

# Computer Networks and Applications

COMP 3331/COMP 9331

Week 2

Application Layer (Principles)

**Chapter 2, Sections 2.1-2.3**

## 2. Application Layer: 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 (CDNs)

2.7 socket programming with UDP and TCP

## 2. Application layer

### our goals:

- ❖ conceptual, implementation aspects of network application protocols
  - transport-layer service models
  - client-server paradigm
  - peer-to-peer paradigm
- ❖ learn about protocols by examining popular application-level protocols
  - HTTP
  - SMTP / POP3 / IMAP
  - DNS
- ❖ creating network applications
  - socket API

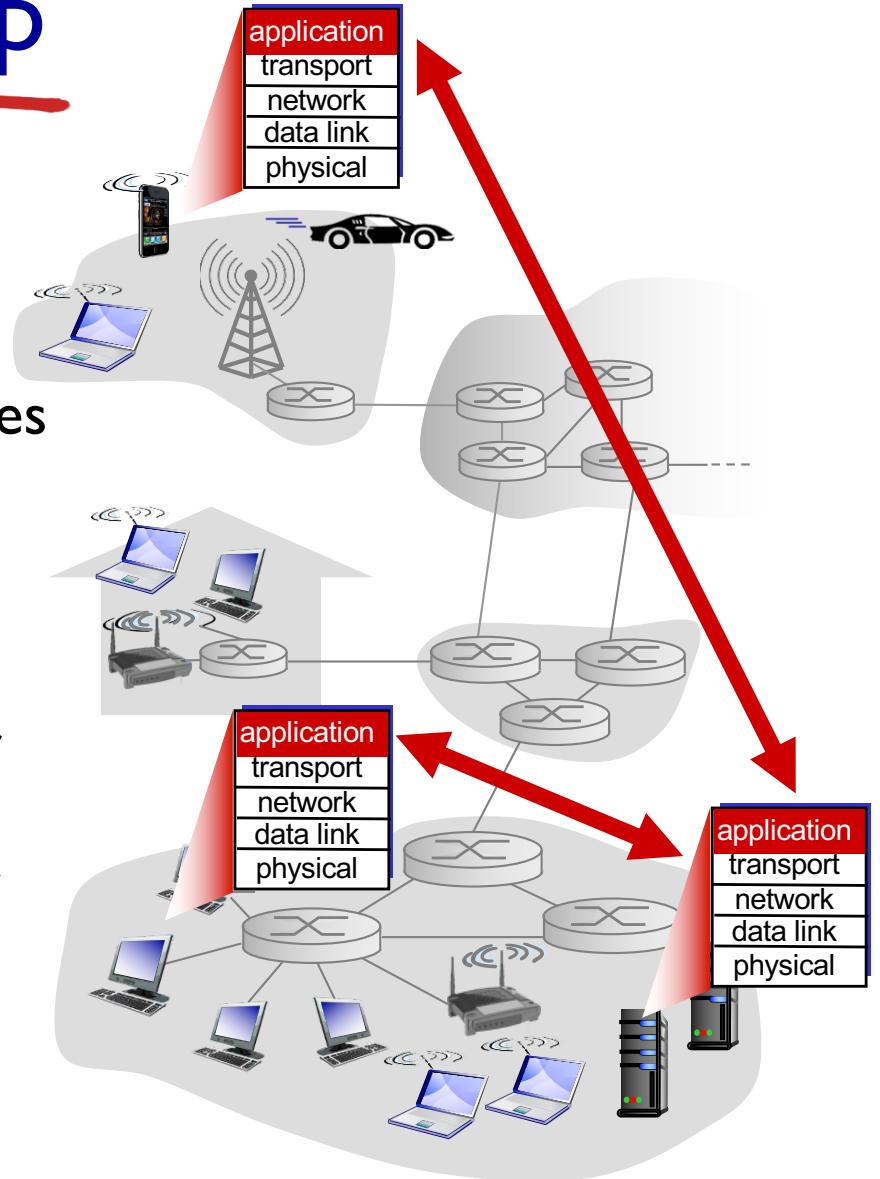
# Creating a network app

Write programs that:

- ❖ run on (different) end systems
- ❖ communicate over network
- ❖ e.g., web server software communicates with browser software

No need to write software for network-core devices

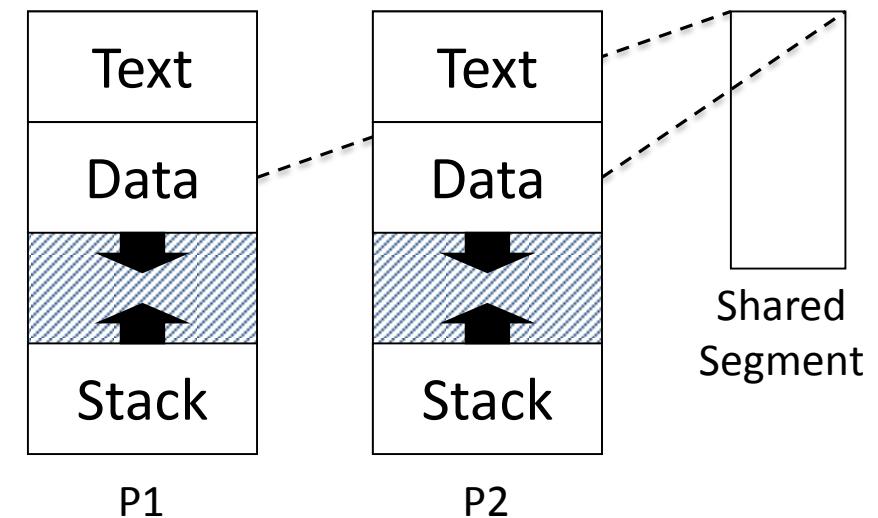
- ❖ network-core devices do not run user applications
- ❖ applications on end systems allows for rapid app development



# Interprocess Communication (IPC)

- ❖ Processes talk to each other through Inter-process communication (IPC)

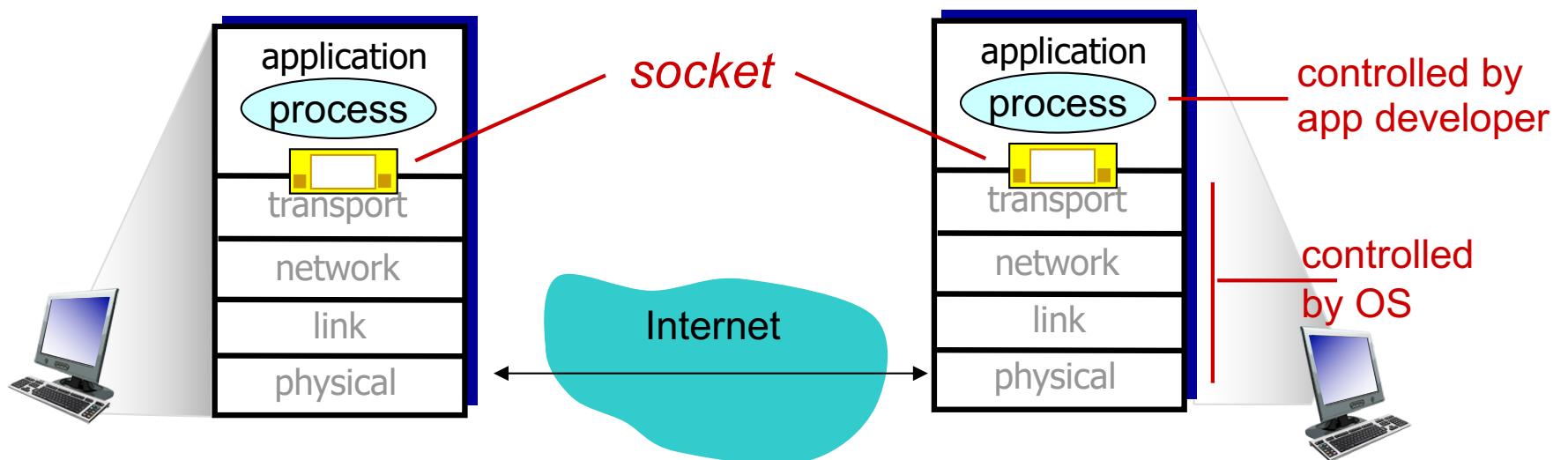
- ❖ On a single machine:
  - Shared memory



- ❖ Across machines:
  - We need other abstractions (message passing)

# Sockets

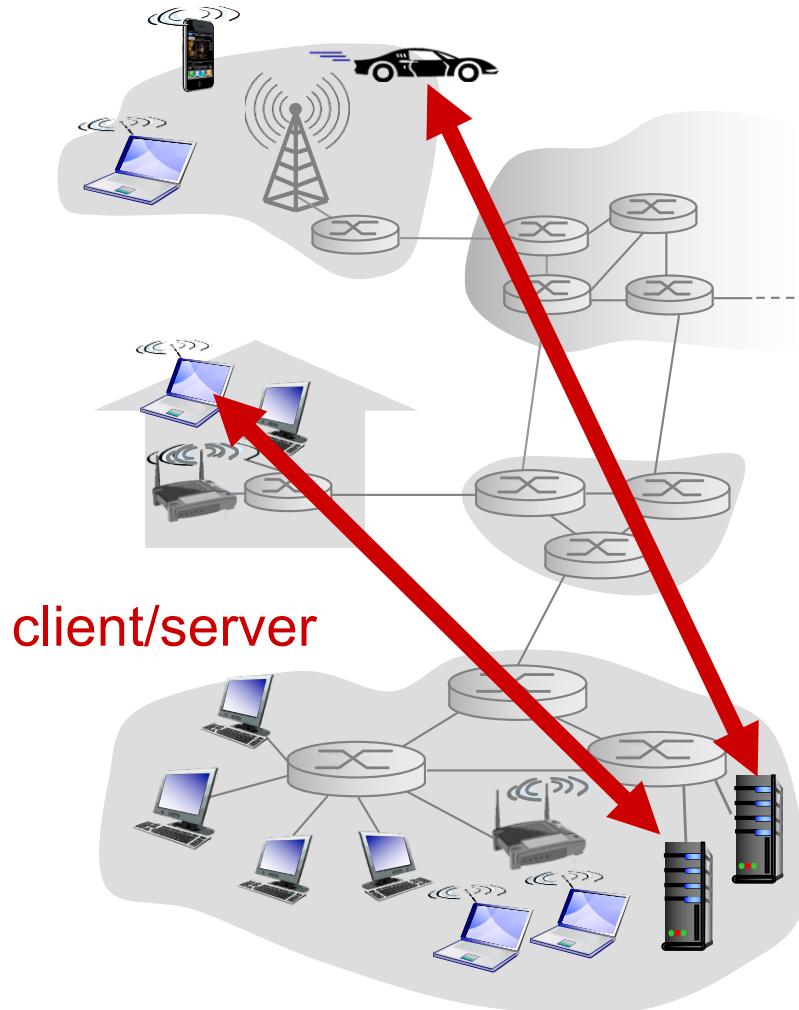
- ❖ process sends/receives messages to/from its **socket**
- ❖ socket analogous to door
  - sending process shoves message out door
  - sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process
- ❖ Application has a few options, OS handles the details



# Addressing processes

- ❖ to receive messages, process must have *identifier*
- ❖ host device has unique 32-bit IP address
- ❖ Q: does IP address of host on which process runs suffice for identifying the process?
  - A: no, many processes can be running on same host
- ❖ *identifier* includes both IP address and port numbers associated with process on host.
- ❖ example port numbers:
  - HTTP server: 80
  - mail server: 25
- ❖ to send HTTP message to cse.unsw.edu.au web server:
  - IP address: 129.94.242.51
  - port number: 80

# Client-server architecture



## server:

- ❖ Exports well-defined request/response interface
- ❖ long-lived process that waits for requests
- ❖ Upon receiving request, carries it out

## clients:

- ❖ Short-lived process that makes requests
- ❖ “User-side” of application
- ❖ Initiates the communication

# Client versus Server

## ❖ Server

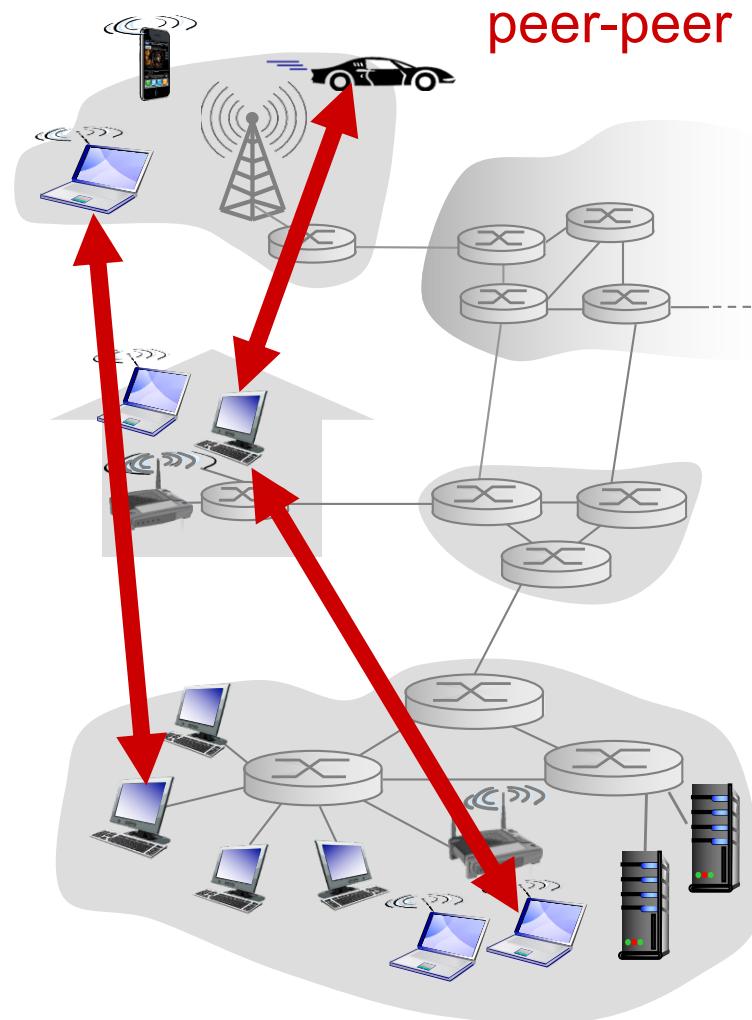
- Always-on host
- Permanent IP address (rendezvous location)
- Static port conventions (http: 80, email: 25, ssh:22)
- Data centres for scaling
- May communicate with other servers to respond

## ❖ Client

- May be intermittently connected
- May have dynamic IP addresses
- Do not communicate directly with each other

# P2P architecture

- ❖ no always-on server
  - No permanent rendezvous involved
- ❖ arbitrary end systems (peers) directly communicate
- ❖ Symmetric responsibility (unlike client/server)
- ❖ Often used for:
  - File sharing (BitTorrent)
  - Games
  - Video distribution, video chat
  - In general: “distributed systems”



# P2P architecture: Pros and Cons

+ peers request service from other peers, provide service in return to other peers

- *self scalability* – new peers bring new service capacity, as well as new service demands

+ Speed: parallelism, less contention

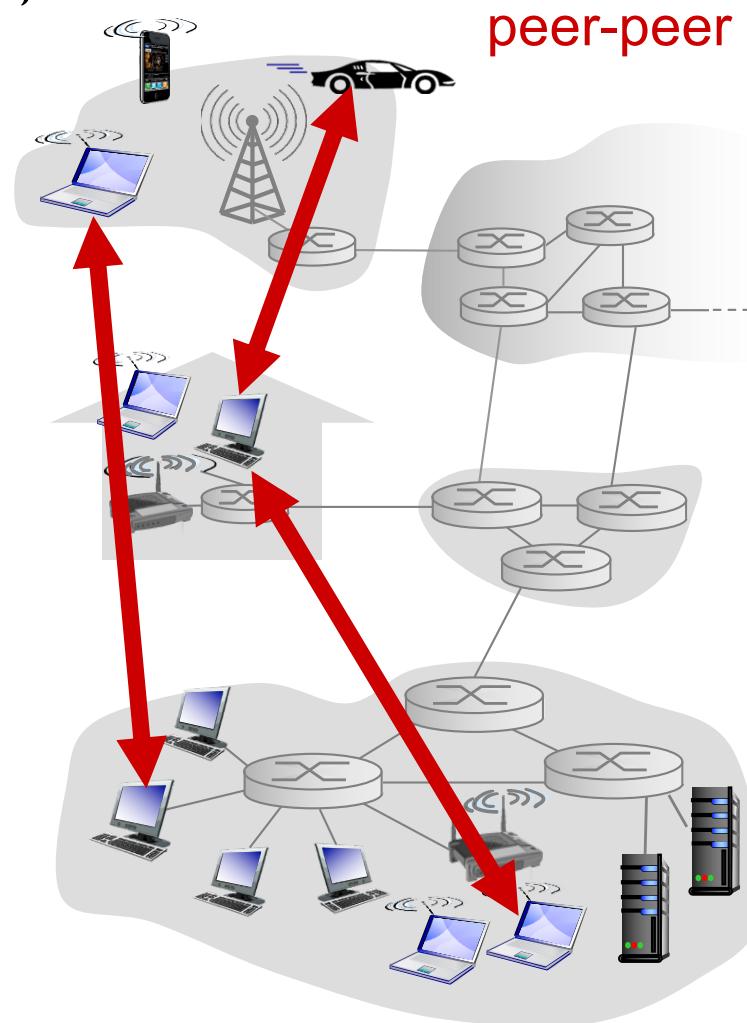
+ Reliability: redundancy, fault tolerance

+ Geographic distribution

-Fundamental problems of decentralized control

- State uncertainty: no shared memory or clock
- Action uncertainty: mutually conflicting decisions

-Distributed algorithms are complex



# App-layer protocol defines

- ❖ types of messages exchanged,
  - e.g., request, response
- ❖ message syntax:
  - what fields in messages & how fields are delineated
- ❖ message semantics
  - meaning of information in fields
- ❖ rules for when and how processes send & respond to messages

**open protocols:**

- ❖ defined in RFCs
- ❖ allows for interoperability
- ❖ e.g., HTTP, SMTP

**proprietary protocols:**

- ❖ e.g., Skype

# What transport service does an app need?

## data integrity

- ❖ some apps (e.g., file transfer, web transactions) require 100% reliable data transfer
- ❖ other apps (e.g., audio) can tolerate some loss

## timing

- ❖ some apps (e.g., Internet telephony, interactive games) require low delay to be “effective”

## throughput

- ❖ some apps (e.g., multimedia) require minimum amount of throughput to be “effective”
- ❖ other apps (“elastic apps”) make use of whatever throughput they get

## security

- ❖ encryption, data integrity,

...

# Transport service requirements: common apps

<b>application</b>	<b>data loss</b>	<b>throughput</b>	<b>time sensitive</b>
file transfer	no loss	elastic	no
e-mail	no loss	elastic	no
Web documents	no loss	elastic	no
real-time audio/video	loss-tolerant	audio: 50kbps-1Mbps video:100kbps-5Mbps	yes, 100's msec
stored audio/video	loss-tolerant	same as above	yes, few secs
interactive games	loss-tolerant	few kbps up	yes, 100's msec
Chat/messaging	no loss	elastic	yes and no

# Internet transport protocols services

## TCP service:

- ❖ ***reliable transport*** between sending and receiving process
- ❖ ***flow control***: sender won't overwhelm receiver
- ❖ ***congestion control***: throttle sender when network overloaded
- ❖ ***does not provide***: timing, minimum throughput guarantee, security
- ❖ ***connection-oriented***: setup required between client and server processes

## 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?

**NOTE:** More on transport later on

# Internet apps: application, transport protocols

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



## Quiz: Transport

Pick the true statement

- A. TCP provides reliability and guarantees a minimum bandwidth
- B. TCP provides reliability while UDP provides bandwidth guarantees
- C. TCP provides reliability while UDP does not
- D. Neither TCP nor UDP provides reliability

## 2. Application Layer: outline

### 2.1 principles of network applications

- app architectures
- app requirements

### 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 (CDNs)

### 2.7 socket programming with UDP and TCP

# The Web – Precursor



Ted Nelson

- ❖ **1967, Ted Nelson, Xanadu:**
  - A world-wide publishing network that would allow information to be stored not as separate files but as connected literature
  - Owners of documents would be automatically paid via electronic means for the virtual copying of their documents
- ❖ **Coined the term “Hypertext”**

# The Web – History

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Tim Berners-Lee

- ❖ World Wide Web (WWW): a distributed database of “pages” linked through **Hypertext Transport Protocol (HTTP)**
  - First HTTP implementation - 1990
    - Tim Berners-Lee at CERN
  - HTTP/0.9 – 1991
    - Simple GET command for the Web
  - HTTP/1.0 – 1992
    - Client/Server information, simple caching
  - HTTP/1.1 – 1996
  - HTTP2.0 - 2015

<http://info.cern.ch/hypertext/WWW/TheProject.html>

# Web and HTTP

*First, a review...*

- ❖ *web page* consists of *objects*
- ❖ object can be HTML file, JPEG image, Java applet, audio file,...
- ❖ web page consists of *base HTML-file* which includes *several referenced objects*
- ❖ each object is addressable by a *URL*, e.g.,

www.someschool.edu/someDept/pic.gif

host name

path name

# Web and HTTP

```
<!DOCTYPE html>
<html>
    <head>
        <title>Hyperlink Example</title>
    </head>
    <body>
        <p>Click the following link</p>
        <a href = "http://www.cnn.com" target ="_self">CNN</a>
    </body>
</html>
```

# Uniform Resource Locator (URL)

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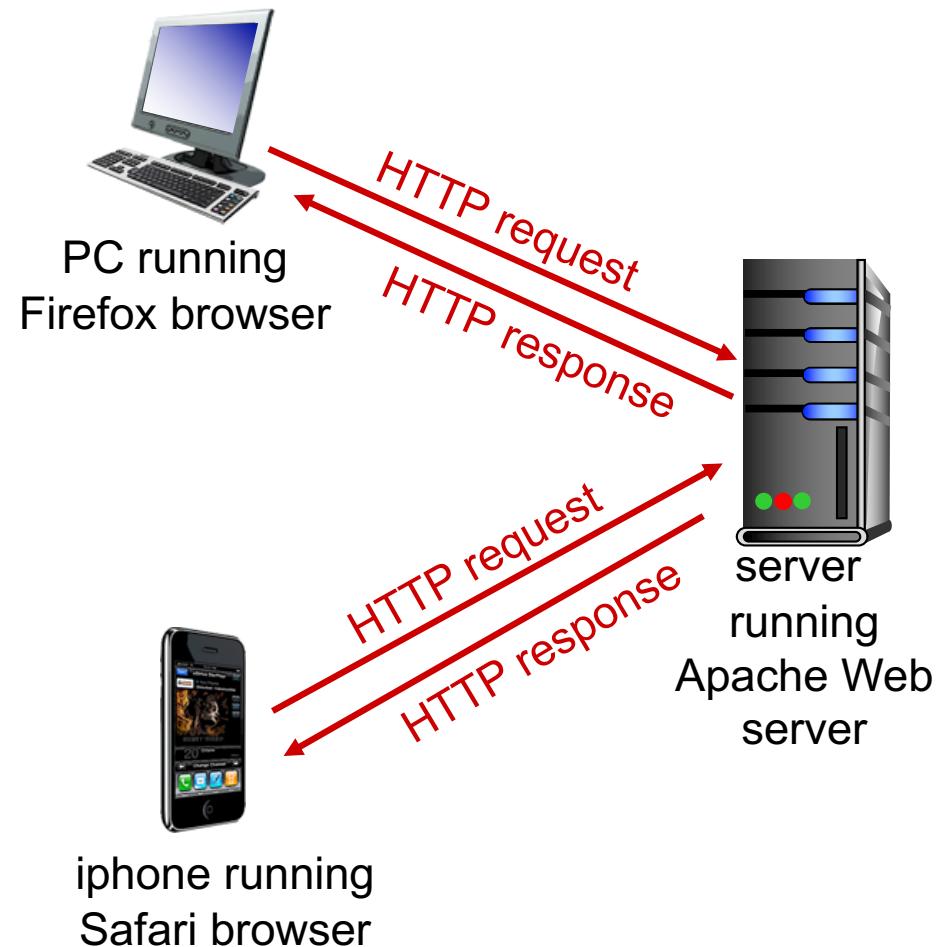
**protocol://host-name[:port]/directory-path/resource**

- ❖ *protocol*: http, ftp, https, smtp etc.
- ❖ *hostname*: DNS name, IP address
- ❖ *port*: defaults to protocol's standard port; e.g. http: 80 https: 443
- ❖ *directory path*: hierarchical, reflecting file system
- ❖ *resource*: Identifies the desired resource

# HTTP overview

## HTTP: hypertext transfer protocol

- ❖ Web's application layer protocol
- ❖ client/server model
  - **client:** browser that requests, receives, (using HTTP protocol) and "displays" Web objects
  - **server:** Web server sends (using HTTP protocol) objects in response to requests



# HTTP overview (continued)

## *uses TCP:*

- ❖ client initiates TCP connection (creates socket) to server, port 80
- ❖ server accepts TCP connection from client
- ❖ HTTP messages (application-layer protocol messages) exchanged between browser (HTTP client) and Web server (HTTP server)
- ❖ TCP connection closed

## *HTTP is “stateless”*

- ❖ server maintains no information about past client requests

*aside*  
protocols that maintain “state” are complex!

- ❖ past history (state) must be maintained
- ❖ if server/client crashes, their views of “state” may be inconsistent, must be reconciled

# HTTP 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 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

# HTTP response message

status line  
(protocol  
status code  
status phrase)

header  
lines

data, e.g.,  
requested  
HTML file

```
HTTP/1.1 200 OK\r\nDate: Sun, 26 Sep 2010 20:09:20 GMT\r\nServer: Apache/2.0.52 (CentOS) \r\nLast-Modified: Tue, 30 Oct 2007 17:00:02  
GMT\r\nETag: "17dc6-a5c-bf716880"\r\nAccept-Ranges: bytes\r\nContent-Length: 2652\r\nKeep-Alive: timeout=10, max=100\r\nConnection: Keep-Alive\r\nContent-Type: text/html; charset=ISO-8859-  
1\r\n\r\ndata data data data data ...
```

# 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**

## **451 Unavailable for Legal Reasons**

## **429 Too Many Requests**

## **418 I'm a Teapot**

# HTTP is all text

- ❖ Makes the protocol simple
  - Easy to delineate messages (\r\n)
  - (relatively) human-readable
  - No issues about encoding or formatting data
  - Variable length data
- ❖ Not the most efficient
  - Many protocols use binary fields
    - Sending "12345678" as a string is 8 bytes
    - As an integer, 12345678 needs only 4 bytes
  - Headers may come in any order
  - Requires string parsing/processing

# Request Method types (“verbs”)

## HTTP/1.0:

- ❖ GET
  - Request page
- ❖ POST
  - Uploads user response to a form
- ❖ 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
- ❖ TRACE, OPTIONS, CONNECT, PATCH
  - For persistent connections

# Uploading form input

## POST method:

- ❖ web page often includes form input
- ❖ input is uploaded to server in entity body

## Get (in-URL) method:

- ❖ uses GET method
- ❖ input is uploaded in URL field of request line:

`www.somesite.com/animalsearch?monkeys&banana`

# User-server state: cookies

many Web sites use cookies

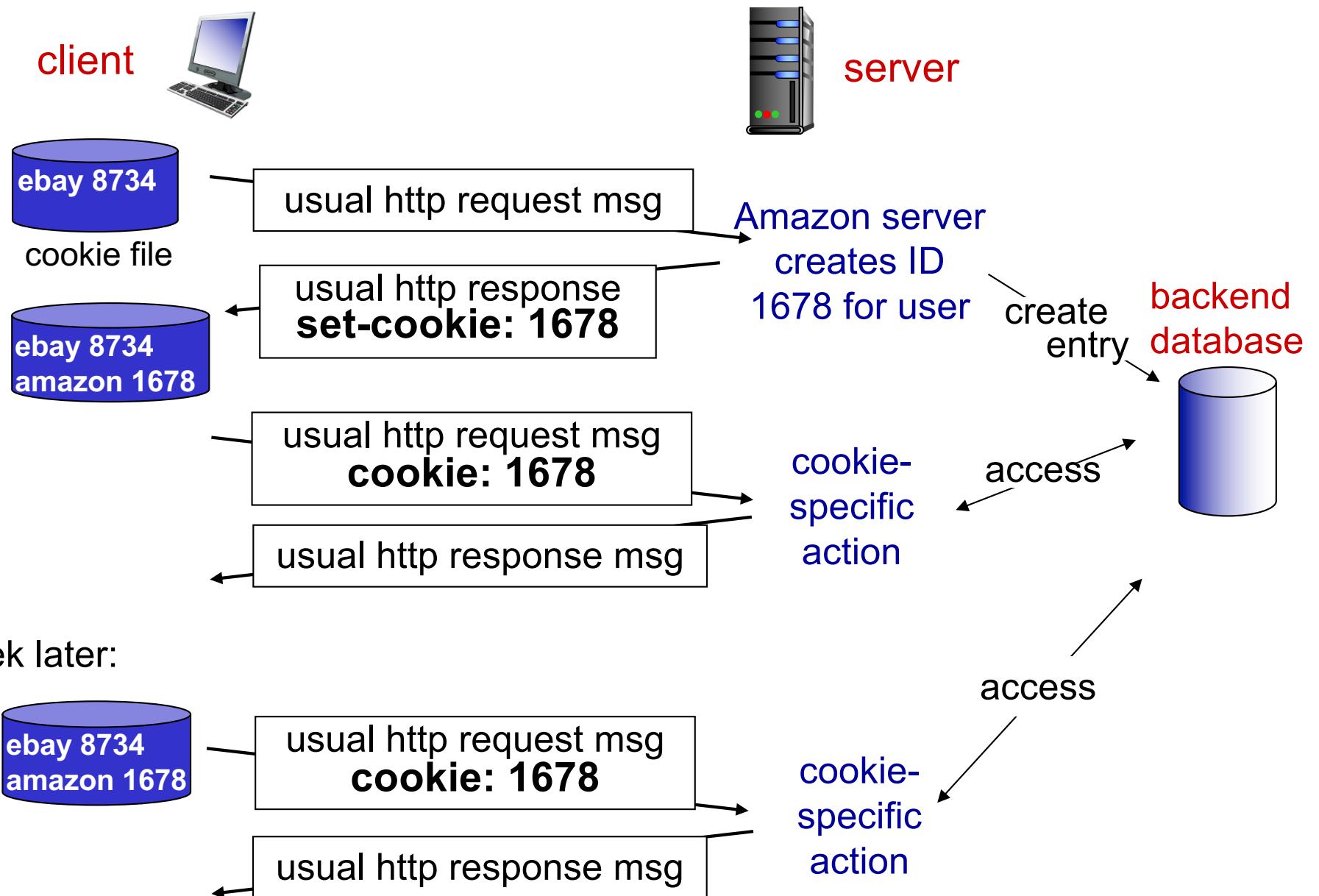
*four components:*

- 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

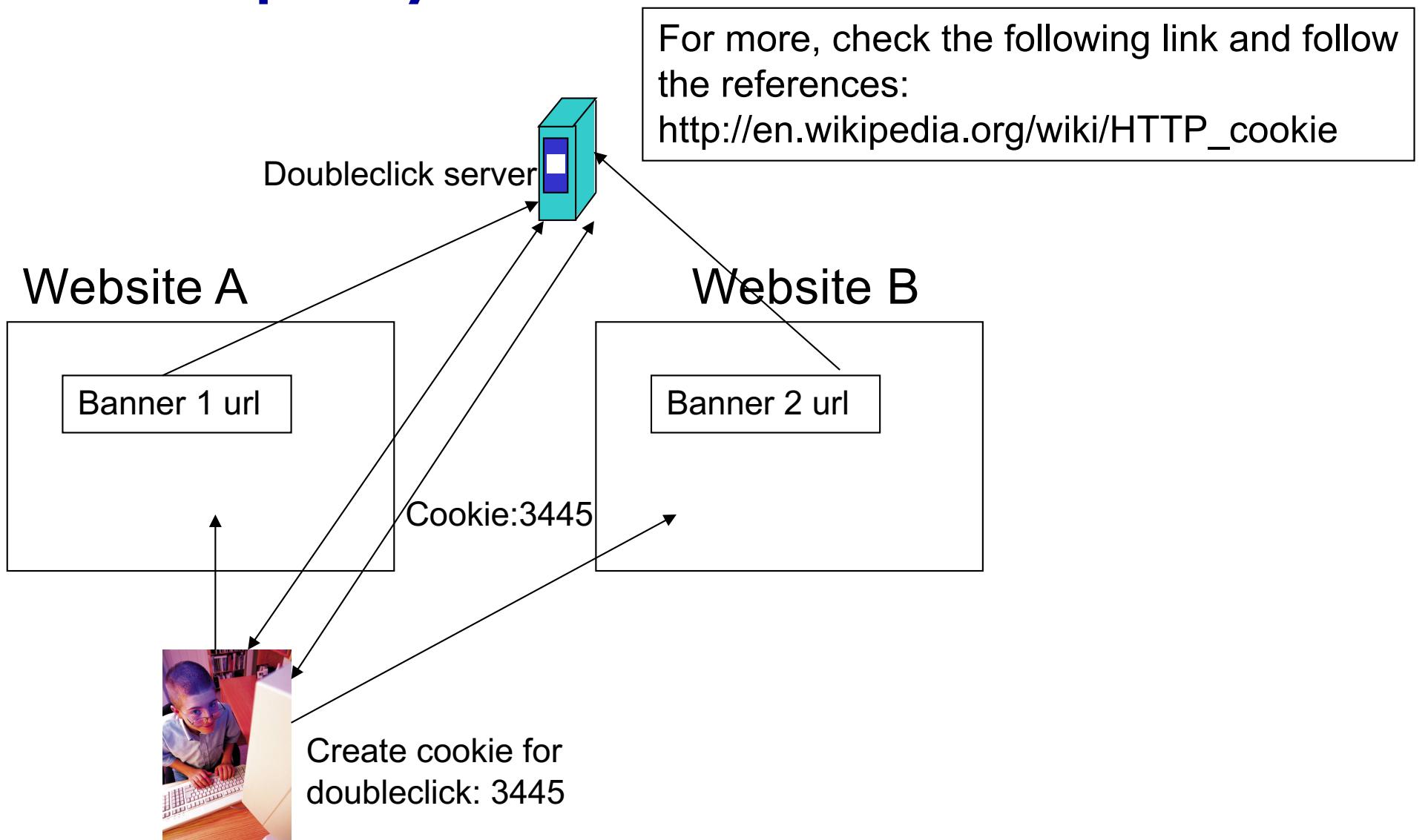
# Cookies: keeping “state” (cont.)



# The Dark Side of Cookies

- ❖ Cookies permit sites to learn a lot about you
- ❖ You may supply name and e-mail to sites (and more)
- ❖ 3<sup>rd</sup> party cookies (from ad networks, etc.) can follow you across multiple sites
  - Ever visit a website, and the next day ALL your ads are from them ?
    - Check your browser's cookie file (cookies.txt, cookies.plist)
    - Do you see a website that you have never visited
- ❖ You COULD turn them off
  - But good luck doing anything on the Internet !!

# Third party cookies



# Performance of HTTP

- Page Load Time (PLT) as the metric
  - From click until user sees page
  - Key measure of web performance
- Depends on many factors such as
  - page content/structure,
  - protocols involved and
  - Network bandwidth and RTT

# Performance Goals

- ❖ User
  - fast downloads
  - high availability
- ❖ Content provider
  - happy users (hence, above)
  - cost-effective infrastructure
- ❖ Network (secondary)
  - avoid overload

# Solutions?

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- ❖ User
  - fast downloads
  - high availability
- ❖ Content provider
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- ❖ Network (secondary)
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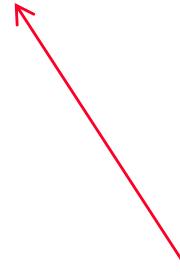
Improve HTTP to  
achieve faster  
downloads



# Solutions?

- ❖ User
    - fast downloads
    - high availability
  - ❖ Content provider
    - happy users (hence, above)
    - cost-effective delivery infrastructure
  - ❖ Network (secondary)
    - avoid overload
- 
- Improve HTTP to achieve faster downloads
- Caching and Replication
- Caching and Replication

# Solutions?

- ❖ User
    - fast downloads
    - high availability
  - ❖ Content provider
    - happy users (hence, above)
    - cost-effective delivery infrastructure
  - ❖ Network (secondary)
    - avoid overload
- Improve HTTP to  
achieve faster  
downloads
- Caching and Replication
- Exploit economies of scale  
(Webhosting, CDNs, datacenters)
- 

# How to improve PLT

- Reduce content size for transfer
  - Smaller images, compression
- Change HTTP to make better use of available bandwidth
  - Persistent connections and pipelining
- Change HTTP to avoid repeated transfers of the same content
  - Caching and web-proxies
- Move content closer to the client
  - CDNs

# HTTP Performance

- ❖ Most Web pages have multiple objects
  - e.g., HTML file and a bunch of embedded images
- ❖ How do you retrieve those objects (naively)?
  - *One item at a time*
- ❖ New TCP connection per (small) object!

## *non-persistent HTTP*

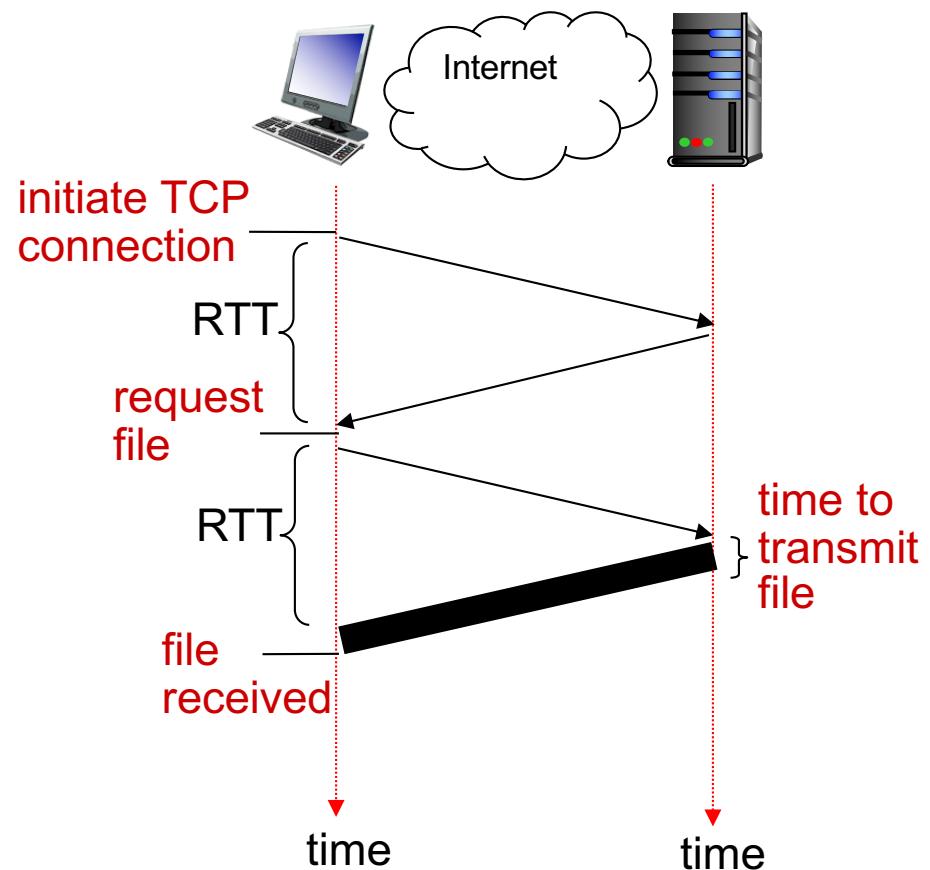
- ❖ at most one object sent over TCP connection
  - connection then closed
- ❖ downloading multiple objects required multiple connections

# Non-persistent HTTP: response time

**RTT (definition):** time for a small packet to travel from client to server and back

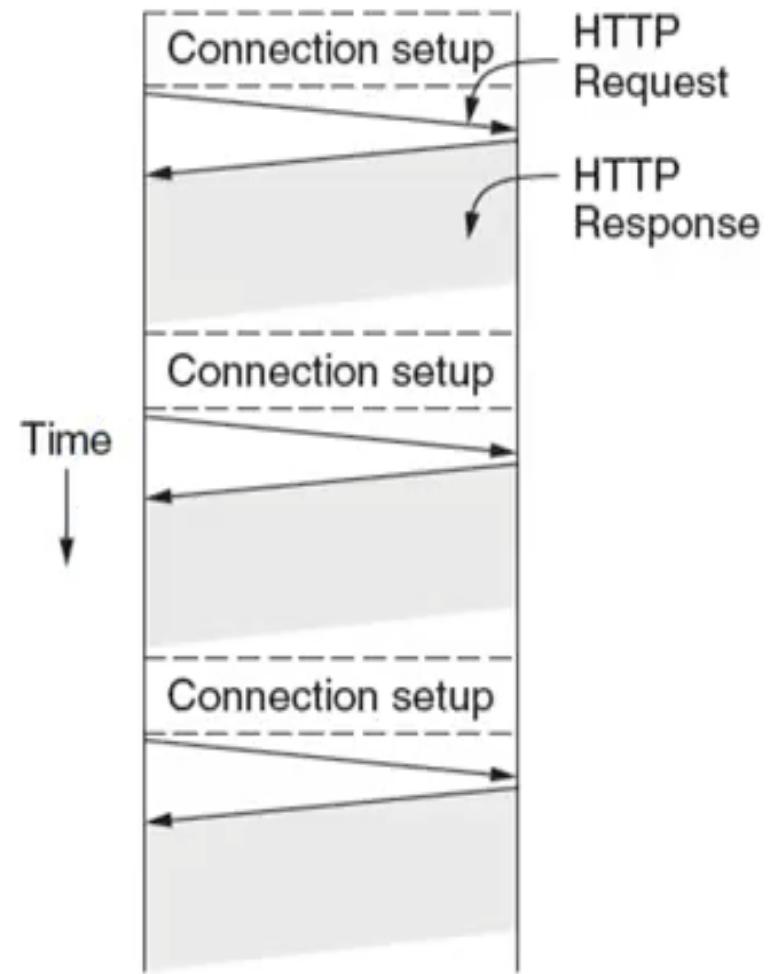
**HTTP response time:**

- ❖ one RTT to initiate TCP connection
- ❖ one RTT for HTTP request and first few bytes of HTTP response to return
- ❖ file transmission time
- ❖ non-persistent HTTP response time =  $2\text{RTT} + \text{file transmission time}$



# HTTP/1.0

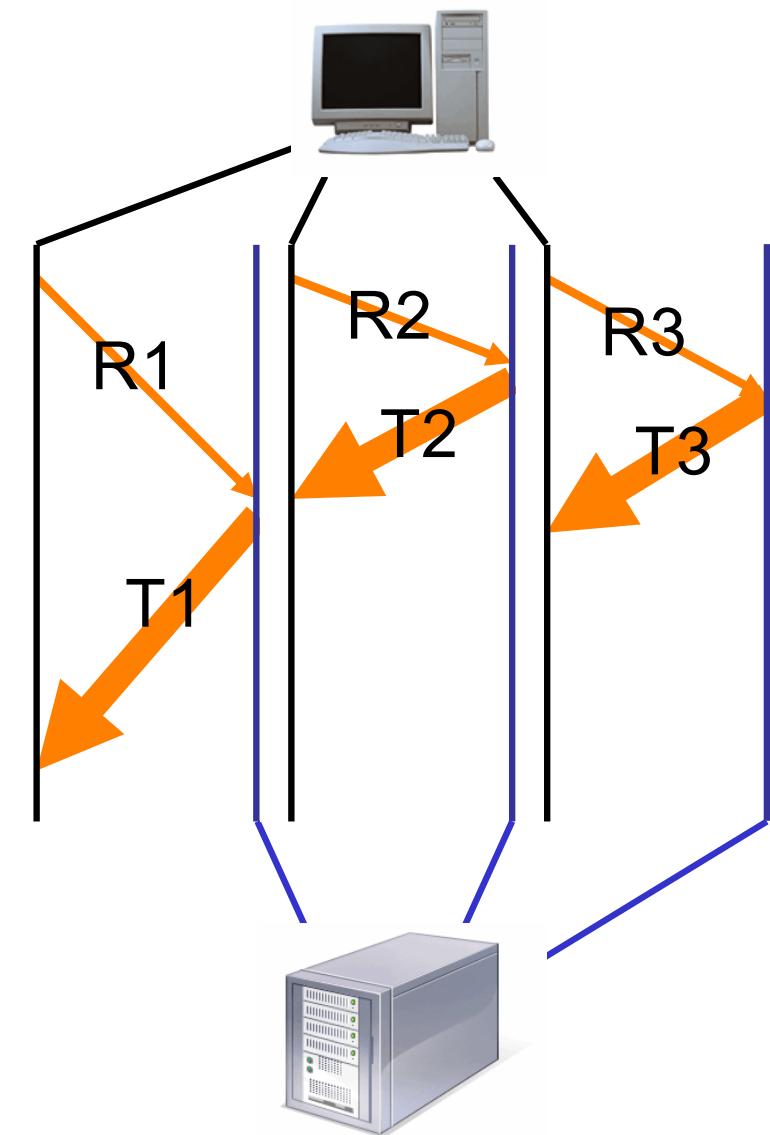
- Non-Persistent: One TCP connection to fetch one web resource
- Fairly poor PLT
- 2 Scenarios
  - Multiple TCP connections setups to the **same server**
  - Sequential request/responses even when resources are located on **different servers**
- Multiple TCP slow-start phases (more in lecture on TCP)



# Improving HTTP Performance: Concurrent Requests & Responses

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- ❖ Use multiple connections *in parallel*
- ❖ Does not necessarily maintain order of responses



# Quiz: Parallel HTTP Connections



- ❖ What are potential downsides of parallel HTTP connections, i.e. can opening too many parallel connections be harmful and if so in what way?

# Persistent HTTP

## Persistent HTTP

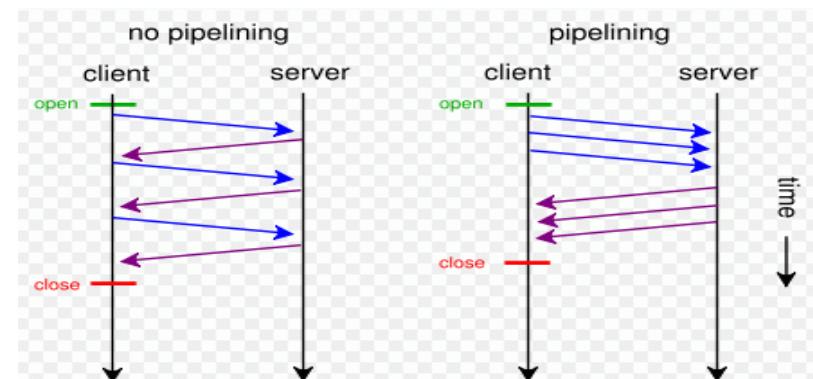
- ❖ server leaves TCP connection open after sending response
- ❖ subsequent HTTP messages between same client/server are sent over the same TCP connection
- ❖ Allow TCP to learn more accurate RTT estimate (APPARENT LATER IN THE COURSE)
- ❖ Allow TCP congestion window to increase (APPARENT LATER)
- ❖ i.e., leverage previously discovered bandwidth (APPARENT LATER)

## Persistent without pipelining:

- ❖ client issues new request only when previous response has been received
- ❖ one RTT for each referenced object

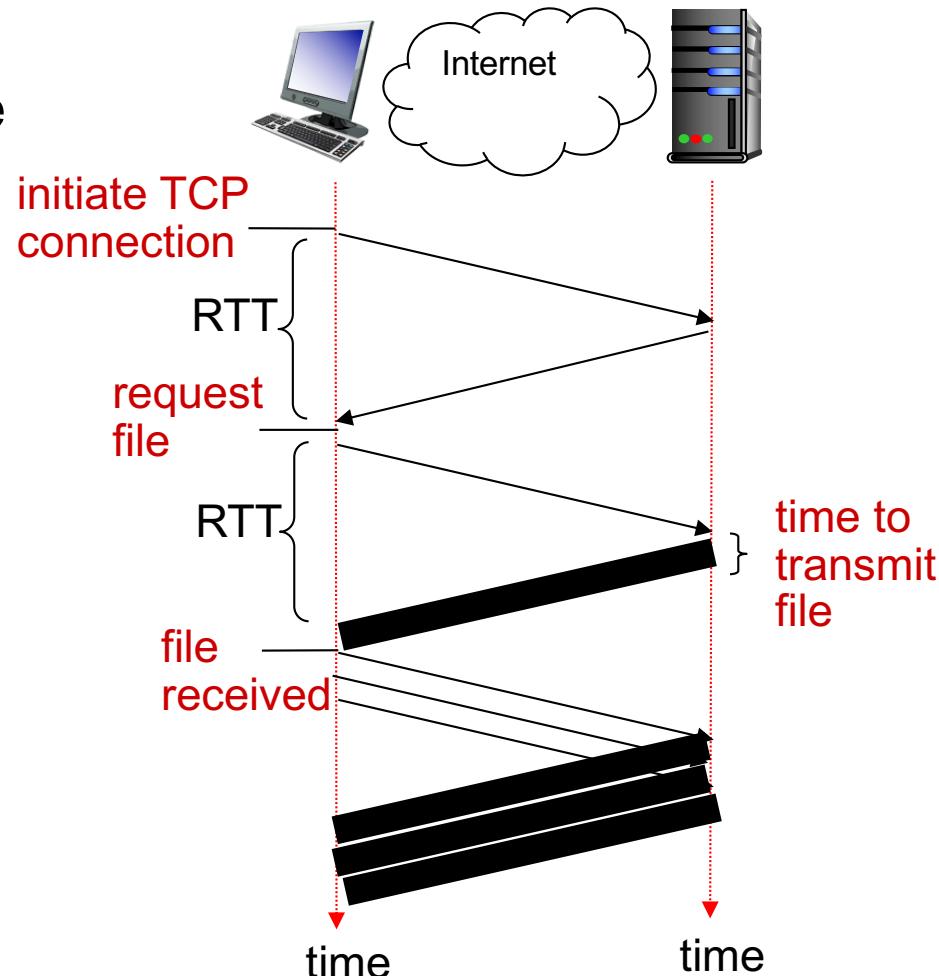
## Persistent with pipelining:

- ❖ introduced in HTTP/1.1
- ❖ client sends requests as soon as it encounters a referenced object
- ❖ as little as one RTT for all the referenced objects



# HTTP 1.1: response time with pipelining

Website with one index page and three embedded objects



# How to improve PLT

- Reduce content size for transfer
  - Smaller images, compression
- Change HTTP to make better use of available bandwidth
  - Persistent connections and pipelining
- Change HTTP to avoid repeated transfers of the same content
  - Caching and web-proxies
- Move content closer to the client
  - CDNs

# Improving HTTP Performance: Caching

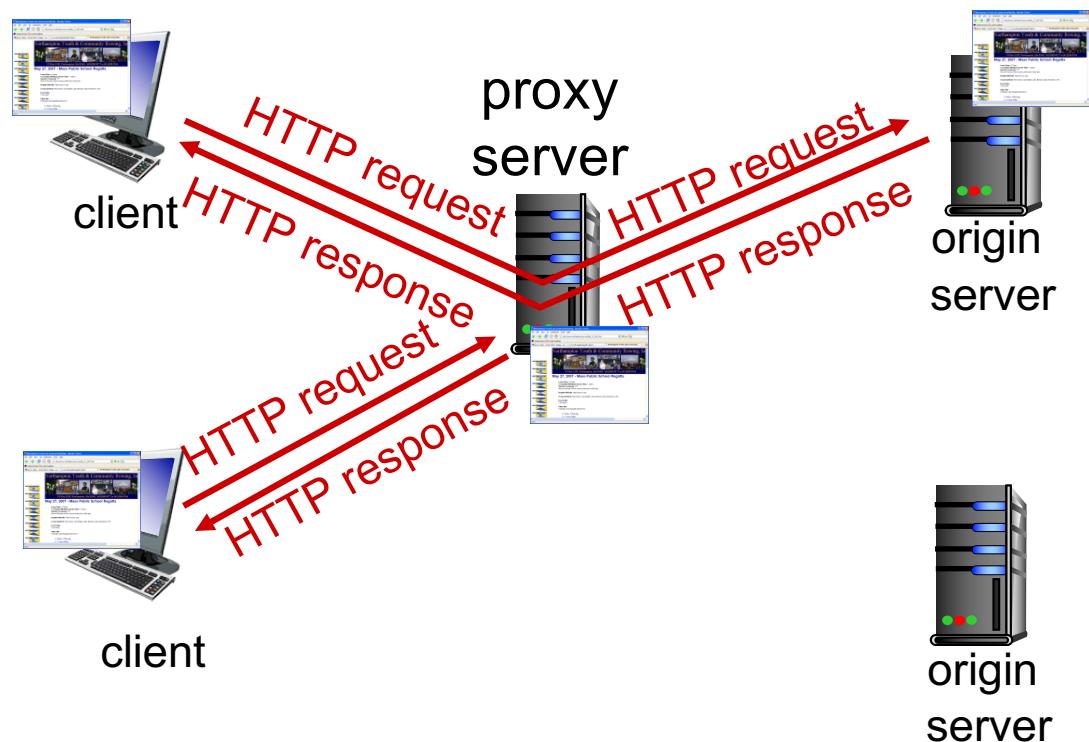
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- ❖ Why does caching work?
  - Exploits *locality of reference*
  
- ❖ How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests

# Web caches (proxy server)

**goal:** satisfy client request without involving origin server

- ❖ user sets browser: Web accesses via cache
- ❖ browser sends all HTTP requests to cache
  - object in cache: cache returns object
  - else cache requests object from origin server, then returns object to client



# More about Web caching

- ❖ cache acts as both client and server
  - server for original requesting client
  - client to origin server
- ❖ typically cache is installed by ISP (university, company, residential ISP)

## *why Web caching?*

- ❖ reduce response time for client request
- ❖ reduce traffic on an institution's access link
- ❖ Internet dense with caches: enables “poor” content providers to effectively deliver content

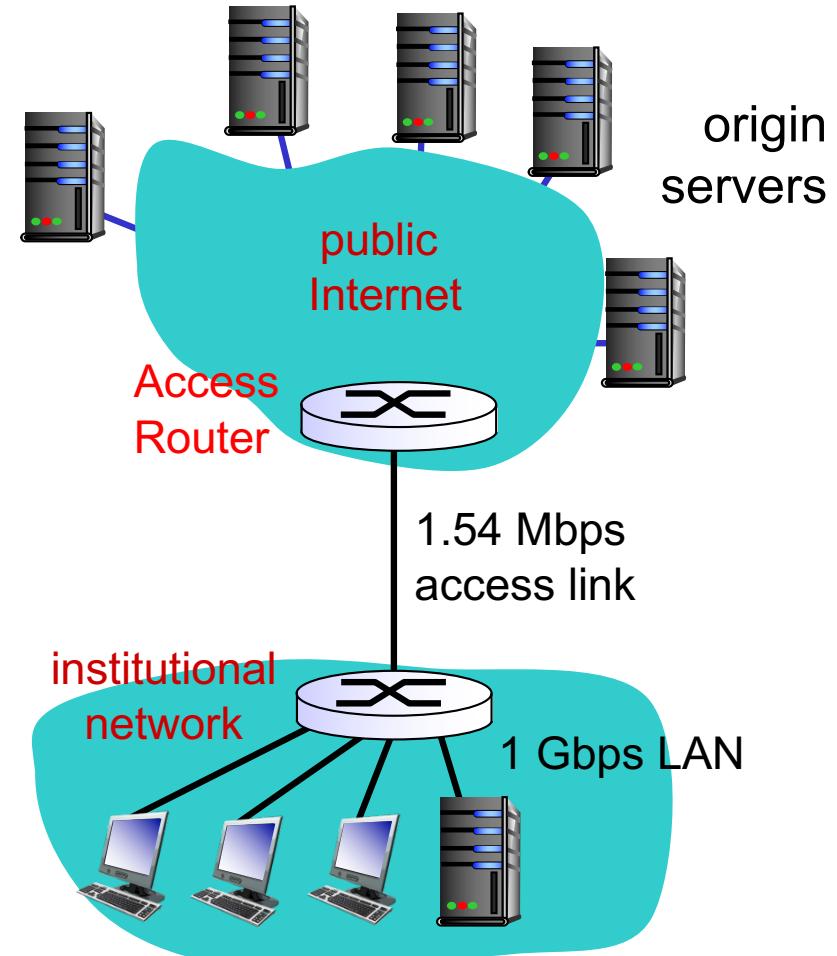
# Caching example:

## *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 access router to any origin server: 2 sec
- ❖ access link rate: 1.54 Mbps

## *consequences:*

- ❖ LAN utilization: 0.15%
- ❖ access link utilization = **99%**
- ❖ total delay = Internet delay +  
access delay + LAN delay  
= 2 sec + minutes + usecs



*problem!*

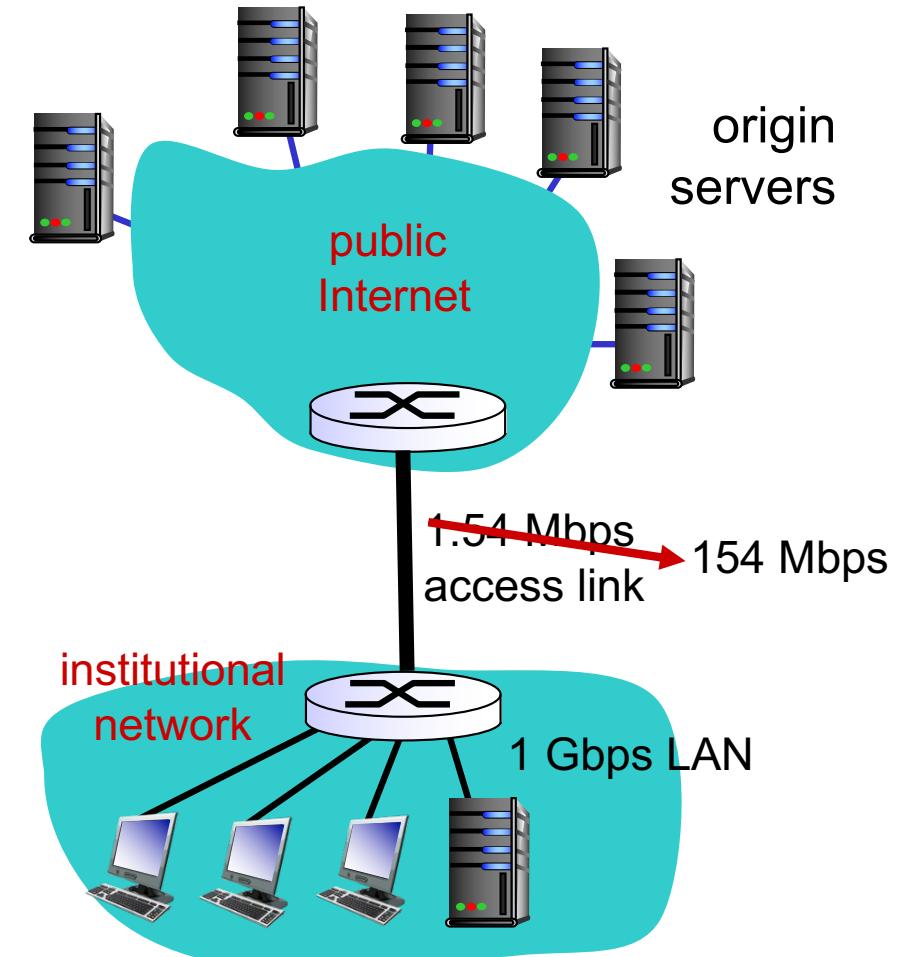
# Caching example: fatter access link

## 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 access router to any origin server: 2 sec
- ❖ access link rate: 1.54 Mbps

## consequences:

- ❖ LAN utilization: 0.15%
- ❖ access link utilization = ~~99%~~ 0.99%
- ❖ total delay = Internet delay + access delay + LAN delay  
= 2 sec + ~~minutes + usecs~~ msec



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

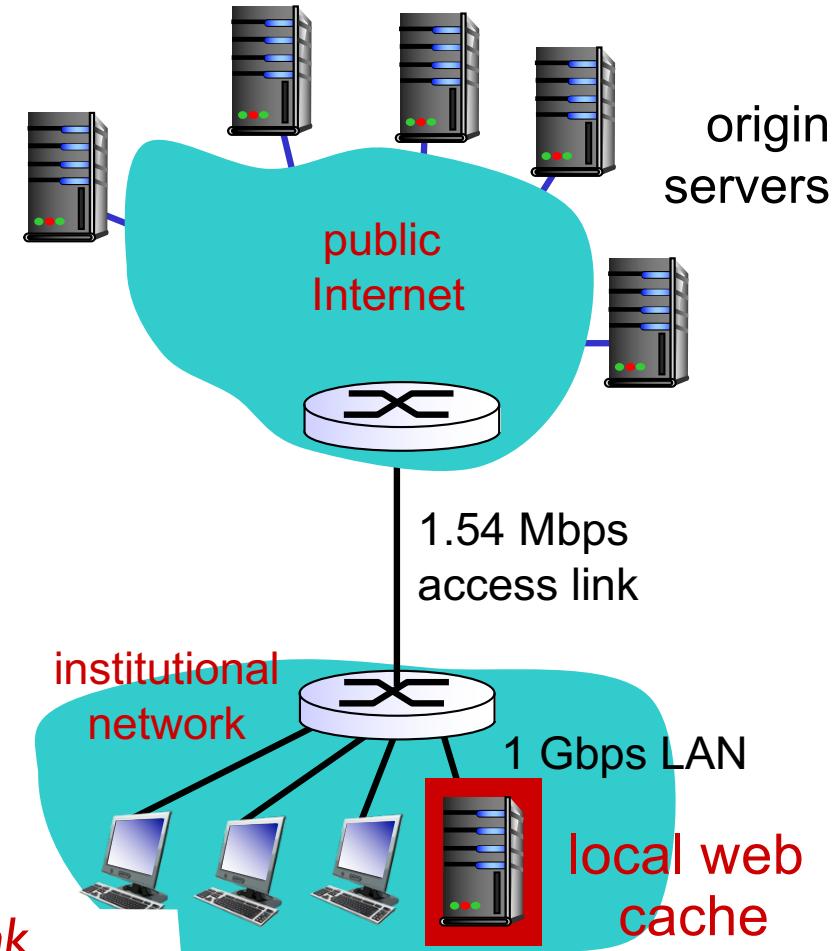
# Caching example: install local cache

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- ❖ RTT from access router to any origin server: 2 sec
- ❖ access link rate: 1.54 Mbps

## *consequences:*

- ❖ LAN utilization: ?
- ❖ access link utilization = ?
- ❖ total delay = ?      *How to compute link utilization, delay?*

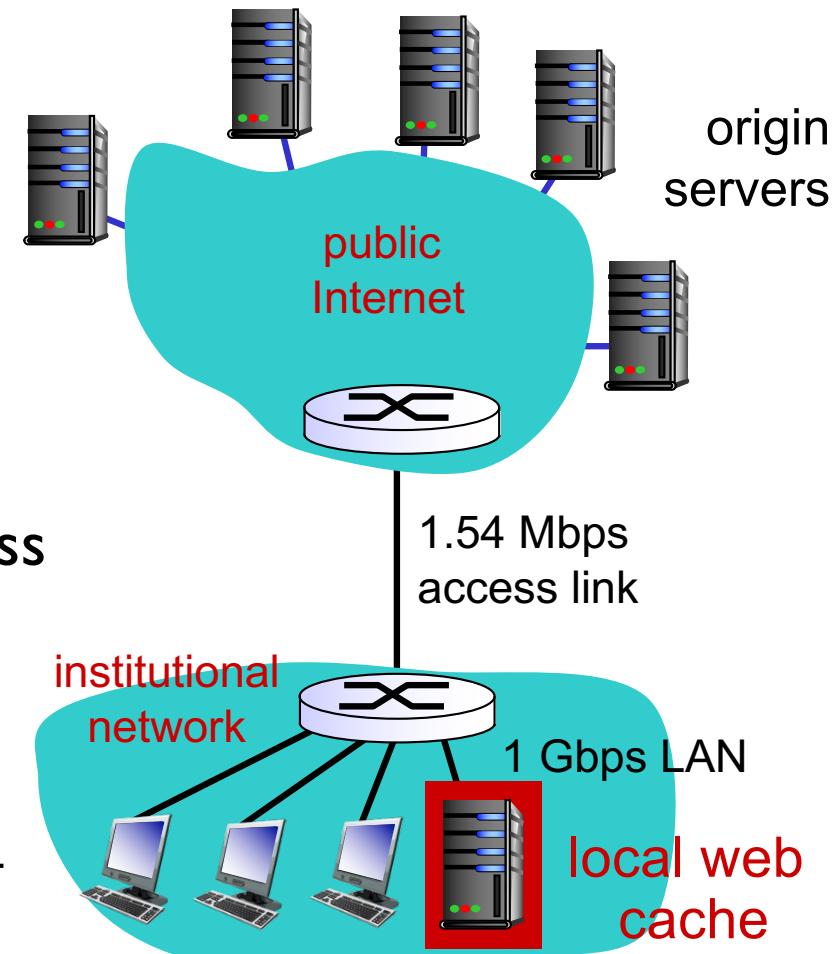


*Cost:* web cache (cheap!)

# 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 =  $0.9 / 1.54 = .58$
- ❖ 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:

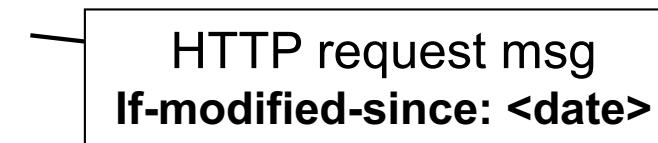
**HTTP/1.0 304 Not Modified**

client

server



object  
not  
modified  
before  
<date>



object  
modified  
after  
<date>

# Example Cache Check Request

GET / HTTP/1.1

Accept: \*/\*

Accept-Language: en-us

Accept-Encoding: gzip, deflate

If-Modified-Since: Mon, 29 Jan 2001 17:54:18 GMT

If-None-Match: "7a11f-10ed-3a75ae4a"

User-Agent: Mozilla/4.0 (compatible; MSIE 5.5; Windows NT  
5.0)

Host: www.intel-iris.net

Connection: Keep-Alive

# Example Cache Check Response

HTTP/1.1 304 Not Modified

Date: Tue, 27 Mar 2001 03:50:51 GMT

Server: Apache/1.3.14 (Unix) (Red-Hat/Linux) mod\_ssl/2.7.1  
OpenSSL/0.9.5a DAV/1.0.2 PHP/4.0.1pl2 mod\_perl/1.24

Connection: Keep-Alive

Keep-Alive: timeout=15, max=100

ETag: "7a11f-10ed-3a75ae4a"

# Improving HTTP Performance: Replication

---

- ❖ Replicate popular Web site across many machines
  - Spreads load on servers
  - Places content closer to clients
  - Helps when content isn't cacheable
- ❖ Problem:
  - Want to direct client to particular replica
    - Balance load across server replicas
    - Pair clients with nearby servers
  - Expensive
- ❖ Common solution:
  - DNS returns different addresses based on client's geo location, server load, etc.

# Improving HTTP Performance: CDN

---

- ❖ Caching and replication as a service
- ❖ Integrate forward and reverse caching functionality
- ❖ Large-scale distributed storage infrastructure (usually) administered by one entity
  - e.g., Akamai has servers in 20,000+ locations
- ❖ Combination of (pull) caching and (push) replication
  - **Pull:** Direct result of clients' requests
  - **Push:** Expectation of high access rate
- ❖ Also do some processing
  - Handle *dynamic* web pages
  - *Transcoding*
  - *Maybe do some security function – watermark IP*

# What about HTTPS?

- ❖ HTTP is insecure
- ❖ HTTP basic authentication: password sent using base64 encoding (can be readily converted to plaintext)
- ❖ HTTPS: HTTP over a connection encrypted by Transport Layer Security (TLS)
- ❖ Provides:
  - Authentication
  - Bidirectional encryption
- ❖ Widely used in place of plain vanilla HTTP



# What's on the horizon: HTTP/2

- ❖ Google SPDY (speedy) -> HTTP/2: (RFC 7540 May 2015)
- ❖ Better content structure
- ❖ Improvements
  - Servers can **push** content and thus reduce overhead of an additional request cycle
  - Fully multiplexed
    - Requests and responses are sliced in smaller chunks called frames, frames are tagged with an ID that connects data to the request/response
    - overcomes Head-of-line blocking in HTTP 1.1
  - Prioritisation of the order in which objects should be sent (e.g. CSS files may be given higher priority)
  - Data compression of HTTP headers
    - Some headers such as cookies can be very long
    - Repetitive information

More details: <https://http2.github.io/faq/>  
Demo: <https://http2.akamai.com/demo> 63



## Quiz: HTTP (1)

Consider an HTML page with a base file of size  $S_0$  bits and  $N$  inline objects each of size  $S$  bits. Assume a client fetching the page across a link of capacity  $C$  bits/s and RTT of  $D$ . How long does it take to download the page using **non-persistent HTTP (without parallelism)?**

- A.  $D + (S_0 + NS)/C$
- B.  $2D + (S_0 + NS)/C$
- C.  $N(D + S/C)$
- D.  $2D + S_0/C + N(2D + S/C)$
- E.  $2D + S_0/C + N(D + S/C)$



## Quiz: HTTP (2)

Consider an HTML page with a base file of size  $S_0$  bits and  $N$  inline objects each of size  $S$  bits. Assume a client fetching the page across a link of capacity  $C$  bits/s and RTT of  $D$ . How long does it take to download the page using **persistent HTTP (without parallelism or pipelining)**?

- A.  $2D + (S_0 + NS)/C$
- B.  $3D + (S_0 + NS)/C$
- C.  $N(D + S/C)$
- D.  $2D + S_0/C + N(2D + S/C)$
- E.  $2D + S_0/C + N(D + S/C)$



## Quiz: HTTP (3)

Consider an HTML page with a base file of size  $S_0$  bits and  $N$  inline objects each of size  $S$  bits. Assume a client fetching the page across a link of capacity  $C$  bits/s and RTT of  $D$ . How long does it take to download the page using **persistent HTTP with pipelining**?

- A.  $2D + (S_0 + NS)/C$
- B.  $4D + (S_0 + NS)/C$
- C.  $N(D + S/C)$
- D.  $3D + S_0/C + NS/C$
- E.  $2D + S_0/C + N(D + S/C)$

# Application Layer: outline

## 2.1 principles of network applications

- app architectures
- app requirements

## 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 (CDNs)

## 2.7 socket programming with UDP and TCP

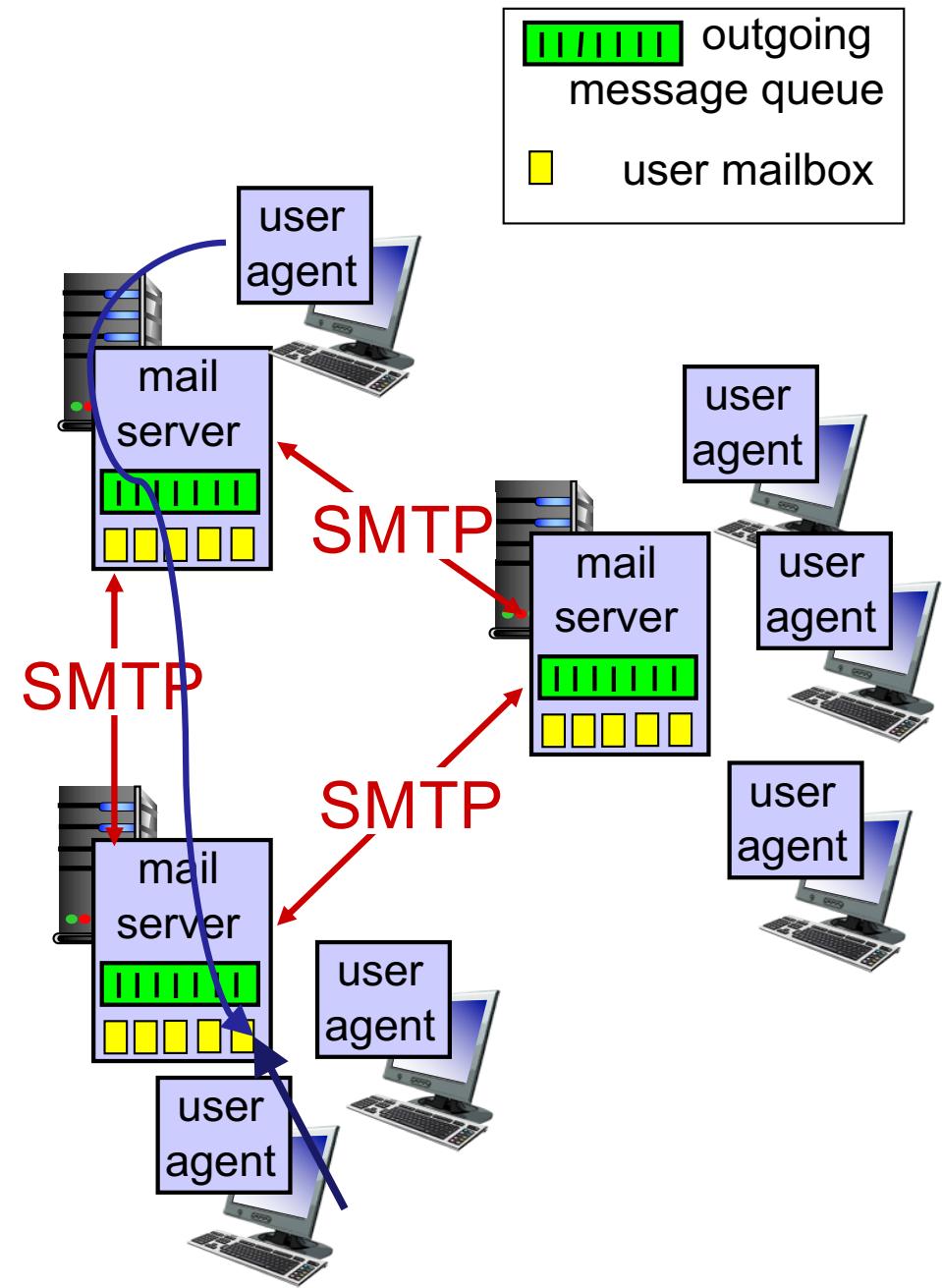
# Electronic mail

*Three major components:*

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

## User Agent

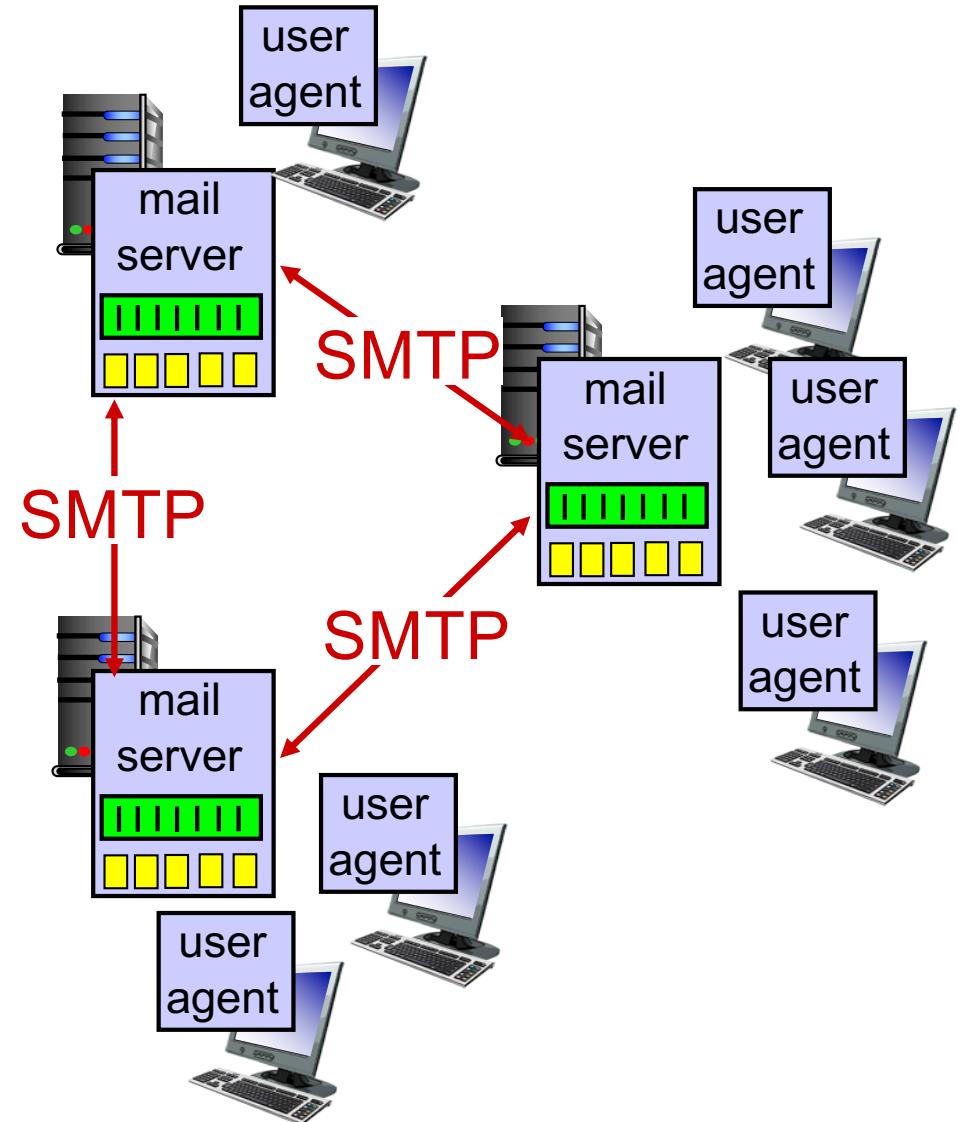
- ❖ a.k.a. “mail reader”
- ❖ composing, editing, reading mail messages
- ❖ e.g., Outlook, Thunderbird, iPhone mail client
- ❖ outgoing, incoming messages stored on server



# 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

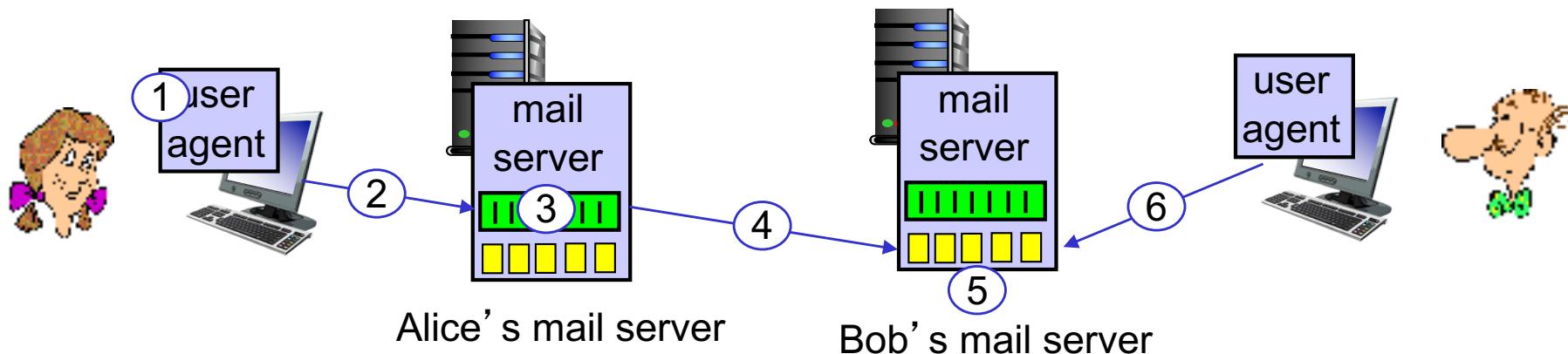


# Electronic Mail: SMTP [RFC 2821]

- ❖ 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, FTP)
  - **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
```

# 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 msg
- ❖ SMTP: multiple objects sent in multipart msg

# Mail message format

SMTP: protocol for  
exchanging email msgs

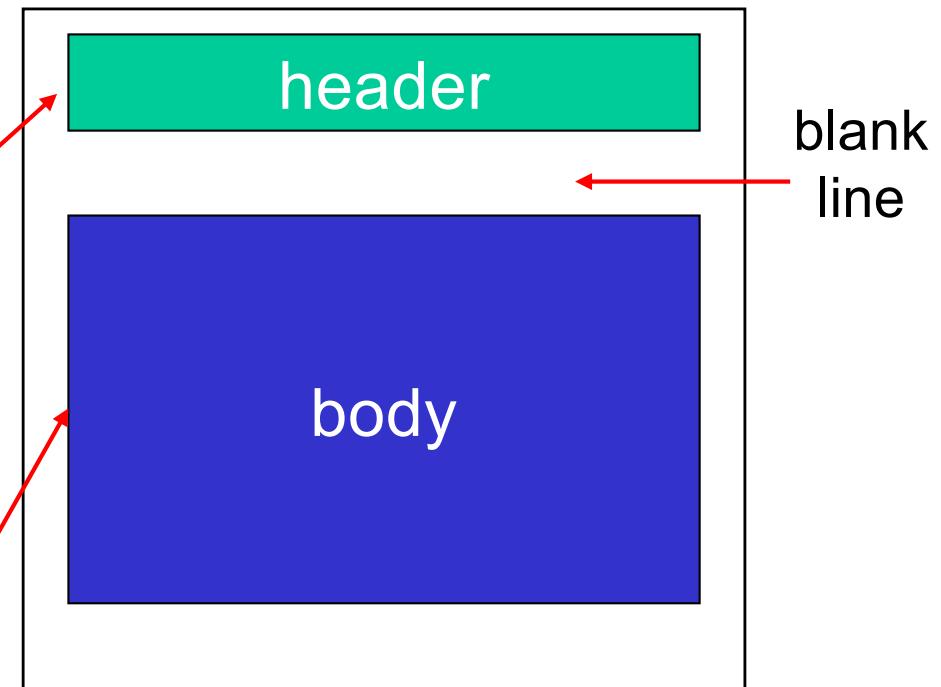
RFC 5322 (822,2822):  
standard for text message  
format (Internet Message  
Format, IMF):

- ❖ header lines, e.g.

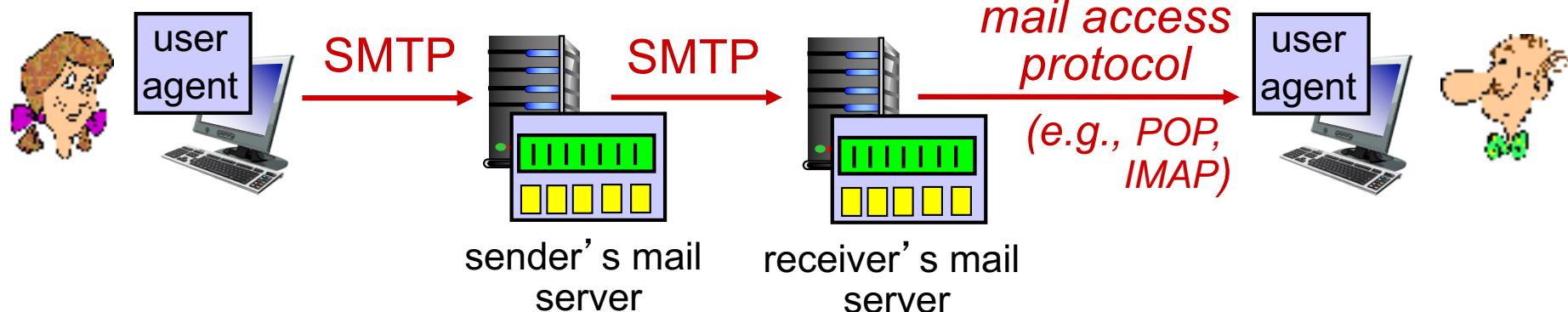
- To:
  - From:
  - Subject:

*different from SMTP MAIL  
FROM, RCPT TO:  
commands!*

- ❖ Body: the “message”
  - ASCII characters only



# 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 msgs on server
  - **HTTP(S):** Gmail, Yahoo! Mail, etc.

**Read about POP and IMAP from the text in your own time**

# Quiz: SMTP

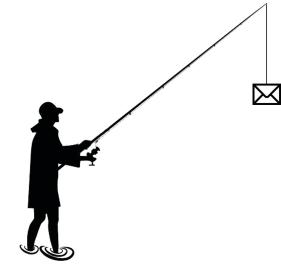
**Why do we have Sender's mail server?**

- User agent can directly connect with recipient mail server without the need of sender's mail server? What's the catch?

**Why do we have a separate Receiver's mail server?**

- Can't the recipient run the mail server on own end system?

# Phishing

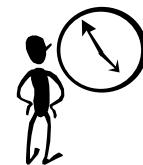


- ❖ Spear phishing
  - Phishing attempts directed at specific individuals or companies
  - Attackers may gather personal information (social engineering) about their targets to increase their probability of success
  - Most popular and accounts for over 90% of attacks
- ❖ Clone phishing
  - A type of phishing attack whereby a legitimate, and previously delivered email containing an attachment or link has had its content and recipient address(es) taken and used to create an almost identical or cloned email.
  - The attachment or link within the email is replaced with a malicious version and then sent from an email address spoofed to appear to come from the original sender.



# Summary

- ❖ Application Layer (Chapter 2)
  - Principles of Network Applications
  - HTTP
  - E-mail
- ❖ Next:
  - DNS
  - P2P



**Reading Exercise  
Chapter 2: 2.4 – 2.7**