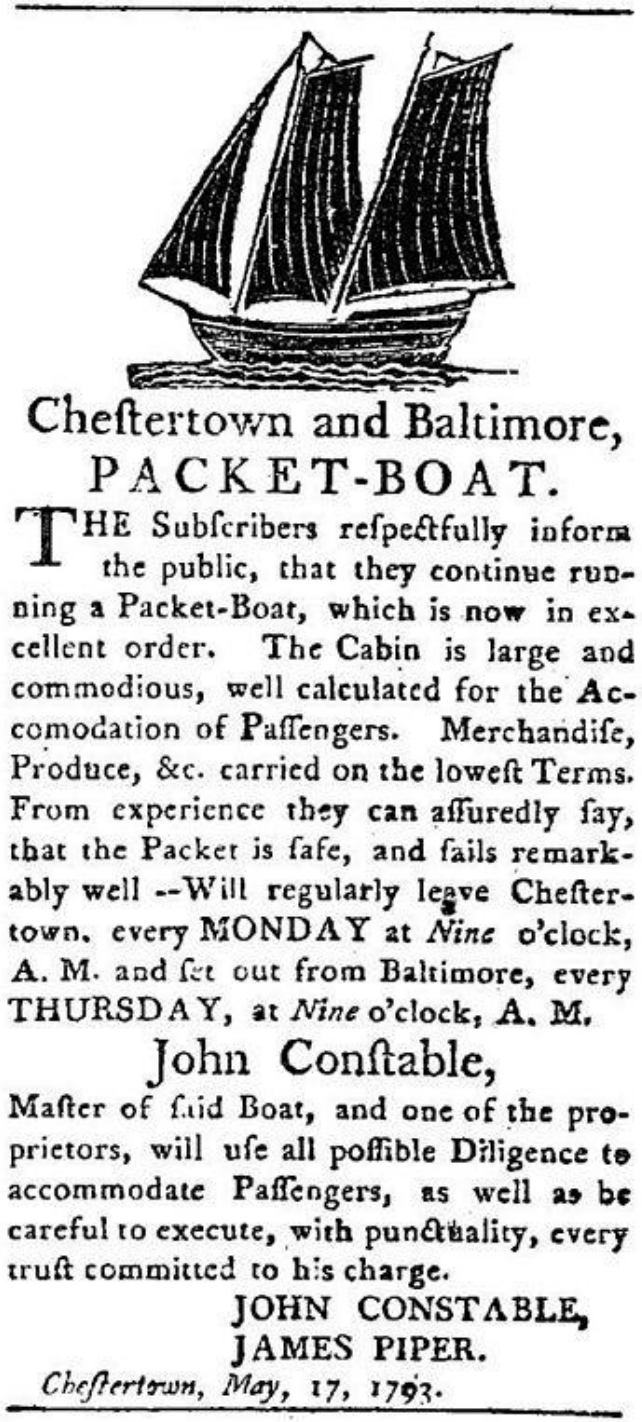
History of the Internet

What are some pre-Internet communication technologies?

- ?

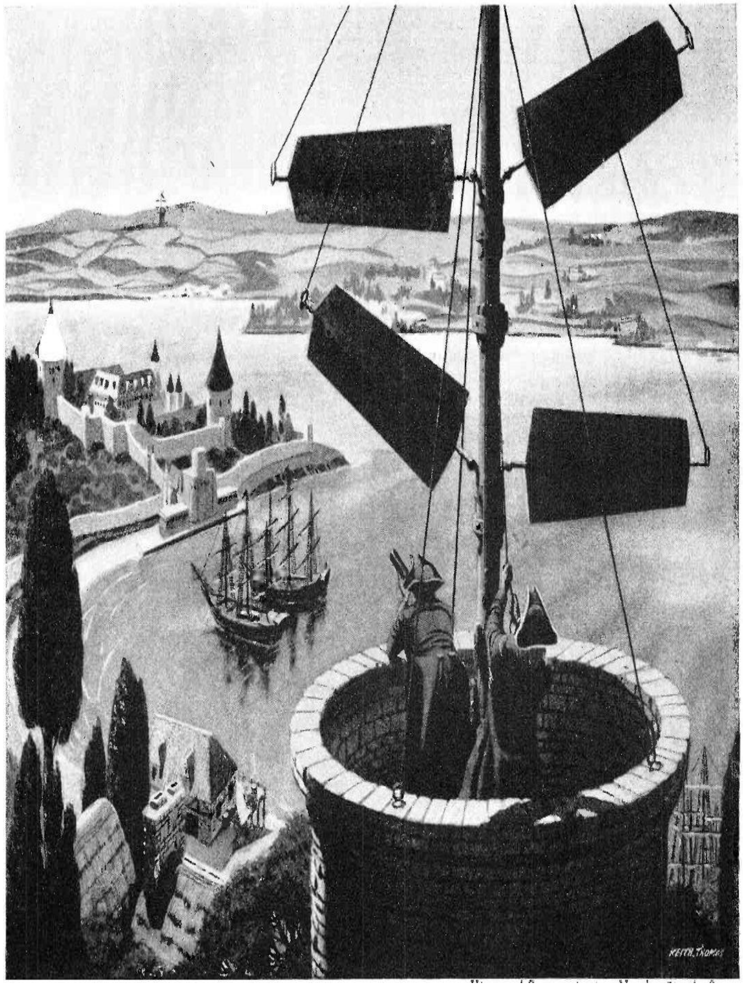
Pre-history

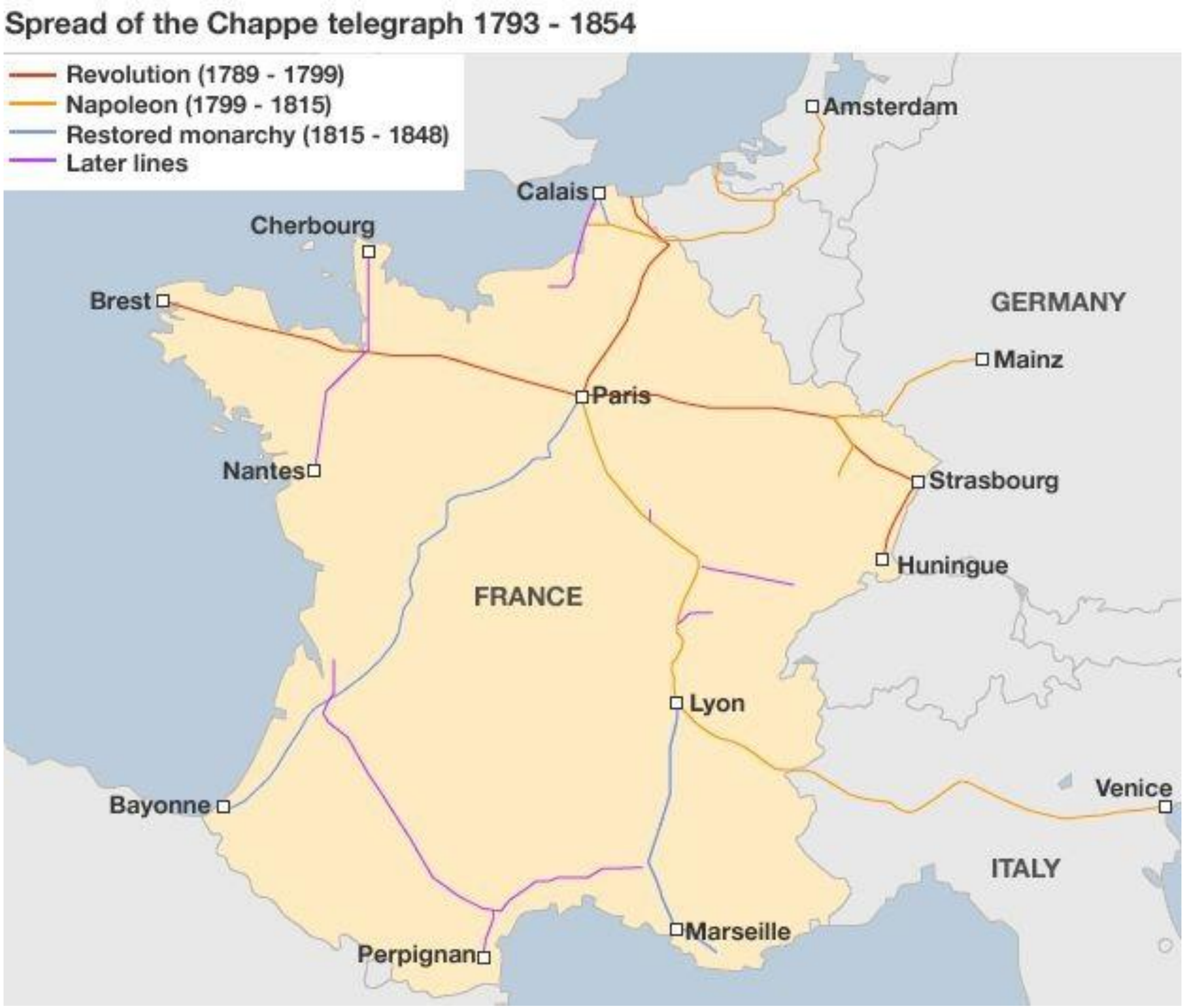
- Communication is a basic human *need*
    - I've never been in a place without some form of communications
- All require some form of *addressing, routing,* and *transport*
- Long history
    - Cyrus the Great credited with first mail service
        - Chapar Khaneh
    - Onto: Pony Express, Packet Boats, etc



Optical Semaphores

- Basic idea: Use visual indications to signal next tower and repeat.
- Long history of use in Greece and Byzantines.
- Claude Chappe (France, 1792): Built 556 of these stations across France for communicating about war effort.
- First Message:“Si vous réussissez, vous serez bientôt couverts de gloire” (If you succeed, you will soon bask in glory) – 16km
- “Mechanical Internet”





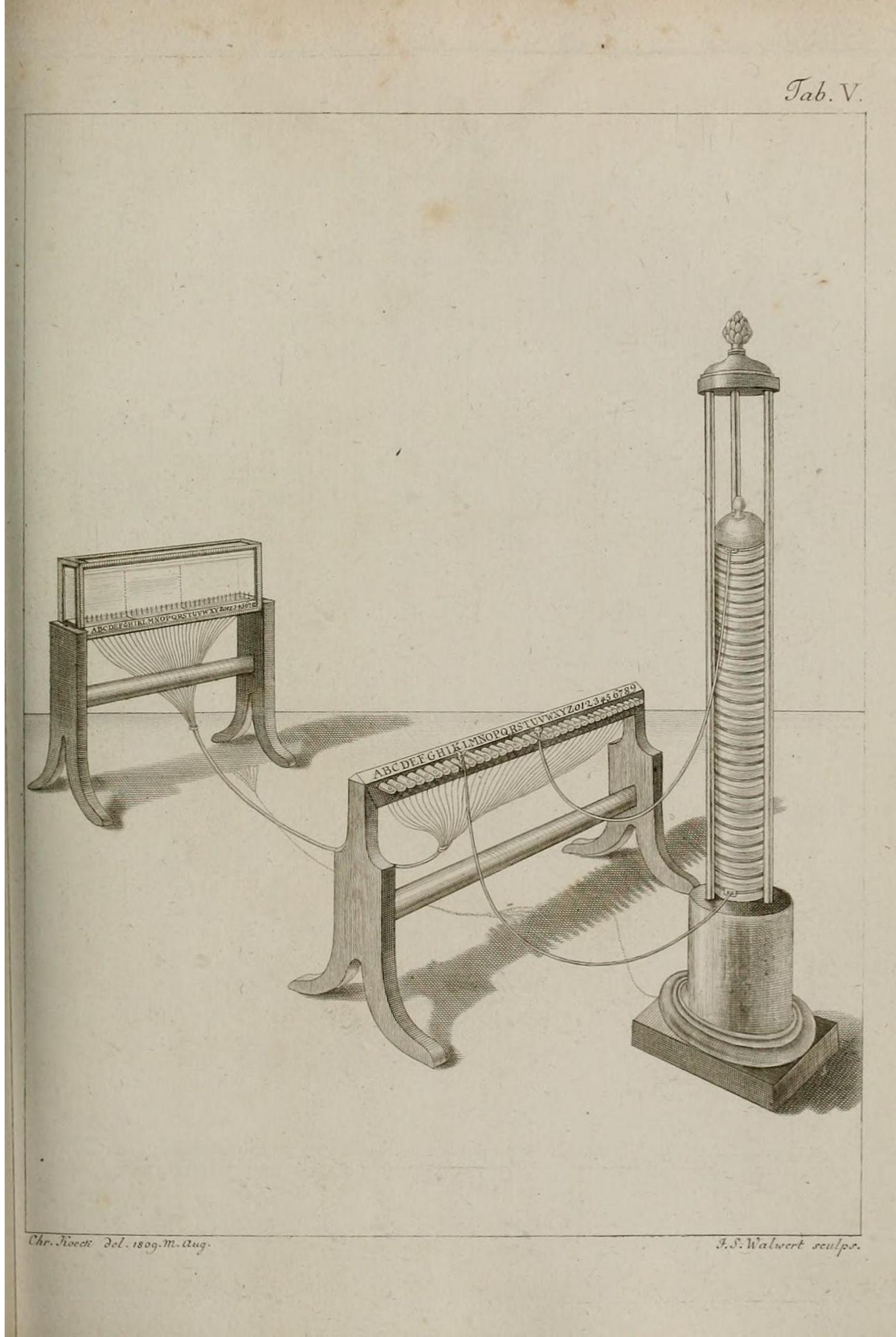
Spread of the Chappe telegraph 1793 - 1854
Revolution (1789 - 1799)
Napoleon (1799 - 1815)
Restored monarchy (1815 - 1848)
Later lines
Amsterdam
Calais
Cherbourg
Brest
GERMANY
Mainz
Paris
Nantes
Strasbourg
Huningue
FRANCE
Lyon
Venice
Bayonne
ITALY
Marseille
Perpignan

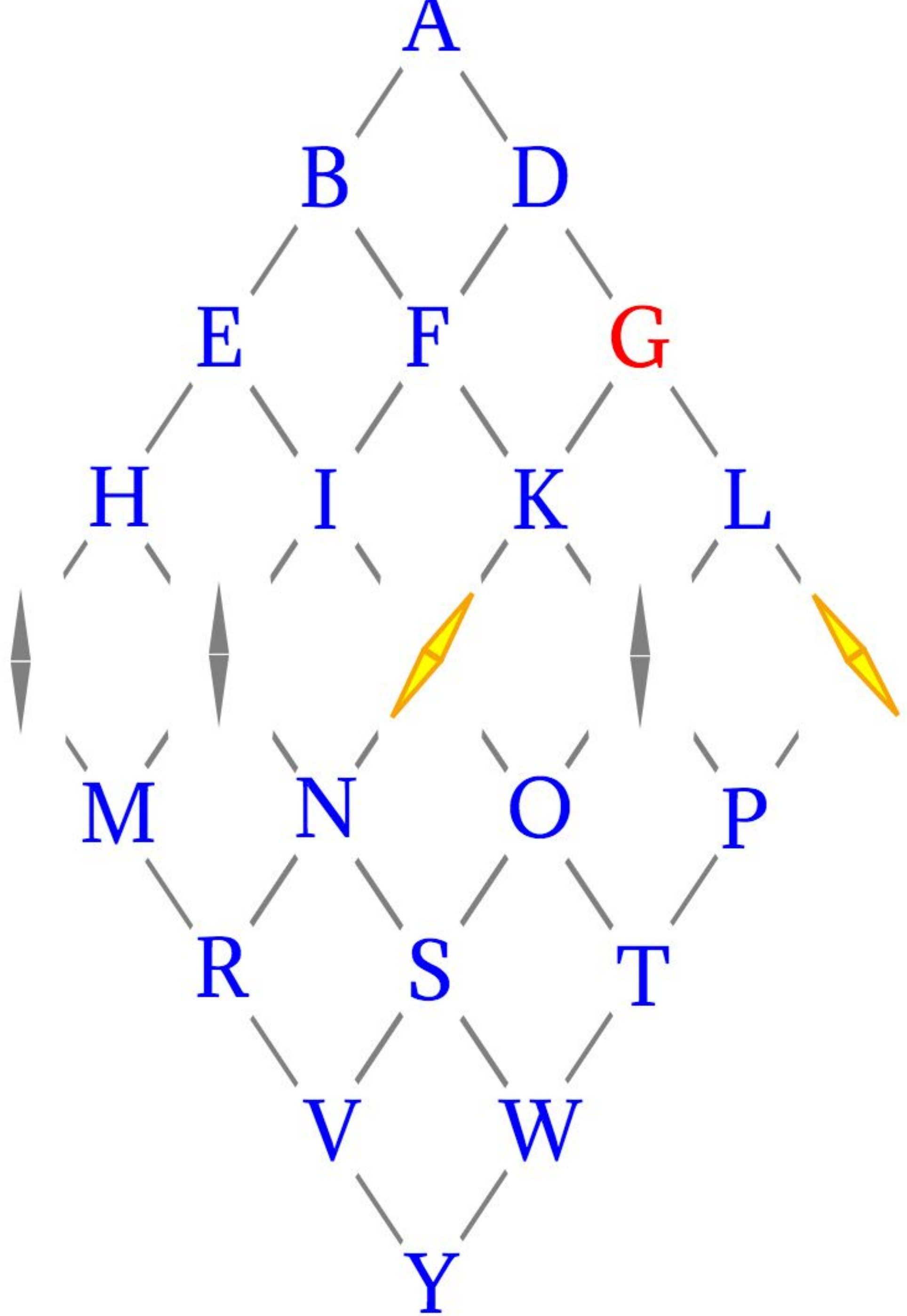
Late 1700s - Development of Electricity/Batteries

- Alessandro Volta - Development of the first battery
  - And a bunch of other stuff
- Travels extremely fast (basically instantaneous to people of the era)
- Seems like communication is an obvious use case:
  - How would you do it?

Telegraph

- Robust work in trying to use electricity to transmit information instead.
- Many problems: Didn't have consistent generators so coding was hard; early solutions used a wire for each letter.

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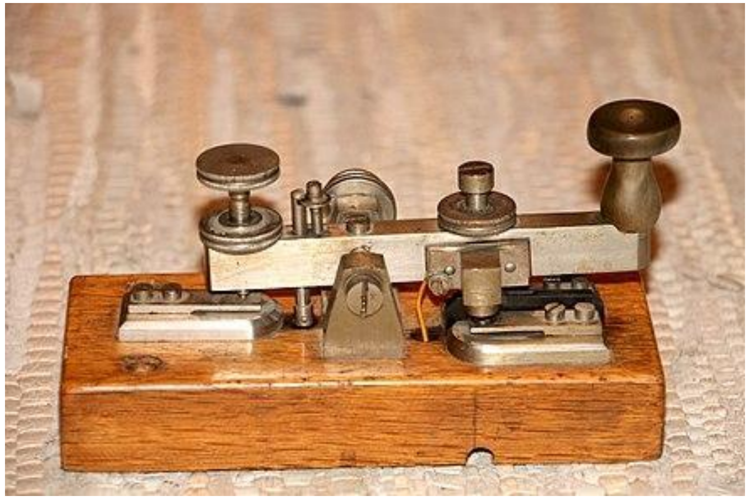
Telegraph

- Samuel Morse changes this to have the signal move a pen, creating a mark.
- Morse first message: was in 1838
  - 3 miles in New Jersey
- More famously sent "WHAT HATH GOD WROUGHT?“ 44 miles between DC and Baltimore
- Core innovation: Relays at frequent intervals that send a message through ten miles (16 km) of wire.



Telephone

- Basic problem: How to modulate voice onto electrical signals
- Reis (1861 Germany): "Das Pferd frisst keinen Gurkensalat" (The horse does not eat cucumber salad). Speech issues.
- Elisha Gray (1876) patents first method for encoding.
- Bell (1876) makes first call: "Mr. Watson, come here, I want to see you.“

Circuit-Switching

- In January 1878, the first telephone switch went into operation in New Haven Connecticut
- Establish a complete circuit every time there’s a communication
- Still the case in cellular (sorta)!
  - Circuit is established to “packet gateway”

The Connections Museum Seattle - Exhibits

Thanks to the hard work and care of our volunteers, Connections Museum Seattle is fortunate to have working examples of switching systems throughout the 20th century, along a central plant, outside plant, and a variety of telephones, telegraphs teletypes, and other telecom-related equipment. Our volunteers are happy to point you in the right direction to explore yourself or take you on a tour to share their knowledge of our collections.

The Connections Museum Seattle is open every Sunday from 10:00 am to 3:00 pm. The museum is handicap-accessible and the suggested donation is $5 for adults and $2 for youths aged 12 to 18. For directions and more information about visiting Connections Museum Seattle, Click Here.

How to Visit the **Museum**

Mechanical Switching

Electronic Switching

The Outside Plant

Telephone Equipment

Telegraphs & Teletypes

Other Equipment

Issues w/ Circuit Switching

- ?

Issues w/ Circuit Switching

- Large setup cost
  - Switching costs all along circuit
- Contention
  - Only X links, what if X+1 want to use?
- Inefficient
  - Circuit established even if not in use
- Fragile
  - Intermediary links go down circuit is broken

USAF wanted their networks to survive nuclear strikes… circuits would not.

Pre-internet: Packetization

The solution focused on three big ideas:

1. Use decentralized network with multiple paths between any two points
2. Divide user messages into message blocks, later called **packets**
3. Deliver these messages by store and forward switching.

Pre-Internet: Why Packetization?

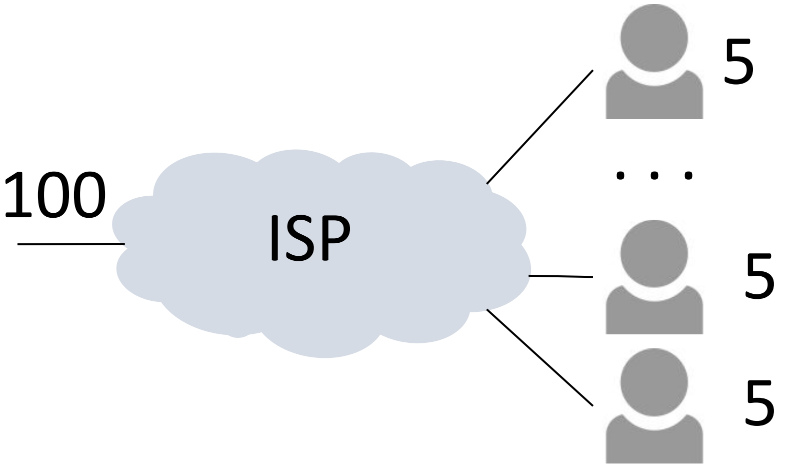
- Efficiency
  - Lines only used when trafficked
- Handles contention
  - Queue packets
- Robust
  - Routes can change
- Kleinrock (UCLA, 1969)
  - UCLA -> Stanford Research Institute
  - “Lo” – Was supposed to be “LOGIN” but crashed

Efficiency: Statistical Multiplexing

- Sharing of network bandwidth between users according to the statistics of their demand
  - (<u>Multiplexing</u> basically means sharing)
  - Useful if:
    - users are mostly idle and/or
    - traffic is bursty
- Key question:
  - How much does it help?

Efficiency: Statistical Multiplexing (2)

- Example: Users in an ISP network
  - Network has 100 Mbps (units of bandwidth)
  - Each user subscribes to 5 Mbps, for videos
  - But a user is active only 50% of the time …

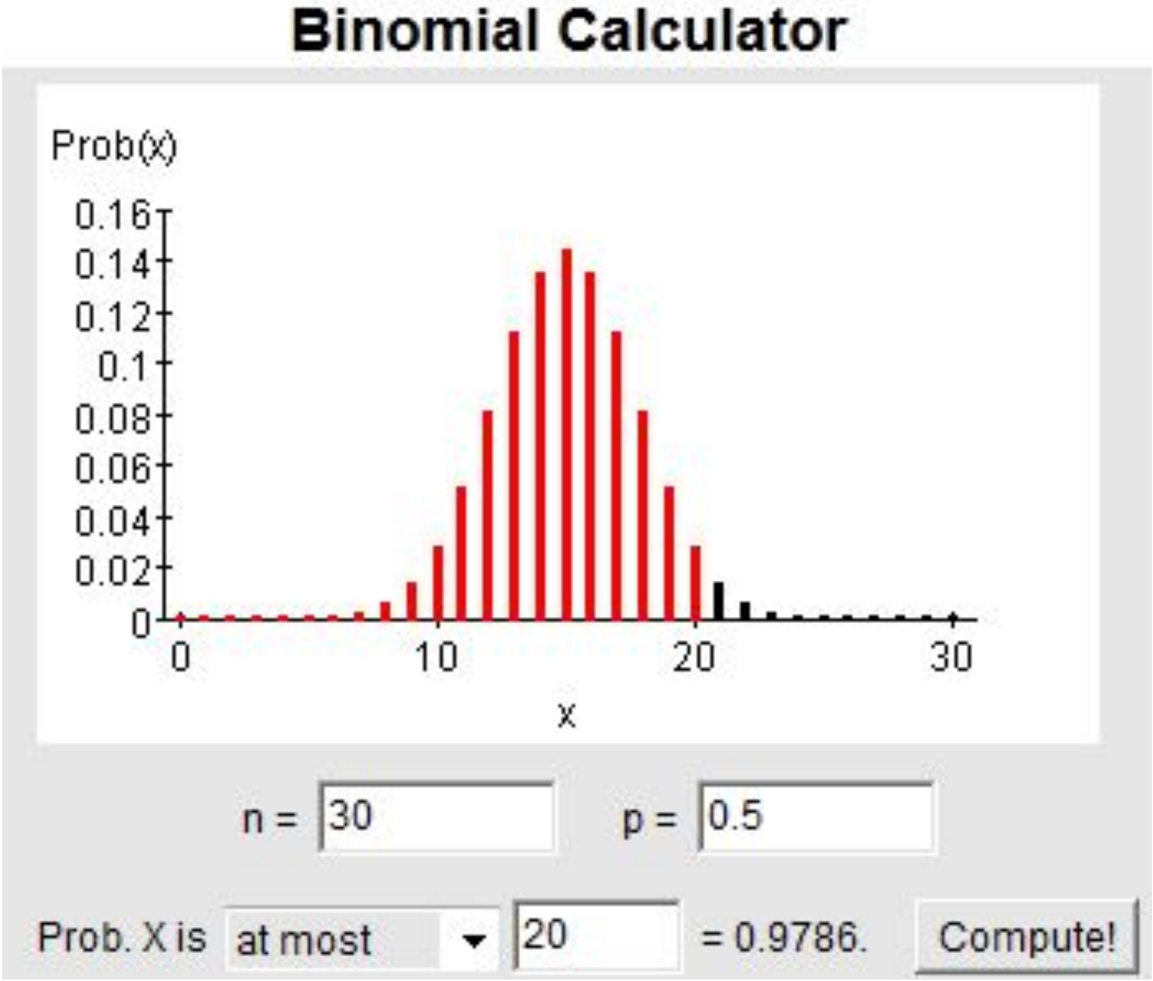


- How many users can the ISP support?
  - With dedicated bandwidth for each user:
  - Probability all bandwidth is used: (assuming independent users)

Efficiency: Statistical Multiplexing (3)

- With 30 independent users, still unlikely (2% chance) to need more than 100 Mbps!
  - Binomial probabilities

→ Can serve more users with the same size network
  - <u>Statistical multiplexing gain</u> is 30/20 or 1.5X
  - But may get unlucky; users will have degraded service



Pre-Internet: Networks

Started building individual packet networks at different institutions:

- Octopus Network
  - 4 Machines at the Lawrence Livermore National Lab
- ALOHAnet
  - Wireless packets at University of Hawaii
- CYCLADES
  - French network exploring network responsibilities
- ARPANET
  - First US packet network, a few universities online

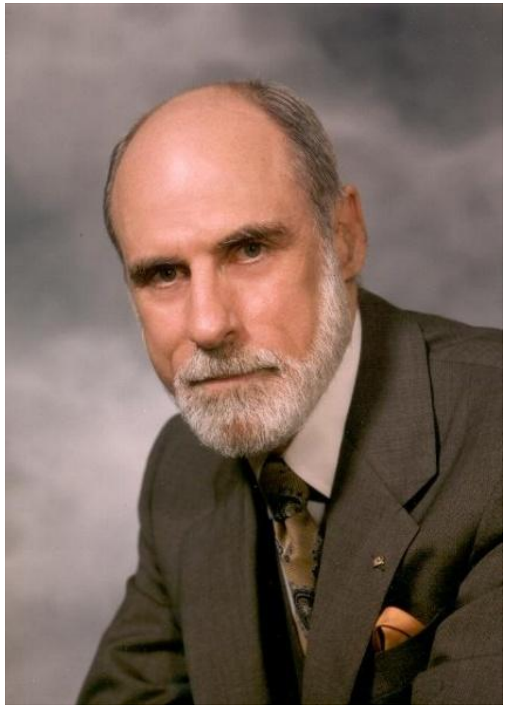
The Beginning – ARPANET

- ARPANET by U.S. DoD was the precursor to the Internet
  - Motivated for resource sharing
  - Core idea: connect different local networks together to create bigger network (“The Network of Networks”)
  - Launched with 4 nodes in 1969, grew to hundreds
  - First “killer app” was email

ARPANET

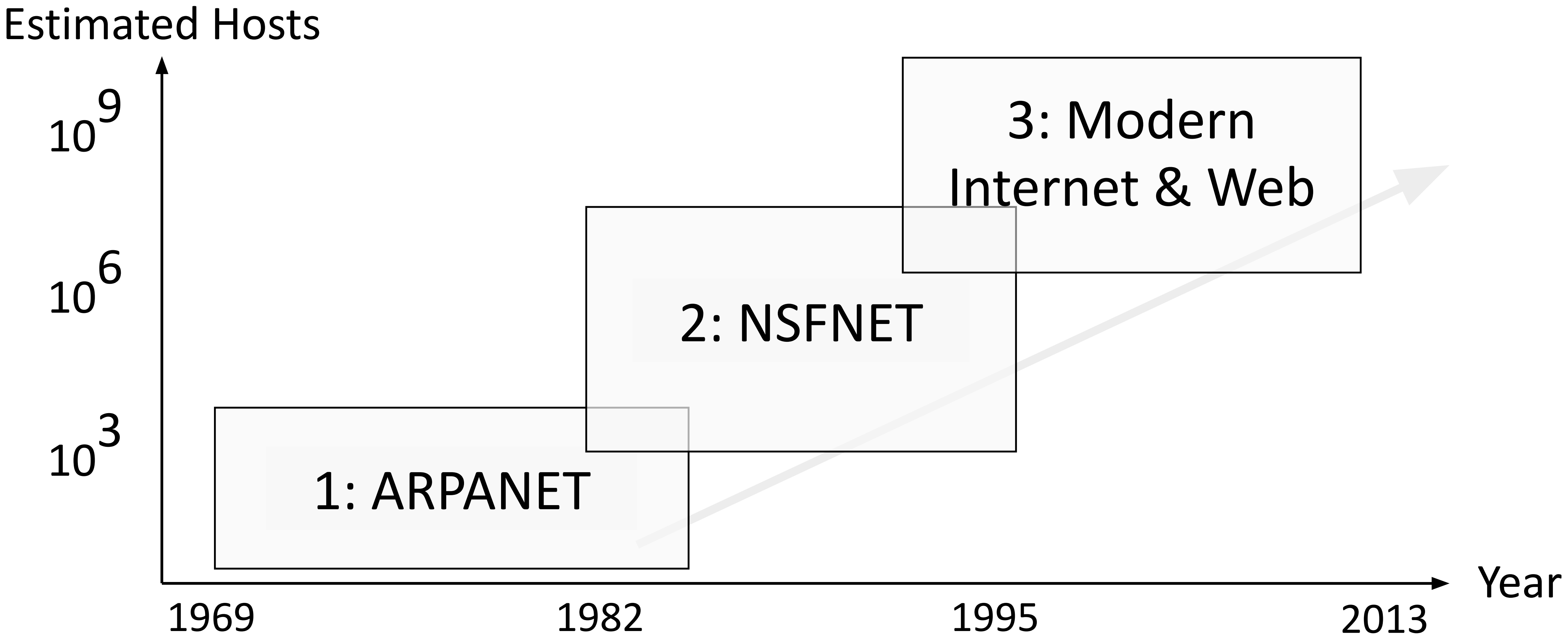
- In the early ARPANET
  - Internetworking became the basis for the Internet
  - Pioneered by Cerf & Kahn in 1974, later became TCP/IP
  - They are popularly known as the “fathers of the Internet”

Vint Cerf

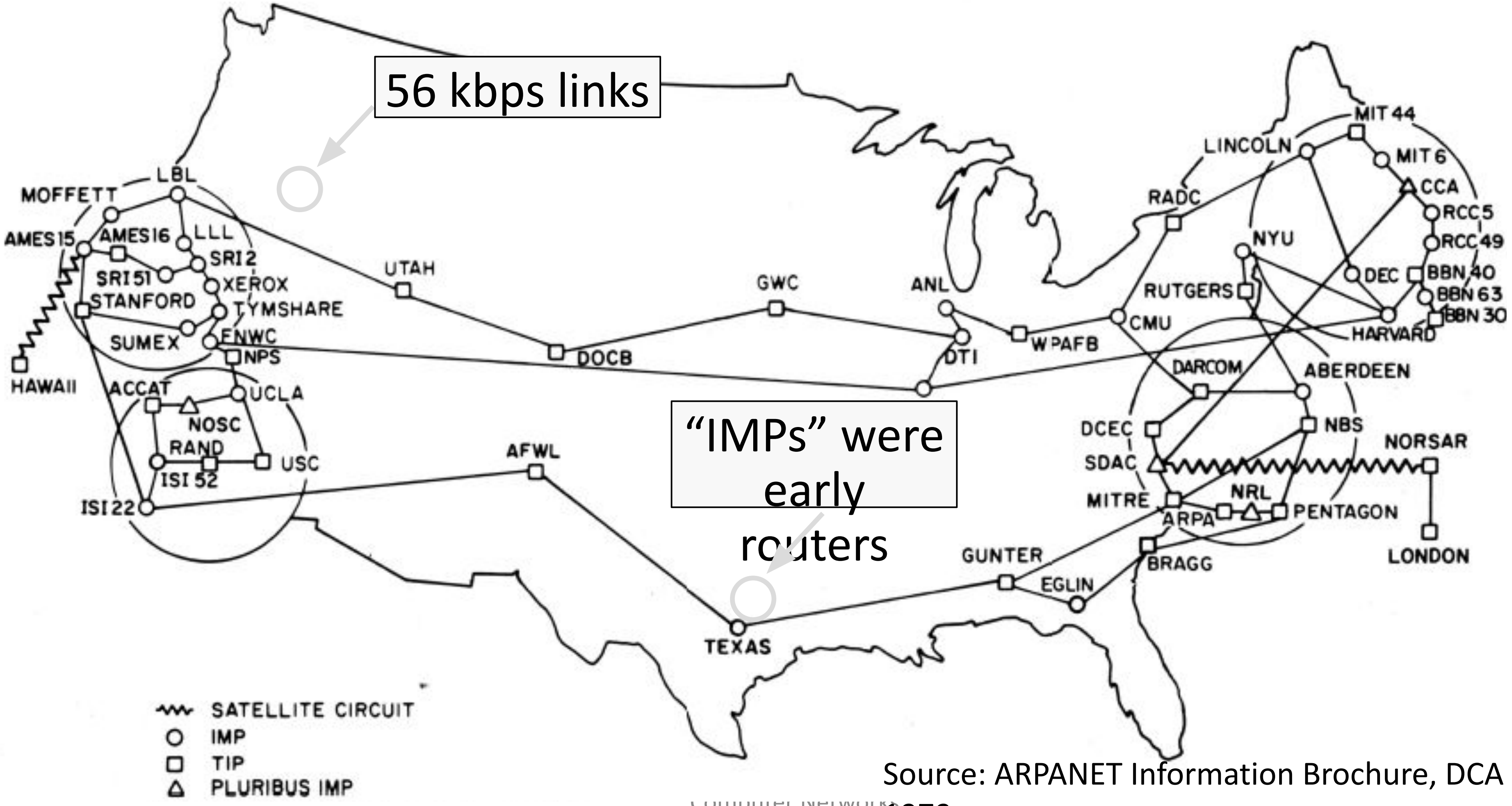


Bob Kahn

Rough Internet Timeline



ARPANET Geographical Map (Dec. 1978)

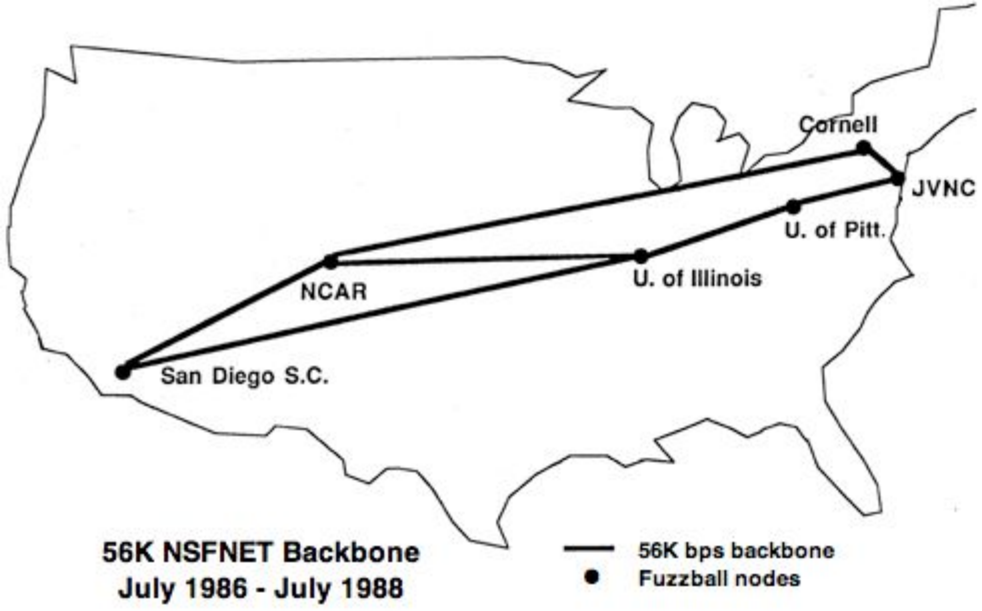


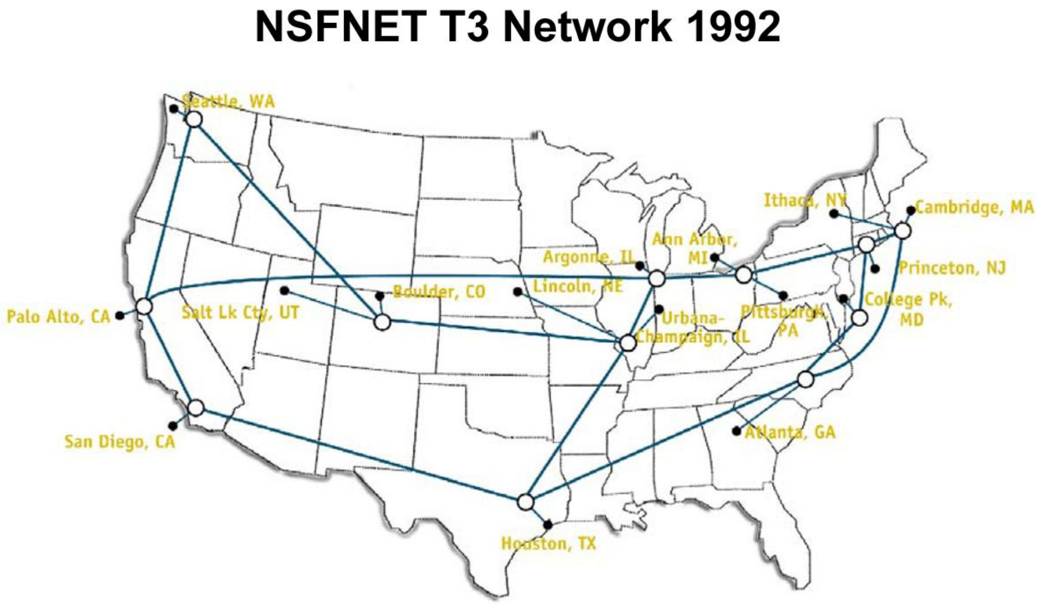
Source: ARPANET Information Brochure, DCA 1979

Growing Up – NSFNET

- NSFNET ’85 supports educational networks
  - Initially connected supercomputers, but became the backbone for all networks
- Classic Internet protocols we use emerged
  - TCP/IP (transport), DNS (naming), Berkeley sockets (API) ’83, BGP (routing) ’93
- Much growth from PCs and Ethernet LANs
  - Campuses, businesses, then homes
  - 1 million hosts by 1993 …

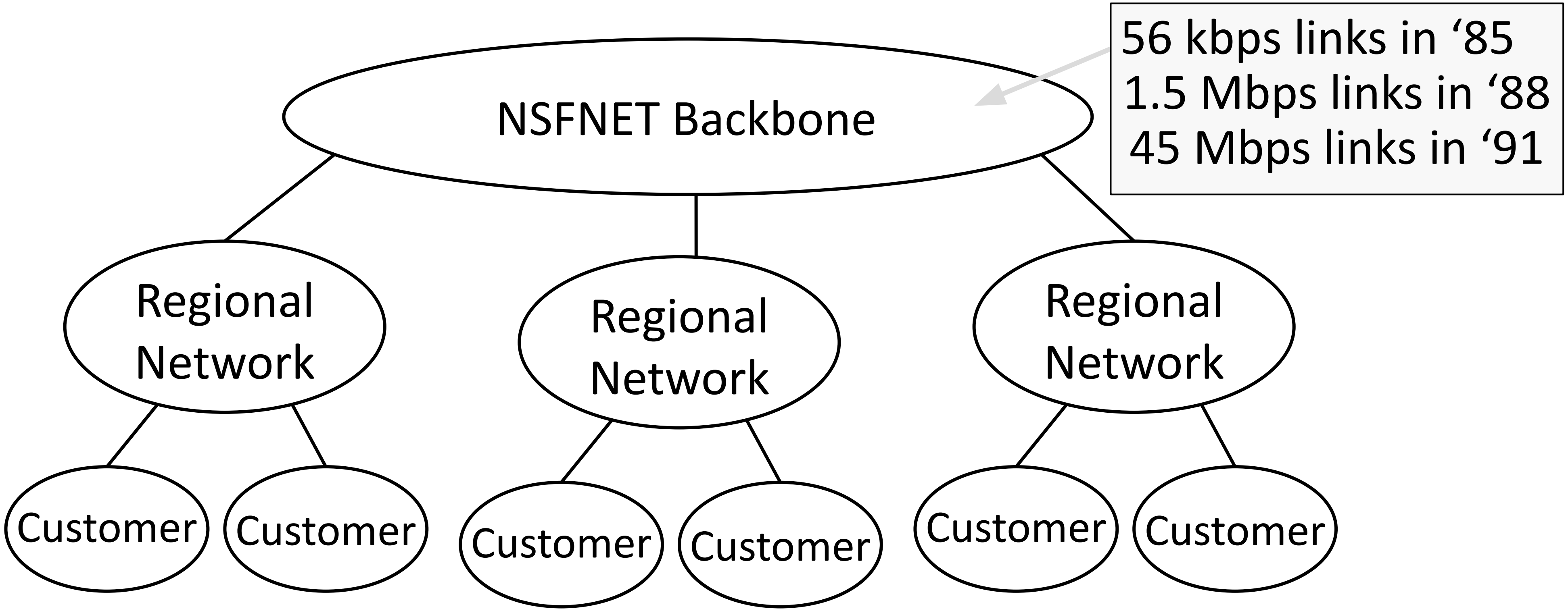
Growing Up- NSFNET





Early Internet Architecture

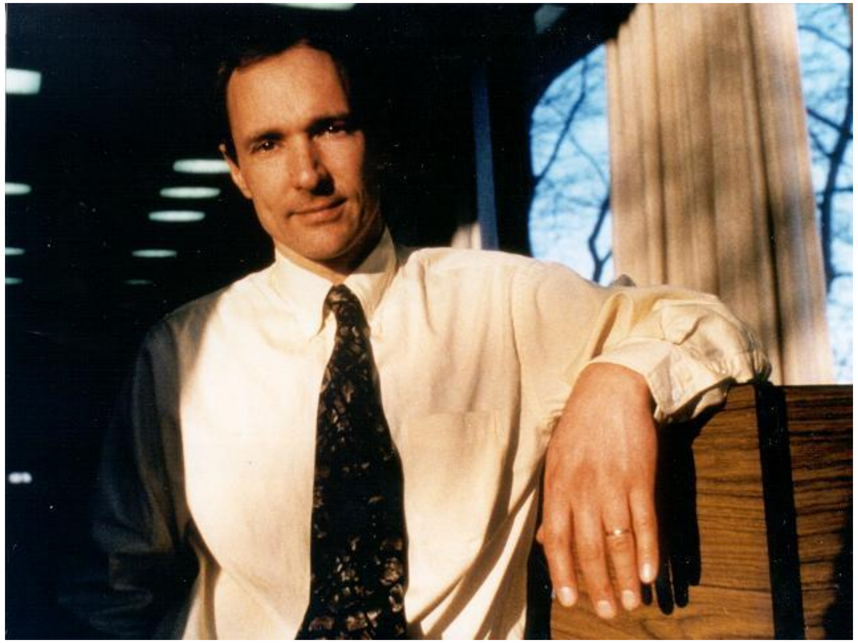
- Hierarchical, with NSFNET as the backbone



Modern Internet – Birth of the Web

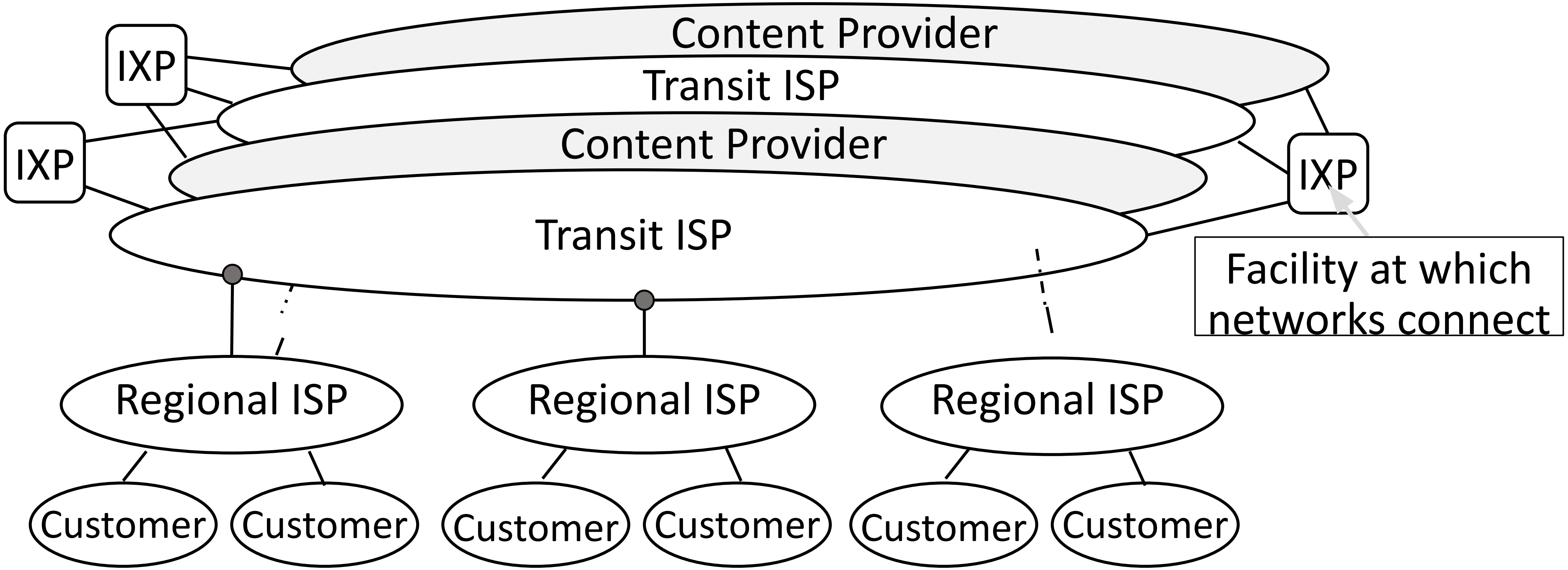
- After ’95, connectivity is provided by large ISPs who are competitors
  - They connect at Internet eXchange Point (IXP) facilities
  - Later, large content providers connect
- Web bursts on the scene in ’93
  - Key idea: Hyperlink
  - Growth leads to CDNs, ICANN in ‘98
  - Most bits are video (soon wireless)
  - Content is driving the Internet

Tim Berners-Lee



Modern Internet Architecture

- Complex business arrangements affect connectivity
  - Still decentralized, other than registering identifiers



Modern Internet Architecture (2)

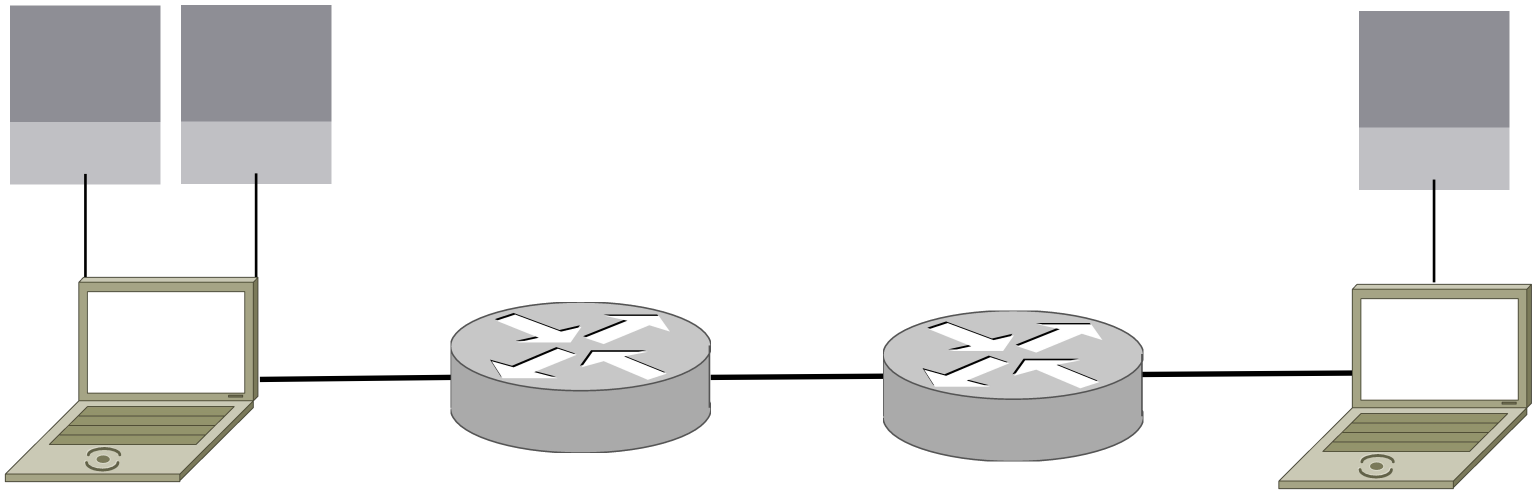
Major Transit ISPs:

- Level 3 (200,000mi of fiber)
- Century Link (550,000mi)
- ATT (410,000mi)
- Verizon (500,000mi)

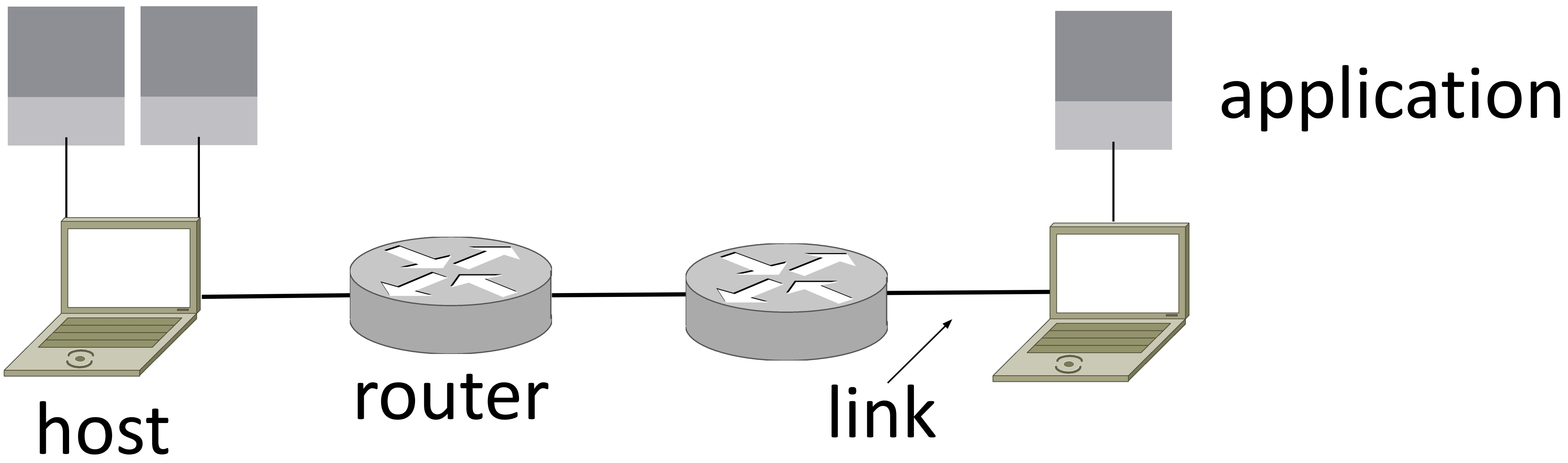
Major Regional ISPs

- Dakotanet
- Dixienet
- Local telecoms (e.g., MTA)
- US West

Parts of a Computer Network



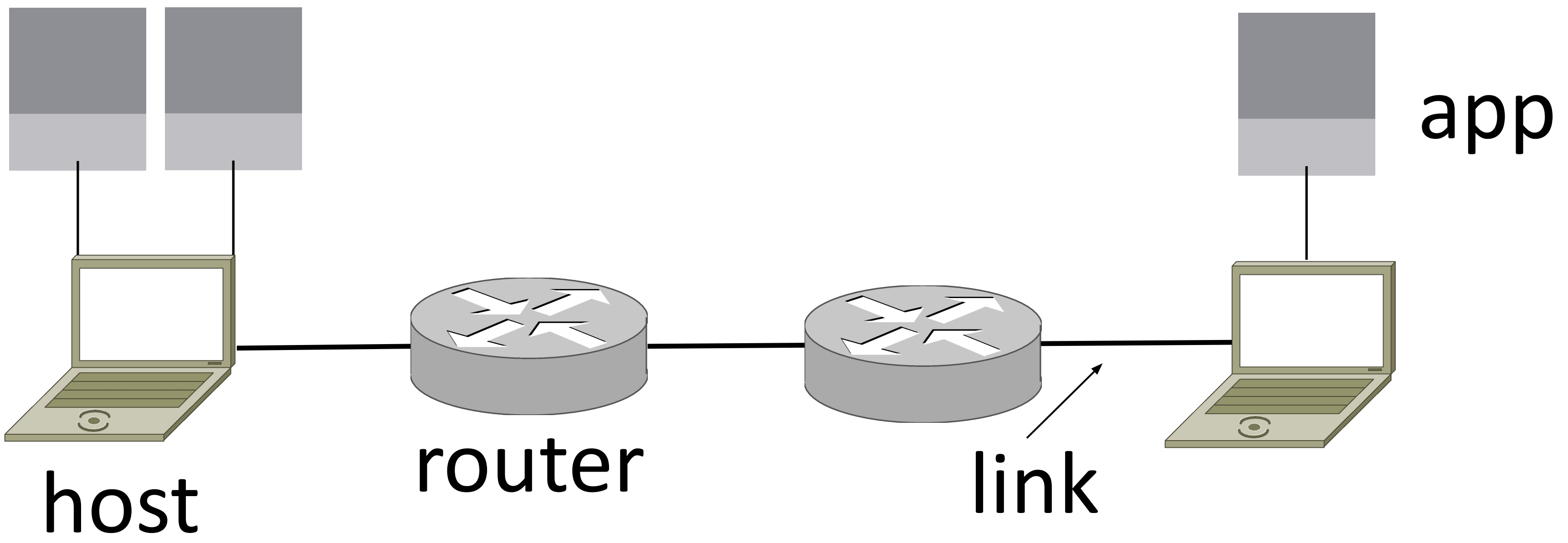
Parts of a Computer Network



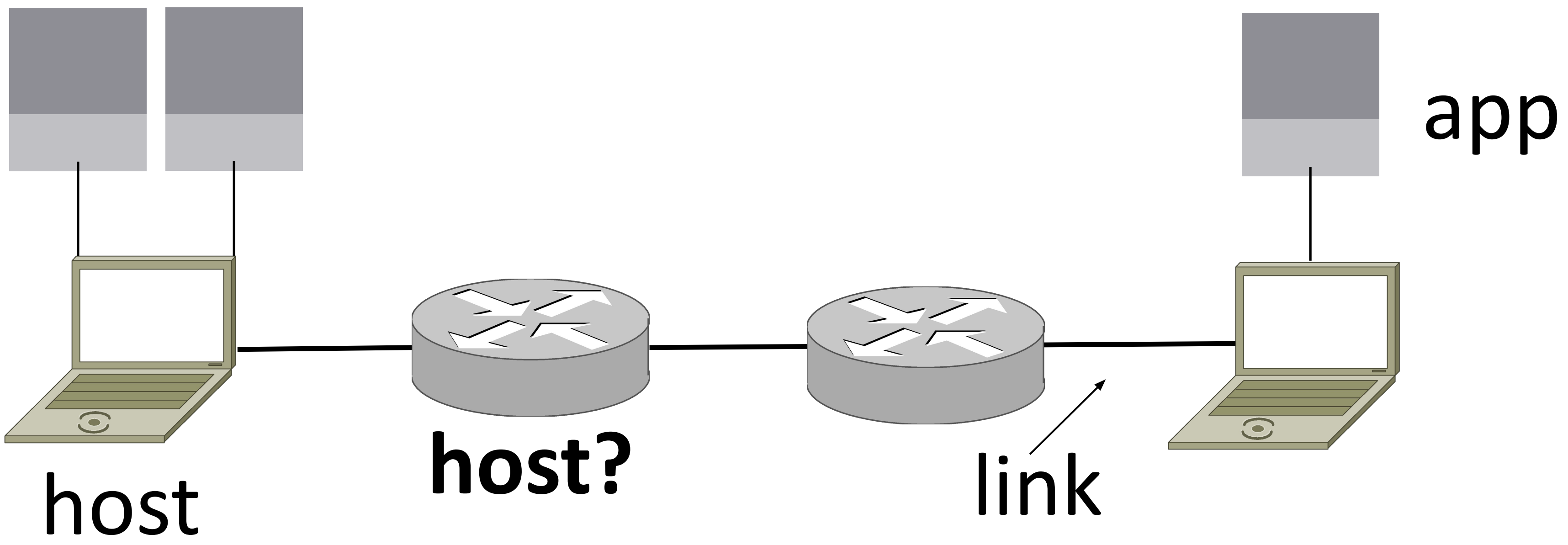
Component Names

Component	**Function**	**Example**
Application, or app, user	Uses the network	Zoom, Spotify, Amazon
Host, or end-system, edge device, node, source, sink	Supports apps	Laptop, mobile, desktop
Router, or switch, node, hub, intermediate system	Relays messages between links	Access point, cable/DSL modem
Link, or channel	Connects nodes	Wires, wireless

Parts of a Computer Network

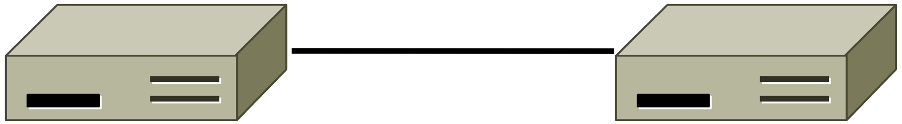


Parts of a Computer Network



A Small Network

- Connect a couple of computers



- Next, a large network …

Internet2 Network Infrastructure Topology

October 2012

Internet2 Network *by the numbers*

10 Juniper T1600 routers
7 Juniper MX960 nodes for TR-CPS
40 custom colocation facilities
250+ amplification racks
15,500 miles of newly acquired dark fiber
2,400 miles of partnered capacity with NTNC
8.8 Tbps of optical capacity
100 Gbps of IP capacity
300+ Ciena ActiveFlex 6500 network elements

IN SUPPORT OF
U.S.UCAN

NETWORK PARTNERS
ciena
cisco.
INDIANA UNIVERSITY
Infinera
Juniper

Source: Internet2

Example Computer Networks?

Example Computer Network Types/Terms

- WiFi (802.11)
- Enterprise / Ethernet
- ISP (Internet Service Provider)
- Cable / DSL
- Mobile phone / cellular (2G, 3G, 4G)
- Bluetooth
- Telephone
- Satellite ...

Computer network names by scale

Scale	**Type**	**Example**
Vicinity	PAN (Personal Area Network)	Bluetooth (e.g., headset)
Building	LAN (Local Area Network)	WiFi, Ethernet
City	MAN (Metropolitan Area Network)	Cable, DSL
Country	WAN (Wide Area Network)	Large ISP
Planet	The Internet (network of all networks)	The Internet!

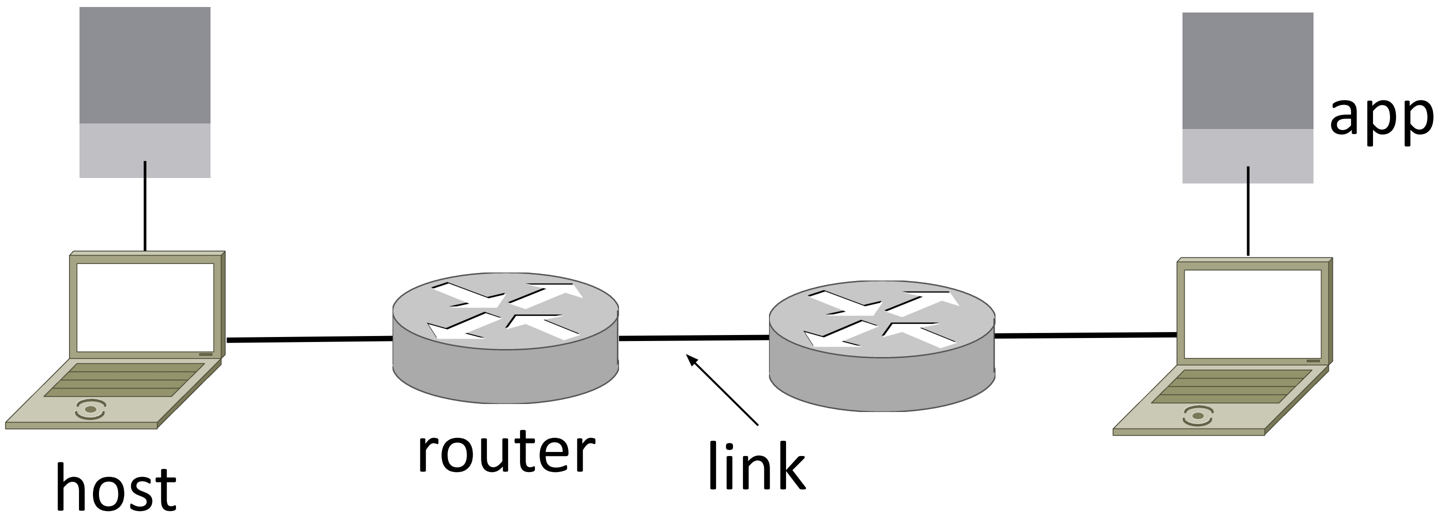
Internetworks

- An internetwork, or internet, is what you get when you join networks together
  - Just another network

- The Internet (capital "I") is the internet we all use

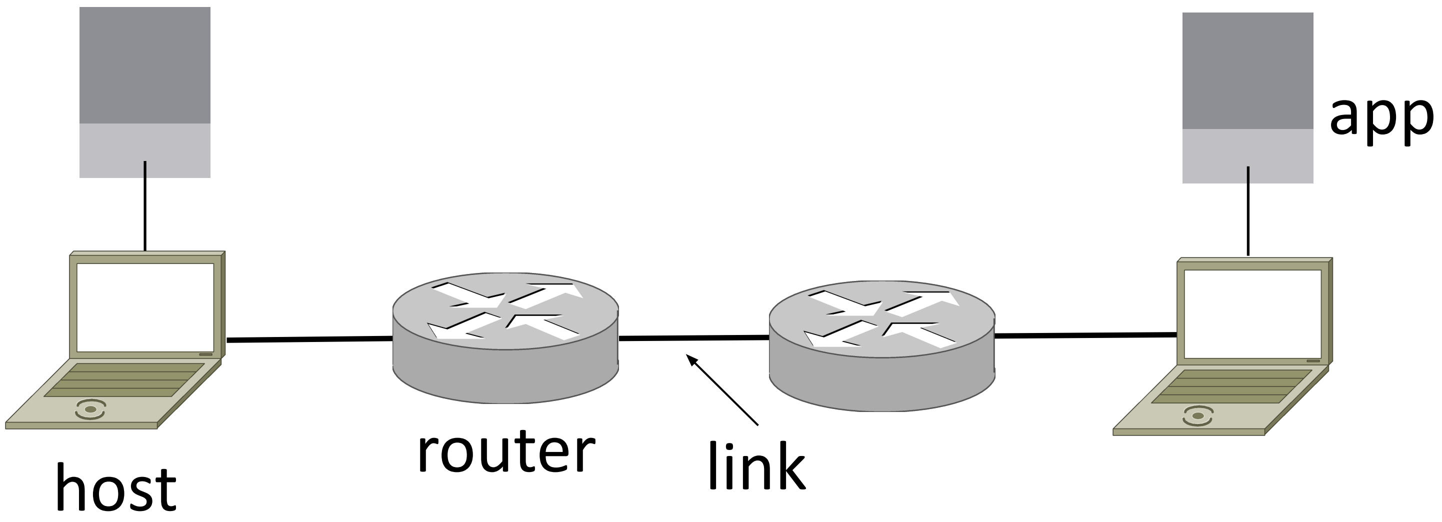
Network Boundaries

- What part is the “network”?



Network Boundaries (2)

- What part represents an “ISP”?

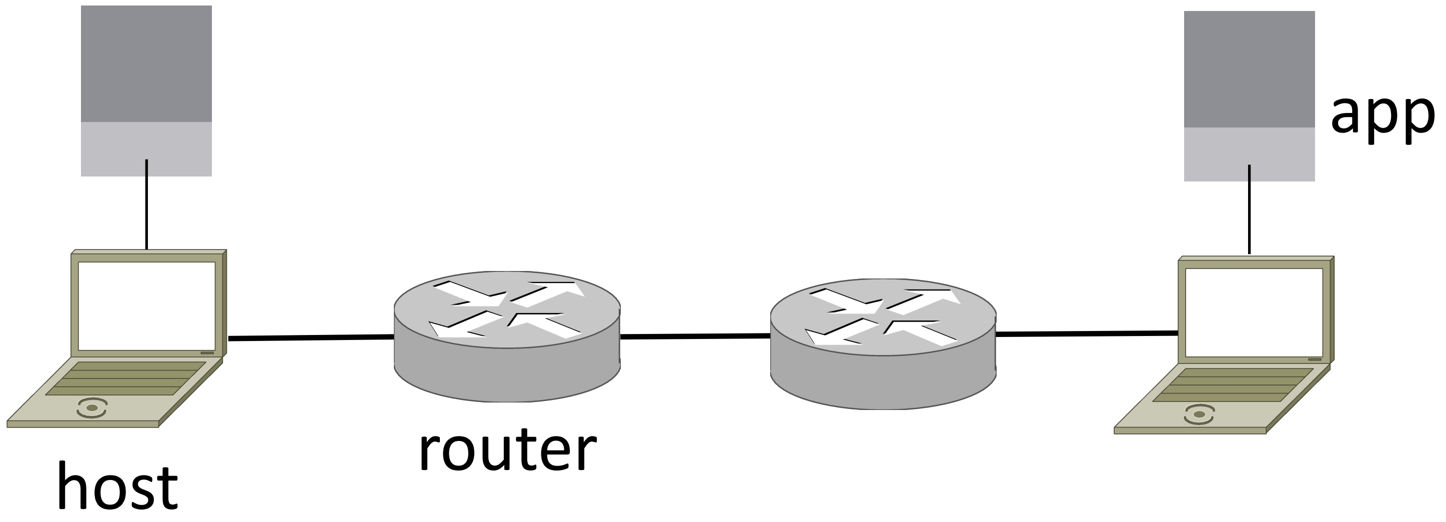


Network Boundaries (3)

- Cloud as a generic network

Key Interfaces

- Between (1) apps and network, and (2) network components



What services should networks provide?

Networks Need Modularity

- The network does much for apps:
  - Make and break connections
  - Find a path through the network
  - Transfers information reliably
  - Transfers arbitrary length information
  - Send as fast as the network allows
  - Shares bandwidth among users
  - Secures information in transit
  - Lets many new hosts be added
  - …

Networks Need Modularity

- The network does much for apps:

We need a form of modularity, to help manage complexity and support reuse

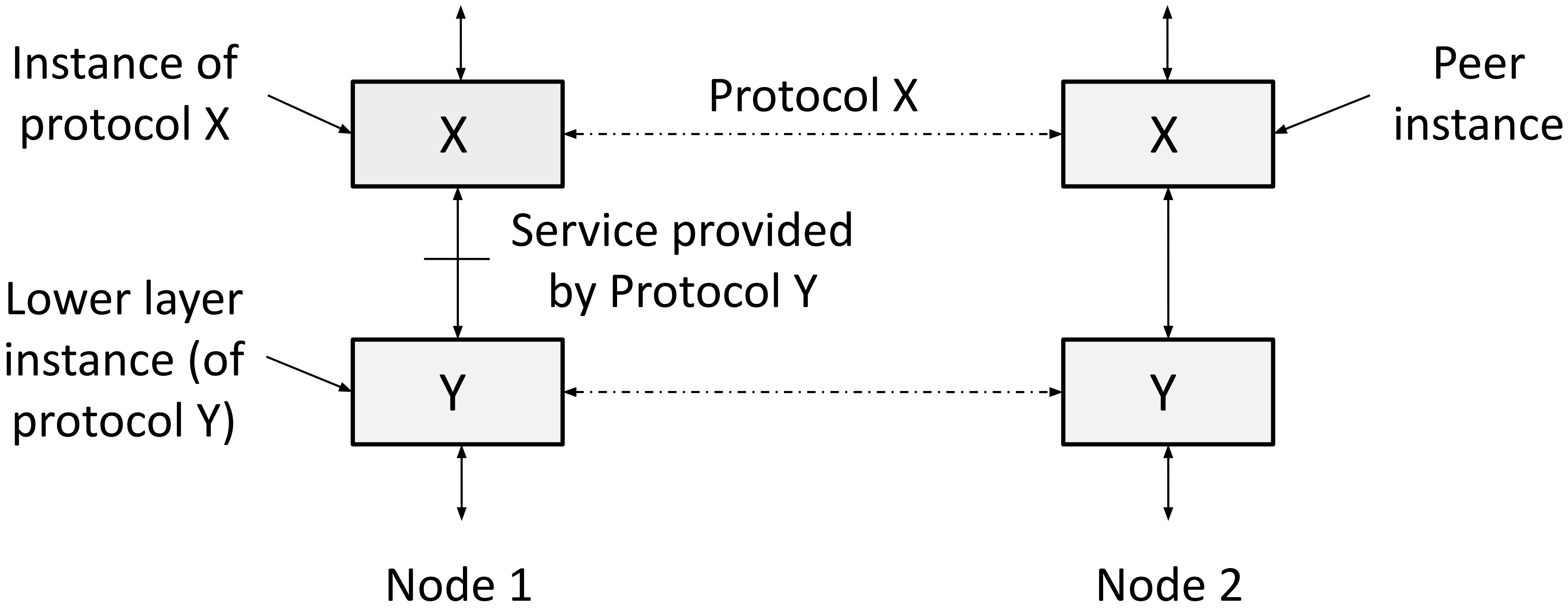
  - Secures information in transit
  - Lets many new hosts be added
  - …

Protocols and Layers

- Protocols and layering is the main structuring method used to divide up network functionality
  - “Protocol Stack”
  - Each instance of a protocol talks virtually to its peer using the protocol
  - Each instance of a protocol uses only the services of the layers around it

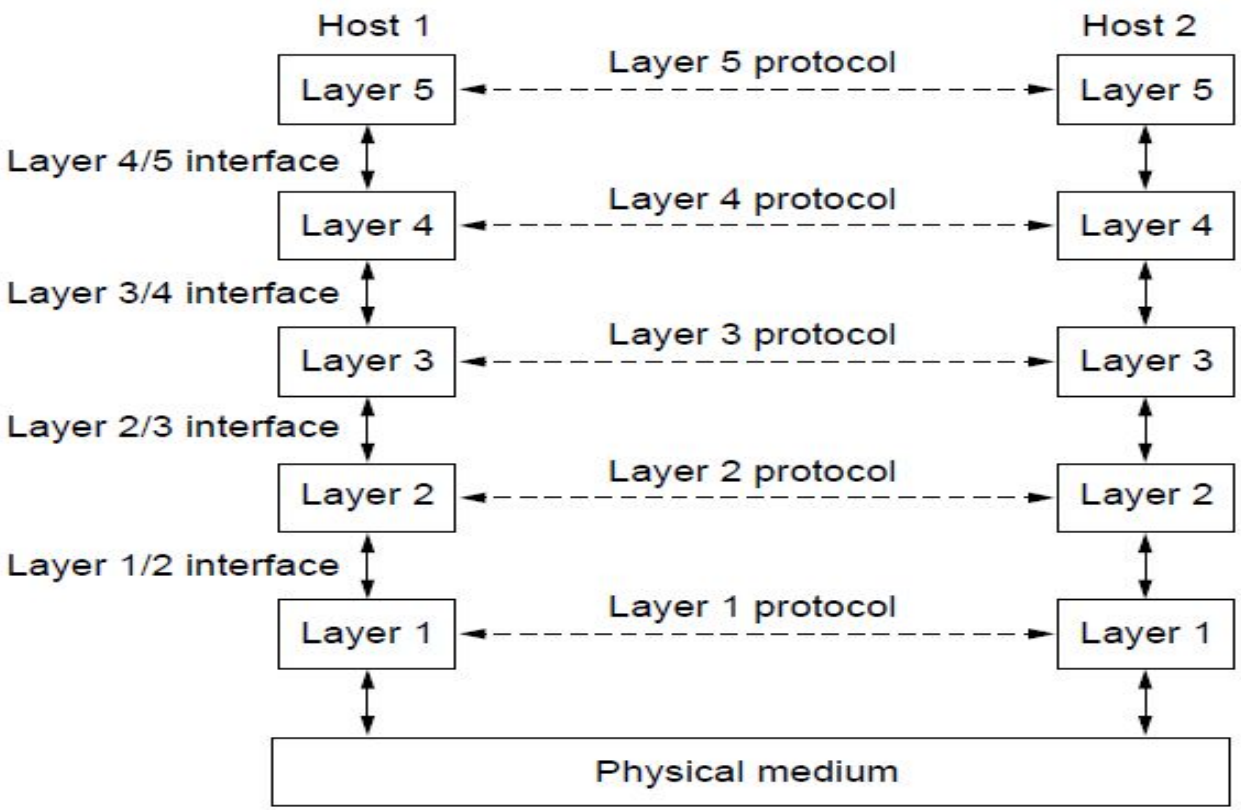
Protocols and Layers (2)

- Protocols are horizontal, layers are vertical



Protocols and Layers (3)

- Set of protocols in use is called a <u>protocol stack</u>

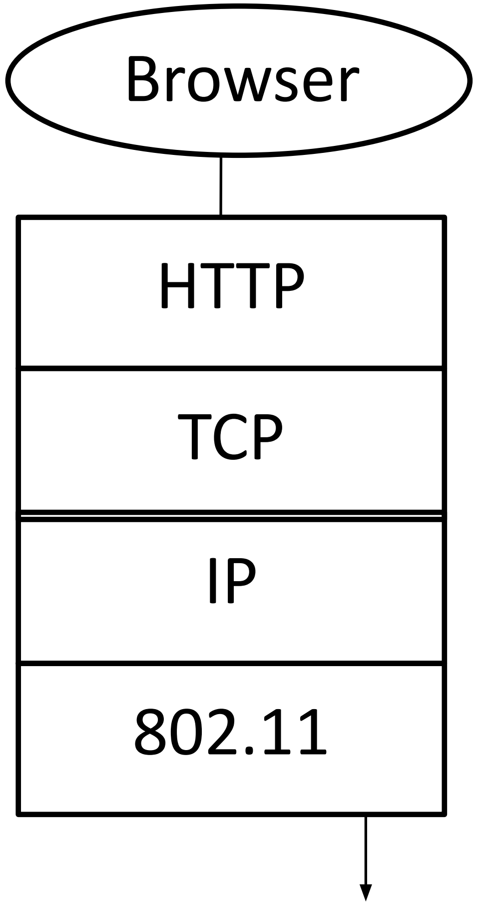


Protocols and Layers (4)

- Protocols you've probably heard of:
  - TCP, IP, 802.11, Ethernet, HTTP, SSL, DNS, … and many more

Protocols and Layers (5)

- Protocols you've probably heard of:
  - TCP, IP, 802.11, Ethernet, HTTP, SSL, DNS, … and many more
- An example protocol stack
  - Used by a web browser on a host that is wirelessly connected to the Internet

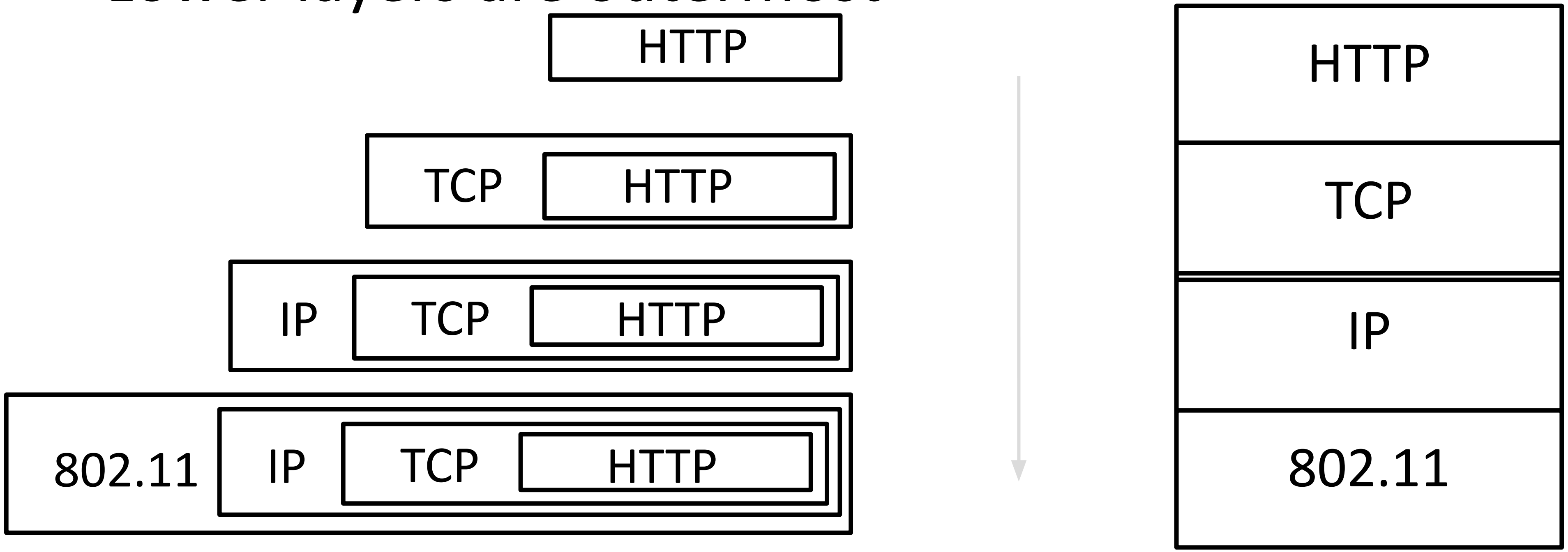


Encapsulation

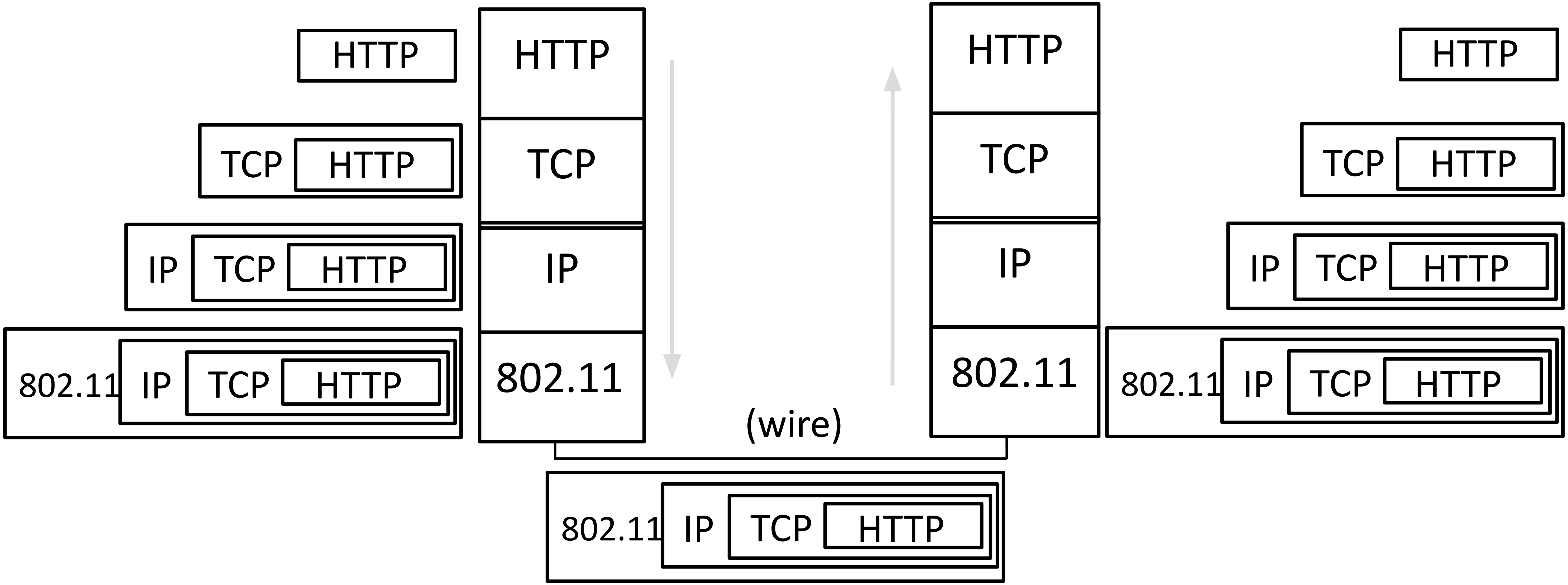
- Encapsulation is the mechanism used to effect protocol layering
  - Lower layer wraps higher layer content, adding its own information to make a new message for delivery
  - Like sending a letter in an envelope; postal service doesn’t look inside

Encapsulation (2)

- Message "on the wire" begins to look like an onion
  - Lower layers are outermost

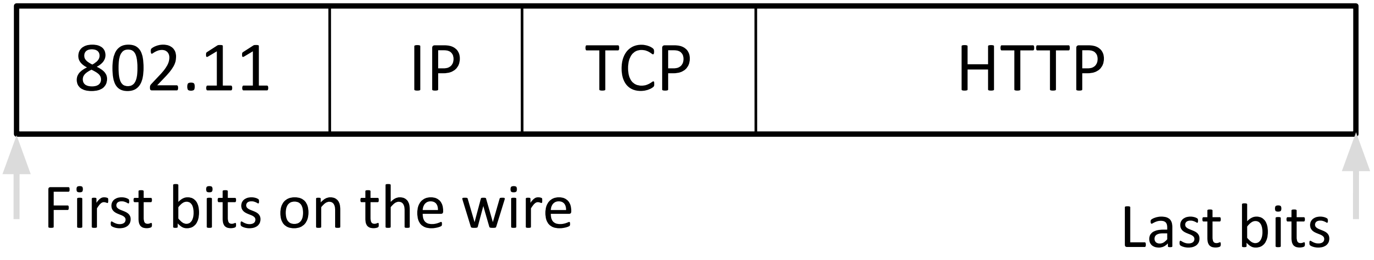


Encapsulation (3)



Encapsulation (4)

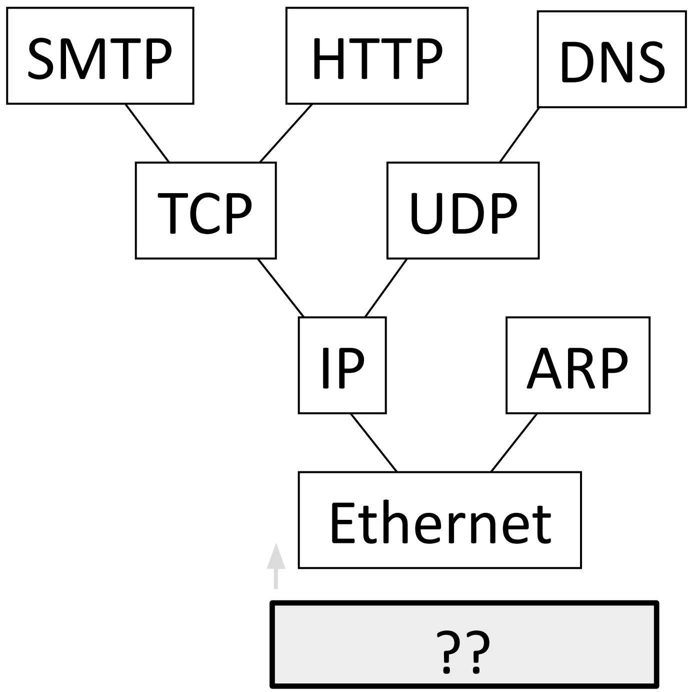
- Normally draw message like this:
  - Each layer adds its own header



- More involved in practice
  - Trailers as well as headers, encrypt/compress contents
  - Segmentation (divide long message) and reassembly

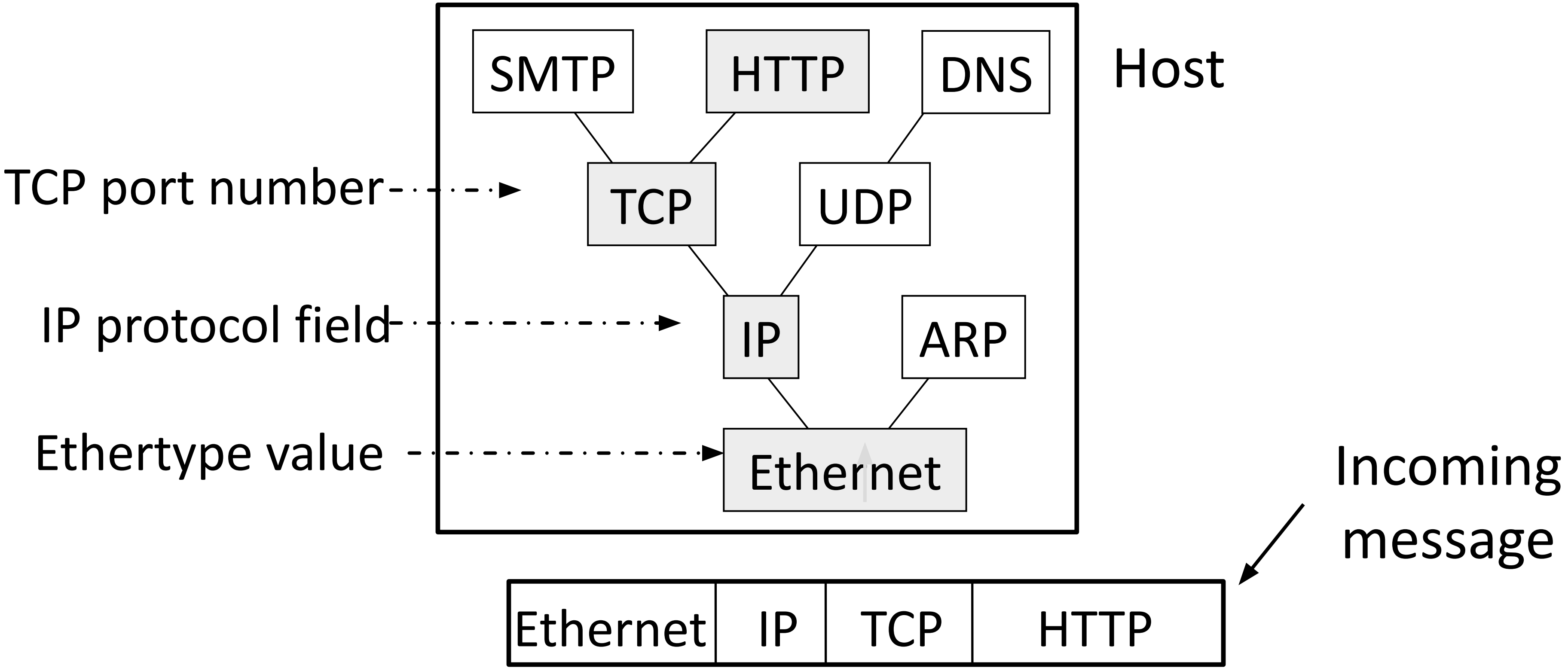
Demultiplexing

- Incoming message must be passed to the protocols that it uses



Demultiplexing (2)

- Done with <u>demultiplexing keys</u> in the headers



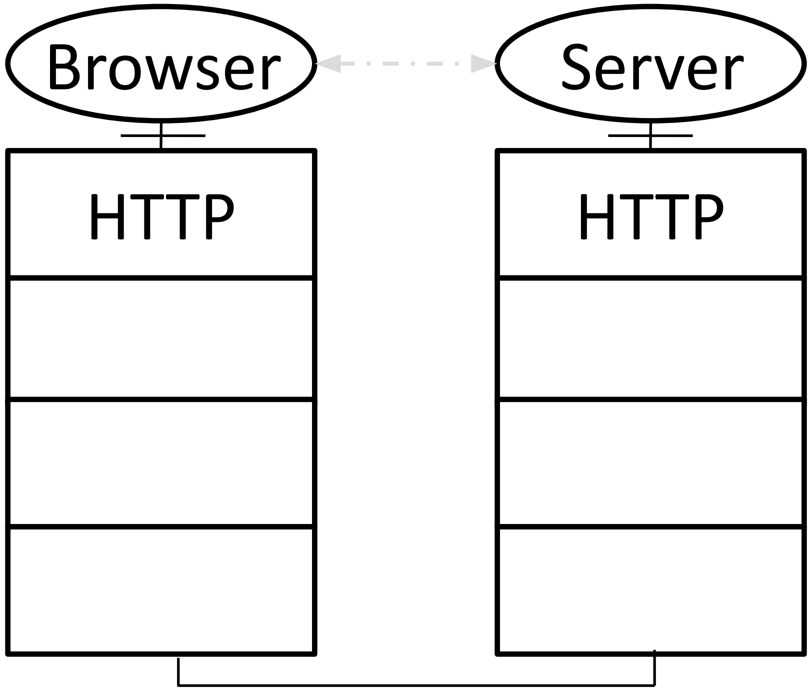
From the reading, your other experiences and/or intuition,

what are some advantages of layering,

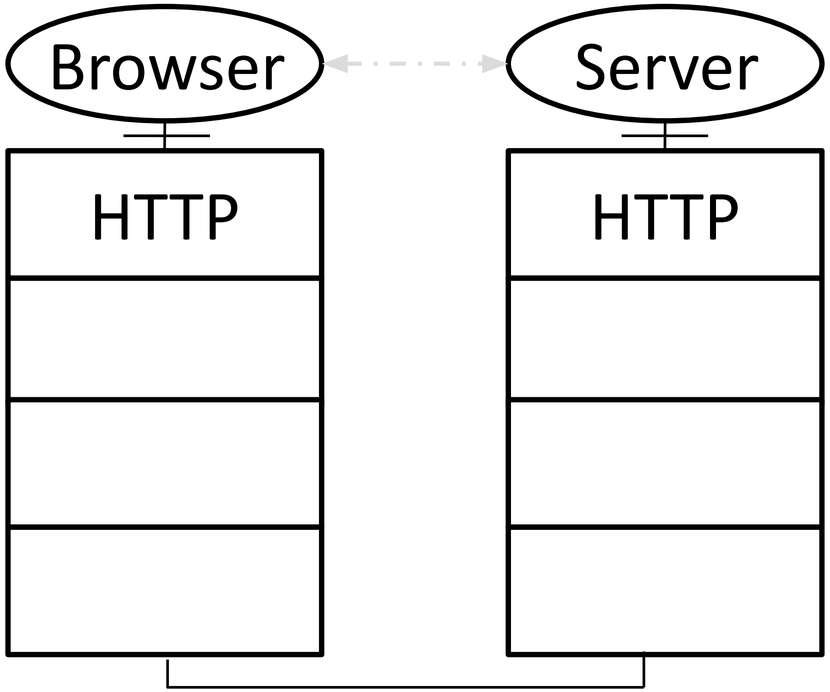
and what are some disadvantages?

Advantage of Layering

- Information hiding and reuse



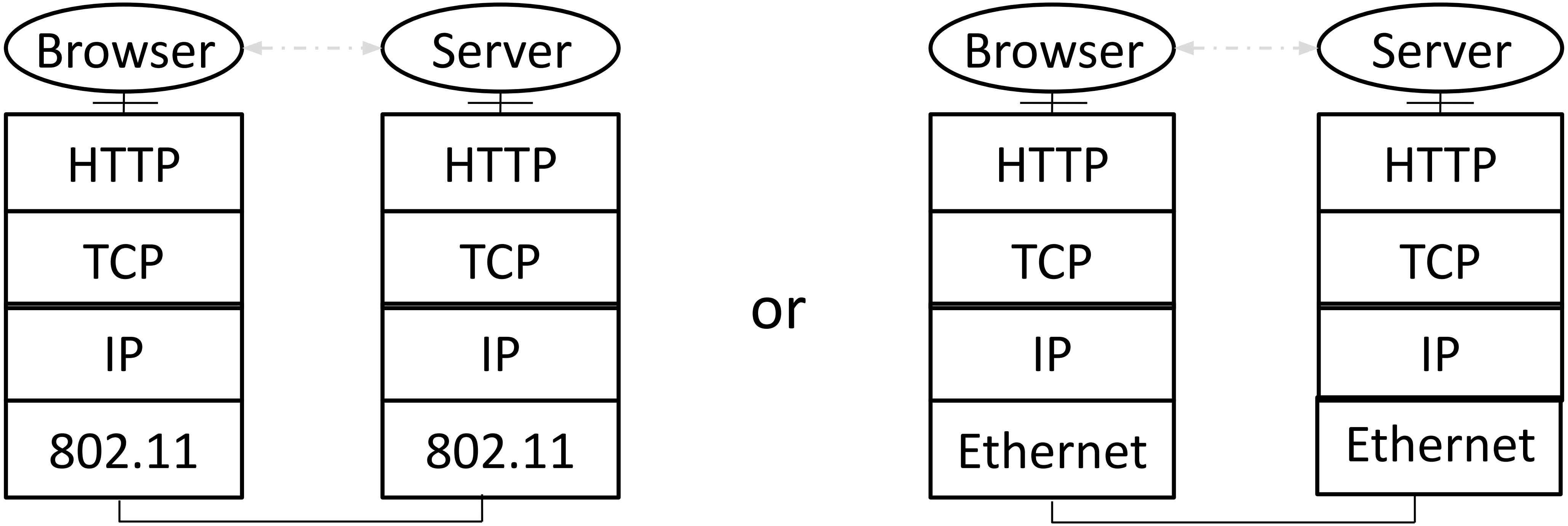
or



Advantage of Layering (2)

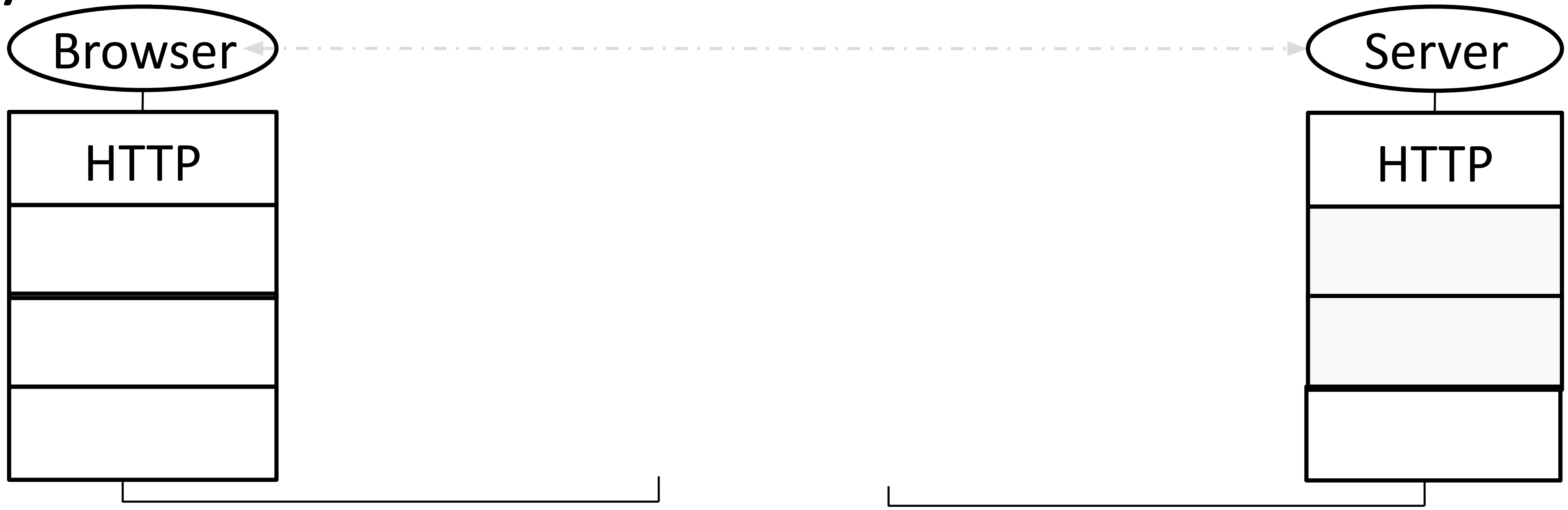
- Information hiding and reuse

Completely changed how the systems communicate, but most of the stack doesn't need to know!



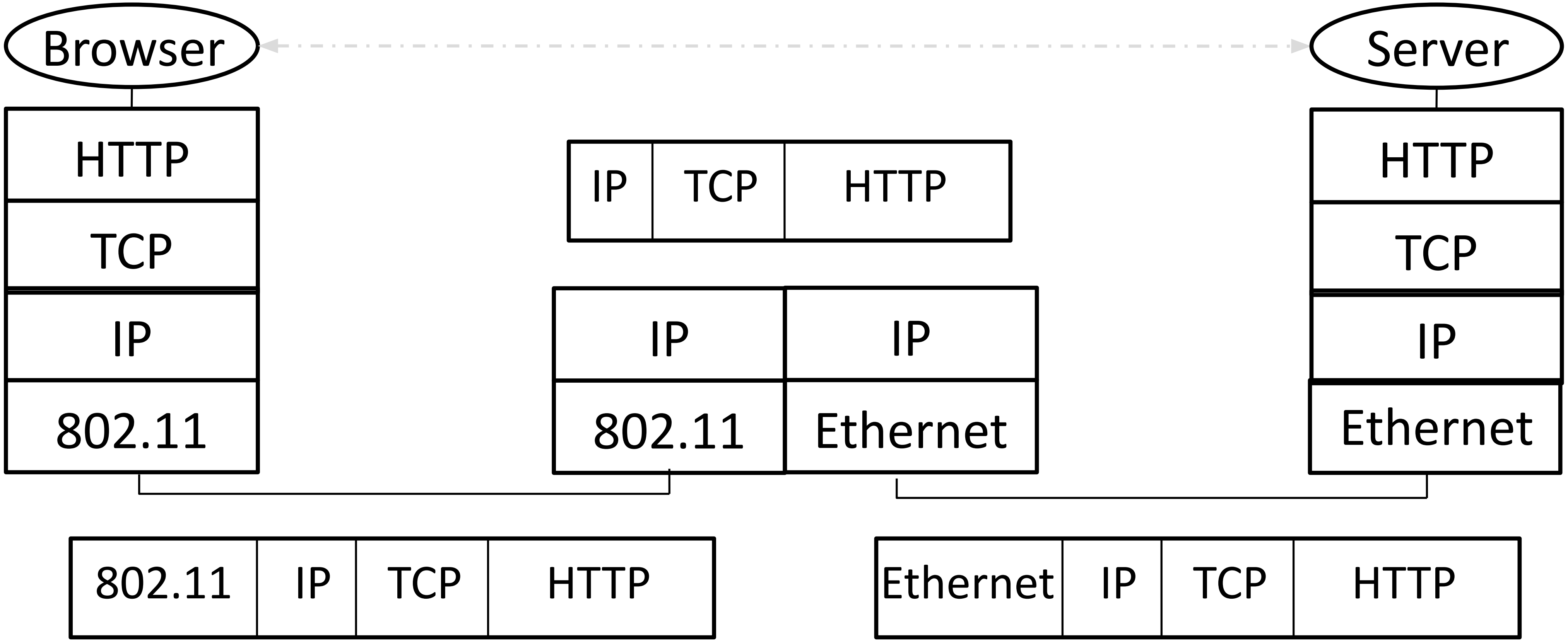
Advantage of Layering (3)

- Using information hiding to connect different systems



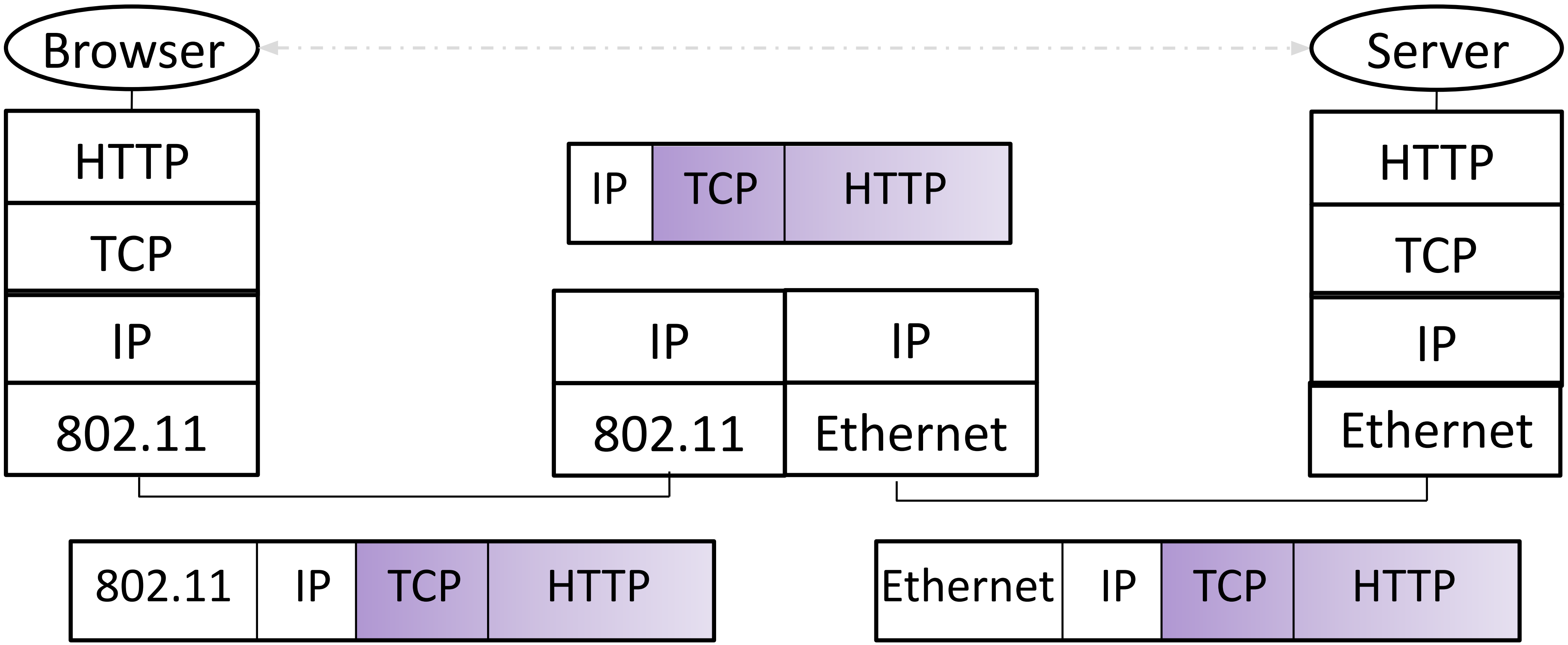
Advantage of Layering (4)

- Information hiding to connect different systems



Advantage of Layering (5)

- Information hiding to connect different systems



Disadvantages of Layering…

- ?

Disadvantage of Layering

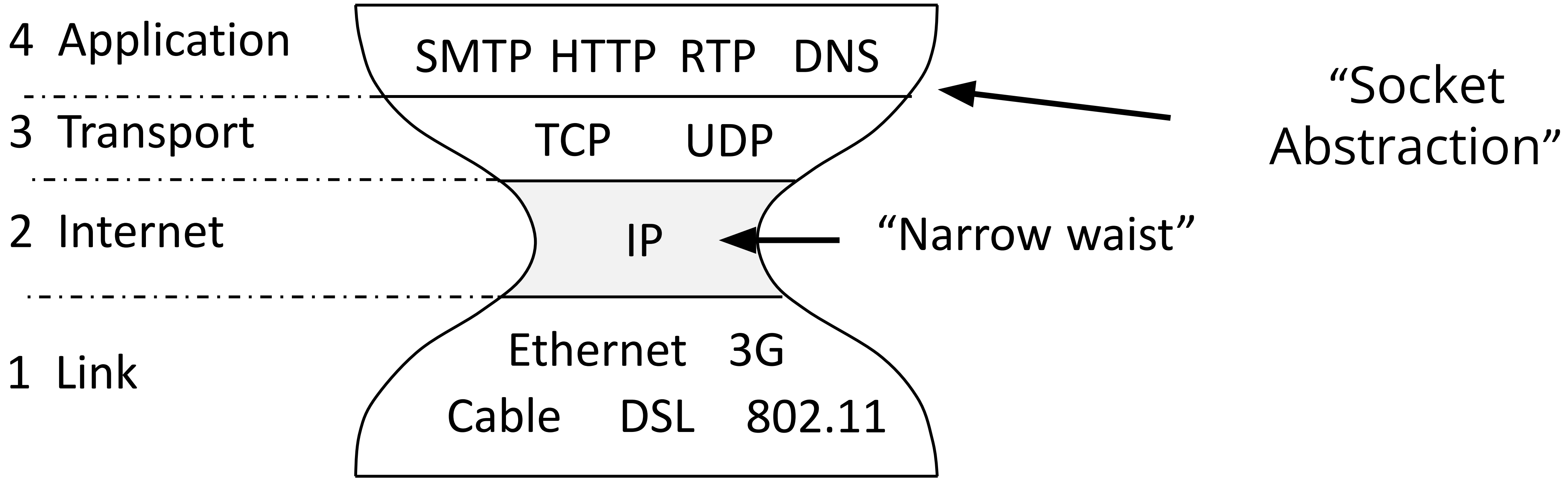
- Adds overhead
  - More problematic with short messages
- Hides information
  - App might care about network properties (e.g., latency, bandwidth, etc)
  - Network may need to know about app priorities (e.g., QoS)

OSI Layers

Layer	Function	Example
Application (7)	Services that are used with end user applications	SMTP,
Presentation (6)	Formats the data so that it can be viewed by the user Encrypt and decrypt	JPG, GIF, HTTPS, SSL, TLS
Session (5)	Establishes/ends connections between two hosts	NetBIOS, PPTP
Transport (4)	Responsible for the transport protocol and error handling	TCP, UDP
Network (3)	Reads the IP address form the packet.	Routers, Layer 3 Switches
Data Link (2)	Reads the MAC address from the data packet	Switches
Physical (1)	Send data on to the physical wire.	Hubs, NICS, Cable

Protocols and Layering

- Hot take: the "real" internet protocol stack:



Course Reference Model

- We mostly follow the Internet
  - A little more about the Physical layer, and alternatives

5	Application	– Programs that use network service
4	Transport	– Provides end-to-end data delivery
3	Network	– Send packets over multiple networks
2	Link	– Send frames over one or more links
1	Physical	– Send bits using signals

Lecture Progression

- Bottom-up through the layers:

Layer	
Application	- HTTP, DNS, CDNs
Transport	- TCP, UDP
Network	- IP, NAT, BGP
Link	- Ethernet, 802.11
Physical	- wires, fiber, wireless

- Followed by more detail on cross-cutting elements:
  - Quality of service, Security (VPN, SSL)

Any lingering questions about layers?

Let’s talk about channels…

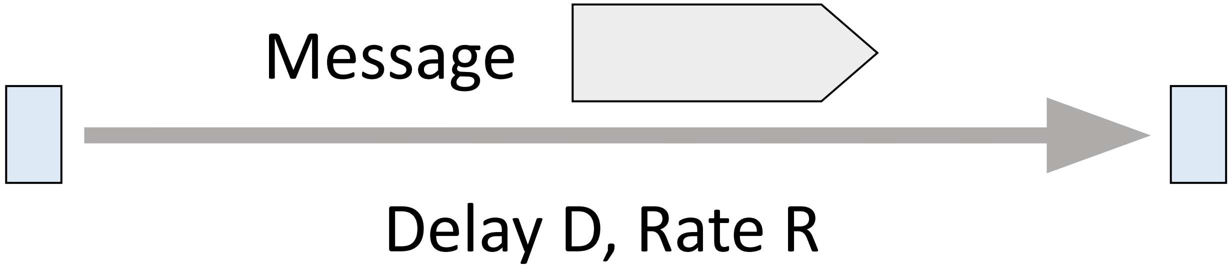
Common Properties of any Channel

- Bandwidth
- Delay
- Loss

- Higher order derivatives
  - Bandwidth -> Consistency
  - Delay -> Jitter
  - Loss -> Stability

Simple Link Model

- An abstraction of a physical channel
  - Rate (or bandwidth, capacity, speed) in bits/second
  - Delay in seconds, related to length of medium



- Other important properties:
  - Whether the channel is broadcast, and its error rate

Message Latency

- Latency is the delay to send a message over a link
  - Transmission delay: time to put M-bit message "on the wire" or "on the air"
  - Propagation delay: time for bits to propagate across the medium
  - Combining the two terms we have:

Message Latency (2)

- Latency is the delay to send a message over a link
  - Transmission delay: time to put M-bit message "on the wire"

    T-delay = M (bits) / Rate (bits/sec) = M/R seconds

  - Propagation delay: time for bits to propagate across the wire

    P-delay = Length / speed of signals = D seconds

    For a copper wire, the propagation speed of the signal is ~2/3c, (c is the speed of light in vacuum), so the delay is the wire's physical length/(2/3c).

  - Combining the two terms we have: L = M/R + D

Latency Examples

Remembering L = M/R + D

- "Dialup" with a telephone modem:
  - D = 5 ms, R = 56 kbps, M = 1250 Bytes

- "Broadband" cross-country link:
  - D = 50 ms, R = 10 Mbps, M = 1250 Bytes

Latency Examples (2)

- "Dialup" with a telephone modem:
  - D = 5 ms, R = 56 kbps, M = 1250 Bytes
  - L = $(1250 \times 8)/(56 \times 10^3)$ sec + 5ms = 184 ms!

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Latency Examples (2)

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  - D = 5 ms, R = 56 kbps, M = 1250 Bytes
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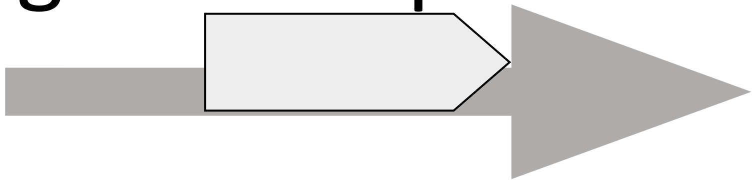
- "Broadband" cross-country link:
  - D = 50 ms, R = 10 Mbps, M = 1250 Bytes
  - L = (1250x8) / (10 x 10^6) sec + 50ms = 51 ms

- A long link or a slow rate means high latency: One component dominates

Bandwidth-Delay Product

- Messages take space on the wire!



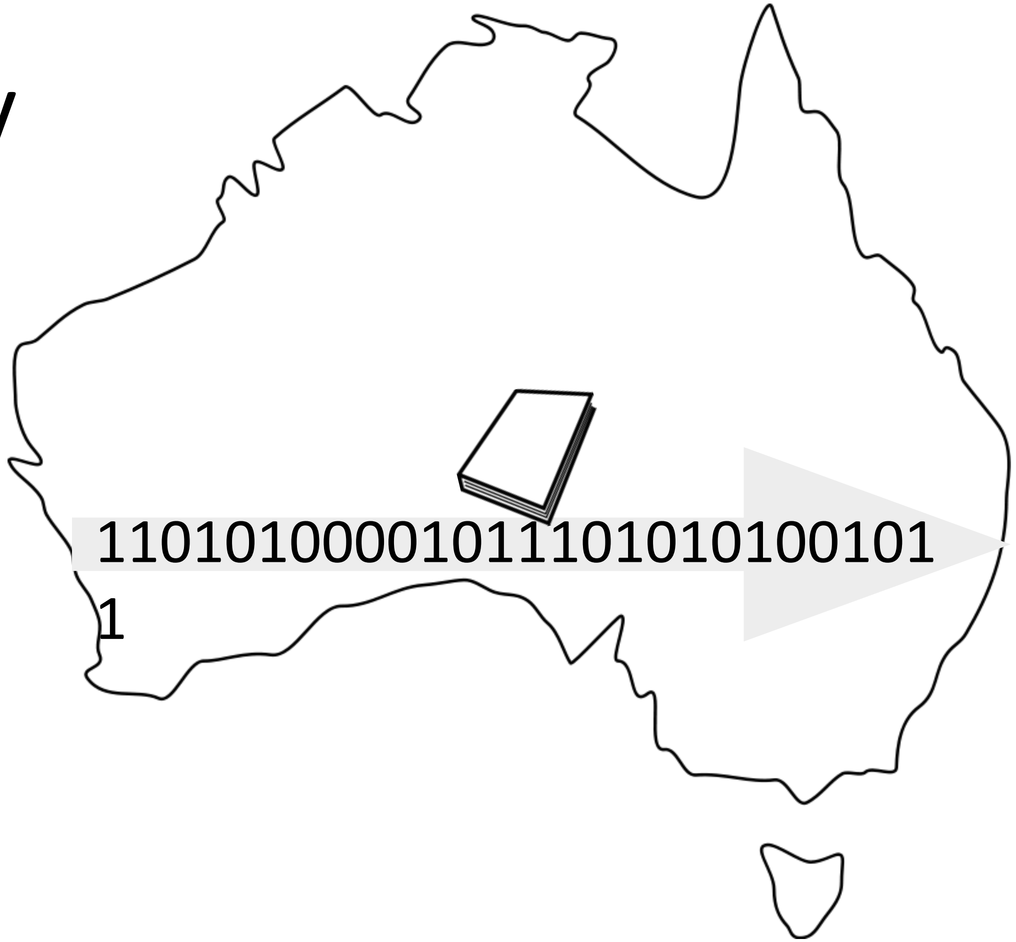
- The amount of data in flight is the <u>bandwidth-delay (BD) product</u>

  BD = R x D

  - Measure in bits, or in messages
  - Small for LANs, big for “long fat” pipes

Bandwidth-Delay Example

- Fiber at home, cross-country
  R=40 Mbps, D=50 ms



Bandwidth-Delay Example (2)

- Fiber at home, cross-country

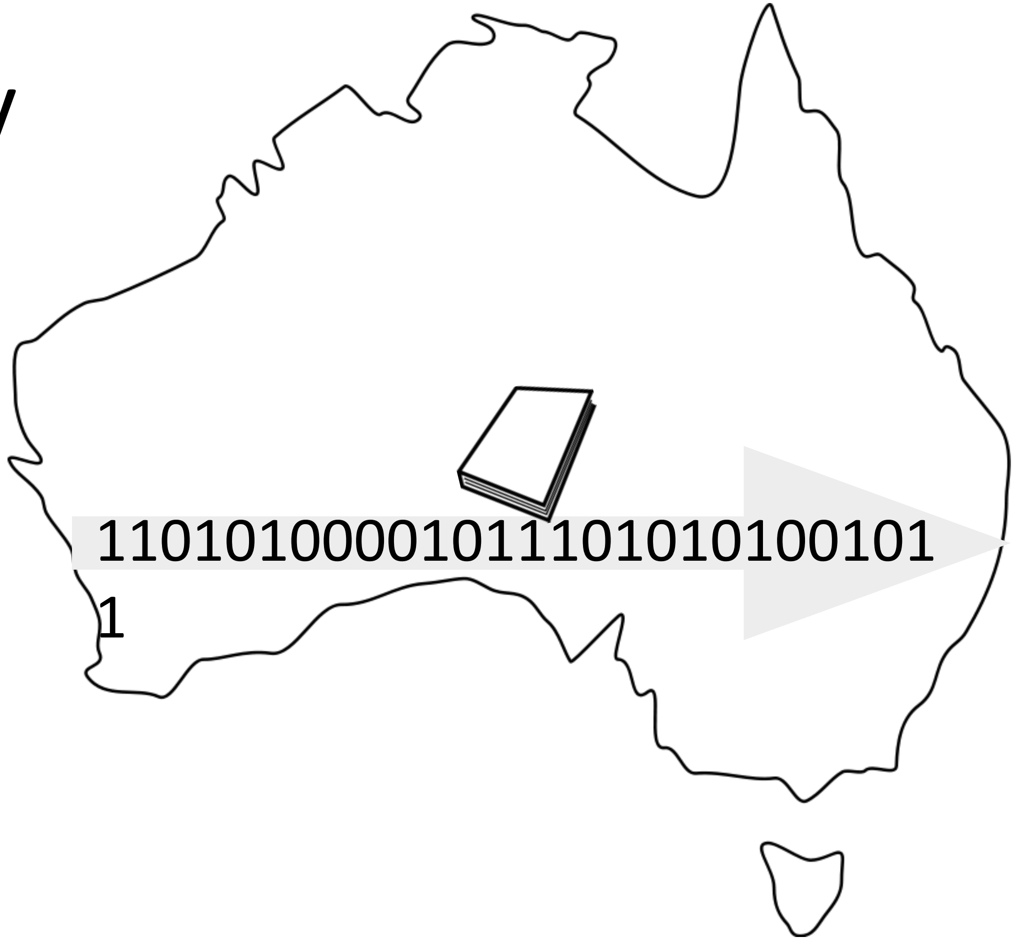
  R=40 Mbps, D=50 ms

  BD = $40 \times 10^6 \times 50 \times 10^{-3}$ bits

  = 2000 Kbit

  = 250 KB

- That’s quite a lot of data in the network”!



Some food for thought… and a common exam question theme ;)

Think back to some of the examples of pre-internet communication tech…

Pick a technology (let’s use a horseback messenger) and then identify:

- What is its rate/bandwidth?
- What is its delay?
- What is the latency to send a message from one town to the other via this technology?
- What abstractions are used in this technology?
- How are messages transmitted? Addressed? Is there a forwarder?

Debrief

- What is the rate? □ Limited by rider carrying capacity
- What is the delay? -> The amount of time the rider takes to move between the towns