Romain Fontugne

2023 Fall Semester

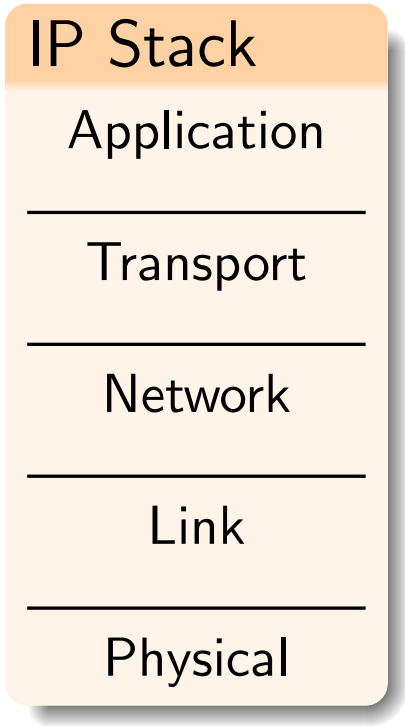
Information Network Systems

The Application Layer

Last lecture:

The transport layer

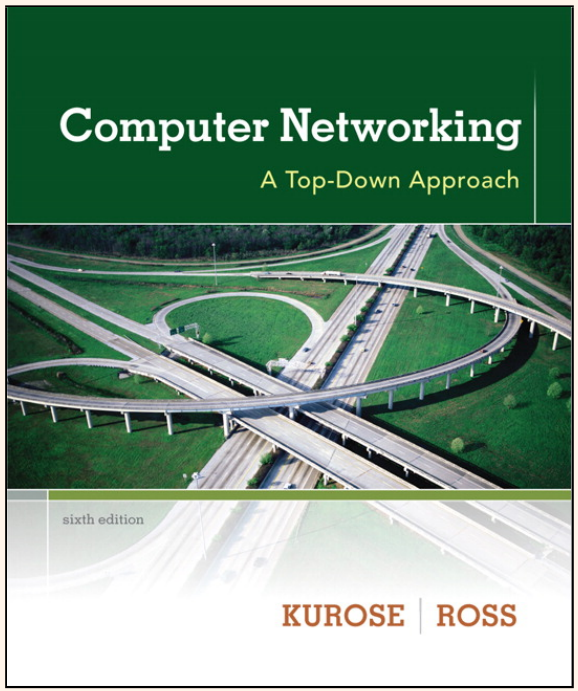
- Multiplexing / Demultiplexing
- UDP
  - Connection-less
  - Best effort
- TCP
  - Connection oriented
  - Reliable communication



Today's Lecture: Application layer

1. Principles of Network Applications

2. Protocols
   - HTTP
   - Email: SMTP, POP3, IMAP
   - DNS
   - FTP
   - P2P Applications



- Chapter 2

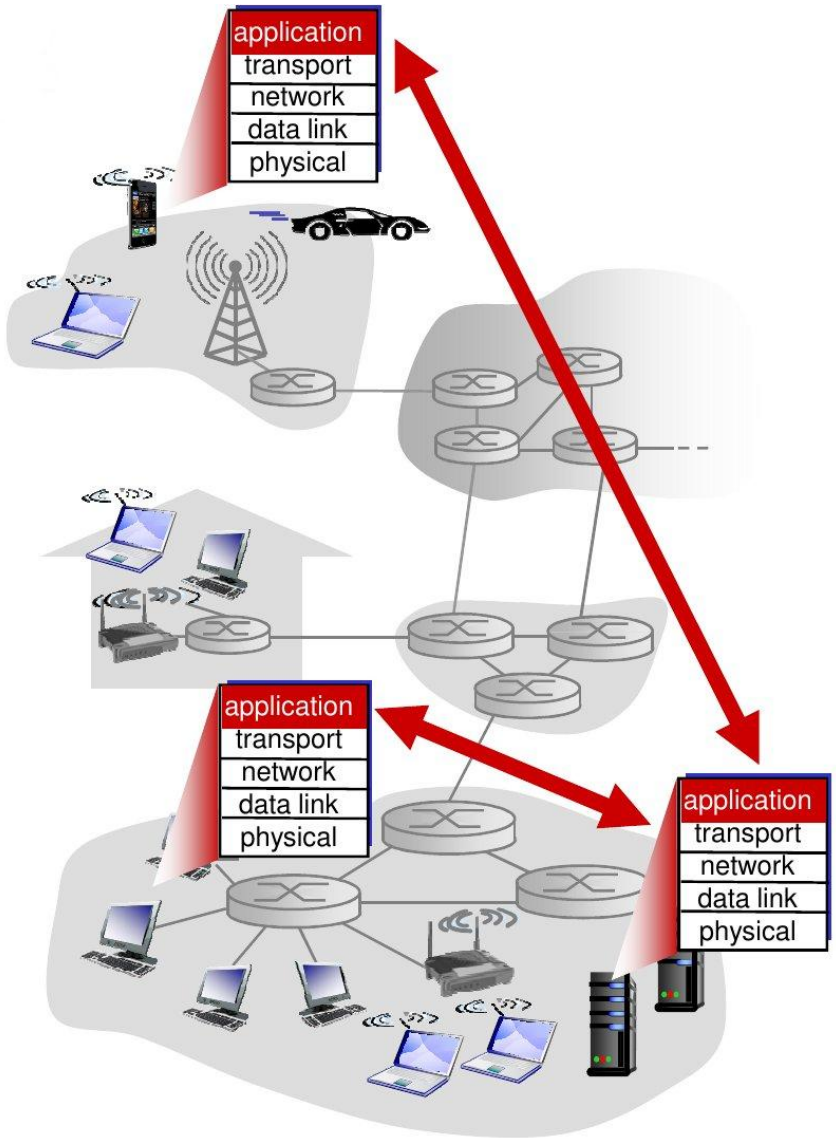
Creating a Network Application

Application that

- run on (different) end systems
- communicate over network
- e.g., web server software communicates with browser software

No need to write software for network-core devices

- network-core devices do not run user applications
- data transport is done by lower level protocols



Application Architectures

Possible structure of applications:

- client-server
- peer-to-peer (P2P)

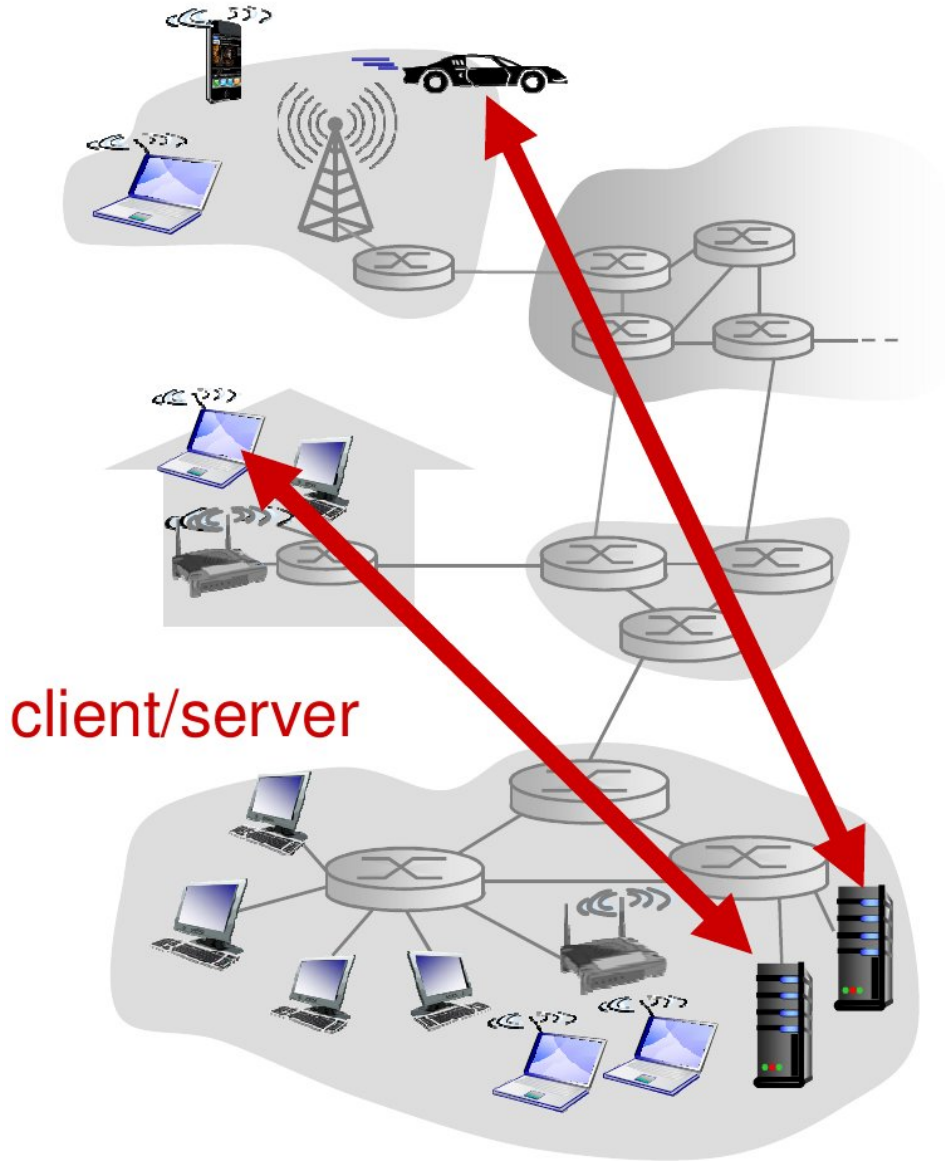
Client-Server Architecture

Server:

- always-on host
- permanent IP address
- data centers for scaling

Clients:

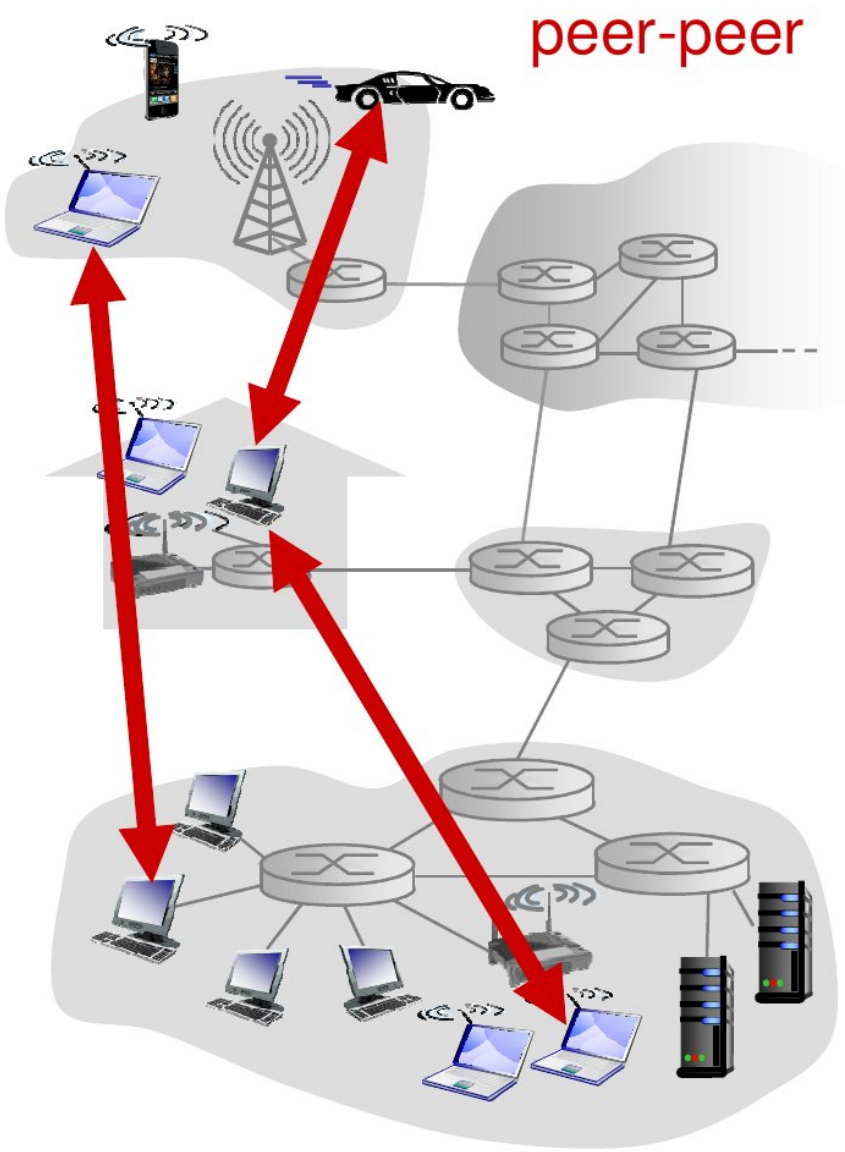
- communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other



P2P Architecture

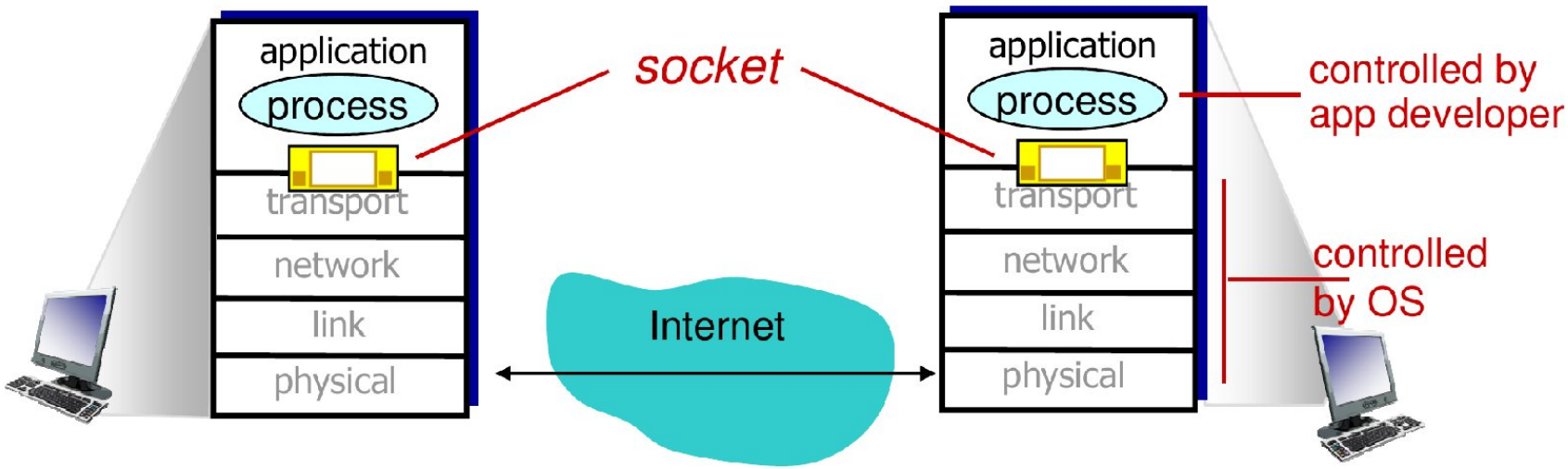
P2P

- no always-on server
- arbitrary end systems directly communicate
- peers request service from other peers, provide service in return to other peers
  - **self scalability** – new peers bring new service capacity, as well as new service demands
- peers are intermittently connected and change IP addresses
  - complex management



Sockets

- Two applications communicate via sockets
- Interface between application and network
- Identified by IP address and port number
- The application has little control (and trouble) with the transport-layer



Application Layer

Application layer protocols define:

- Types of messages exchanged:
  - e.g., request, response
- Message syntax:
  - what fields in messages & how fields are delineated
- Message semantics:
  - meaning of information in fields
- Rules for when and how processes send & respond to messages

- Open protocols:
  - defined in RFCs
  - allows for interoperability
  - e.g., HTTP, SMTP
- Proprietary protocols:
  - e.g., Skype

What transport service does an app need?

Data integrity

- Some apps (e.g. file transfer, web transactions) require 100% reliable data transfer
- Other apps (e.g. audio) can tolerate some loss

Timing

- Some apps (e.g. Internet telphony, interactive games) require low delay to be "effective"

Throughput

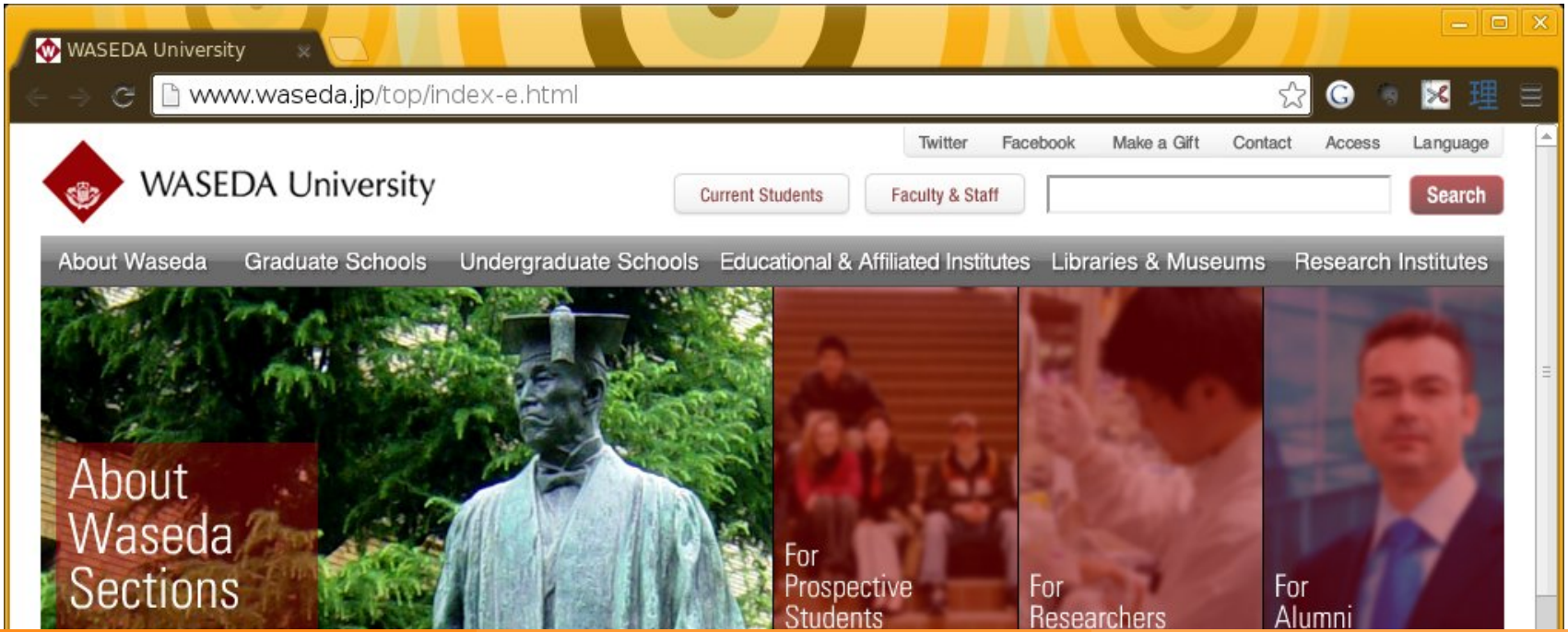
- Some apps (e.g. multimedia) require minimum amount of throughput to be "effective"
- Other apps make use of whatever throughput they get

HTTP: Hyper Text Transfer Protocol

Webpage and URL

- Webpages consist of a base HTML file and several referenced objects (e.g. JPEG image, Java applet, video, audio file,...)
- each object is addressable by a Uniform Resource Locator (URL), e.g.,

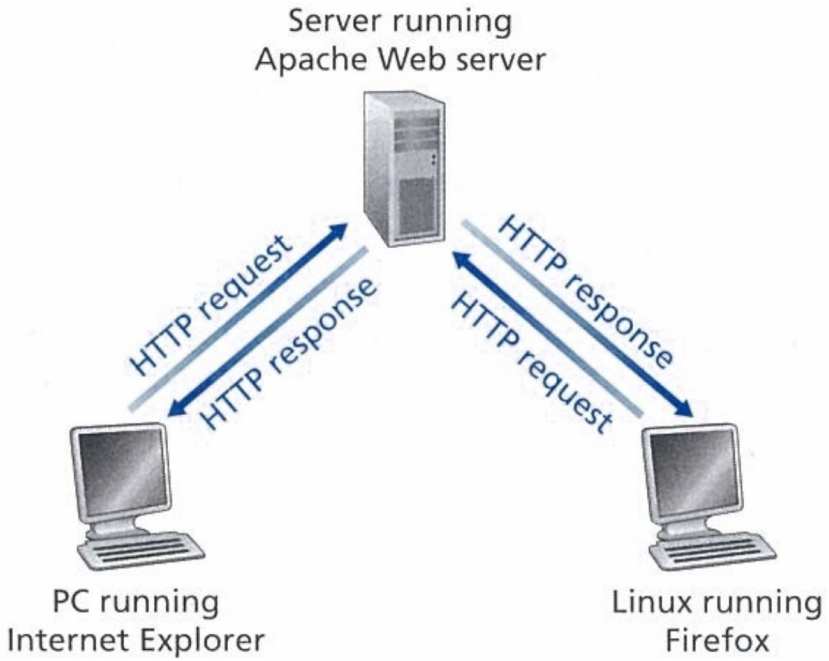
$$\underbrace{http://}_{\text{protocol}}\underbrace{www.someschool.edu}_{\text{host}}\underbrace{/someDept/pic.gif}_{\text{path name}}$$



HTTP overview

HTTP: Hyper Text Transfer Protocol

- Web's application layer protocol
- Client/server model:
  - Client:
    - browser that requests, receives, (using HTTP protocol) and "displays" Web objects
    - e.g. Firefox, Chrome, Safari, Internet Explorer
  - Server:
    - Web server sends (using HTTP protocol) objects in response to requests
    - e.g. Apache



HTTP overview

HTTP uses **TCP**:

- Server is constantly waiting for request on port 80
- Client initiates TCP connection (creates socket) to server
- Server accepts TCP connection from client
- HTTP messages (application-layer protocol messages) exchanged between browser (HTTP client) and Web server (HTTP server)
- TCP connection closed

HTTP connections

non-persistent HTTP

- at most one object sent over TCP connection (connection then closed)
- downloading multiple objects required multiple connections

persistent HTTP

- multiple objects can be sent over single TCP connection between client, server

Non-persistent HTTP

Example:

- User enters URL, http://www.someSchool.edu/someDept/index.html
- Webpage contains text and references to 10 jpeg images

1. HTTP client initiates connection with server www.someSchool.edu on port 80. A socket is created at both client and server
2. HTTP client sends an HTTP request message to the server indicating that client wants /someDept/index.html
3. HTTP server receives request message, forms response message containing requested object, and sends message
4. HTTP server tells TCP to close connection
5. HTTP client receives the response message containing html file, display/parse it and finds URLs of 10 images
6. For each image, the steps 1-4 are repeated

Persistent HTTP

non-persistent HTTP issues:

- requires 2 RTTs per object (TCP connection establishment and HTTP request/response)
- OS overhead for each TCP connection
- browsers often open parallel TCP connections to fetch referenced objects

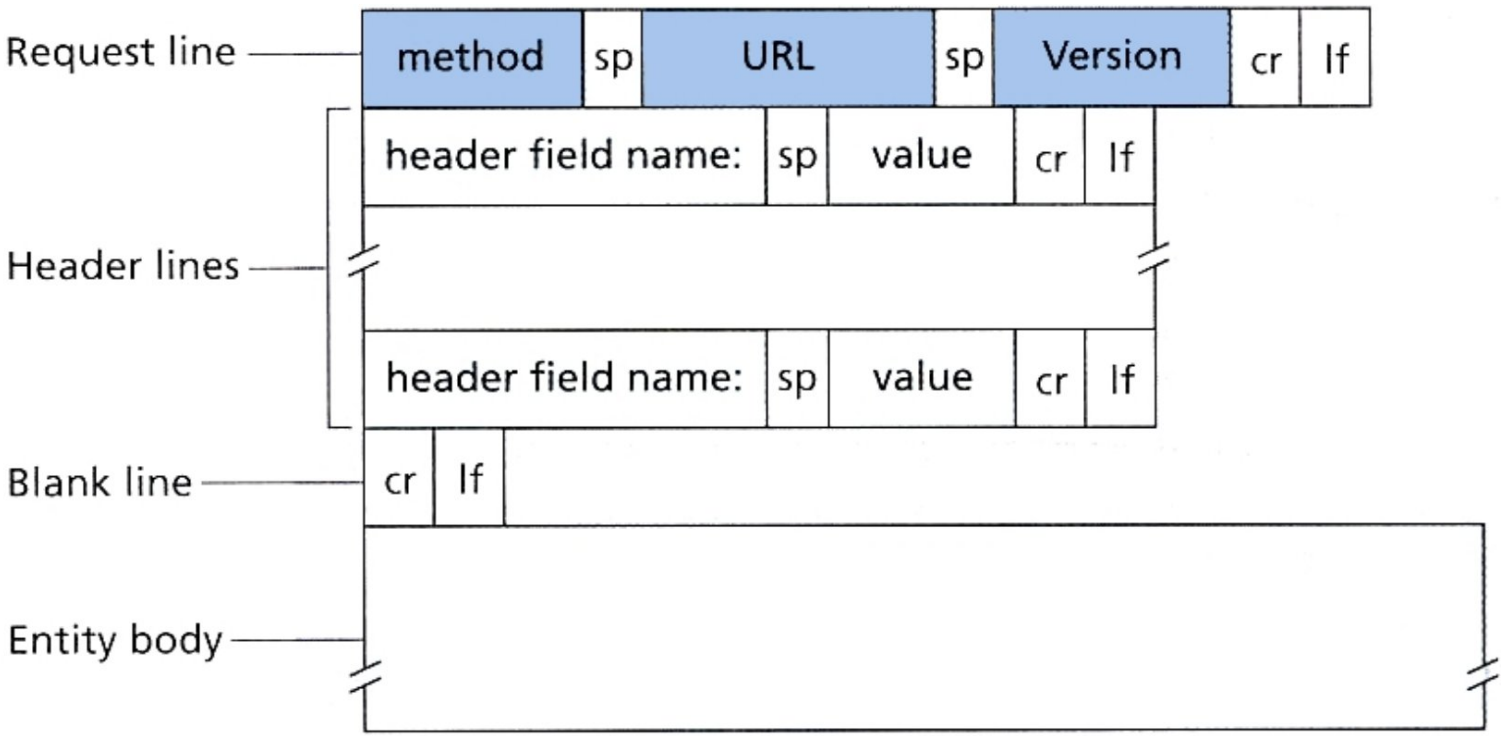
persistent HTTP:

- server leaves connection open after sending response
- subsequent HTTP messages between same client/server sent over open connection
- client sends requests as soon as it encounters a referenced object
- as little as one RTT for all the referenced objects

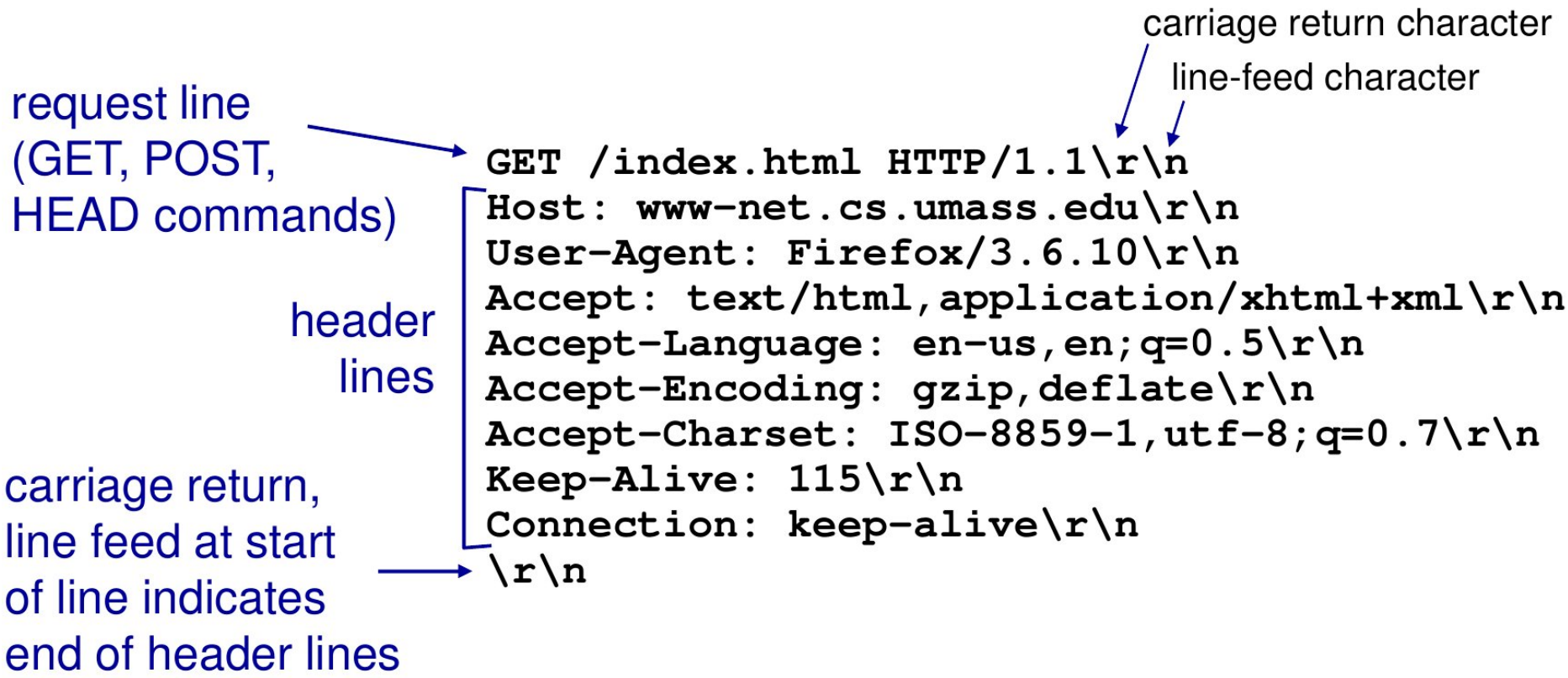
HTTP Request Message

HTTP request message

- ASCII text (human-readable format)
- Includes URL and method type (GET, POST, HEAD, PUT, DELETE)



Example: HTTP GET Request



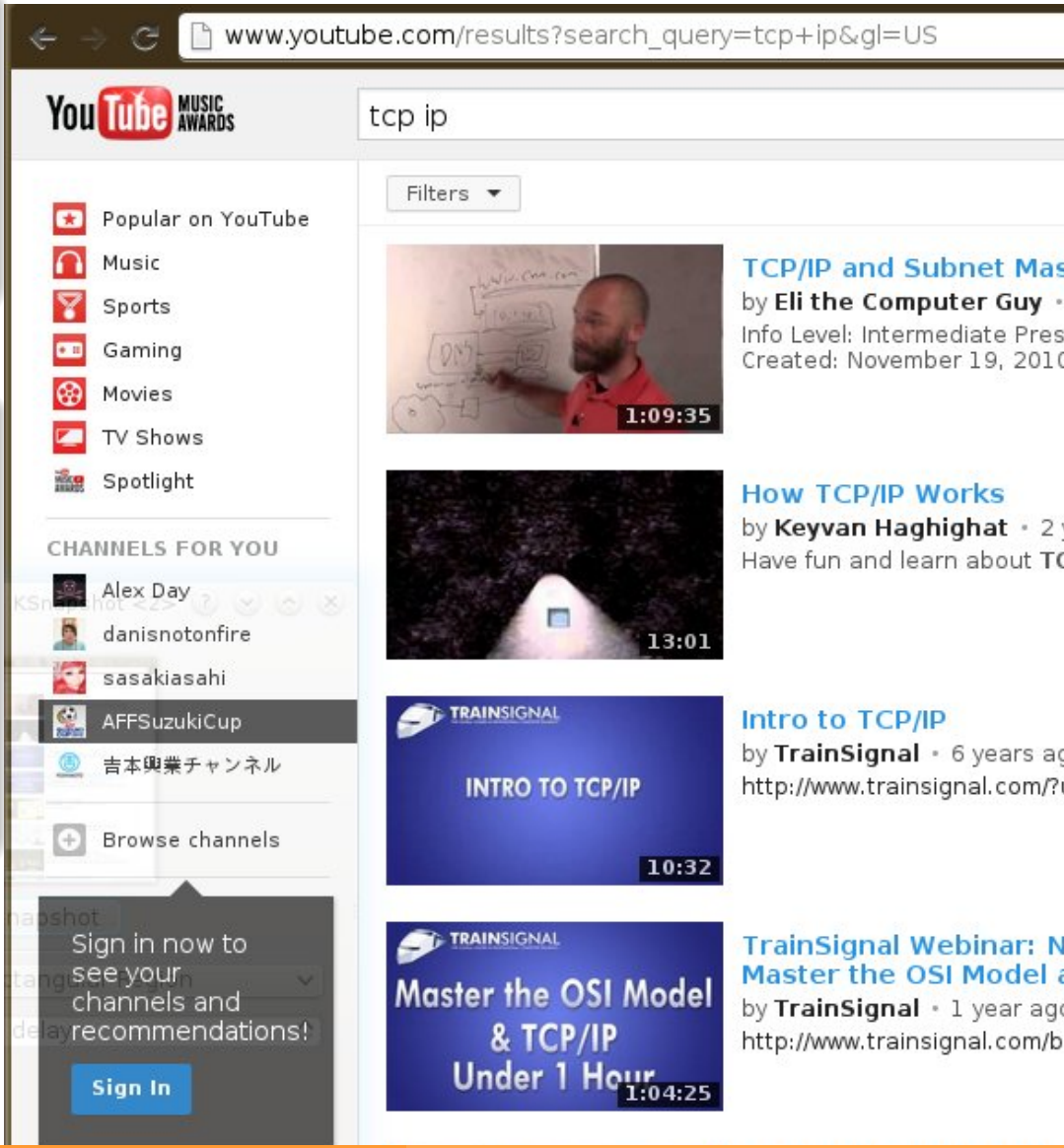
Uploading Form Input

GET method

- Input is added in the requested URL
- e.g. search on youtube

POST method

- Usually used with complex form input (e.g. long text, images, pdf)
- Input is uploaded to server in entity body



Method Types

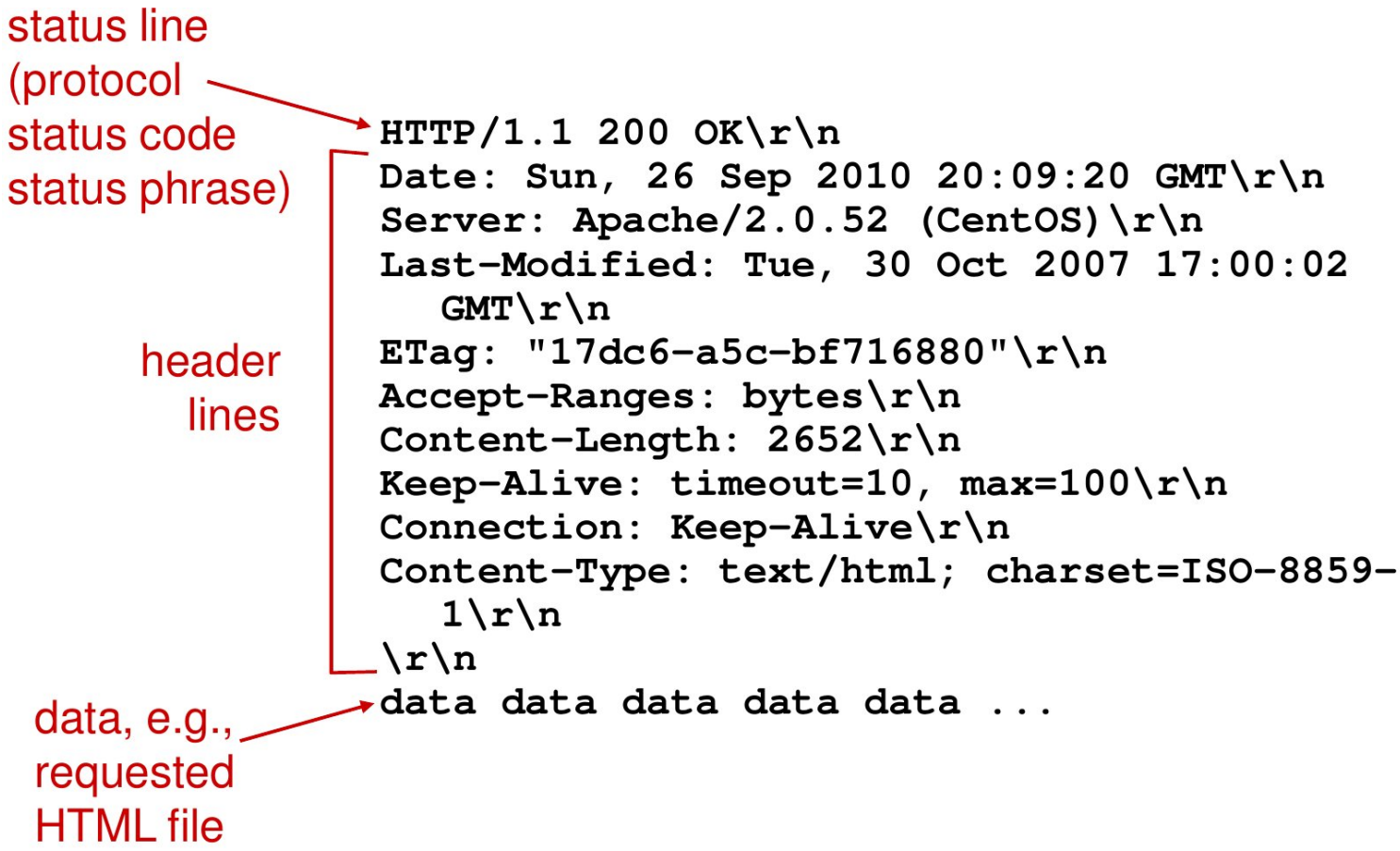
HTTP/1.1

- GET
  - Obtain object at specified address
- POST
  - Request of a webpage with specific input to form-fields
- HEAD
  - Ask reply with empty message (e.g. debugging)
- PUT
  - Upload file in entity body to path specified in URL field
- DELETE
  - Delete file specified in the URL field

HTTP Response Message

HTTP response message

- ASCII text (human-readable format)
- Includes status code and requested file



HTTP Response Status Code

Some sample codes:

- 200 OK
  - request succeeded, requested object later in this msg
- 301 Moved Permanently
  - requested object moved, new location specified later in the header (Location:)
- 400 Bad Request
  - request msg not understood by server
- 404 Not Found
  - requested document not found on this server
- 505 HTTP Version Not Supported

User-Server State: Cookies

HTTP is a stateless protocol

- HTTP does NOT track states of clients
- Websites implement user sessions on top of HTTP
- Users state is usually kept thanks to cookies

What cookies are used for:

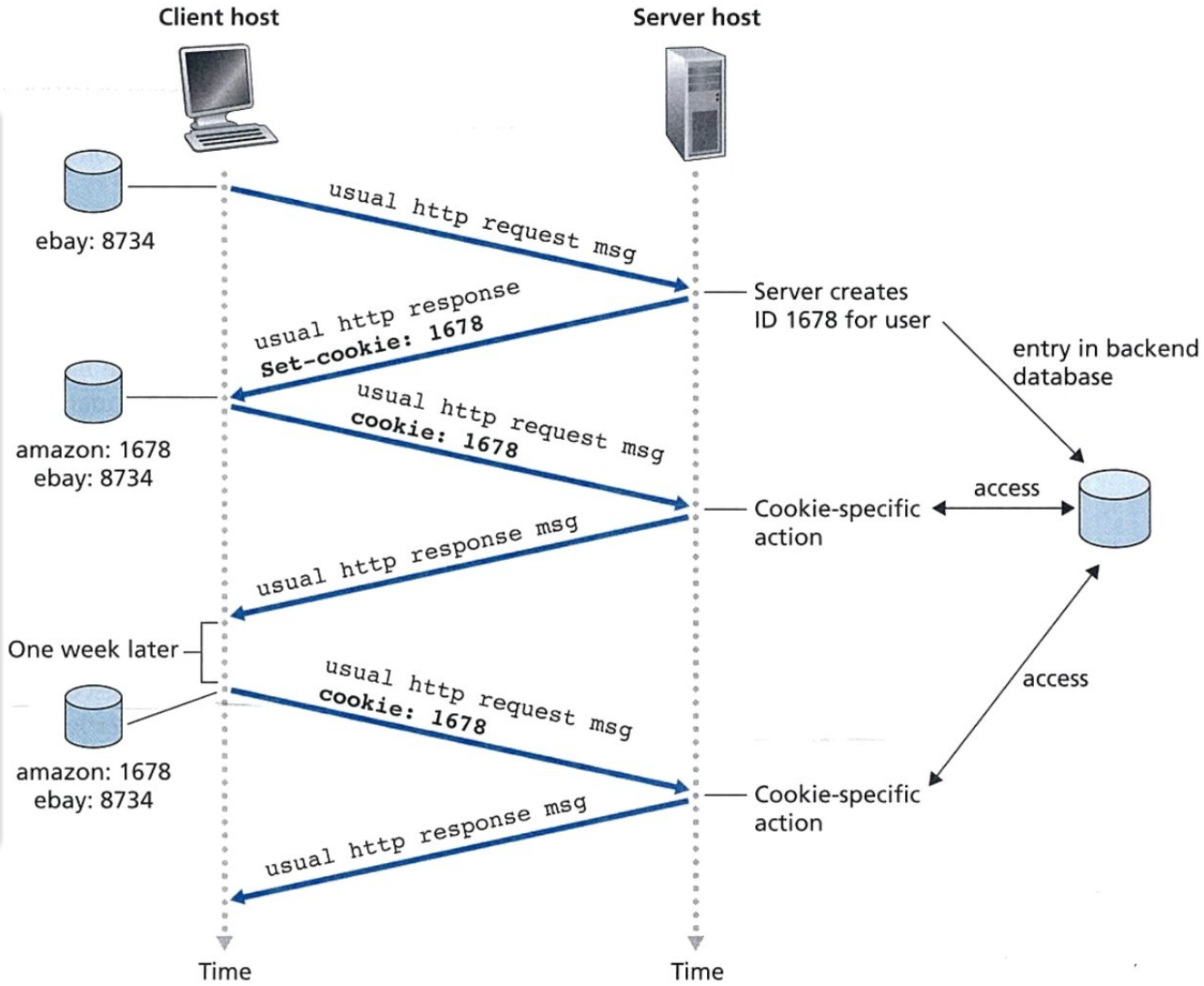
- authorization, shopping carts, recommendations, user session state (Web e-mail), advertising

Cookies consist of four components

- Cookie header line in HTTP response message (Set-cookie:)
- Cookie header line in HTTP request message (Cookie:)
- Cookie file kept on the users end system managed by the browser
- Back-end database at the web site

Cookies: Example

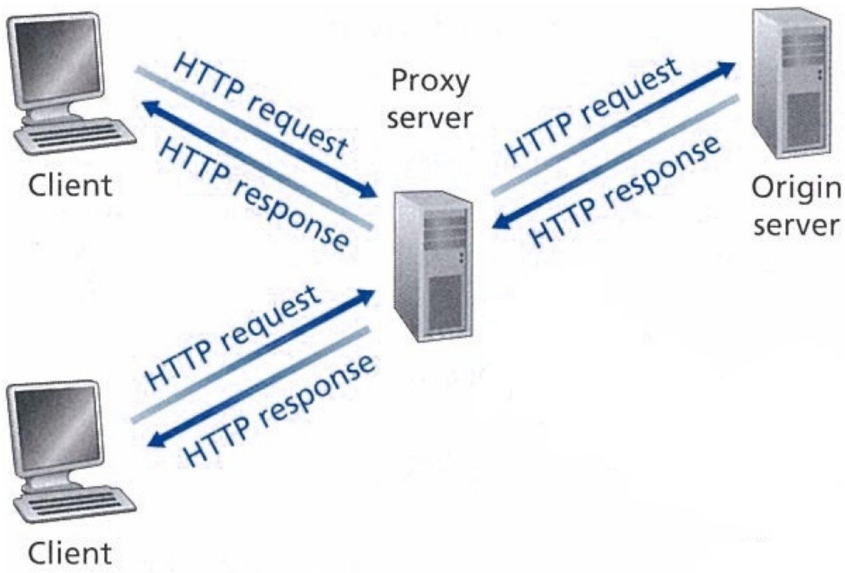
- Client visits amazon for first time
- Amazon creates an ID, attached to the reply
- Client stores the ID in a file with the server host name
- Client provides the ID with all following requests to amazon



Web Caches (Proxy Server)

Goal: Satisfy client request without involving origin server

- User sets browser: Web accesses via cache
- Browser sends all HTTP requests to cache
  - Object in cache: cache returns object
  - Else cache requests object from origin server, then returns object to client



Web Caches (Proxy Server)

More about web caching:

- Cache acts as both client and server
- Typically cache is installed by university, company, residential ISP...
- Cache reduces traffic and response time

How to know if the cache is up-to-date?

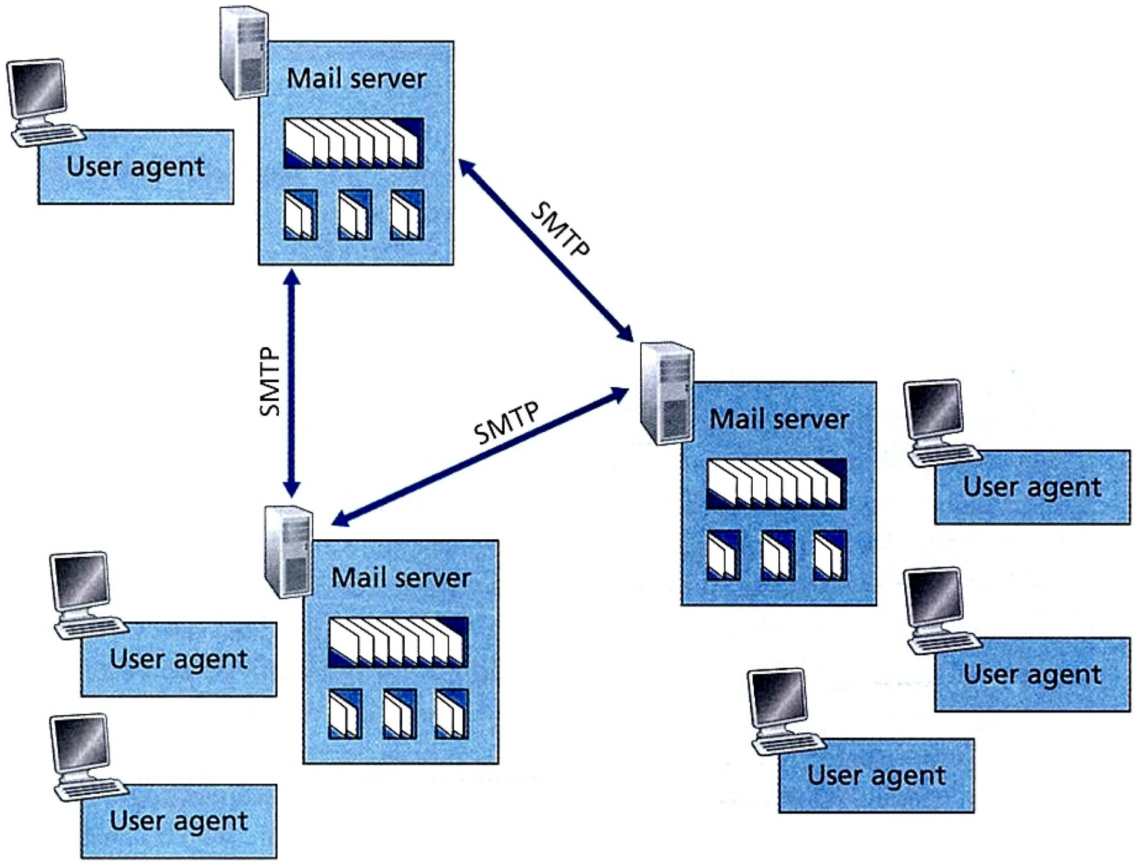
- HTTP defines a conditional GET to verify the validity of an object
- Request message header includes "If-Modified-Since: <*date*>", e.g.
- Server response contains no object if cached copy is up-to-date
- For example, client request:
  - `GET /fruit/kiwi.gif HTTP/1.1`
    `Host: www.exotiquecuisine.com`
    `If-modified-since: Wed, 7 Nov 2013 09:23:24`

  Server response:
  - `HTTP/1.1 304 Not Modified`

Electronic Mail in the Internet

Electronic Mail

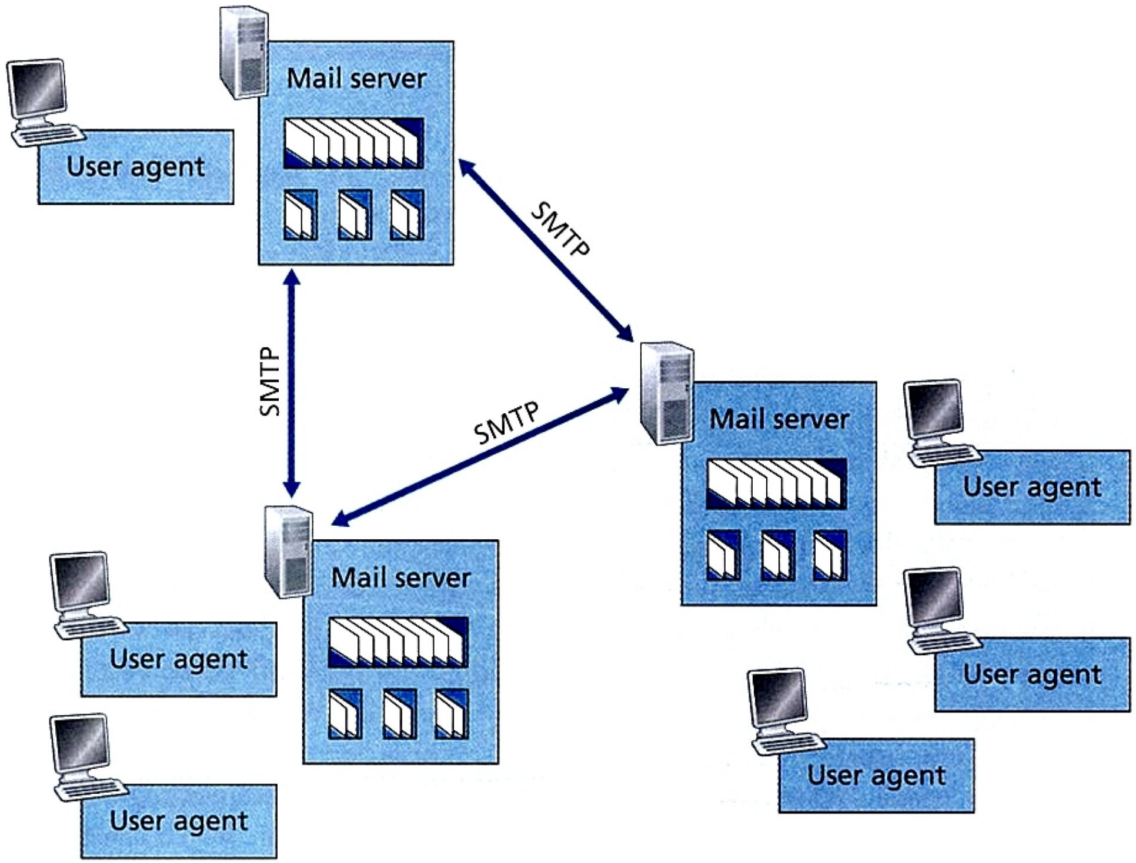
- Three major components:
  - User agents
  - Mail servers
  - Simple mail transfer protocol: SMTP



Electronic Mail in the Internet

User Agent

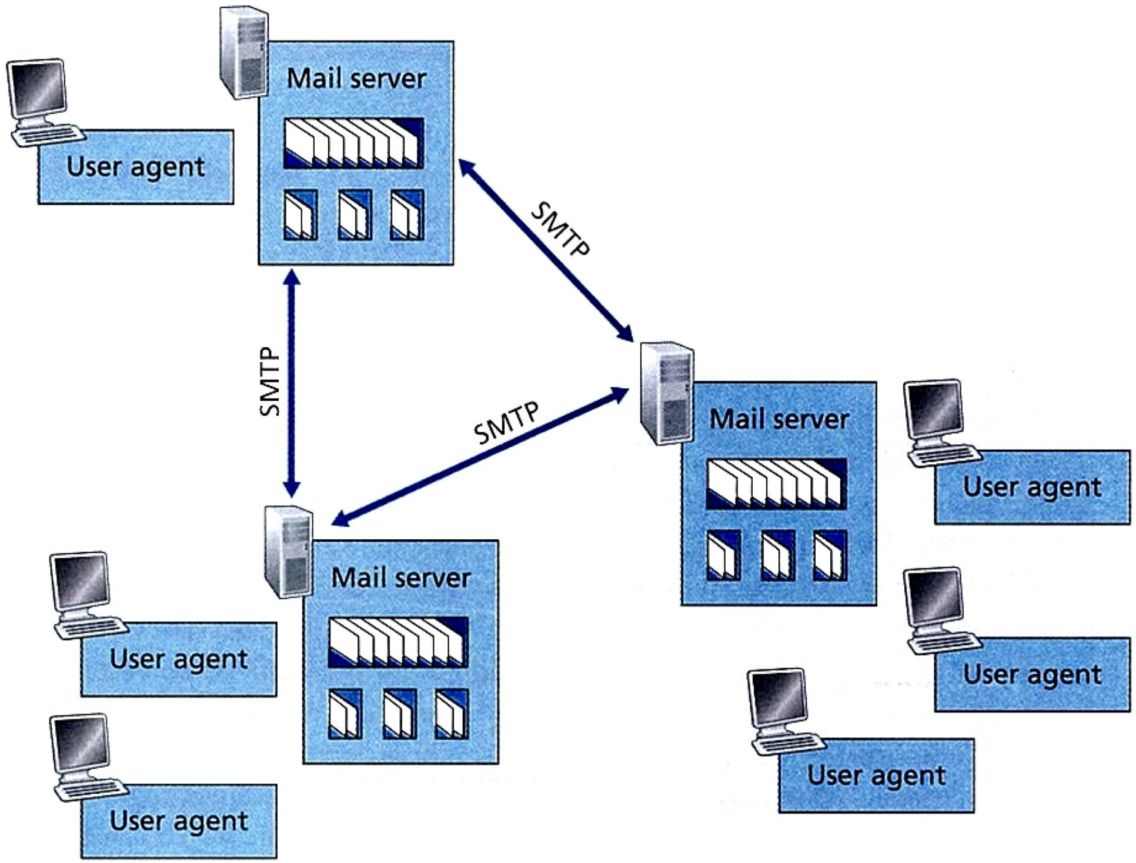
- a.k.a. “mail reader”
- Composing, reading e-mail
- e.g. Outlook, Thunderbird, iPhone mail client...



Electronic Mail in the Internet

Mail Servers:

- mailbox contains incoming messages for user
- message queue of outgoing (to be sent) mail messages
- SMTP protocol between mail servers to send email messages



Electronic Mail: SMTP [RFC 2821]

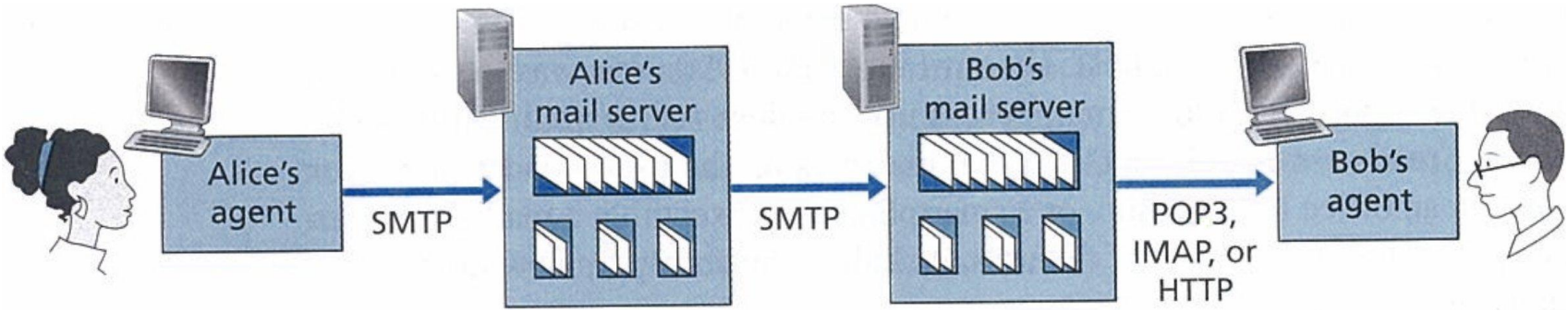
SMTP: Simple mail transfer protocol

- Uses TCP to reliably transfer email message (port 25)
- Direct transfer: sending server to receiving server
- Three phases of transfer
  - handshaking (greeting)
  - transfer of messages
  - closure
- Command/response interaction (like HTTP, FTP)
  - commands: ASCII text
  - response: status code and phrase
- Comparison with HTTP:
  - HTTP: pull
  - SMTP: push

Scenario:

Alice sends message to Bob

1. Alice uses her user agent to compose a message "to" bob@someschool.edu
2. Alice's user agent sends message to her mail server; message placed in message queue
3. client side of SMTP opens TCP connection with Bob's mail server
4. SMTP client sends Alice's message over the TCP connection
5. Bob's mail server places the message in Bob's mailbox
6. Bob invokes his user agent to read message



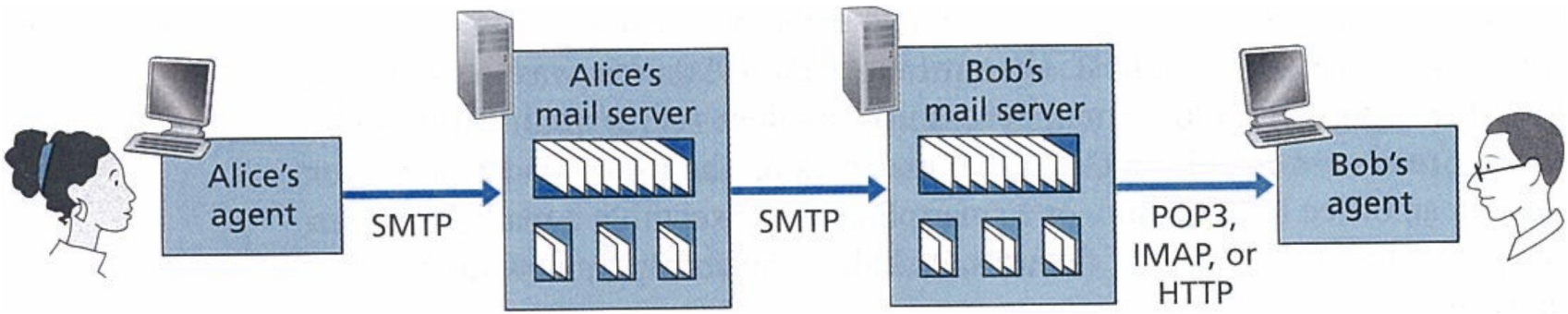
Electronic Mail

SMTP

- Delivery/storage to receiver's server
- Not to the receiver's computer!

Mail access protocols

- Mail access protocol: retrieval from server
  - POP3: Post Office Protocol: authorization, download
  - IMAP: Internet Mail Access Protocol: more features, including manipulation of stored msgs on server
  - HTTP: gmail, Hotmail, Yahoo! Mail, etc.



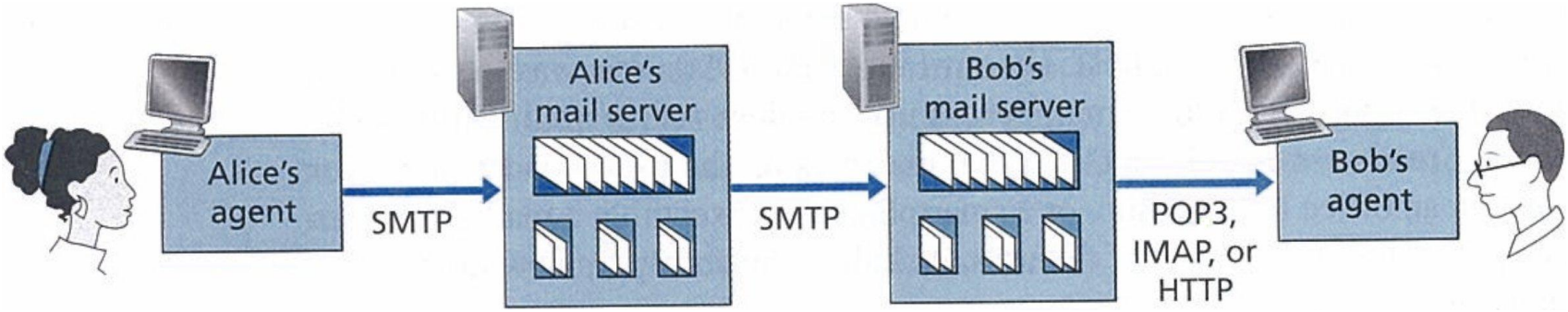
Mail access protocols: POP3 and IMAP

Post Office Protocol ver.3

- Simple mail access protocol
- Authorization and transaction
- 2 transaction modes:
  - "download and delete": cannot re-read e-mail using another user agent
  - "download and keep": copies of messages on different user agent
- Stateless across sessions

Internet Mail Access Protocol

- Provides additional features
- Keeps all messages in one place: at server
- Allows user to organize messages in folders
- Keeps user state across sessions:
  - names of folders and mappings between message IDs and folder name



Domain Name System (DNS)

Domain Name System

- Internet hosts can be identified either by their hostname or their IP address:
  - **Hostname**: www.google.com
  - **IP address**: 74.125.235.144
- DNS is a directory service that maps IP addresses to hostnames
- Distributed database implemented in hierarchy of many name servers
- DNS queries use UDP for fast communication (port 53)

DNS: Services

DNS Services

- Hostname to IP address translation
  - www.gmail.com $\rightarrow$ 74.125.235.86
- Host aliasing (alias $\rightarrow$ canonical names)
  - e.g. www.gmail.com $\rightarrow$ mail.google.com
- Mail server aliasing (alias $\rightarrow$ mail server)
  - e.g. gmail.com $\rightarrow$ gmail-smtp-in.l.google.com
- Load distribution
  - Replicated Web servers: many IP addresses correspond to one name
  - www.google.com $\rightarrow$ $\begin{cases} 74.125.235.83 \\ 74.125.235.80 \\ 74.125.235.82 \\ 74.125.235.81 \\ 74.125.235.84 \end{cases}$

DNS: A Distributed, Hierarchical Database

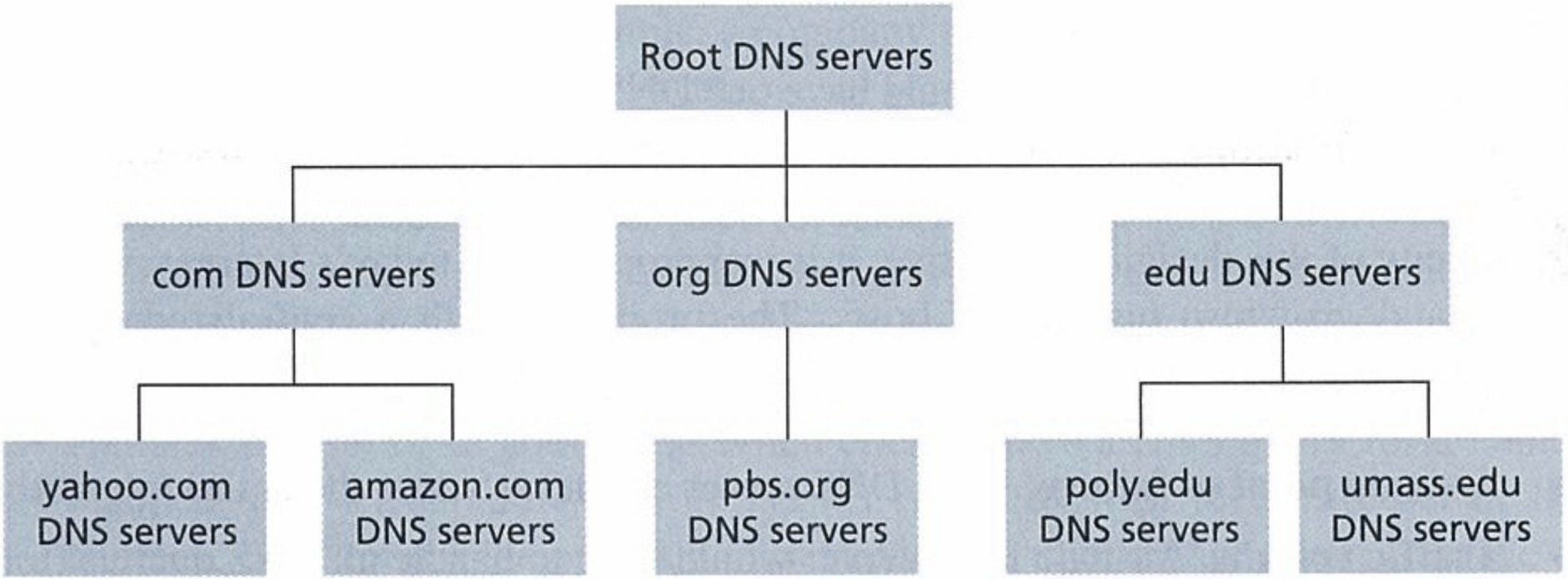
Why not centralized DNS? doesn't scale!

- Single point of failure
- Traffic volume
- Distant centralized database
- Maintenance

DNS: A Distributed, Hierarchical Database

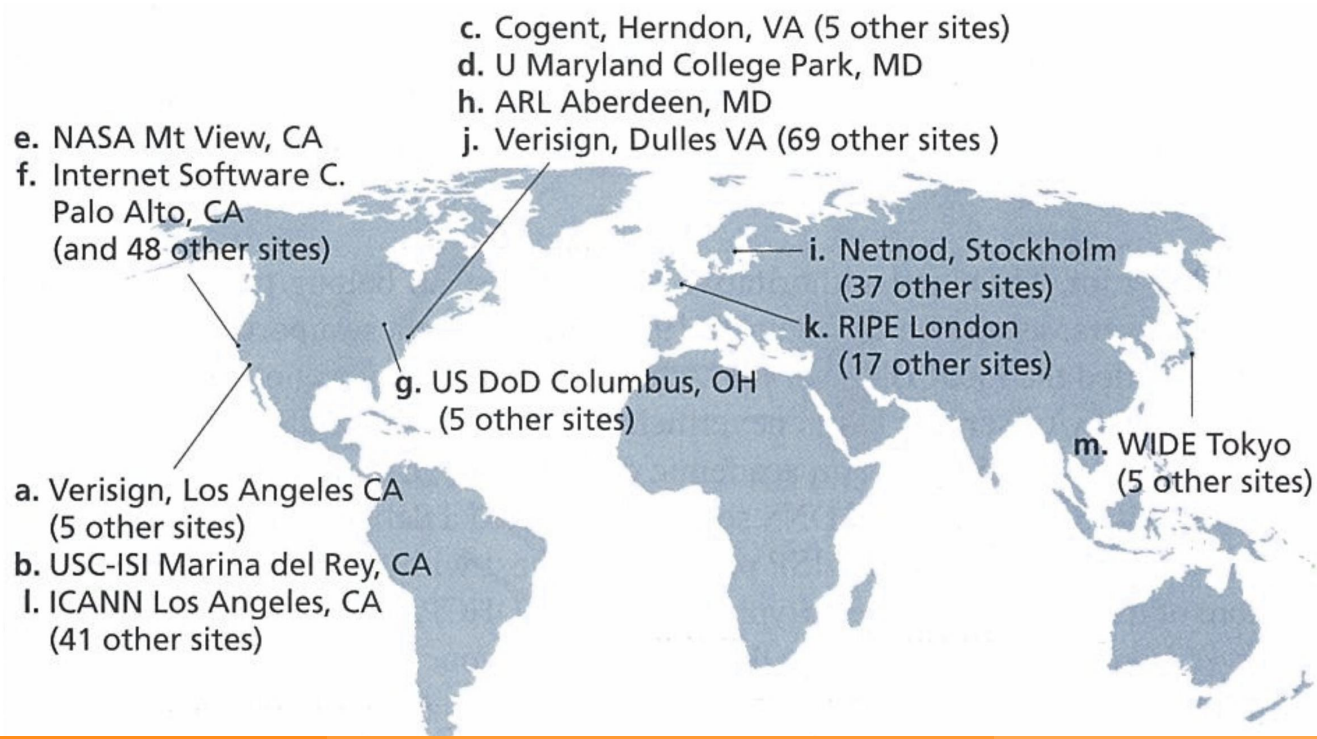
DNS Hierarchy

- DNS uses a large number of hierarchically organized servers
- No single DNS server has all of the mappings for all of the hosts in the Internet
- 3 levels: root, top-level-domain (TLD), authoritative servers (+ local DNS server)



DNS: Root Name Servers

- Contacted by local name server that can not resolve name
- Root name server:
  - Contacts authoritative name server if name mapping not known
  - Gets mapping
  - Returns mapping to local name server
- 13 DNS root "servers" (network of replicated servers, 377 sites as in 2013)



TLD and Authoritative Servers

Top-level-domain (TLD) servers:

- Responsible for .com, .org, .net, .edu, .gov,... and all top-level country domains, e.g.: uk, fr, ca, jp
- e.g. Network Solutions maintains servers for .com TLD
- e.g. Educause for .edu TLD

Authoritative DNS servers:

- Organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
- Can be maintained by organization or service provider
- e.g. ns1.google.com, ns2.google.com, ns3.google.com, ns4.google.com, are the authoritative name servers for the domain google.com

Local DNS Name Server

Local DNS (a.k.a. default name server)

- Does not strictly belong to hierarchy
- Each ISP (residential ISP, company, university) has one
- When host makes DNS query, query is sent to its local DNS server
  - has local cache of recent name-to-address translation pairs (but may be out of date!)
  - acts as proxy, forwards query into hierarchy

DNS Name Resolution Example

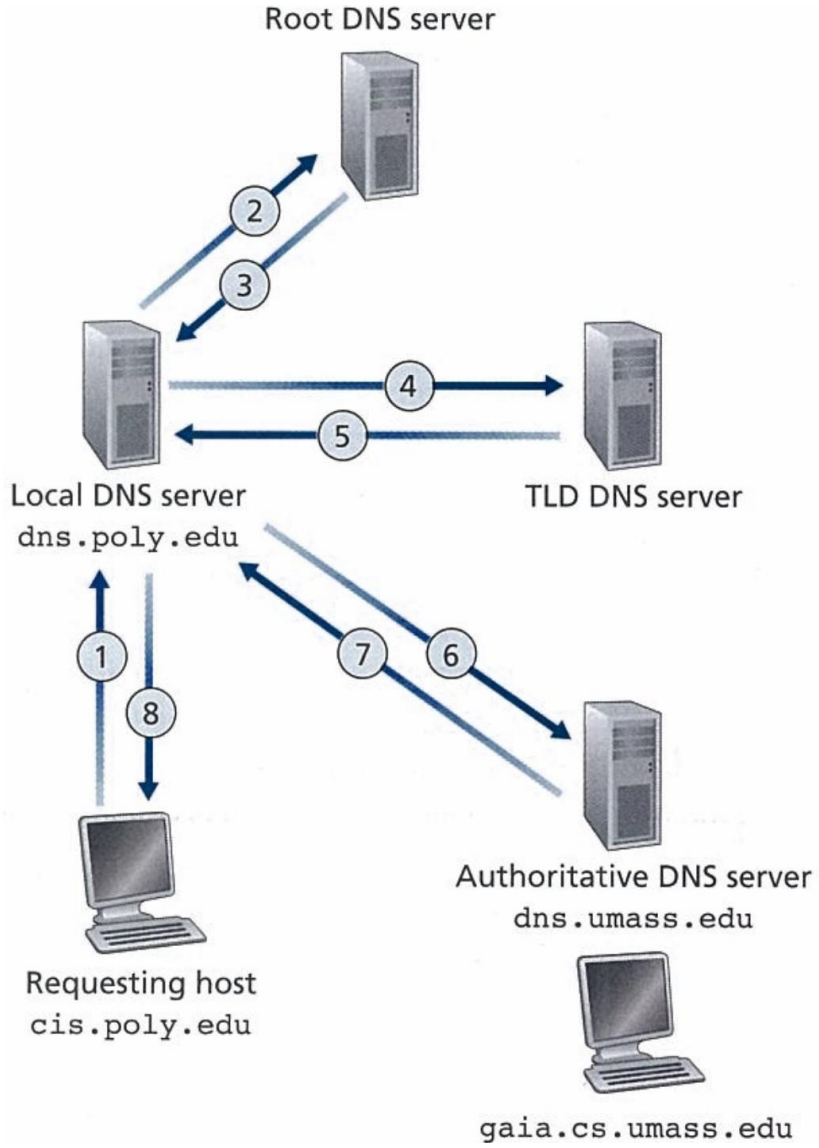
Iterated query:

- Contacted server replies with name of server to contact
- "I don't know this name, but ask this server"

Example:

Host cis.poly.edu wants IP address for gaia.cs.umass.edu

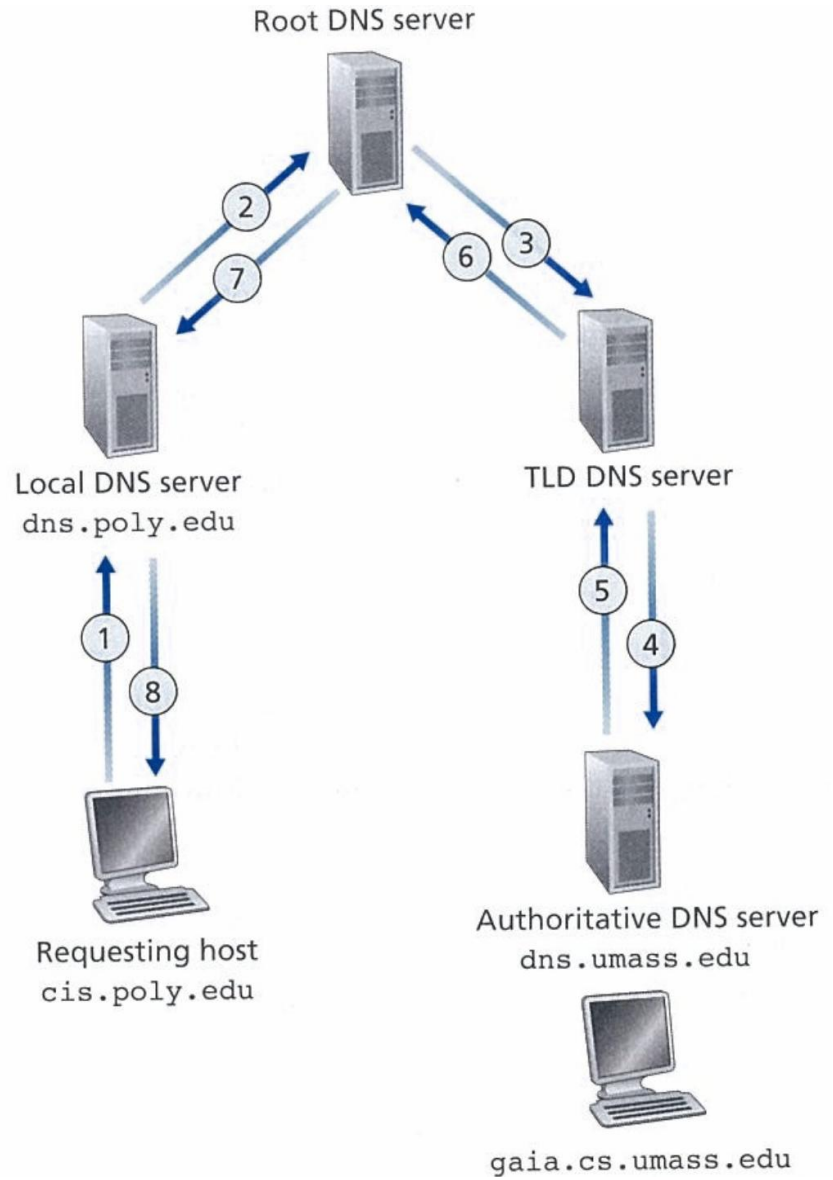
- Root server provides the IP of the TLD server .edu
- TLD server provides the IP of the Authoritative server responsible for umass.edu
- Authoritative server provides the IP for gaia.cs.umass.edu



DNS Name Resolution Example

Recursive query:

- Contacted server forward the request
- Put burden on contacted name server
- More load at upper levels of hierarchy



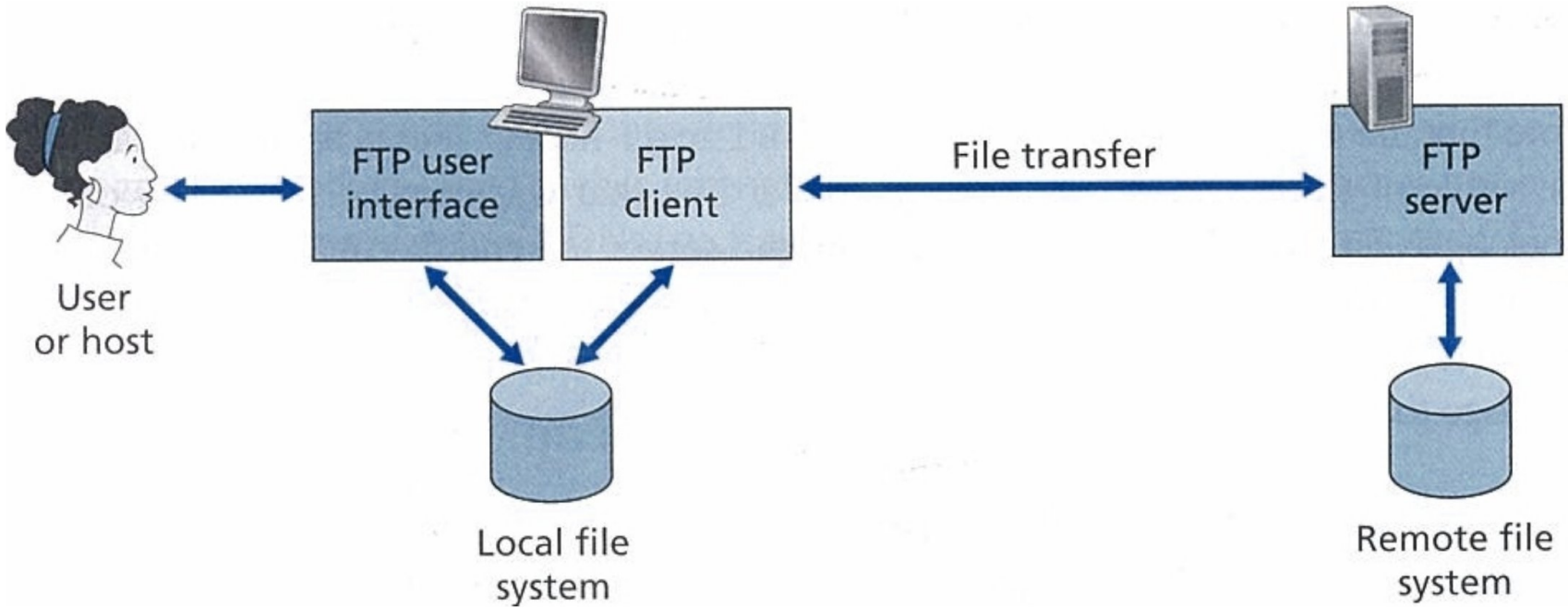
DNS: Caching

DNS servers cache responses

- Once (any) name server learns mapping, it caches mapping
- Cache entries timeout (disappear) after some time (TTL)
- TLD servers typically cached in local name servers (thus root server are not visited all the time)
- Cached entries may be out-of-date:
  - if name host changes IP address, may not be known Internet-wide until all TTLs expire

$\rightarrow$ Selecting TTL value is a trade-off between performance (using cached data/less queries) and up-to-date data

File Transfer Protocol (FTP)



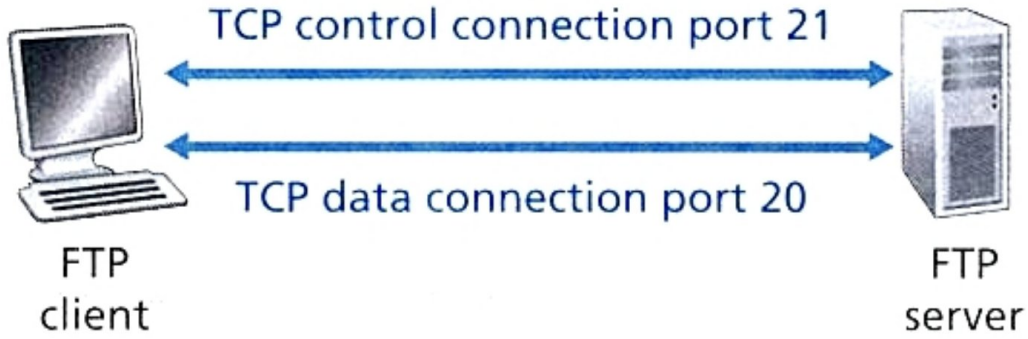
FTP: File Transfer over TCP

- Transfer file to/from remote host
- Client/server model
  - Client: side that initiates transfer (either to/from remote)
  - Server: remote host
- FTP server listen on port 21 (port 20 is used for file transfer)

File Transfer Protocol (FTP)

FTP uses two types of connection

- **Control connection**: Transmit control information between the two hosts (user authentication, password, commands to change remote directory, put or get files)
- **Data connection**: Transfer files



Peer-to-Peer Architecture

In P2P networks:

- No always-on server
- Arbitrary end systems directly communicate
- Peers are intermittently connected and change IP addresses

Examples:

- File distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)

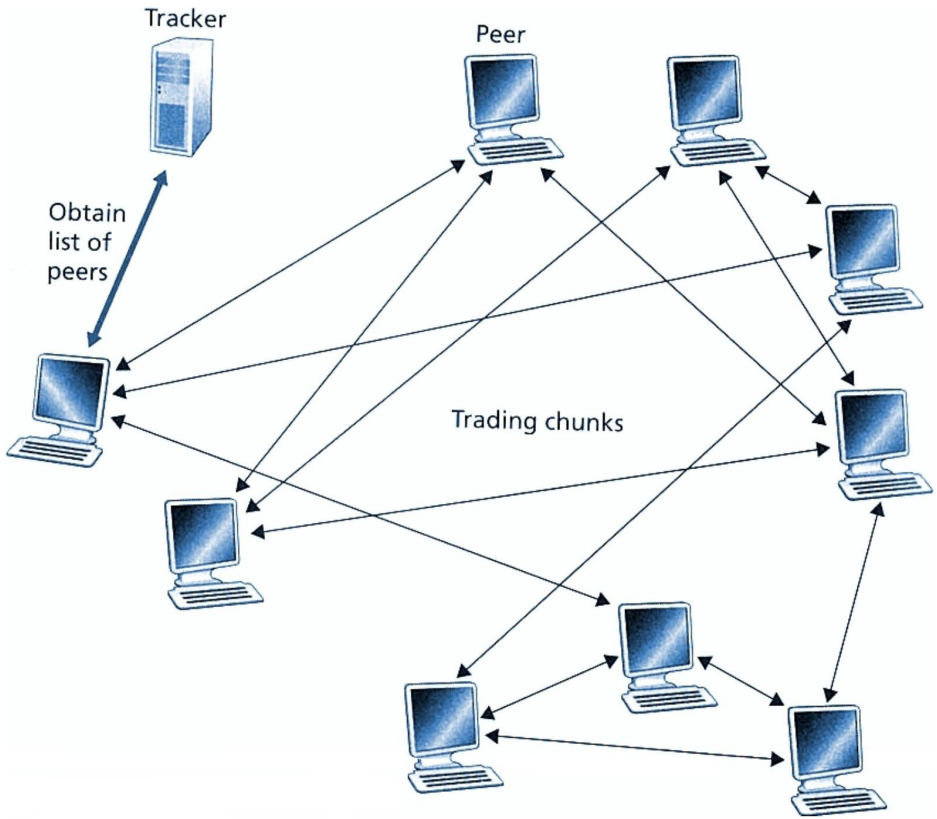
P2P File Distribution: BitTorrent

Why P2P for file distribution?

- In client-server model, enormous burden on the server
- In P2P model, distributed peers share the load for distributing the file

BitTorrent

- File divided into 256Kb chunks
- Torrent: group of peers exchanging chunks of a file
- Tracker: tracks peers that belongs to the torrent



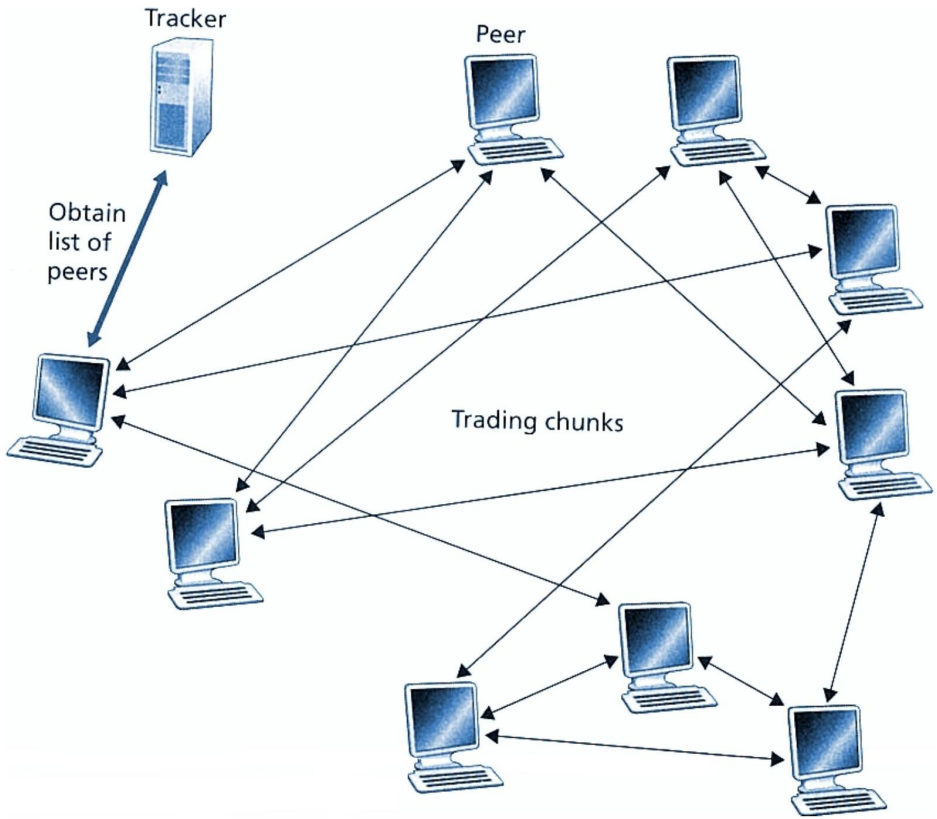
P2P File Distribution: BitTorrent

Peer joining torrent

- Has no chunks yet
- Registers with tracker and get a list of peers ("neighbors")

File sharing

- Downloaded chunks are uploaded to other peers
- Peers may leave so it may connect to new neighbors
- Neighbors periodically ask list of downloaded chunks
- Download rarest chunks first



The Application Layer: Summary

Today's lecture covered:

- HTTP
- Email
- DNS
- FTP
- P2P

Next week: Midterm exam!

- Covers all layers of the protocol stack
  From Physical to Application layer
- Goal: check that you know the basics for each layer
- Less than 20 short questions

Then we'll see:

Network management:
Monitoring network performance, fault, security...

Today's important points

- Client/server vs. P2P
- HTTP
- DNS
- Common port numbers