Last time

- Wireless link-layer
  - Introduction
    - Wireless hosts, base stations, wireless links
  - Characteristics of wireless links
    - Signal strength, interference, multipath propagation
    - Hidden terminal, signal fading problems
  - 802.11 wireless LANs
    - CSMA/CA
    - Frame structure
  - 802.15 networking
  - Cellular Internet access

This time

- Start on the Network layer
  - Introduction
  - Virtual circuit vs. datagram details
  - IP: the Internet Protocol

Chapter 4: Network Layer

Chapter goals:

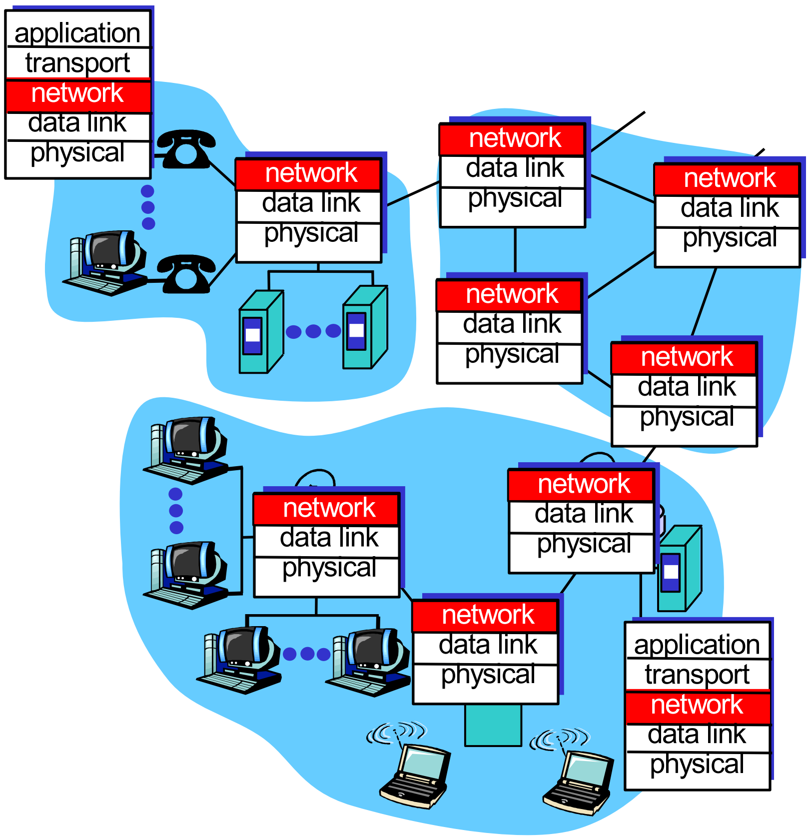
- Understand principles behind network layer services:
  - network layer service models
  - forwarding versus routing
  - how a router works
  - routing (path selection)
  - dealing with scale
  - advanced topics: IPv6, mobility
- Instantiation, implementation in the Internet

Chapter 4: Network Layer

- 4. 1 Introduction
- 4.2 Virtual circuit and datagram networks
- 4.3 What’s inside a router
- 4.4 IP: Internet Protocol
  - Datagram format
  - IPv4 addressing
  - ICMP
  - IPv6
- 4.5 Routing algorithms
  - Link state
  - Distance Vector
  - Hierarchical routing
- 4.6 Routing in the Internet
  - RIP
  - OSPF
  - BGP
- 4.7 Broadcast and multicast routing

Network layer

- Move segment from sending to receiving host
- On sending side encapsulates segments into datagrams
- On receiving side, delivers segments to transport layer
- Network layer protocols in *every* host, router
  - But not switches, hubs
- Router examines header fields in all IP datagrams passing through it



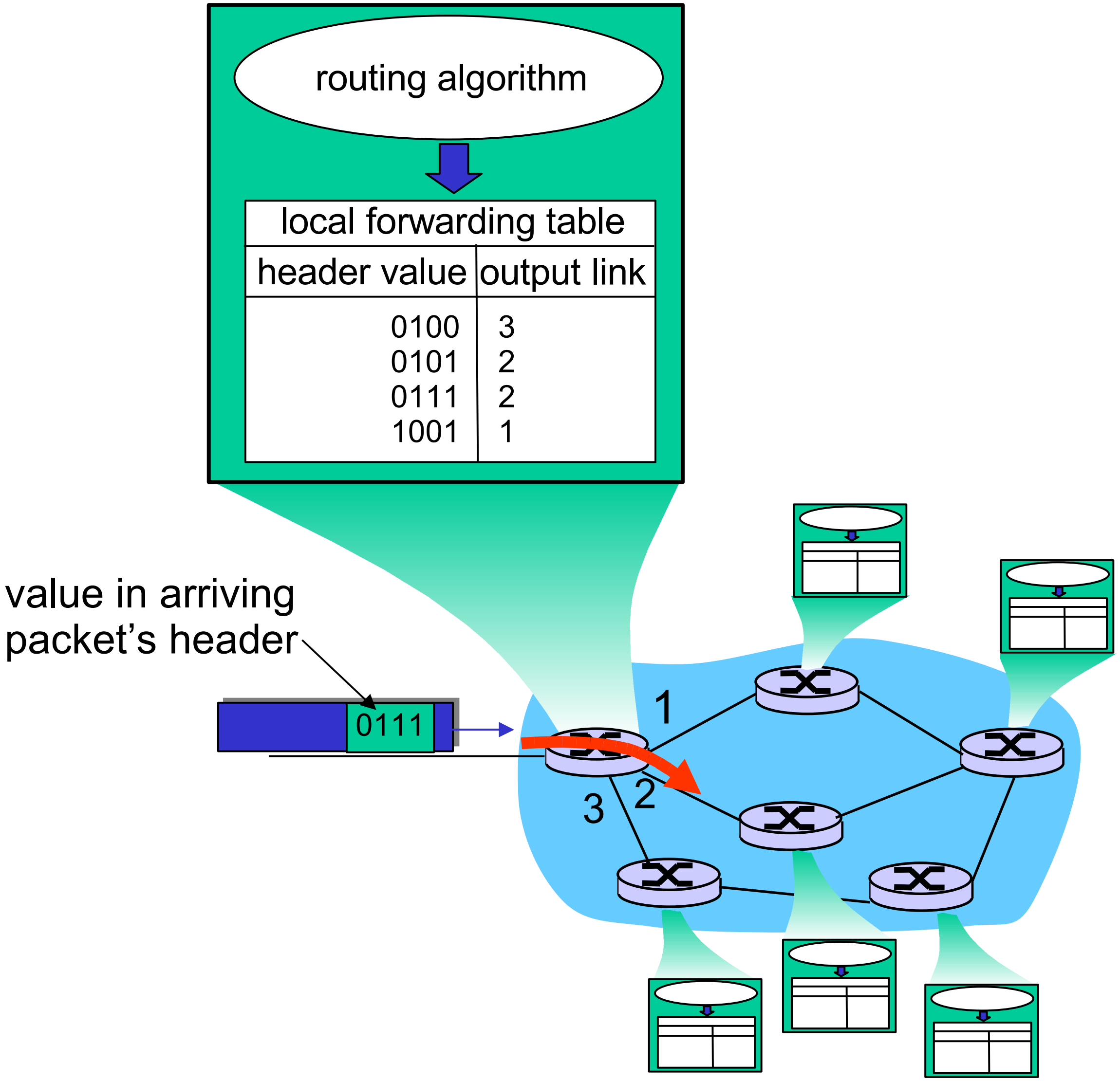
Two Key Network-Layer Functions

- *Forwarding:* move packets from router's input to appropriate router output
- *Routing:* determine route taken by packets from source to dest.
  - *routing algorithms*

analogy:

- Routing: process of planning trip from source to dest
- Forwarding: process of getting through single interchange

Interplay between routing and forwarding



Connection setup

- 3rd important function in *some* network architectures:
  - ATM, frame relay, X.25
- Before datagrams flow, two end hosts *and* intervening routers establish virtual connection
  - routers get involved

Network service model

Q: What *service model* for "channel" transporting packets from sender to receiver?

Example services for individual packets:

- guaranteed delivery
- guaranteed delivery with less than 40 msec delay

Example services for a flow of packets:

- in-order packet delivery
- guaranteed minimum bandwidth to flow
- restrictions on changes in inter-packet spacing

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Network layer connection and connectionless service

- Datagram network provides network-layer connectionless service
- VC network provides network-layer connection service
- Specifically:
  - service: host-to-host
  - no choice: network provides one or the other
  - implementation: in network core

Virtual circuits

Source-to-dest path behaves much like telephone circuit
- performance-wise
- network actions along source-to-dest path

- Call setup, teardown for each call *before* data can flow
- Each packet carries VC identifier (not destination host address)
- *Every* router on source-dest path maintains "state" for *each* passing connection
- Link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

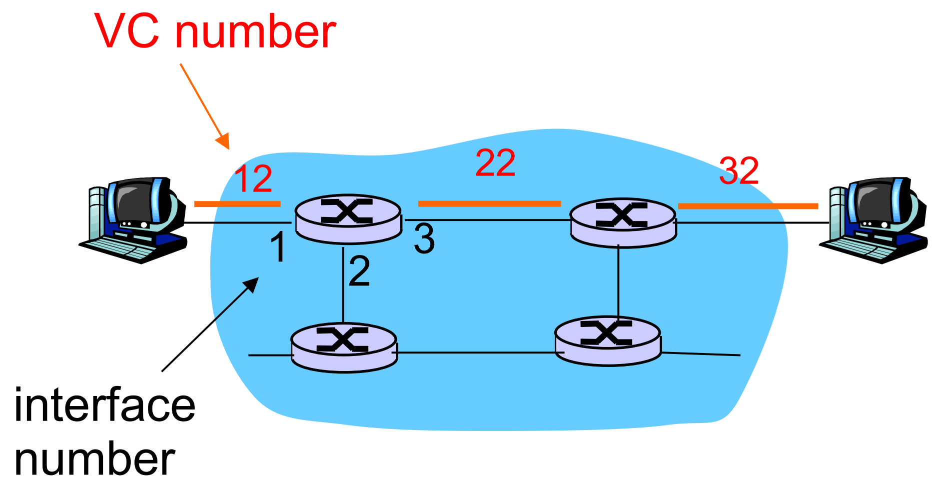
VC implementation

A VC consists of:

1. path from source to destination
2. VC numbers, one number for each link along path
3. entries in forwarding tables in routers along path

- packet belonging to VC carries VC number (rather than dest address)
- VC number can be changed on each link.
  - New VC number comes from forwarding table

Forwarding table



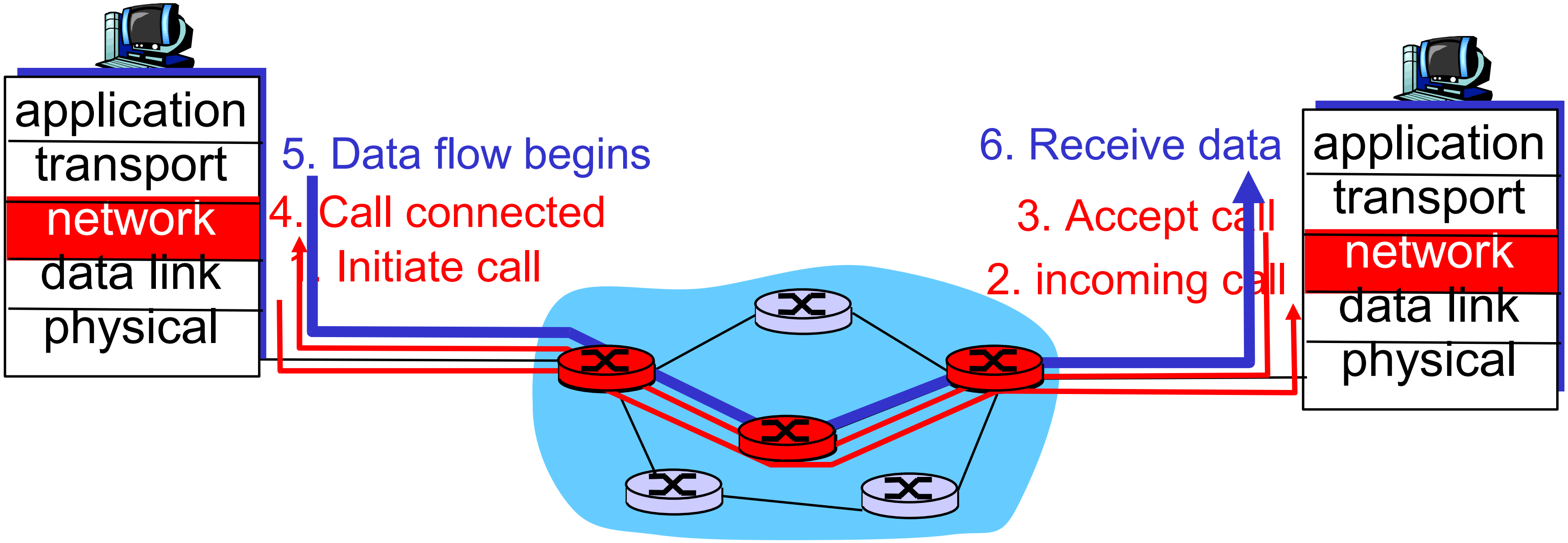
Forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

Routers maintain connection state information!

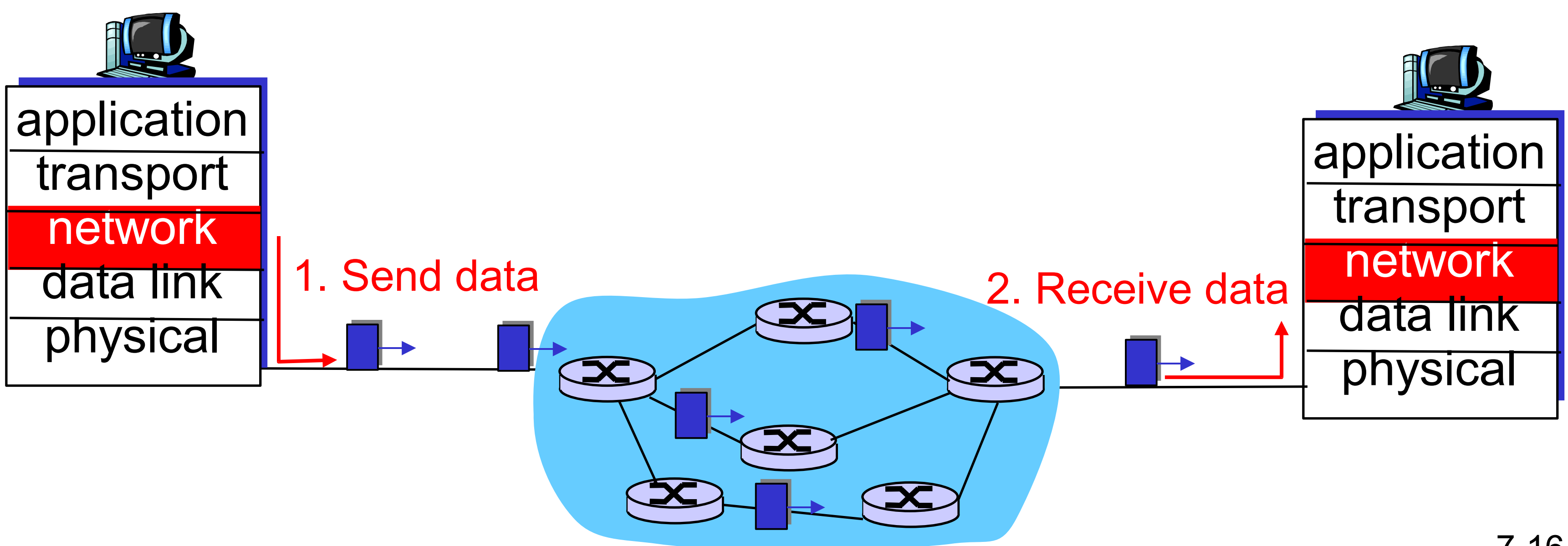
Virtual circuits: signaling protocols

- Used to setup, maintain teardown VC
- Used in ATM, frame-relay, X.25
- Not used in today's Internet



Datagram networks

- No call setup at network layer
- Routers: no state about end-to-end connections
  - no network-level concept of "connection"
- Packets forwarded using destination host address
  - packets between same source-dest pair may take different paths



Forwarding table

4 billion possible entries

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Longest prefix matching

Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 00011	2
otherwise	3

Examples

DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

Datagram or VC network: why?

Internet (datagram)

- data exchange among computers
  - "elastic" service, no strict timing req.
- "smart" end systems (computers)
  - can adapt, perform control, error recovery
  - simple inside network, complexity at "edge"
- many link types
  - different characteristics
  - uniform service difficult

ATM (VC)

- evolved from telephony
- human conversation:
  - strict timing, reliability requirements
  - need for guaranteed service
- "dumb" end systems
  - telephones
  - complexity inside network

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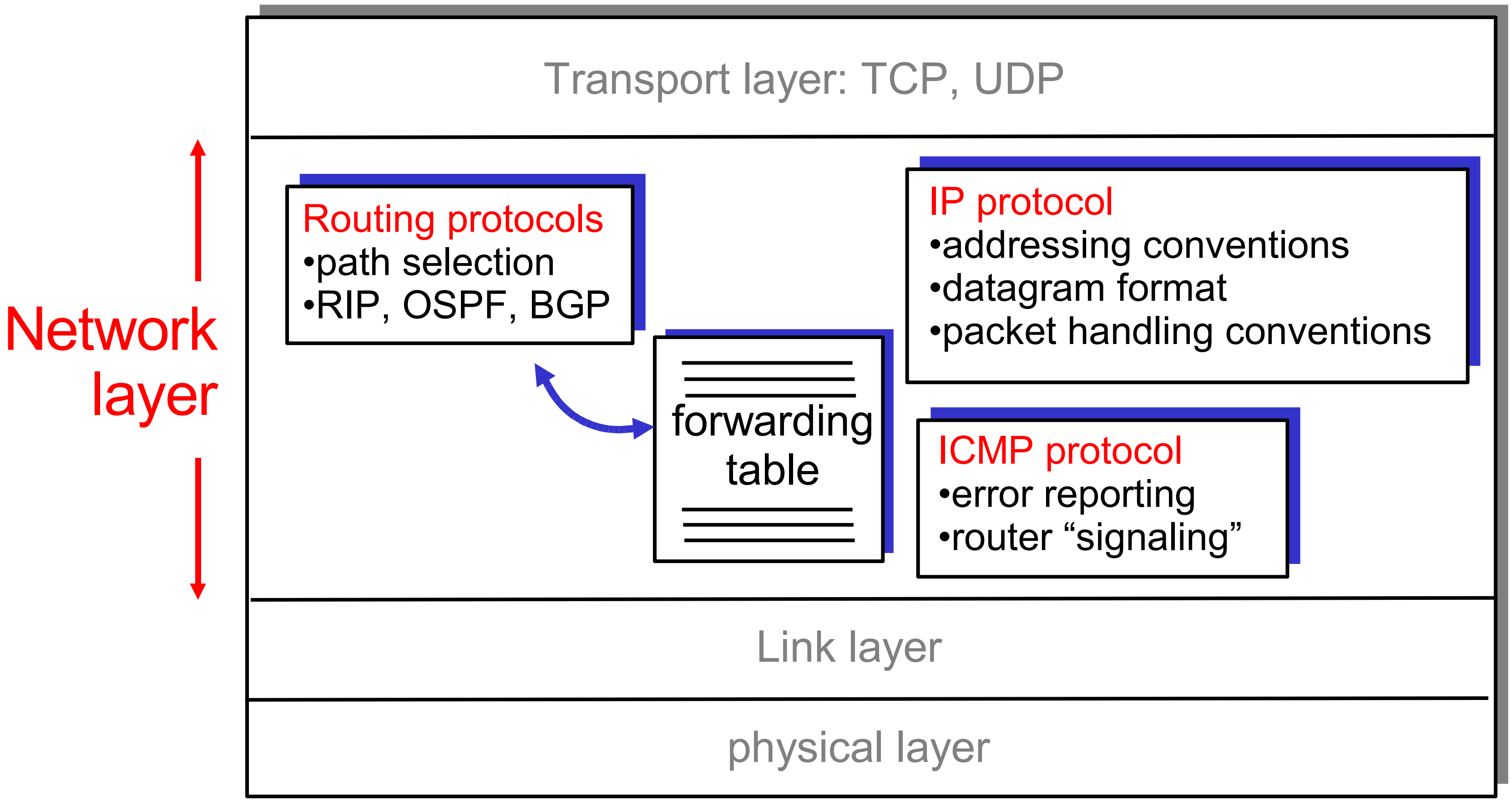
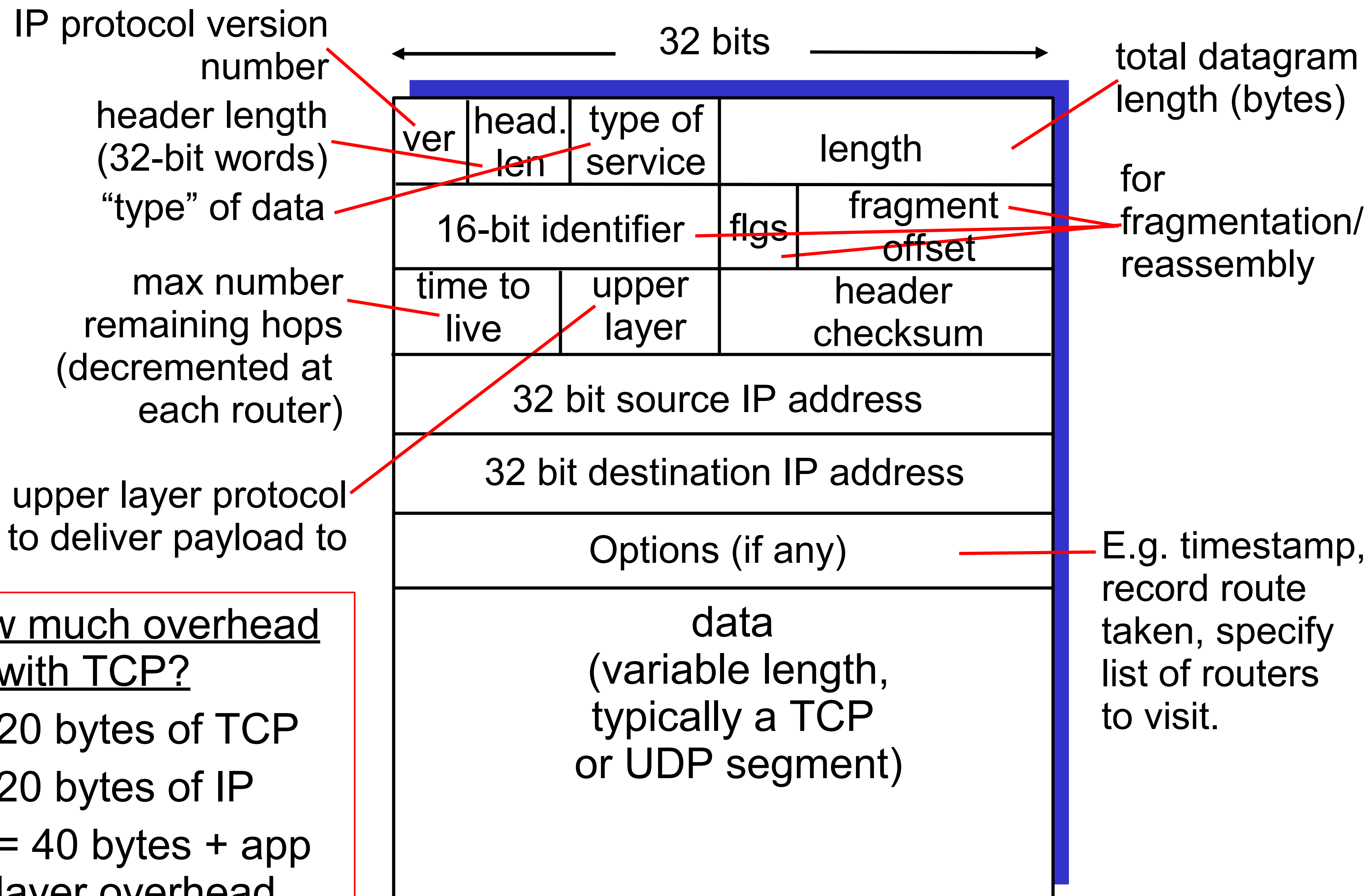
The Internet Network layer

Host, router network layer functions:



IP datagram format

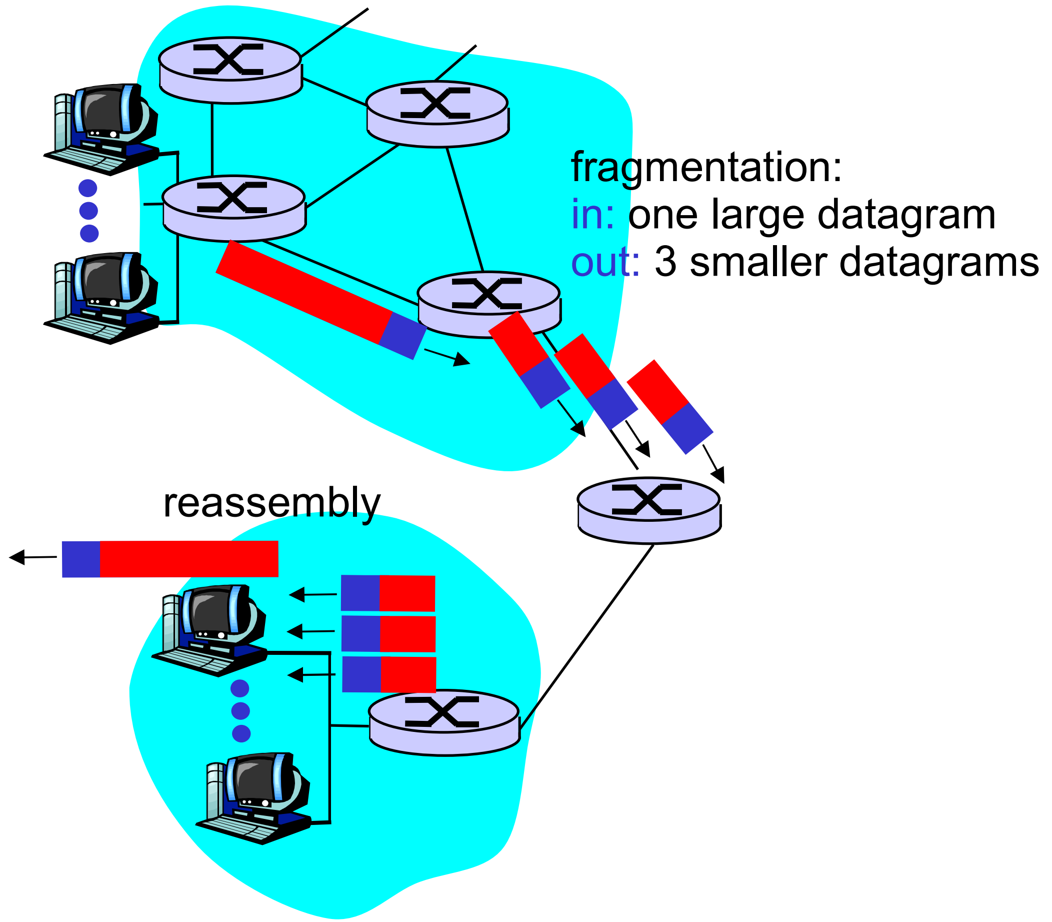


<u>how much overhead with TCP?</u>

- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes + app layer overhead

IP Fragmentation & Reassembly

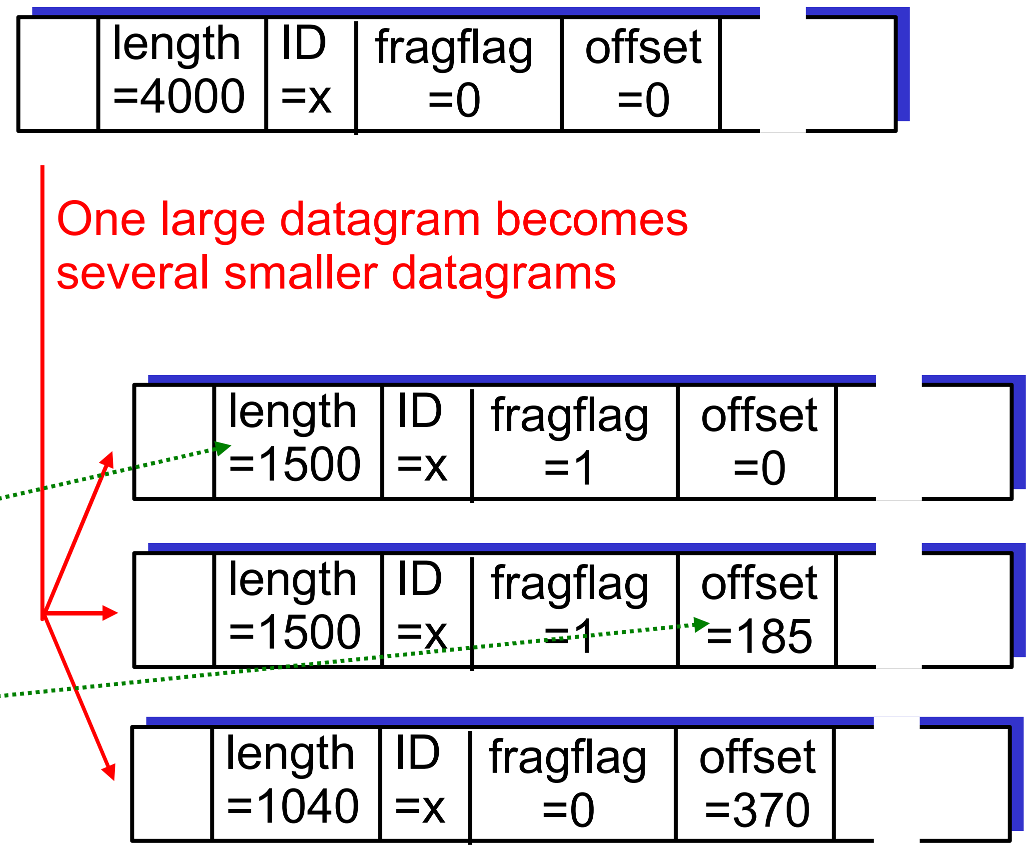
- Network links have MTU (max.transfer size) - largest possible link-level frame.
  - different link types, different MTUs
- Large IP datagram divided ("fragmented") within net
  - one datagram becomes several datagrams
  - "reassembled" only at final destination
  - IP header bits used to identify, order related fragments



IP Fragmentation and Reassembly

Example

- 4000 byte datagram
- MTU = 1500 bytes



See the fragmentation applet on UW-ACE

Recap

- Network layer
  - Introduction
    - forwarding vs. routing
  - Virtual circuit vs. datagram details
    - connection setup, teardown
    - VC# switching
    - forwarding tables, longest prefix matching
  - IP: the Internet Protocol
    - packet structure
    - fragmentation & reassembly

Next time

- ARP
- DHCP
- ICMP
- IPv6