Lecture 10: Link State Routing

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COS 461: Computer Networks

Slides adapted from B. Karp

Outline

- Link State Approach to Routing
- Finding Links: Hello Protocol
- Building a Map: Flooding Protocol
- Healing after Partitions: Bringing up Adjacencies
- Finding Routes: Dijkstra's Shortest-Path-First Algorithm
- Properties of Link State Routing

Link State Approach to Routing

- Shortest paths in graph: classic theory problem
- Classic centralized single-source shortest paths algorithm: Dijkstra's Algorithm
  - requires map of entire network
- Link State (LS) Routing:
  - push network map to every router
  - each router learns link state database
  - each router runs Dijkstra's locally

Finding Links: Hello Protocol

- Each router configured to know its interfaces

- On each interface, every period P, transmit a hello packet containing:
  - sender's ID
  - list of neighbors from which sender has heard hello during period D
  - D > P (*e.g.*, D = 3P)

- Link becomes up if have received hello containing own ID on it in last period D
- Link becomes down if no such hello received in last period D

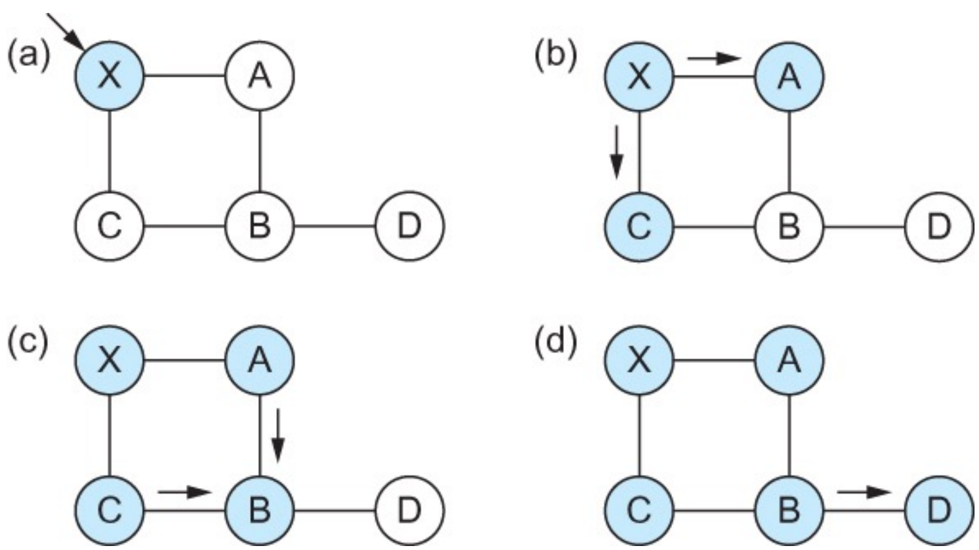
Building a Map: Flooding Protocol (I)

- Whenever link becomes up or becomes down, router **floods** announcement to whole network:
  - two link endpoint addresses
  - metric for link (configured by administrator)
  - sequence number

- Sequence number stored in link state database; incremented on every changed announcement
  - prevents old link states from overwriting new ones

Building a Map: Flooding Protocol (II)

- Upon receiving new link state msg on interface i:
  - if link not in database (db), add it, flood elsewhere
  - if link in db & seqno in msg > one in db, write into database, flood elsewhere
  - if link in db & seqno in msg <= one in db, send link state from database on interface i



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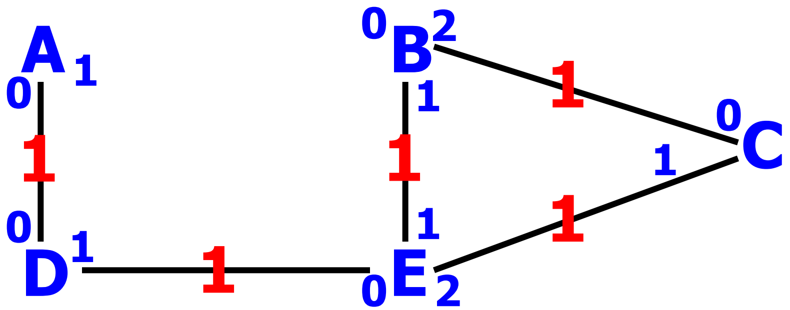
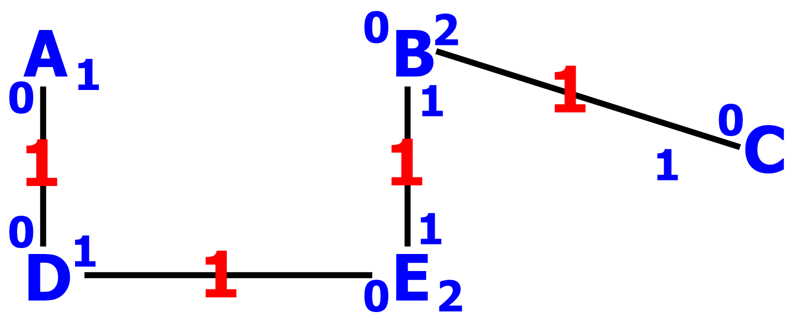
Healing Network Partitions

- Recall example from Distance Vector routing where network partitions
- Consider flooding behavior when partitions heal



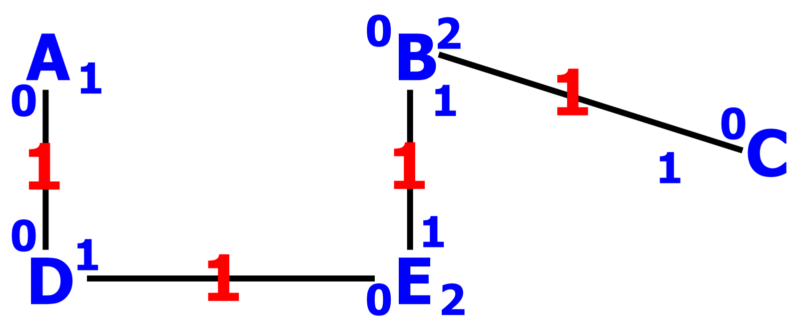
Healing Network Partitions (II)

- D detects link (D, E), floods link state to A
- A and D may still think link (C, E) exists!
- If first time link (D, E) comes up, how will A learn about links (B, E), (B, C)?
  - Flooding to report changes only in neighboring links not always sufficient!



Healing Network Partitions (III)

- Bringing up adjacencies:
  - when link comes up, routers at ends exchange short summaries (link endpoints, sequence numbers) of their whole databases
  - routers then request missing or newer entries from one another
  - saves bandwidth; real LS database entries contain more than link endpoints, seqnos



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Link State Database → Routing Table

- After flooding each router holds map of entire network graph in memory
  - Need to transform network map into routing table

- How: single-source shortest paths algorithm
- Router views itself as source s, all other routers as destinations

Shortest Paths: Definitions

- Each router is a vertex, $v \in V$
- Each link is an edge, $e \in E$, also written (u, v)
  - edge weights are non-negative
- Each link metric an edge weight, $w(u, v)$
- Series of edges is a path, whose cost is sum of edges' weights

Shortest Paths: Data Structures

- Single-source shortest paths: seek path with least cost from s to all other vertices

- Data structures:
  - $\pi[v]$ is predecessor of v: $\pi[v]$ is vertex before v along shortest path from s to v
  - d[v] is shortest path estimate: least cost found from s to v so far

Shortest Paths: Initialization

- When we start, we know little:
  - no estimate of cost of any path from s to any other vertex
  - no predecessor of v along shortest path from s to any v

```
initialize-single-source(V, s)
   for each vertex v ∈ V do
      d[v] ← infinity
      π[v] ← NULL
   d[s] = 0
```

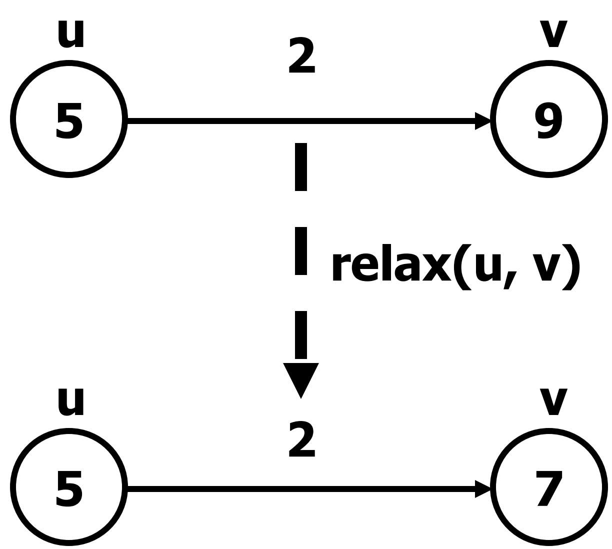
Shortest Paths Building Block: Relaxation

- Relaxation:
  - Suppose we have current estimates d[u], d[v] of shortest path cost from s to u and v
  - Does it reduce cost of shortest path from s to v to reach v via (u, v)?

```
relax(u, v, w)
    if d[v] > d[u] + w(u, v) then
        d[v] ← d[u] + w(u, v)
        π[v] ← u
```

Relaxation: Example

- Suppose
  - d[u] = 5
  - d[v] = 9
  - w(u, v) = 2
- relax(u, v, w) computes:
  - d[v] ?> d[u] + w(u, v)
  - 9 ?> 5 + 2
    - Yes, so reaching v via (u, v) reduces path cost
  - d[v] = d[u] + w(u, v)
  - π[v] = u



Dijkstra’s Algorithm: Overall Strategy

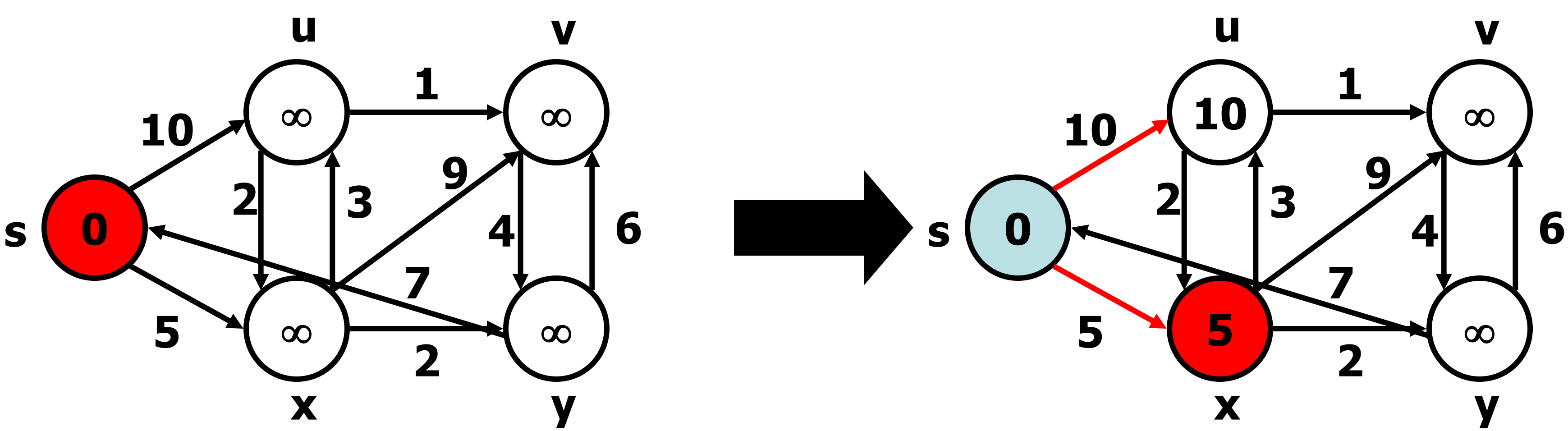
- Maintain running estimates of costs of shortest paths to all vertices (initially all infinity)
- Keep a set S of vertices that are “finished”; shortest paths to these vertices already found (initially empty)
- Repeatedly pick the unfinished vertex v with least shortest path cost estimate
- Add v to set S
- Relax all edges leaving v

Dijkstra's Algorithm: Pseudocode

```
Dijkstra(V, E, w, s)
    initialize-single-source(V, s)
    S ← ∅
    Q ← V
    while Q ≠ ∅ do
        u ← extract-min(Q)
        S ← S ∪ {u}
        for each vertex v that neighbors u do
            relax(u, v, w)
```

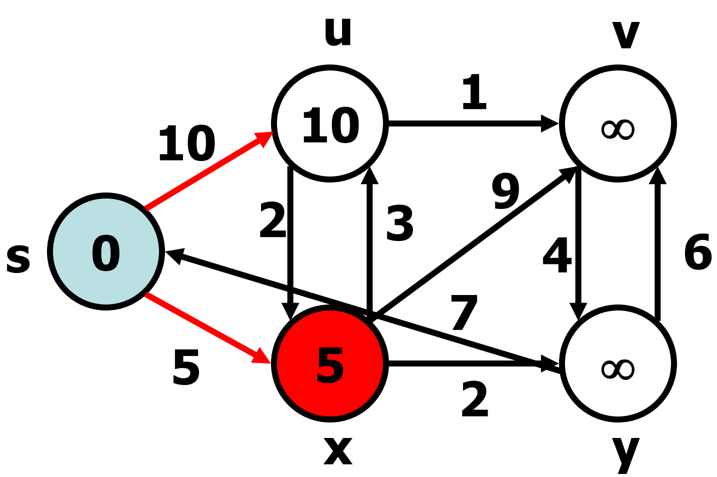
extract-min(Q): return vertex v in Q with minimal shortest-path estimate d[v]

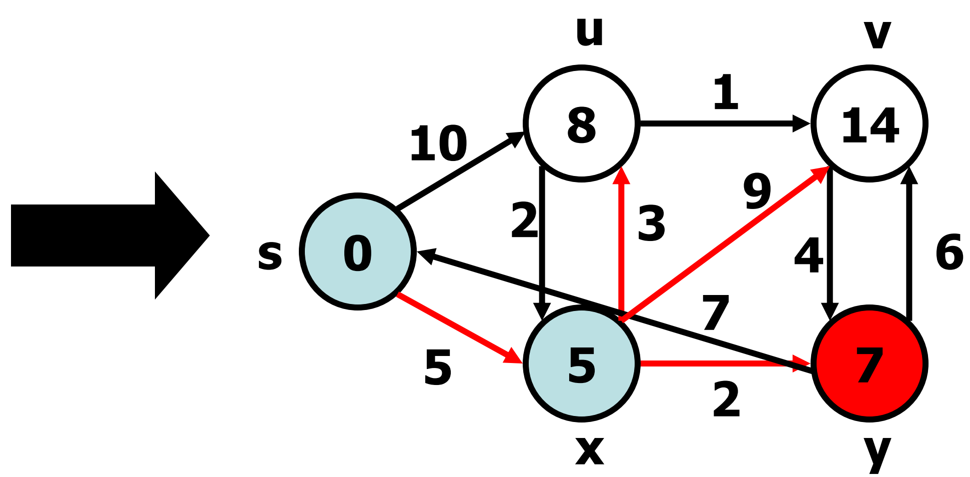
Dijkstra's Algorithm: Example



- s: source
- d[i]: number inside of vertex i
- π[b]: if (a, b) red, then π[b] = a
- members of set S: blue-shaded vertices
- members of priority queue Q: non-shaded vertices

Dijkstra's Algorithm Example (cont'd)





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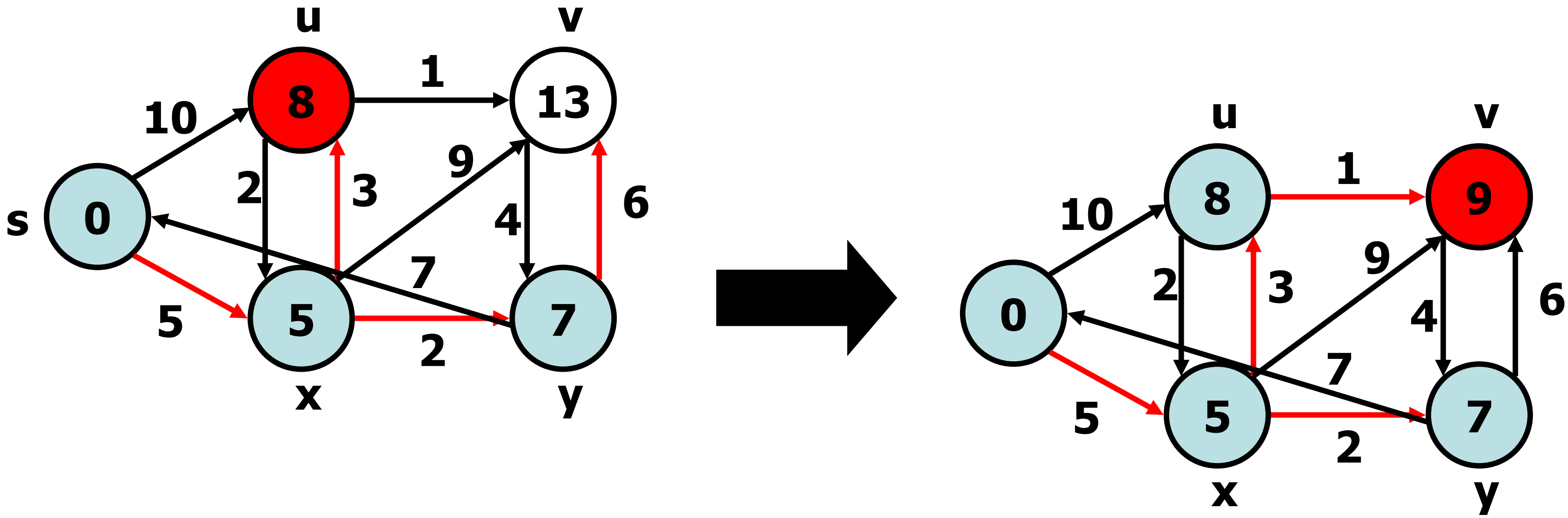
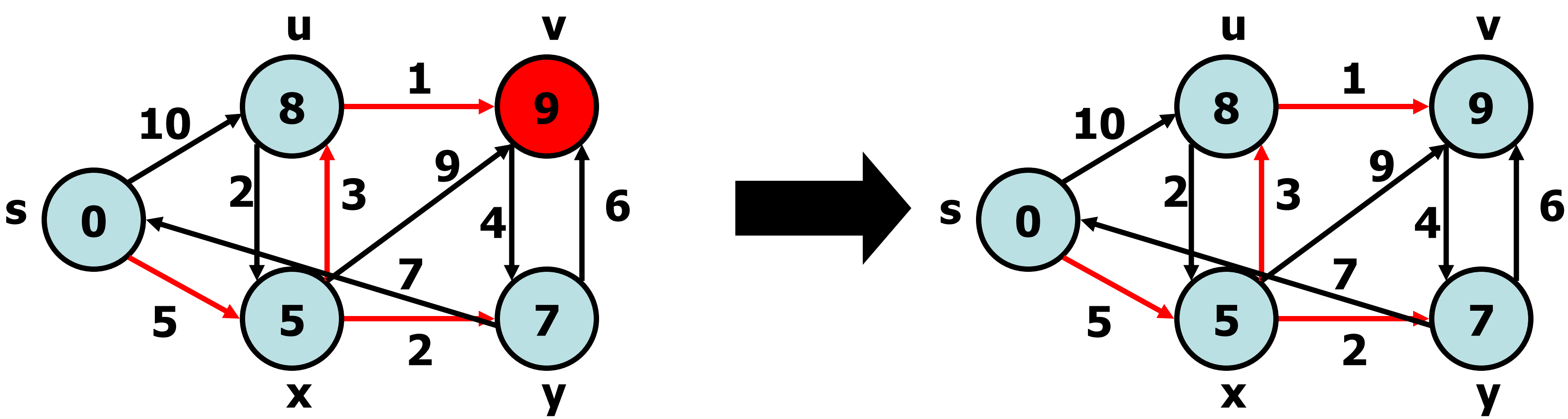


Dijkstra's Algorithm Example (cont'd)



- At termination, know shortest-path routes from s to all other routers
- Shortest-path tree, rooted at s

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Link State Routing: Drawbacks

- LS more complex to implement than DV
  - Sequence numbers crucial to protect against stale announcements
  - Bringing up adjacencies
  - Maintains both link state database and routing table

Link State Routing: Advantages + Summary

- At first glance, flooding status of all links seems costly
  - It is! Doesn't scale to thousands of nodes without other tricks, namely hierarchy (more when we discuss BGP)
  - Cost reasonable for networks of 100s/routers

- In practice, for **intra-**domain routing, LS has won, and DV no longer used
  - LS: after flooding, no loops in routes, provided all nodes have consistent link state databases
  - LS: flooding offers fast convergence after topology changes