Q: Compare & Contrast Routing

- What is the objective of routing algorithms?
- Compare and contrast Link-State and Distance-Vector
  - What does each algorithm do?
  - What do the routers do in each case?
  - What does each do the same as the other algorithm?
  - What do they do differently?

More Comparison of LS and DV

- Information requirements
- Message complexity and volume
- Robustness: what happens if router malfunctions?
- Convergence time varies
- Oscillations possible?
- Loops possible?

Comparison of LS and DV algorithms

Message communication
- **LS**: with \( n \) nodes, \( E \) links, \( O(nE) \) msgs sent each
- **DV**: exchange between neighbors only
  - convergence time varies

Speed of Convergence
- Start-up vs. steady-state
  - **LS**: \( O(n^2) \) algorithm requires \( O(nE) \) msgs
  - may have oscillations
  - **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 its own table using own info
- **DV**: DV node can advertise incorrect path cost
  - each node's table used by others
    - errors propagate through the network
Routing Algorithms

The **objective** of a routing algorithm is to:

![Routing Algorithm Diagram]

Overview of Routing & Recap...

- The set of routers comprise a distributed database
  - Routers propagate network topology information to other routers
- Distribute State of Links
  - 'Advertise' information about _______
  - Communicates with _______
- Distribute Vectors
  - 'Advertise' _______
  - Communicates with _______

Review of Link State

- Each router advertises:
  -
  -
- As information is received, each router adds it to its own 'link-data' database, and passes it on **unchanged**
  -
  -
- Each router constructs its own complete topology map and runs the routing algorithm with itself as the center of the 'tree'
  -

Review of Distance Vector

- Each router advertises:
  -
  -
- The information is processed by each router before it is passed along.
  -
  -
**Problem: Dijkstra's Algorithm**

Oscillations possible: (ADAPTING TOO QUICKLY)
- If Link cost = traffic on link
  1. D initiates sending a packet to A, B to A, and C, a tiny packet of size 'e' also to A
  2. C and B observe 'clockwise' is cheaper, so reroute
  3. All observe 'counter-clockwise' is cheaper, so reroute...

Problem: LS algorithm pathology
- Oscillations possible, if routers adapt too quickly
- SOLUTION – have routers run algorithm asynchronously, randomize the times when a router sends a link advertisement

Problem: DV algorithm pathology
- Loops possible:
  - i.e., Route from x to y and back to x to get to z
- If a link-cost decreases – good news
  - Then any least-cost path previously using that link has a decrease in cost, but the path remains unchanged
- If a link-cost increases – bad news
  - Then the path itself is likely to change, as well as the cost of the path, and this takes forever to propagate through the network...
  - Count-to-infinity problem

Q: The Hierarchical Structure
- What is the hierarchy within the Internet
  - What would be 'top' levels, down to the 'bottom' levels
- What decisions need to be made within this hierarchy
  - ... so that it operates successfully as our unified Internet
- For comparison, what could be done poorly, such that the Internet would not function?
Hierarchical Routing

- Aggregate routers into regions, "autonomous systems" (AS)
- Routers in the same AS run the same routing protocol
  - "intra-AS" routing protocol
- Routers in different AS can run different intra-AS routing protocol

Intra-AS and Inter-AS routing

Internet AS Hierarchy

Internet structure: network of networks

Gateway routers
- Special routers in AS
- Run intra-AS routing protocol with all other routers in AS
- Also responsible for routing to destinations outside AS
  - Run inter-AS routing protocol with other gateway routers
Intra-AS Routing

- Also known as *interior gateway protocols (IGP)*
- Most common intra-AS routing protocols:
  - **RIP**: Routing Information Protocol
    - Distance Vector
    - Used typically in lower tier ISPs – what might influence this?
  - **OSPF**: Open Shortest Path First
    - Link State
    - Typically in upper tier ISPs

OSPF (Open Shortest Path First)

- “open”: publicly available
- uses link state algorithm
  - LS packet dissemination
  - topology map at each node
  - route computation using Dijkstra’s algorithm
- OSPF advertisement carries one entry per neighbor
- advertisements flooded to *entire AS*
  - carried in OSPF messages directly over IP (rather than TCP or UDP)

RIP (Routing Information Protocol)

- Included in BSD-UNIX distribution in 1982
- Distance vector algorithm
  - distance metric: # hops (max = 15 hops), each link has cost 1
  - DVs exchanged with neighbors every 30 sec in response message (aka advertisement)
  - each advertisement: list of up to 25 destination *subnets* (in IP addressing sense)

<table>
<thead>
<tr>
<th>subnet</th>
<th>hops</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>1</td>
</tr>
<tr>
<td>v</td>
<td>2</td>
</tr>
<tr>
<td>w</td>
<td>2</td>
</tr>
<tr>
<td>x</td>
<td>3</td>
</tr>
<tr>
<td>y</td>
<td>3</td>
</tr>
<tr>
<td>z</td>
<td>2</td>
</tr>
</tbody>
</table>

*From router A to destination subnets:*

**Question: RIP vs. OSPF**

- Given what we know of LS and DV algorithms, compare the advertisements used by RIP and OSPF
- **OSPF** - (link state) router periodically broadcasts state of only its links to *all* other routers in the AS
- **RIP** - (distance vector) advertisement (message) contains information about all the networks in the AS; is only sent to its neighboring routers
Inter-AS routing

Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): the de facto standard
- Path Vector protocol:
  - similar to Distance Vector protocol
  - each Border Gateway broadcasts to neighbors (peers) entire path (i.e., a sequence of ASs) to destination

BGP basics

- BGP session: two BGP routers (“peers”) exchange BGP messages:
  - advertising paths to different destination network prefixes (“path vector” protocol)
  - exchanged over semi-permanent TCP connections

Concepts: RIP vs. BGP

- RIP ads announce the number of hops to various destinations while BGP updates announce the __________ to various destinations
- Describe how loops in paths can be detected in BGP.
Why different Intra- and Inter-AS routing?

Policy:
- **Inter-AS**: admin wants control over how its traffic is routed, and who routes through its net.
- **Intra-AS**: single admin, so no policy decisions needed

Scale:
- hierarchical routing saves table size, reduced update traffic

Performance:
- **Intra-AS**: can focus on performance
- **Inter-AS**: policy may dominate over performance

Broadcast Routing

- **Uses? →** Link-state routing algorithms
- **Deliver packets from source to all other nodes**

Multicast Routing

- **Uses?**
  - Bulk data (software upgrade) transfer
  - Streaming audio-visual media
  - Shared data application (teleconference)
  - Data feeds (stock quotes)
  - Interactive gaming

Summary

**Forwarding:**
- Leads to questions of addressing
  - Assignment of IP addresses (& DHCP)
  - NAT, IPv6 ...

**Routing:**
- Routing objectives
- Routing notation
- Link state v. Distance Vector
- Hierarchical structure