Hyperconverged Infrastructure

- Internet as a global system
- Seamless integration of compute, network and storage
- Performance vs. Layering
- New technologies
- New Applications

Subjects To Be Covered

- Software Defined Network
- Software Defined Storage
- Solid State Drives
- Non-Volatile Memory
- Virtual Machine + Docker Container
- Data Deduplication
- Key-Value Store

A Global System: Future Internet

- Data can be stored and accessed from any where on the earth (as long as they are parts of Internet)
- Internet consists of compute, storage and networking components
- Services are offered via Internet (where is end-to-end?)
- A new thinking and new design of Internet are required
- Most of Internet components become white-boxes

Review of Old Internet Architecture

- Internet in a Nutshell:
  - Internet service model
  - Fundamental issues in network design
- Basic Internet Architecture
  - "Hour-glass" architecture
  - IP datagram formats; UDP/TCP segment formats
  - IP addressing and routing protocols
- Internet Philosophy (and Design Principles)
  - "end-to-end" argument

What is a Network/Internet?

Compare Internet with

Postal Service and Telephone System

- **Various Key Pieces and Their Functions**
- **Services Provided**
- **How the pieces work together to provide services**

Service Perspective

Basic Services Provided

- Postal: deliver mail/package from people to people
  - First class, express mail, bulk rate, certified, registered, …
- Telephone: connect people for talking
  - You may get a busy dial tone
  - Once connected, consistently good quality, unless using cell phones
- Internet: transfer information between people/machines
  - Reliable connection-oriented or unreliably connectionless services!
  - You never get a busy dial tone, but things can be very slow!
  - You can't ask for express delivery (not at the moment at least!)

IP Service Model

- Packet-switching data network
  - shared infrastructure, statistical multiplexing!
  - each packet carries source and destination
  - "logical" network of networks, "overlaid" on top of various "physical networks, running TCP/IP protocol suite
- Best-effort delivery (unreliable service)
  - connectionless ("packet" or datagram-based)
  - packets may be lost, duplicated, delivered out of order
  - packets can be delayed for a long time
  - ……
- Global reachability
  - global addressing (public IPv4 and IPv6 addresses)
    - but firewalls, NATs, …
  - BGP network reachability announcement (next class!)

Fundamental Issues in Networking

- Naming/Addressing
  - How to find name/address of the party (or parties) you would like to communicate with
  - Address: byte-string that identifies a node
  - Types of addresses
    - Unicast: node-specific
    - Broadcast: all nodes in the network
    - Multicast: some subset of nodes in the network
- Routing/Forwarding: process of determining how to send packets towards the destination based on its address
  - Finding out neighbors, building routing tables

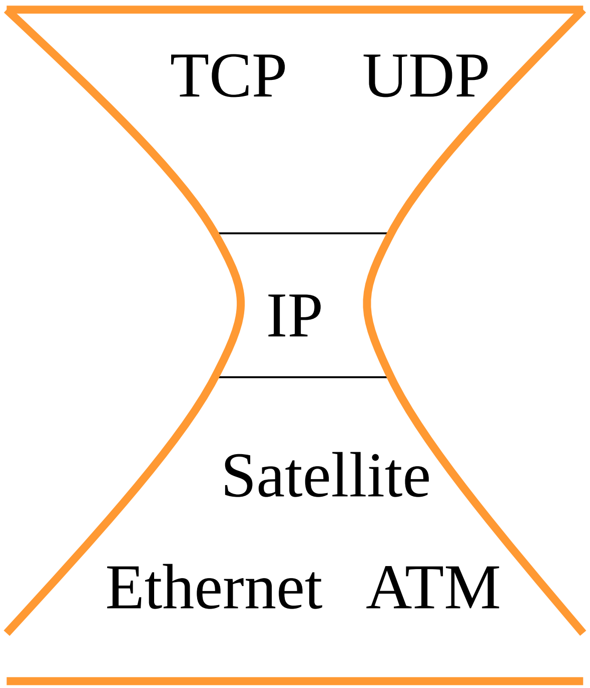
Fundamental Problems in Networking …

What can go wrong?

- Bit-level errors: due to electrical interferences
- Packet-level errors: packet loss due to buffer overflow/congestion
- Out of order delivery: packets may takes different paths
- Link/node failures: cable is cut or system crash
- Human configuration/operational errors
- Malicious attacks!

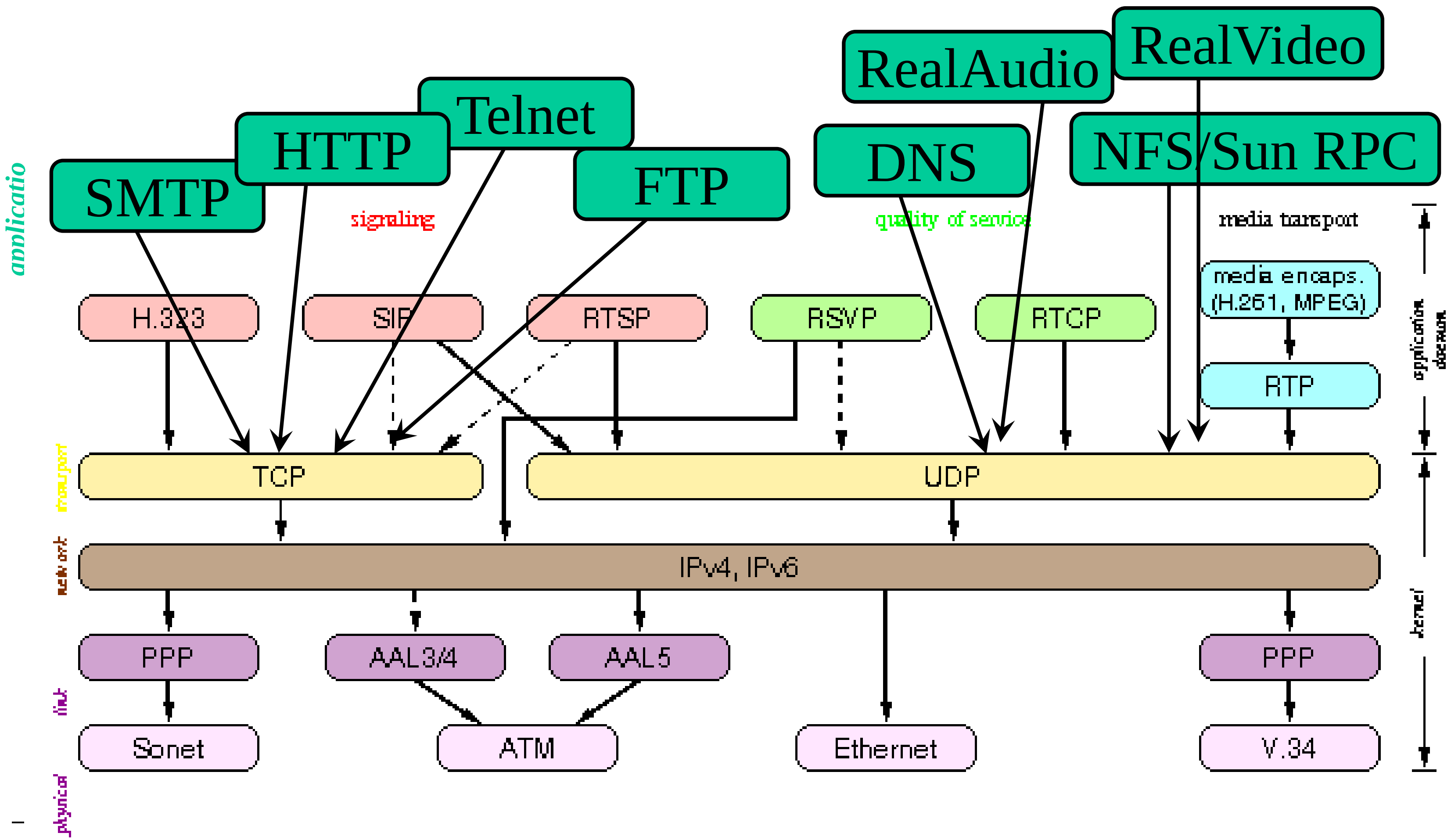
Internet Architecture

- packet-switched datagram network
- IP is the glue (network layer overlay)
- IP hourglass architecture
  - all hosts and routers run IP
- stateless architecture
  - no per flow state inside network

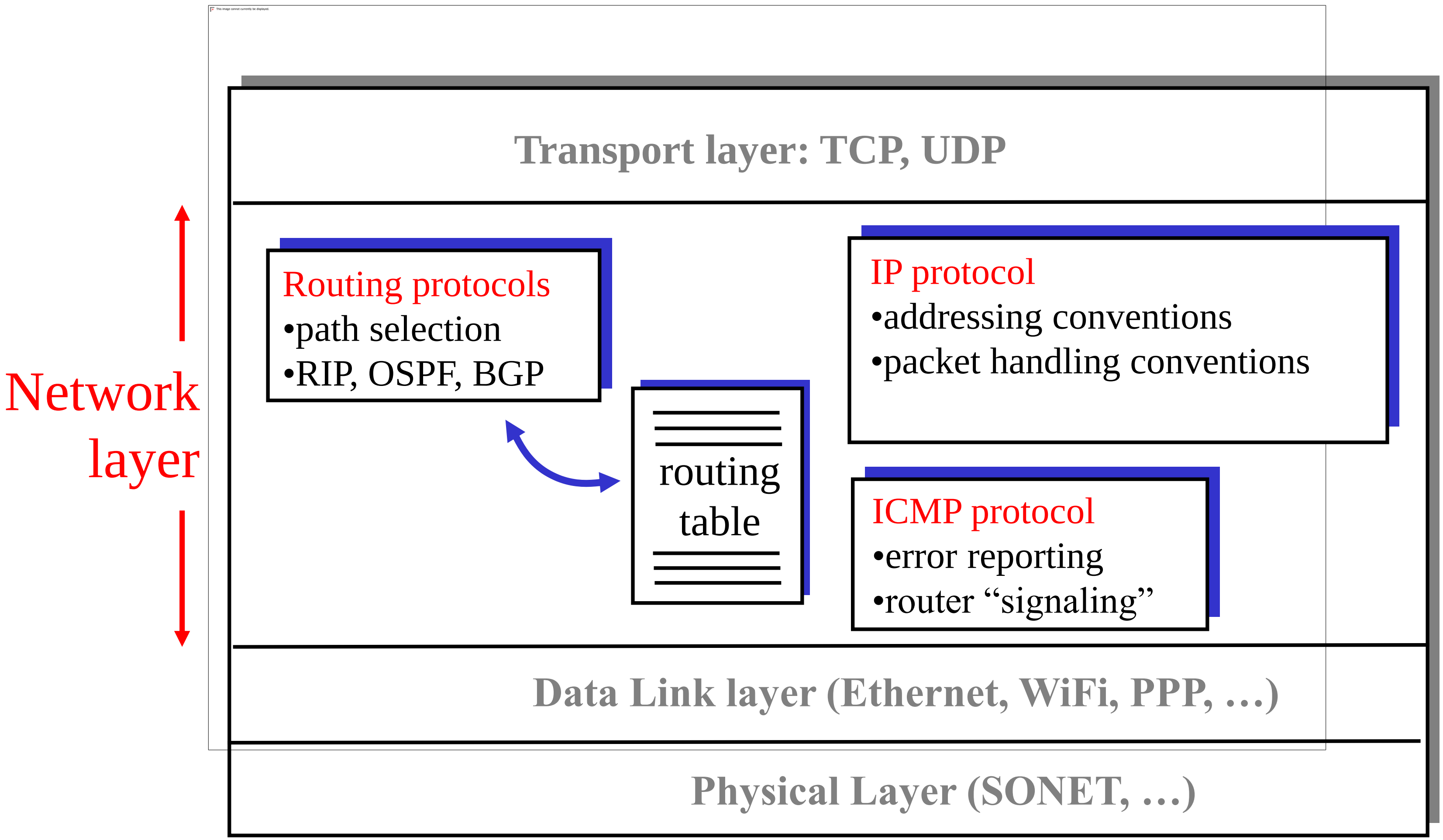


IP hourglass

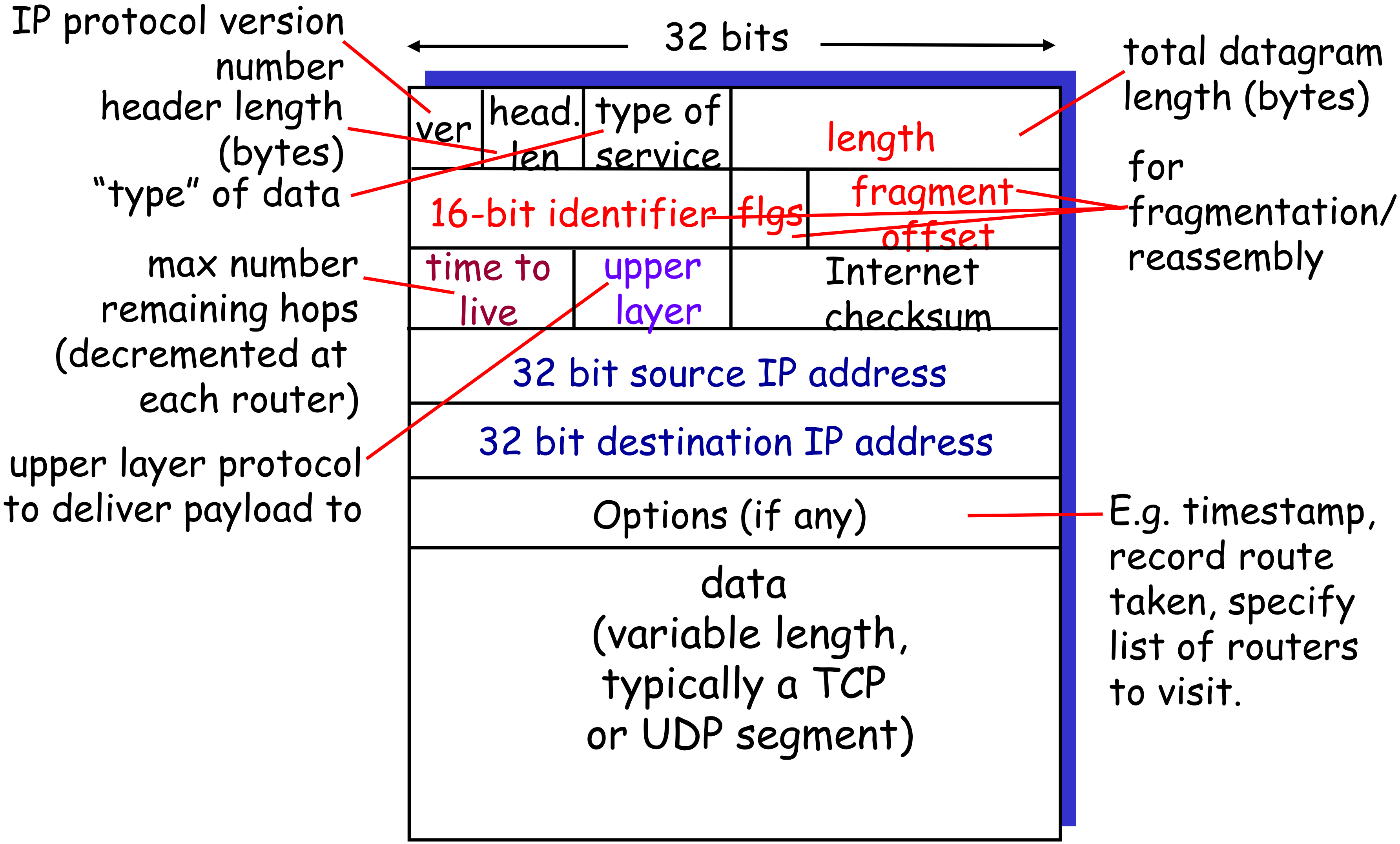
Internet Protocol "Zoo"



The Internet Network layer



IP Datagram Format



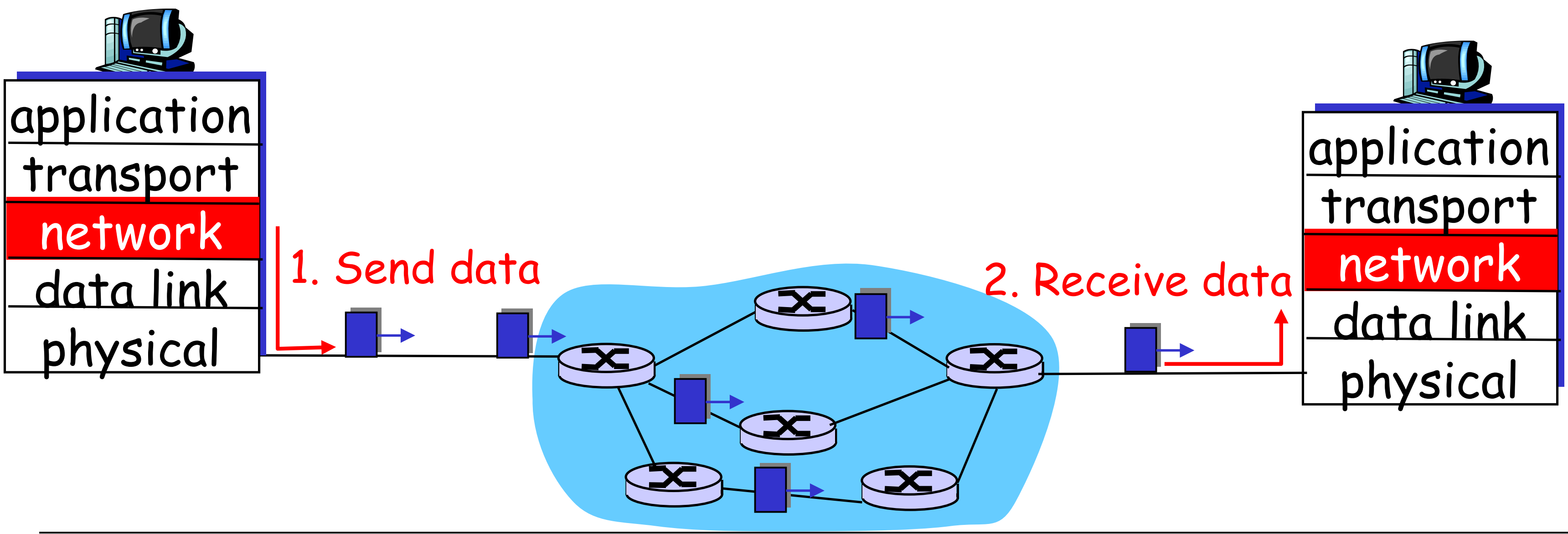
IP Addresses & Datagram Forwarding

- IPv4 Address
  - 32 bits
  - two-parts: network prefix and host parts
  - E.g., 128.101.33.101
    network prefix: 128.101.0.0/16

- Forwarding and IP address
  - forwarding based on network prefix
    - Delivers packet to the appropriate network
    - Once on destination network, direct delivery using host id
- IP destination-based next-hop forwarding paradigm
  - Each host/router has IP forwarding table
    - Entries like <network prefix, next-hop, output interface>

Datagram Networks: the Internet model

- routers: no state about end-to-end connections
  - no network-level concept of "connection"
- packets forwarded using destination host address
  - packets between same source-dest pair may take different paths, when intermediate routes change!



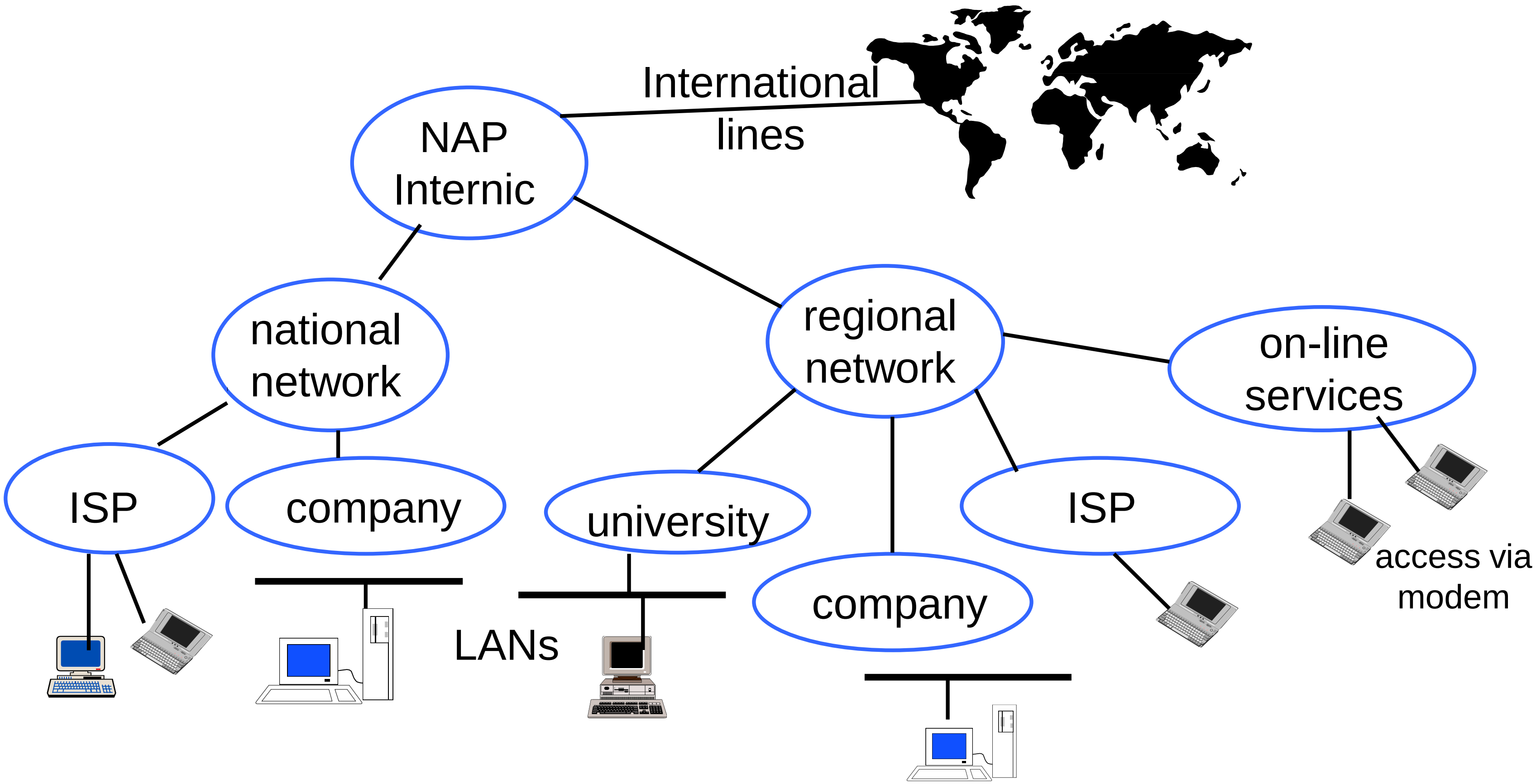
Routing in the Internet

- The Global Internet consists of Autonomous Systems (AS) interconnected with each other:
  - Stub AS: small corporation: one connection to other AS's
  - Multihomed AS: large corporation (no transit): multiple connections to other AS's
  - Transit AS: provider, hooking many AS's together

- Two-level routing:
  - Intra-AS: administrator responsible for choice of routing algorithm within network
  - Inter-AS: unique standard for inter-AS routing: BGP

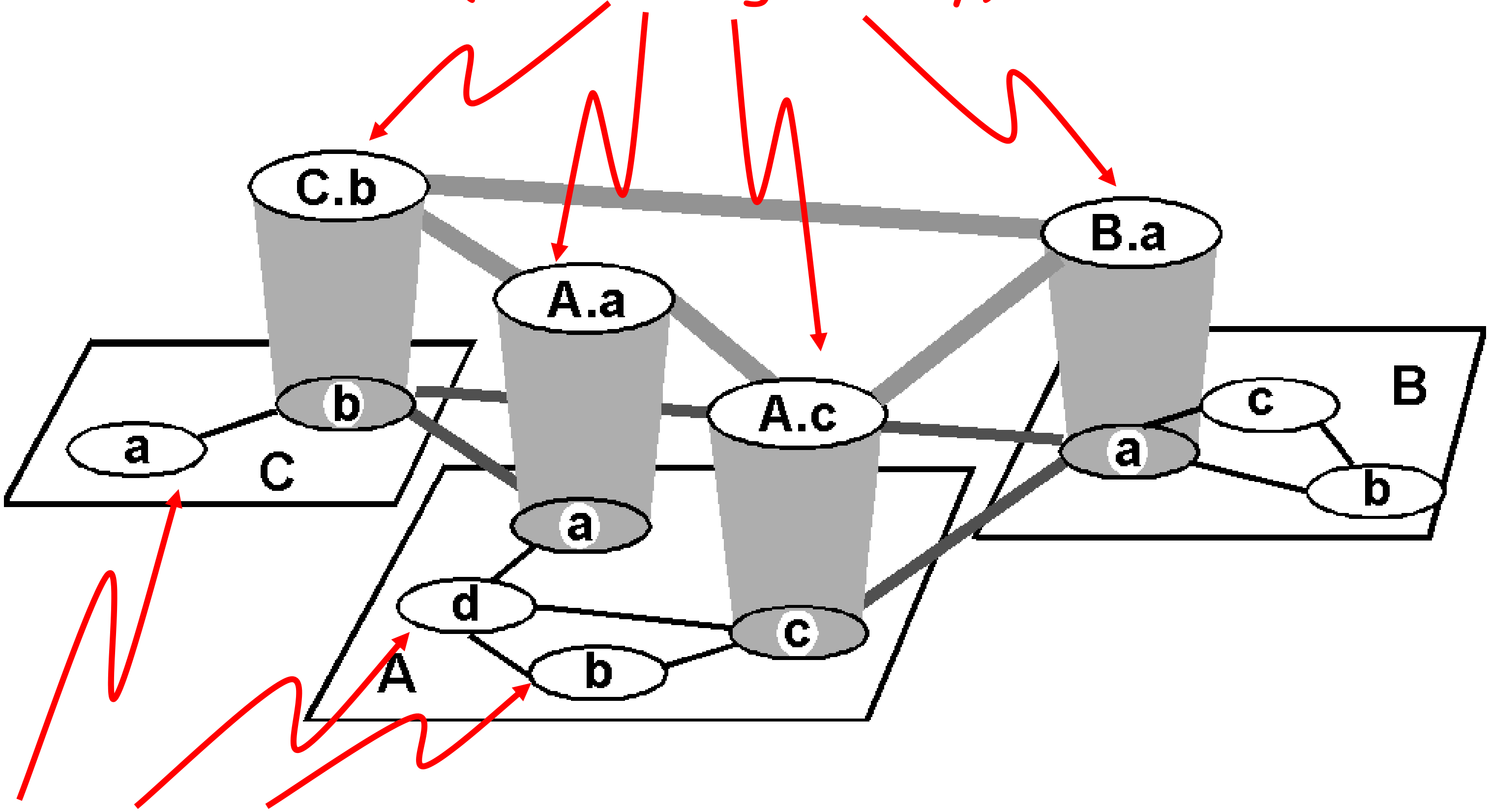
Internet Architecture

Internet: “networks of networks”!



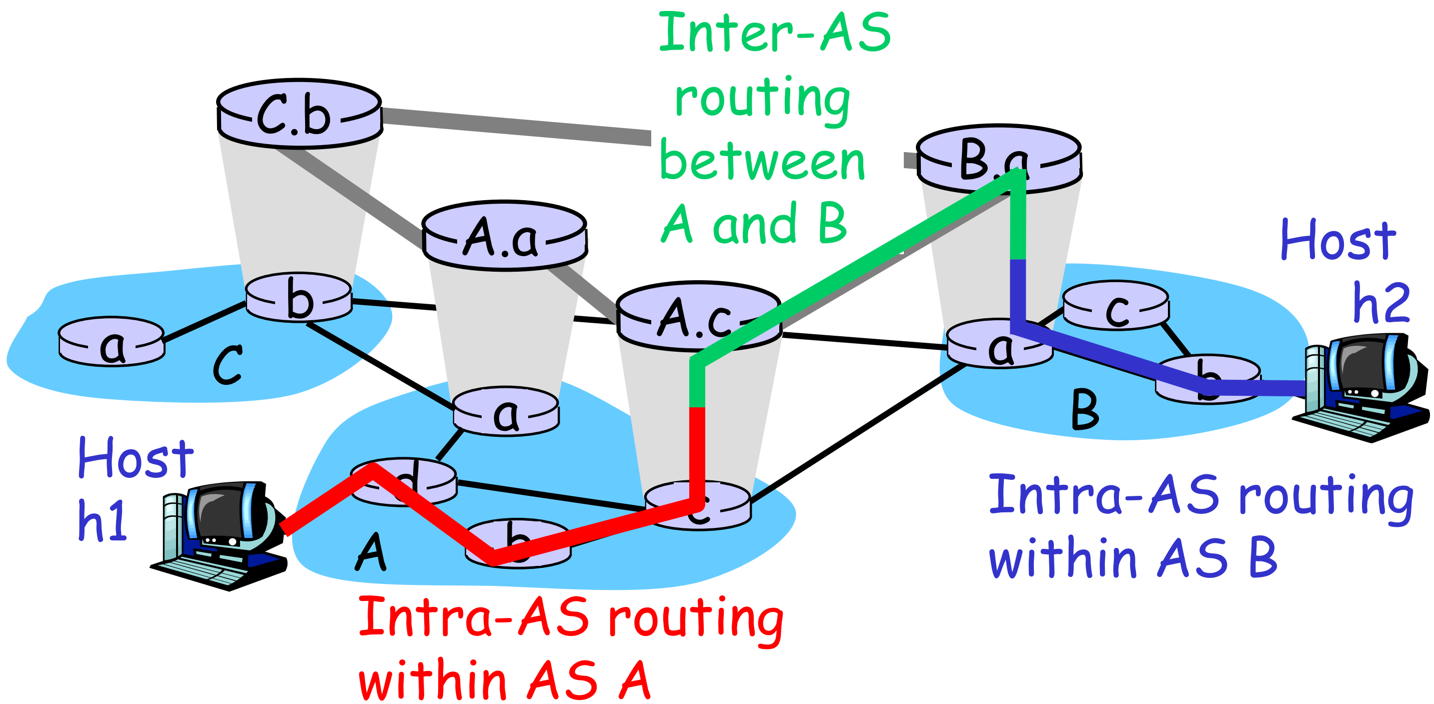
Internet AS Hierarchy

Intra-AS border (exterior gateway) routers



Inter-AS interior (gateway) routers

Intra-AS vs. Inter-AS Routing



Inter-AS Routing in the Internet: BGP

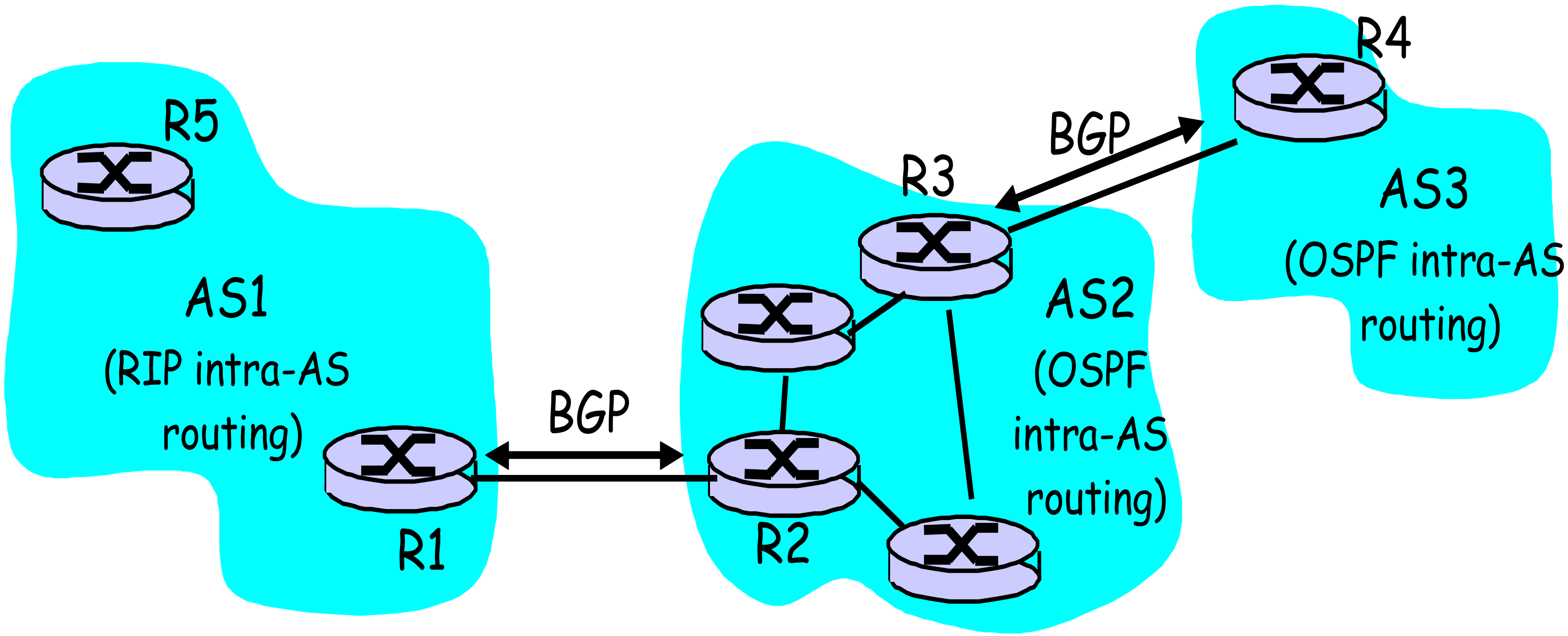


Figure 4.5.2-new2: BGP use for inter-domain routing

Internet Transport Protocols

TCP service:

- *connection-oriented:* setup required between client, server
- *reliable transport* between sender and receiver
- *flow control:* sender won't overwhelm receiver
- *congestion control:* throttle sender when network overloaded

UDP service:

- unreliable data transfer between sender and receiver
- does not provide: connection setup, reliability, flow control, congestion control

Both provide *logical communication* between app processes running on different hosts!

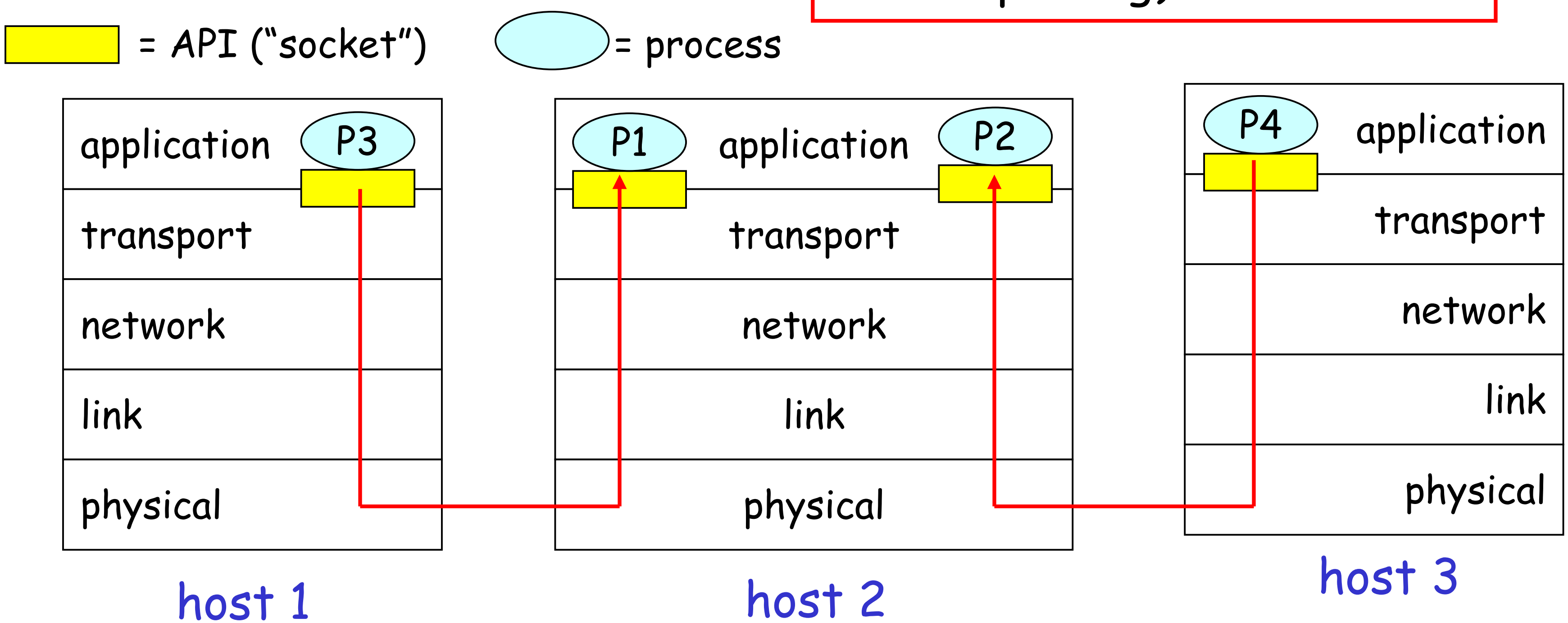
Multiplexing/Demultiplexing

Demultiplexing at rcv host:

delivering received segments to correct application process

Multiplexing at send host:

gathering data from multiple app processes, enveloping data with header (later used for demultiplexing)



UDP: User Datagram Protocol [RFC 768]

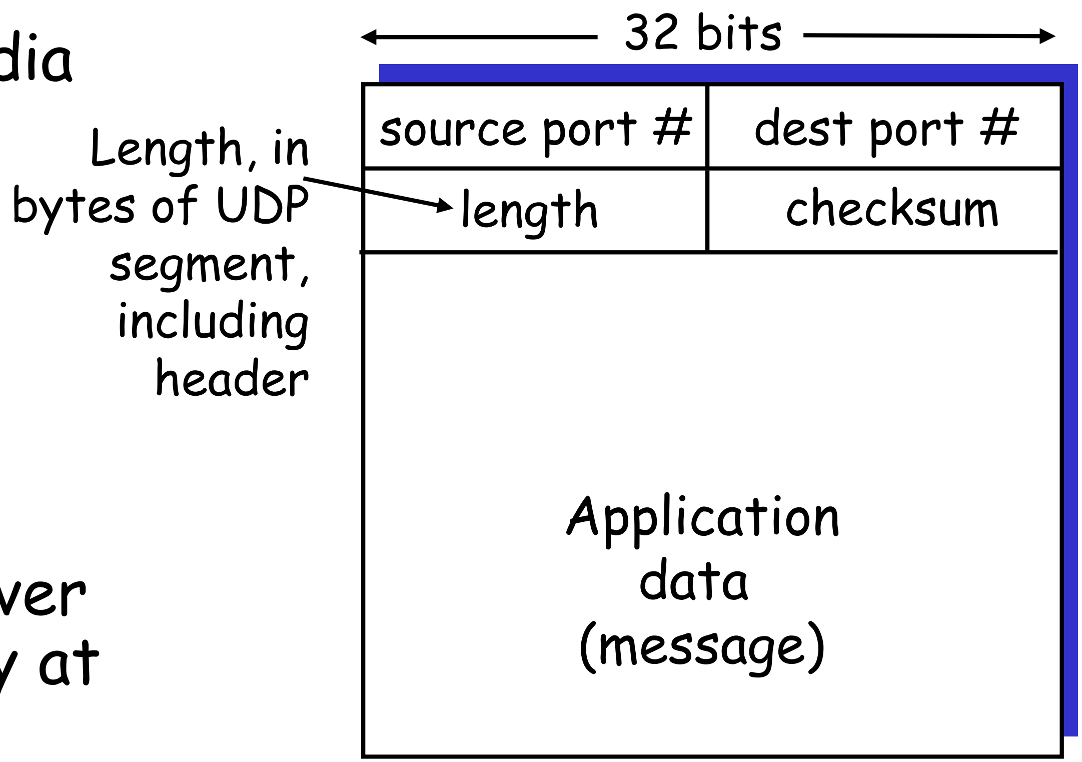
- "no frills," "bare bones" Internet transport protocol
- "best effort" service, UDP segments may be:
  - lost
  - delivered out of order to app
- *connectionless:*
  - no handshaking between UDP sender, receiver
  - each UDP segment handled independently of others

Why is there a UDP?

- no connection establishment (which can add delay)
- simple: no connection state at sender, receiver
- small segment header
- no congestion control: UDP can blast away as fast as desired

UDP (cont'd)

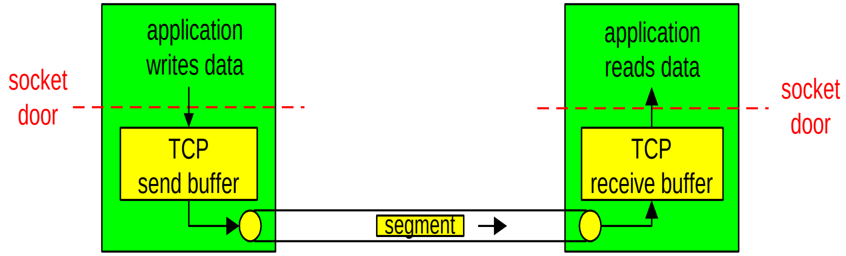
- often used for streaming multimedia apps
  - loss tolerant
  - rate sensitive
- other UDP uses
  - DNS
  - SNMP
- reliable transfer over UDP: add reliability at application layer
  - application-specific error recovery!



UDP segment format

TCP: Overview

- point-to-point:
  - one sender, one receiver
- reliable, in-order *byte steam:*
  - no "message boundaries"
- pipelined:
  - TCP congestion and flow control set window size
- *send & receive buffers*



- full duplex data:
  - bi-directional data flow in same connection
  - MSS: maximum segment size
- connection-oriented:
  - handshaking (exchange of control msgs) init's sender, receiver state before data exchange
- flow controlled:
  - sender will not overwhelm receiver

TCP Segment Structure

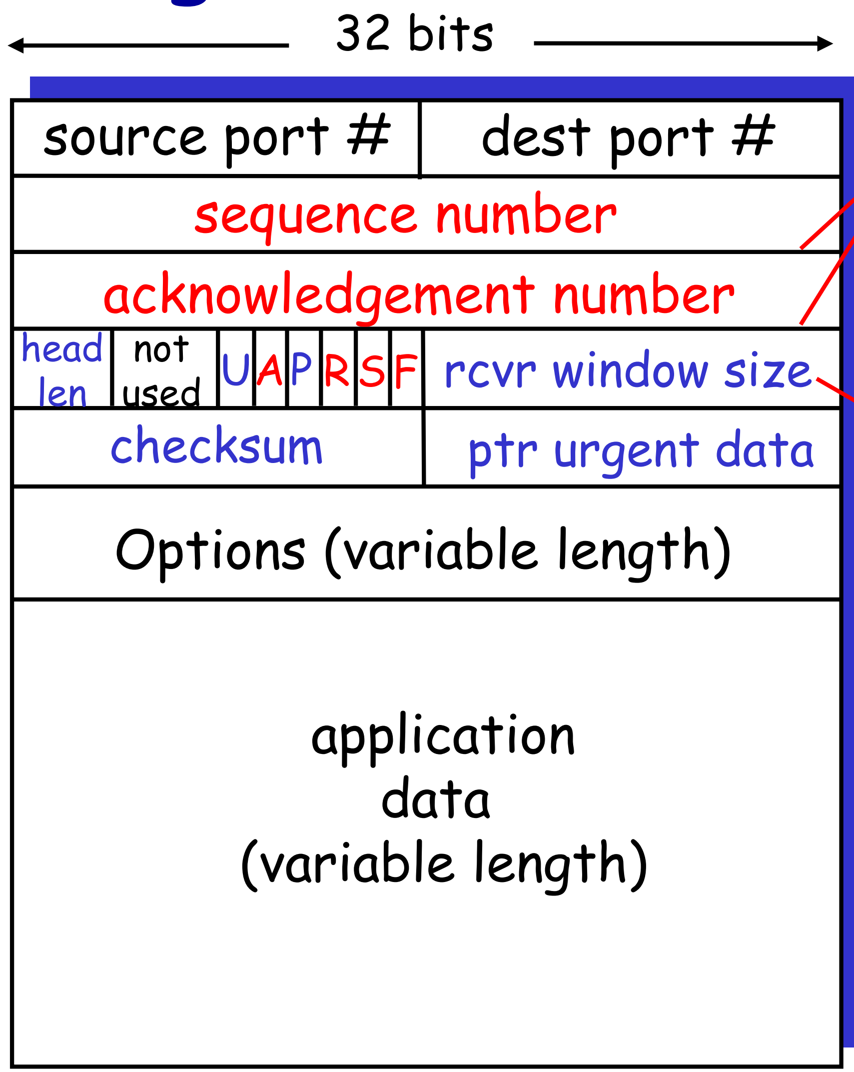
URG: urgent data (generally not used)

ACK: ACK # valid

PSH: push data now (generally not used)

RST, SYN, FIN: connection estab (setup, teardown commands)

Internet checksum (as in UDP)



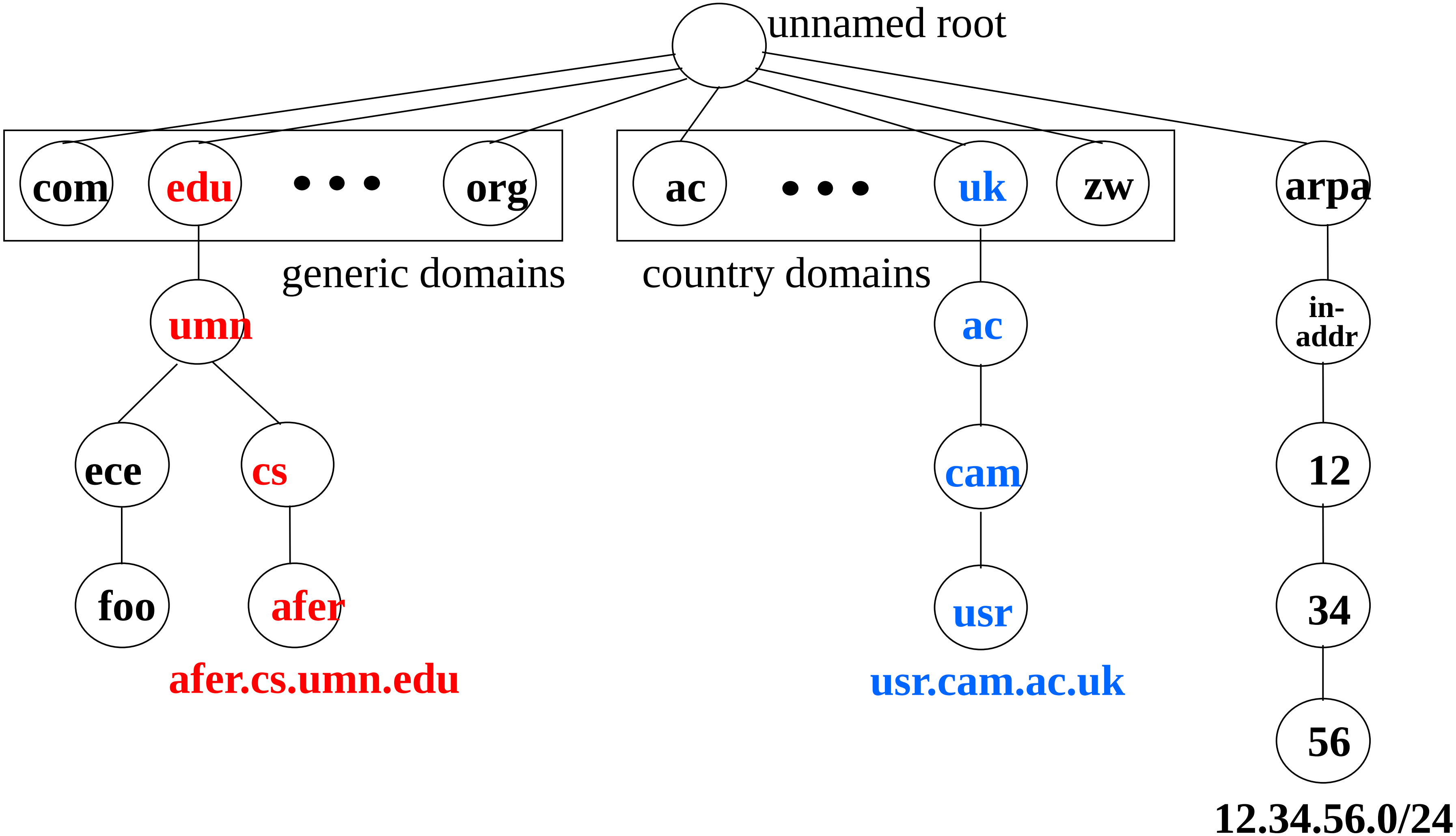
counting by bytes of data (not segments!)

bytes rcvr willing to accept

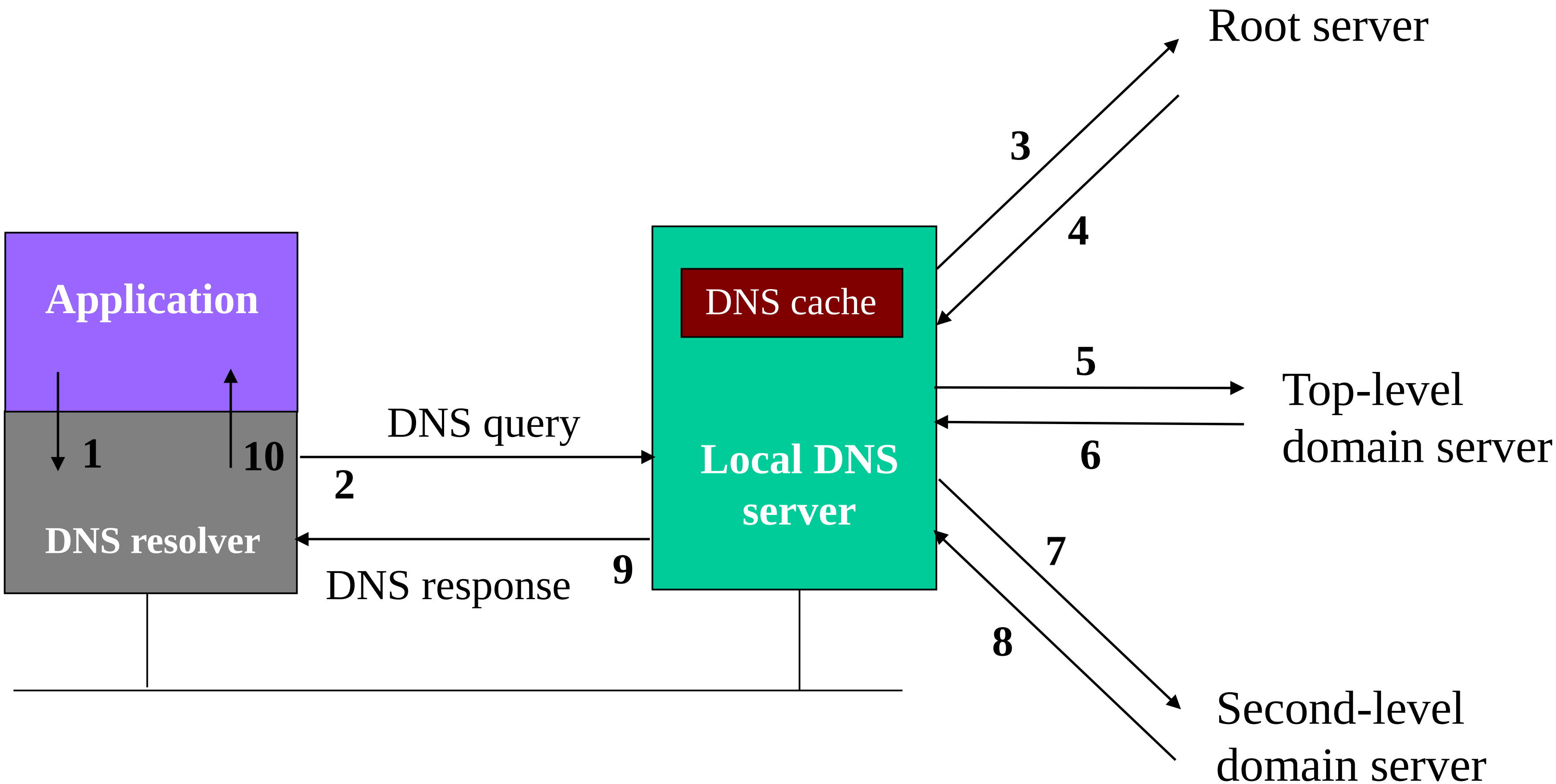
Domain Name System (DNS)

- 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.foo.com"
- 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



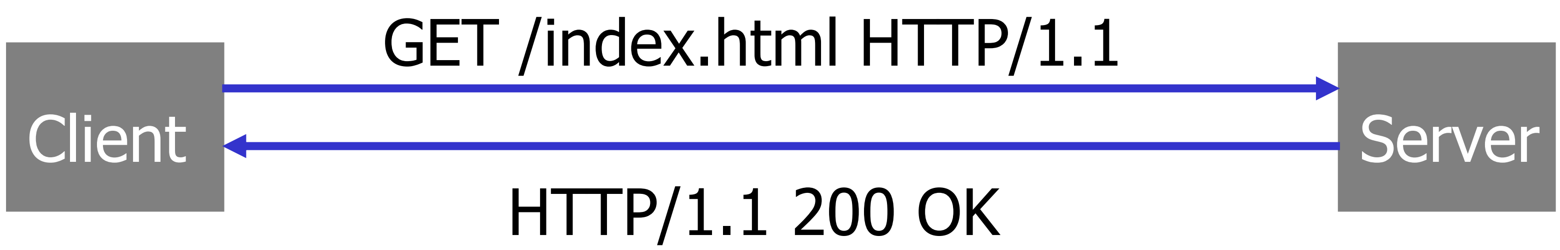
DNS Resolver and Local DNS Server



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

Application-Layer Protocols

- Messages exchanged between applications
  - Syntax and semantics of the messages between hosts
  - Tailored to the specific application (e.g., Web, e-mail)
  - Messages transferred over transport connection (e.g., TCP)
- Popular application-layer protocols
  - Telnet, FTP, SMTP, NNTP, HTTP, …

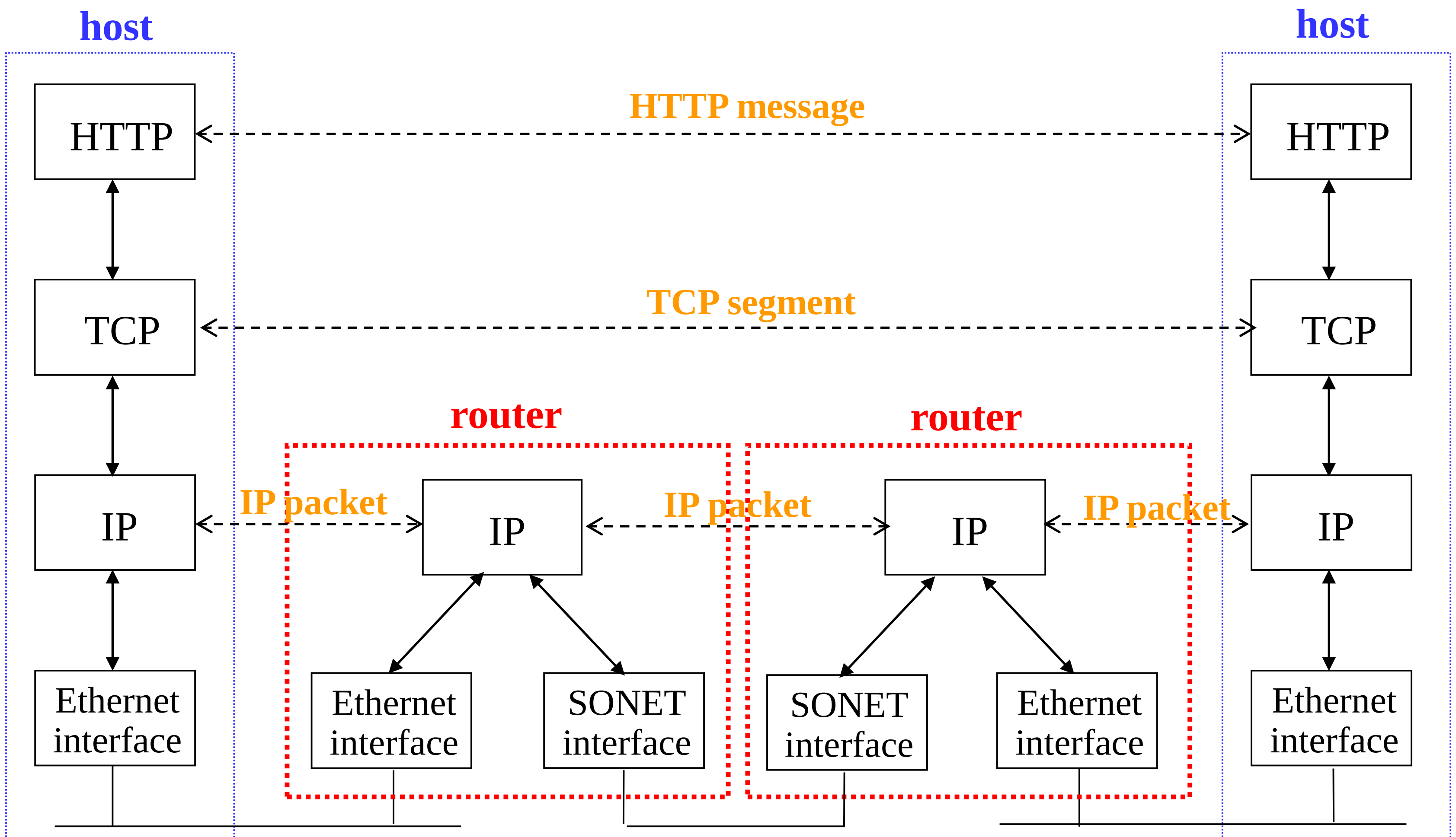


Example: Many Steps in Web Download

<u>Sources of variability of delay</u>

- Browser cache hit/miss, need for cache revalidation
- DNS cache hit/miss, multiple DNS servers, errors
- Packet loss, high RTT, server accept queue
- RTT, busy server, CPU overhead (e.g., CGI script)
- Response size, receive buffer size, congestion
- … downloading embedded image(s) on the page

IP Suite: End Hosts vs. Routers



This course focuses on the routers…

Happy Routers Make Happy Packets

- Routers forward packets
  - Forward incoming packet to outgoing link
  - Store packets in queues
  - Drop packets when necessary
- Routers compute paths
  - Routers run routing protocols
  - Routers compute forwarding tables
- A famous quotation from RFC 791
  - "A name indicates what we seek.
    An address indicates where it is.
    A route indicates how we get there."
    -- Jon Postel

Internet Philosophy and Design Principles

Architecture: the big picture

Goals:

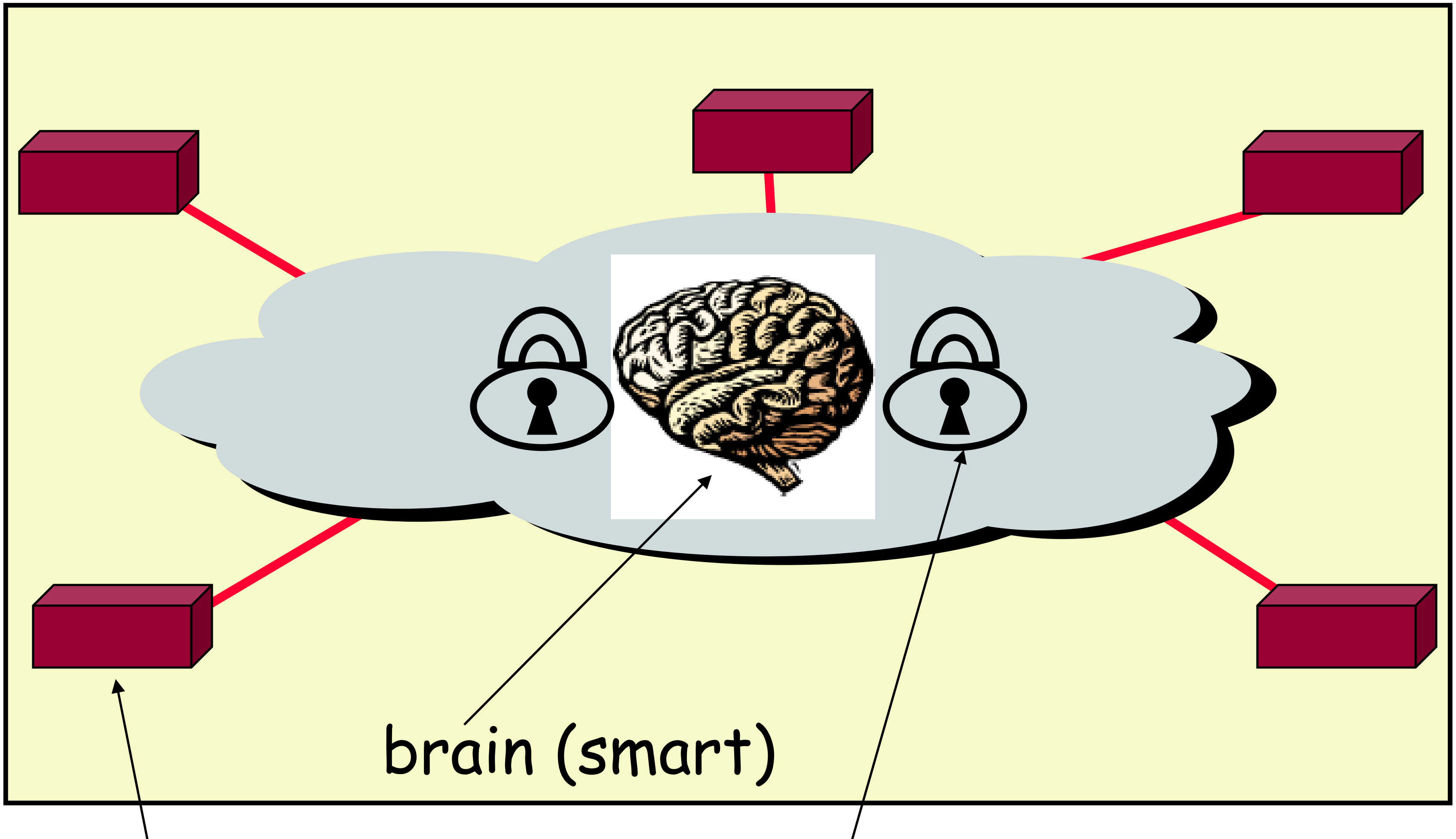
- identify, study principles that can guide network architecture
- "bigger" issues than specific protocols or implementation tricks
- *synthesis:* the *really* big picture

Key questions

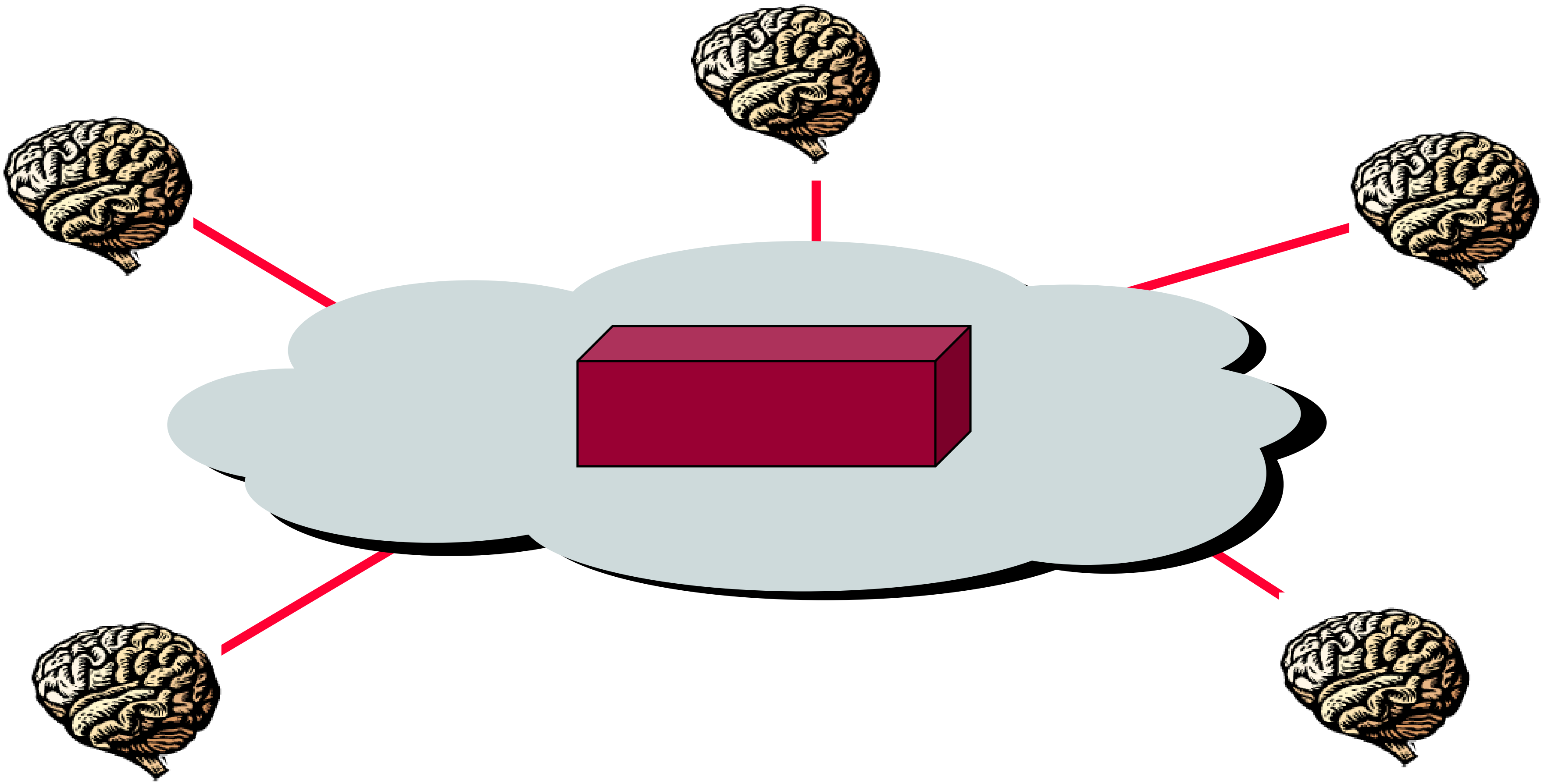
- How to decompose the complex system functionality into protocol layers?
- Which functions placed *where* in network, at which layers?
- Can a function be placed at multiple levels ?

Answer these questions in context of Internet, telephone network

Common View of the Telco Network



Common View of the IP Network



Readings: Saltzer84

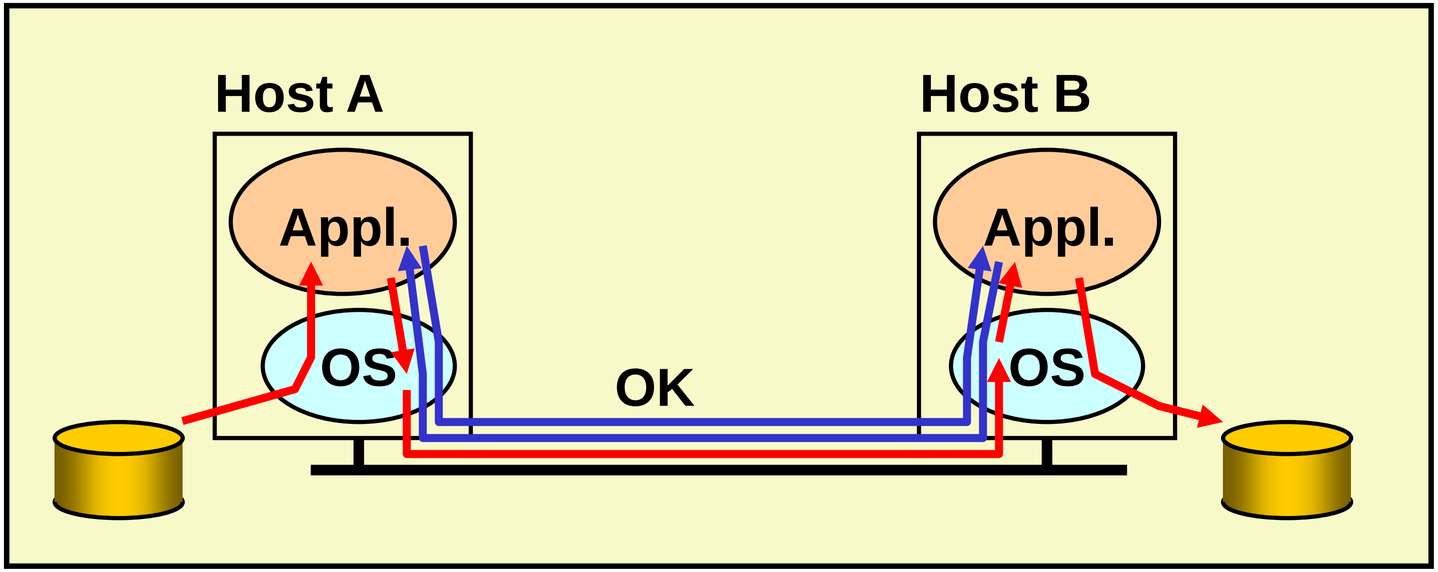
- End-to-end argument
  - Better to implement functions close to application
  - … except when performance requires otherwise
- Why?
  - …
- What should be the "end" for network "functionalities", e.g., routing?
  - Router?
  - End host?
  - Enterprise edge?
  - Autonomous System?

Internet End-to-End Argument

According to [Saltzer84]:

- "…functions placed at the lower levels may be *redundant* or of *little value* when compared to the cost of providing them at the lower level…"
- "…sometimes an *incomplete* version of the function provided by the communication system (lower levels) may be useful as a *performance enhancement*…"
- This leads to a philosophy diametrically opposite to the telephone world of dumb end-systems (the telephone) and intelligent networks.

Example: Reliable File Transfer



- Solution 1: make each step reliable, and then concatenate them
- Solution 2: each step unreliable: end-to-end check and retry

Discussion

- Solution 1 not good enough!
  - what happens if the sender or/and receiver misbehave?
- so receiver has to do check anyway!
- Thus, full functionality can be entirely implemented at application layer; *no* need for reliability from lower layers

Discussion

Q: Is there any reason to implement reliability at lower layers?

A: Yes, but only to improve performance

- Example:
  - assume high error rate in network
  - reliable communication service at data link layer might help (why)?
  - fast detection /recovery of errors

E2E Argument: Interpretations

- One interpretation:
  - A function can only be completely and correctly implemented with the knowledge and help of the applications *standing at the communication endpoints*
- Another: (more precise…)
  - a system (or subsystem level) should consider only functions that can be *completely and correctly* implemented within it.
- Alternative interpretation: (also correct …)
  - Think twice before implementing a functionality that you believe that is useful to an application at a lower layer
  - If the application can implement a functionality correctly, implement it a lower layer *only* as a performance enhancement

Internet & End-to-End Argument

- network layer provides one simple service: best effort datagram (packet) delivery
- transport layer at network edge (TCP) provides end-end error control
  - performance enhancement used by many applications (which could provide their own error control)
- all other functionalities …
  - all application layer functionalities
  - network services: DNS

  implemented at application level

Internet & End-to-End Argument

Discussion: congestion control, "error" control, flow control: why at transport, rather than link or application layers?

- Claim: common functions should migrate down the stack
  - Everyone shares same implementation: no need to redo it (reduces bugs, less work, etc…)
  - Knowing everyone is doing the same thing, can help
- congestion control too important to leave up to application/user: true but hard to police
  - TCP is "outside" the network; compliance is "optional"
  - We do this for fairness (but realize that people could cheat)
- Why error control, flow control in TCP, not (just) in app

Trade-offs

- application has more information about the data and semantics of required service (e.g., can check only at the end of each data unit)
- lower layer has more information about constraints in data transmission (e.g., packet size, error rate)
- *Note:* these trade-offs are a direct result of layering!

End-to-End Argument: Critical Issues

- end-to-end principle emphasizes:
  - *function placement*
  - *correctness, completeness*
  - *overall system costs*
- Philosophy: if application can do it, don't do it at a lower layer -- application best knows what it needs
  - add functionality in lower layers iff (1) used by and improves performances of many applications, (2) does not hurt other applications
- allows *cost-performance* tradeoff

End-to-End Argument: Discussion

- end-end argument emphasizes correctness & completeness, but *not*
  - complexity: is complexity at edges result in a "simpler" architecture?
  - evolvability, ease of introduction of new functionality: ability to evolve because easier/cheaper to add new edge applications than change routers?
  - technology penetration: simple network layer makes it "easier" for IP to spread everywhere

Summary: End-to-End Arguments

- If the application can do it, don't do it at a lower layer -- anyway the application knows the best what it needs
  - add functionality in lower layers iff it is (1) used and improves performances of a large number of applications, and (2) does not hurt other applications
- Success story: Internet
  - But …

Next Week

- Read the required readings:
  - Internet design philosophy: Clark88,
    - also [Clark:Tussle] and [CerfKahn] if you have time
  - Cisco BGP Tutorial and [Huston99]
  - no need to submit reviews, but use your brain!
- Questions for you to think about:
  - What are the "architectural" advantages of Internet, and also its limitations?
  - If you can redesign it, how would you do it?