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DEEMED TO BE UNIVERSITY

21AIE211
Introduction to COMPUTER NETWORKS
2-0-3-3

APPLICATION LAYER

- **Learn about protocols by examining popular application-level protocols**
  1. HTTP
     - User-Server Interaction: Cookies
     - WebCaching (Proxy Servers)
  2. FTP
  3. SMTP / POP3 / IMAP

User-Server Interaction: Cookies

We mentioned above that an HTTP server is stateless. This simplifies server design and has permitted engineers to develop high-performance Web servers that can handle thousands of simultaneous TCP connections. However, it is often desirable for a Web site to identify users, either because the server wishes to restrict user access or because it wants to serve content as a function of the user identity. For these purposes, HTTP uses cookies. Cookies, defined in [RFC 6265], allow sites to keep track of users. Most major commercial Web sites use cookies today

User-server state: cookies

many Websites use cookies

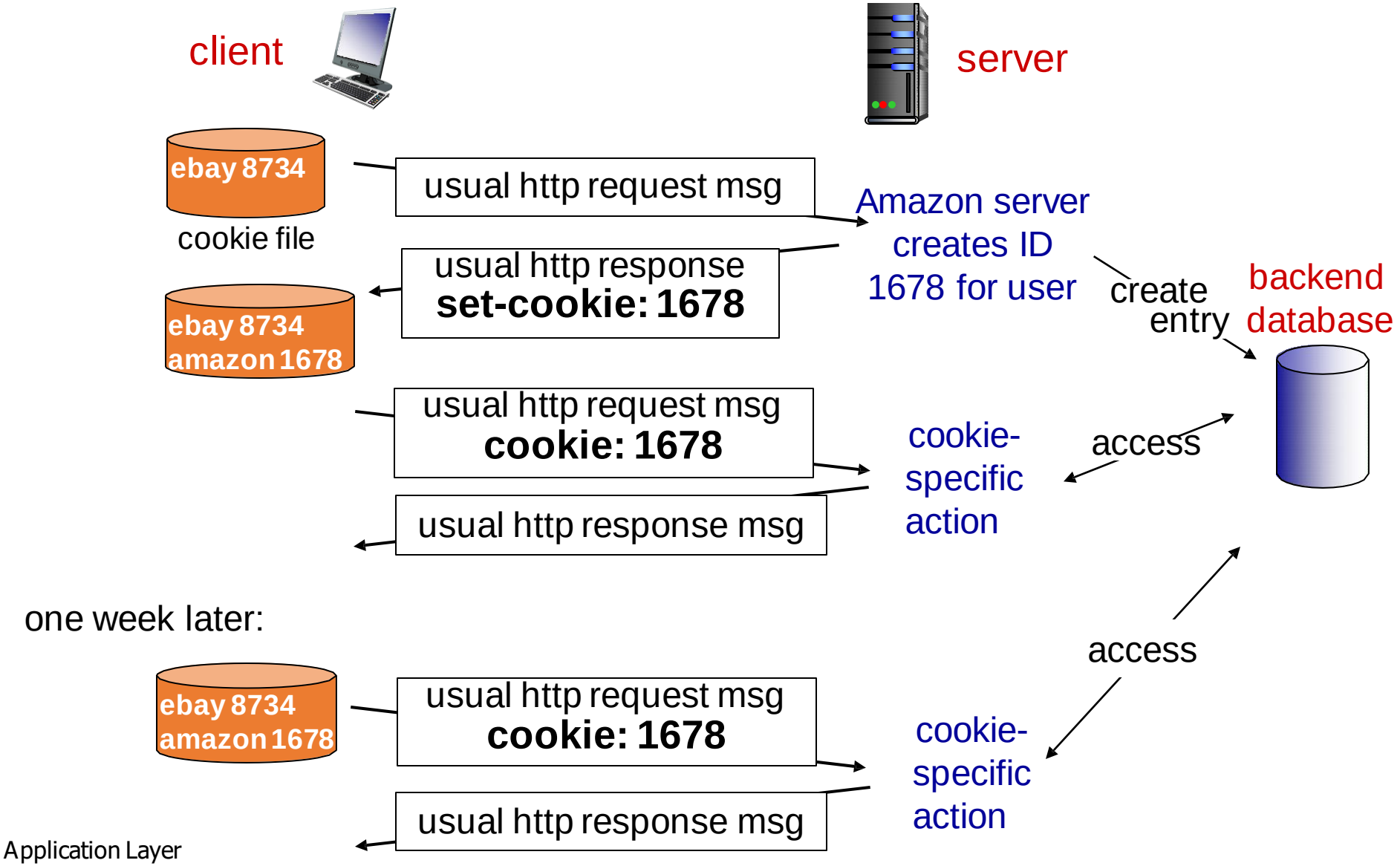
four components:

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.)



Cookies (continued)

what cookies can be used for:

- authorization
- shopping carts
- recommendations
- user session state (Web e-mail)
- "one-click shopping"—

how to keep "state":

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

  Cookies can thus be used to create a user session layer on top of stateless HTTP. For example, when a user logs in to a Web-based e-mail application (such as Hotmail), the browser sends cookie information to the server, permitting the server to identify the user throughout the user's session with the application.

cookies and privacy:

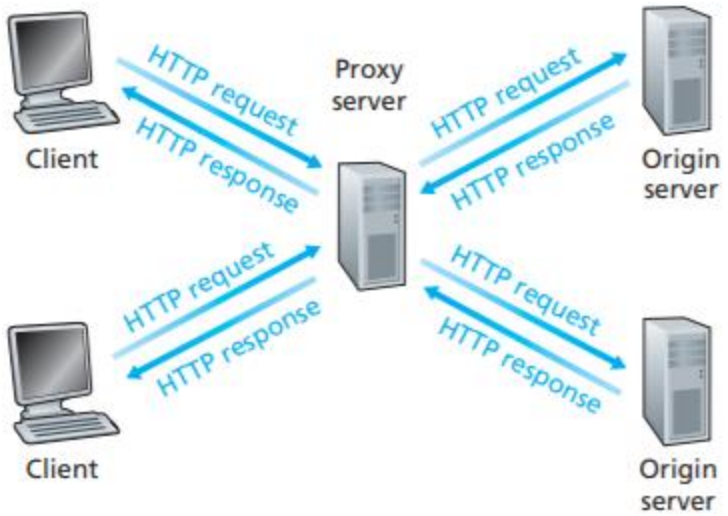
- cookies permit sites to learn a lot about you
- Using a combination of cookies and user-supplied account information, a Web site can learn a lot about a user and potentially sell this information to a third party. - cookies controversy

As in previous slide, in that manner, the Amazon server is able to track Susan's activity at the Amazon site. Although the Amazon Web site does not necessarily know Susan's name, it knows exactly which pages user 1678 visited, in which order, and at what times!

Web caches (proxy server)

- A Web cache—also called a proxy server—is a network entity that satisfies HTTP requests on the behalf of an origin Web server. The Web cache has its own disk storage and keeps copies of recently requested objects in this storage
- 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

goal: satisfy client request without involving origin server



What happens when a browser requests an object?

As an example, suppose a browser is requesting the object `http://www.someschool.edu/campus.gif`. Here is what happens

- The browser establishes a TCP connection to the Web cache and sends an HTTP request for the object to the Web cache.
- The Web cache checks to see if it has a copy of the object stored locally. If it does, the Web cache returns the object within an HTTP response message to the client browser.
- If the Web cache does not have the object, the Web cache opens a TCP connection to the origin server, that is, to www.someschool.edu.
- The Web cache then sends an HTTP request for the object into the cache-to-server TCP connection.
- After receiving this request, the origin server sends the object within an HTTP response to the Web cache.
- When the Web cache receives the object, it stores a copy in its local storage and sends a copy, within an HTTP response message, to the client browser (over the existing TCP connection between the client browser and the Web cache).

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- not to upgrade bandwidth
- Web caches can substantially reduce Web traffic in the Internet as a whole, thereby improving performance for all applications.
- Internet dense with caches: enables "poor" content providers to effectively deliver content (so too does P2P file sharing)

Caching example:

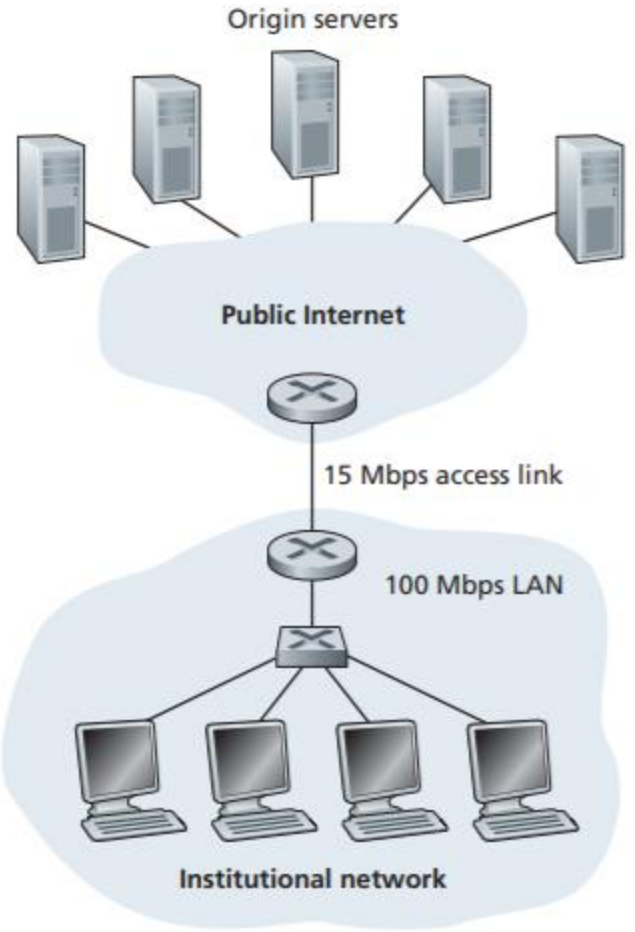
assumptions:

- avg object size: 1 Mbits
- avg request rate from browsers to origin servers: 15 requests/sec
- avg data rate to browsers: 1.50 Mbps
- "Internet delay.":two seconds on average

The total response time—that is, the time from the browser's request of an object until its receipt of the object—is the sum of the LAN delay, the access delay ,and the Internet delay

The traffic intensity on the LAN s = 0.15

whereas the traffic intensity on the access link (from the Internet router to institution
router) is = 1

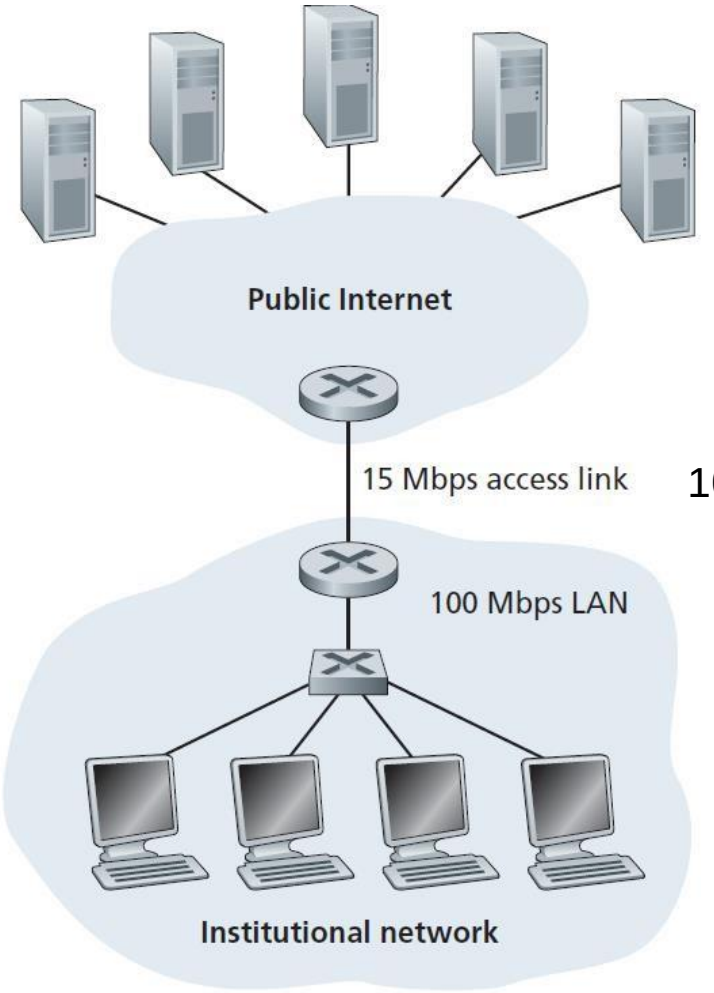


As the traffic intensity approaches 1 , the delay on a link becomes very large and grows without bound

average response time to satisfy requests is going to be on the **order of minutes**, if not more

Caching example: faster access link

One possible solution is to increase the access rate from 15 Mbps to, say, 100 Mbps. This will lower the traffic intensity on the access link to 0.15, which translates to negligible delays between the two routers. In this case, the total response time will roughly be **two seconds**, that is, the Internet delay. But this solution also means that the institution must upgrade its access link from 15 Mbps to 100 Mbps, a costly proposition.



Cost: increased access link speed (not cheap!)

Caching example: install local cache

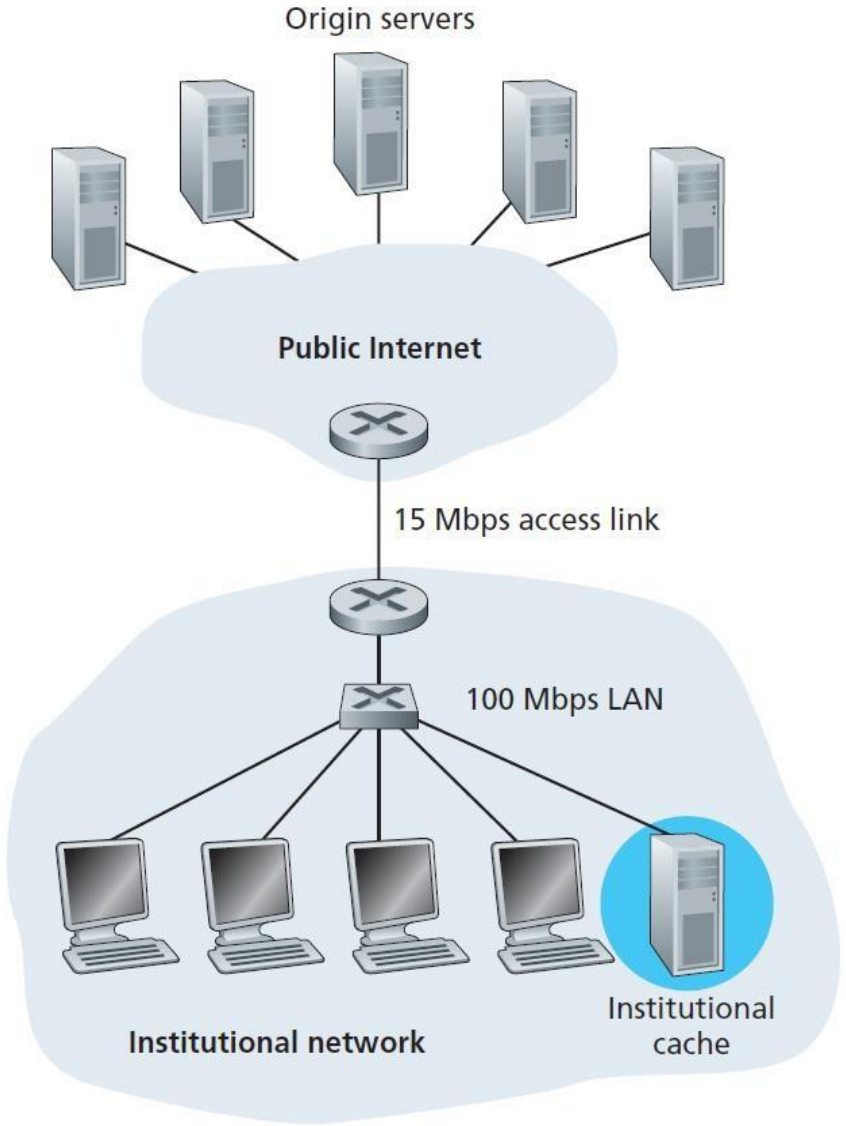
Now consider the alternative solution of not upgrading the access link but instead installing a Web cache in the institutional network

let's
suppose that the cache provides a hit rate of 0.4 for this institution.

40 percent of the requests will be satisfied almost immediately, say, within 10 milliseconds, by the cache. Nevertheless, the remaining 60 percent of the requests still need to be satisfied by the origin servers. But with only 60 percent of the requested objects passing through the access link, the traffic intensity on the access link is reduced from 1.0 to 0.6.

Average Delay is just **slightly greater than 1.2 seconds**

Cost: web cache (cheap!)

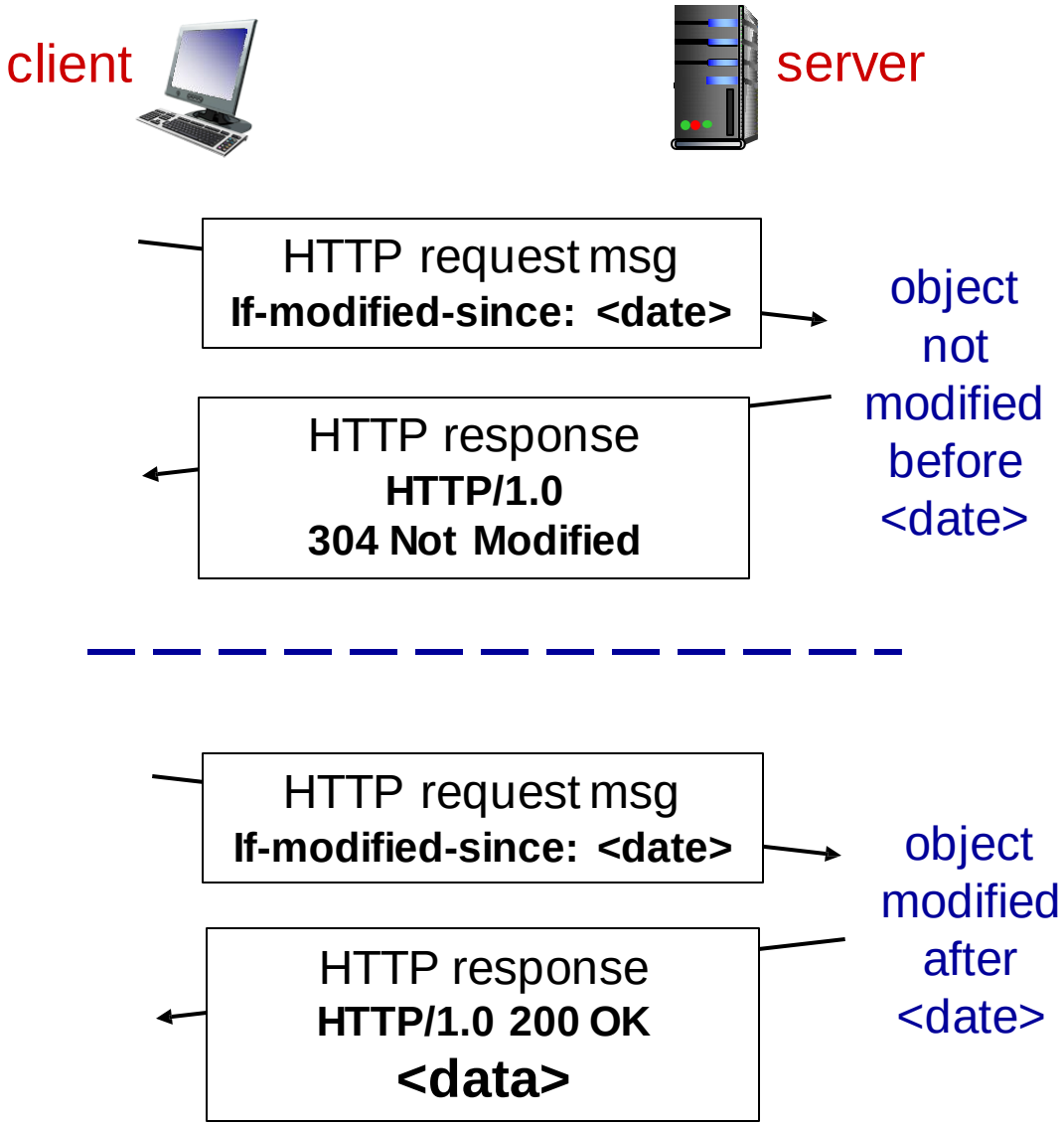


Conditional GET

- *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`



Conditional GET

On the behalf of a requesting browser, a proxy cache sends a request message to a Web server

```
GET /fruit/kiwi.gif HTTP/1.1
Host: www.exotiquecuisine.com
```

The Web server sends a response message with the requested object to the cache:

```
HTTP/1.1 200 OK
Date: Sat, 8 Oct 2011 15:39:29
Server: Apache/1.3.0 (Unix)
Last-Modified: Wed, 7 Sep 2011 09:23:24
Content-Type: image/gif

(data data data data data ...)
```

One week later, another browser requests the same object via the cache, and the object is still in the cache

```
GET /fruit/kiwi.gif HTTP/1.1
Host: www.exotiquecuisine.com
If-modified-since: Wed, 7 Sep 2011 09:23:24
```

The Web server sends a response message to the cache:

```
HTTP/1.1 304 Not Modified
Date: Sat, 15 Oct 2011 15:39:29
Server: Apache/1.3.0 (Unix)

(empty entity body)
```

APPLICATION LAYER

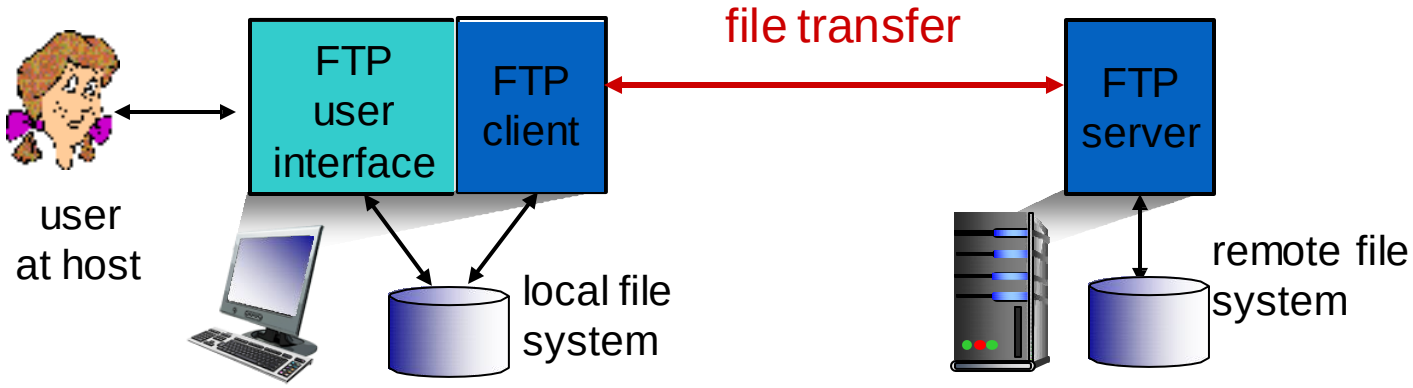
File Transfer Protocol : FTP

File Transfer Protocol: FTP

In a typical FTP session, the user is sitting in front of one host (the local host) and wants to transfer files to or from a remote host. In order for the user to access the remote account, the user must provide a user identification and a password. After providing this authorization information, the user can transfer files from the local file system to the remote file system and vice versa

- The user interacts with FTP through an FTP user agent.
- The user first provides the hostname of the remote host, causing the FTP client process in the local host to establish a TCP connection with the FTP server process in the remote host.
- The user then provides the user identification and password, which are sent over the TCP connection as part of FTP commands.
- Once the server has authorized the user, the user copies one or more files stored in the local file system into the remote file system (or vice versa).

FTP: the file transfer protocol



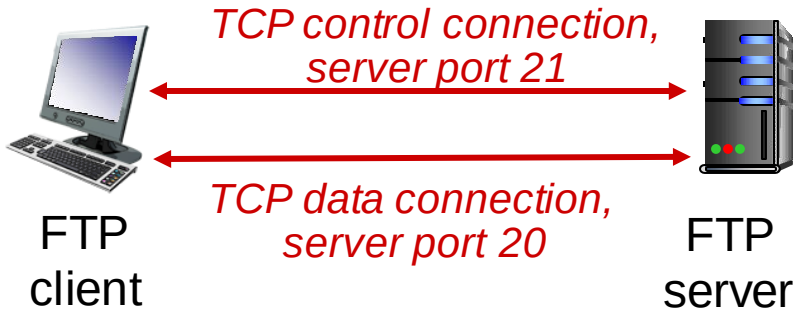
- transfer file to/from remote host
- client/server model
  - *client:* side that initiates transfer (either to/from remote)
  - *server:* remote host
- ftp: RFC959
- ftp server: port 21

FTP: separate control, data connections

- The most striking difference of FTP and HTTP is that FTP uses two parallel TCP connections to transfer a file, a **control connection** and a **data connection**.
- The **control connection** is used for sending control information between the two hosts—information such as user identification, password, commands to change remote directory, and commands to "put" and "get" files
- The **data connection** is used to actually send a file.
- 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

FTP: separate control, data connections

- server opens another TCP data connection to transfer another file- data connection – non persistent
- control connection: *"out of band"*
- Throughout a session, the FTP server must maintain state about the user .The server must associate the control connection with a specific user account, and the server must keep track of the user's current directory as the user wanders about the remote directory tree.
- Keeping track of this state information for each ongoing user session significantly constrains the total number of sessions that FTP can maintain simultaneously



FTP commands, responses

sample commands:

- sent as ASCII text over control channel
- **USER *username***
- **PASS *password***
- **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**

The commands, from client to server, and replies, from server to client, are sent across the control connection in 7-bit ASCII format
Each command consists of four uppercase ASCII characters, some with optional arguments

APPLICATION LAYER

Electronic Mail in the Internet

- **SMTP (Simple Mail Transfer Protocol)**
- **POP3**
- **IMAP**

Reference: Chapter2, J. Kurose and K. Ross 2012, Computer Network,6th ed.

Electronic Mail in the Internet

- Electronic mail has been around since the beginning of the Internet. It was the most popular application when the Internet was in its infancy, and has become more and more elaborate and powerful over the years. It remains one of the Internet's most important and utilized applications
- e-mail is an asynchronous communication medium—people send and read messages when it is convenient for them, without having to coordinate with other people's schedules
  - In contrast with postal mail, electronic mail is fast, easy to distribute, and inexpensive
  - Modern e-mail has many powerful features, including messages with attachments, hyperlinks, HTML-formatted text, and embedded photos

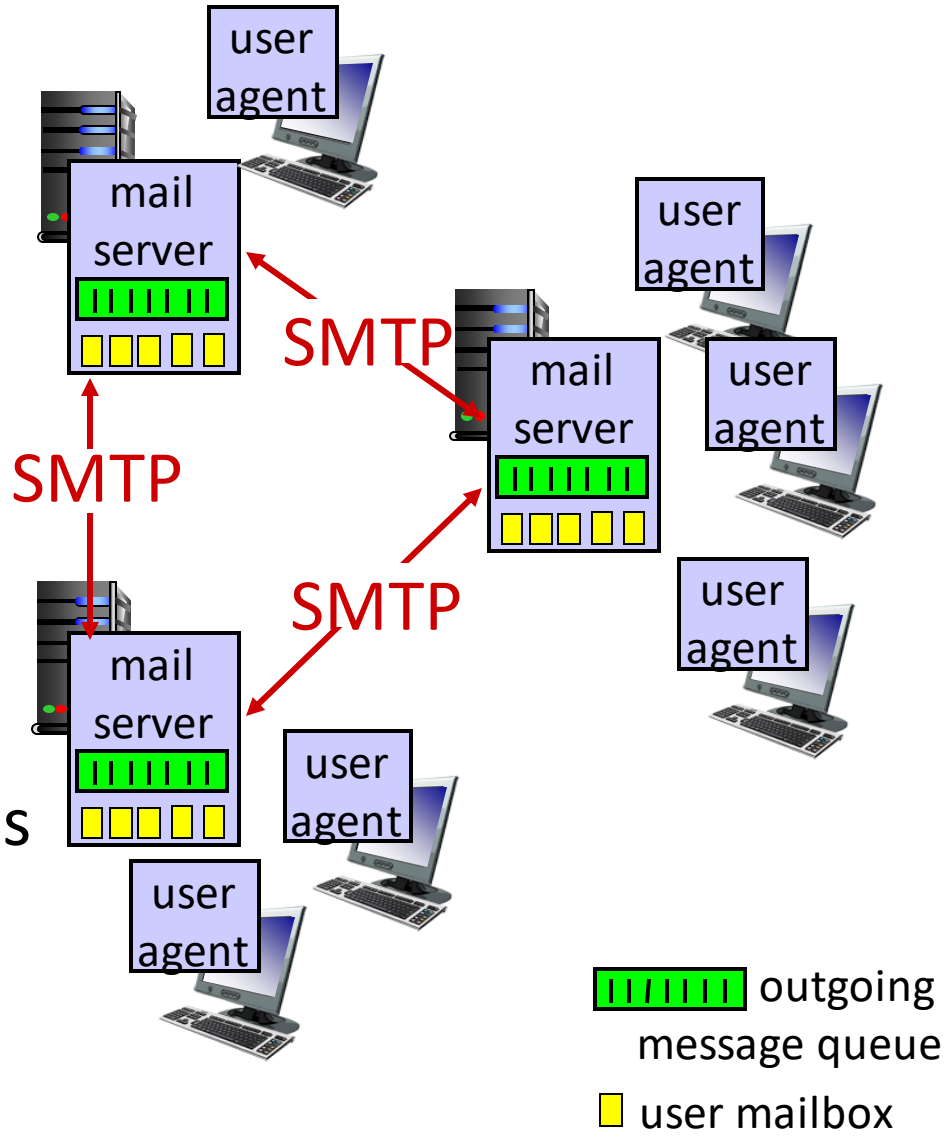
Electronic mail

Three major components:

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

User Agent

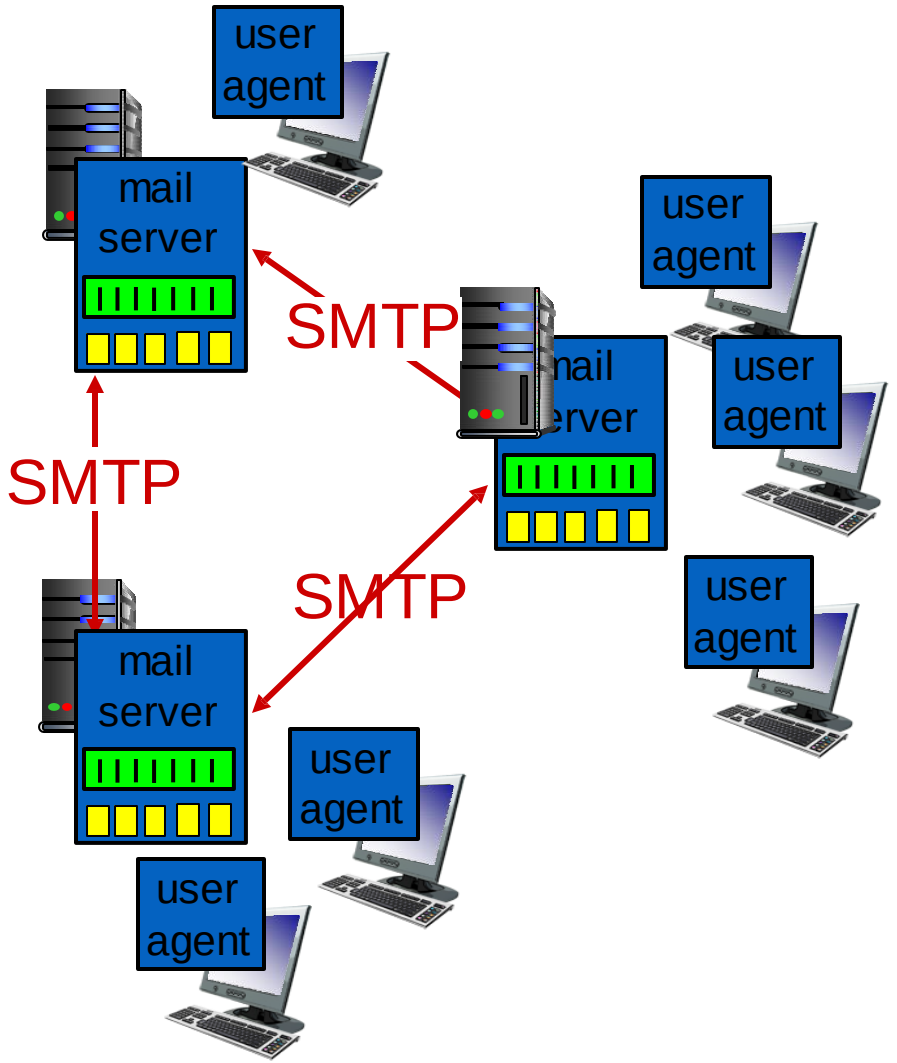
- a.k.a. “mail reader”
- composing, editing, reading mail messages
- e.g., Outlook, iPhone mail client
- outgoing, incoming messages stored on server



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



Atypical message starts its journey in the sender's user agent, travels to the sender's mail server, and travels to the recipient's mail server, where it is deposited in the recipient's mailbox

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

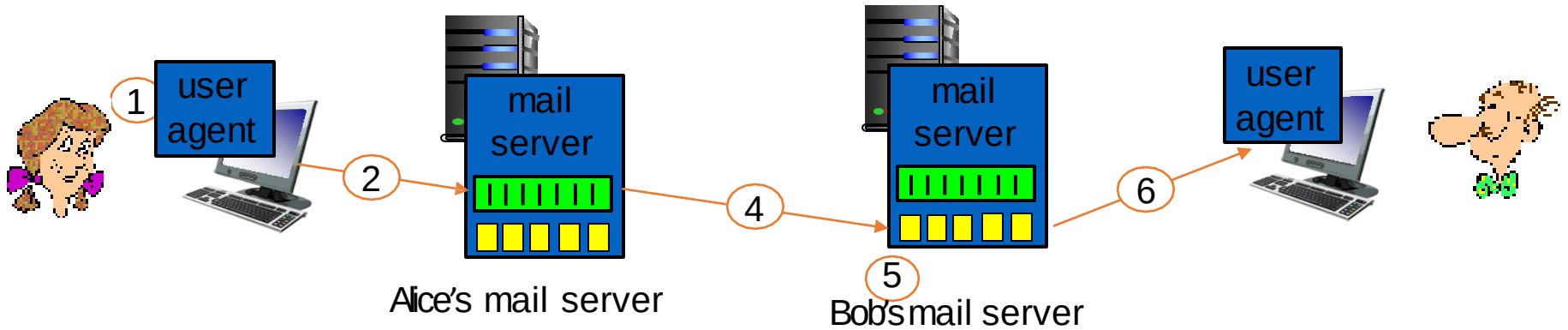
- SMTP restricts the body (not just the headers) of all mail messages to simple 7-bit ASCII.But today, in the multimedia era, the 7-bit ASCII restriction is a bit of a pain—it requires binary multimedia data to be encoded to ASCII before being sent over SMTP; and it requires the corresponding ASCII message to be decoded back to binary after SMTP transport

- HTTP does not require multimedia data to be ASCII encoded before transfer.

Scenario: Alice sends message to Bob

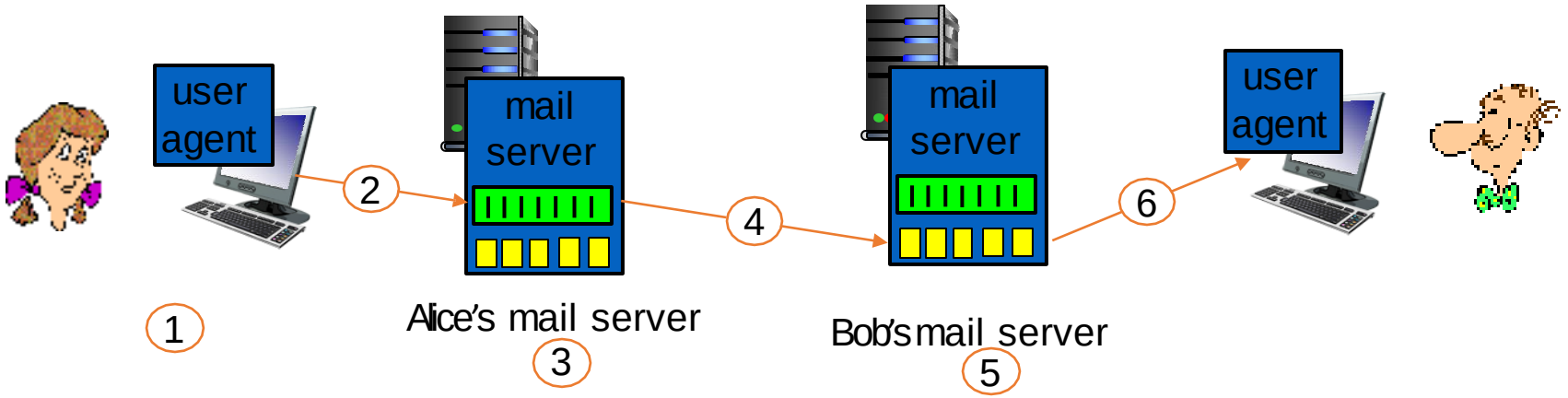
We now describe each of the components in the context of a sender, Alice, sending an e-mail message to a recipient, Bob. User agents allow users to read, reply to, forward, save, and compose messages. Microsoft Outlook and Apple Mail are examples of user agents for e-mail. When Alice is finished composing her message, her user agent sends the message to her mail server, where the message is placed in the mail server's outgoing message queue. When Bob wants to read a message, his user agent retrieves the message from his mailbox in his mail server.

When Bob wants to access the messages in his mailbox, the mail server containing his mailbox authenticates Bob (with usernames and passwords). Alice's mail server must also deal with failures in Bob's mail server. If Alice's server cannot deliver mail to Bob's server, Alice's server holds the message in a ***message queue*** *and attempts to transfer the message later. Reattempts are often done every 30 minutes or so; if there is no success after several days, the server removes the message and notifies the sender (Alice) with an e-mail message*



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



The client then repeats this process over the same TCP connection if it has other messages to send to the server; otherwise, it instructs TCP to close the connection.

Sample SMTP interaction

- Let's next take a look at an example transcript of messages exchanged between an SMTP client (C) and an SMTP server (S). The hostname of the client is crepes.fr and the hostname of the server is hamburger.edu.
- The ASCII text lines prefaced with C: are exactly the lines the client sends into its TCP socket,
- The ASCII text lines prefaced with S: are exactly the lines the server sends into its TCP socket. The following transcript begins as soon as the TCP connection is established

In the example in next slide, the client sends a message ("`Do you like ketchup? How about pickles?`") from mail server `crepes.fr` to mail server `hamburger.edu`

As part of the dialogue, the client issued five commands: `HELO` (an abbreviation for HELLO), `MAIL FROM`, `RCPT TO`, `DATA`, and `QUIT`.

The client also sends a line consisting of a single period, which indicates the end of the message to the server. In ASCII jargon, each message ends with `CRLF.CRLF`,

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
```

SMTP uses persistent connections: If the sending mail server has several messages to send to the same receiving mail server, it can send all of the messages over the same TCP connection

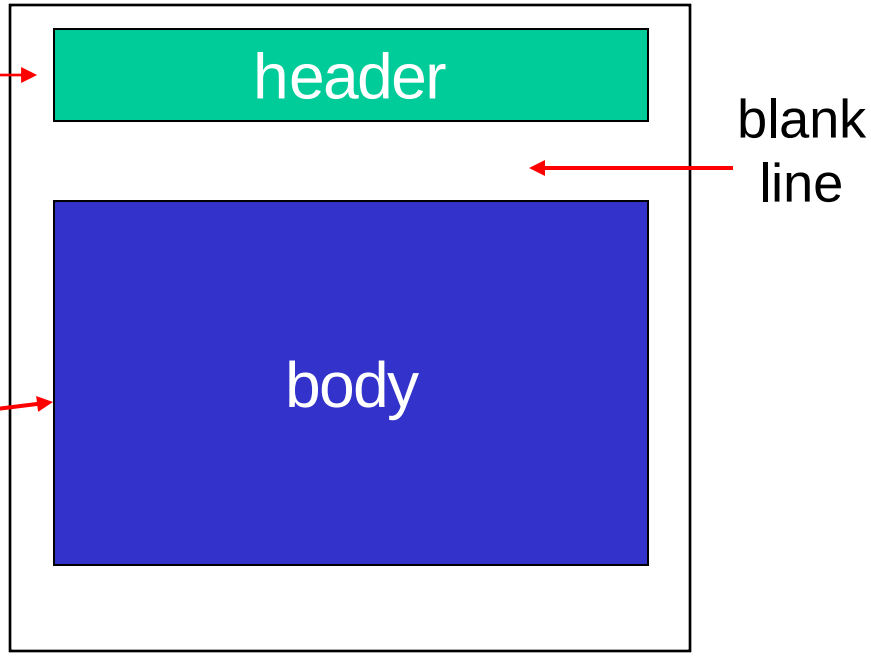
Mail message format

SMTP: protocol for exchanging e-mail messages, defined in RFC 5321 (like RFC 7231 defines HTTP)

RFC 2822 defines *syntax* for e-mail message itself (like HTML defines syntax for web documents)

- header lines, e.g.,
  - To:
  - From:
  - Subject:

  these lines, within the body of the email message area 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

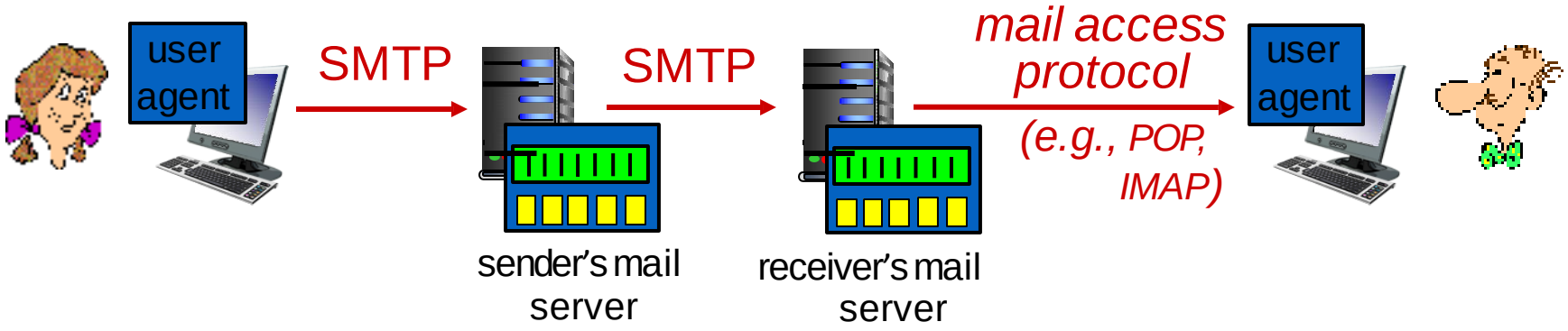
comparison with HTTP:

- 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.

Difference - HTTP and SMTP

HTTP	SMTP
It is a pull protocol, i.e., a client pulls the information available on a server by initiating a TCP connection.	It is a push protocol, i.e., the sending mail server pushes the data onto the receiving mail server by initiating a TCP connection.
HTTP can use both a persistent and non-persistent connection	SMTP uses a persistent connection.
By default, HTTP uses port 80.	By default, SMTP uses port 25.
It does not require binary multimedia data to be encoded in 7-bit ASCII.	It requires binary multimedia data to be encoded in 7-bit ASCII
It places each object in its own HTTP message	• It places all the objects into a single message.

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)

POP3 protocol

authorization phase

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

transaction phase, client:

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

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

```
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

Chapter 2: outline - upcoming

1. principles of network applications
2. Web and HTTP
3. electronic mail
   - SMTP, POP3, IMAP
4. DNS
5. P2P applications
6. video streaming and content distribution networks
7. socket programming with UDP and TCP

Namah Shivaya