CE 443: Computer Networks

Acknowledgments: Lecture slides are from Computer networks course thought by Jennifer Rexford at Princeton University. When slides are obtained from other sources, a a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

Goals for Today's Class

- Overview
  - –Goals of the course
  - –Structure of the course
- Key concepts in data networking
  - –Protocols
  - –Layering
  - –Resource allocation
  - –Naming

What You Learn in This Course

- Knowledge: how the Internet works
  - –IP protocol suite
  - –Internet architecture
  - –Applications (Web, e-mail, P2P, VoIP, …)
- Insight: key concepts in networking
  - –Protocols
  - –Layering
  - –Resource allocation
  - –Naming
- Skill: network programming
  - –Socket programming
  - –Designing and implementing protocols

Structure of the Course (1st Half)

- Start at the top
  - Sockets: how applications view the Internet
  - Protocols: essential elements of a protocol
- Then study the "narrow waist" of IP
  - IP best-effort packet-delivery service
  - IP addressing and packet forwarding
- And how to build on top of the narrow waist
  - Transport protocols (TCP, UDP)
  - Domain Name System (DNS)
  - Glue (ARP, DHCP, ICMP)
  - End-system security and privacy (NAT, firewalls)
- Looking underneath IP
  - Link technologies (Ethernet, wireless, …)

Structure of the Course (2nd Half)

- And how to get the traffic from here to there
  - Internet routing architecture (the "inter" in Internet)
  - Intradomain and interdomain routing protocols
- Building applications
  - Web and content-distribution networks
  - E-mail
  - Peer-to-peer file sharing
  - Multimedia streaming and voice-over-IP
- Other approaching to building networks
  - Circuit switching (e.g., ATM, MPLS, …)
  - More on wireless networks, multicast, …

Learning the Material: Books

- Required textbook
  - *Computer Networks: A Systems Approach (5th edition)*, by Peterson and Davie
- Optional textbooks
  - Networking text books
    - *Computer Networking: A Top-Down Approach Featuring the Internet (3rd edition),* by Kurose and Ross
    - *Computer Networks (4th edition)*, by Tanenbaum
  - Network programming references
    - *TCP/IP Illustrated, Volume 1: The Protocols*, by Stevens
    - *Unix Network Programming, Volume 1: The Sockets Networking API (3rd Edition)*, by Stevens, Fenner, & Rudolf
- Online resources
  - E.g. on socket programming

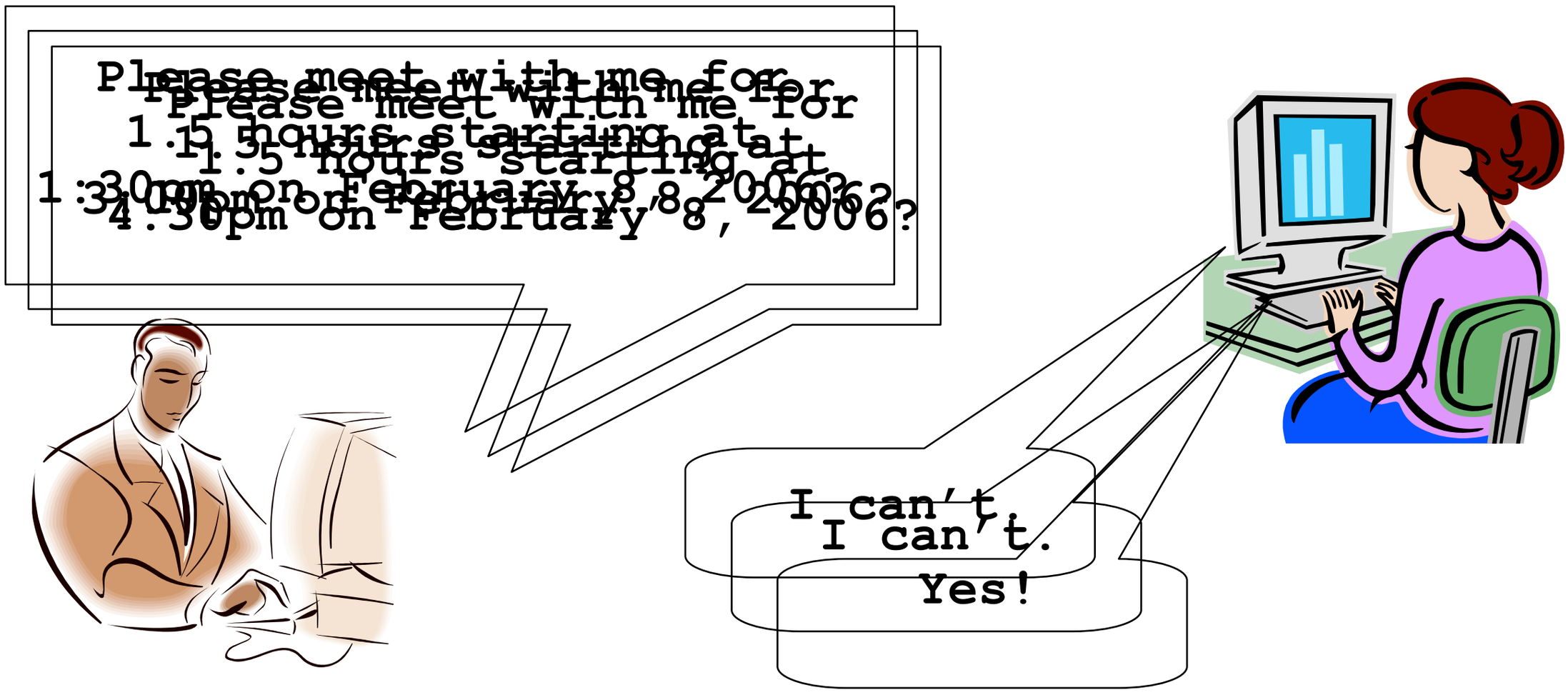
Okay, so let's get started… with a crash course in data networking

Key Concepts in Networking

- Protocols
  - –Speaking the same language
  - –Syntax and semantics
- Layering
  - –Standing on the shoulders of giants
  - –A key to managing complexity
- Resource allocation
  - –Dividing scare resources among competing parties
  - –Memory, link bandwidth, wireless spectrum, paths, …
  - –Distributed vs. centralized algorithms
- Naming
  - –What to call computers, services, protocols, …

Protocols: Calendar Service

- Making an appointment with your advisor



- Specifying the messages that go back and forth
  - And an understanding of what each party is doing

Okay, So This is Getting Tedious

- You: When are you free to meet for 1.5 hours during the next two weeks?
- Advisor: 10:30am on Feb 8 and 1:15pm on Feb 9.
- You: Book me for 1.5 hours at 10:30am on Feb 8.
- Advisor: Yes.

Well, Not Quite Enough

- Student #1: When can you meet for 1.5 hours during the next two weeks?
- Advisor: 10:30am on Feb 8 and 1:15pm on Feb 9.
- Student #2: When can you meet for 1.5 hours during the next two weeks?
- Advisor: 10:30am on Feb 8 and 1:15pm on Feb 9.
- Student #1: Book me for 1.5 hours at 10:30am on Feb 8.
- Advisor: Yes.
- Student #2: Book me for 1.5 hours at 10:30am on Feb 8.
- Advisor: Uh… well… I can no longer can meet then. I'm free at 1:15pm on Feb 9.
- Student #2: Book me for 1.5 hours at 1:15pm on Feb 9.
- Advisor: Yes.

Specifying the Details

- How to identify yourself?
  - Name? Student ID?
- How to represent dates and time?
  - Time, day, month, year? In what time zone?
  - Number of seconds since Jan 1, 1970?
- What granularities of times to use?
  - Any possible start time and meeting duration?
  - Multiples of five minutes?
- How to represent the messages?
  - Strings? Record with name, start time, and duration?
- What do you do if you don't get a response?
  - Ask again? Reply again?

Example: HyperText Transfer Protocol

Request

```
GET /courses/archive/ce443/ HTTP/1.1
Host: www.cs.sharif.edu
User-Agent: Mozilla/4.03
CRLF
```

Response

```
HTTP/1.1 200 OK
Date: Mon, 4 Feb 2010 13:09:03 GMT
Server: Netscape-Enterprise/3.5.1
Last-Modified: Mon, 4 Feb  2010 11:12:23 GMT
Content-Length: 21
CRLF
Site under construction
```

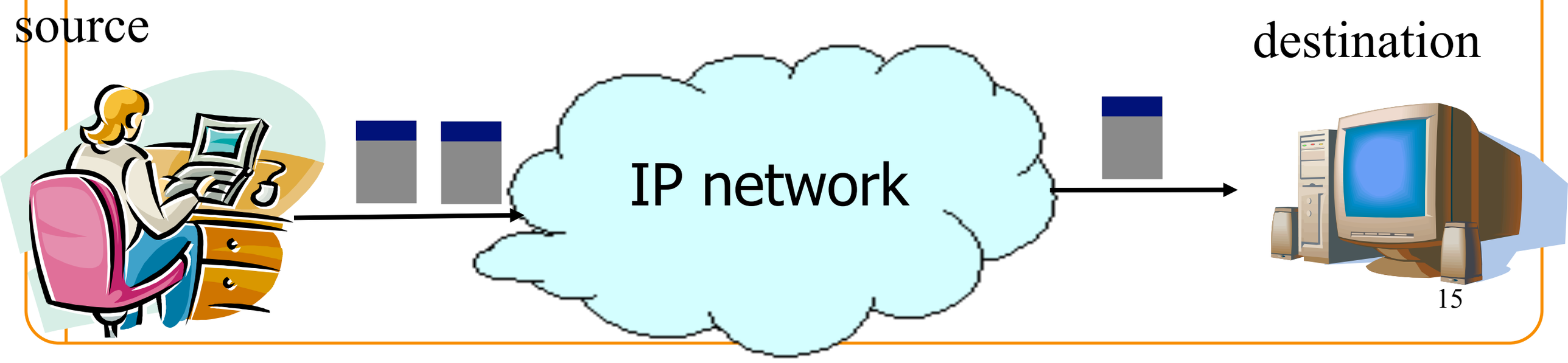
Example: IP Packet

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			
Options (if any)			
Payload			

20-byte header

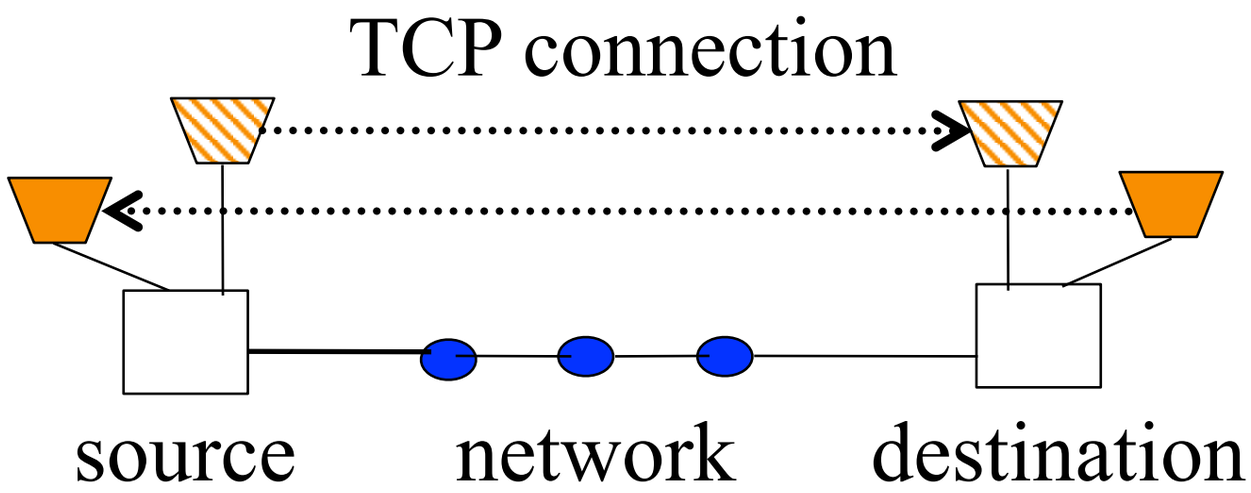
IP: Best-Effort Packet Delivery

- Packet switching
  - –Send data in packets
  - –Header with source & destination address
- Best-effort delivery
  - –Packets may be lost
  - –Packets may be corrupted
  - –Packets may be delivered out of order



Example: Transmission Control Protocol

- Communication service (socket)
  - –Ordered, reliable byte stream
  - –Simultaneous transmission in both directions
- Key mechanisms at end hosts
  - –Retransmit lost and corrupted packets
  - –Discard duplicate packets and put packets in order
  - –Flow control to avoid overloading the receiver buffer
  - –Congestion control to adapt sending rate to network load



Protocol Standardization

- Communicating hosts speaking the same protocol
  - –Standardization to enable multiple implementations
  - –Or, the same folks have to write all the software
- Standardization: Internet Engineering Task Force
  - –Based on working groups that focus on specific issues
  - –Produces “Request For Comments” (RFCs)
    - Promoted to standards via rough consensus and running code
    - E.g., RFC 1945 on “HyperText Transfer Protocol – HTTP/1.0”
  - –IETF Web site is http://www.ietf.org
- De facto standards: same folks writing the code
  - –P2P file sharing, Skype, <your protocol here>…

Key Concepts in Networking

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- Layering
  - –Standing on the shoulders of giants
  - –A key to managing complexity
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  - –Dividing scare resources among competing parties
  - –Memory, link bandwidth, wireless spectrum, paths, …
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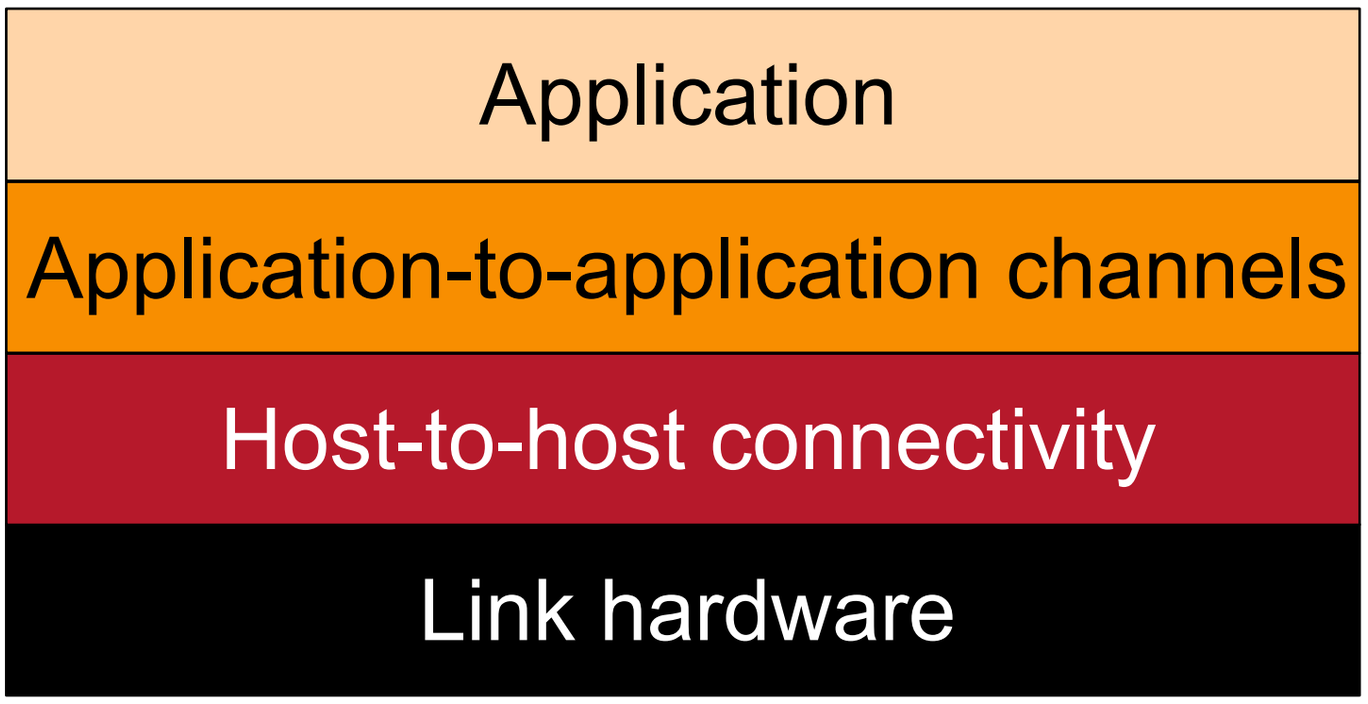
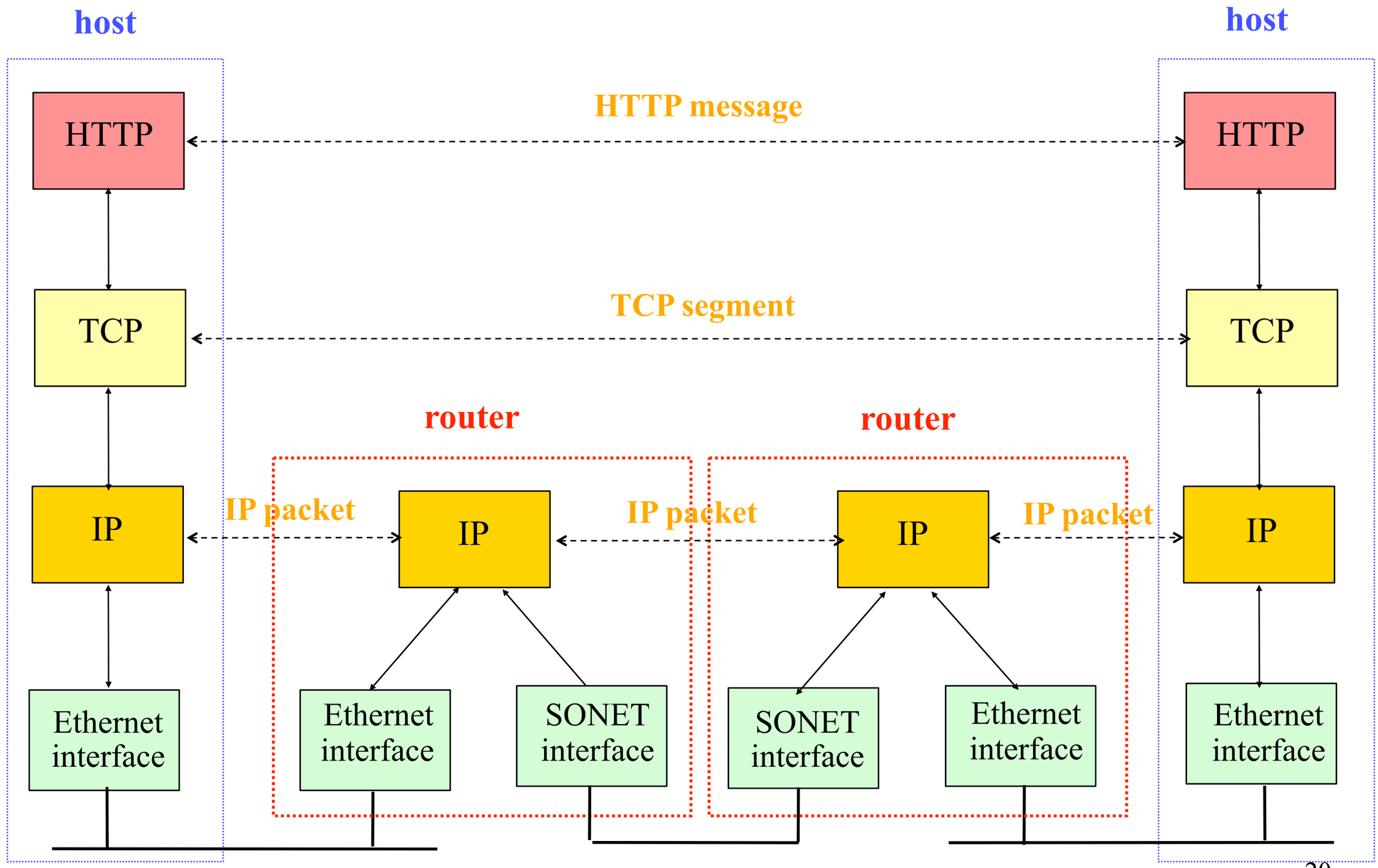
Layering: A Modular Approach

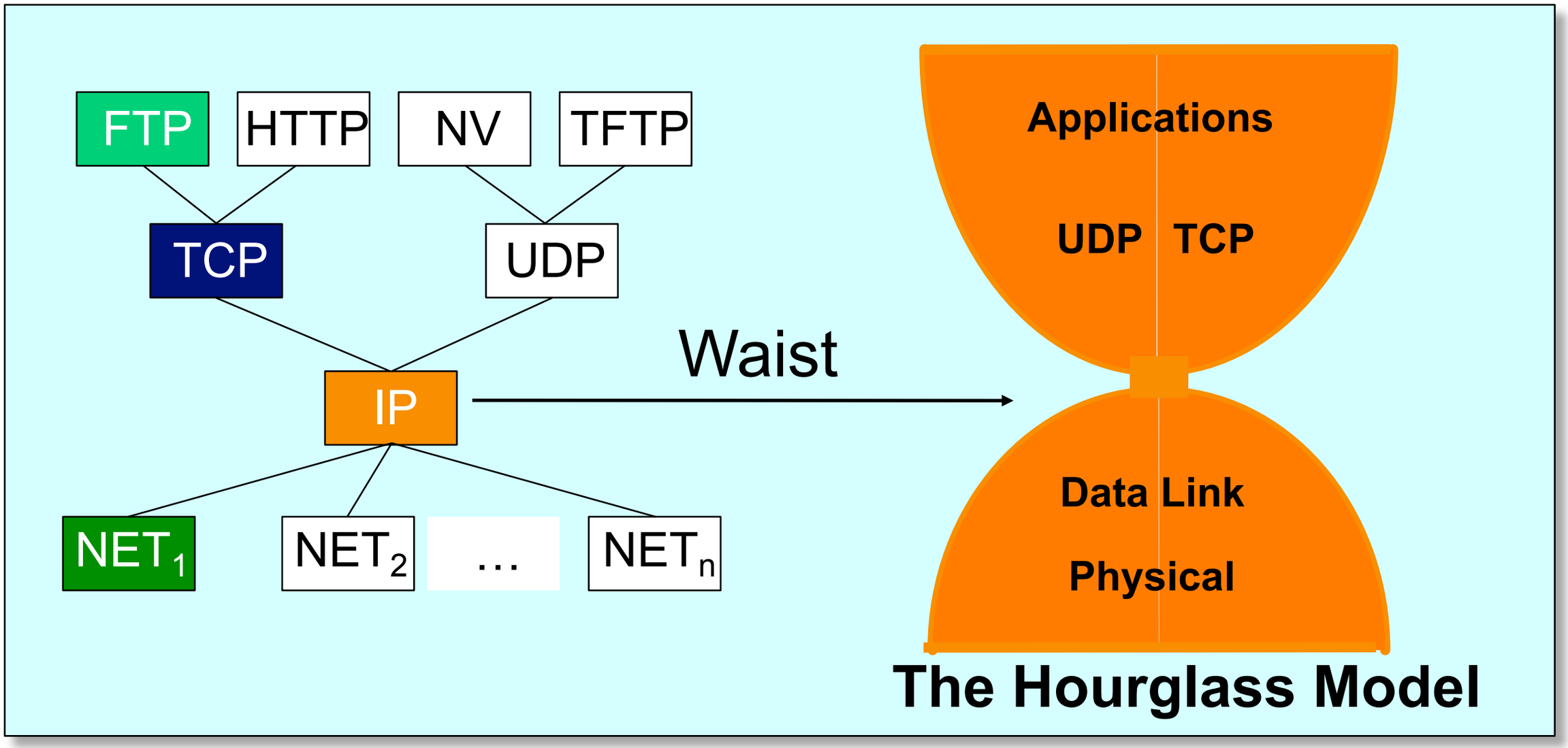
- Sub-divide the problem
  - –Each layer relies on services from layer below
  - –Each layer exports services to layer above
- Interface between layers defines interaction
  - –Hides implementation details
  - –Layers can change without disturbing other layers



IP Suite: End Hosts vs. Routers

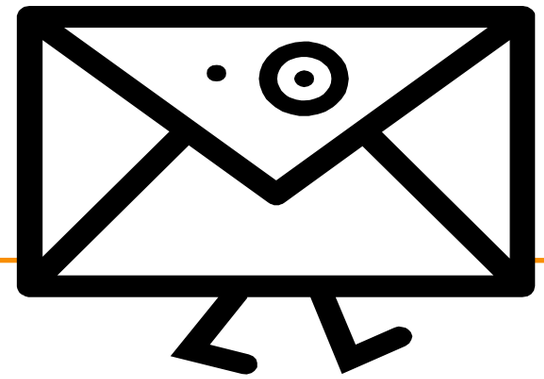


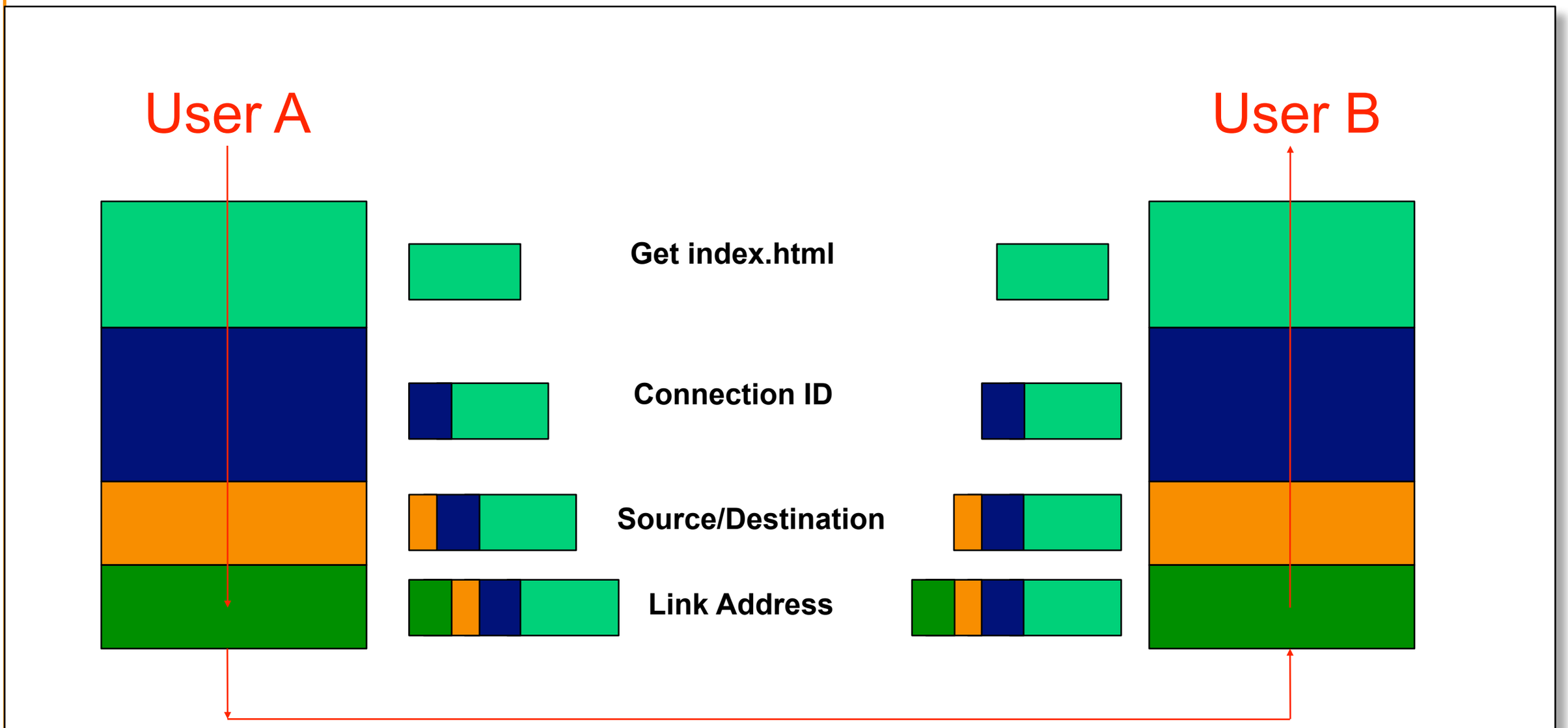
The Internet Protocol Suite



The waist facilitates interoperability

Layer Encapsulation



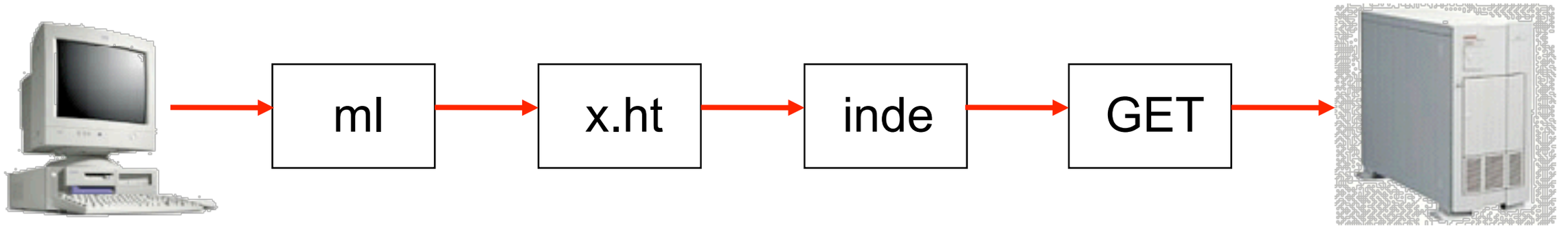


What if the Data Doesn't Fit?

Problem: Packet size

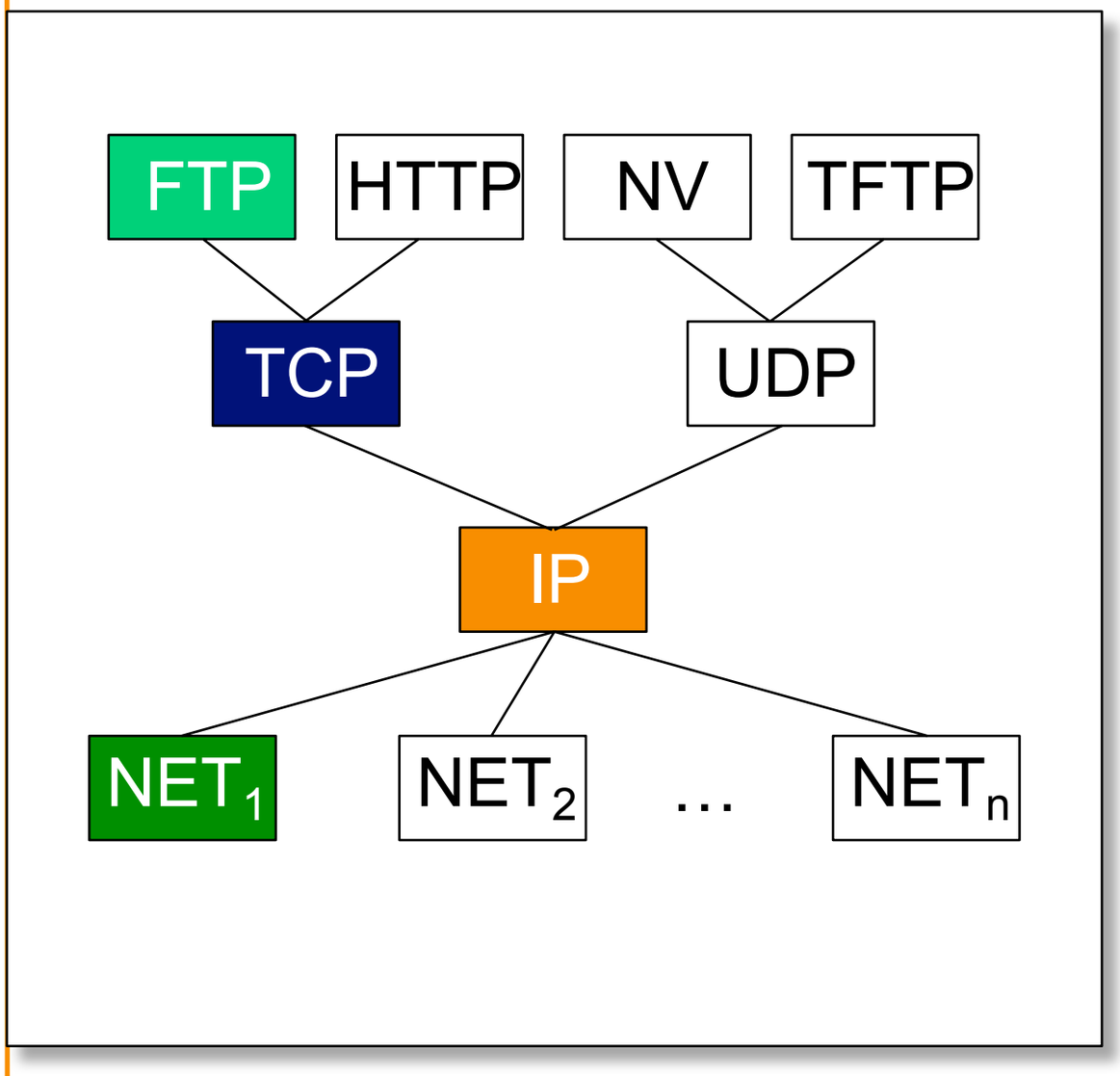
- On Ethernet, max IP packet is 1500 bytes
- Typical Web page is 10 kbytes

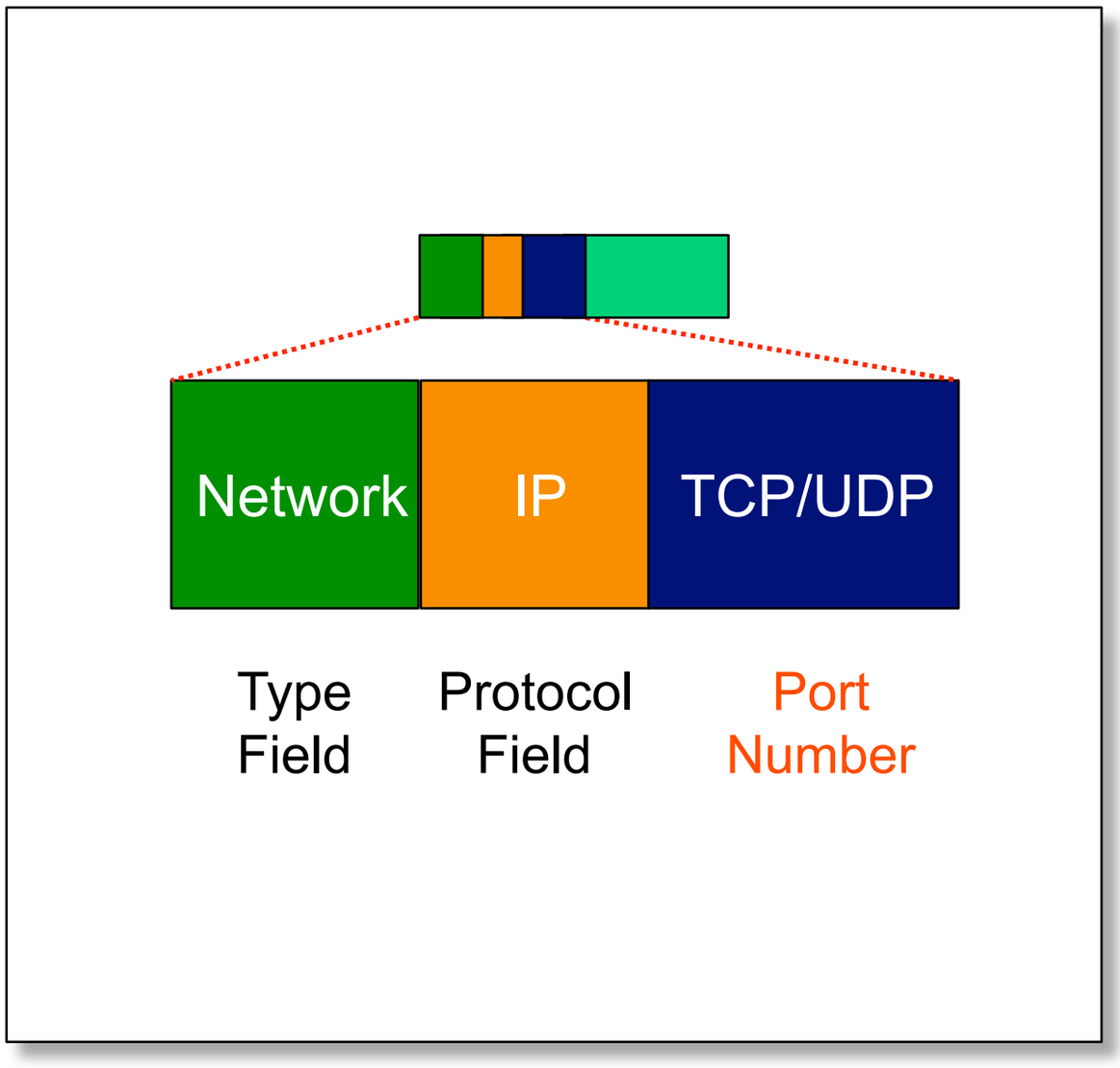
Solution: Split the data across multiple packets



Protocol Demultiplexing

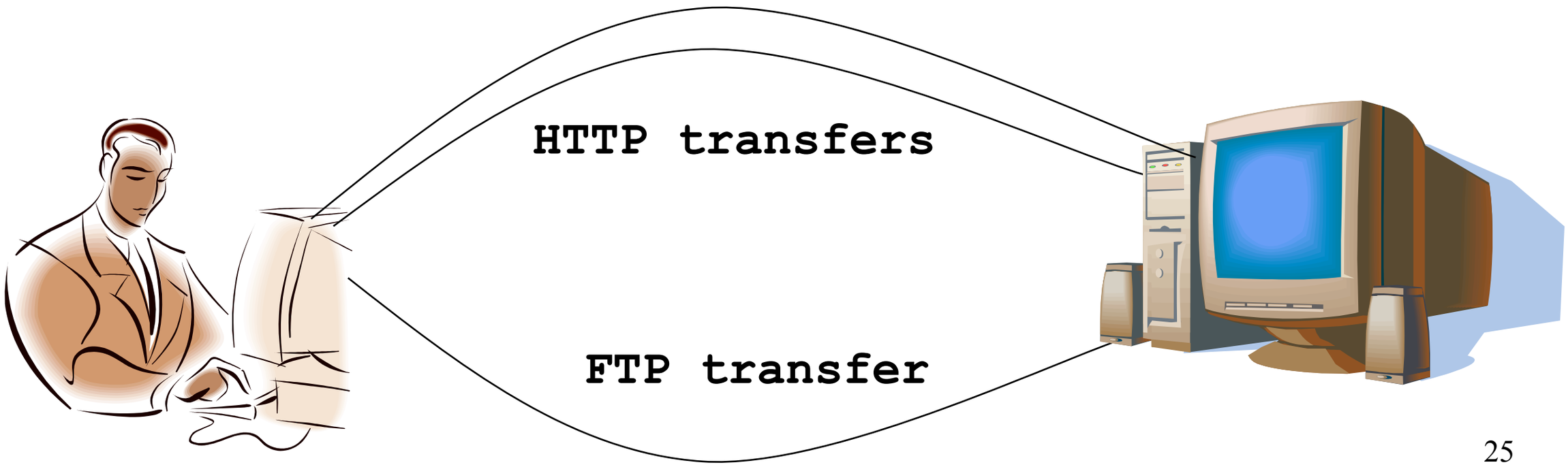
- Multiple choices at each layer





Demultiplexing: Port Numbers

- Differentiate between multiple transfers
  - –Knowing source and destination host is not enough
  - –Need an id for *each transfer* between the hosts
- Specify a particular service running on a host
  - –E.g., HTTP server running on port 80
  - –E.g., FTP server running on port 21



Is Layering Harmful?

- Layer N may duplicate lower level functionality
  - –E.g., error recovery to retransmit lost data
- Layers may need same information
  - –E.g., timestamps, maximum transmission unit size
- Strict adherence to layering may hurt performance
  - –E.g., hiding details about what is really going on
- Some layers are not always cleanly separated
  - –Inter-layer dependencies for performance reasons
- Headers start to get really big
  - –Sometimes more header bytes than actual content

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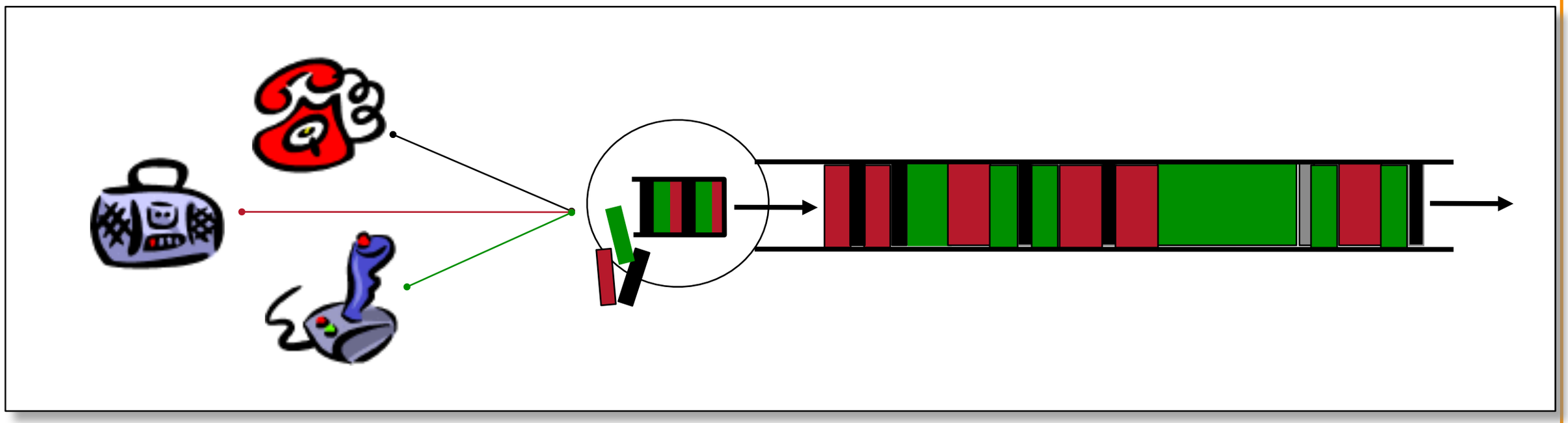
Resource Allocation: Queues



- Sharing access to limited resources
  - E.g., a link with fixed service rate
- Simplest case: first-in-first out queue
  - Serve packets in the order they arrive
  - When busy, store arriving packets in a buffer
  - Drop packets when the queue is full

What if the Data gets Dropped?

Problem: Lost Data

GET index.html

Solution: Timeout and Retransmit

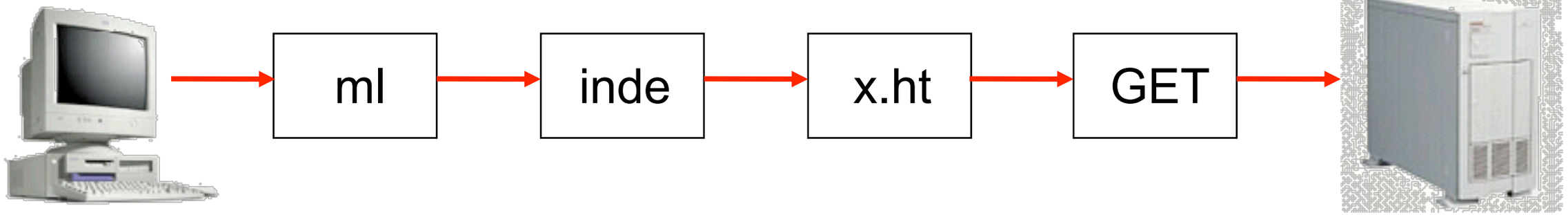
GET index.html

GET index.html

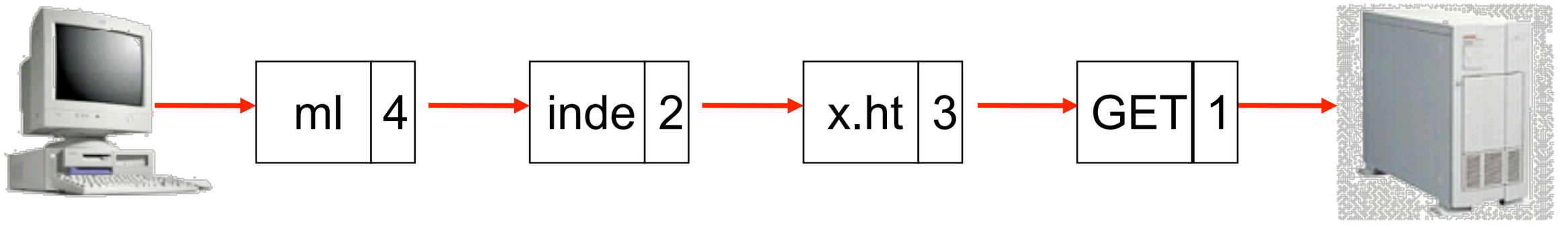
GET index.html

What if the Data is Out of Order?

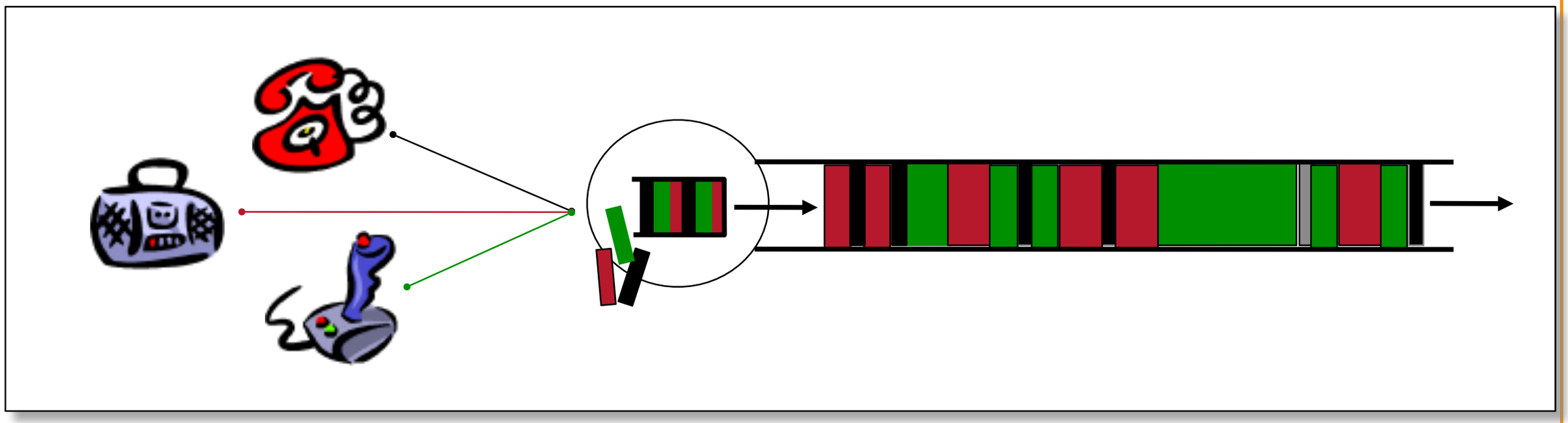
Problem: Out of Order



Solution: Add Sequence Numbers



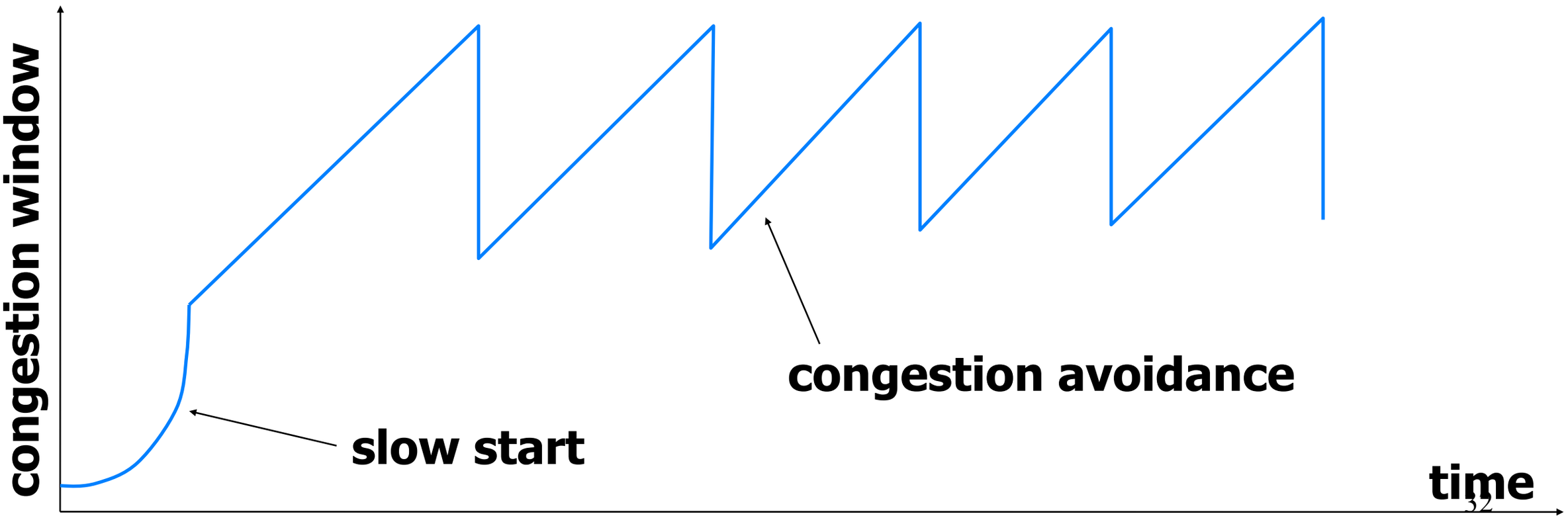
Resource Allocation: Congestion Control



- What if too many folks are sending data?
  - Senders agree to slow down their sending rates
  - … in response to their packets getting dropped
- The essence of TCP congestion control
  - Key to preventing congestion collapse of the Internet

Transmission Control Protocol

- Flow control: window-based
  - Sender limits number of outstanding bytes (window size)
  - *Receiver window* ensures data does not overflow receiver
- Congestion control: adapting to packet losses
  - *Congestion window* tries to avoid overloading the network (increase with successful delivery, decrease with loss)
  - TCP connection starts with small initial congestion window



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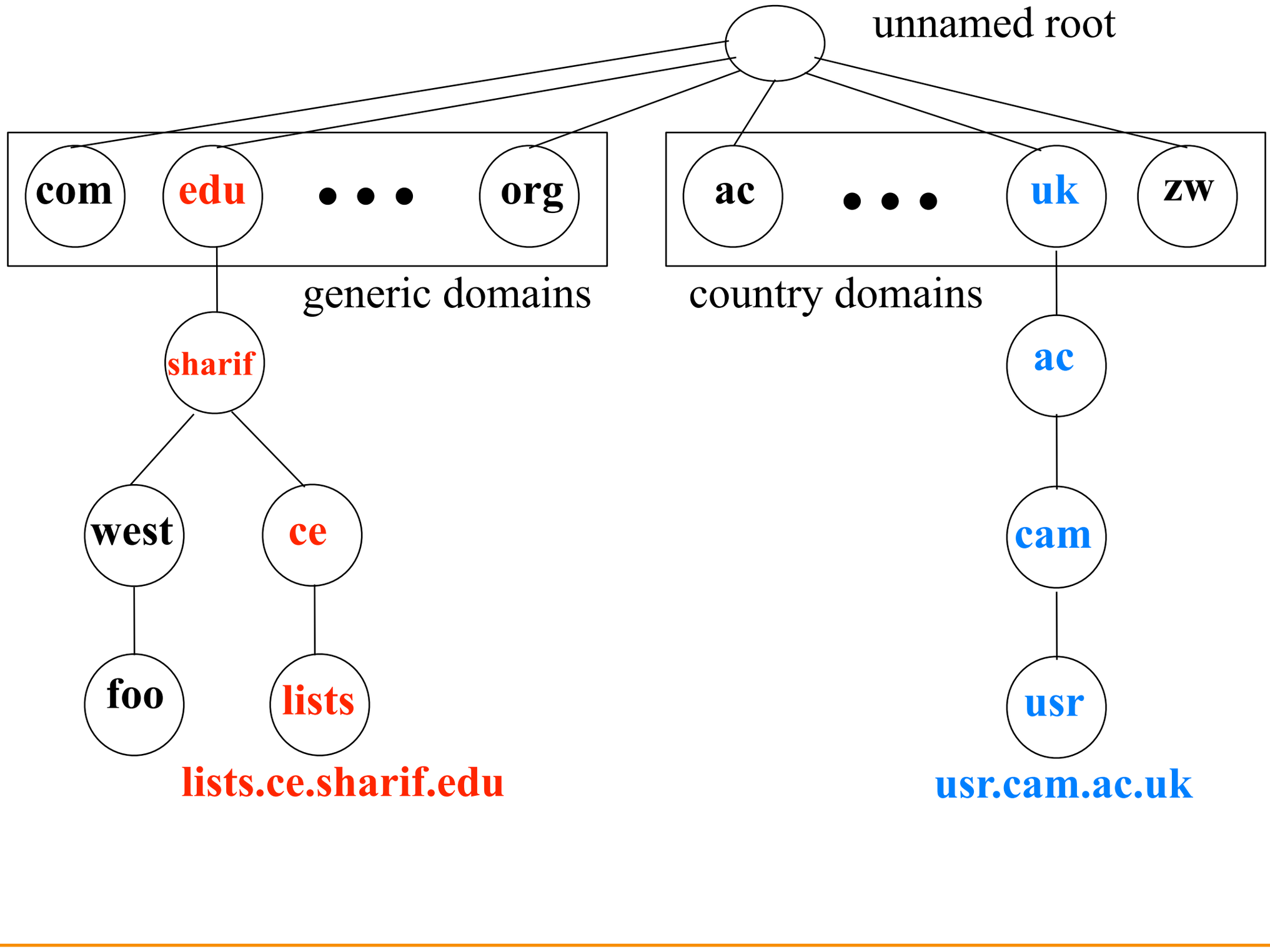
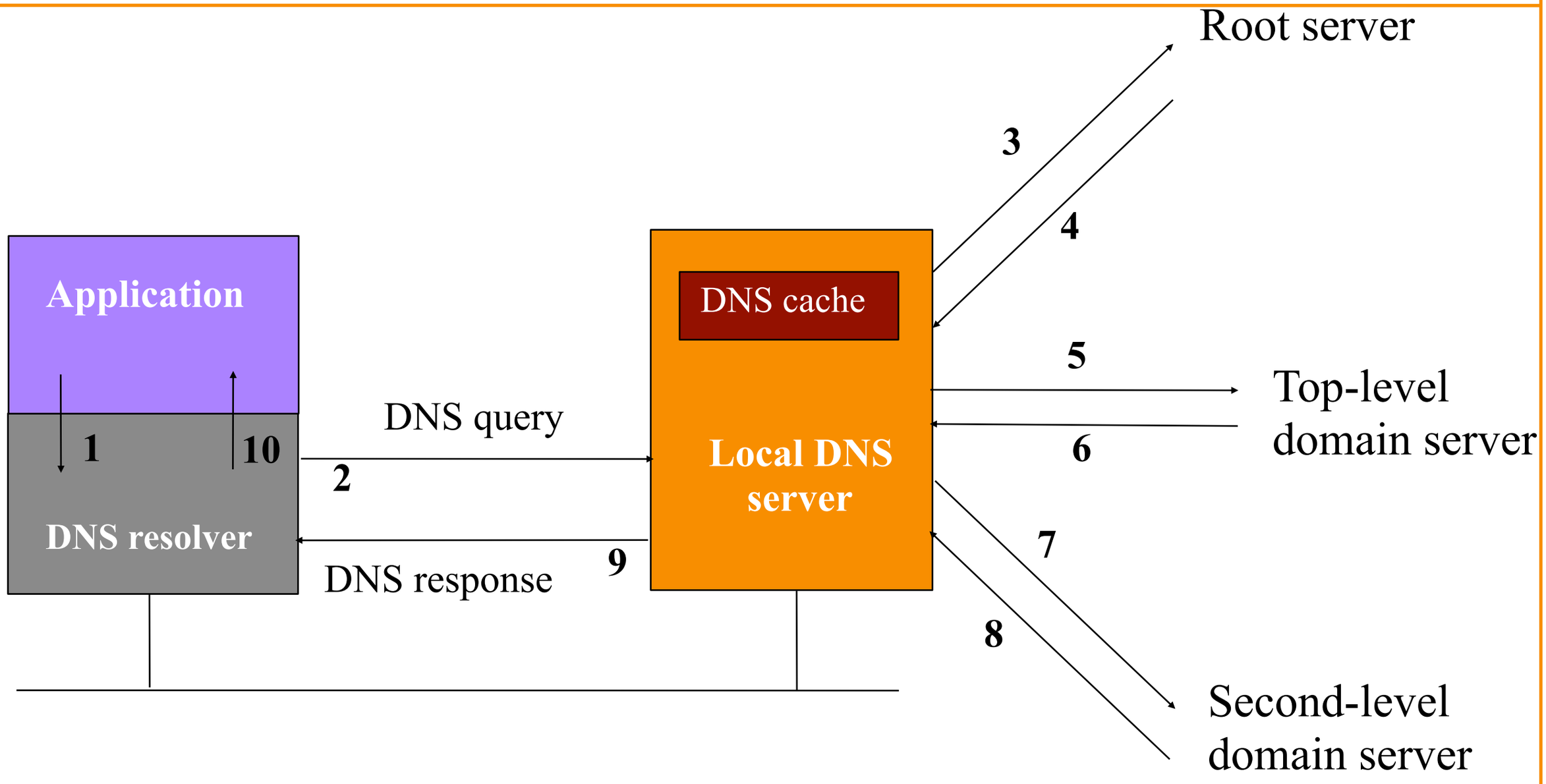
Naming: Domain Name System (DNS)

- Properties of DNS
  - –Hierarchical name space divided into zones
  - –Translation of names to/from IP addresses
  - –Distributed over a collection of DNS servers
- Client application
  - –Extract server name (e.g., from the URL)
  - –Invoke system call to trigger DNS resolver code
    - E.g., *gethostbyname()* on "www.cs.sharif.edu"
- Server application
  - –Extract client IP address from socket
  - –Optionally invoke system call to translate into name
    - E.g., *gethostbyaddr()* on "12.34.158.5"

Domain Name System



DNS Resolver and Local DNS Server



Caching based on a time-to-live (TTL) assigned by the DNS server responsible for the host name to reduce latency in DNS translation.

Conclusions

- Course objectives
  - How the Internet works, key concepts in networking, and Network programming
- Key concepts in networking
  - Protocols, layers, resource allocation, and naming
- Next lecture:
  - Read Chapter 1 of the Peterson/Davie book
  - Skim the online reference material on sockets
  - (Re)familiarize yourself with C programming