# Computer Networks

Internet Routing Protocols

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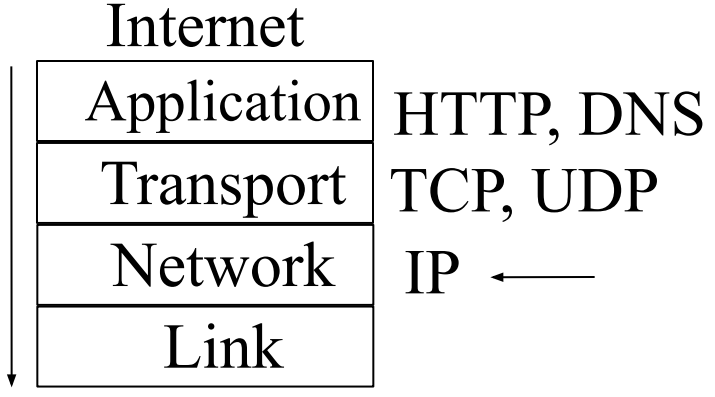
Fall 2022

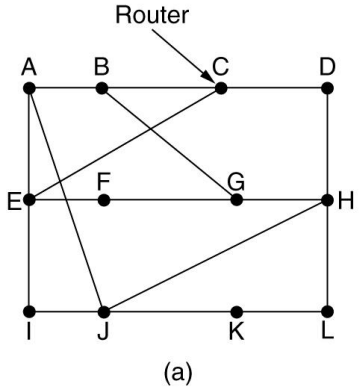
# Review




- Internet Protocol (IP)
  - IP header
  - addressing
    - class-based, classless, hierarchical, NAT
  - routing algorithms
    - flooding
    - distance vector
    - link state
    - *hierarchical*

# Distance vector routing

- Distributed Bellman-Ford algorithm



(a)

New estimated delay from J

| To | A | I | H | K | Line |
|---|---|---|---|---|---|
| A | 0 | 24 | 20 | 21 | 8 A |
| B | 12 | 36 | 31 | 28 | 20 A |
| C | 25 | 18 | 19 | 36 | 28 I |
| D | 40 | 27 | 8 | 24 | 20 H |
| E | 14 | 7 | 30 | 22 | 17 I |
| F | 23 | 20 | 19 | 40 | 30 I |
| G | 18 | 31 | 6 | 31 | 18 H |
| H | 17 | 20 | 0 | 19 | 12 H |
| I | 21 | 0 | 14 | 22 | 10 I |
| J | 9 | 11 | 7 | 10 | 0 – |
| K | 24 | 22 | 22 | 0 | 6 K |
| L | 29 | 33 | 9 | 9 | 15 K |

JA delay is 8 | JI delay is 10 | JH delay is 12 | JK delay is 6

Vectors received from J's four neighbors

New routing table for J

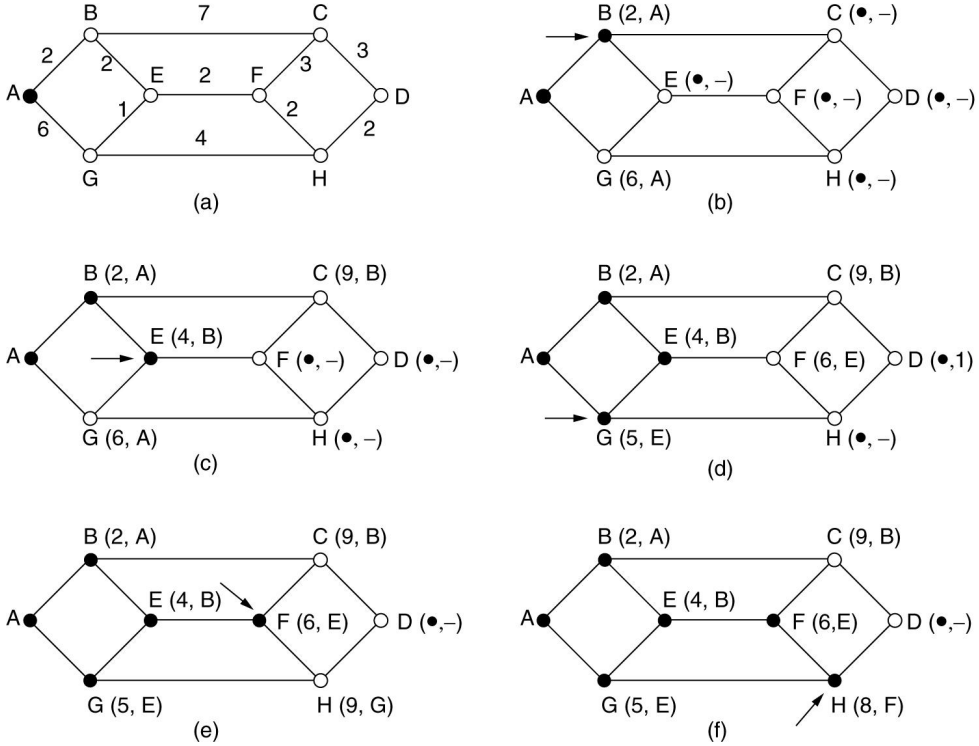
(b)

A B X

$$\text{Path}_{new}(A, X) = \min_B\{\text{Path}_{old}(A,X), \text{Link}(A,B) + \text{Path}(B,X)\}$$

# Link state routing

- Dijkstra algorithm



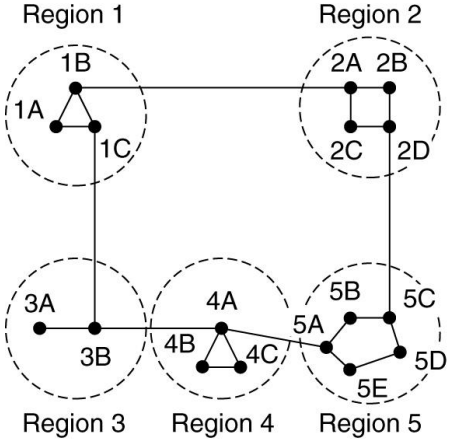



D(v) = min( D(v), D(w) + c(w,v)

# *Hierarchical routing*

- Why hierarchical
  - scalability
- Internet
  - autonomous system (AS)
  - Inter-domain routing
    - distance vector
  - Intra-domain routing
    - distance vector or link state

# Hierarchical routing: example




(a)

Full table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2A | 1B | 2 |
| 2B | 1B | 3 |
| 2C | 1B | 3 |
| 2D | 1B | 4 |
| 3A | 1C | 3 |
| 3B | 1C | 2 |
| 4A | 1C | 3 |
| 4B | 1C | 4 |
| 4C | 1C | 4 |
| 5A | 1C | 4 |
| 5B | 1C | 5 |
| 5C | 1B | 5 |
| 5D | 1C | 6 |
| 5E | 1C | 5 |

(b)

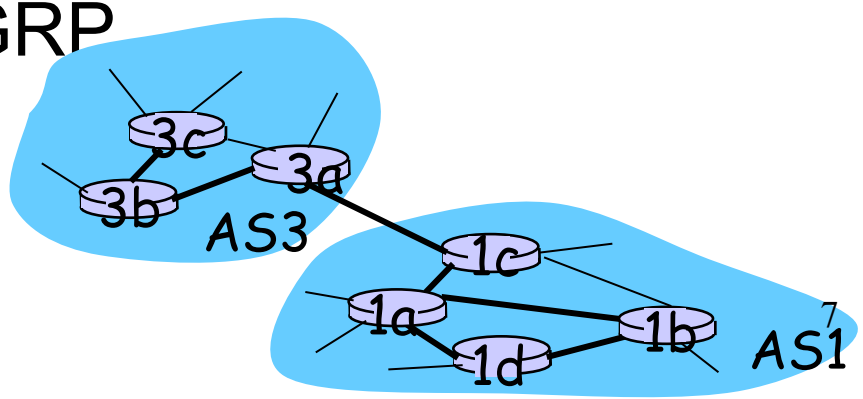
Hierarchical table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2 | 1B | 2 |
| 3 | 1C | 2 |
| 4 | 1C | 3 |
| 5 | 1C | 4 |

(c)

# Today's topics

- Internet routing protocols
  - how does the Internet really route *my* packets?
  - hierarchical structures
- Intra-domain routing
  - AS: autonomous systems
  - e.g., RIP, OSPF, ISIS, IGRP
- Inter-domain routing
  - e.g., BGP






% traceroute google.com

# Intra-AS Routing

- Also known as Interior Gateway Protocols (IGP)
- Most common Intra-AS routing protocols:
  - RIP: Routing Information Protocol
  - OSPF: Open Shortest Path First
  - IGRP: Interior Gateway Routing Protocol (Cisco proprietary)

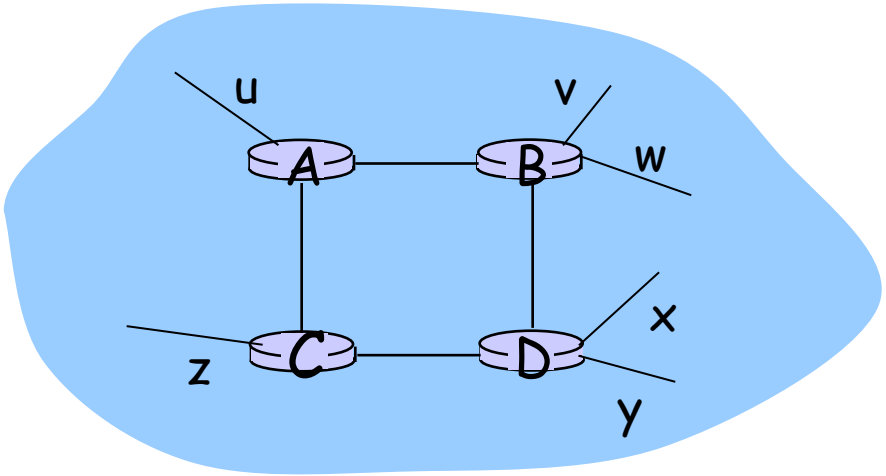
algorithm

DV

LS

# RIP (Routing Information Protocol)

- Distance vector algorithm
- Included in BSD-UNIX Distribution in 1982
- Distance metric: # of hops (max = 15 hops)




From router A to subsets:

| destination | hops | next-hop |
|---|---|---|
| u | 1 | B |
| v | 2 | B |
| w | 2 | C |
| x | 3 | C |
| y | 3 | C |
| z | 2 | |



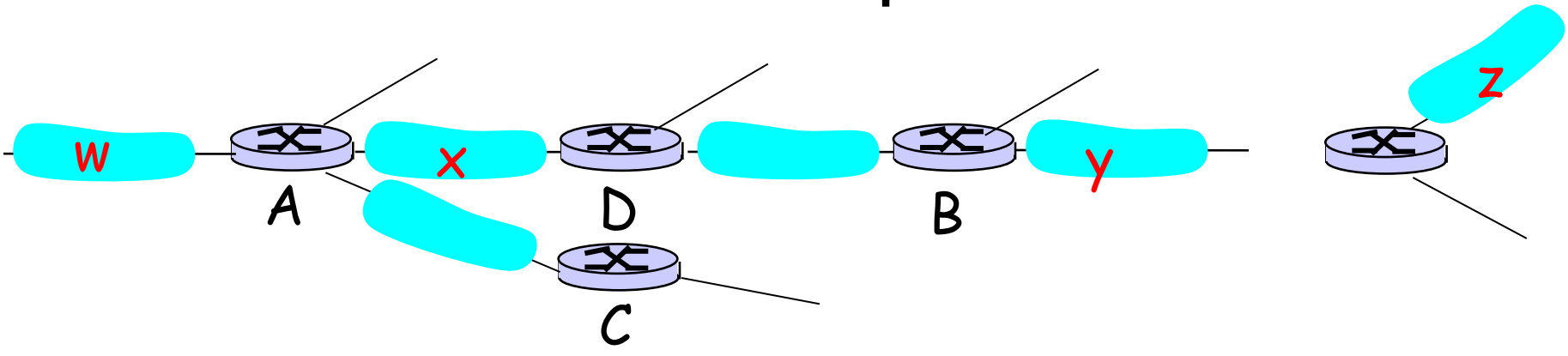
Q: why max 15 hops?

H: CTI problems in DV

# RIP advertisements

- Distance vectors: exchanged among neighbors every 30 sec via RIP Response Message (also called advertisement)
- Each advertisement: list of up to 25 destination subnets within AS.
  - UDP port 520
    - /etc/services
  - newer implementations also use TCP
- Routing metric: the number of hops

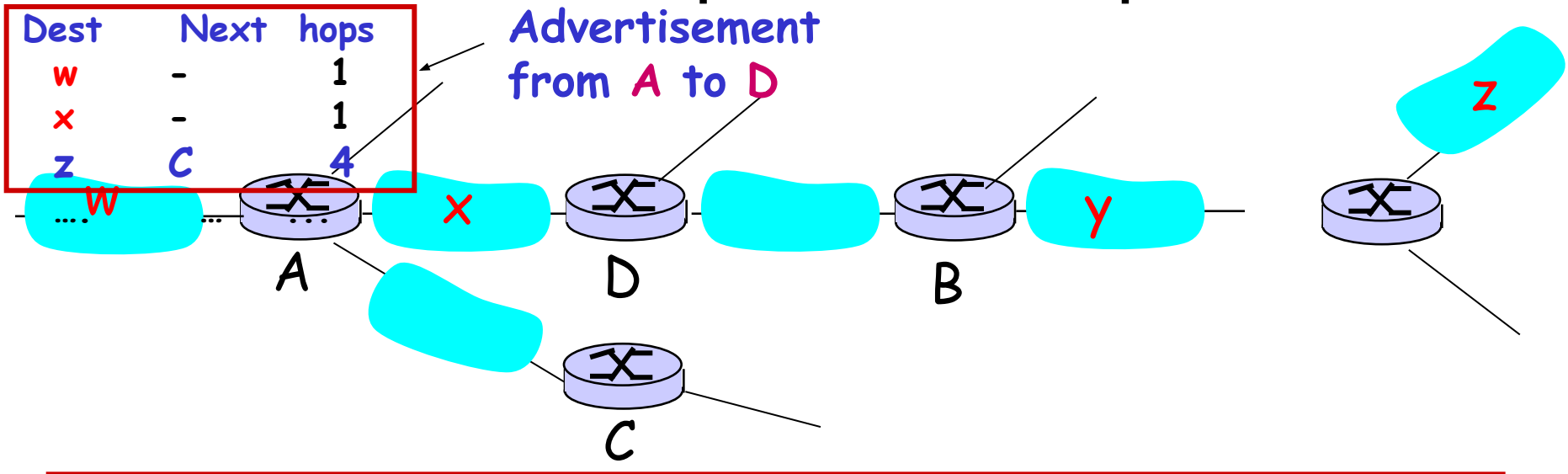
# RIP: Example




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

Routing table in router D

# RIP: Route update example




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

Routing table in D

# RIP: Link Failure and Recovery

If no RIP advertisement heard after 180 sec --> neighbor/link declared dead (not reachable)

- 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)

# OSPF (Open Shortest Path First)

- "open": publicly available
- Uses Link State algorithm
  - LS packet dissemination
  - A router constructs a complete topological map (i.e., a graph)
  - Route computation using Dijkstra's algorithm to determine a shortest path tree to all subnets
- OSPF advertisement carries one entry per neighbor router
- Advertisements disseminated to entire AS (via flooding)
  - Carried in OSPF messages directly over **IP** (rather than TCP or UDP)
  - IP protocol ID: 89
    - /etc/protocols
- Multiple routing metrics

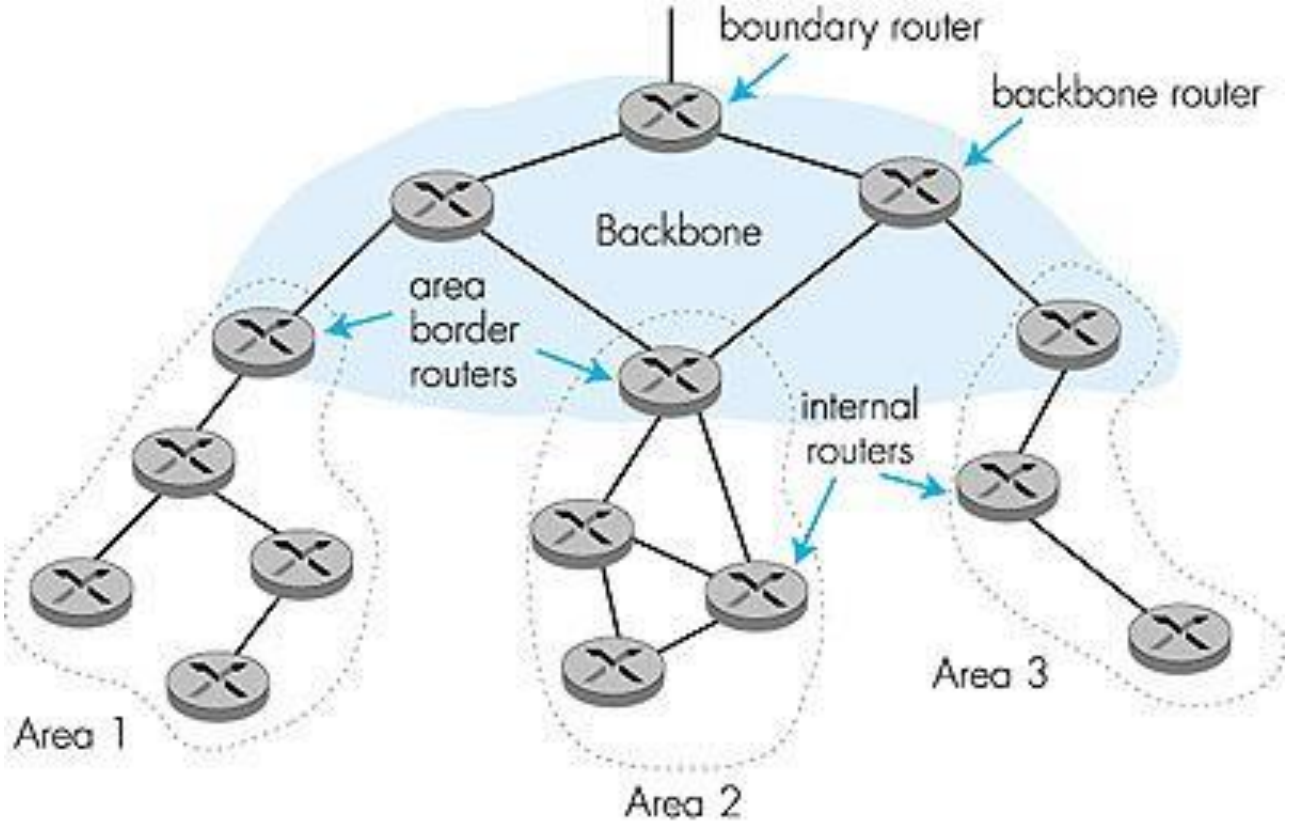
# OSPF messages

| Message type | Description |
|---|---|
| Hello | Used to discover who the neighbors are |
| Link state update | Provides the sender's costs to its neighbors |
| Link state ack | Acknowledges link state update |
| Database description | Announces which updates the sender has |
| Link state request | Requests information from the partner |



Q: flooding LSA?

# Hierarchical OSPF



# Hierarchical OSPF

- Two-level hierarchy: local area, backbone.
  - Link-state advertisements only in area
  - each node has detailed area topology; only know direction (shortest path) to subnets in other areas.
- **Area border routers:** "summarize" distances to nets in own area, advertise to other Area Border routers.
- **Backbone routers:** run OSPF routing limited to backbone.
- **Boundary routers:** connect to other AS's.



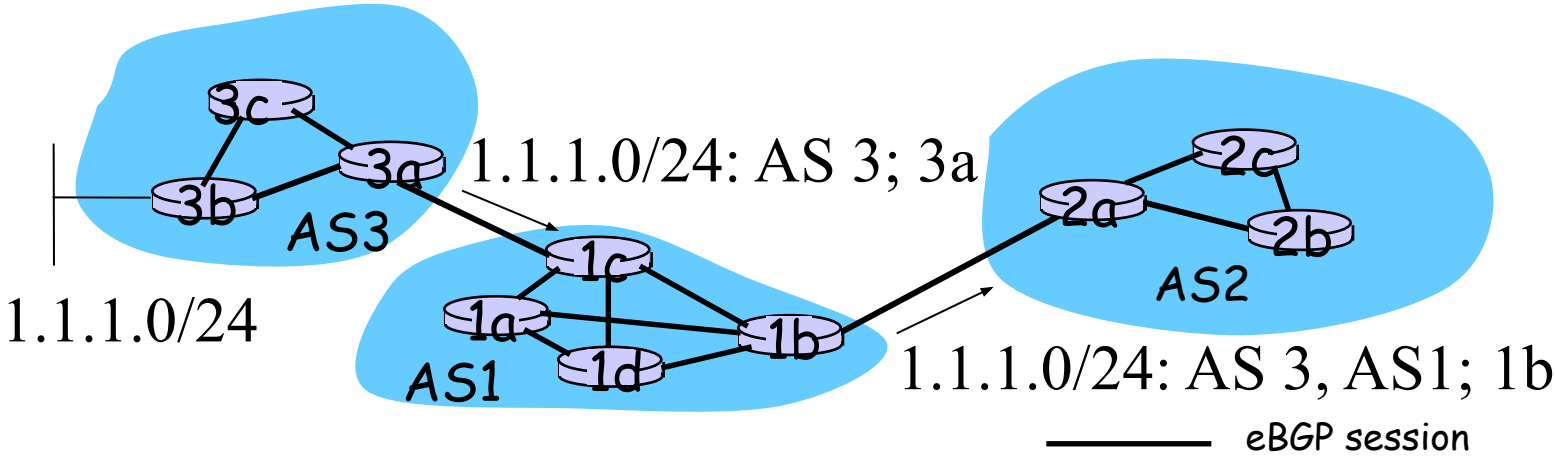
Q: boundary routers?

# Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): *the* de facto exterior gateway protocol (version 4)
- BGP provides each AS a means to:
  - Obtain subnet reachability information from neighboring ASs.
  - Propagate the reachability information to all routers internal to the AS.
  - Determine "good" routes to subnets based on reachability information and policy.
- Allows a subnet to advertise its existence to rest of the Internet: *"I am here"*

# Distributing reachability info

- With eBGP session between 3a and 1c, AS3 sends a prefix reachability info, reachable from AS3 to the prefix, to AS1.
- 1c can then use iBGP do distribute this new prefix reach info to all routers in AS1
- 1b can then re-advertise the new reach info to AS2 over the 1b-to-2a eBGP session
- When a router learns about a new prefix, it creates an entry for the prefix in its forwarding table.






Q: why Path Vector?

# Path attributes & BGP routes

- When advertising a prefix, advertisement includes BGP attributes.
  - prefix + attributes = "**route**"
  - path vector routing
- Two important attributes:
  - AS-PATH: contains the ASs through which the advert for the prefix passed: AS3 AS1
  - NEXT-HOP: Indicates the specific internal-AS router to next-hop AS. (There may be multiple links from current AS to next-hop-AS.)
- When gateway router receives route advert, uses import routing policy to accept/decline.

# BGP messages

- BGP messages exchanged using TCP.
- BGP messages:
  - OPEN: opens TCP connection to peer and authenticates sender
  - 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 route selection

- Router may learn about more than 1 route to some prefixes. Router must select route.
- Elimination rules:
  - Local preference value attribute: routing policy decision
  - Shortest AS-PATH
  - Closest NEXT-HOP router: hot potato routing
  1. Additional criteria

# Comparison: intra/inter-domain 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

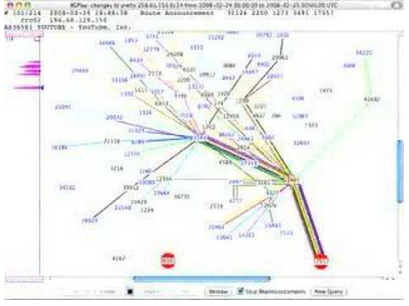
## Scale:

- hierarchical routing saves table size, reduced update traffic

**Performance**:

- Intra-AS: can focus on performance
- Inter-AS: policy may dominate over performance

# This lecture



- Internet routing
  - RIP: distance vector routing
  - OSPF: hierarchical, link-state routing
  - BGP basics: path vector routing
- Explore further
  - Advanced Computer Networks (CSC466)
  - IGP routing metrics, BGP routing dynamics
  - routing security

# Next lectures

- The Link Layer
  - framing control
  - flow/error control
  - media access control
- IEEE 802 family
  - IEEE 802.3: Ethernet
  - IEEE 802.11: “wireless Ethernet” (WiFi)