Network Security:
Background and Start on Attacks

CS 161: Computer Security

Prof. Raluca Ada Popa

February 26, 2019

Some slides credit David Wagner.

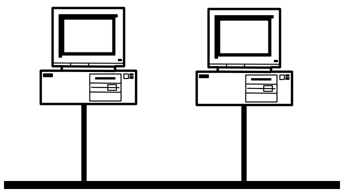
Announcements

- Project collaboration policy: every teammate must do every part
- Midterm 1 grades will be out by hopefully end of this week, one week for regrades
- Project 2 due March 11, get started
- Switching order of network security with web security in syllabus

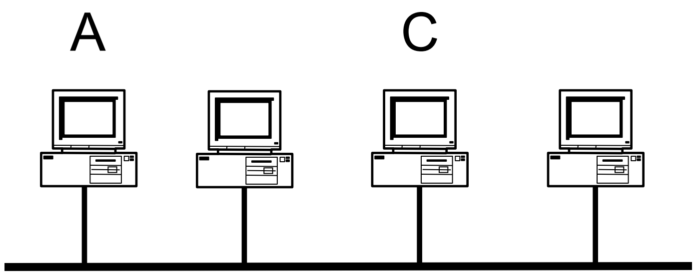
Networking overview

Pay attention to this material (part of 168) because you will need this to understand it for the class

Local-Area Networks (LAN)



point-to-point



shared

If two computers transmit at the same time, they interfere

How does computer A send a message to computer C?

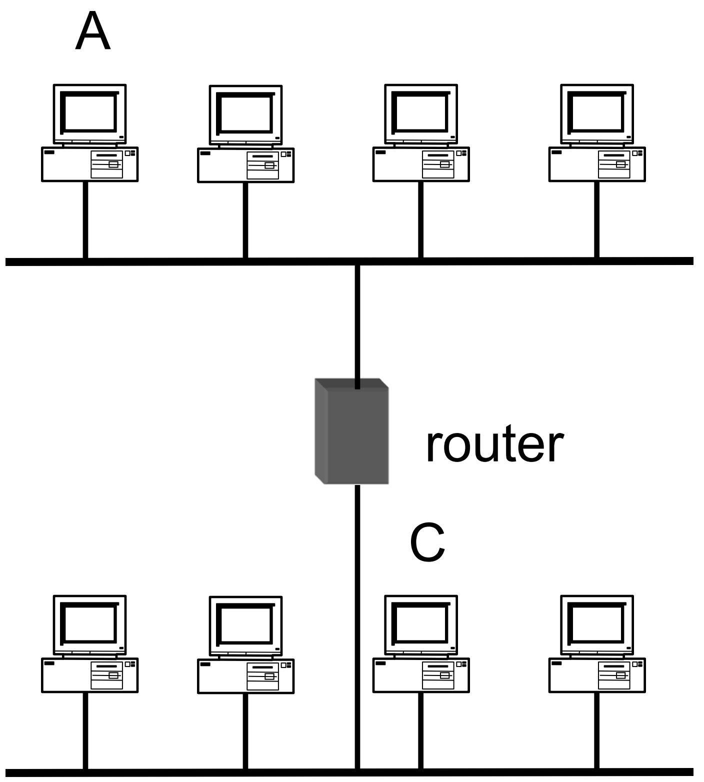
Packets

```
Source: A
Destination: C
Message: Hello world!
```

A	C	Hello world!

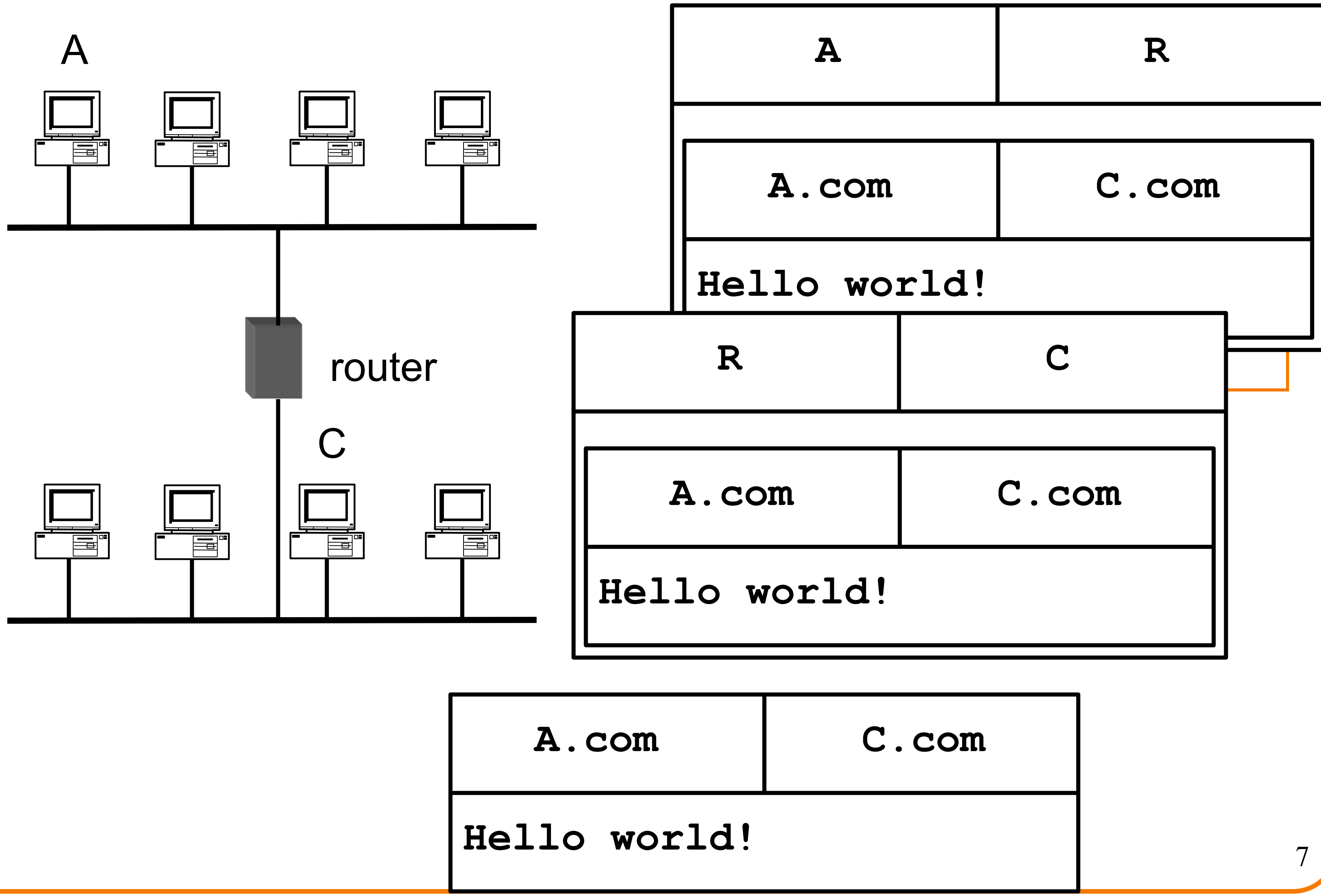
A	C
Hello world!	

Wide-Area Networks



How do we connect two LANs?

Wide-Area Networks



Key Concept #1: *Protocols*

- A protocol is an agreement on how to communicate
- Includes syntax and semantics
  - How a communication is specified & structured
    - Format, order messages are sent and received
  - What a communication means
    - Actions taken when transmitting, receiving, or timer expires
- Example: making a comment 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): say “excuse me”

Key Concept #2: *Dumb Network*

- Original Internet design: interior nodes ("routers") have no knowledge* of ongoing connections going through them
- **Not** how you the telephone system works
  - Which internally tracks all of the active voice calls
- Instead: the postal system!
  - Each Internet message ("packet") self-contained

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

Self-Contained IP Packet Format

IP = Internet *Protocol*

4-bit Version	4-bit Header Length	8-bit Type of Service (TOS)	16-bit Total Length (Bytes)	
16-bit Identification			3-bit Flags	13-bit Fragment Offset
8-bit Time to Live (TTL)	8-bit Protocol		16-bit Header Checksum	
32-bit Source IP Address				
32-bit Destination IP Address				

Payload (remainder of message)

.
.
.
.

Header **is like a letter envelope: contains all info needed for delivery**

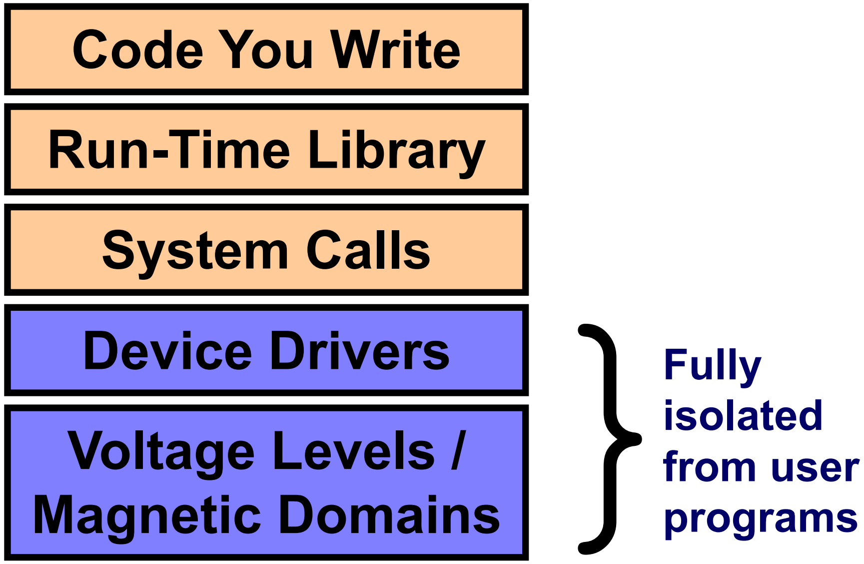
Key Concept #2: *Dumb Network*

- Original Internet design: interior nodes ("routers") have <u>no</u> 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

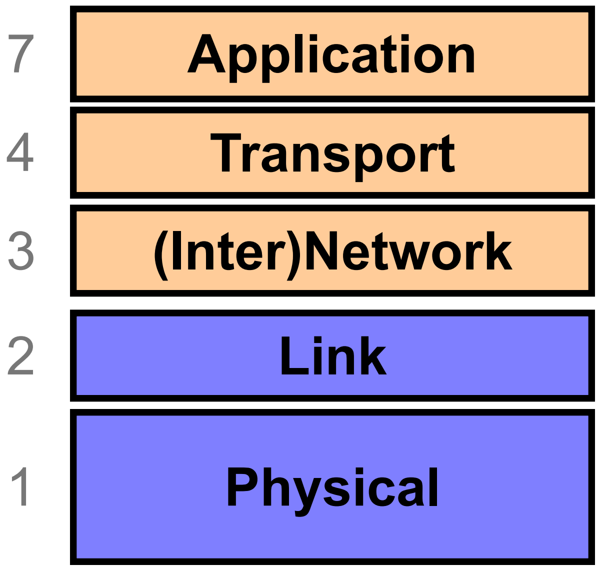
* Today's Internet is full of hacks that violate this

Key Concept #3: *Layering*

- The 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



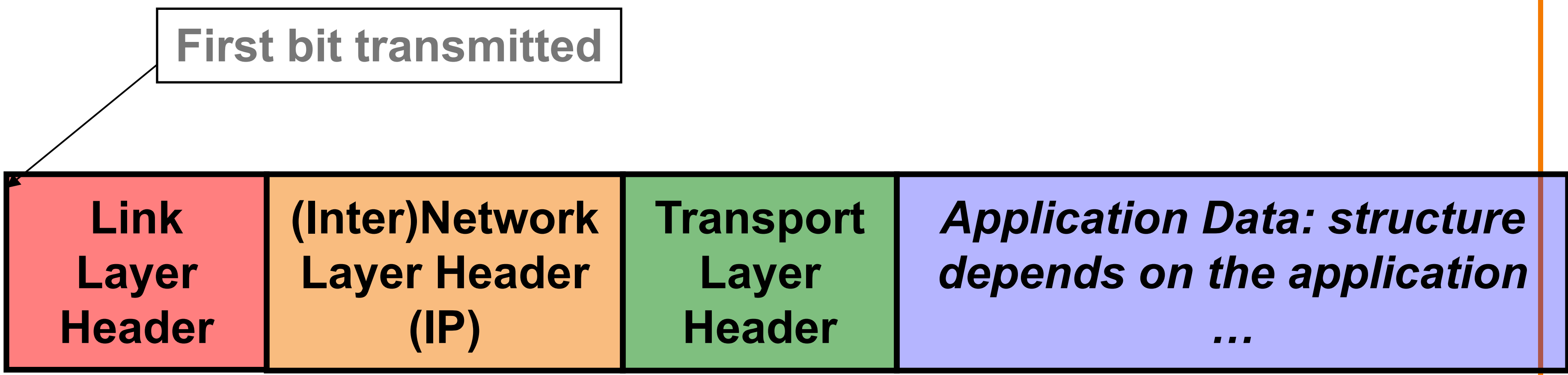
Internet Layering ("Protocol Stack")



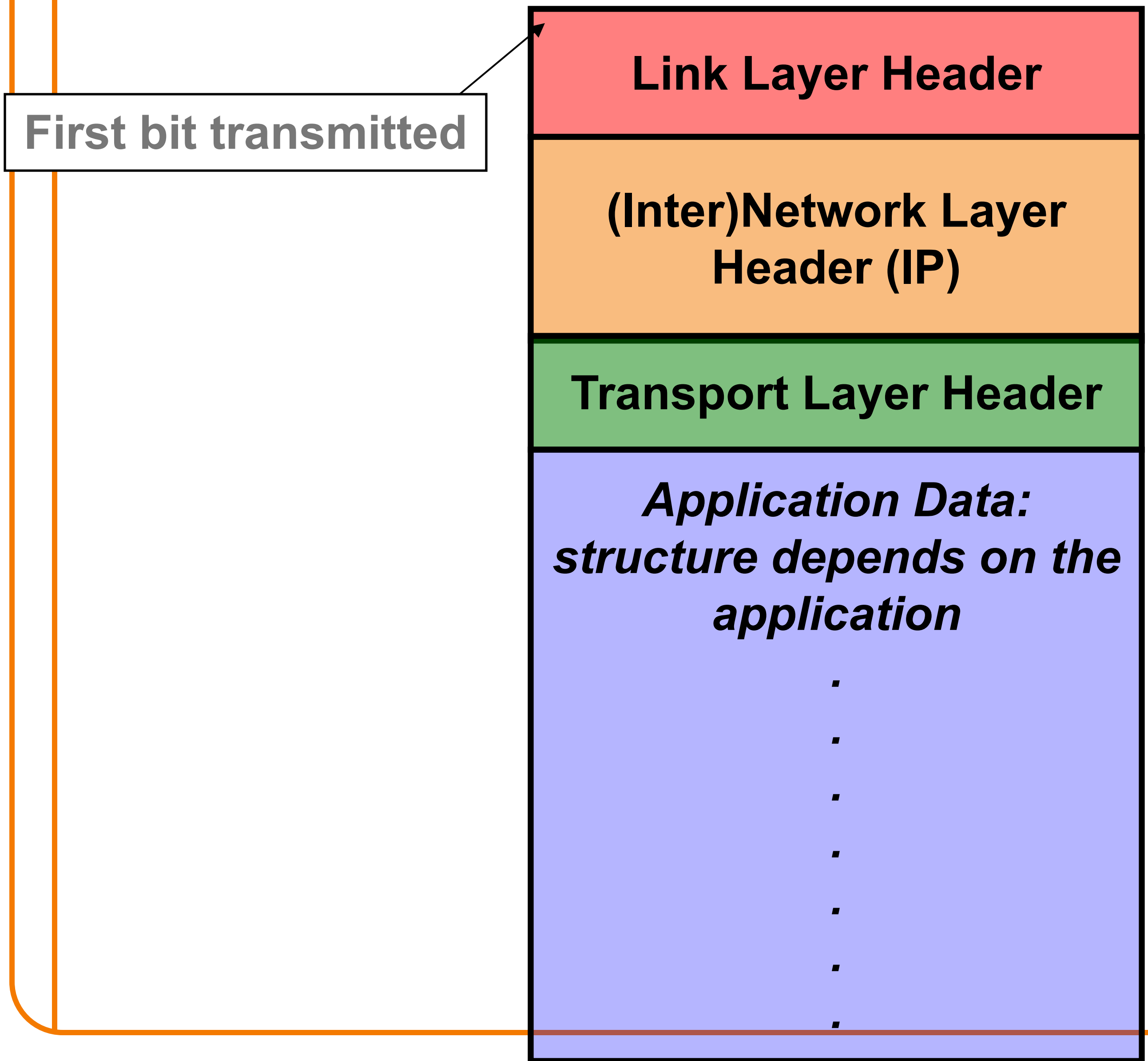
Note on a point of potential confusion: these diagrams are always drawn with lower layers **below** higher layers …

But diagrams showing the layouts of packets are often the *opposite*, with the lower layers at the **top** since their headers <u>precede</u> those for higher layers

Horizontal View of a Single Packet



Vertical View of a Single Packet



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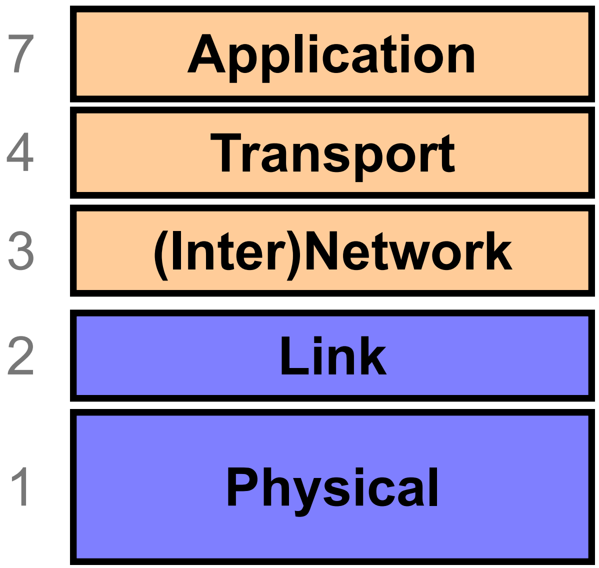
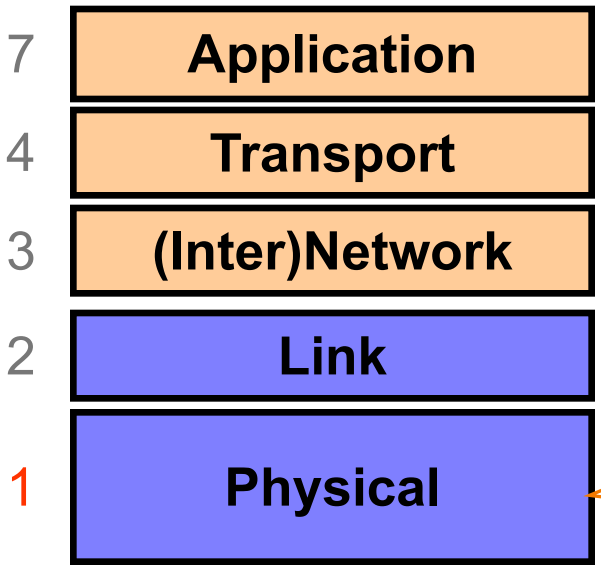


Layer 1: Physical Layer



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

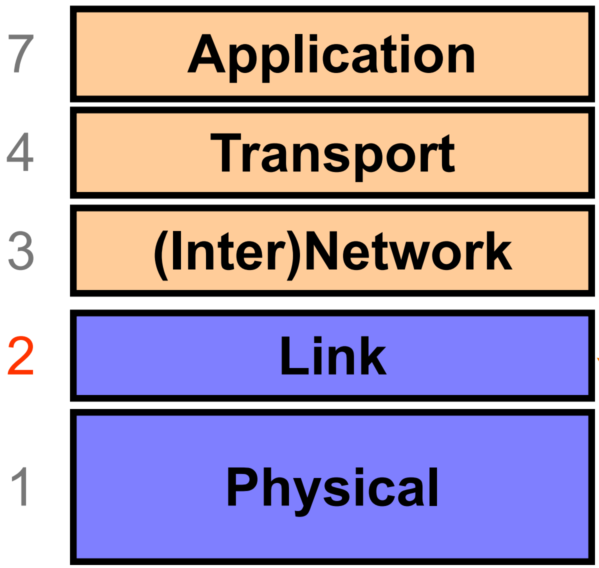
e.g. patterns of

voltage levels /

photon intensities /

RF modulation

Layer 2: Link Layer

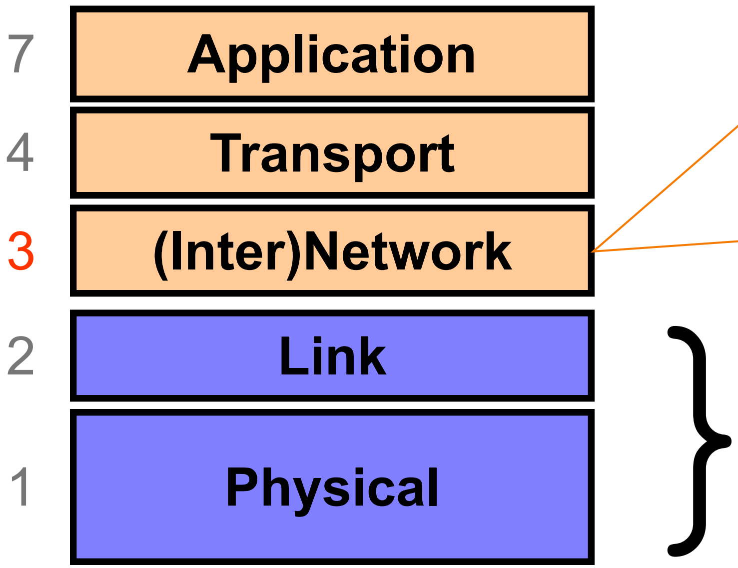


Framing and transmission of a collection of bits into individual messages sent across a single "subnetwork" (one physical technology)

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 *(IP)*



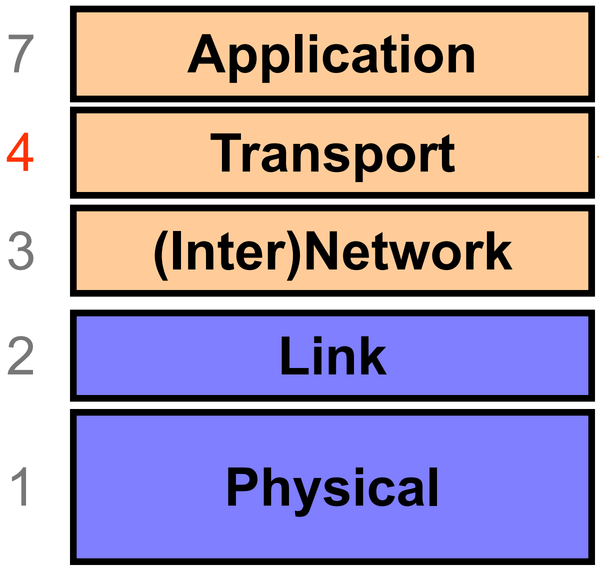
Bridges multiple "subnets" to provide *end-to-end* internet connectivity between nodes

- Provides global addressing

Works across different link technologies

Different **for each Internet "hop"**

Layer 4: Transport Layer

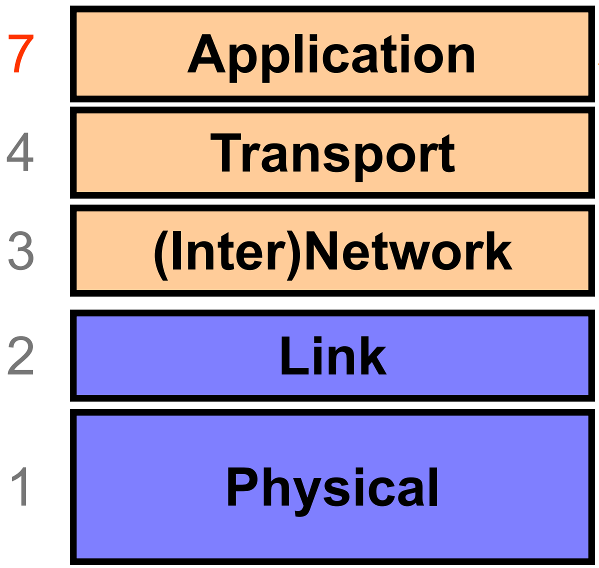


End-to-end communication between processes

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

(Datagram = single packet message)

Layer 7: Application Layer



Communication of whatever you wish

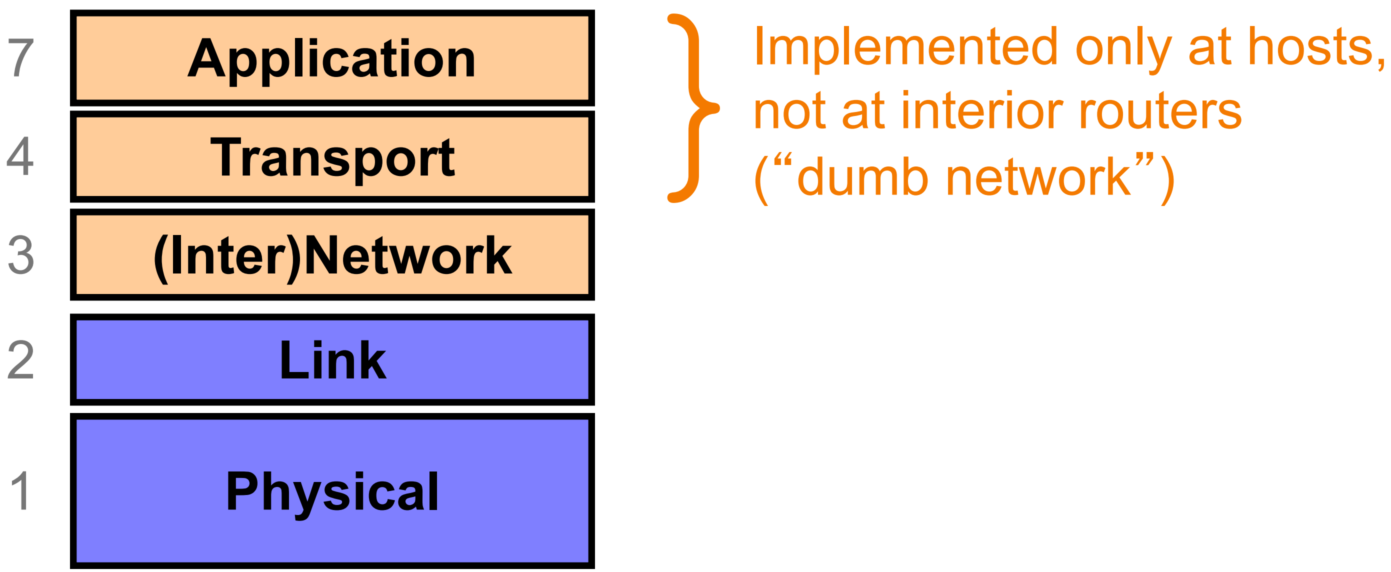
Can use whatever transport(s) is convenient

Freely structured

E.g.:

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

Internet Layering ("Protocol Stack")



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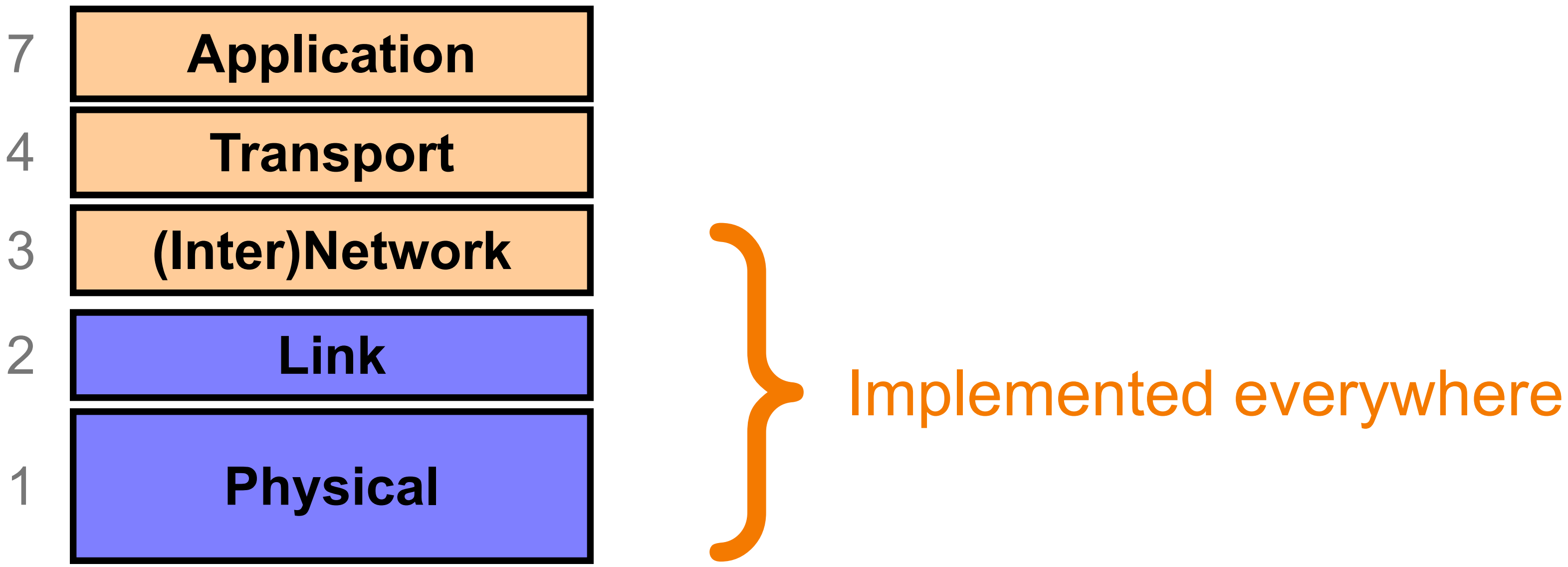

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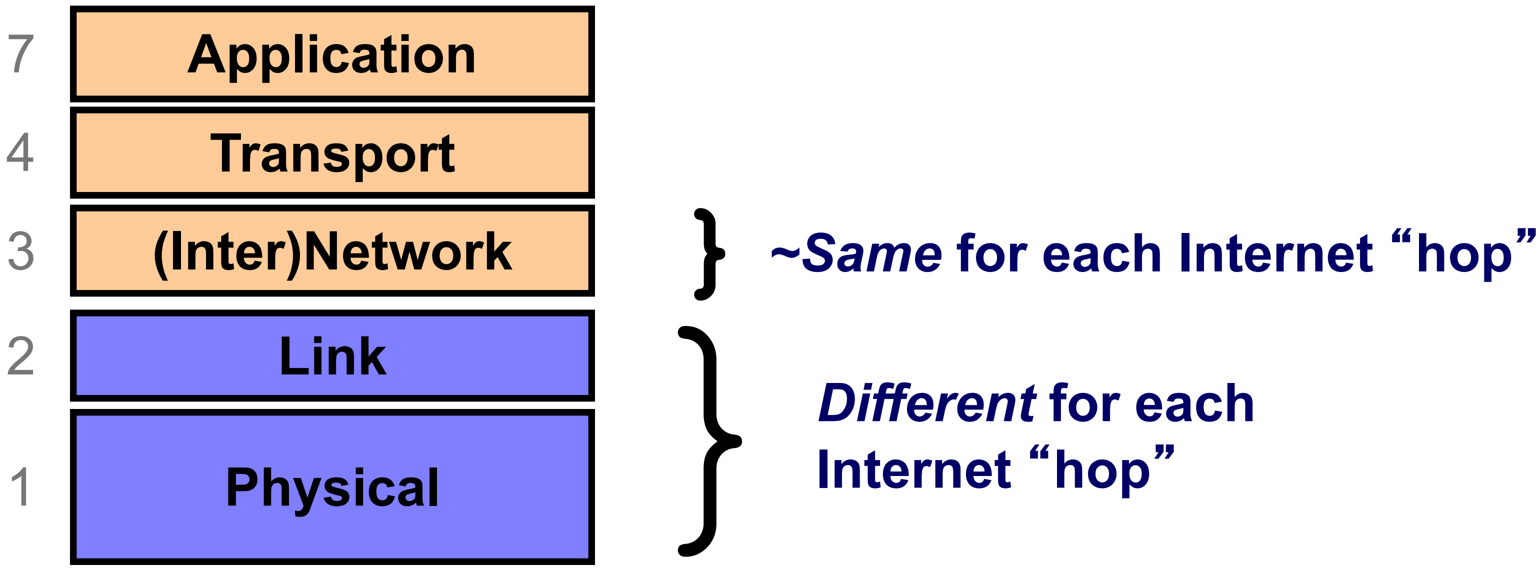
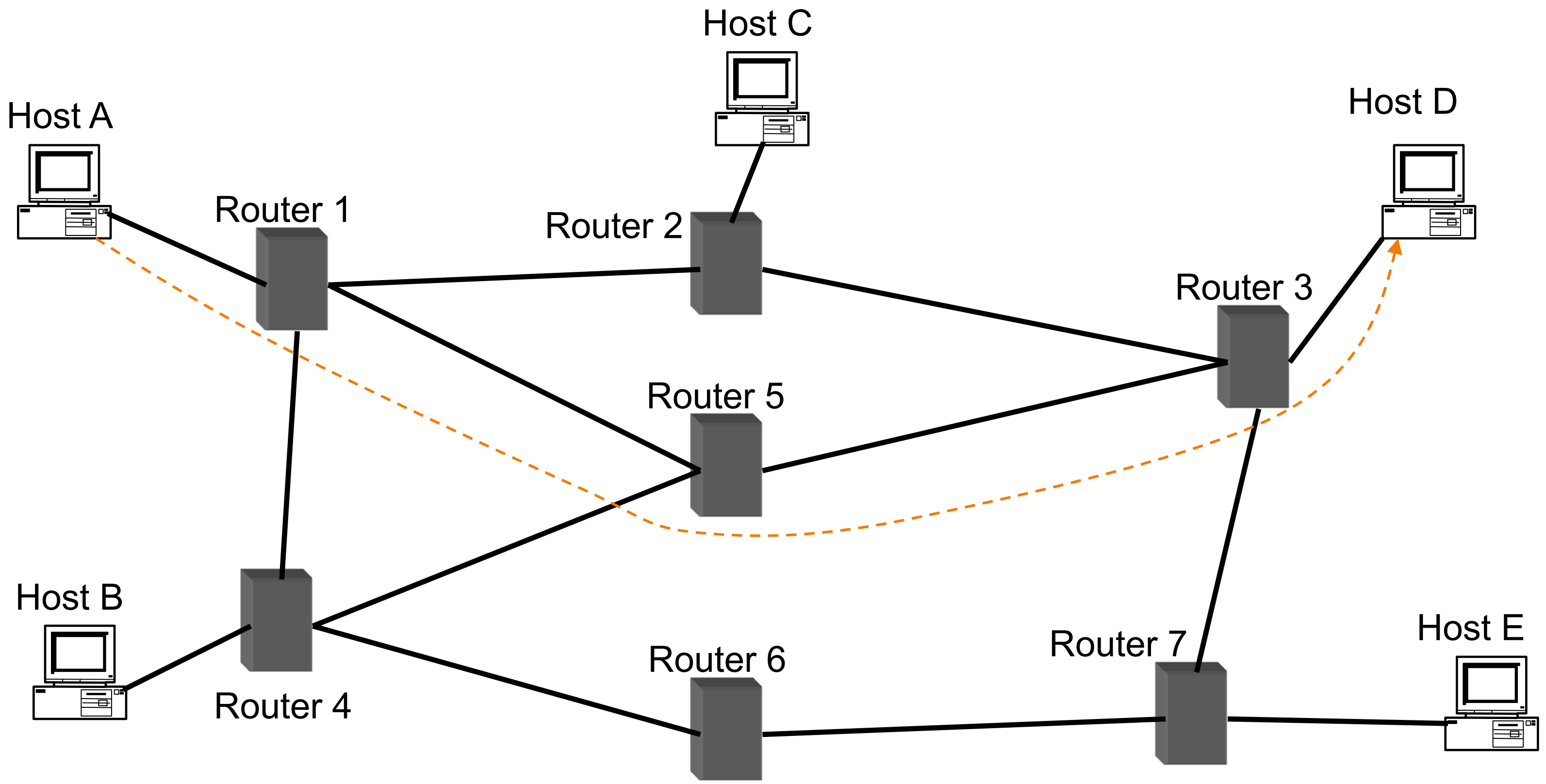


Hop-By-Hop vs. End-to-End Layers

Host A communicates with Host D



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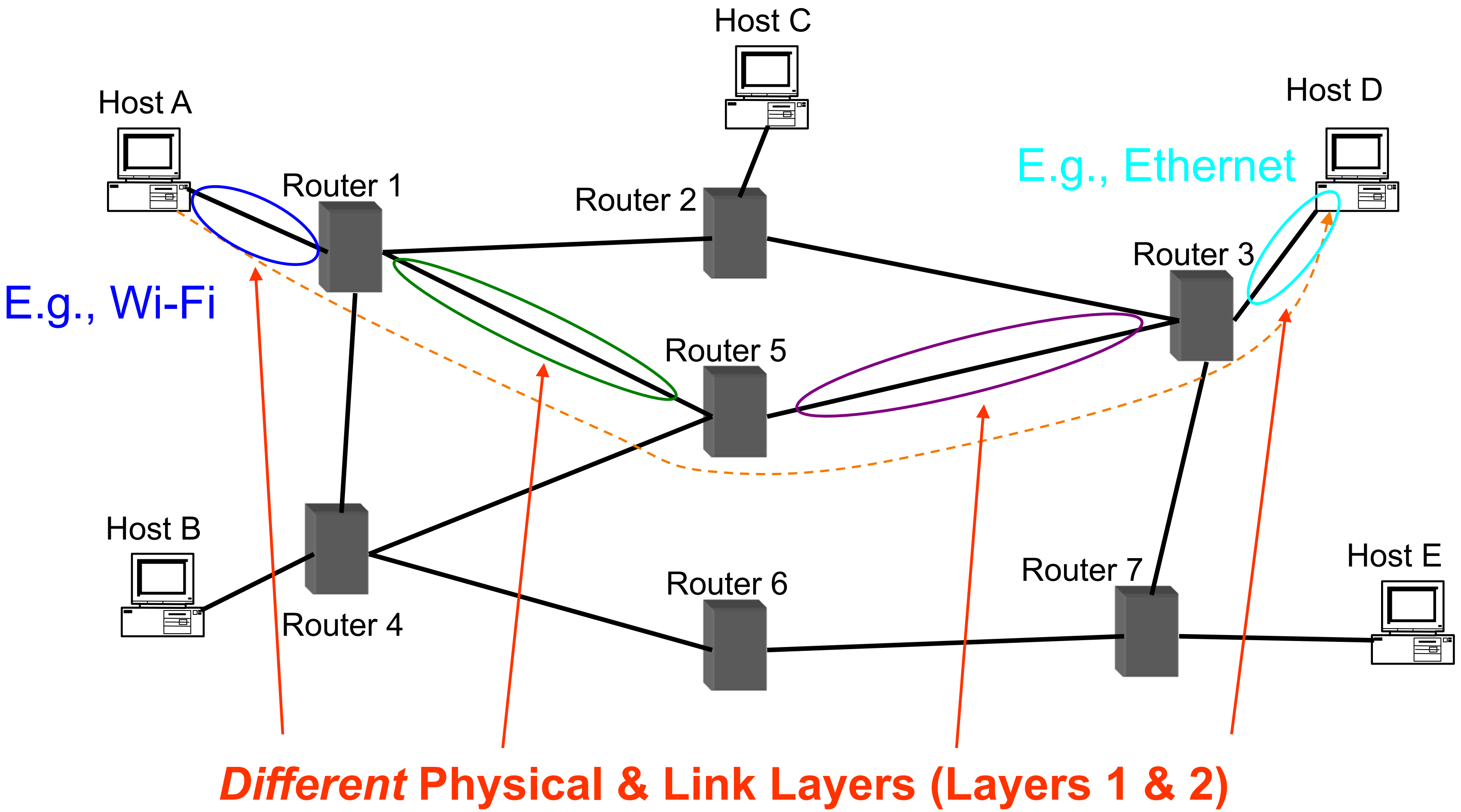

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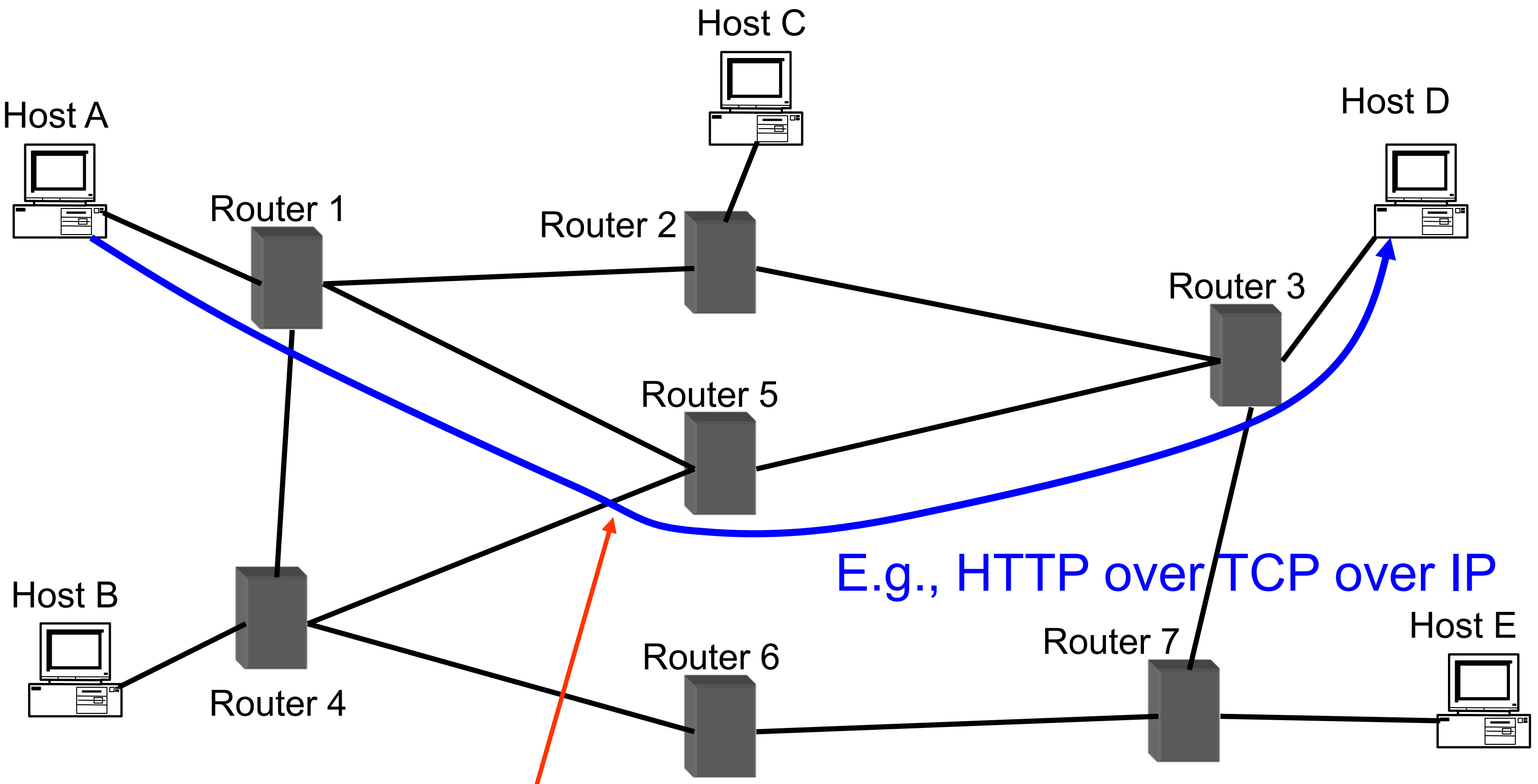
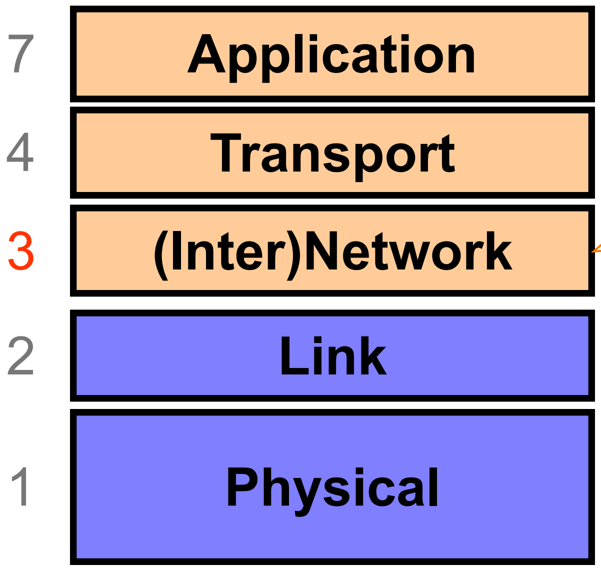


Same Network / Transport / Application Layers
(Routers **ignore** Transport & Application layers)

Layer 3: (Inter)Network Layer *(IP)*

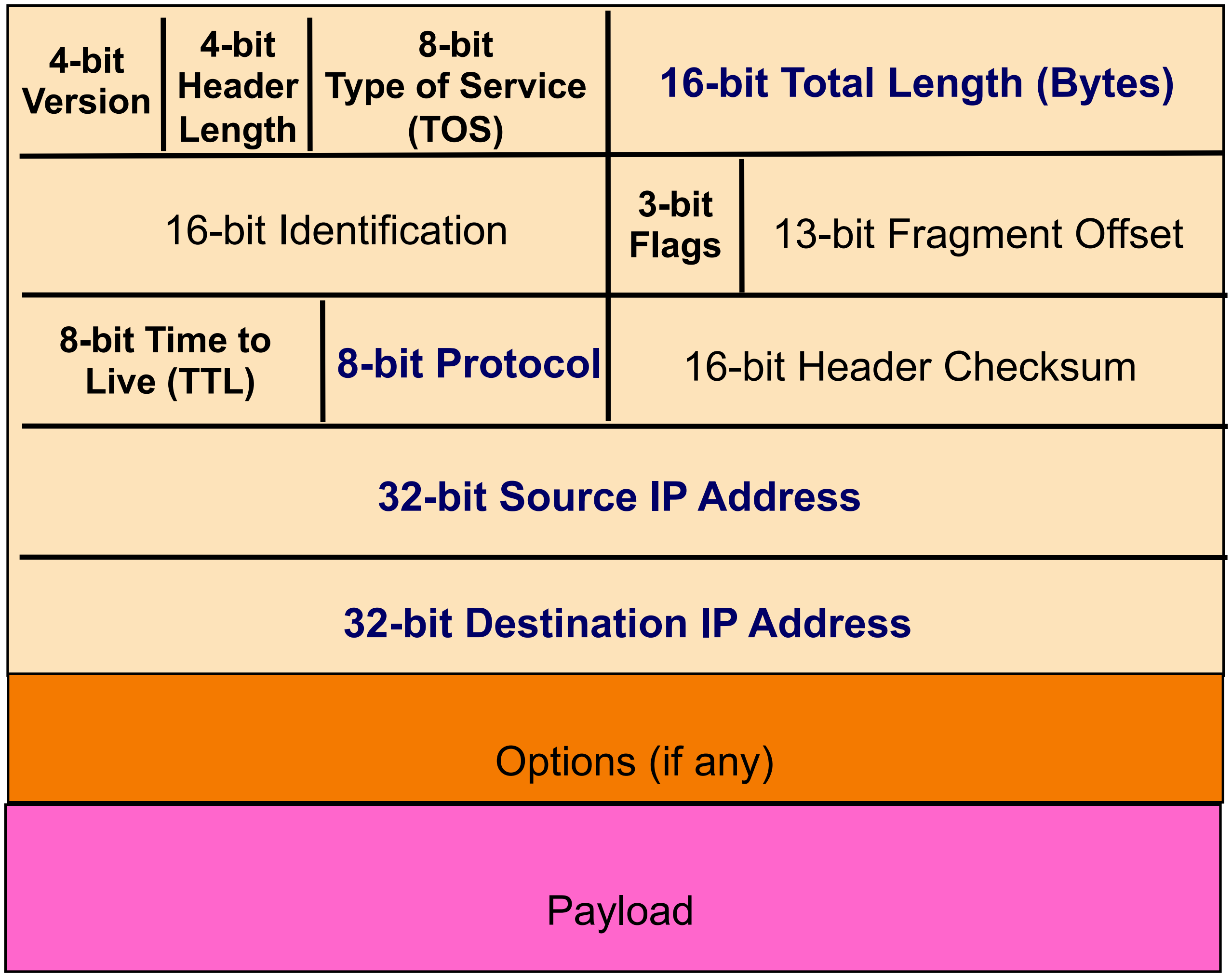


Bridges multiple "subnets" to provide *end-to-end* internet connectivity between nodes

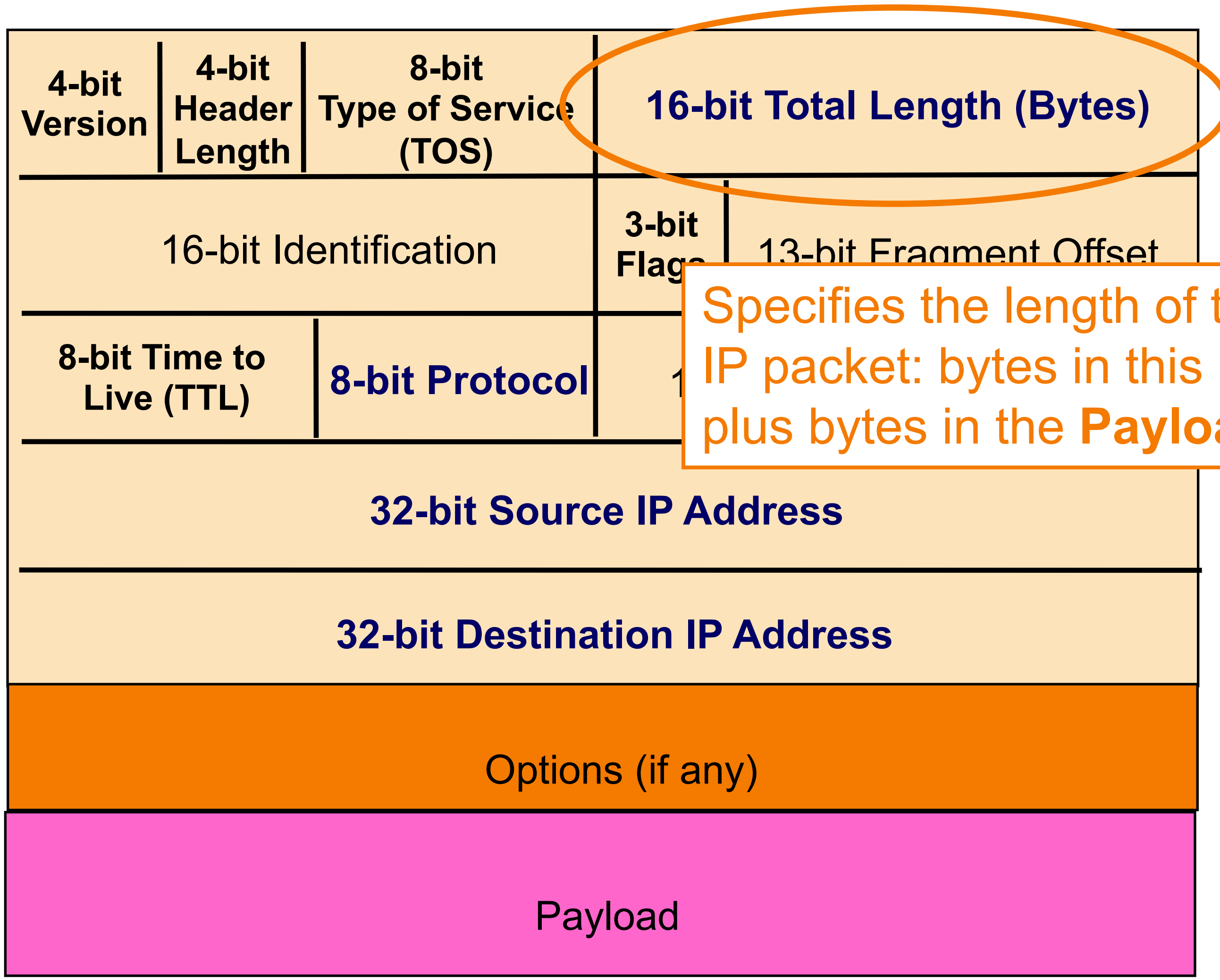
- Provides global addressing

Works across different link technologies

IP Packet Structure

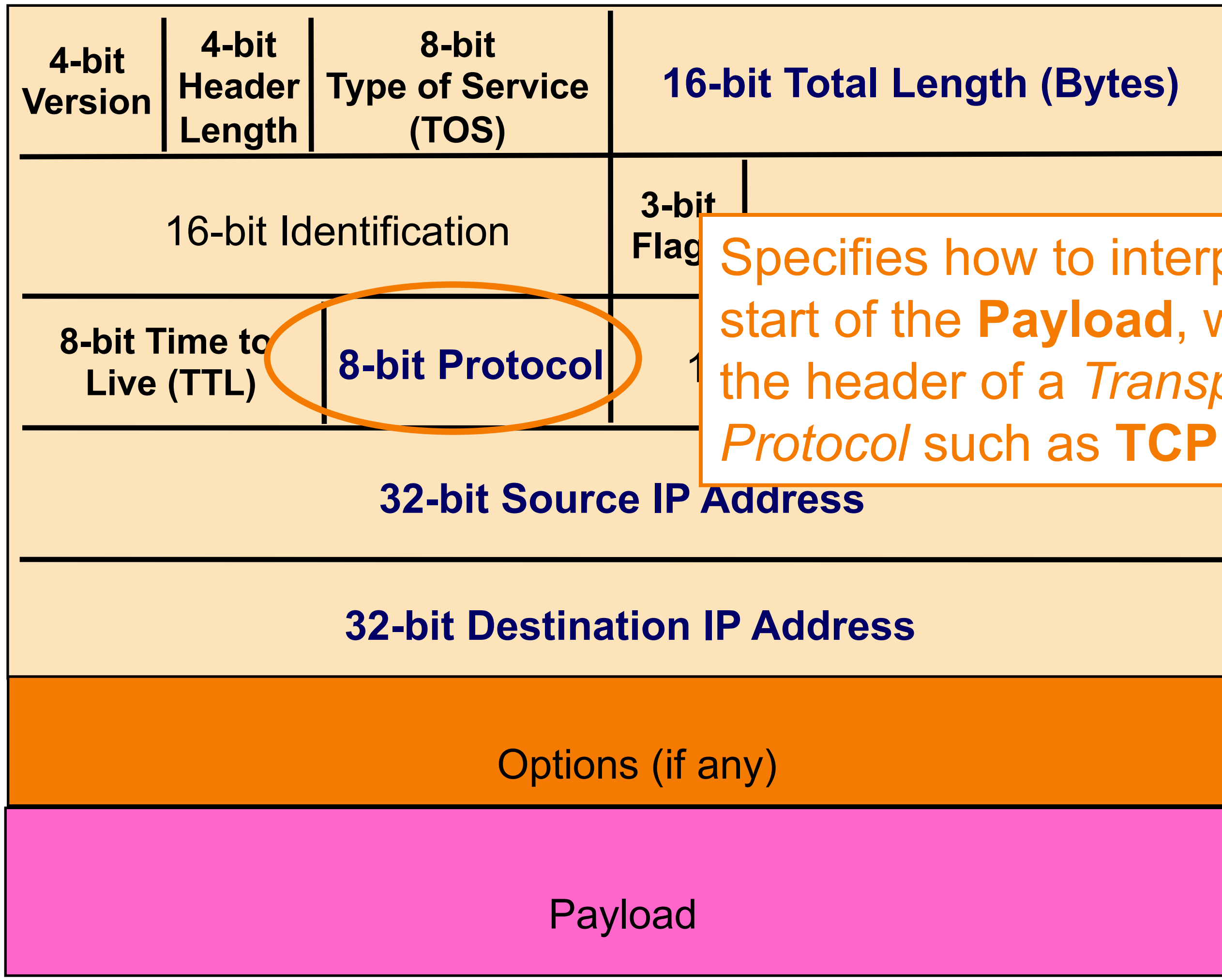


IP Packet Structure



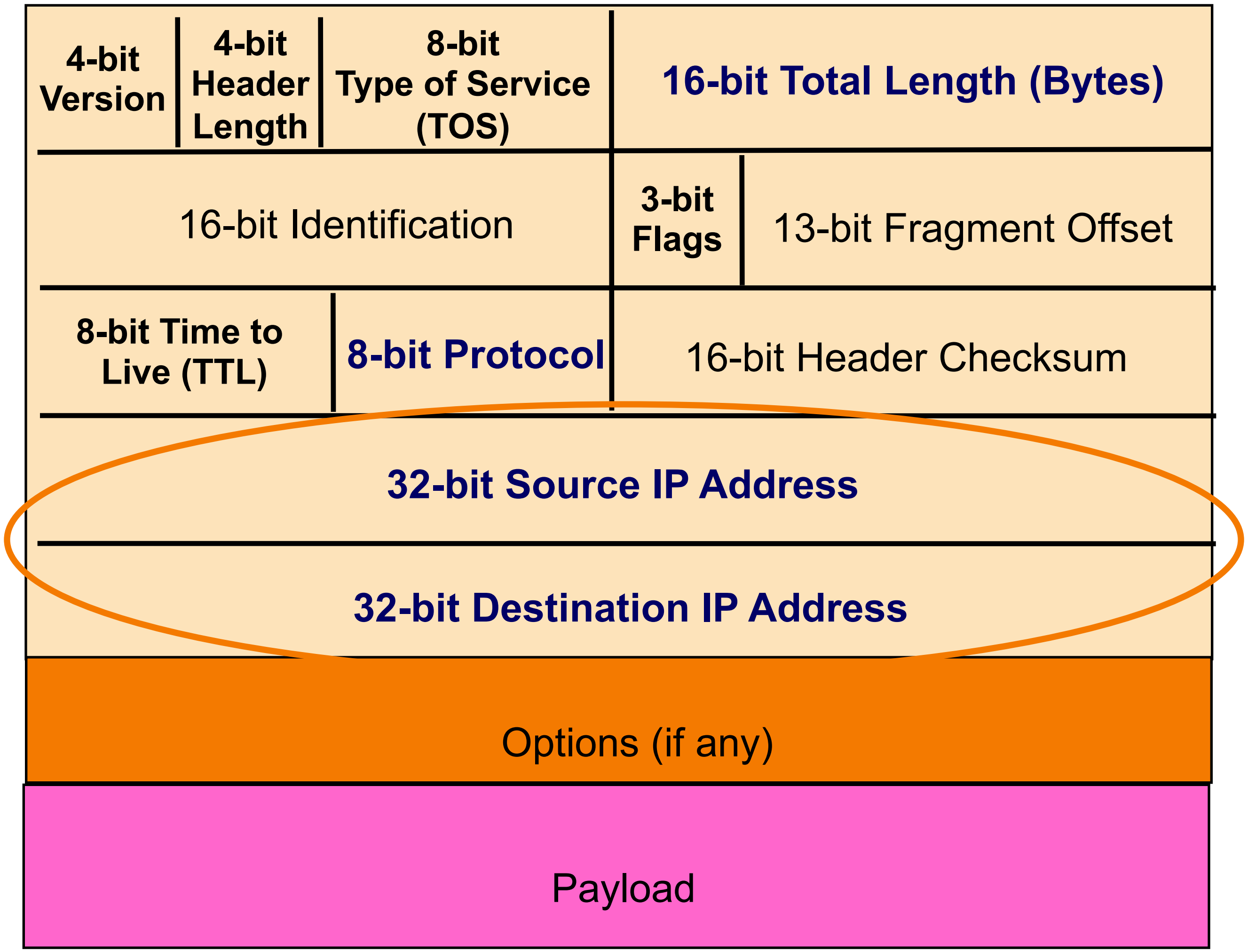
Specifies the length of the entire IP packet: bytes in this header plus bytes in the **Payload**

IP Packet Structure



Specifies how to interpret the start of the **Payload**, which is the header of a *Transport Protocol* such as **TCP** or **UDP**

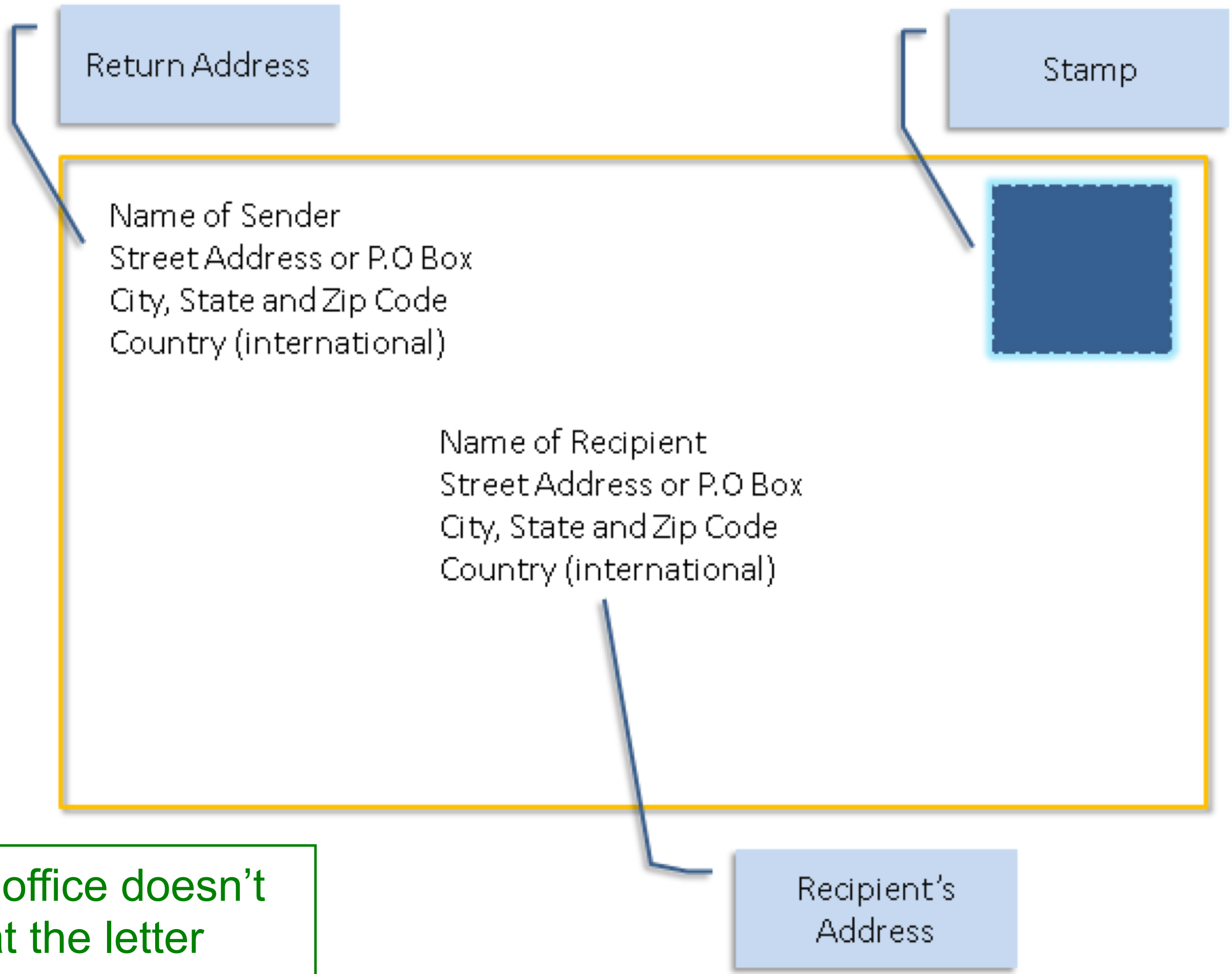
IP Packet Structure



IP Packet Header (Continued)

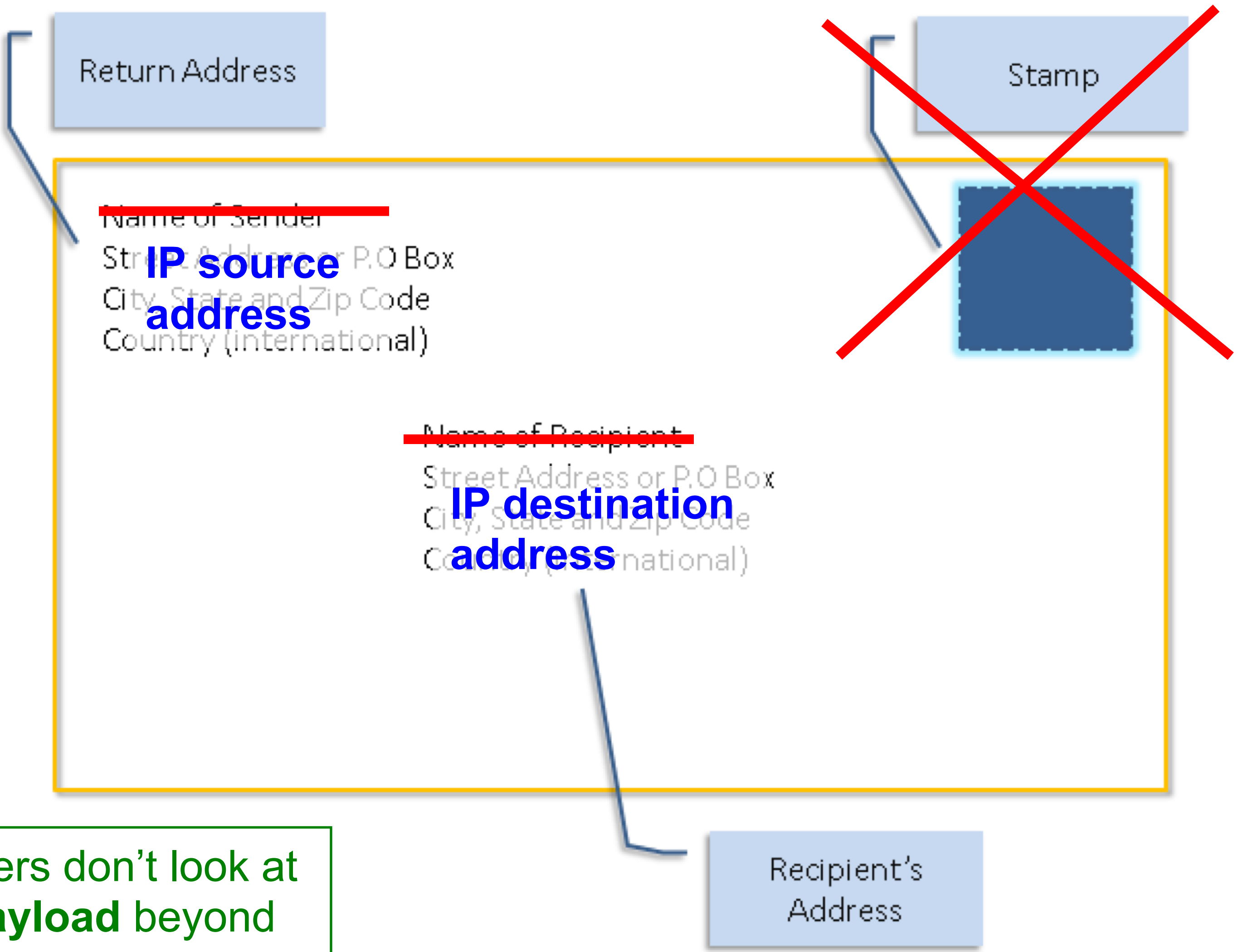
- Two IP addresses
  - Source IP address (32 bits)
  - Destination IP address (32 bits)
- Destination address
  - Unique identifier/locator for the receiving host
  - Allows each node to make forwarding decisions
- Source address
  - Unique identifier/locator for the sending host
  - Recipient can decide whether to accept packet
  - Enables recipient to send a reply back to source

Postal Envelopes:



(Post office doesn't look at the letter inside the envelope)

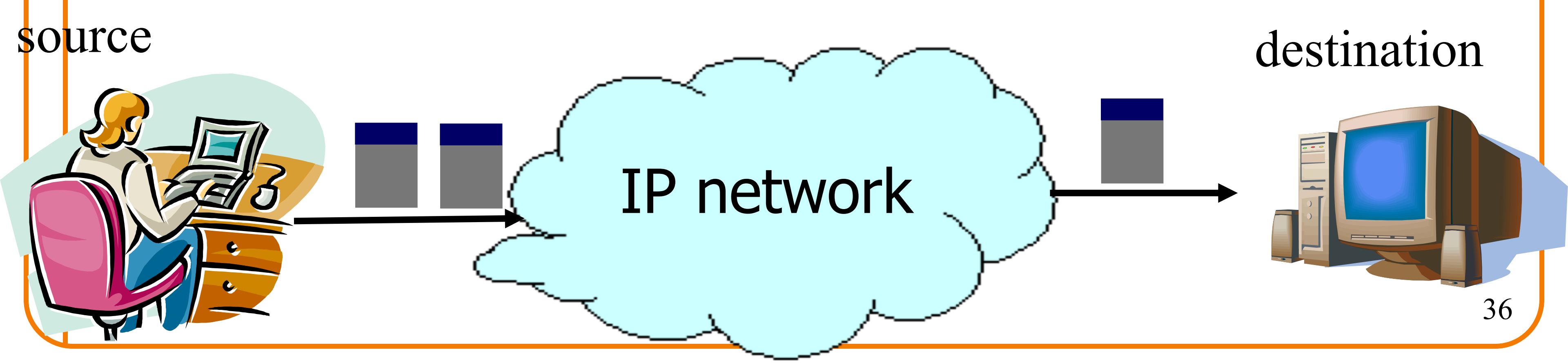
Analogy of IP to Postal Envelopes:



(Routers don't look at the **payload** beyond the IP header)

IP: "*Best Effort*" Packet Delivery

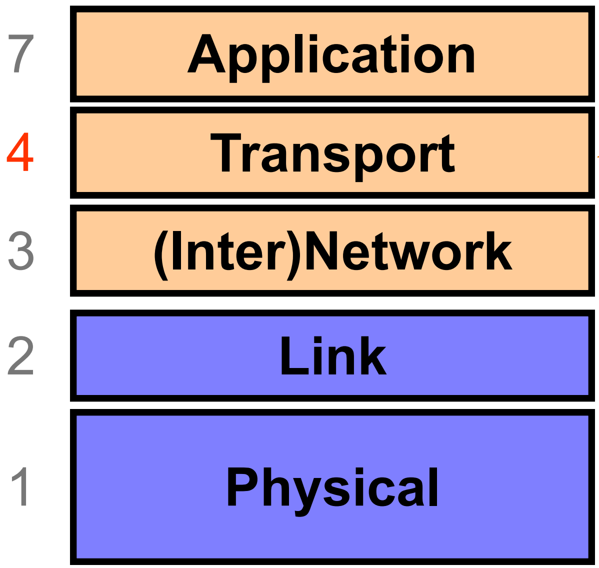
- Routers inspect destination address, locate "next hop" in forwarding table
  - Address = ~unique identifier/locator for the receiving host
- Only provides a "*I'll give it a try*" delivery service:
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order



"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

Layer 4: Transport Layer



End-to-end communication between processes

Different services provided:

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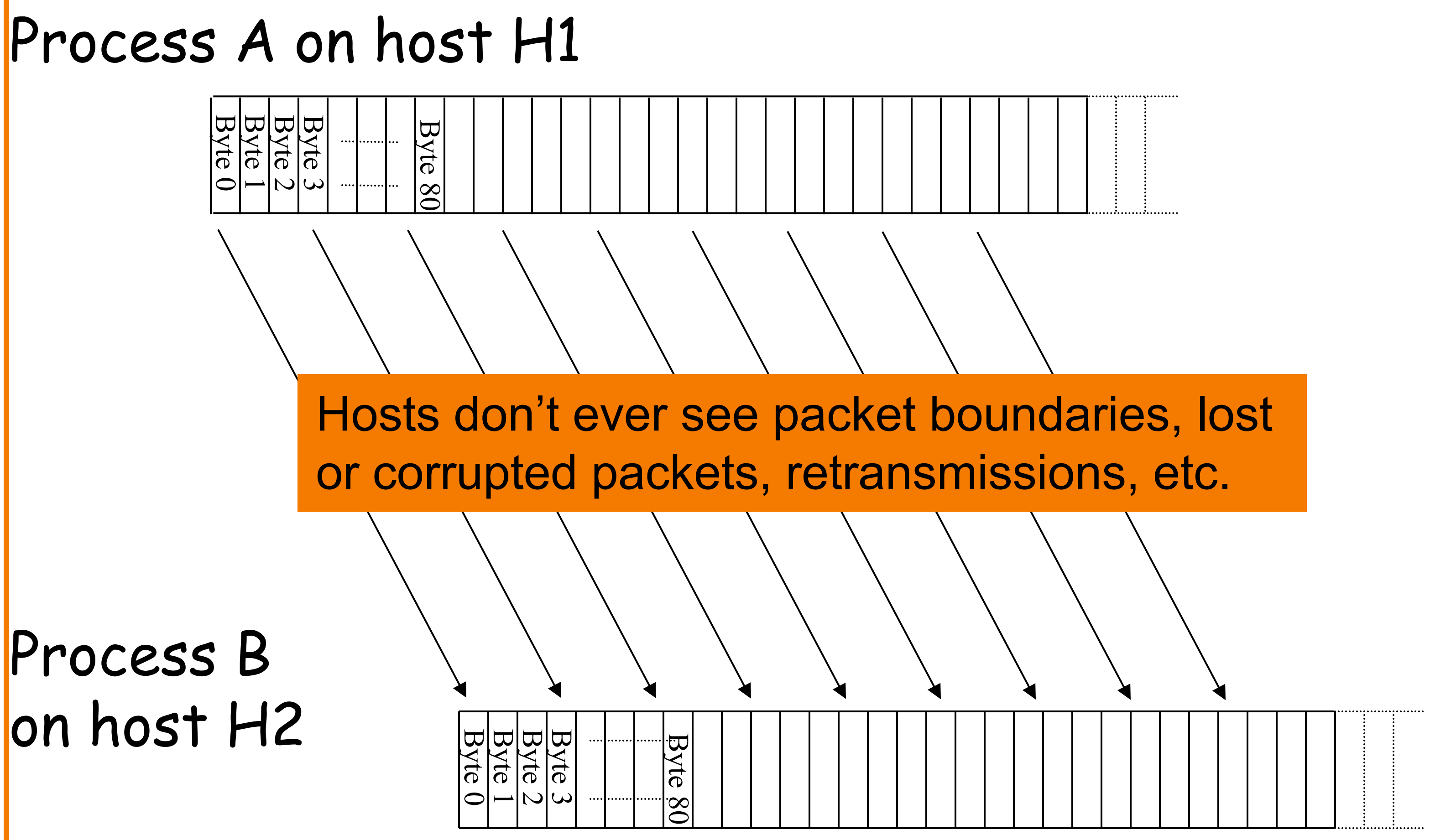
(Datagram = single packet message)

"Best Effort" is Lame! What to do?

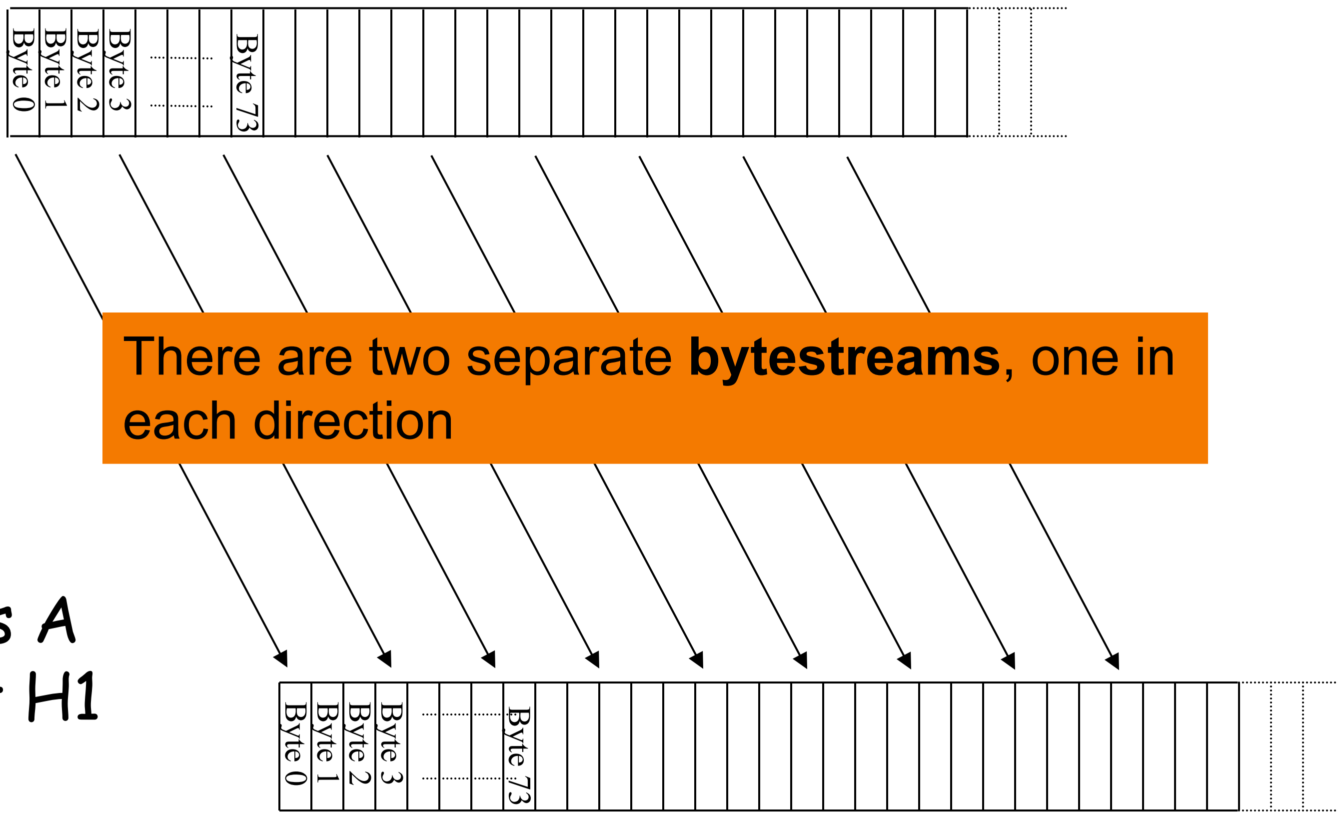
- It's the job of our Transport (layer 4) protocols to build services our apps need out of IP's modest layer-3 service
- #1 workhorse: TCP (Transmission Control Protocol)
- Service provided by TCP:
  - Connection oriented (explicit set-up / tear-down)
    - o End hosts (processes) can have multiple concurrent long-lived communication
  - **Reliable**, in-order, *byte-stream* delivery
    - o Robust detection & retransmission of lost data

TCP "Bytestream" Service



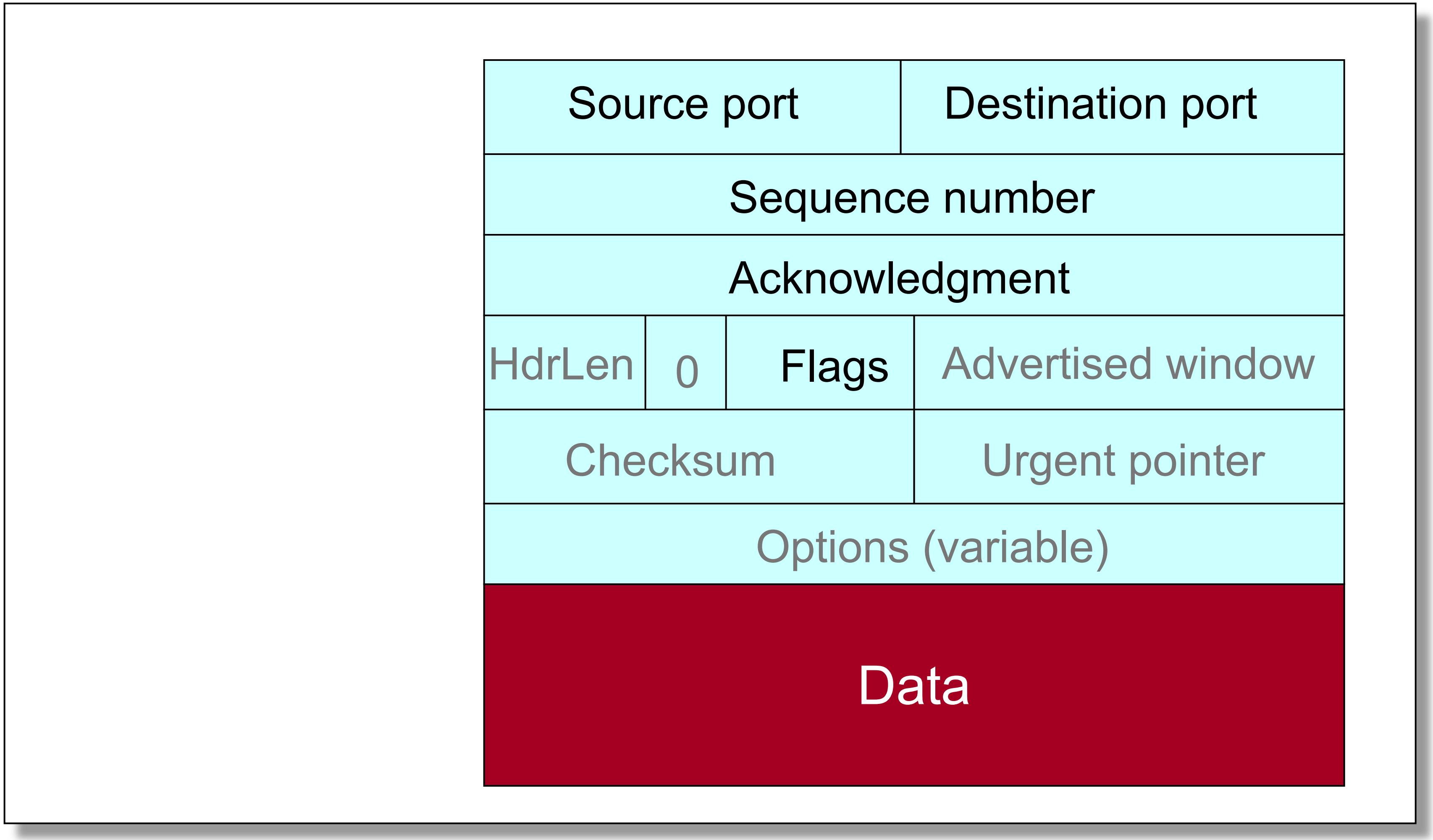
Bidirectional communication:

Process B on host H2

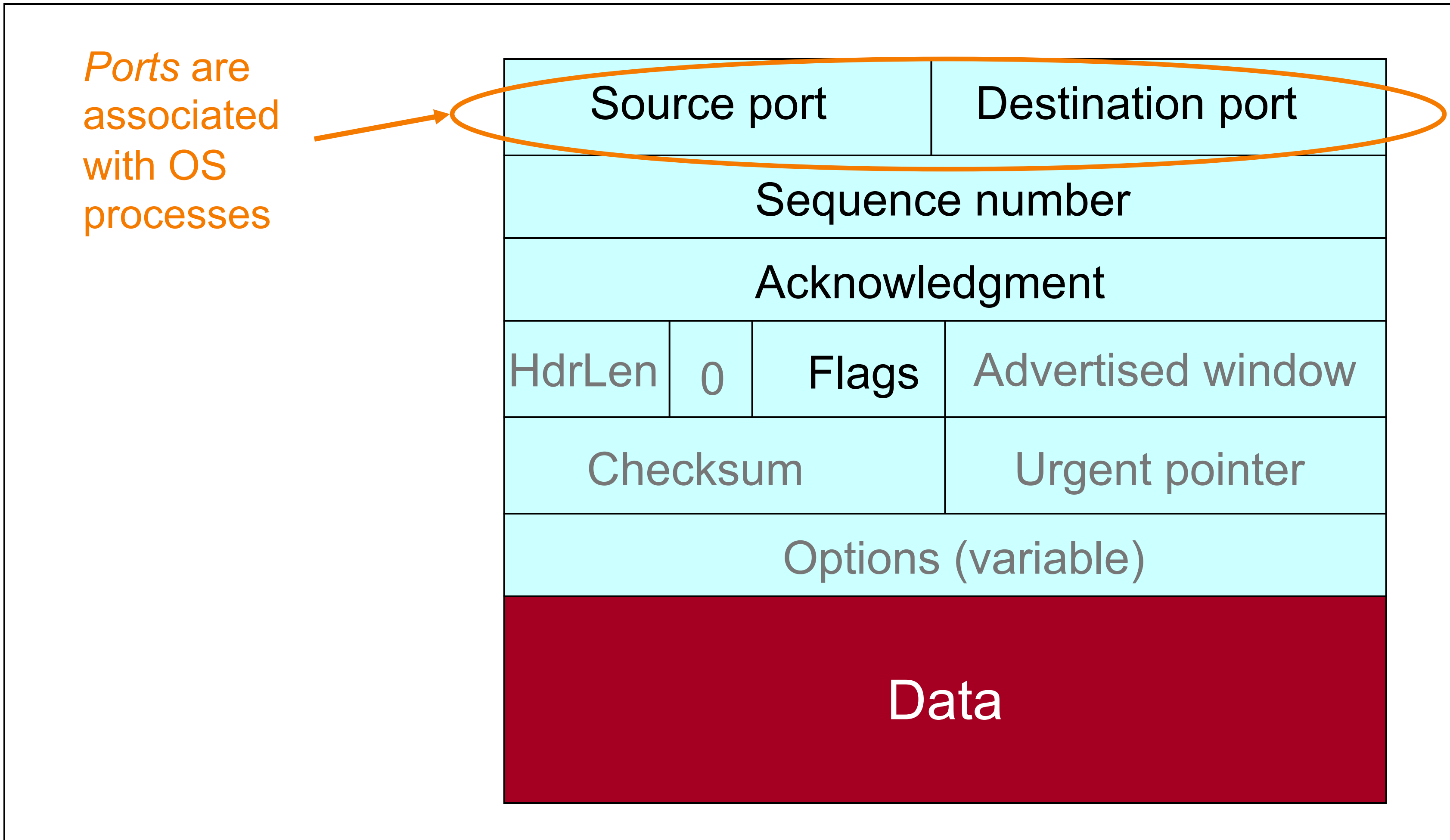


Process A
on host H1

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
Source port
Destination port
Sequence number
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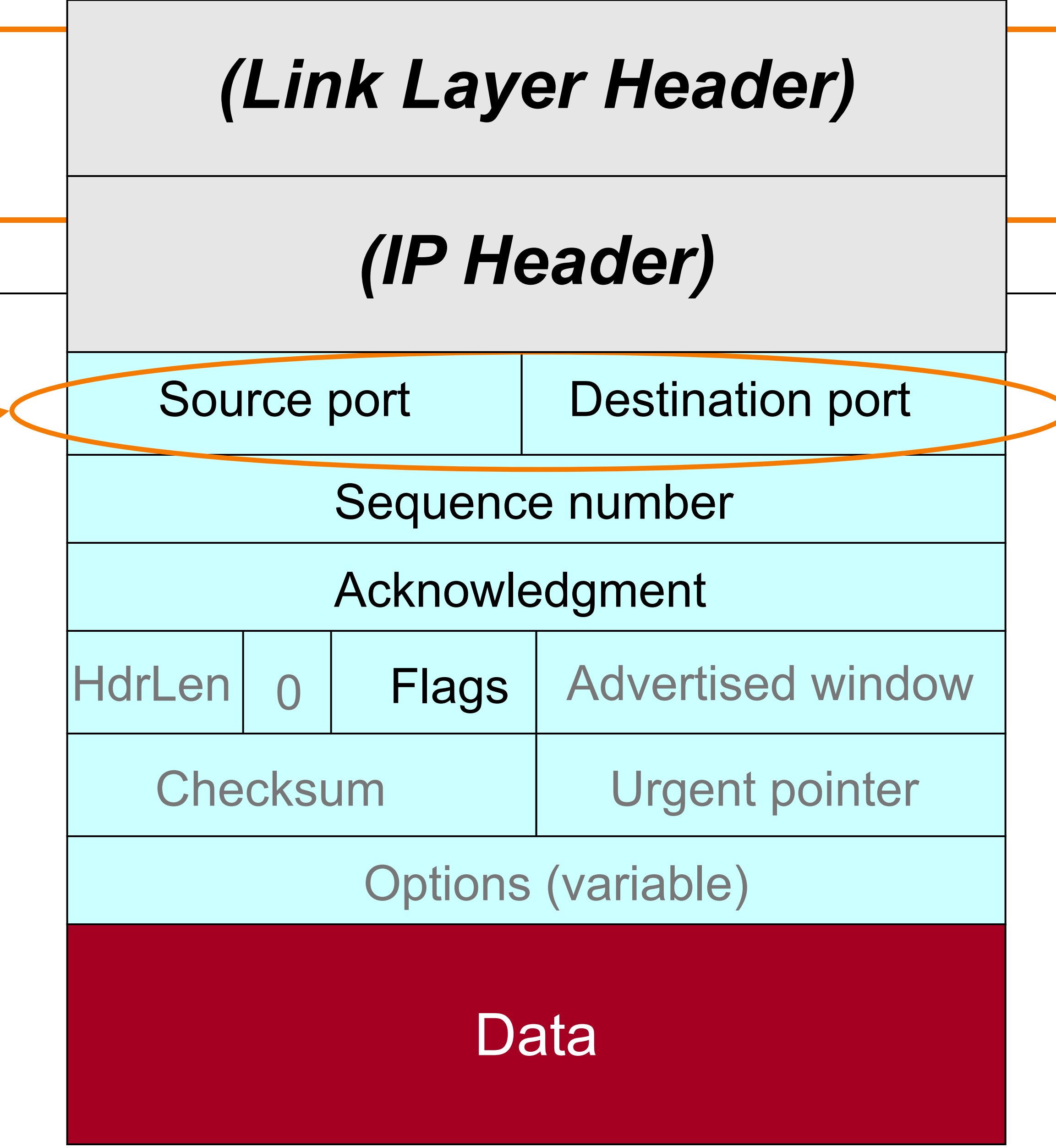
Urgent pointer
Options (variable)
Data

TCP Header

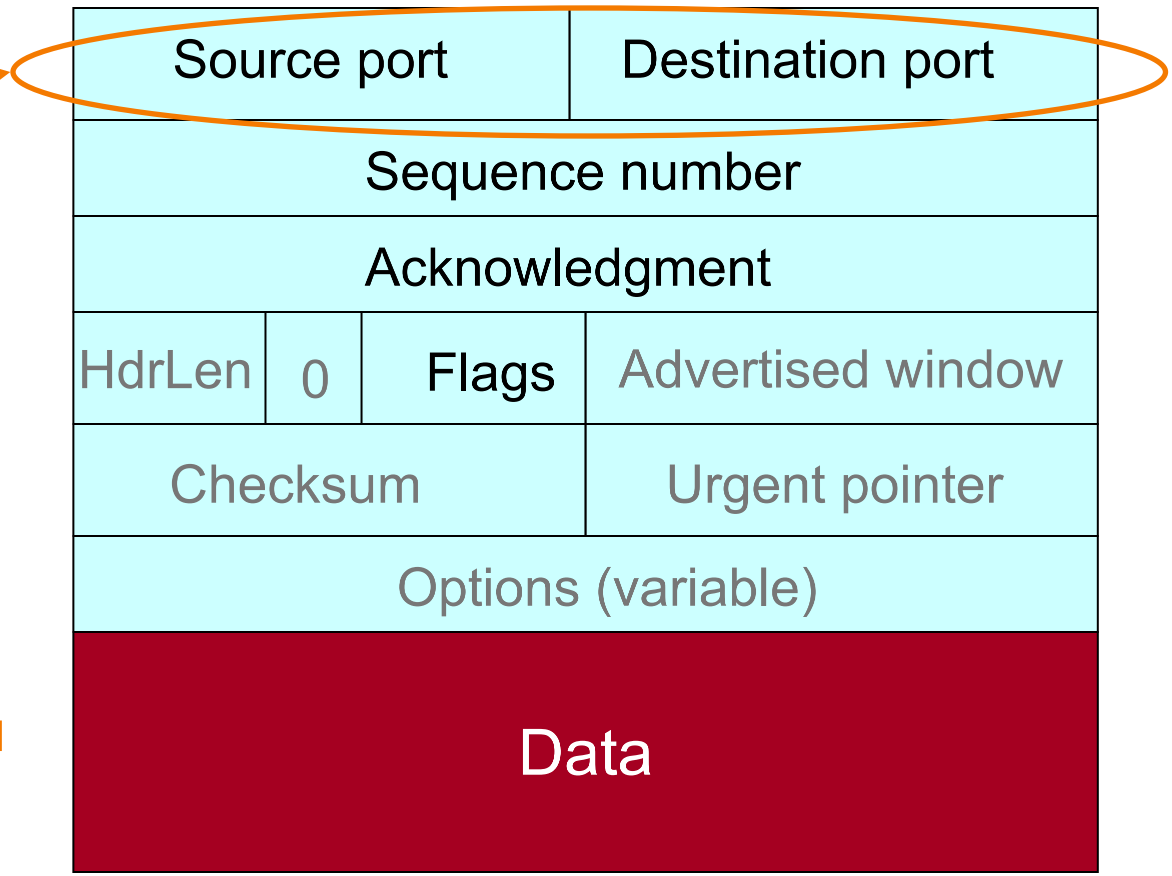
Ports are associated with OS processes



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

TCP Header

Ports are associated with OS processes

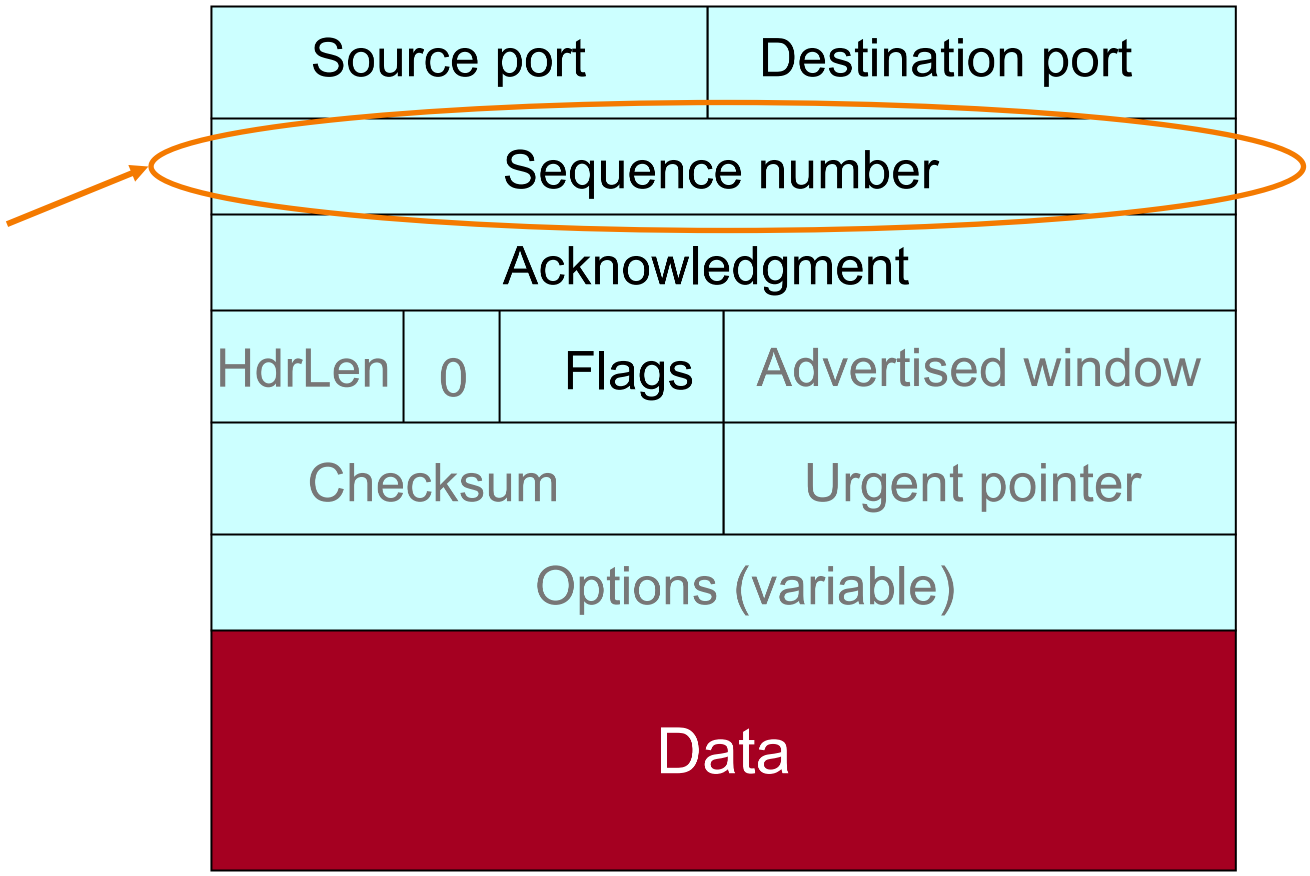


IP source & destination addresses plus TCP source and destination ports uniquely identifies a TCP connection

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



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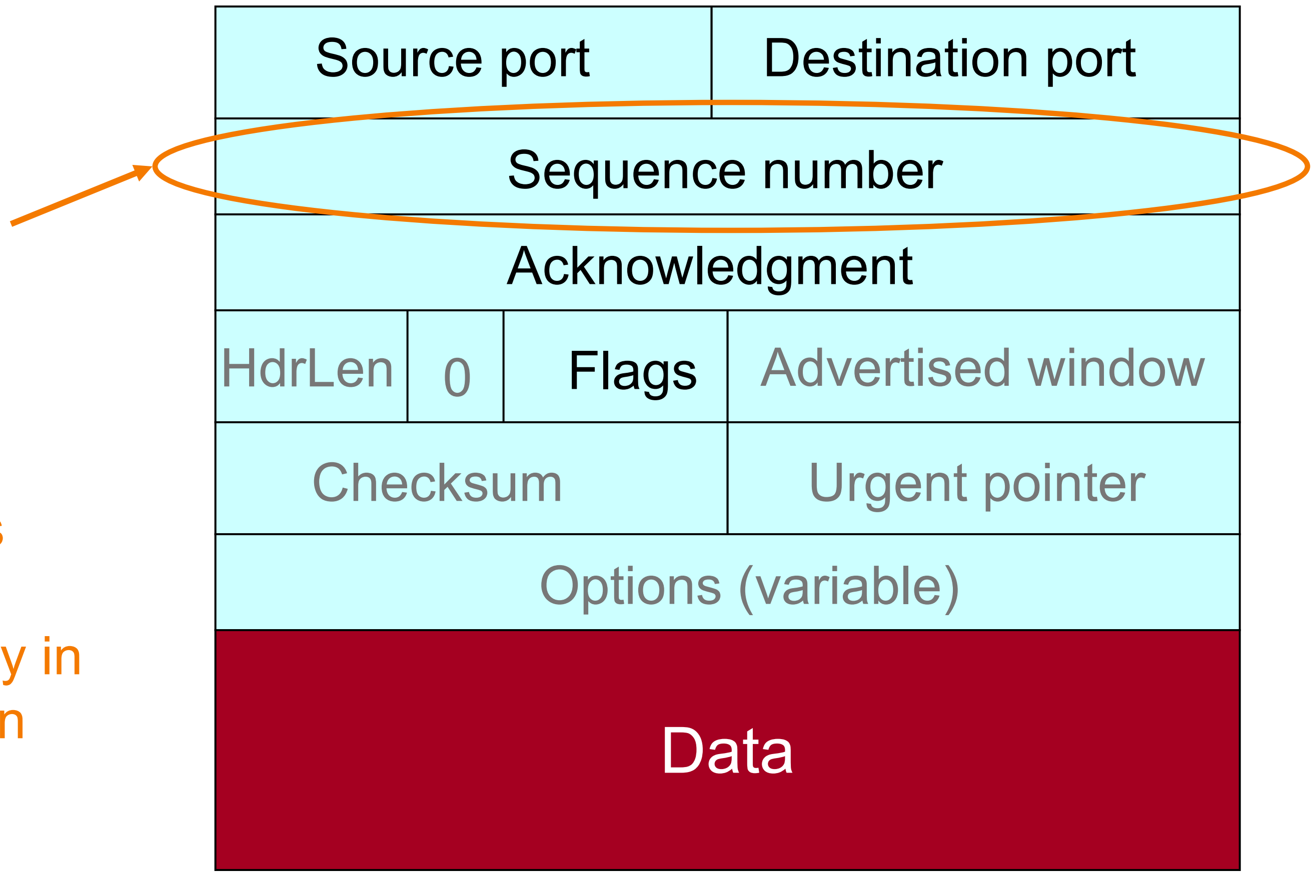
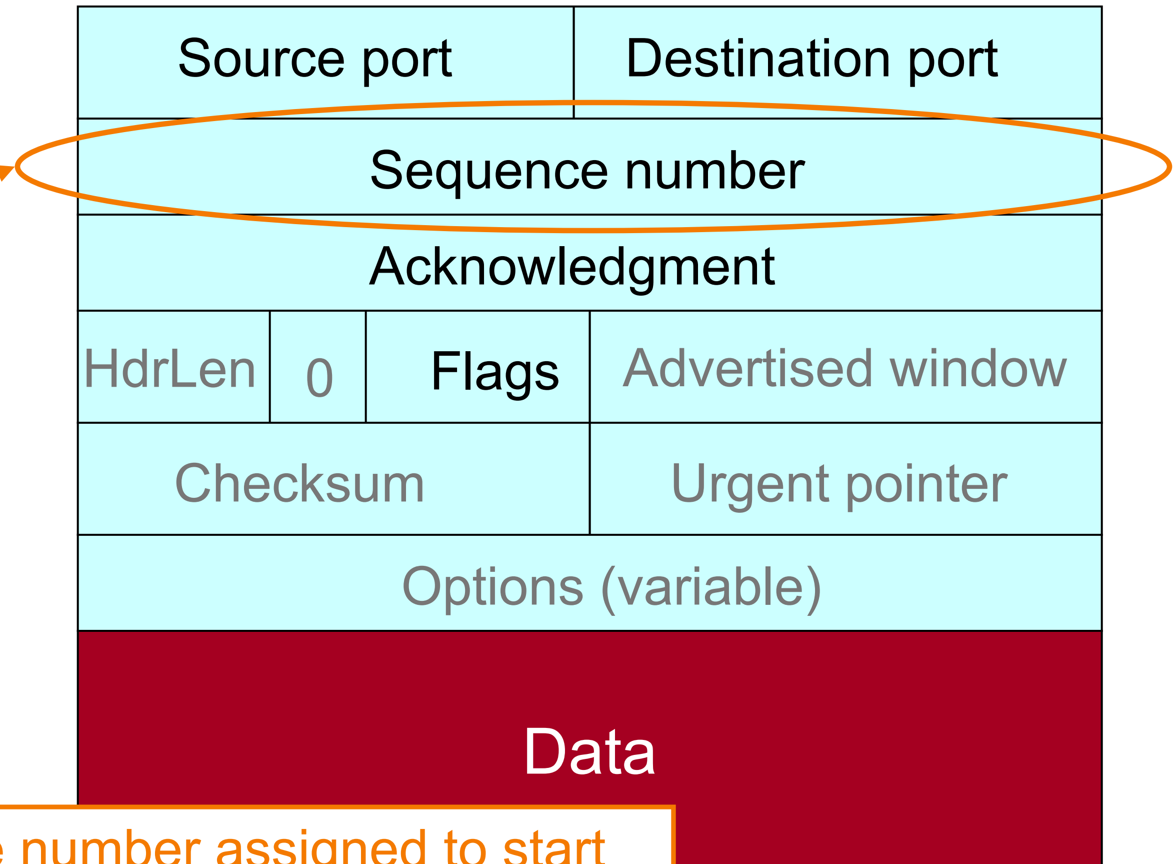


Byte streams numbered independently in each direction

TCP Header

Starting sequence number (byte offset) of data carried in this packet



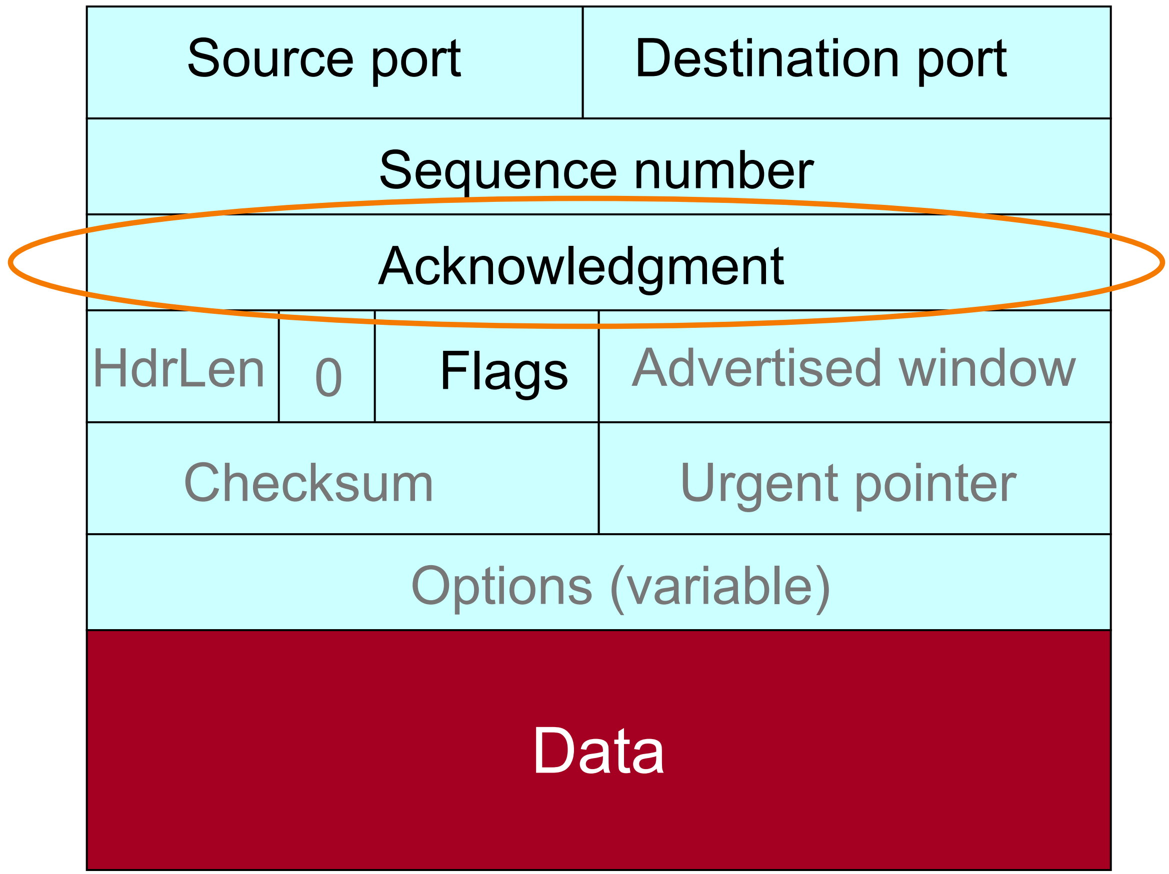
Byte stream numbered independently in each direction

Sequence number assigned to start of byte stream is picked when connection begins; **doesn't** start at 0

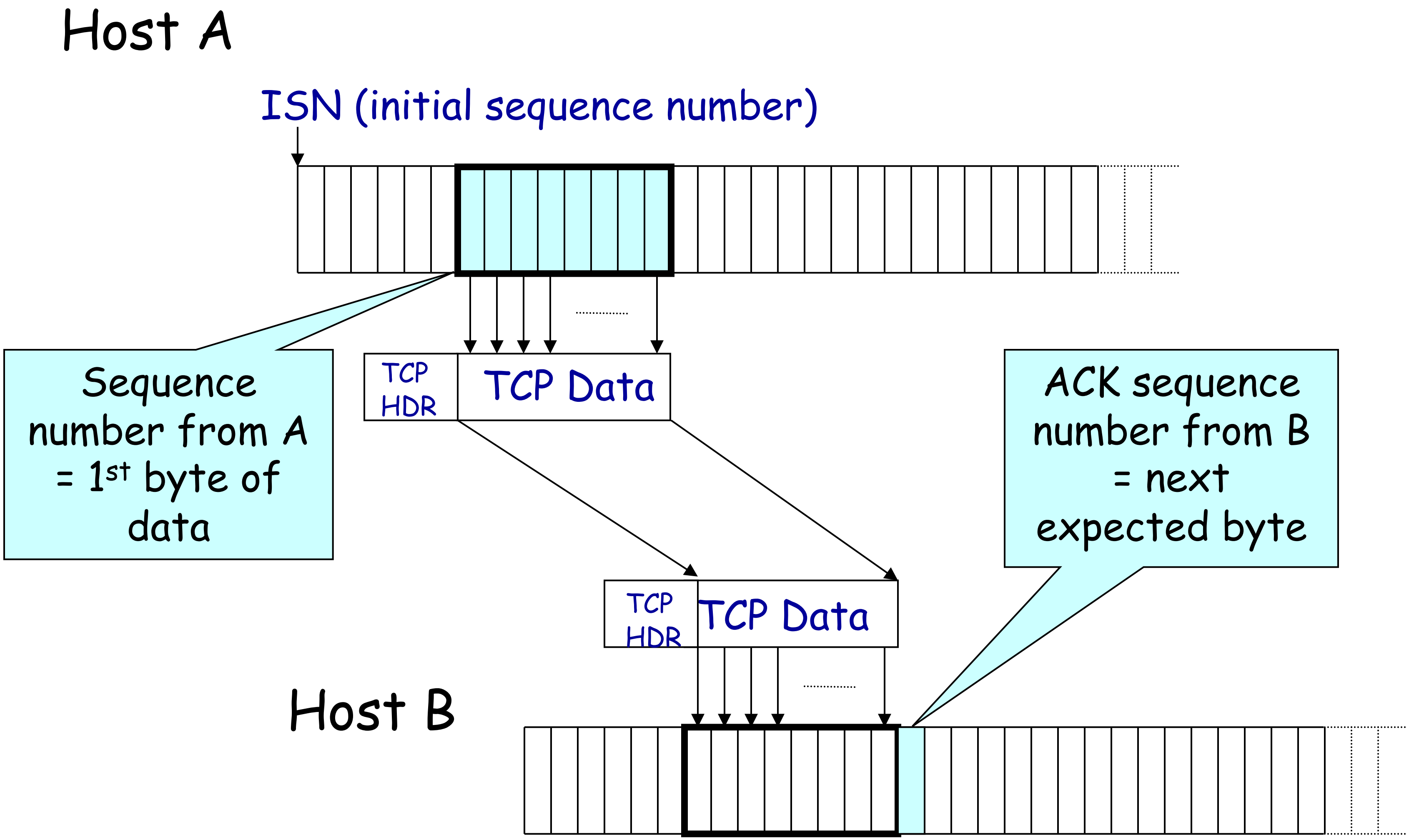
TCP Header

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

If sender sends **N** bytestream bytes starting at seq **S** then "ack" for it will be **S+N**.



Sequence Numbers

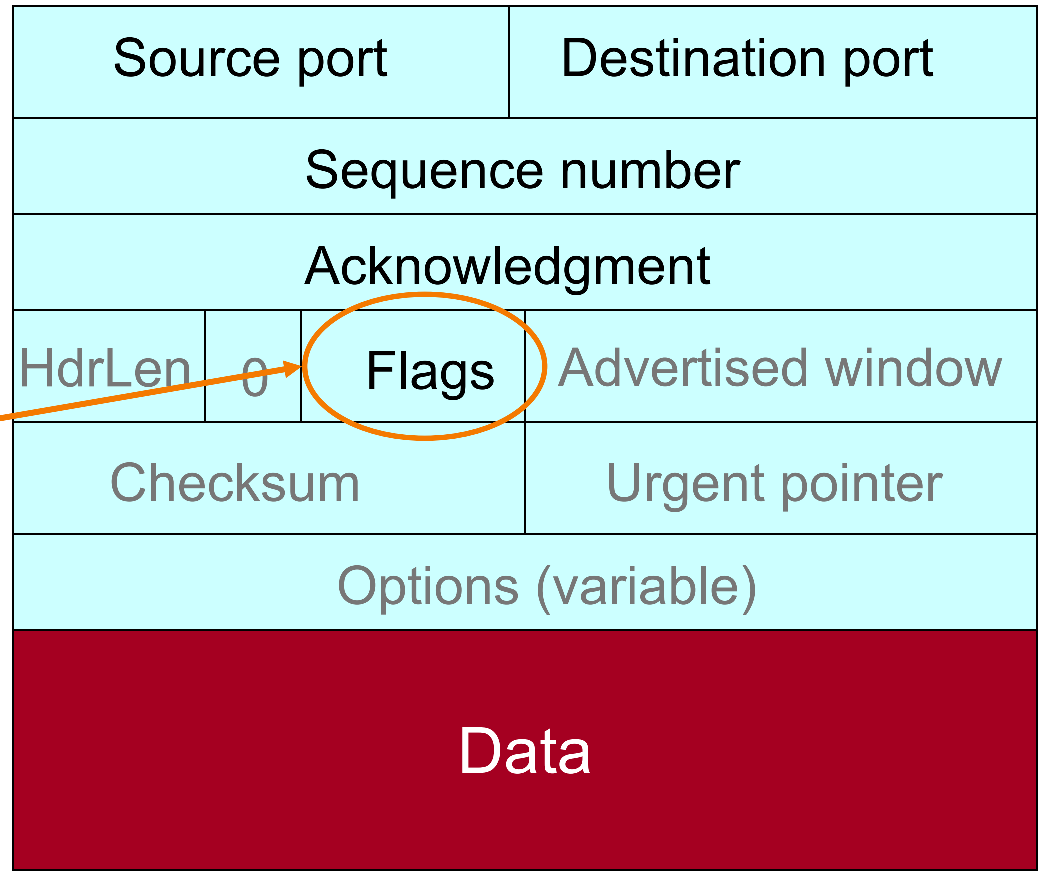


TCP Header

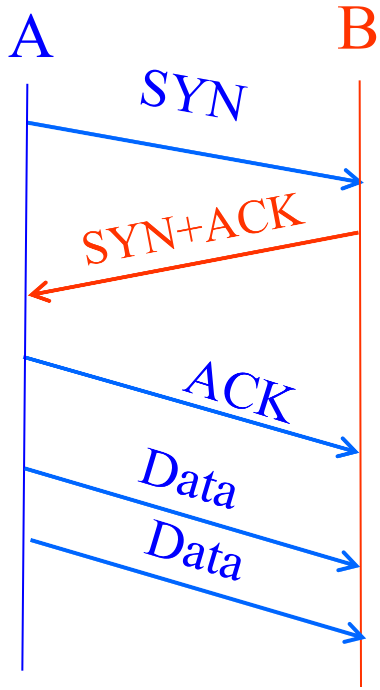
Uses include:

acknowledging data ("**ACK**")

setting up ("**SYN**") and closing connections ("**FIN**" and "**RST**")



Establishing a TCP Connection

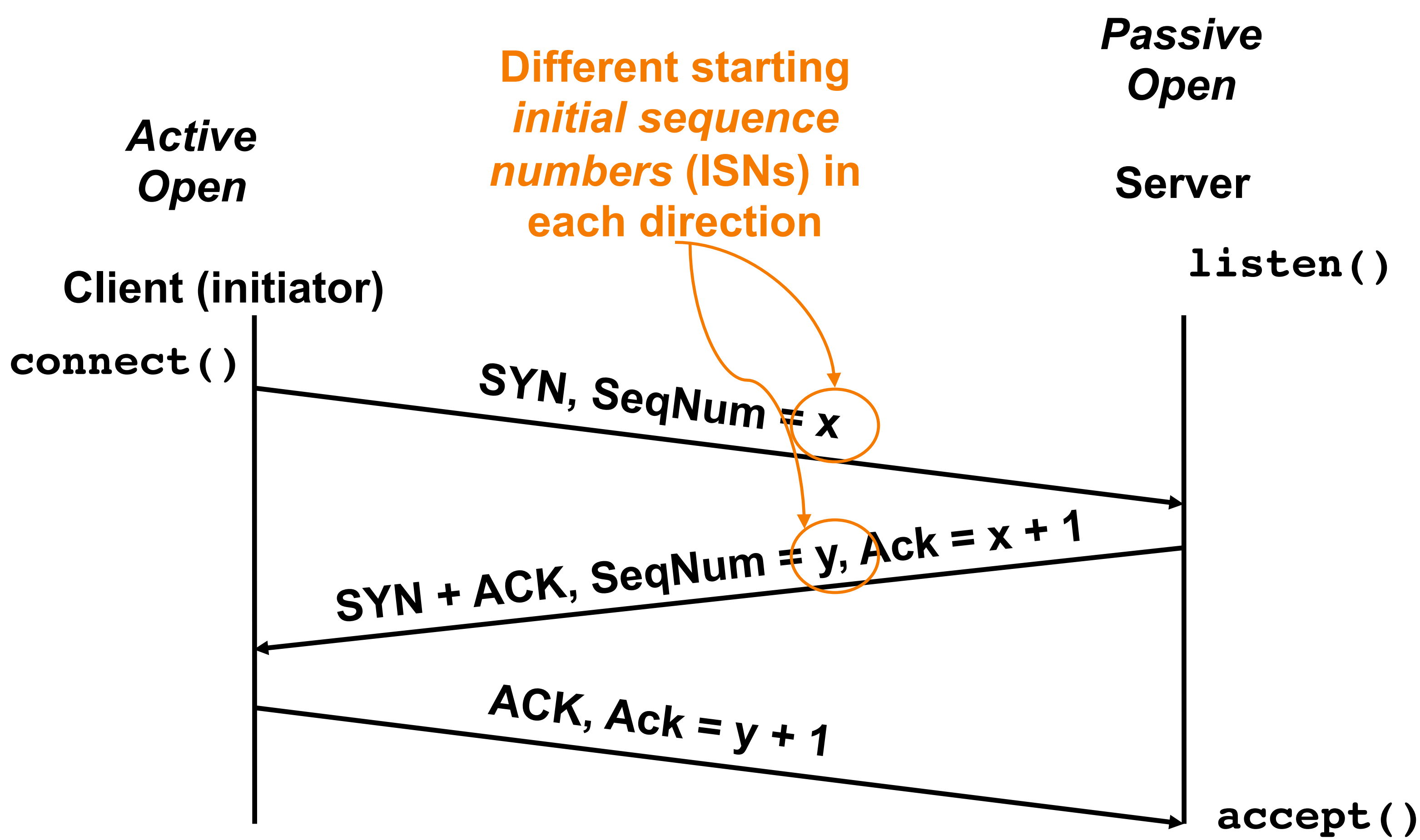


Each host tells its *Initial Sequence Number* (ISN) to the other host.

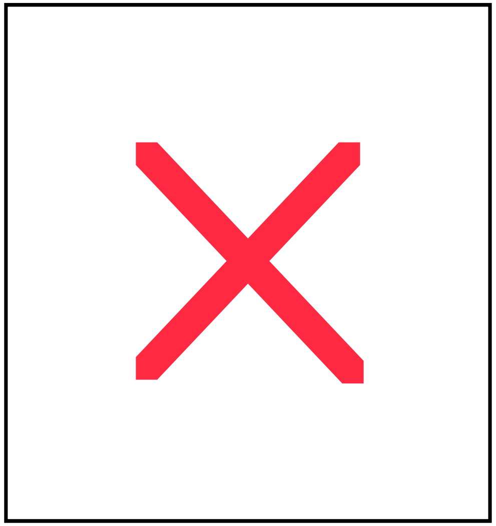
(Spec says to pick based on local clock)

- 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



Fact about … Dave Patterson



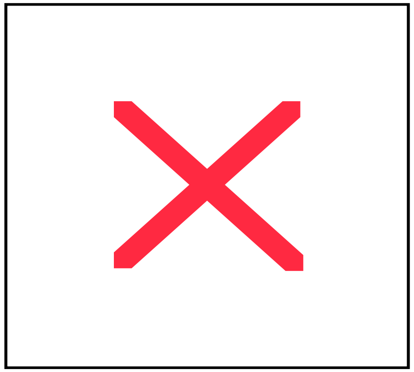
- He taught various computer architecture courses
- Patterson & Henessy: classical computer architecture textbook
- Won the Turing award in 2017 (RAID, RISCV)

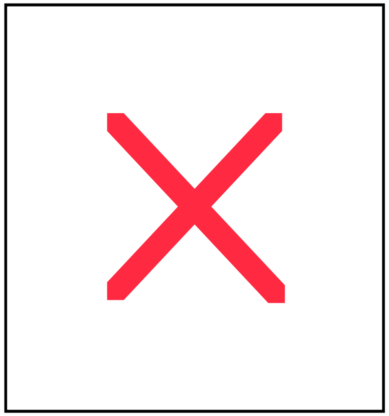
UC Berkeley has the largest number of Turing award winners if you count by where they did their Turing award work

In his Turing lecture, Dave tried to distinguish himself from other Turing award winners:

Dave is the strongest of them (literally).

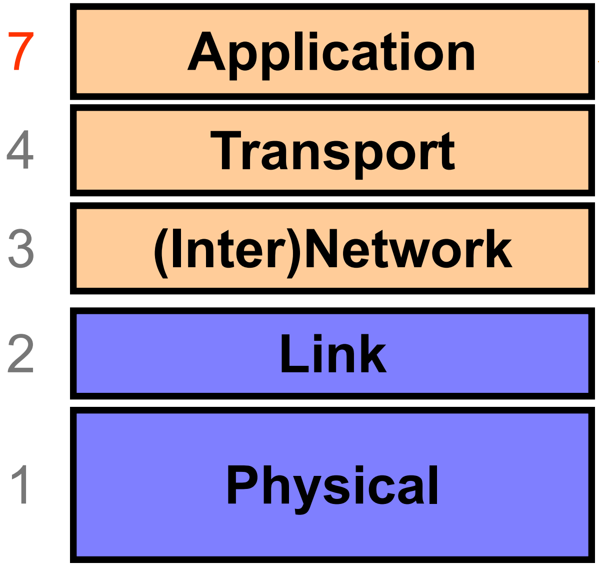
Won California powerlifting championship in 2013 for his age range.





2min break

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

Web (HTTP) Request

Method **Resource** **HTTP version** **Headers**

```
GET /index.html HTTP/1.1
Accept: image/gif, image/x-bitmap, image/jpeg, */*
Accept-Language: en
Connection: Keep-Alive
User-Agent: Mozilla/1.22 (compatible; MSIE 2.0; Windows 95)
Host: www.example.com
Referer: http://www.google.com?q=dingbats

```

Blank line

Data (if POST; none for GET)

GET: download data. POST: upload data.

Web (HTTP) Response

HTTP version **Status code** **Reason phrase** **Headers** **Data**

```
HTTP/1.0 200 OK
Date: Sun, 19 Apr 2009 02:20:42 GMT
Server: Microsoft-Internet-Information-Server/5.0
Connection: keep-alive
Content-Type: text/html
Last-Modified: Sat, 18 Apr 2009 17:39:05 GMT
Set-Cookie: session=44eb; path=/servlets
Content-Length: 2543

<HTML> Some data... blah, blah, blah </HTML>
```

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

Networking Attacks: Link-, IP-, and TCP-layer attacks

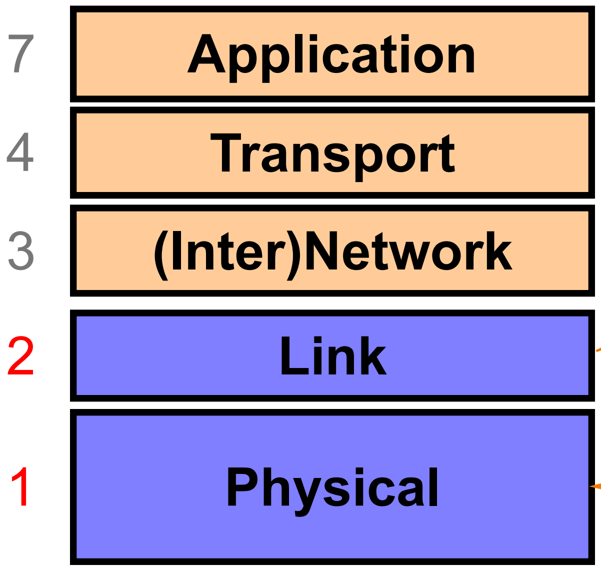
General Communication Security Goals: CIA

- Confidentiality:
  - No one can *read* our data / communication unless we want them to
- Integrity
  - No one can *manipulate* our data / processing / communication unless we want them to
- Availability
  - We can *access* our data / conduct our processing / use our communication capabilities when we want to

No security built in at the network level

- Everything you have seen in this lecture is just plaintext, to integrity attached to it so an attacker can easily spoof packets at multiple levels
- TLS will give application level security

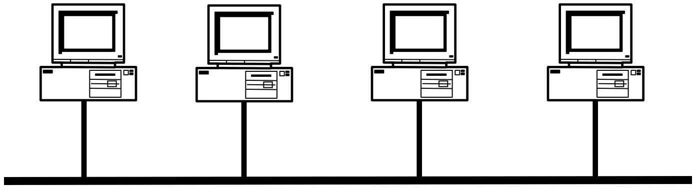
Layers 1 & 2: General Threats?



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

Encoding bits to send them over a single **physical link**
e.g. patterns of
voltage levels /
photon intensities /
RF modulation

Link-layer threats



- Confidentiality: eavesdropping (aka sniffing)
- Integrity: injection of spoofed packets
- Availability: delete legit packets (e.g., jamming)

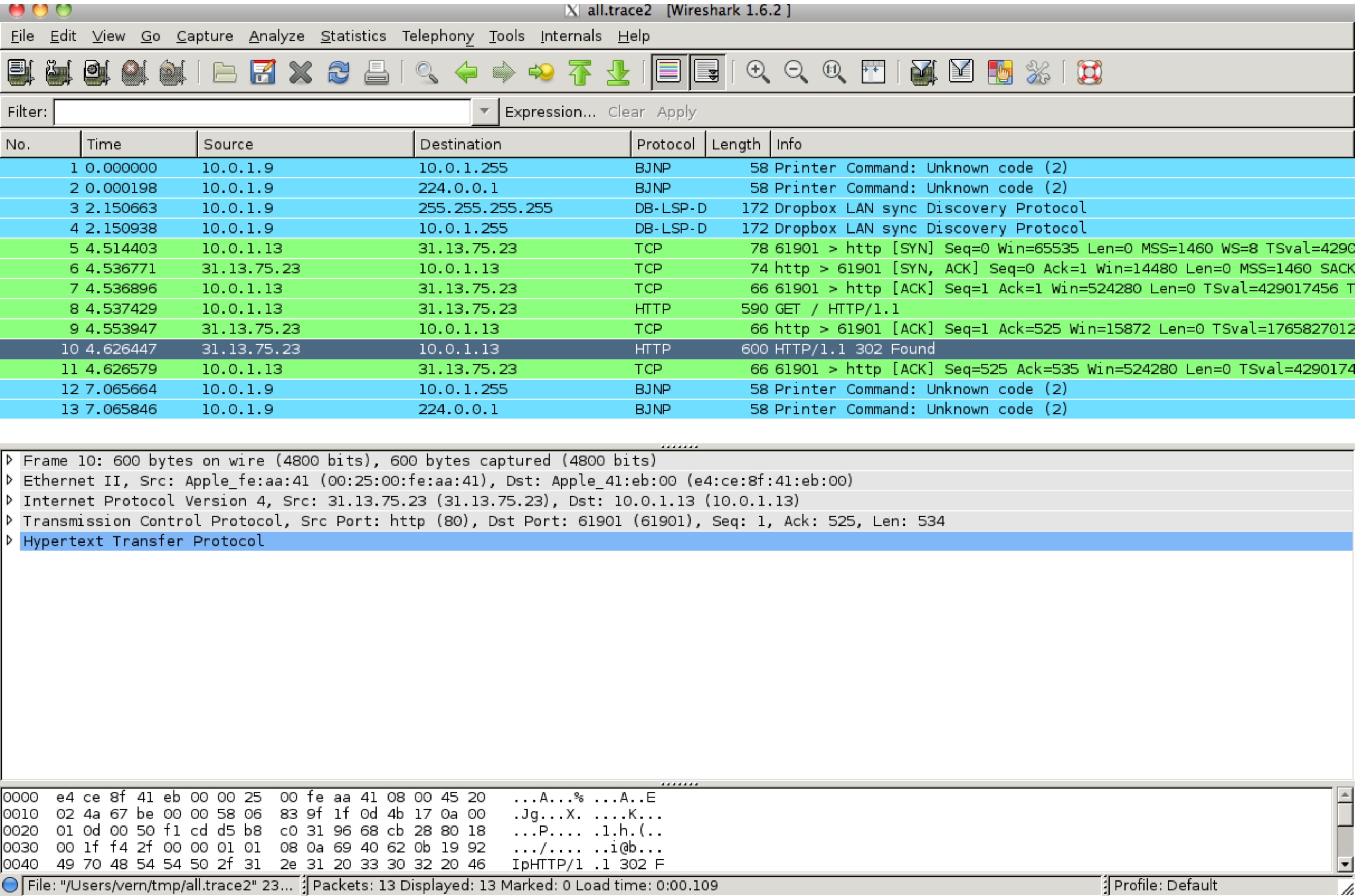
Eavesdropping

- For subnets using broadcast technologies (e.g., WiFi, some types of Ethernet), eavesdropping comes for "free"
  - Each attached system's NIC (= Network Interface Card) can capture any communication on the subnet
  - Some handy tools for doing so
    - tcpdump / windump (low-level ASCII printout)
    - Wireshark (GUI for displaying 800+ protocols)

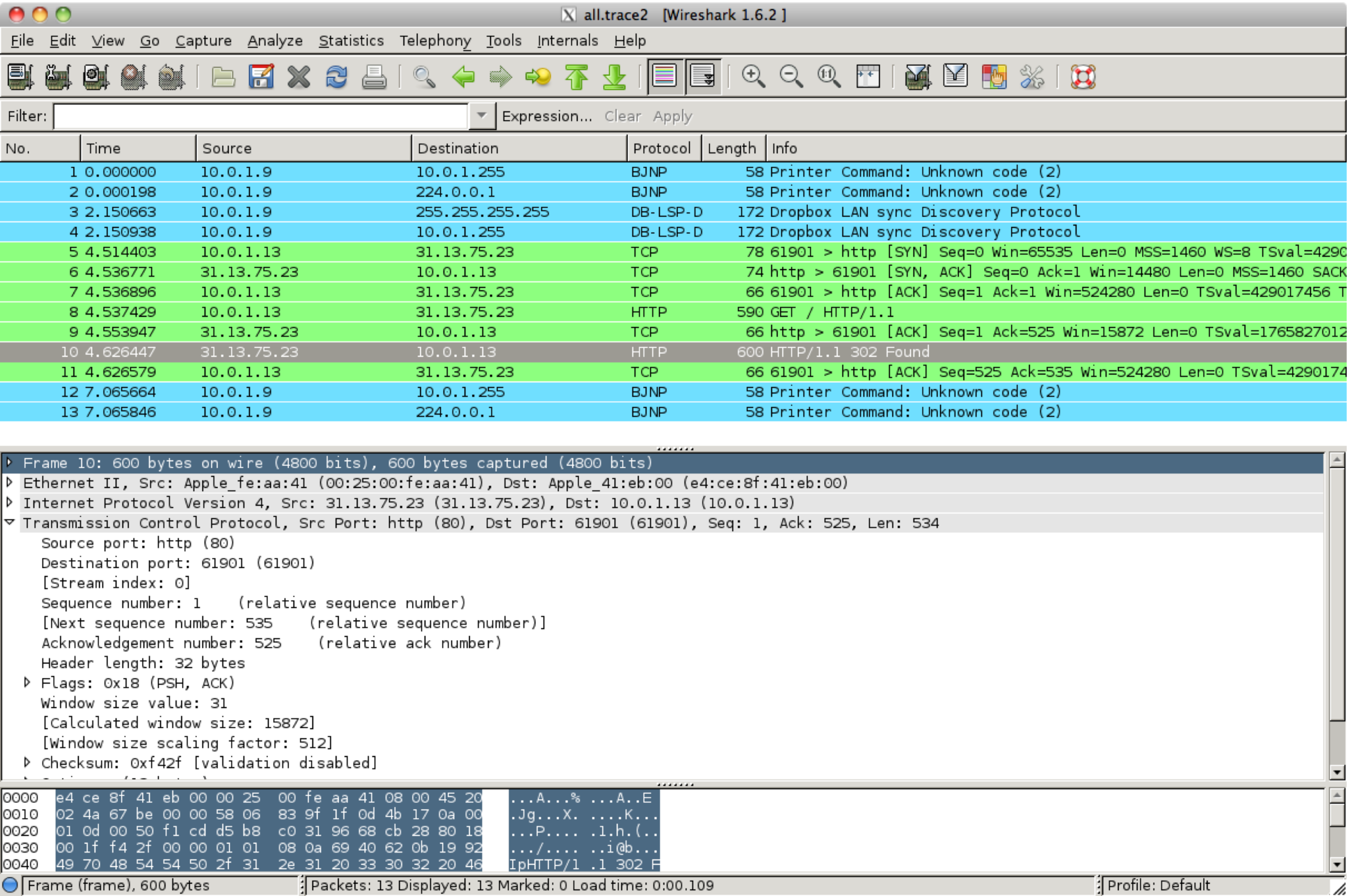
TCPDUMP: Packet Capture & ASCII Dumper

```
demo 2 % tcpdump -r all.trace2
reading from file all.trace2, link-type EN10MB (Ethernet)
21:39:37.772367 IP 10.0.1.9.60627 > 10.0.1.255.canon-bjnp2: UDP, length 16
21:39:37.772565 IP 10.0.1.9.62137 > all-systems.mcast.net.canon-bjnp2: UDP, length 16
21:39:39.923030 IP 10.0.1.9.17500 > broadcasthost.17500: UDP, length 130
21:39:39.923305 IP 10.0.1.9.17500 > 10.0.1.255.17500: UDP, length 130
21:39:42.286770 IP 10.0.1.13.61901 > star-01-02-pao1.facebook.com.http: Flags [S], seq 2
523449627, win 65535, options [mss 1460,nop,wscale 3,nop,nop,TS val 429017455 ecr 0,sack
OK,eol], length 0
21:39:42.309138 IP star-01-02-pao1.facebook.com.http > 10.0.1.13.61901: Flags [S.], seq
3585654832, ack 2523449628, win 14480, options [mss 1460,sackOK,TS val 1765826995 ecr 42
9017455,nop,wscale 9], length 0
21:39:42.309263 IP 10.0.1.13.61901 > star-01-02-pao1.facebook.com.http: Flags [.], ack 1
, win 65535, options [nop,nop,TS val 429017456 ecr 1765826995], length 0
21:39:42.309796 IP 10.0.1.13.61901 > star-01-02-pao1.facebook.com.http: Flags [P.], seq
1:525, ack 1, win 65535, options [nop,nop,TS val 429017456 ecr 1765826995], length 524
21:39:42.326314 IP star-01-02-pao1.facebook.com.http > 10.0.1.13.61901: Flags [.], ack 5
25, win 31, options [nop,nop,TS val 1765827012 ecr 429017456], length 0
21:39:42.398814 IP star-01-02-pao1.facebook.com.http > 10.0.1.13.61901: Flags [P.], seq
1:535, ack 525, win 31, options [nop,nop,TS val 1765827083 ecr 429017456], length 534
21:39:42.398946 IP 10.0.1.13.61901 > star-01-02-pao1.facebook.com.http: Flags [.], ack 5
35, win 65535, options [nop,nop,TS val 429017457 ecr 1765827083], length 0
21:39:44.838031 IP 10.0.1.9.54277 > 10.0.1.255.canon-bjnp2: UDP, length 16
21:39:44.838213 IP 10.0.1.9.62896 > all-systems.mcast.net.canon-bjnp2: UDP, length 16
```

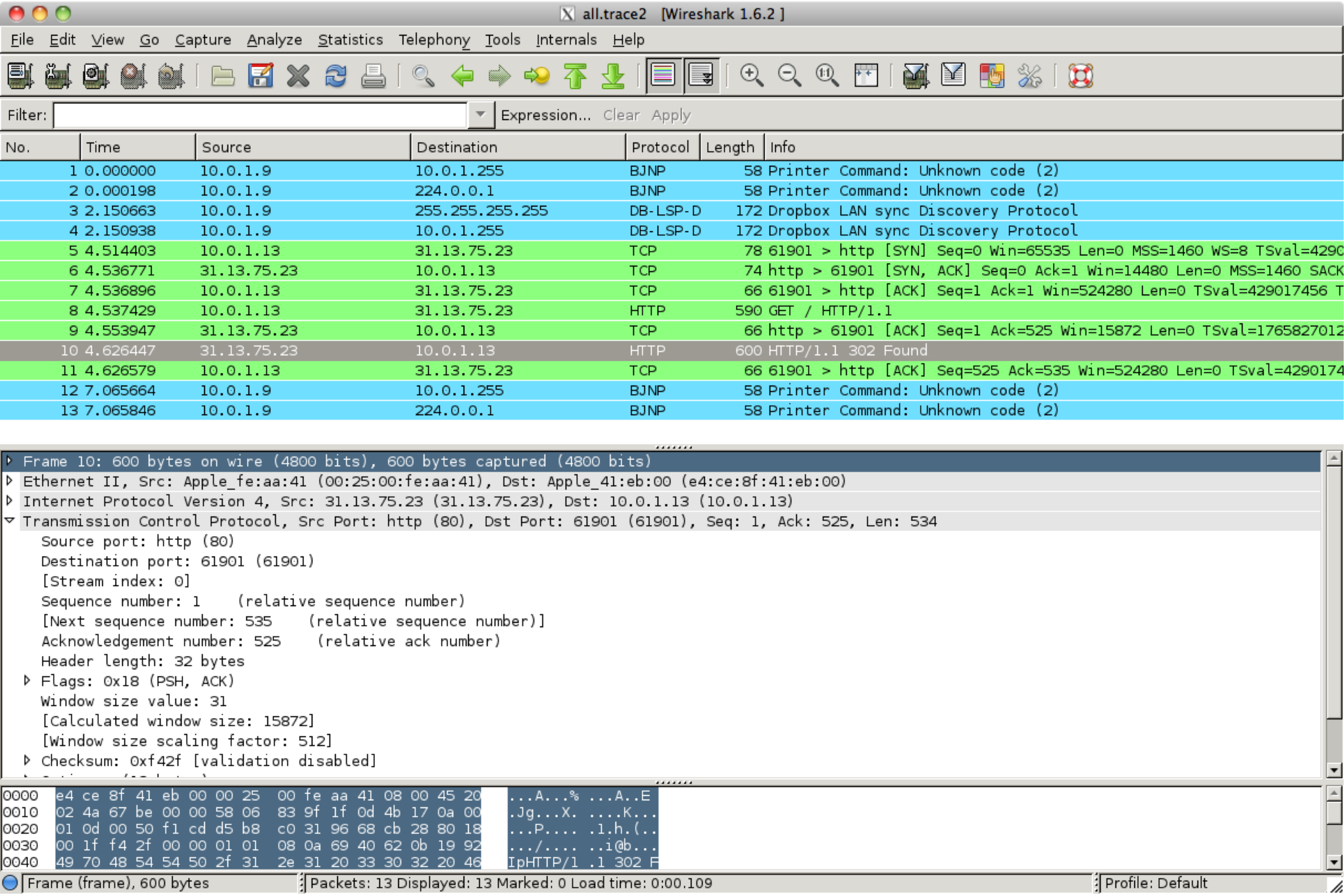
Wireshark: GUI for Packet Capture/Exam.



Wireshark: GUI for Packet Capture/Exam.



Wireshark: GUI for Packet Capture/Exam.



Link-Layer Threat: Disruption

- If attacker sees a packet he doesn't like, he can jam it (integrity)
- Attacker can also overwhelm link-layer signaling, e.g., jam WiFi's RF (denial-of-service)

Link-Layer Threat: Disruption

- If attacker sees a packet he doesn't like, he can jam it (integrity)
- Attacker can also overwhelm link-layer signaling, e.g., jam WiFi's RF (denial-of-service)
- There's also the heavy-handed approach …

Sabotage attacks knock out phone service

Nanette Asimov, Ryan Kim,Kevin Fagan, Chronicle Staff Writers
Friday, April 10, 2009

PRINT E-MAIL SHARE COMMENTS (477) FONT | SIZE: – +

(04-10) 04:00 PDT SAN JOSE --

Police are hunting for vandals who chopped fiber-optic cables and killed landlines, cell phones and Internet service for tens of thousands of people in Santa Clara, Santa Cruz and San Benito counties on Thursday.

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The sabotage essentially froze operations in parts of the three counties at hospitals, stores, banks and police and fire departments that rely on 911 calls, computerized medical records, ATMs and credit and debit cards.

The full extent of the havoc might not be known for days, emergency officials said as they finished repairing the damage late Thursday.

Whatever the final toll, one thing is certain: Whoever did this is in a world of trouble if he, she or they get caught.

"I pity the individuals who have done this," said San Jose Police Chief Rob Davis.

Ten fiber-optic cables carrying were cut at four locations in the predawn darkness. Residential and business customers quickly found that telephone service was perhaps more laced into their everyday needs than they thought. Suddenly they couldn't draw out money, send text messages, check e-mail or Web sites, call anyone for help, or even check on friends or relatives down the road.

Several people had to be driven to hospitals because they were unable to summon ambulances. Many businesses lapsed into idleness for hours, without the ability to contact associates or customers.

More than 50,000 landline customers lost service - some were residential, others were business lines that needed the connections for ATMs, Internet and bank card transactions. One line alone could affect hundreds of users.

UPDATE LOOK Vancouver's Venues Shine

NEWS | LOCAL BEAT

$250K Reward Out for Vandals Who Cut AT&T Lines

Local emergency declared during outage

By LORI PREUITT

Updated 2:12 PM PST, Fri, Apr 10, 2009

PRINT EMAIL SHARE BUZZ UP! TWITTER FACEBOOK

AT&T is now offering a $250,000 reward for information leading to the arrest of whoever is responsible for severing lines fiber optic cables in San Jose tha left much of the area without phone or cell service Thursday.

John Britton of AT&T said the reward is the largest ever offered by the company.

Link-Layer Threat: Spoofing

- Attacker can inject spoofed packets, and lie about the source address

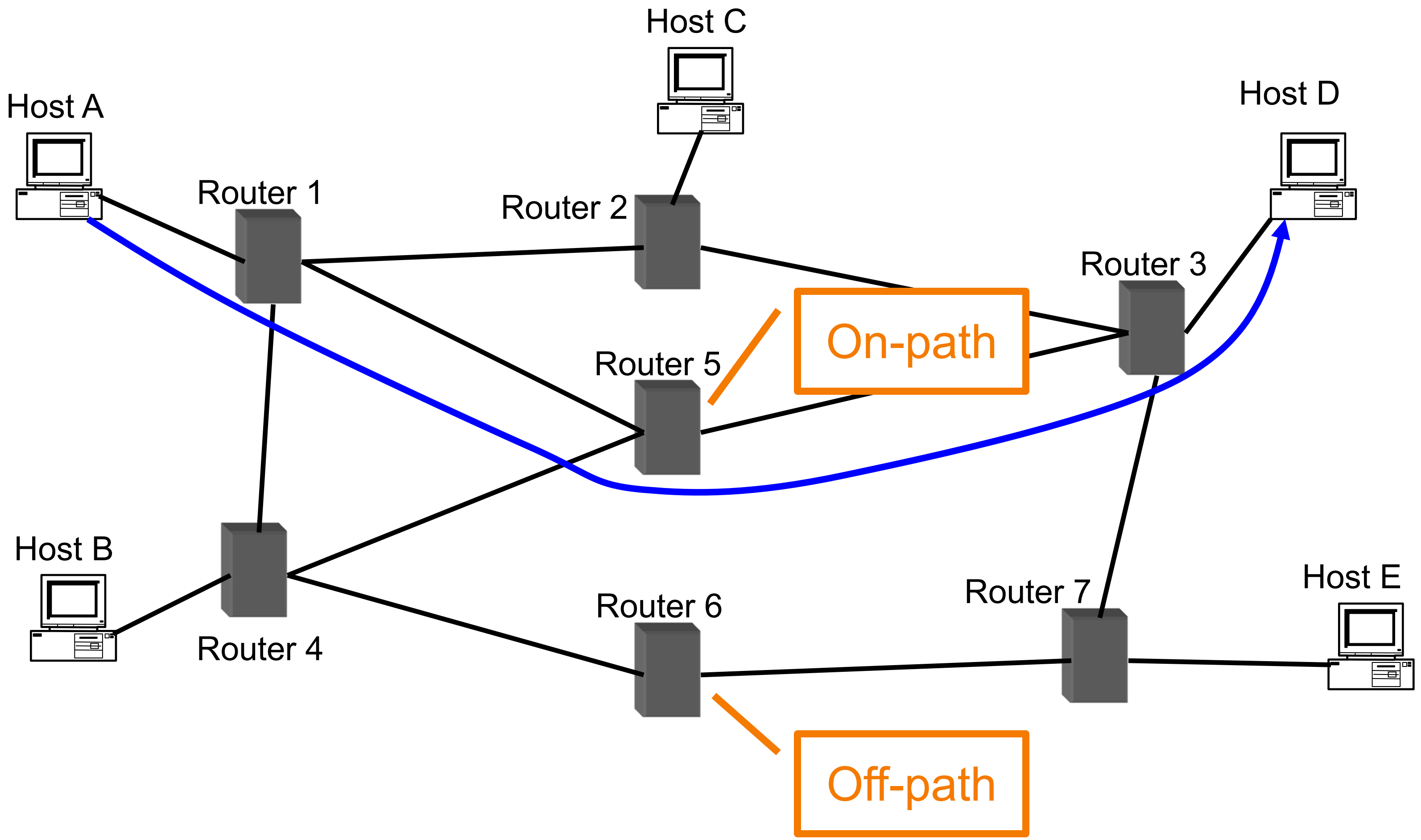
`D`	`C`	`Hello world!`

Physical/Link-Layer Threats: *Spoofing*

- With physical access to a local network, attacker can create any message they like
  - When with a bogus source address: *spoofing*
- When using a typical computer, may require root/administrator to have full freedom
- Particularly powerful when combined with *eavesdropping*
  - Because attacker can understand exact state of victim's communication and craft their spoofed traffic to match it
  - Spoofing w/o eavesdropping = *blind spoofing*

On-path vs Off-path Spoofing

Host A communicates with Host D



Spoofing on the Internet

- On-path attackers can see victim's traffic $\Rightarrow$ spoofing is easy
- Off-path attackers can't see victim's traffic
  - They have to resort to blind spoofing
  - Often must guess/infer header values to succeed
    - We then care about work factor: how hard is this
  - But sometimes they can just **brute force**
    - E.g., 16-bit value: just try all 65,536 possibilities!
- When we say an attacker "can spoof", we usually mean "w/ reasonable chance of success"

IP-Layer Threats

- Can set arbitrary source address
  - "Spoofing" - receiver has no idea who you are
  - Could be blind, or could be coupled w/ sniffing
  - Note: many attacks require two-way communication
    - So successful off-path/blind spoofing might not suffice
- Can set arbitrary destination address
  - Enables "scanning" – brute force searching for hosts
- Can *send like crazy* (flooding)
  - IP has no general mechanism for tracking overuse
  - IP has no general mechanism for tracking consent
  - Very hard to tell where a spoofed flood comes from!
- **If** attacker can manipulate routing, can bring traffic to themselves for *eavesdropping* (not easy)