Networking Overview

CS 161 - Computer Security

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Focus For Today's Lecture

- Sufficient background in networking to then explore security issues in next 4 lectures
  - Networking = the Internet
- Complex topic with many facets
  - We will omit concepts/details that aren't very security-relevant
  - We'll mainly look at IP, TCP, DNS and DHCP
- Networking is full of abstractions
  - Goal is for you to develop apt *mental models* / analogies
  - ASK questions when things are unclear
    - (but we may skip if not ultimately relevant for security, or postpone if question itself is directly about security)

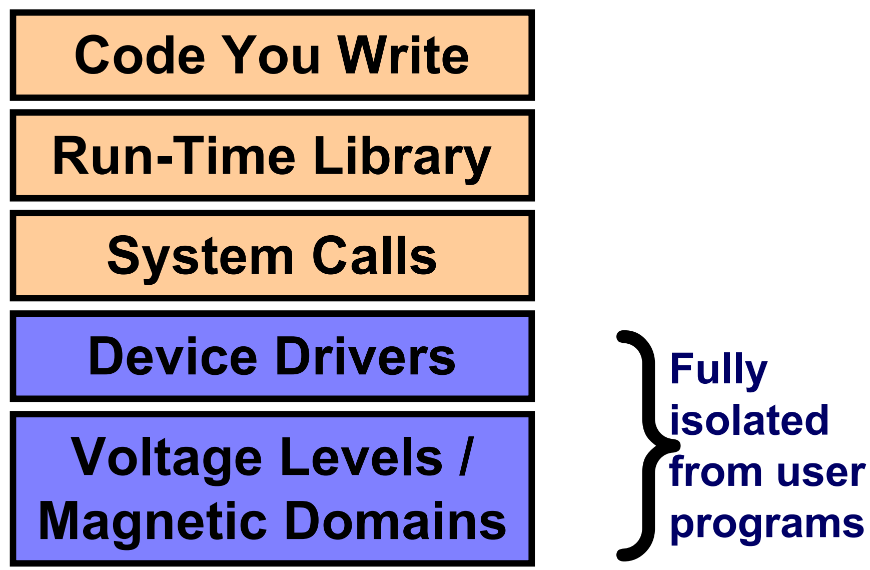
Key Concept #1: *Dumb Network*

- Internet design: interior nodes ("routers") have no knowledge* of ongoing connections going through them
- Not: how you picture the telephone system works
  - Which internally tracks all of the active voice calls
- Instead: the postal system!
  - Each Internet message ("packet") self-contained
  - Interior "routers" look at destination address to forward
  - If you want smarts, build it "end-to-end"
  - Buys simplicity & robustness at the cost of shifting complexity into end systems

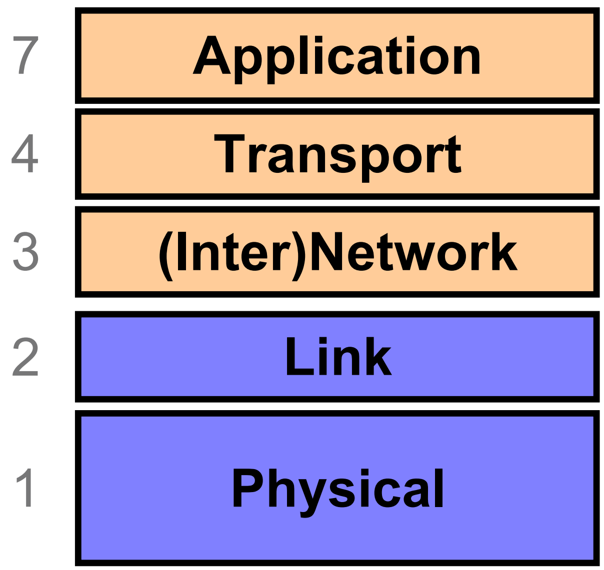
* Today's Internet is full of hacks that violate this

Key Concept #2: *Layering*

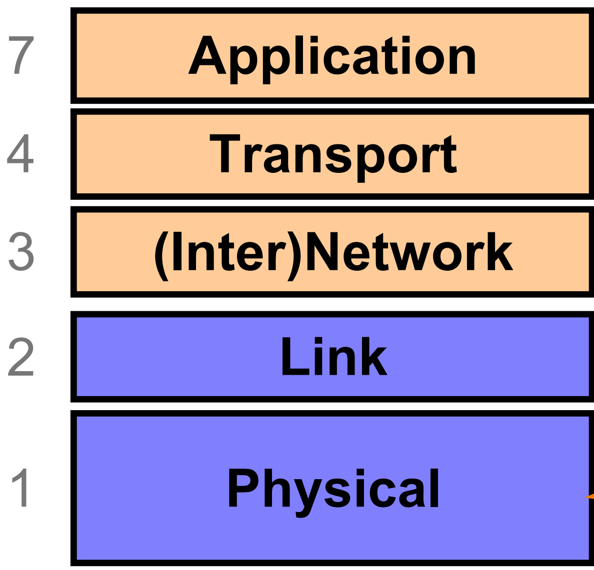
- Internet design is strongly partitioned into layers
  - Each layer relies on services provided by next layer below …
  - … and provides services to layer above it
- Analogy:
  - Consider structure of an application you've written and the "services" each layer relies on / provides



Internet Layering ("Protocol Stack")



Layer 1: Physical Layer

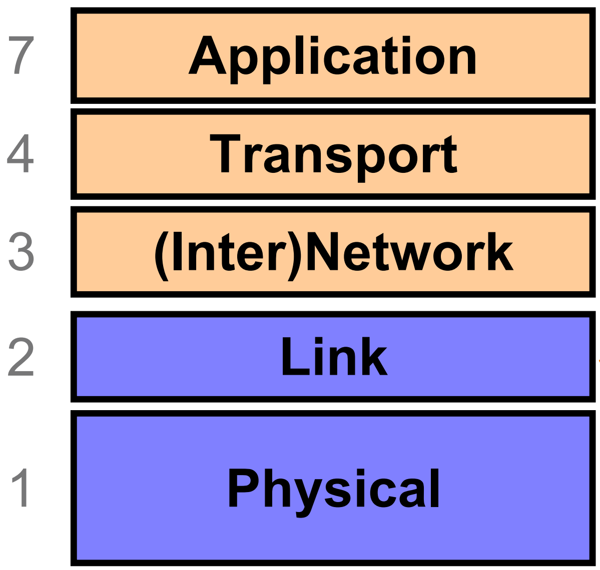


Encoding bits to send them over a single **physical link**

e.g. patterns of

voltage levels /
photon intensities /
RF modulation

Layer 2: Link Layer

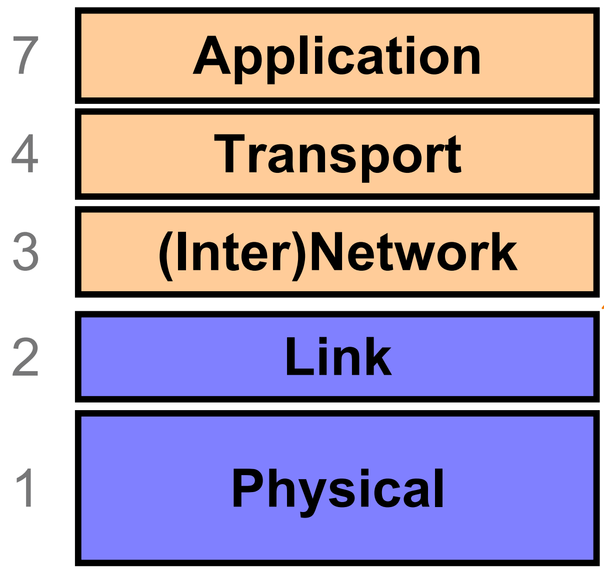


Framing and transmission of a collection of bits into individual messages sent across a single "subnetwork" (one physical technology)

Might involve multiple *physical links* (e.g., modern Ethernet)

Often technology supports broadcast transmission (**every** "node" connected to subnet receives)

Layer 3: (Inter)Network Layer



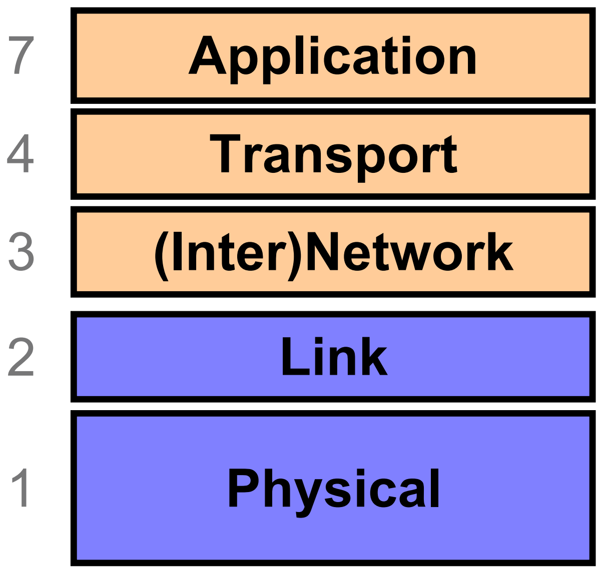
Bridges multiple subnets to provide *end-to-end* internet connectivity between nodes

- Provides global addressing

Works across different link technologies

Different **for each Internet "hop"**

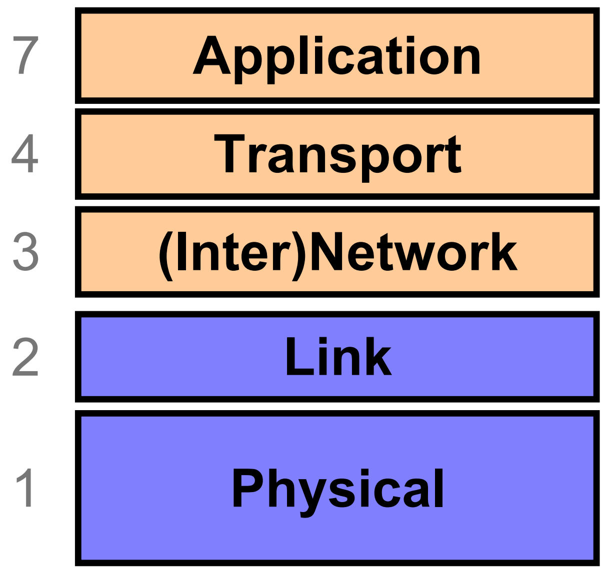
Layer 4: Transport Layer



End-to-end communication between processes

Different services provided:
TCP = reliable *byte stream*
UDP = unreliable *datagrams*

Layer 7: Application Layer



Communication of whatever you wish

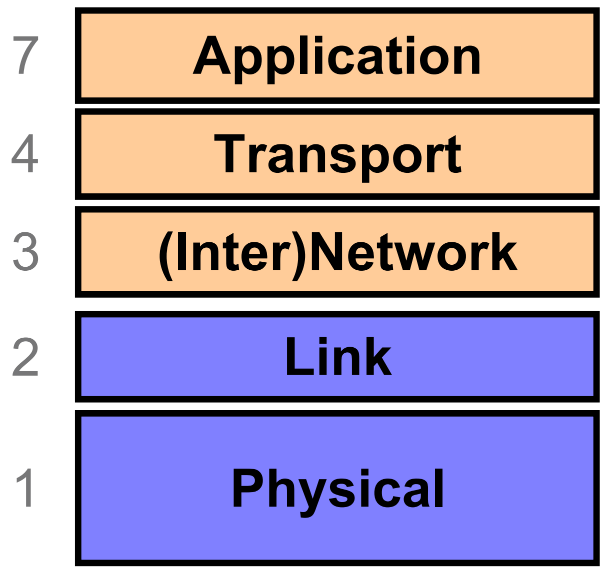
Can use whatever transport(s) is convenient

Freely structured

E.g.:

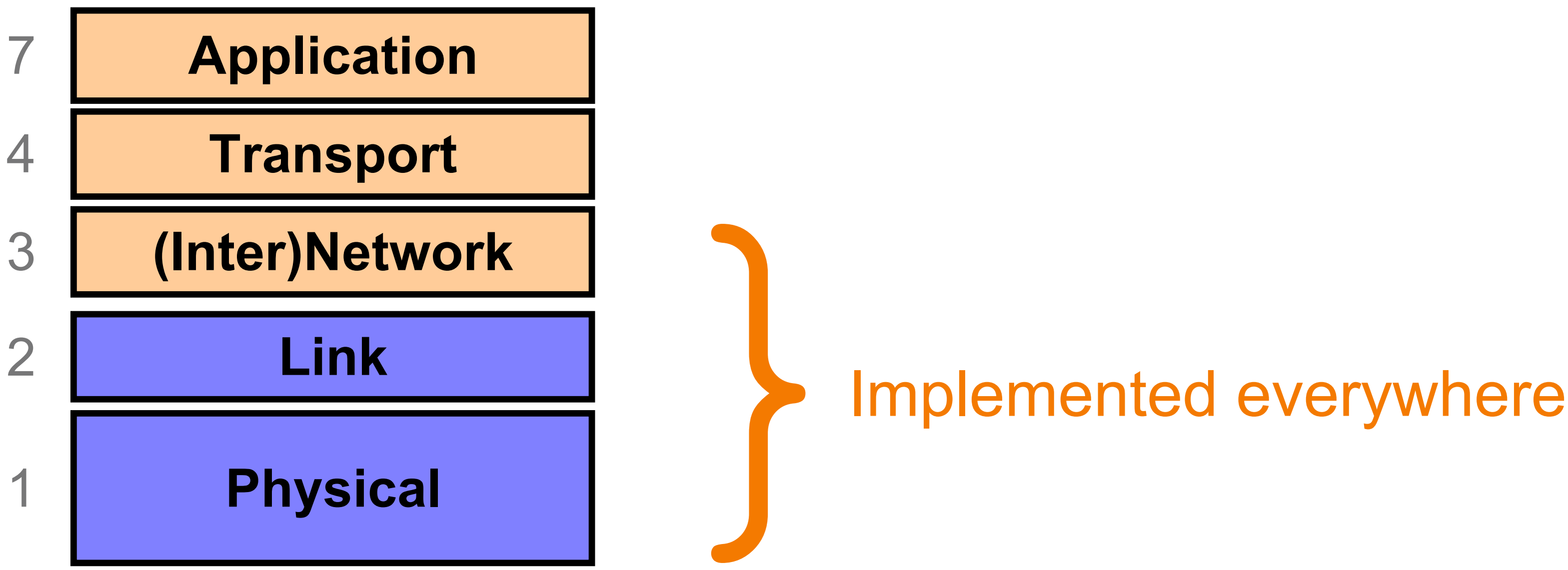
Skype, SMTP (email), HTTP (Web), Halo, BitTorrent

Internet Layering ("Protocol Stack")



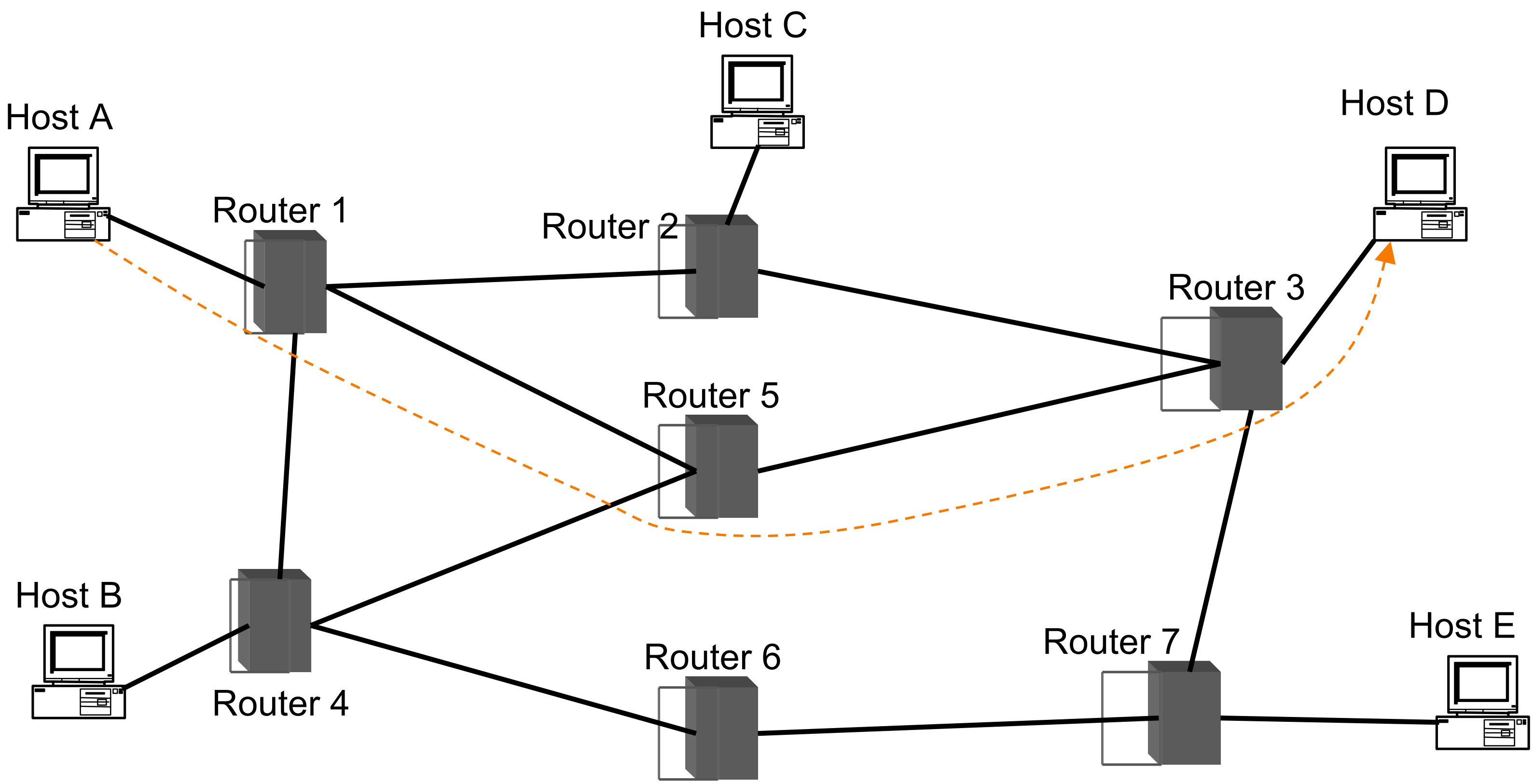
Implemented only at hosts,
not at interior routers
("dumb network")

Internet Layering ("Protocol Stack")



Hop-By-Hop vs. End-to-End Layers

Host A communicates with Host D



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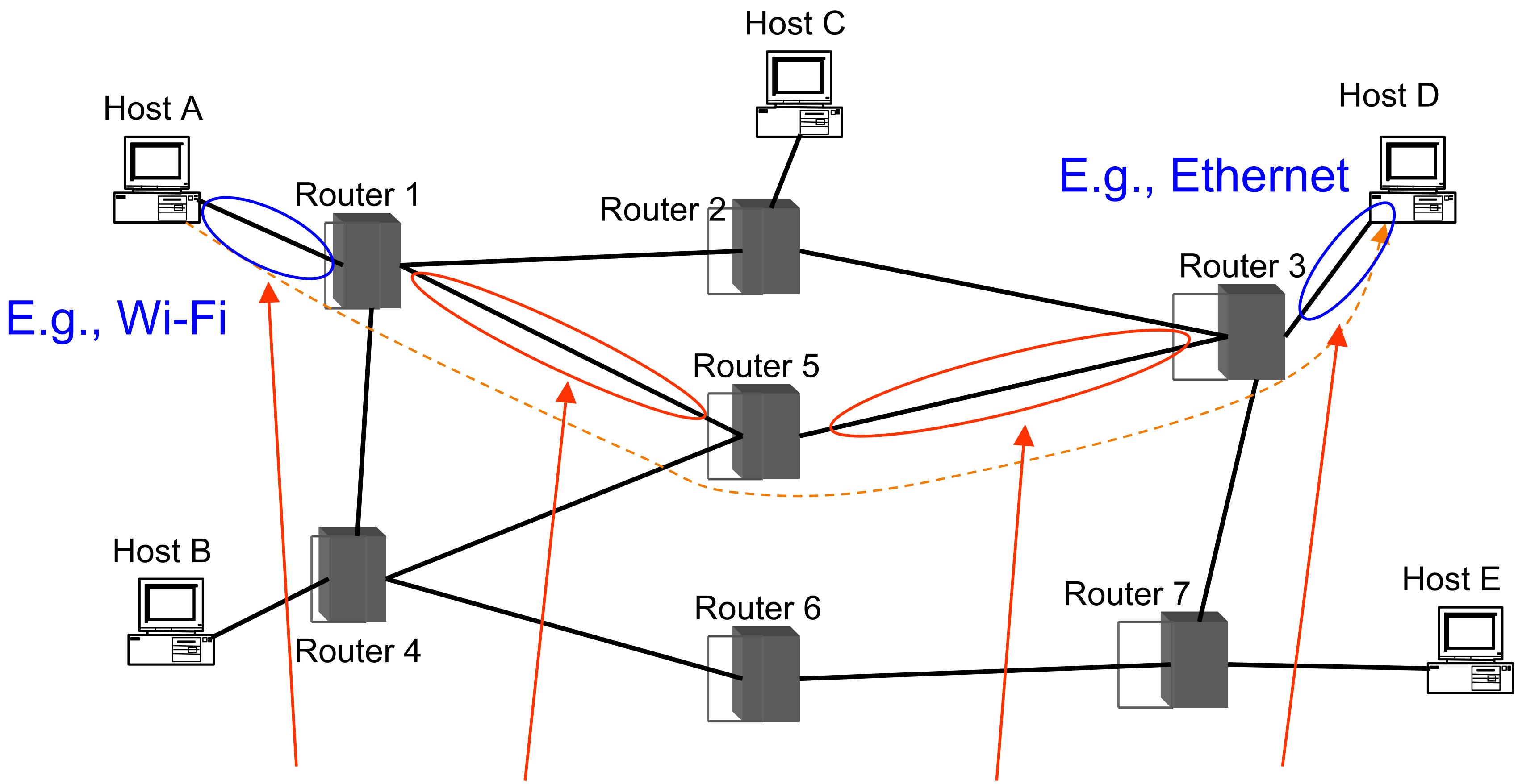

***Different* Physical & Link Layers (Layers 1 & 2)**

Hop-By-Hop vs. End-to-End Layers

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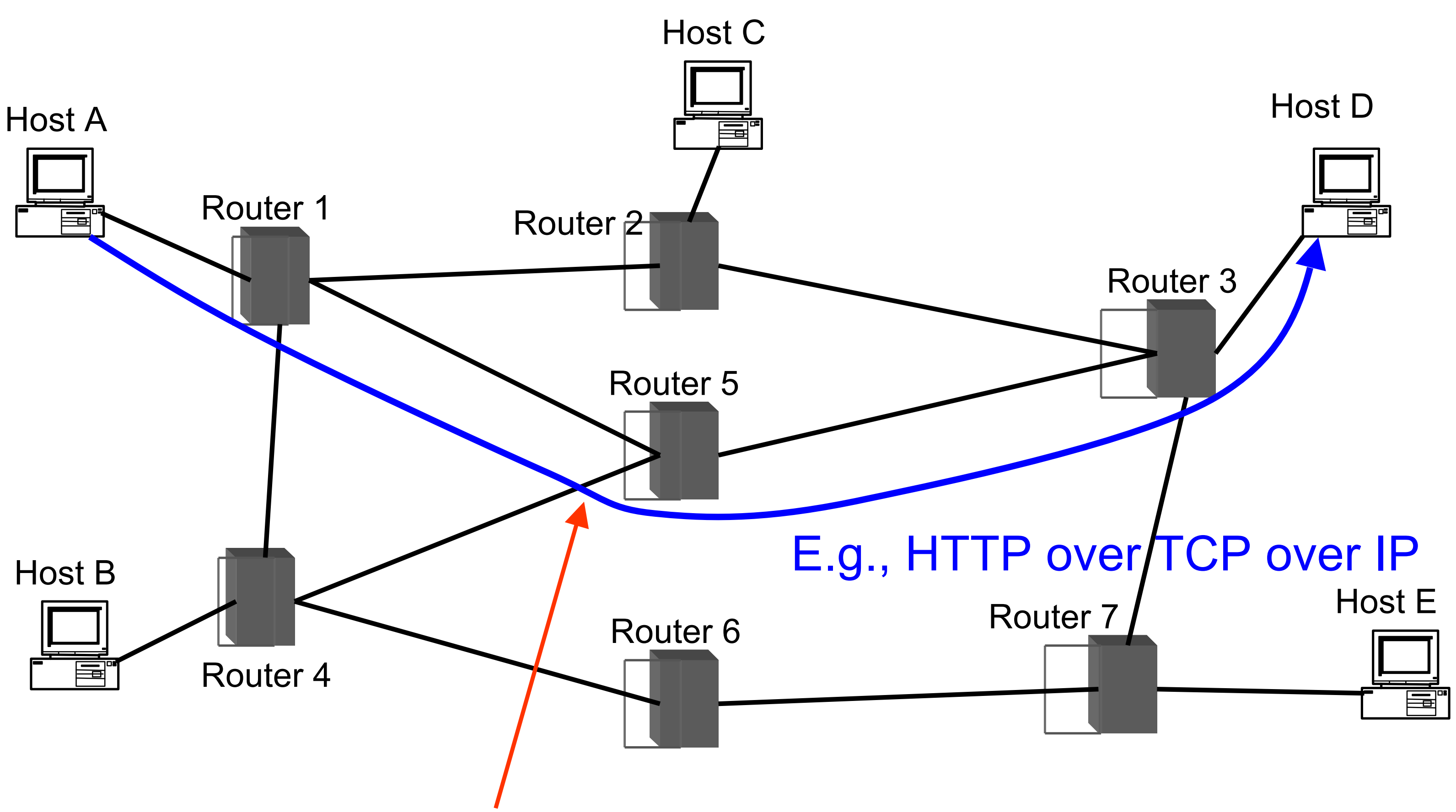
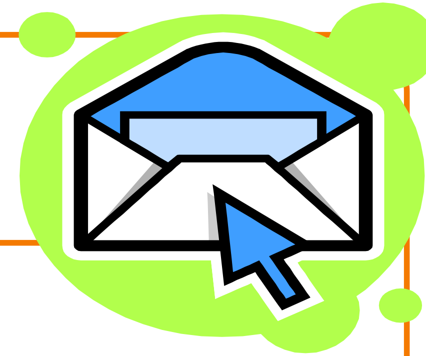


Same Network / Transport / Application Layers (3/4/7)
(Routers **ignore** Transport & Application layers)

Key Concept #3: *Protocols*

- A protocol is an agreement on how to communicate
- Includes syntax and semantics
  - How a communication is specified & structured
    - o Format, order messages are sent and received
  - What a communication means
    - o Actions taken when transmitting, receiving, or timer expires
- E.g.: asking a question in lecture?
  1. Raise your hand.
  2. Wait to be called on.
  3. Or: wait for speaker to **pause** and vocalize
  4. If unrecognized (after timeout): vocalize w/ "excuse me"

Example: IP Packet *Header*



(Network layer / layer 3)

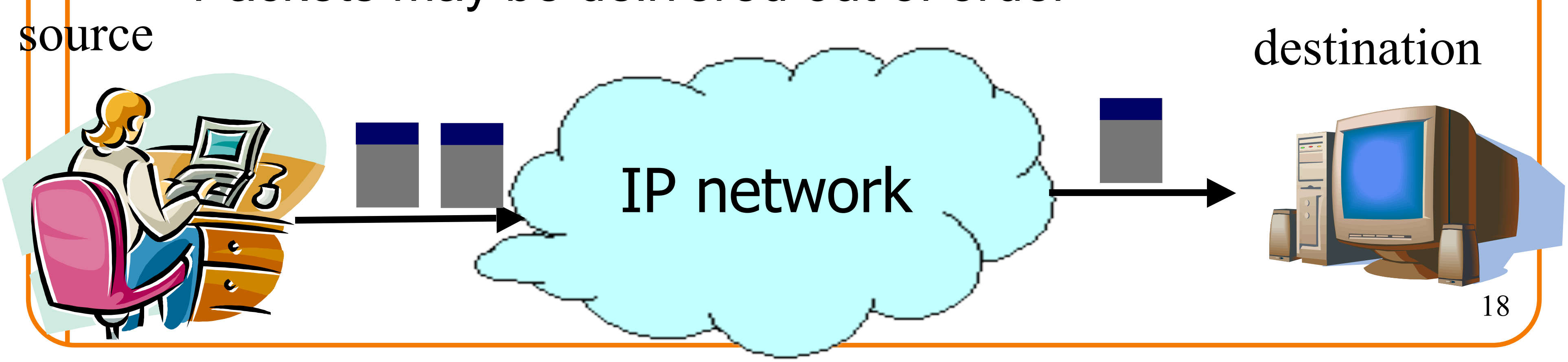
<table>
<tr><td>4-bit Version</td><td>4-bit Header Length</td><td>8-bit Type of Service (TOS)</td><td colspan="2">16-bit Total Length (Bytes)</td></tr>
<tr><td colspan="3">16-bit Identification</td><td>3-bit Flags</td><td>13-bit Fragment Offset</td></tr>
<tr><td colspan="2">8-bit Time to Live (TTL)</td><td>8-bit Protocol</td><td colspan="2">16-bit Header Checksum</td></tr>
<tr><td colspan="5">32-bit Source IP Address</td></tr>
<tr><td colspan="5">32-bit Destination IP Address</td></tr>
<tr><td colspan="5">Payload</td></tr>
</table>

20-byte header

IP = Internet Protocol

IP: "*Best Effort*" Packet Delivery

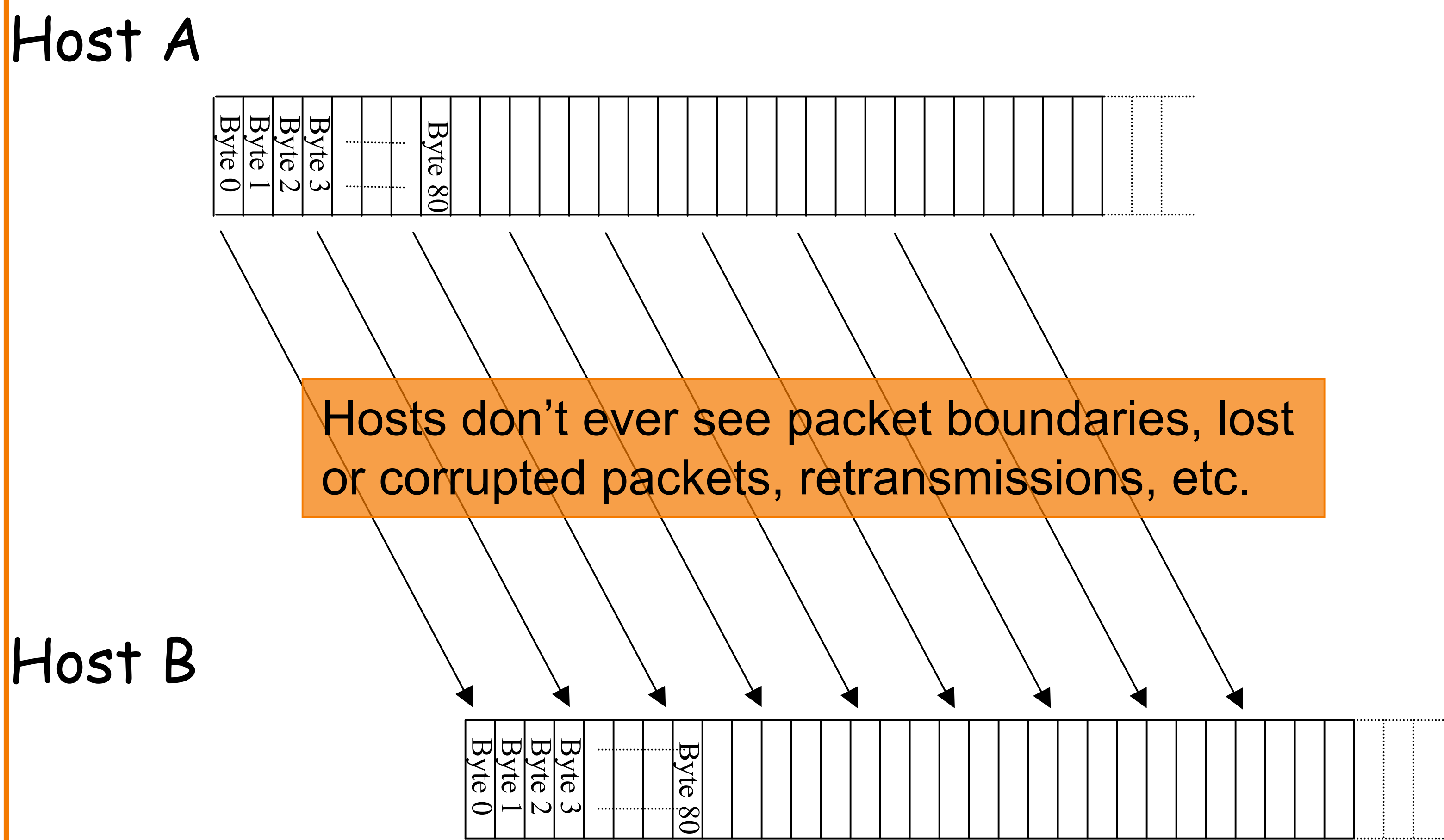
- Routers inspect destination address, locate "next hop" in forwarding table
  - Address = ~unique identifier/locator for the receiving host
  - (decrements TTL "Time To Live" field, drops packet if = 0)
- Only provides a "I'll give it a try" delivery service:
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order



“Best Effort” is Lame! What to do?

- It’s the job of our Transport (layer 4) protocols to build services our apps need out of IP’s modest layer-3 service
- #1 workhorse: TCP (Transmission Control Protocol)
- TCP service:
  - Connection oriented (explicit set-up / tear-down)
    - End hosts (processes) can have multiple concurrent long-lived dialog
  - Reliable, in-order, byte-stream delivery
    - Robust detection & retransmission of lost data
  - Congestion control
    - Dynamic adaptation to network path’s capacity
    - (Also adaptation to receiver’s ability to absorb data)

TCP "Stream of Bytes" Service



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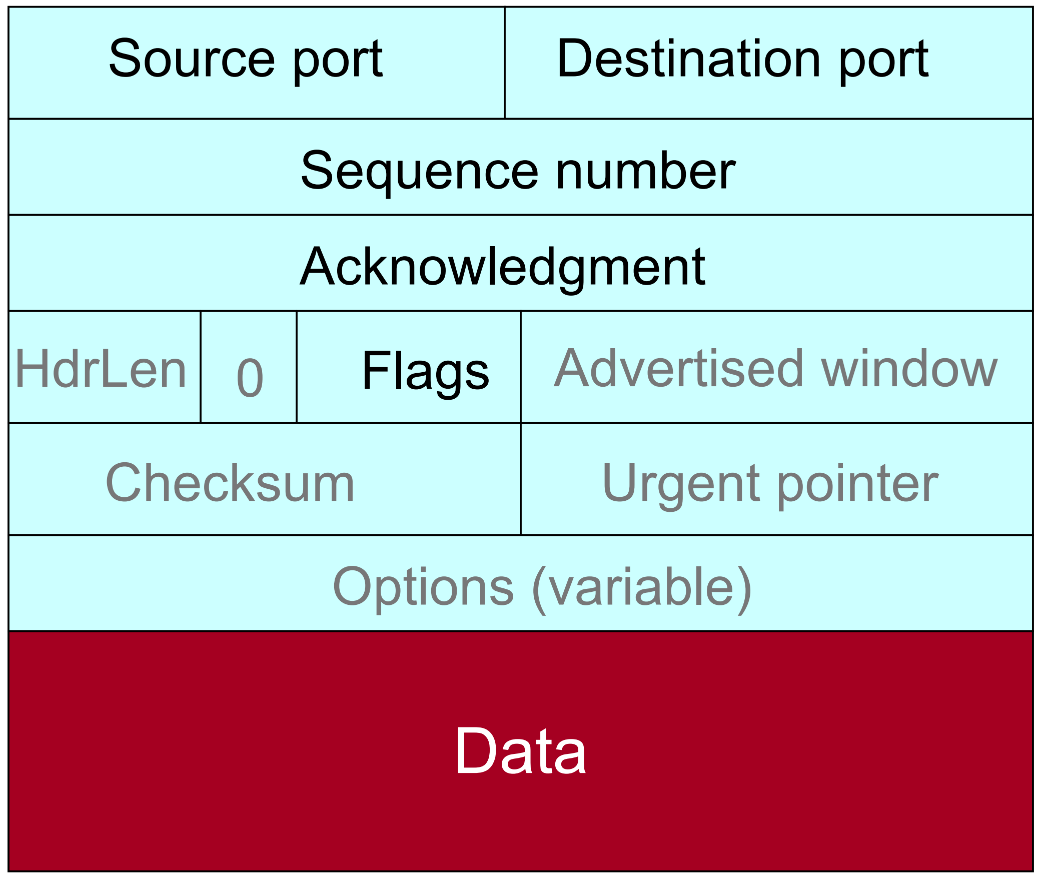
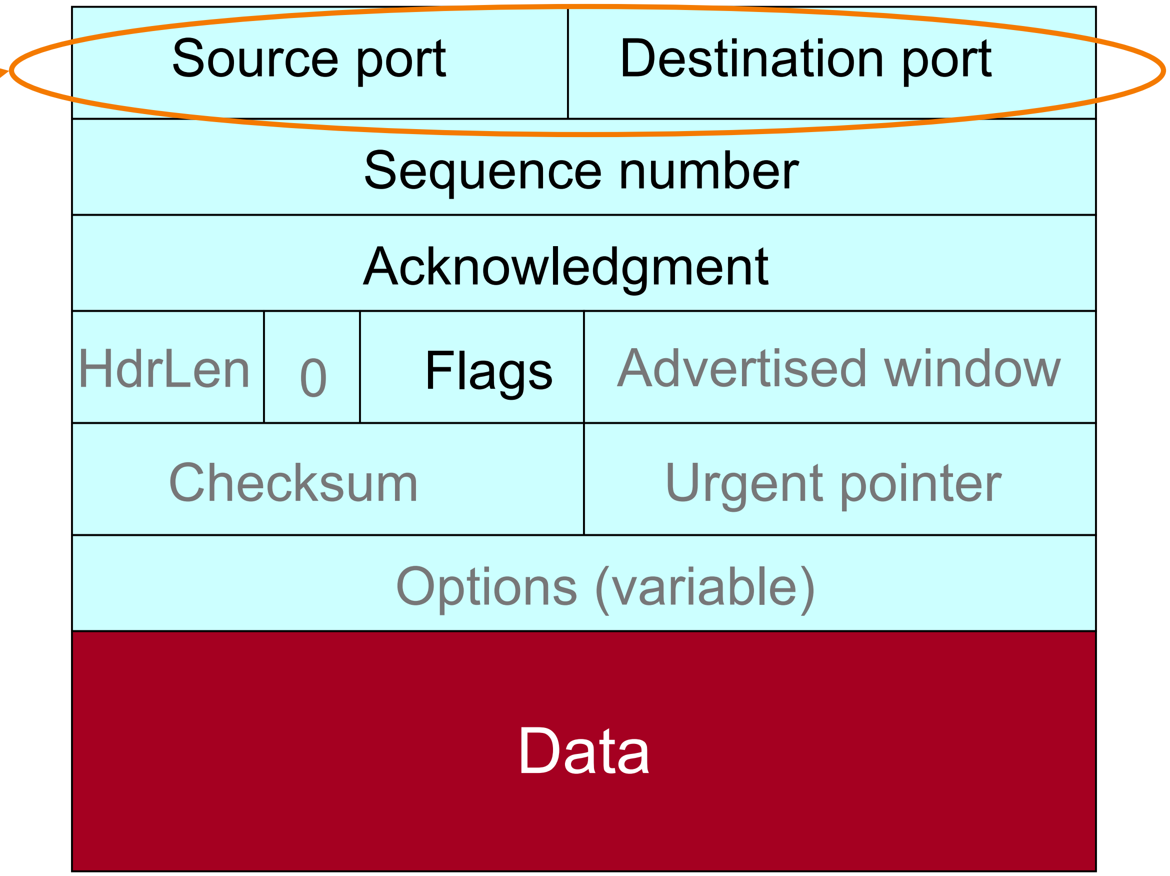
TCP Header



Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data

TCP Header

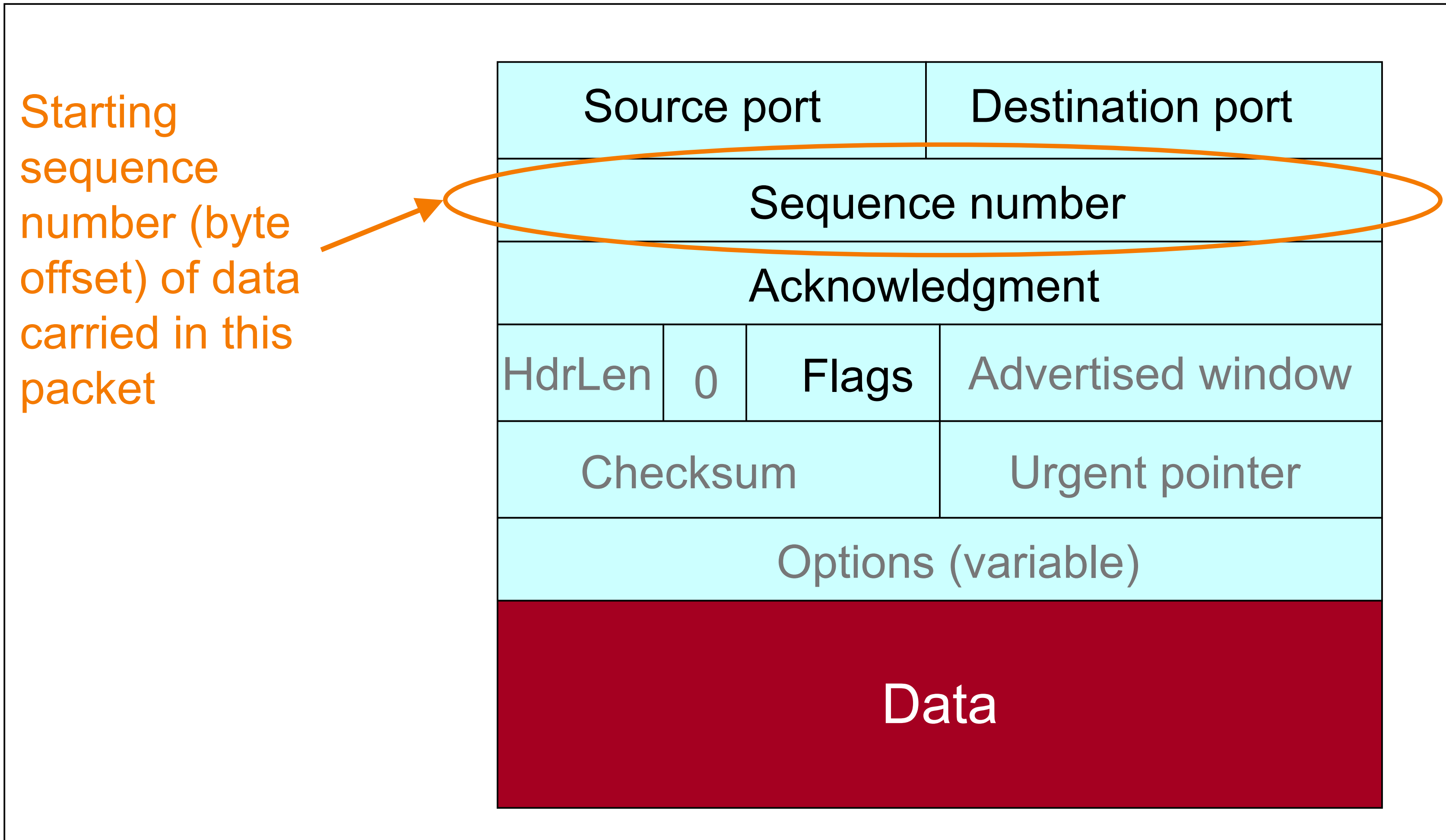
Ports are associated with OS processes



IP source & destination addresses plus TCP source and destination ports uniquely identifies a TCP connection

Some port numbers are "well known" / reserved e.g. port 80 = HTTP

TCP Header

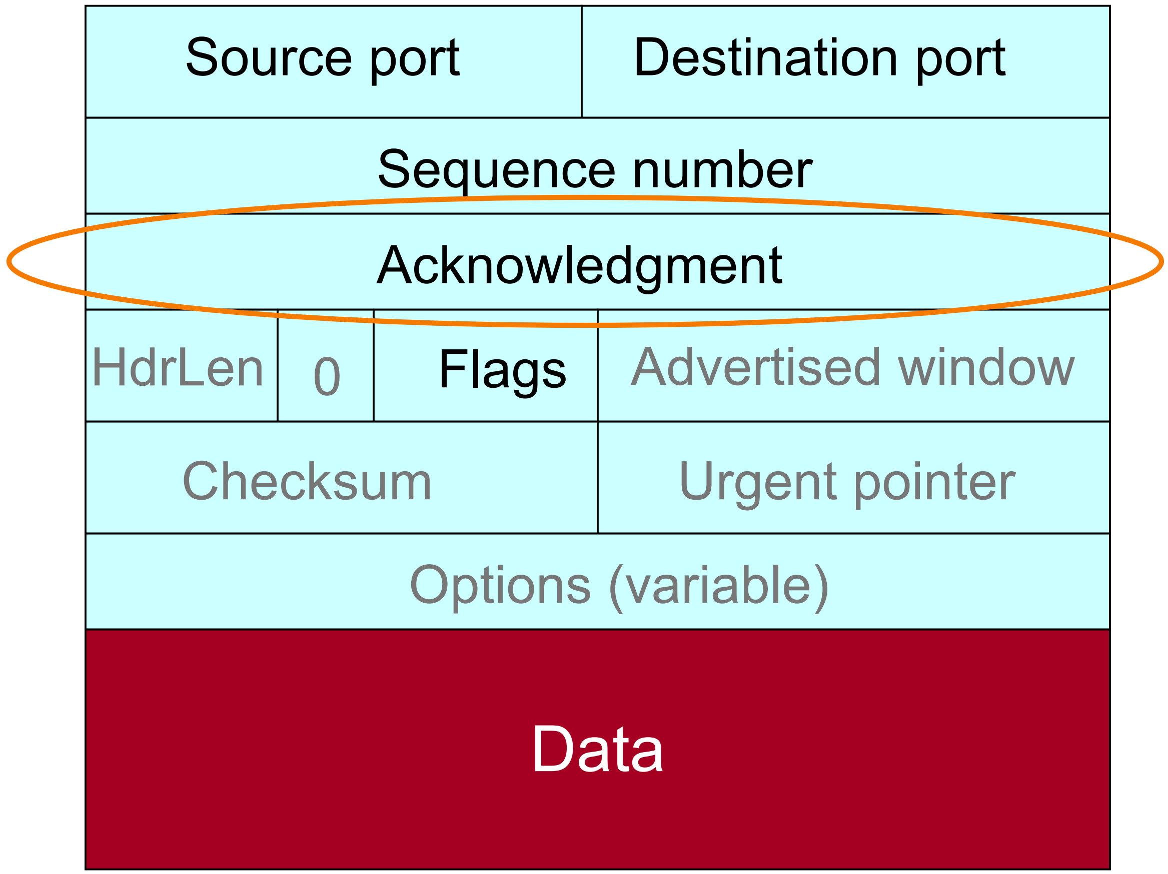


Starting sequence number (byte offset) of data carried in this packet
Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data

TCP Header

Acknowledgment gives seq # **just beyond** highest seq. received **in order**.

If sender sends **N** in-order bytes starting at seq **S** then ack for it will be **S+N**.

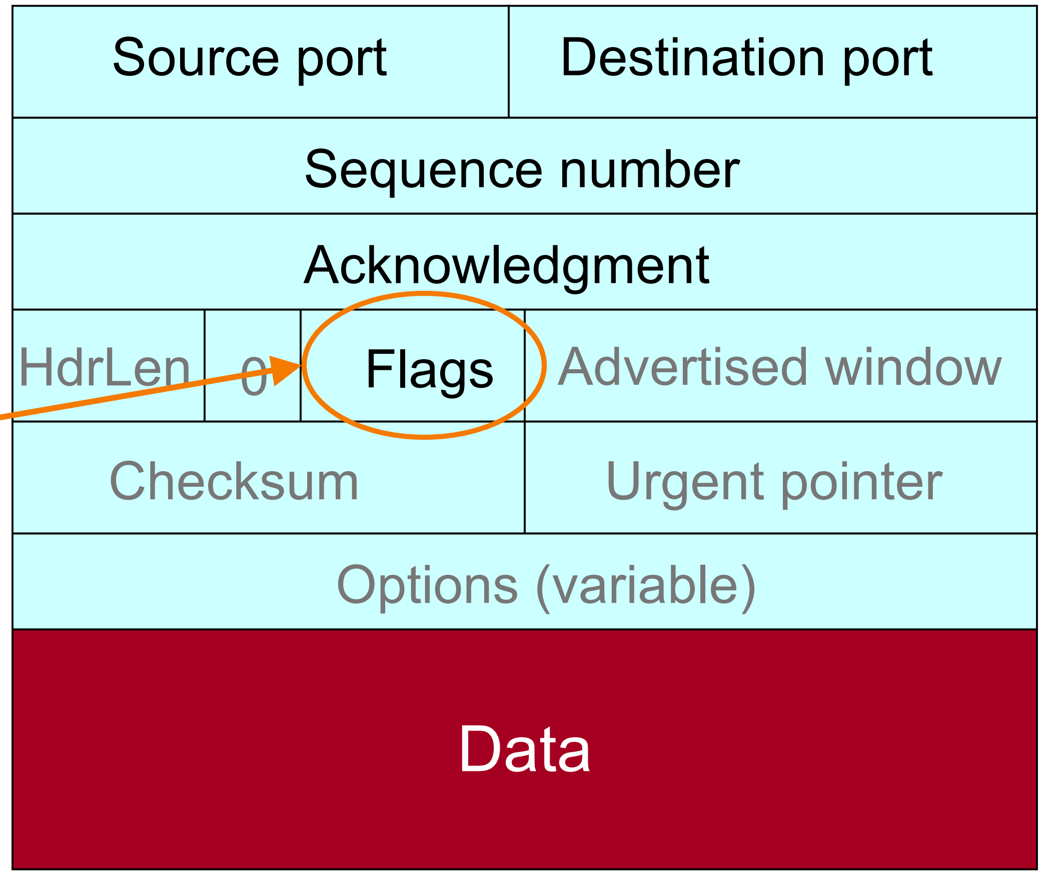


TCP Header

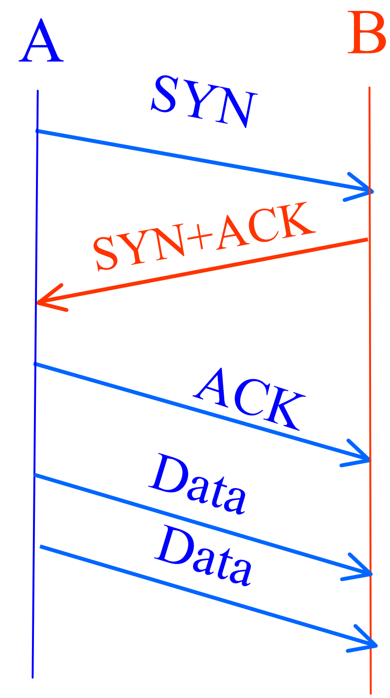
Uses include:

acknowledging data (“**ACK**”)

setting up (“**SYN**”) and closing connections (“**FIN**” and “**RST**”)



Establishing a TCP Connection

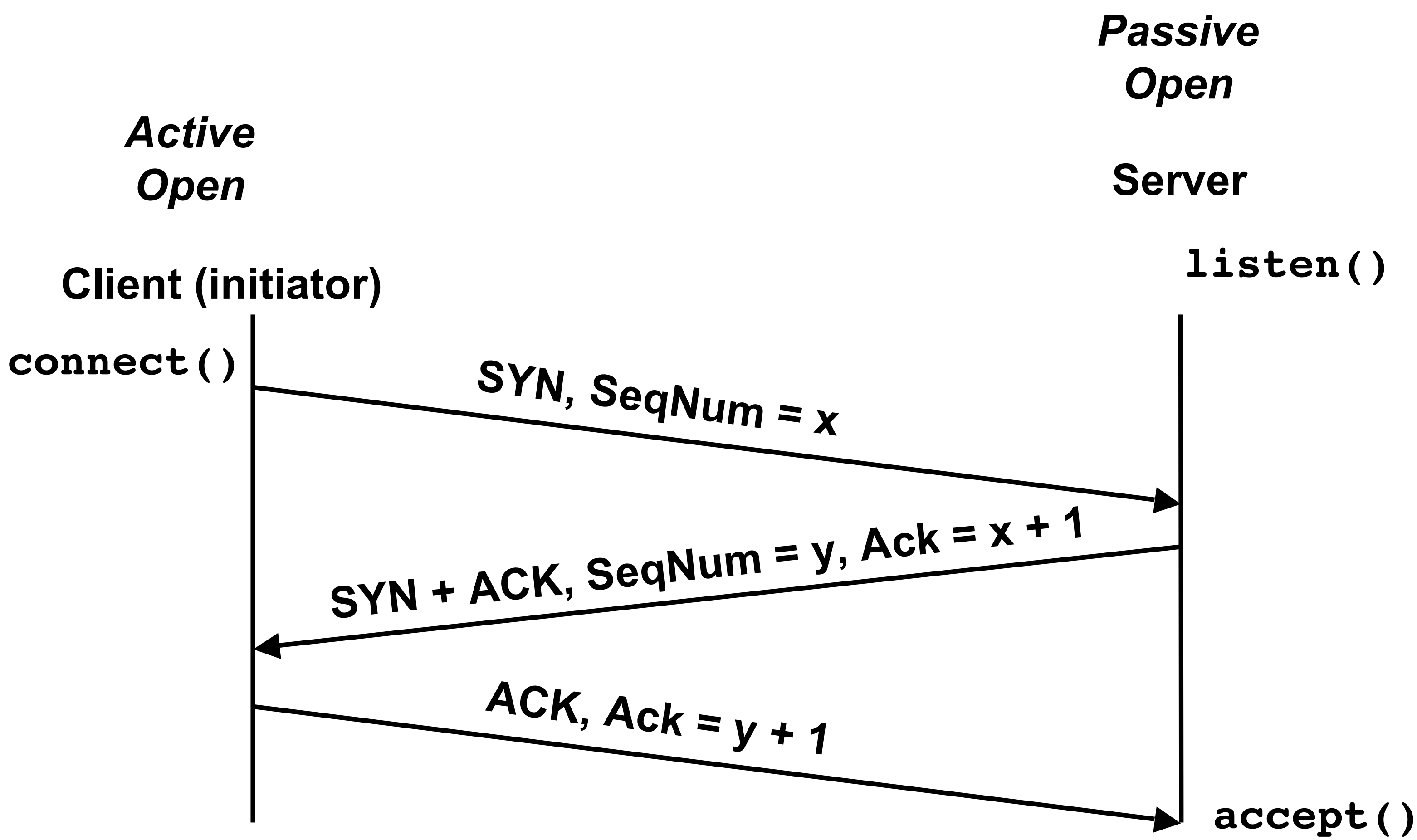


Each host tells its *Initial Sequence Number* (ISN) to the other host.

Spec says to pick based on local clock

- Three-way handshake to establish connection
  - Host A sends a **SYN** (open; "synchronize sequence numbers") to host B
  - Host B returns a SYN acknowledgment (**SYN+ACK**)
  - Host A sends an **ACK** to acknowledge the SYN+ACK

Timing Diagram: 3-Way Handshaking



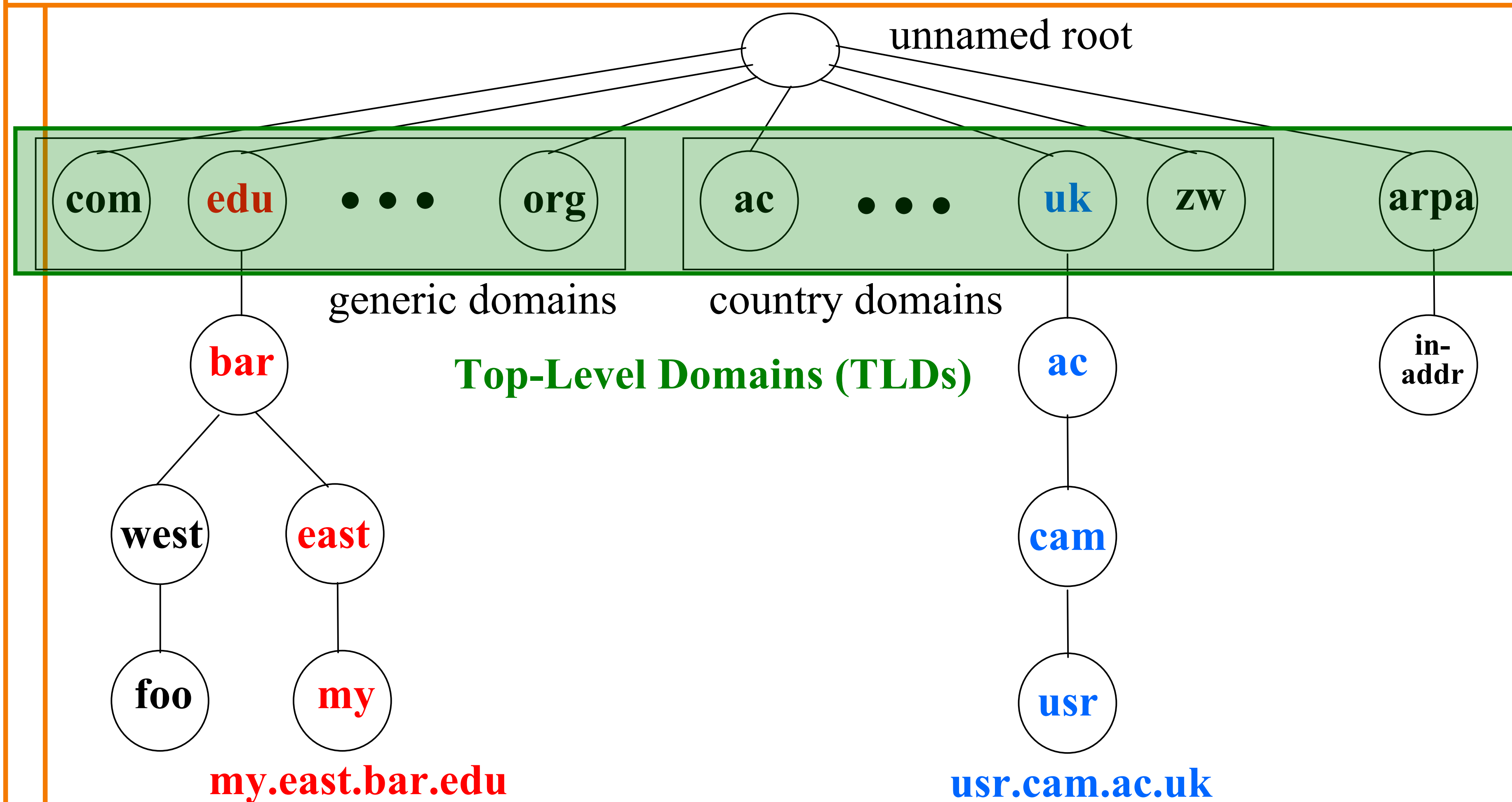
Host Names vs. IP addresses

- Host names
  - –Examples: `www.cnn.com` and `bbc.co.uk`
  - –Mnemonic name appreciated by humans
  - –Variable length, full alphabet of characters
  - –Provide little (if any) information about location
- IP addresses
  - –Examples: `64.236.16.20` and `212.58.224.131`
  - –Numerical address appreciated by routers
  - –Fixed length, binary number
  - –Hierarchical, related to host location

Mapping Names to Addresses

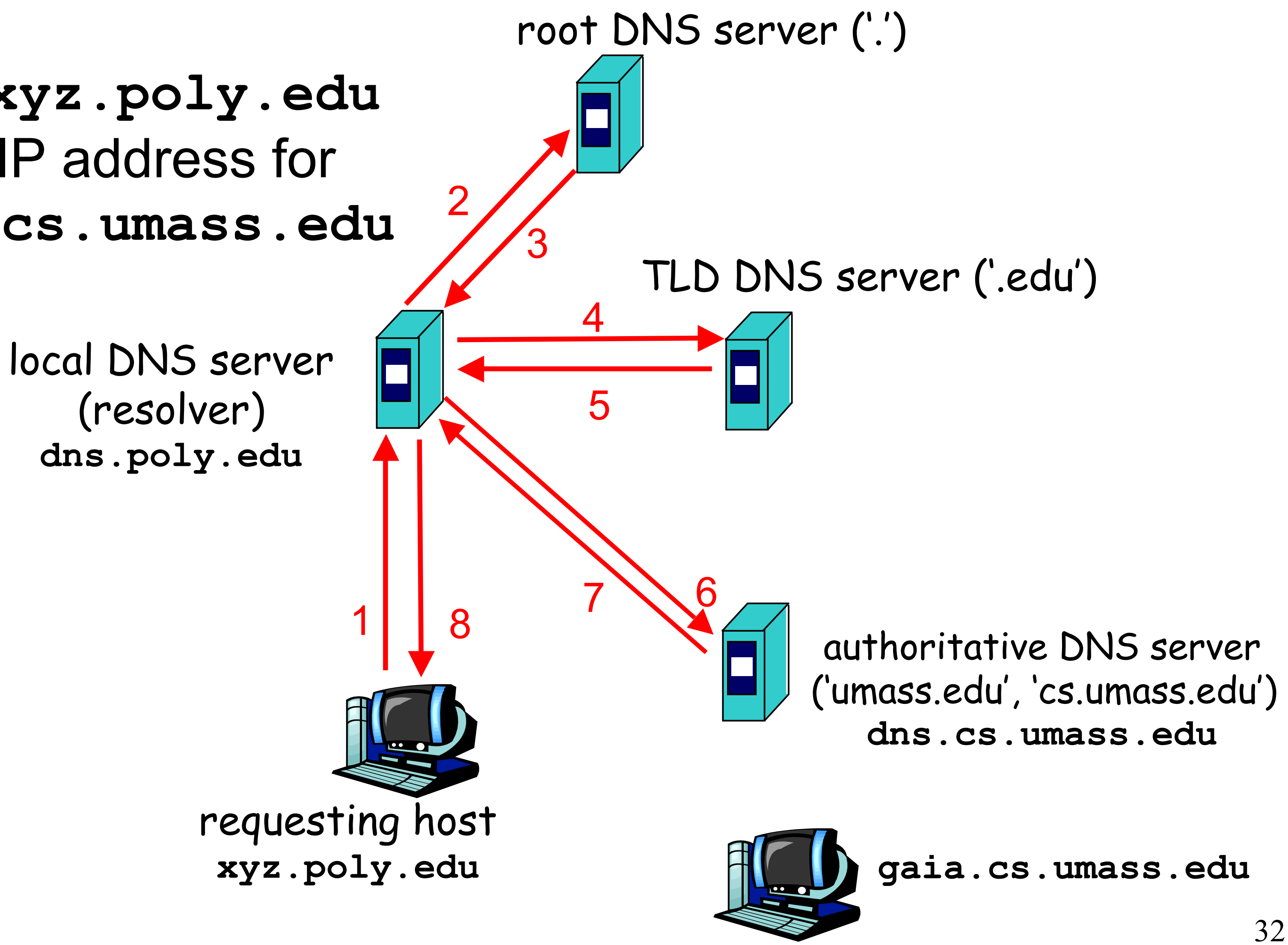
- Domain Name System (DNS)
  - Hierarchical name space divided into zones
  - Zones distributed over collection of DNS servers
  - (Also separately maps addresses to names)
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - "Authoritative" DNS servers (e.g. for *berkeley.edu*)
- Performing the translations
  - Each computer configured to contact a *resolver*

Distributed Hierarchical Database



Example

Host at **`xyz.poly.edu`** wants IP address for **`gaia.cs.umass.edu`**



DNS Protocol

DNS protocol: *query* and *reply* messages, both with same *message format*

(Mainly uses UDP transport rather than TCP)

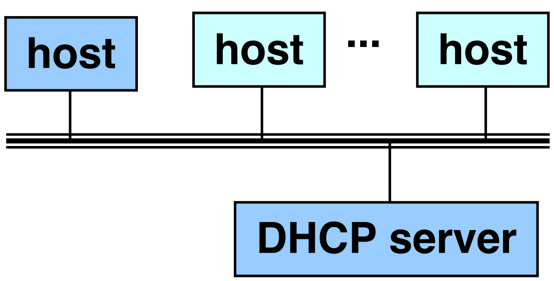
Message header:

- Identification: 16 bit # for query, reply to query uses same #
- Replies can include “Authority” (name server responsible for answer) and “Additional” (info client is likely to look up soon anyway)
- Replies have a Time To Live (in seconds) for **caching**

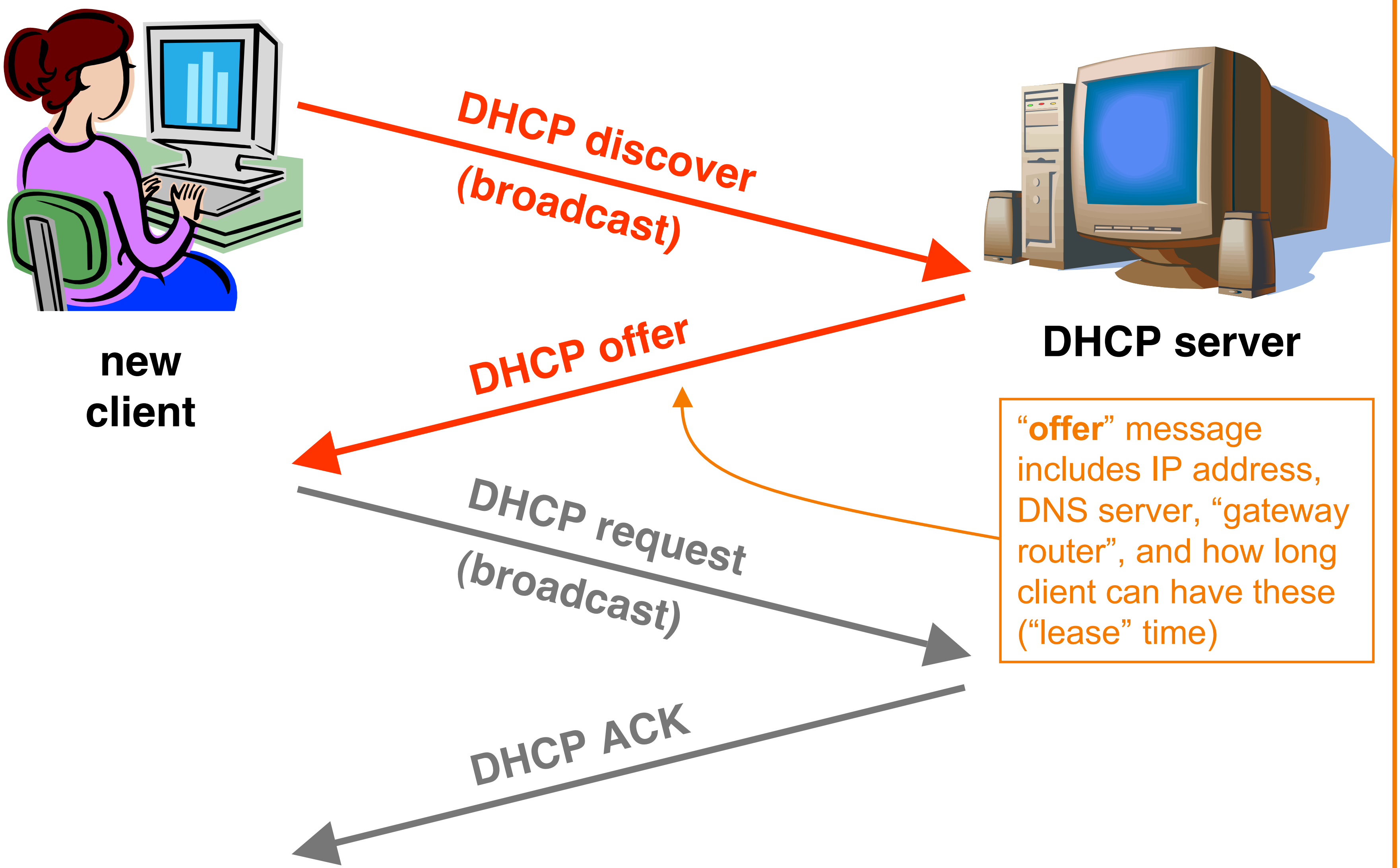
16 bits	*16 bits*
Identification	**Flags**
# Questions	**# Answer RRs**
# Authority RRs	**# Additional RRs**
Questions (variable # of resource records)	
Answers (variable # of resource records)	
Authority (variable # of resource records)	
Additional information (variable # of resource records)	

Bootstrapping Problem

- New host doesn't have an IP address yet
  - So, host doesn't know what source address to use
- Host doesn't know *who to ask* for an IP address
  - So, host doesn't know what destination address to use
- Solution: shout to "**discover**" server that can help
  - Broadcast a server-discovery message (layer 2)
  - Server(s) sends a reply offering an address



Dynamic Host Configuration Protocol



Questions?