Network layer: Overview
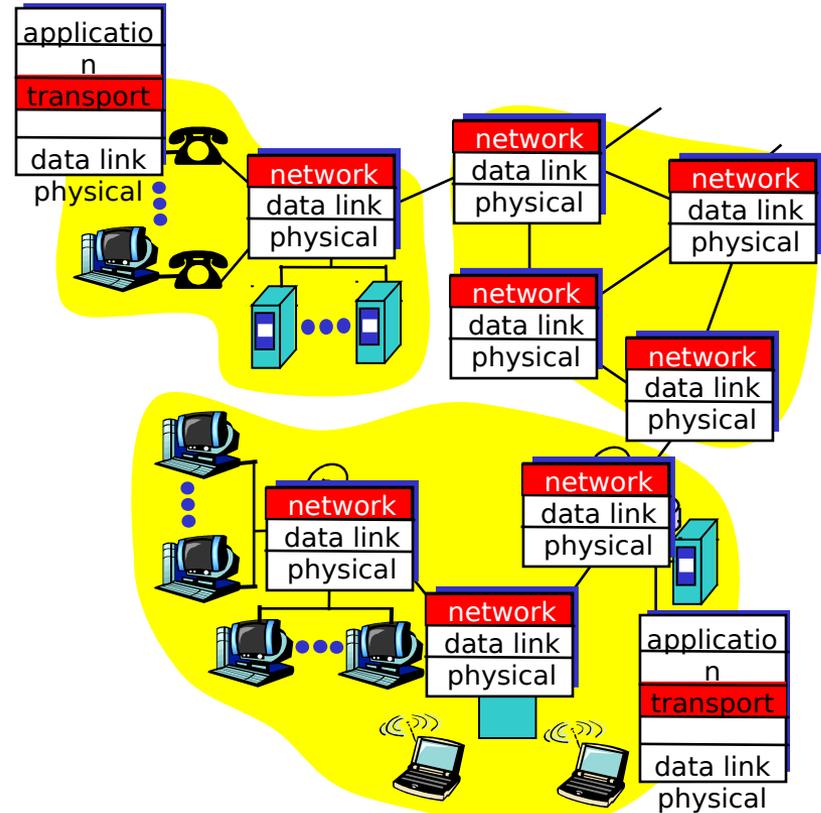
- ❐ Network layer functions
- ❐ IP
- ❐ Routing and forwarding

Network layer functions

- Transport packet from sending to receiving hosts
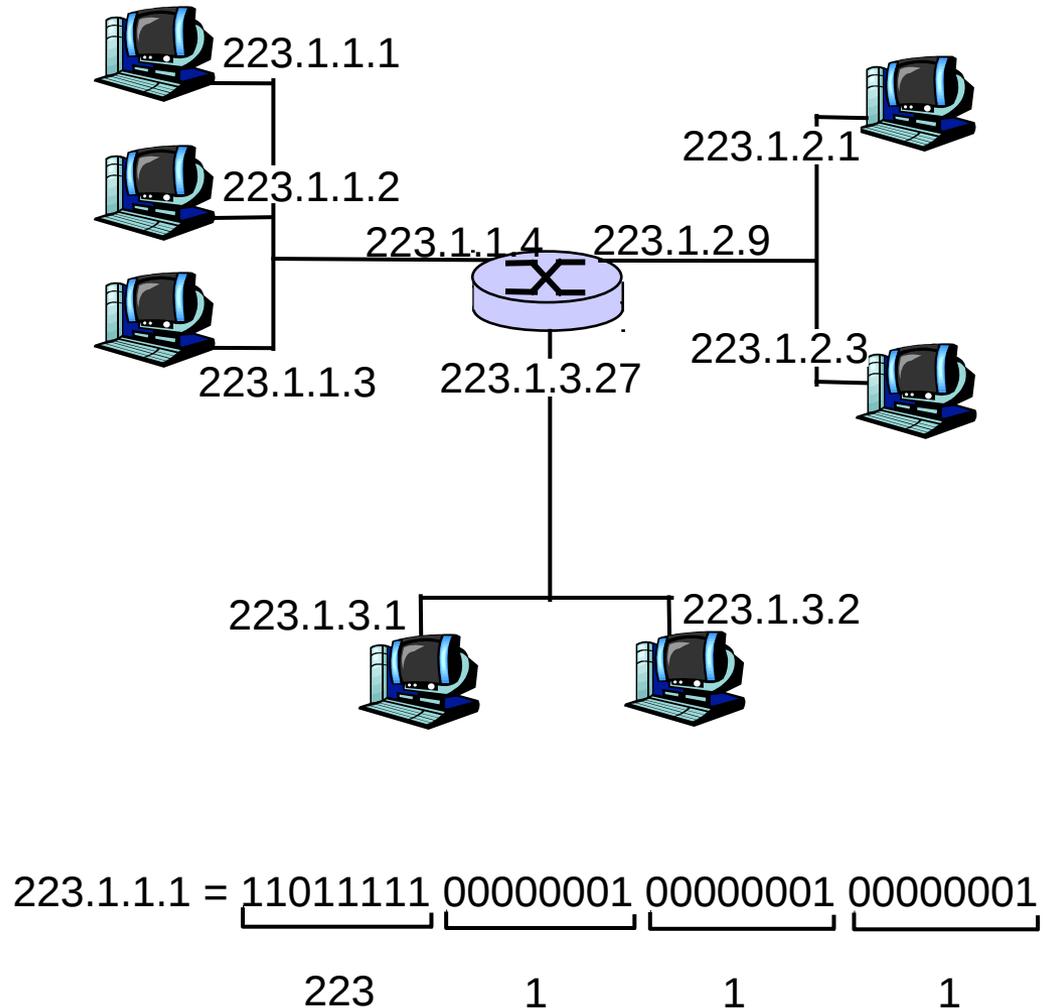- Network layer protocols in *every* host, router

Three important functions:

- *Path determination:* route taken by packets from source to dest. *Routing algorithms*
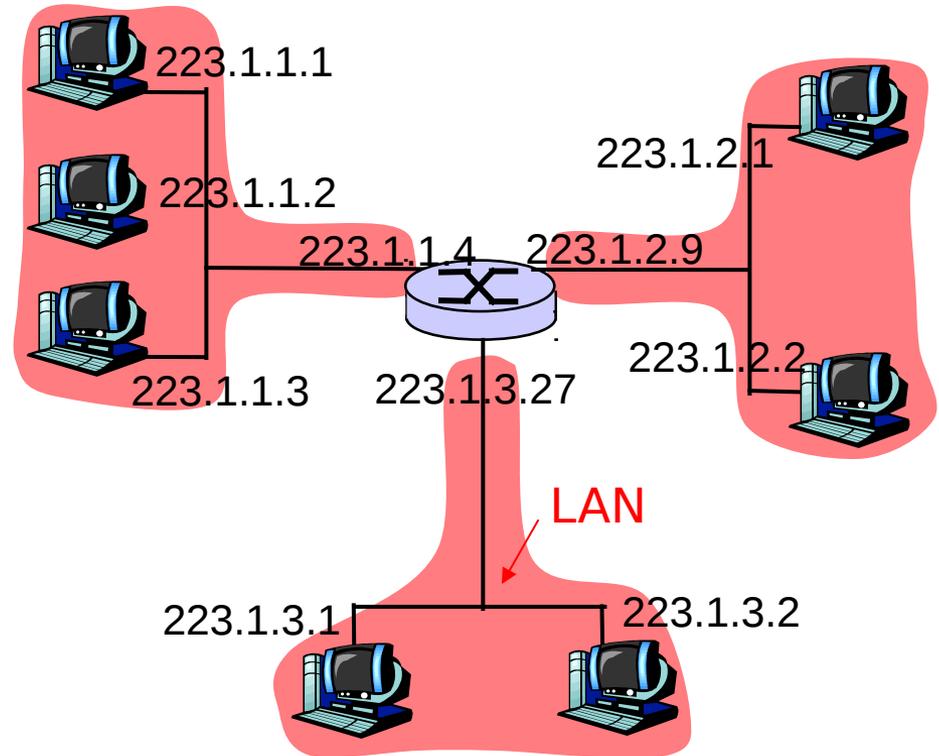- *Switching:* move packets from router's input to appropriate router output

IP addressing

- ❐ IP address: 32-bit identifier for host, router *interface*
- ❐ *Interface:* connection between host, router and physical link
  - ○ Routers typically have multiple interfaces
  - ○ Host may have multiple interfaces
  - ○ IP addresses associated with interface, not host, router

223.1.1.1

223.1.1.2

223.1.1.4   223.1.2.9

223.1.1.3   223.1.3.27

223.1.2.1

223.1.2.3

223.1.3.1   223.1.3.2

223.1.1.1 = 11011111 00000001 00000001 00000001

          223   1   1   1

IP addressing (2)

- IP address:
  - Network part (high order bits)
  - Host part (low order bits)
- *What's a network?* (from IP address perspective)
  - Device interfaces with same network part of IP address
  - Can physically reach each other without intervening router

223.1.1.1

223.1.1.2

223.1.1.4   223.1.2.9

223.1.1.3   223.1.3.27

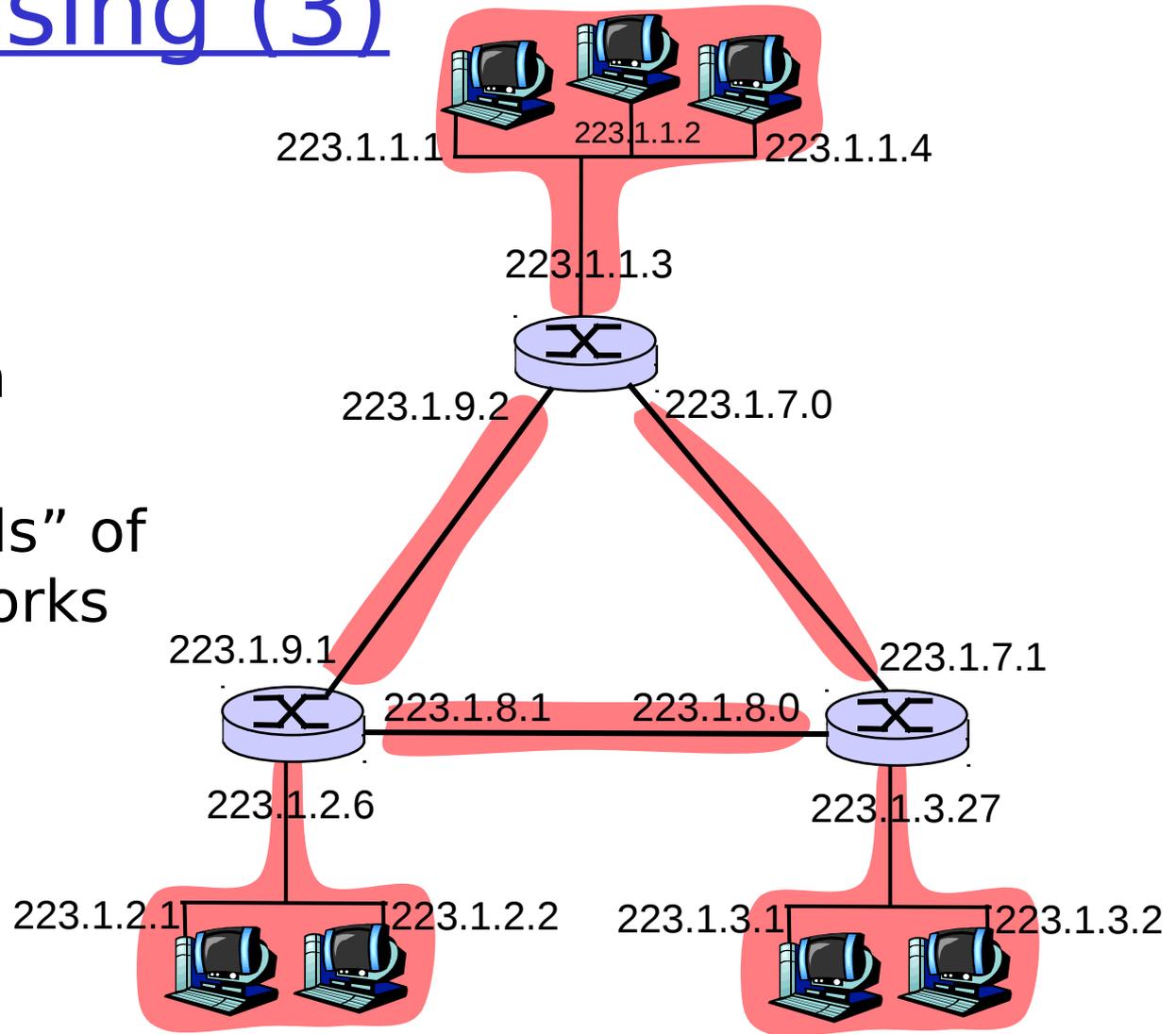223.1.2.1

223.1.2.2

LAN

223.1.3.1   223.1.3.2

network consisting of 3 IP networks (for IP addresses starting with 223, first 24 bits are network address)
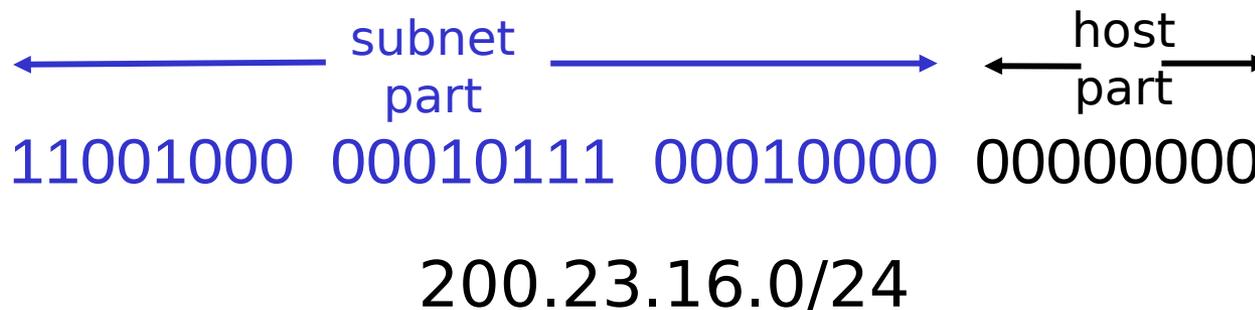
IP addressing (3)

How to find the networks?

- Detach each interface from router, host
- Create "islands" of isolated networks

Interconnected system consisting of six networks

223.1.1.1
223.1.1.2
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

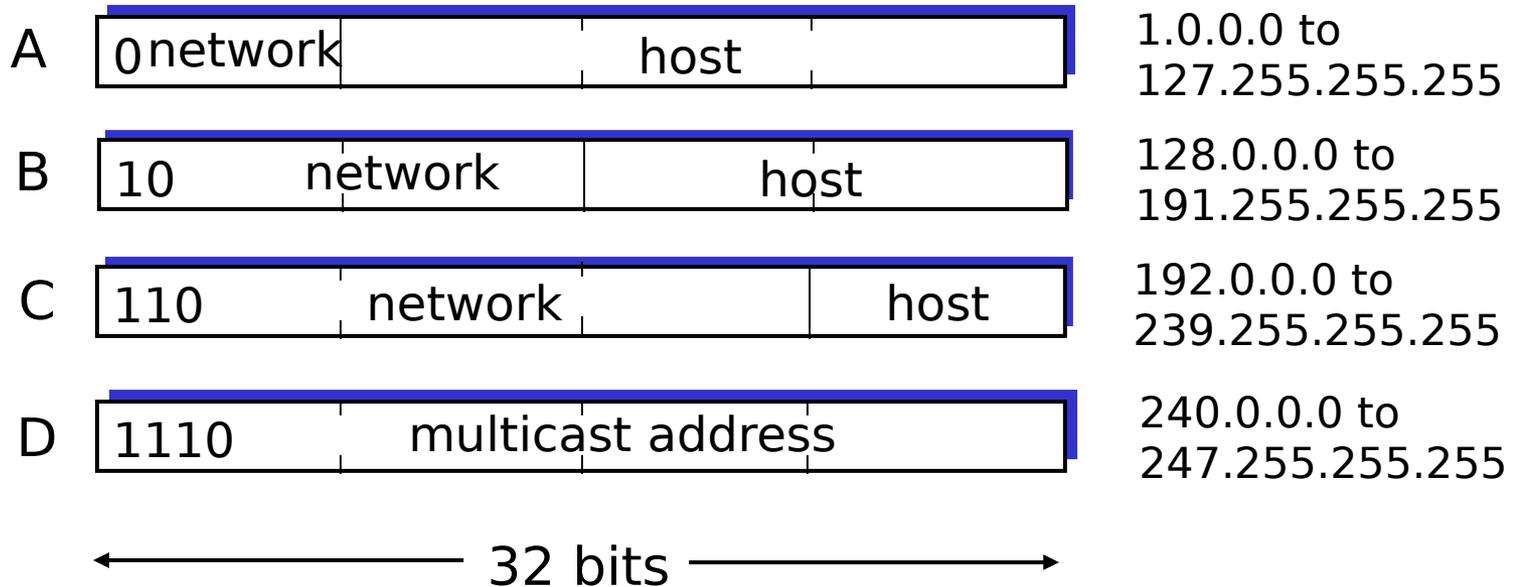# IP networks: Subnets

- Sub divide address space
    - Network part
    - Host address
- Address format: a.b.c.d/x, where x is # bits in subnet portion of address

subnet part   host part

11001000 00010111 00010000 00000000

200.23.16.0/24

Fixed subnetting (classful)

class

A	0 network	host	1.0.0.0 to 127.255.255.255
B	10 network	host	128.0.0.0 to 191.255.255.255
C	110 network	host	192.0.0.0 to 239.255.255.255
D	1110	multicast address	240.0.0.0 to 247.255.255.255

←——————— 32 bits ———————→

Address management

□ Problem: we are running out of networks

□ Solution

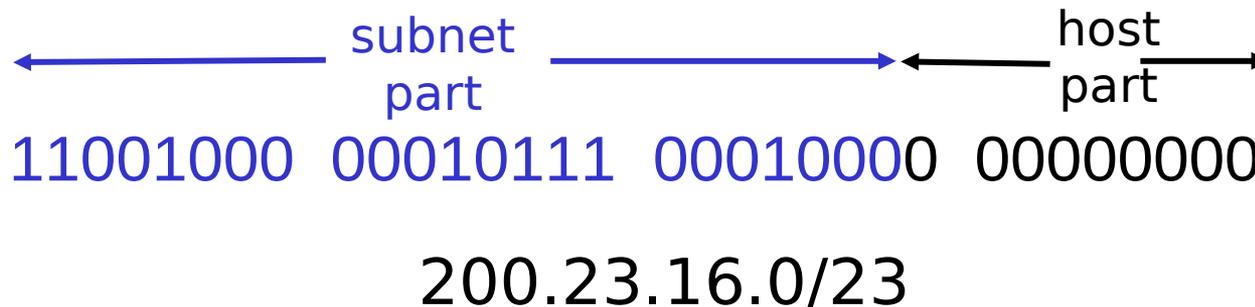   ○ **Subnetting**

    ○ **CIDR** (Classless Inter Domain Routing)

CIDR

- Classless InterDomain Routing
- Class A is too large, Class C is too small
- Everyone has a Class B address!!!

- Solution: sites are given contiguous blocks of class-C addresses (256 addresses each) and a mask or parts of former class A/B networks.

CIDR

CIDR: Classless InterDomain Routing

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

```
      ◄─────────── subnet ──────────► ◄─ host ─►
                    part                  part
      11001000  00010111  00010000  00000000
```

200.23.16.0/23

Hierarchical address structure

- Recall: CIDR

18 relevant bits

128.119.48.12/18 = 10000000 01110111 00110000 00001100

- High order bits form the **prefix**
- Once inside the network, can **subnet**: divide remaining bits
- Subnet example:

129.160.0.0/12

129.128.0.0/10

129.176.0.0/14

129.188.0.0/14
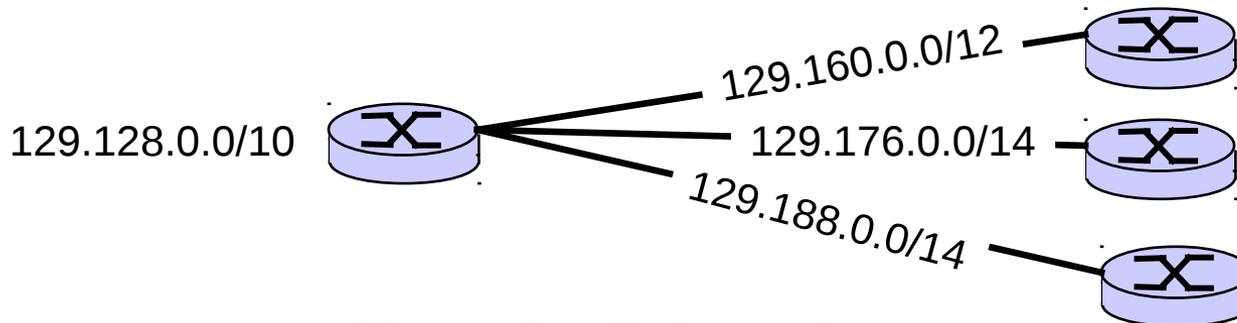
Note: Picture shows prefix masks, not interface addrs!

- **Forwarding decision: longest prefix match**

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IPv6 Motivation and History

- IPv4 address space is 32 bit
  - quite limited
- IPv4 was designed in the 1970ies
  - some requirements changed

Timeline:

1992 IETF begins discussion about IPv4 successor

1995 First IPv6 RFCs published

2000 50% of IPv4 address space assigned

2007 All major OS have IPv6 enabled by default

2011 IANA IPv4 assigned last IPv4 block
World IPv6 Day – Major sites test IPv6 for a day

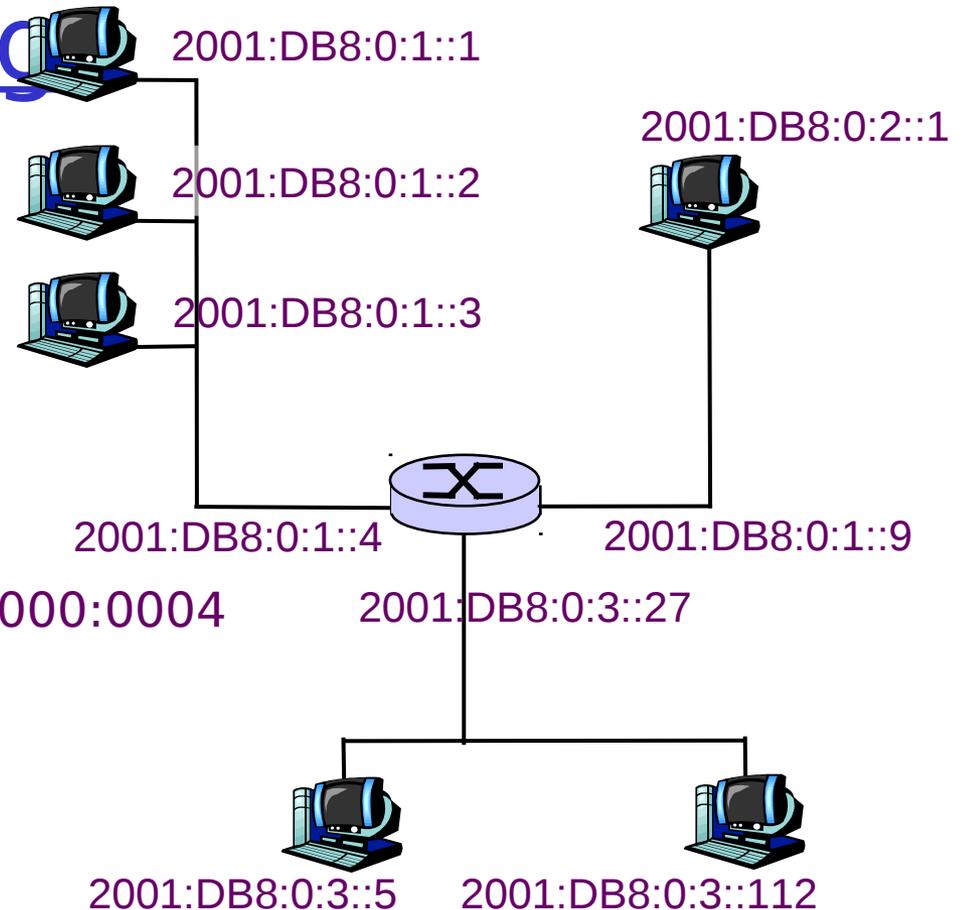2012 World IPv6 Launch Day – Major sites enable IPv6

IPv6 Addressing

- ❐ IP address: Identifier for host or router *interface*
- ❐ IPv6 address: 128bit written as 8x 16bit in hex
  - ○ Hextets are separated by colons

2001:0DB8:0000:0001:0000:0000:0000:0004

  - ○ Leading zeros can be left out
  - ○ Multiple "empty" (all zero) hextets can be abbreviated by a double-colon at one position

    shortening multiple times would lead to ambiguous addresses

2001:DB8:0:1::1

2001:DB8:0:1::2

2001:DB8:0:1::3

2001:DB8:0:2::1

2001:DB8:0:1::4   2001:DB8:0:1::9

2001:DB8:0:3::27

2001:DB8:0:3::5   2001:DB8:0:3::112

2001:DB8:0:1::4

Forwarding vs. Routing

- **Forwarding:** the process of moving packets from input to output
  - The forwarding table
  - Information in the packet

- **Routing:** process by which the forwarding table is built and maintained
  - One or more routing protocols
  - Procedures (algorithms) to convert routing info to forwarding table.

  (Much more later ...)

Lookup (longest prefix match):

❑ Forwarding table:

<Network>/<mask> <next-hop>

❑ IP Packets: destination IP address

  ○ Find next-hop

❑ Example:

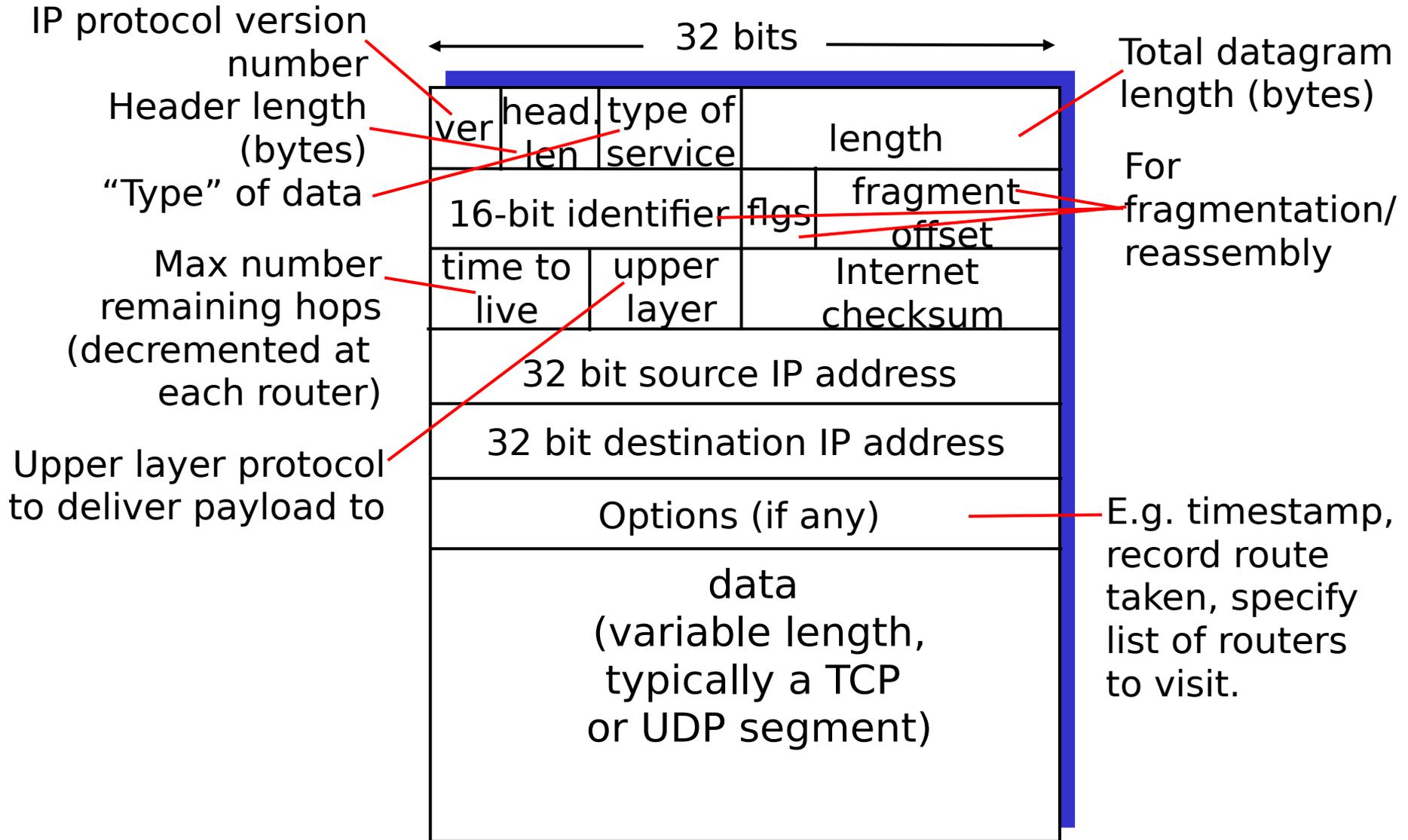| Forwarding table		Packets
134.96.252.0/24	A	134.96.252.200
134.96.0.0/16	C	134.96.254.2
134.96.240.0/20	B	134.96.239.200
134.96.252.192/28	B	134.97.239.200
134.96.252.128/28	A	134.96.252.191

IPv4 datagram format

IP protocol version number

Header length (bytes)

"Type" of data

Max number remaining hops (decremented at each router)

Upper layer protocol to deliver payload to

32 bits

ver	head. len	type of service	length
16-bit identifier		flgs	fragment offset
time to live	upper layer	Internet checksum	
32 bit source IP address			
32 bit destination IP address			
Options (if any)			
data (variable length, typically a TCP or UDP segment)			

Total datagram length (bytes)

For fragmentation/ reassembly

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

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ICMP: Internet Control Message Protocol

□ Used by hosts, routers, gateways to communication network-level information

  ○ Error reporting: unreachable host, network, port, protocol
  ○ Echo request/reply (used by ping)

□ Network-layer "above" IP:

  ○ ICMP msgs carried in IP datagrams

□ ICMP message: type, code plus first 8 bytes of IP datagram causing error

Type	Code	description
0	0	echo reply (ping)
3	0	dest network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control – not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Network layer: Summary

- Network layer functions
- IP
- Routing and forwarding