CSCI 491-01
Topics: Internet Programming
Fall 2008

Network Layer

Derek Leonard
Hendrix College

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Comparison of LS and DV Algorithms

Message complexity

- LS: with n nodes, E links, $O(nE)$ msgs sent
- DV: exchange between neighbors only
  - Convergence time varies

Speed of Convergence

- LS: $O(n^2)$ algorithm requires $O(nE)$ msgs
  - May have oscillations
- DV: convergence time varies
  - May have 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:

- DV node can advertise incorrect *path* cost
- Each node's table used by others
- Errors propagate thru network

Chapter 4: Roadmap

4.1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router

4.4 IP: Internet Protocol

4.5 Routing algorithms

- Link state
- Distance Vector
- Hierarchical routing

4.6 Routing in the Internet

4.7 Broadcast and multicast routing

Hierarchical Routing

Problems in practice:

- Memory: can't store paths to all destinations in a routing table (several billion links)
- CPU time: can't overload routers with such huge computational expense
- Message overhead: routing table exchanges would overload links
- Competitiveness: ISPs not willing to share their topology with others

Solution: administrative autonomy

- Internet = network of networks
- Each network admin may want to control routing in its own network

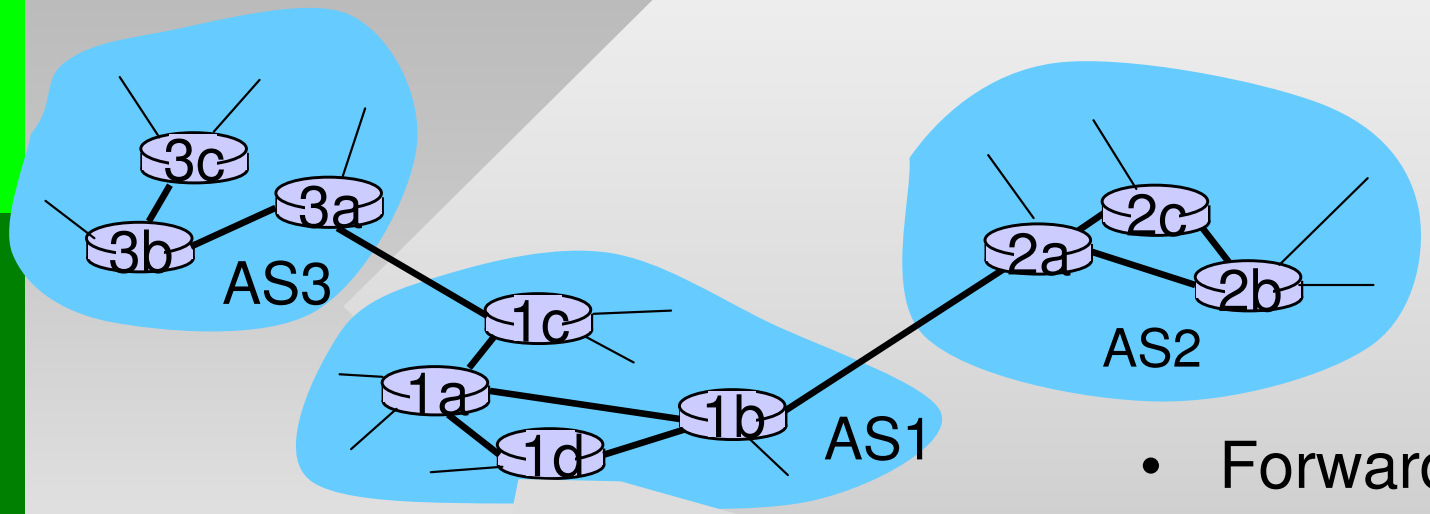
Hierarchical Routing

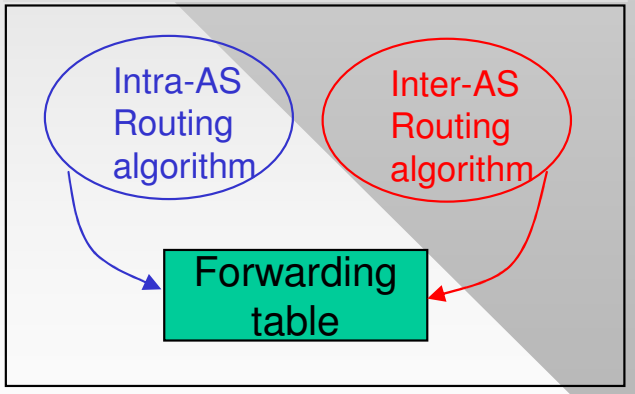
- Aggregate routers into regions, "autonomous systems" (AS)
- Routers in the same AS run the same routing protocol
  - "Intra-AS" routing protocol
  - Routers in different AS may run different intra-AS routing protocols

Gateway routers

- Direct links to routers in another ASes
- Exchange routing view of each AS using an inter-AS protocol

Interconnected ASes





- Forwarding table is configured by both intra- and inter-AS routing algorithm
  - Intra-AS sets entries for internal dests
  - Inter-AS & Intra-As sets entries for external dests

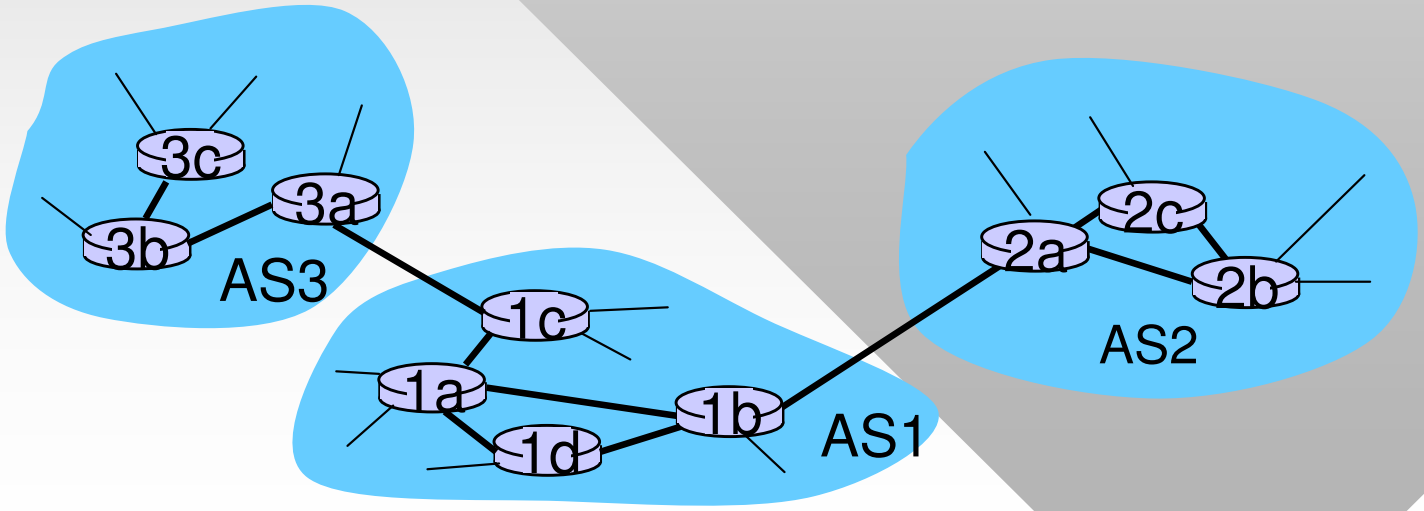
Inter-AS Tasks

- Suppose router in AS1 receives datagram for which dest is outside of AS1
  - Router should forward packet towards one of the gateway routers, but which one?

AS1 needs:

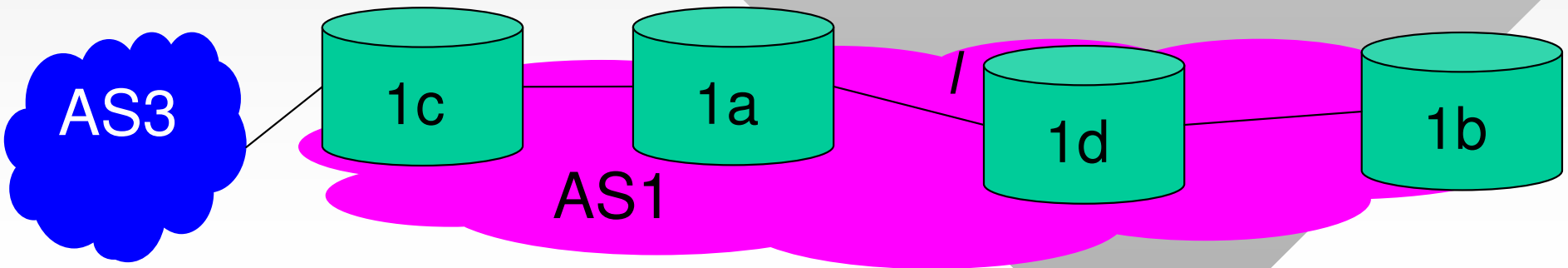
1. To learn which dests are reachable through AS2 and which through AS3
2. To propagate this reachability info to all routers in AS1

Job of inter-AS routing!



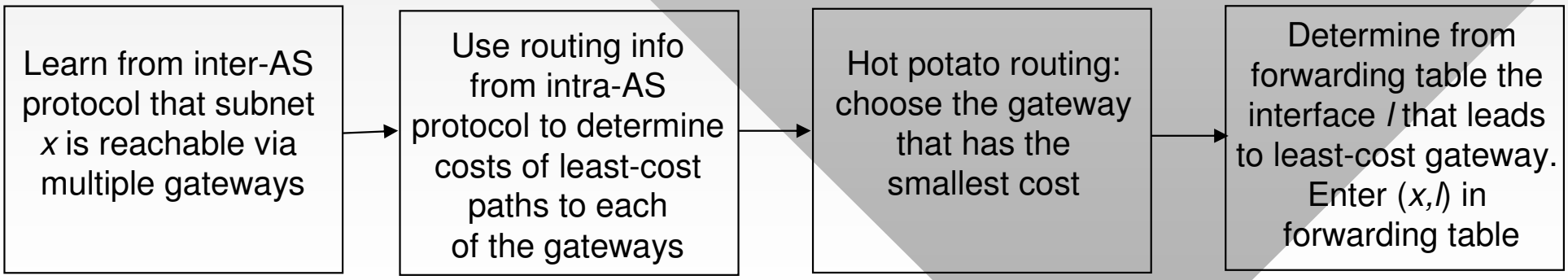
Example: Setting Forwarding Table in Router 1d

- Suppose AS1 learns from the inter-AS protocol that subnet *x* is reachable from AS3 (gateway 1c), but not from AS2
- Inter-AS protocol propagates reachability info to all internal routers
- Router 1d determines from intra-AS routing info that its interface *I* is on the least cost path to 1c
- Puts in forwarding table entry (*x*,*I*)



Example: Choosing Among Multiple ASes

- Now suppose AS1 learns from the inter-AS protocol that subnet *x* is reachable from AS3 *and* from AS2.
  - To configure forwarding table, router 1d must determine towards which gateway it should forward packets for dest *x*
- This is also the job of inter-AS routing protocol!
- Hot potato routing: send packet towards closest of two routers



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- RIP
- OSPF
- BGP

4.7 Broadcast and multicast routing

Intra-AS Routing

- Also known as Interior Gateway Protocols (IGP)
- Most common Intra-AS routing protocols:
  - RIP: Routing Information Protocol
  - OSPF: Open Shortest Path First
  - IGRP: Interior Gateway Routing Protocol (Cisco proprietary)

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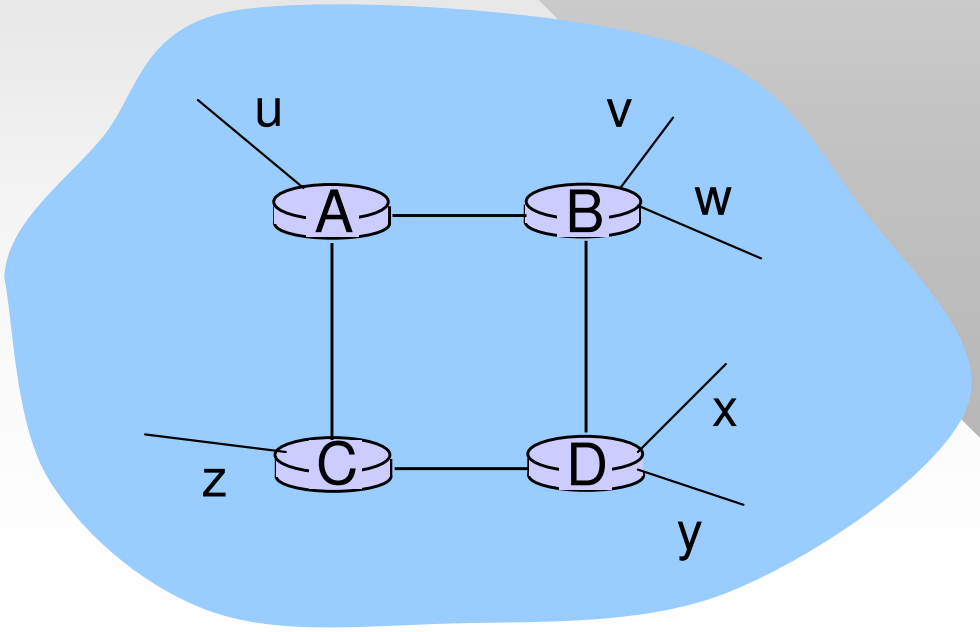
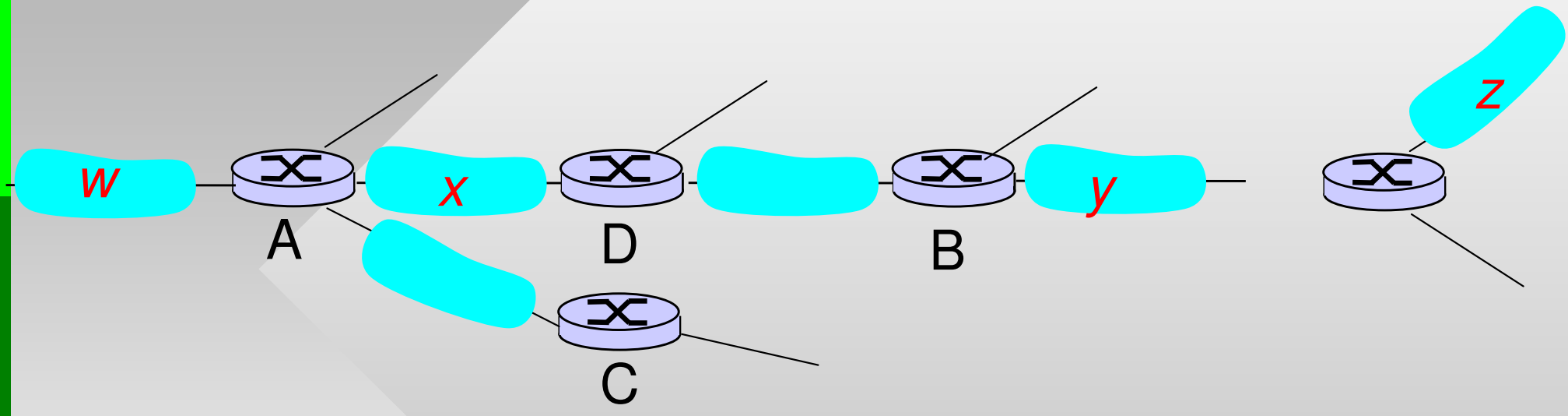
RIP (Routing Information Protocol)

- Included in BSD-UNIX Distribution in 1982
  - Distance vector algorithm
- Distance metric: # of hops (max = 15 hops)
  - Distance vectors: exchanged among neighbors every 30 sec using advertisement messages
  - Each message: list of up to 25 destination nets within AS



destination subnet	hops from A
u	1
v	2
w	2
x	3
y	3
z	2

RIP: Example



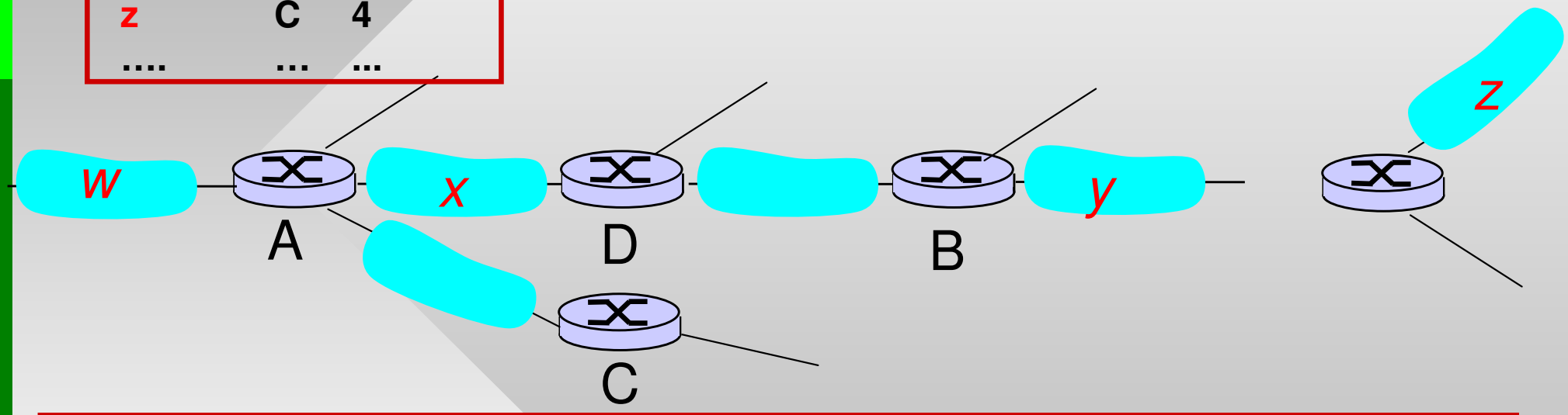
Destination Network	Next Router	Number of hops to dest
w	*A*	2
y	*B*	2
z	*B*	7
x	--	1
....	....	....

Routing table in *D*

RIP: Example

Dest	Next	hops
w	-	-
x	-	-
z	C	4
....	...	...

Advertisement from A to D



Destination Network	Next Router	Number of hops to dest.
w	A	2
y	B	2
z	~~B~~ A	~~7~~ 5
x	--	1
....	....	....

Routing table in *D*

RIP: Link Failure and Recovery

- If no advertisement heard after 180 sec → neighbor/link declared dead
  - Routes via neighbor invalidated
  - New advertisements sent to neighbors
  - Neighbors in turn send out new advertisements (if tables changed)
  - Link failure info propagates to entire network
- Poisoned reverse used to prevent ping-pong loops (infinite distance = 16 hops)

RIP Table Processing

- RIP routing tables managed by an **application-level** process called *routed* (daemon)
- Advertisements sent in UDP packets, periodically repeated