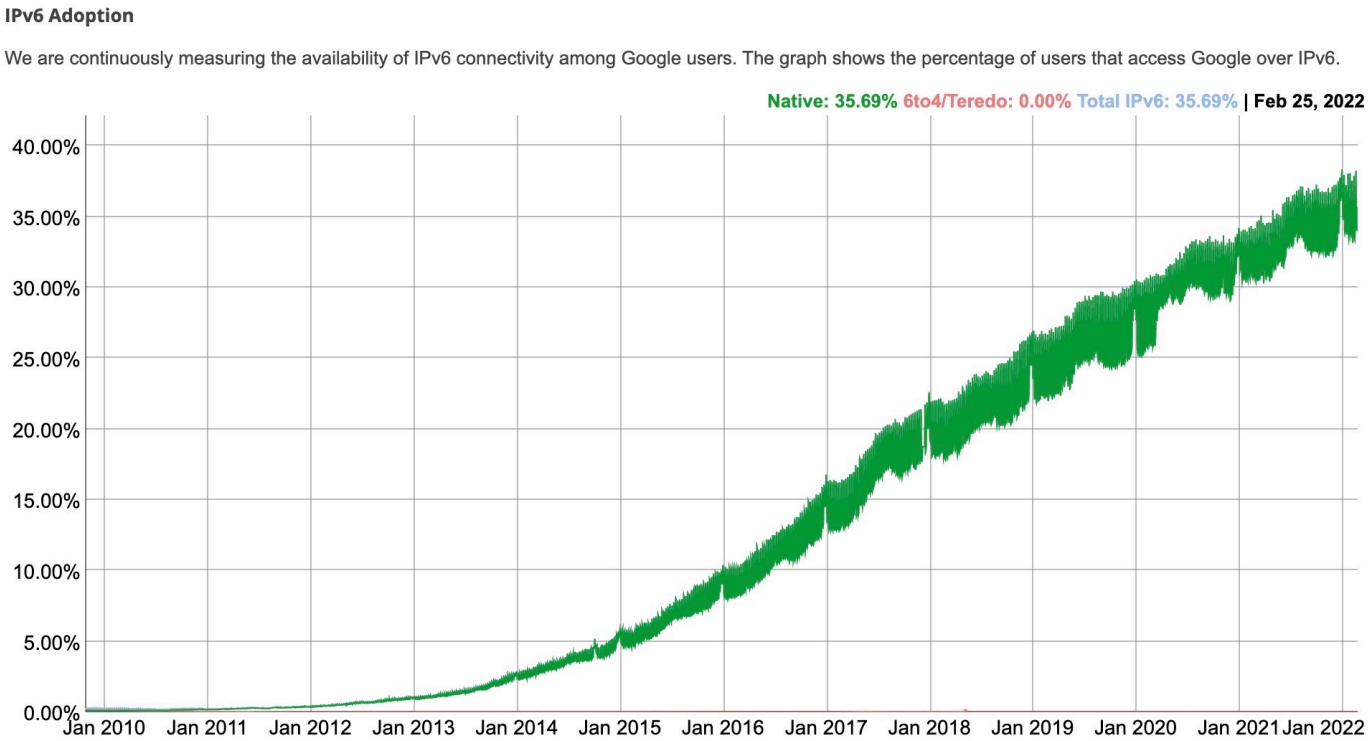
Note source and destination addresses!

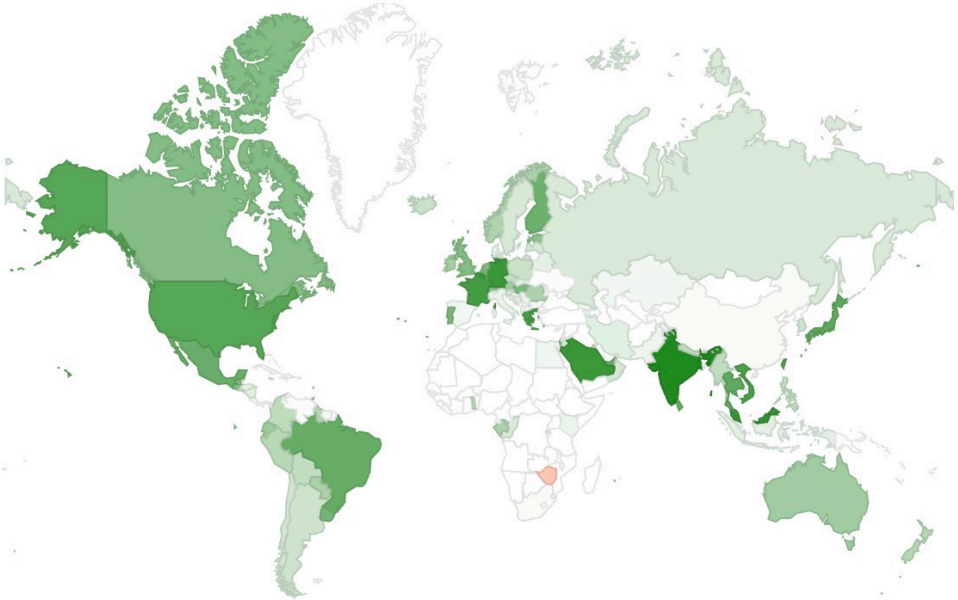


IPv6 Adoption

Google[1]: ~ 35% of clients access services via IPv6

NIST: 1/3 of all US government domains are IPv6 capable





1

https://www.google.com/intl/en/ipv6/statistics.html

Thank You!


Tell me and I
forget. Teach me
and I remember.
Involve me and I
learn.
~ Benjamin Franklin

Routing Protocols and Dijkstra's algorithm

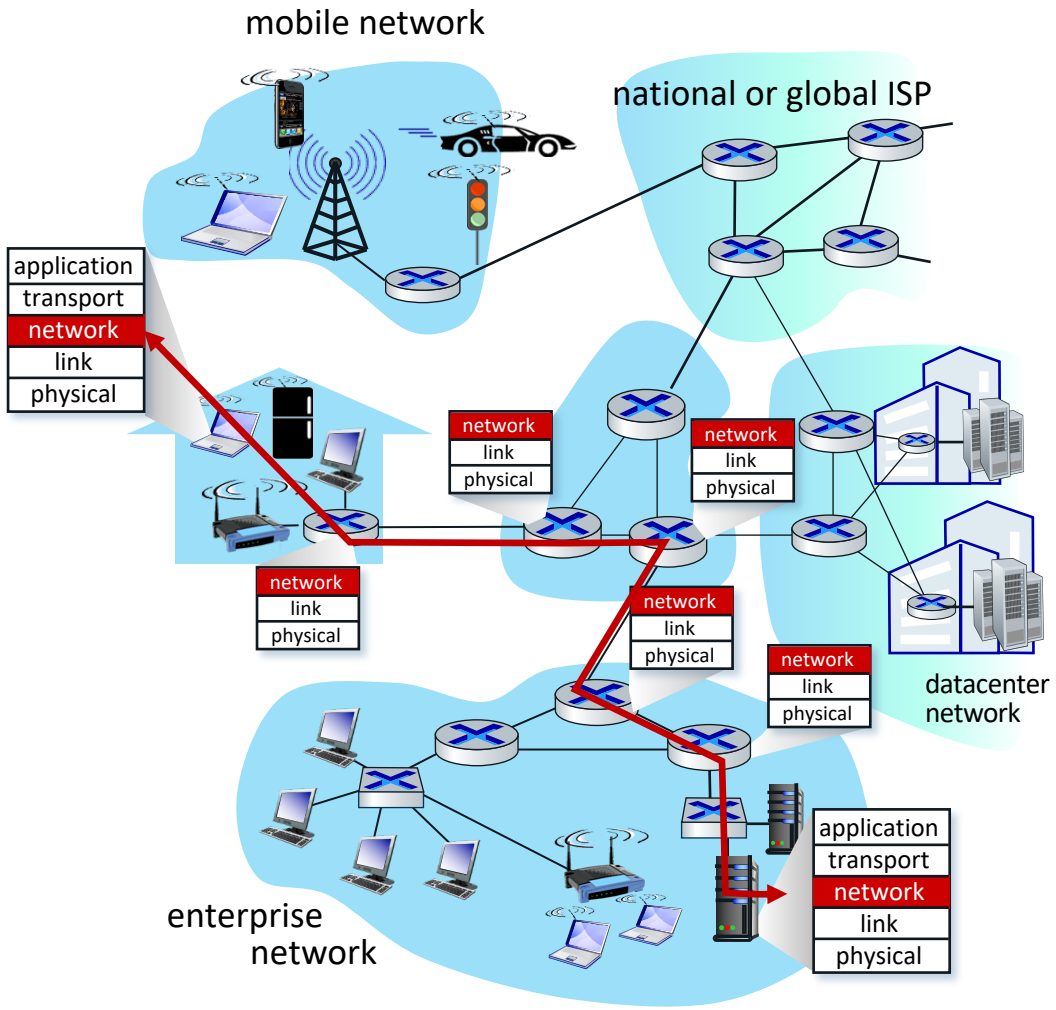
Routing Protocols

Routing protocol goal: determine "good" paths (equivalently, routes), from sending hosts to receiving host, through network of routers

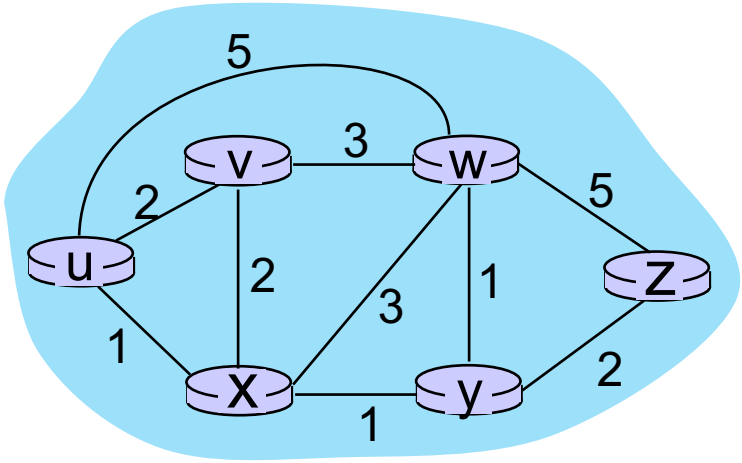
path: sequence of routers packets traverse from given initial source host to final destination host

"good": least "cost", "fastest", "least congested"

routing: a "top-10" networking challenge!



Graph Abstraction: Link Costs



$c_{a,b}$: cost of *direct* link connecting *a* and *b*

e.g., $c_{w,z} = 5$, $c_{u,z} = \infty$

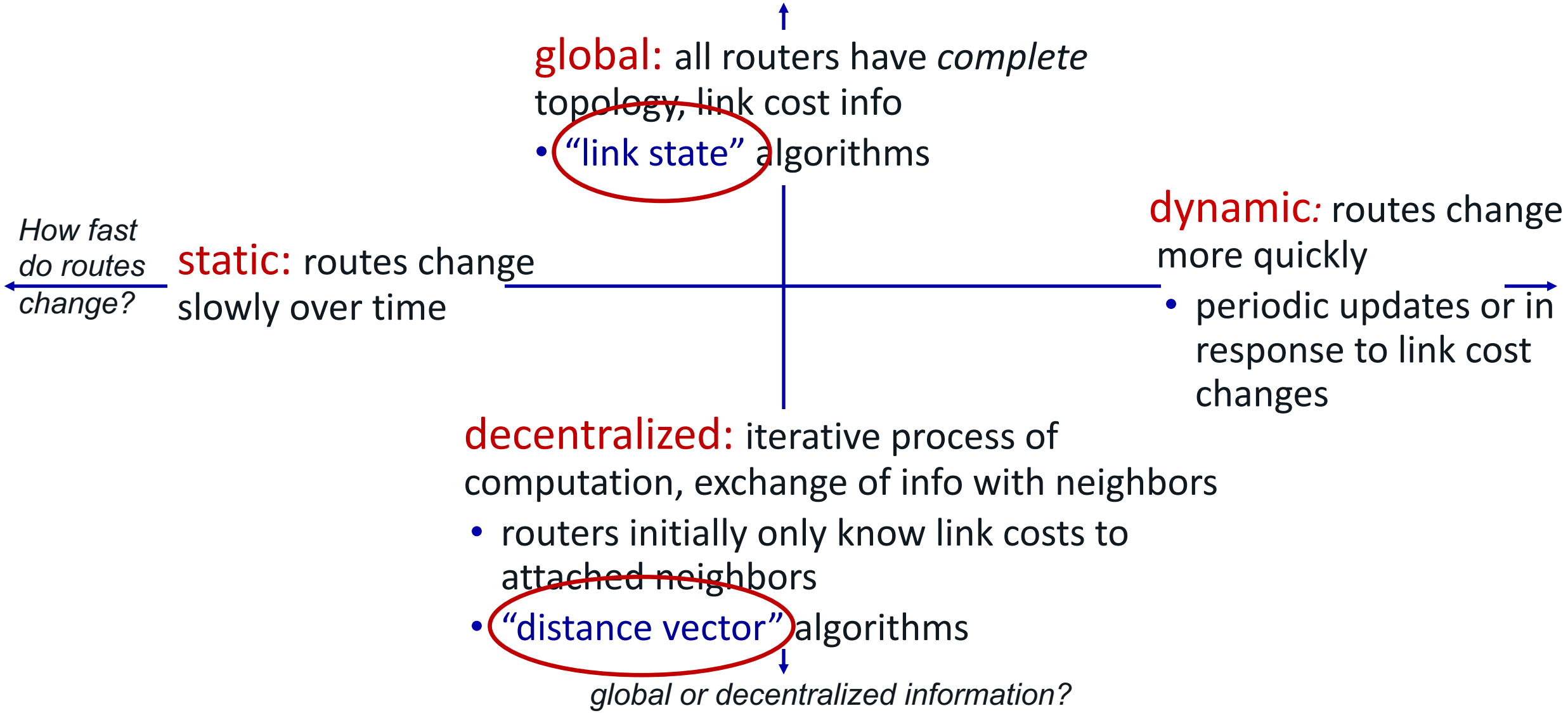
cost defined by network operator: could always be 1, or inversely related to bandwidth, or inversely related to congestion

graph: *G = (N,E)*

N: set of routers = { *u, v, w, x, y, z* }

E: set of links ={ *(u,v), (u,x), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z)* }

Routing Algorithm Classification



Dijkstra's Link-State Routing Algorithm

- centralized: network topology, link costs known to *all* nodes
  - accomplished via "link state broadcast"
  - all nodes have same info
- computes least cost paths from one node ("source") to all other nodes
  - gives *forwarding table* for that node
- iterative: after *k* iterations, know least cost path to *k* destinations

notation

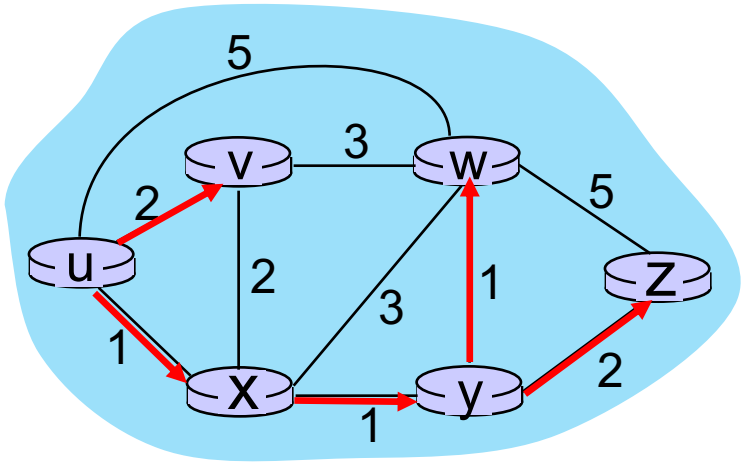
- $c_{x,y}$: direct link cost from node *x* to *y*; = ∞ if not direct neighbors
- *D(v): current* estimate of cost of least-cost-path from source to destination *v*
- *p(v):* predecessor node along path from source to *v*
- *N':* set of nodes whose least-cost-path *definitively* known

Dijkstra's Link-State Routing Algorithm

```
1  Initialization:
2    N' = {u}                    /* compute least cost path from u to all other nodes */
3    for all nodes v
4      if v adjacent to u        /* u initially knows direct-path-cost only to  direct neighbors  */
5        then D(v) = c_u,v       /* but may not be minimum cost!                                  */
6      else D(v) = ∞
7
8    Loop
9      find w not in N' such that D(w) is a minimum
10     add w to N'
11     update D(v) for all v adjacent to w and not in N' :
12       D(v) = min ( D(v),  D(w) + c_w,v )
13     /* new least-path-cost to v is either old least-cost-path to v or known
14     least-cost-path to w plus direct-cost from w to v */
15   until all nodes in N'
```

Dijkstra's Algorithm: Example

Step	N'	v D(v),p(v)	w D(w),p(w)	x D(x),p(x)	y D(y),p(y)	z D(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					

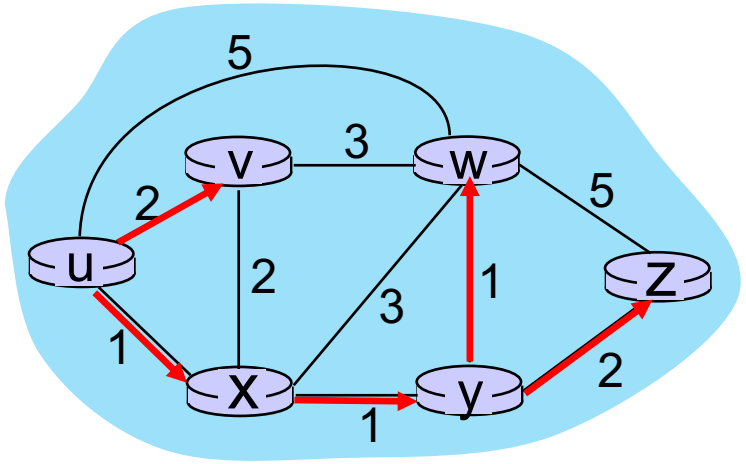


Initialization (step 0): For all a: if *a* adjacent to then $D(a) = c_{u,a}$

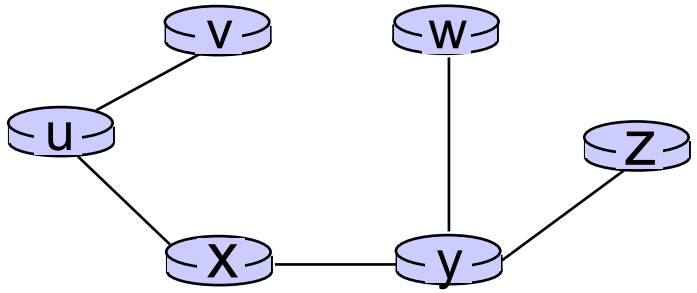
find *a* not in *N'* such that *D(a)* is a minimum
add *a* to *N'*
update *D(b)* for all *b* adjacent to *a* and not in *N'* :

$$D(b) = \min (D(b), D(a) + c_{a,b})$$

Dijkstra's Algorithm: Example



resulting least-cost-path tree from u:



resulting forwarding table in u:

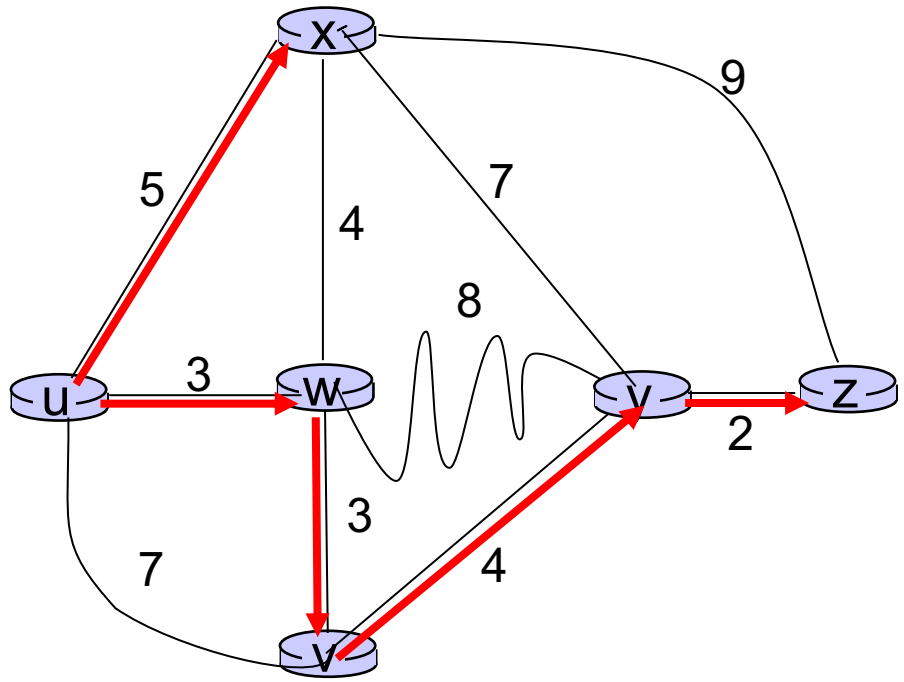
destination	outgoing link
v	(u,v)
x	(u,x)
y	(u,x)
w	(u,x)
x	(u,x)

route from *u* to *v* directly

route from u to all other destinations via *x*

Dijkstra's Algorithm: Another Example

Step	N′	v D(v), p(v)	w D(w), p(w)	x D(x), p(x)	y D(y), p(y)	z D(z), p(z)
0	u	7,u	3,u	5,u	∞	∞
1	uw	6,w		5,u	11,w	∞
2	uwx	6,w			11,w	14,x
3	uwxv				10,v	14,x
4	uwxvy					12,y
5	uwxvyz					



notes:

- construct least-cost-path tree by tracing predecessor nodes
- ties can exist (can be broken arbitrarily)

Thank You!


Tell me and I
forget. Teach me
and I remember.
Involve me and I
learn.
~ Benjamin Franklin

Distance Vector Algorithm

Distance Vector Algorithm

Based on *Bellman-Ford* (BF) equation (dynamic programming):

Bellman-Ford equation

Let $D_x(y)$: cost of least-cost path from x to y.
Then:

$$D_x(y) = \min_v \{ c_{x,v} + D_v(y) \}$$

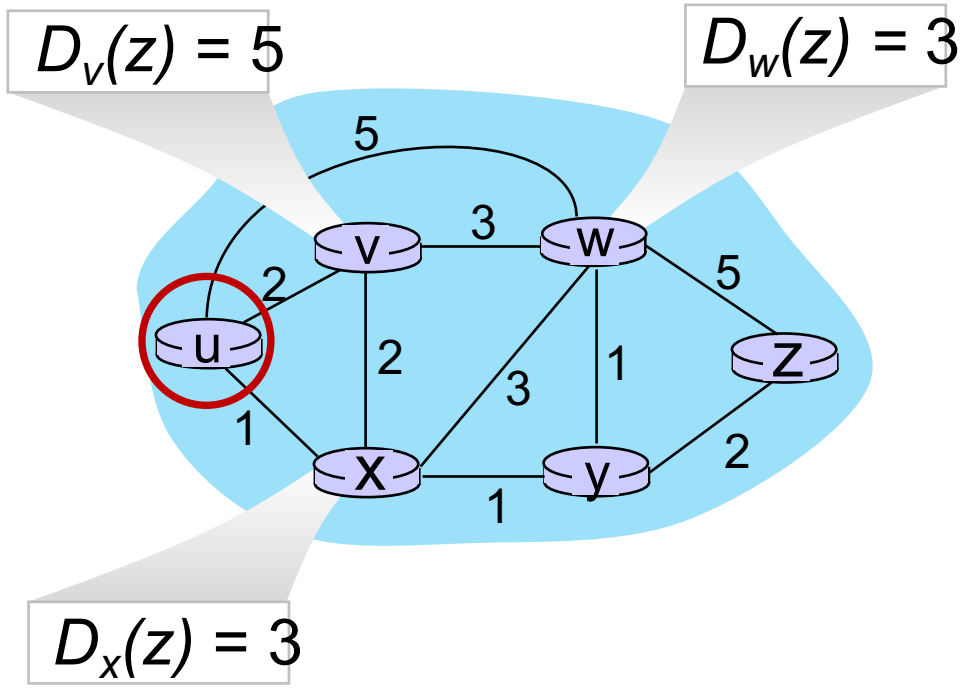
v's estimated least-cost-path cost to y

min taken over all neighbors v of x

direct cost of link from x to v

Bellman-Form Example

Suppose that *u*'s neighboring nodes, *x,v,w,* know that for destination *z*:



Bellman-Ford equation says:

$$D_u(z) = \min \{ c_{u,v} + D_v(z), \; c_{u,x} + D_x(z), \; c_{u,w} + D_w(z) \}$$
$$= \min \{2 + 5, \; 1 + 3, \; 5 + 3\} = 4$$

node achieving minimum (x) is next hop on estimated least-cost path to destination (z)

Distance Vector Algorithm

key idea:

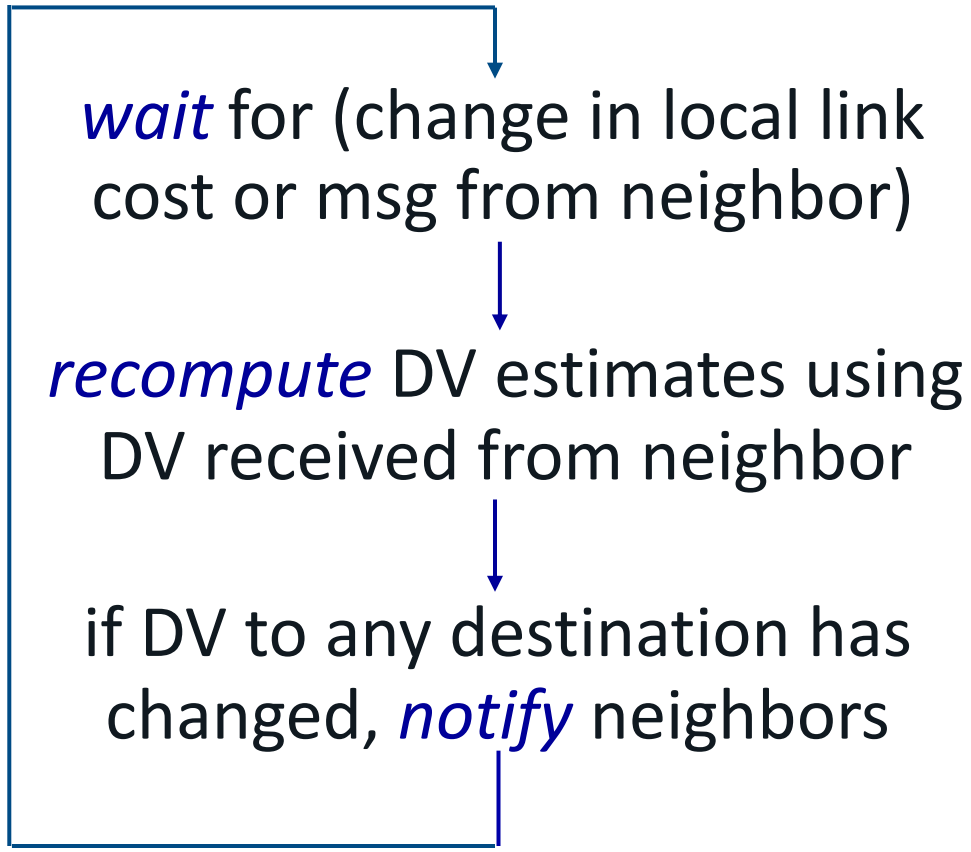
- from time-to-time, each node sends its own distance vector estimate to neighbors
- when *x* receives new DV estimate from any neighbor, it updates its own DV using B-F equation:

$$D_x(y) \leftarrow min_v\{c_{x,v} + D_v(y)\} \text{ for each node } y \in N$$

- under minor, natural conditions, the estimate $D_x(y)$ *converge to the actual least cost* $d_x(y)$

Distance Vector Algorithm

each node:



iterative, asynchronous: each local iteration caused by:

- local link cost change
- DV update message from neighbor

distributed, self-stopping: each node notifies neighbors *only* when its DV changes

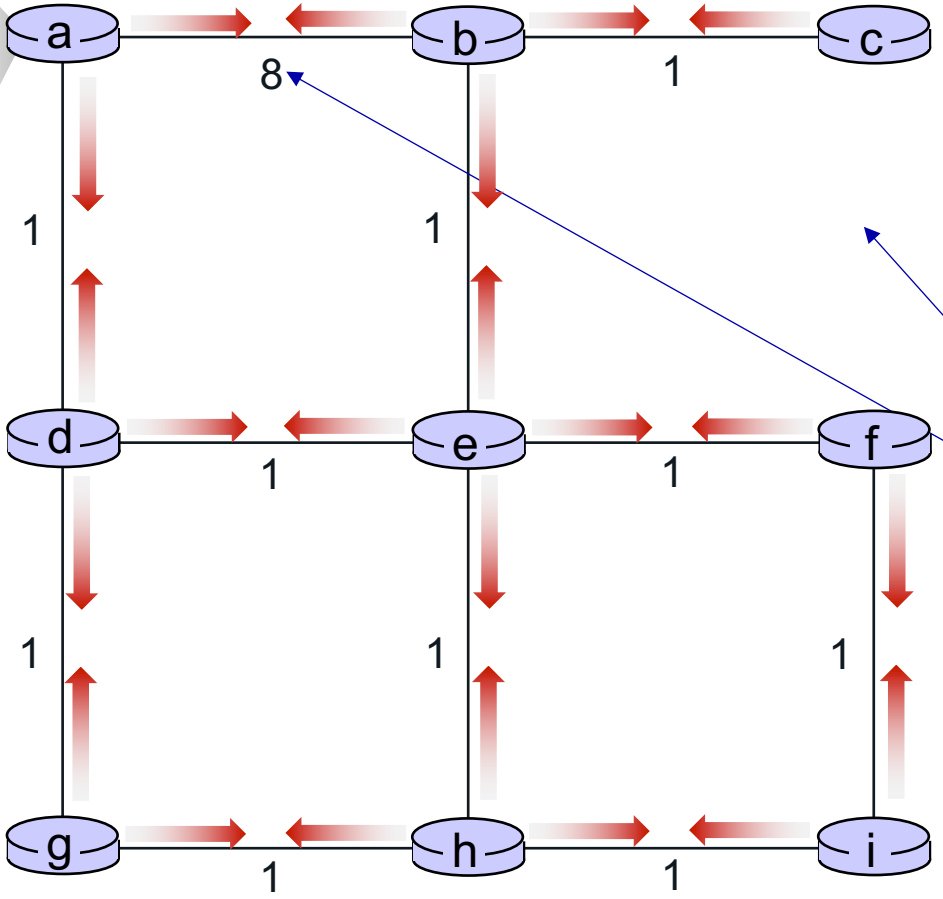
- neighbors then notify their neighbors – *only if necessary*
- no notification received, no actions taken!

Distance Vector: Example-Iteration

t=0

- All nodes have distance estimates to nearest neighbors (only)
- All nodes send their local distance vector to their neighbors

DV in a:
$D_a(a)=0$
$D_a(b) = 8$
$D_a(c) = \infty$
$D_a(d) = 1$
$D_a(e) = \infty$
$D_a(f) = \infty$
$D_a(g) = \infty$
$D_a(h) = \infty$
$D_a(i) = \infty$



A few asymmetries:

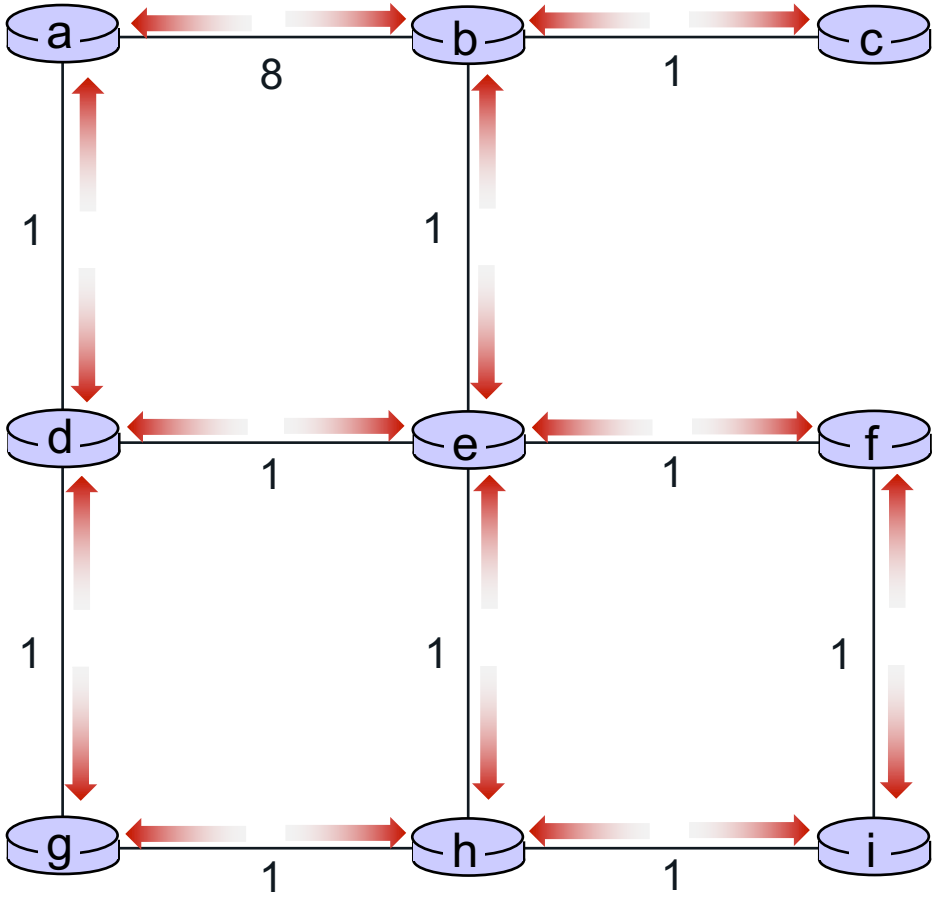
- missing link
- larger cost

Distance Vector: Example-Iteration

t=1

All nodes:

- receive distance vectors from neighbors
- compute their new local distance vector
- send their new local distance vector to neighbors

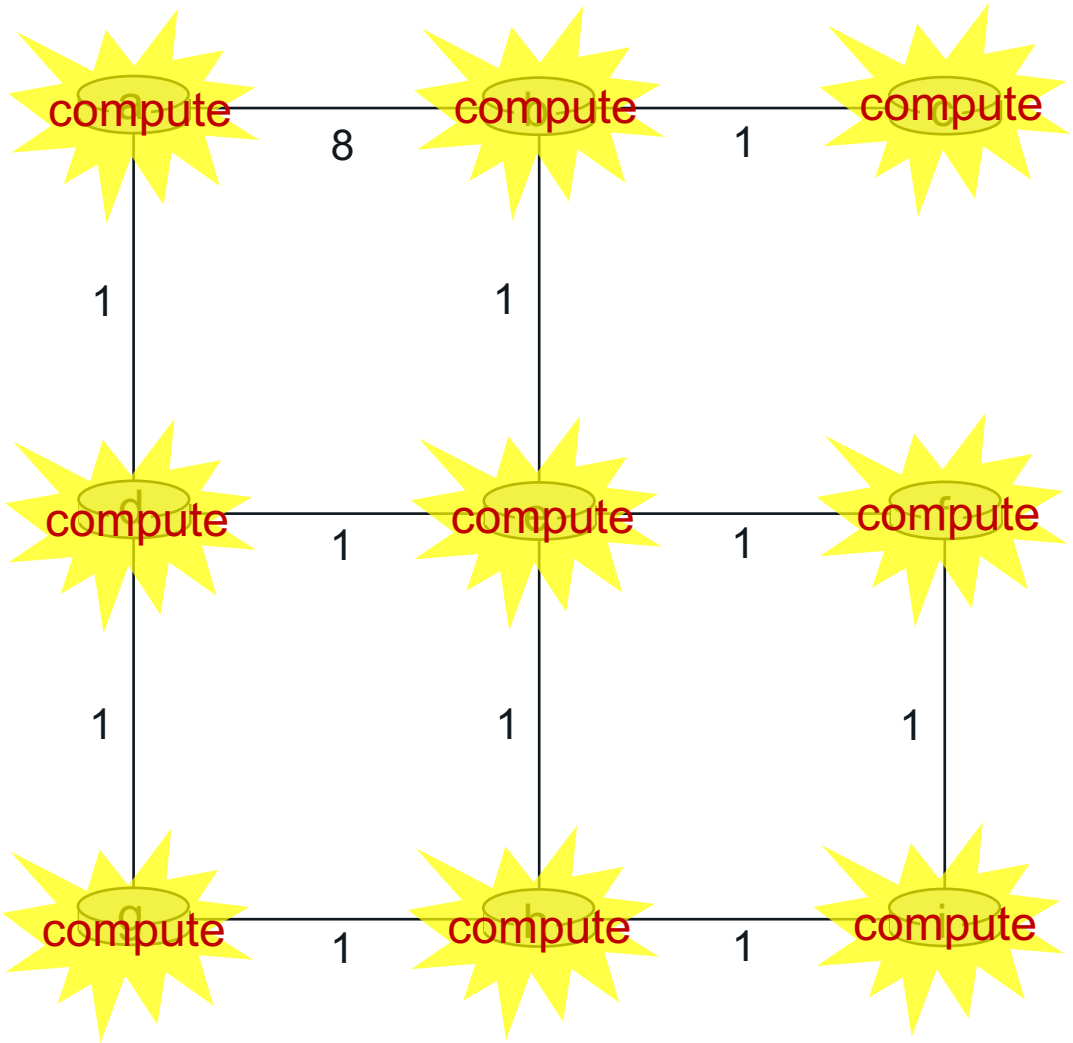


Distance Vector: Example-Iteration

t=1

All nodes:

- receive distance vectors from neighbors
- compute their new local distance vector
- send their new local distance vector to neighbors

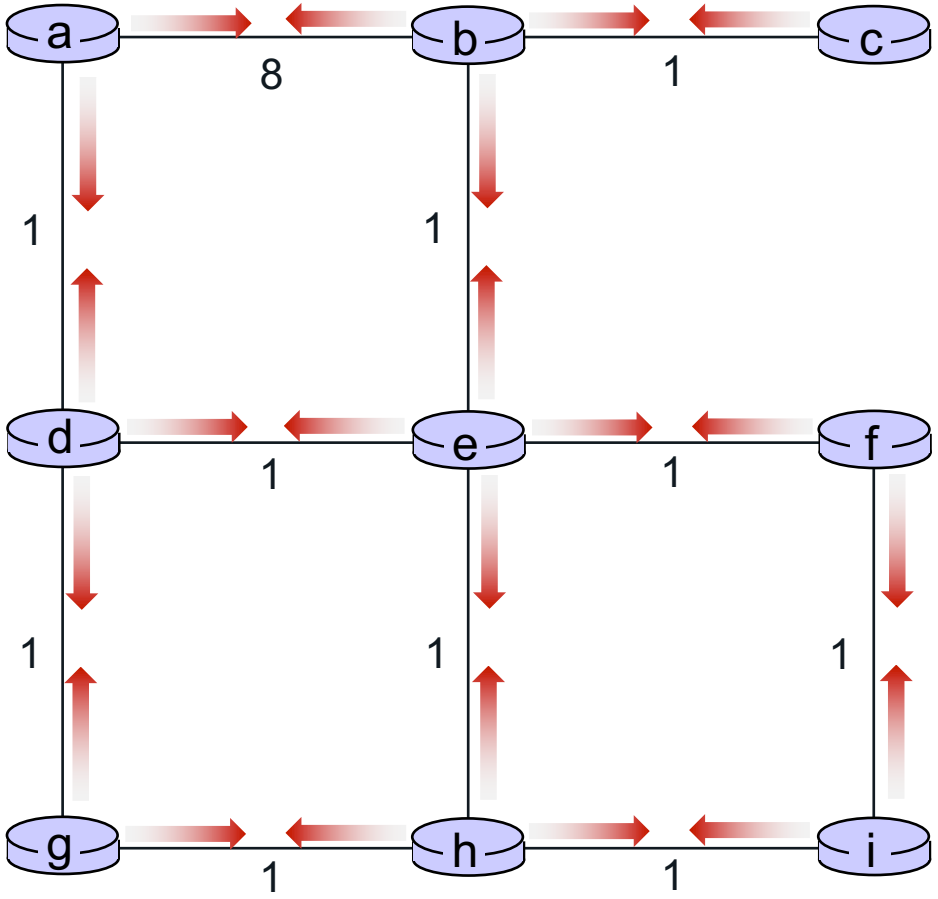


Distance Vector: Example-Iteration

t=1

All nodes:

- receive distance vectors from neighbors
- compute their new local distance vector
- send their new local distance vector to neighbors

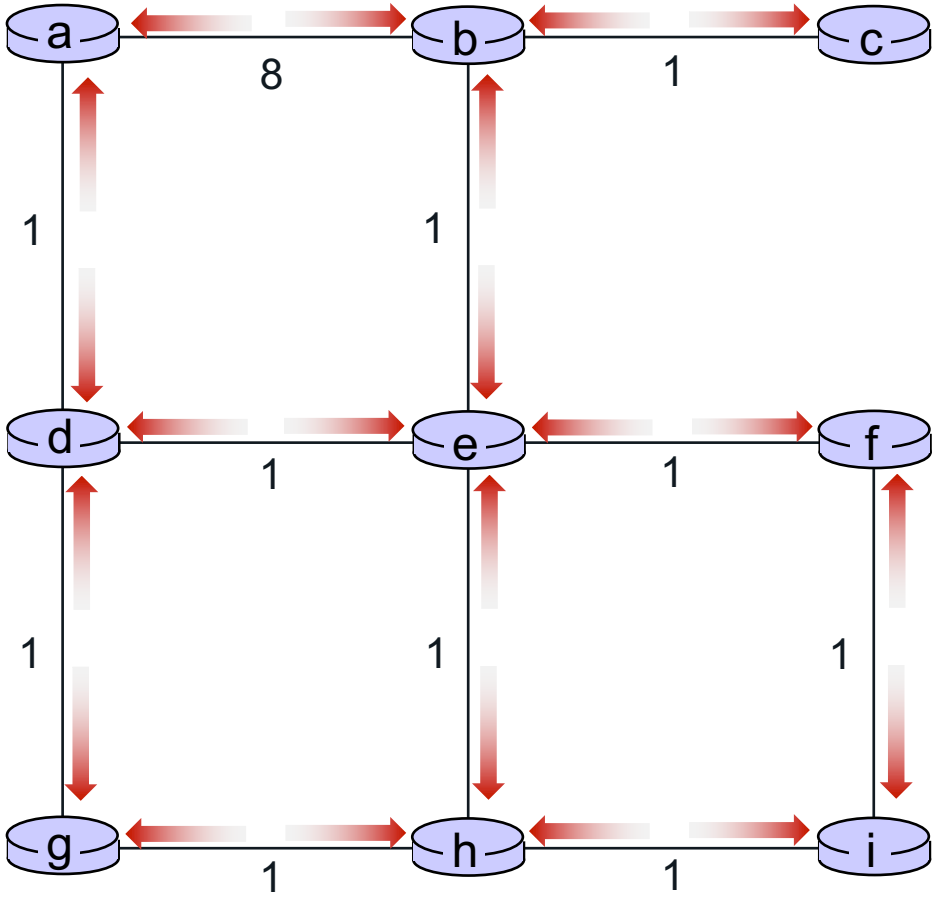


Distance Vector: Example-Iteration

t=2

All nodes:

- receive distance vectors from neighbors
- compute their new local distance vector
- send their new local distance vector to neighbors

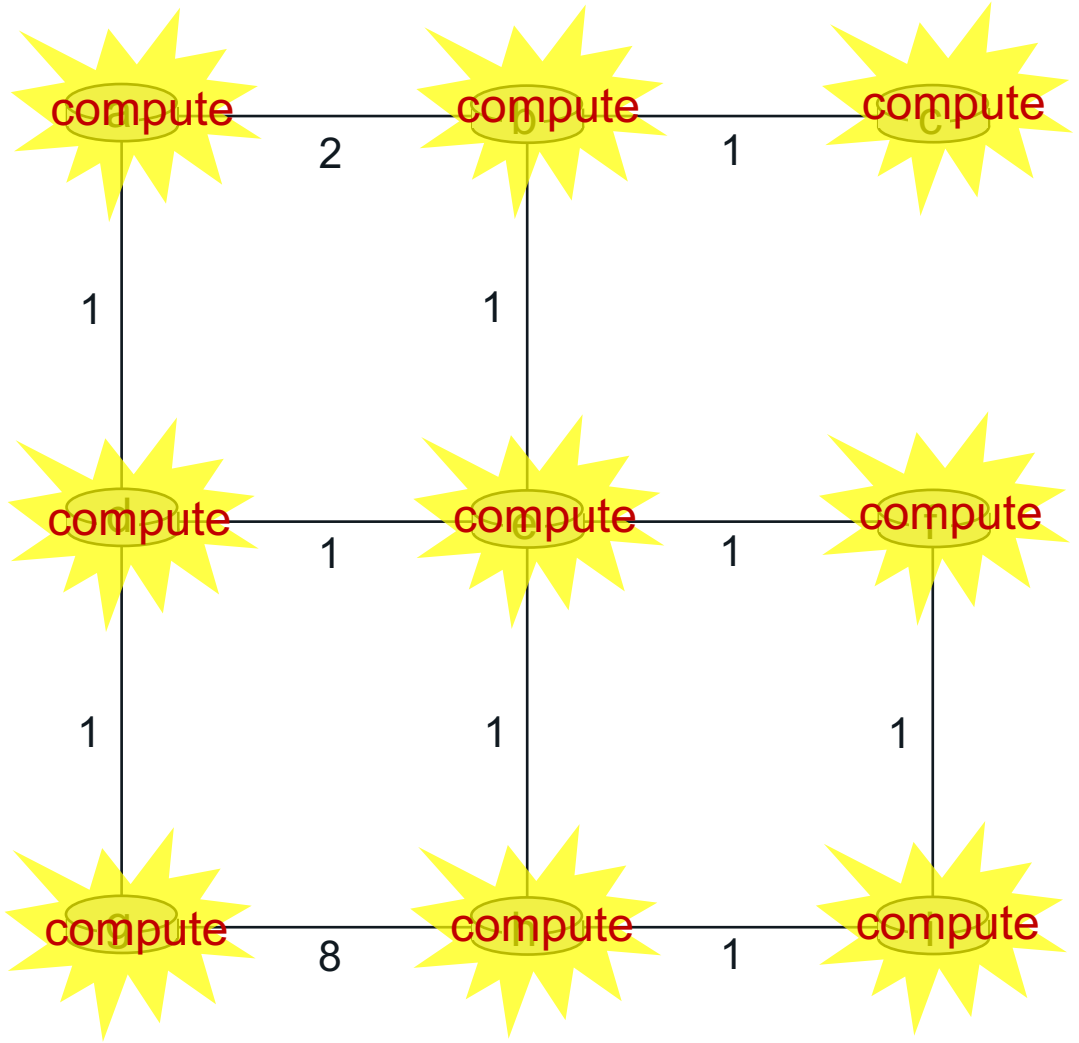


Distance Vector: Example-Iteration

t=2

All nodes:

- receive distance vectors from neighbors
- compute their new local distance vector
- send their new local distance vector to neighbors

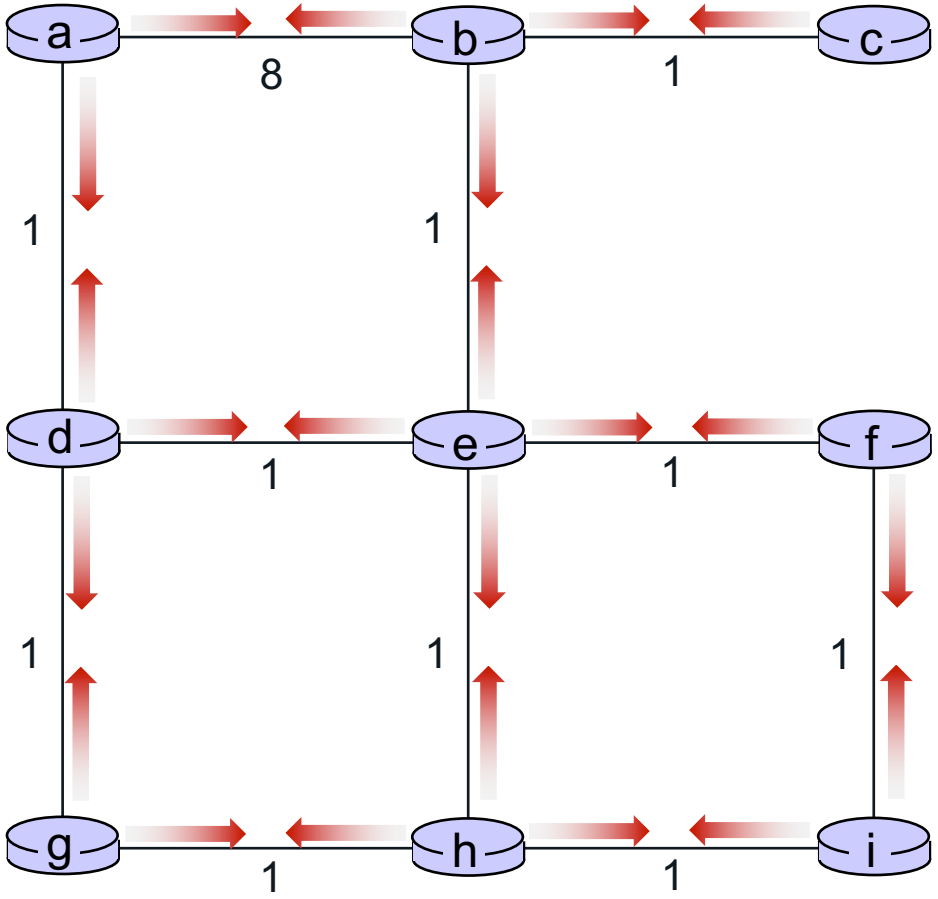


Distance Vector: Example-Iteration

t=2

All nodes:

- receive distance vectors from neighbors
- compute their new local distance vector
- send their new local distance vector to neighbors



Distance Vector: Example-Iteration

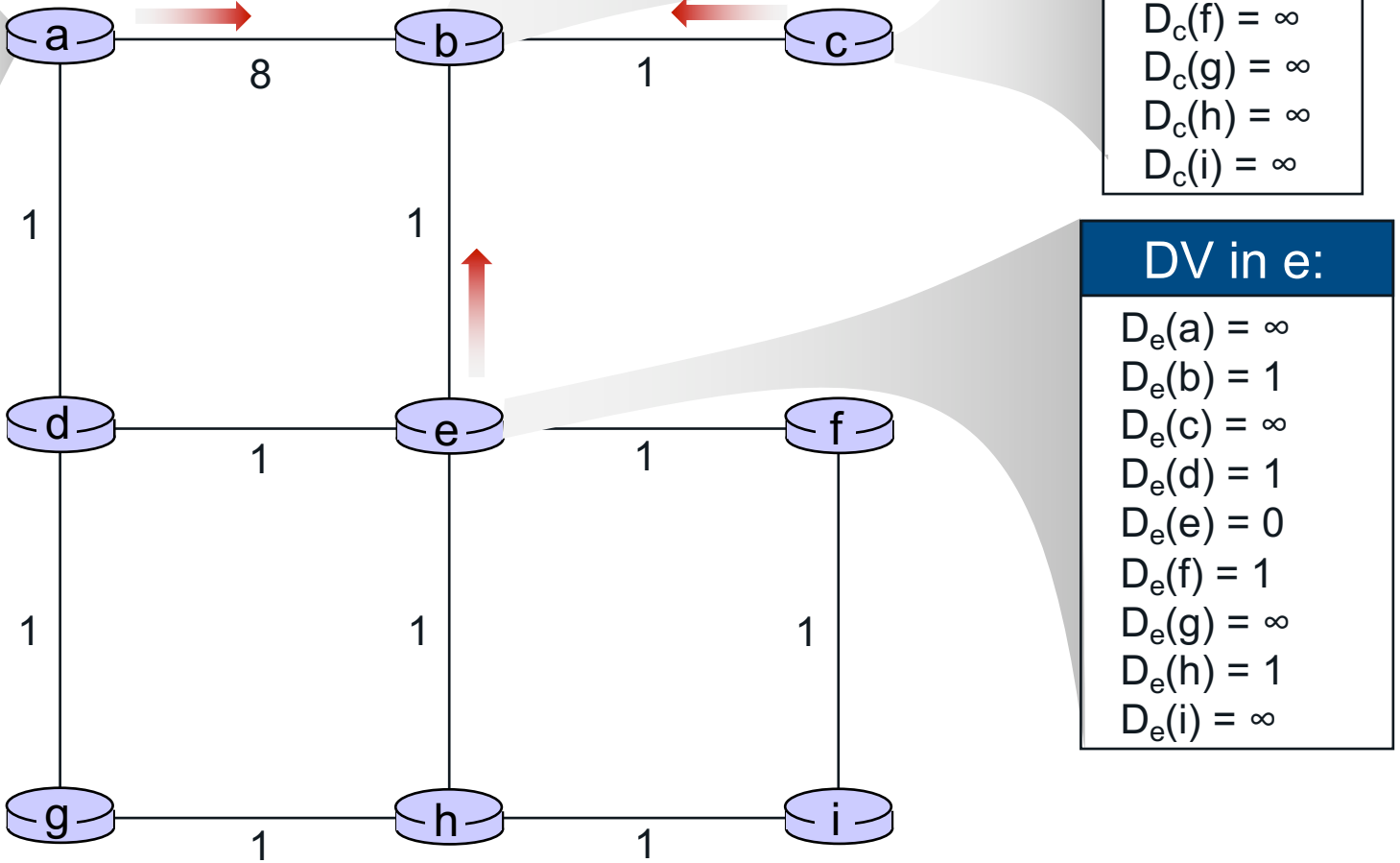
…. and so on

Let’s next take a look at the iterative *computations* at nodes

Distance Vector: Example-Node

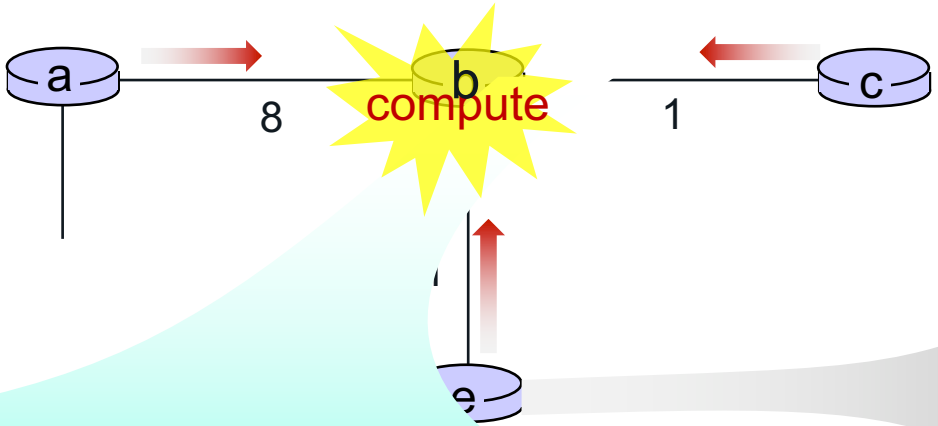
t=1

- b receives DVs from a, c, e



Distance Vector: Example-Node

t=1



- b receives DVs from a, c, e, computes:

$D_b(a) = \min\{c_{b,a}+D_a(a), c_{b,c}+D_c(a), c_{b,e}+D_e(a)\} = \min\{8,\infty,\infty\} = 8$

$D_b(c) = \min\{c_{b,a}+D_a(c), c_{b,c}+D_c(c), c_{b,e}+D_e(c)\} = \min\{\infty,1,\infty\} = 1$

$D_b(d) = \min\{c_{b,a}+D_a(d), c_{b,c}+D_c(d), c_{b,e}+D_e(d)\} = \min\{9,2,\infty\} = 2$

$D_b(e) = \min\{c_{b,a}+D_a(e), c_{b,c}+D_c(e), c_{b,e}+D_e(e)\} = \min\{\infty,\infty,1\} = 1$

$D_b(f) = \min\{c_{b,a}+D_a(f), c_{b,c}+D_c(f), c_{b,e}+D_e(f)\} = \min\{\infty,\infty,2\} = 2$

$D_b(g) = \min\{c_{b,a}+D_a(g), c_{b,c}+D_c(g), c_{b,e}+D_e(g)\} = \min\{\infty, \infty, \infty\} = \infty$

$D_b(h) = \min\{c_{b,a}+D_a(h), c_{b,c}+D_c(h), c_{b,e}+D_e(h)\} = \min\{\infty, \infty, 2\} = 2$

$D_b(i) = \min\{c_{b,a}+D_a(i), c_{b,c}+D_c(i), c_{b,e}+D_e(i)\} = \min\{\infty, \infty, \infty\} = \infty$

DV in b:

$D_b(a) = 8$ $D_b(f) = 2$
$D_b(c) = 1$ $D_b(g) = \infty$
$D_b(d) = 2$ $D_b(h) = 2$
$D_b(e) = 1$ $D_b(i) = \infty$

Distance Vector: Example-Node

Iterative communication, computation steps diffuses information through network:

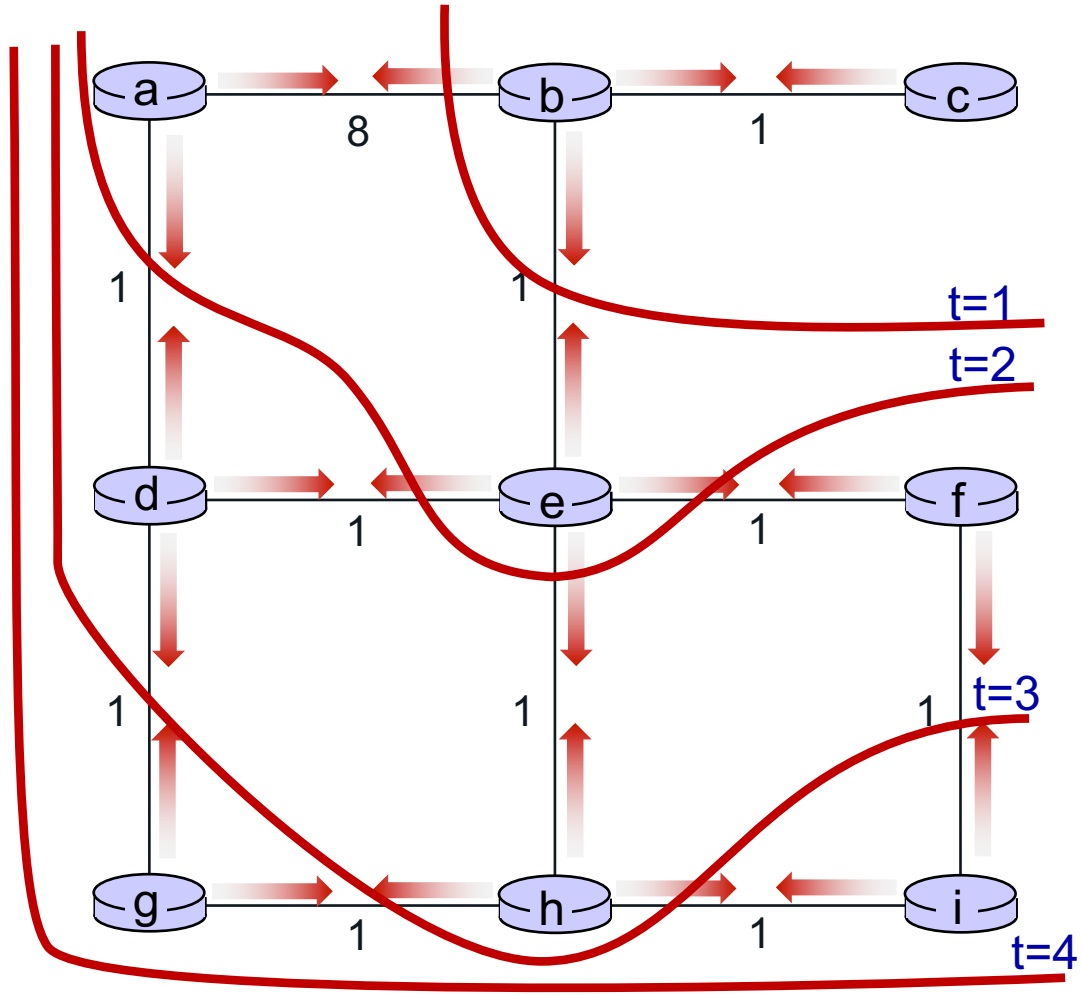
t=0 c's state at t=0 is at c only

t=1 c's state at t=0 has propagated to b, and may influence distance vector computations up to **1** hop away, i.e., at b

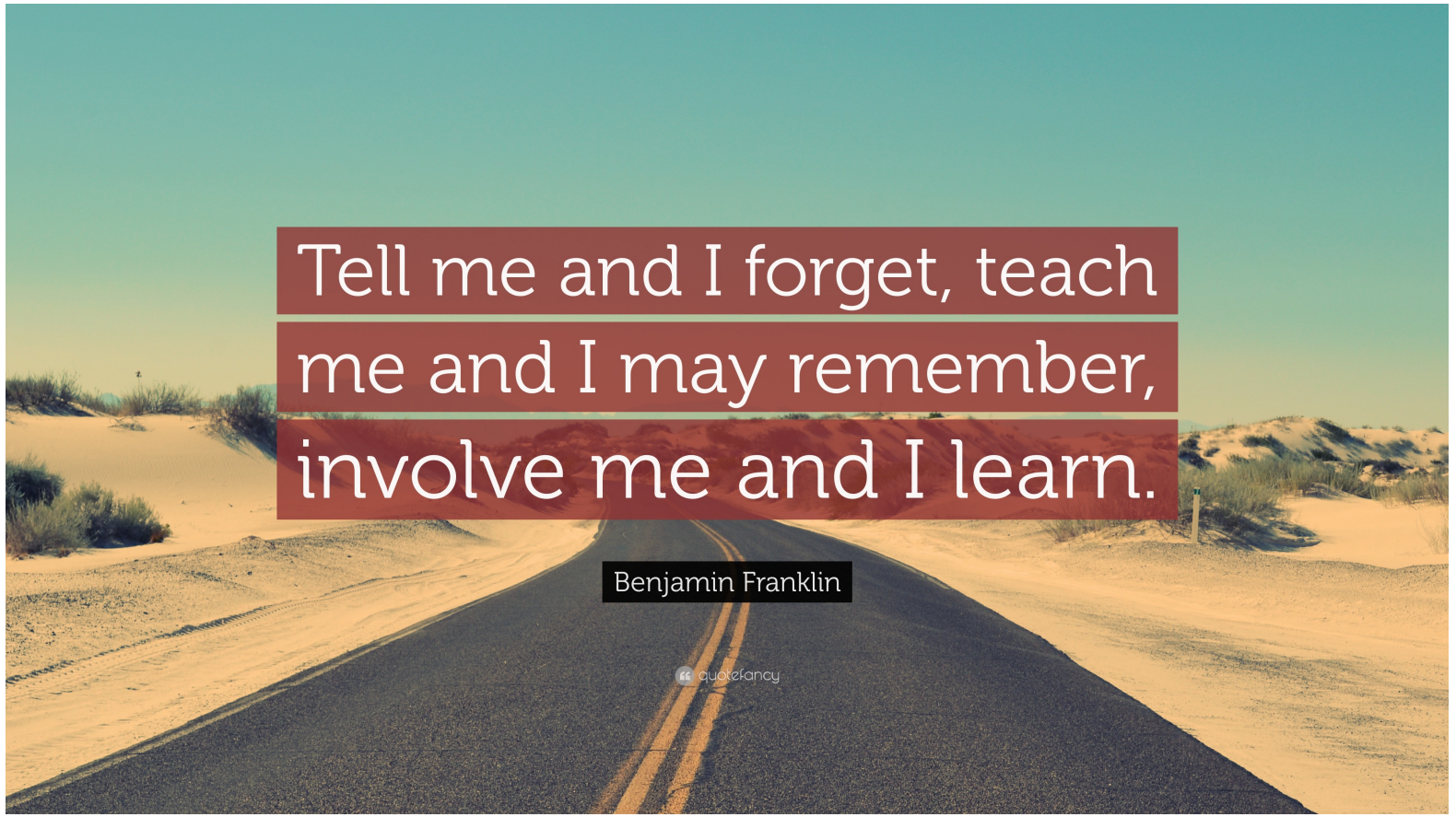
t=2 c's state at t=0 may now influence distance vector computations up to **2** hops away, i.e., at b and now at a, e as well

t=3 c's state at t=0 may influence distance vector computations up to **3** hops away, i.e., at b,a,e and now at c,f,h as well

t=4 c's state at t=0 may influence distance vector computations up to **4** hops away, i.e., at b,a,e, c, f, h and now at g,i as well



Thank You!


Tell me and I forget, teach
me and I may remember,
involve me and I learn.
Benjamin Franklin
quotefancy

Intra AS Routing

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")

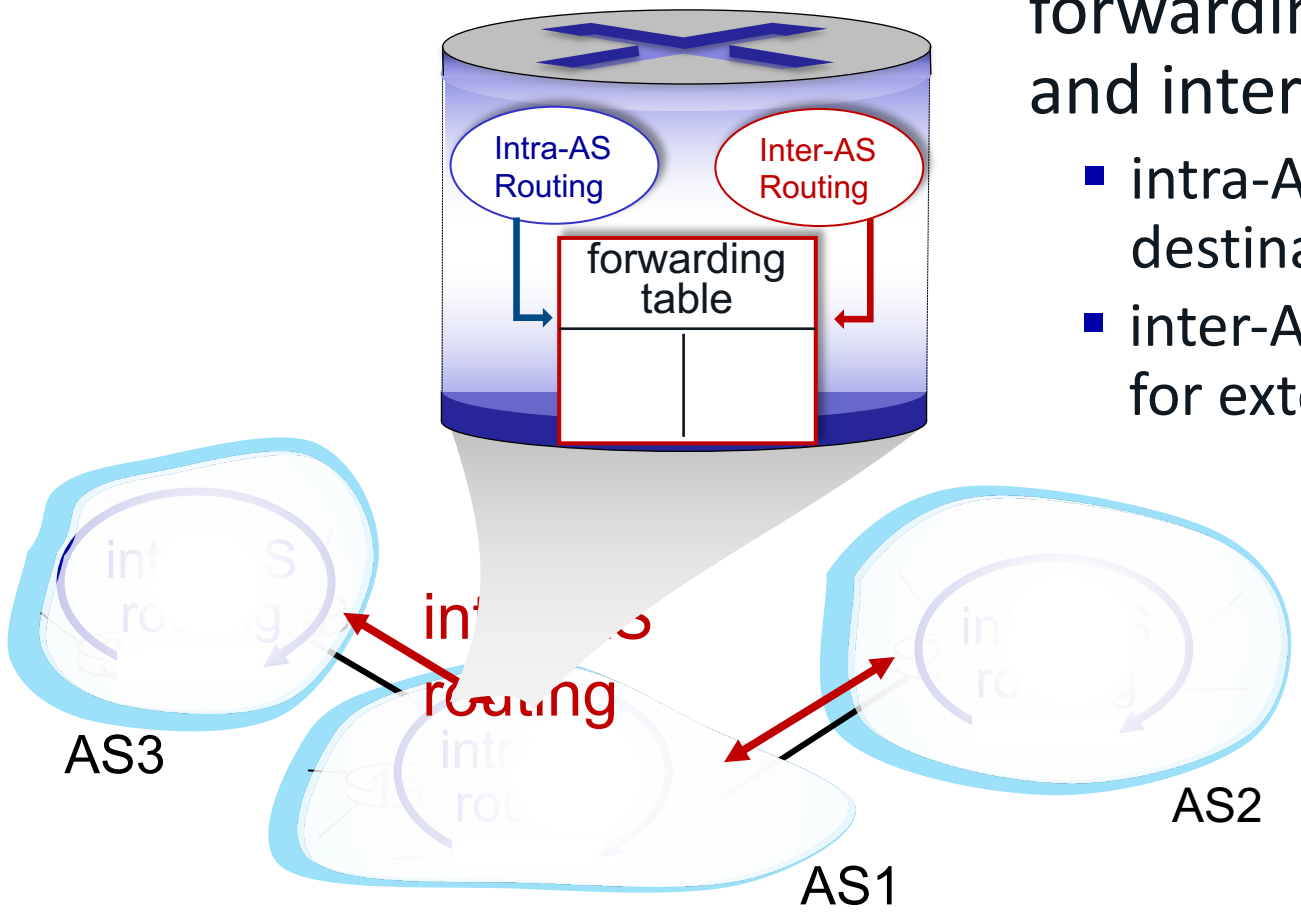
intra-AS (aka "intra-domain"):
routing among *within same AS ("network")*

- 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 ASs



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

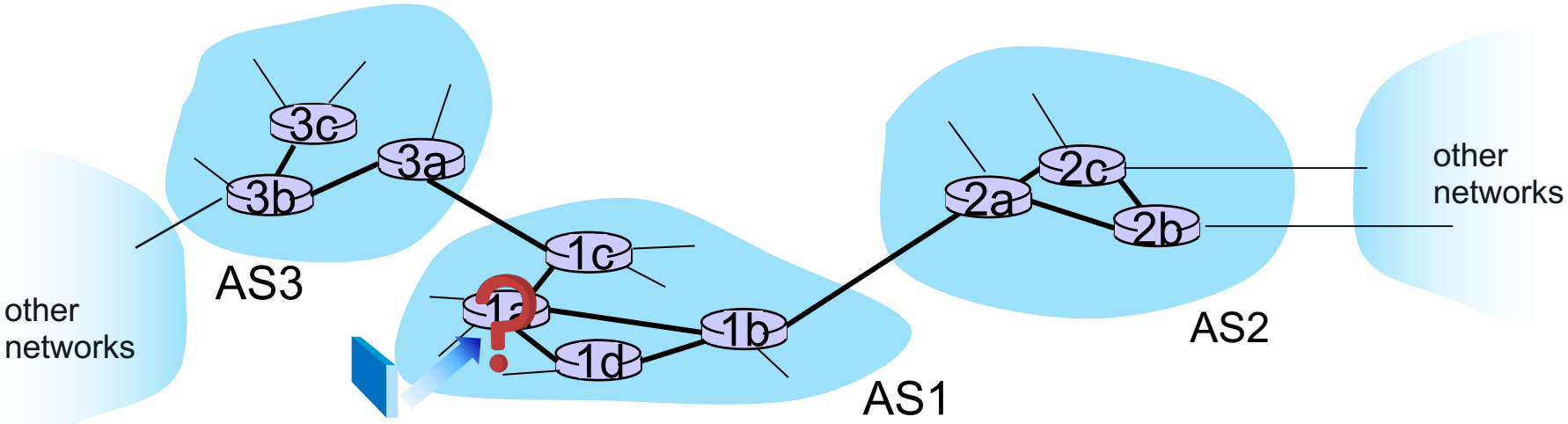
- intra-AS routing determine entries for destinations within AS
- inter-AS & intra-AS determine entries for external destinations

Inter AS Routing: 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

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

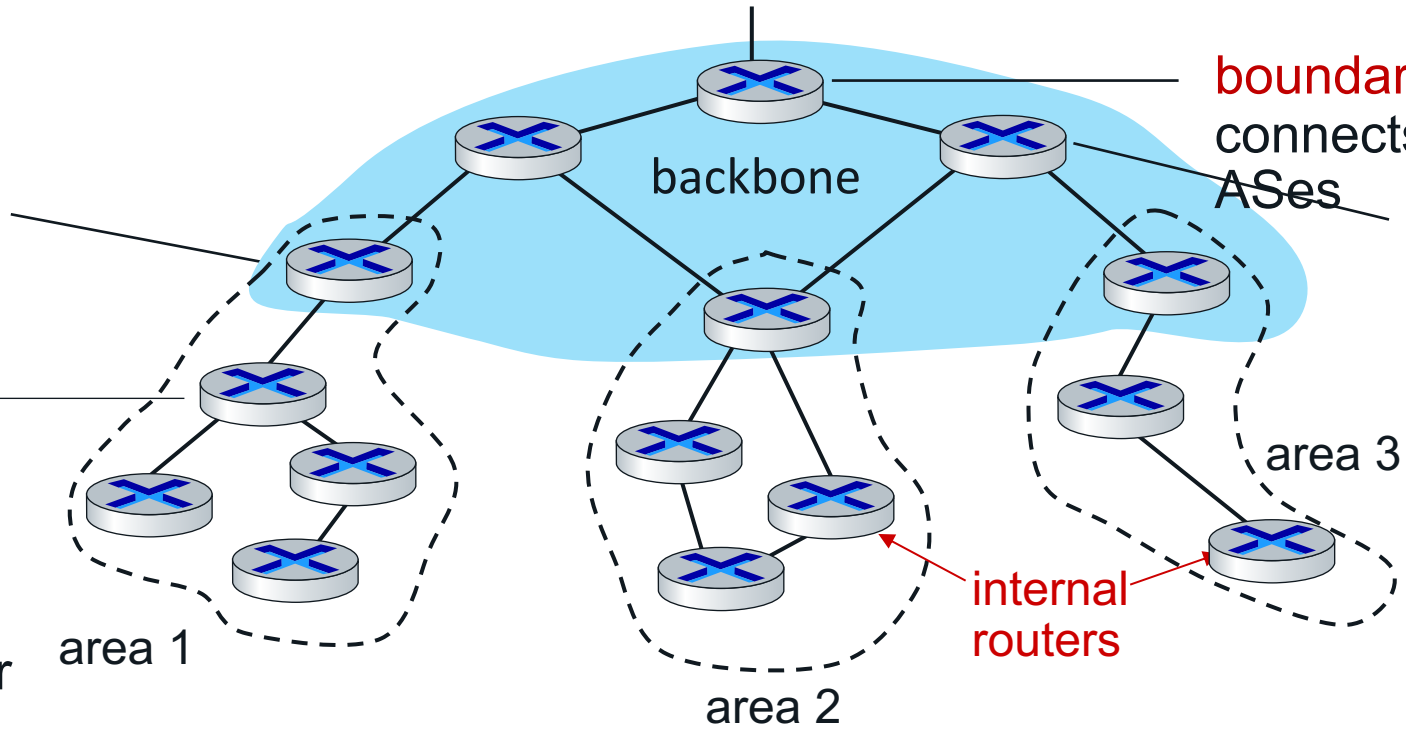
- "open": publicly available
- classic link-state
  - each router floods OSPF link-state advertisements (directly over IP rather than using TCP/UDP) to all other routers in entire AS
  - multiple link costs metrics possible: bandwidth, delay
  - each router has full topology, uses Dijkstra's algorithm 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

area border routers:
"summarize" distances to destinations in own area, advertise in backbone

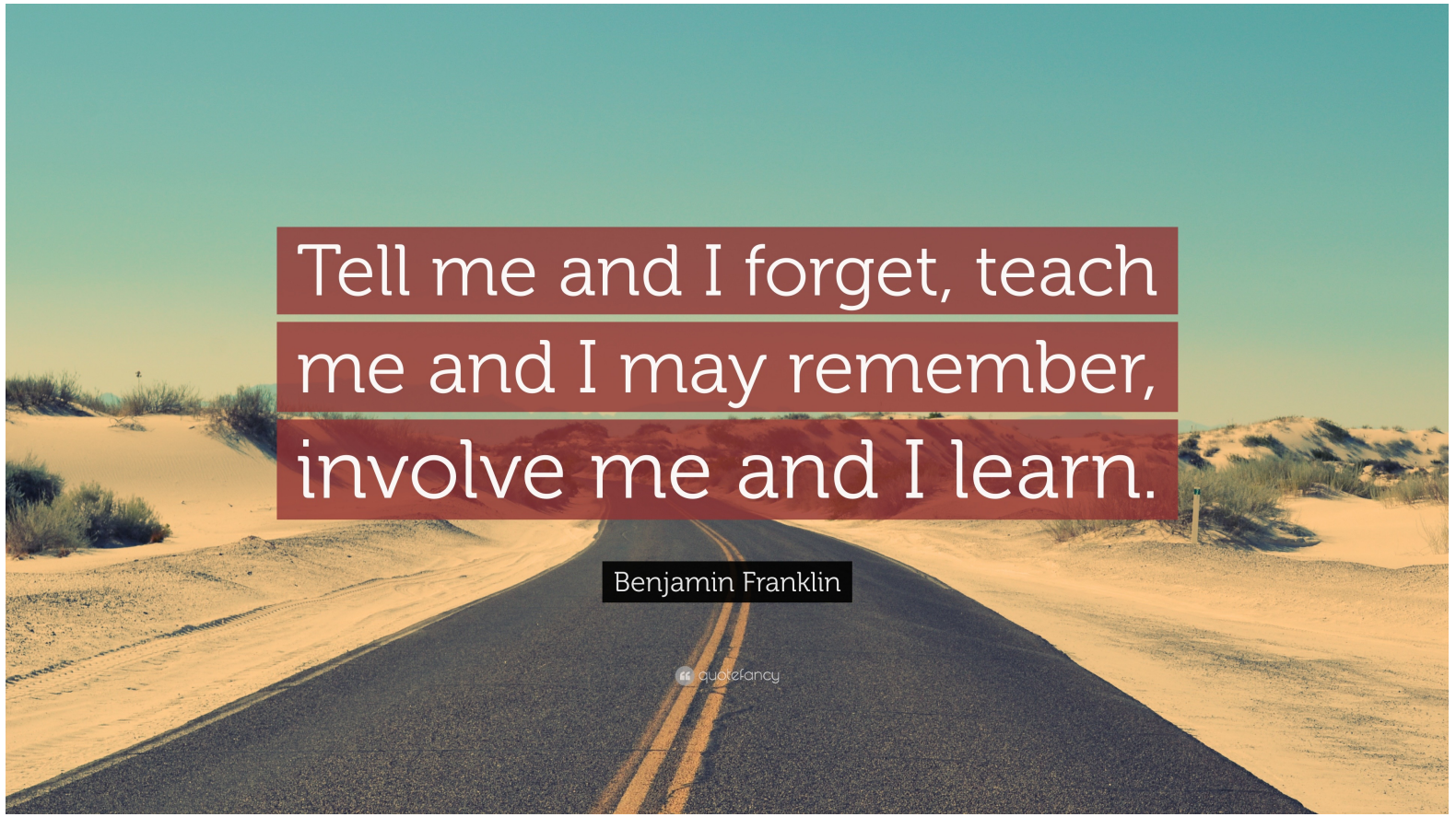
local routers:
- flood LS in area only
- compute routing within area
- forward packets to outside via area border router



boundary router:
connects to other ASes

backbone router:
runs OSPF limited to backbone

Thank You!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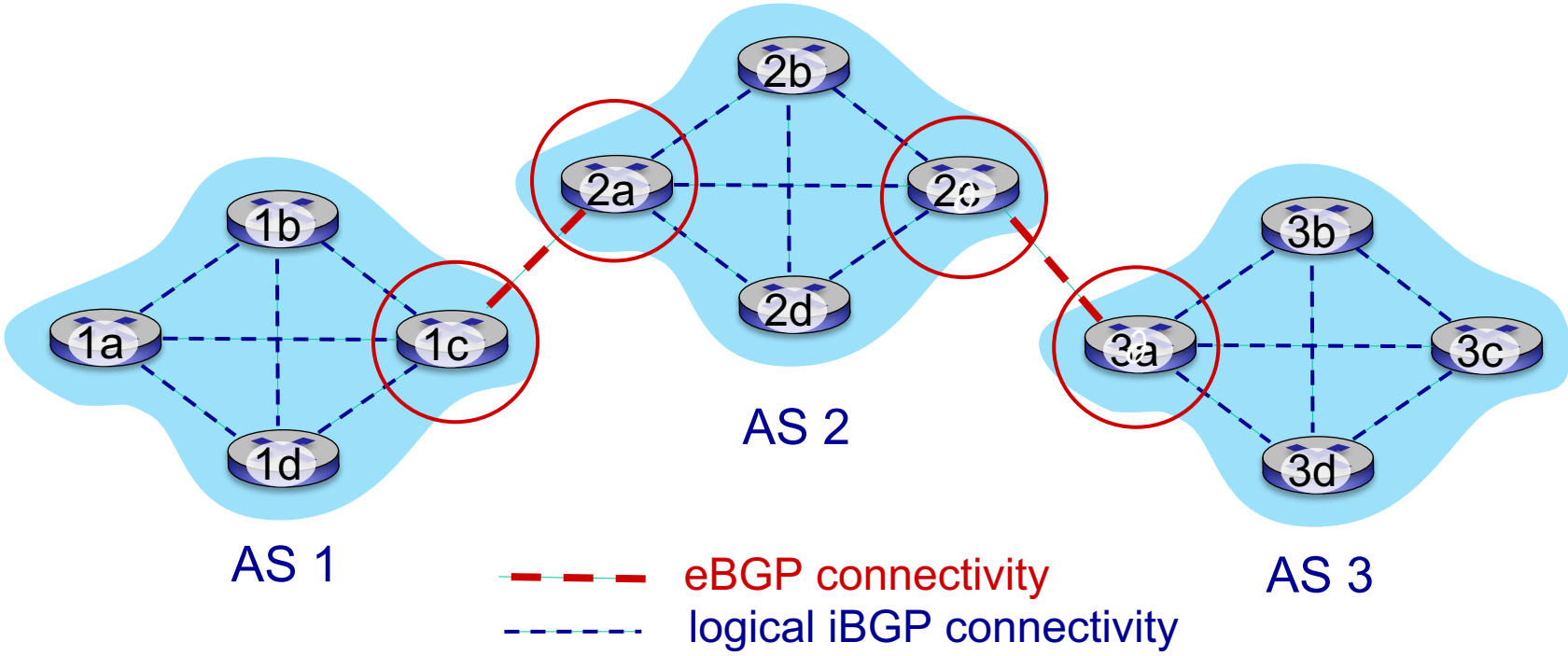
quotefancy

Inter AS Routing

Inter AS Routing

- 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*

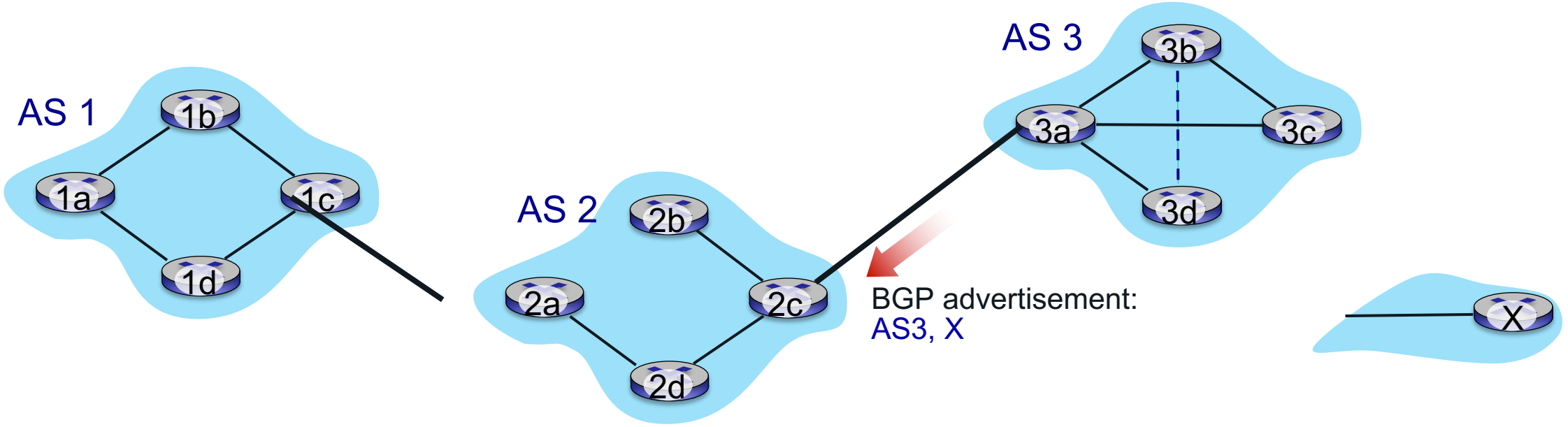
eBGP, iBGP Connections



gateway routers run both eBGP and iBGP protocols

BGP Basics

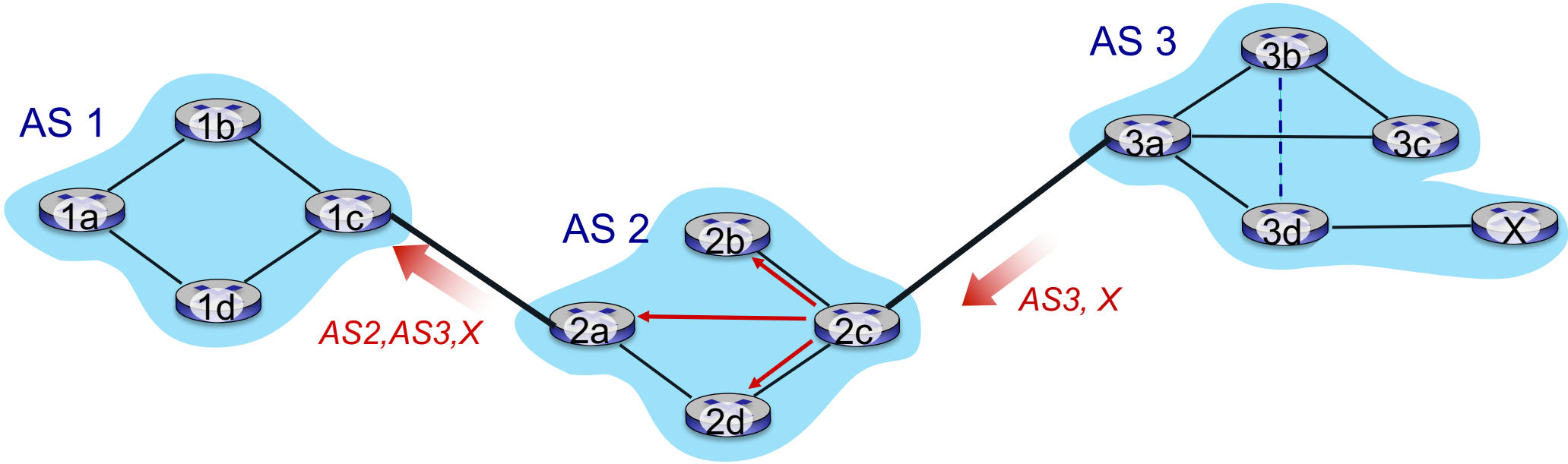
- BGP session: two BGP routers (“peers”) exchange BGP messages over semi-permanent TCP connection:
  - advertising *paths* to different destination network prefixes (BGP is a “path vector” protocol)
- when AS3 gateway 3a advertises path AS3,X to AS2 gateway 2c:
  - AS3 *promises* to AS2 it will forward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



Path Attributes and BGP Routes

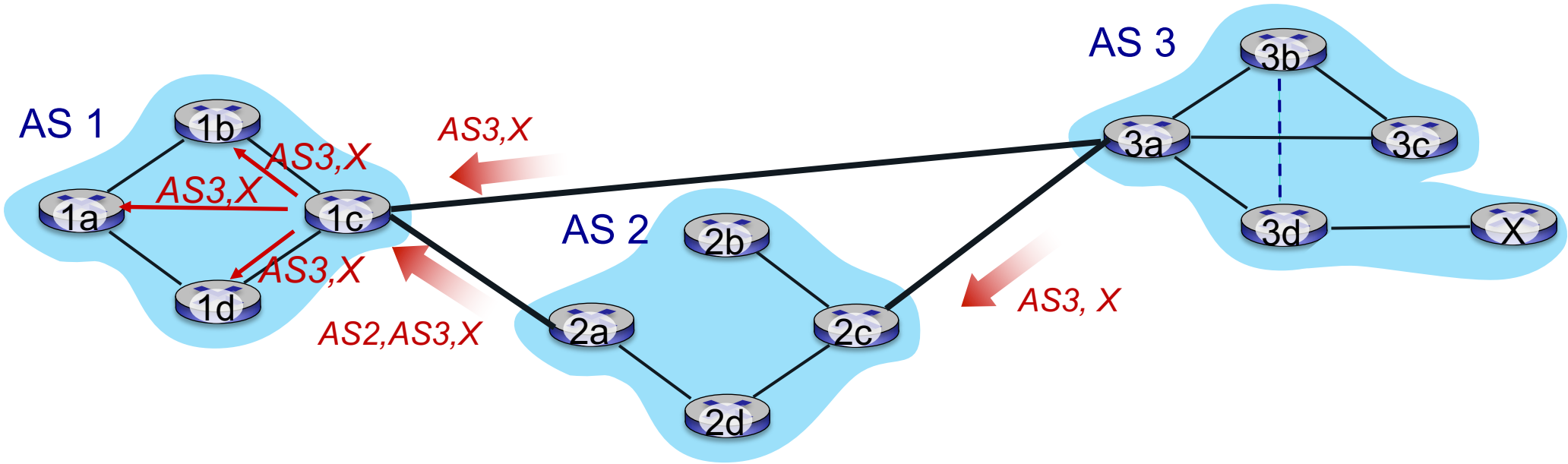
- BGP advertised route: prefix + attributes
  - prefix: destination being advertised
  - two important attributes:
    - AS-PATH: list of ASes through which prefix advertisement has passed
    - NEXT-HOP: indicates specific internal-AS router to next-hop AS
- policy-based routing:
  - gateway receiving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



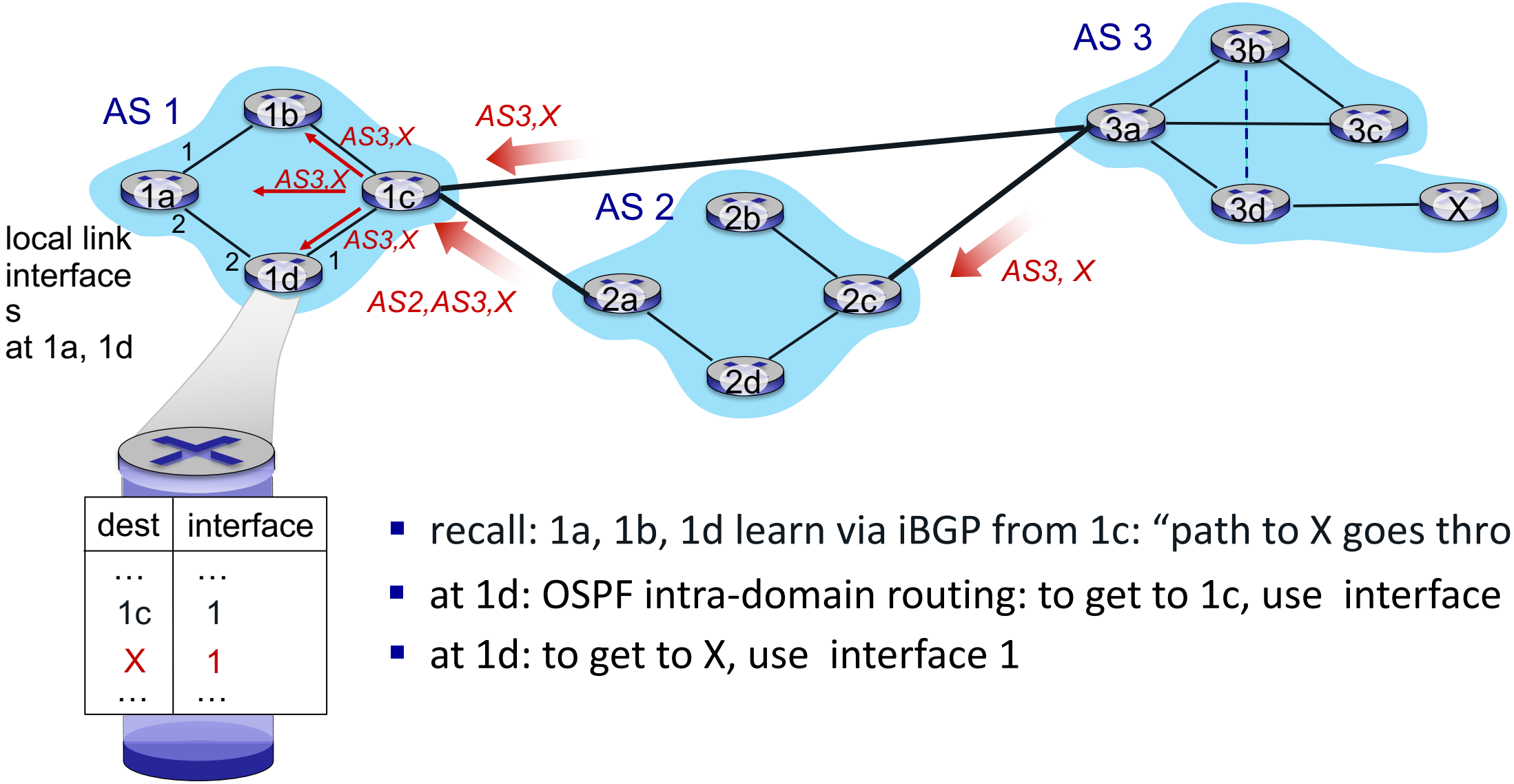
gateway router may learn about multiple paths to destination:

- 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

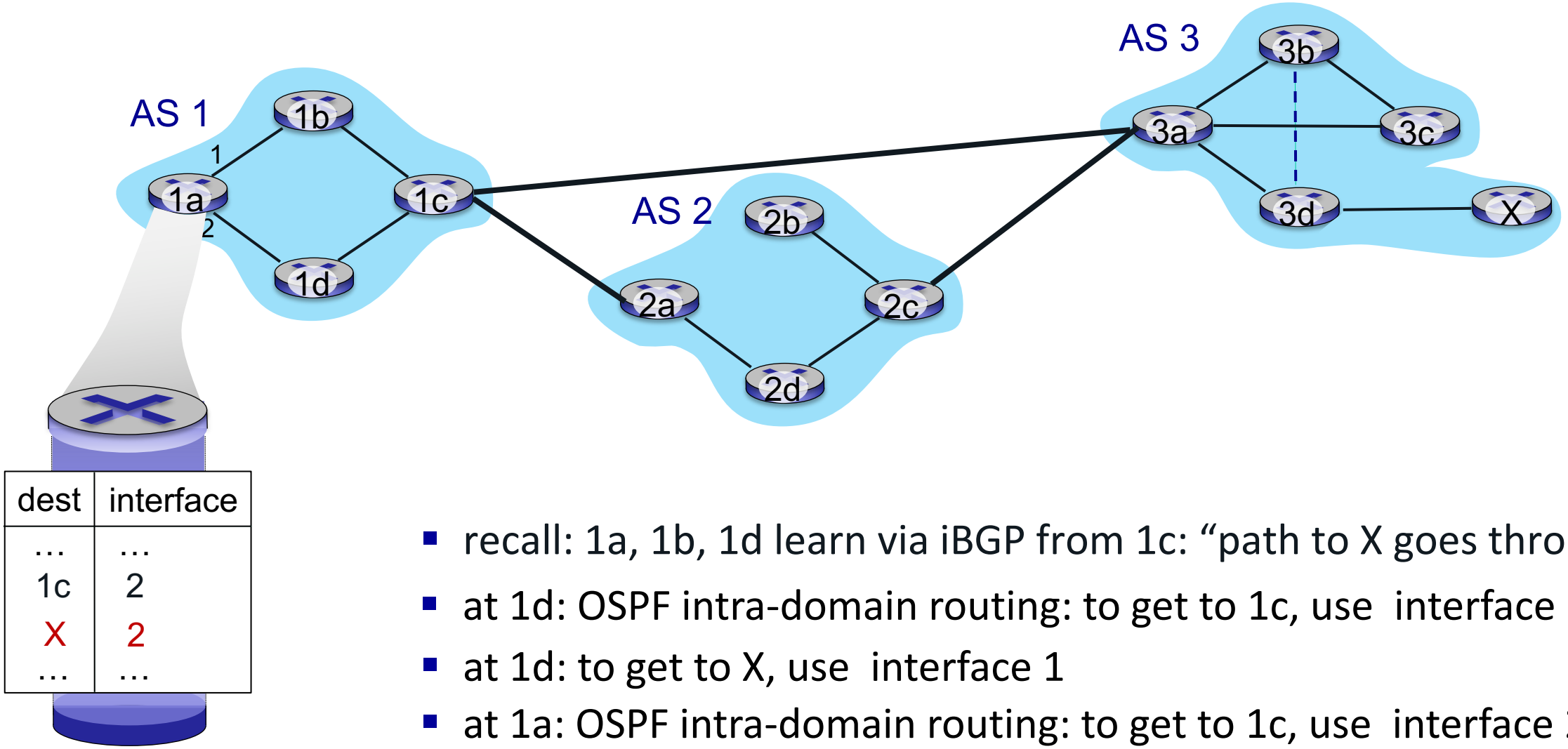
- BGP messages exchanged between peers over TCP connection
- BGP messages:
  - OPEN: opens TCP connection to remote BGP peer and authenticates sending BGP peer
  - UPDATE: advertises new path (or withdraws old)
  - KEEPALIVE: keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - NOTIFICATION: reports errors in previous msg; also used to close connection

BGP Path Advertisement



- 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 Path Advertisement



- 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

Why Different Intra- and 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

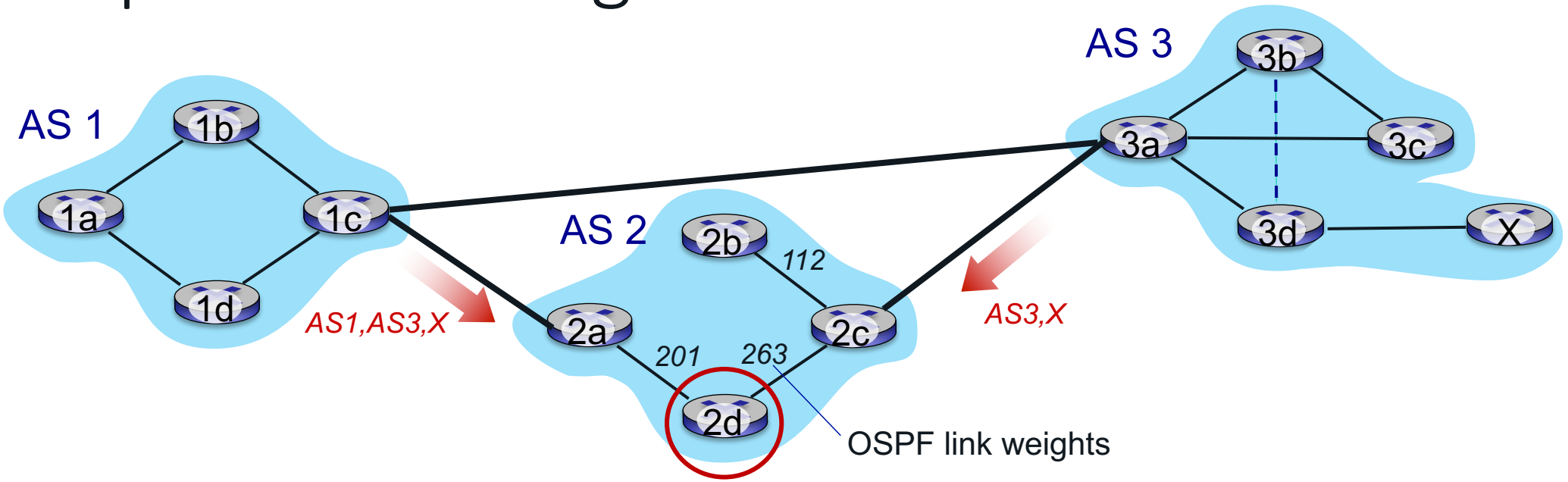
scale:

- hierarchical routing saves table size, reduced update traffic

performance:

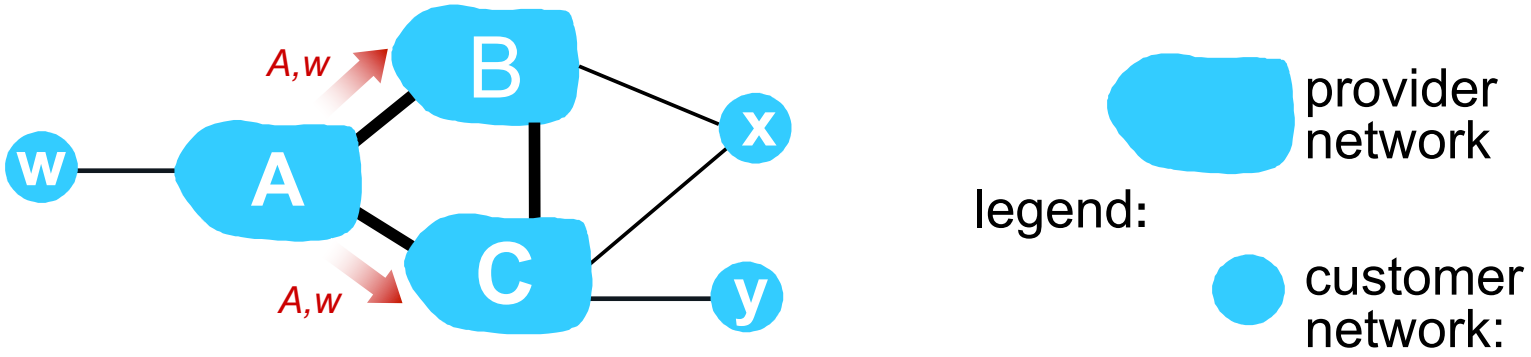
- intra-AS: can focus on performance
- inter-AS: policy dominates over performance

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!

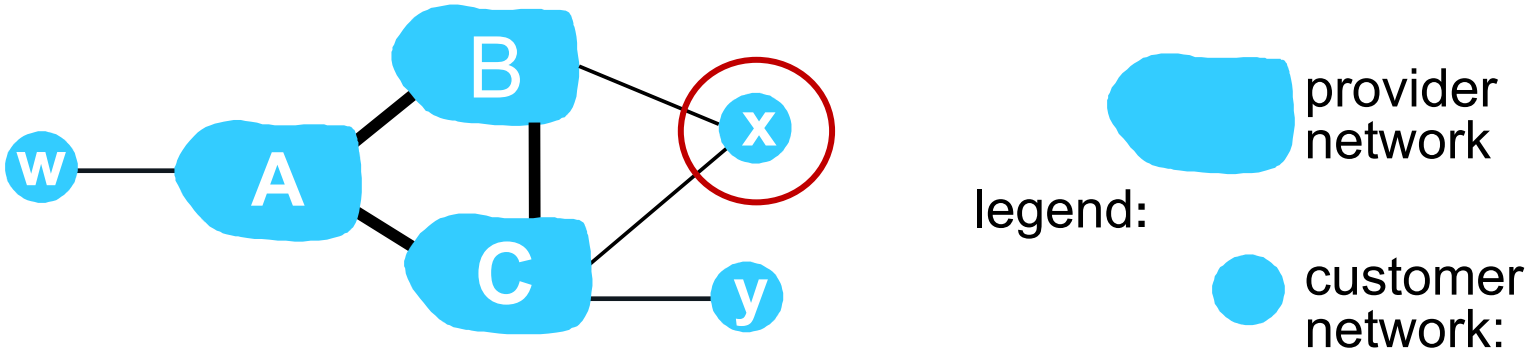
BGP: achieving policy via advertisements



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)



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,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

Thank You!


Tell me and I
forget. Teach me
and I remember.
Involve me and I
learn.
~ Benjamin Franklin