CS 640 Introduction to Computer Networks

Lecture11

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Routing – the big picture

- Internet divided into Autonomous Systems (ASes)
  - corresponds to an administrative domain
  - examples: University, company, backbone network
  - assign each AS a 16-bit number
- Two-level route propagation hierarchy
  - interior gateway protocol (RIP, OSPF)
  - exterior gateway protocol (Internet-wide standard)

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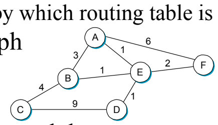
Overview

- Forwarding vs Routing
  - forwarding: to select an output port based on destination address and routing table
  - routing: process by which routing table is built
- Network as a Graph



- Problem: Find best path between two nodes
- Factors
  - static: topology
  - dynamic: load

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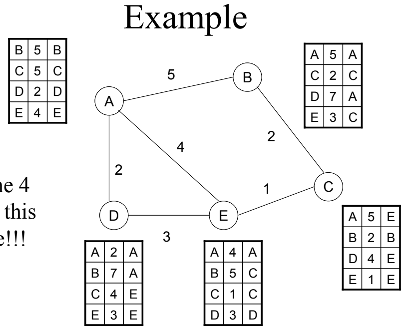
Families of routing algorithms

- Distance vector
  - Tell your neighbors about everybody you know of
  - Lower memory
  - RIP: Route Information Protocol
    - based on hop-count
- Link state
  - Tell everybody about your neighbors
  - Most used today
  - OSPF: Open Shortest Path First

Distance Vector

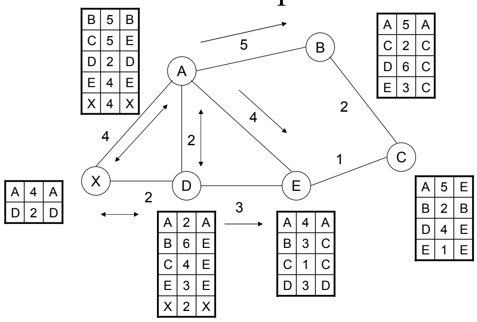
- Each node maintains a set of triples
  - **`(Destination, Cost, NextHop)`**
- Neighbors exchange updates
  - periodically (on the order of several seconds)
  - whenever table changes (called *triggered* update)
- Each update is a list of pairs: (**`Dest, Cost)`**
- Update local table if receive a "better" route
  - smaller cost
  - came from next-hop
- Refresh existing routes; delete if they time out

Example



Find the 4 bugs in this picture!!!

Example



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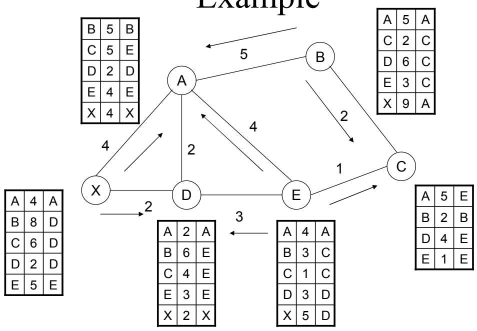
Example



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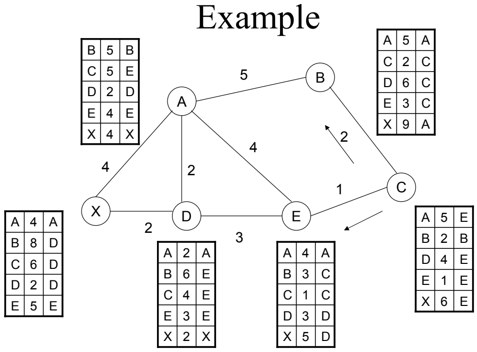

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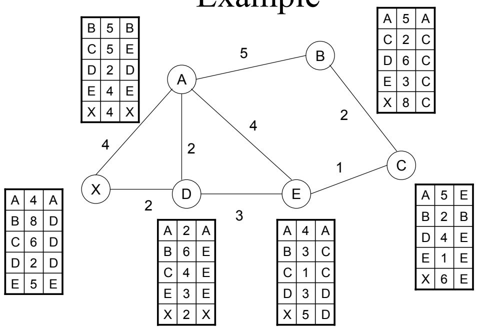

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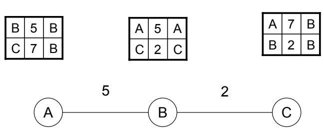
Link failure example



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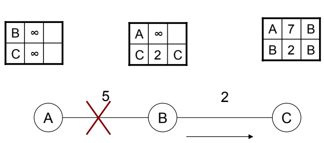
Link failure example



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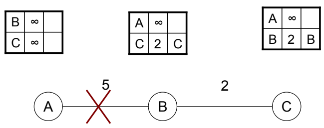
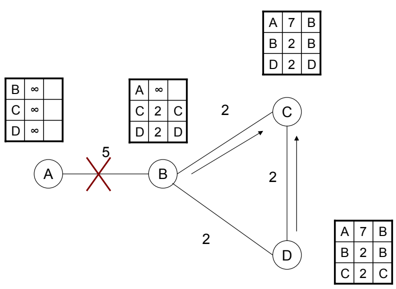
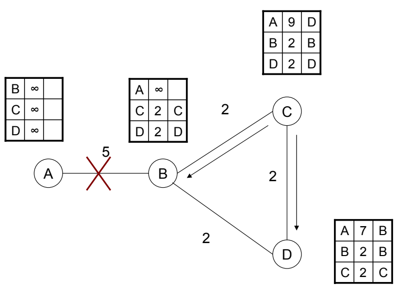
Link failure example



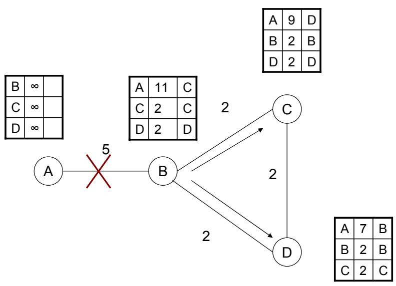
Count to infinity example



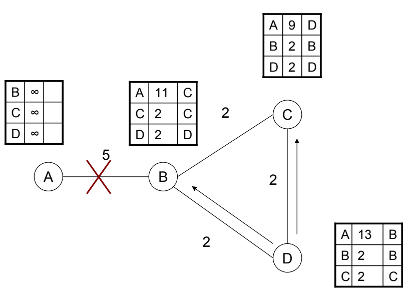
Count to infinity example



Count to infinity example



Count to infinity example



Loop-Breaking Heuristics

- Set infinity to 16
- Split horizon
  - Don't advertise route to neighbor you heard it from
- Split horizon with poison reverse
  - Advertise it with ∞ cost

Link State

- Strategy
  - send to all nodes (not just neighbors) information about directly connected links (not entire routing table)
- Link State Packet (LSP)
  - id of the node that created the LSP
  - cost of link to each immediate neighbor
  - sequence number (SEQNO)
  - time-to-live (TTL) for this packet

Link State (cont)

- Reliable flooding
  - store most recent LSP from each node
  - forward **new** LSPs to all neighbors (except the one that sent it)
  - generate new LSP periodically
    - increment SEQNO
  - start SEQNO at 0 when reboot
  - decrement TTL of each stored LSP
    - discard when TTL=0

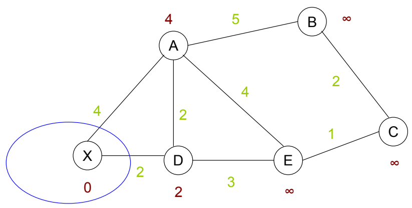
Route Calculation

- Dijkstra's shortest path algorithm
  - *s* denotes node performing calculation
  - *l* (*i*, *j*) denotes non-negative cost (weight) for edge (*i*, *j*)
  - *C*(*n*) denotes cost of the path from *s* to node *n*
  - *N* denotes set of all nodes in the graph
  - *M* denotes the set of nodes incorporated so far

```
M = {s}
for each n in N - {s}
    C(n) = l(s, n)
while (N != M)
    M = M+{w} such that C(w) is the min for all w in N-M
    for each n in (N - M)
        C(n) = MIN(C(n), C (w)+l(w,n))
```

- Invariant of Dijkstra's algorithm
  - We have shortest path for nodes from M to s
  - For nodes outside M we have shortest path that goes to s only using nodes in M as next hop

Example



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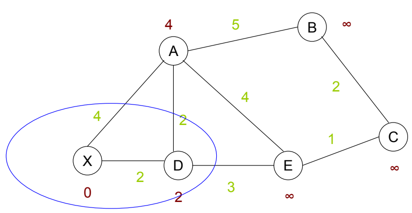

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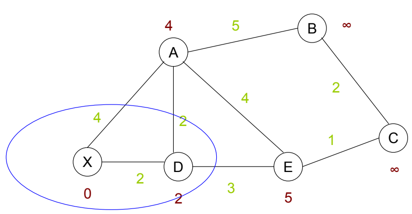

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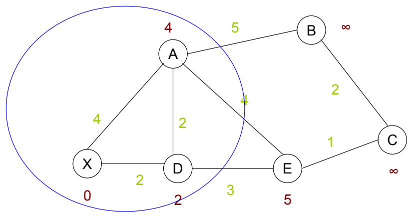

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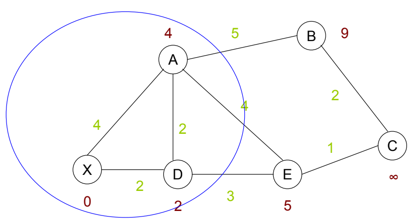

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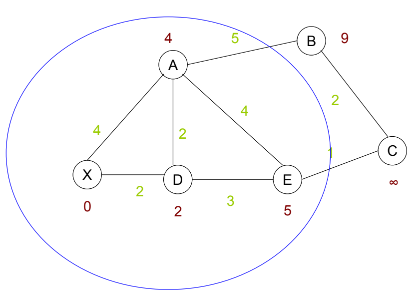

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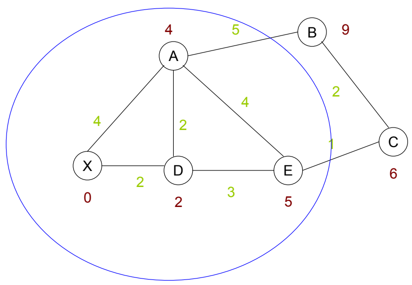

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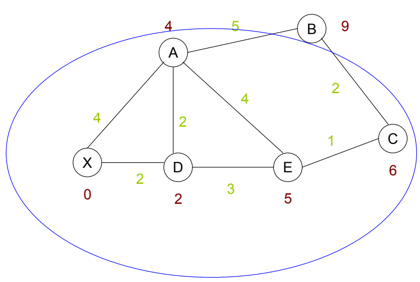

Example