ECE 356/COMPSI 356
Computer Network Architecture

Application Layer Protocols

Monday November 25, 2019

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Previous Lecture Recap

- Enterprise networking
- Duke University networks

- Readings for this lecture: **PD 9.1.1, 9.1.2**

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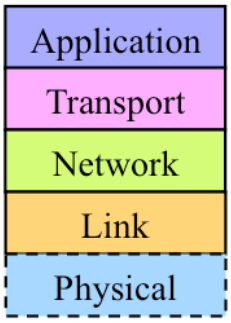
Lecture Outline

- **Application protocols**
- Web and HTTP
- Electronic Mail
  - SMTP
  - Mail access protocols

Application-Layer Protocols (1/2)

- Run above the transport layer
- E.g., DNS is an application-level protocol

- Only some application-layer protocols are in the public domain
  - E.g., Telnet, FTP, HTTP are defined in RFCs
  - Skype is private



Application-Layer Protocols (2/2)

Protocols define:

- Types of messages (e.g., requests and responses)
- Message syntax (e.g., fields, and how to delineate)
- Semantics of the fields (i.e., meaning of the information)
- Rules for when and how a process sends messages
- Platform and programming language independent

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Lecture Outline

- Application protocols
- **Web and HTTP**
  - Cookies
- Electronic Mail
  - SMTP
  - Mail access protocols

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Web and HTTP: An Introduction

- *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.,

`www.someschool.edu`/`someDept/pic.gif`

host name path name

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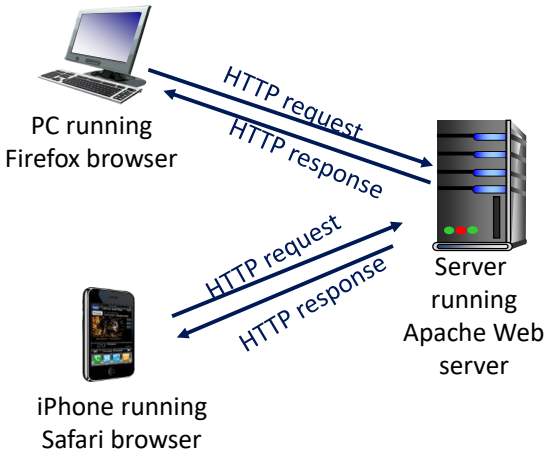
HTTP Overview (1/3)

- 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



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HTTP Overview (2/3)

- *Uses TCP*
- Process flow:
  - Client initiates TCP connection 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

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HTTP Overview (3/3)

*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

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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
- Default option

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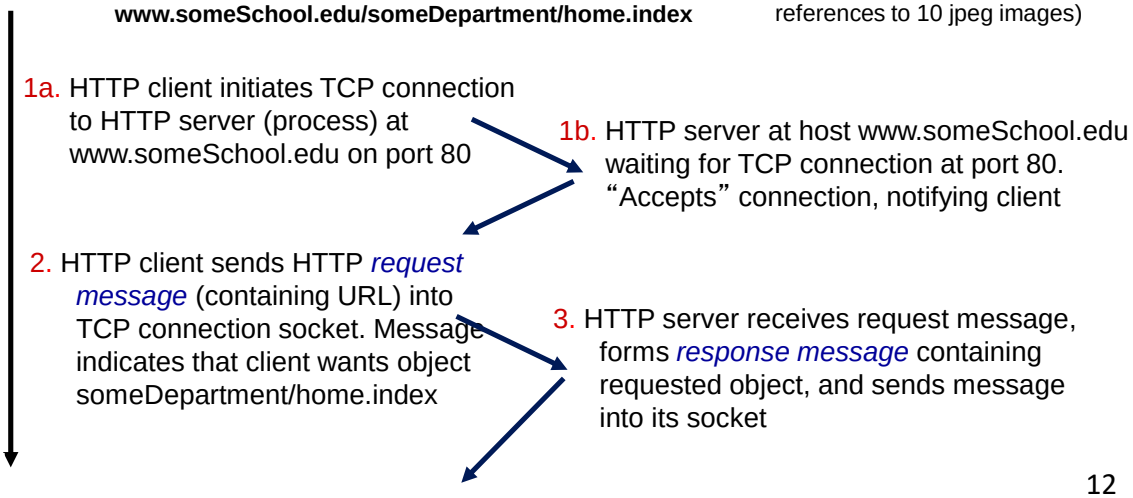
Non-persistent HTTP (1/2)

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

(contains text, references to 10 jpeg images)



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Non-persistent HTTP (2/2)

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

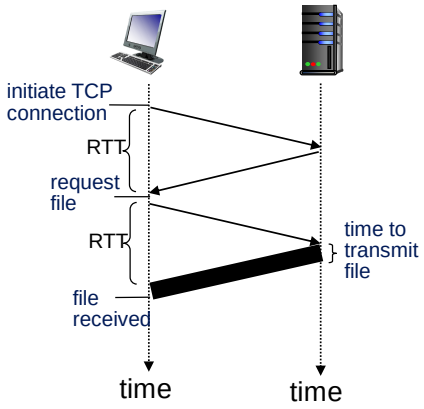
6. Steps 1-5 repeated for each of 10 jpeg objects

time

Non-persistent 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:

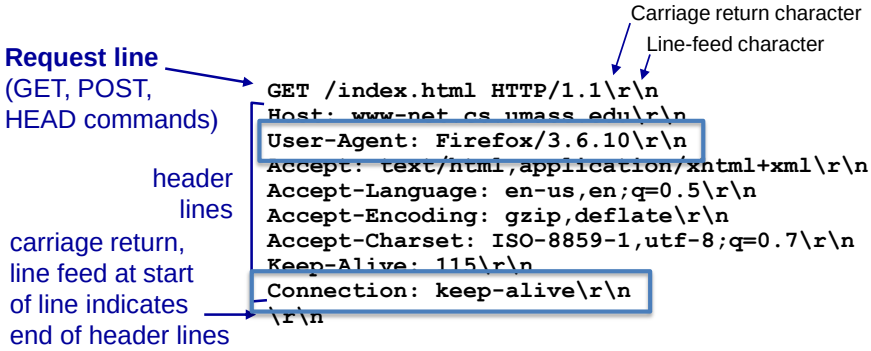
- Requires 2 RTTs per object
- OS overhead for *each* TCP connection
- Browsers often open parallel TCP connections to fetch referenced objects

Persistent HTTP:

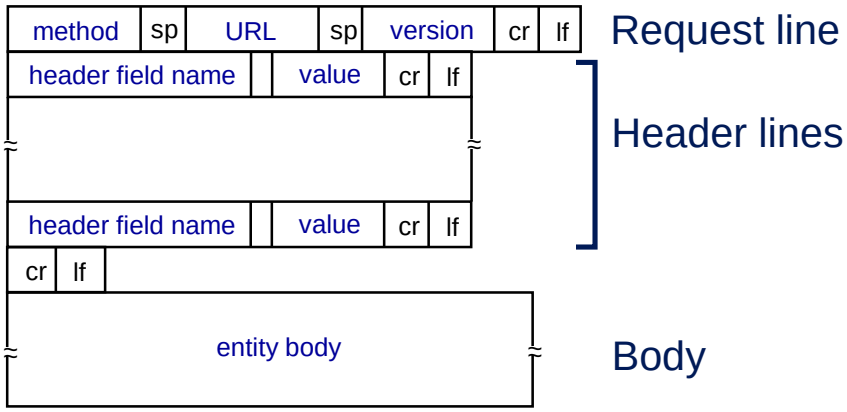
- Server leaves connection open after sending response
- Subsequent HTTP messages between same client/server sent over open connection
- Client sends requests as soon as it encounters a referenced object
- As little as one RTT for all the referenced objects

HTTP Request Message

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



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 ...
```

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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

400 Bad Request
- Request msg not understood by server

404 Not Found
- Requested document not found on this server

505 HTTP Version Not Supported

Hyper Text Coffee Pot Control Protocol

- April Fool's RFCs:
  - 1998 Hyper Text Coffee Pot Control Protocol (HTCPCP): communication protocol for controlling, monitoring, and diagnosing coffee pots
  - 2014 HTCPCP-TEA to support brewing teas
- Commands: BREW, WHEN
- Status codes:

418 I'm a teapot

- Save418.com

Web and HTTP: Key Points to Remember (1/2)

- HTTP:
  - **Ubiquitous**
  - **Client-server**
  - **Stateless** application-layer protocol
- Client downloads a webpage consisting of multiple objects
  - Multiple objects can be handled in persistent and non-persistent manner

Web and HTTP: Key Points to Remember (2/2)

- HTTP defines *request* and *response* messages
- Request: methods: GET, POST, HEAD, PUT, DELETE
- Reply includes a status code

Lecture Outline

- Application protocols
- Web and HTTP
  - **Cookies**
- Electronic Mail
  - SMTP
  - Mail access protocols

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User-server State: Cookies (1/2)

- While HTTP is stateless, state information is useful for web transactions
- 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

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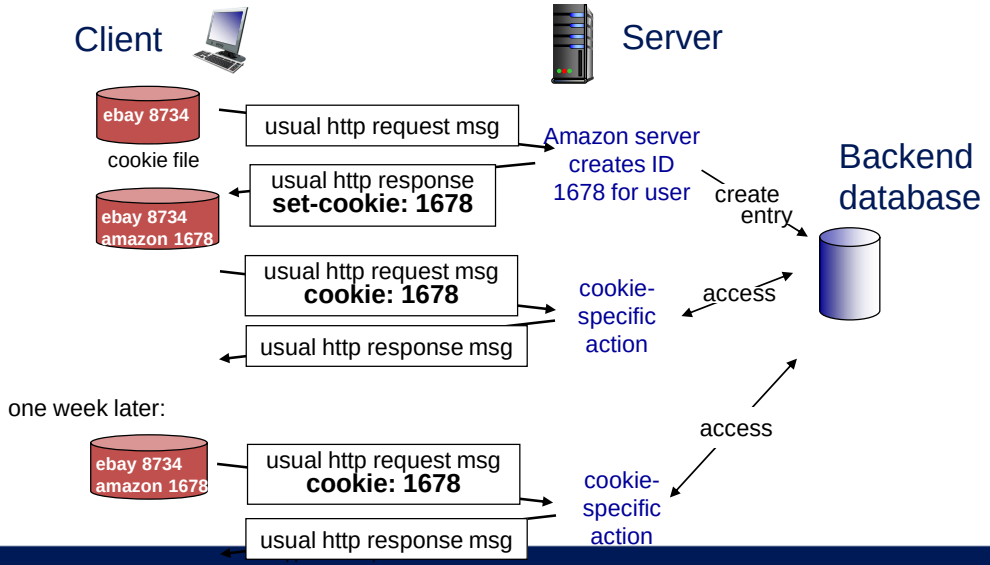
User-server State: Cookies (2/2)

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: An Example



Cookies: Usage and Concerns

What cookies can be used for:

- 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

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Where Cookies Get Creepy

- (Arguably) OK for a service provider to help orient you on their website: these are so-called "first-party cookies"
- "Third-party cookies" are another matter
- Ad servers, Facebook can track your behavior across *multiple disjoint websites*
  - A page with a Facebook "like" button generates a Facebook cookie
  - *You do not have to engage with the "like" button to be tracked*: only need to visit the website

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Lecture Outline

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Electronic Mail in the Internet

- Has been around since the beginning of the Internet
- Was the most popular application when Internet was in its infancy
- *Asynchronous* communication medium
  - People send and read messages when it is convenient for them
- A suite of protocols:
  - Simple Mail Transfer Protocol (**SMTP**)
  - Post Office Protocol (**POP3**)
  - Internet Message Access Protocol (**IMAP**)

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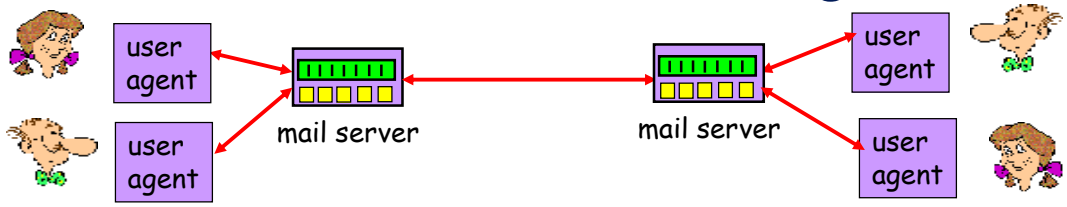
Electronic Mail: Mail Servers and User Agents



- Mail servers
  - Always on and always accessible
  - Transferring e-mail to and from other servers
- User agents
  - Sometimes on and sometimes accessible
  - Intuitive interface for the user

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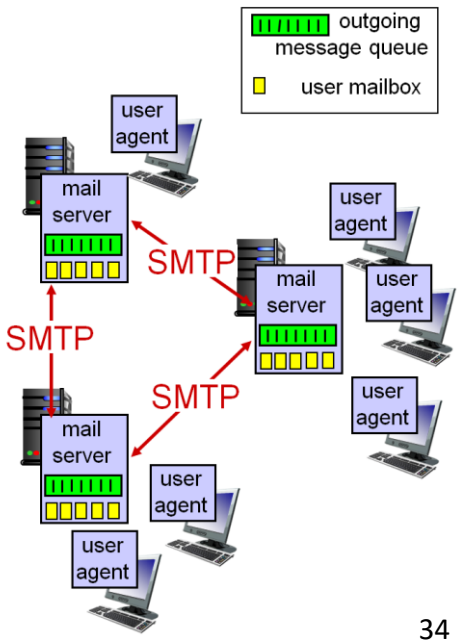
Electronic Mail: 3 Major Components

- User agents
- Mail servers
- Simple mail transfer protocol: SMTP



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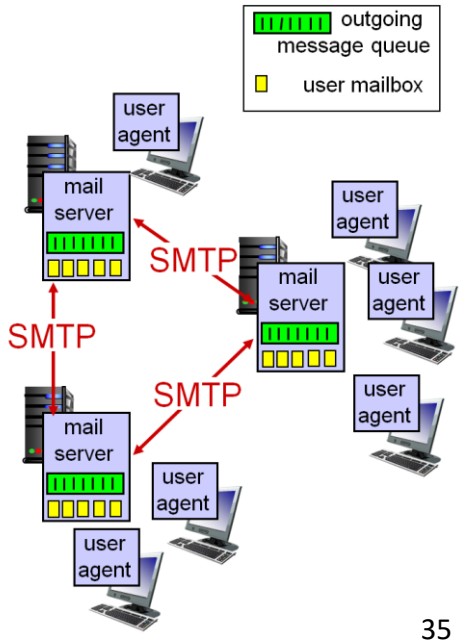
Electronic Mail: User Agent

- A.k.a. “mail reader”
- Composing, editing, reading mail messages
- E.g., Outlook, Thunderbird, iPhone mail client
- Outgoing, incoming messages stored on server



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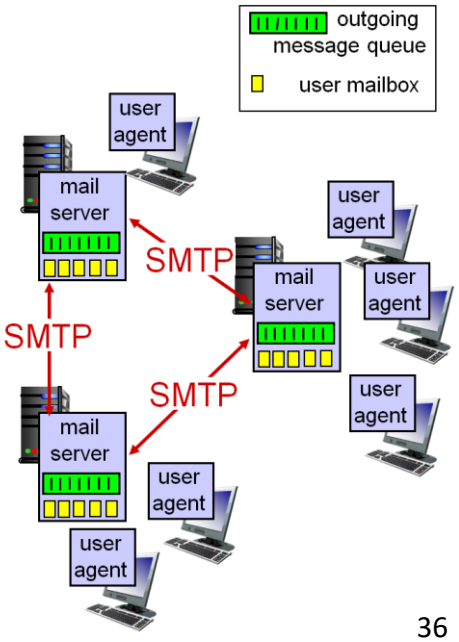
Electronic Mail: Mail Server

- *Mailbox* contains incoming messages for each user
- Message queue of outgoing (to be sent) mail messages
- SMTP protocol between mail servers to send email messages
- Client/server architecture:
  - Client: sending mail server
  - “Server”: receiving mail server



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SMTP (1/2)

- Uses TCP to reliably transfer email message from client to server
  - Port 25
- Three phases of transfer
  - Handshaking (greeting)
  - Transfer of messages
  - Closure

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SMTP (2/2)

- Command/response interaction (like HTTP)
  - Commands: ASCII text
  - Response: status code and phrase
- Messages must be in 7-bit ASCII

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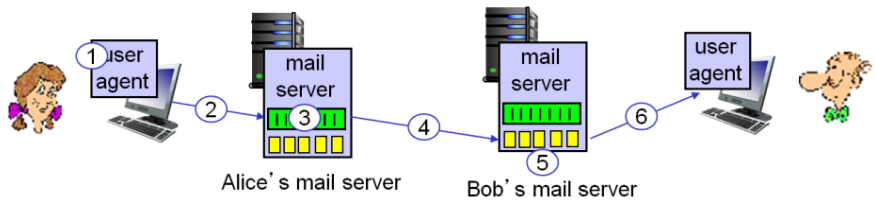
Scenario: Alice Sends Message to Bob (1/2)

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



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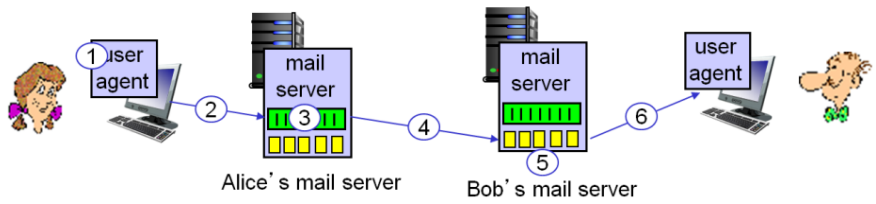
Scenario: Alice Sends Message to Bob (2/2)

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



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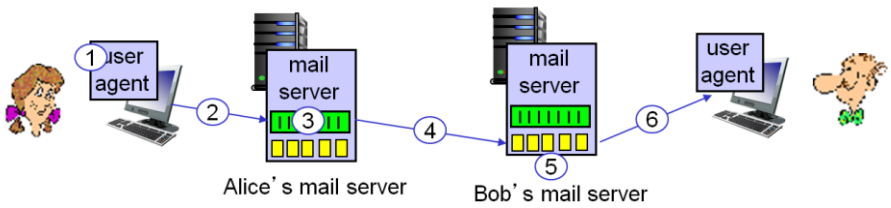
Question: Why Do We Need Mail Servers?

Why not let user agents do the work of the servers?



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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
```

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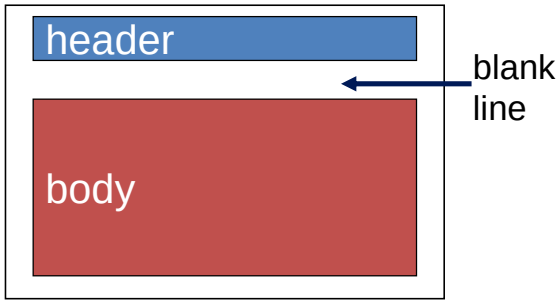
SMTP vs. HTTP

- HTTP: pull
  - TCP connection initiated by the machine that wants to *receive* a file
- SMTP: **push protocol**
  - TCP connection initiated by the machine that wants to *send* a file
- Both have ASCII command/response interaction, status codes
- HTTP: each object encapsulated in its own response message
- SMTP: multiple objects sent in multipart message
  - Persistent connections

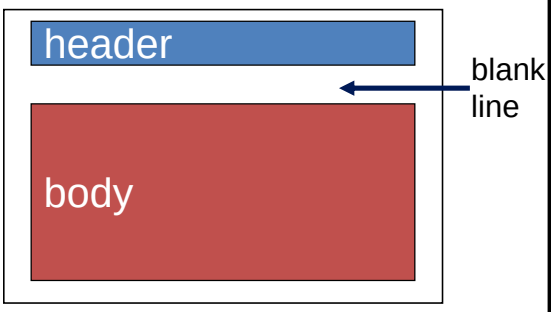
E-Mail Message Format (1/2)

- E-mail messages have two parts
  - A header, in 7-bit U.S. ASCII text
  - A body, also represented in 7-bit U.S. ASCII text
- A blank line between the two



E-Mail Message Format (2/2)

- Header
  - *To*, *from*, *subject* lines with "type: value"
  - "To: xyz@cs.duke.edu"
  - "Subject: Hello!"
- Body
  - The text message
  - No particular structure or meaning



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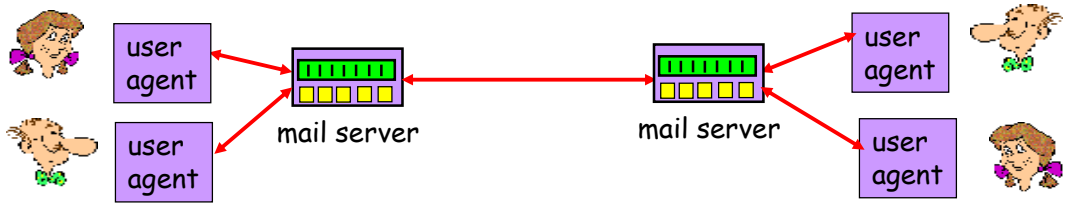
Electronic Mail and SMTP: Key Points To Remember



- SMTP protocol between mail servers to send email messages
- Client/server architecture:
  - Client: sending mail server
  - "Server": receiving mail server
- Push protocol

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Lecture Outline

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- Web and HTTP
- Electronic Mail
  - SMTP
  - **Mail access protocols**

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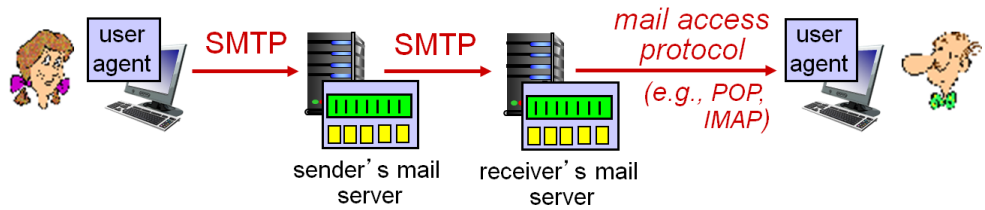
Mail Access Protocols



- **SMTP:** delivery/storage to receiver's server
- Mail access protocol: retrieval from server
  - POP: Post Office Protocol: authorization, download
  - IMAP: Internet Mail Access Protocol: more features, including manipulation of stored messages on server
  - HTTP: gmail, Hotmail, Yahoo! Mail, etc.

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Retrieving E-Mail From the Server

- Server stores incoming e-mail by mailbox
  - Based on the "From" field in the message
- Users need to retrieve e-mail
  - *Asynchronous access*
  - Need to view, reply, organize, and store messages
- In the pre-PC days…
  - User logged on to the machine where mail was delivered
  - Users received e-mail on their main work machine

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Influence of PCs on E-Mail Retrieval

- Separate machine for personal use
  - Users did not want to log in to remote machines
- Resource limitations
  - Most PCs did not have enough resources to act as a full-fledged e-mail server
- Intermittent connectivity
  - PCs only sporadically connected to the network
  - … due to dial-up connections, and shutting down of PC
  - Too unwieldy to have sending server keep trying
- Led to the creation of Post Office Protocol (POP)

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Post Office Protocol (POP) (1/3)

- Simple protocol with limited capabilities
- POP goals
  - Allow users retrieve e-mail messages when connected
  - … and view/manipulate messages when disconnected
- *User agent still uses SMTP to send messages*

Post Office Protocol (POP) (2/3)

- Typical user agent interaction with a POP server
  - Open a TCP connection to the mail server
    - Port 110
  - Retrieve all e-mail messages
  - Store messages on the user's PCs as new messages
  - Delete the messages from the server
  - Disconnect from the server

Post Office Protocol (POP) (3/3)

- 3 operational phases: **authorization**, **transaction**, **update**
  - Authorization: username, password sent in the clear
  - Transaction: user agent retrieves messages, marks messages for deletion
  - Update: after the *quit* command, mail server deletes messages

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POP3 Protocol (1/2)

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
```

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POP3 Protocol (2/2)

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
```


POP: Comments and Limitations

- 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
  - ➢ Simple implementation, limited capability

Interactive Mail Access Protocol (IMAP)

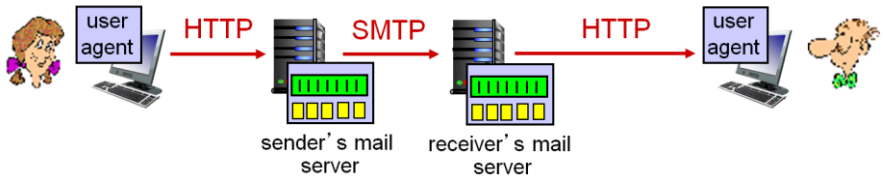
- POP: protocol for retrieving content of a mailbox
- IMAP: remote access mailbox protocol
  - Keeps all messages in one place: at server
- Allows user to organize messages in folders
- Keeps user state across sessions:
  - Names of folders and mappings between message IDs and folder name

Web-Based E-Mail (1/2)

- Introduced by Hotmail in mid 1990s
- User agent is an ordinary Web browser
  - User communicates with server via HTTP
  - Gmail, Yahoo mail, …
- Reading e-mail
  - Web pages display the contents of folders
  - … and allow users to download and view messages
  - "GET" request to *retrieve* the various Web pages

Web-Based E-Mail (2/2)

- Sending e-mail
  - User types the text into a form and submits to the server
  - "POST" request to *upload* data to the server
- ***Server uses SMTP to deliver message to other servers***



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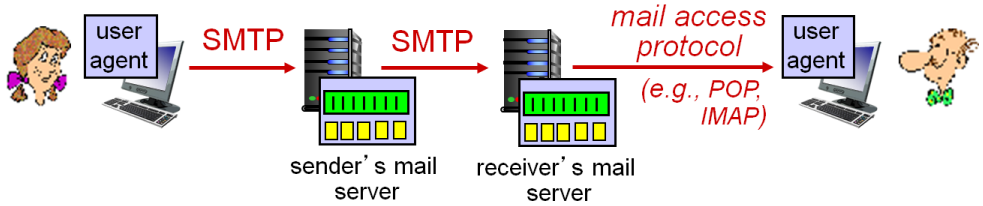
Mail Access Protocols: Key Points To Remember



- POP: Post Office Protocol: authorization, download
- IMAP: Internet Mail Access Protocol: more features, including manipulation of stored messages on server
- HTTP: gmail, Hotmail, Yahoo! Mail, etc.

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Lecture Summary

- Application protocols
- Web and HTTP
- Electronic Mail
  - SMTP
  - Mail access protocols

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Next Lecture

- Network security