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

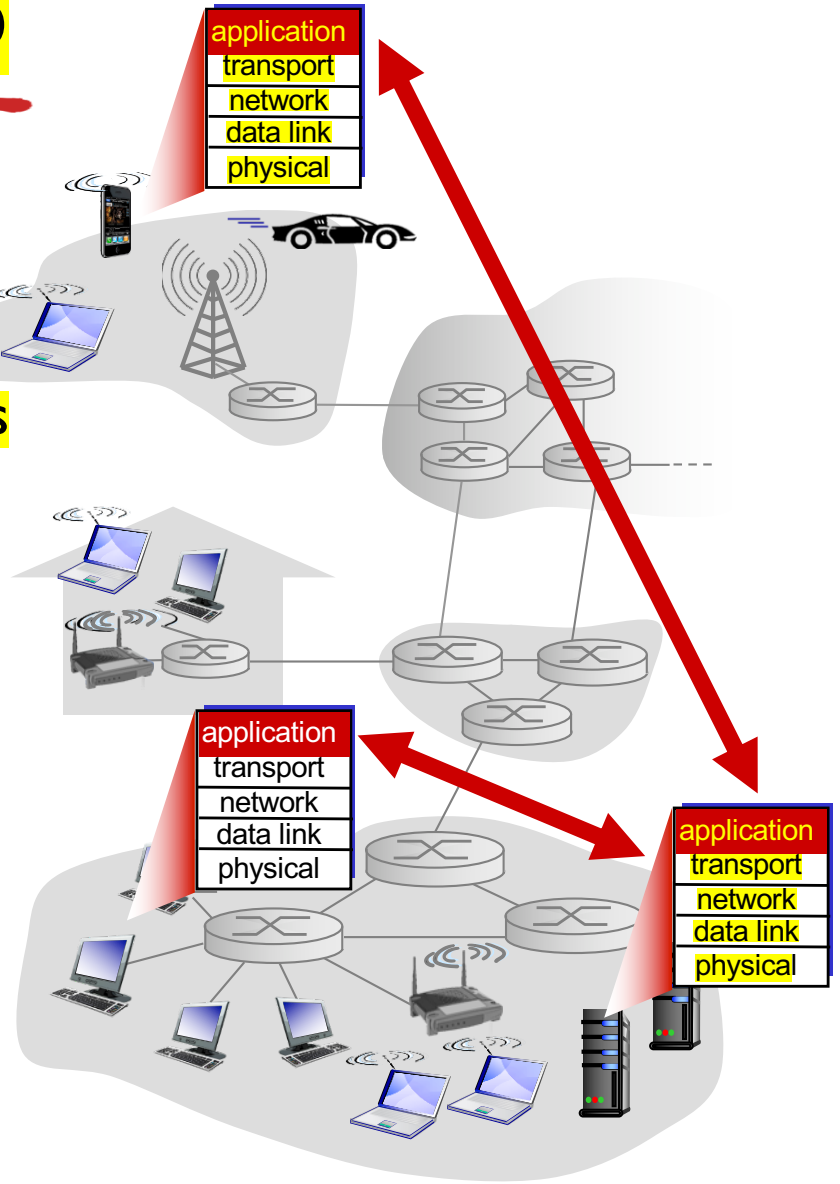
Write programs that:

- 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

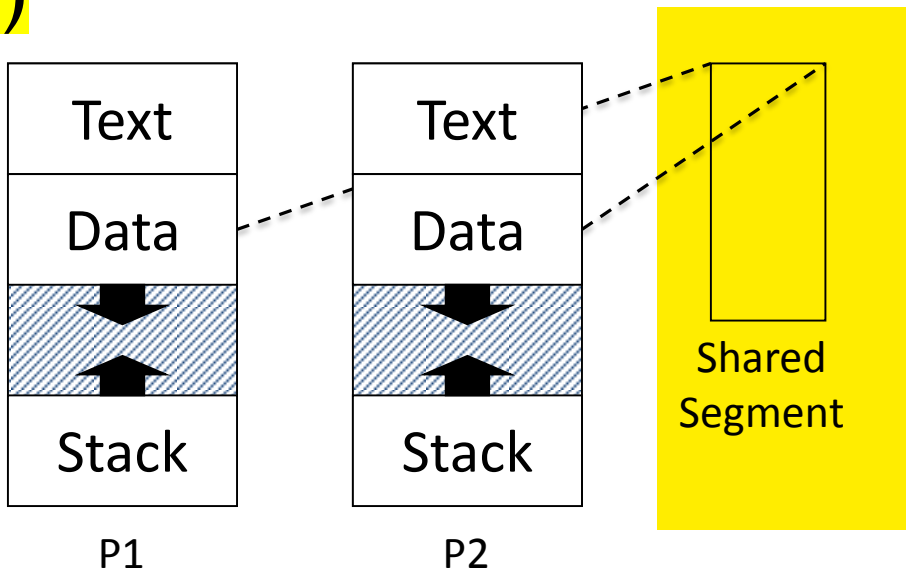
because you don't have to worry about any of the lower levels, it is very easy to write network apps



Interprocess Communication (IPC)

- Processes talk to each other through Inter-process communication (IPC)
- On a single machine:
  - Shared memory

or message passing like in sel4



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

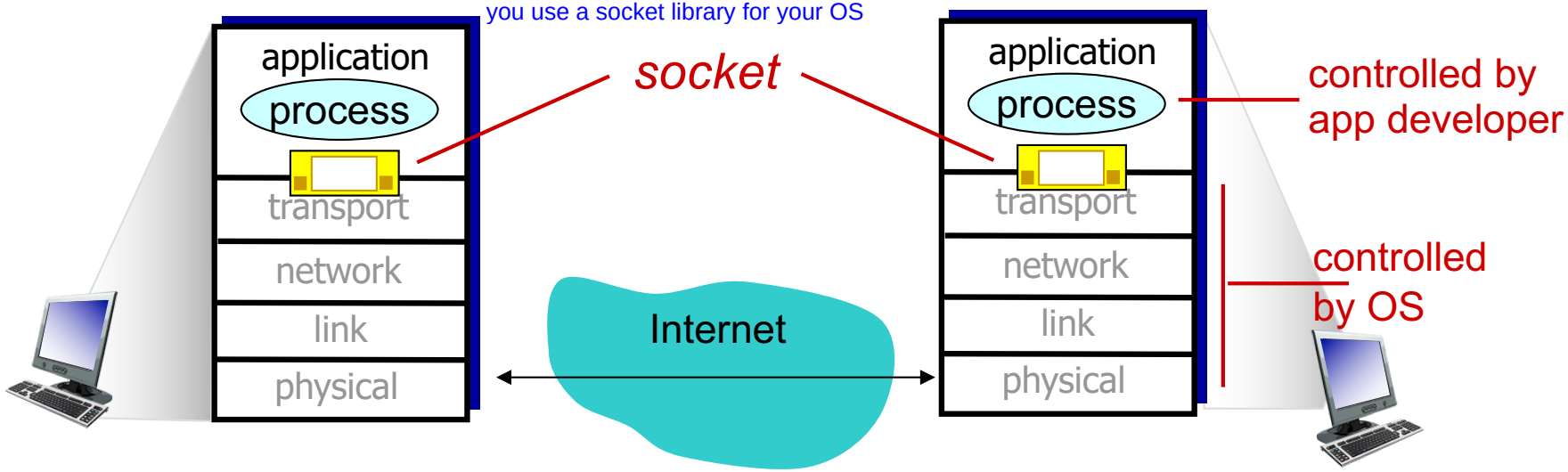
Sockets

- 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

many sockets can be bound to one port.

you control what you want as the programmer by specifying flags, the OS does the actual work in privilege though

sockets are very much API based programming e.g. you don't write much, you use a socket library for your OS



Addressing processes

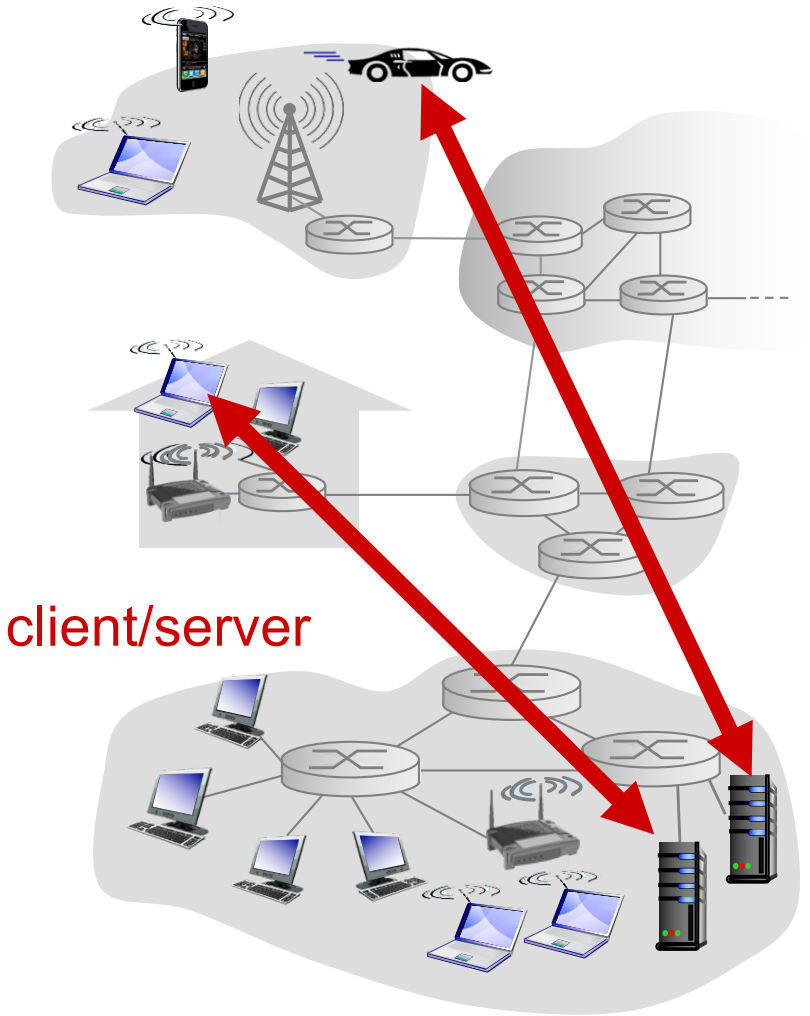
- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- *Q:* does IP address of host on which process runs suffice for identifying the process?
  - *A:* no, *many* processes can be running on same host

- *identifier* includes both IP address and port numbers associated with process on host.
- example port numbers:
  - HTTP server: 80
  - mail server: 25

well defined port numbers
i.e. reserved for these apps by convention! OS protects this

- 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:

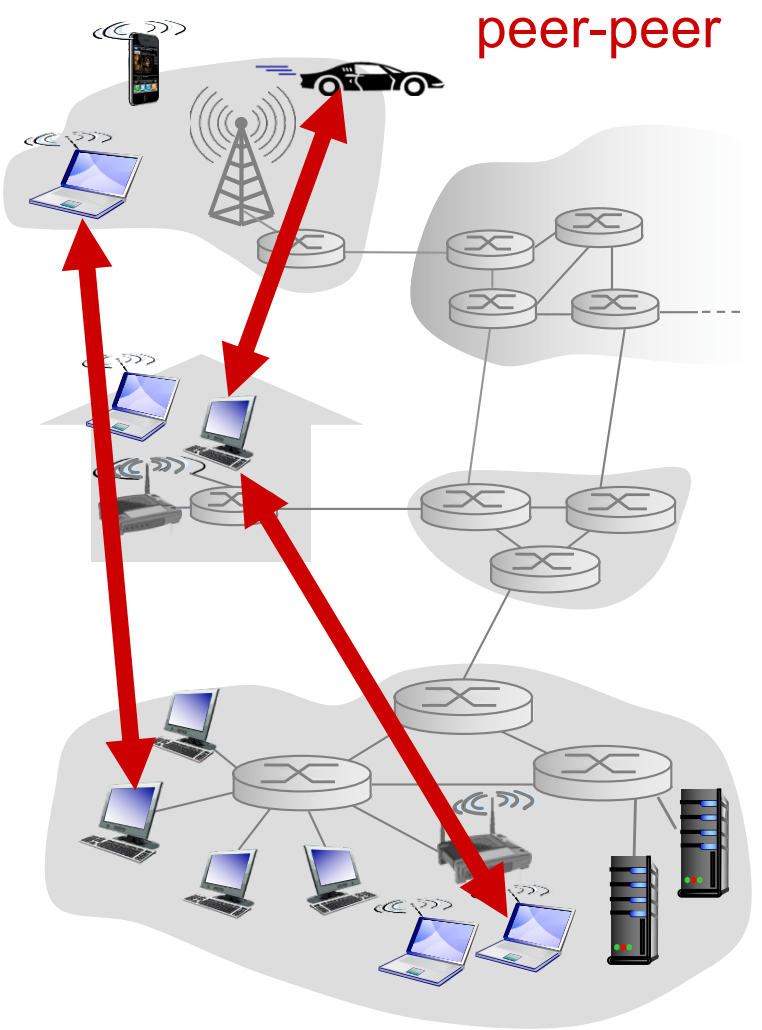
- Short-lived process that makes requests
- "User-side" of application
- Initiates the communication

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

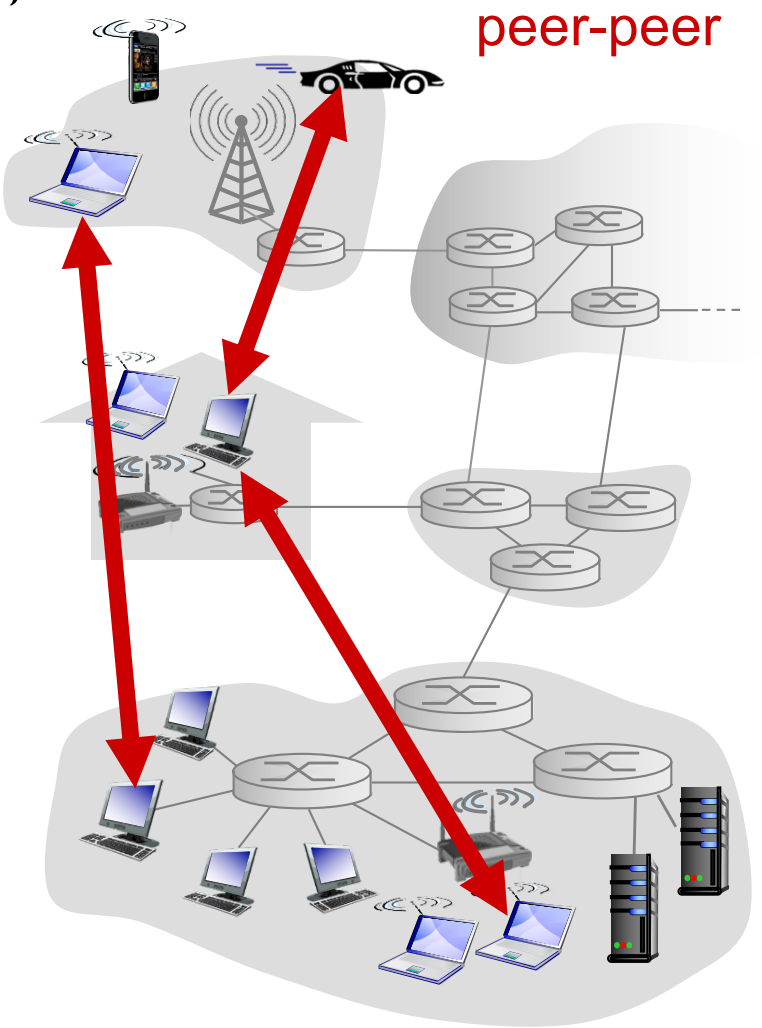
P2P architecture

- *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. HTTP's GET and POST
  - 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

application	data loss	throughput	time sensitive
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

can restrict amount of data coming out of sender with respect to just this client or the network in general

because of throttling

reliability means timing is sacrificed

security not guaranteed? why?

UDP service:

- *unreliable data transfer* between sending and receiving process
- *does not provide:* reliability, flow control, congestion control, timing, throughput guarantee, security, orconnection setup,

Q: why bother? Why is there a UDP?

NOTE: More on transport later on

Internet apps: application, transport protocols

application	application layer protocol	underlying transport protocol	
e-mail	SMTP [RFC 2821]	TCP	cant miss chars
remote terminal access	Telnet [RFC 854]	TCP	commands and such need to be as is
Web	HTTP [RFC 2616]	TCP	also cant miss chars and stuff
file transfer	FTP [RFC 959]	TCP	files will corrupt without certain bits
streaming multimedia	HTTP (e.g., YouTube), RTP [RFC 1889]	TCP or UDP	
Internet telephony	SIP, RTP, proprietary (e.g., Skype)	TCP or UDP	

vids can lose a few pixels on some frames and be okay, same with audio

Quiz: Transport

Pick the true statement

A. TCP provides reliability and ~~guarantees a minimum bandwidth~~ nope, sender can be throttled

B. TCP provides reliability while ~~UDP provides bandwidth guarantees~~ UDP doesn't have throughput guarantee, lower level bottleneck can destroy that

C. TCP provides reliability while UDP does not yes, tcp is relaible (bytes delivered and in order) whilst udp doesnt

D. Neither TCP nor UDP provides reliability tcp does

2. Application Layer: outline

2.1 principles of network applications
- app architectures
- app requirements

2.2 Web and HTTP

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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

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)

which protocol is being used for this

the port at that host

the resource name

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

the host name or ip

the directory at that host

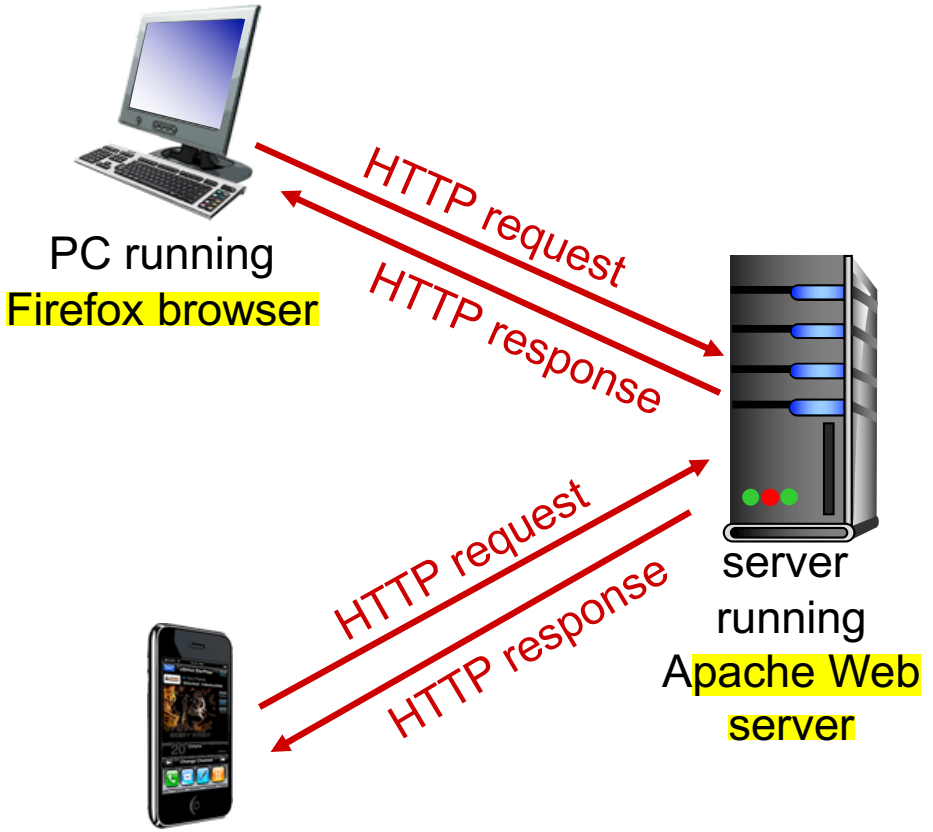
- *protocol*: http, ftp, https, smtp *etc.*
- *hostname*: DNS name, IP address
- *port:* defaults to protocol's standard port; *e.g.* http: 80 https: 443
- *directory path*: hierarchical, reflecting file system
- *resource*: Identifies the desired resource

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

so HTTP is the protocol you must follow for web apps
so you can write any browser api you like as long as it adheres to this protocols (exports/imports data as expected)



These are all different apps, so have different programming (API), but they all adhere to the same protocol (HTTP), so they all uphold the same promises about order and format of data etc and so have no troubles speaking to one another

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

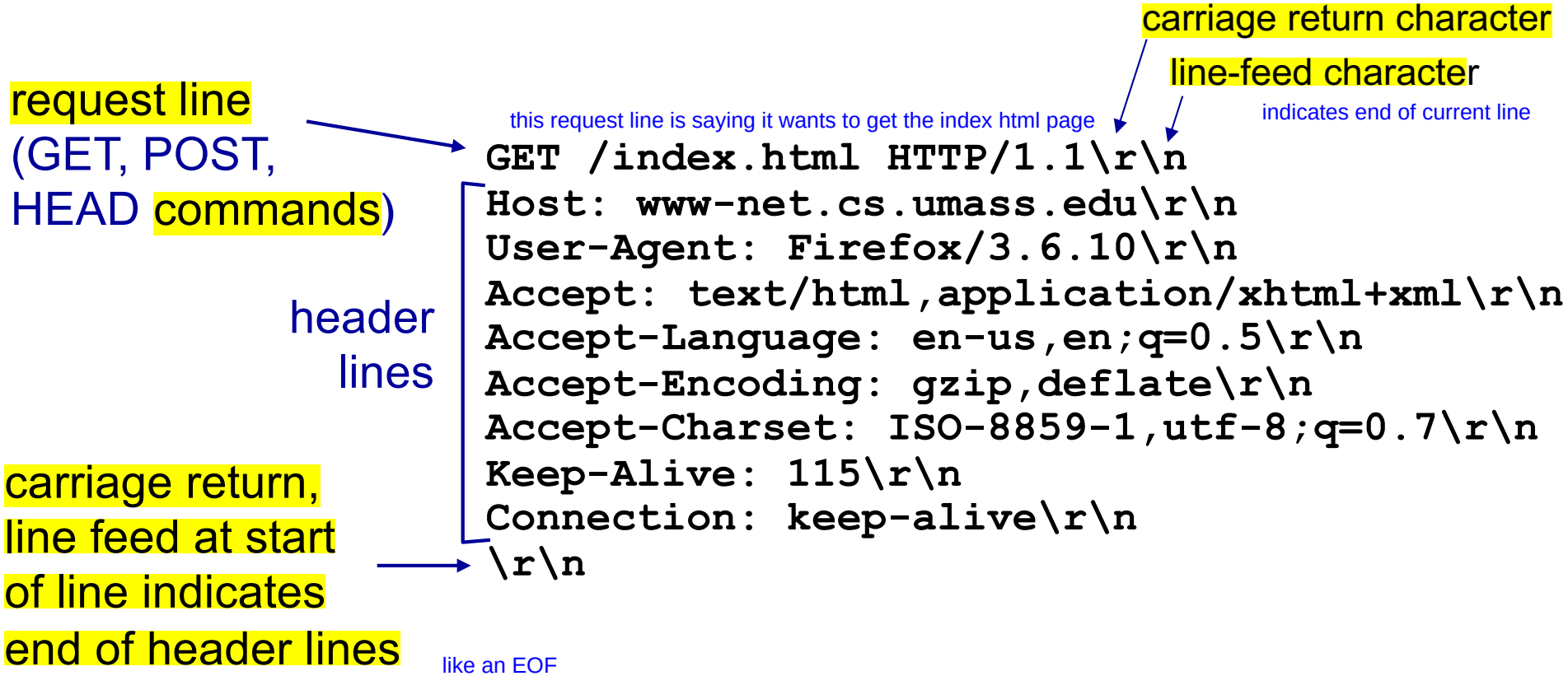
aside

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)



HTTP response message

status line (protocol status code status phrase)

header lines

data, e.g., requested HTML file

code, phrase

```
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 ...
```

end of line, this is what i fucked up in the lab!!!

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 dafuq?

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

no strict order on headers so you must split based on \r\n and then look at the different lines you have, can also then split on : if you want header field and contents split

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

    i.e. just give me the HEADer of the 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

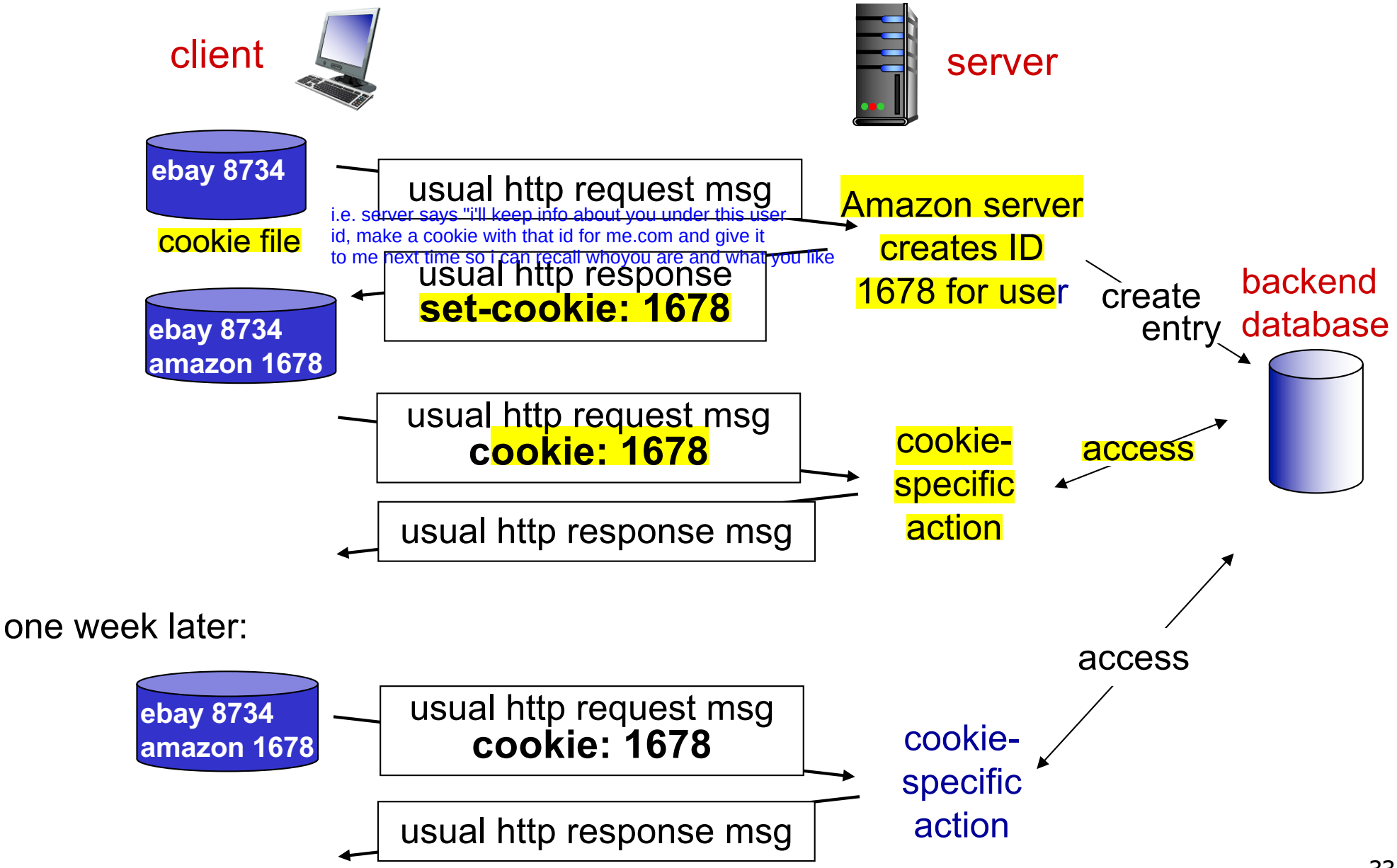
four components:

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.)

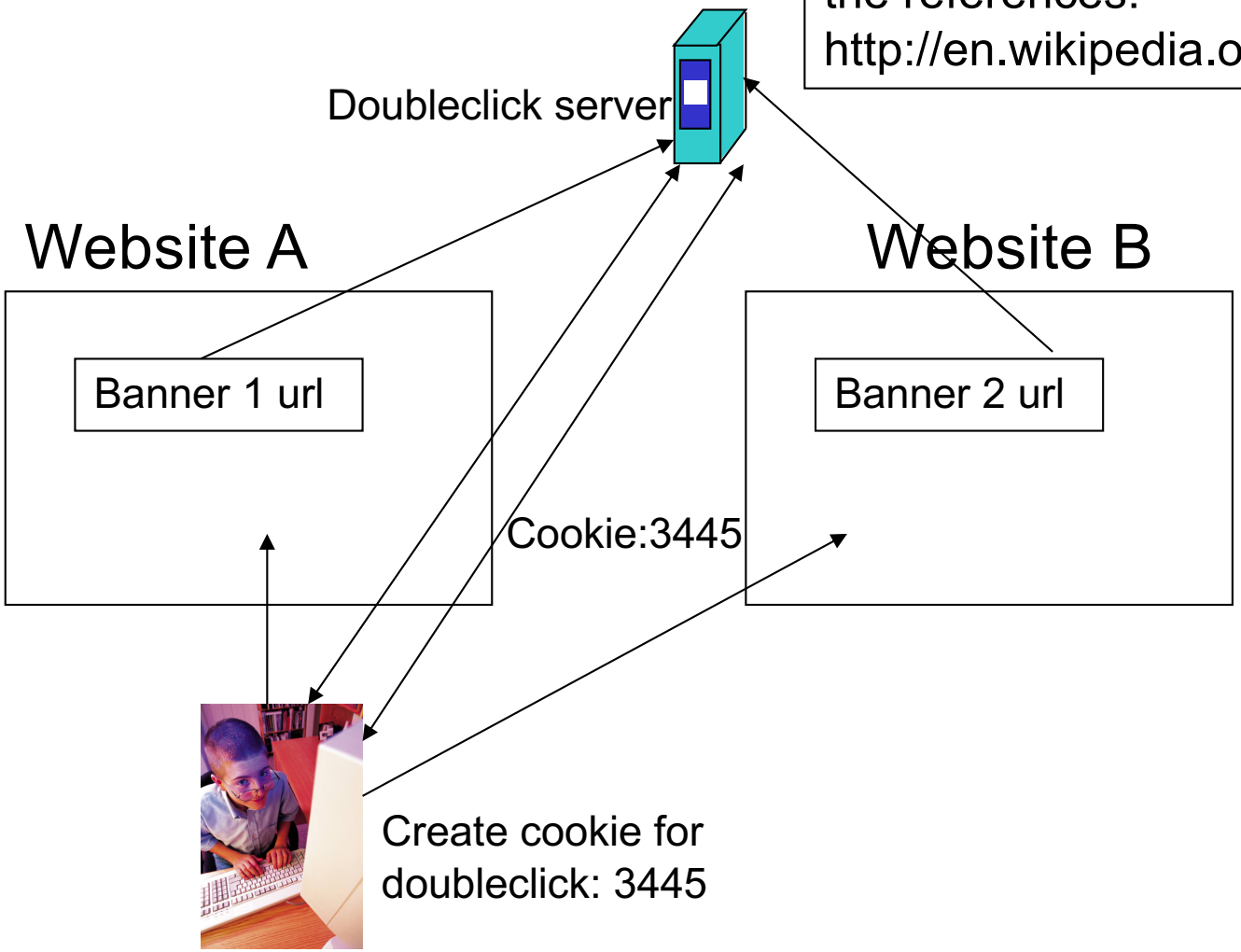


The Dark Side of Cookies

- Cookies permit sites to learn a lot about you
- You may supply name and e-mail to sites (and more)
- 3rd 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

For more, check the following link and follow the references:
http://en.wikipedia.org/wiki/HTTP_cookie



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?

Improve HTTP to achieve faster downloads

- User
  - fast downloads
  - high availability
- Content provider
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Solutions?

Improve HTTP to achieve faster downloads

- User
  - fast downloads
  - high availability
- Content provider
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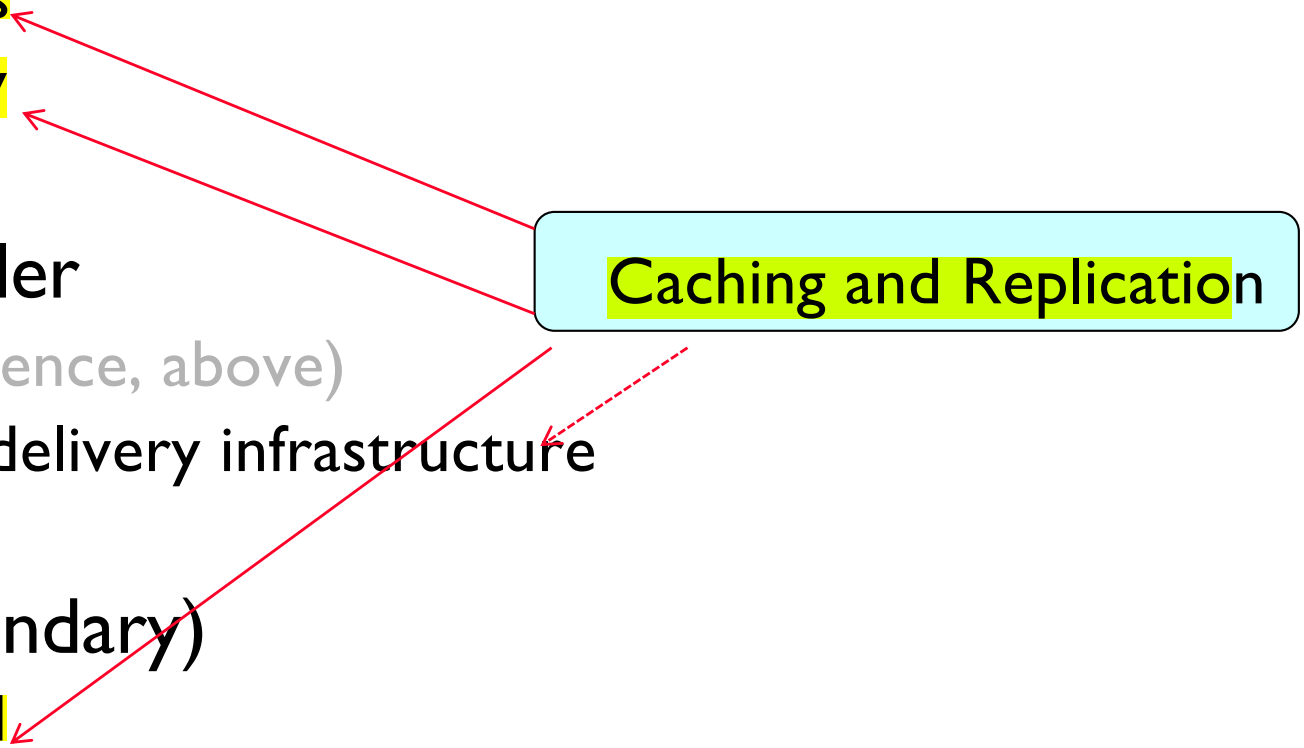
Caching and Replication



Solutions?

- User
  - fast downloads
  - high availability

Improve HTTP to achieve faster downloads

- Content provider
  - happy users (hence, above)
  - cost-effective delivery infrastructure

Caching and Replication

- Network (secondary)
  - avoid overload

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!

they didn't really explain why it needs to make a new TCP connection per object here, but it does (at least in HTTP 0.9)

non-persistent HTTP

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

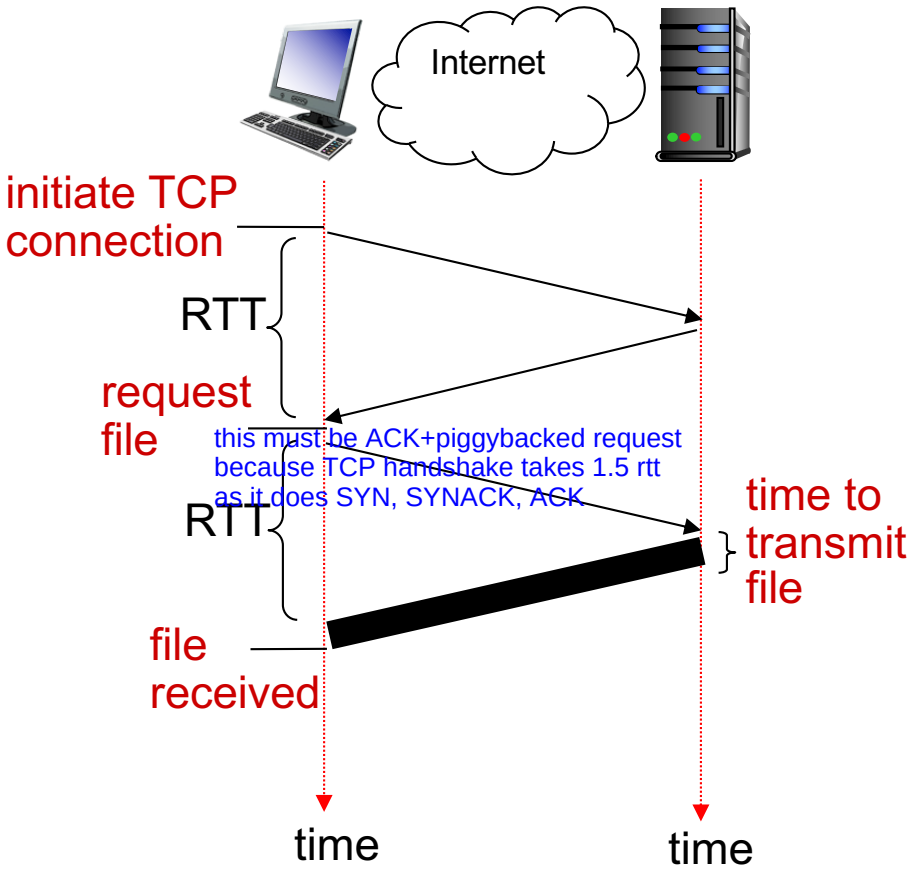
Non-persistent HTTP: response time

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

HTTP response time:

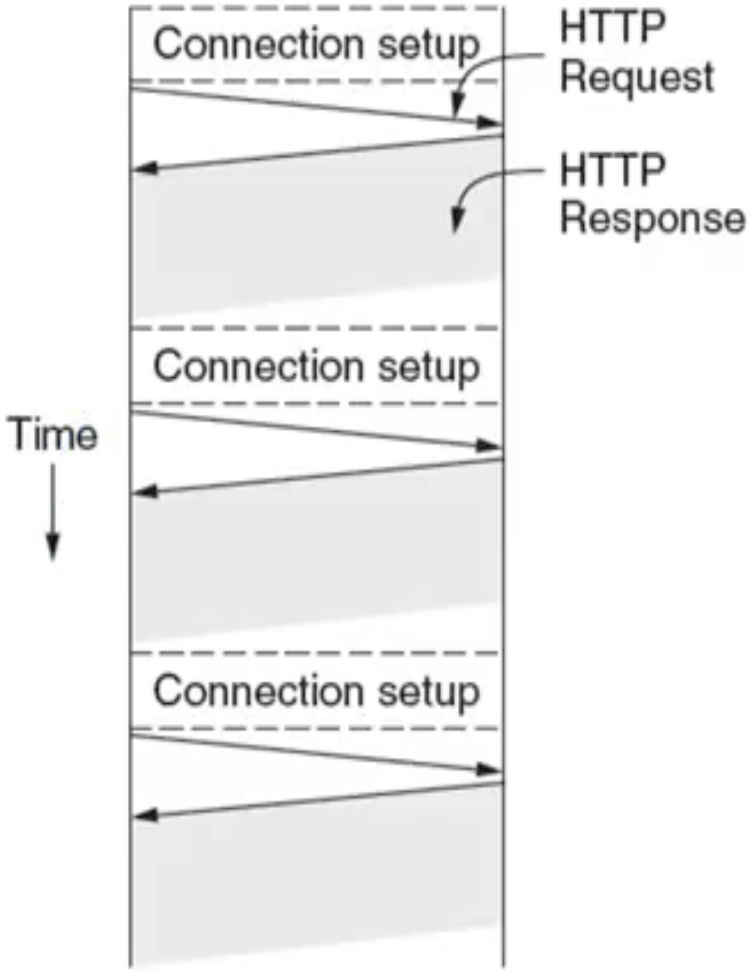
- one RTT to initiate TCP connection
- one RTT for HTTP request and first few bytes of HTTP response to return
- file transmission time
- non-persistent HTTP response time =

  2RTT+ file transmission time



HTTP/1.0

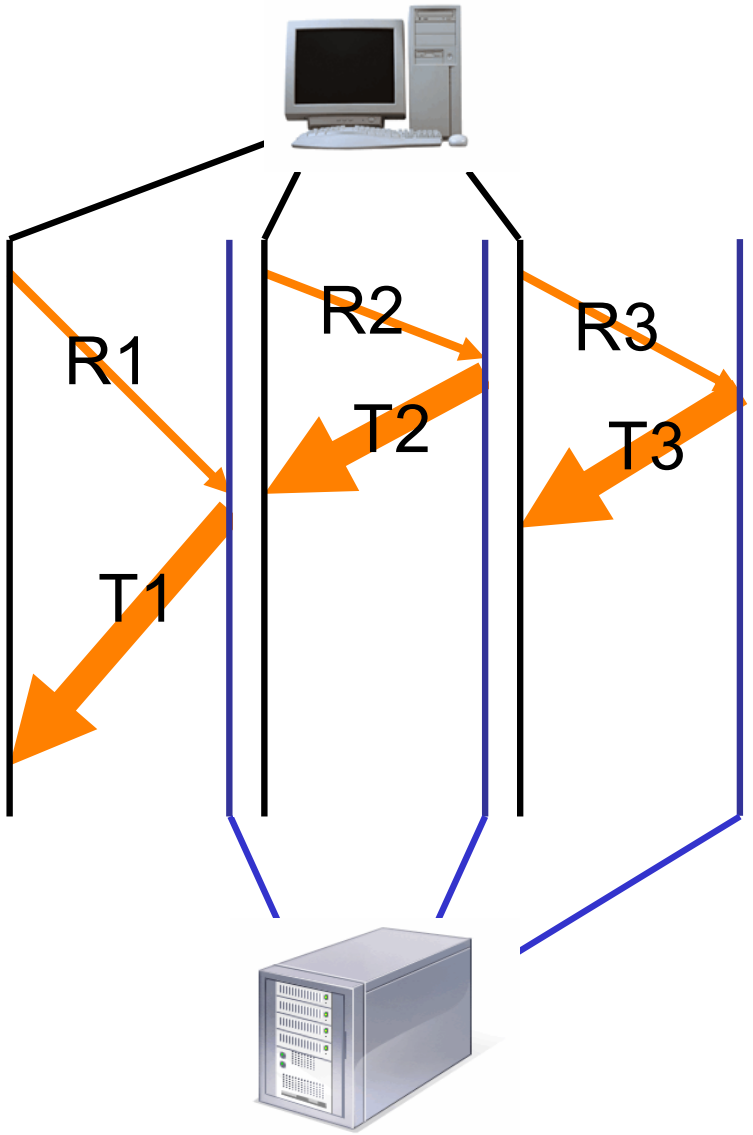
- Non-Persistent: One TCP connection to fetch one web resource
- Fairly poor PLT
- 2 Scenarios
  - Multiple TCP connections setups to the same server
  - Sequential request/responses even when resources are located on different servers
- Multiple TCP slow-start phases (more in lecture on TCP)



Improving HTTP Performance:

Concurrent Requests & Responses

- 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?

the server now has to keep track of these N connections you have made to it.
putting a lot of strain on the server just for connections alone.

Persistent HTTP

Persistent HTTP

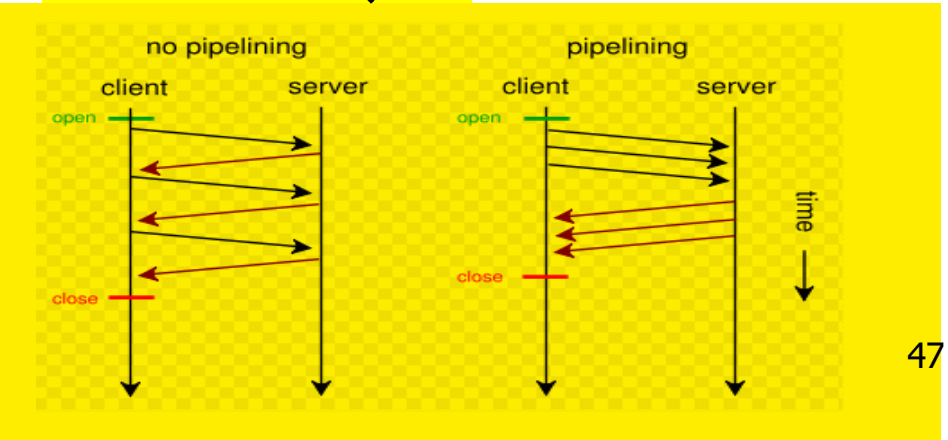
- server leaves TCP connection open after sending response
- subsequent HTTP messages between same client/server are sent over the same TCP connection
- Allow TCP to learn more accurate RTT estimate for setting timer (APPARENT LATER IN THE COURSE)
- Allow TCP congestion window to increase (APPARENT LATER)
- 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

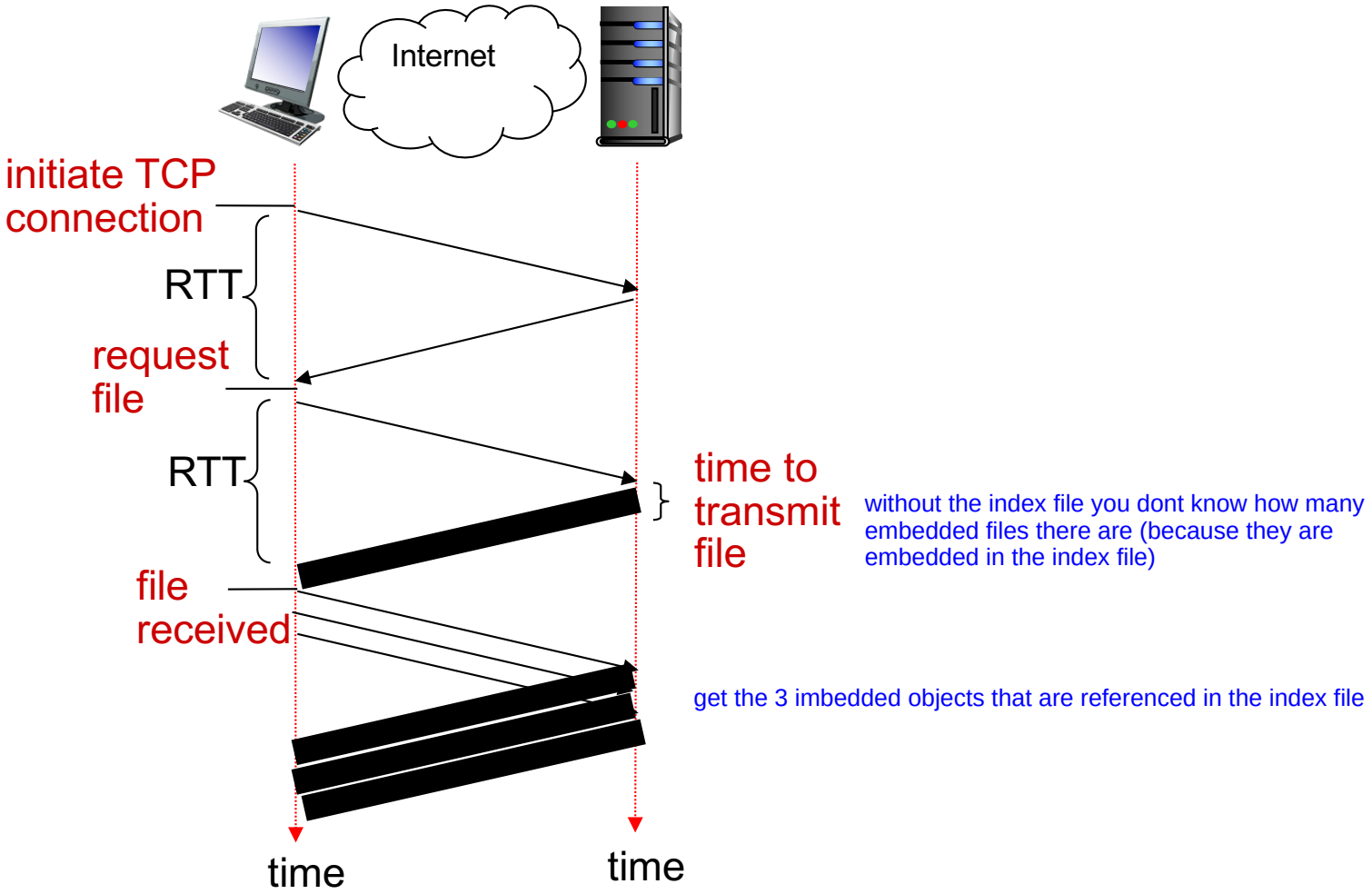
Persistent with pipelining:

- 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



without the index file you dont know how many embedded files there are (because they are embedded in the index file)

get the 3 imbedded objects that are referenced in the index file

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

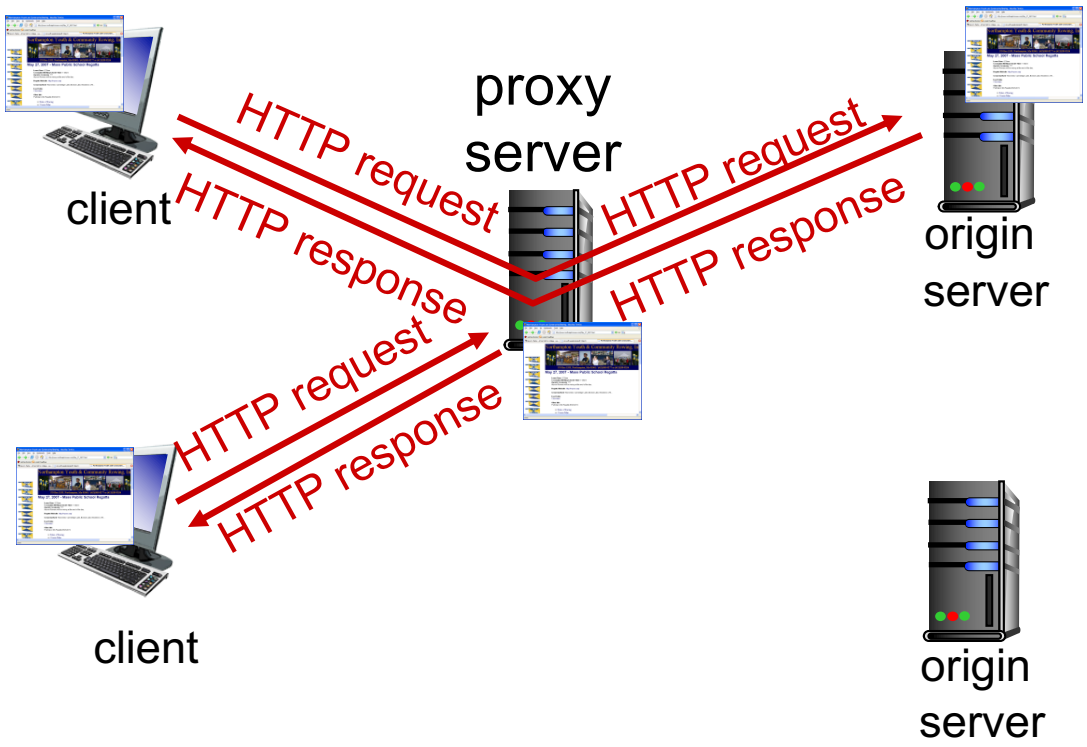
Improving HTTP Performance: Caching

- 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)

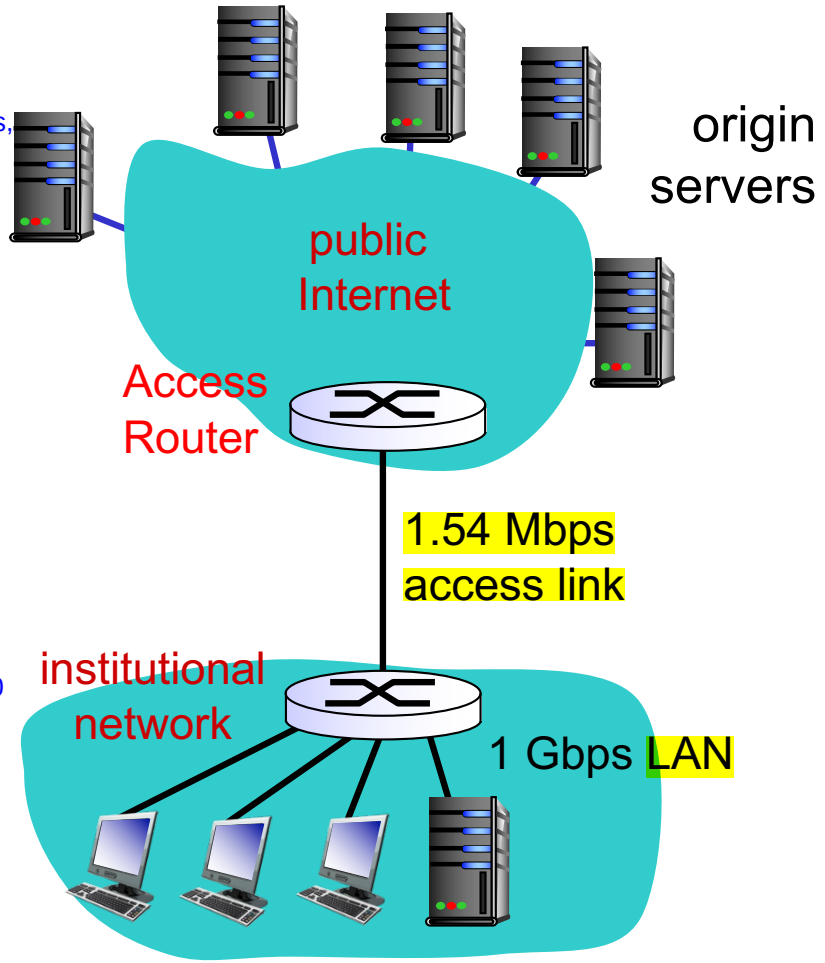
why Web caching?

- 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
  - each req is 100,000 bytes, so 15*100,000 = 1,500,000 bits/sec
  - 15 reqs per sec
  - 1,540,000 bits/sec access link is almost full
- avg data rate to browsers: 1.50 Mbps
  - 1,500,000 bits/sec from server to client
- RTT from access router to any origin server: 2 sec
  - 2 sec trip
- access link rate: 1.54 Mbps



consequences:

- sending 1,500,000 bits/sec down a 1,000,000,000 bits/sec LAN, 1,500,000/1,000,000,000/ = 15/10,000 = 0.0015 ratio, 1= 100%, so 0.0015 = 0.15%
- 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 → 154 Mbps

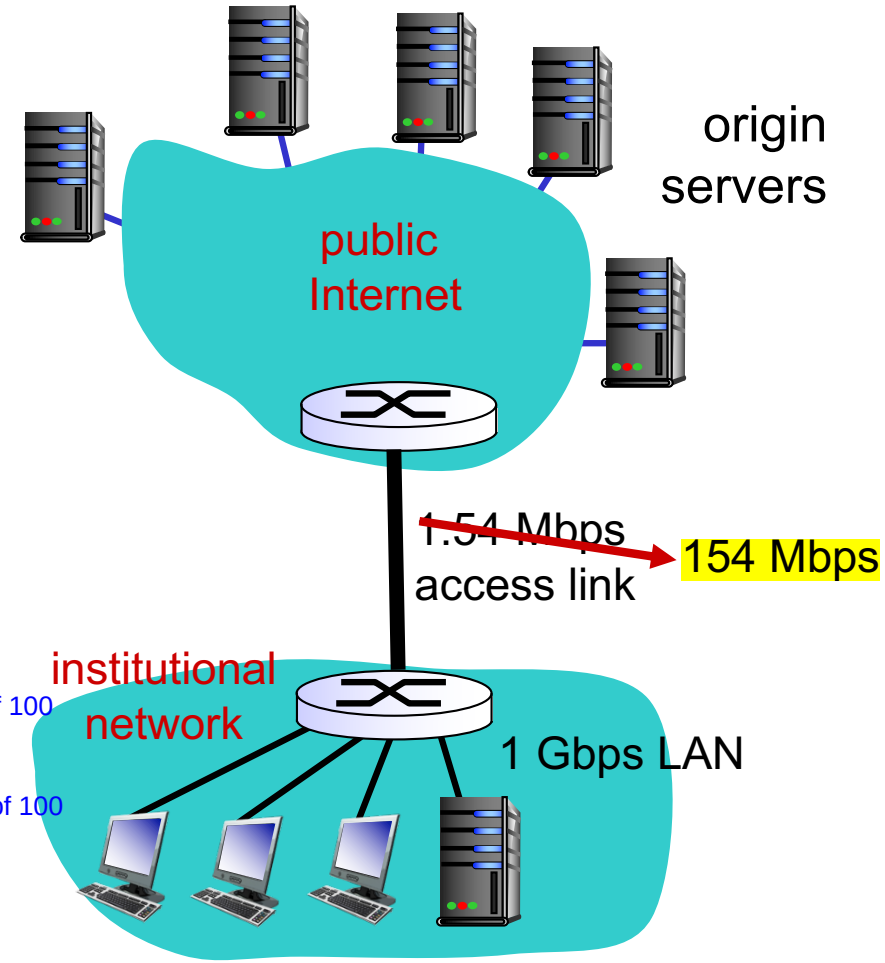
increase by factor of 100

consequences:

- LAN utilization: 0.15%
- access link utilization = 99% → 0.99%

decreases load by factor of 100

- total delay = Internet delay + access delay + LAN delay
  = 2 sec + minutes + usecs → msecs



Cost: increased access link speed (not cheap!)

so improving the bottleneck worked, but it wasn't cheap and that may only be for extreme scenarious (only happens once a week or so)

Caching example: install local cache

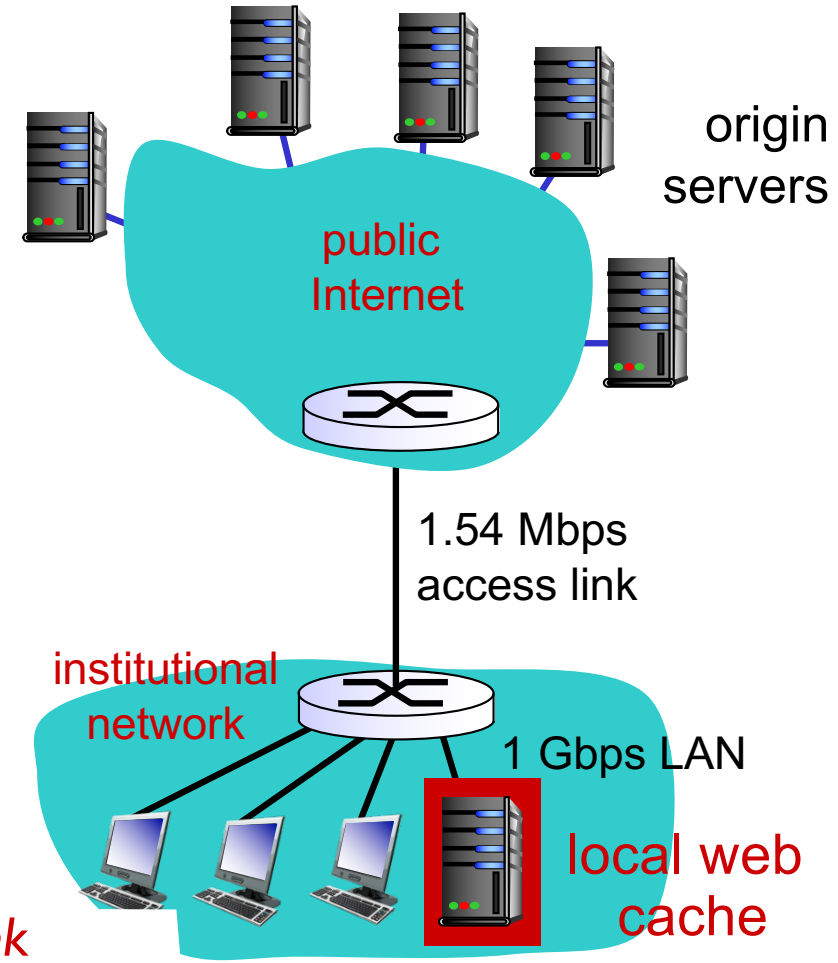
assumptions:

- 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 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?

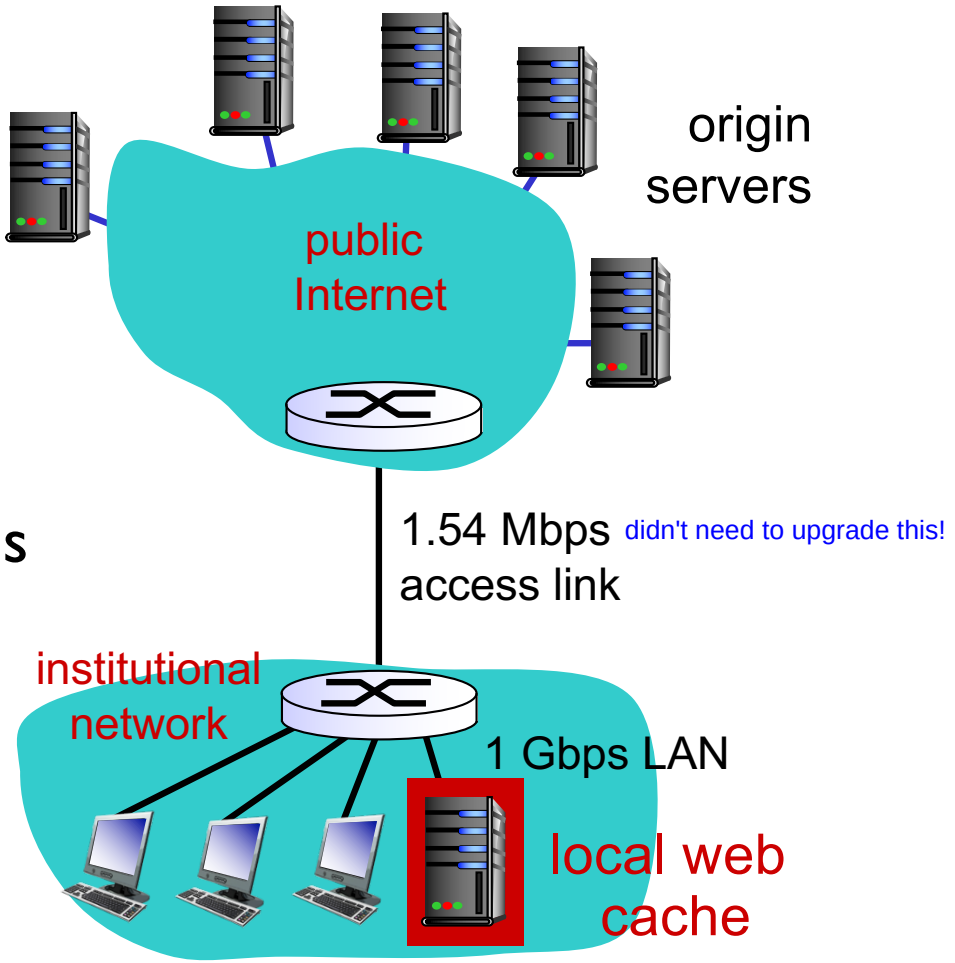


Cost: web cache (cheap!)

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 Mbps = .9 Mbps
  - utilization = 0.9/1.54 = .58
- total delay
  - = 0.6 * (delay from origin servers) +0.4 * (delay when satisfied at cache)
  - = 0.6 (2.01) + 0.4 (~msecs)
  - = ~ 1.2 secs eliminates a lot of the costly RTT
  - less than with 154 Mbps link (and cheaper too!) didnt even need that costly upgrade and got better performance than it gave anyway



Conditional GET

i.e. how to know whether cache is good or not

- *Goal:* don't send object if cache has up-to-date cached version
  - no object transmission delay
  - lower link utilization

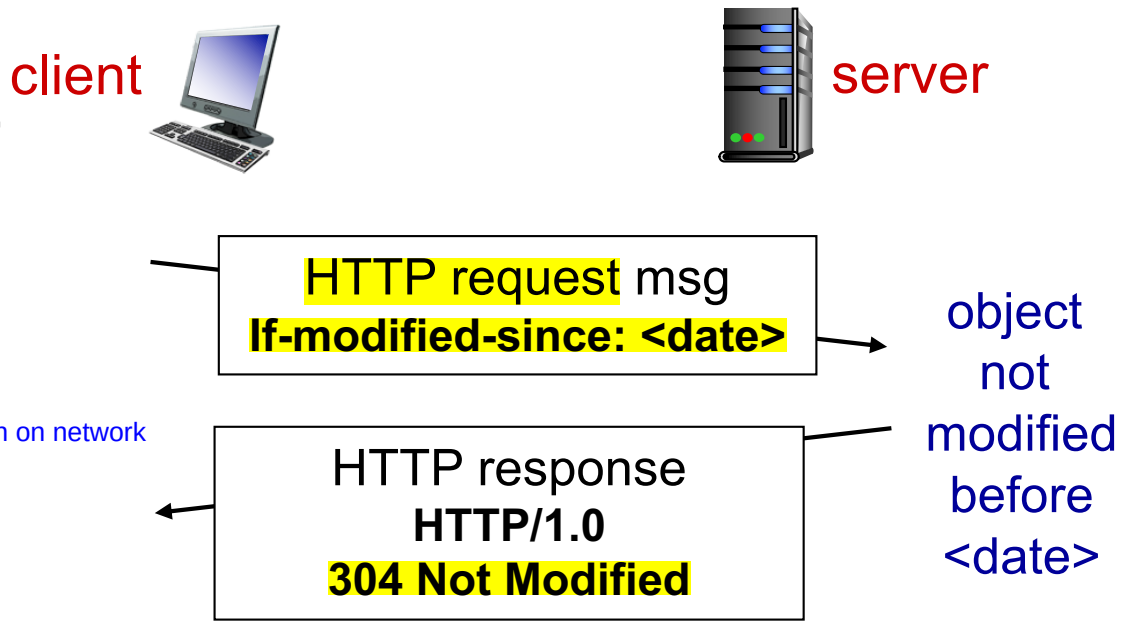
quicker and less strain on network

- *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
```



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"
```

same etag as the request

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

i.e. you can't cache weather data for very long at all. it constantly changes, what you had 1hr ago is no longer relevant

- Problem:
  - Want to direct client to particular replica
    - Balance load across server replicas
    - Pair clients with nearby servers

cant just spread servers evenly geographically, its not likely most csgo players are in africa, you probs need waaay more in aus, europe, amerika etc.

  - Expensive

machines cost mula

- Common solution:
  - DNS returns different addresses based on client's geo location, server load, *etc.*

still doesn't solve the problem of acutally needing to buy machines or rent them

More on this later

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

"your connection is not secure"

What's on the horizon: HTTP/2

- Google SPDY (speedy) -> HTTP/2: (RFC 7540 May 2015)
- Better content structure
- Improvements
  - Severs 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

Head of Line blocking in HTTP terms is often referring to the fact that each browser/client has a limited number of connections to a server and doing a new request over one of those connections has to wait for the ones before to complete before it can fire it off.

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

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)**?

new TCP connection per object + 1 for the setup

getting an object take an RTT + file trans time

A. $D + (S_0 + NS)/C$

B. $2D + (S_0 + NS)/C$

C. $N(D + S/C)$

D (setup TCP conn) + D (request index) + S0/C (get index) + N*(2D + S/C) (per object, make a new TCP connection +1D, request obj +1D, object retreival time + 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)**?

dont need to setup new connection as long as all content is on same server (assuming it is)

so 1RTT to setup connection, then 1RTT for each object

remember index page is an object

A. $2D + (S_0 + NS)/C$

B. $3D + (S_0 + NS)/C$

C. $N(D + S/C)$

D. $2D + S_0/C + N(2D + S/C)$

set up TCP connection (+D), request index page (+D), transmit index page (+S0/C), then for N other objects embedded in index page you must do an RTT to request it and S/C for file transmit time

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?**

now you can request all objects embedded in index page all at once

A. $2D + (S_0 + NS)/C$

B. $4D + (S_0 + NS)/C$

C. $N(D + S/C)$

set up TCP connection (+D), get index page (+S0/C), then send out all 3 requests for objects at once (+1D), then wait for file transfer time (N objects of size 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 email bro
- 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

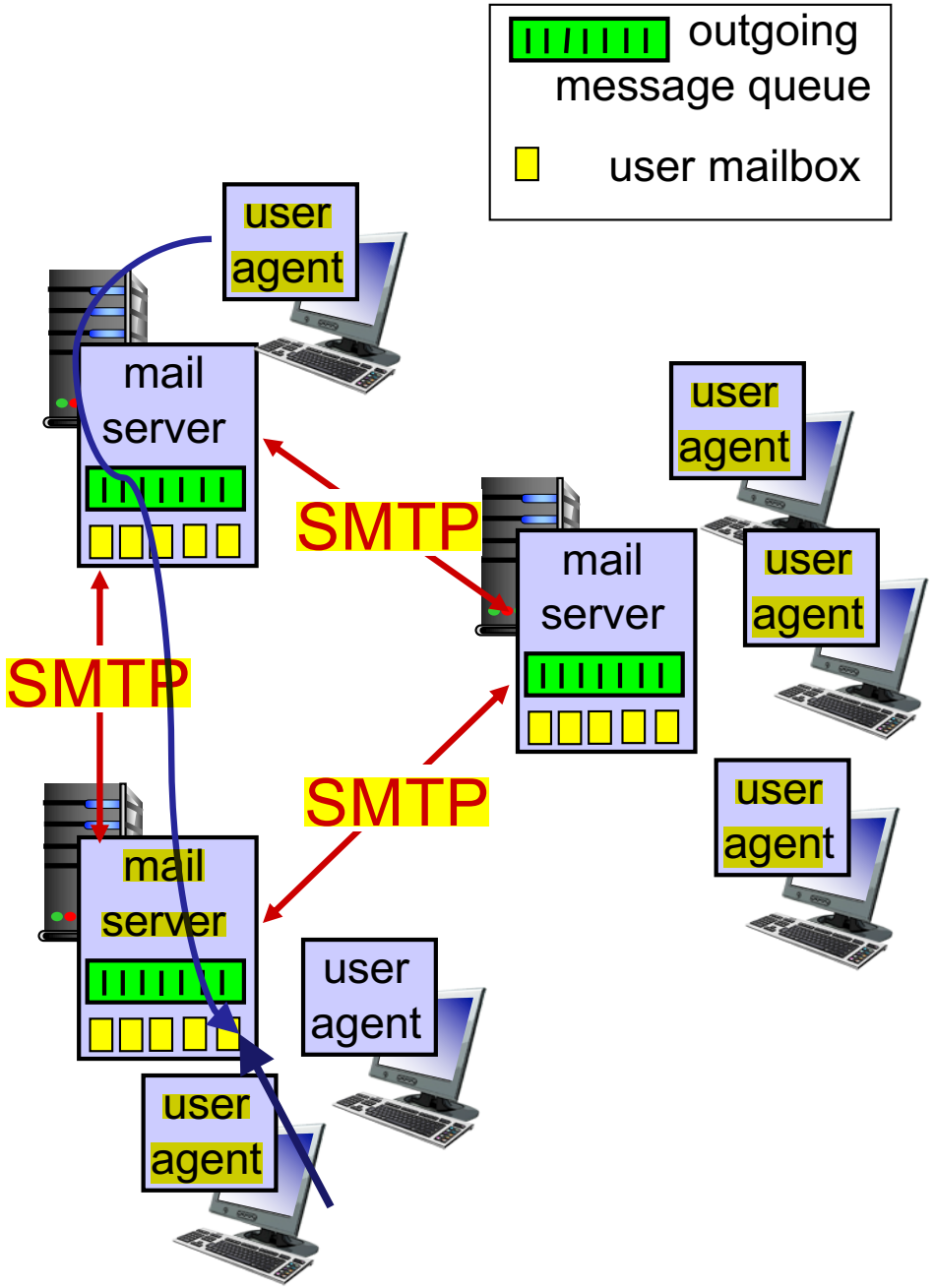
Electronic mail

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

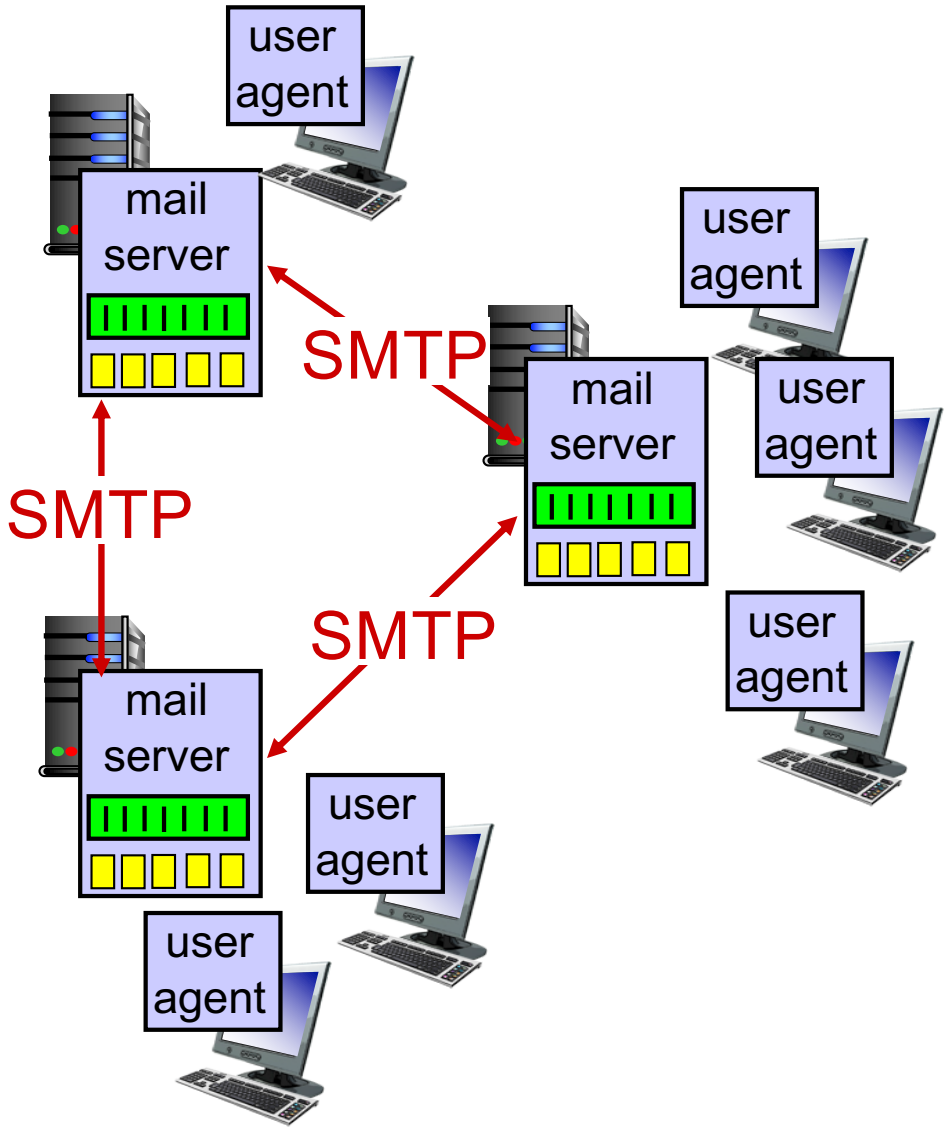


Electronic mail: mail servers

the electronic mail boxes

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

very similar to HTTP

- messages must be in 7-bit ASCII

Scenario: Alice sends message to Bob

1) Alice uses UA to compose message "to" bob@someschool.edu

alice writes on outlook and then presses send

2) Alice's UA sends message to her mail server; message placed in message queue

outlook sends that email to mail server, possibly goes into queue

3) client side of SMTP opens TCP connection with Bob's mail server

mail server acts as client because it is doing the opening/sending to another mail server

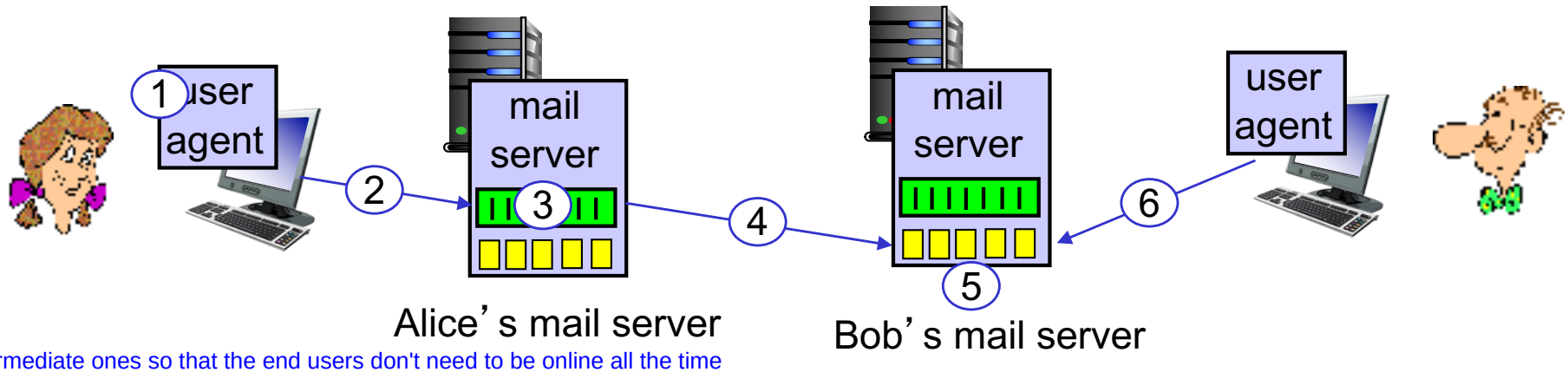
4) SMTP client sends Alice's message over the TCP connection

alice's mail server (acting as client) send email over tcp connection to bobs mail server. adheres to smtp protocol otherwise it wouldnt work (how do i interpret this?

5) Bob's mail server places the message in Bob's mailbox

server for bob now has the email. bob can read it whenever he logs onto outlook

6) Bob invokes his user agent to read message

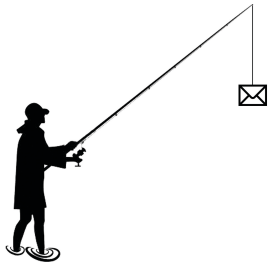


need the intermediate ones so that the end users don't need to be online all the time
i.e. if alice tried to send to bob but he was offline then it wouldnt work, to prevent her from having to try again later manually we give alice a server, she sends to that and her job is done. but we still have the problem of bob being offline! mail server could re-send intermittently, but that is wasteful, instead, give bob a server as well and now alice's server can send to bobs server without him being online, then the server just puts it in bobs inbox.

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
```

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 even i would fall for this one, because there is nothing to fall for, all looks legit :S
  - 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.

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

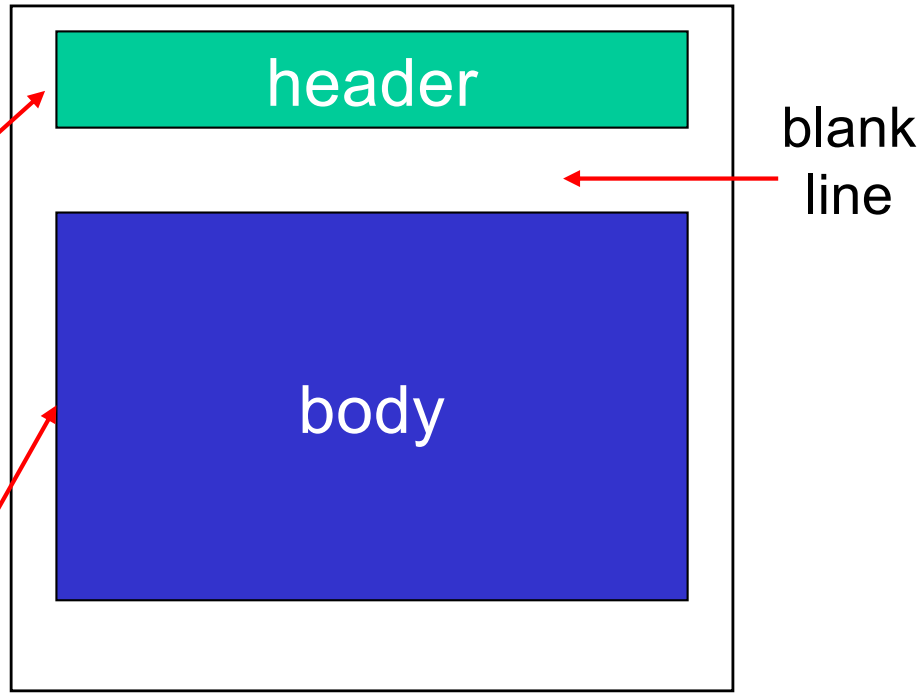
Mail message format

SMTP: protocol for exchanging email msgs

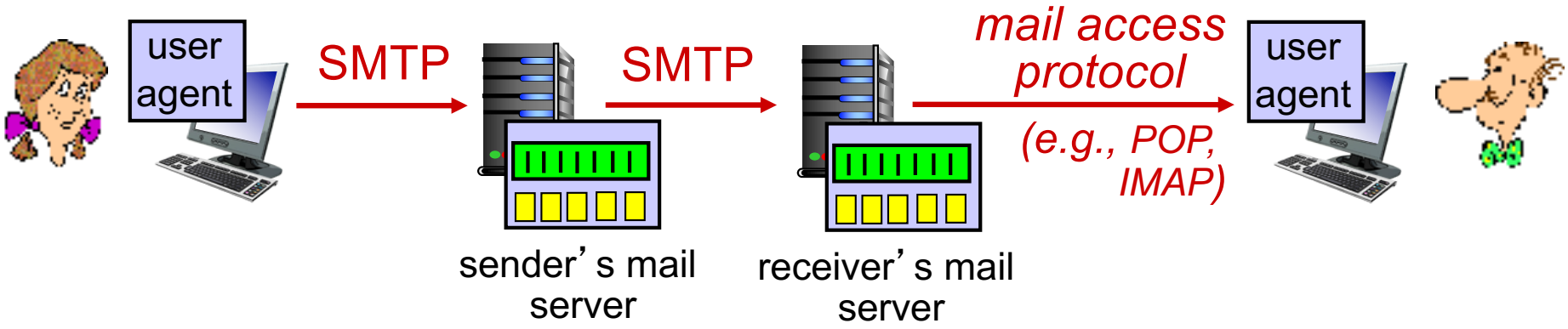
RFC 5322 (822,2822): standard for text message format (Internet Message Format, IMF):

- 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?

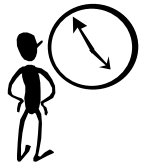
- User agent can directly connect with recipient mail server without the need of sender's mail server? What's the catch?

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

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

Summary

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



Reading Exercise
Chapter 2: 2.4 – 2.7