CSCE 463/612
Networks and Distributed Processing
Fall 2020

Network Layer II

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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
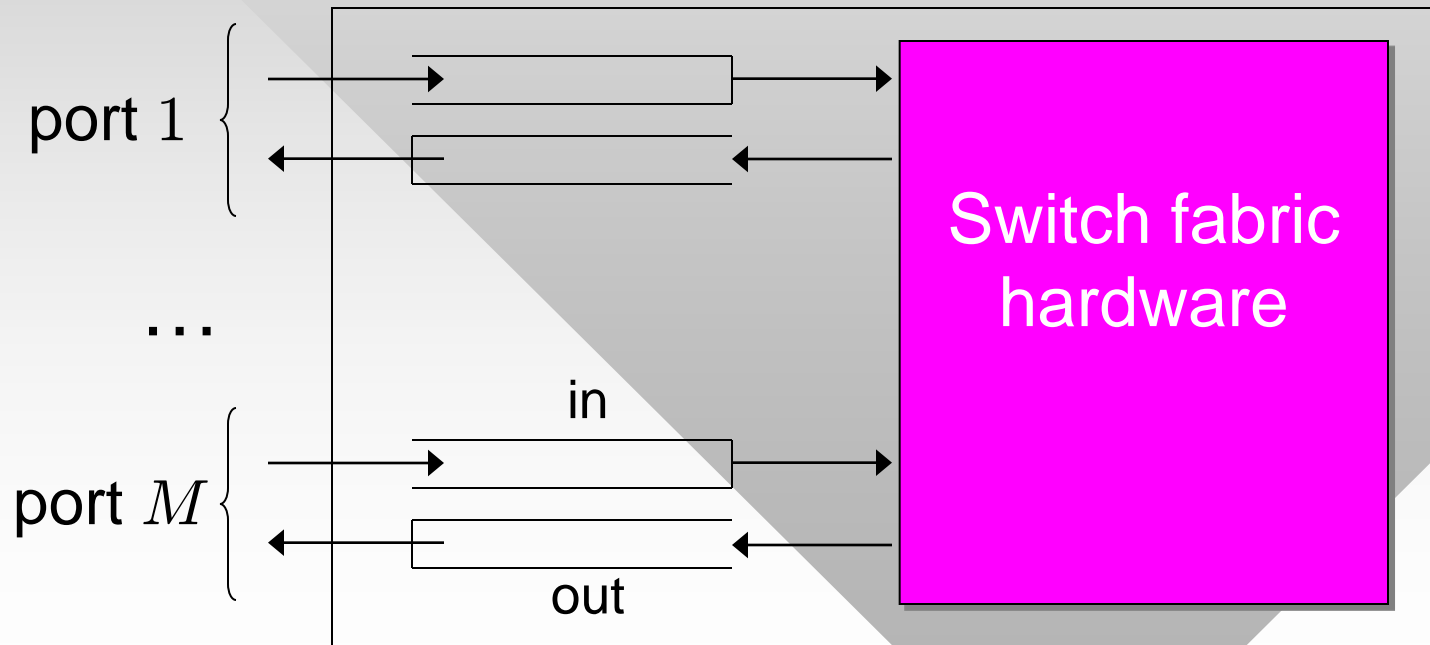
4.5 Routing algorithms

4.6 Routing in the Internet
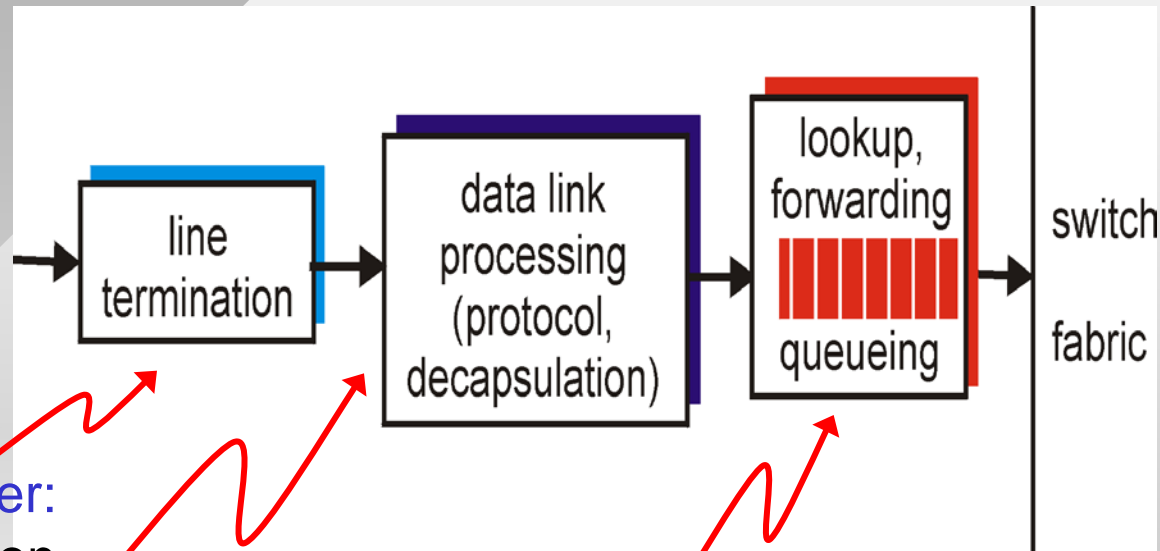
4.7 Broadcast and multicast routing

Router Architecture Overview

Two key router functions:

- Run routing algorithms/protocol (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"

- Queuing: if datagrams arrive faster than forwarding rate into switch fabric

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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) →
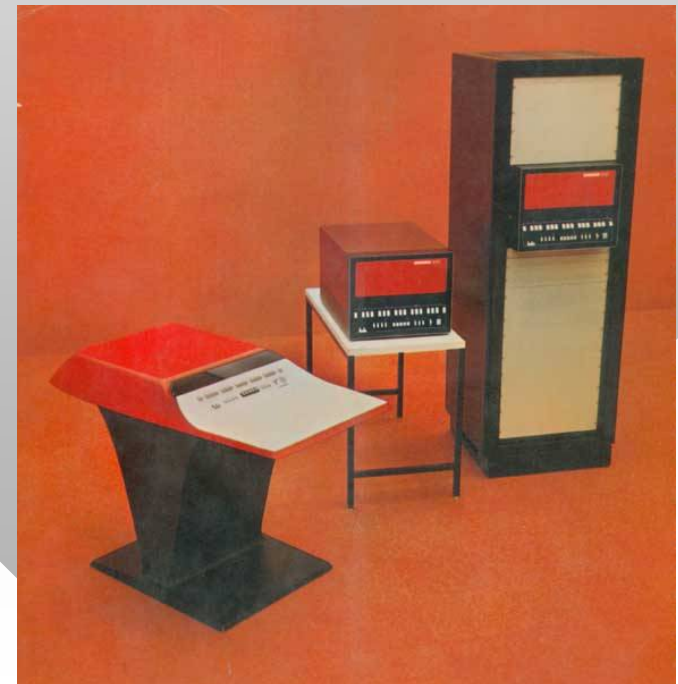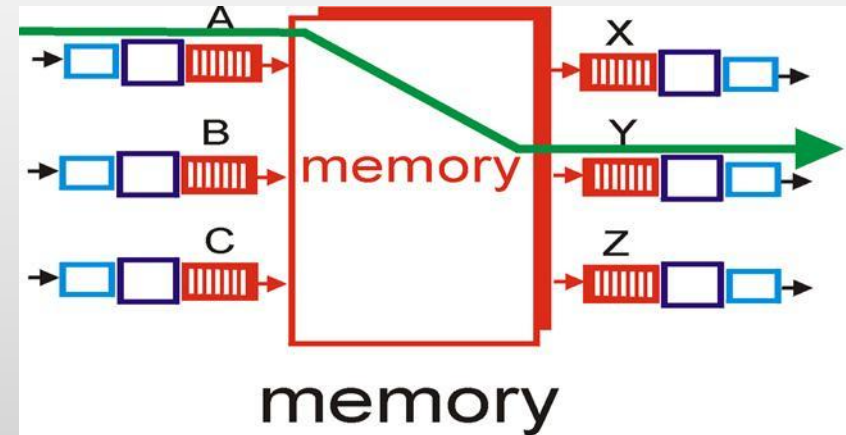
# Switching Via a Bus

- 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)
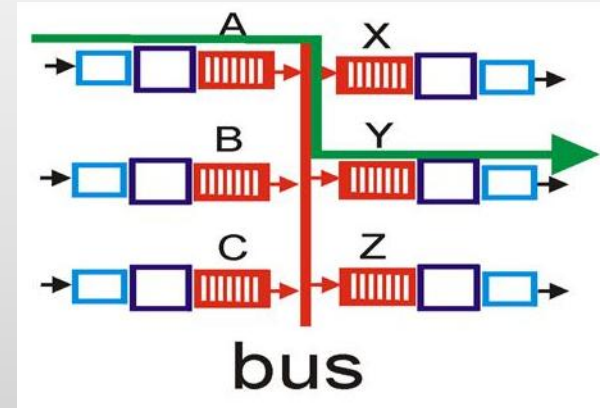
Switching Via An Interconnection Network

- 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
  - CSR-X (2013): 1600 lbs, 84" rack, 7.6 KWatt, 800 Gbps/slot
  - 16 slots/rack = 12.8 Tbps
  - Up to 72 racks (922 Tbps)
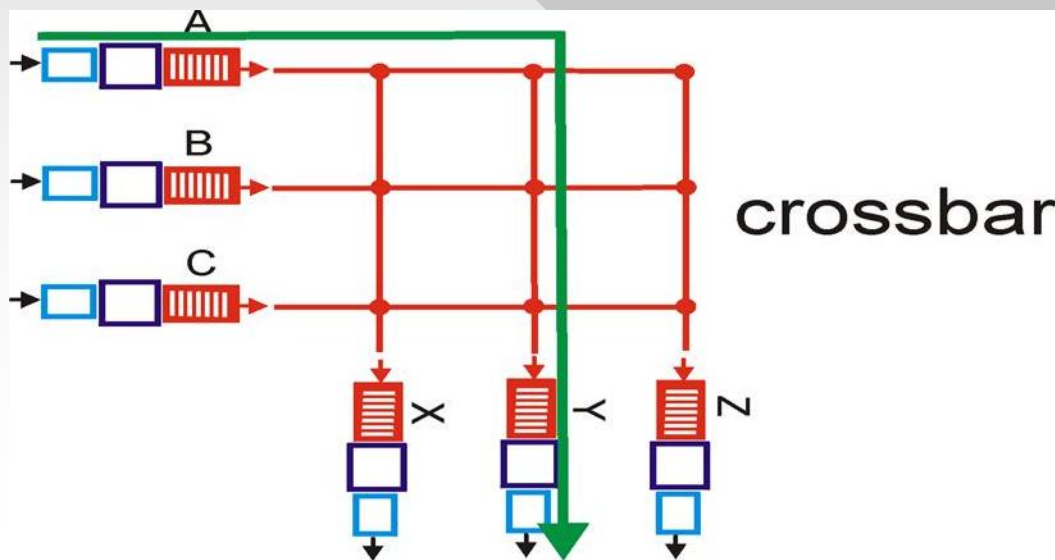
Output Ports
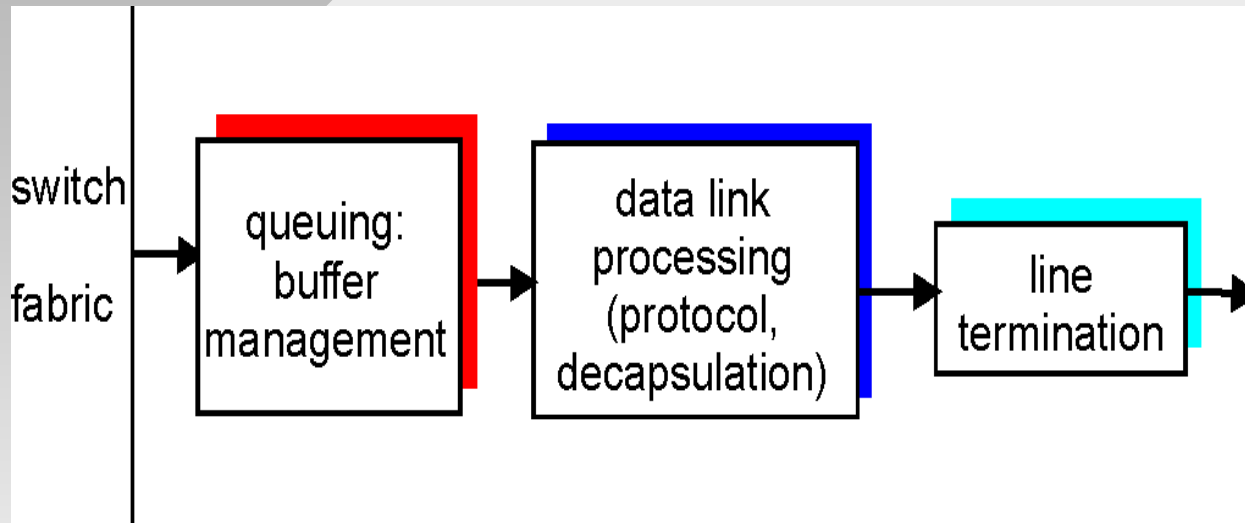
- *Buffering/queuing* required when datagrams arrive from fabric faster than the transmission rate
- *Scheduling discipline* chooses among queued datagrams for transmission
  - Customer traffic: single FIFO drop-tail queue
  - ISP traffic: multiple queues with WRR or priority queuing

Output Port Queuing

time t　　　　　　　　time $t+3$ ← time units of switch fabric
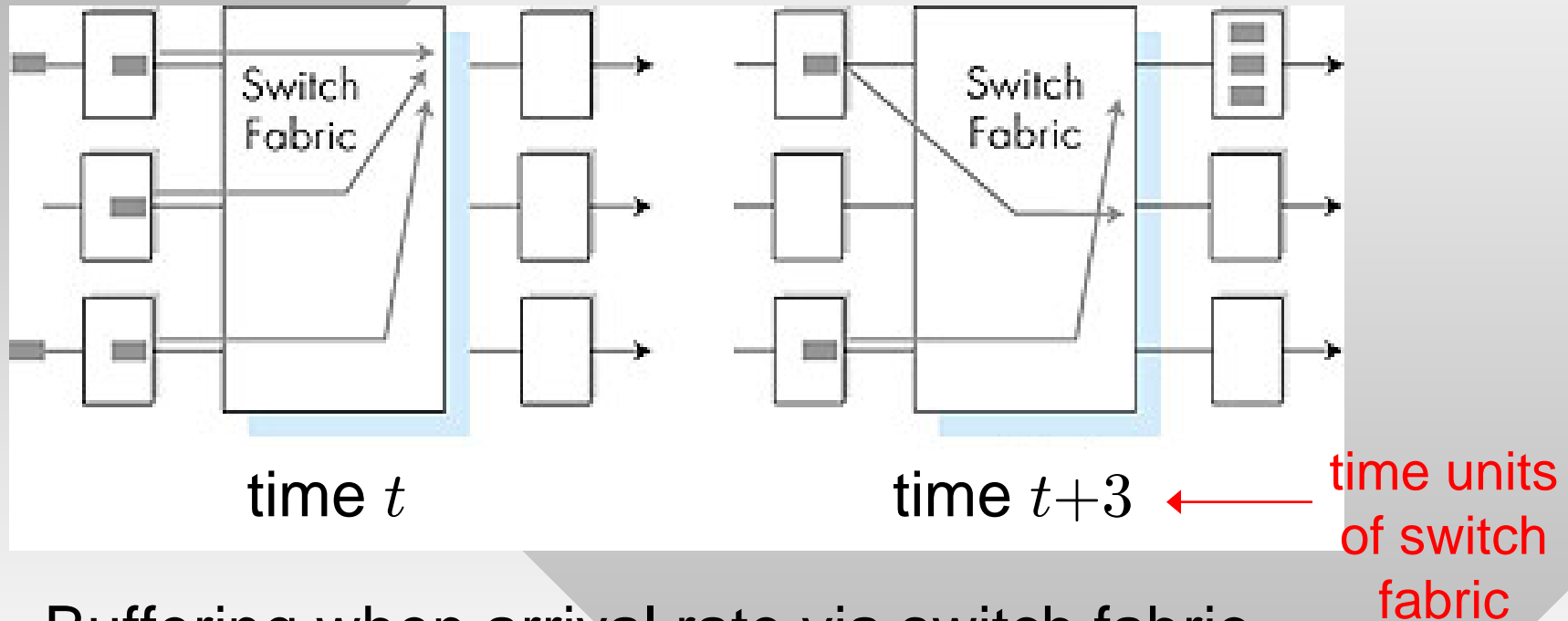
- Buffering when arrival rate via switch fabric exceeds output line speed
  - Queuing delay and loss due to output buffer overflow
- Switch fabric is M times faster than individual ports
  - Produces large bursts of arrivals into output queues

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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

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

green packet experiences HOL blocking

time t time $t{+}1$
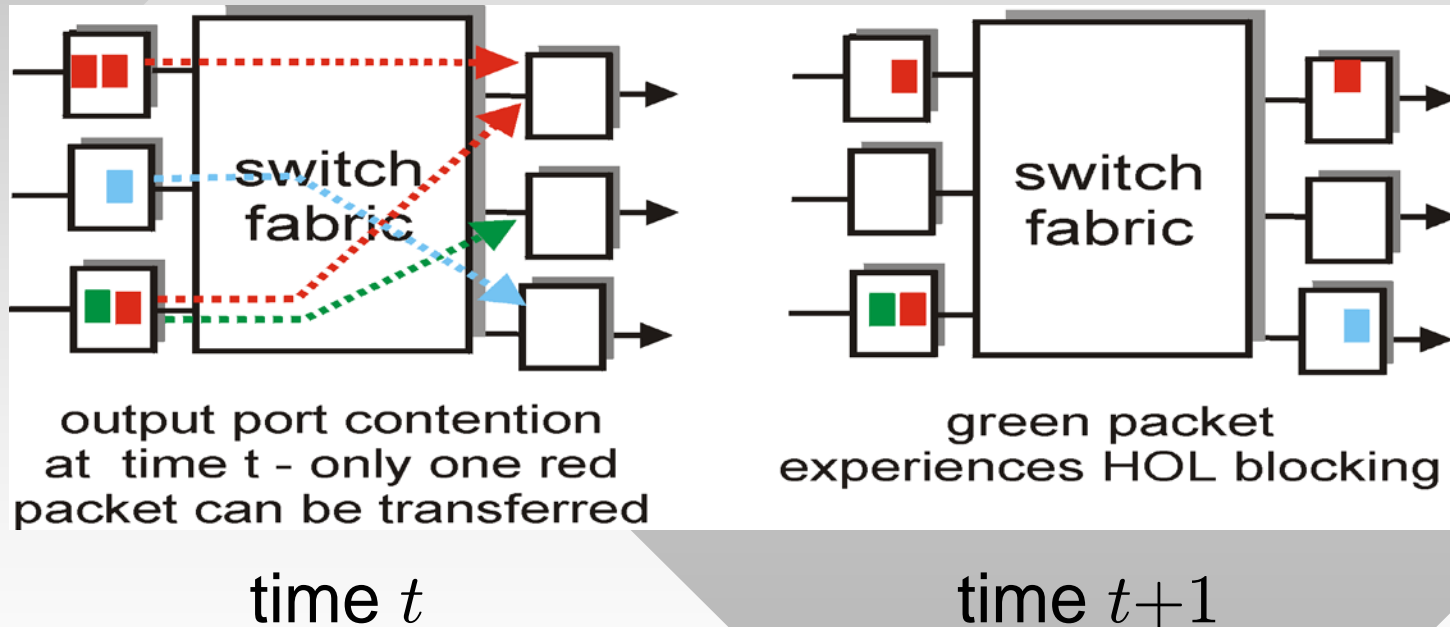
- Queuing delay and loss due to input buffer overflow!
  - How likely is this compared to output port queuing/loss?

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The Internet Network Layer

Host and router network layer functions:

Network layer

Transport layer: TCP, UDP	

Routing protocols
- Path selection
- RIP, OSPF, BGP

IP protocol
- Datagram format
- Addressing conventions

forwarding table

IGMP protocol
- Multicast

ICMP protocol
- Error reporting
- Ping, traceroute

Link layer

Physical layer

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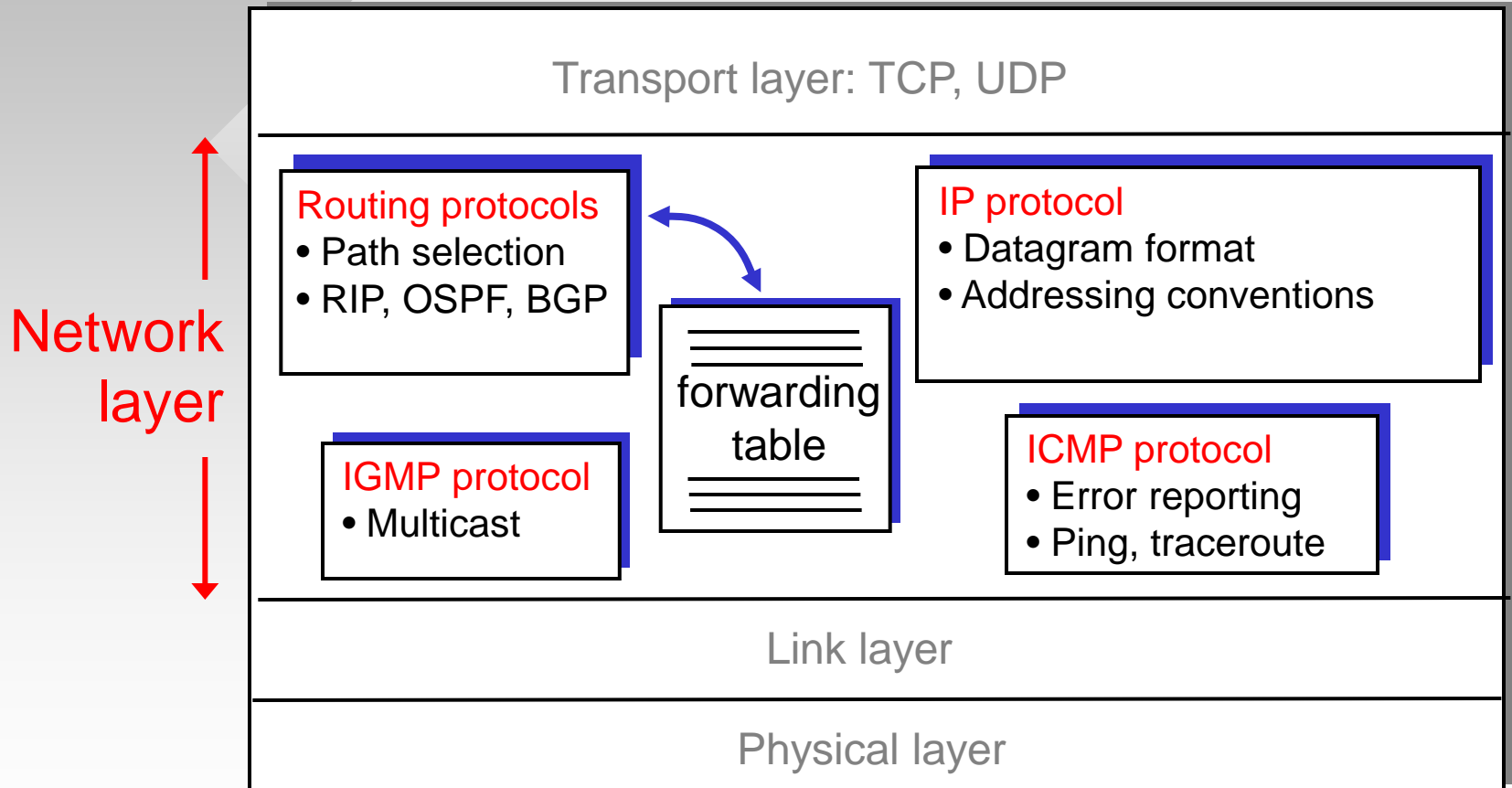
4.3 What's inside a router

4.4 IP: Internet Protocol
- Datagram format
- IPv4 addressing
- ICMP
- IPv6

4.5 Routing algorithms

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IP Datagram Format
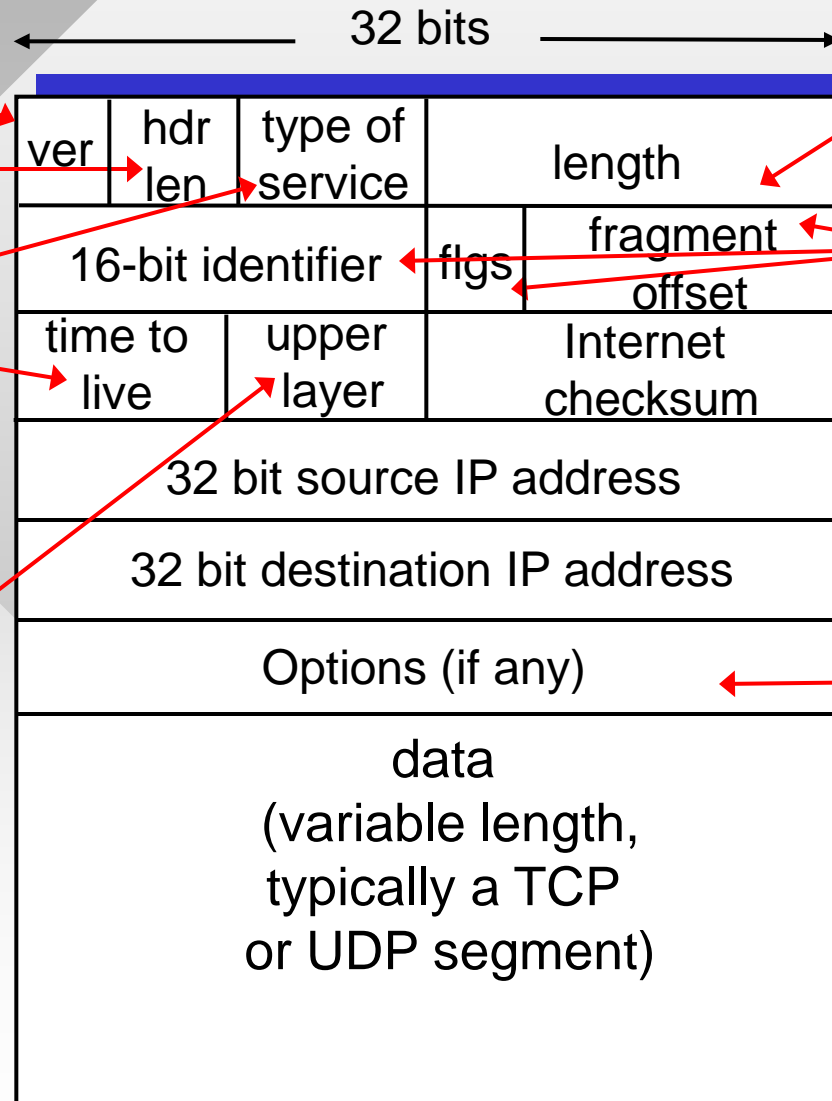
IP protocol version number

Header length (in 4-byte words)

QoS requested

Max number remaining hops (decremented at each router)

Upper layer protocol to deliver payload to

Total datagram length (bytes)

For fragmentation/reassembly

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

32 bits

ver	hdr len	type of service	length	
time to live	upper layer		Internet checksum	
16-bit identifier		flgs	fragment offset	

32 bit source IP address

32 bit destination IP address

Options (if any)

data
(variable length,
typically a TCP
or UDP segment)

How much overhead with TCP?

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

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
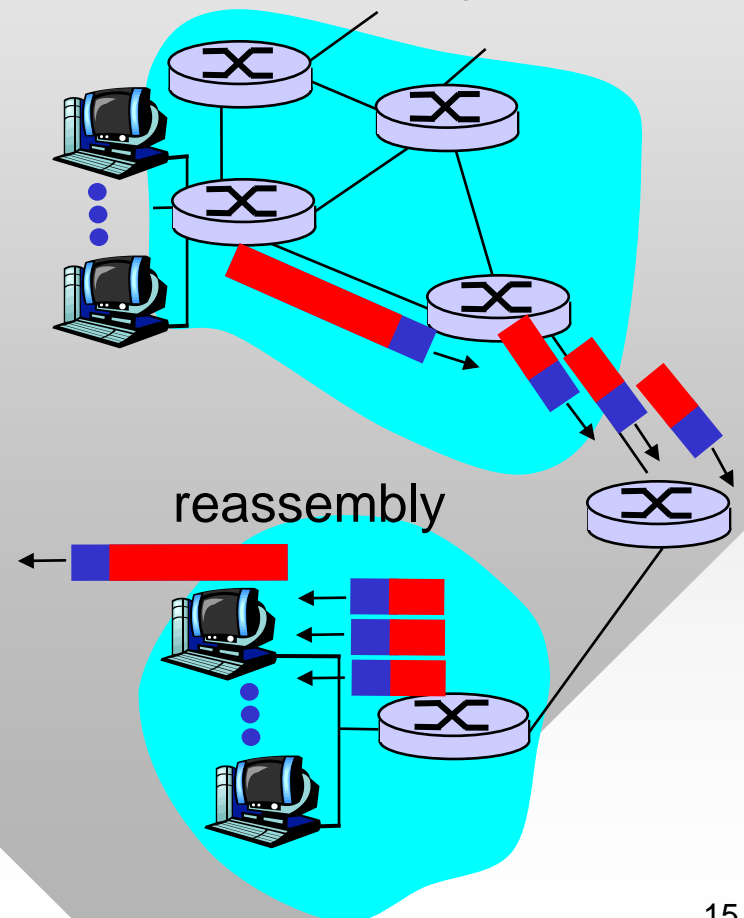
reassembly

IP Fragmentation and Reassembly

Example

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

1480 bytes in payload

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

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

One large datagram becomes several smaller datagrams

| | 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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- Datagram format
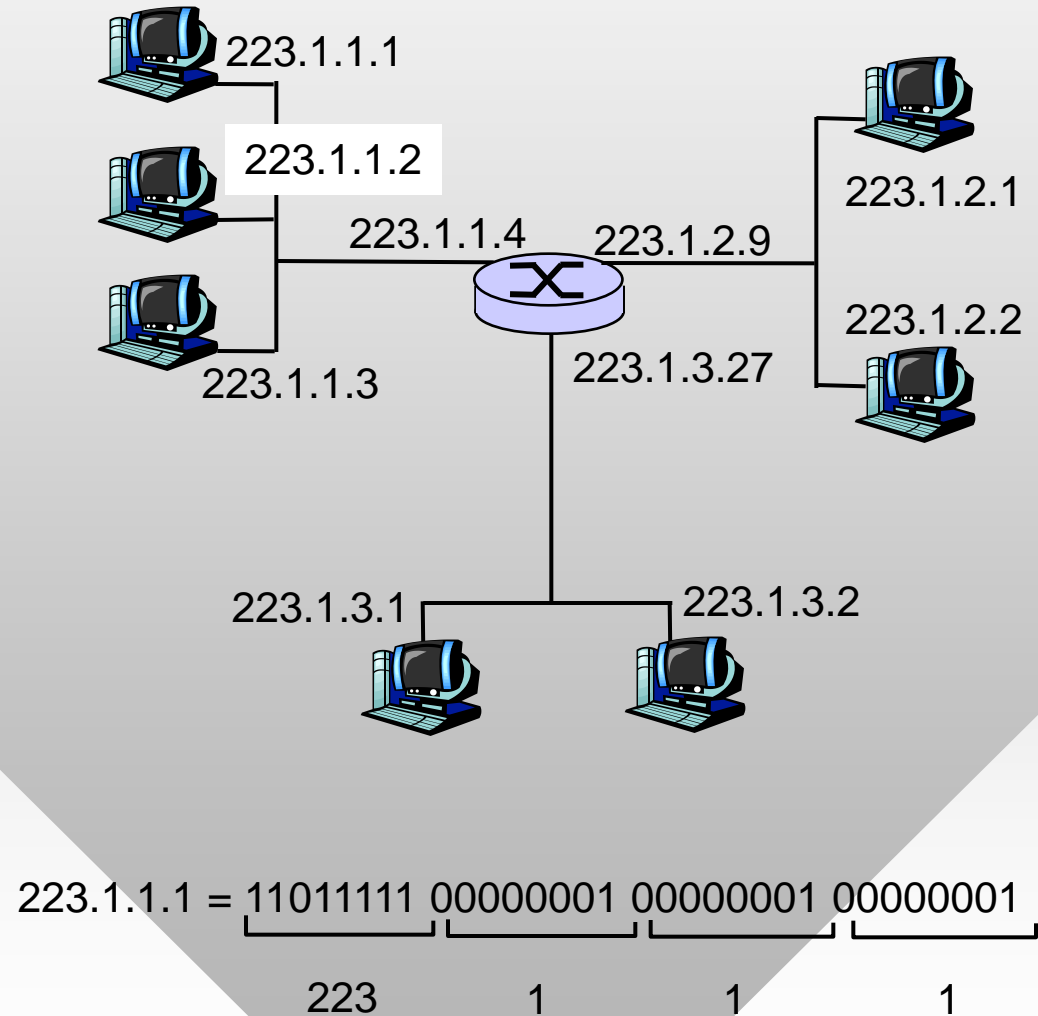- IPv4 addressing
- ICMP
- IPv6

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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

223.1.1.1

223.1.1.2

223.1.1.4   223.1.2.9   223.1.2.1

223.1.1.3   223.1.3.27   223.1.2.2

223.1.3.1   223.1.3.2

223.1.1.1 = 11011111 00000001 00000001 00000001

223   1   1   1

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Subnets

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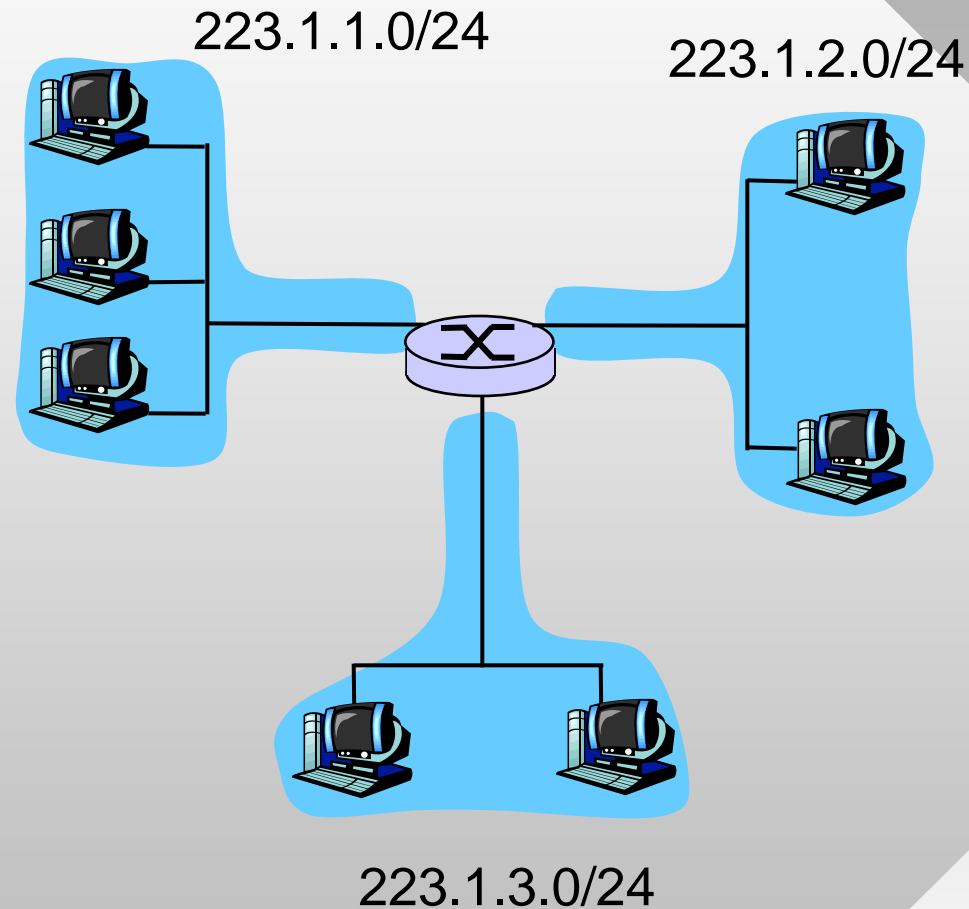- *What's a subnet (LAN)?*
  - Network composed of devices with the same subnet prefix of IP address
  - Can physically reach each other without intervening router

network consisting of 3 subnets
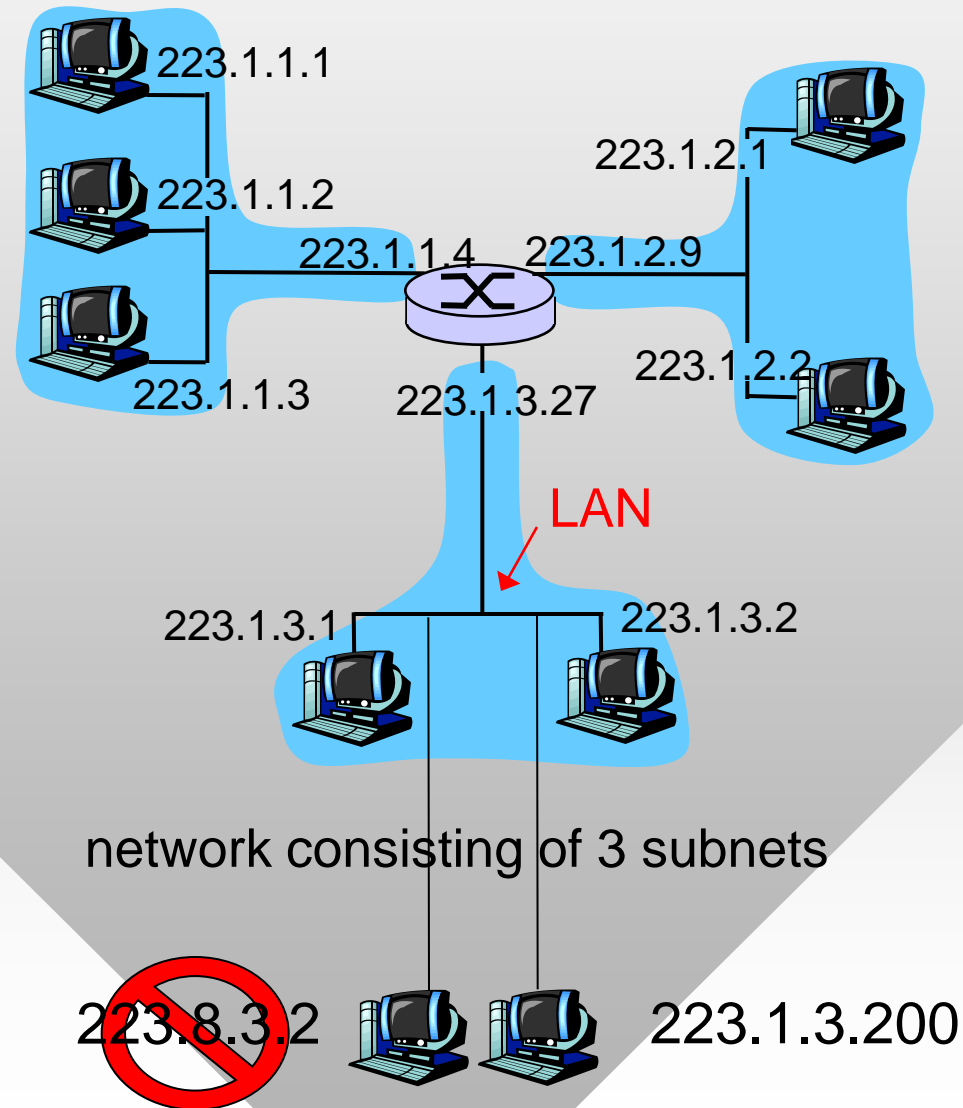
Subnets

Recipe

- To determine the subnets, detach each interface from its host or router, creating islands of isolated networks

- Each isolated network is a subnet

223.1.1.0/24

223.1.2.0/24

223.1.3.0/24

Subnet mask:
- 255.255.255.0
- or /24

Subnets

How many?

223.1.1.2

223.1.1.1   223.1.1.4

223.1.1.3

223.1.9.2   223.1.7.0

223.1.9.1   223.1.7.1

223.1.8.1   223.1.8.0

223.1.2.6   223.1.3.27

223.1.2.1   223.1.2.2   223.1.3.1   223.1.3.2
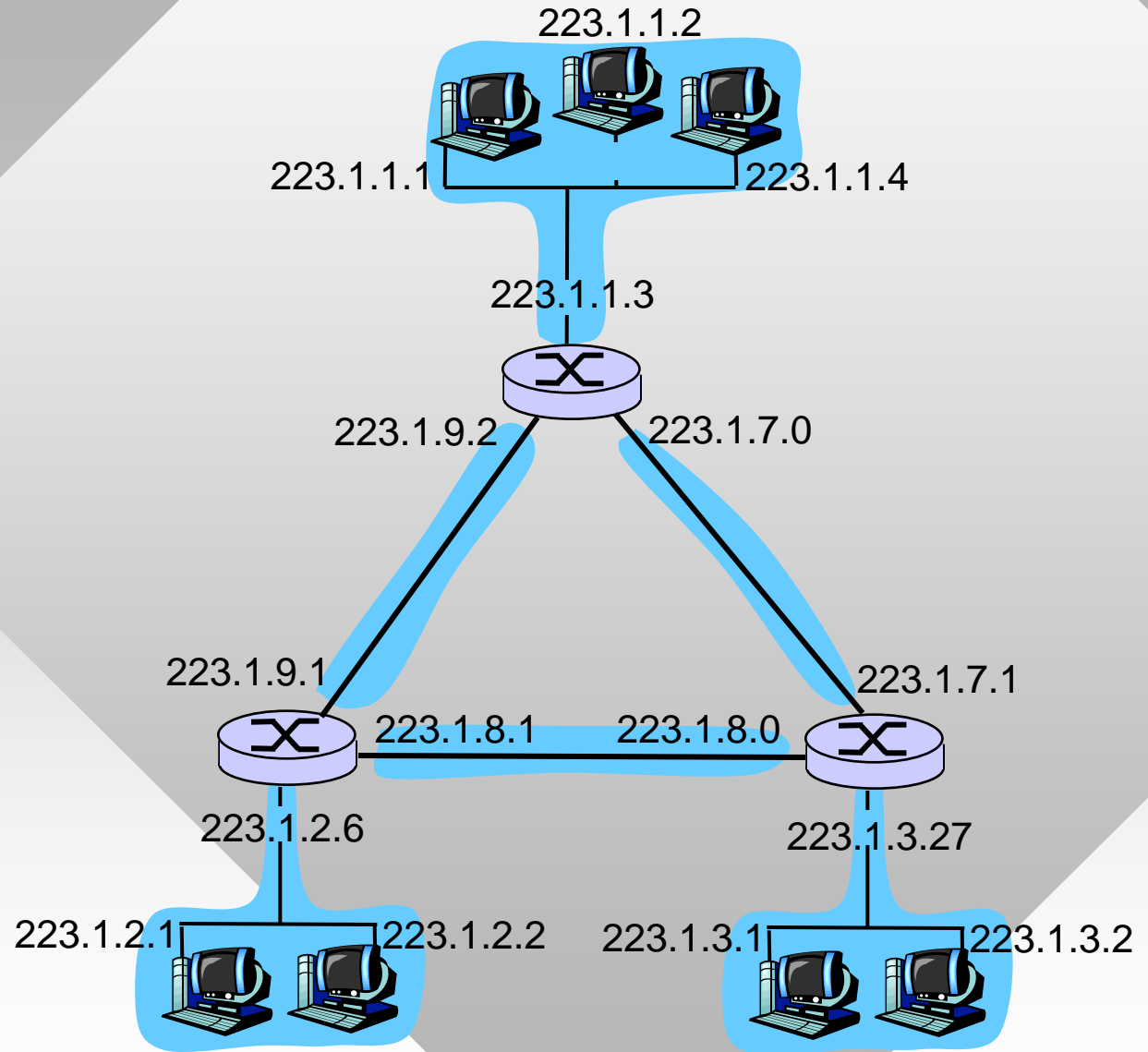
IP Addressing: CIDR

- 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

subnet part   host part

11001000 00010111 00010000 00000000

200.23.16.0/23
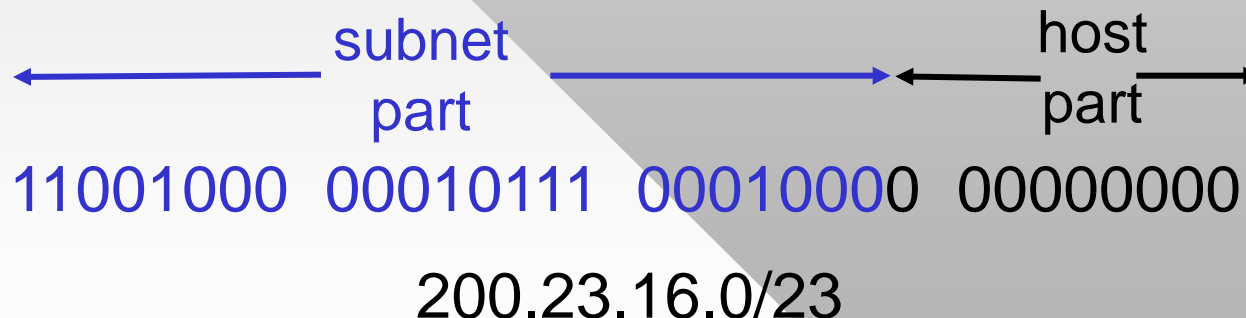
IP Addresses: How to Get One?

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?

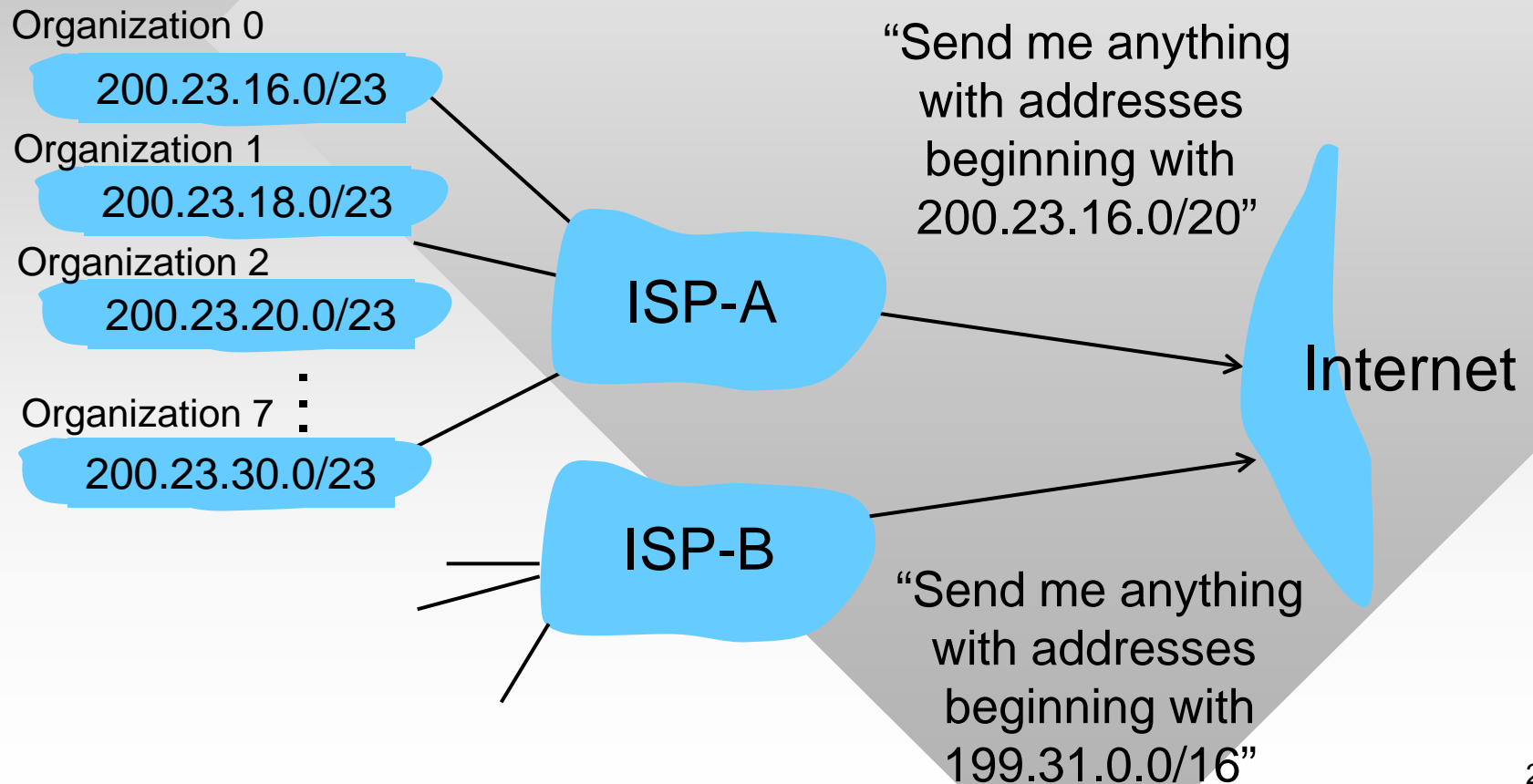Q: How does a *network* get subnet part of IP addr?

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

ISP's block	11001000 00010111 00010000 00000000	200.23.16.0/20
Organization 0	11001000 00010111 0001000<u>0</u> 00000000	200.23.16.0/23
Organization 1	11001000 00010111 0001001<u>0</u> 00000000	200.23.18.0/23
Organization 2	11001000 00010111 0001010<u>0</u> 00000000	200.23.20.0/23
...	…..	…. ….
Organization 7	11001000 00010111 0001111<u>0</u> 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:

Organization 0
200.23.16.0/23

Organization 1
200.23.18.0/23

Organization 2
200.23.20.0/23

⋮

Organization 7
200.23.30.0/23

ISP-A

ISP-B

"Send me anything with addresses beginning with 200.23.16.0/20"

Internet

"Send me anything with addresses beginning with 199.31.0.0/16"

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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

"Send me anything
in 200.23.16.0/20"

Internet

"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)