Lecture 12:
Link-state Routing

CSE 123: Computer Networks
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HW 3 due next Tuesday

UCSDCSE

Lecture 12 Overview

- Routing overview
- Intra vs. Inter-domain routing
- Link-state routing protocols

Router Tasks

- Forwarding
  - Move packet from input link to the appropriate output link
  - Purely local computation
  - Must go be very fast (executed for every packet)

- Routing
  - Make sure that the next hop actually leads to the destination
  - Global decisions; distributed computation and communication
  - Can go slower (only important when topology changes)

Forwarding Options

- Source routing
  - Complete path listed in packet
- Virtual circuits
  - Set up path out-of-band and store path identifier in routers
  - Local path identifier in packet
- Destination-based forwarding
  - Router looks up address in forwarding table
  - Forwarding table contains (address, next-hop) tuples

Source Routing

- Routing
  - Host computes path
    - » Must know global topology and detect failures
  - Packet contains complete ordered path information
    - » I.e. node A then D then X then J…
  - Requires variable length path header
- Forwarding
  - Router looks up next hop in packet header, strips it off and forwards remaining packet
    - » Very quick forwarding, no lookup required
- In practice
  - ad hoc networks (DSR), some HPC networks (Myrinet), and for debugging on the Internet (LSR,SSR)

Virtual Circuits

- Routing
  - Hosts sets up path out-of-band, requires connection setup
  - Write (input id, output id, next hop) into each router on path
  - Flexible (one path per flow)
- Forwarding
  - Send packet with path id
  - Router looks up input, swaps for output, forwards on next hop
  - Repeat until reach destination
  - Table lookup for forwarding (why faster than IP lookup?)
- In practice
  - ATM: fixed VC identifiers and separate signaling code
  - MPLS: ATM meets the IP world (why? *traffic engineering*)

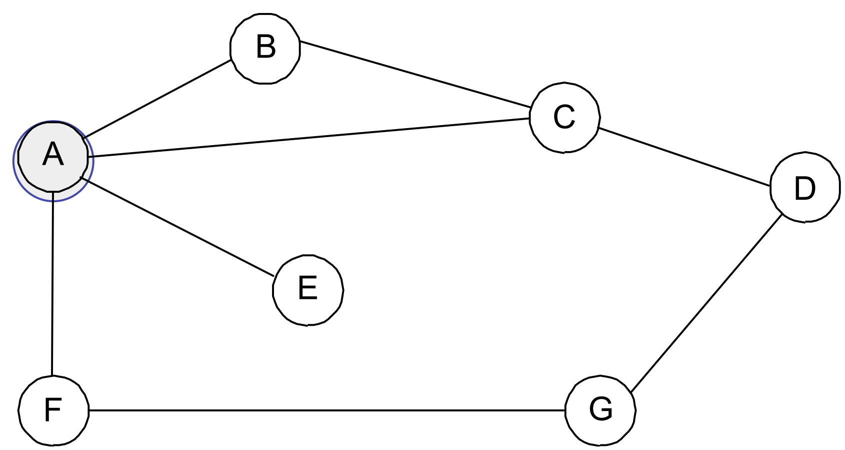
Destination-based Forwarding

- Routing
  - All addresses are globally known
    - » No connection setup
  - Host sends packet with destination address in header
    - » No path state; only routers need to worry about failure
  - Distributed routing protocol used to routing tables
- Forwarding
  - Router looks up destination in table
    - » Must keep state proportional to destinations rather than connections
  - Lookup address, send packet to next-hop link
    - » All packets follow same path to destination
- In Practice: IP routing

Routing Tables

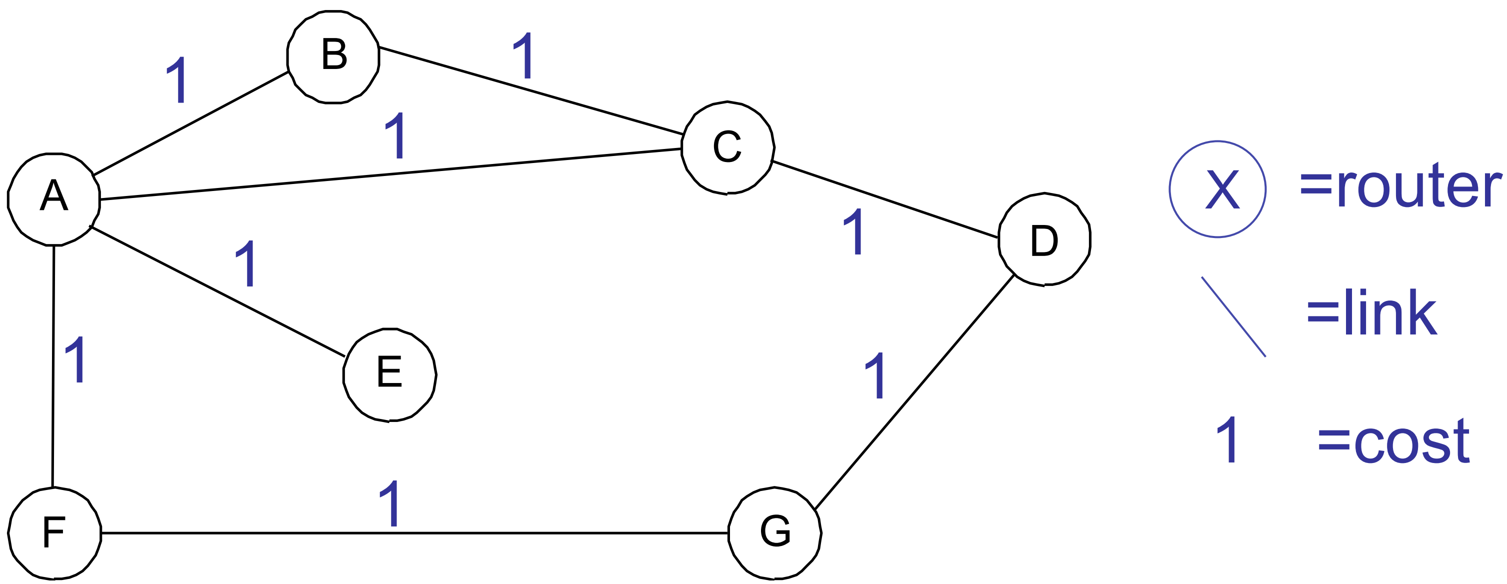
- The routing table at A, lists – *at a minimum* – the next hops for the different destinations

Dest	Next Hop
B	B
C	C
D	C
E	E
F	F
G	F



Routing on a Graph

- Essentially a graph theory problem
  - Network is a directed graph; routers are vertices
- Find "best" path between every pair of vertices
  - In the simplest case, best path is the shortest path



Routing Challenges

- How to choose best path?
  - Defining "best" can be slippery
- How to scale to millions of users?
  - Minimize control messages and routing table size
- How to adapt to failures or changes?
  - Node and link failures, plus message loss

Intra-domain Routing

- Routing within a network/organization
  - A single administrative domain
  - The administrator can set edge costs
- Overall goals
  - Provide intra-network connectivity
  - Adapt quickly to failures or topology changes
  - Optimize use of network resources
- Non-goals
  - Extreme scalability
  - Lying, and/or disagreements about edge costs

Basic Approaches

- Static
  - Type in the right answers and hope they are always true
  - …So far
- Link state
  - Tell everyone what you know about your neighbors
  - Today's lecture!
- Distance vector
  - Tell your neighbors when you know about everyone
  - Next time…

Link-state Routing

- 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

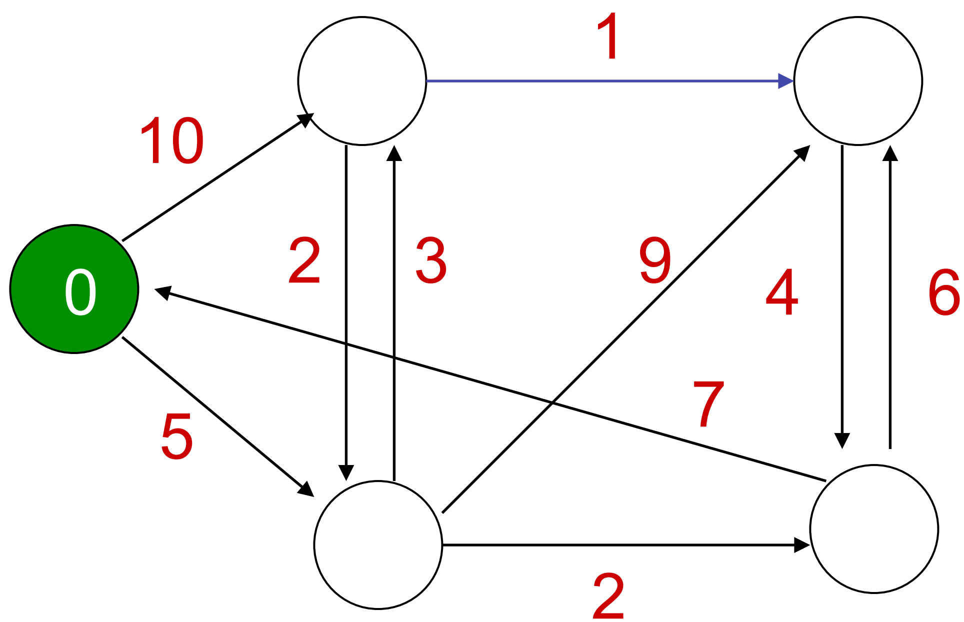
- Motivation
  - Global information allows optimal route computation
  - Straightforward to implement and verify

Dijkstra’s Shortest Path

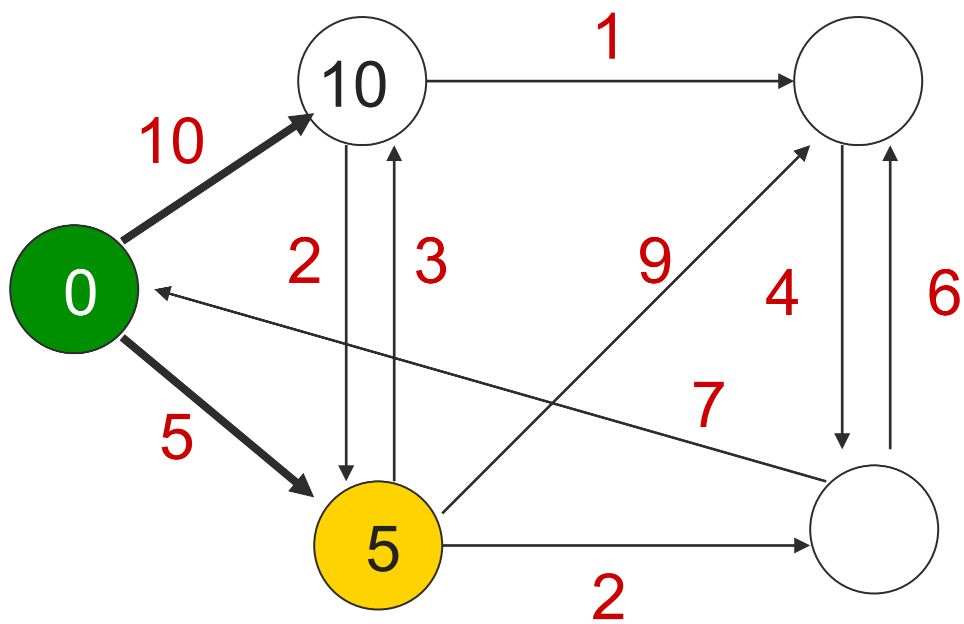
- Graph algorithm for single-source shortest path tree

```
S ← {}
Q ← <remaining nodes keyed by distance>
While Q != {}
        u ← extract-min(Q)
        S ← S plus {u}                    ← u is done
        for each node v adjacent to u
                “relax” the cost of v
```

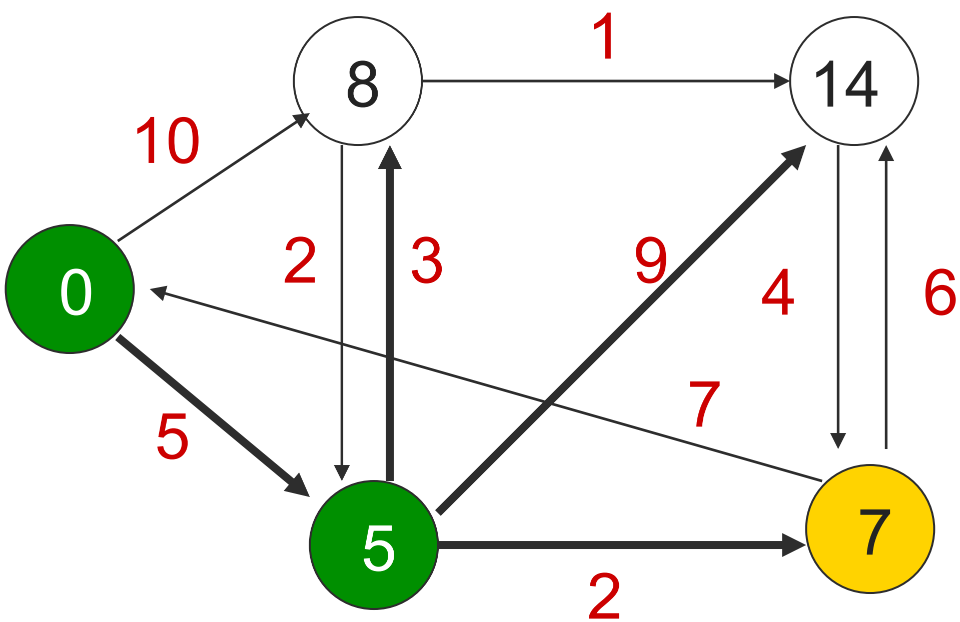
Example: Step 1



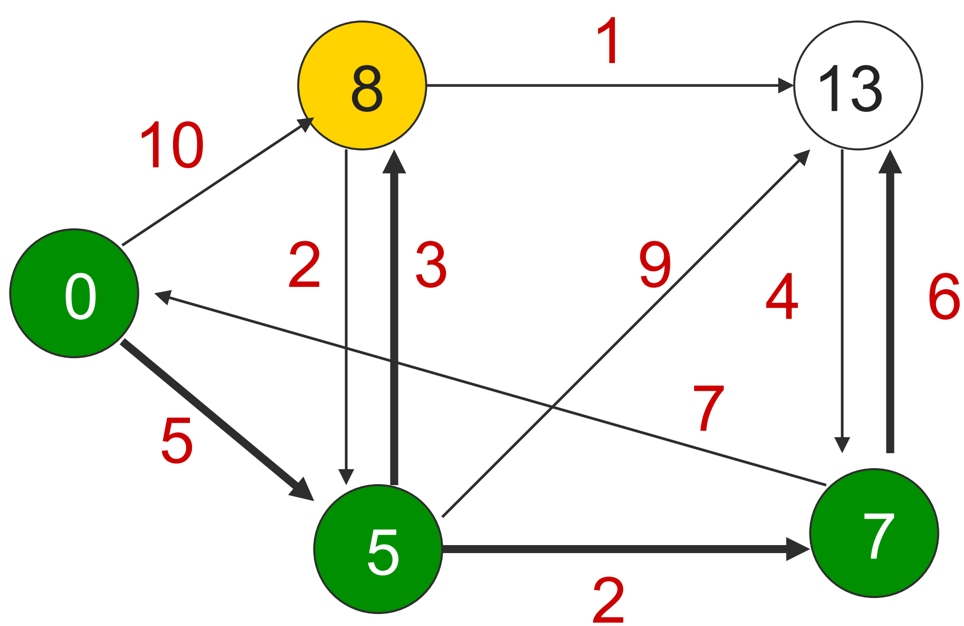
Example: Step 2



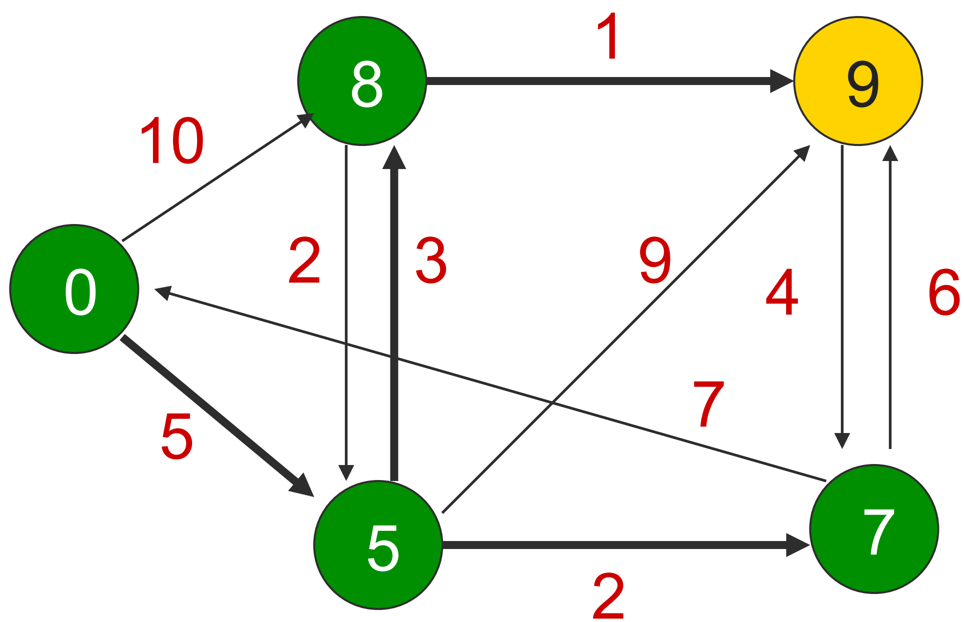
Example: Step 3



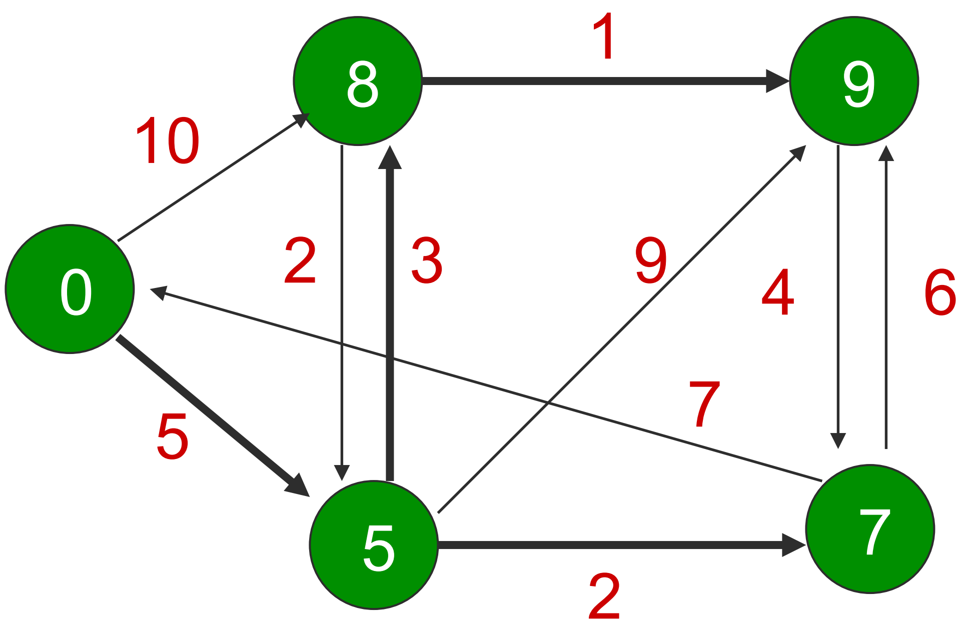
Example: Step 4



Example: Step 5



Example: Conclusion

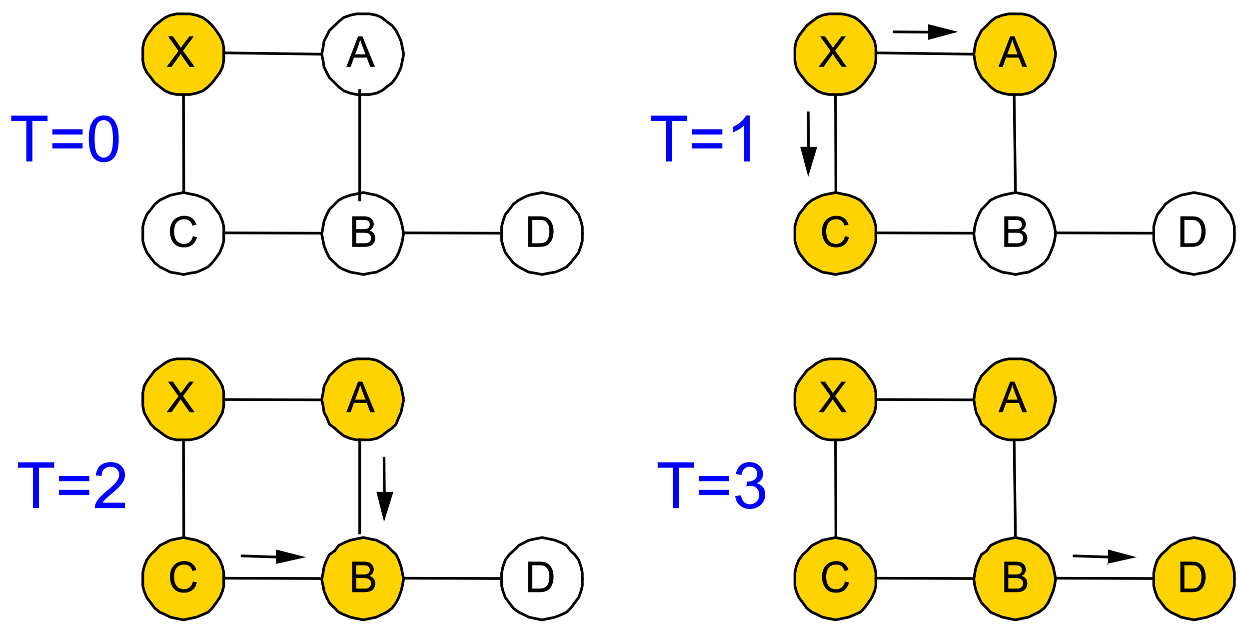


Broadcasting Link State

- 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



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

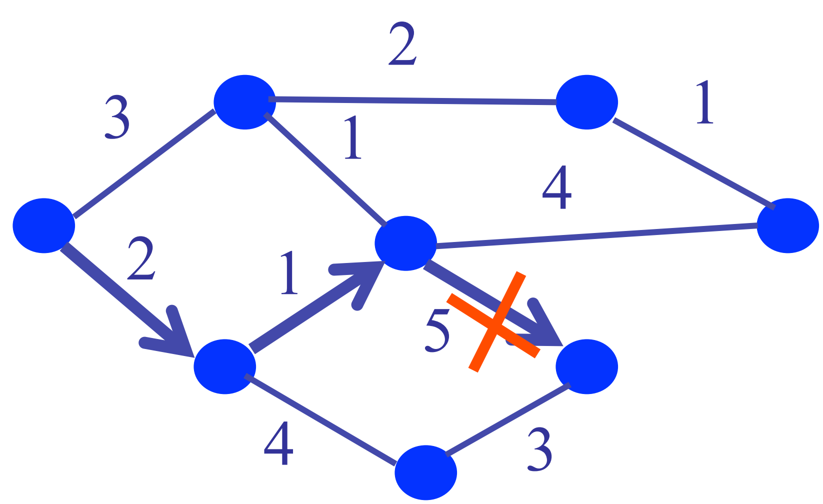
- Periodically
  - Typically (say) every 30 minutes
  - Corrects for possible corruption of the data
  - Limits the rate of updates, but also failure recovery

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

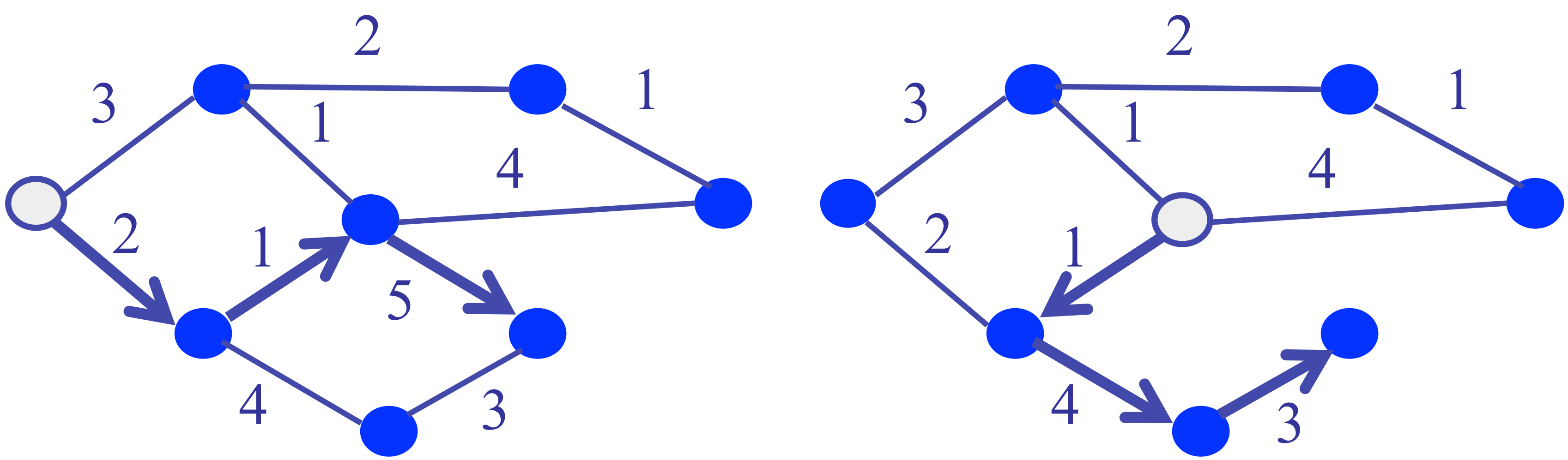
Transient Disruptions

- 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

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

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

For next time…

- No class Thursday: Happy Veterans' Day!
- Read Ch 4.2.2 in P&D
- Homework 3 due next time