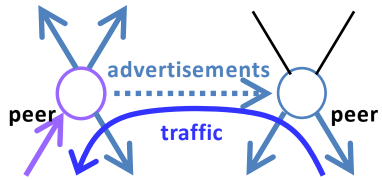
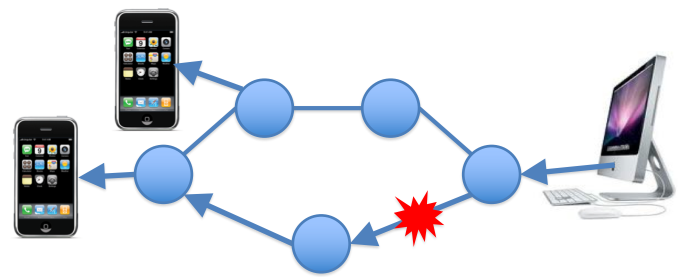


Routing Convergence

Mike Freedman
COS 461: Computer Networks

http://www.cs.princeton.edu/courses/archive/spr20/cos461/

Routing Changes

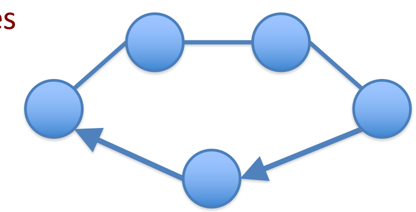


- Topology changes: new route to the same place
- Host mobility: route to a different place

Topology Changes

Two Types of Topology Changes

- Planned
  - Maintenance: shut down a node or link
  - Energy savings: shut down a node or link
  - Traffic engineering: change routing configuration
- Unplanned Failures
  - Fiber cut, faulty equipment, power outage, software bugs, …



Detecting Topology Changes

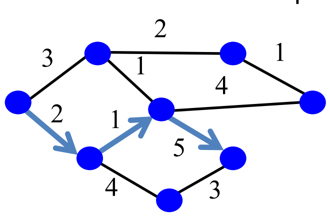
- Beaconing
  - Periodic "hello" messages in both directions
  - Detect a failure after a few missed "hellos"

- Performance trade-offs
  - Detection delay
  - Overhead on link bandwidth and CPU
  - Likelihood of false detection

Routing Convergence: Link-State Routing

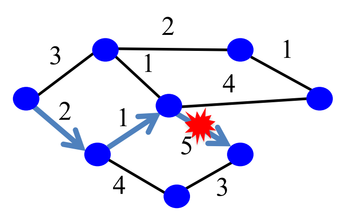
Convergence

- Control plane
  - All nodes have consistent information
- Data plane
  - All nodes forward packets in a consistent way



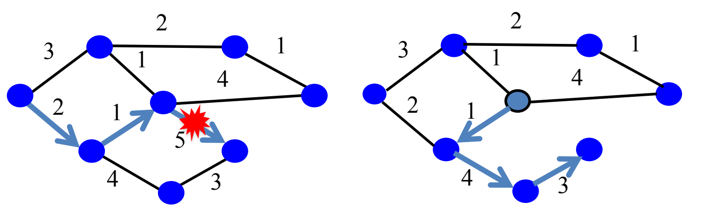
Transient Disruptions

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



Transient Disruptions

- Inconsistent link-state database
  - Some routers know about failure before others
  - Inconsistent paths cause transient forwarding loops



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Convergence Delay

- Sources of convergence delay
  - Detection latency
  - Updating control-plane information
  - Computing and install new forwarding tables
- 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

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Slow Convergence in Distance-Vector Routing

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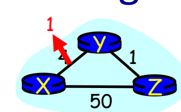
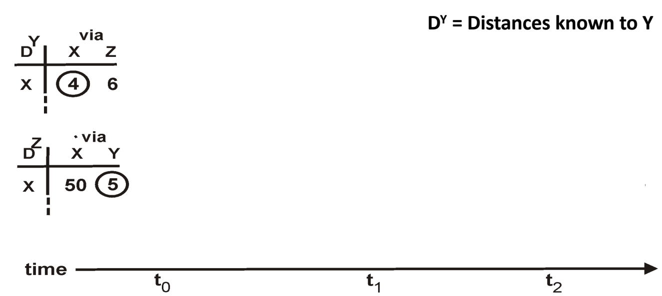
Distance Vector: Link Cost Changes

- Link cost decreases and recovery
  - Node updates the distance table
  - If cost change in least cost path, notify neighbors





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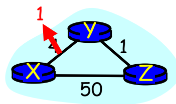

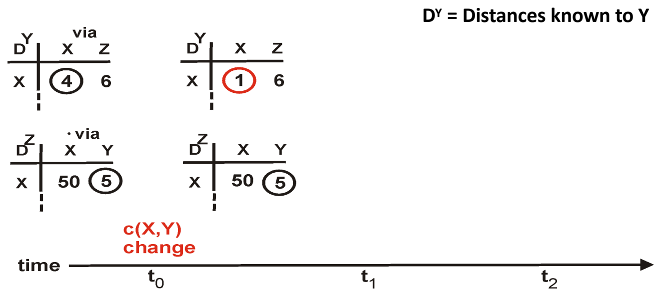

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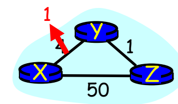

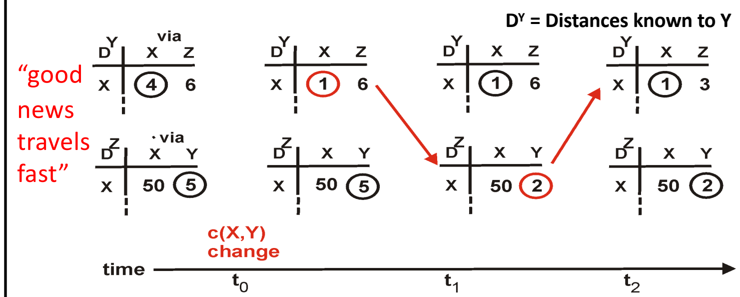

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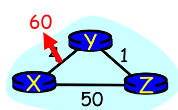
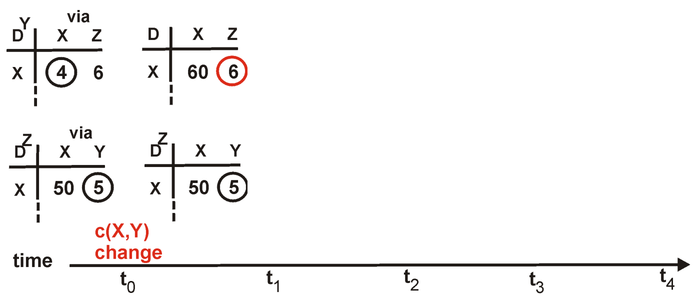
Distance Vector: Link Cost Changes

- Link cost increases and failures
  - Bad news travels slowly
  - "Count to infinity" problem!





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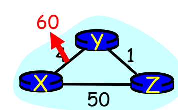

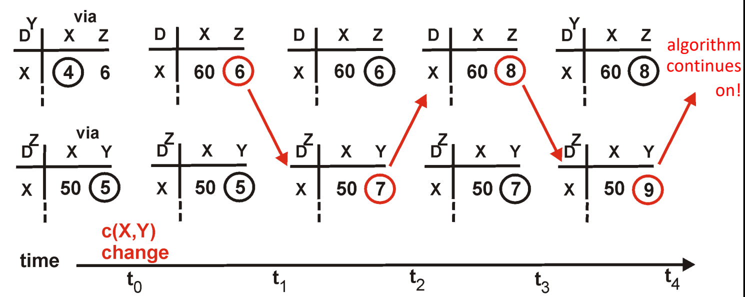

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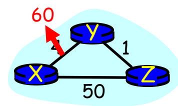
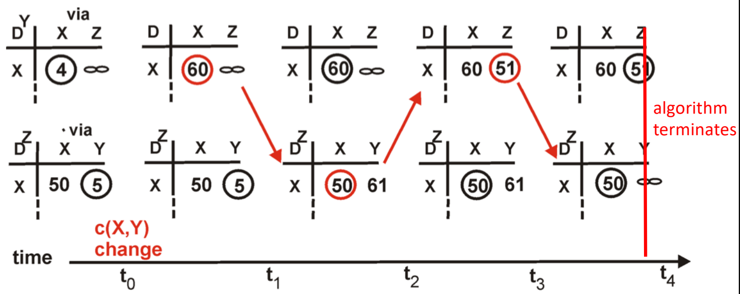
Distance Vector: Poison Reverse

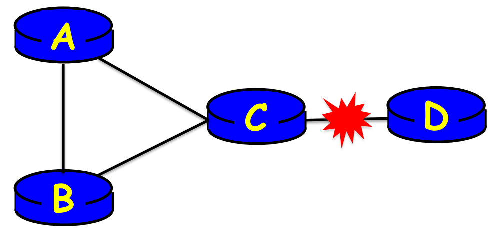
- If Z routes through Y to get to X :
  - Z tells Y its (Z's) distance to X is infinite (so Y won't route to X via Z)





Distance Vector: Poison Reverse

- Can still have problems in larger networks



1. A and B use ACD and BCD, so A and B both poison to C.
2. But when CD withdrawn (cost goes to infinity), B switches to BACD, so BC no longer poisoned to C.
3. C then starts using CBACD. Loop.

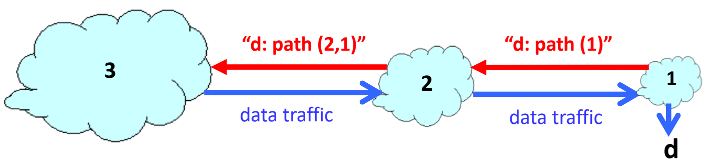
Redefining Infinity

- Avoid "counting to infinity"
  - By making "infinity" smaller!
- Routing Information Protocol (RIP)
  - All links have cost 1
  - Valid path distances of 1 through 15
  - … with 16 representing infinity
- Used mainly in small networks

Reducing Convergence Time With Path-Vector Routing (e.g., Border Gateway Protocol)

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



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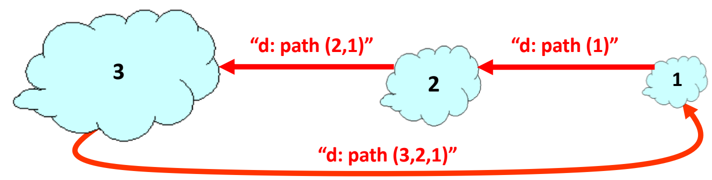
Faster Loop Detection

- 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



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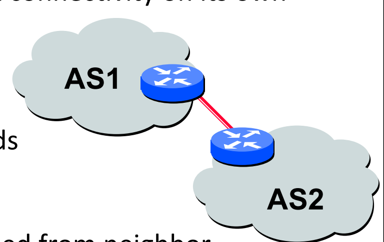
BGP Session Failure

- BGP runs over TCP
  - BGP only sends updates when changes occur
  - TCP doesn't detect lost connectivity on its own
- Detecting a failure
  - Keep-alive: 60 seconds
  - Hold timer: 180 seconds
- Reacting to a failure
  - Discard all routes learned from neighbor
  - Send new updates for any routes that change



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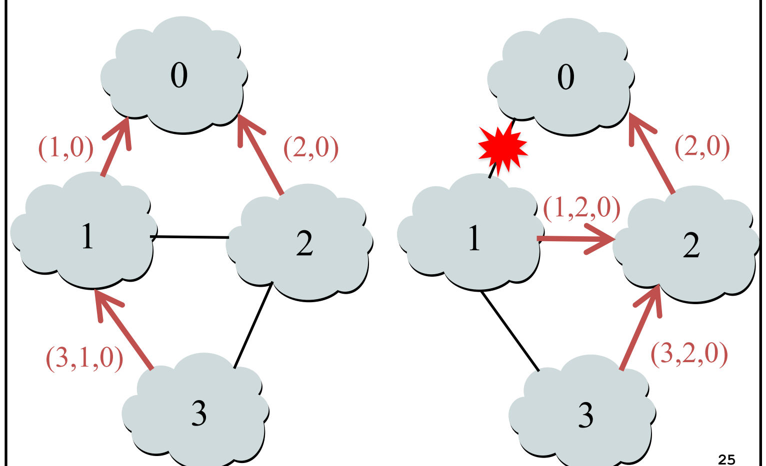
Routing Change: Before and After



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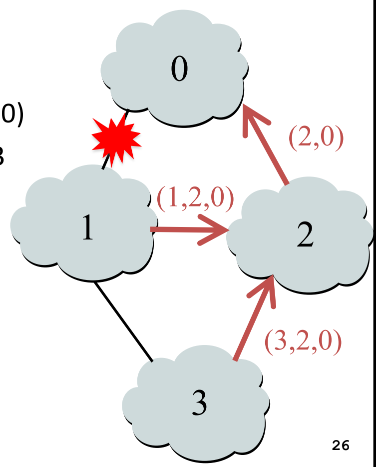
Routing Change: Path Exploration

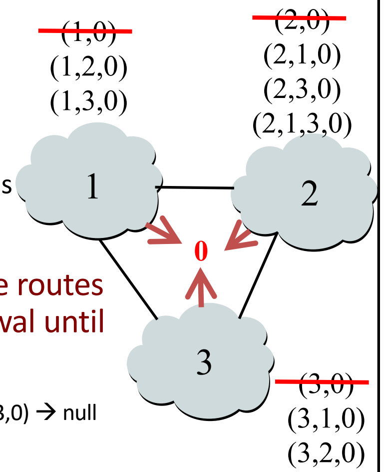
- AS 1
  - Delete the route (1,0)
  - Switch to next route (1,2,0)
  - Send route (1,2,0) to AS 3
- AS 3
  - Sees (1,2,0) replace (1,0)
  - Compares to route (2,0)
  - Switches to using AS 2



Routing Change: Path Exploration

- Initial: All AS use direct
- Then destination 0 dies
  - All ASes lose direct path
  - All switch to longer paths
  - Eventually withdrawn
- How many intermediate routes following (2,0) withdrawal until no route known to 2?

(2,0) → (2,1,0) → (2,3,0) → (2,1,3,0) → null



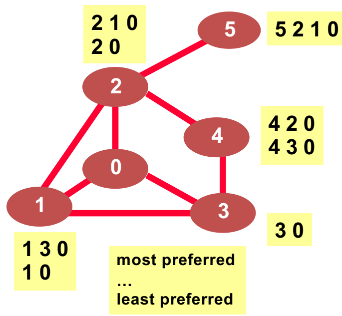
BGP Converges Slowly

- Path vector avoids count-to-infinity
  - But, ASes still must explore many alternate paths to find highest-ranked available path
- Fortunately, in practice
  - Most popular destinations have stable BGP routes
  - Most instability lies in a few unpopular destinations
- Still, lower BGP convergence delay is a goal
  - Can be tens of seconds to tens of minutes

BGP Instability

Stable Paths Problem (SPP) Instance

- Node
  - BGP-speaking router
  - Node 0 is destination
- Edge
  - BGP adjacency
- Permitted paths
  - Set of routes to 0 at each node
  - Ranking of the paths



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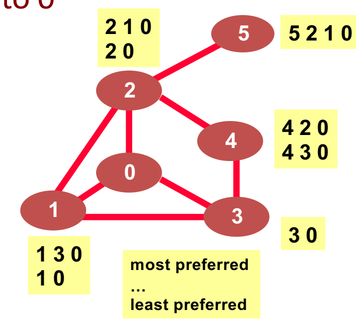
Stable Paths Problem (SPP) Instance

- 1 will use a direct path to 0

  (Y) True (M) False

- 5 has a path to 0

  (Y) True (M) False



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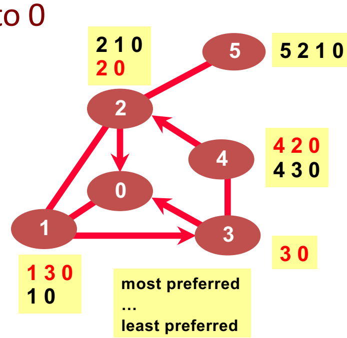

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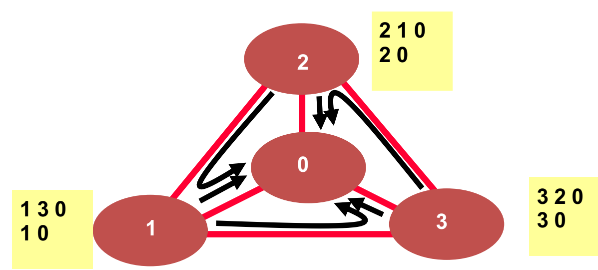
An SPP May Have No Solution



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Avoiding BGP Instability

- Detecting conflicting policies
  - Computationally expensive
  - Requires too much cooperation
- Detecting oscillations
  - Observing the repetitive BGP routing messages
- Restricted routing policies and topologies
  - Policies based on business relationships

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Conclusion

- The only constant is change
  - Planned topology and configuration changes
  - Unplanned failure and recovery
- Routing-protocol convergence
  - Transient period of disagreement
  - Blackholes, loops, and out-of-order packets
- Routing instability
  - Permanent conflicts in routing policy
  - Leading to bi-stability or oscillation

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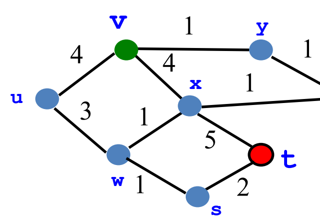
Link State: Shortest-Path Tree



Find shortest path *t* to *v*

- Forwarding table entry at *t*
  (Y) (t,x) (M) (t, s)
- Distance from *t* to *v*
  (Y) 6 (M) 7 (C) 8 (A) 9
- Rounds to find shortest path
  (Y) 5 (M) 6 (C) 7 (A) 8

Rounds: Add s (distance 2), w (distance 3), x (distance 4), z (distance 5), equi-distance to u or y (distance 6)
So could be 5 (via y) or 6 (via u then y)

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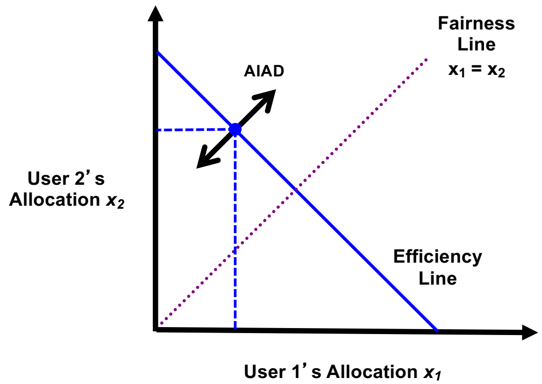
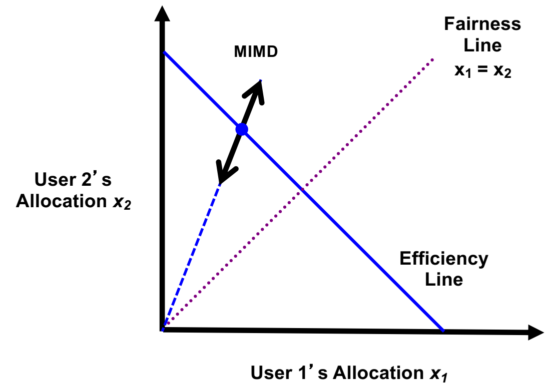
Additive Increase/Decrease



Multiplicative Increase/Decrease



Additive Increase / Multiplicative Decrease