Lecture 1:
Course Overview

CS/ECE 438: Communication Networks

Prof. Matthew Caesar

January 20, 2010

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- Includes content by Robin Kravets, Steve Lumetta, Bruce Hajek, Nitin Vaidya, Larry Peterson, Jennifer Rexford, Ion Stoica, Brighten Godfrey, and others

Course Information

- Instructors:
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- TAs:
  - Brian Cho, Virajith Jalaparti
- Class Webpage:
  - http://www.cs.illinois.edu/class/sp10/cs438
- Class News group:
  - cs.illinois.class.cs438

Prerequisites

- Operating Systems Concepts
  - CS 241 or equivalent
- C or C++ Programming
  - Preferably Unix
- Probability and Statistics

Grading Policy

• Homework	15%
– 7 homework assignments	
• Programming Projects	35%
– 3 Programming projects	
• Mid-term Exam	20%
– March 17	
• Final Exam	30%
– May 12, 7 – 10 PM	

Homework and Projects

- Homework:
  - Due Wednesdays at start of class.
  - General extension to Fridays start of class (hard deadline).
    - Solutions handed out in class on Fridays
  - No questions to Professor, TAs or on newsgroup after class on Wednesday.
- Projects:
  - Due Fridays at 9:00pm.
  - 2% off per hour late
  - MP1 is solo
  - MP2 and MP3 are 2 person teams

Academic Honesty

- Your work in this class **must** be your own.
- If students are found to have collaborated excessively or to have blatantly cheated (e.g., by copying or sharing answers during an examination or sharing code for the project), **all** involved will at a minimum receive grades of 0 for the first infraction.
  - We will run a similarity-checking system on code and binaries
- Further infractions will result in failure in the course and/or recommendation for dismissal from the university.

Graduate Students

- Graduate students MAY take an extra one hour project in conjunction with this class
  - Graduate students
    - Write a survey paper in a networking research area of your choice
    - Project proposal with list of 10+ academic references (no URL's) due February 11th
    - Paper due last day of class
  - Undergraduates may not take this project course
    - However, if you are interested in networking research, please contact me

Course Objectives

- At the end of the semester, you should be able to
  - Identify the problems that arise in networked communication
  - Explain the advantages and disadvantages of existing solutions to these problems in the context of different networking regimes
  - Understand the implications of a given solution for performance in various networking regimes
  - Evaluate novel approaches to these problems

Programming Objectives

- At the end of the semester, you should be able to
  - Identify and describe the purpose of each component of the TCP/IP protocol suite
  - Develop solid client-server applications using TCP/IP
  - Understand the impact of trends in network hardware on network software issues

Course Contents

- Introduction to UNIX Network Programming
- Direct Link Networks
- Packet Switched Networks
- Internetworking
- End-to-End Protocols
- Congestion Control
- Performance Analysis and Queueing Theory

Some

- Mobile Ad hoc Networks
- P2P Networks
- Network Security

Why study networks?

- Internet has drastically changed the way we interact with computers
  - Business, collaborations, retail, news, communications, gaming, media… all increasingly conducted online
- Emergence of new distributed software to support these applications
  - Webmail, online retail, online auctions, wikis, online storage, search, utility computing, network management, messaging and email, wireless services, social networking

What do these two things have in common?

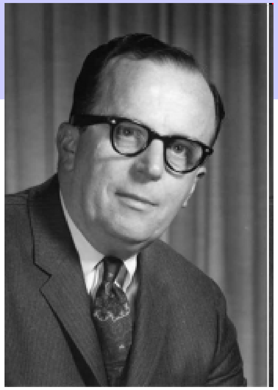
Johann Gutenberg
(1398-1468)

- First printing press
  - Key idea: movable type

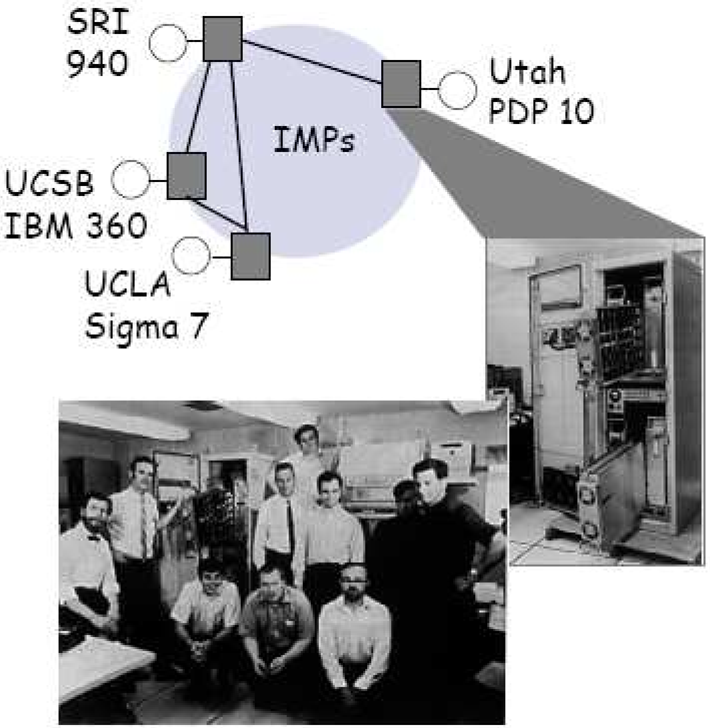
- The Internet

Both lowered the cost of distributing information

The ARPANet



- 1962: J.C.R. Licklider appointed head of ARPA
  - Envisions shared network to connect computers at different sites
- 1968: RFQ sent to 140 potential bidders to build ARPANet
  - 12 submissions (most regard proposal as outlandish)
  - BBN Technologies selected as winner
- 2 September 1969: UCLA first node on ARPANet
- December 1969: 4 nodes connected by phone lines



BBN team that implemented the interface message processor

ARPANet evolves into Internet

1965	1975	1985	1995	2008
ARPANet SATNet PRNet	TCP/IP	NSFNet	Deregulation & Commercialization WWW	SaS ASP AIP

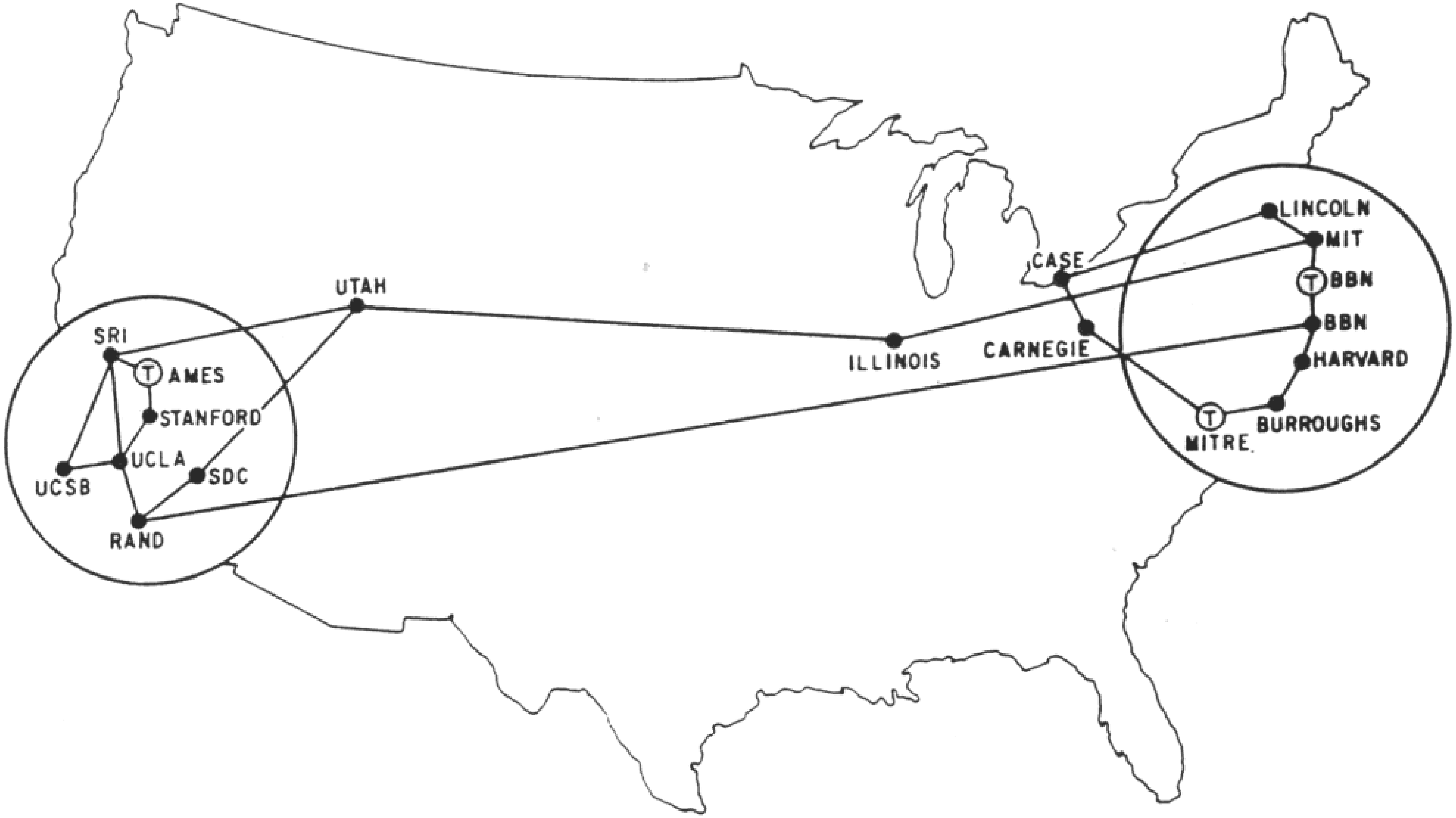
SATNet: Satelite network
PRNet: Radio Network

Web Hosting
Multiple ISPs
Internet2 Backbone
Internet Exchanges

→

Application Hosting
ASP: Application Service Provider
SaS: Software as a Service
Provider (e-commerce tookit, etc.)

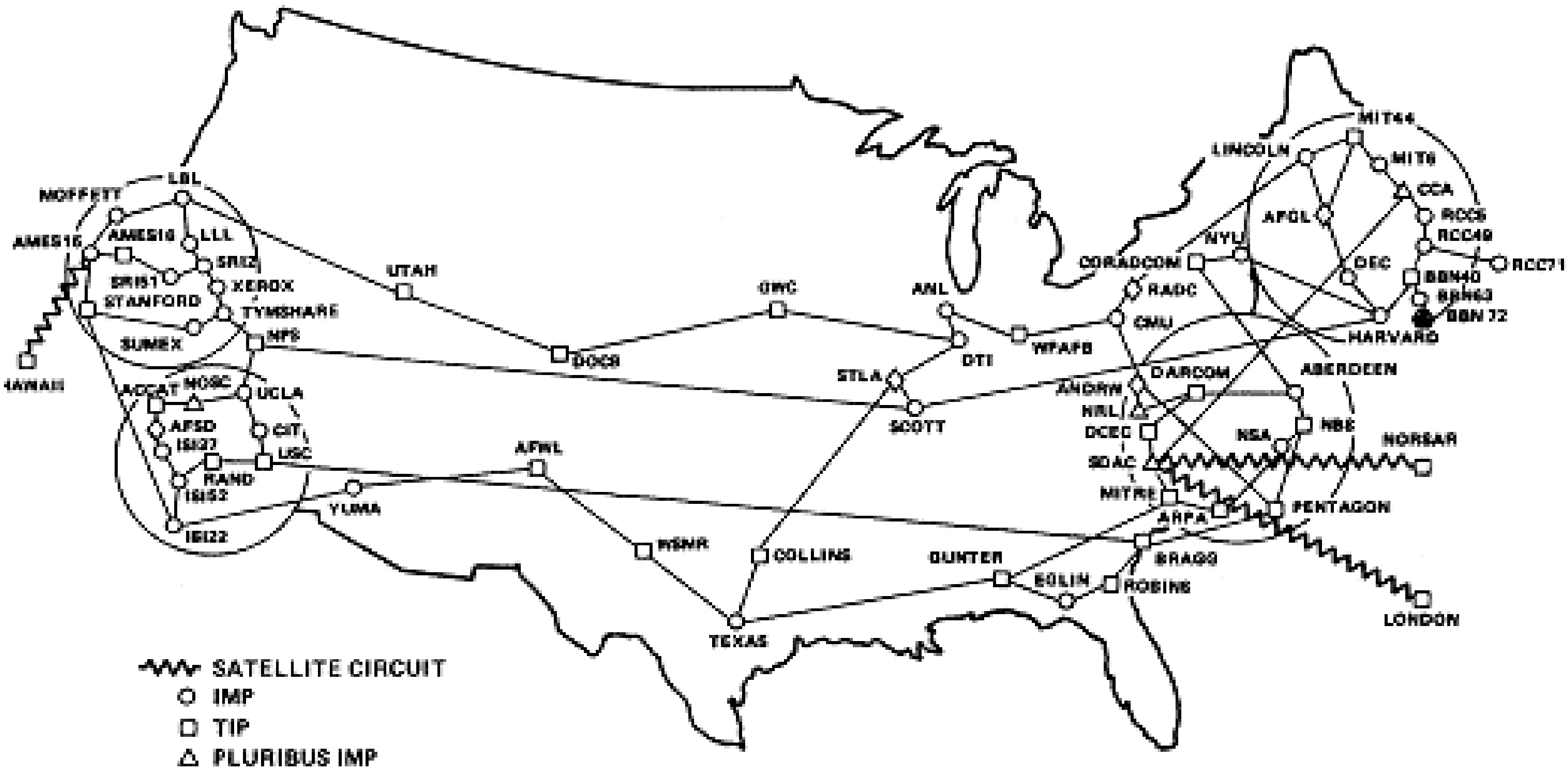
ARPANet, 1971



MAP 4 September 1971

ARPANet, 1980

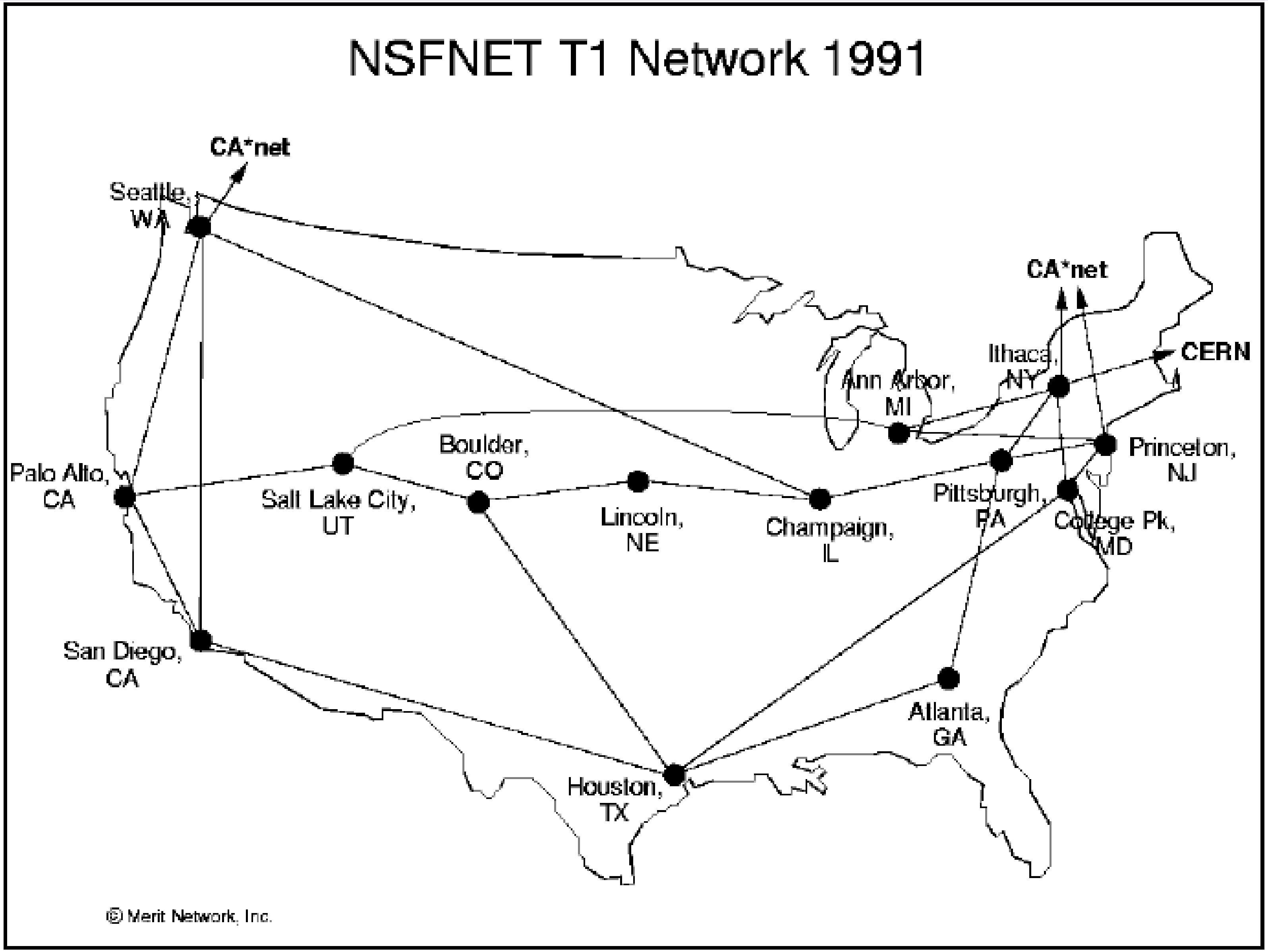
ARPANET GEOGRAPHIC MAP, OCTOBER 1980



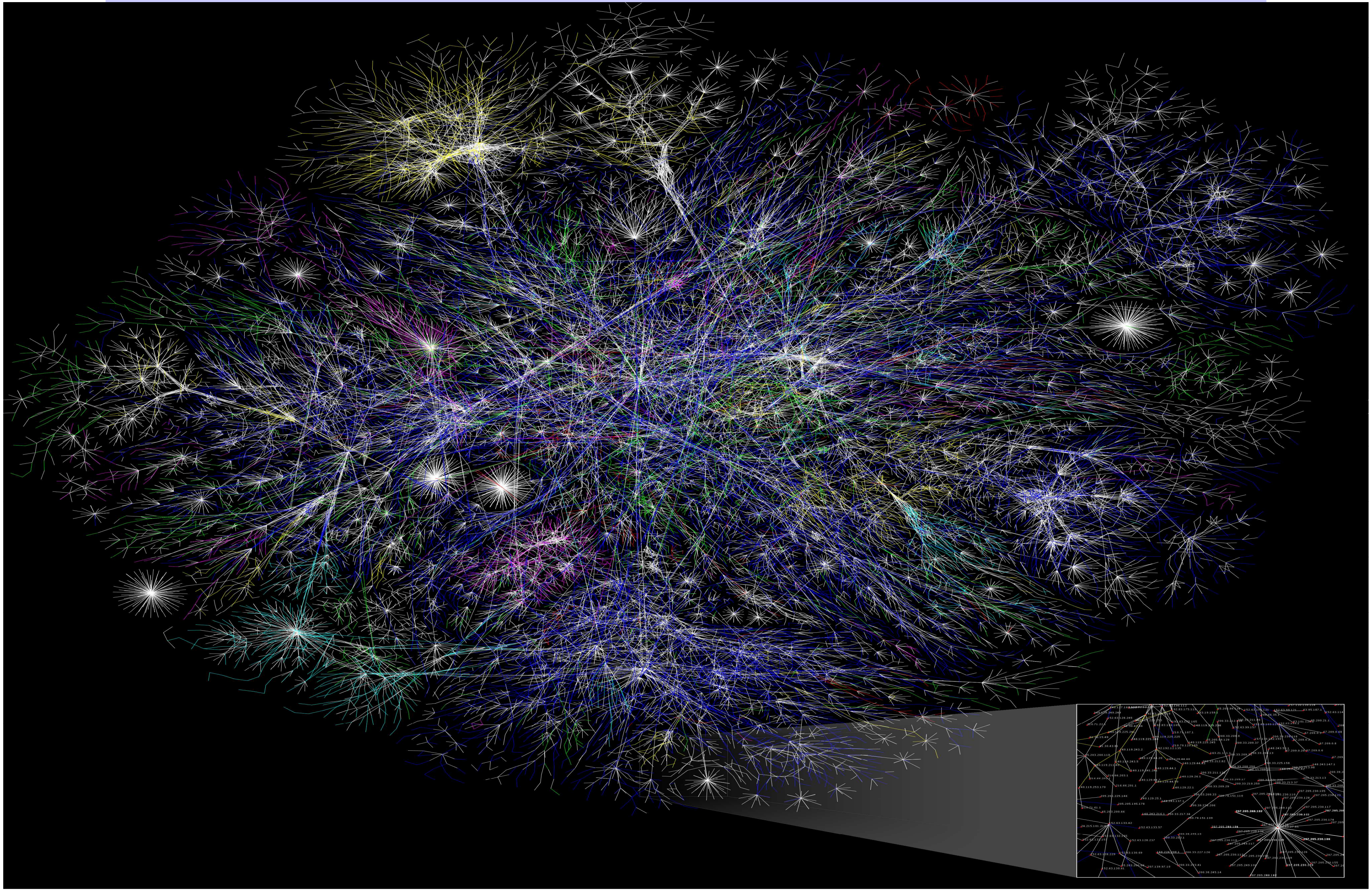
SATELLITE CIRCUIT
IMP
TIP
PLURIBUS IMP
PLURIBUS TIP
C30

(NOTE: THIS MAP DOES NOT SHOW ARPA'S EXPERIMENTAL SATELLITE CONNECTIONS)
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

Transition to NSFNet



Internet, today



Networking: Actually Not Boring

- How hard can it be?

- You just string a wire (or other signaling path) between two computers…
- … first one pushes bits down the link…
- … and the second one gets them up… right?
- Where does it get tricky?
- What are the challenges?

Why Networking is Challenging

- Fundamental challenge: the speed of light
- Question: how long does it take light to travel from UIUC to Mountain View, CA (Google Headquarters)?
- Answer:
  - Distance UIUC --> Mountain View is 2,935 km
  - Traveling 300,000 km/s: 9.78ms

Fundamental Challenge: Speed of Light

- Question: how long does it take an Internet "packet" to travel from UIUC to Mountain View?
- Answer:
  - For sure >= 9.78ms
  - But also depends on:
    - The route the packet takes (could be circuitous!)
    - The propagation speed of the links the packet traverses
      - E.g. in optical fiber light propagates only at 2/3 C
    - The transmission rate (bandwidth) of the links (bits/sec)
      - And also the size of the packet
    - Number of hops traversed ("store and forward" delay)
    - The "competition" for bandwidth the packet encounters (congestion). It may have to wait in router queues.
  - In practice this boils down to >=40ms
    - With variance (can be hard to predict!)

Fundamental Challenge: Speed of light

- Question: how many cycles does your PC execute before it can possibly get a reply to a message it sent to a Mountain View web server?
- Answer:
  - Round trip takes >= 80ms
  - PC runs at (say) 3 GHz
  - 3,000,000,000 cycles/sec * 0.08 sec = 240,000,000 cycles
- Thus,
  - Communication feedback is always *dated*
  - Communication fundamentally asynchronous

Fundamental Challenge: Speed of Light

- Question: what about machines directly connected (via a *local area network* or LAN)?
- Answer:

```
% ping www.cs.uiuc.edu
 PING dcs-www.cs.uiuc.edu (128.174.252.83) 56(84) bytes of data.
 64 bytes from 128.174.252.83: icmp_seq=1 ttl=63 time=0.263 ms
 64 bytes from 128.174.252.83: icmp_seq=2 ttl=63 time=0.595 ms
 64 bytes from 128.174.252.83: icmp_seq=3 ttl=63 time=0.588 ms
 64 bytes from 128.174.252.83: icmp_seq=4 ttl=63 time=0.554 ms
 ...
```

- 500us = 1,500,000 cycles
  - Still a loooooong time…
  - … and asynchronous…

Why networking is challenging (cont'd)

- Fundamental challenge: components fail
  - Network communication involves a chain of interfaces, links, routers, and switches…

Examples of Network Components

Links

Fibers

Coaxial Cable

Interfaces

Ethernet card

Wireless card

Switches/routers

Large router

Telephone switch

Why networking is challenging (cont'd)

- Fundamental challenge: components fail
  - Network communication involves a chain of interfaces, links, routers, and switches…
  - **All** of which must function correctly
- Question: suppose a communication involves 50 components which work correctly (independently) 99% of the time. What's the likelihood the communication fails at a given point in time?
  - Answer: success requires that they all funciton, so failure probability = $1 - 0.99^{50} = 39.5\%$
- So we have a **lot** of components, which tend to fail…
  - … and we may not find out for a loooong time

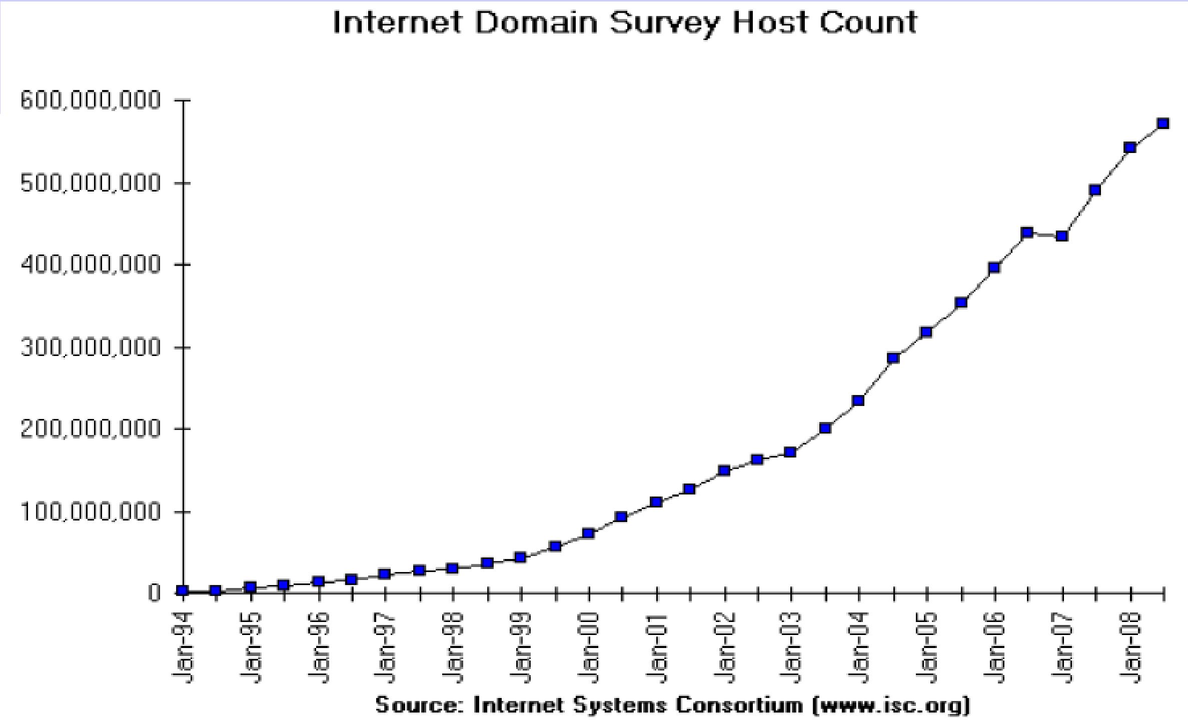
Why networking is challenging (cont'd)

- Challenge: enormous dynamic range
  - Round trip times (latency) vary from 10 us's to sec's (10^5)
  - Data rates (bandwidth) vary from kbps to 10 Gbps (10^7)
  - Queuing delays inside the network vary from 0 to sec's
  - Packet loss varies from 0 to 90+%
  - End system (host) capabilities vary from *cell phones* to *supercomputing clusters*
  - Application needs vary enormously: size of transfers, bidirectionality, need for reliability, tolerance of jitter
- Related challenge: very often, there is no such thing as "typical". Beware of your "mental models"!
  - Must think in terms of design ranges, not points
  - Mechanisms need to be adaptive

Why networking is challenging (cont'd)

- Challenge: different parties must work together
  - Multiple parties with different agendas must agree how to divide the task between them
- Working together requires:
  - Protocols (defining who does what)
    - These generally need to be standardized
  - Agreements regarding how different types of activity are treated (policy)
- Different parties very well might try to "game" the network's mechanisms to their advantage

Why networking is challenging



- Challenge: incessant rapid growth
  - Utility of the network scales with its size
    - Fuels exponential growth (for more than 2 decades!)
  - Data centers contain 100k+ of hosts, Internet contains 600M+ hosts, 2.6M routers
    - Microsoft's data center in Chicago: 500k servers
- Adds another dimension of dynamic range…
  - and quite a number of ad hoc artifacts…

Why networking is challenging (cont'd)

- Challenge: there are Bad Guys out there
- As the network population grows in size, so does the number of
  - Vandals
  - Crazies
- What really matters, though: as network population grows, it becomes more and more attractive to
  - Crooks
  - (and also spies and militaries)

Why Crooks Matter for Networking

- They (and other attackers) seek ways to misuse the network towards their gain
  - Carefully crafted "bogus" traffic to manipulate the network's operation
  - Torrents of traffic to overwhelm a service (denial-of-service) for purposes of extortion/competition
  - Passively recording network traffic in transit (sniffing)
  - Exploit flaws in clients and servers using the network to trick into executing the attacker's code (compromise)
- They all do this energetically because there is significant $$$ to be made

Why networking is challenging (cont'd)

- Challenge: you cannot reboot the Internet!
  - Everyone depends on the Internet
    - Businesses
    - Hospitals
    - Education institutions
    - Financial sector
    - …
  - Cannot stop, fix, or restart it
  - … akin to changing the engine while you are flying the plane!

Summary so far…

- Networking is about design in the presence of challenges/contraints:
  - Not akin to e.g., programming languages/compilers
    - Which have well-developed theories to draw upon
  - Much more akin to operating systems
    - Abstractions
    - Tradeoffs
    - Design principles / "taste"

Roadmap for rest of lecture

- Today, let's study a few key questions that networks need to solve:

1. How can many hosts communicate?
2. How can we identify hosts?
3. How can we make protocols easy to design/deploy?

Roadmap for rest of lecture

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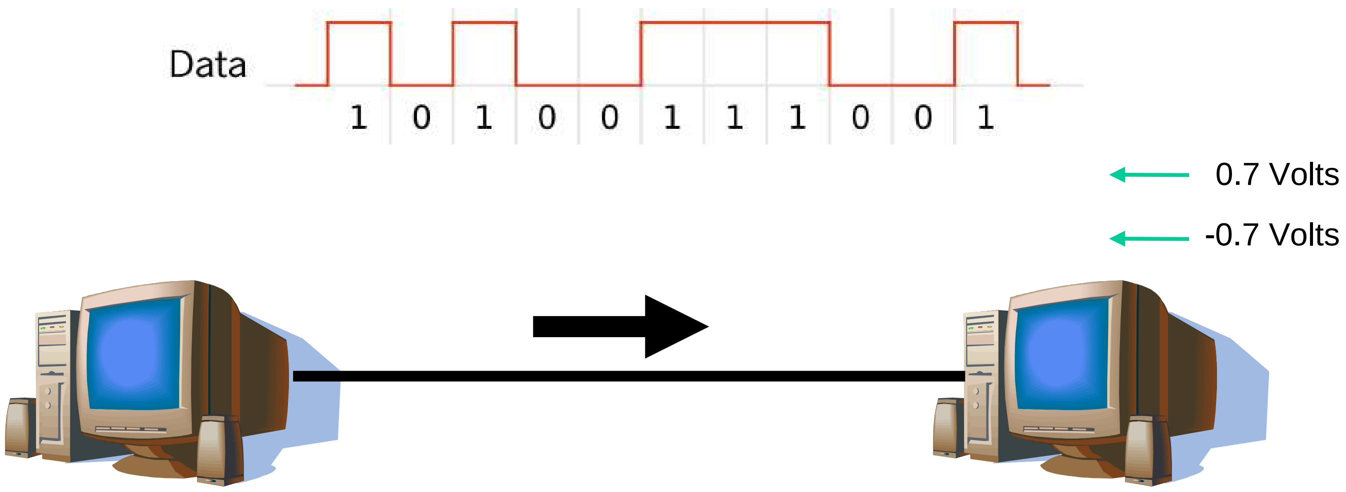
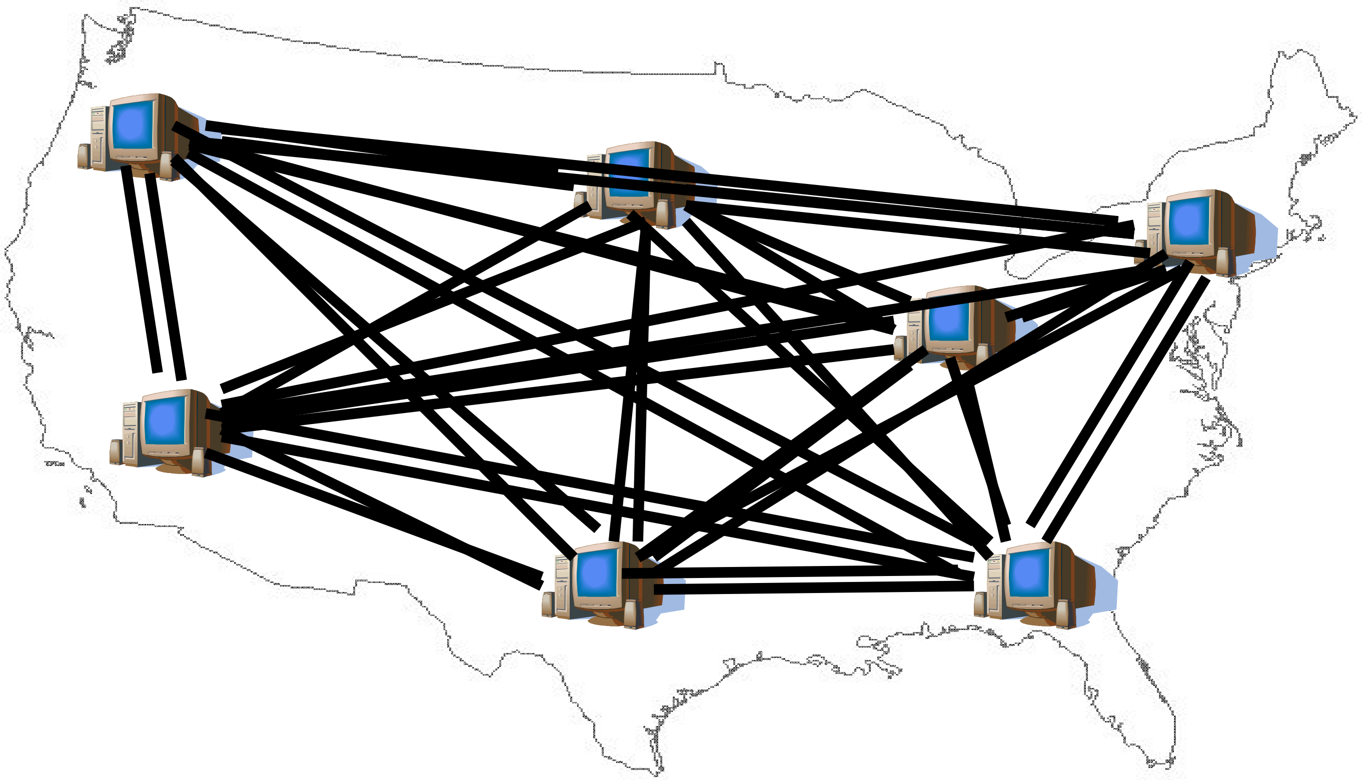
How can two hosts communicate?



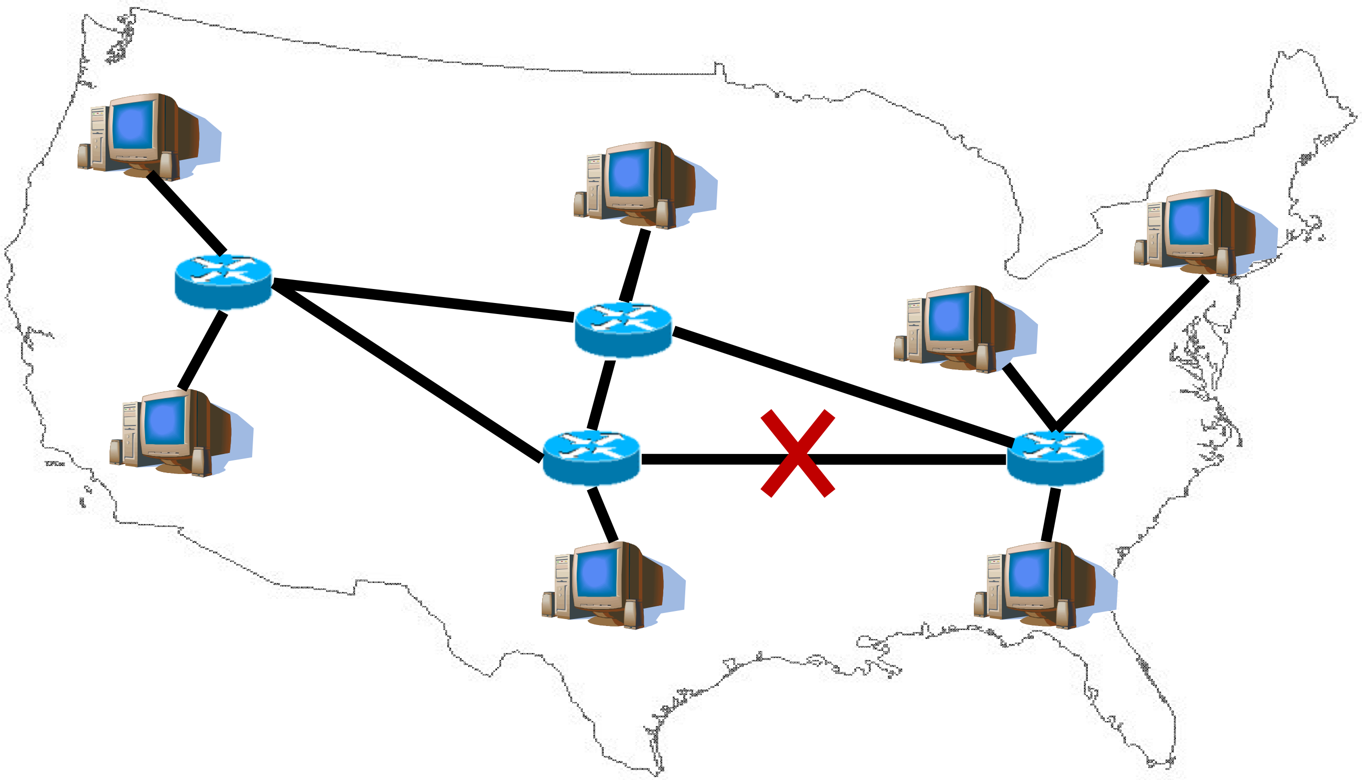
- Encode information on modulated “Carrier signal”
  - Phase, frequency, and amplitude modulation, and combinations thereof
  - Ethernet: self-clocking Manchester coding ensures one transition per clock
  - Technologies: copper, optical, wireless

How can many hosts communicate?



- Naïve approach: full mesh
- Problem:
  - Obviously doesn't scale to the 570,937,778 hosts in the Internet (estimated, Aug 2008)

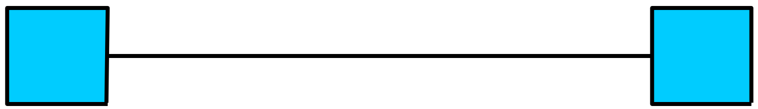
How can many hosts communicate?



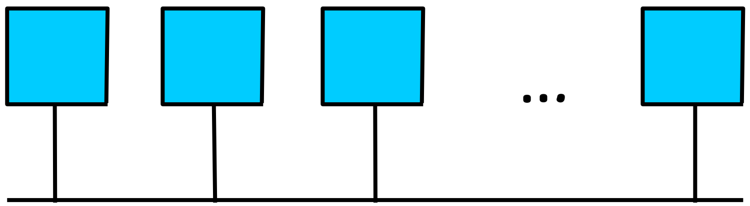
- Multiplex traffic with routers
- Goals: make network robust to failures, maintain spare capacity, reduce operational costs

Connectivity

- Building Block
  - Links: coax cable, optical fiber, …
  - Nodes: workstations, routers, …
- Links:
  - Point-to-point



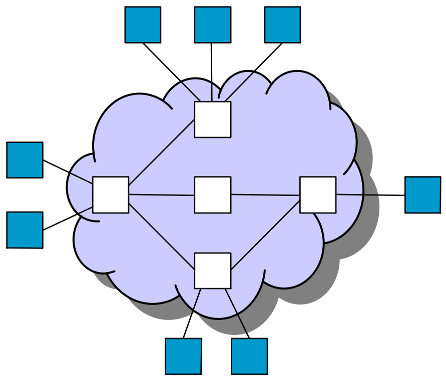
  - Multiple access

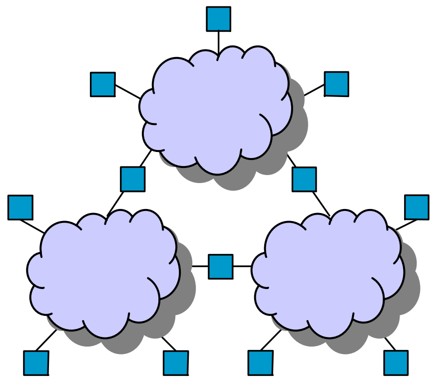


Indirect Connectivity

- Switched Networks
- Internetworks

- Recursive definition of a network
  - Two or more nodes connected by a physical link
  - Two or more networks connected by one or more nodes





Effects of Indirect Connectivity

- Nodes receive data on one link and forward it onto the next $\Rightarrow$ switching network
  - Circuit Switching
    - Telephone
    - Stream-based (dedicated circuit)
    - Links reserved for use by communication channel
    - Send/receive bit stream at constant rate
  - Packet Switching
    - Internet
    - Message-based (store-and-forward)
    - Links used dynamically
    - Admission policies and other traffic determine bandwidth

Roadmap for rest of lecture

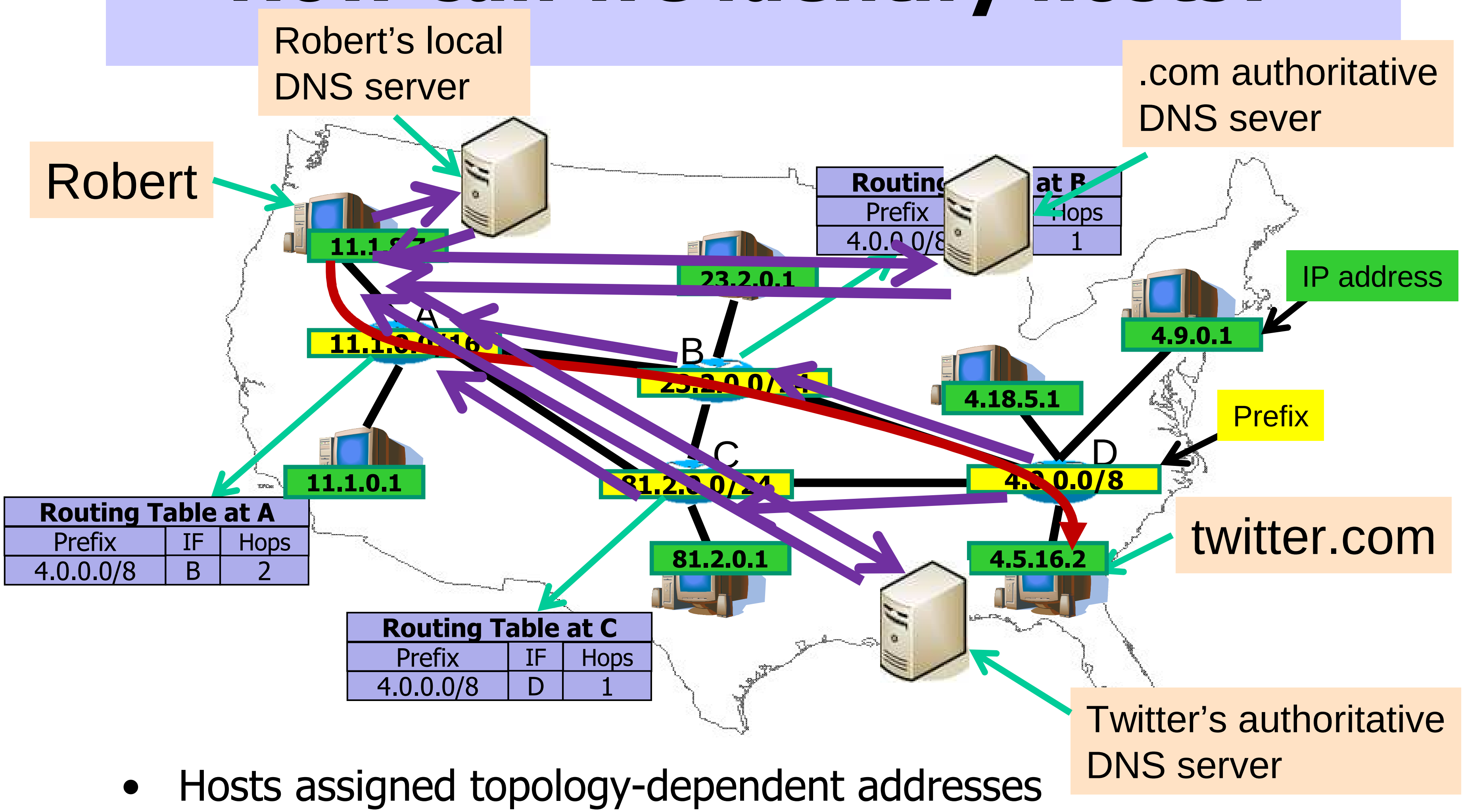
- Today, let's study a few key questions that networks need to solve:

1. How can many hosts communicate?

2. How can we identify hosts?

3. How can we make protocols easy to design/deploy?

How can we identify hosts?



- Hosts assigned topology-dependent addresses
- Routers advertise address blocks ("prefixes")
- Routers compute "shortest" paths to prefixes
- Map IP addresses to names with DNS

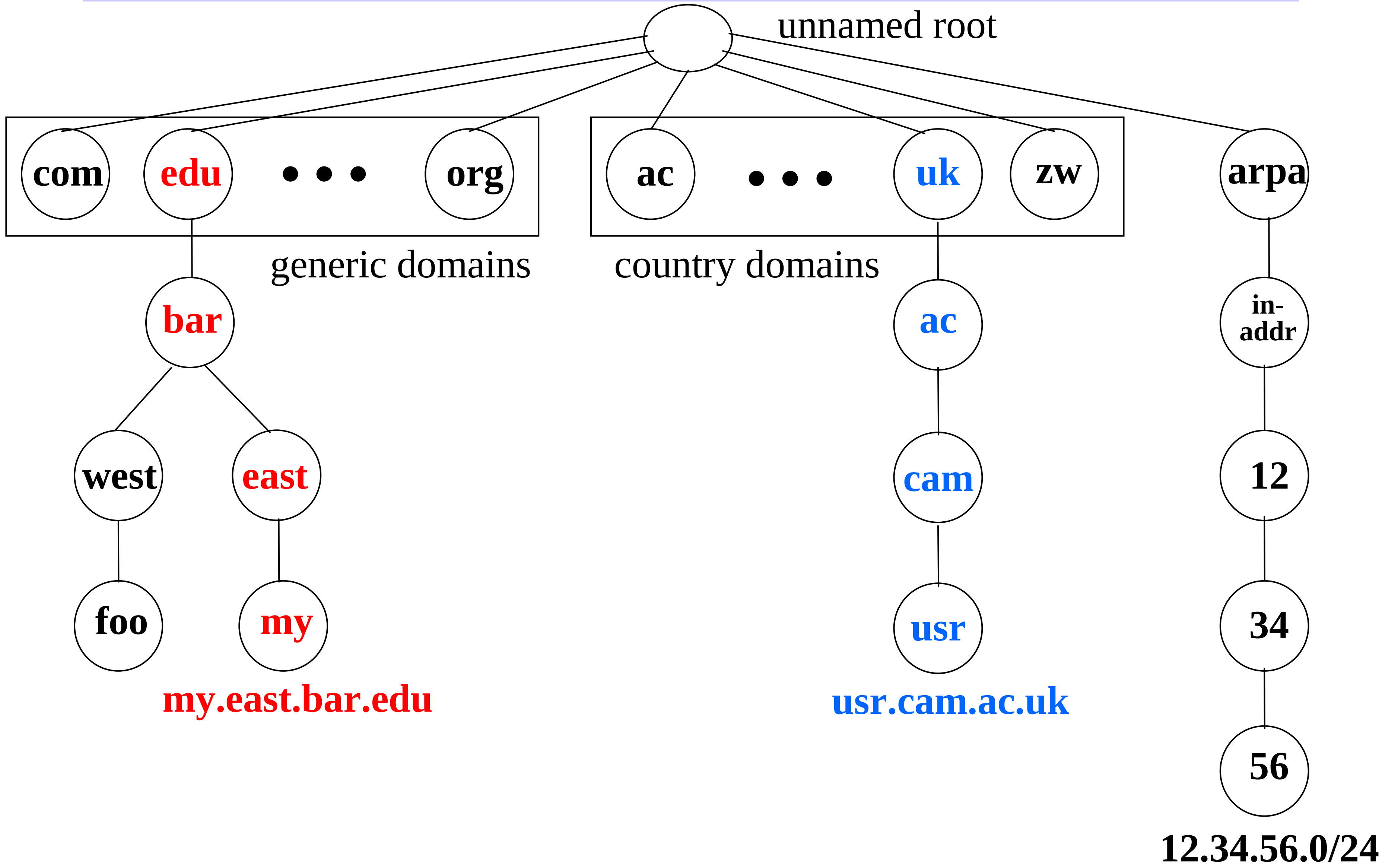
Addressing

- Addressing
  - Unique byte-string used to indicate which node is the target of communication
- Types of Addresses
  - Unicast: node-specific
  - Broadcast: all nodes on the network
  - Multicast: subset of nodes on the network
- Routing
  - The process of determining how to forward messages toward the destination node based on its address

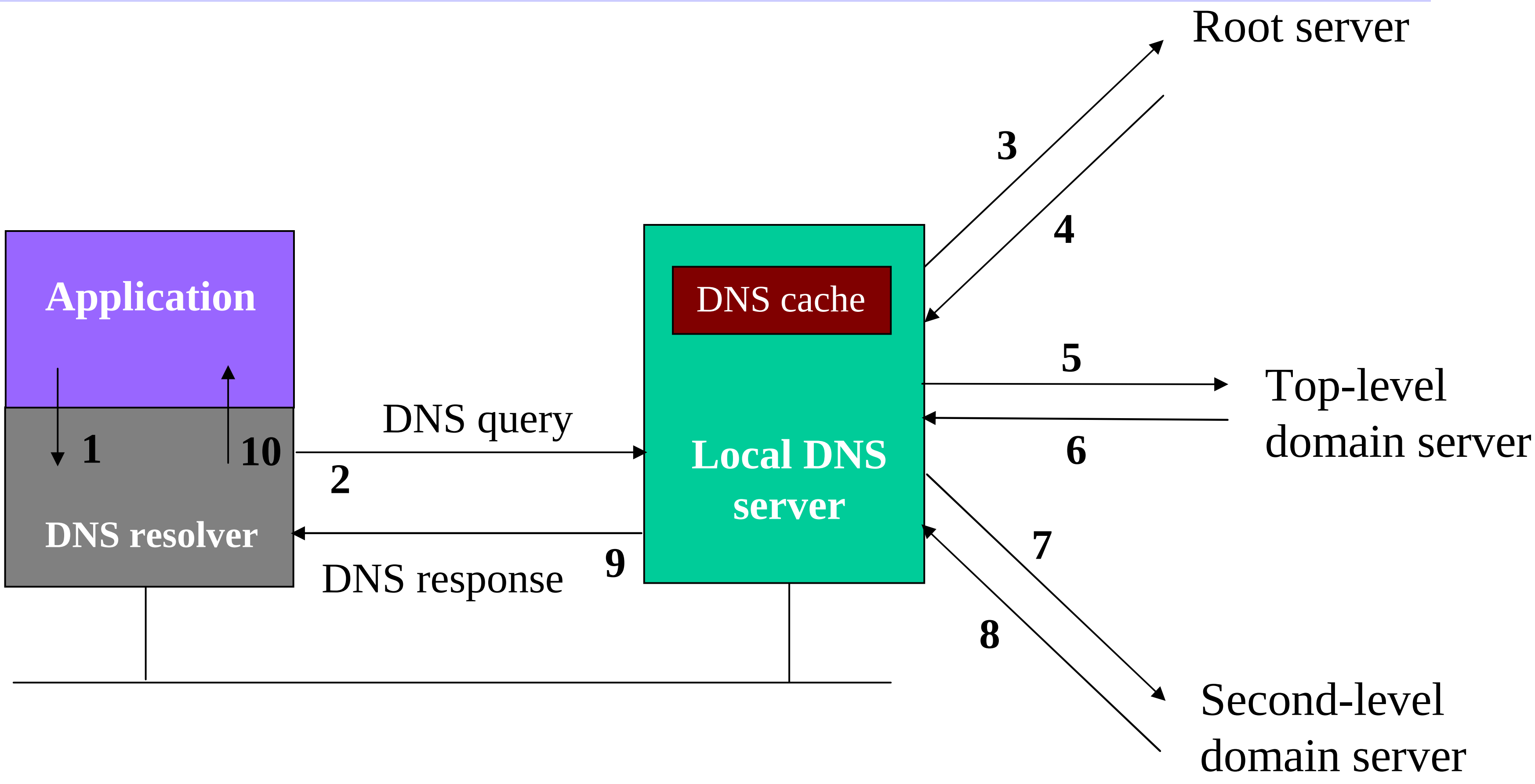
Naming: Domain Name System (DNS)

- 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.princeton.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.

Roadmap for rest of lecture

- Today, let's study a few key questions that networks need to solve:

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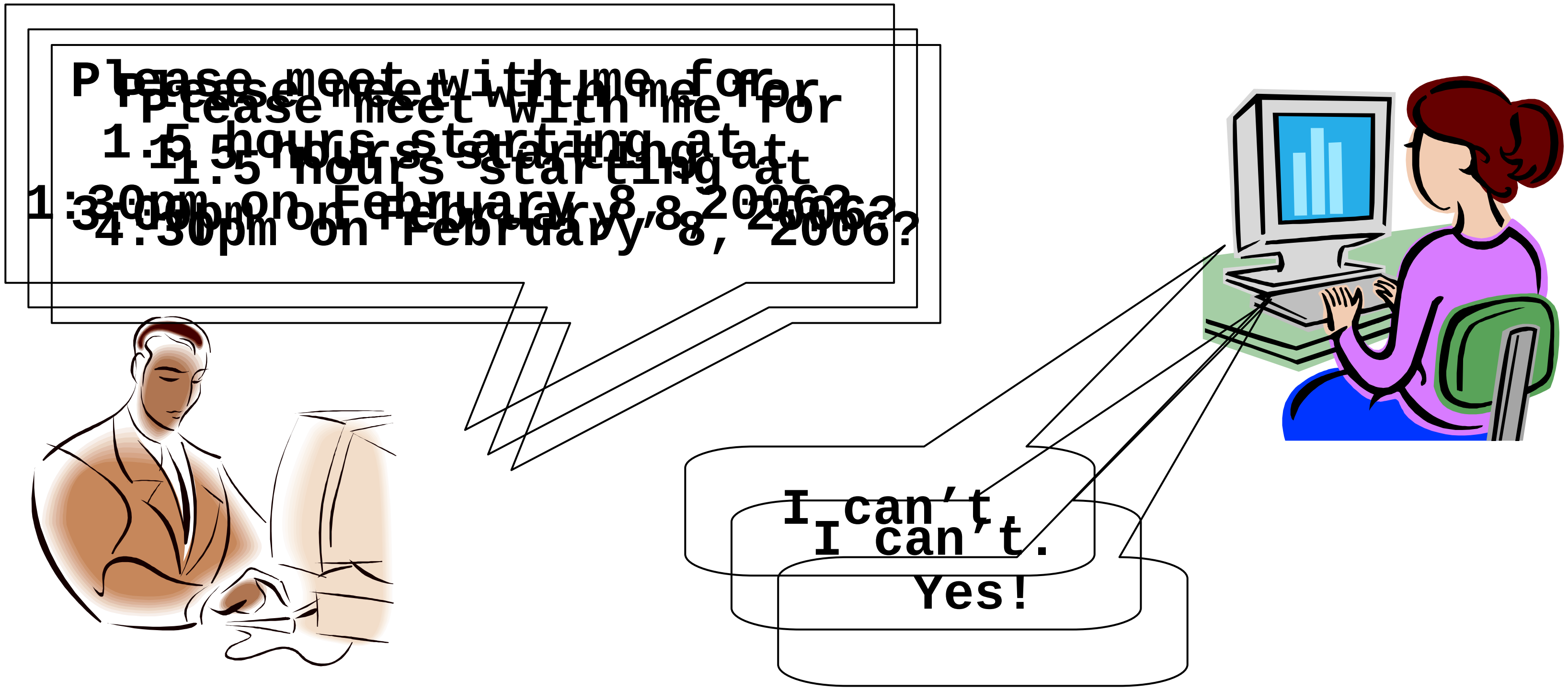
3. How can we make protocols easy to design/deploy?

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? Social security number?
- 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

```
GET /courses/archive/spring08/cos461/ HTTP/1.1
Host: www.cs.princeton.edu
User-Agent: Mozilla/4.03
CRLF
```

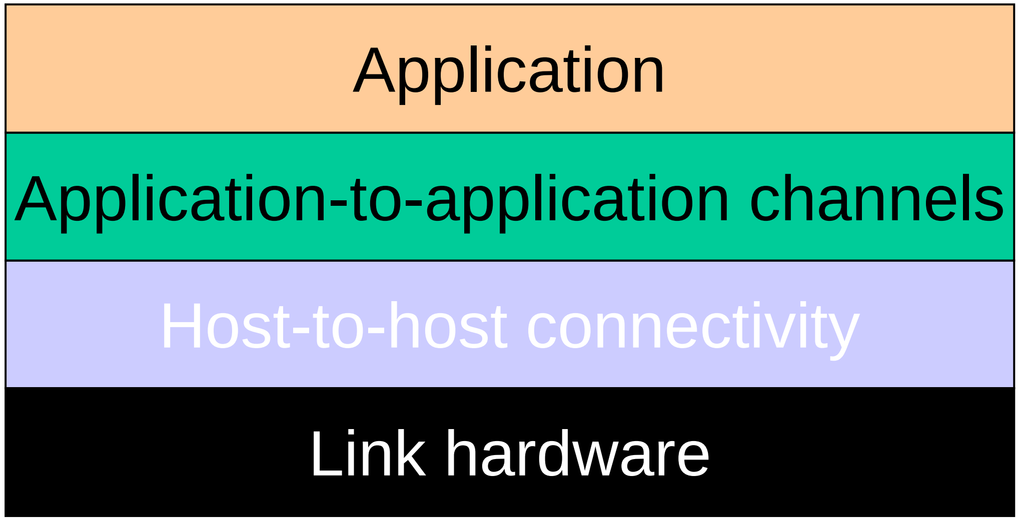
Request

```
HTTP/1.1 200 OK
Date: Mon, 4 Feb 2008 13:09:03 GMT
Server: Netscape-Enterprise/3.5.1
Last-Modified: Mon, 4 Feb  2008 11:12:23 GMT
Content-Length: 21
CRLF
Site under construction
```

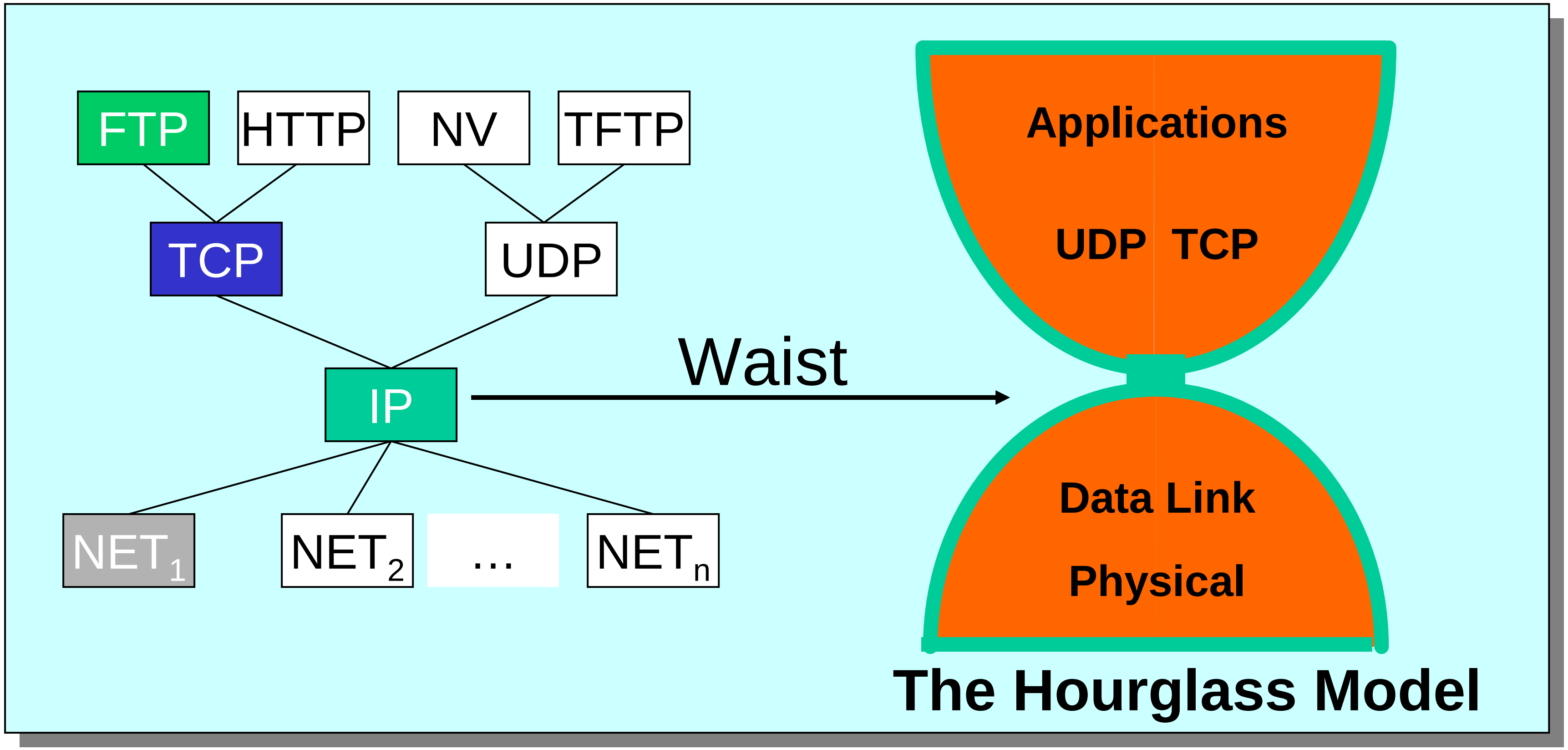
Response

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

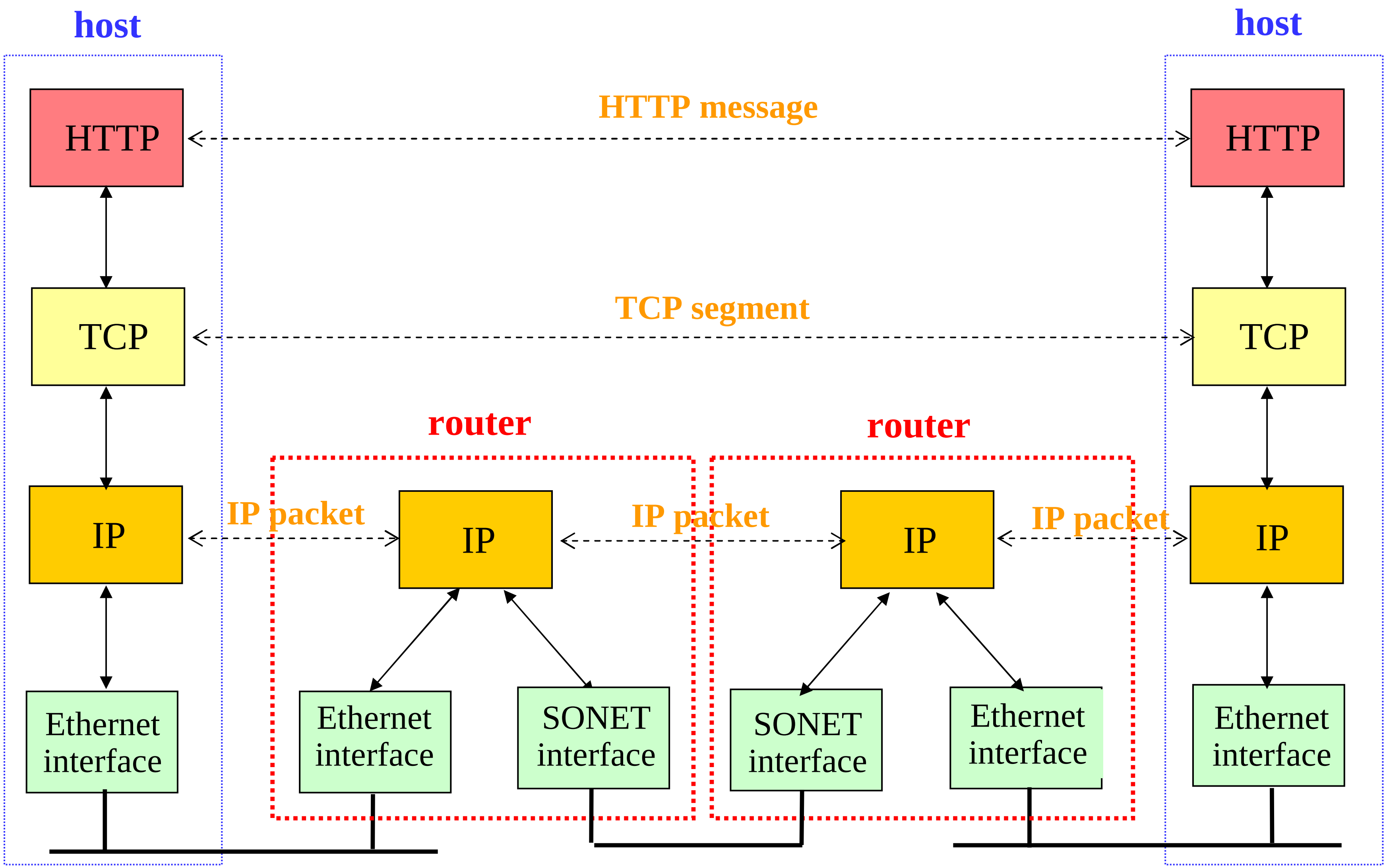


The Internet protocol suite

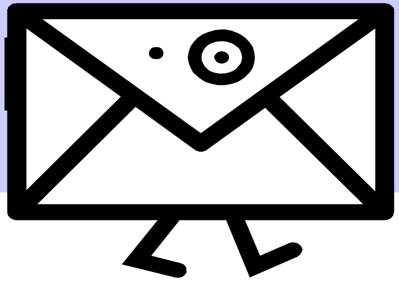


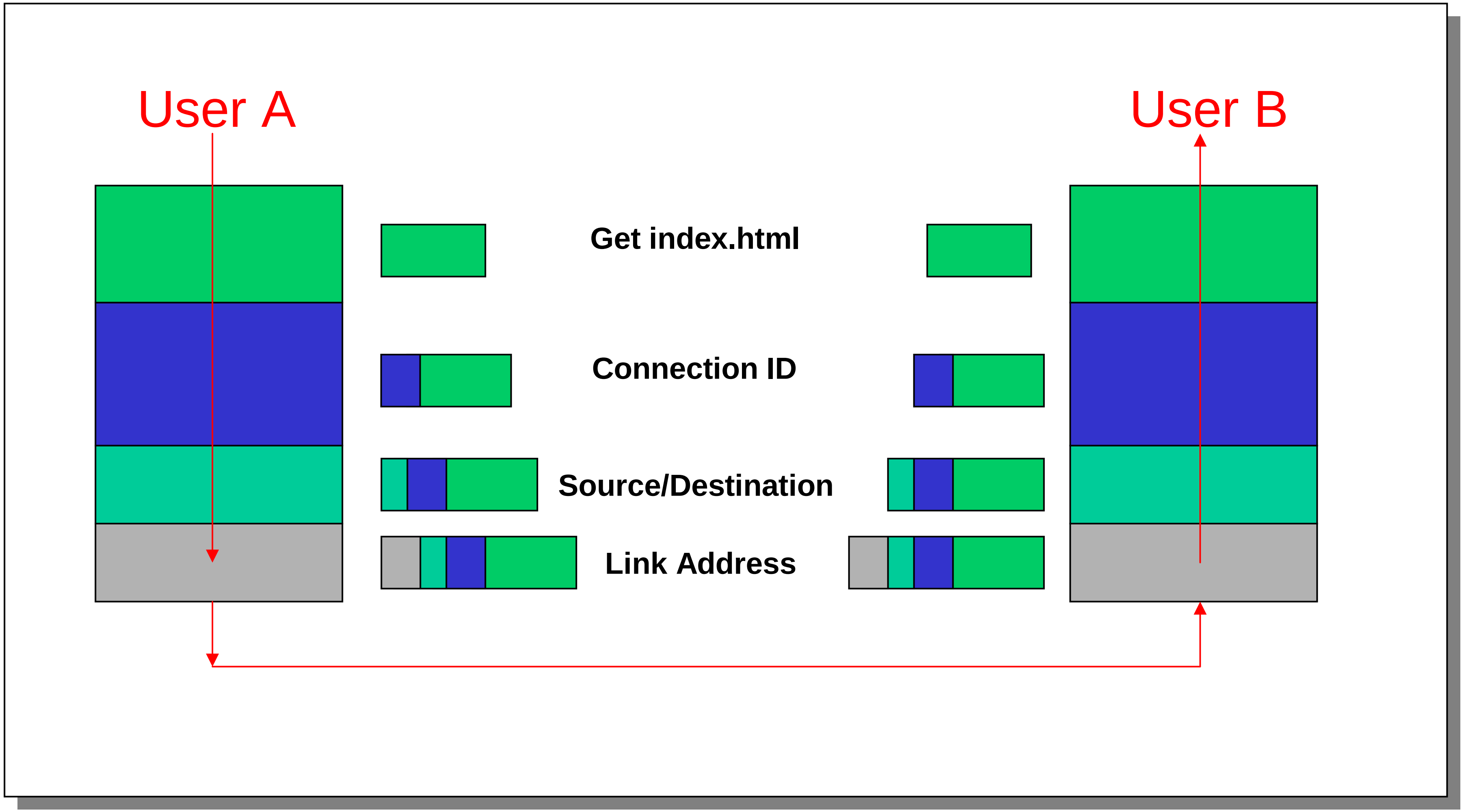
The waist facilitates interoperability

IP Suite: End Hosts vs. Routers



Layer Encapsul



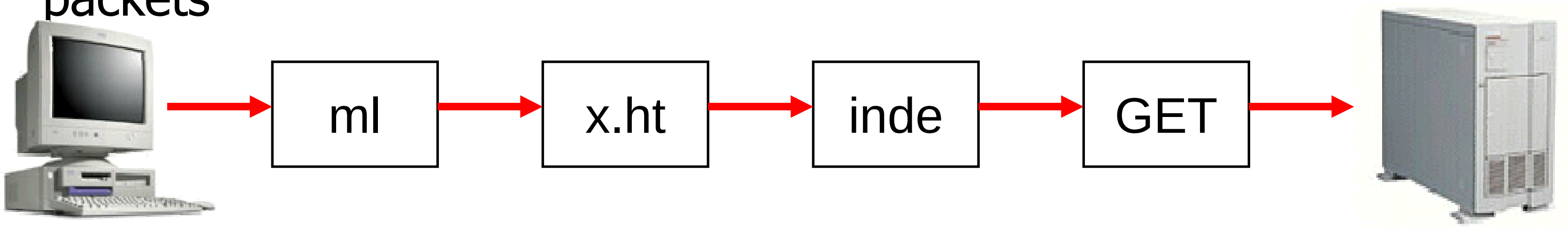


What if the Data Doesn't Fi

Problem: Packet size

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

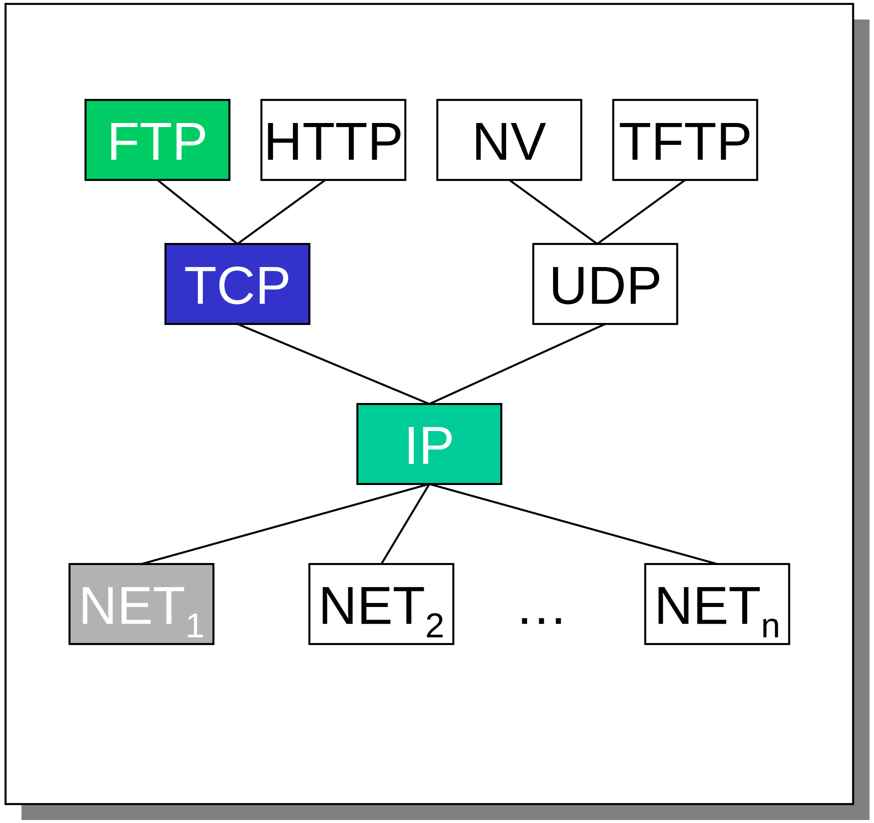
Solution: Split the data across multiple packets

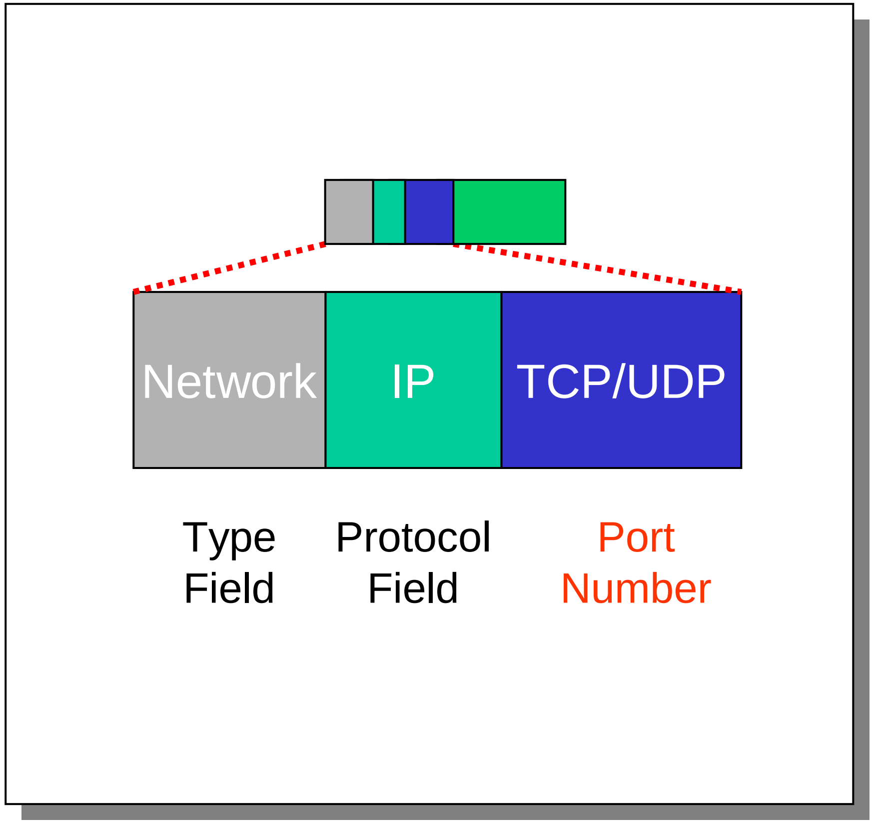


GET index.html

Protocol Demultiplexing

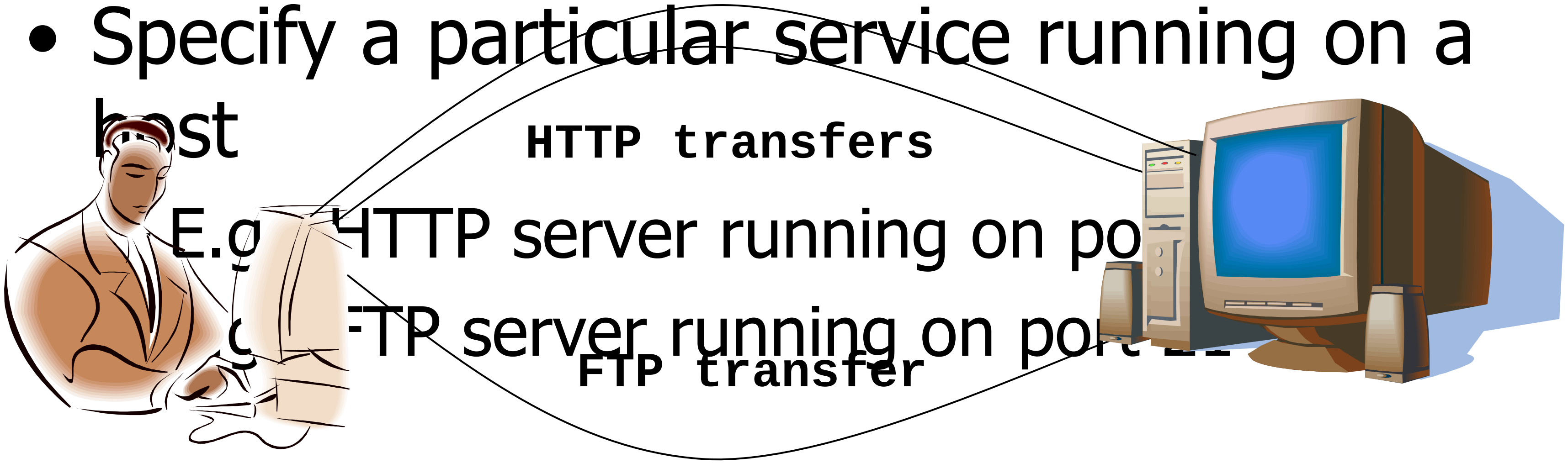
- Multiple choices at each layer





Demultiplexing: Port Numbers

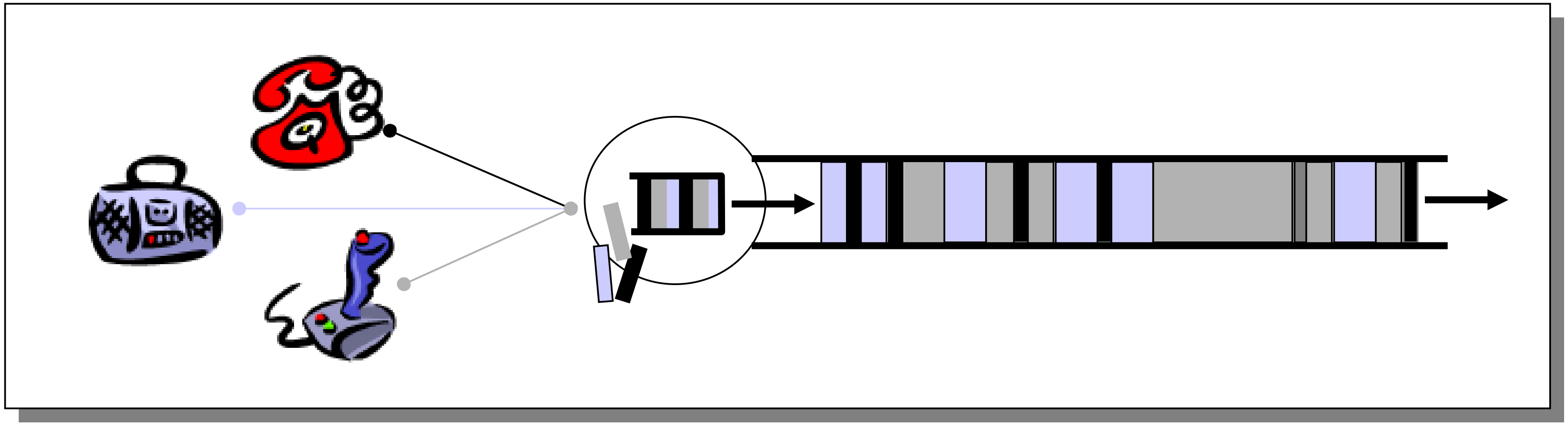
- Differentiate between multiple transfers
  - Knowing source and destination host is not enough
  - Need an id for *each transfer* between the hosts
- Specify a particular service running on a host
  - E.g. HTTP server running on po
  - g. FTP server running on port 21



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
  - Some dependencies in standards (header checksums)
- Headers start to get really big
  - Sometimes more header bytes than actual content

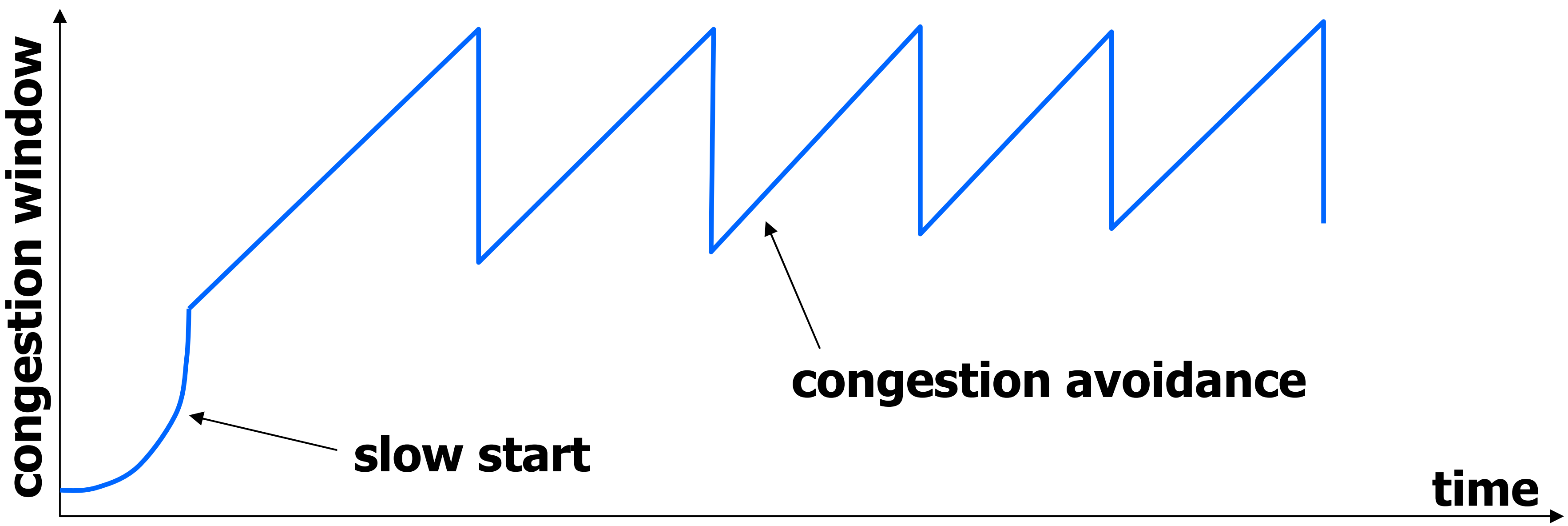
Resource Allocation: Congestion Control



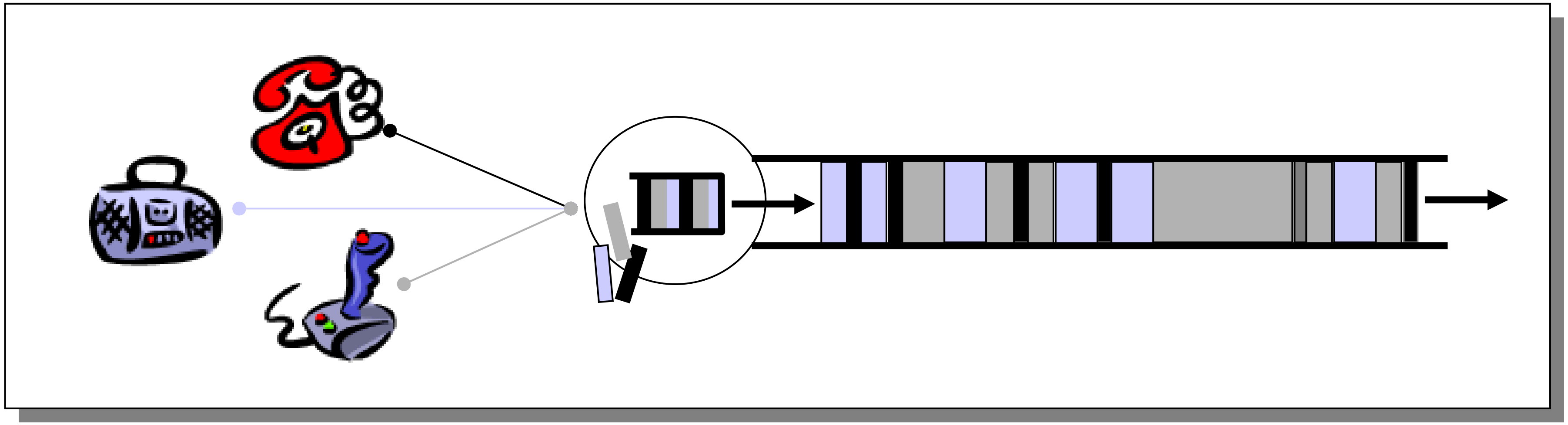
- What if too many folks are sending data?
  - Senders agree to slow down their sending rates
  - … in response to their packets getting dropped
- The essence of TCP congestion control
  - Key to preventing congestion collapse of the Internet

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



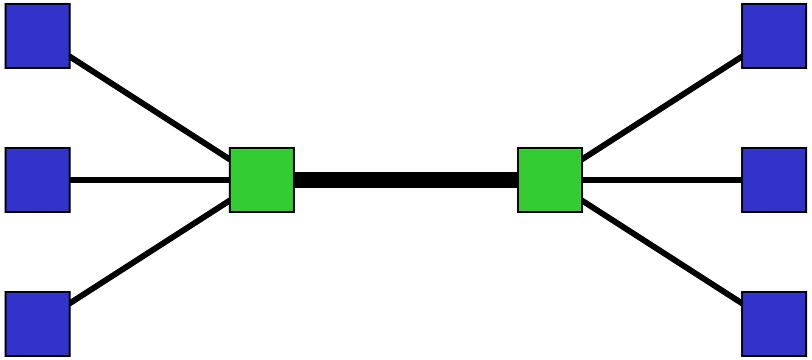
Resource Allocation: Queues



- 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

Cost-Effective Sharing of Resources

- Physical links and switches must be shared among many users



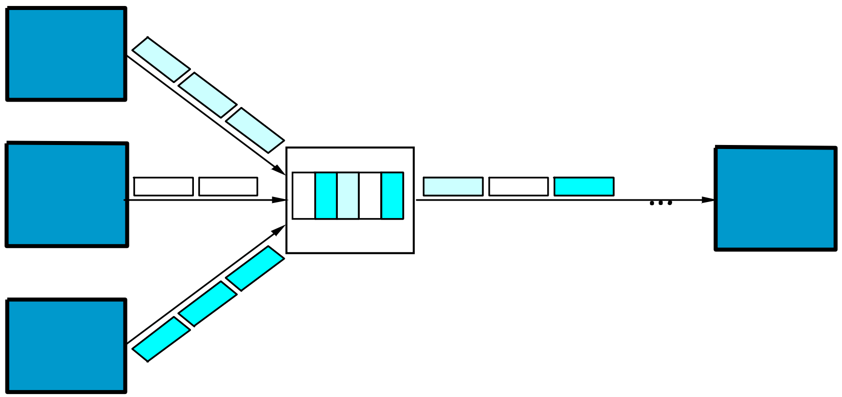
- Common multiplexing strategies
  - (Synchronous) time-division multiplexing (TDM)
  - Frequency-division multiplexing (FDM)

Statistical Multiplexing

- Statistical Multiplexing (SM)
  - On-demand time-division multiplexing
  - Scheduled on a per-packet basis
  - Packets from different sources are interleaved
  - Uses upper bounds to limit transmission
    - Queue size determines capacity per source

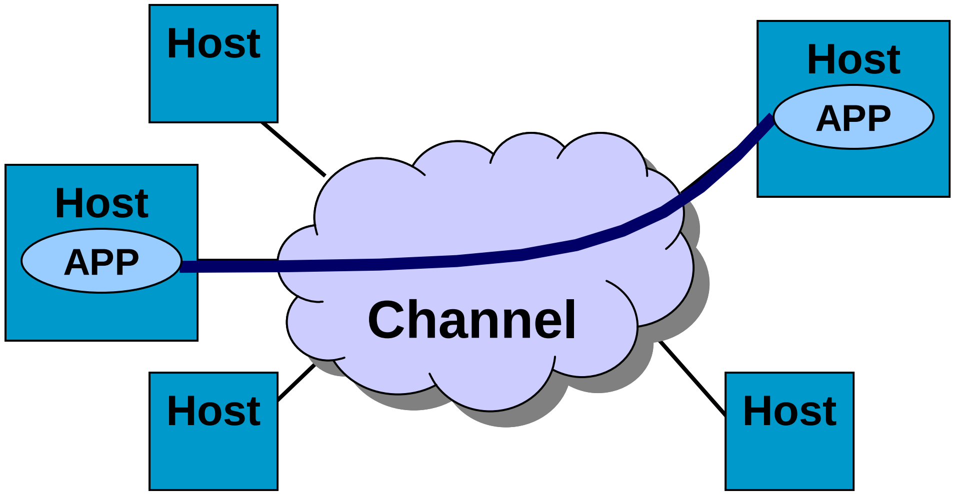
Statistical Multiplexing in a Switch

- Packets buffered in switch until forwarded
- Selection of next packet depends on policy
  - How do we make these decisions in a fair manner? Round Robin? FIFO?
  - How should the switch handle congestion?



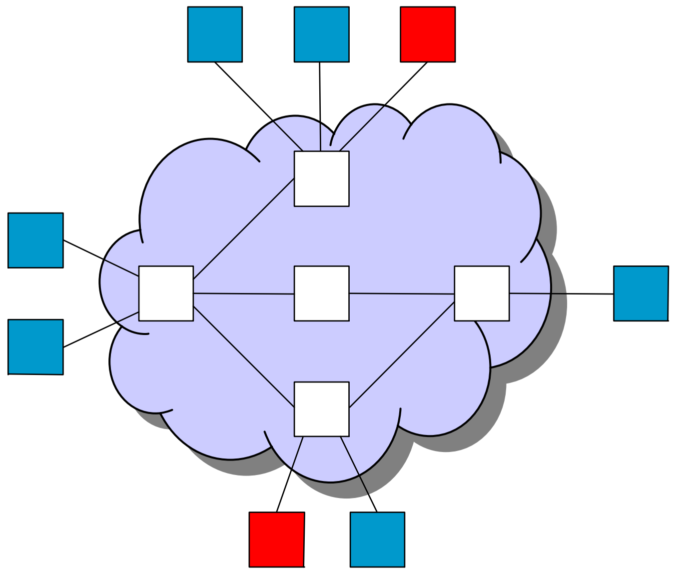
Channels

- Channel
  – The abstraction for application-level communication
- Idea
  – Turn host-to-host connectivity into process-to-process communication



Performance

- Latency/delay
  - Time from A to B
  - Example: 30 msec (milliseconds)
  - Many applications depend on round-trip time (RTT)
  - Components
    - Propagation delay over links
    - Transmission time
    - Queueing delays
    - Software processing overheads

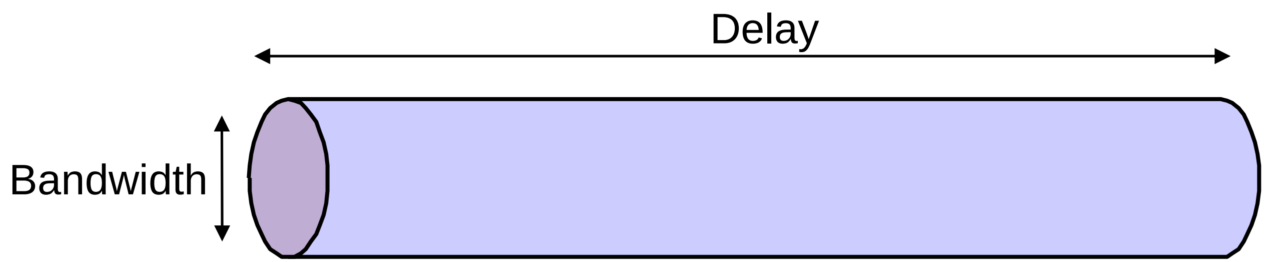


Bandwidth vs. Latency

- Relative importance of bandwidth and latency
  - Depends on application
- Large file transfers
  - bandwidth is critical
- Small messages (HTTP, NFS, etc.)
  - latency is critical
- Variance in latency (jitter)
  - Can also affect some applications (e.g., audio/video conferencing)

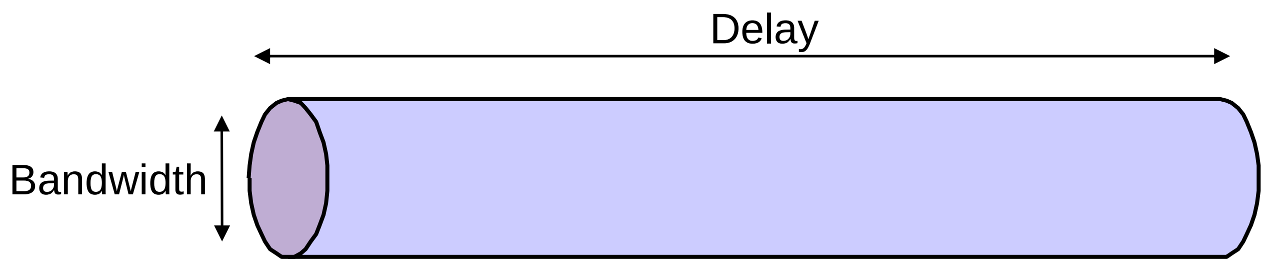
Delay x Bandwidth Product

- Amount of data in “pipe”
  - channel = pipe
  - delay = length
  - bandwidth = area of a cross section
  - bandwidth x delay product = volume



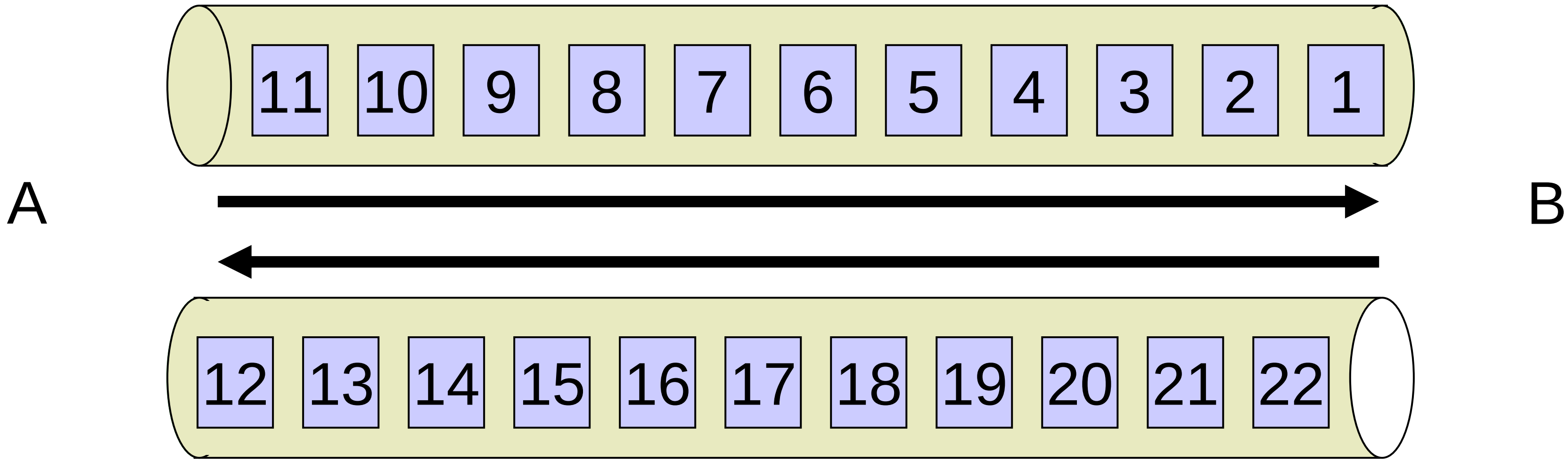
Delay x Bandwidth Product

- Pipe
  - Half of data that must be buffered before sender responds to slowdown request



Delay x Bandwidth Product

- Bandwidth x delay product
  - How many bits the sender must transmit before the first bit arrives at the receiver if the sender keeps the pipe full
  - Takes another one-way latency to receive a response from the receiver



Delay x Bandwidth Product

- Example: Transcontinental Channel
  - BW = 45 Mbps
  - delay = 50ms
  - bandwidth x delay product

    $= (50 \times 10^{-3}\ \text{sec}) \times (45 \times \boxed{10^{6}\ \text{bits/sec}})$

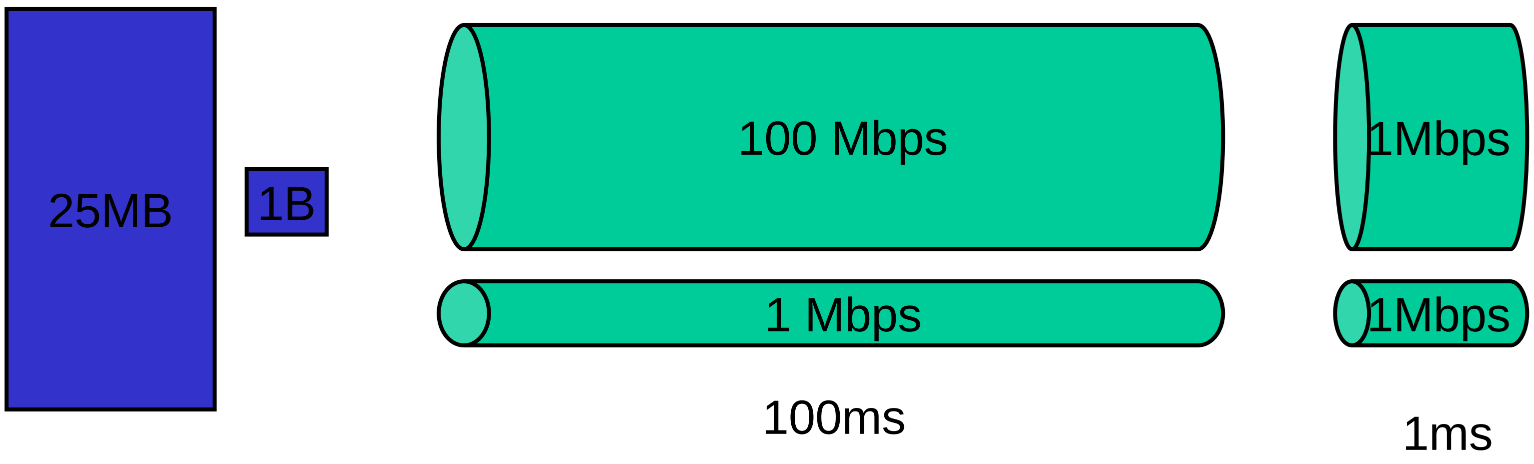
    $= 2.25 \times \boxed{10^{6}\ \text{bits}}$

Mbps

ms

Bandwidth vs. Latency

- Relative importance
  - 1-byte: Latency bound
    - 1ms vs 100ms latency dominates 1Mbps vs 100Mbps BW
  - 25MB: Bandwidth bound
    - 1Mbps vs 100Mbps BW dominates 1ms vs 100ms latency



Bandwidth vs. Latency

- Infinite bandwidth
  - RTT dominates
    - Throughput = TransferSize / TransferTime
    - TransferTime = RTT + 1/Bandwidth x TransferSize
- Its all relative
  - 1-MB file on a 1-Gbps link looks like a 1-KB packet on a 1-Mbps link

Performance Notes

- Speed of Light
  - 3.0×10^8 meters/second in a vacuum
  - 2.3×10^8 meters/second in a cable
  - 2.0×10^8 meters/second in a fiber
- Comments
  - No queueing delays in a direct link
  - Bandwidth is not relevant if size = 1bit
  - Software overhead can dominate when distance is small
- Key Point
  - Latency dominates small transmissions
  - Bandwidth dominates large

Supplementary slides

Network Architecture

- Challenge
  - Fill the gap between hardware capabilities and application expectations, and to do so while delivering “good” performance
- Hardware and expectations are moving targets
- How do network designers cope with complexity?
  - Layering
  - Protocols
  - Standards

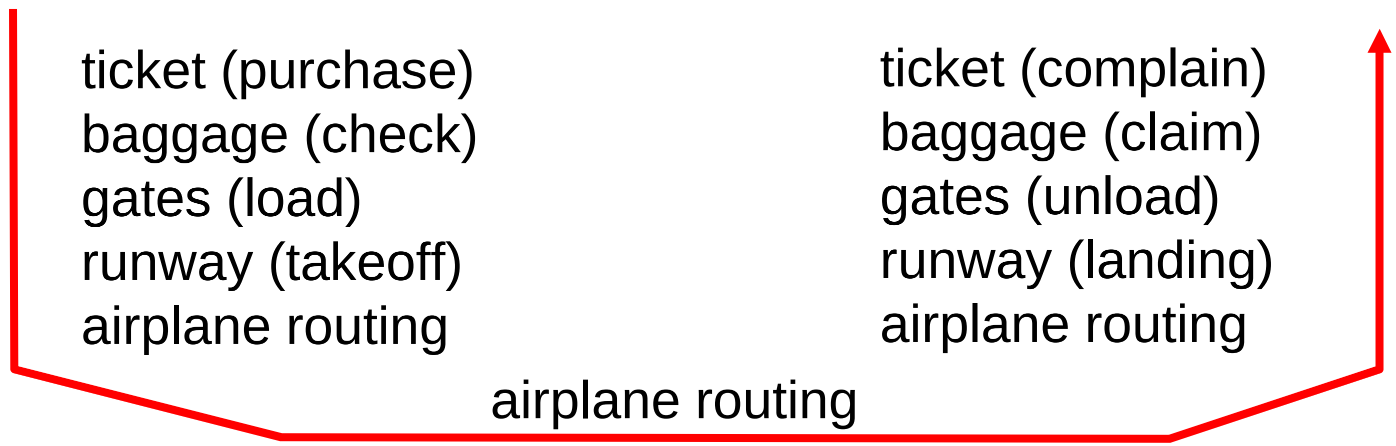
Abstraction through Layering

- Abstract system into layers:
  - Decompose the problem of building a network into manageable components
    - Each layer provides some functionality
  - Modular design provides flexibility
    - Modify layer independently
    - Allows alternative abstractions

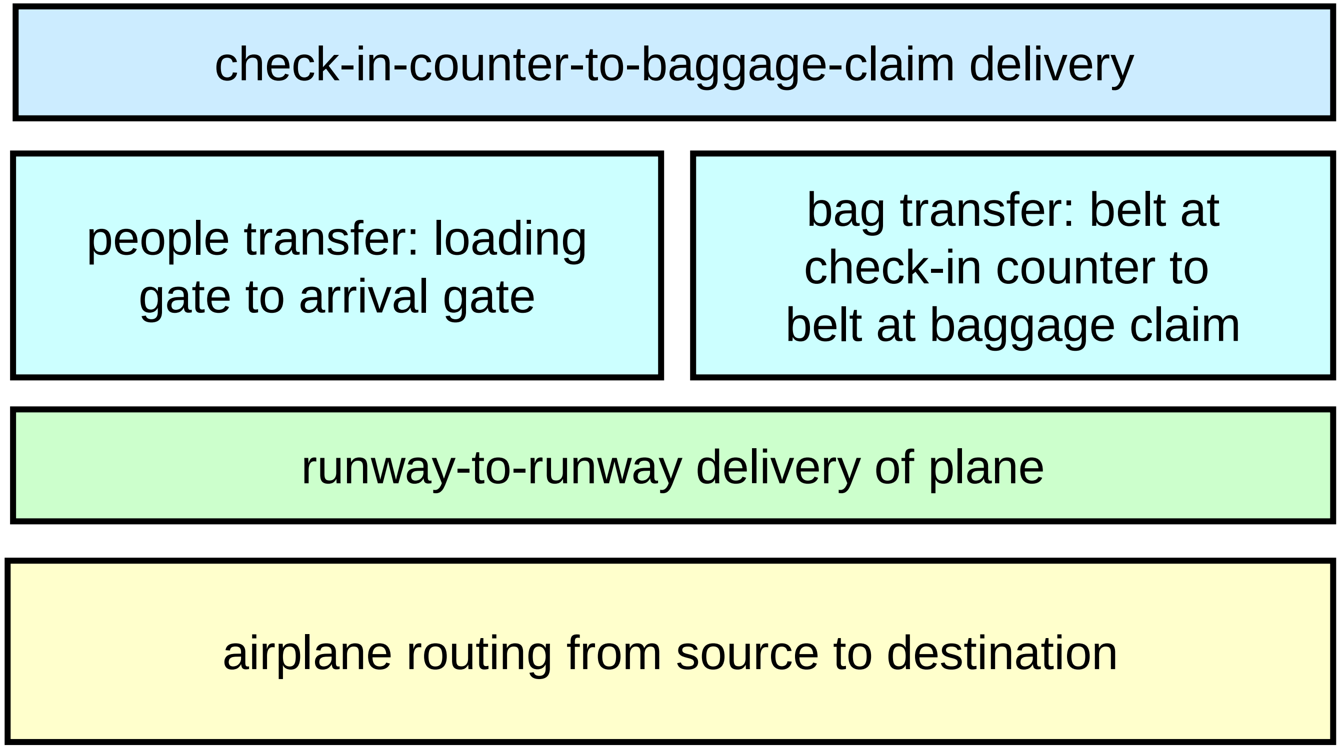
Application programs	
Message stream channel	Request/reply channel
Host-to-host connectivity	
Hardware	

Example: Air Travel

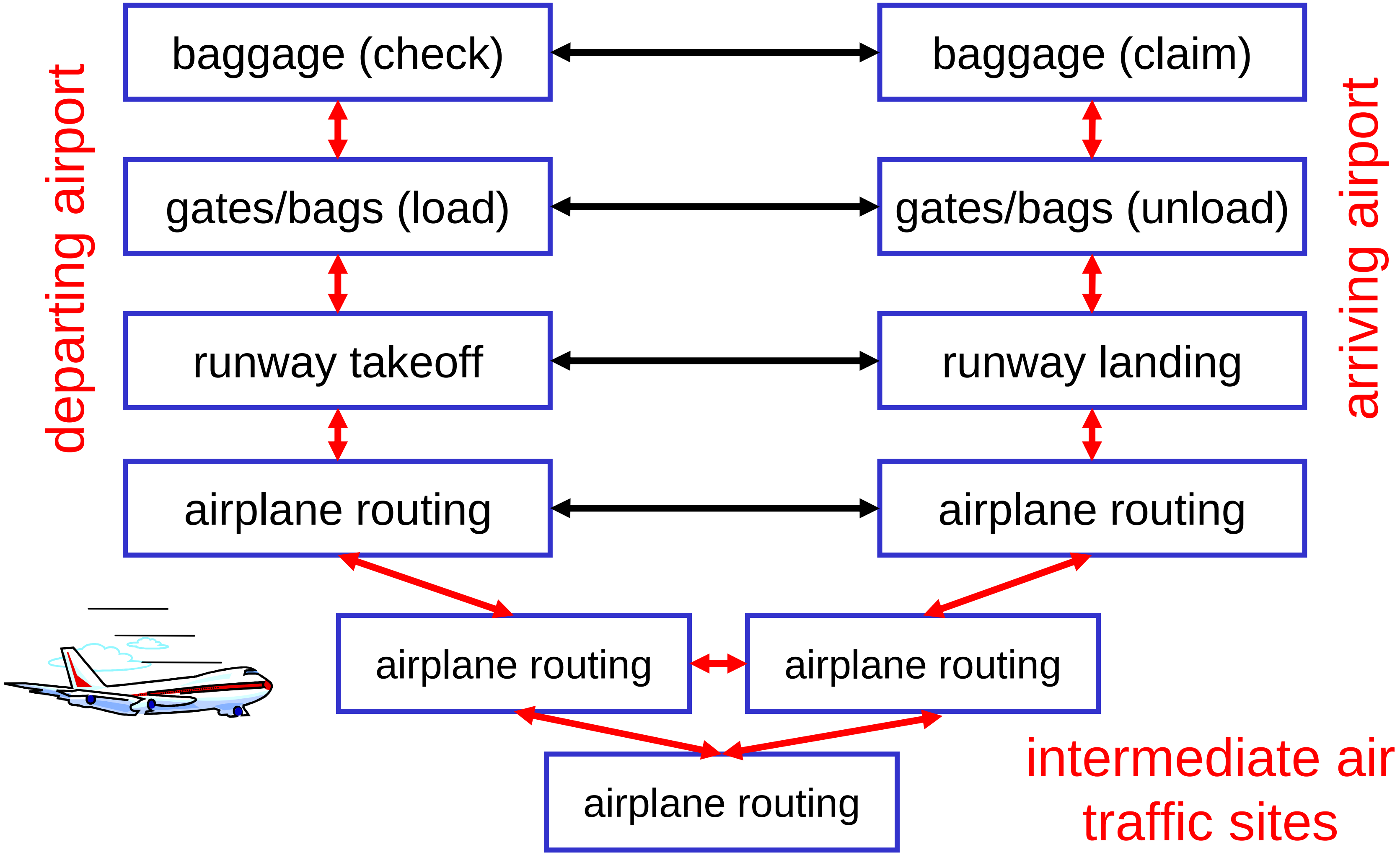
- Layers
  - Each layer implements a service
  - Via its own internal-layer actions
  - Relying on services provided by layer below



Air Travel: Services



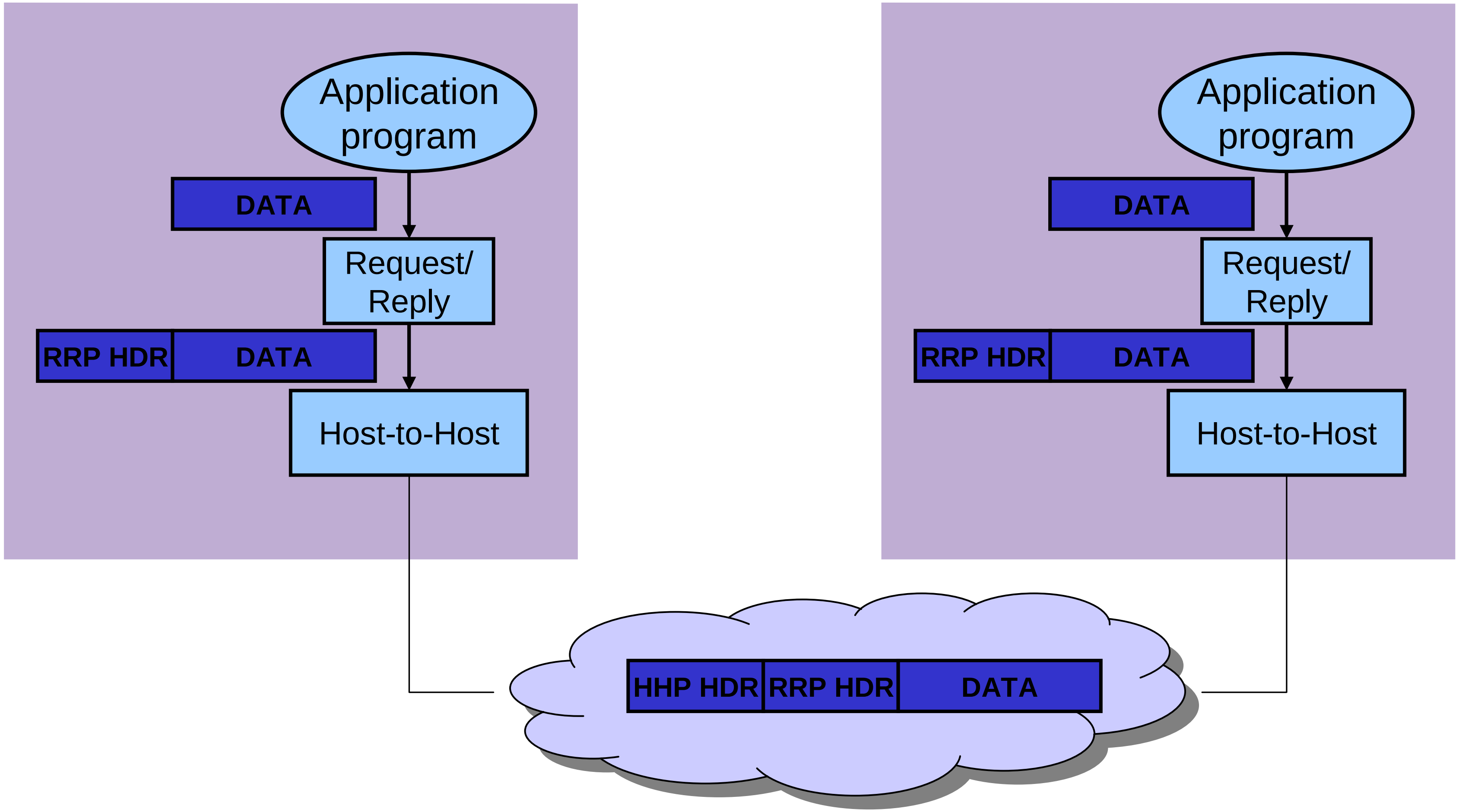
Distributed Layering



Layering Concepts

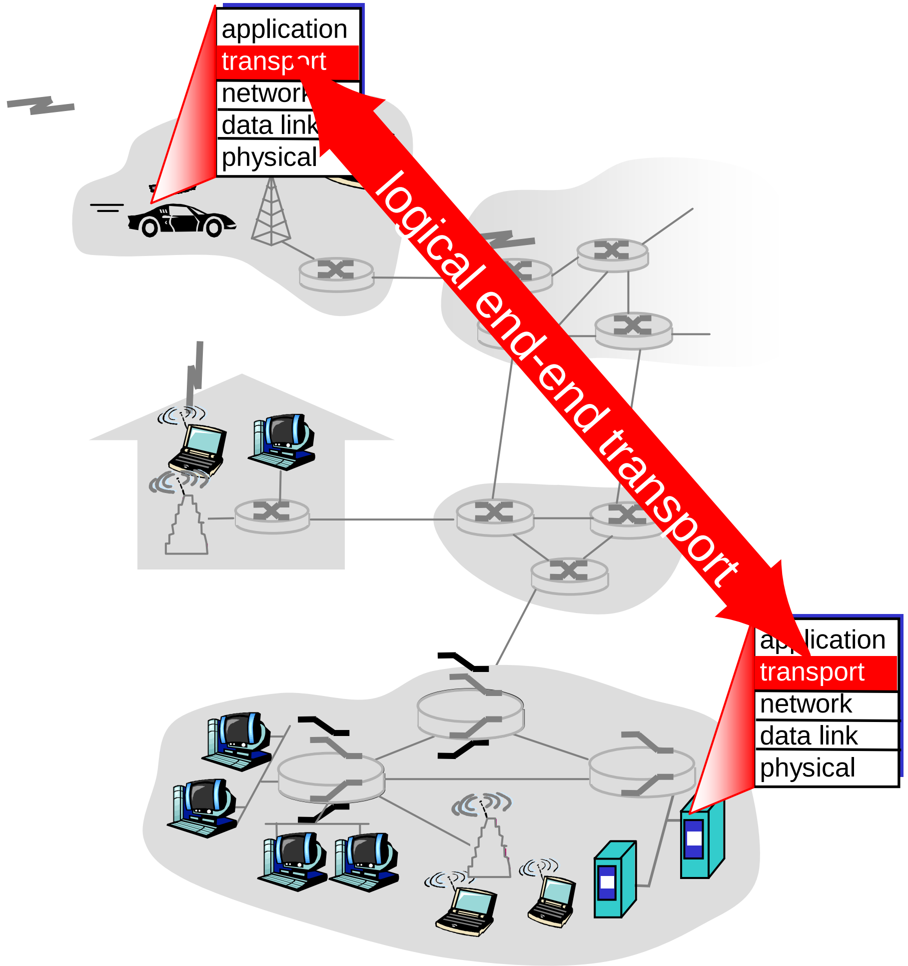
- Encapsulation
  - Higher layer protocols create messages and send them via the lower layer protocols
  - These messages are treated as data by the lower-level protocol
  - Higher-layer protocol adds its own control information in the form of headers or trailers
- Multiplexing and Demultiplexing
  - Use protocol keys in the header to determine correct upper-layer protocol

Encapsulation



Multiplexing/Demultiplexing

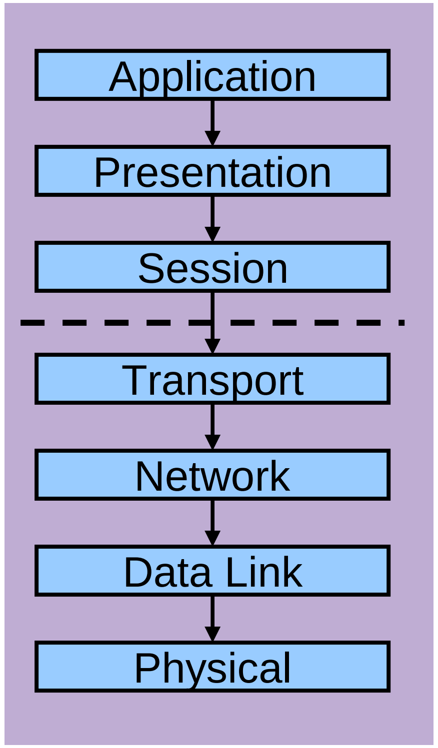
- Transport Layer
  - Provide logical communication between application processes running on different hosts
- Transport protocols run in end systems
  - Send side:
    - Break application messages into segments
    - Pass to network layer
  - Receive side:
    - Reassemble segments into messages
    - Pass to application layer
- Multiple available transport protocols
  - Internet: TCP and UDP



OSI Architecture

- Open Systems Interconnect (OSI) Architecture
  - International Standards Organization (ISO)
  - International Telecommunications Union (ITU, formerly CCITT)
  - "X dot" series: X.25, X.400, X.500
  - Primarily a reference model

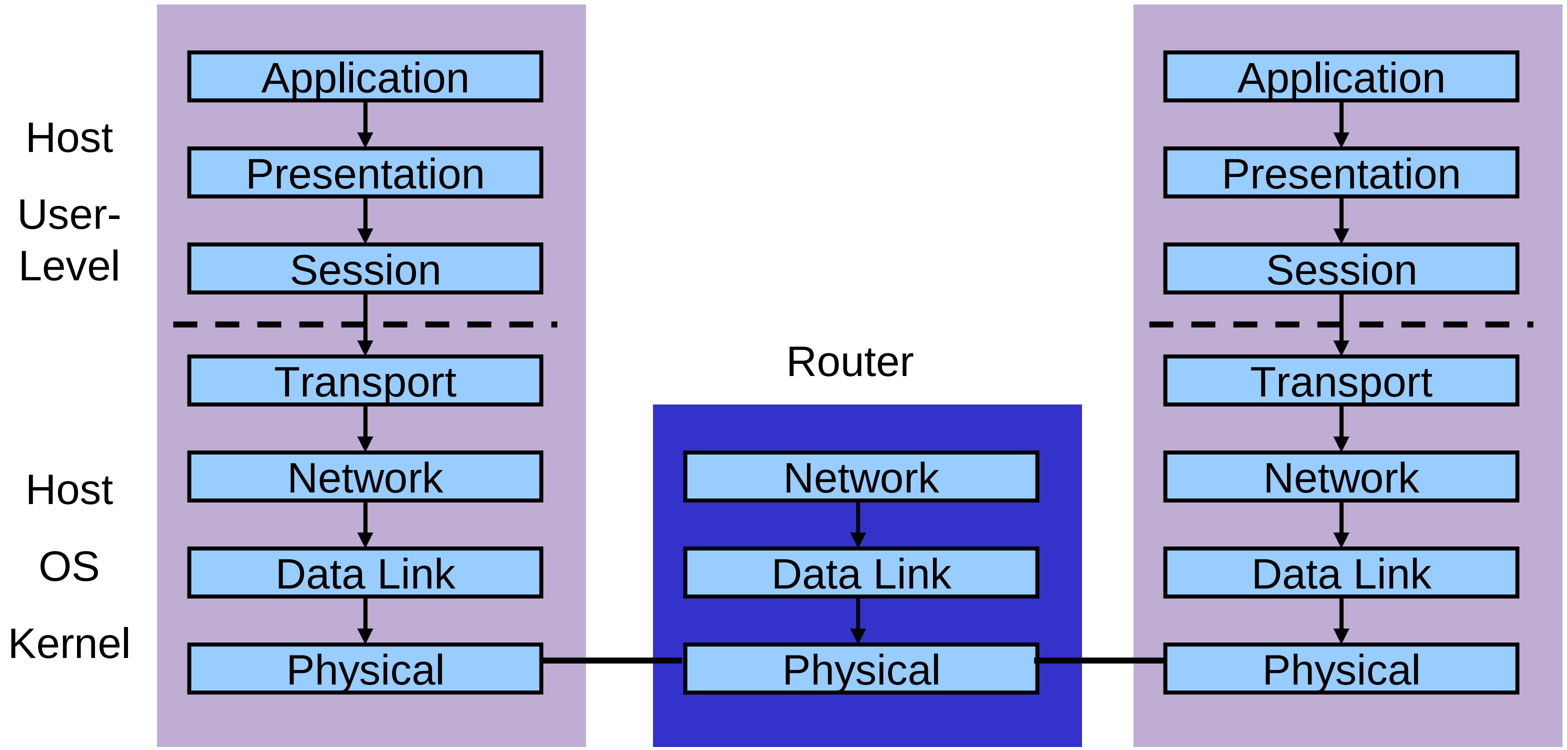
OSI Protocol Stack



- Application: Application specific protocols
- Presentation: Format of exchanged data
- Session: Name space for connection mgmt

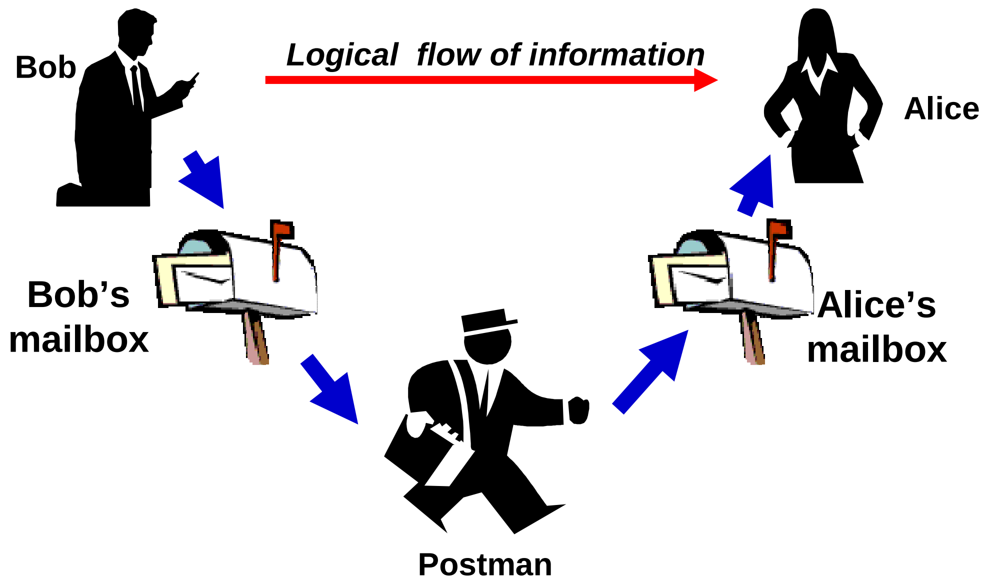
- Transport: Process-to-process channel
- Network: Host-to-host packet delivery
- Data Link: Framing of data bits
- Physical: Transmission of raw bits

OSI Protocol Stack



Transport vs. Network Layer

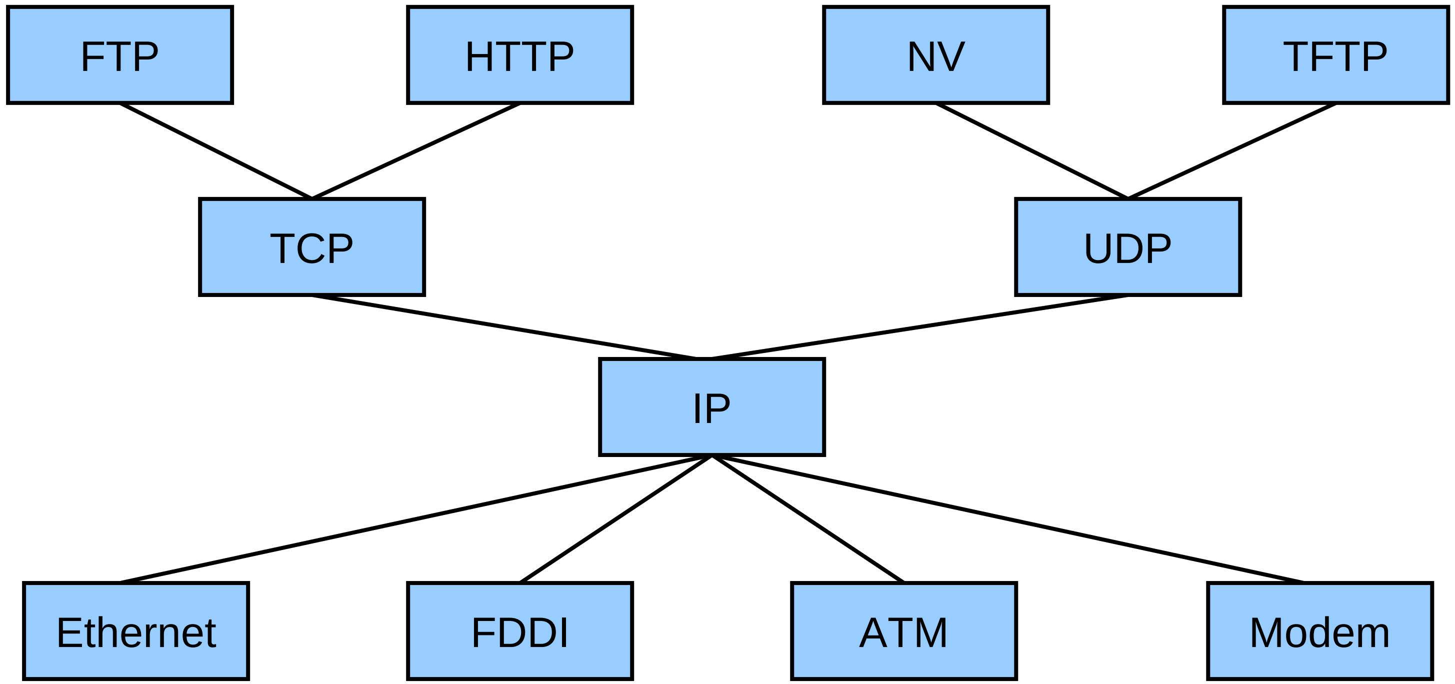
- Network layer
  - Logical communication between hosts
- Transport layer
  - Logical communication between processes
  - relies on, enhances, network layer services



Internet Architecture

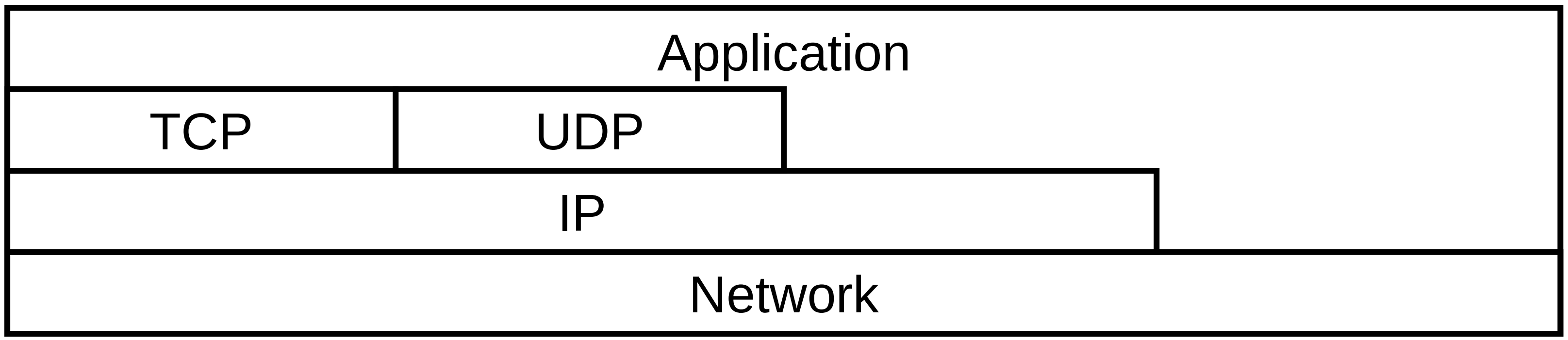
- Internet Architecture (TCP/IP)
  - Developed with ARPANET and NSFNET
  - Internet Engineering Task Force (IETF)
    - Culture: implement, then standardize
    - OSI culture: standardize, then implement
  - Made popular with release of Berkeley Software Distribution (BSD) Unix; i.e., free software
  - Standard suggestions debated publicly through “requests for comments” (RFC’s)
    - We reject kings, presidents, and voting. We believe in rough consensus and running code. – David Clark

Internet Architecture – Hourglass Design



Internet Architecture

- Features:
  - No strict layering
  - Hourglass shape – IP is the focal point



Protocol Acronyms

- (T)FTP - (Trivial) File Transfer Protocol
- HTTP - HyperText Transport Protocol
- NV - Network Video
- SMTP – Simple Mail Transfer Protocol
- NTP - Network Time Protocol
- TCP - Transmission Control Protocol
- UDP - User Datagram Protocol
- IP - Internet Protocol
- FDDI - Fiber Distributed Data Interface
- ATM - Asynchronous Transfer Mode

Summary

- Goal
  - Understanding of computer network functionality, with experience building and using computer networks
- Steps
  - Identify what concepts we expect from a network
  - Define a layered architecture
  - Implement network protocols and application programs

Assignments

- Homework 1
  - Due Wednesday February 3rd at the start of class
- Project 1
  - Due Friday February 5th at 9:00pm