Digital Communication in the Modern World

Network Layer: Routing in the Internet

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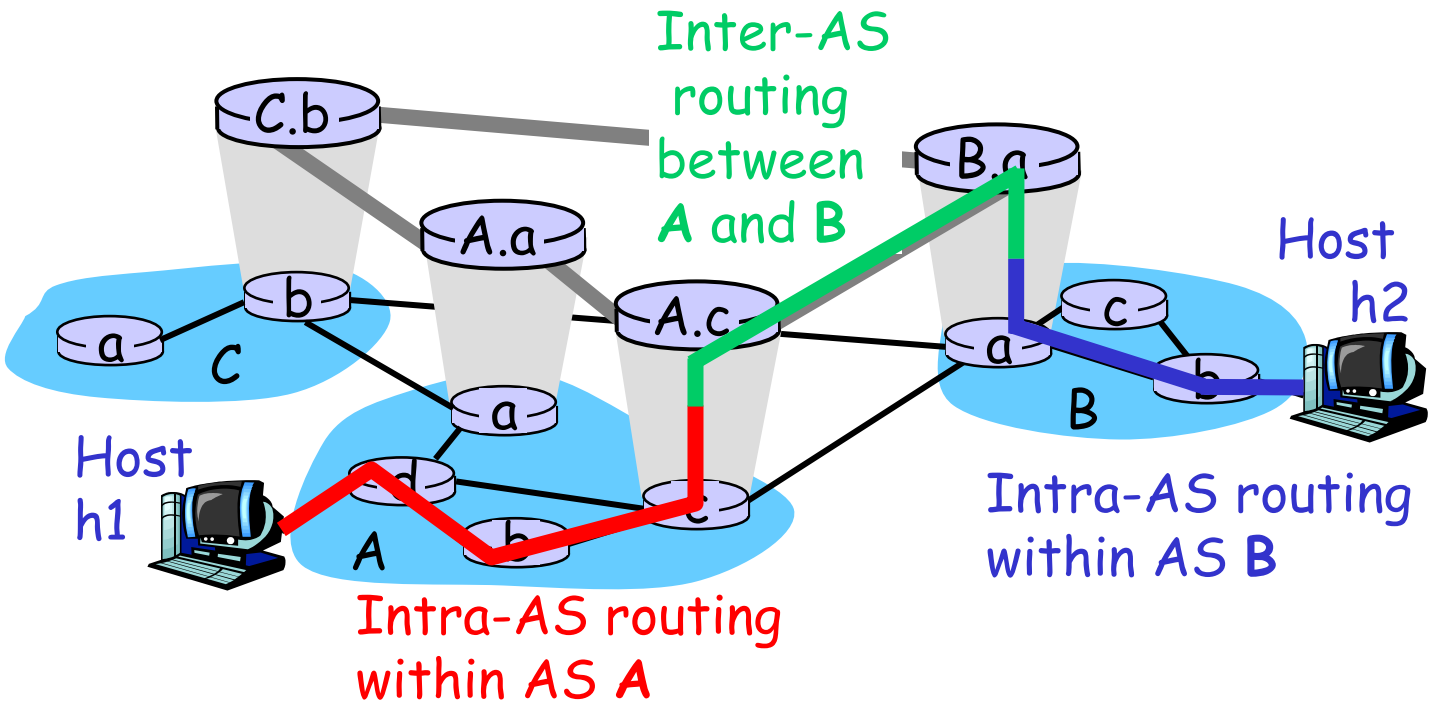
Some of the slides have been borrowed from:
Computer Networking: A Top Down Approach Featuring the Internet,
2nd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2002.

Intra-AS and Inter-AS routing



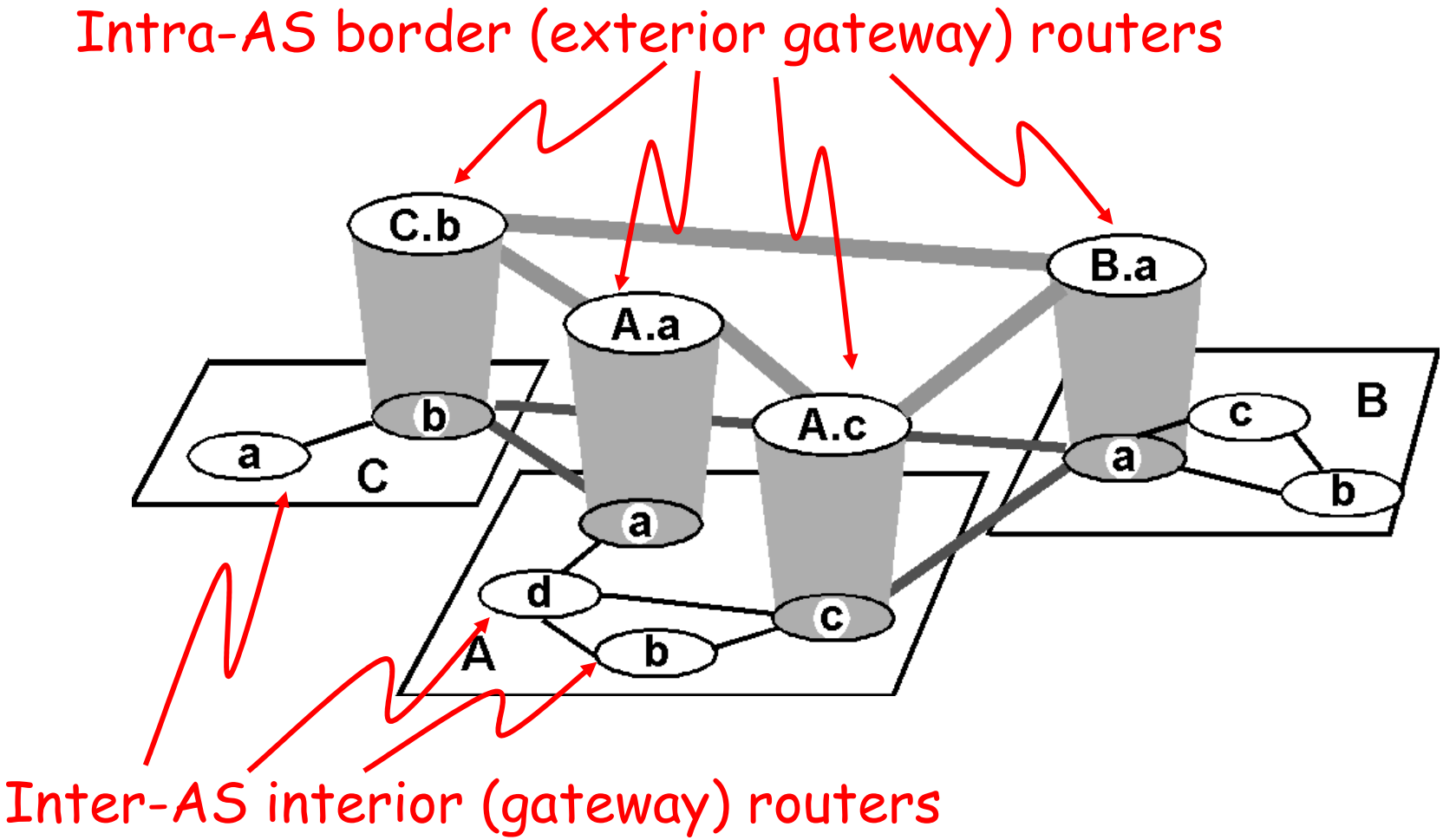
- We'll examine specific inter-AS and intra-AS Internet routing protocols shortly

Routing in the Internet

- The Global Internet consists of Autonomous Systems (AS) interconnected with each other:
  - **Stub AS**: small corporation: one connection to other AS's
  - **Multihomed AS**: large corporation (no transit): multiple connections to other AS's
  - **Transit AS**: provider, hooking many AS's together

- Two-level routing:
  - **Intra-AS**: administrator responsible for choice of routing algorithm within network
  - **Inter-AS**: unique standard for inter-AS routing: BGP

Internet AS Hierarchy



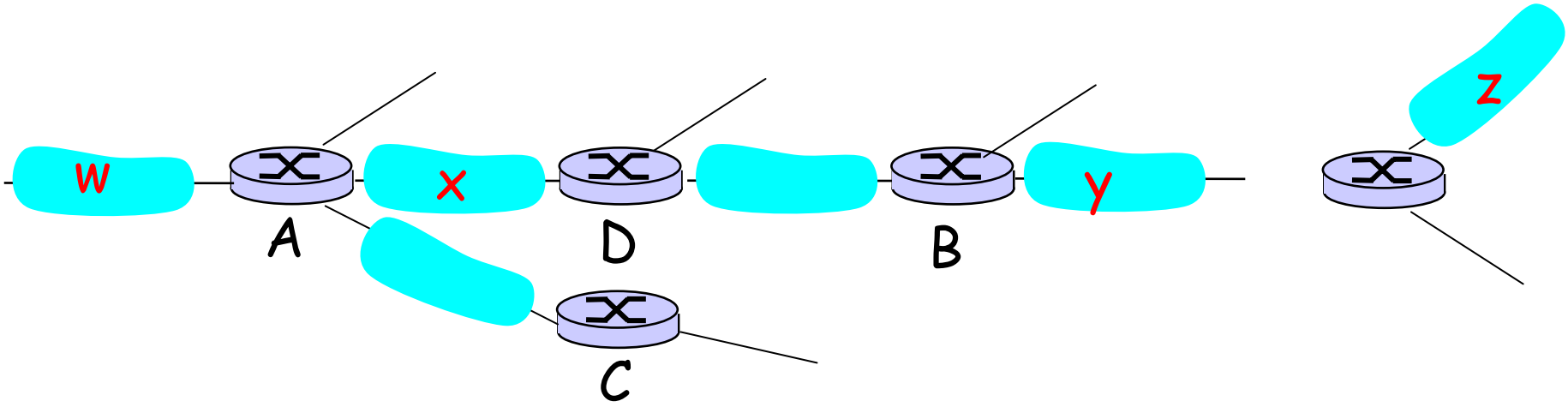
Intra-AS Routing

- 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)

RIP (Routing Information Protocol)

- Distance Vector algorithm
- Included in BSD-UNIX Distribution in 1982
- Distance metric: # of hops (max = 15 hops)
- Distance vectors: exchanged among neighbors every 30 sec via Response Message (also called **advertisement**)
- Each advertisement: list of up to 25 destination **nets** within AS

RIP: Example



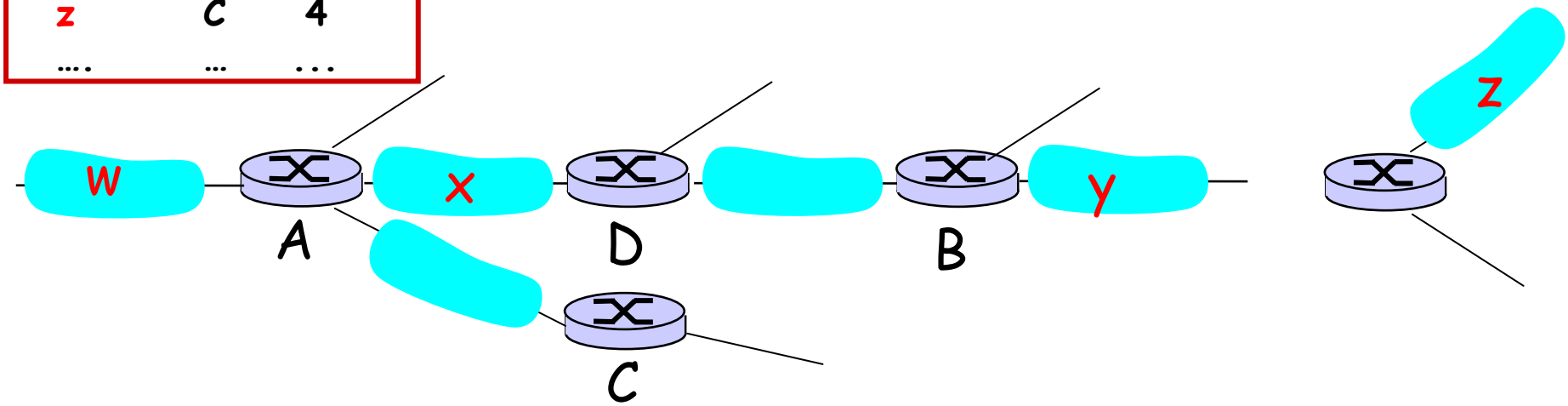
Destination Network	Next Router	Num. of hops to dest.
w	A	2
y	B	2
z	B	7
x	--	1
….	….	....

Routing table in D

RIP: Example

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

Advertisement from A to D



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

Routing table in D

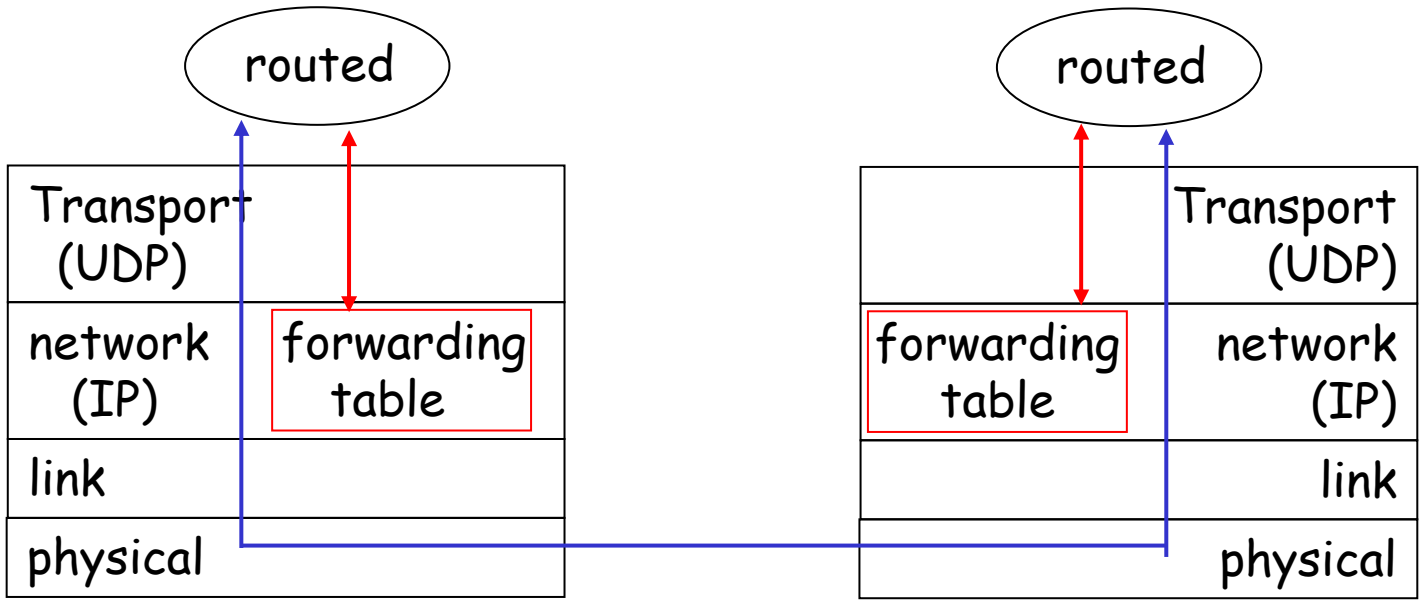
RIP: Link Failure and Recovery

If no advertisement heard after 180 sec --> neighbor/link declared dead

- routes via that neighbor invalidated
- new advertisements sent to neighbors
- neighbors in turn send out new advertisements (if tables changed)
- link failure info quickly propagates to entire net
- **poisoned reserve** used to prevent ping-pong loops (infinite distance = 16 hops)

RIP Table processing

- RIP routing tables managed by **application-level** process called route-d (unix daemon)
- advertisements sent in UDP packets



RIP Table example (continued)

netstat –r at router *giroflee.eurocom.fr*

Destination	Gateway	Flags	Ref	Use	Interface
127.0.0.1	127.0.0.1	UH	0	26492	lo0
192.168.2.	192.168.2.5	U	2	13	fa0
193.55.114.	193.55.114.6	U	3	58503	le0
192.168.3.	192.168.3.5	U	2	25	qaa0
224.0.0.0	193.55.114.6	U	3	0	le0
default	193.55.114.129	UG	0	143454	

- Three attached class C networks (LANs)
- Router only knows routes to attached LANs
- 'Default router' used to go to unlisted destinations
- Router multicast address: 224.0.0.0
- Loopback interface (for debugging)

OSPF (Open Shortest Path First)

- RIP not sufficient for large nets, inherited from ARPANET
- In 1979 IETF started replacing RIP with a link state gateway routing protocol
- In 1988 IETF started the design of a successor called OSPF which became a standard in 1990
- OSPF was designed to deal with a variety of issues:
  - Routing based on type of service
  - Enable variable distance metrics
  - Load balancing
  - Security
  - Scalability

OSPF

- "open": publicly available
- Uses Link State algorithm
  - LS packet dissemination (diffusion)
  - Topology map at each node
  - Route computation using Dijkstra's algorithm

- OSPF advertisement carries one entry per neighbor router
- Advertisements disseminated to entire AS (via flooding)
  - Carried in OSPF messages directly over IP (rather than TCP or UDP

OSPF

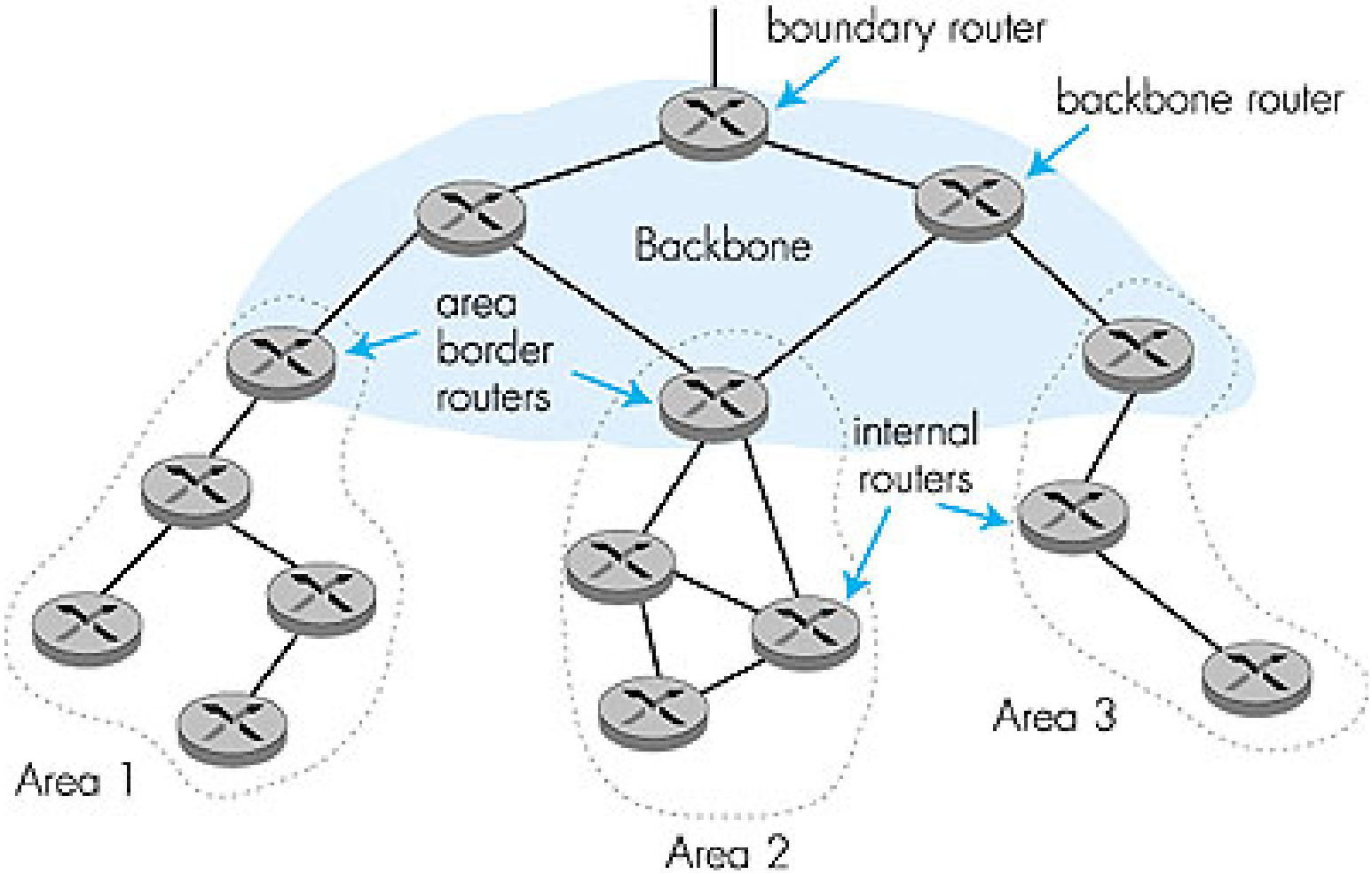
The five types of OSPF messages:

Message type	Description
Hello	Used to discover who the neighbors are
Link state update	Provides the sender's costs to its neighbors
Link state ack	Acknowledges link state update
Database description	Announces which updates the sender has
Link state request	Requests information from the partner

OSPF "advanced" features (not in RIP)

- Security: all OSPF messages authenticated (to prevent malicious intrusion)
- Multiple same-cost paths allowed (only one path in RIP); can use next-shortest path first for load balancing
- For each link, multiple cost metrics (e.g., satellite link cost set to "low" for best effort; high for real time)
- Integrated uni- and multicast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- Hierarchical OSPF in large domains.

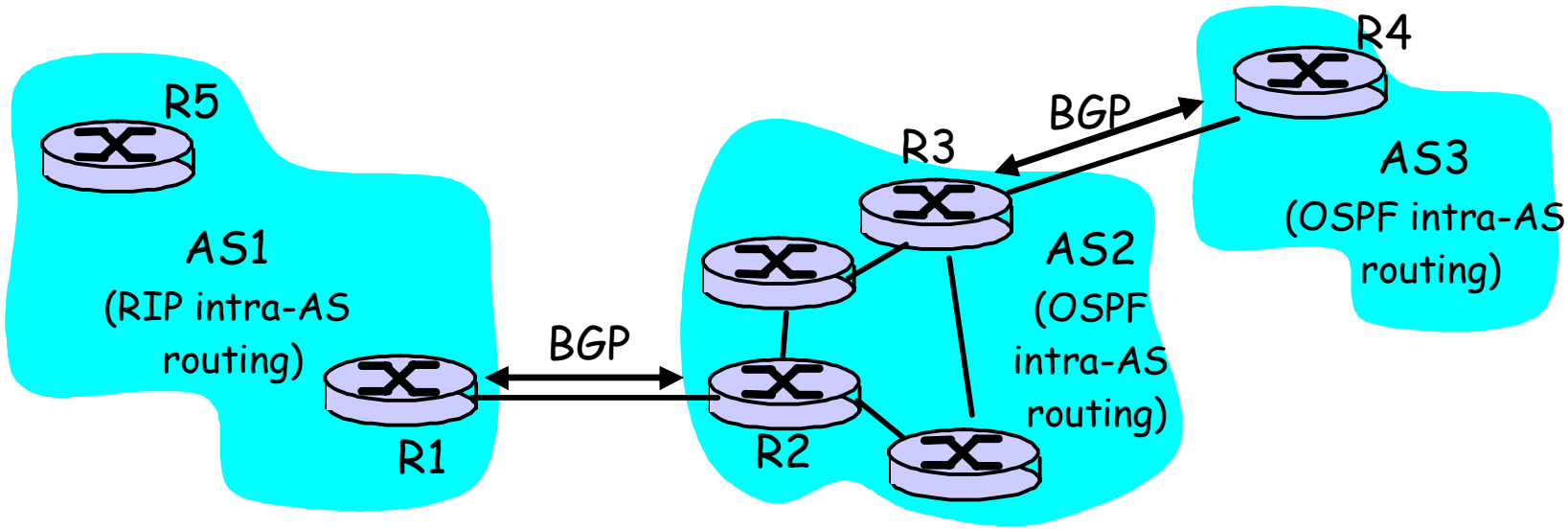
Hierarchical OSPF



Hierarchical OSPF

- Two-level hierarchy: local area, backbone.
  - Link-state advertisements only in area
  - each nodes has detailed area topology; only know direction (shortest path) to nets in other areas.
- **Area border routers:** "summarize" distances to nets in own area, advertise to other Area Border routers.
- **Backbone routers:** run OSPF routing limited to backbone.
- **Boundary routers:** connect to other AS's.

Inter-AS routing in the Internet: BGP



Internet inter-AS routing: BGP

- BGP (Border Gateway Protocol): *the* de facto standard
- **Path Vector** protocol:
  - similar to Distance Vector protocol
  - each Border Gateway broadcast to neighbors (peers) *entire path* (i.e., sequence of AS's) to destination
  - BGP routes to networks (ASs), not individual hosts
  - E.g., Gateway X may send its path to dest. Z:

Path (X,Z) = X,Y1,Y2,Y3,…,Z

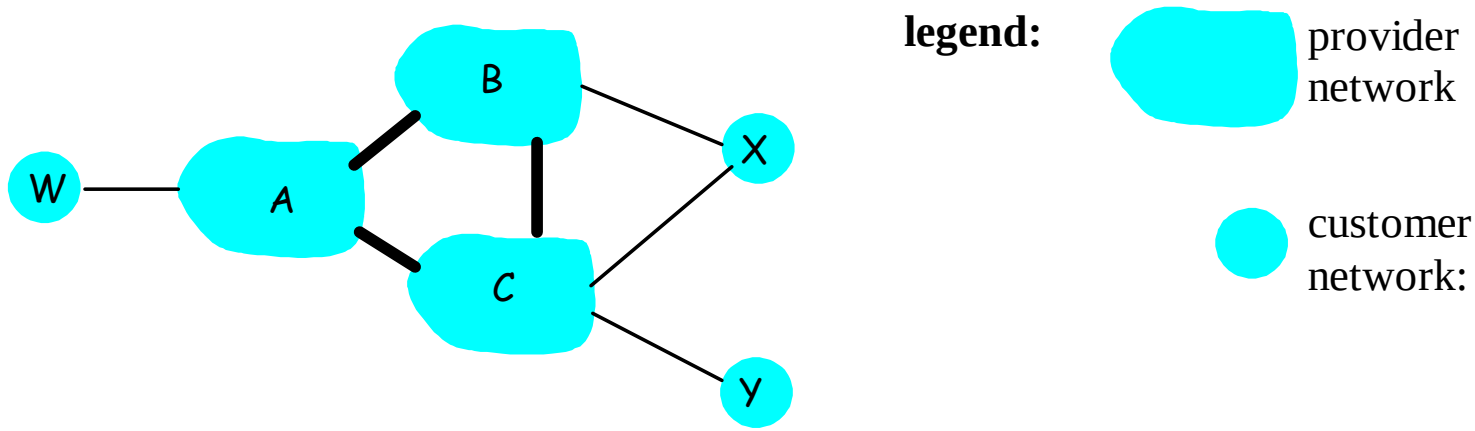
Internet inter-AS routing: BGP

Suppose: gateway X sends its path to peer gateway W

- W may or may not select path offered by X due to:
  - cost, policy (don't route via competitors AS), loop prevention reasons.
- If W selects path advertised by X, then:

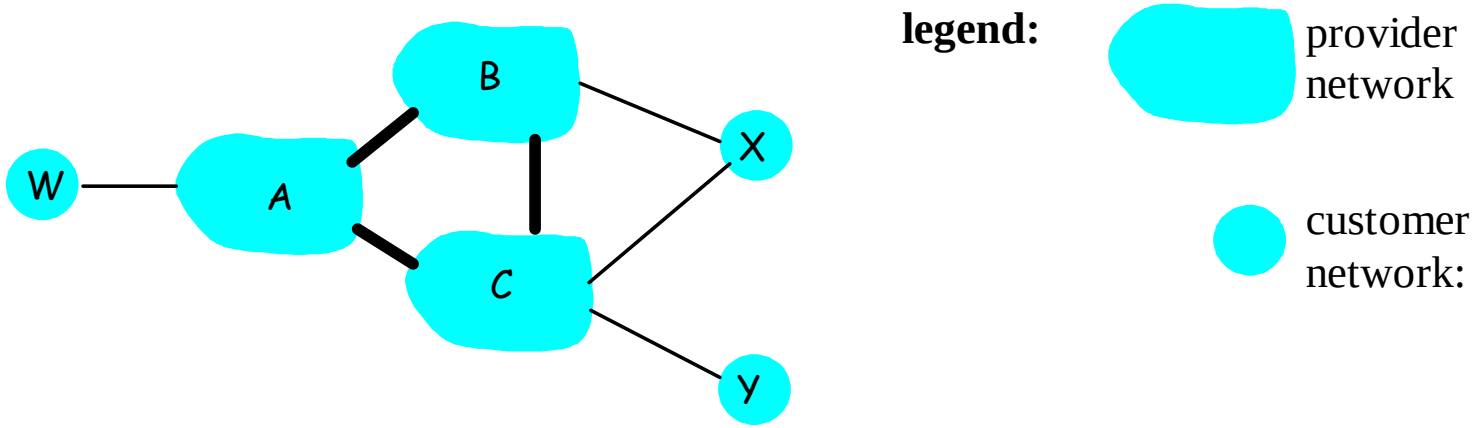
  Path (W,Z) = w, Path (X,Z)
- Note: X can control incoming traffic by controlling its route advertisements to peers:
  - e.g., don't want to route traffic to Z? => don't advertise any routes to Z!

BGP: controlling who routes to you



- A,B,C are provider networks
- x,w,y are customers (of the provider networks)
- x is dual-homed: attached to two networks
  - x does not want to route from B (via x) to C
  - .. so x will not advertise to B a route to C

BGP: controlling who routes to you



- A advertises to B the path Aw
- B advertises to x the path BAw
- Should B advertise to C the path BAw?
  - No way! B gets no "revenue" for routing CBAw since neither w nor C are B's customers
  - B wants to force C to route to w via A
  - B wants to route *only* to/from its customers!

BGP operation

Q: What does a BGP router do?

- Receiving and filtering route advertisements from directly attached neighbors
- Route selection
  - To route to destination X, which path will be taken? (of several advertised)
- Sending route advertisements to neighbors

BGP messages

- BGP messages exchanged using TCP.
- BGP messages:
  - OPEN: opens TCP connection to peer and authenticates sender
  - UPDATE: advertises new path (or withdraws old)
  - KEEPALIVE keeps connection alive in absence of UPDATES; also ACKs OPEN request
  - NOTIFICATION: reports errors in previous msg; also used to close connection

Why different Intra- and Inter-AS routing ?

Policy:

- Inter-AS: admin wants control over how its traffic is routed, who routes through its net.
- Intra-AS: single admin, so no policy decisions needed
- Examples of policy decisions: traffic starting or ending at IBM should not pass through Microsoft; Never put Iraq on a route starting at the Pentagon; Only use Bangladesh if no other route

Scale:

- hierarchical routing saves table size, reduced update traffic

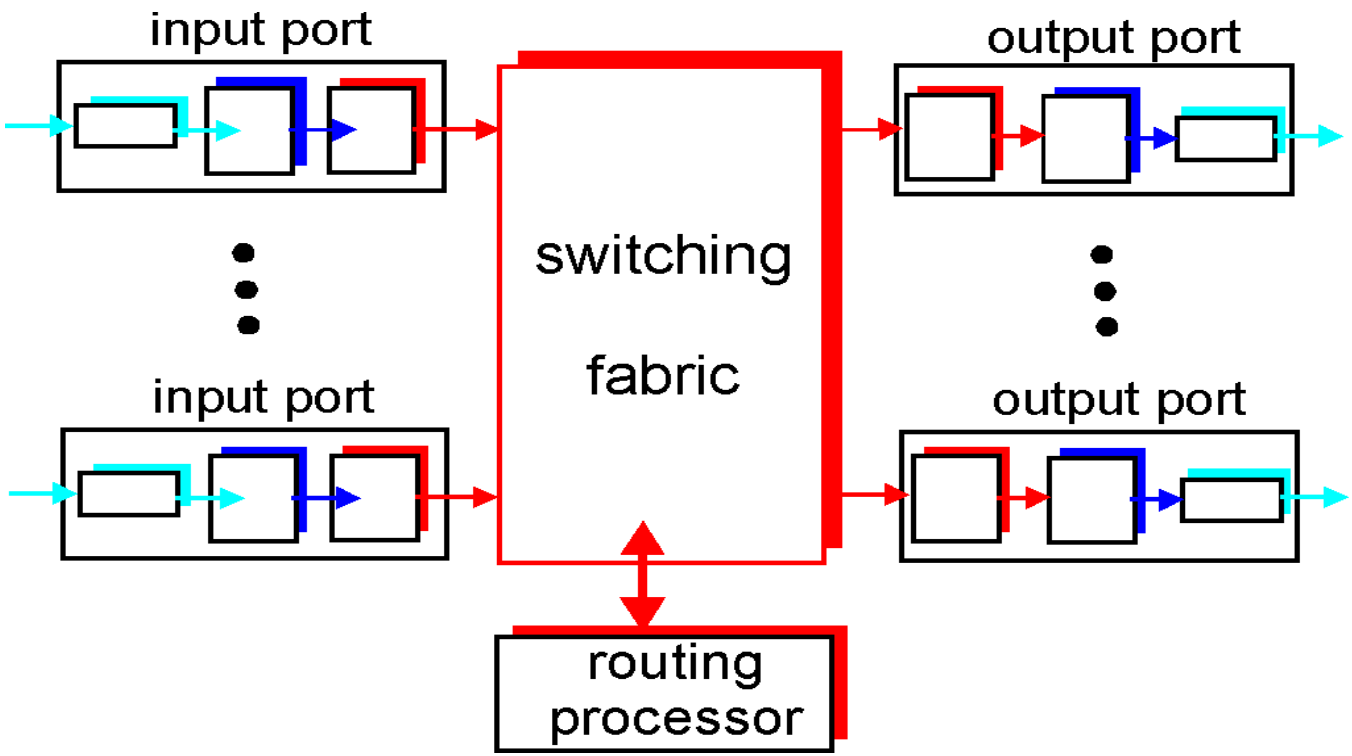
Performance:

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

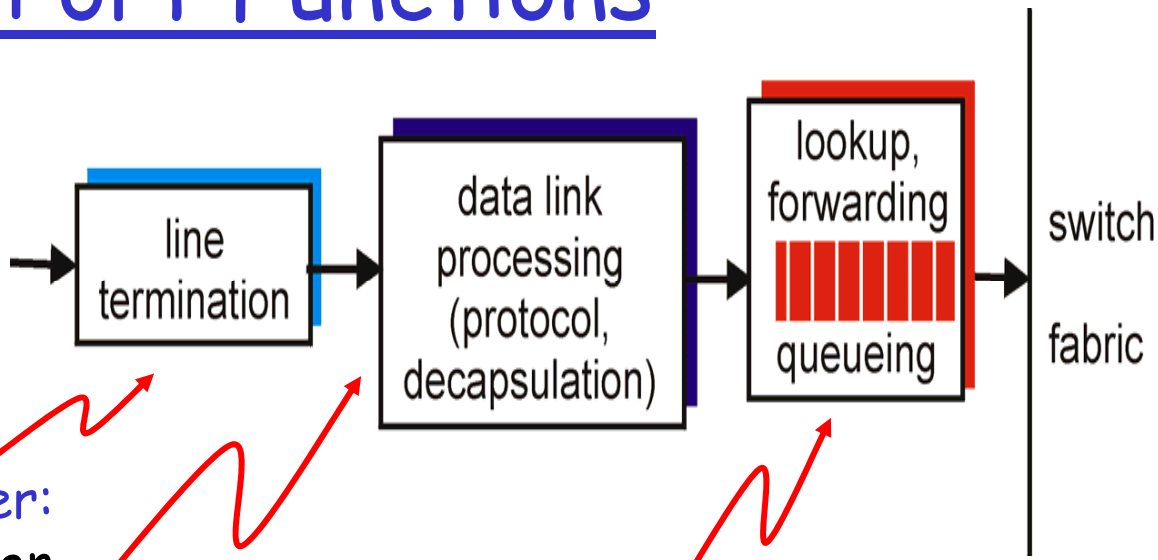
Router Architecture Overview

Two key router functions:

- run routing algorithms/protocol (RIP, OSPF, BGP, etc..)
- *switching* datagrams from incoming to outgoing link



Input Port Functions



Physical layer:
bit-level reception

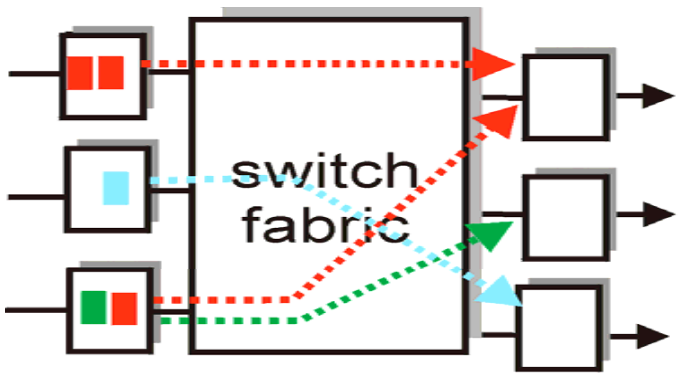
Data link layer:
e.g., Ethernet

Decentralized switching:

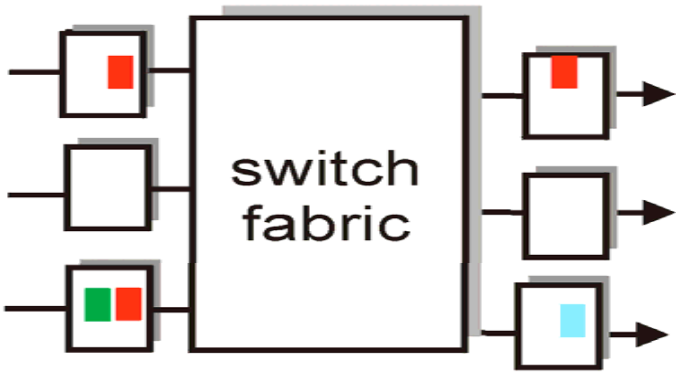
- given datagram dest., lookup output port using routing table in input port memory
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch fabric

Causes of Input Port Queuing

- If fabric slower than input ports combined => queueing may occur at input queues
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward
- *queueing delay and loss due to input buffer overflow!*

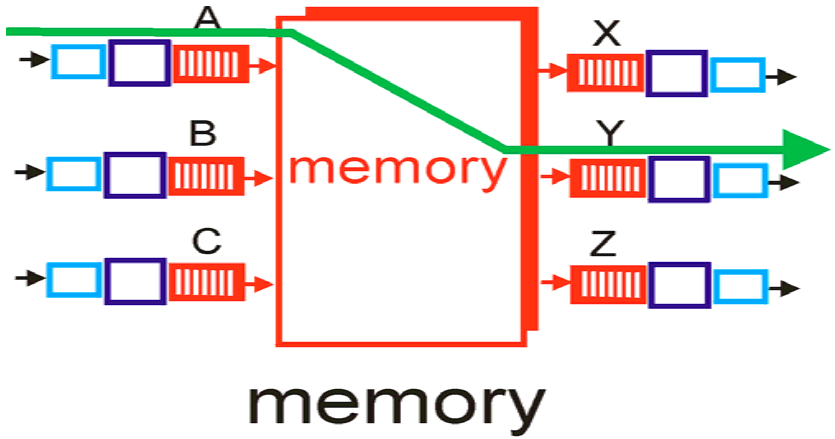


output port contention at time t - only one red packet can be transferred

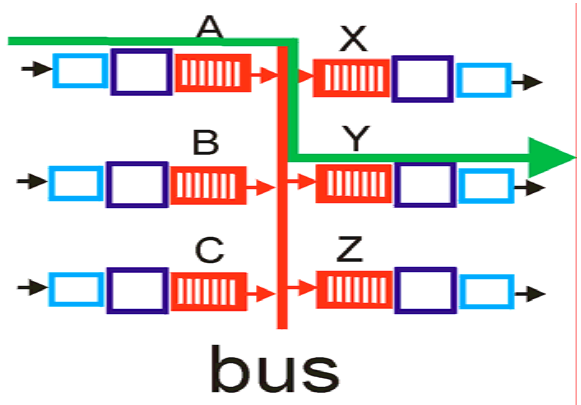


green packet experiences HOL blocking

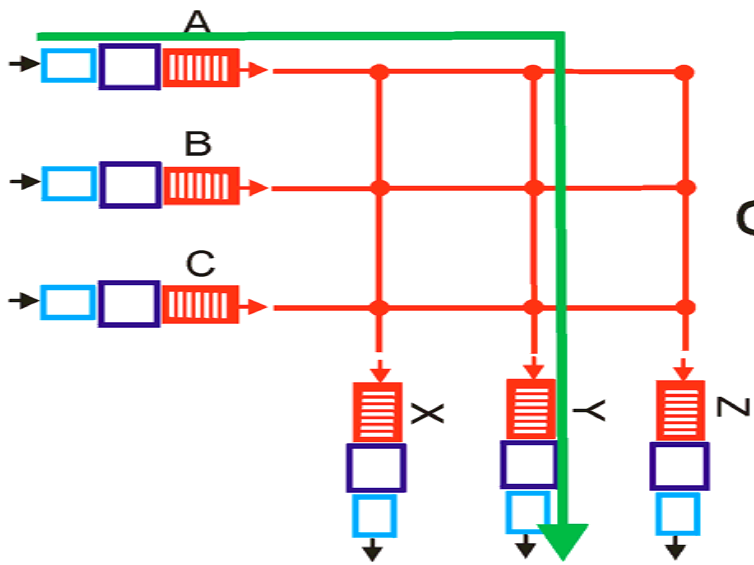
Three types of switching fabrics



memory



bus

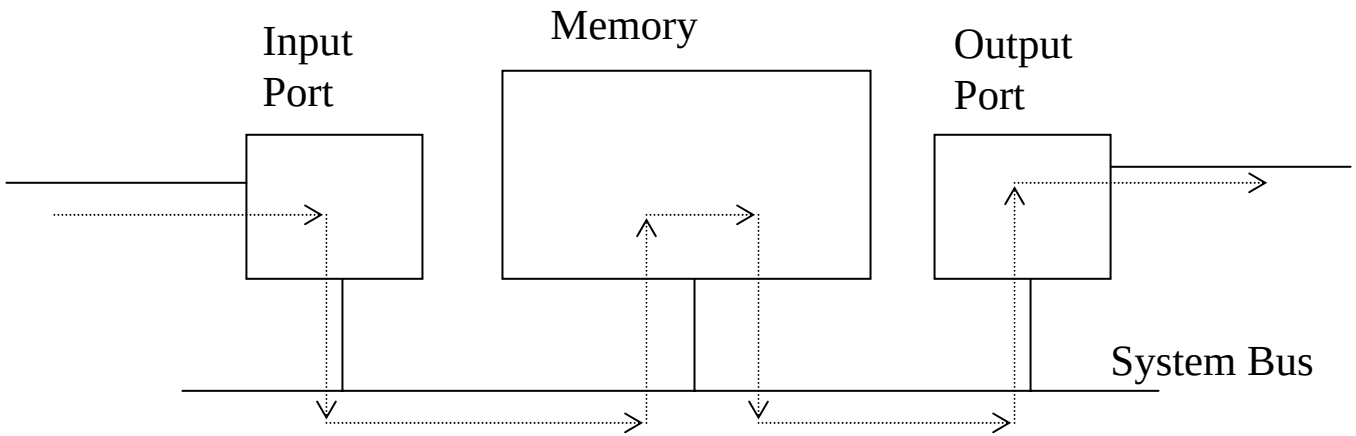


crossbar

Switching Via Memory

First generation routers:

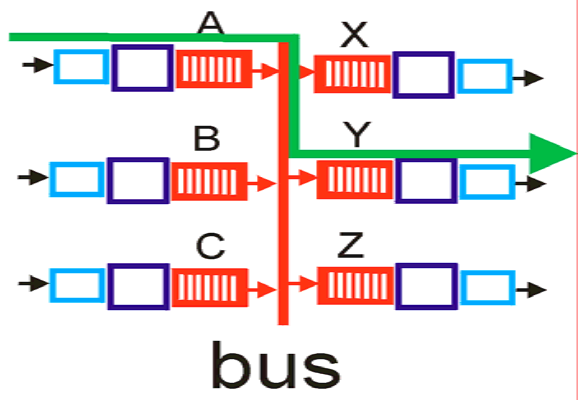
- packet copied by system's (single) CPU
- speed limited by memory bandwidth (2 bus crossings per datagram)



Modern routers:

- input port processor performs lookup, copy into memory
- Cisco Catalyst 8500

Switching Via a Bus

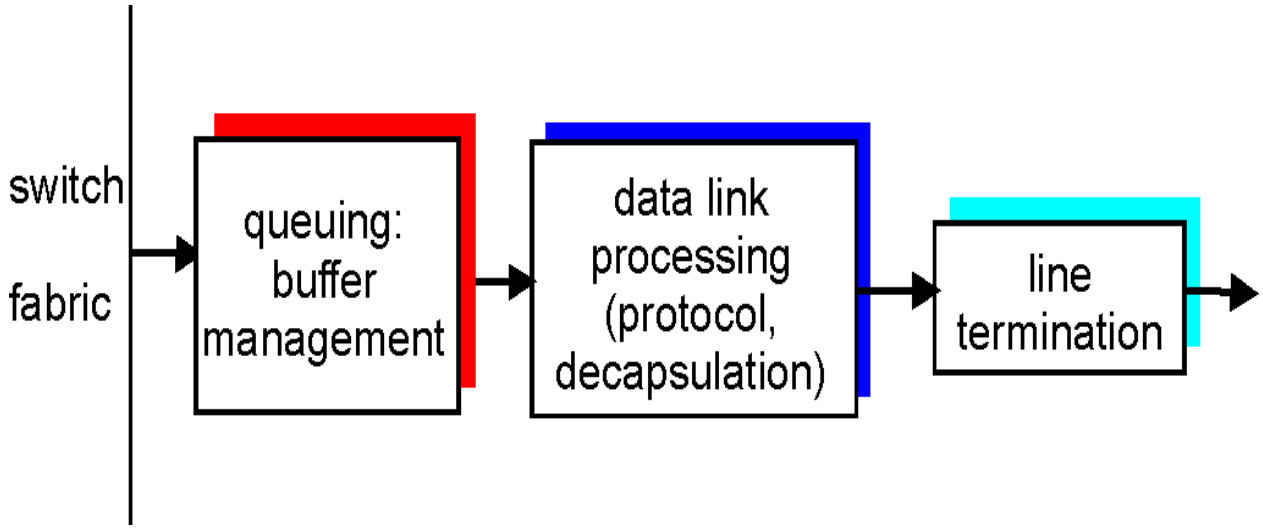


- datagram from input port memory to output port memory via a shared bus
- bus contention: switching speed limited by bus bandwidth
- 1 Gbps bus, Cisco 1900: sufficient speed for access and enterprise routers (not regional or backbone)

Switching Via An Interconnection Network

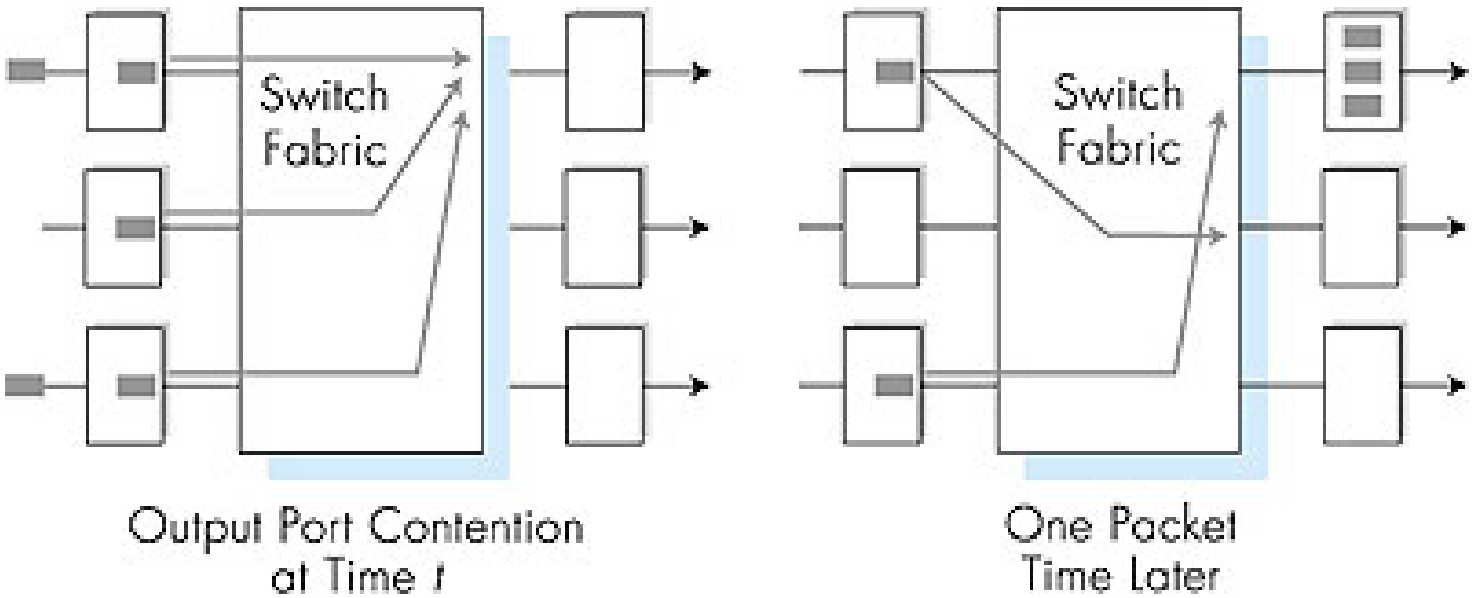
- overcome bus bandwidth limitations
- initially developed to connect processors in multiprocessor systems
- advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.
- Cisco 12000: switches Gbps through the interconnection network

Output Ports



- *Buffering* required when datagrams arrive from fabric faster than the transmission rate
- *Scheduling discipline* chooses among queued datagrams for transmission

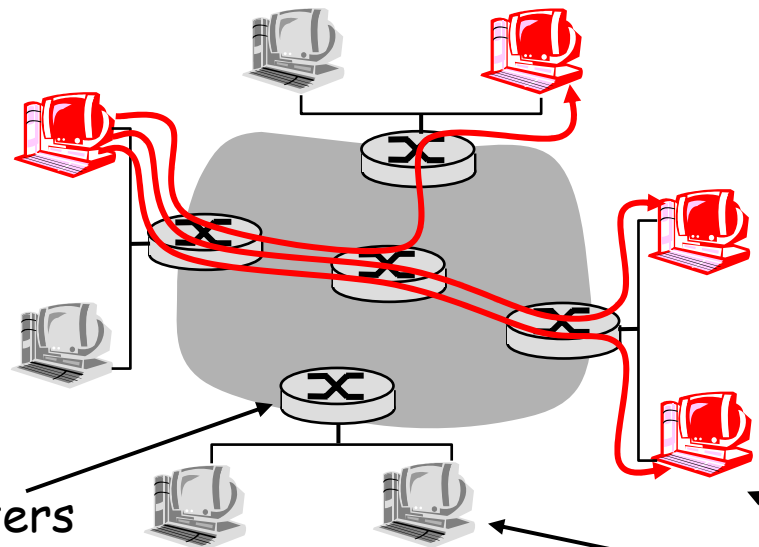
Causes of Output port queueing



- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*

Multicast: one sender to many receivers

- Multicast: act of sending datagram to multiple receivers with single "transmit" operation
  - analogy: one teacher to many students
- Question: how to achieve multicast



routers forward unicast datagrams

multicast receiver (red)

not a multicast receiver (red)

Multicast via unicast

- source sends N unicast datagrams, one addressed to each of N receivers

Multicast: one sender to many receivers

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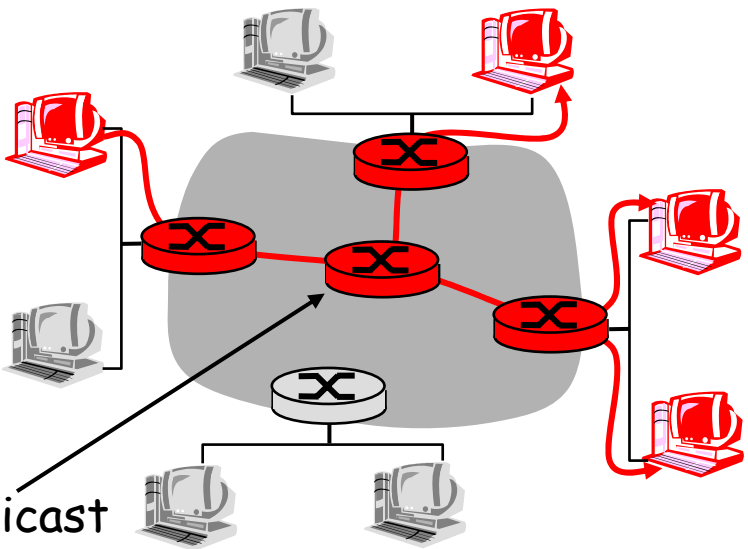

Multicast routers (red) duplicate and forward multicast datagrams

Network multicast

- Router actively participate in multicast, making copies of packets as needed and forwarding towards multicast receivers

Multicast: one sender to many receivers

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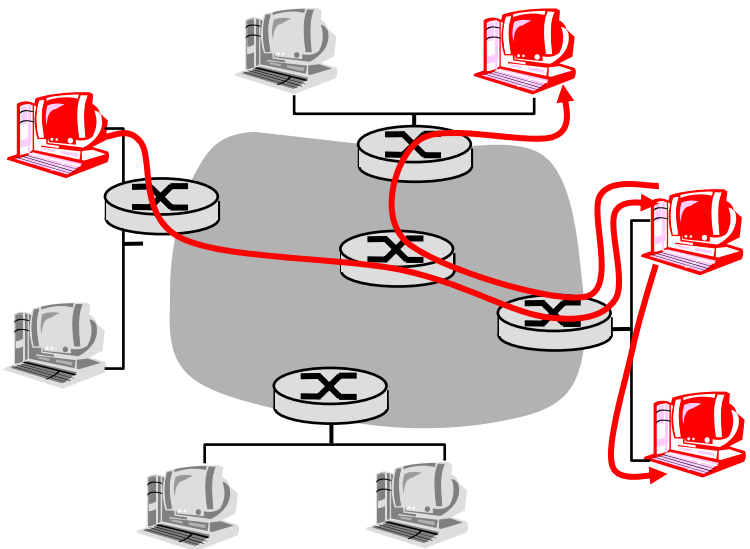
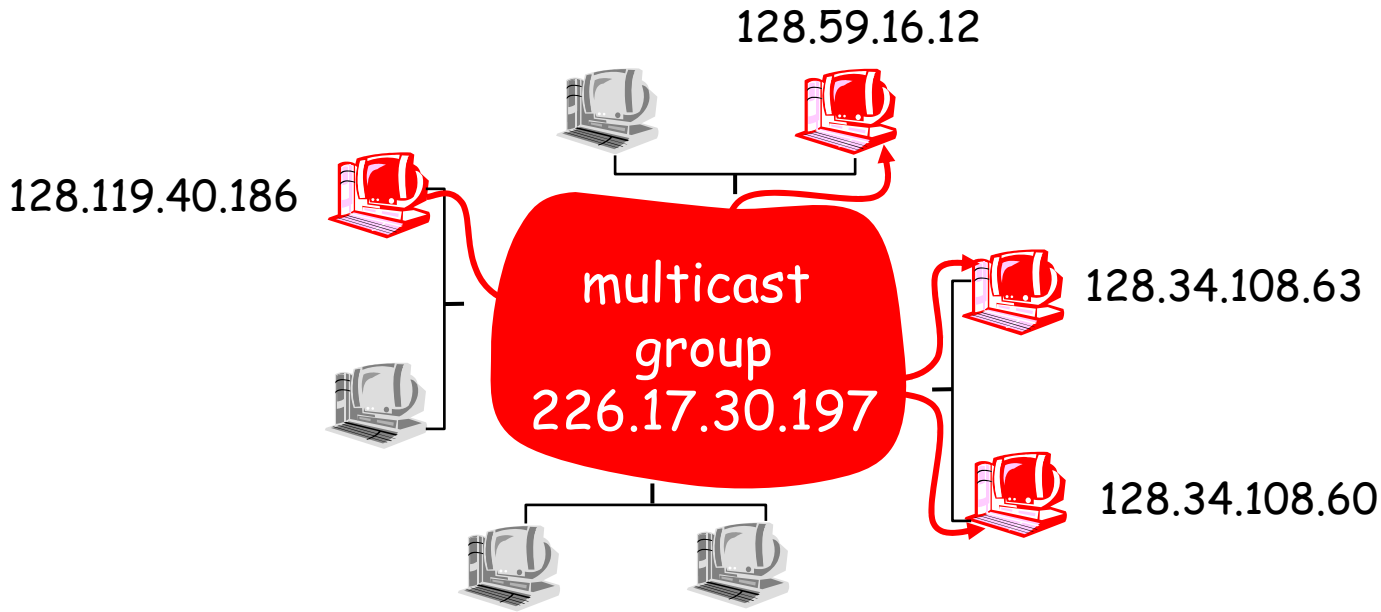


Application-layer multicast

- end systems involved in multicast copy and forward unicast datagrams among themselves

Internet Multicast Service Model



multicast group concept: use of indirection

- hosts addresses IP datagram to multicast group
- routers forward multicast datagrams to hosts that have "joined" that multicast group