

Overview of last class

Principles of network applications

- Application architectures
 - Client-server
 - Peer-to-peer (P2P)
 - An entity may play both roles as client or server
 - Hybrid of client-server and P2P
- Process, socket, port number
- Transport service (TCP/UDP and more)
 - Data loss
 - Timing
 - Throughput
 - Security

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,

Q: why bother? Why is there a UDP?

Scalability, shorter delay,
easier rate control

Web and HTTP

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

Persistent and Non-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:

- multiple objects can be sent over single TCP connection between client, server
- as little as one RTT for all the referenced objects
- **There may be idling time before next object request**

HTTP request message

- two types of HTTP messages: *request, response*
- **HTTP request message:**
 - ASCII (human-readable format)
 - <https://developer.mozilla.org/en-US/docs/Web/HTTP/Headers>

request line
(GET, POST,
HEAD commands)

header
lines

carriage return,
line feed at start
of line indicates
end of header lines

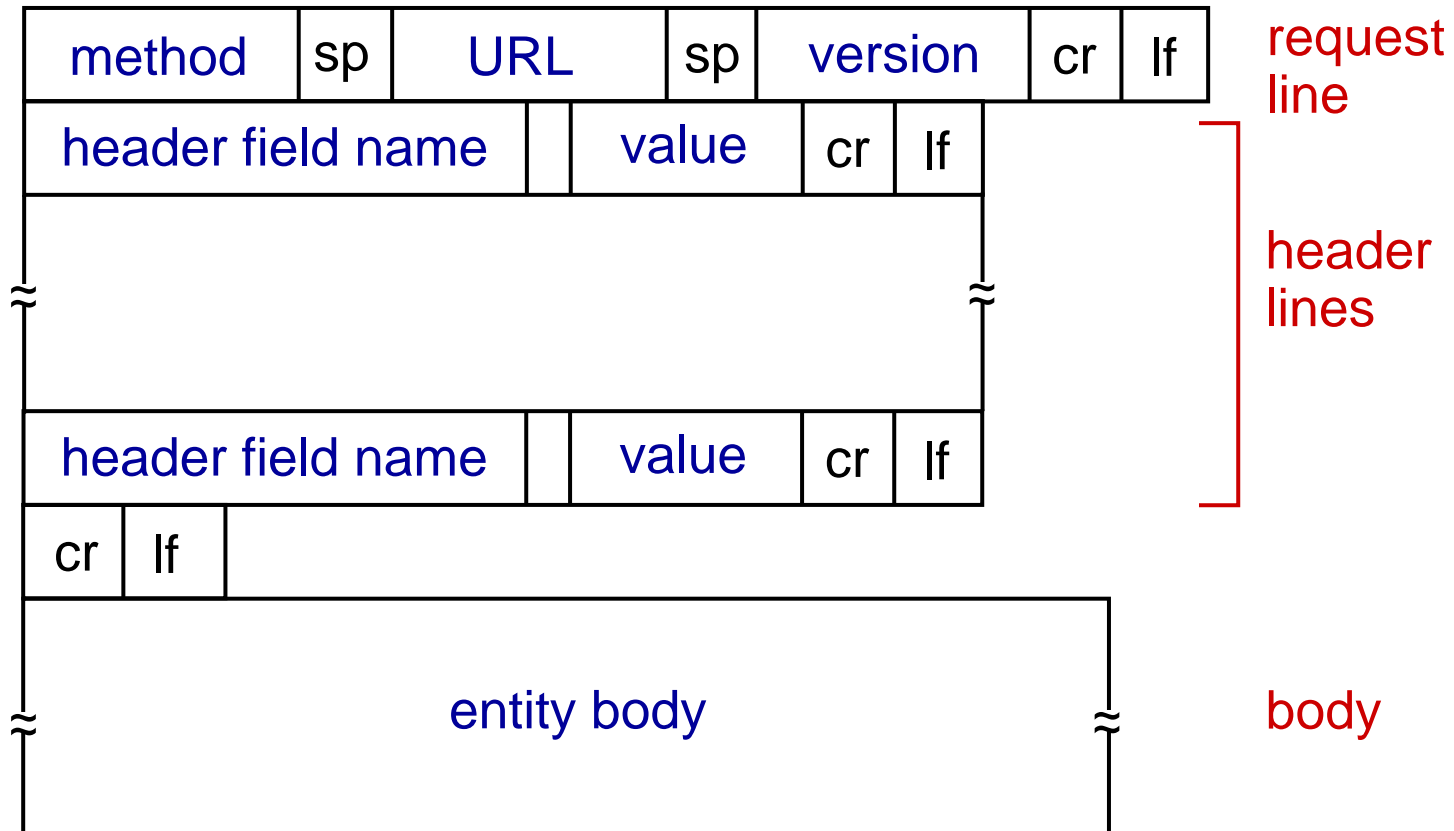
```
GET /index.html HTTP/1.1\r\n
Host: www-net.cs.umass.edu\r\n
User-Agent: Firefox/3.6.10\r\n
Accept: text/html,application/xhtml+xml\r\n
Accept-Language: en-us,en;q=0.5\r\n
Accept-Encoding: gzip,deflate\r\n
Accept-Charset: ISO-8859-1,utf-8;q=0.7\r\n
Keep-Alive: 115\r\n
Connection: keep-alive\r\n
\r\n
```

carriage return character

line-feed character

* Check out the online interactive exercises for more
examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

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

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 ...
```

* Check out the online interactive exercises for more
examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

HTTP response status codes

- status code appears in 1st line in server-to-client response message.
- some sample codes:

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

Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet gaia.cs.umass.edu 80
```

{ opens TCP connection to port 80
(default HTTP server port)
at gaia.cs.umass.edu.
anything typed in will be sent
to port 80 at gaia.cs.umass.edu

2. type in a GET HTTP request:

```
GET /kurose_ross/interactive/index.php HTTP/1.1  
Host: gaia.cs.umass.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!
(or use Wireshark to look at captured HTTP request/response)

Class Today

User-server state: cookies

many Web sites use cookies

four components:

- 1) cookie header line of HTTP *response* message
- 2) cookie header line in next 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 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.)

client



server



cookie file



ebay 8734
amazon 1678

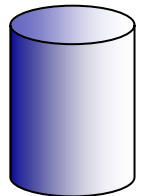
usual http request msg

Amazon server
creates ID
1678 for user

usual http response
set-cookie: 1678

create
entry

backend
database



usual http request msg
cookie: 1678

cookie-
specific
action

access

usual http response msg

access

cookie-
specific
action

one week later:



ebay 8734
amazon 1678

usual http request msg
cookie: 1678

usual http response msg

Cookies (continued)

what cookies can be used for:

- authorization
- shopping carts
- recommendations
- user session state

aside

cookies and privacy:

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

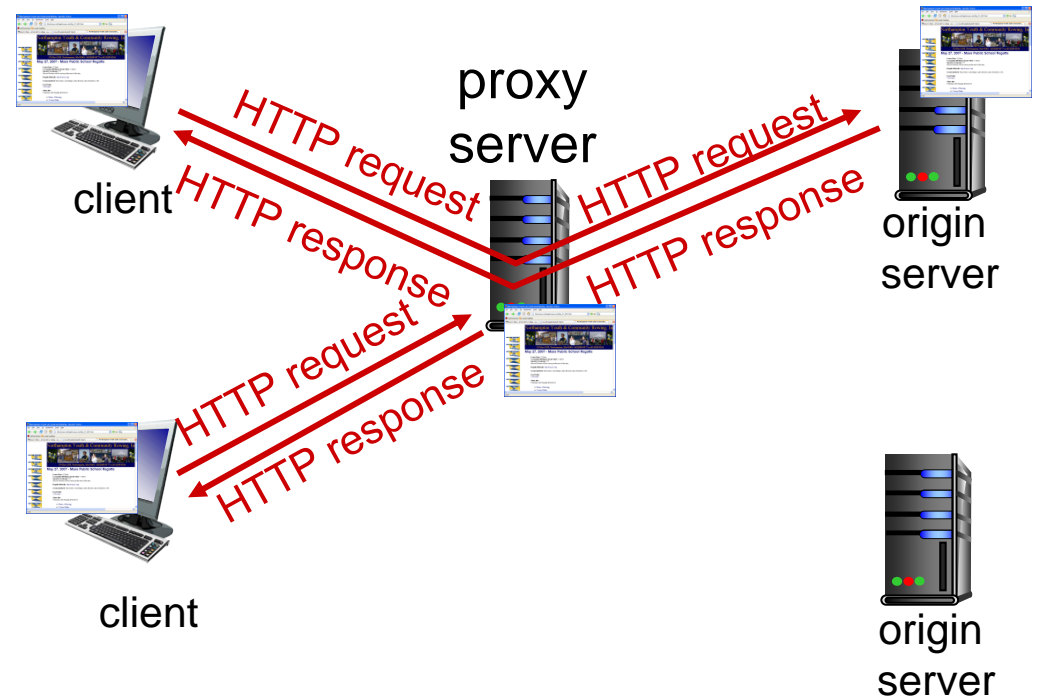
how to keep “state”:

- 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**
 - server for original requesting client
 - client to origin server
- typically cache is installed by ISP (university, company, residential ISP)

Contents can be reused

why Web caching?

- reduce response time for client request
- reduce traffic on an institution's access link
- reduce traffic load to server
- Internet dense with caches: enables “poor” content providers to effectively deliver content (so too does P2P file sharing)

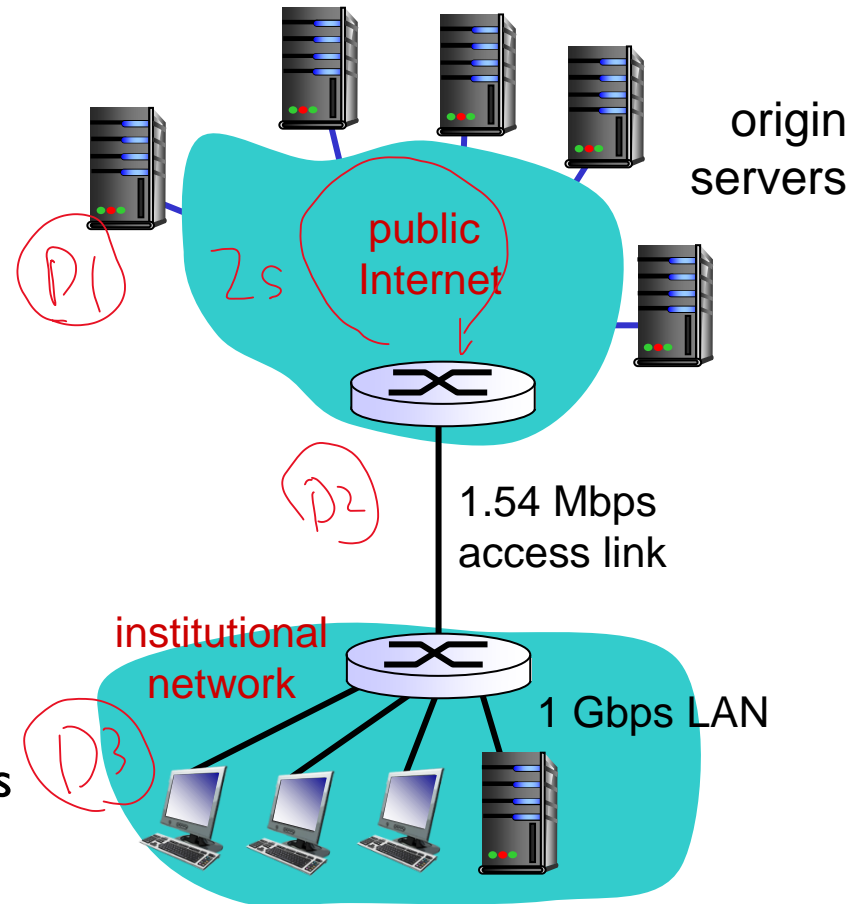
Caching example:

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

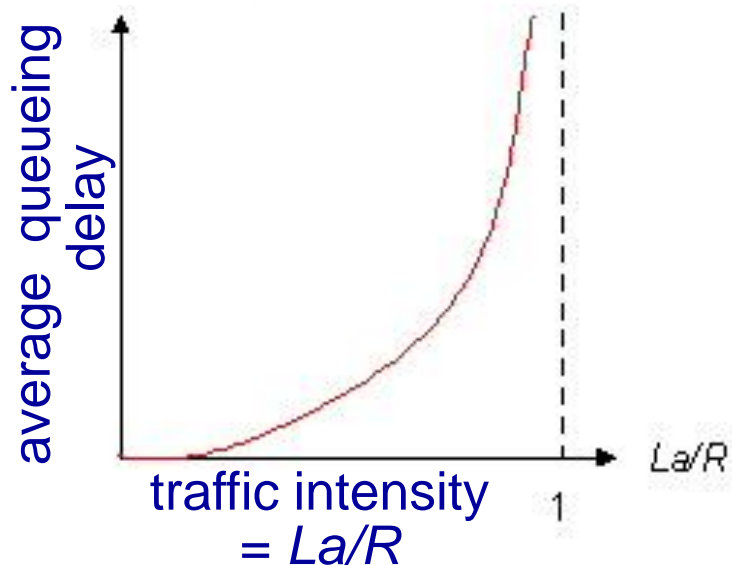
consequences:

- LAN utilization: 15%
- access link utilization = **99%** *problem!*
- total delay = Internet delay + access delay + LAN delay
= 2 sec + minutes + usecs



Queueing delay (revisited)

- R : link bandwidth (bps)
- L : packet length (bits)
- a : average packet arrival rate



- $La/R \sim 0$: avg. queueing delay small
- $La/R \rightarrow 1$: avg. queueing delay large
- $La/R > 1$: more “work” arriving than can be serviced, average delay infinite!



$La/R \sim 0$



$La/R \rightarrow 1$

* Check online interactive animation on queueing and loss

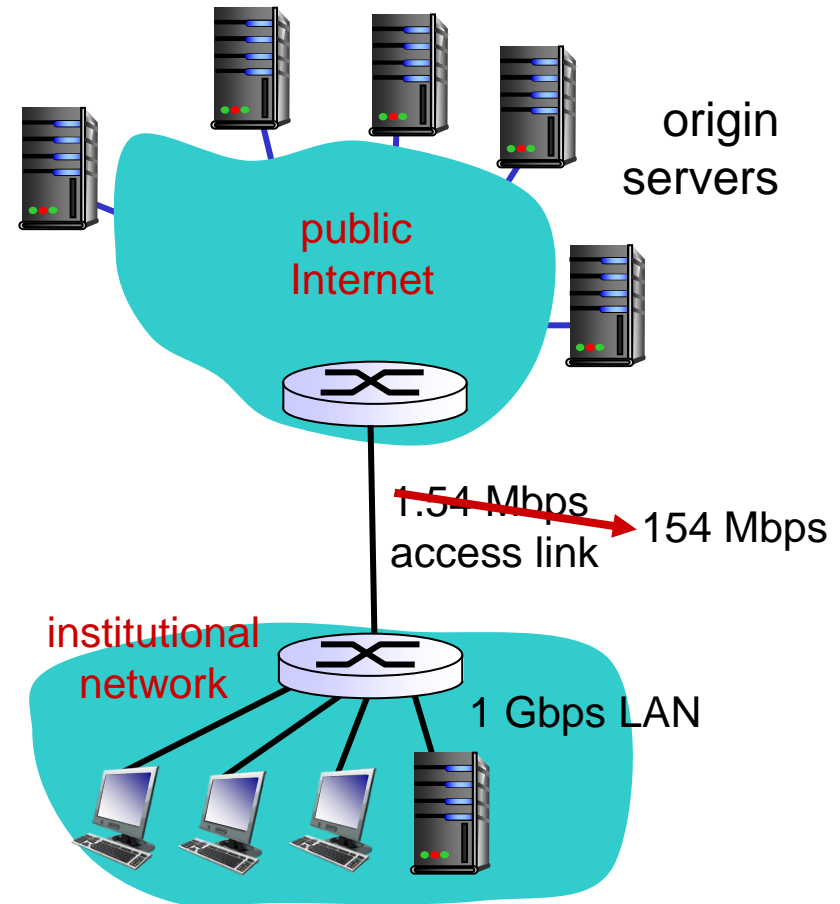
Caching example: fatter access link

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~~ → 154 Mbps

consequences:

- LAN utilization: 15%
- access link utilization = ~~99%~~ → 9.9%
- total delay = Internet delay + access delay + LAN delay
= 2 sec + ~~minutes~~ → msec



Cost: increased access link speed (not cheap!)

Caching example: install local cache

assumptions:

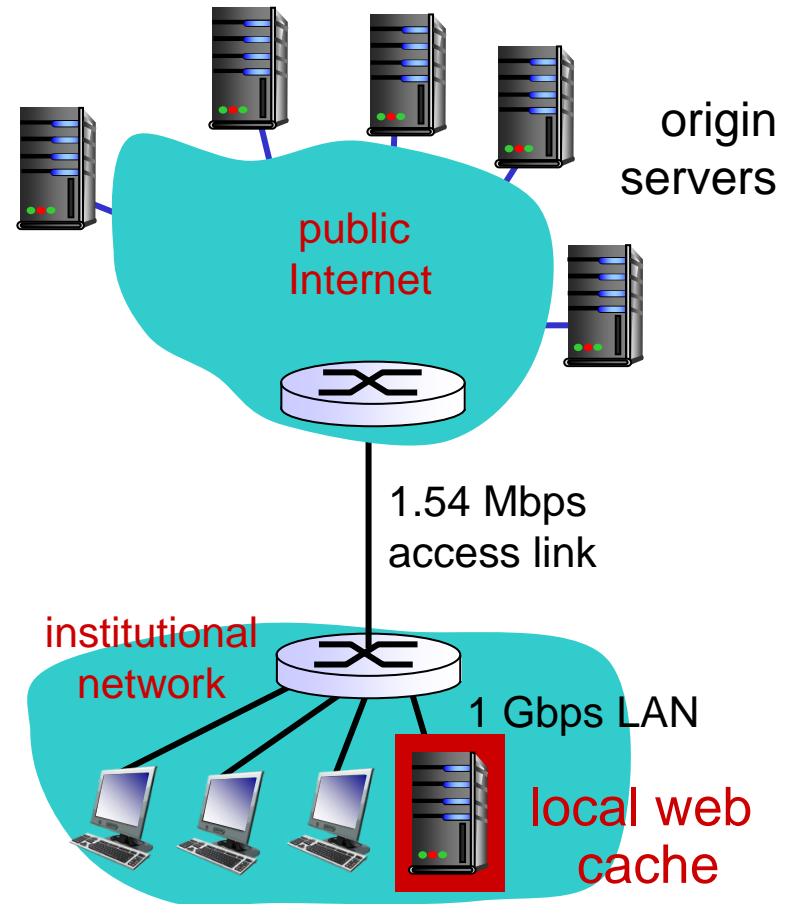
- avg object size: 100K bits
- avg request rate from browsers to origin servers: 15/sec
- avg data rate to browsers: 1.50 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54 Mbps

consequences:

- LAN utilization: 15%
- access link utilization = ?
- total delay = ?

How to compute link utilization, delay?

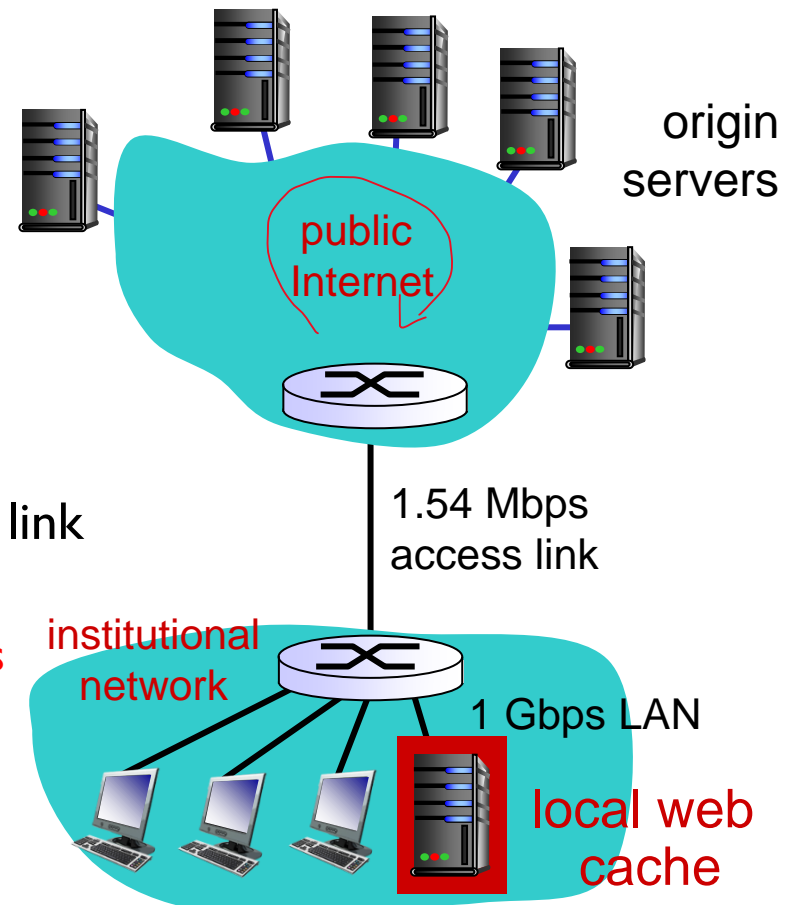
Cost: web cache (cheap!)



Caching example: install local cache

Calculating access link utilization, delay with cache:

- suppose cache hit rate is 0.4
 - 40% requests satisfied at cache, 60% requests satisfied at origin
- access link utilization:
 - 60% of requests use access link
- data rate to browsers over access link
 $= 0.6 * 1.50 \text{ Mbps} = .9 \text{ Mbps}$
 - **utilization** = $0.9 / 1.54 = .58$ (around 10ms delay over the access link)
- total delay
 - $= 0.6 * (\text{delay from origin servers}) + 0.4 * (\text{delay when satisfied at cache})$
 - $= 0.6 (2.01) + 0.4 (\sim \text{msecs}) = \sim 1.2 \text{ secs}$
 - less than with 154 Mbps link (and cheaper too!)



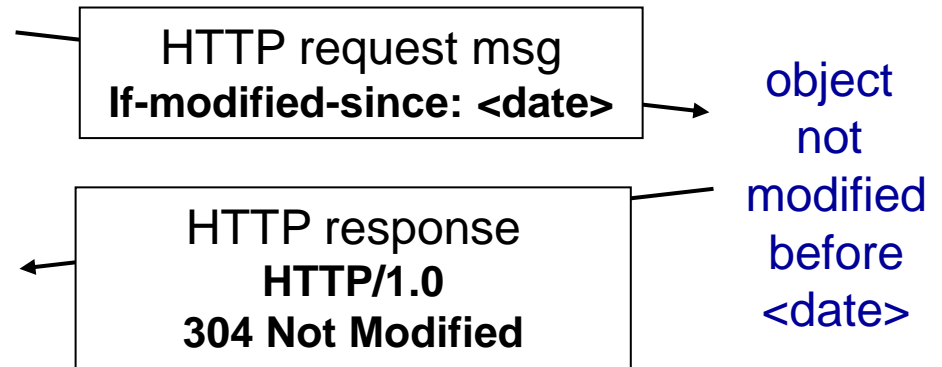
Conditional GET

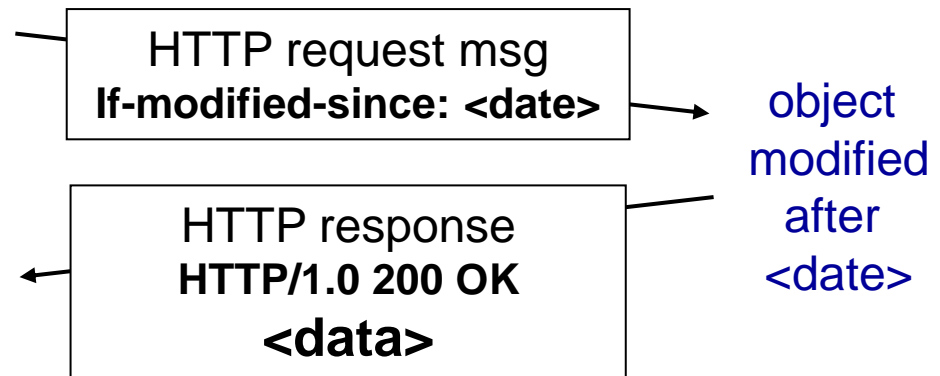
- **Goal:** don't send object if cache has up-to-date cached version
 - no object transmission delay
 - lower link utilization
- **cache:** specify date of cached copy in HTTP request
If-modified-since: <date>
- **server:** response contains no object if cached copy is up-to-date:
HTTP/1.0 304 Not Modified

client



server





Research

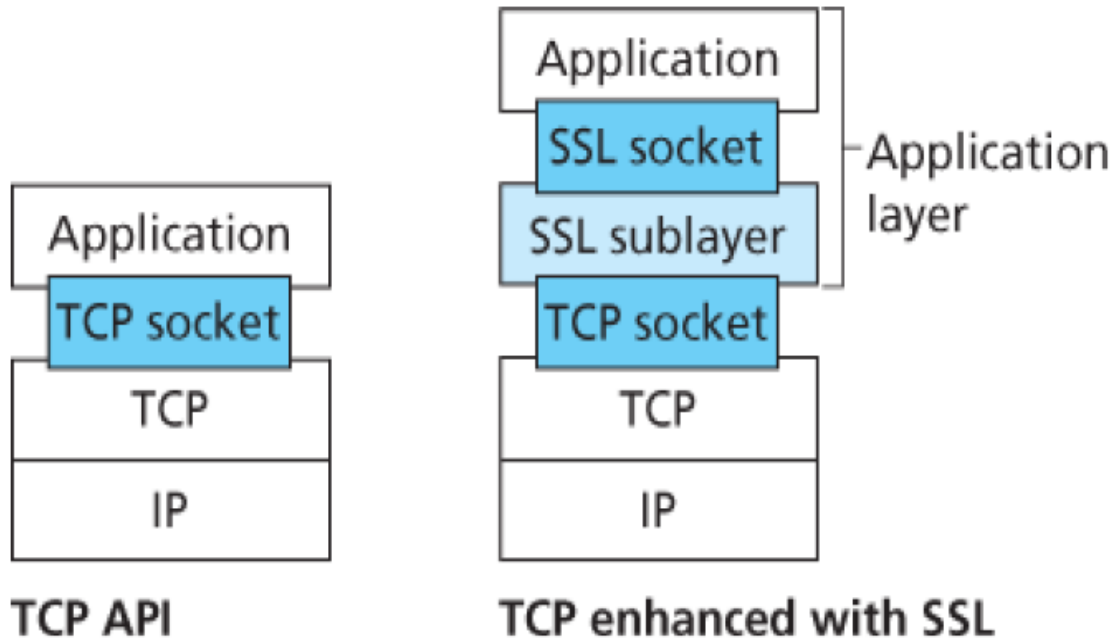
- Local cache has finite capacity
- Caching strategy design to improve the hit rate
- A core part for edge computing

HTTPS

HTTP over SSL or HTTP over TLS

(<https://en.wikipedia.org/wiki/HTTPS>)

- SSL: Security Sockets Layer
- TLS: Transport Layer Security



Chapter 2: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks

2.7 socket programming with UDP and TCP

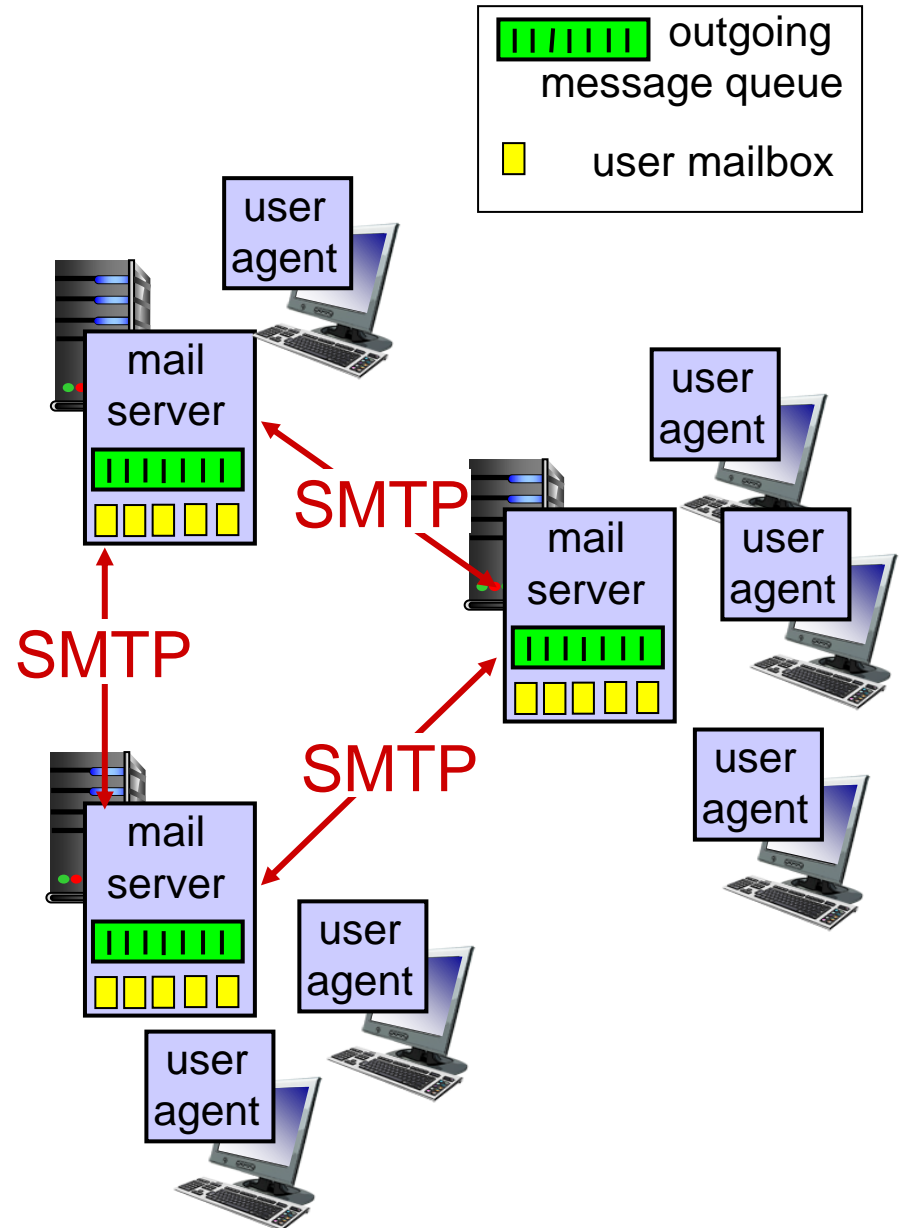
Electronic mail

Three major components:

- user agents
- mail servers
- simple mail transfer protocol: SMTP

User Agent

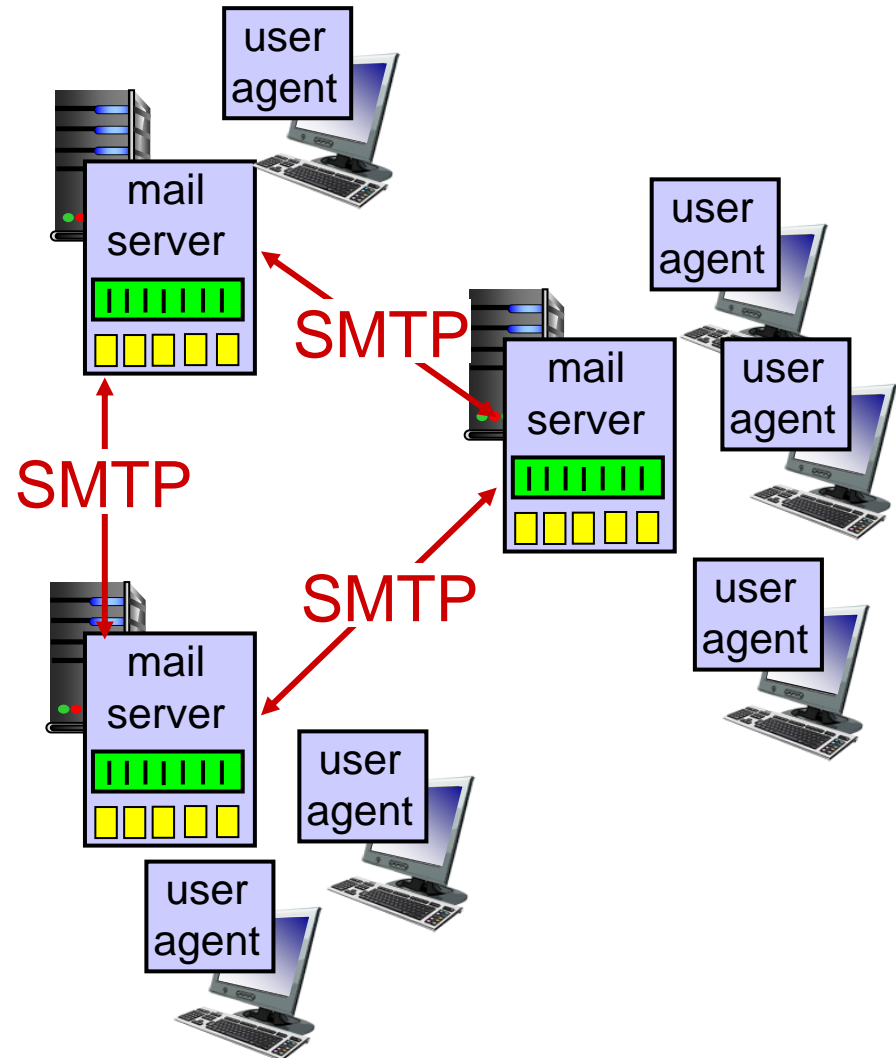
- a.k.a. “mail reader”
- composing, editing, reading mail messages
- e.g., Outlook, Thunderbird, iPhone mail client
- outgoing, incoming messages stored on server



Electronic mail: mail servers

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
 - client: sending mail server
 - “server”: receiving mail server

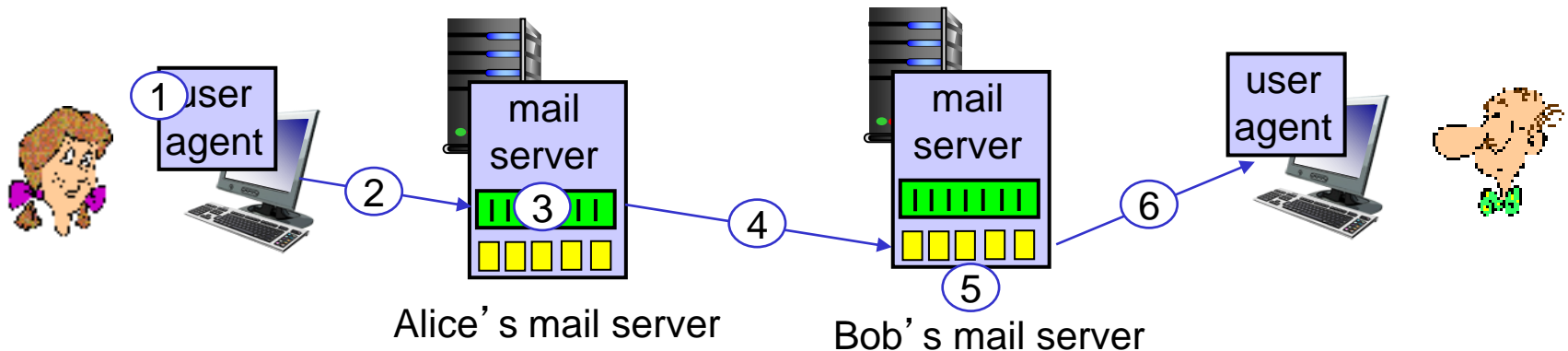


Electronic Mail: SMTP [RFC 2821]

- uses TCP to reliably transfer email message from client to server, port 25
- direct transfer: sending server to receiving server
- three phases of transfer
 - handshaking (greeting)
 - transfer of messages
 - closure
- command/response interaction (like HTTP)
 - **commands:** ASCII text
 - **response:** status code and phrase
- messages must be in 7-bit ASCII

Scenario: Alice sends message to Bob

- 1) Alice uses UA to compose message "to" bob@someschool.edu
- 2) Alice's UA 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



Sample SMTP interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250 Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

Try SMTP interaction for yourself:

- `telnet servername 25`
- see 220 reply from server
- enter HELO, MAIL FROM, RCPT TO, DATA, QUIT commands

above lets you send email without using email client (reader)

Mail message format

SMTP: protocol for exchanging email messages

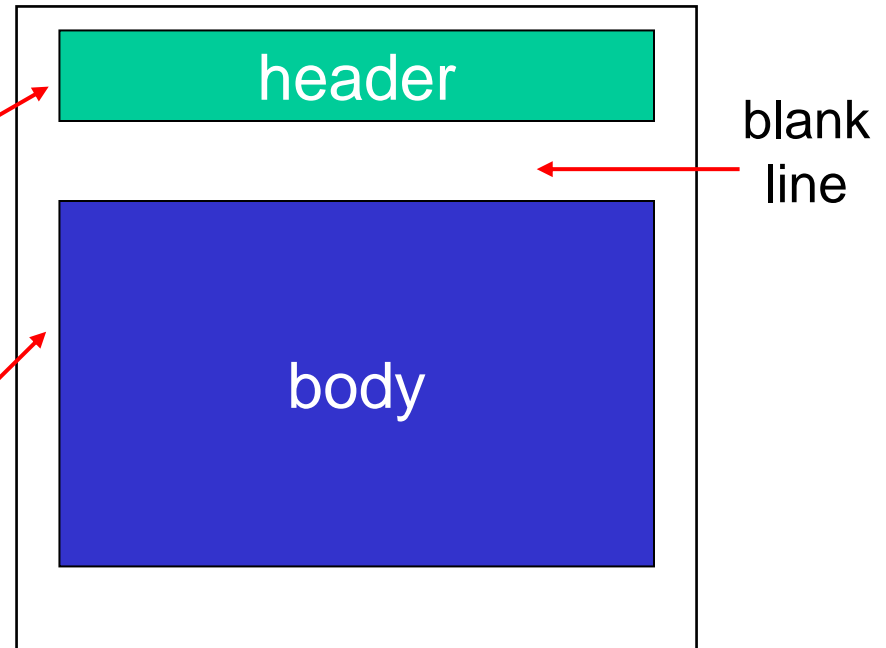
RFC 822: standard for text message format:

- header lines, e.g.,

- To:
- From:
- Subject:

different from SMTP MAIL
FROM, RCPT TO:
commands!

- Body: the “message”
 - ASCII characters only



SMTP: final words

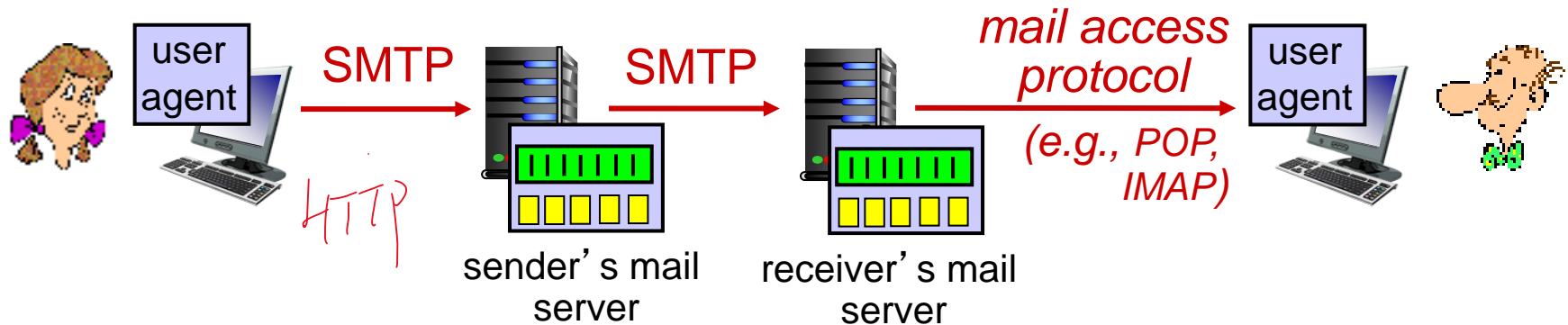
- SMTP uses persistent connections
- SMTP requires message (header & body) to be in 7-bit ASCII
- SMTP server uses CRLF.CRLF to determine end of message
- The MIME (multipurpose Internet mail extension) extensions for non-ascii data

Q: why persistent mode is selected?

comparison with HTTP:

- HTTP: pull
- SMTP: push
- both have ASCII command/response interaction, status codes
- HTTP: each object encapsulated in its own response message
- SMTP: multiple objects sent in multipart message

Mail access protocols



- **SMTP**: delivery/storage to receiver's server
- mail access protocol: retrieval from server
 - **POP**: Post Office Protocol [RFC 1939]: authorization, download
 - **IMAP**: Internet Mail Access Protocol [RFC 1730]: more features, including manipulation of stored messages on server
 - **HTTP**: gmail, Hotmail, Yahoo! Mail, etc.
- Integrating multiple protocols in one application

POP3 protocol

authorization phase

- client commands:
 - **user**: declare username
 - **pass**: password
- server responses
 - **+OK**
 - **-ERR**

```
S: +OK POP3 server ready
C: user bob
S: +OK
C: pass hungry
S: +OK user successfully logged on
```

transaction phase, client:

- **list**: list message numbers
- **retr**: retrieve message by number
- **dele**: delete
- **quit**

```
C: list
S: 1 498
S: 2 912
S: .
C: retr 1
S: <message 1 contents>
S: .
C: dele 1
C: retr 2
S: <message 1 contents>
S: .
C: dele 2
C: quit
S: +OK POP3 server signing off
```

POP3 (more) and IMAP

more about POP3

- previous example uses POP3 “download and delete” mode
 - Bob cannot re-read e-mail if he changes client
- POP3 “download-and-keep”: copies of messages on different clients
- POP3 is stateless across sessions

IMAP

- 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