

CSCE 463/612

Networks and Distributed Processing

Spring 2025

Network Layer II

Dmitri Loguinov

Texas A&M University

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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

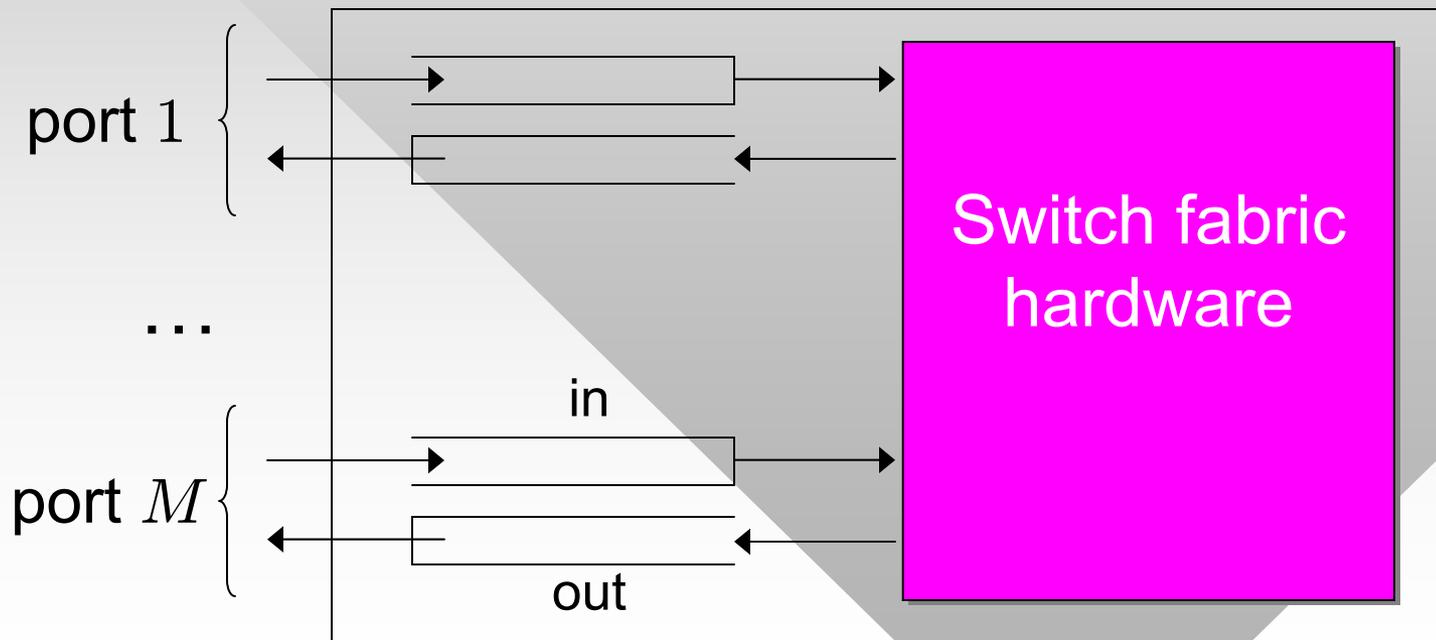
4.6 Routing in the Internet

4.7 Broadcast and multicast routing

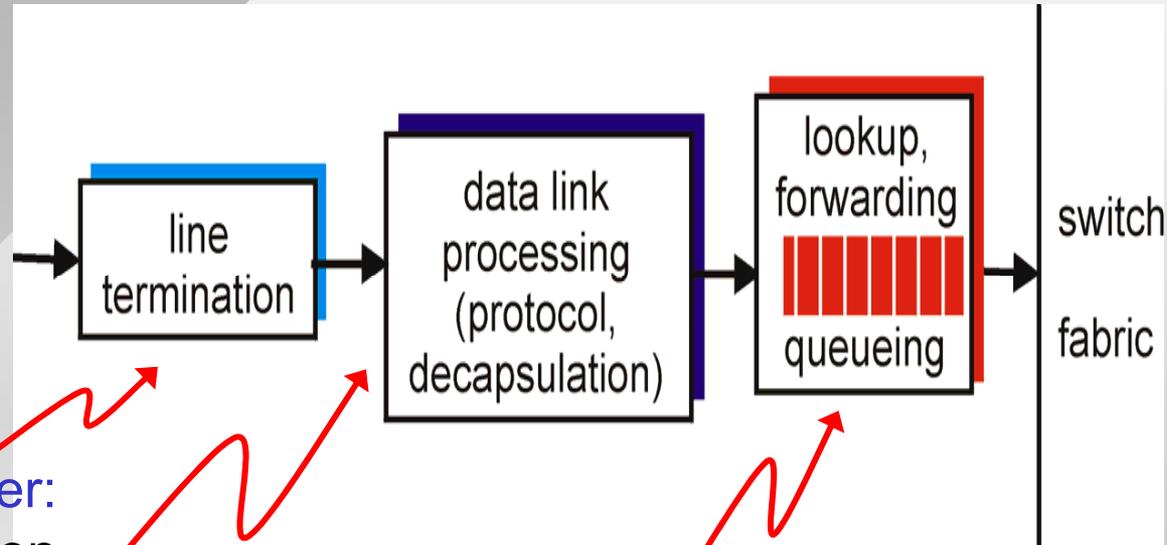
Router Architecture Overview

Two key router functions:

- Run routing algorithms/protocols (RIP, OSPF, BGP)
- Forward datagrams from incoming to outgoing link
 - Terminology: **port** = interface capable of sending/receiving



Input Port (Queue) Functions



Physical layer:
bit-level reception

Data link layer
(e.g., Ethernet,
ATM, Token Ring,
802.11b): see ch. 5

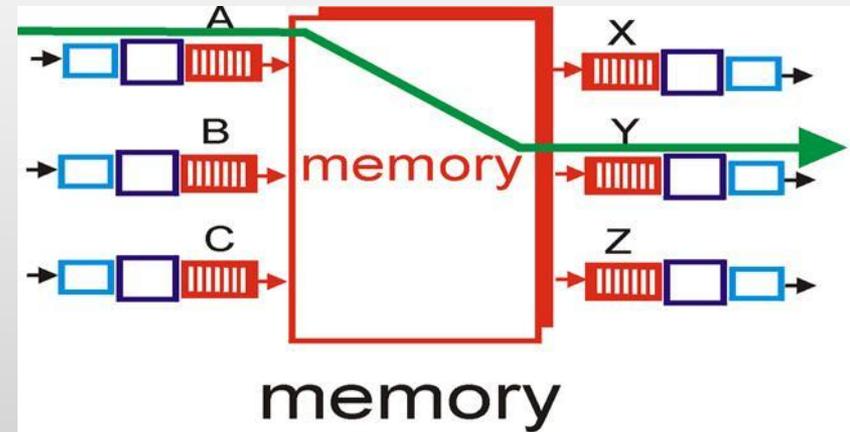
Decentralized switching:

- Given datagram destination, look up output port using forwarding table in input port memory
- **Goal:** complete input port processing at “line speed”
- **Queueing:** if datagrams arrive faster than forwarding rate into switch fabric

Switching Via Memory

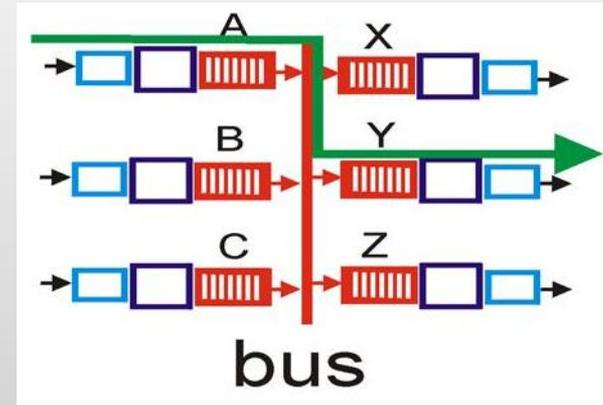
First generation routers (1960s-mid 1980s):

- Traditional computers with switching under direct control of CPU
- Packet copied to system memory
- Speed limited by CPU, memory latency/bandwidth, and bus bandwidth (two bus crossings per datagram)
- Honeywell 316 (1969) →



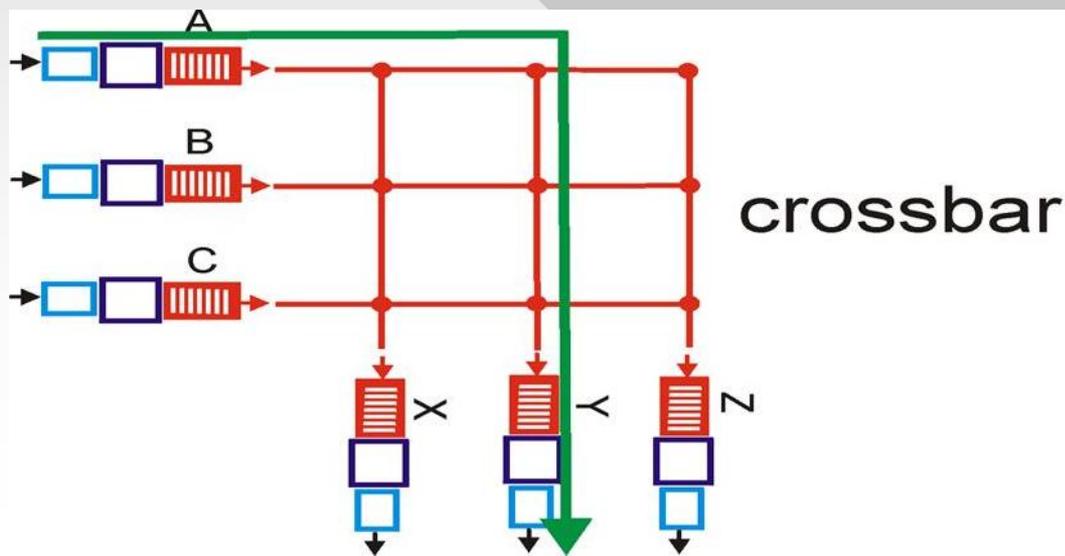
Switching Via a Bus

- Datagram from input port memory to output port memory via a shared bus
- **Bus contention:** switching speed limited by bus bandwidth
- 1 Gbps bus in Cisco 1900: sufficient speed for access and small enterprise networks (not ISPs)

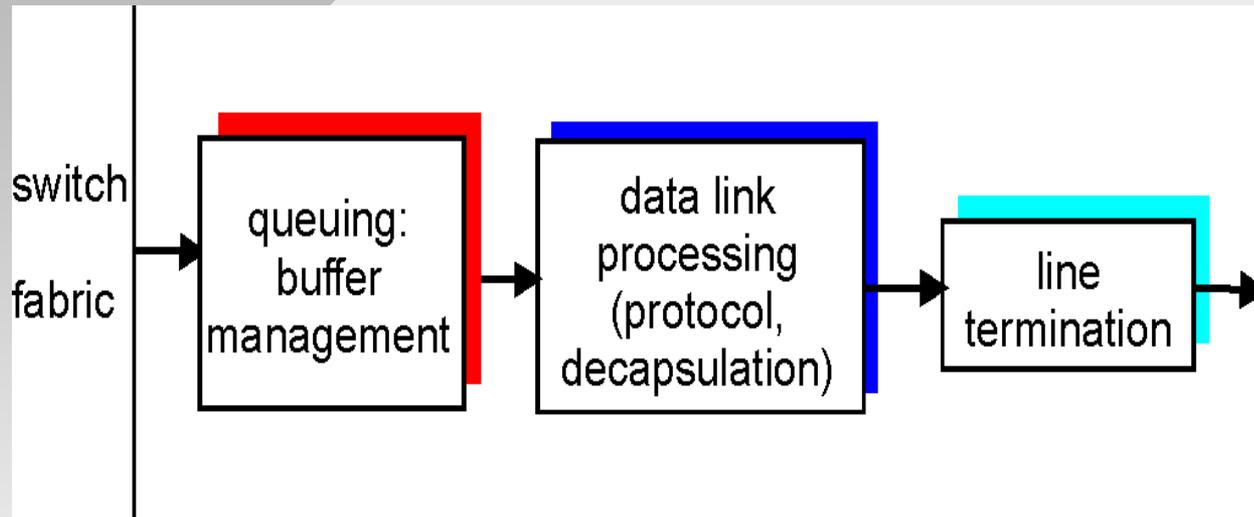


Switching Via An Interconnection Network

- Overcomes bus bandwidth limitations
 - Crossbar: packets transmitted in parallel as long as they do not occupy the same horizontal or vertical bus
- Cisco 12000 (1996): uses an interconnection network
 - CRS-X (2013): 1600 lbs, 84" rack, 7.6 KWatt, 800 Gbps/slot
 - 16 slots/rack = 12.8 Tbps
 - Up to 72 racks (922 Tbps)

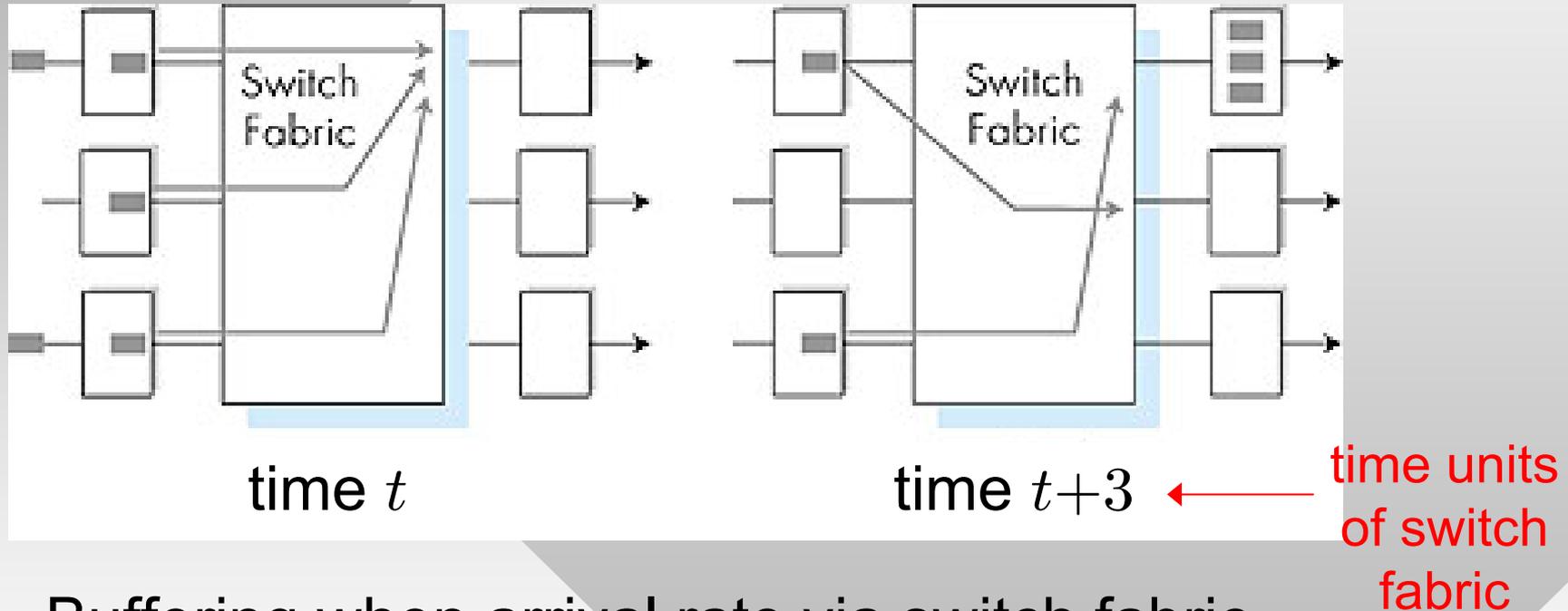


Output Ports



- *Buffering/queuing* required when datagrams arrive from fabric faster than the transmission rate
- *Scheduling discipline* chooses among queued datagrams for transmission
 - Customer traffic: single FIFO drop-tail queue
 - ISP traffic: multiple queues with WRR or priority queuing

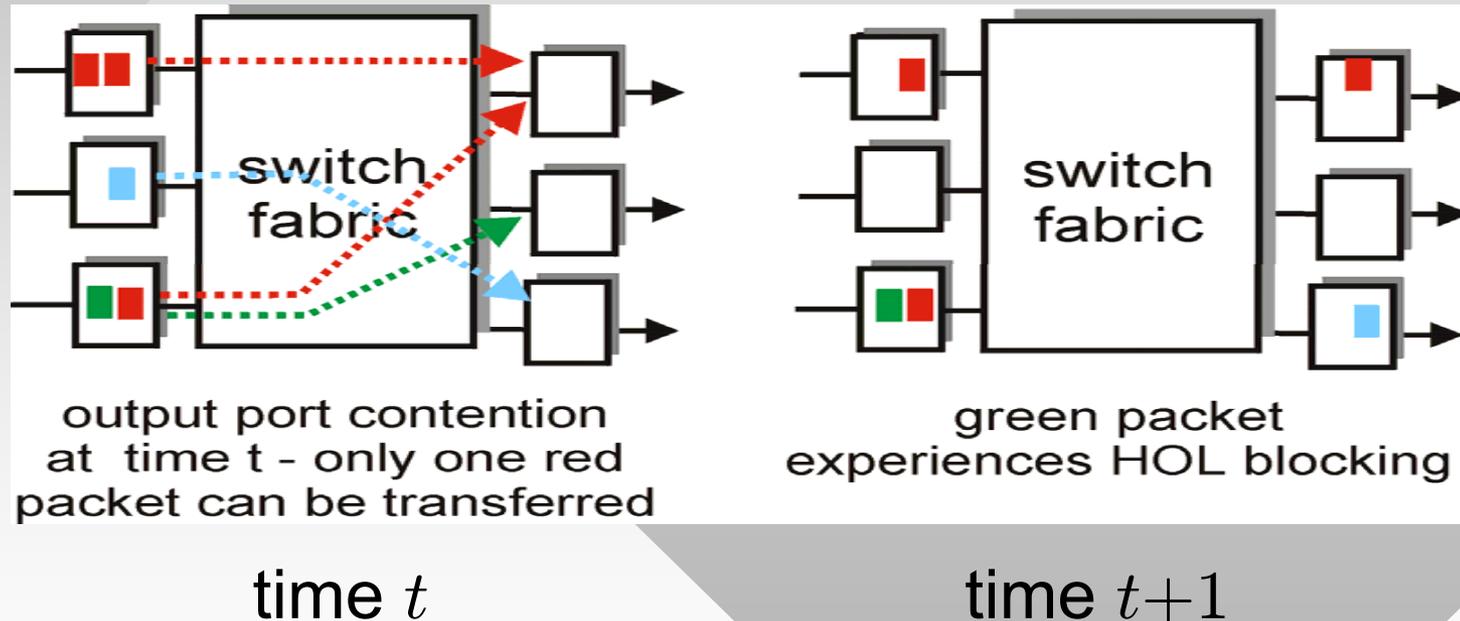
Output Port Queuing



- Buffering when arrival rate via switch fabric exceeds output line speed
 - Queuing delay and loss due to output buffer overflow
- Switch fabric often faster than individual ports
 - Produces large bursts of arrivals into output queues

Input Port Queuing

- Reasons for input-port queuing:
 - **Head-of-Line (HOL) blocking:** queued datagram at front of queue prevents others in queue from moving forward



- Queuing delay and loss due to input buffer overflow!
 - How likely is this compared to output port queuing/loss?

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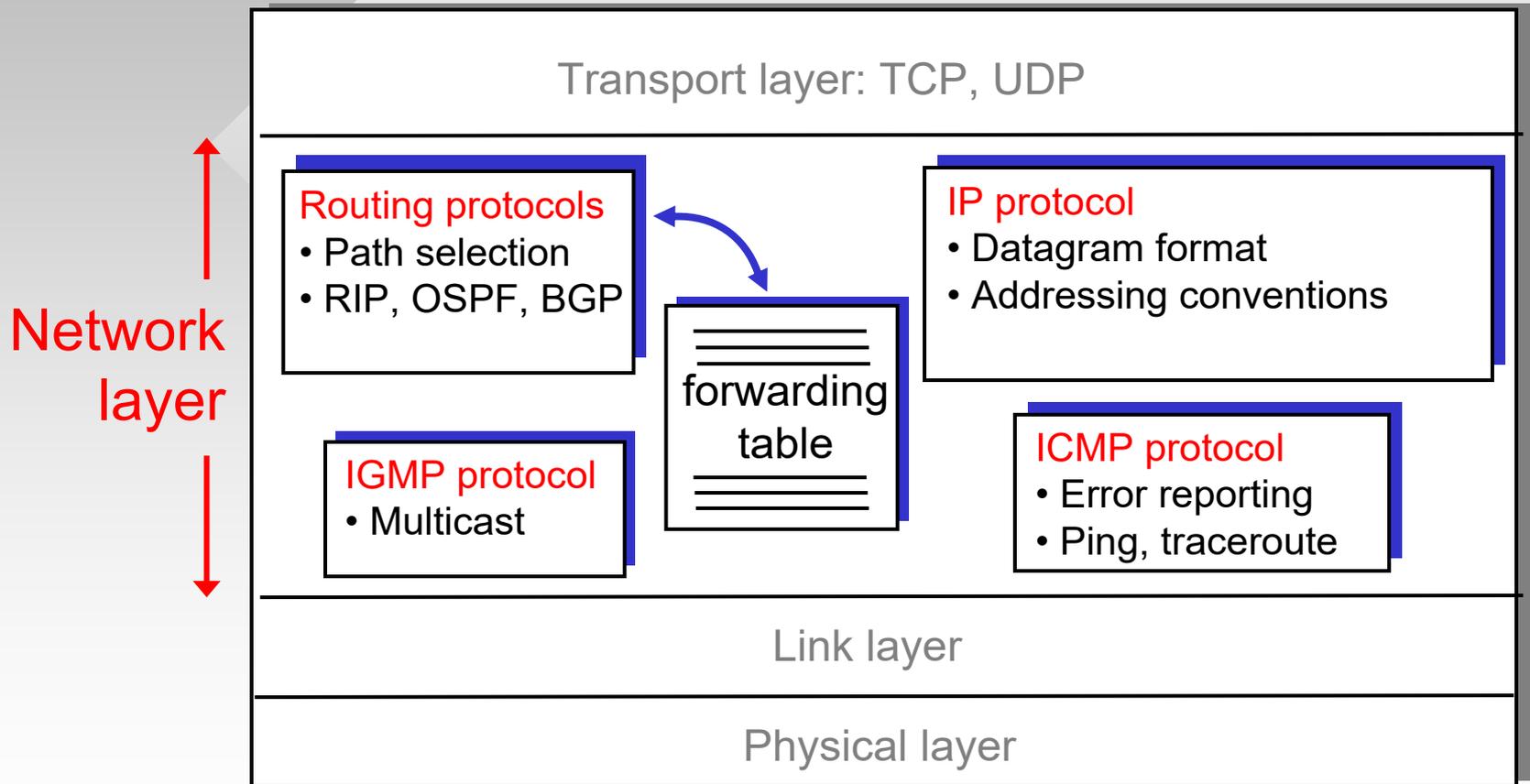
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The Internet Network Layer

Host and router network layer functions:



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- Datagram format
- IPv4 addressing
- ICMP
- IPv6

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IPv4 Datagram Format

IP protocol version number

Header length (in 4-byte words)

QoS requested

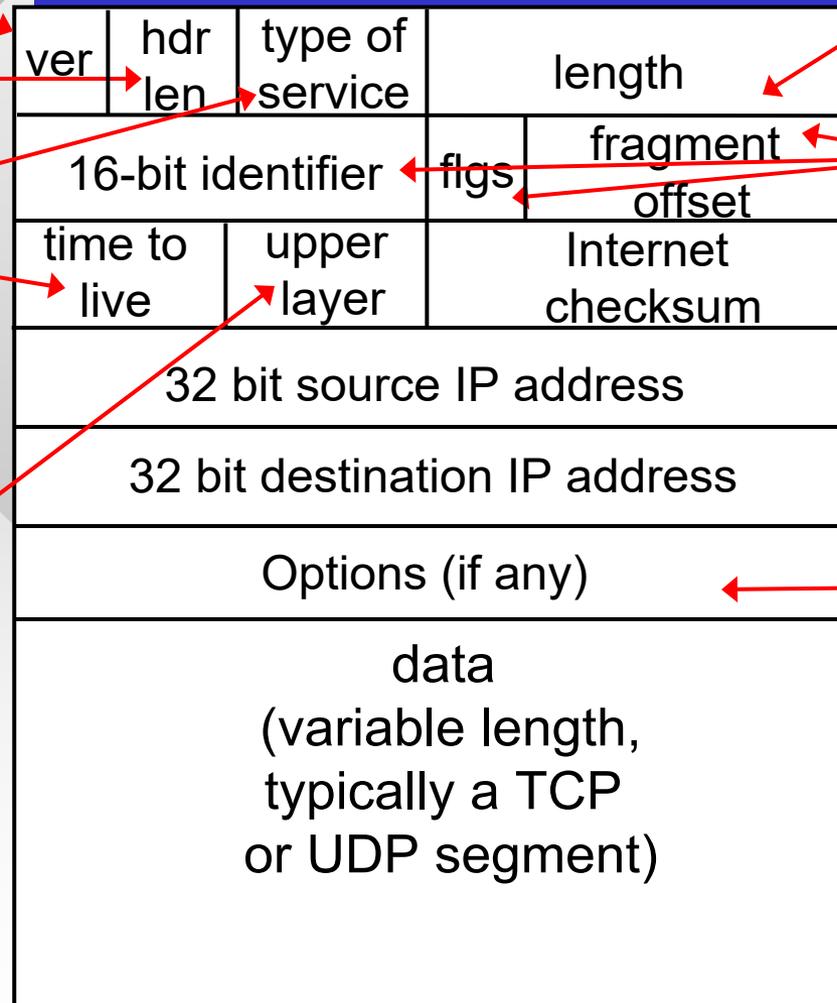
Max number remaining hops (decremented at each router)

Upper layer protocol to deliver payload to

How much overhead with TCP?

- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes

32 bits



Total datagram length (bytes)

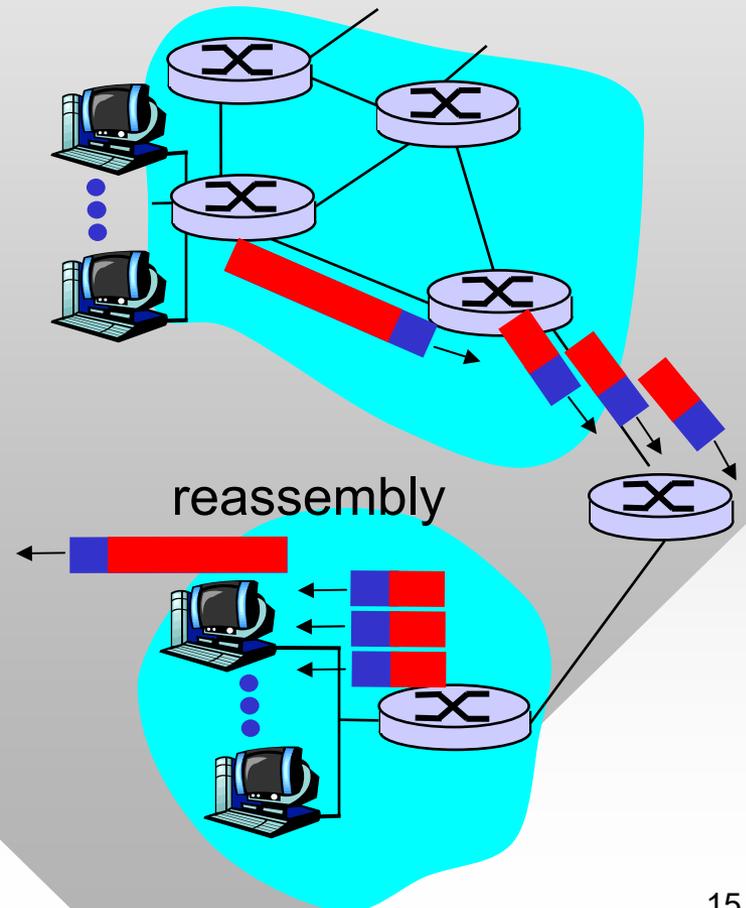
For fragmentation/reassembly

E.g. timestamp, record route taken, specify list of routers to visit

IP Fragmentation & Reassembly

- Network links have varying **MTUs (maximum transmission units)** – largest possible link-level frames
 - Different link types, different MTUs (most common 1500)
- Large IP datagram divided (“fragmented”) within network
 - One datagram becomes several datagrams
 - “Reassembled” only at final destination
 - IP header bits used to identify, order related fragments

fragmentation:
in: one large datagram
out: 3 smaller datagrams



IP Fragmentation and Reassembly

Example

- 4000 byte datagram (including IP header)
- MTU = 1500 bytes

	length =4000	ID =x	fragflag =0	offset =0	
--	-----------------	----------	----------------	--------------	--

One large datagram becomes several smaller datagrams

1480 bytes in payload

offset is in 8-byte words: $185 = 1480/8$

	length =1500	ID =x	fragflag =1	offset =0	
--	-----------------	----------	----------------	--------------	--

	length =1500	ID =x	fragflag =1	offset =185	
--	-----------------	----------	----------------	----------------	--

	length =1040	ID =x	fragflag =0	offset =370	
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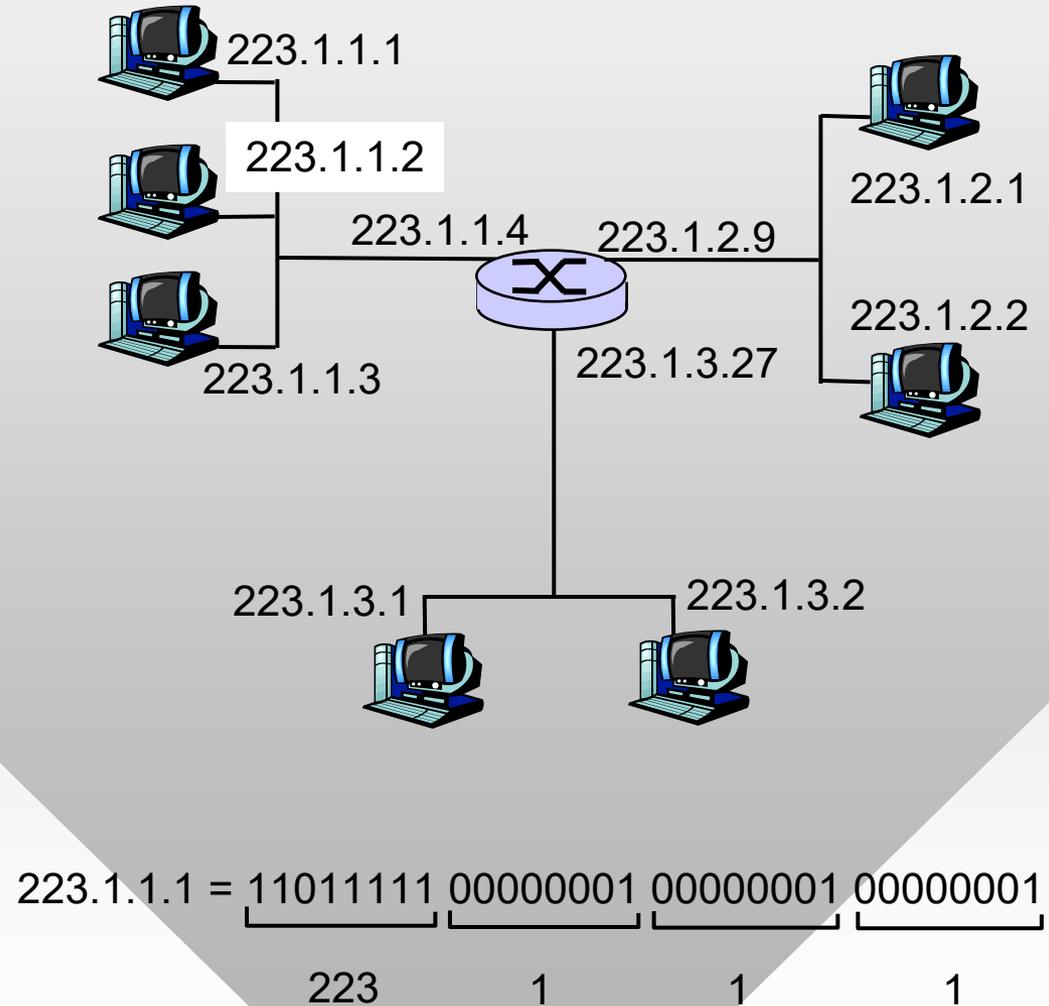
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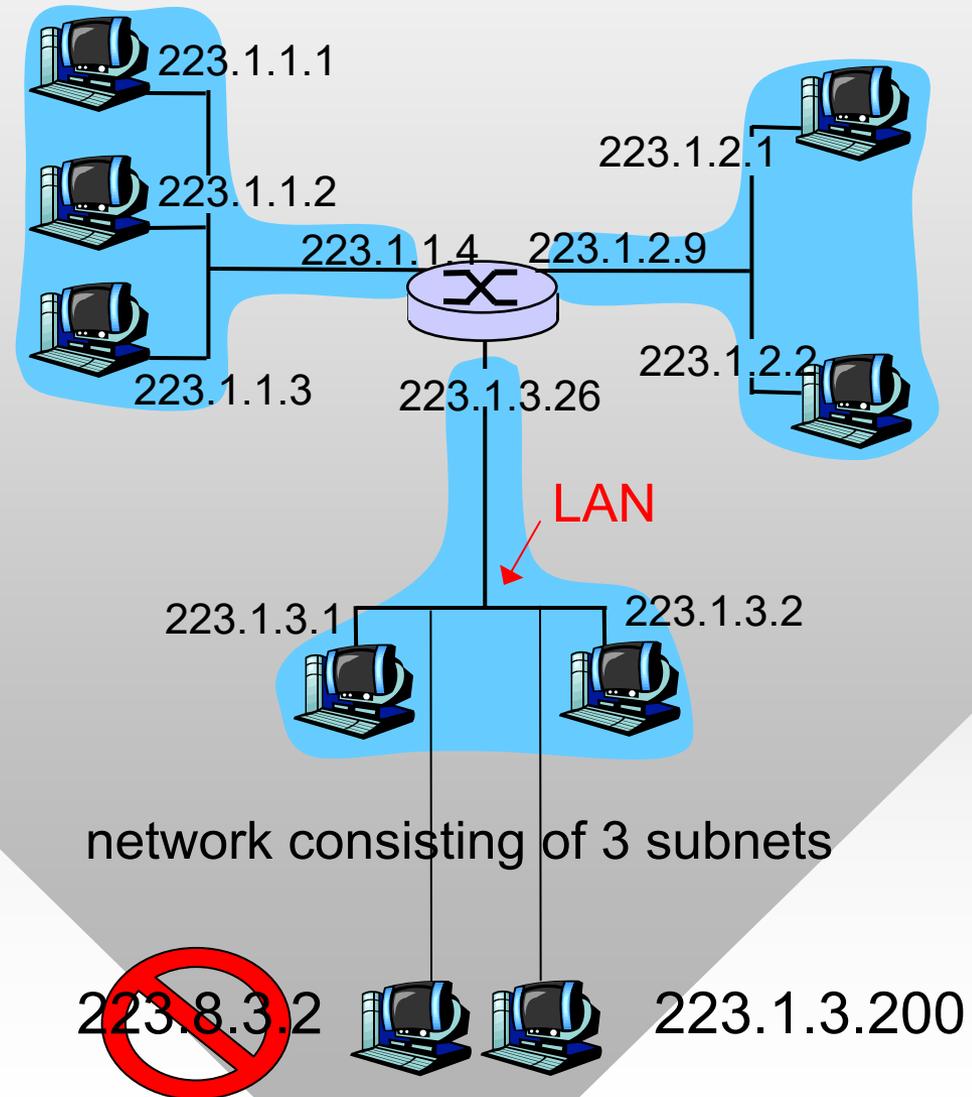
IP Addressing: Introduction

- **IP address:** 32-bit identifier for host or router *interface*
- **Interface:** connection between host/router and physical link
 - Also called a **port**
 - Routers have many interfaces
- Can hosts have multiple interfaces?
 - Yes, it's called **multi-homing**



Subnets

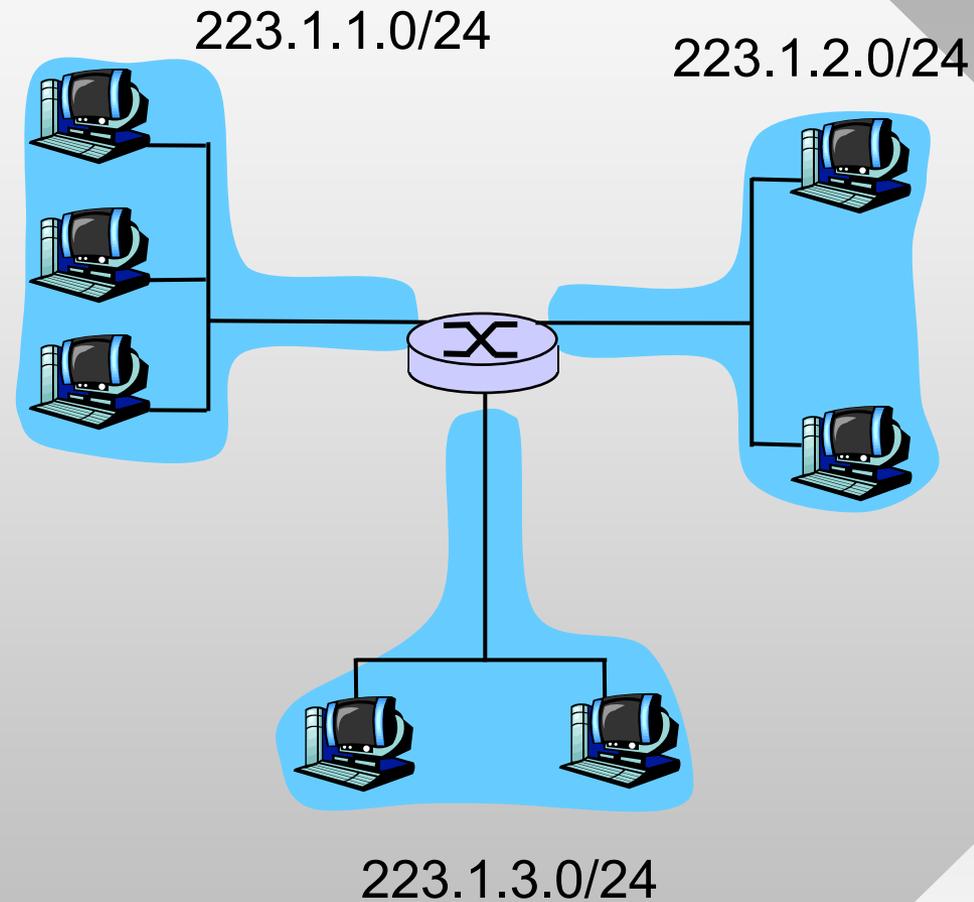
- **IP address:**
 - Subnet prefix: k bits
 - Host suffix: $32-k$ remaining bits
- *What's a subnet (LAN)?*
 - Network composed of devices with the same subnet prefix of IP address
 - Can physically reach each other without intervening router



Subnets

Recipe

- To determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- Each isolated network is a **subnet**

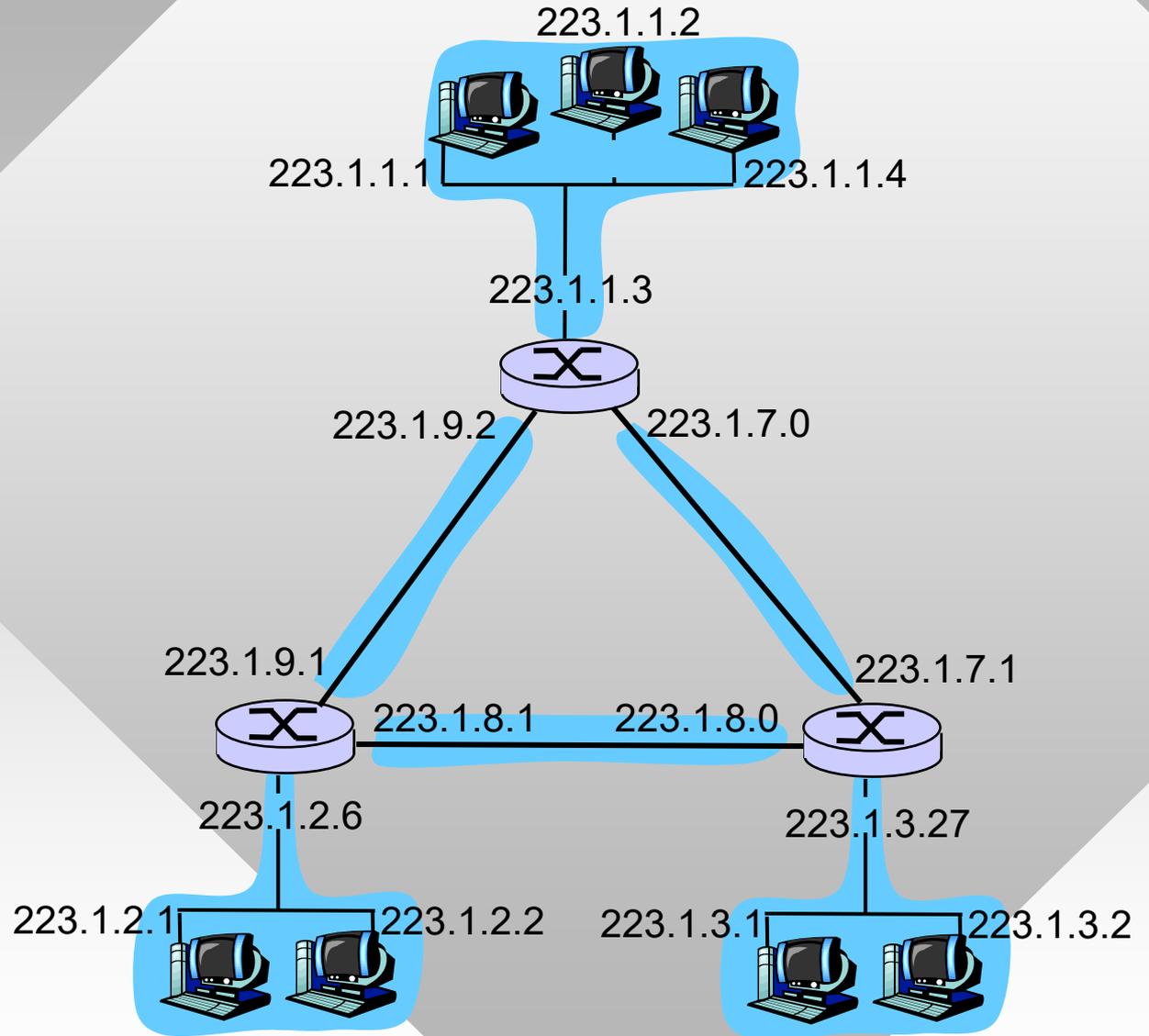


Subnet mask:

- 255.255.255.0
- or /24

Subnets

How many?



IP Addressing: CIDR

- In the early Internet, only subnets with 8, 16, or 24 bit prefixes were allowed (“class A, B, C” networks)
- This was inflexible and wasteful as well

CIDR: Classless InterDomain Routing

- Subnet portion of address of arbitrary length
- Address format: **a.b.c.d/x**, where x is # bits in the subnet portion of address



IP Addresses: How to Get One?

Q: How does a *host* get an IP address?

- Either hard-coded by system admin in a file
 - Windows: Control-panel → network → configuration → tcp/ip → properties
 - Linux: /etc/rc.config
- Or dynamically assigned by **DHCP** (Dynamic Host Configuration Protocol)
 - “Plug-and-play” (more in Chapter 5)

IP Addresses: How to Get One?

Q: How does a *network* get subnet part of IP addr?

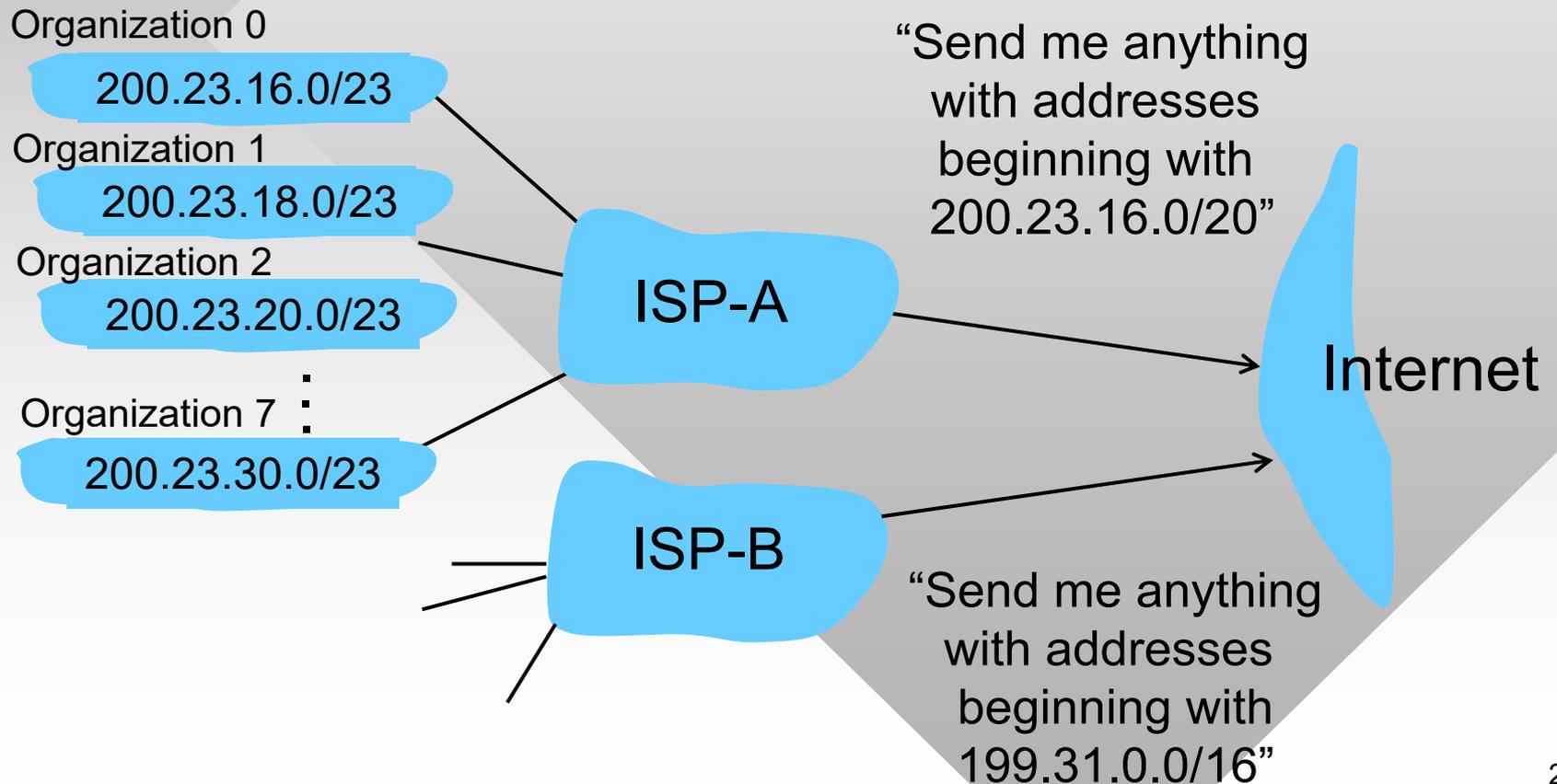
A: Gets allocated portion of its provider ISP's address space

ISP's block	<u>11001000</u>	<u>00010111</u>	<u>00010000</u>	00000000	200.23.16.0/20
Organization 0	<u>11001000</u>	<u>00010111</u>	0001 <u>000</u> 0	00000000	200.23.16.0/23
Organization 1	<u>11001000</u>	<u>00010111</u>	0001 <u>001</u> 0	00000000	200.23.18.0/23
Organization 2	<u>11001000</u>	<u>00010111</u>	0001 <u>010</u> 0	00000000	200.23.20.0/23
...
Organization 7	<u>11001000</u>	<u>00010111</u>	0001 <u>111</u> 0	00000000	200.23.30.0/23

- **Task:** split this ISP into one /21, three /23, and eight /26

Hierarchical Addressing: Route Aggregation

Hierarchical addressing allows efficient advertisement of routing information:



Hierarchical Addressing: More Specific Routes

ISP-B has a more specific route to Organization 1

Organization 0

200.23.16.0/23

Organization 2

200.23.20.0/23

Organization 7 :

200.23.30.0/23

Organization 1

200.23.18.0/23

ISP-A

ISP-B

Internet

“Send me anything
in 200.23.16.0/20”

“Send me anything
in 199.31.0.0/16
or 200.23.18.0/23”

IP Addressing: Last Word...

Q: How does an ISP get a block of addresses?

A: **ICANN**: Internet Corporation for Assigned Names and Numbers assigns IPs to regional registries

- These are ARIN (North/South America), RIPE (Europe), APNIC (Asia-Pacific), and AfriNIC (Africa)
- These registries process ISP and user requests for subnet space
 - Also manage DNS and resolve disputes
- Quiz #3 covers
 - Chapter 3: P7-9, 22-24, 26-28, 31-37, 40-41, 43-49
 - Chapter 4: P1-17 (including today's lecture)