Distance-Vector and Path-Vector Routing

Sections 4.2.2., 4.3.2, 4.3.3

COS 461: Computer Networks
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Mike Freedman
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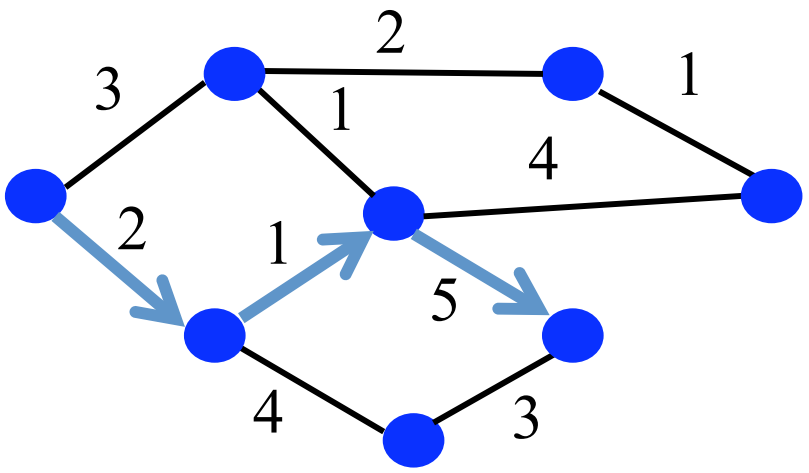
Goals of Today's Lectures

- Distance-vector routing
  - Pro: Less information than link state
  - Con: Slower convergence
- Path-vector routing
  - Faster convergence than distance vector
  - More flexibility in selecting paths
- Different goals / metrics if inter- or intra-domain

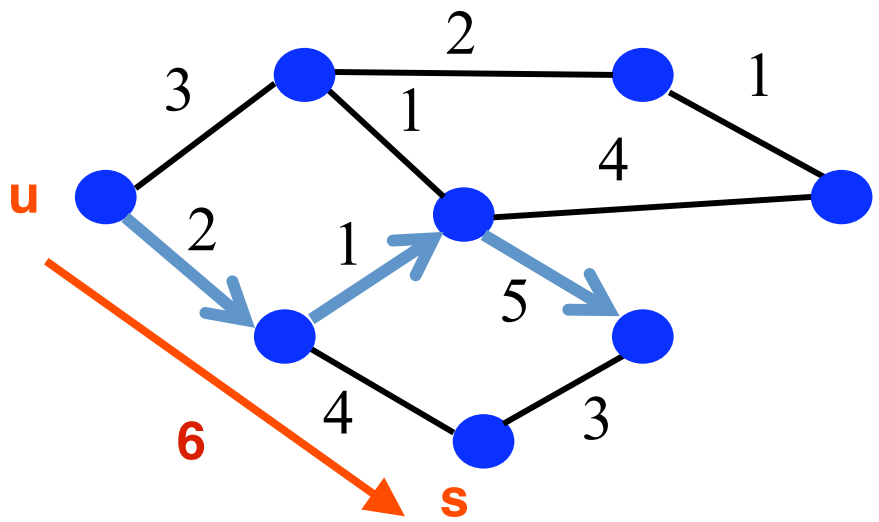
Distance Vector: Still Shortest-Path Routing

- Path-selection model
  - Destination-based
  - Load-insensitive (e.g., static link weights)
  - Minimum hop count or sum of link weights



Shortest-Path Problem

- Compute: *path costs* to all nodes
  - From a given source u to all other nodes
  - Cost of the path through each outgoing link
  - Next hop along the least-cost path to s



Ex) Forwarding table at u

	link
v	(u,v)
w	(u,w)
x	(u,w)
y	(u,v)
z	(u,v)
s	(u,w)
t	(u,w)

Comparison of Protocols

Link State

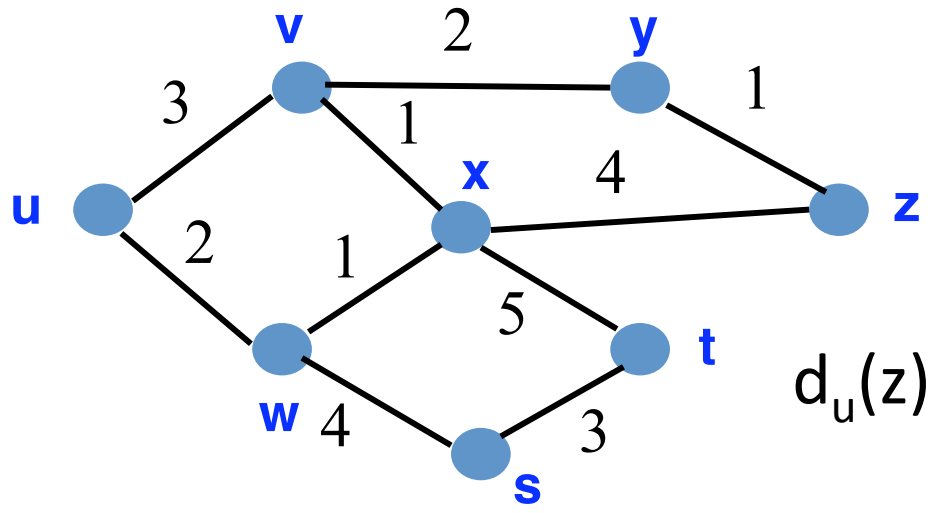
- Knowledge of every router's links (entire graph)
- Every router has O(# edges)
- Trust a peer's info, do routing computation yourself
- Use Dijkstra's algorithm
- Send updates on any link-state changes
- Ex: OSPF, IS-IS
- Adv: Fast to react to changes

Distance Vector

- Knowledge of neighbors' distance to destinations
- Every router has O (#neighbors * #nodes)
- Trust a peer's routing computation
- Use Bellman-Ford algorithm
- Send updates periodically or routing decision change
- Ex: RIP, IGRP
- Adv: Less info & lower computational overhead

Bellman-Ford Algorithm

- Define distances at each node x
  - $d_x(y)$ = cost of least-cost path from x to y
- Update distances based on neighbors
  - $d_x(y) = \min \{c(x,v) + d_v(y)\}$ over all neighbors v



$$d_u(z) = \min\{\ c(u,v) + d_v(z),\ c(u,w) + d_w(z)\ \}$$

Distance Vector Algorithm

- Node x maintains state:
  - c(x,v) = cost for direct link from x to neighbor v
  - Distance vector $D_x(y)$ (estimate of least cost x to y) for *all* nodes y
  - Distance vector $D_v(y)$ for each neighbor v, for all y
- Node x periodically sends D_x to its neighbors v
  - Neighbors update their own distance vectors:

    $D_v(y) \leftarrow \min_x\{c(v,x) + D_x(y)\}$ for each node $y \in N$
- Over time, the distance vector D_x converges

Distance Vector Algorithm

Iterative, asynchronous:

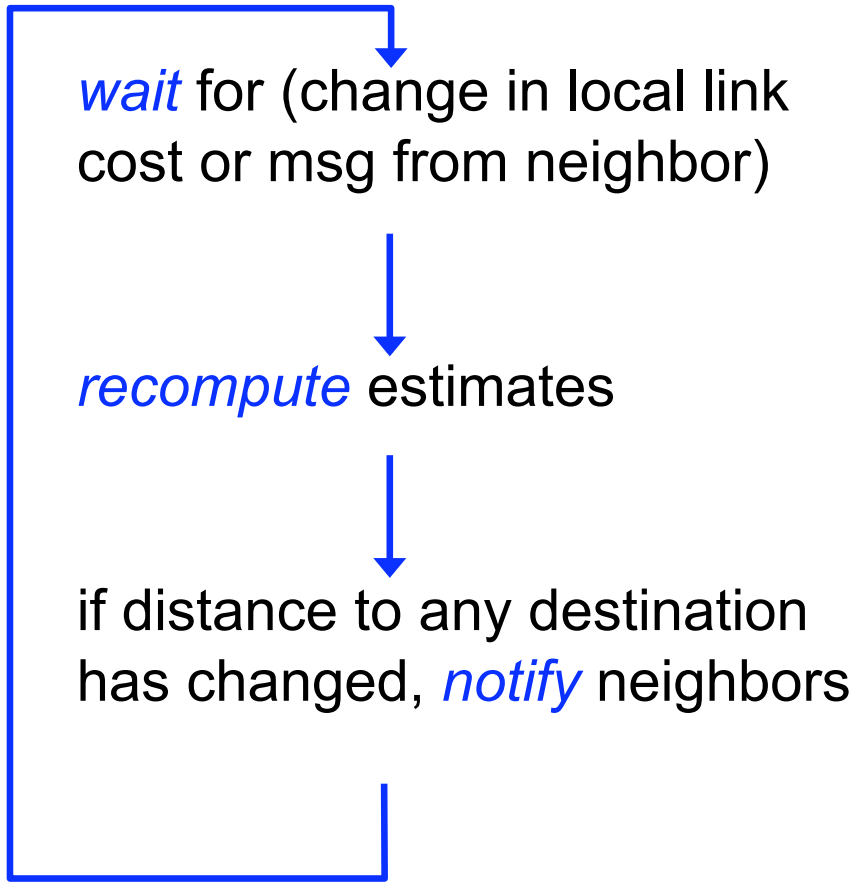
Each local iteration by

- Local link cost change
- Distance vector update message from neighbor

Distributed:

- Each node notifies neighbors *only* when its DV changes
- Neighbors then notify their neighbors if necessary

Each node:



Distance Vector Example: Step 1

Optimum 1-hop paths

Table for A			Table for B		
Dst	Cst	Hop	Dst	Cst	Hop
A	0	A	A	4	A
B	4	B	B	0	B
C	∞	–	C	∞	–
D	∞	–	D	3	D
E	2	E	E	∞	–
F	6	F	F	1	F

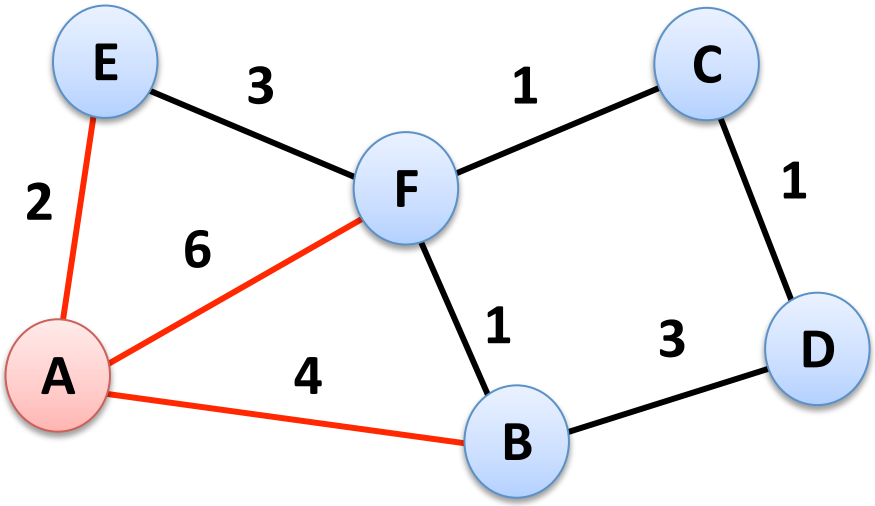


Table for C			Table for D			Table for E			Table for F		
Dst	Cst	Hop	Dst	Cst	Hop	Dst	Cst	Hop	Dst	Cst	Hop
A	∞	–	A	∞	–	A	2	A	A	6	A
B	∞	–	B	3	B	B	∞	–	B	1	B
C	0	C	C	1	C	C	∞	–	C	1	C
D	1	D	D	0	D	D	∞	–	D	∞	–
E	∞	–	E	∞	–	E	0	E	E	3	E
F	1	F	F	∞	–	F	3	F	F	0	F

Distance Vector Example: Step 2

Optimum 2-hop paths

Table for A			Table for B		
Dst	Cst	Hop	Dst	Cst	Hop
A	0	A	A	4	A
B	4	B	B	0	B
C	7	F	C	2	F
D	7	B	D	3	D
E	2	E	E	4	F
F	5	E	F	1	F

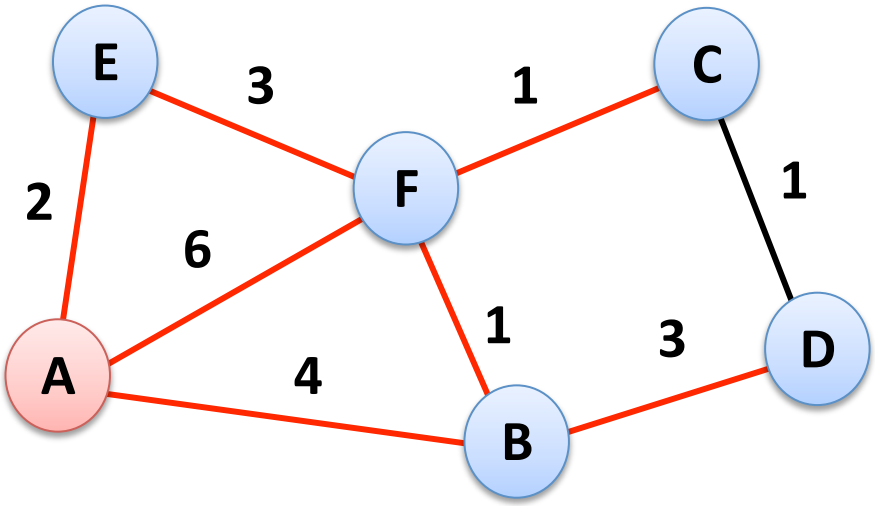


Table for C			Table for D			Table for E			Table for F		
Dst	Cst	Hop	Dst	Cst	Hop	Dst	Cst	Hop	Dst	Cst	Hop
A	7	F	A	7	B	A	2	A	A	5	B
B	2	F	B	3	B	B	4	F	B	1	B
C	0	C	C	1	C	C	4	F	C	1	C
D	1	D	D	0	D	D	∞	–	D	2	C
E	4	F	E	∞	–	E	0	E	E	3	E
F	1	F	F	2	C	F	3	F	F	0	F

Distance Vector Example: Step 3

Optimum 3-hop paths

Table for A			Table for B		
Dst	Cst	Hop	Dst	Cst	Hop
A	0	A	A	4	A
B	4	B	B	0	B
C	6	E	C	2	F
D	7	B	D	3	D
E	2	E	E	4	F
F	5	E	F	1	F

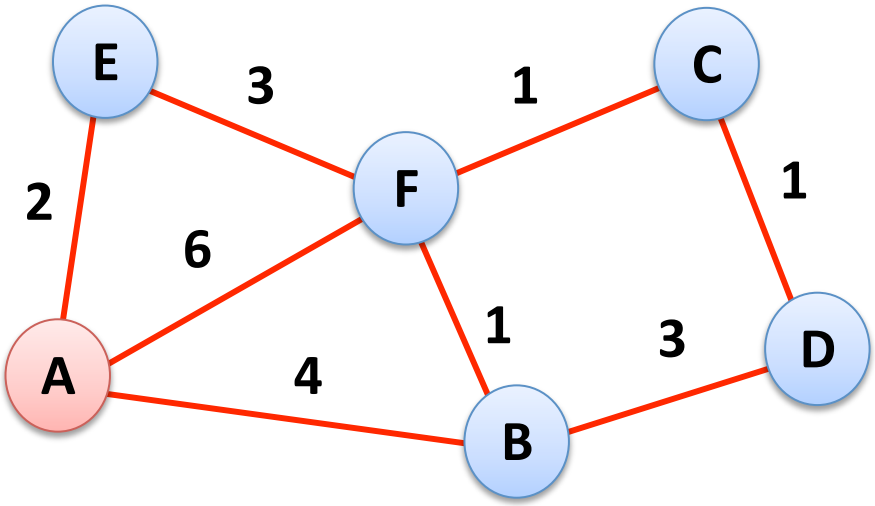
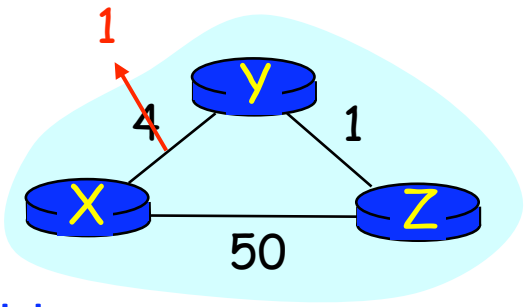


Table for C			Table for D			Table for E			Table for F		
Dst	Cst	Hop	Dst	Cst	Hop	Dst	Cst	Hop	Dst	Cst	Hop
A	6	F	A	7	B	A	2	A	A	5	B
B	2	F	B	3	B	B	4	F	B	1	B
C	0	C	C	1	C	C	4	F	C	1	C
D	1	D	D	0	D	D	5	F	D	2	C
E	4	F	E	5	C	E	0	E	E	3	E
F	1	F	F	2	C	F	3	F	F	0	F

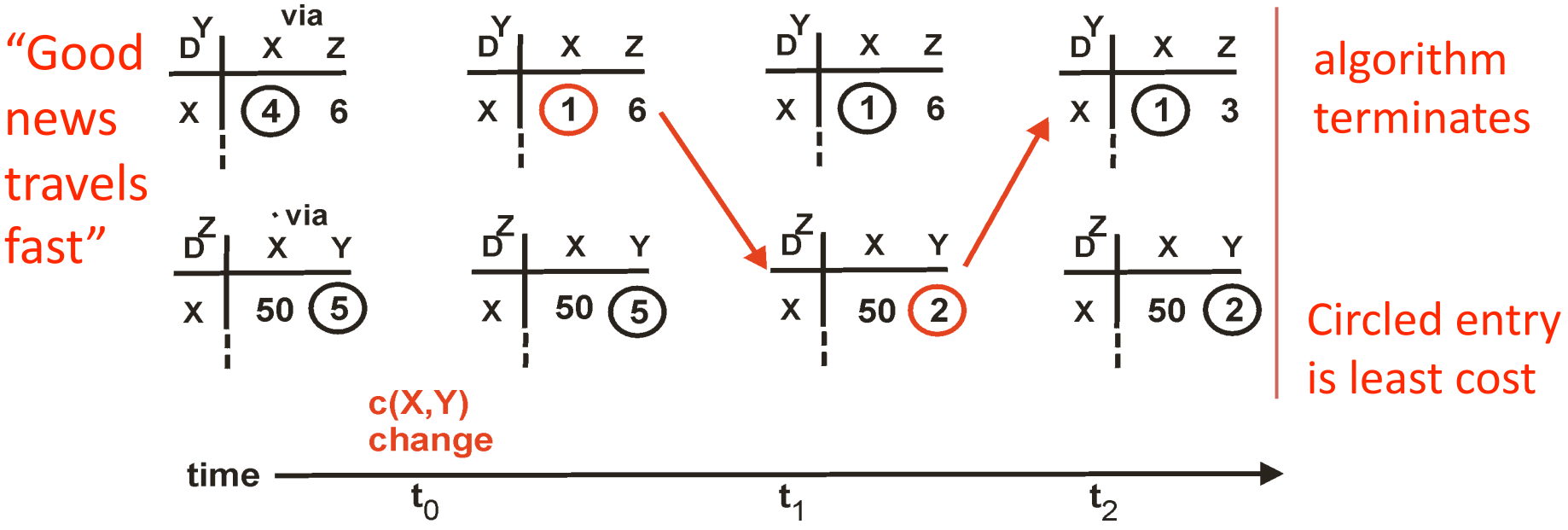
Distance Vector: Link Cost Changes

Link cost changes:

- Node detects local link cost change
- Updates the distance table
- If cost change in least cost path, notify neighbors



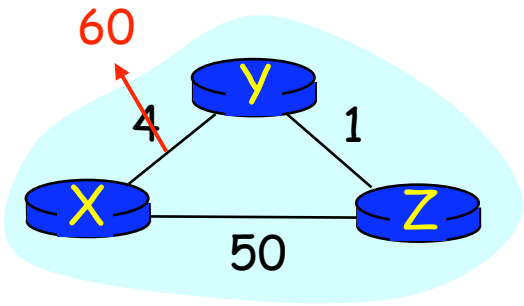
View of X (about neighbor y and z's routing tables)



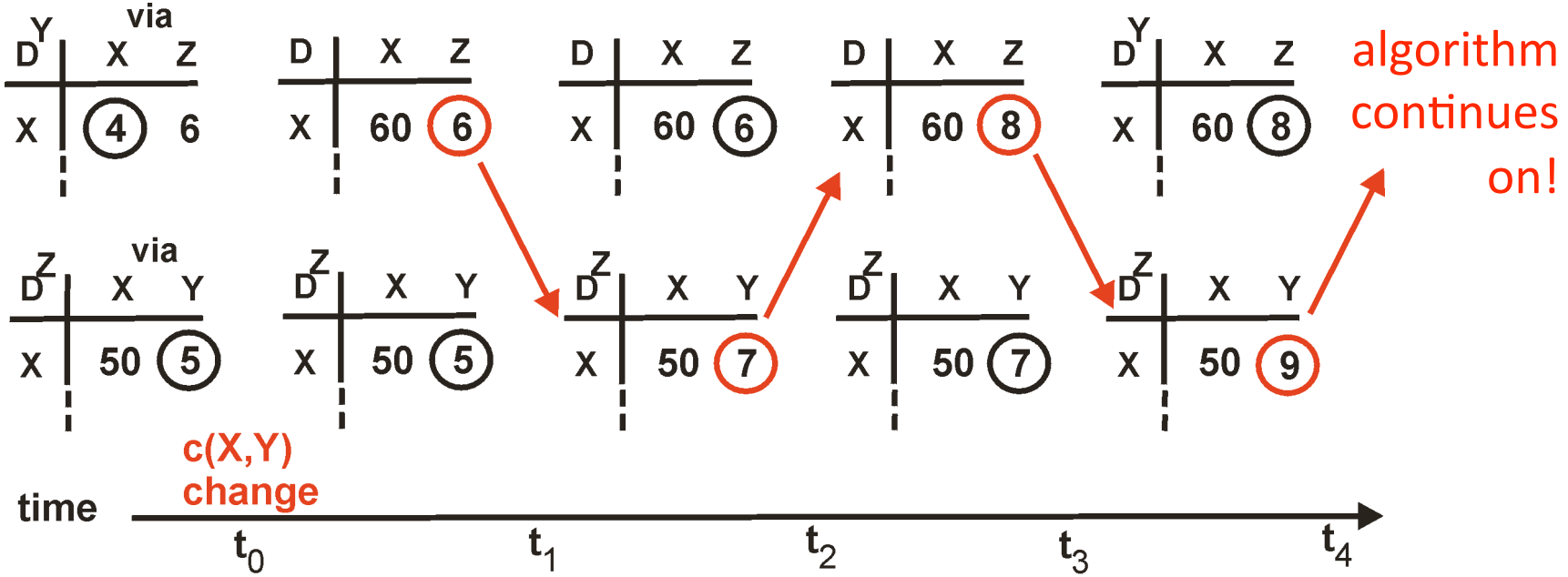
Distance Vector: Link Cost Changes

Link cost changes:

- Good news travels fast
- Bad news travels slow - "count to infinity" problem!



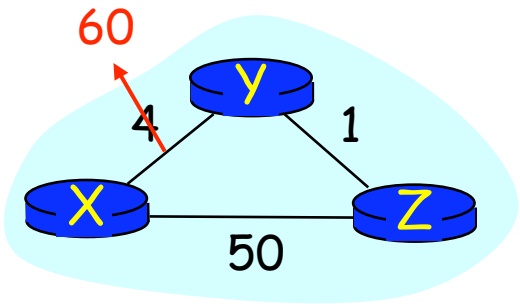
View of X (about neighbor y and z's routing tables)



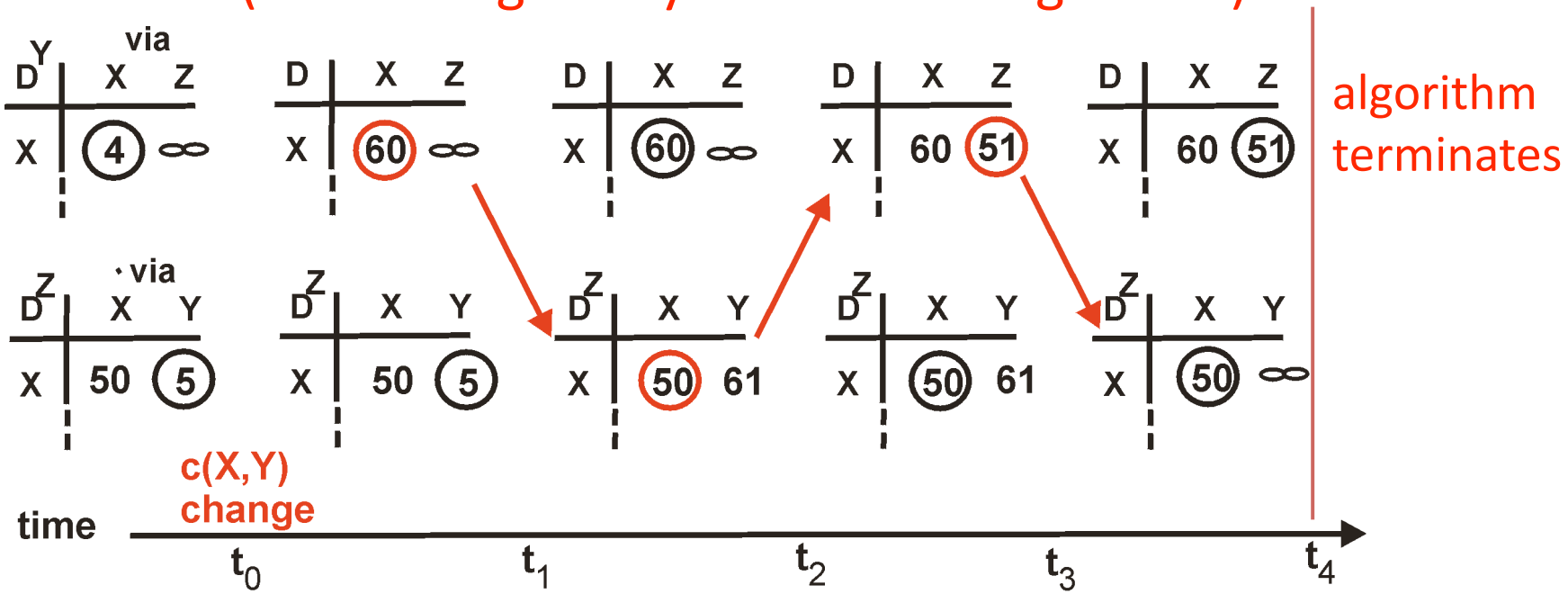
Distance Vector: Poison Reverse

If Z routes through Y to get to X :

- Z tells Y its (Z's) distance to X is infinite (so Y won't route to X via Z)
- Still, can have problems when more than 2 routers are involved



View of X (about neighbor y and z's routing tables)



Routing Information Protocol (RIP)

- Distance vector protocol
  - Nodes send distance vectors every 30 seconds
  - … or, when an update causes a change in routing
- Link costs in RIP
  - All links have cost 1
  - Valid distances of 1 through 15
  - … with 16 representing infinity
  - Small "infinity" → smaller "counting to infinity" problem
- RIP is limited to fairly small networks
  - E.g., used in the Princeton campus network

Comparison of LS and DV Routing

Message complexity

- LS: with n nodes, E links, O(nE) messages sent
- DV: exchange between neighbors only

Speed of Convergence

- LS: relatively fast
- DV: convergence time varies
  - May be routing loops
  - Count-to-infinity problem

Robustness: what happens if router malfunctions?

LS:

- Node can advertise incorrect *link* cost
- Each node computes only its *own* table

DV:

- DV node can advertise incorrect *path* cost
- Each node's table used by others (error propagates)

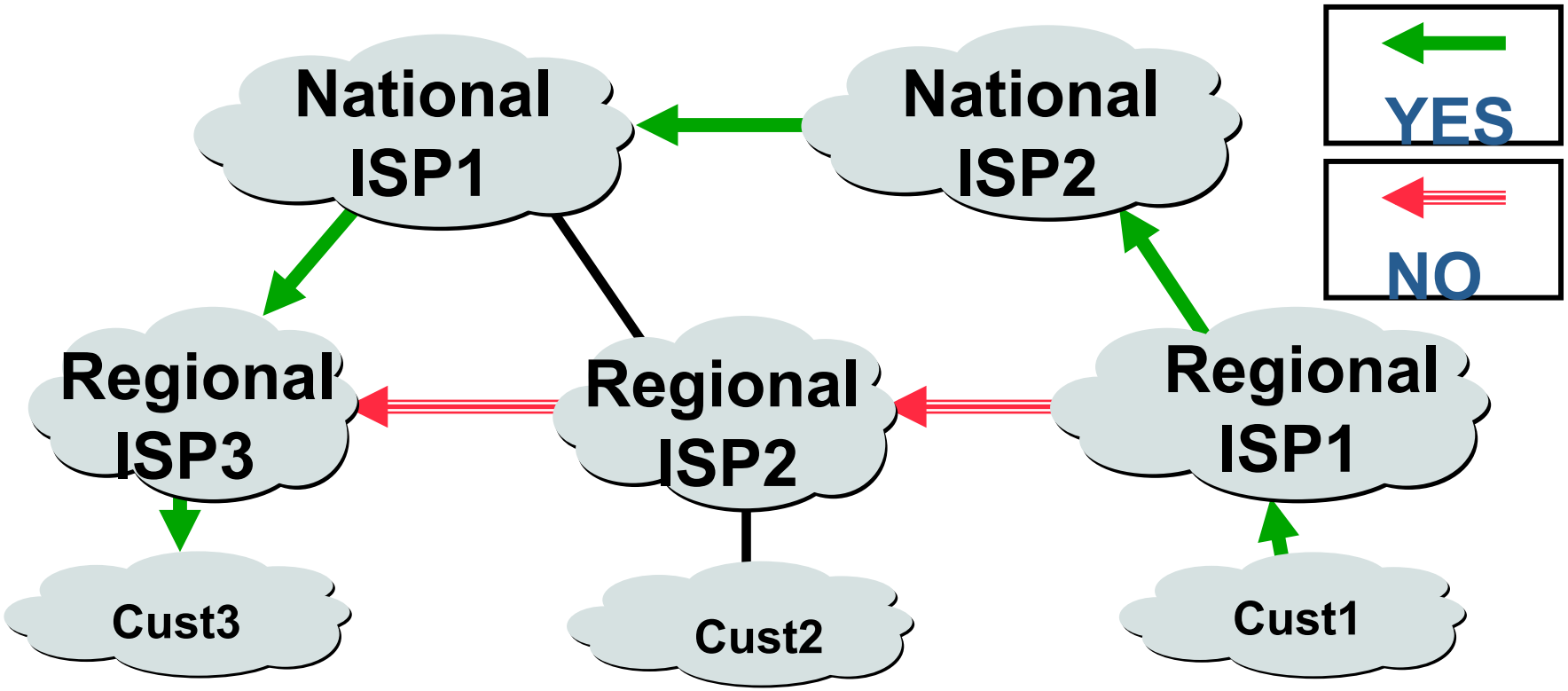
Similarities of LS and DV Routing

- Shortest-path routing
  - Metric-based, using link weights
  - Routers share a common view of how good a path is
- As such, commonly used *inside* an organization
  - RIP and OSPF are mostly used as *intra*-domain protocols
  - E.g., Princeton uses RIP, and AT&T uses OSPF
- But the Internet is a "network of networks"
  - How to stitch the many networks together?
  - When networks may not have common goals
  - … and may not want to share information

Path-Vector Routing

Shortest-Path Routing is Restrictive

- All traffic must travel on shortest paths
- All nodes need common notion of link costs
- Incompatible with commercial relationships



Link-State Routing is Problematic

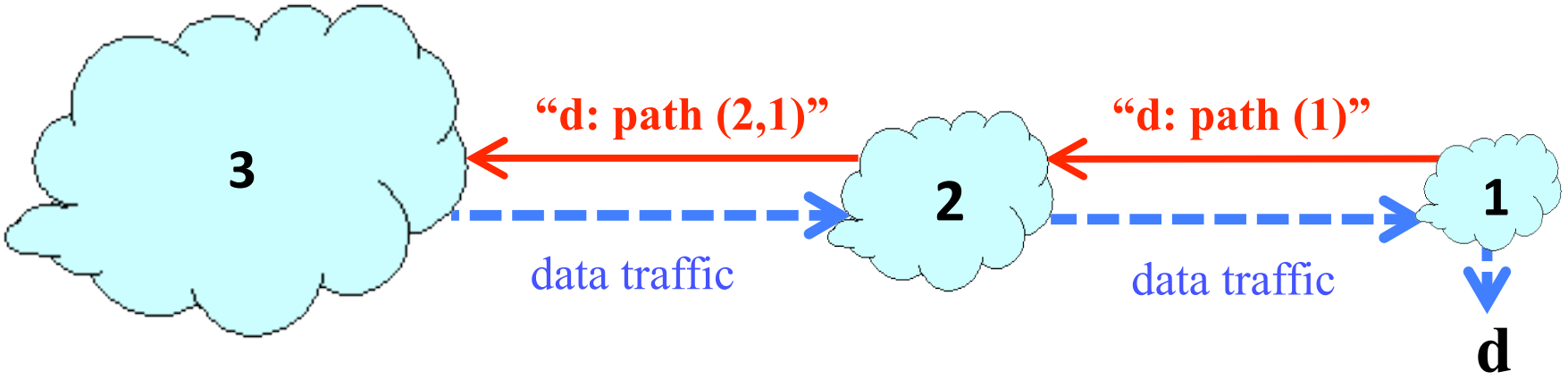
- Topology information is flooded
  - High bandwidth and storage overhead
  - Forces nodes to divulge sensitive information
- Entire path computed locally per node
  - High processing overhead in a large network
- Minimizes some notion of total distance
  - Works only if policy is shared and uniform
- Typically used only inside an AS
  - E.g., OSPF and IS-IS

Distance Vector is on the Right Track

- Advantages
  - Hides details of the network topology
  - Nodes determine only "next hop" toward the dest
- Disadvantages
  - Minimizes some notion of total distance, which is difficult in an interdomain setting
  - Slow convergence due to the counting-to-infinity problem ("bad news travels slowly")
- Idea: extend the notion of a distance vector
  - To make it easier to detect loops

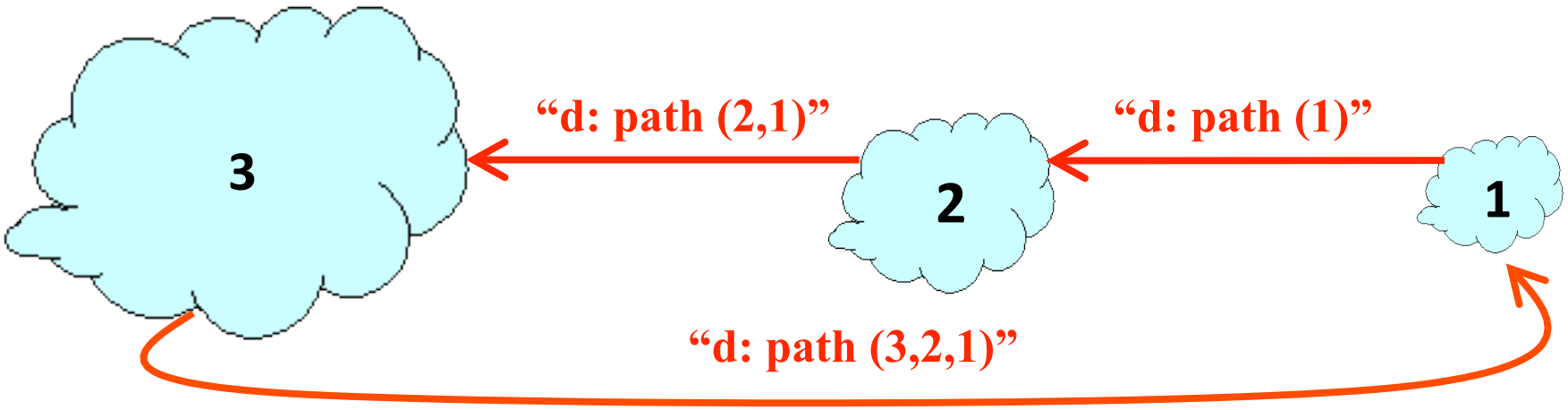
Path-Vector Routing

- Extension of distance-vector routing
  - Support flexible routing policies
  - Avoid count-to-infinity problem
- Key idea: advertise the entire path
  - Distance vector: send *distance metric* per dest d
  - Path vector: send the *entire path* for each dest d



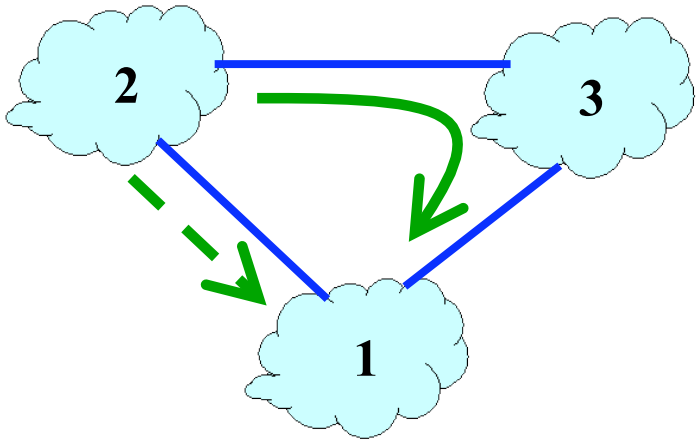
Faster Loop Detection

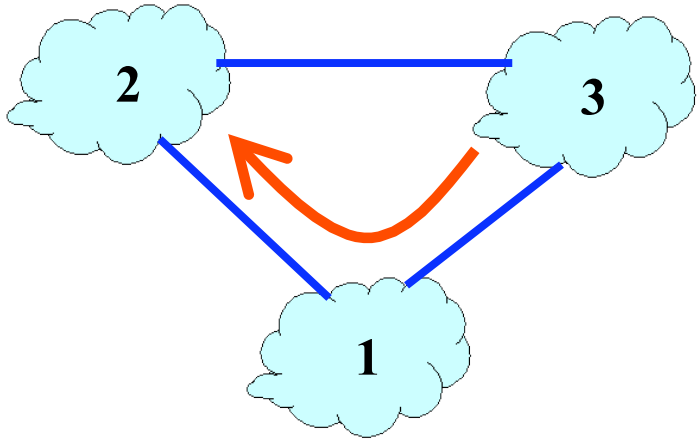
- Node can easily detect a loop
  - Look for its own node identifier in the path
  - E.g., node 1 sees itself in the path "3, 2, 1"
- Node can simply discard paths with loops
  - E.g., node 1 simply discards the advertisement



Flexible Policies

- Each node can apply local policies
  - Path selection: Which path to use?
  - Path export: Which paths to advertise?
- Examples
  - Node 2 may prefer the path “2, 3, 1” over “2, 1”
  - Node 1 may not let node 3 hear the path “1, 2”





Conclusions

- Distance-vector routing
  - Pro: Less information and computation than link state
  - Con: Slower convergence (e.g., count to infinity)
- Path-vector routing
  - Share entire path, not distance: faster convergence
  - More flexibility in selecting paths
- Different goals / metrics if inter- or intra-domain
- Next week: BPG (path-vector protocol b/w ASes)