Applications Layer Protocols

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Acknowledgements

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- The instructor used the following references
  - Larry L. Peterson and Bruce S. Davie, Computer Networks: A Systems Approach, 5th Edition, Elsevier, 2011
  - Andrew S. Tanenbaum, Computer Networks, 5th Edition, Prentice-Hall, 2010
  - James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach, 5th Ed., Addison Wesley, 2009
  - Larry L. Peterson's (http://www.cs.princeton.edu/~llp/) Computer Networks class web site

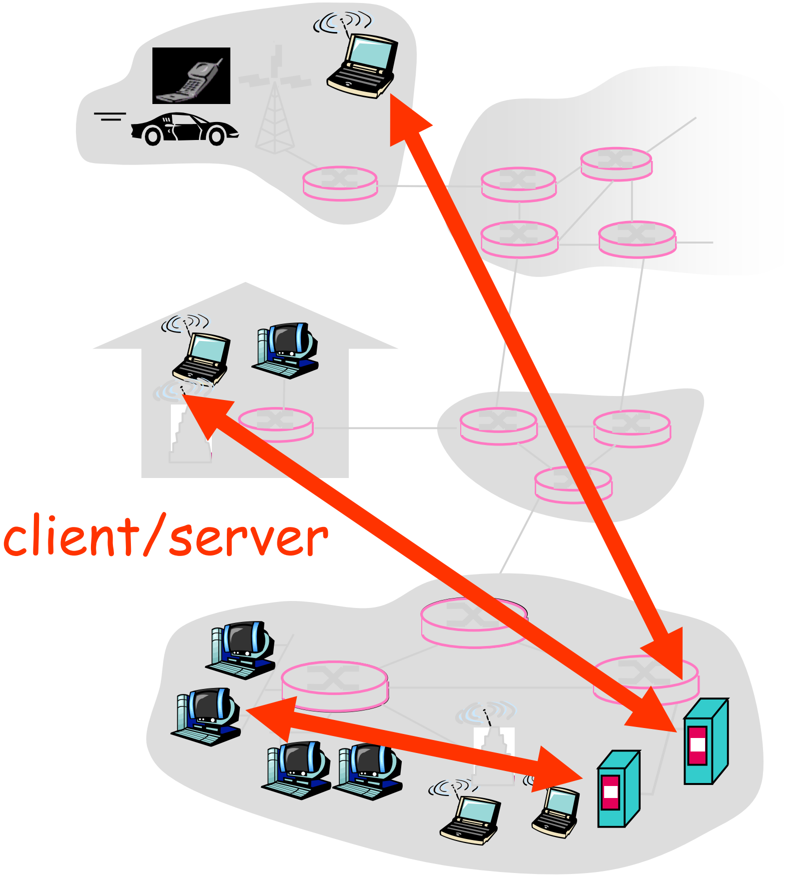
Outline

- Network application architecture
  - Peer-to-peer
  - Client-server
  - Hybrid
- Naming services
  - DNS
- The World Wide Web
  - HTTP
- E-mail
  - SMTP

Application architectures

- Client-server
- Peer-to-peer (P2P)
- Hybrid of client-server and P2P

Client-Server Architecture



server:

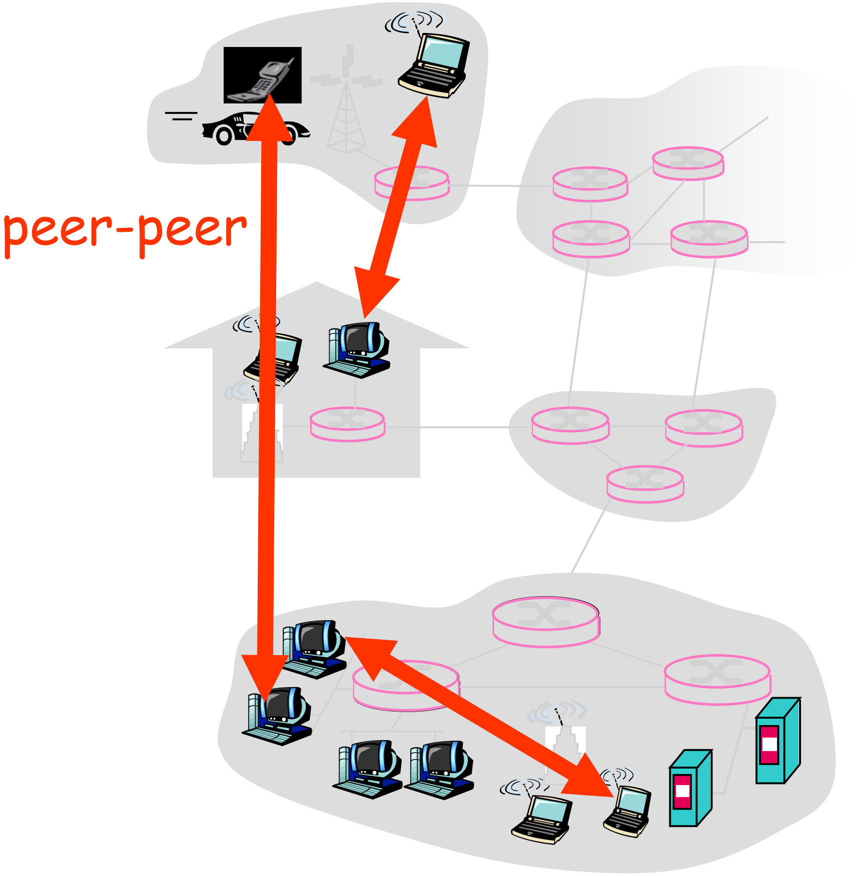
- always-on host
- permanent IP address
- server farms for scaling

clients:

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

Pure P2P architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and change IP addresses



Highly scalable but difficult to manage

Hybrid of Client-Server and P2P

Skype

- voice-over-IP P2P application
- centralized server: finding address of remote party:
- client-client connection: direct (not through server)

Instant messaging

- chatting between two users is P2P
- centralized service: client presence detection/location
  - user registers its IP address with central server when it comes online
  - user contacts central server to find IP addresses of buddies

Naming

- Terminology
- Domain Naming System
- Distributed File Systems

Overview

- Why do names do?
    - Identify objects
    - Help locate objects
    - Define membership in a group
    - Specify a role
    - Convey knowledge of a secret
- Name space
    - Defines set of possible names
    - Consists of a set of name to value bindings
        - Example:

Value	Name
123	ABC

- Resolution mechanism
    - Returns the corresponding value when invoked with a name

Properties

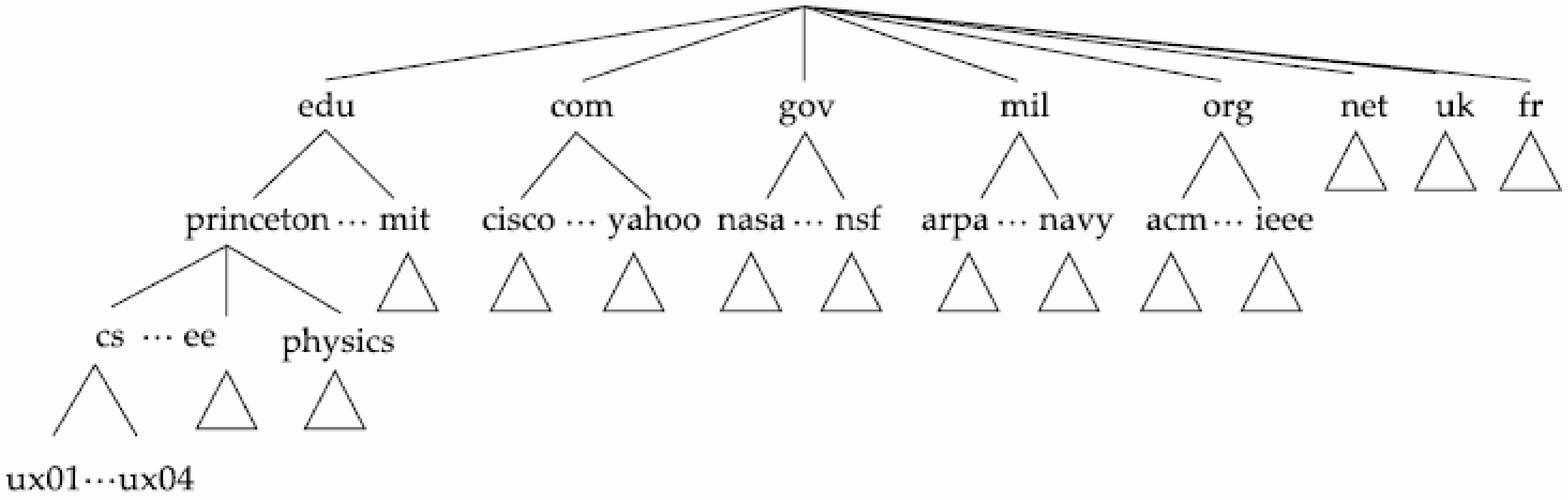
- Names vs. addresses
- Location transparent vs. location-dependent
- Flat vs. hierarchical
- Global vs. local
- Absolute vs. relative
- By architecture vs. by convention
- Unique vs. ambiguous

Naming Services: Name Resolution

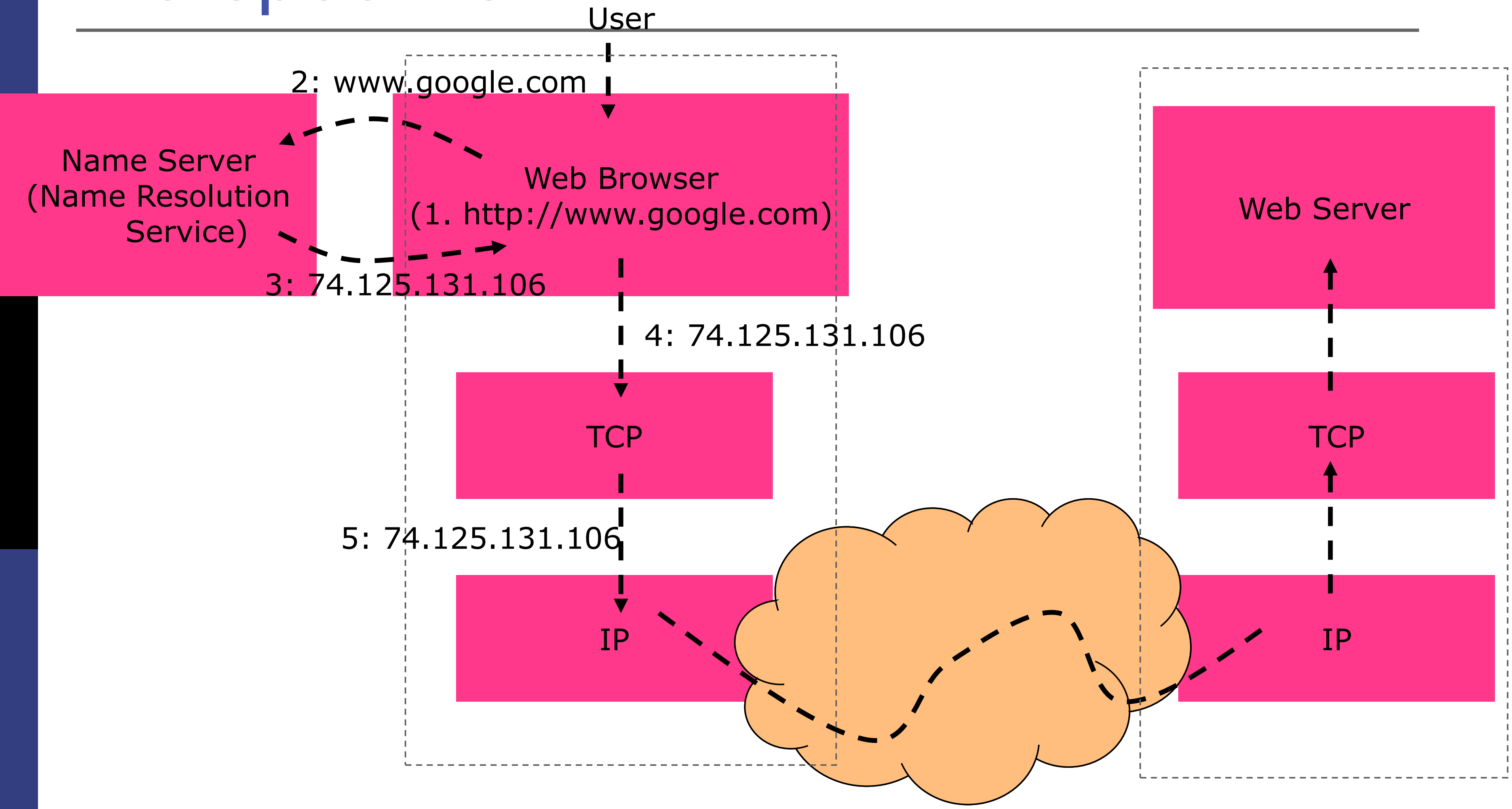
- Files
  - Examples
    - Unix/Linux: /etc/hosts
    - Windows: C:\WINDOWS\system32\drivers\etc\hosts
- Sun Network Information Service (NIS) and NIS+
- Network Security Services (NSS) Database
  - Example: NSS library for the Berkeley DB
- Light Weight Directory Service (LDAP)
  - Example: OpenLDAP
- Domain Name Service (DNS)
- Put things together: real life example
  - Unix/Linux:
    - System Databases and Name Service Switch configuration file: /etc/nsswitch.conf
    - man nsswitch.conf
  - Windows:
    - \HKEY_LOCAL_MACHINE\System\CurrentControlSet\Services\TCPIP\ServiceProvider

Domain Naming System

- Hierarchy



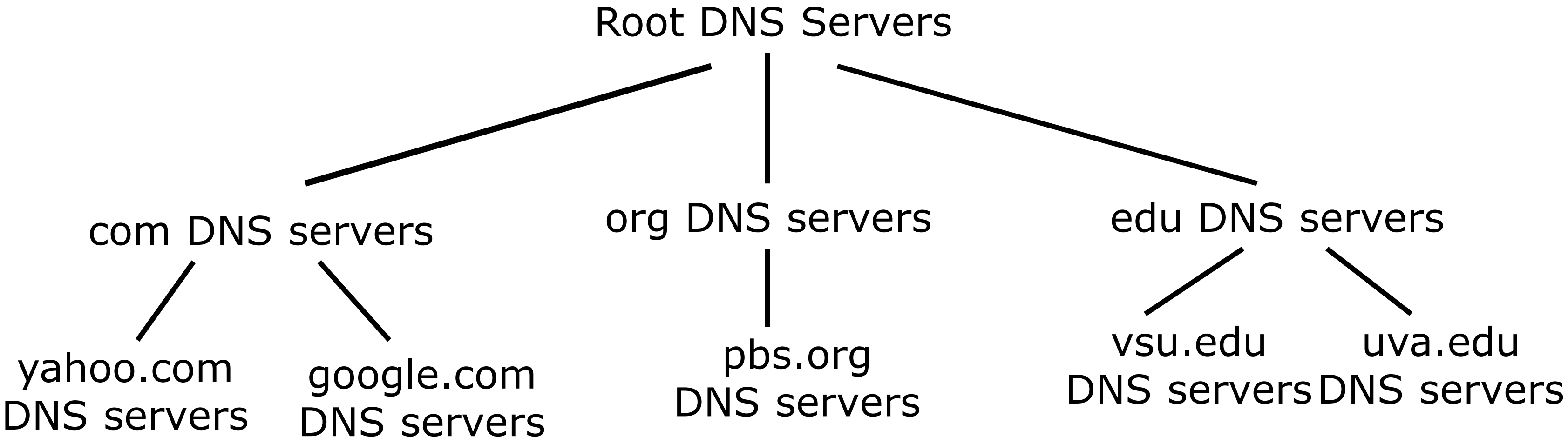
Name Resolution: Application Perspective



Name Resolution: Name System Perspective

- DNS consists of distributed and hierachical database servers
- Naming resolution may involves multiple rounds of message exchanges

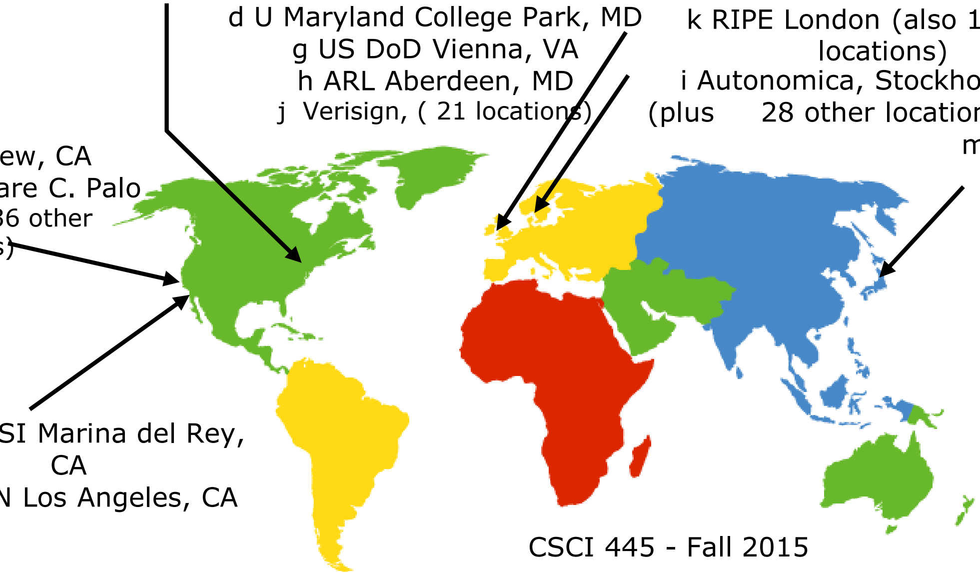
Distributed and Hierarchical Database



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

http://www.root-servers.org/



a Verisign, Dulles, VA
c Cogent, Herndon, VA (also LA)
d U Maryland College Park, MD
g US DoD Vienna, VA
h ARL Aberdeen, MD
j Verisign, (21 locations)

k RIPE London (also 16 other locations)
i Autonomica, Stockholm (plus 28 other locations)

m WIDE Tokyo (also Seoul, Paris, SF)

e NASA Mt View, CA
f Internet Software C. Palo Alto, CA (and 36 other locations)

b USC-ISI Marina del Rey, CA
l ICANN Los Angeles, CA

13 root name servers worldwide

TLD and Authoritative Servers

- Top-level domain (TLD) servers
  - Reesponsible for com, org, net, edu, etc, and all top-level country domains uk, fr, ca, jp.
    - Examples
      - Network Solutions maintains servers for com TLD
      - Educause for edu TLD
    - See http://www.iana.org/domains/root/db/
- Authoritative DNS servers
  - organization's DNS servers, providing authoritative hostname to IP mappings for organization's servers (e.g., Web, mail).
  - can be maintained by organization or service provider
  - Example: Virginia State University (vsu.edu)
    - external.vsu.edu (150.174.7.17)

Local 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
  - acts as proxy, forwards query into hierarchy
- Example: Virginia State University (vsu.edu)
  - 150.174.7.85 (vsu-dc-02v.vsu.edu)
  - 150.174.7.167 (vsu-dc-03v.vsu.edu)

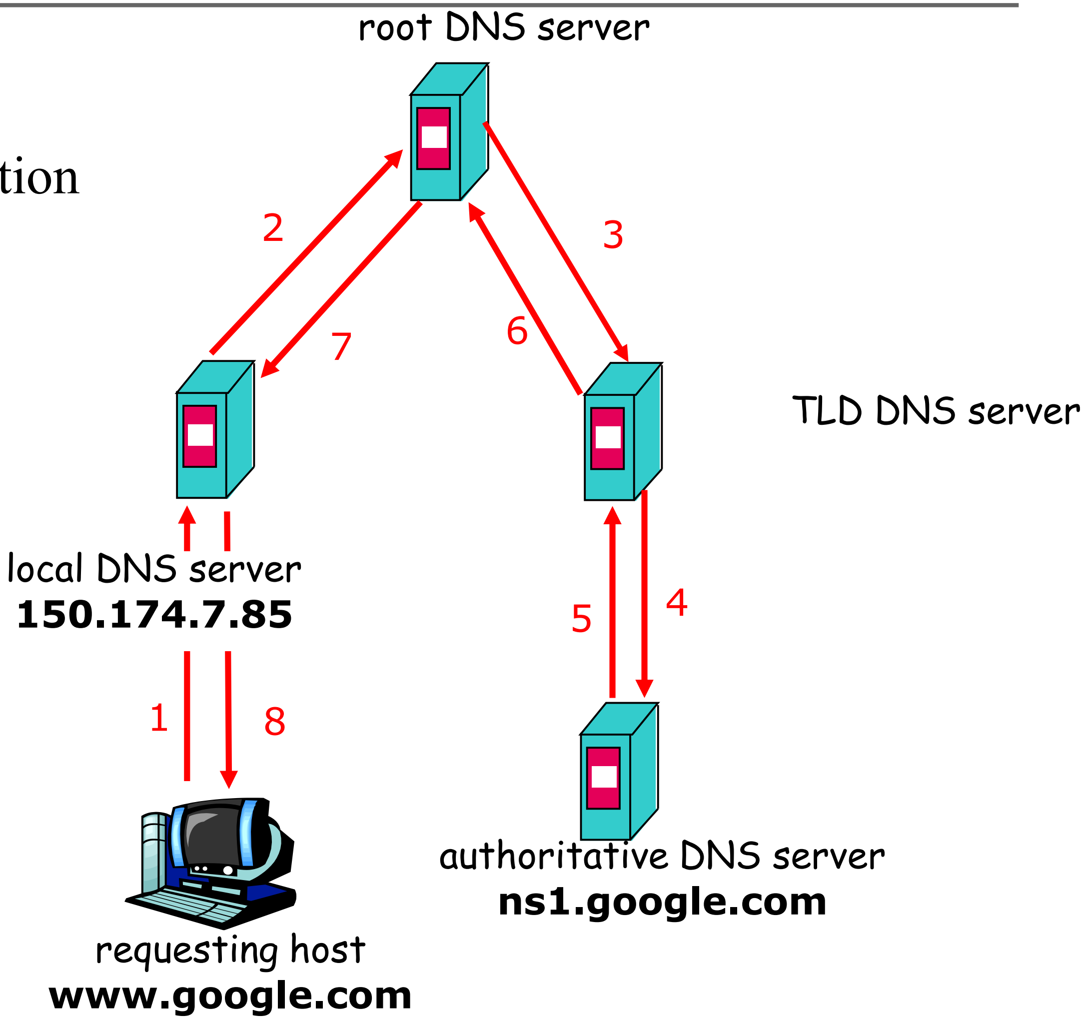
Local Name Servers

- A few well-known public local name servers for testing
- Google’s public DNS servers
  - 8.8.8.8, 8.8.4.4
- Level 3’s Public DNS servers
  - 209.244.0.3, 209.244.0.4, 4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.2.4
- OpenDNS's DNS servers
  - 208.67.222.222, 208.67.220.220

Name Resolution

- Strategies
  - Forward
  - Iterative
  - Recursive
- Local server
  - Need to know root at only one place (not each host)
  - Site-wide cache

DNS Name Resolution Example (2)



recursive query:

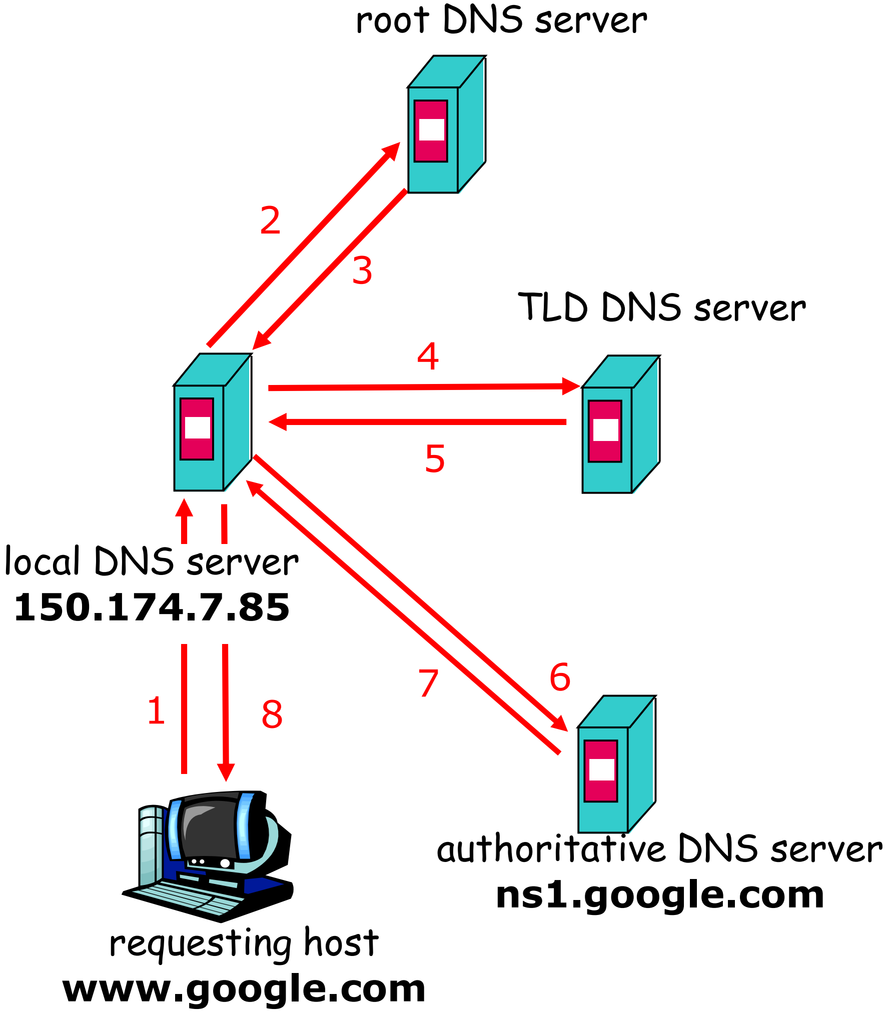
- puts burden of name resolution on contacted name server
- heavy load?

DNS Name Resolution Example (1)

- Host at vsu.edu wants IP address for www.google.com

<u>iterated query:</u>

- contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”



DNS: Caching and Updating Records

- Once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time
  - TLD servers typically cached in local name servers
    - Thus root name servers not often visited
- Dynamic update/notify mechanisms
  - RFC 2136
  - http://tools.ietf.org/html/rfc2136

Example: Windows DNS Cache at Hosts

```
C:\Users\guest>ipconfig /displaydns | more

Windows IP Configuration

    r20swj13mr.microsoft.com
    ----------------------------------------
    Record Name . . . . . : r20swj13mr.microsoft.com
    Record Type . . . . . : 5
    Time To Live  . . . . : 2939
    Data Length . . . . . : 8
    Section . . . . . . . : Answer
    CNAME Record  . . . . : ie9comview.vo.msecnd.net

Record Name . . . . . :
ie9comview.vo.msecnd.net
    Record Type . . . . . : 5
    Time To Live  . . . . : 2939
    Data Length . . . . . : 8
    Section . . . . . . . : Answer
    CNAME Record  . . . . : cs1.wpc.v0cdn.net

 Record Name . . . . . : cs1.wpc.v0cdn.net
    Record Type . . . . . : 1
    Time To Live  . . . . : 2939
-- More  --
```

DNS Records

DNS: distributed db storing resource records (RR)

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

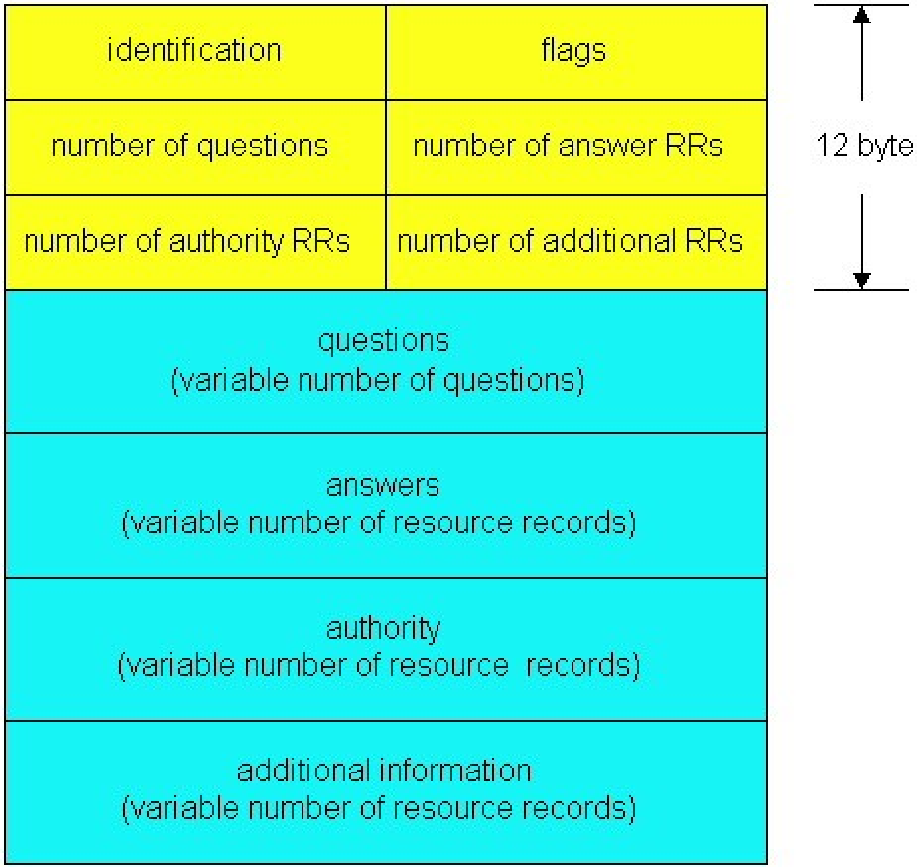
- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is hostname of authoritative name server for this domain
- Type=CNAME
  - **name** is alias name for some "canonical" (the real) name
    `www.ibm.com` is really `servereast.backup2.ibm.com`
  - **value** is canonical name
- Type=MX
  - **value** is name of mailserver associated with **name**

DNS Protocol Messages

DNS protocol : *query* and *reply* messages, both with same *message format*

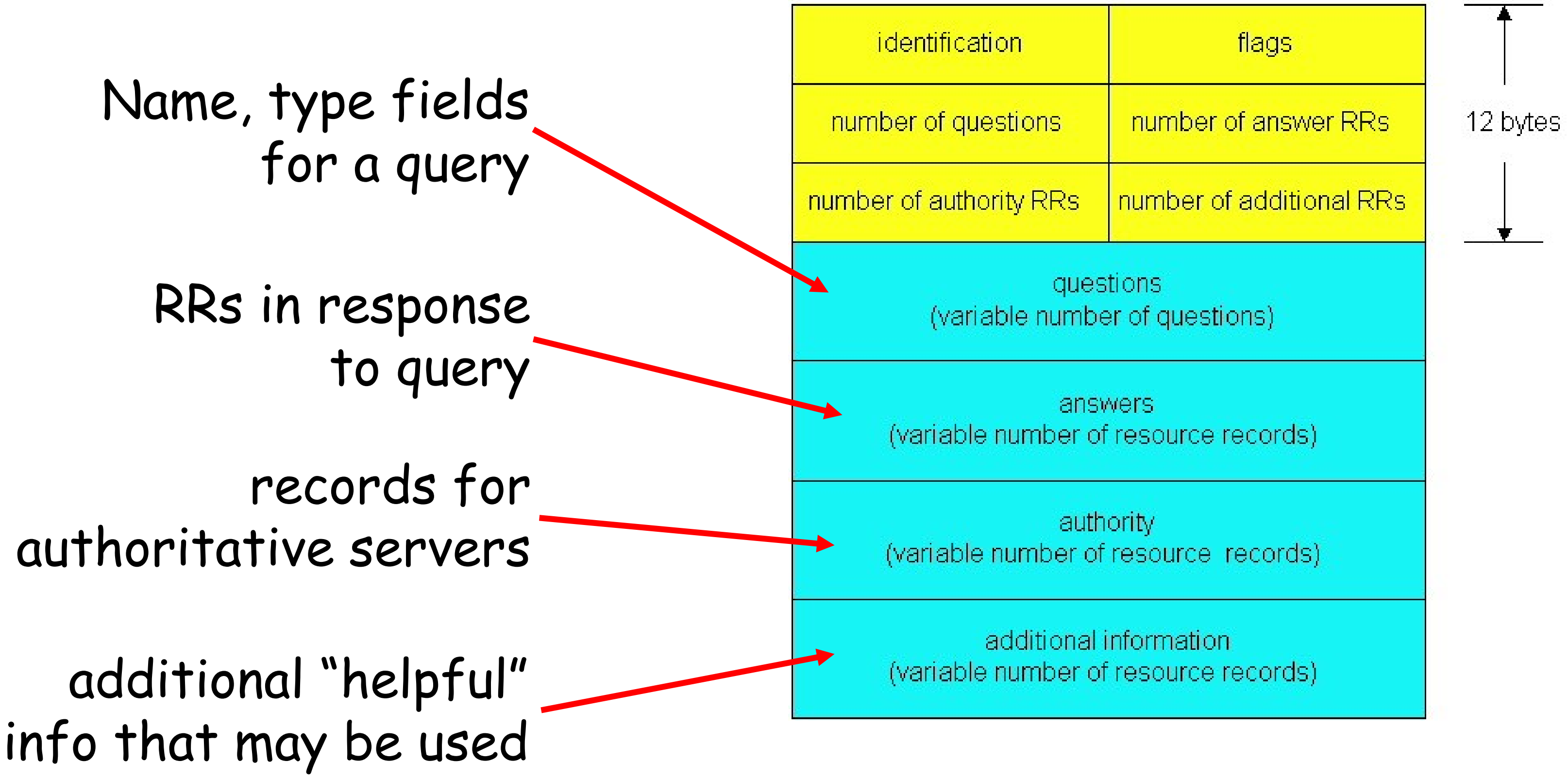
msg header

- identification: 16 bit # for query, reply to query uses same #
- flags:
  - query or reply
  - recursion desired
  - recursion available
  - reply is authoritative



identification	flags
number of questions	number of answer RRs
number of authority RRs	number of additional RRs
questions (variable number of questions)	
answers (variable number of resource records)	
authority (variable number of resource records)	
additional information (variable number of resource records)	

DNS Protocol Messages



Name, type fields for a query

RRs in response to query

records for authoritative servers

additional "helpful" info that may be used

identification	flags
number of questions	number of answer RRs
number of authority RRs	number of additional RRs
questions (variable number of questions)	
answers (variable number of resource records)	
authority (variable number of resource records)	
additional information (variable number of resource records)	

Inserting Records into DNS

- example: new startup "Network Utopia"
- register name networkuptopia.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)
```

- create authoritative server Type A record for www.networkuptopia.com; Type MX record for networkutopia.com

Exercise L19-1

- Q: How do people get IP address of www.networkutopia.com from a computer on VSU campus?

```
(networkutopia.com, dns1.networkutopia.com, NS)
(dns1.networkutopia.com, 212.212.212.1, A)
```

Turn your work in before you leave!

Web and HTTP

First some jargon

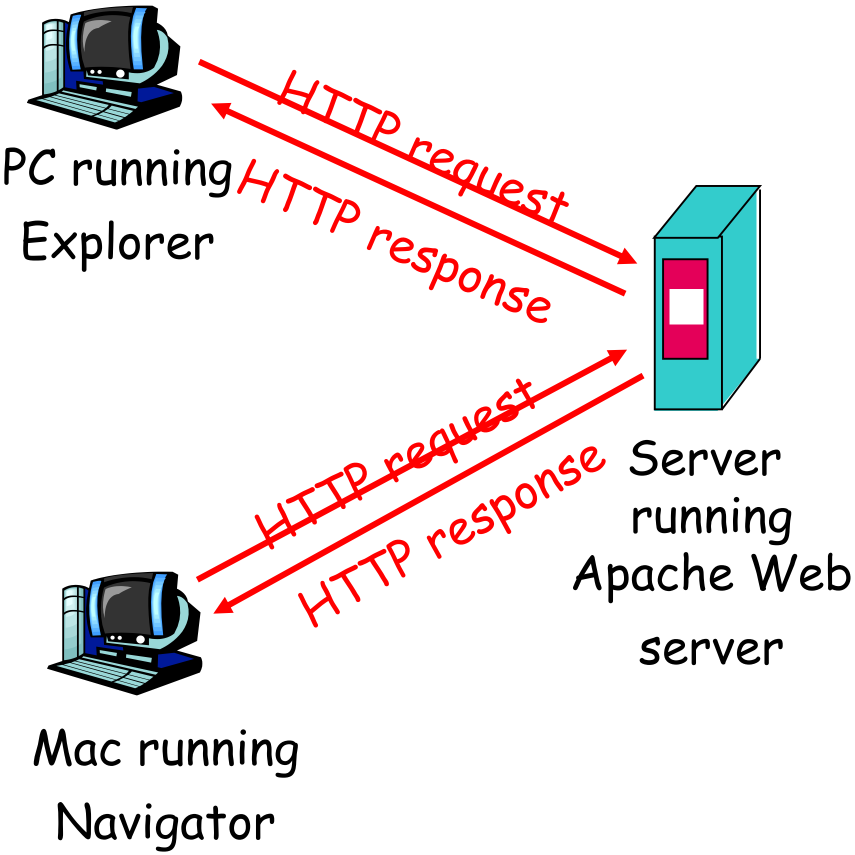
- Web page consists of objects
- Object can be HTML file, JPEG image, Java applet, audio file,…
- Web page consists of base HTML-file which includes several referenced objects
- Each object is addressable by a URL
- Example URL:

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

HTTP overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server model
  - *client:* browser that requests, receives, "displays" Web objects
  - *server:* Web server sends 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

Nonpersistent HTTP

- At most one object is sent over a TCP connection.

Persistent HTTP

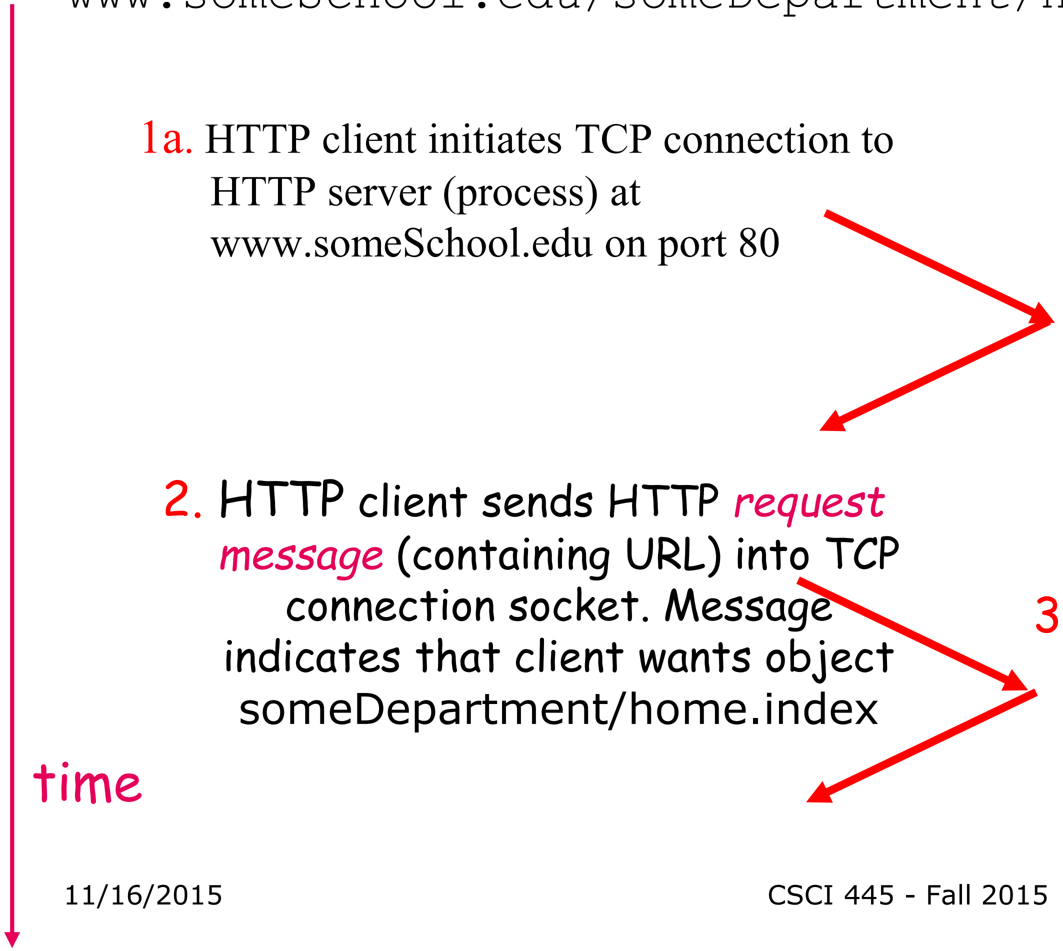
- Multiple objects can be sent over single TCP connection between client and server.

Nonpersistent HTTP

Suppose user enters URL

`www.someSchool.edu/someDepartment/home.index`

(contains text, references to 10 jpeg images)



1a. HTTP client initiates TCP connection to HTTP server (process) at www.someSchool.edu on port 80

1b. HTTP server at host www.someSchool.edu waiting for TCP connection at port 80. “accepts” connection, notifying client

2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket. Message indicates that client wants object someDepartment/home.index

3. HTTP server receives request message, forms *response message* containing requested object, and sends message into its socket

Nonpersistent HTTP (Continued)

4. HTTP server closes TCP connection.

time

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

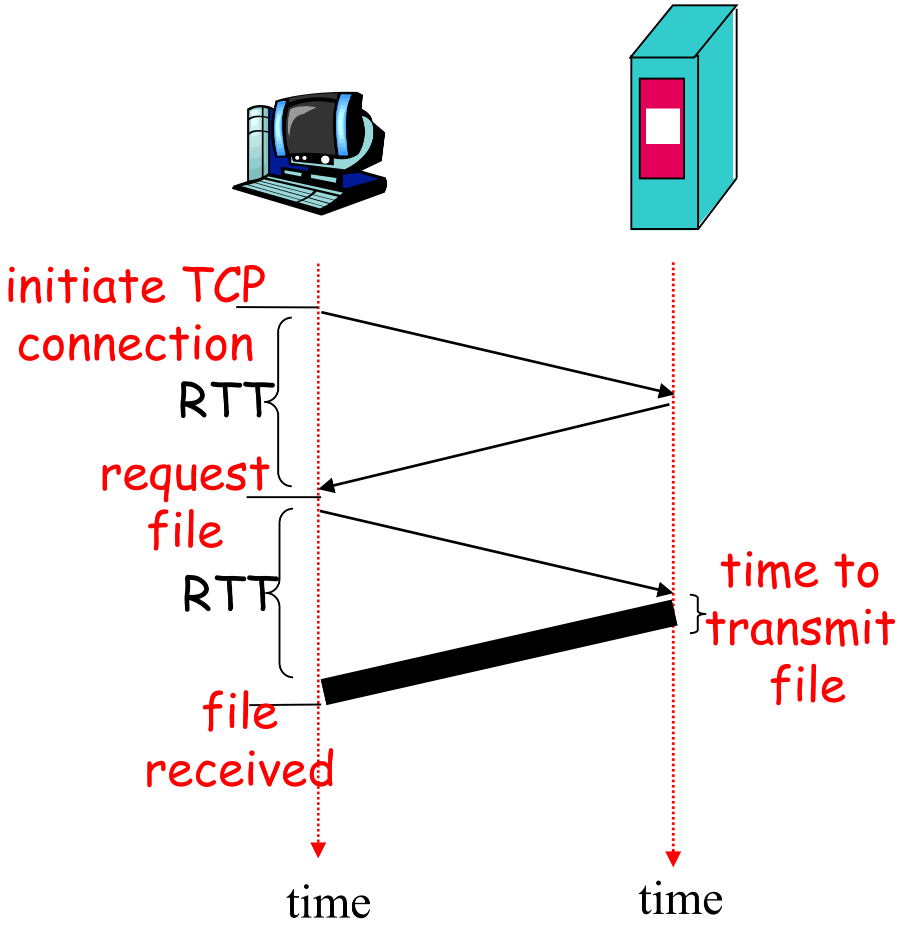
Non-Persistent HTTP: Response time

Definition of RTT: time for a small packet to travel from client to server and back.

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

total = 2RTT+transmit time



Persistent HTTP

Nonpersistent HTTP issues:

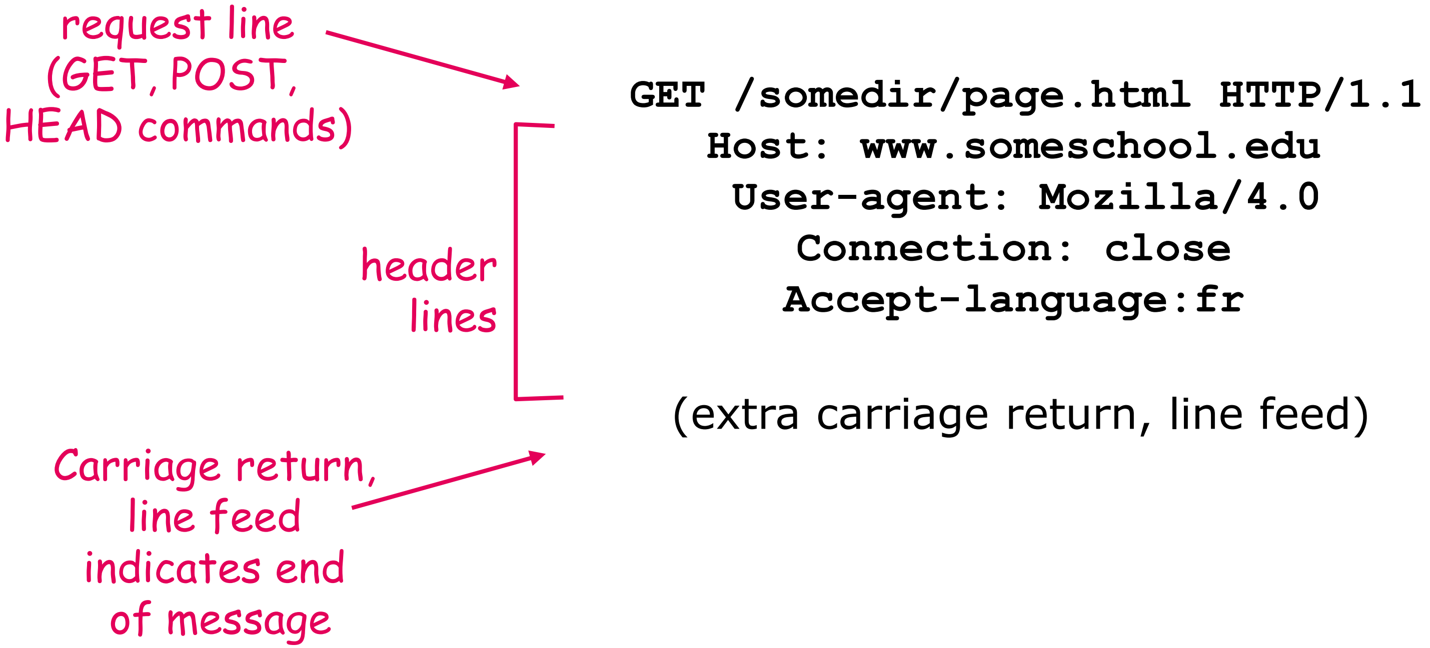
- requires 2 RTTs per object
- OS overhead for *each* TCP connection
- browsers often open parallel TCP connections to fetch referenced objects

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
- as little as one RTT for all the referenced objects

HTTP request message

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



request line (GET, POST, HEAD commands)

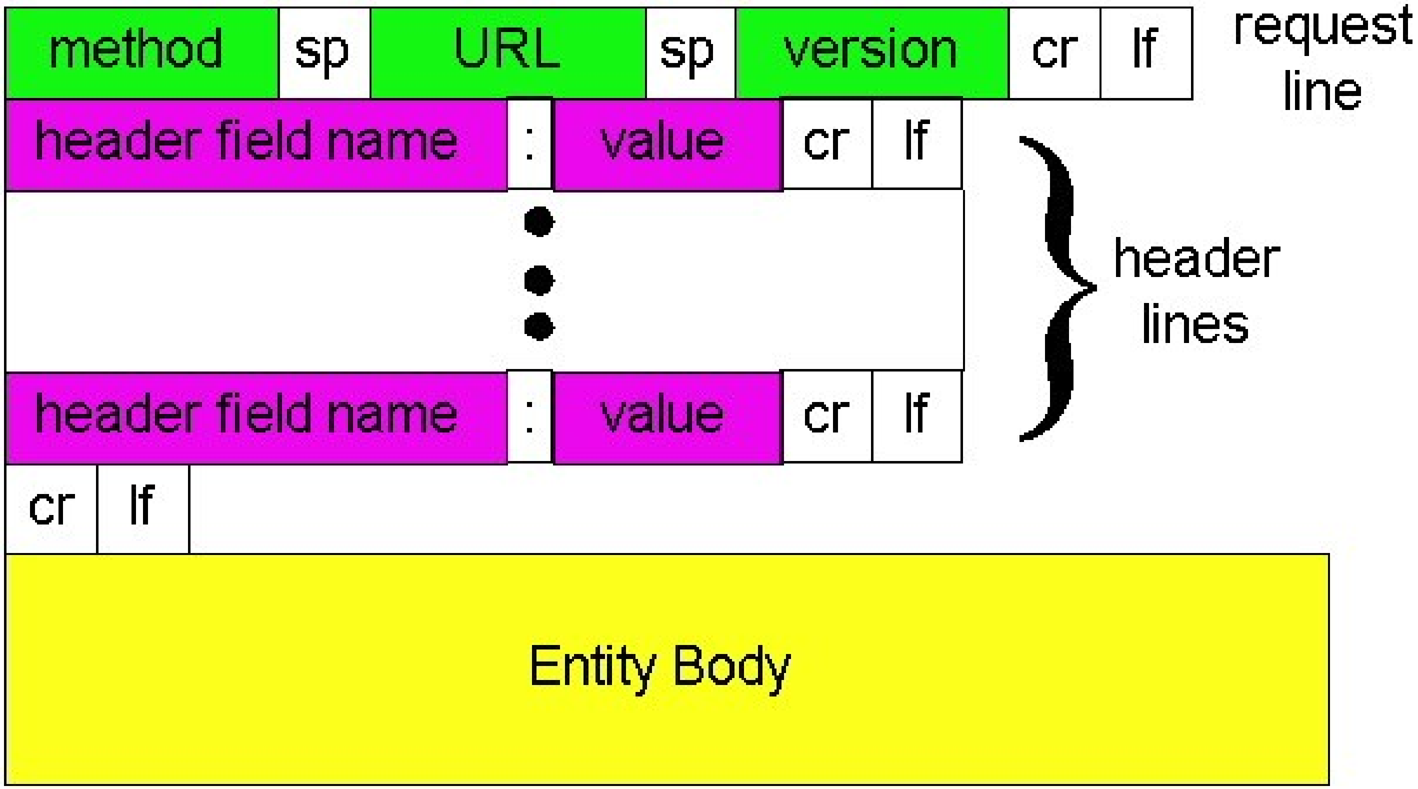
header lines

Carriage return, line feed indicates end of message

```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language:fr
```

(extra carriage return, line feed)

HTTP request message: general format



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

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`

HTTP response message

status line
(protocol
status code
status phrase)

header
lines

```
HTTP/1.1 200 OK
Connection close
Date: Thu, 06 Aug 1998 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 1998 …...
Content-Length: 6821
Content-Type: text/html

data data data data data ...
```

data, e.g.,
requested
HTML file

HTTP response status codes

In first line in server->client response message.
A few sample codes:

`200 OK`

- request succeeded, requested object later in this message

`301 Moved Permanently`

- requested object moved, new location specified later in this message (Location:)

`400 Bad Request`

- request message not understood by server

`404 Not Found`

- requested document not found on this server

`505 HTTP Version Not Supported`

Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet turing.mathcs.vsu.edu 80
```

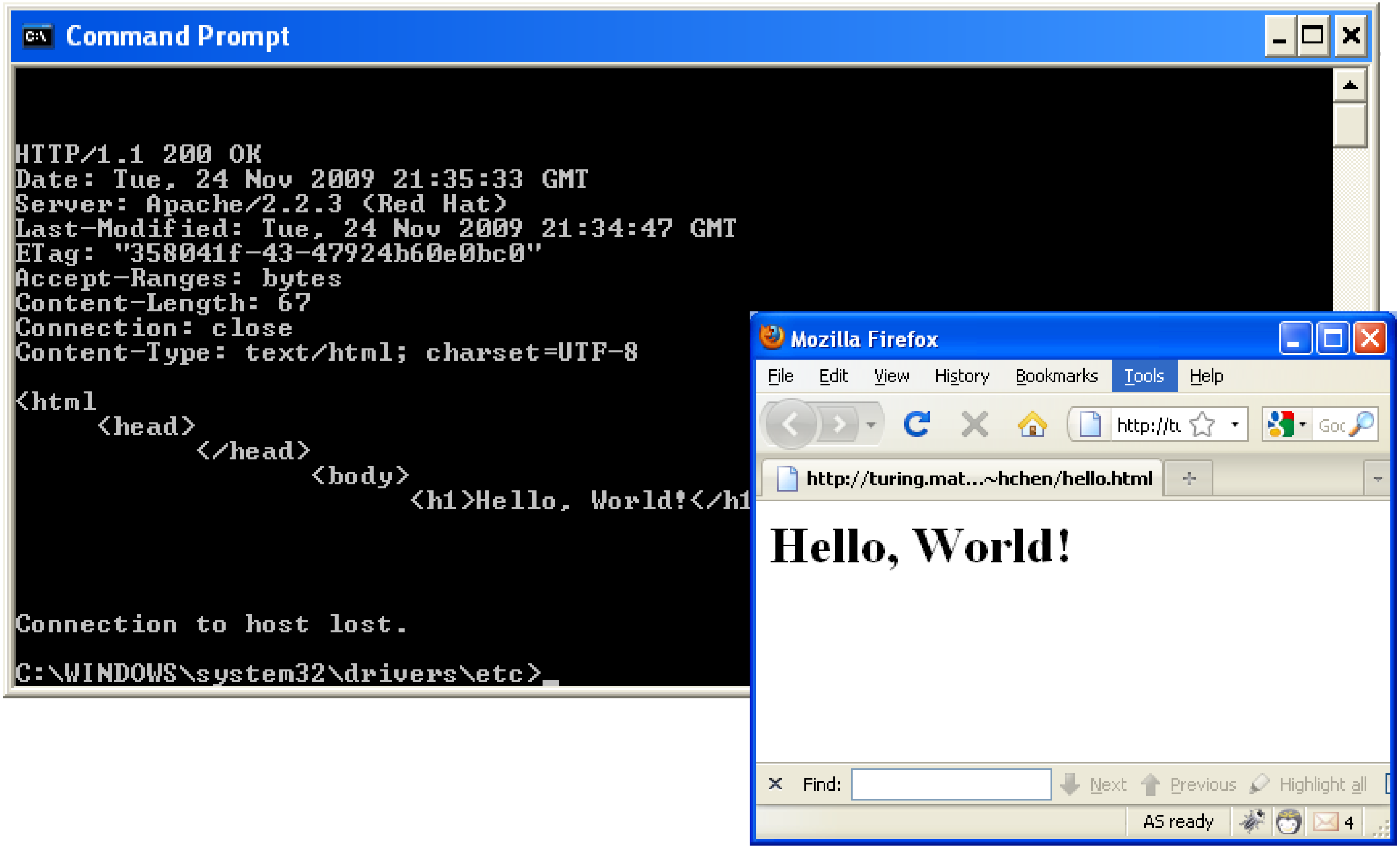
Opens TCP connection to port 80
(default HTTP server port) at turing.mathcs.vsu.e
Anything typed in sent
to port 80 at turing.mathcs.vsu.edu

2. Type in a GET HTTP request:

```
GET /~hchen/hello.html HTTP/1.1
  Host: turing.mathcs.vsu.edu
```

By typing this in (hit carriage
return twice), you send
this minimal (but complete)
GET request to HTTP server

3. Look at response message sent by HTTP server!



```
HTTP/1.1 200 OK
Date: Tue, 24 Nov 2009 21:35:33 GMT
Server: Apache/2.2.3 (Red Hat)
Last-Modified: Tue, 24 Nov 2009 21:34:47 GMT
ETag: "358041f-43-47924b60e0bc0"
Accept-Ranges: bytes
Content-Length: 67
Connection: close
Content-Type: text/html; charset=UTF-8

<html
     <head>
           </head>
                  <body>
                        <h1>Hello, World!</h1



Connection to host lost.

C:\WINDOWS\system32\drivers\etc>_
```

Hello, World!

User-server state: cookies

Many major Web sites use cookies

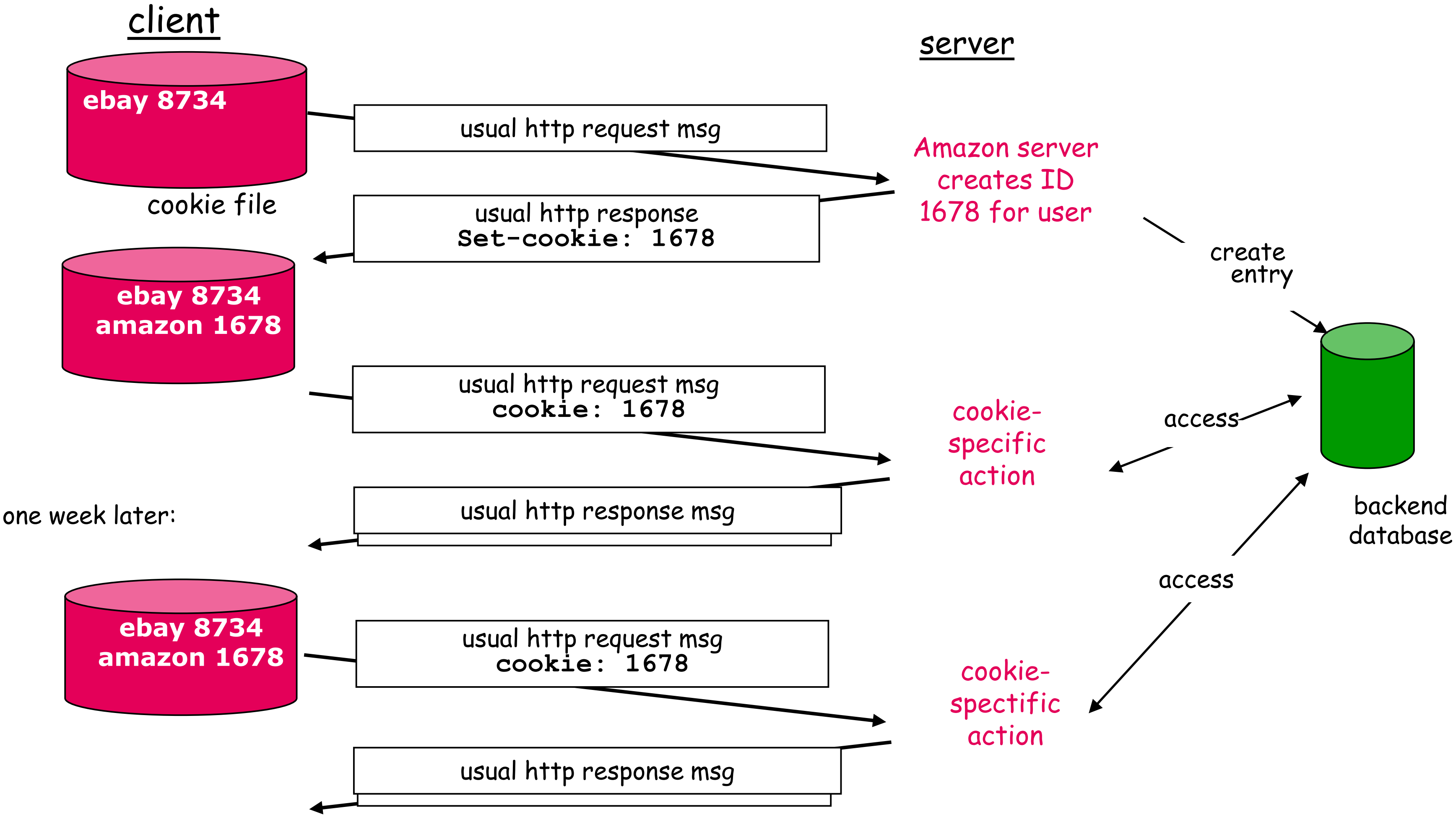
Four components:

1) cookie header line of HTTP *response* message
2) cookie header line in HTTP *request* message
3) cookie file kept on user's host, managed by user's browser
4) back-end database at Web site

Example:

- Susan always access Internet always from 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 bring:

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

aside

Cookies and privacy:

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

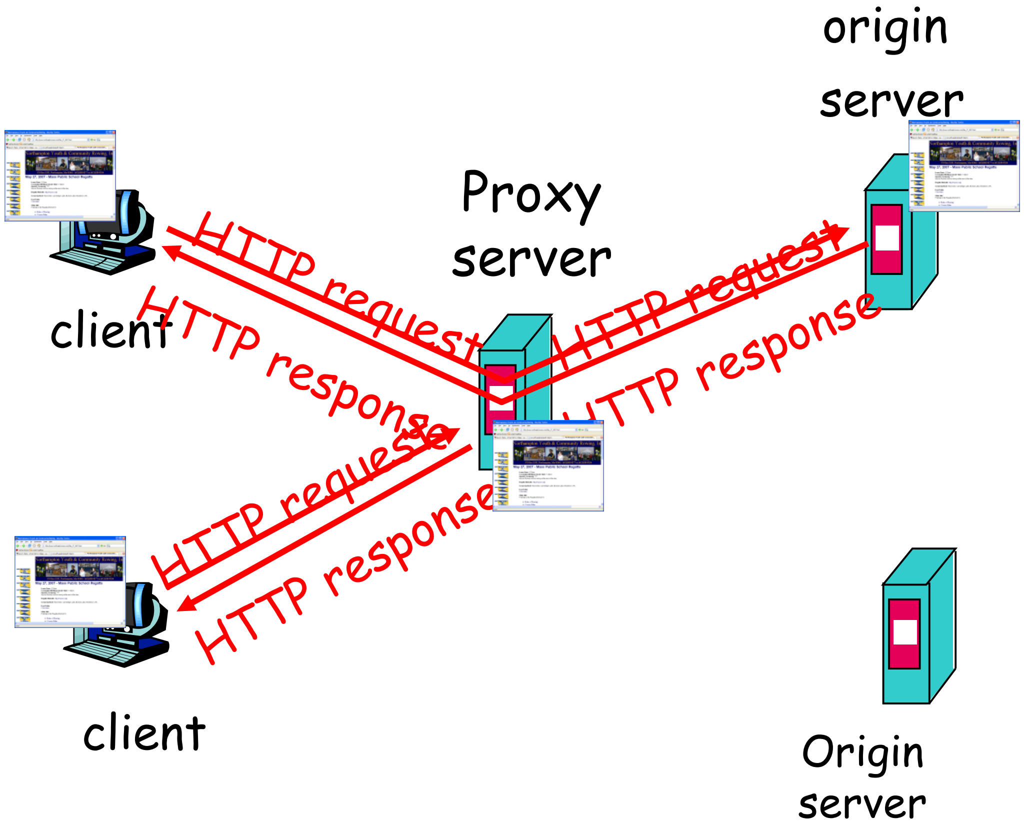
How to keep "state":

- protocol endpoints: maintain state at sender/receiver over multiple transactions
- cookies: http messages carry state

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
- 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 (but so does P2P file sharing)

Caching example

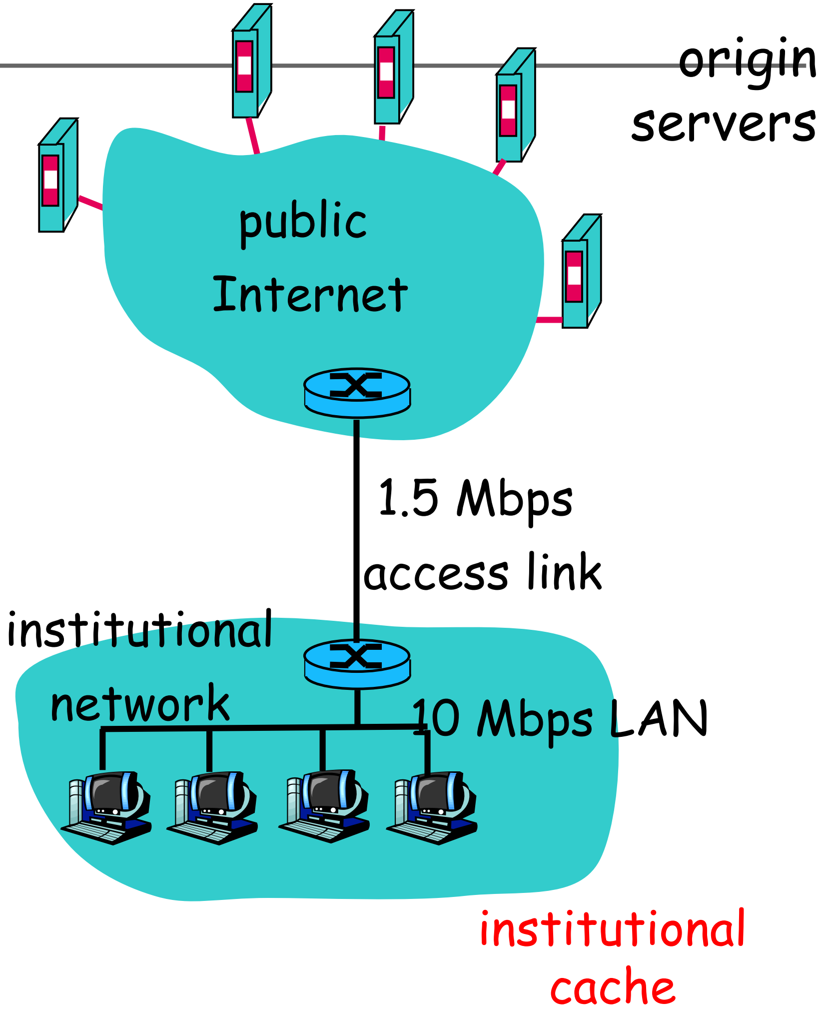
Assumptions

- ☐ average object size = 100,000 bits
- ☐ avg. request rate from institution's browsers to origin servers = 15/sec
- ☐ delay from institutional router to any origin server and back to router = 2 sec

Consequences

- ☐ utilization on LAN = 15%
- ☐ utilization on access link = 100%
- ☐ total delay = Internet delay + access delay + LAN delay

= 2 sec + minutes + milliseconds



Caching example (cont)

possible solution

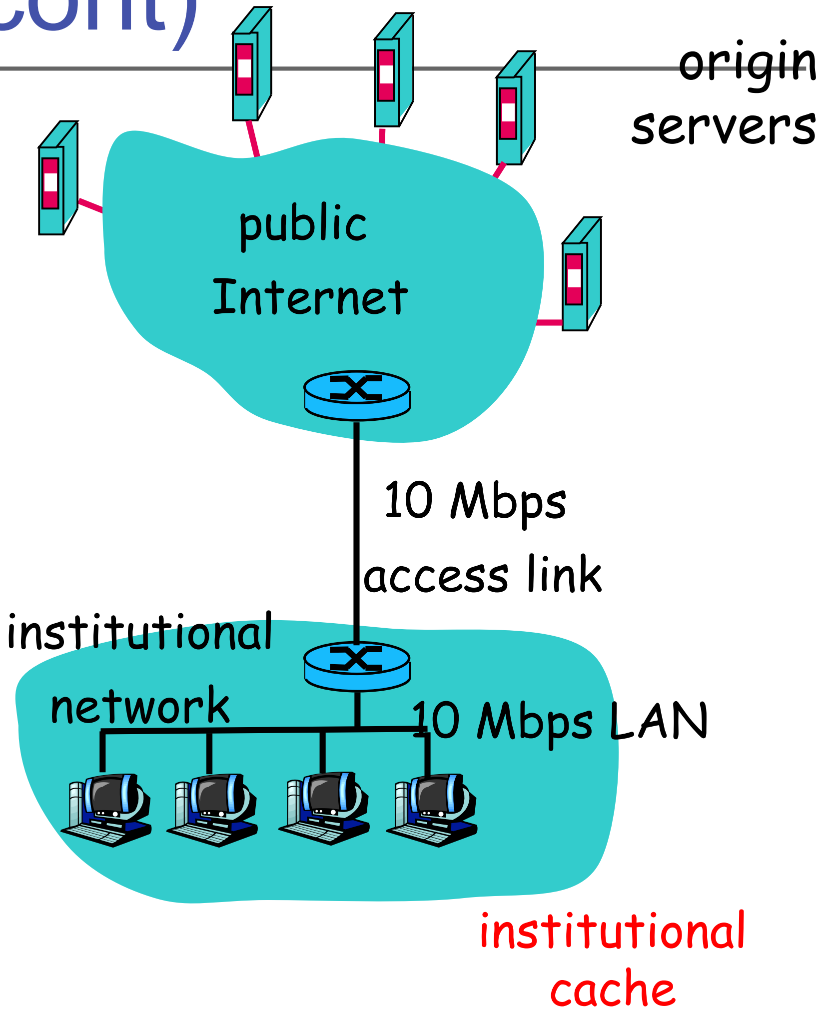
- increase bandwidth of access link to, say, 10 Mbps

consequence

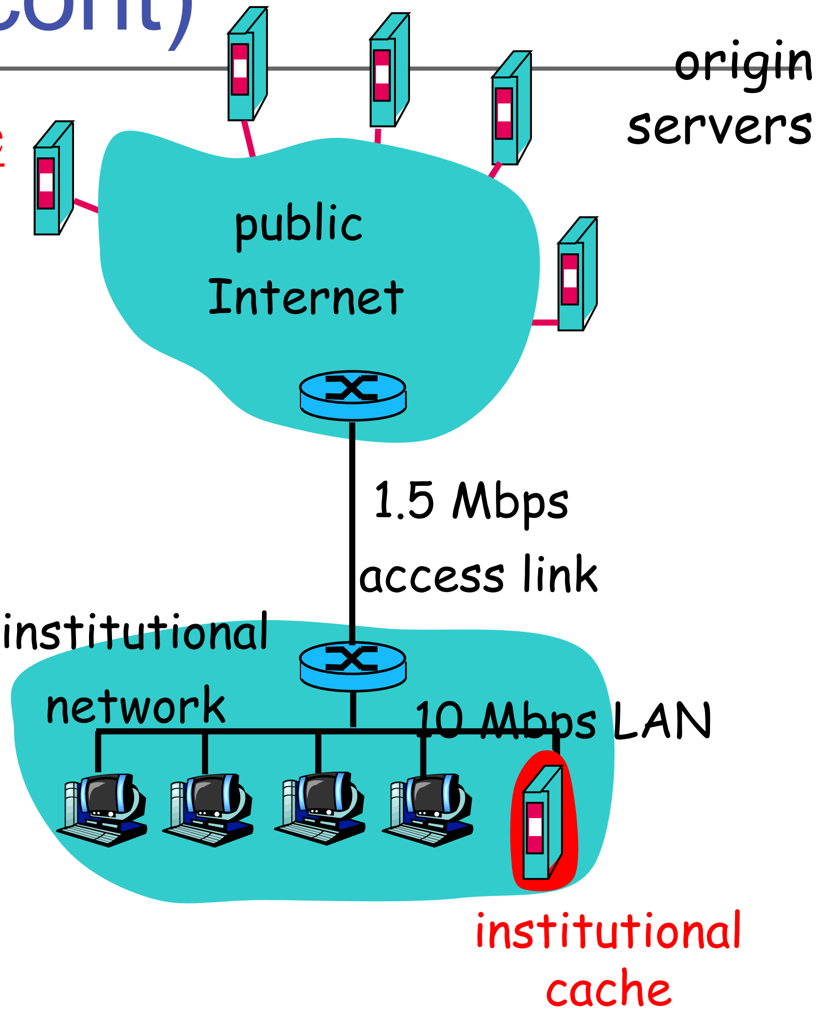
- utilization on LAN = 15%
- utilization on access link = 15%
- Total delay = Internet delay + access delay + LAN delay

= 2 sec + msecs + msecs

- often a costly upgrade



Caching example (cont)



possible solution: install cache

- ☐ suppose hit rate is 0.4

consequence

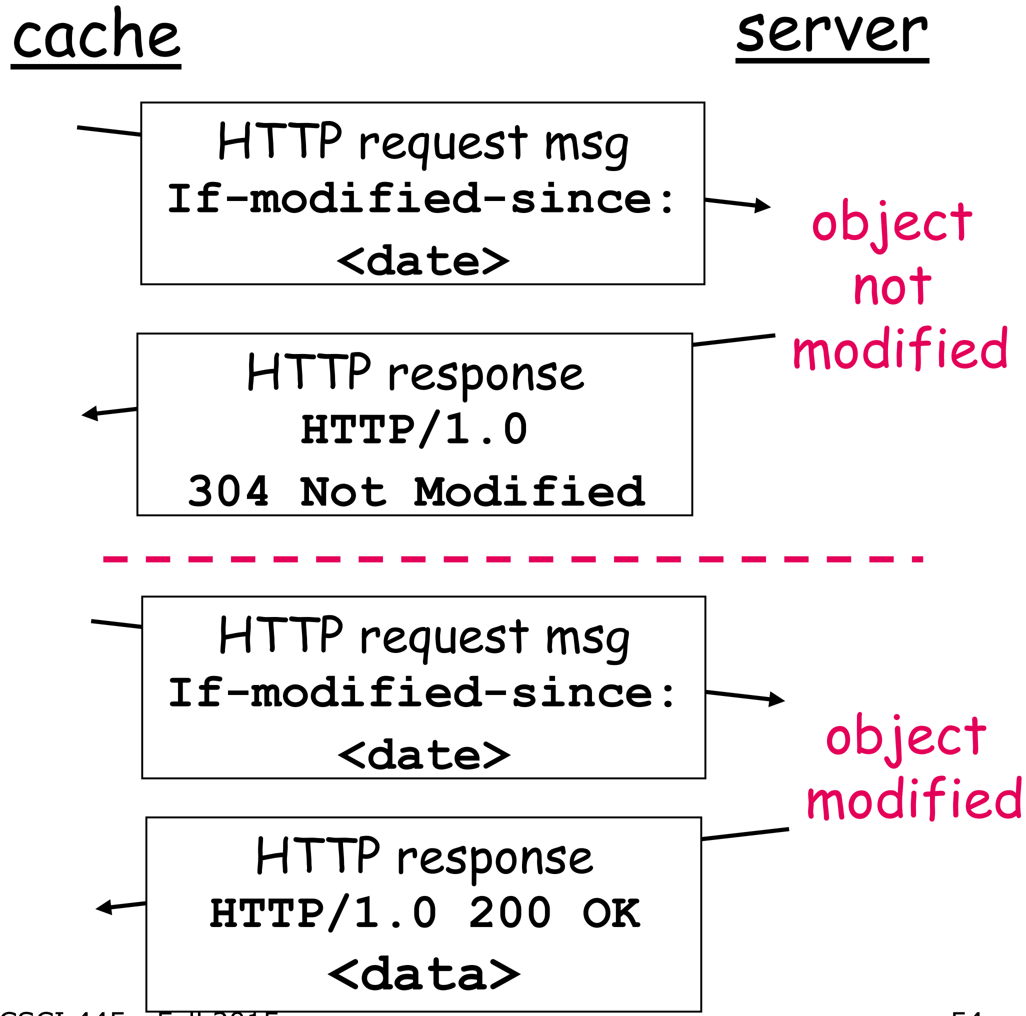
- ☐ 40% requests will be satisfied almost immediately
- ☐ 60% requests satisfied by origin server
- ☐ utilization of access link reduced to 60%, resulting in negligible delays (say 10 msec)
- ☐ total avg delay = Internet delay + access delay + LAN delay = .6*(2.01) secs + .4*milliseconds < 1.4 secs

Conditional GET

- Goal: don’t send object if cache has up-to-date cached version
- 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`



cache

server

HTTP request msg
`If-modified-since: <date>`

object not modified

HTTP response
`HTTP/1.0`
`304 Not Modified`

HTTP request msg
`If-modified-since: <date>`

object modified

HTTP response
`HTTP/1.0 200 OK`
`<data>`

Electronic Mail

- Message Format
- Message Transfer
- Mail Reader

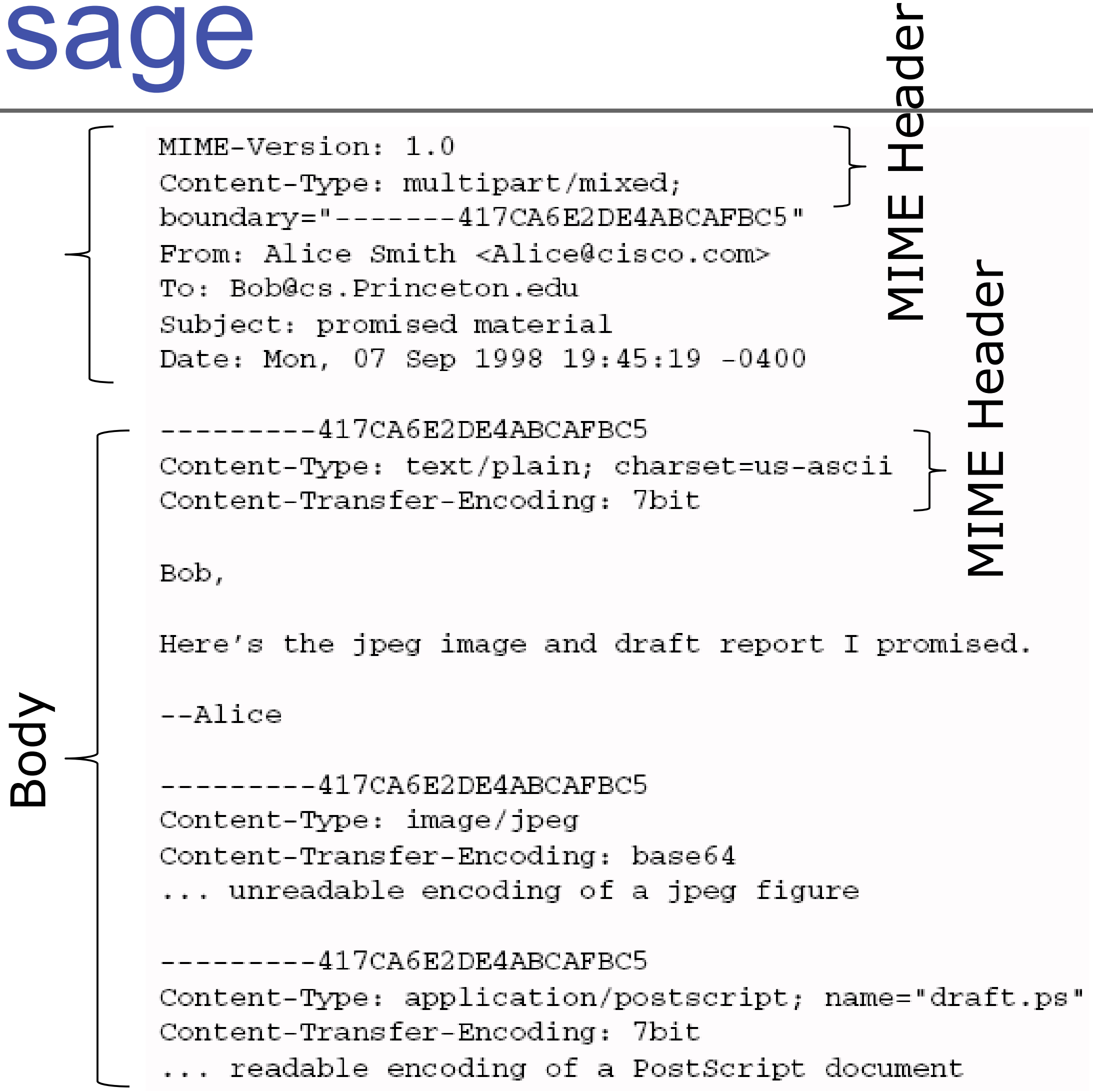
Electronic Mail

- Email is one of the oldest network applications
- It is important
  - to distinguish the user interface (i.e., your mail reader) from the underlying message transfer protocols (such as SMTP or IMAP), and
  - to distinguish between this transfer protocol and a companion protocol (RFC 822 and MIME) that defines the format of the messages being exchanged

Electronic Mail: Message Format – Brief Description

- RFC 822: header + body
  - ASCII text
  - MIME → all sorts of data
- Header
  - <CRLF> terminated lines
    - To: ….
    - From: …
- Body
  - MIME
    - Header lines
      - MIME-Version
      - Content-Description: such as Subject: line
      - Definitions content types: Can be multipart
      - Encoding method: Example: base64
- Header and Body is separated by a blank line

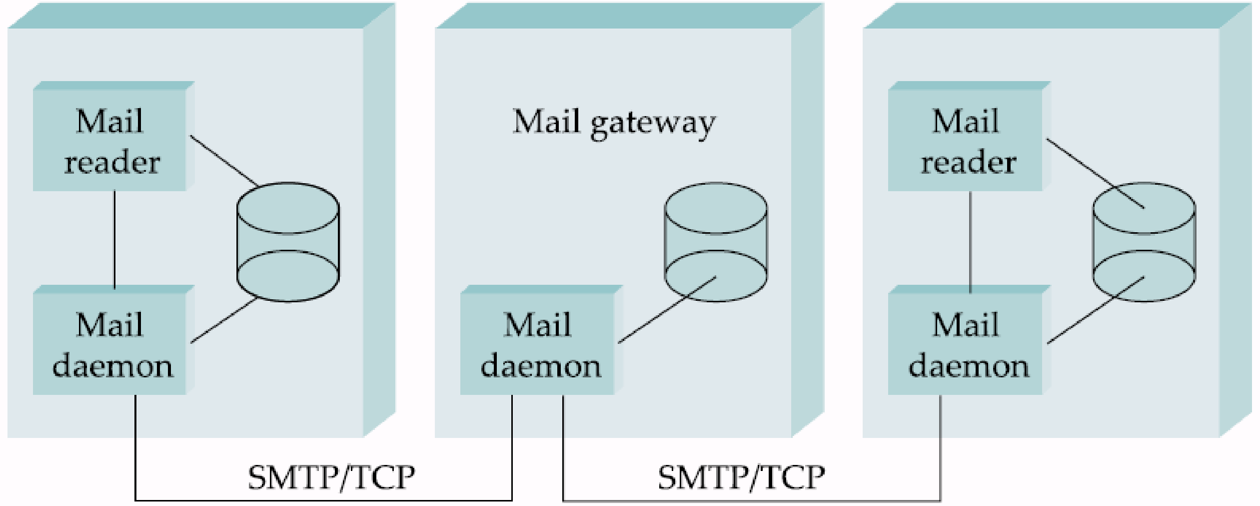
An Example of MIME Email Message



```
MIME-Version: 1.0
Content-Type: multipart/mixed;
boundary="-------417CA6E2DE4ABCAFBC5"
From: Alice Smith <Alice@cisco.com>
To: Bob@cs.Princeton.edu
Subject: promised material
Date: Mon, 07 Sep 1998 19:45:19 -0400

---------417CA6E2DE4ABCAFBC5
Content-Type: text/plain; charset=us-ascii
Content-Transfer-Encoding: 7bit

Bob,

Here's the jpeg image and draft report I promised.

--Alice

---------417CA6E2DE4ABCAFBC5
Content-Type: image/jpeg
Content-Transfer-Encoding: base64
... unreadable encoding of a jpeg figure

---------417CA6E2DE4ABCAFBC5
Content-Type: application/postscript; name="draft.ps"
Content-Transfer-Encoding: 7bit
... readable encoding of a PostScript document
```

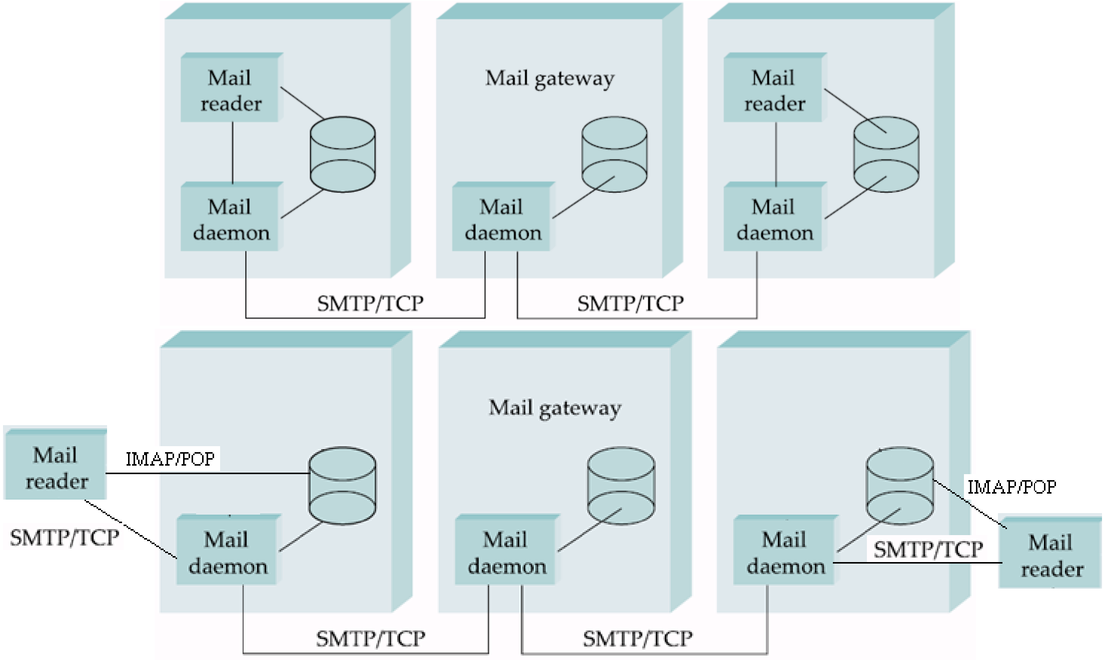
Electronic Mail: Message Transfer

- Message transfer agent (MTA): the mail daemon that uses the Simple Mail Transfer Protocol (SMTP) running over TCP to transmit the message to a daemon running on another machine
- MTA at the receiving end puts incoming messages into the user's mailbox
- Note:
  - SMTP has many different implementations
  - There may be many MTAs in between



Electronic Mail: Mail Reader

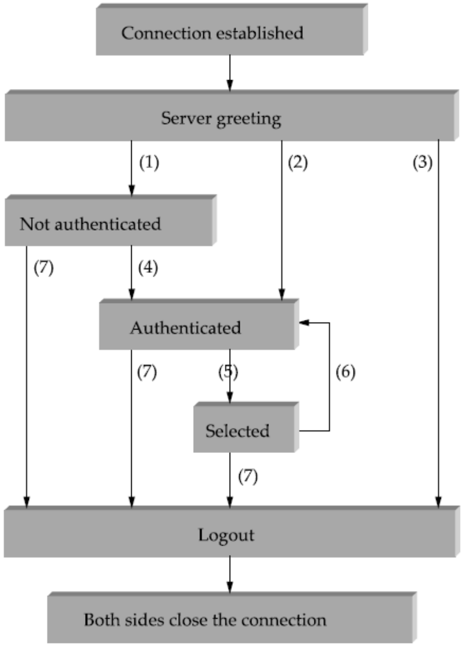
- Users use mail readers to actually retrieve messages from mailbox: read, rely, and save a copy
  - Local reader: reside on the machine where the mailbox is.
  - Remote reader: access mailbox on a remote machine using other protocol
    - Examples: the Post Office Protocol (POP) and the Internet Message Access Protocol (IMAP)



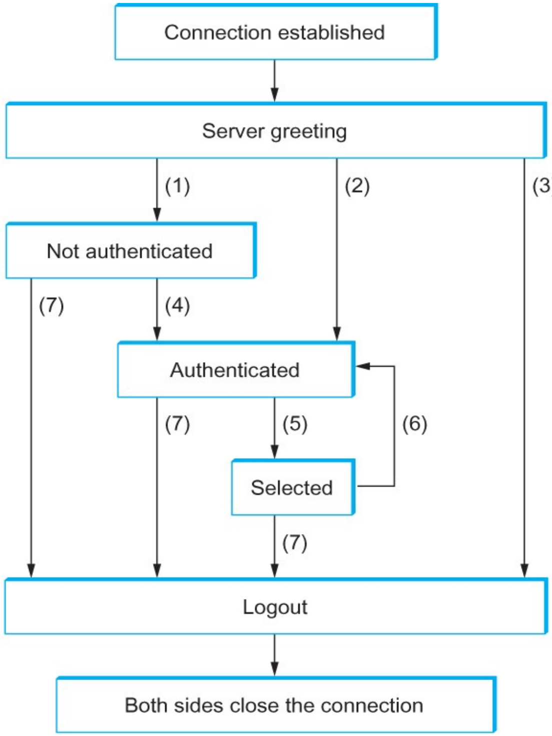
Electronic Mail: IMAP

- IMAP is similar to SMTP in many ways.
- Client/server protocol running over TCP
  - client (running on the user's desktop machine) issues commands in the form of <CRLF>-terminated ASCII text lines
  - mail server (running on the machine that maintains the user's mailbox) responds in-kind.
  - Begins with the client authenticating him or herself, and identifying the mailbox he or she wants to access.

Electronic Mail: IMAP



(1) connection without preauthentication (OK greeting)
(2) preauthenticated connection (PREAUTH greeting)
(3) rejected connection (BYE greeting)
(4) successful LOGIN or AUTHENTICATE command
(5) successful SELECT or EXAMINE command
(6) CLOSE command, or failed SELECT or EXAMINE command
(7) LOGOUT command, server shutdown, or connection closed



(1) Connection without preauthentication (OK greeting)
(2) Preauthenticated connection (PREAUTH greeting)
(3) Rejected connection (BYE greeting)
(4) Successful LOGIN or AUTHENTICATE command
(5) Successful SELECT or EXAMINE command
(6) CLOSE command, or failed SELECT or EXAMINE command
(7) LOGOUT command, server shutdown, or connection closed

IMAP State Transition Diagram

Summary

- Network application architecture
  - Peer-to-peer
  - Client-server
  - Hybrid
- Naming services
  - DNS
- The World Wide Web
  - HTTP
- E-mail
  - SMTP