Lecture 10:
Link-state Routing

CSE 123: Computer Networks
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Link-state Routing

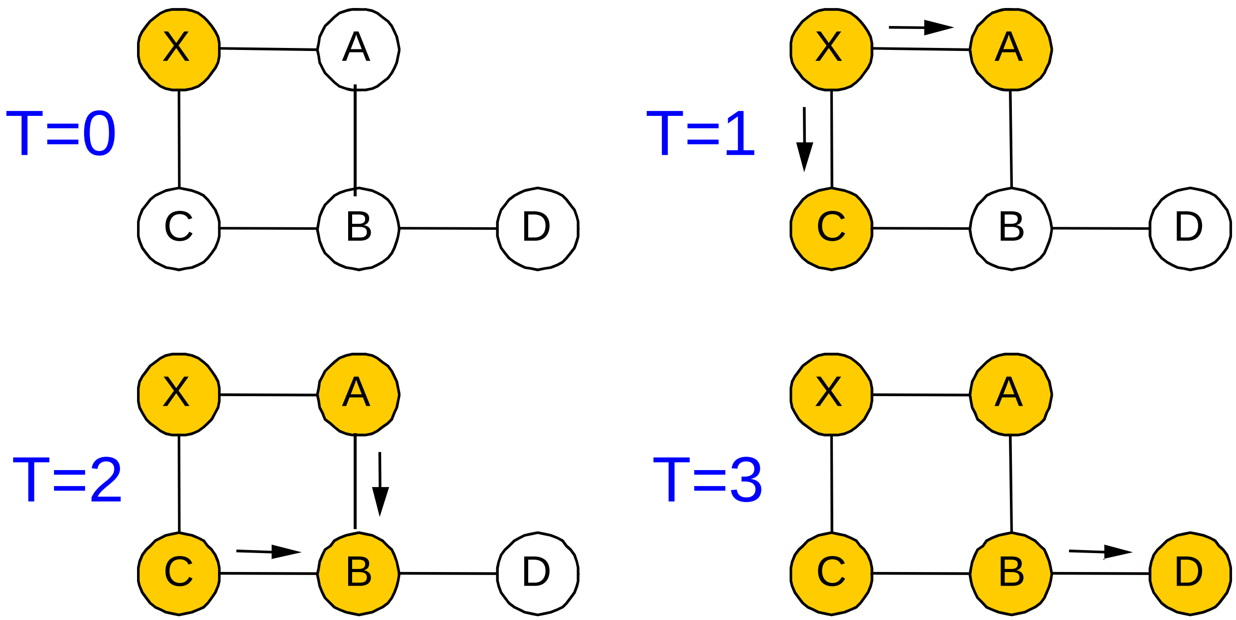
- Same goal as Distance Vector, but different approach
  - Tell **every** node what you know about your **direct neighbors**
- Two phases
  - Reliable flooding
    - » Tell all routers what you know about your local topology
  - Path calculation (Dijkstra's algorithm)
    - » Each router computes best path over complete network
- Motivation
  - Global information allows optimal route computation
  - Straightforward to implement and verify

Broadcasting Link State

- Reliable flooding
  - Each router transmits a Link State Packet (LSP) on all links
  - A neighboring router forwards out all links except incoming
    - Keep a copy locally; don’t forward previously-seen LSPs
- Challenges
  - Packet loss
  - Out-of-order arrival
- Solutions
  - Acknowledgments and retransmissions
  - Sequence numbers
  - Time-to-live for each packet

Flooding Example

- LSP generated by X at T=0
- Nodes become orange as they receive it

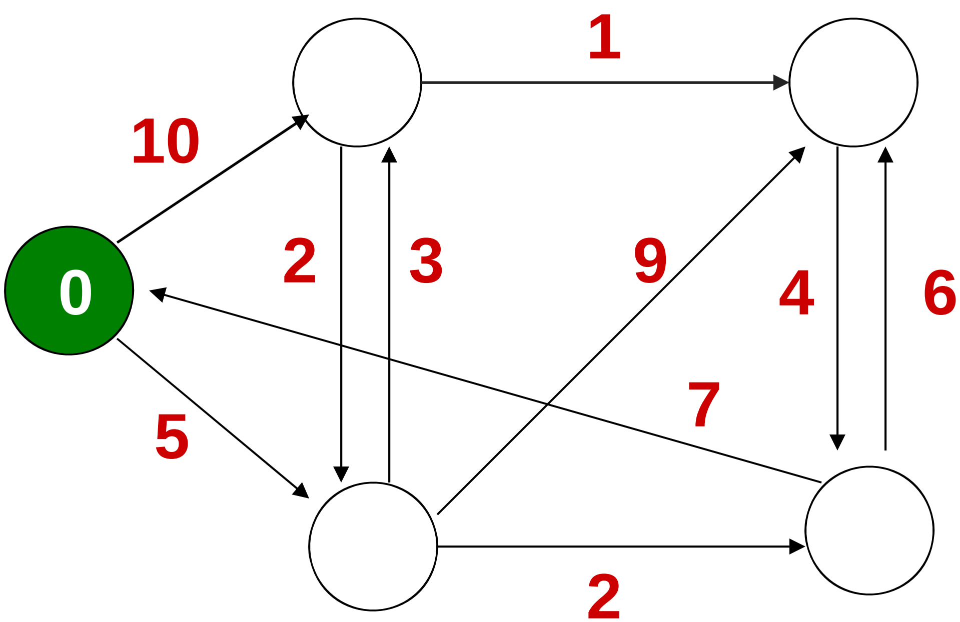


Dijkstra's Shortest Path Tree (SPT)

- So you have all of these LSPs. Now what?
- Graph algorithm for single-source shortest path tree (find best route to all nodes)

```
S ← {}
Q ← <remaining nodes keyed by distance>
While Q != {}
        u ← extract-min(Q)   u = node with lowest cost
        S ← S plus {u}                    ← u is done
        Within Q:
            for each node v adjacent to u
                "relax" the cost of v  is it cheaper to go
                                       through u?
```

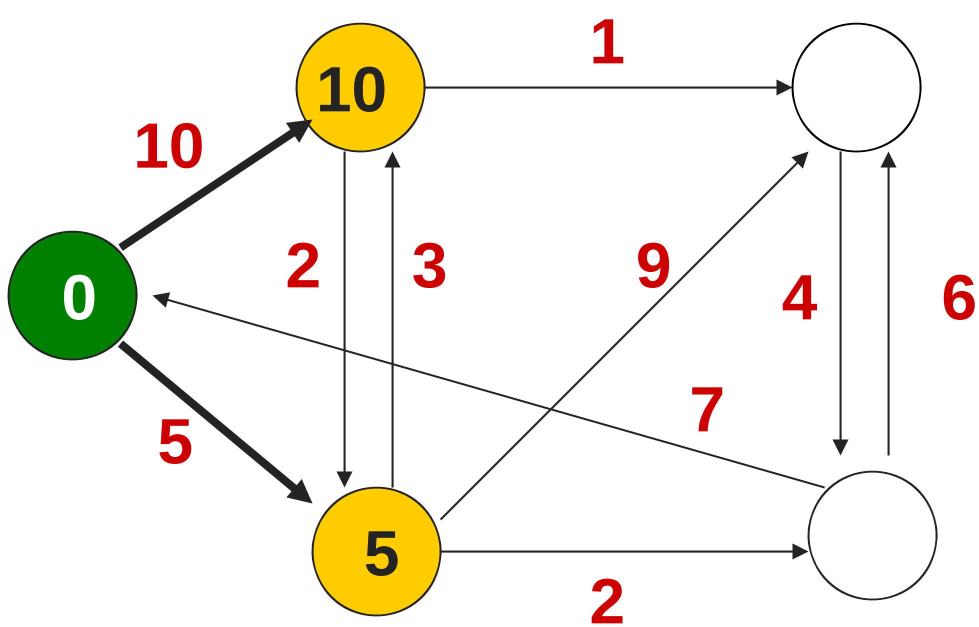
Dijkstra Example – Step 1



- Green nodes are "confirmed"
- Yellow nodes are "tentative"

- We can add ourselves to "confirmed"

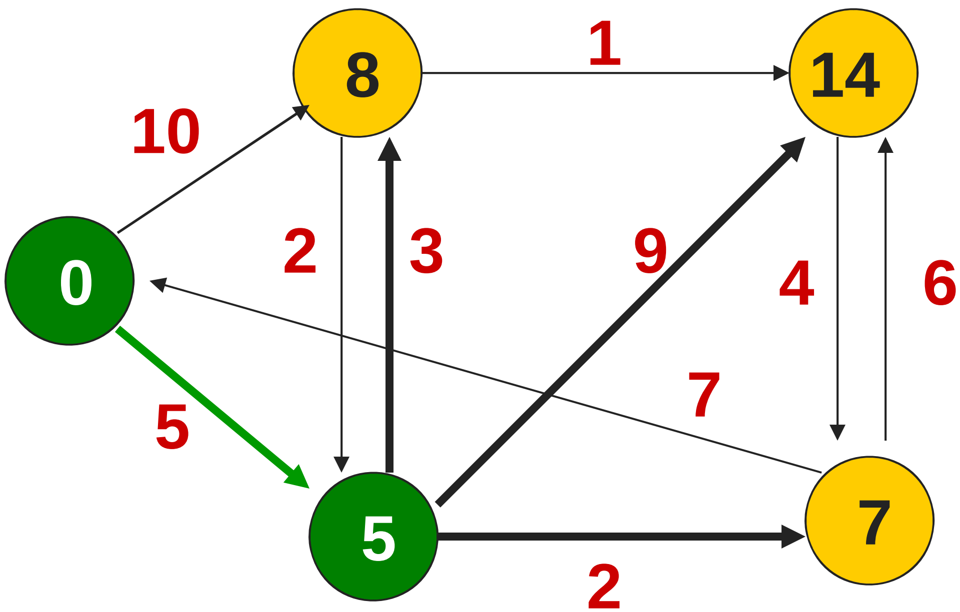
Example – Step 2



- Green nodes are "confirmed"
- Yellow nodes are "tentative"

- First look at neighbors
- "5" is cheaper than "10"
- We can confirm path with cost "5"

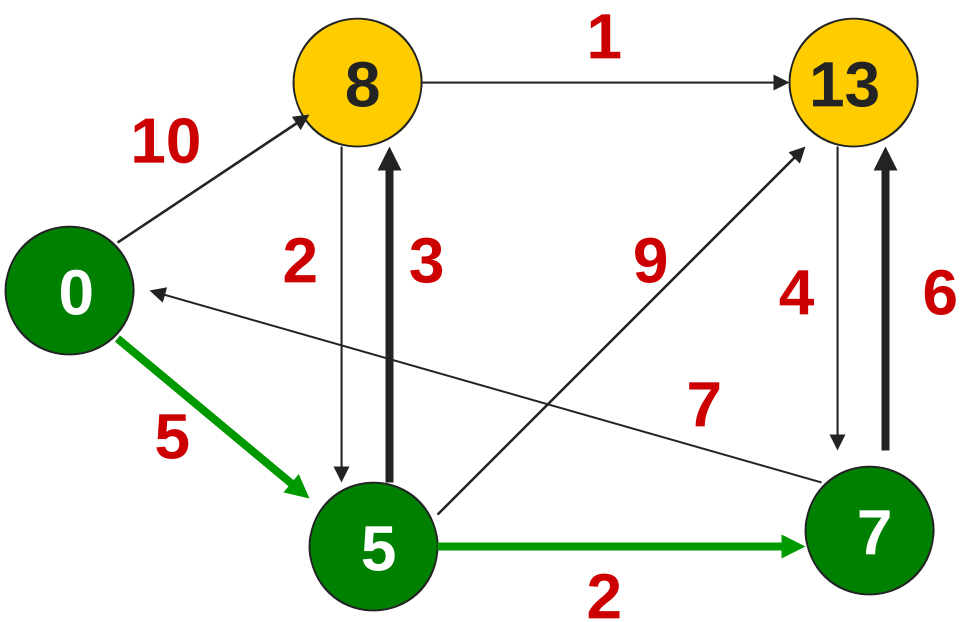
Example – Step 3



- Green nodes are "confirmed"
- Yellow nodes are "tentative"

- Update costs
- Look at 5's neighbors
- 7 is cheapest
- We can confirm path with cost 7

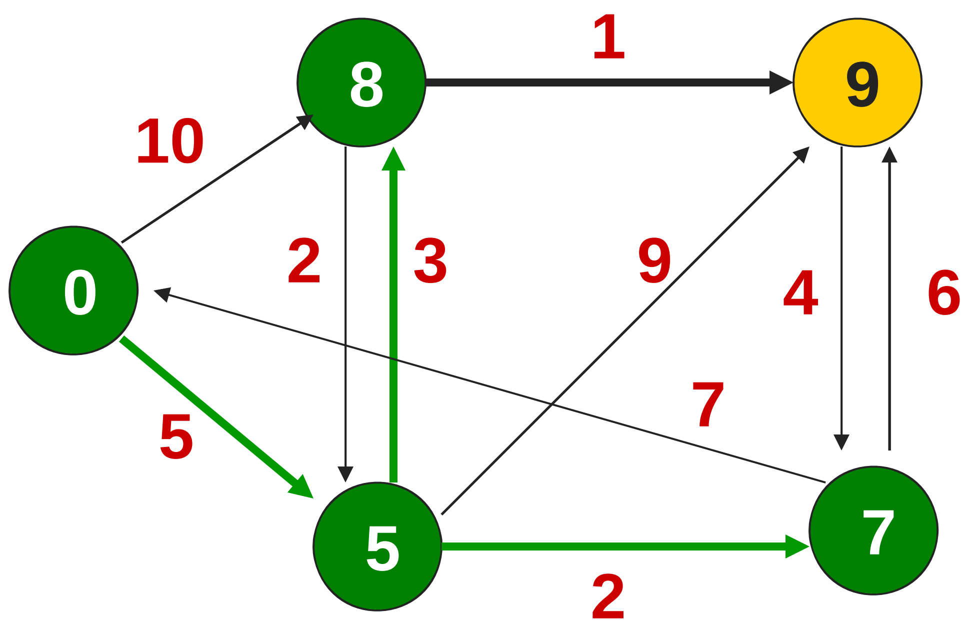
Example – Step 4



- Green nodes are "confirmed"
- Yellow nodes are "tentative"

- Update costs
- 7 has no new neighbors
- 8 is cheapest
- We can confirm 8

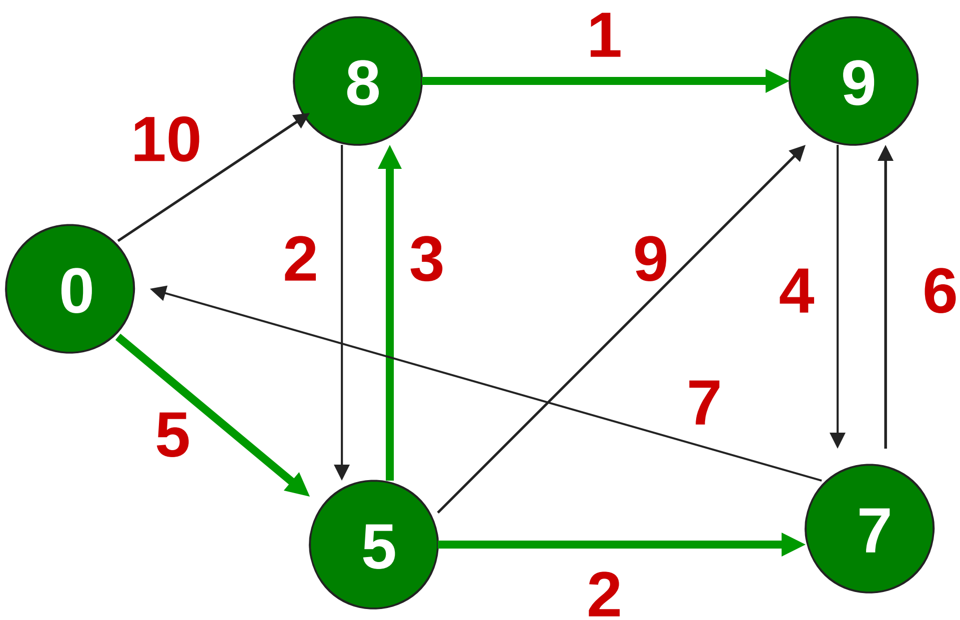
Example – Step 5



- Green nodes are "confirmed"
- Yellow nodes are "tentative"

- Update costs
- No new neighbors
- 9 is cheapest
- We can path with cost 9

Example – Done



Making Something Disappear

- Need to remove failed/old links from topology
  - LSPs carry sequence numbers to distinguish new from old
  - Routers only accept (and forward) the "newest" LSP
  - Send a new LSP with cost infinity to signal a link down

- But also need to remove entire routers
  - TTL in every LSP, decremented periodically by each router
  - When TTL = 0, purge the LSP and flood the network with an LSP with TTL 0 to tell everyone else to do the same

When to Flood?

- Triggered by a topology change
  - Link or node failure/recovery or
  - Configuration change like updated link metric
  - Converges quickly, but can cause flood of updates
- Periodically
  - Typically (say) every 30 minutes
  - Corrects for possible corruption of the data
  - Limits the rate of updates, but also failure recovery

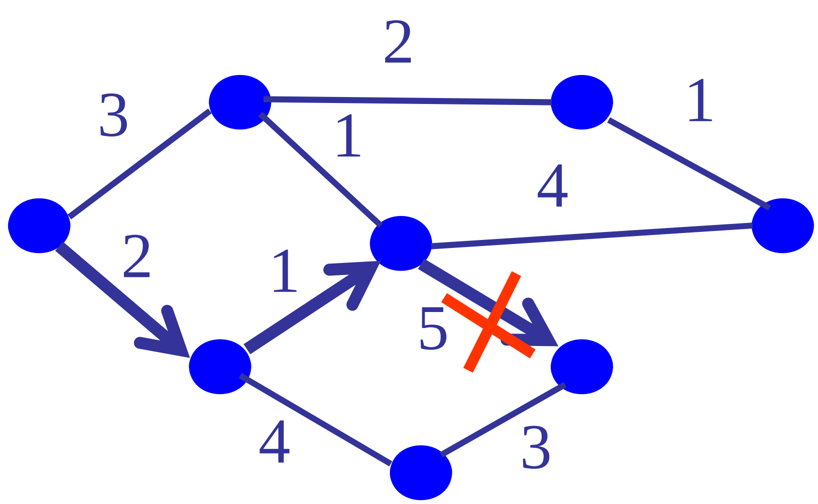
Convergence

- Getting consistent routing information to all nodes
  - E.g., all nodes having the same link-state database
  - Until routing protocol converges, strange things happen…

- Consistent forwarding after convergence
  - All nodes have the same link-state database
  - All nodes forward packets on shortest paths
  - The next router on the path forwards to the next hop

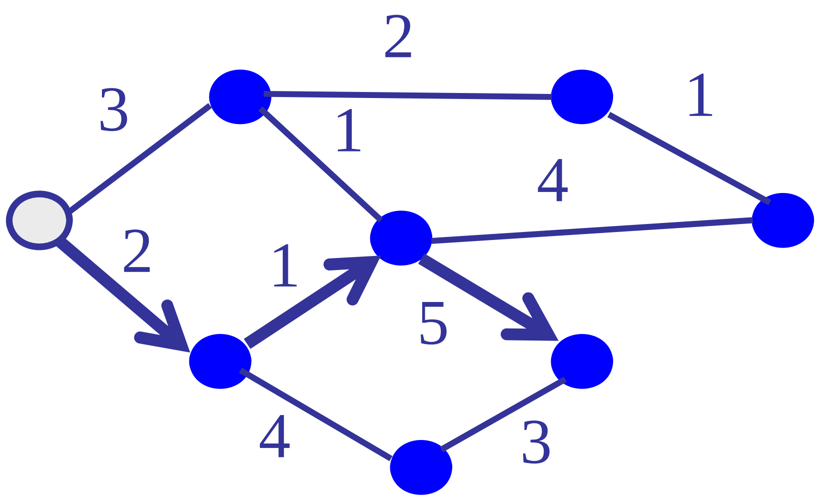
Transient Disruptions

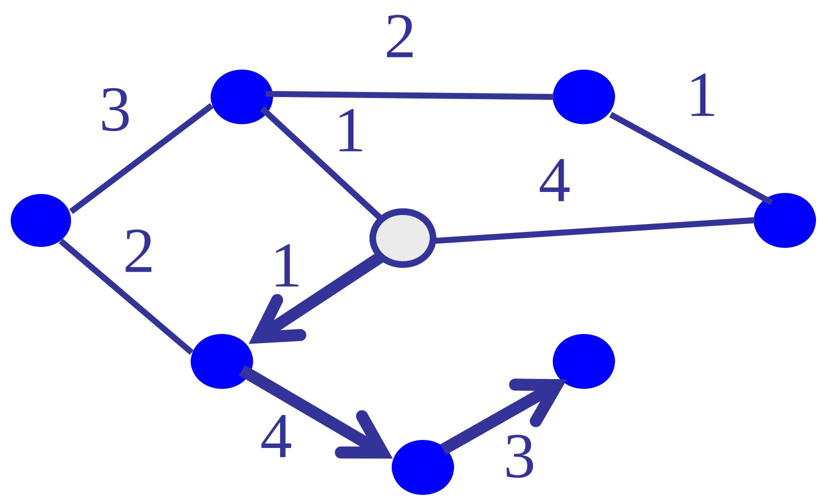
- Detection delay
  - A node does not detect a failed link immediately
  - … and forwards data packets into a black hole
  - Depends on timeout for detecting lost hellos



Transient Disruptions

- Inconsistent link-state database
  - Some routers know about failure before others
  - The shortest paths are no longer consistent
  - Can cause transient forwarding loops





Convergence Delay

- Sources of convergence delay
  - Detection latency
  - Flooding of link-state information
  - Shortest-path computation
  - Creating the forwarding table
- Performance during convergence period
  - Lost packets due to blackholes and TTL expiry
  - Looping packets consuming resources
  - Out-of-order packets reaching the destination
- Very bad for VoIP, online gaming, and video

Reducing Delay

- Faster detection
  - Smaller hello timers
  - Link-layer technologies that can detect failures
- Faster flooding
  - Flooding immediately
  - Sending link-state packets with high-priority
- Faster computation
  - Faster processors on the routers
  - Incremental Dijkstra’s algorithm
- Faster forwarding-table update
  - Data structures supporting incremental updates

Link State evaluation

- Strengths
  - Loop free as long as LS database's are consistent
    - » Can have transient routing loops – shouldn't last long
  - Messages are small
  - Converges quickly
  - Guaranteed to converge
- Weaknesses
  - Must flood data across entire network (scalability?)
  - Must maintain state for entire topology (database)

Real Link-state Protocols

- OSPF (Open Shortest Path First) and IS-IS
  - Most widely used intra-domain routing protocols
  - Run by almost all ISPs and many large organizations

- Basic link state algorithm plus many features:
  - Authentication of routing messages
  - Extra hierarchy: Partition into routing areas
    - "Border" router pretends to be directly connected to all routers in an area (answers for them)
  - Load balancing: Multiple equal cost routes

Link-state *vs.* Distance-vector

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:

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

Routing so far…

- Shortest-path routing
  - Metric-based, using link weights
  - Routers share a common view of path “goodness”
- As such, commonly used *inside* an organization
  - RIP and OSPF are mostly used as *intra*domain protocols
- 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

For next time…

- Interdomain routing
- Read Ch. 4.1 in P&D

Summary

- Routing is a distributed algorithm
  - React to changes in the topology
  - Compute the paths through the network
- Shortest-path link state routing
  - Flood link weights throughout the network
  - Compute shortest paths as a sum of link weights
  - Forward packets on next hop in the shortest path
- Convergence process
  - Changing from one topology to another
  - Transient periods of inconsistency across routers