TECHNISCHE HOCHSCHULE DEGGENDORF

# Netzwerktechnik und IT-Netze

# Chapter 2: Application Layer

**Vorlesung im WS 2016/2017**

**Bachelor Informatik**

**(3. Semester)**

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# Overview

- Introduction
- Computer Networks and the Internet
- Application Layer
  - WWW, Email, DNS, and more
  - Socket programming
- Transport Layer
- Network Layer
- Link Layer
- P2P Networks

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# Introduction

- A note on the use of these power point slides:
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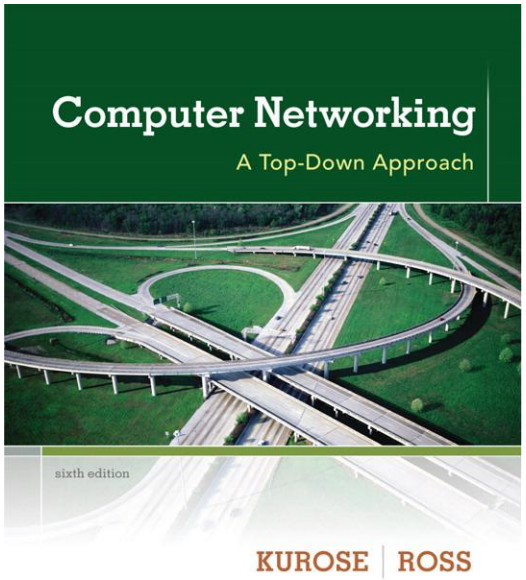



*Computer Networking: A Top Down Approach*
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

# Chapter 2: Roadmap

- Principles of network applications
- Web and HTTP
- FTP
- DNS
- Electronic mail
  - SMTP, POP3, IMAP
- Socket programming with UDP and TCP

# Chapter 2: application layer

- Our goals:
  - Conceptual, implementation aspects of network application protocols
  - Transport-layer service models
  - Client-server paradigm
  - Peer-to-peer paradigm
  - Learn about protocols by examining popular application-level protocols
    - HTTP
    - FTP
    - SMTP / POP3 / IMAP
    - DNS

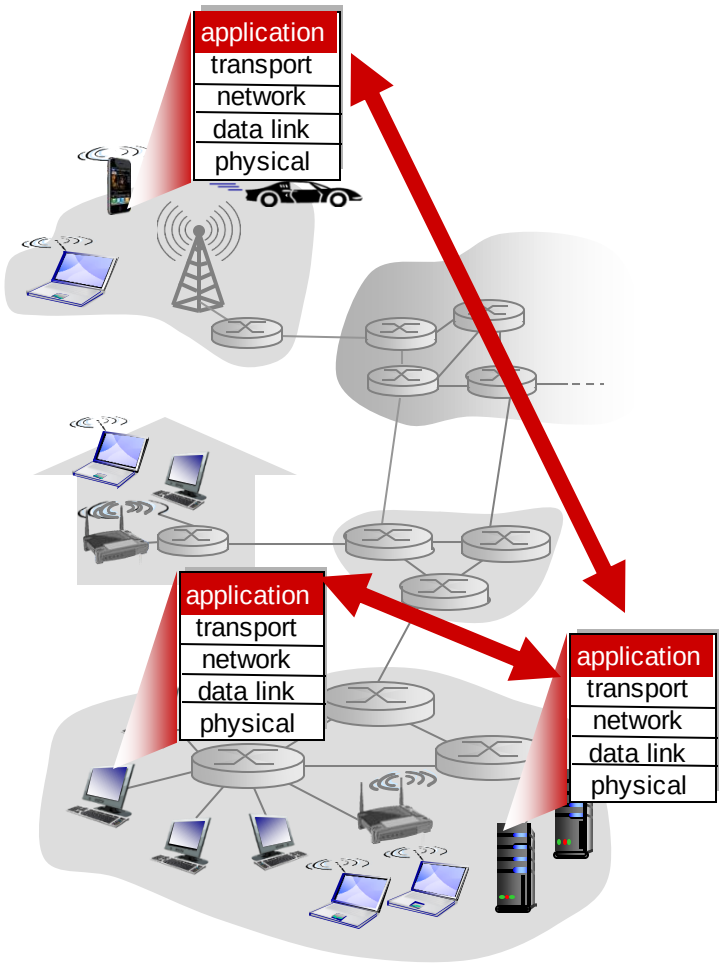
- Our goals:
  - Creating network applications
  - Socket API

# Some network apps

- E-mail
- Web
- Text messaging
- Remote login
- P2P file sharing
- Multi-user network games
- Streaming stored video (YouTube, Hulu, Netflix)
- Voice over IP (e.g., Skype)
- Real-time video conferencing
- Social networking
- Search
- …
- …

# Creating a network app

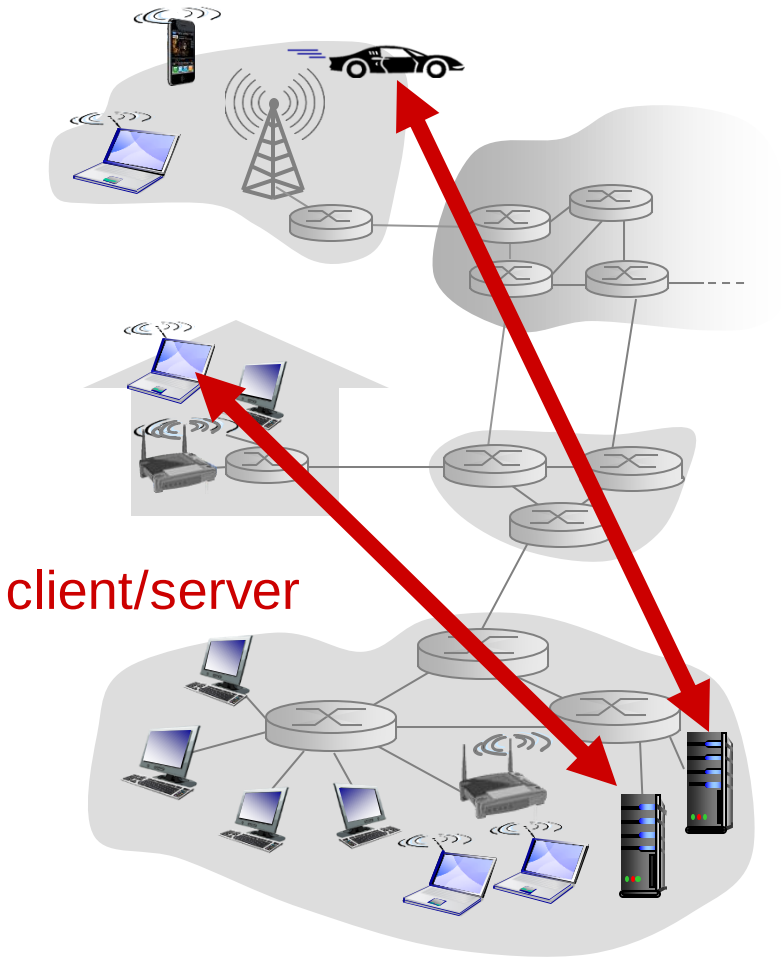
- Write programs that:
  - Run on (different) end systems
  - Communicate over network
  - e.g., Web server software communicates with browser software
- No need to write software for network-core devices
  - Network-core devices do not run user applications
  - Applications on end systems allows for rapid app development, propagation



# Application architectures

- Possible structure of applications:
  - Client-server
  - Peer-to-peer (P2P)

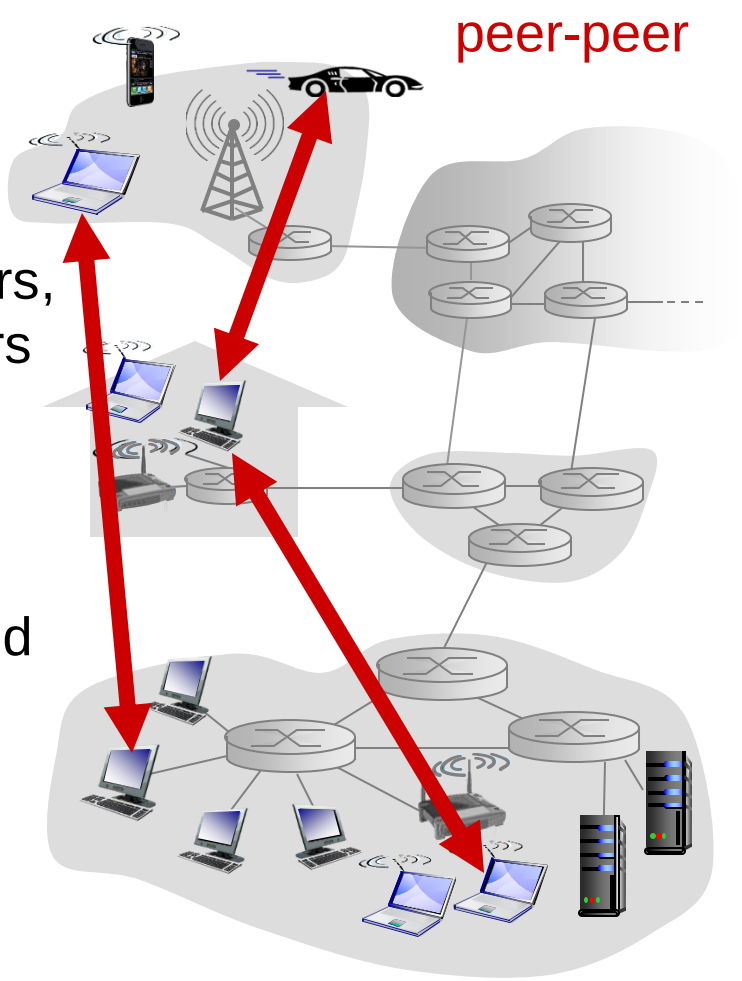
# Client-server architecture




- 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

- 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



# Processes communicating

- Process: program running within a host
  - Within same host, two processes communicate using inter-process communication (defined by OS)
  - Processes in different hosts communicate by exchanging messages
  - Aside: applications with P2P architectures have client processes & server processes

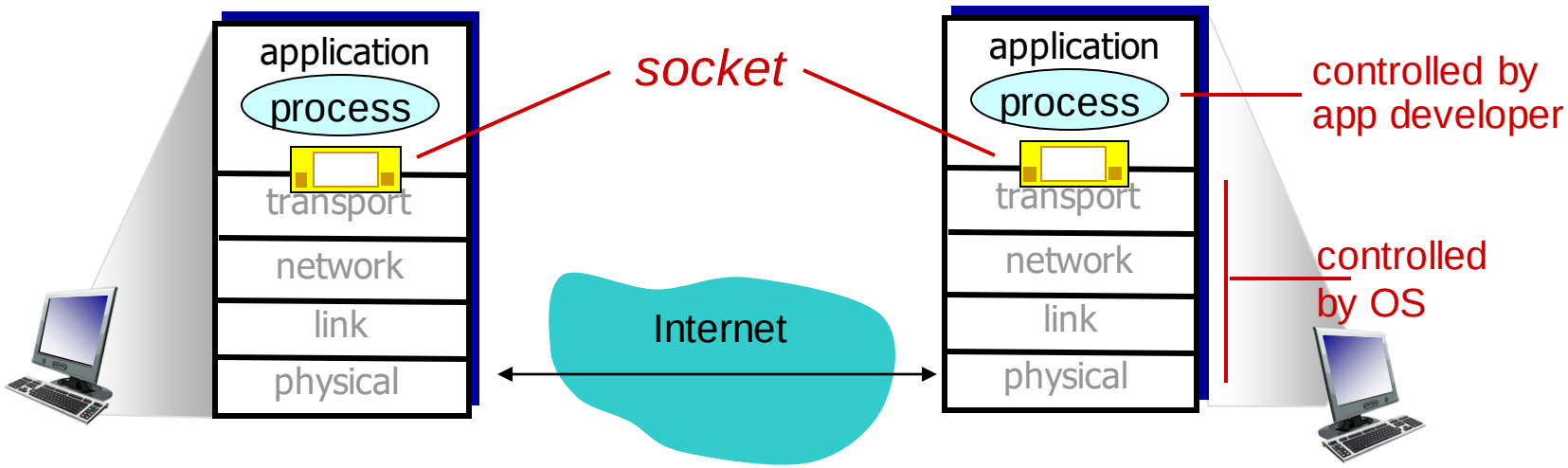
## Clients, Servers

*Client process:* process that initiates communication

*Server process:* process that waits to be contacted

# Sockets

- Process sends/receives messages to/from its socket
- Socket analogous to door
  - Sending process shoves message out door
  - Sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process



# Addressing processes

- To receive messages, process must have identifier
- Host device has unique 32-bit IP address
- Q: does IP address of host on which process runs suffice for identifying the process?
  - A : no, many processes can be running on same host

- Identifier includes both IP address and port numbers associated with process on host.
- Example port numbers:
  - HTTP server: 80
  - Mail server: 25
- To send HTTP message to gaia.cs.umass.edu web server:
  - IP address: 128.119.245.12
  - Port number: 80
- more shortly…

# App-layer protocol defines

- 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 telephony, interactive games) require low delay to be “effective”
- Throughput
  - Some apps (e.g., multimedia) require minimum amount of throughput to be “effective”
  - Other apps (“elastic apps”) make use of whatever throughput they get
- Security
  - Encryption, data integrity, …

# Transport service requirements: common apps

| Application | Data loss | Throughput | Time sensitive |
|---|---|---|---|
| file transfer | no loss | elastic | no |
| e-mail | no loss | elastic | no |
| Web documents | no loss | elastic | no |
| real-time audio/video | loss-tolerant | audio: 5kbps-1Mbps<br>video:10kbps-5Mbps | yes, 100's msec |
| stored audio/video | loss-tolerant | same as above | yes, few secs |
| interactive games | loss-tolerant | few kbps up | yes, 100's msec |
| text messaging | no loss | elastic | yes and no |

# Internet transport protocols services

- TCP service
  - Reliable transport: between sending and receiving process
  - Flow control: sender won't overwhelm receiver
  - Congestion control: throttle sender when network overloaded
  - Connection-oriented: setup required between client and server processes
  - Does not provide: timing, minimum throughput guarantee, security
- UDP service
  - Unreliable data transfer: between sending and receiving process
  - Does not provide: reliability, flow control, congestion control, timing, throughput guarantee, security, or connection setup

# Internet apps: application, transport protocols

| Application | Application layer protocol | Underlying transport protocol |
|---|---|---|
| e-mail | SMTP [RFC 2821] | TCP |
| remote terminal access | Telnet [RFC 854] | TCP |
| Web | HTTP [RFC 2616] | TCP |
| file transfer | FTP [RFC 959] | TCP |
| streaming multimedia | HTTP (e.g., YouTube), RTP [RFC 1889] | TCP or UDP |
| Internet telephony | SIP, RTP, proprietary (e.g., Skype) | TCP or UDP |

# Securing TCP

- TCP & UDP
  - No encryption
  - Cleartext passwds sent into socket traverse Internet in cleartext
- SSL
  - Provides encrypted TCP connection
  - Data integrity
  - End-point authentication

- SSL is at app layer
  - Apps use SSL libraries, which “talk” to TCP
- SSL socket API
  - Cleartext passwds sent into socket traverse Internet encrypted
  - See Chapter 7

# Chapter 2: Roadmap

- Principles of network applications
- Web and HTTP
- FTP
- DNS
- Electronic mail
  - SMTP, POP3, IMAP
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# Web and HTTP

- First, a review…
  - Web page consists of objects
  - Object can be HTML file, JPEG image, Java applet, audio file,…
  - Web page consists of base HTML-file which includes several referenced objects
  - Each object is addressable by a URL, e.g.,


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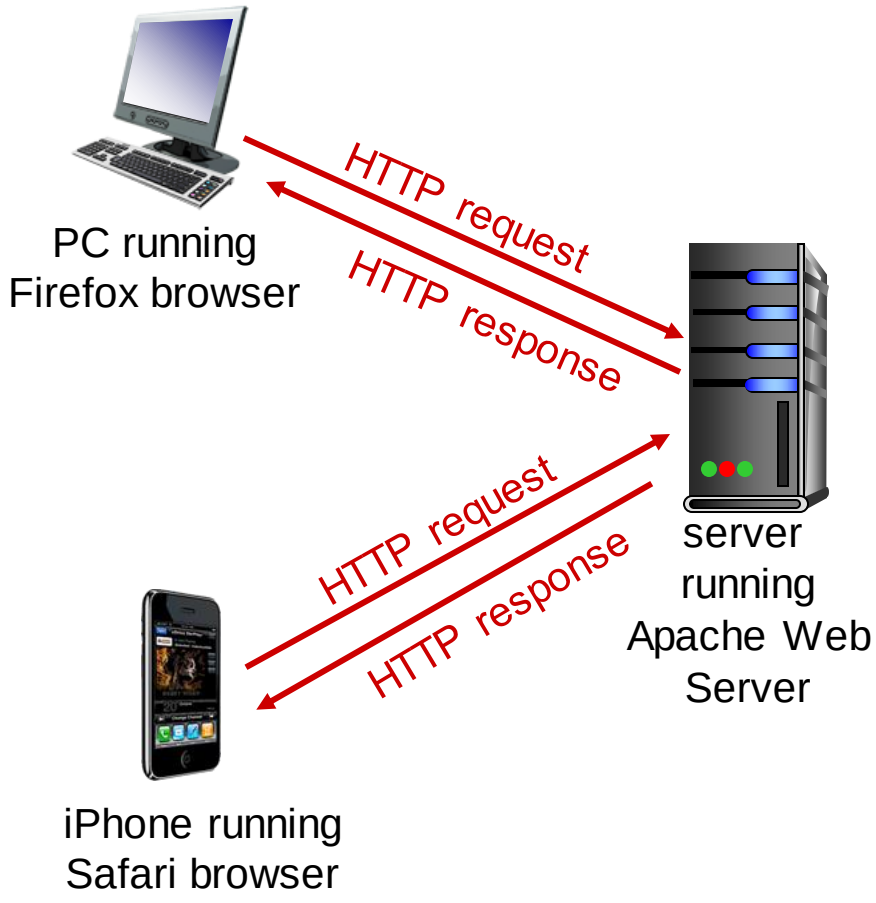
# HTTP overview

- HTTP: hypertext transfer protocol
  - Web's application layer protocol
  - Client/server model
    - Client: Browser that requests, receives, (using HTTP protocol) and "displays" Web objects
    - Server: Web server sends (using HTTP protocol) objects in response to requests



# HTTP overview (continued)

- Uses TCP
  - Client initiates TCP connection (creates socket) to server, port 80
  - 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 is "stateless"
  - Server maintains no information about past client requests

*aside*

Protocols that maintain "state" are complex!

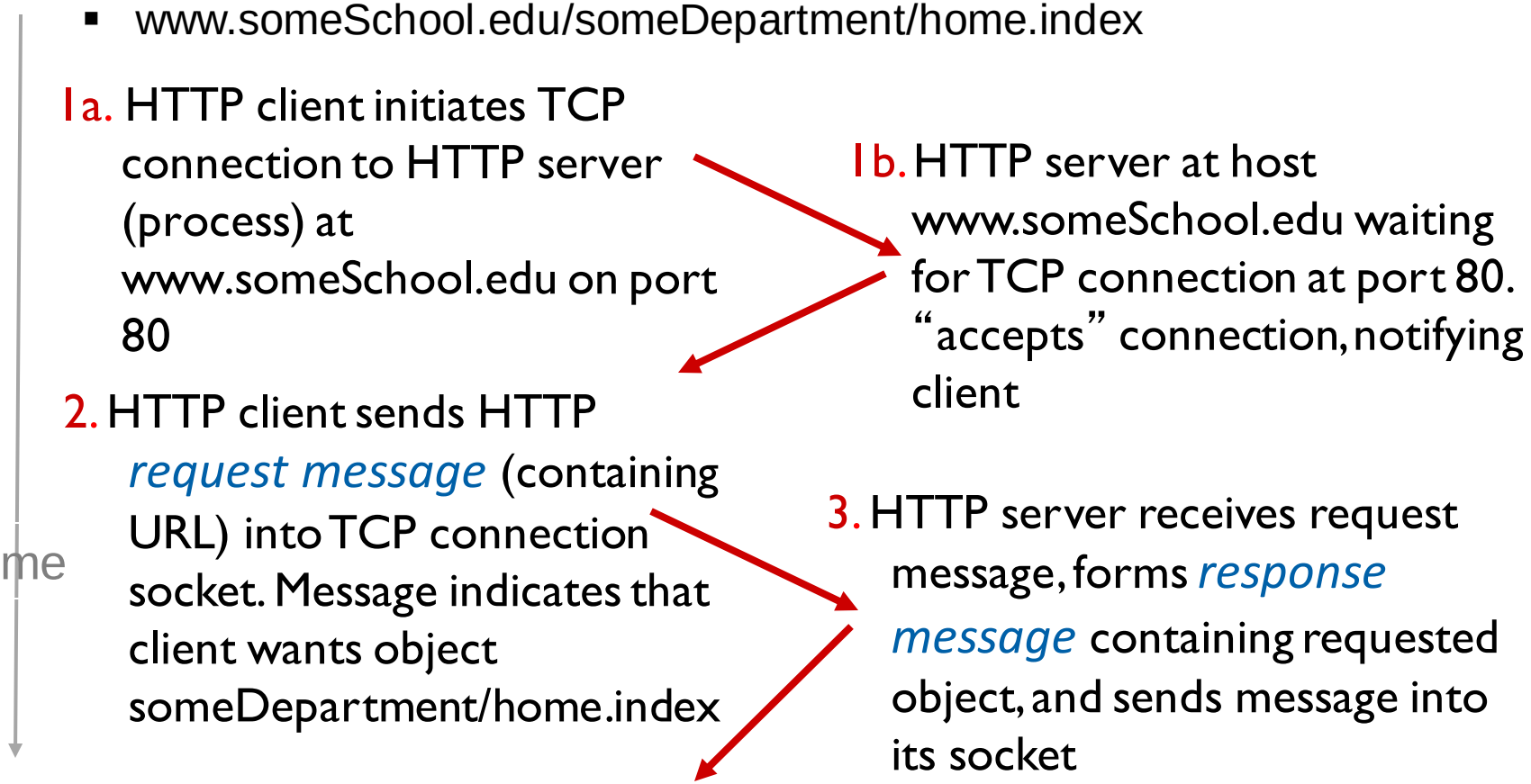
- Past history (state) must be maintained
- If server/client crashes, their views of "state" may be inconsistent, must be reconciled

# HTTP connections

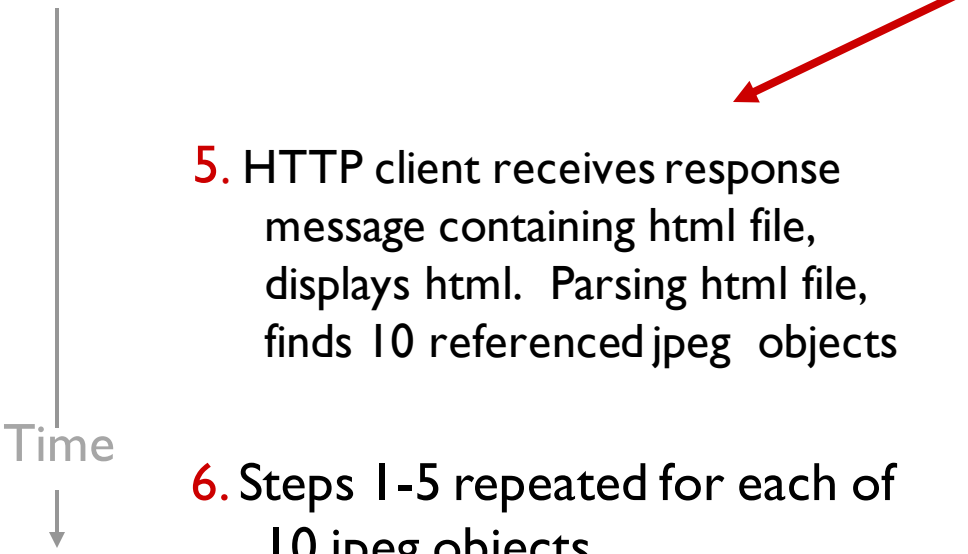
- Non-persistent HTTP
  - At most one object sent over TCP connection
    - Connection then closed
  - Downloading multiple objects required multiple connections
- Persistent HTTP
  - Multiple objects can be sent over single TCP connection between client, server

# Non-persistent HTTP

- Suppose user enters URL:
  - www.someSchool.edu/someDepartment/home.index



# Non-persistent HTTP (cont.)



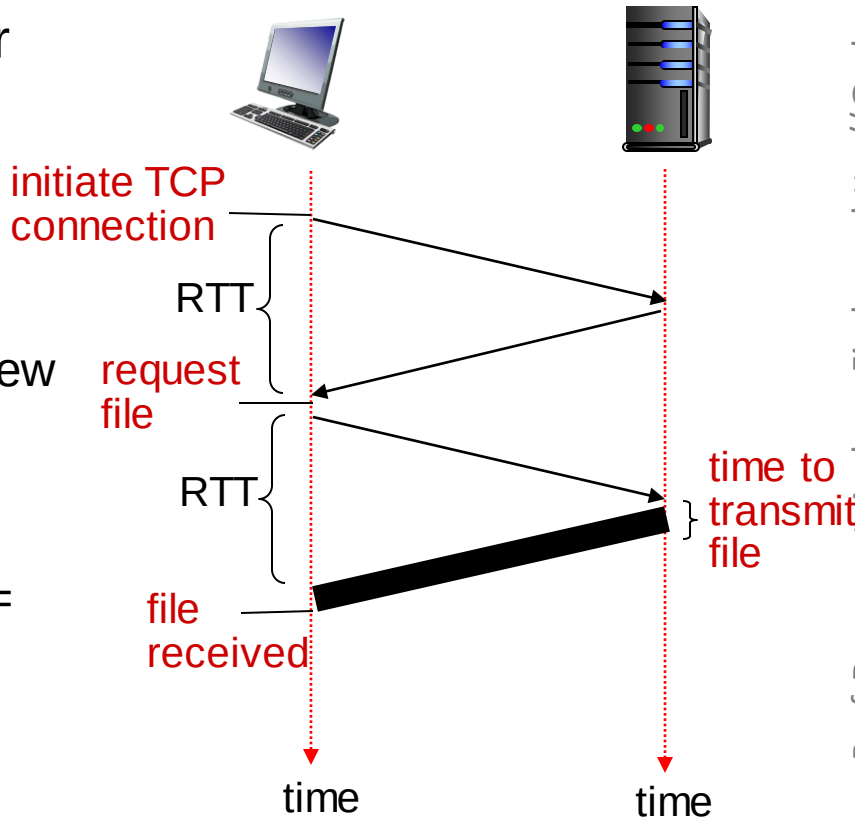

4. HTTP server closes TCP connection.

5. HTTP client receives response message containing html file, displays html. Parsing html file, finds 10 referenced jpeg objects

6. Steps 1-5 repeated for each of 10 jpeg objects

# Non-persistent HTTP: response time

- RTT (round trip time): Time for a small packet to travel from client to server and back
- HTTP response time:
  - One RTT to initiate TCP connection
  - One RTT for HTTP request and first few bytes of HTTP response to return
  - File transmission time
  - Non-persistent HTTP response time = 2RTT+ file transmission time



# Persistent HTTP

- Non-persistent HTTP issues:
  - Requires 2 RTTs per object
  - 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

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# Persistent HTTP

Persistent HTTP **without** pipelining:

- Client sends new request for new objects only, if the response of the previous request has already arrived.
- One RTT for each object.

Persistent **with** pipelining:

- Standard in HTTP/1.1.
- Client sends requests as soon as a reference to an object is found.
- Ideally only a little more than a single RTT for the loading of all referenced objects.

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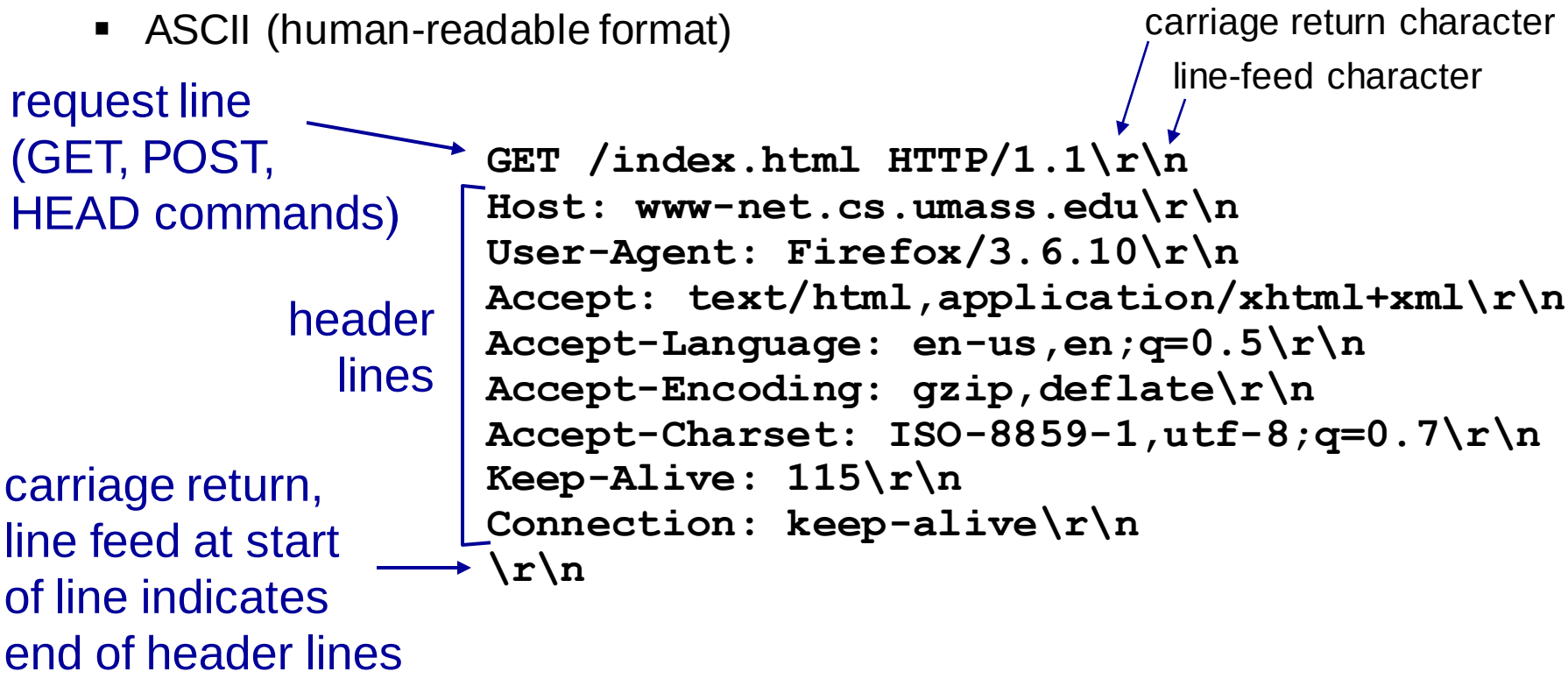
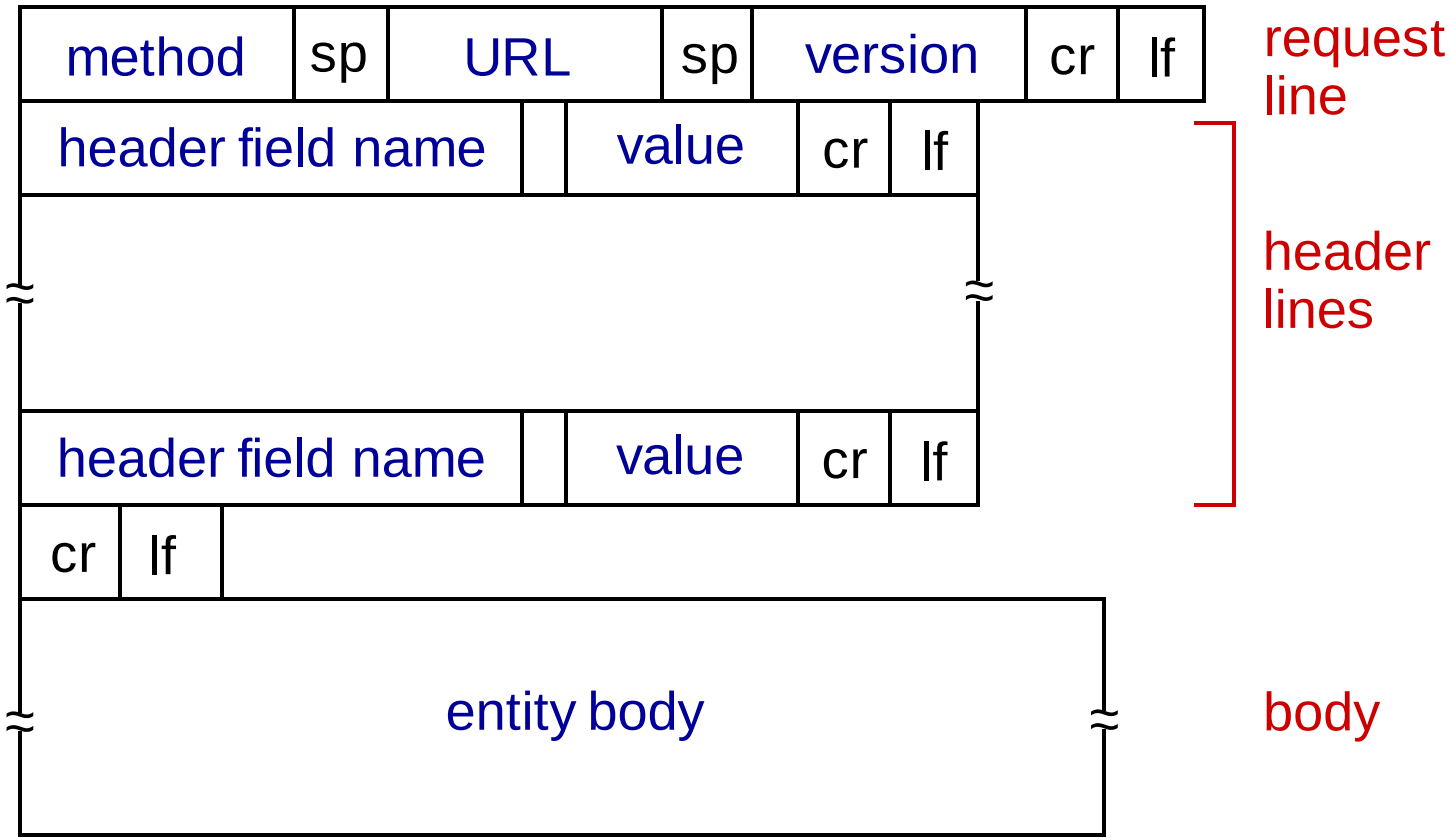
# HTTP request message

- Two types of HTTP messages: request, response
- HTTP request message:
  - ASCII (human-readable format)



# HTTP request message: general format



# Uploading form input

- POST method:
  - Web page often includes form input
  - Input is uploaded to server in entity body
- URL method:
  - Uses GET method
  - Input is uploaded in URL field of request line:
    - www.somesite.com/animalsearch?monkeys&banana

# Method types

- HTTP/1.0:
  - GET
  - POST
  - HEAD
    - Asks server to leave requested object out of response
- HTTP/1.1:
  - GET, POST, HEAD
  - PUT
    - Uploads file in entity body to path specified in URL field
  - DELETE
    - Deletes file specified in the URL field

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# HTTP response message

status line (protocol status code status phrase)

header lines

data, e.g., requested HTML file

```
HTTP/1.1 200 OK\r\n
Date: Sun, 26 Sep 2010 20:09:20 GMT\r\n
Server: Apache/2.0.52 (CentOS)\r\n
Last-Modified: Tue, 30 Oct 2007 17:00:02
   GMT\r\n
ETag: "17dc6-a5c-bf716880"\r\n
Accept-Ranges: bytes\r\n
Content-Length: 2652\r\n
Keep-Alive: timeout=10, max=100\r\n
Connection: Keep-Alive\r\n
Content-Type: text/html; charset=ISO-8859-1\r\n
\r\n
data data data data data ...
```

# HTTP response status codes

- Status code appears in 1st line in server-to-client response message.
  - 200 OK
    - Request succeeded, requested object later in this msg
  - 301 Moved Permanently
    - Requested object moved, new location specified later in this msg (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

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# Using HTTP with Telnet

- Download website with “putty” (Telnet-Client):
- Settings: “RAW”, “Never Close”, Port 80, www.bing.com

```
GET / HTTP/1.1\r\n
Host: www.bing.com\r\n
\r\n
```

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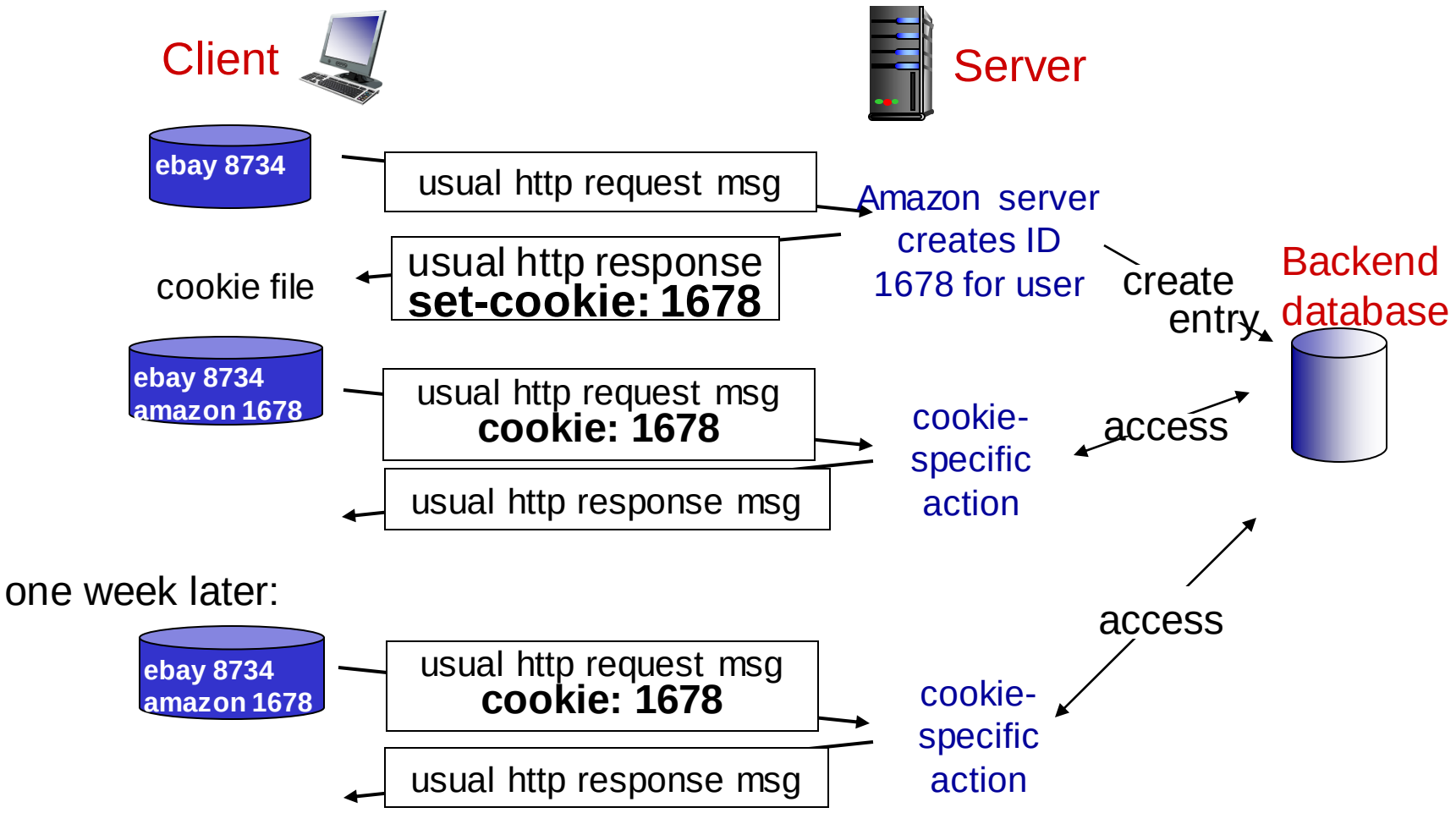
# User-server state: cookies

- Many web sites use cookies
- Four components:
  - Cookie header line of HTTP response message
  - Cookie header line in next HTTP request message
  - Cookie file kept on user's host, managed by user's browser
  - Back-end database at web site

- Example:
  - Susan always accesses Internet from same PC
  - Visits specific e-commerce site for first time
  - When initial HTTP requests arrives at site, site creates:
    - Unique ID
    - Entry in backend database for ID

# Cookies: keeping “state” (cont.)



# Cookies (continued)

- What cookies can be used for:
  - Authorization
  - Shopping carts
  - Recommendations
  - User session state (web e-mail)
- How to keep "state":
  - Protocol endpoints: maintain state at sender/receiver over multiple transactions
  - Cookies: HTTP messages carry state

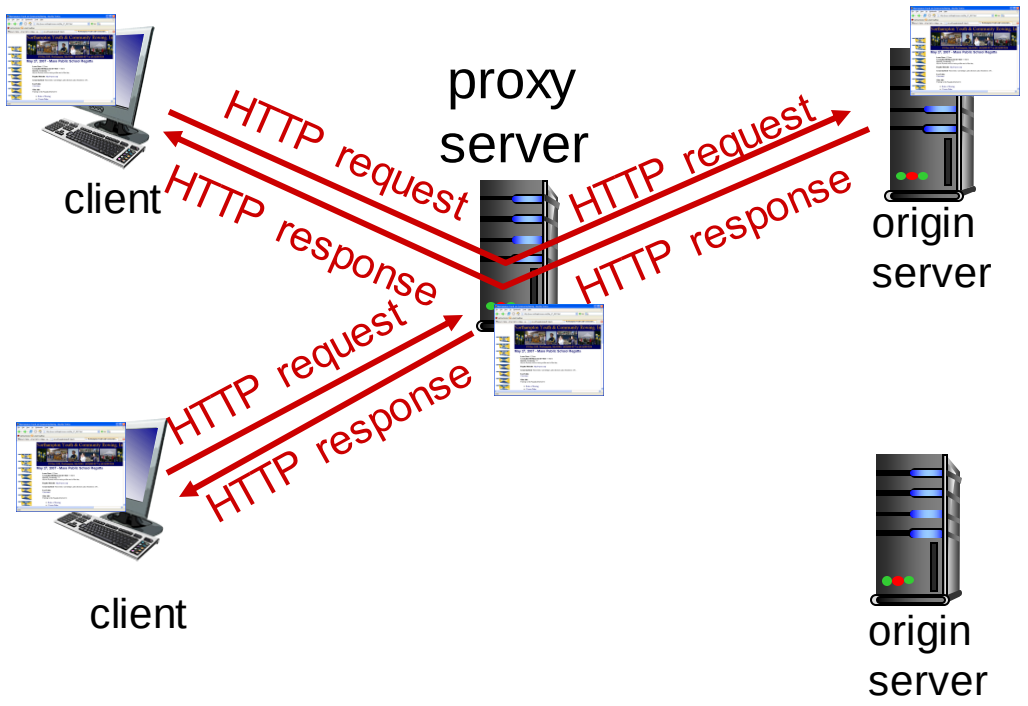
aside

*Cookies and privacy:*

- Cookies permit sites to learn a lot about you
- You may supply name and e-mail to sites

# 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



# More about Web caching

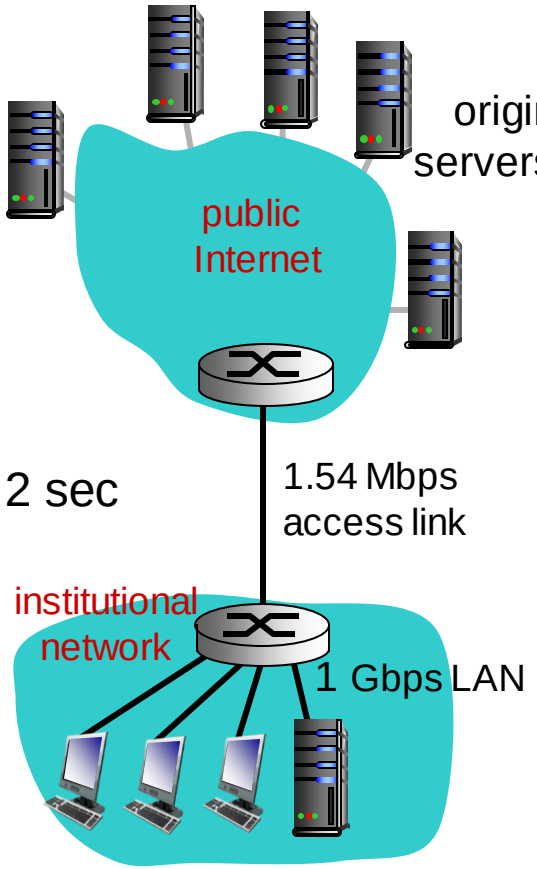
- Cache acts as both client and server
  - Server for original requesting client
  - Client to origin server
- Typically cache is installed by ISP (university, company, residential ISP)

- Why web caching?
  - Reduce response time for client request
  - Reduce traffic on an institution's access link
  - Internet dense with caches: enables "poor" content providers to effectively deliver content (so too does P2P file sharing)

# Caching example

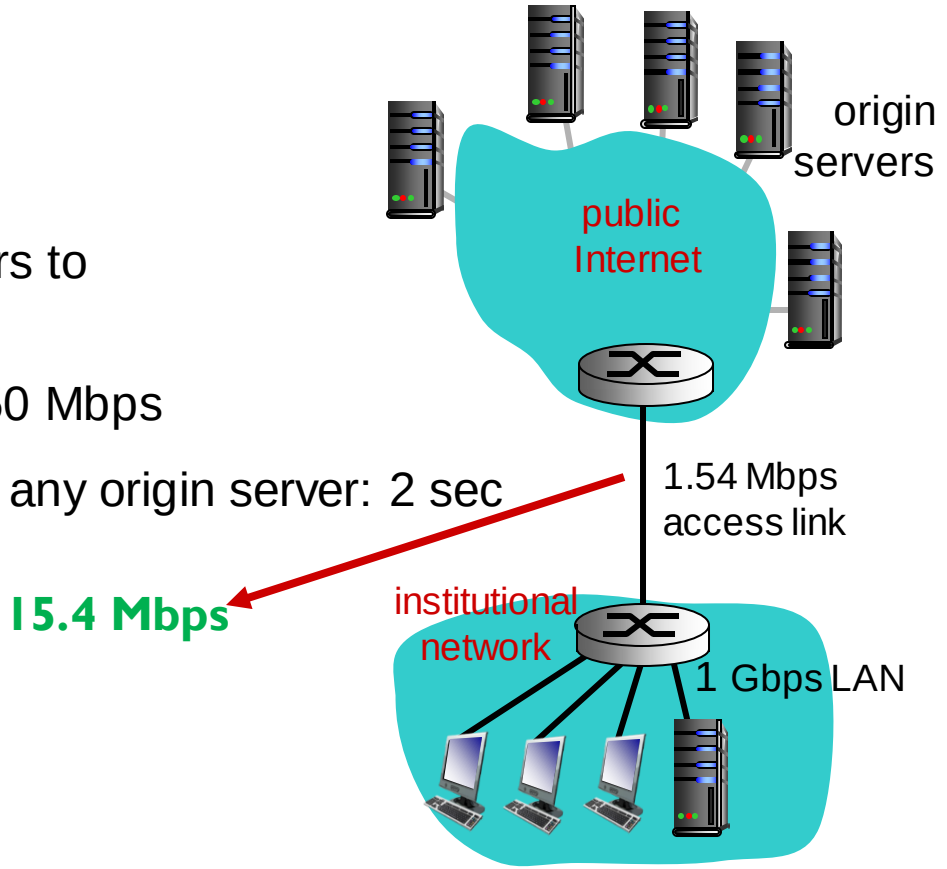
- Assumptions
  - AVG object size: 100K bits
  - AVG request rate from browsers to origin servers:15/sec
  - AVG data rate to browsers: 1.50 Mbps
  - RTT from institutional router to any origin server: 2 sec
  - access link rate: 1.54 Mbps
- Consequences:
  - LAN utilization: 15%
  - Access link utilization = 99% *problem!*
  - Total delay = Internet delay + access delay + LAN delay

= 2 sec + minutes + msecs



# Caching example: Fatter access link

- Assumptions
  - AVG object size: 100K bits
  - AVG request rate from browsers to origin servers:15/sec
  - AVG data rate to browsers: 1.50 Mbps
  - RTT from institutional router to any origin server: 2 sec
  - access link rate: 1.54 Mbps
- Consequences:
  - LAN utilization: 15%
  - Access link utilization = 9,9%
  - Total delay = Internet delay + access delay + LAN delay

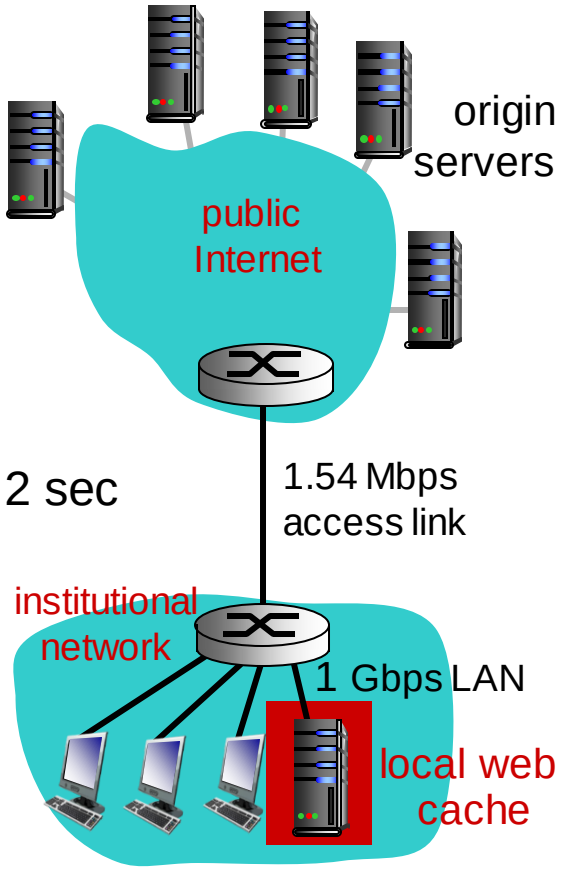



= 2 sec + msecs + msecs

*Cost:* increased access link speed (not cheap!)

# Caching example: Install local cache

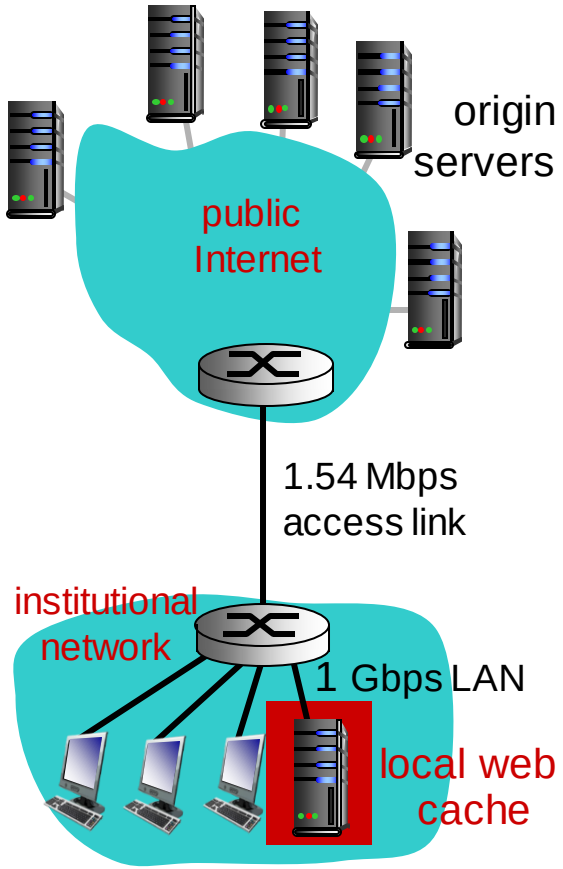
- Assumptions
  - AVG object size: 100K bits
  - AVG request rate from browsers to origin servers:15/sec
  - AVG data rate to browsers: 1.50 Mbps
  - RTT from institutional router to any origin server: 2 sec
  - access link rate: 1.54 Mbps
- Consequences:
  - LAN utilization: ?%
  - Access link utilization = ?%
  - Total delay = ?




*Cost:* web cache (cheap!)

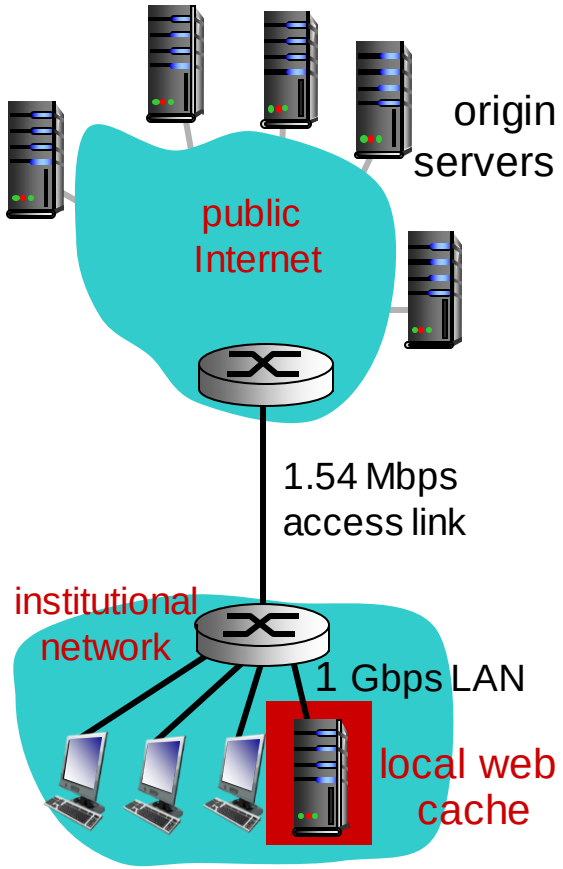
# Caching example: Install local cache

- Calculating access link utilization, delay with cache:
  - Suppose cache hit rate is 0.4
    - 40% requests satisfied at cache
  - Access link utilization:
    - 60% of requests use access link
  - Data rate to browsers over access link = 0.6 * 1.50 Mbps = 0.9 Mbps
    - utilization = 0.9/1.54 = **58%**



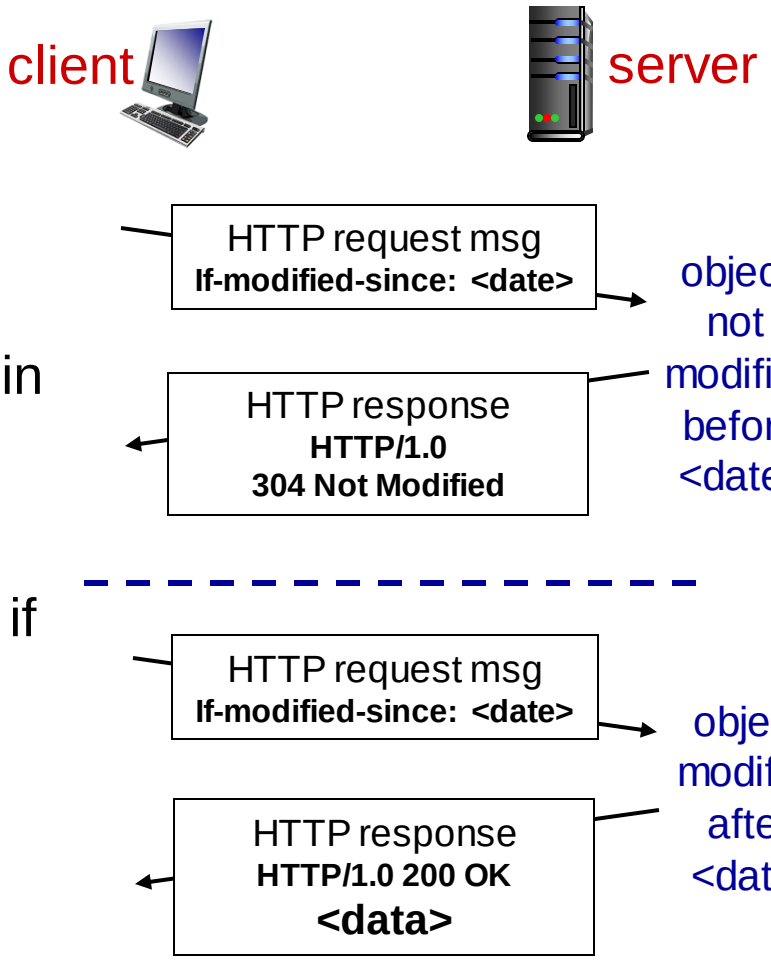
# Caching example: Install local cache

- Calculating access link utilization, delay with cache:
  - Total delay
    - = 0.6 * (delay from origin servers) + 0.4 * (delay when satisfied at cache)
    - = 0.6 (2.01) + 0.4 (~msecs)
    - = ~ 1.2 secs
    - Less than with 154 Mbps link (and cheaper too!)



# Conditional GET

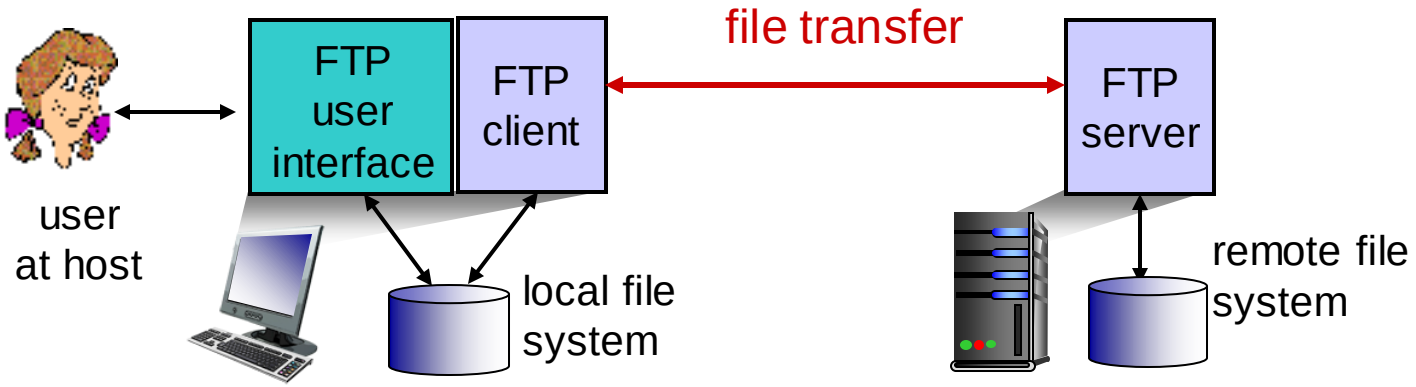
- Goal: don't send object if cache has up-to-date cached version
  - No object transmission delay
  - Lower link utilization
- Cache: specify date of cached copy in HTTP request
  - If-modified-since: <date>
- Server: response contains no object if cached copy is up-to-date:
  - HTTP/1.0 304 not modified



# Chapter 2: Roadmap

- Principles of network applications
- Web and HTTP
- FTP
- DNS
- Electronic mail
  - SMTP, POP3, IMAP
- Socket programming with UDP and TCP

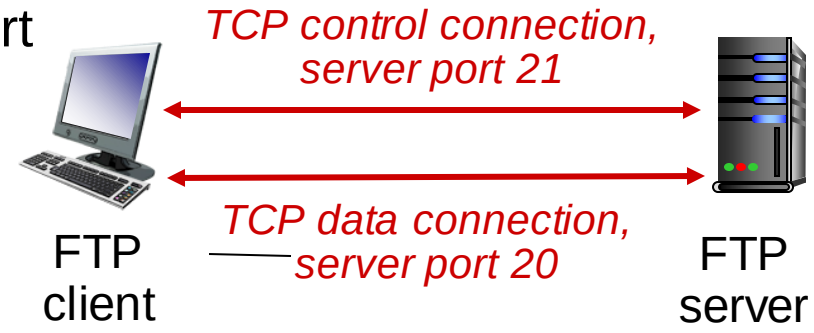
# FTP: the file transfer protocol




- Transfer file to/from remote host
- Client/server model
  - client: side that initiates transfer (either to/from remote)
  - server: remote host
- FTP: RFC 959
- FTP server: port 21

# FTP: separate control, data connections

- FTP client contacts FTP server at port 21, using TCP
- Client authorized over control connection
- Client browses remote directory, sends commands over control connection
- When server receives file transfer command, server opens 2nd TCP data connection (for file) to client
- After transferring one file, server closes data connection




- Server opens another TCP data connection to transfer another file
- Control connection: "out of band"
- FTP server maintains "state": current directory, earlier authentication

# FTP commands, responses

- Sample commands
  - Sent as ASCII text over control channel
  - USER username
    - Open FTP-Servers: “anonymous”
  - PASS password
    - Open FTP-Servers: your mail-address
  - LIST return list of file in current directory
  - RETR filename retrieves (gets) file
  - STOR filename stores (puts) file onto remote host
- Sample return codes
  - Status code and phrase (as in HTTP)
  - 331 username OK, password required
  - 125 data connection already open; transfer starting
  - 425 can’t open data connection
  - 452 error writing file

# FTP commands, responses

- Test FTP-Server: **ftp.avm.de**
- Konsolen ftp:
  - Konsole öffnen: “cmd” (Windows)
  - ftp ftp.avm.de
  - Username “anonymous”
  - Password: your mail-address
  - “help” shows a list of all possible instructions
    - dir – lists all files in directory
    - get file – downloads file from server
    - quit – quits ftp
- Open Source Software: FileZilla (Windows/Mac/Linux)

# Chapter 2: Roadmap

- Principles of network applications
- Web and HTTP
- FTP
- DNS
- Electronic mail
  - SMTP, POP3, IMAP
- Socket programming with UDP and TCP

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# DNS: domain name system

- People: many identifiers:
  - SSN, name, passport #
- Internet hosts, routers:
  - IP address (32 bit) - used for addressing datagrams
  - "Name", e.g., www.yahoo.com - used by humans
- *Q:* How to map between IP address and name, and vice versa ?

- Domain name system:
  - Distributed database implemented in hierarchy of many name servers
  - Application-layer protocol: hosts, name servers communicate to resolve names (address/name translation)
    - Note: core internet function, implemented as application-layer protocol
    - Complexity at network's "edge"

# DNS: services, structure

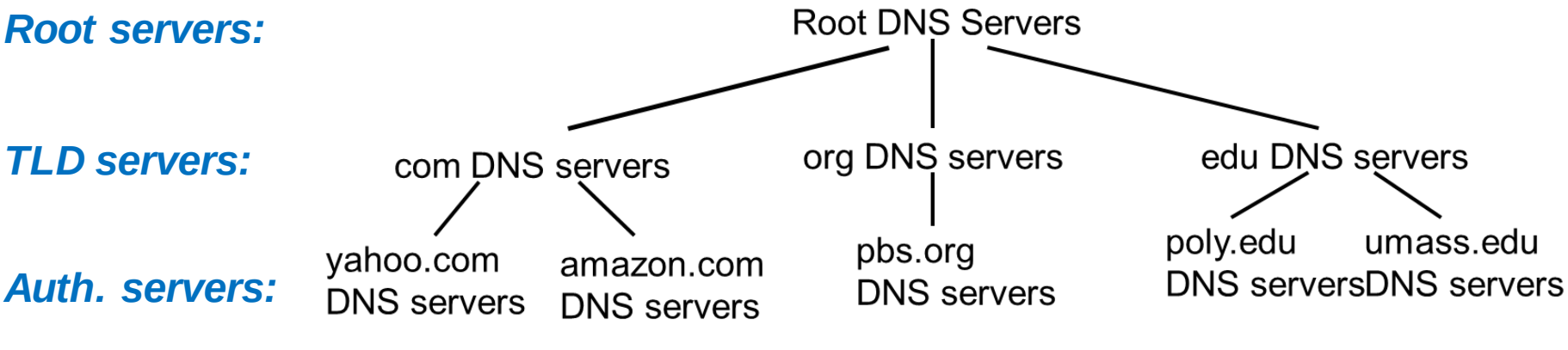
- DNS services
  - Hostname to IP address translation
  - Host aliasing
    - Canonical, alias names
  - Mail server aliasing
  - Load distribution
    - Replicated web servers: many IP addresses correspond to one name

*Why not centralize DNS?*

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

A: *Doesn't scale!*

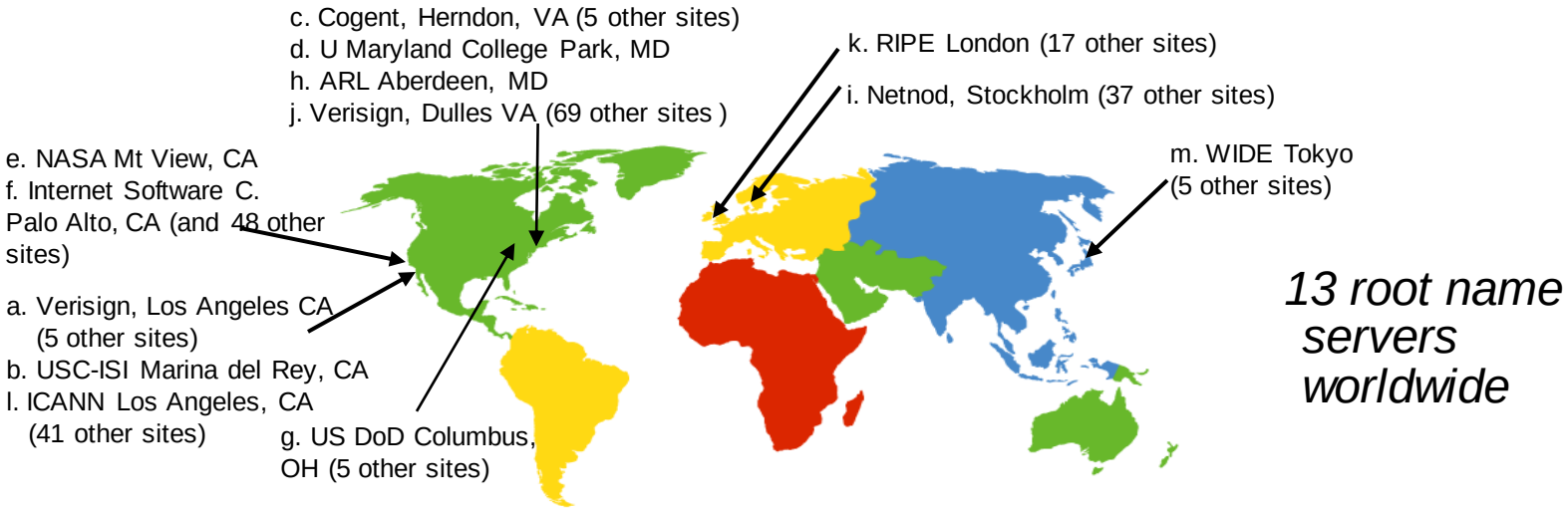
# DNS: a distributed, hierarchical database




- Client wants IP for www.amazon.com; 1st approx:
  - Client queries root server to find .com DNS server
  - Client queries .com DNS server to get amazon.com DNS server
  - Client queries amazon.com DNS server to get IP address for www.amazon.com

# 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 root name servers worldwide*

# TLD, authoritative servers

- Top-level domain (TLD) servers:
  - Responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: **UK, FR, CA, JP, DE**
  - Network solutions maintains servers for .Com TLD
  - 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

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# Local DNS name server

- Does not strictly belong to hierarchy
- Each ISP (residential ISP, company, university) has one
  - Also called "**default name server**"
- 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

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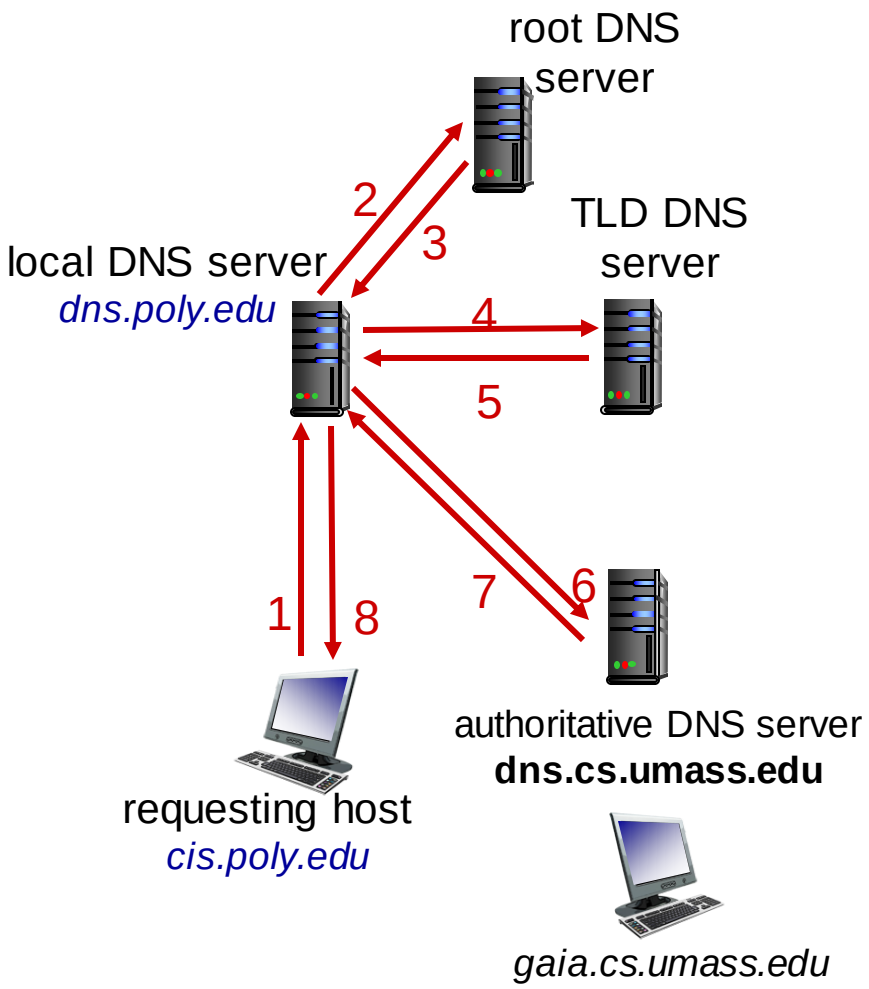
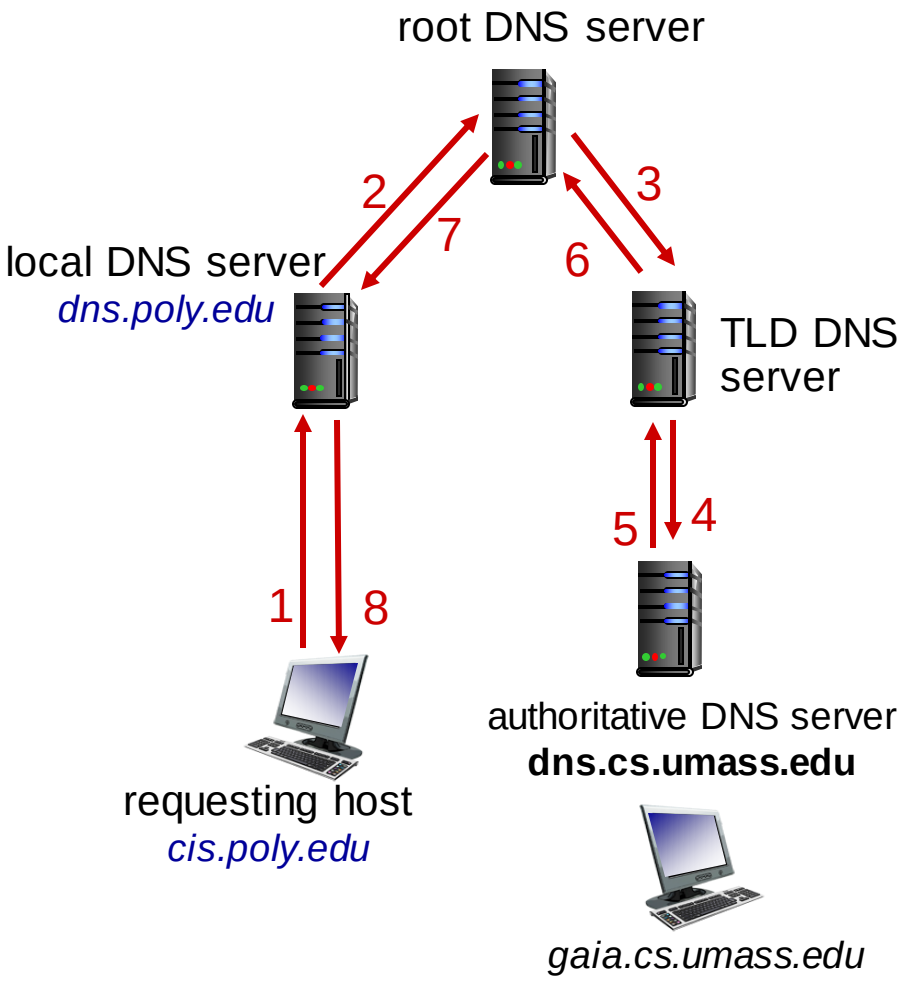
# DNS name resolution example

- Host at cis.Poly.Edu wants IP address for gaia.Cs.Umass.Edu
- Iterated query
  - Contacted server replies with name of server to contact
  - "I don't know this name, but ask this server"



# DNS name resolution example

- Recursive query
  - Puts burden of name resolution on contacted name server
  - Heavy load at upper levels of hierarchy?



# DNS: caching, updating records

- 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 name servers not often visited
- Cached entries may be out-of-date (best effort name-to-address translation!)
  - If name host changes IP address, may not be known internet-wide until all TTLs expire
- Update/notify mechanisms proposed IETF standard
  - RFC 2136

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# DNS records

*DNS:* Distributed DB storing resource records (RR)

RR format: `(name, value, type, ttl)`

## type=A

- **`name`** is hostname
- **`value`** is IP address

## type=NS

- **`name`** is domain (e.g., foo.com)
- **`value`** is hostname of authoritative name server for this domain

## type=CNAME

- **`name`** is alias name for some "canonical" (the real) name
- **`www.ibm.com`** is really **`servereast.backup2.ibm.com`**
- **`value`** is canonical name

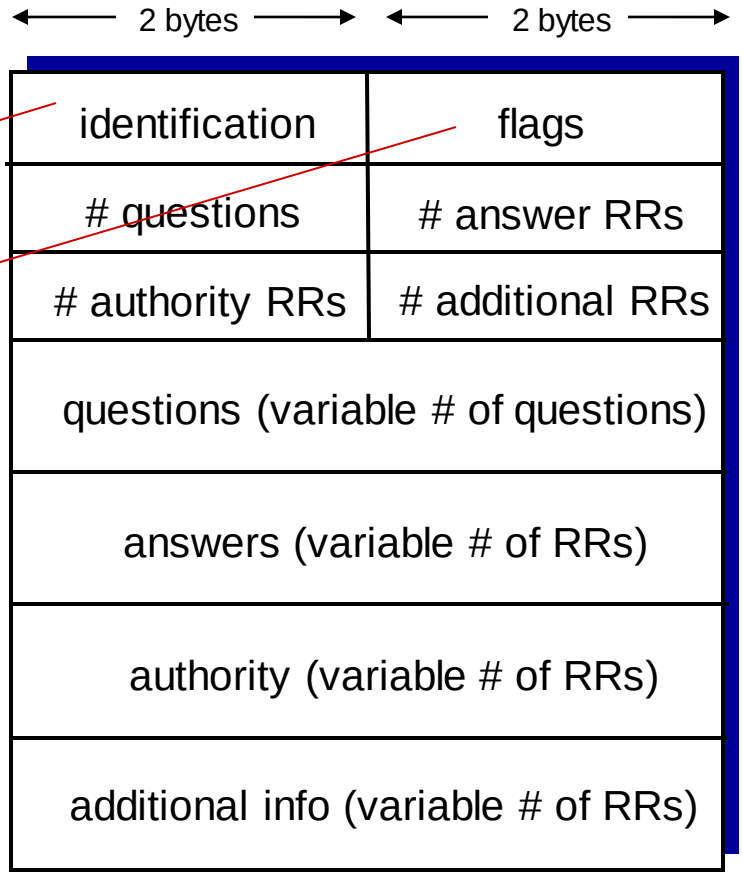
## type=MX

- **`value`** is name of mailserver associated with **`name`**

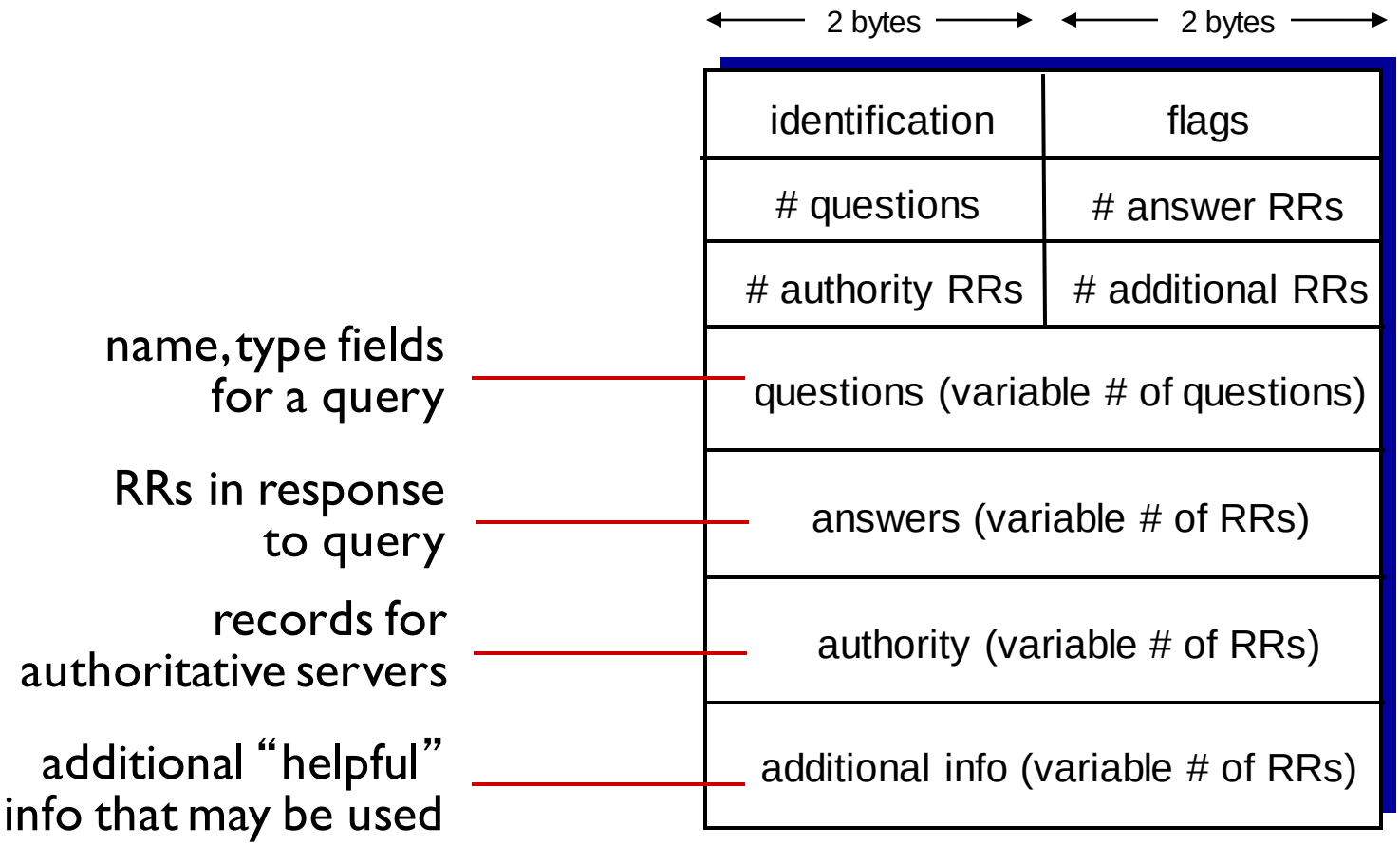
# DNS protocol, messages

- Query and reply messages, both with same message format

- Msg header
  - Identification: 16 bit # for query, reply to query uses same #
  - Flags:
    - Query or reply
    - Recursion desired
    - Recursion available
    - Reply is authoritative



# DNS protocol, messages



# Inserting records into DNS

- Example: new startup “Network Utopia”
  - Register name networkutopia.com at DNS registrar (e.g., Network Solutions)
    - Provide names, IP addresses of authoritative name server (primary and secondary)
    - Registrar inserts two RRs into .com TLD server:
      - (networkutopia.com, dns1.networkutopia.com, NS)
      - (dns1.networkutopia.com, 212.212.212.1, A)

# Attacking DNS

- DDoS attacks
  - Bombard root servers with traffic
    - Not successful to date
    - Traffic Filtering
    - Local DNS servers cache IPs of TLD servers, allowing root server bypass
  - Bombard TLD servers
    - Potentially more dangerous
- Redirect attacks
  - Man-in-middle
    - Intercept queries
  - DNS poisoning
    - Send bogus replies to DNS server, which caches
- Exploit DNS for DDoS
  - Send queries with spoofed source address: target IP