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

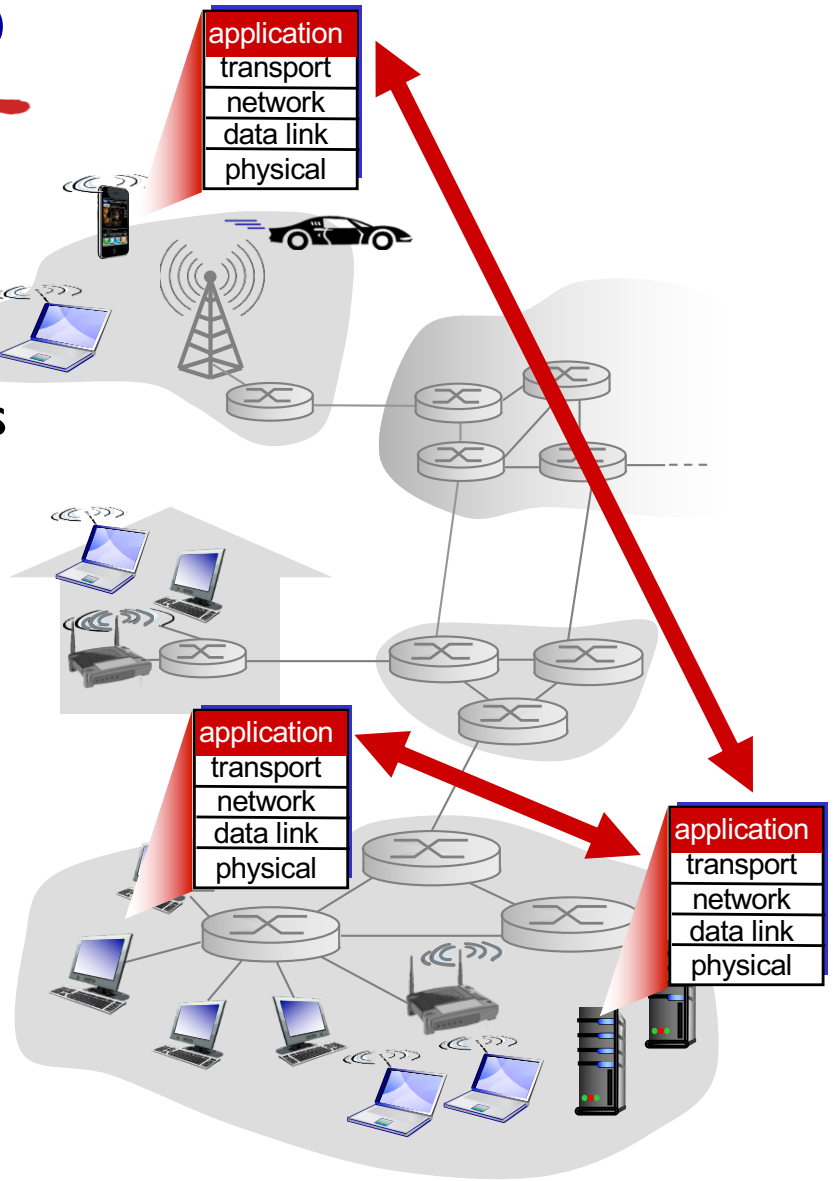
Creating a network app

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

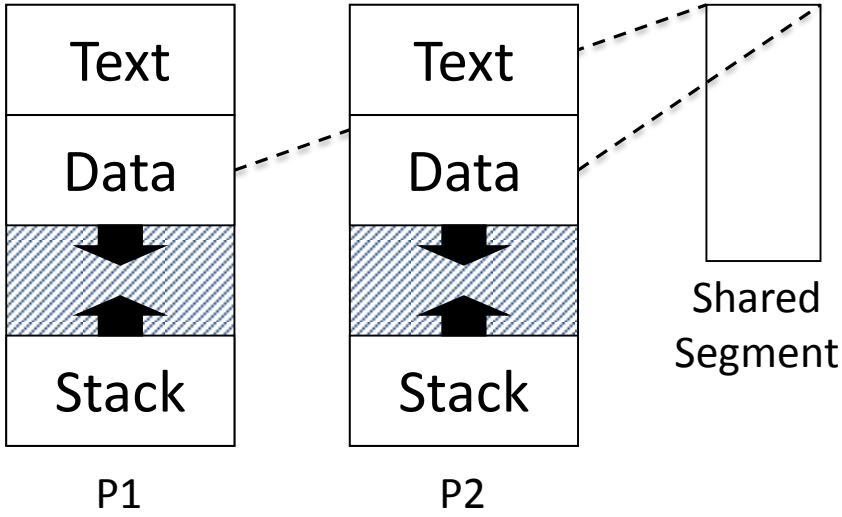
- network-core devices do not run user applications
- applications on end systems allows for rapid app development



Interprocess Communication (IPC)

进程间通信

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



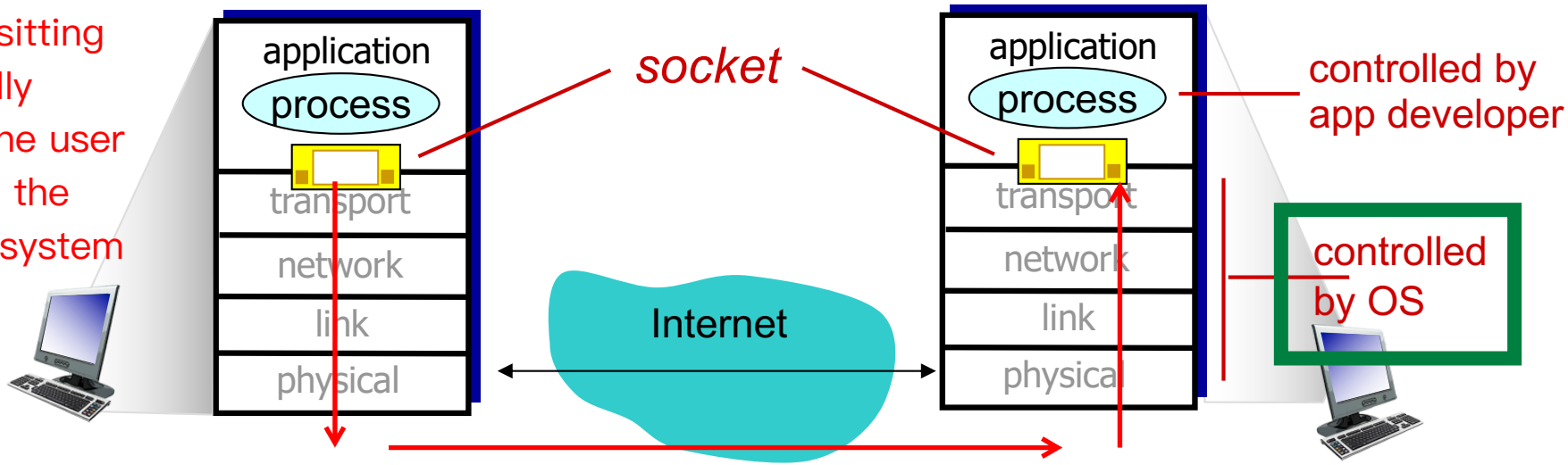
- Across machines:
  - We need other abstractions (message passing)

Sockets

Ip number is unique in a machine
Sockets number

- 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

Socket is sitting strategically between the user space and the operating system



Sockets is a communication tool for different process between different OS

A port is belonged to a sockets, socket = (IP address, port No.)

Addressing processes

插口包含了端口，因为插口 = (IP地址，端口号)。插口是TCP连接的端点。

- 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

IP address is unique for a machine in the world

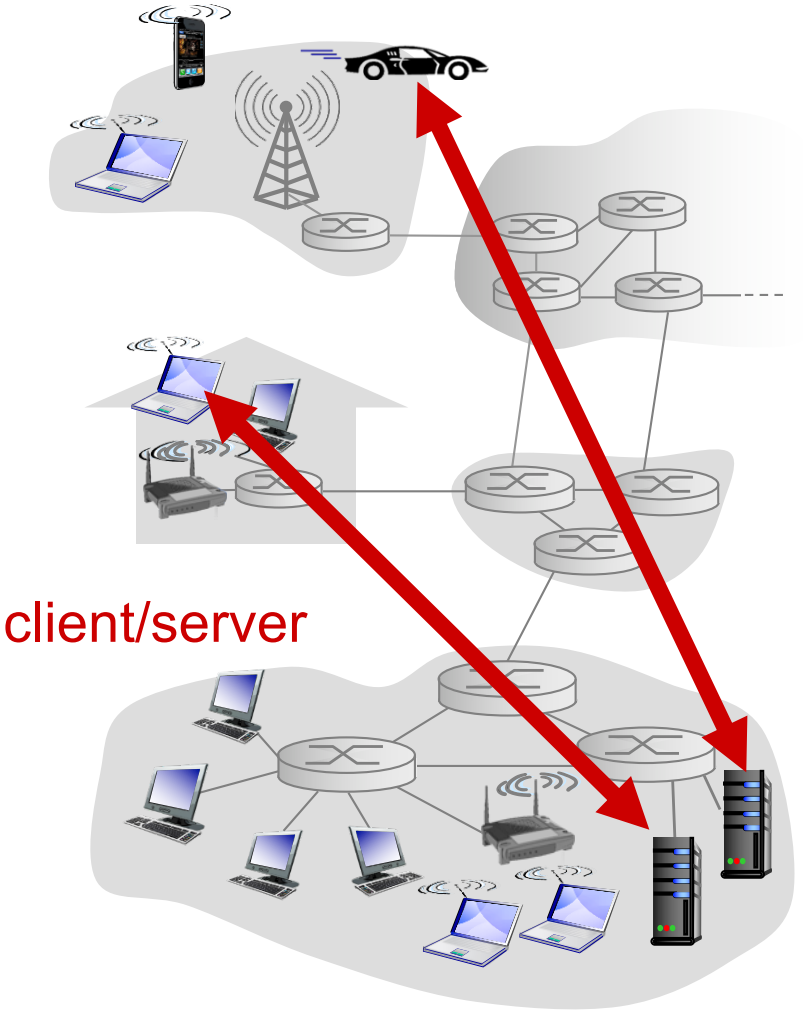
Sockets No. Is unique within that machine

OS generate unique sockets identifier

- *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

Socket number is also called port numbers

Client-server architecture



server:

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

clients:

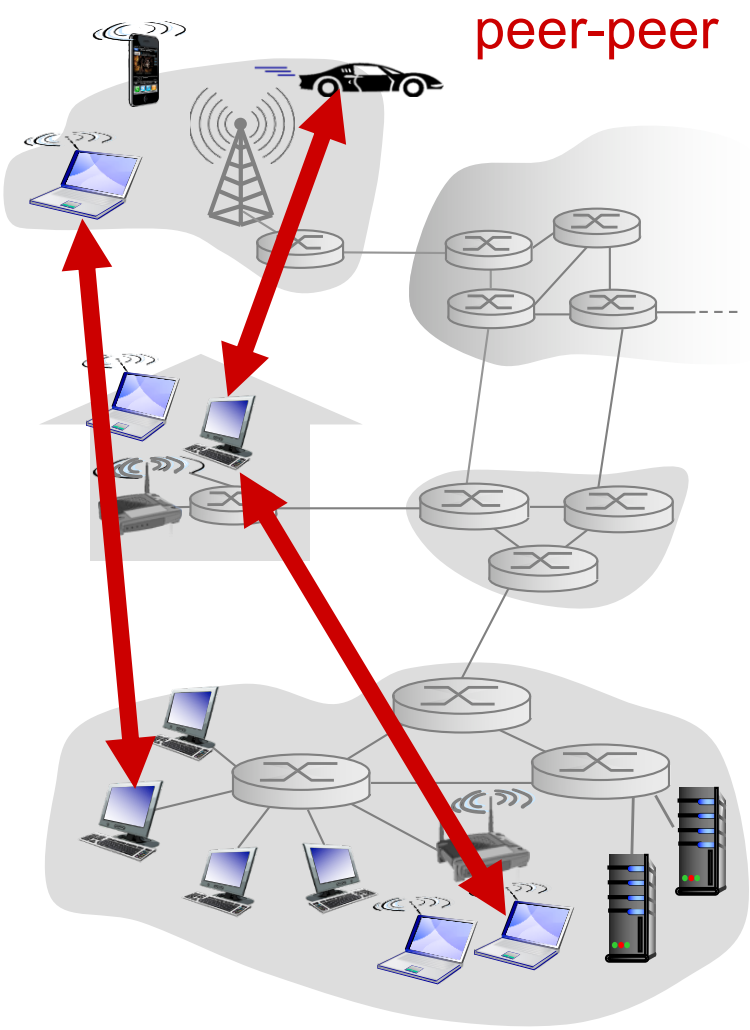
- Short-lived process that makes requests
- "User-side" of application
- Initiates the communication

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

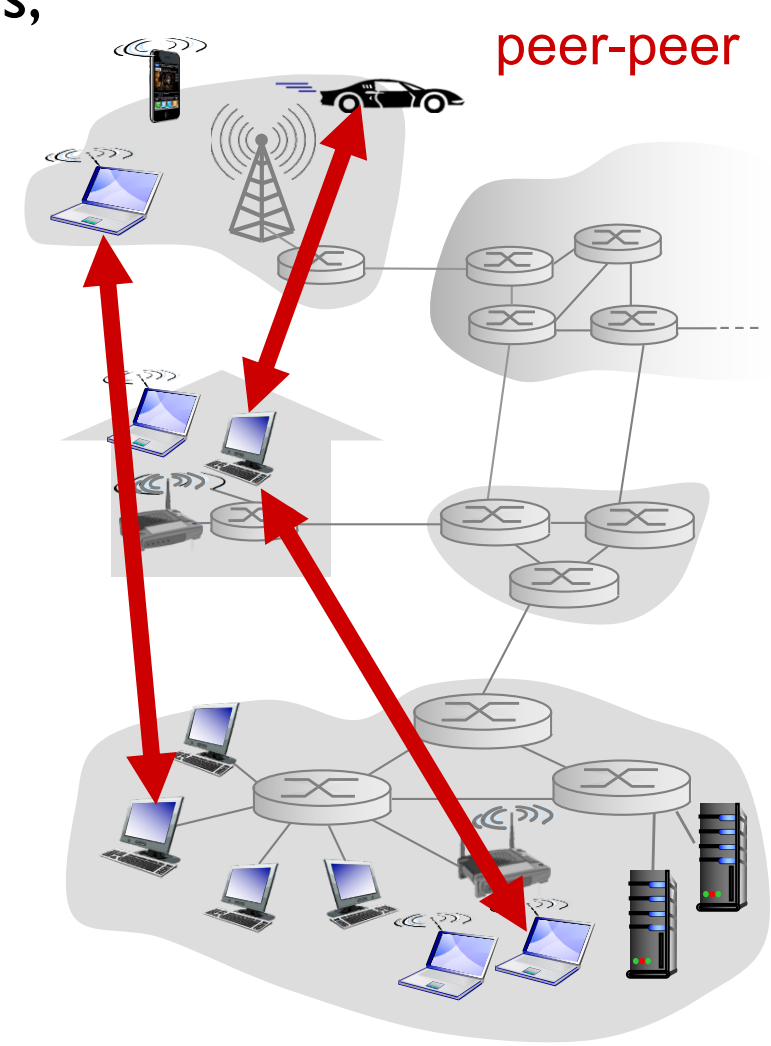
P2P architecture

- *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?

How to use the transportaion layer

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

Transportation layer

TCP service:

- *reliable transport* between sending and receiving process
- *flow control:* sender won't overwhelm receiver
- *congestion control:* throttle sender when network overloaded 节流
- *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, orconnection setup,

1. UDP is faster

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 majority
remote terminal access	Telnet [RFC 854]	TCP
Web	HTTP [RFC 2616]	TCP
file transfer	FTP [RFC 959]	TCP
streaming multimedia Video, music	HTTP (e.g., YouTube), RTP [RFC 1889]	TCP or UDP
Internet telephony	SIP, RTP, proprietary (e.g., Skype)	TCP or UDP

1.先说一下TCP的优缺点吧。优点呢，TCP是可靠的连接，由于有基本的重传确认机制，可以保证把一个数据块完完整整的从A传到B；缺点也是因优点而生，因为有三次握手，所以会传输更多的包，浪费一些带宽；因为需要可靠地连接进行通信，则需要双方都必须持续在线，所以在通信过程中server需要维持非常大的并发连接，浪费了系统资源，甚至会出现宕机；再者就是因为有重传确认，则会浪费一部分的带宽，且在不好的网络中，会因为不断地连接断开连接，严重降低了传输效率。

2.相对于TCP来说，UDP是非面向连接的不可靠的协议，其优点也因为缺点而生。首先，因为没有三次握手，所以会起步比较快，延时小；另外，由于不需要双方持续在线，所以server不用维护巨量的并发连接，节省了系统资源；三，因为没有重传确认，虽然到达的数据可能会有所缺失，但在不影响使用的情况下，能更高效的利用网络带宽。

TCP guarantee that the file can arrive at the destination socket, but it would be transmitted at a stable rate all the time. In fact, nothing can guarantee that today

Quiz: Transport

Pick the true statement C

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

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- app architectures
- app requirements

2.2 Web and HTTP

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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

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)

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

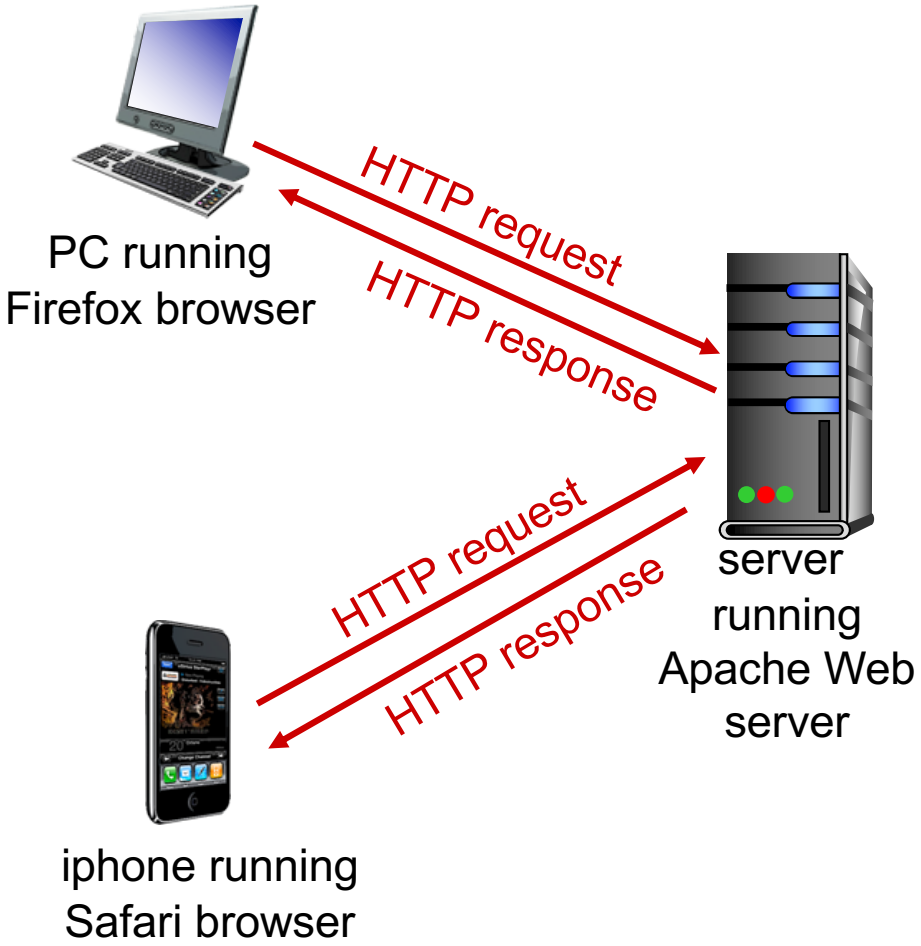
- *protocol*: http, ftp, https, smtp *etc.*
- *hostname*: DNS name, IP address
- *port:* defaults to protocol's standard port; *e.g.* http: 80 https: 443
- *directory path*: hierarchical, reflecting file system
- *resource*: Identifies the desired resource

HTTP是一个基于TCP/IP通信协议来传递数据（HTML 文件, 图片文件, 查询结果等）。

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

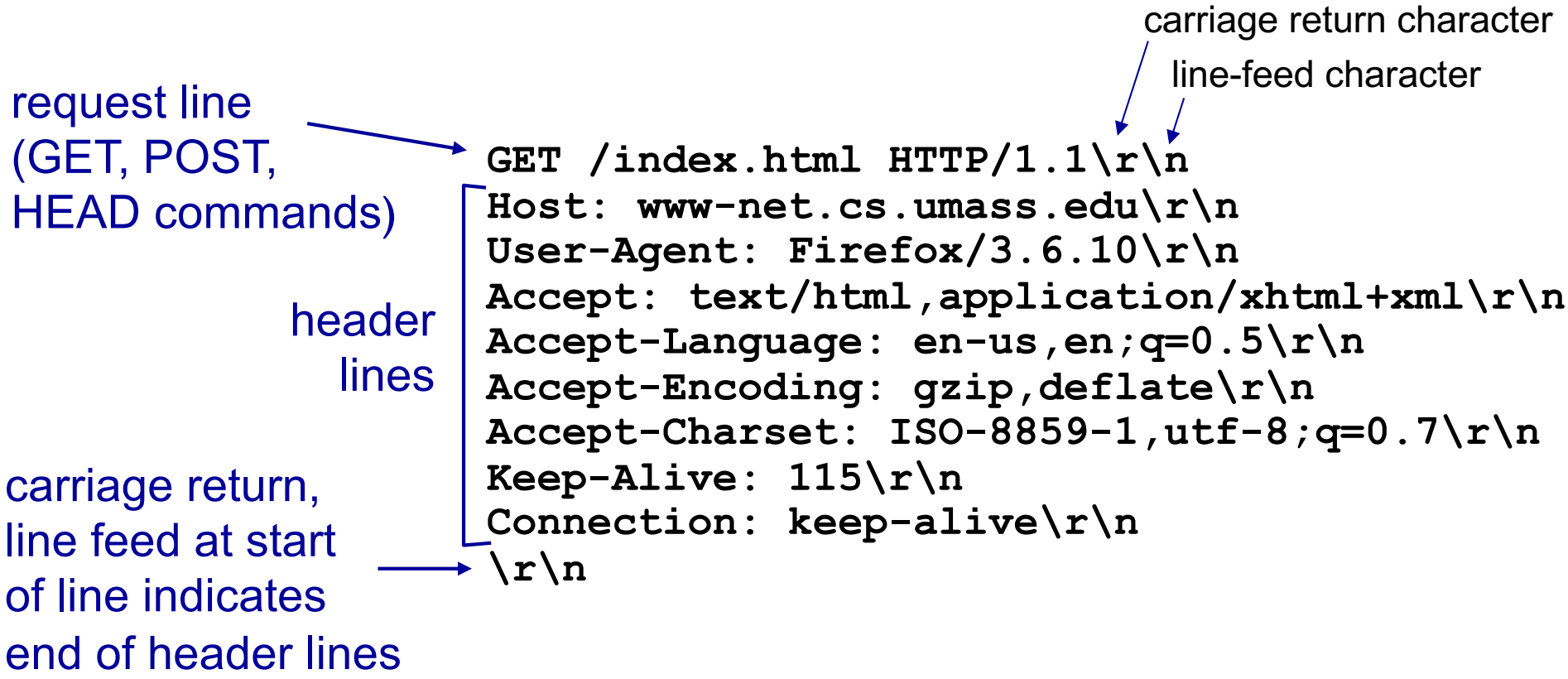
aside

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)



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 ...
```

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

If you delineate something such as an idea or situation, you describe it or define it

- 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

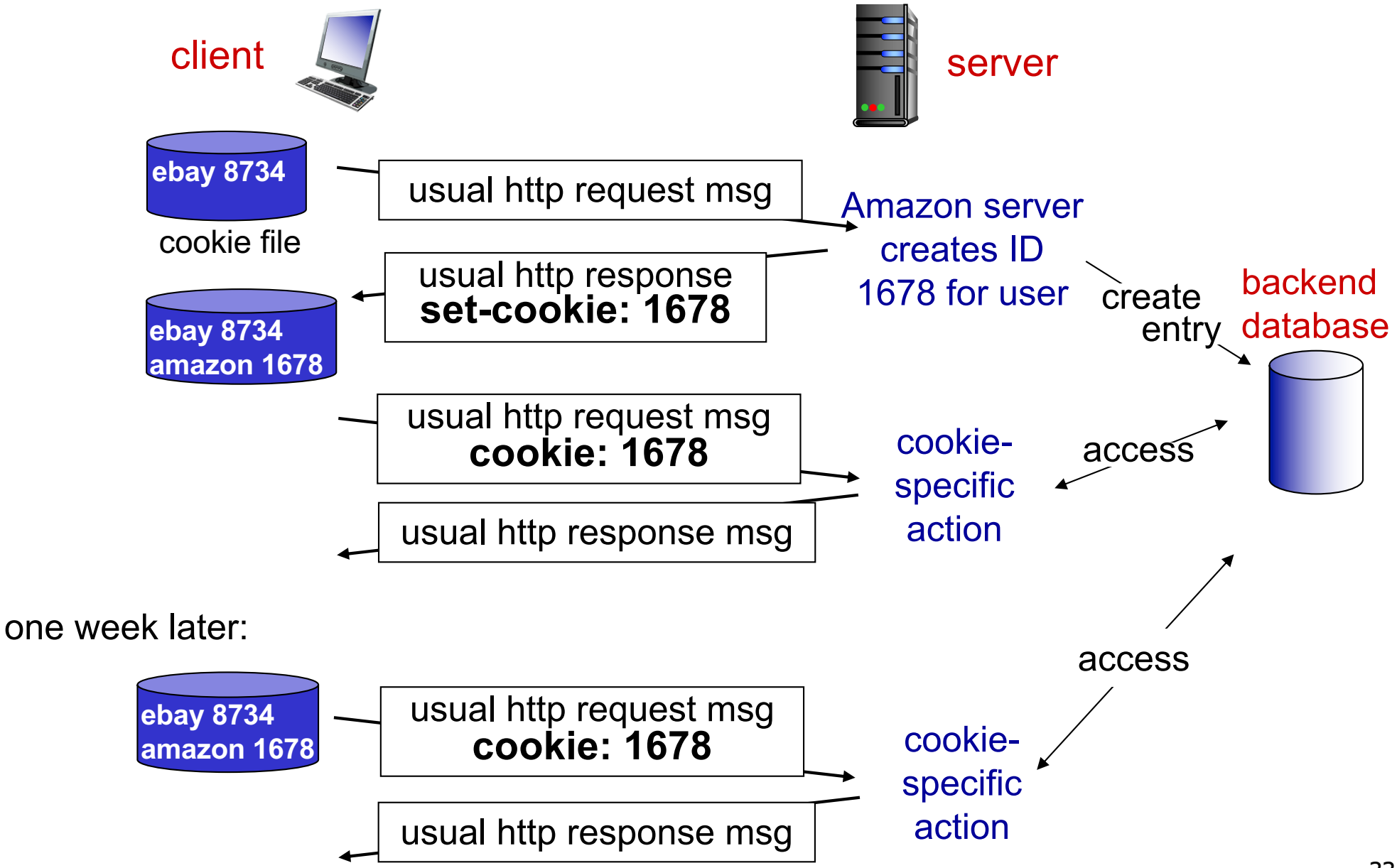
four components:

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.)

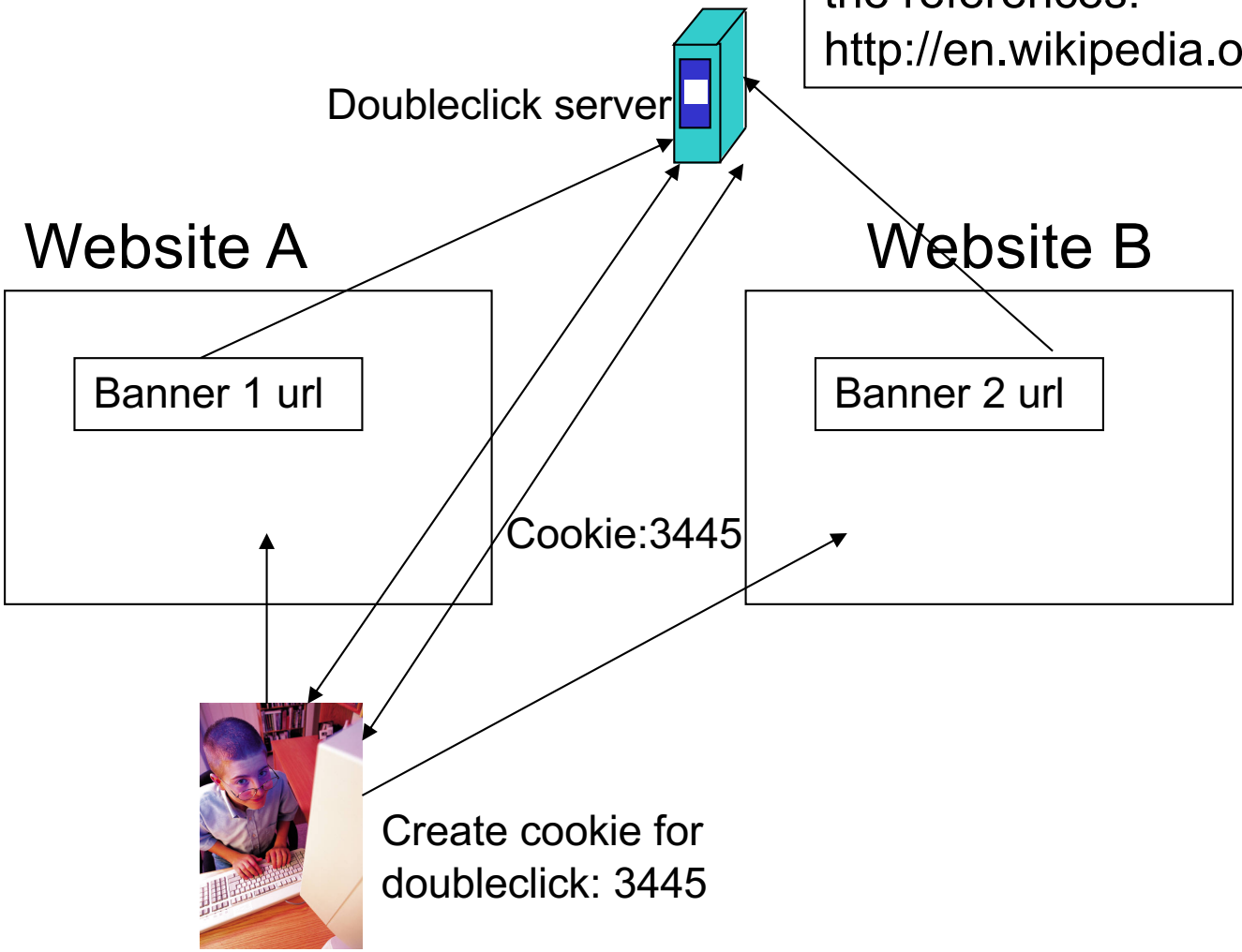


The Dark Side of Cookies

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

Otherwise, delay goes up and packet drop. That is also expensive to put high speed network through the cable

Solutions?

Improve HTTP to achieve faster downloads

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

Improve HTTP to achieve faster downloads

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  - fast downloads
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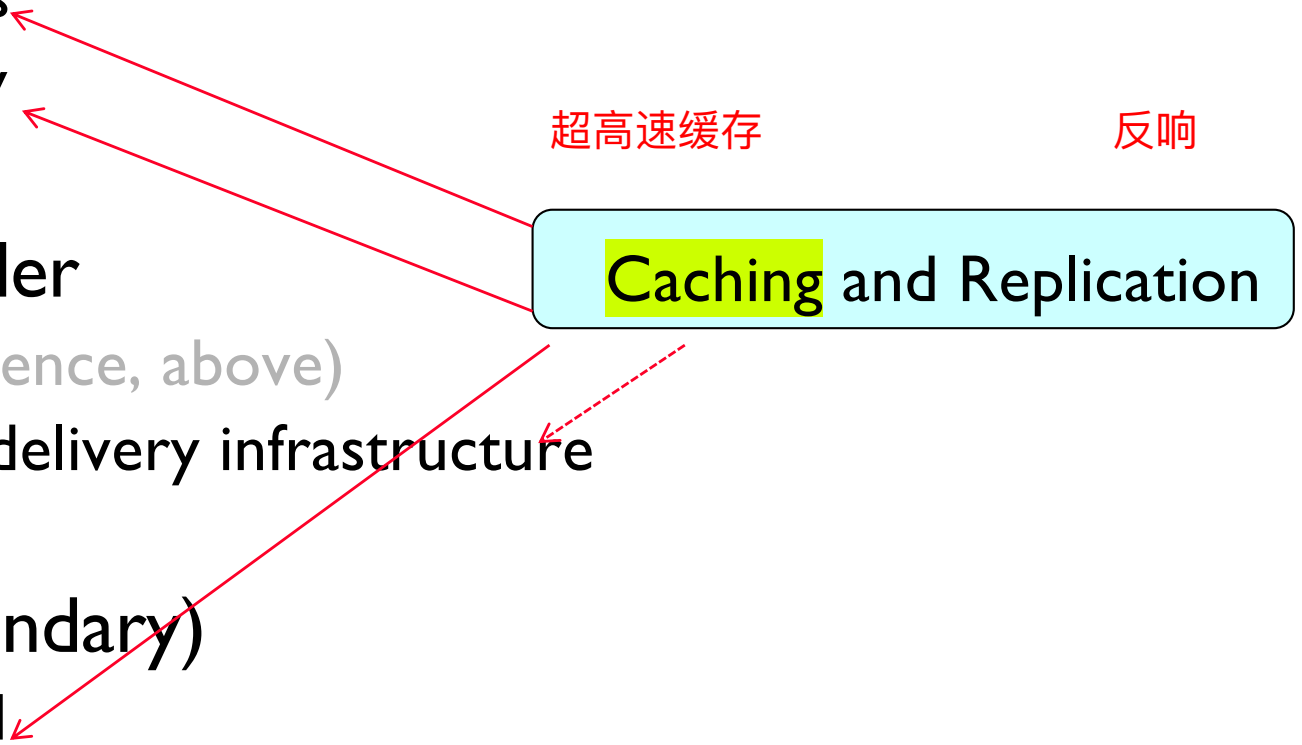


Solutions?

- 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

Page loading time

- 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 base on tcp

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!

To transmit sth by TCP, even small object, a connection has to be built. So that's why it's expensive

non-persistent HTTP

- at most one object sent over TCP connection
  - connection then closed

The most default use of http

- downloading multiple objects required multiple connections

Non-persistent HTTP: response time

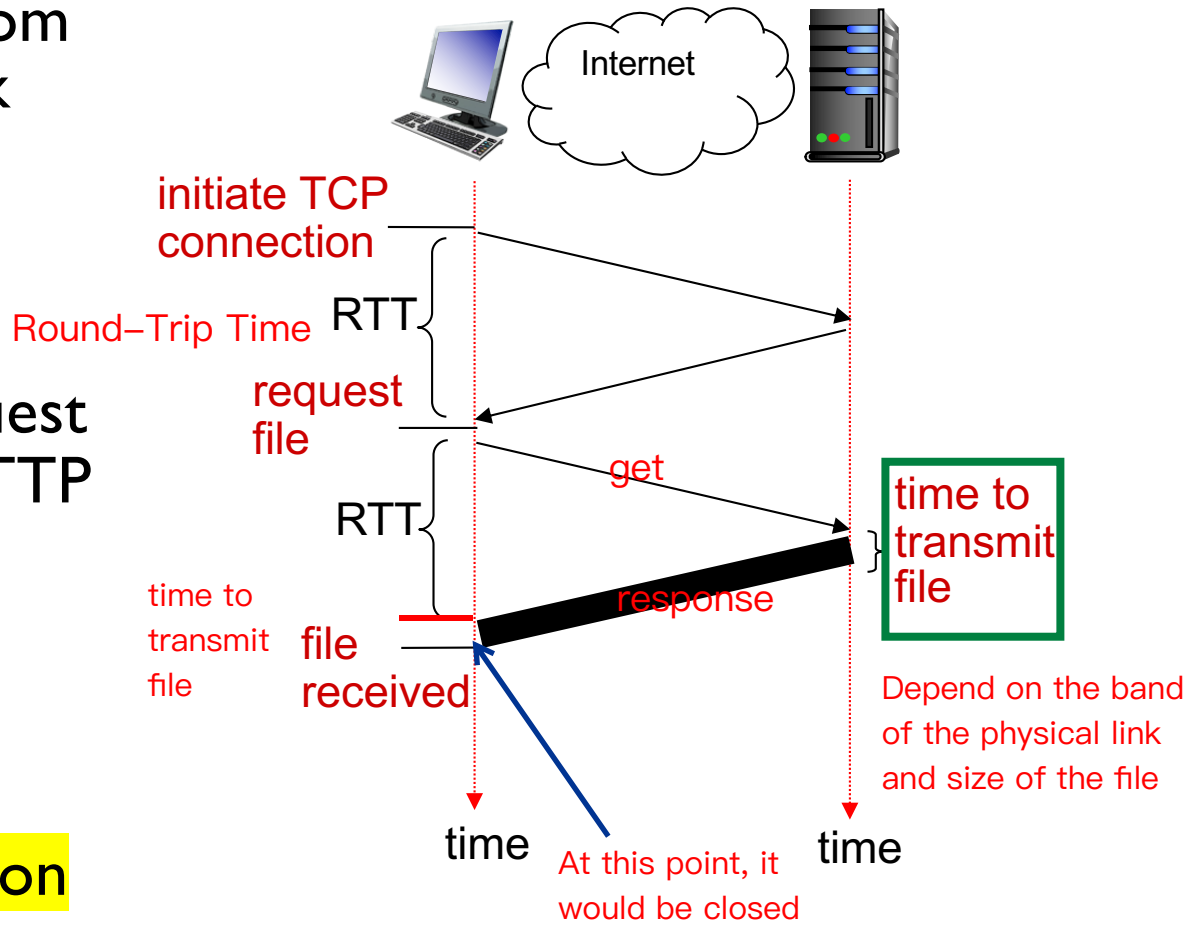
Before you can do anything with HTTP, it takes a RTT to init a connection

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

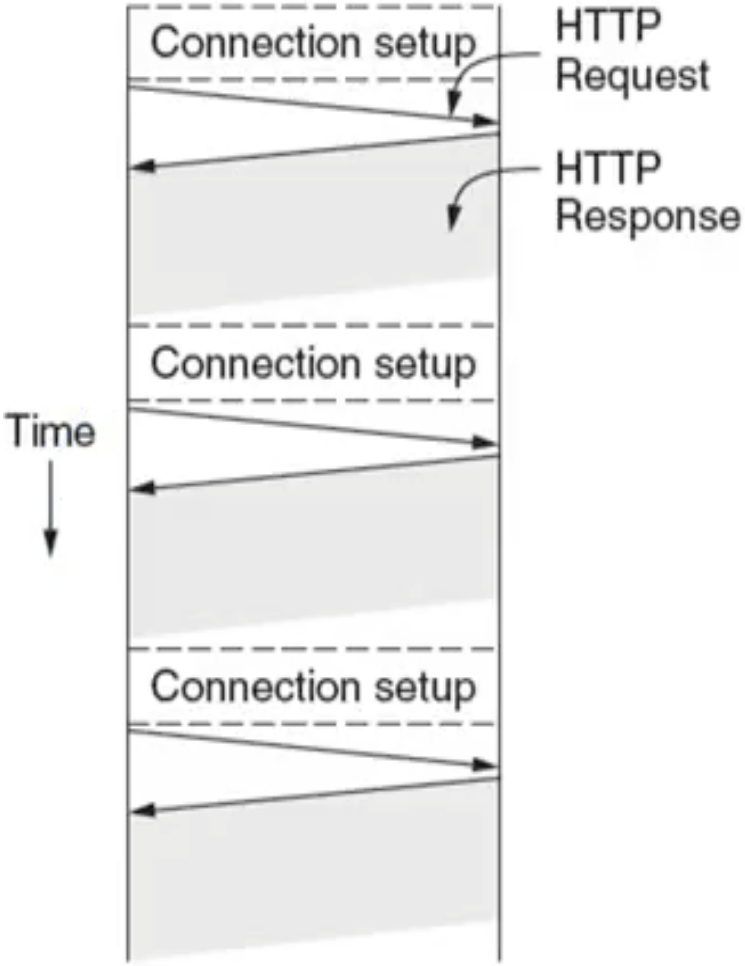


Timing diagram

For every single object, we have to go through the timing diagram
It doesn't process over multiple objects

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)

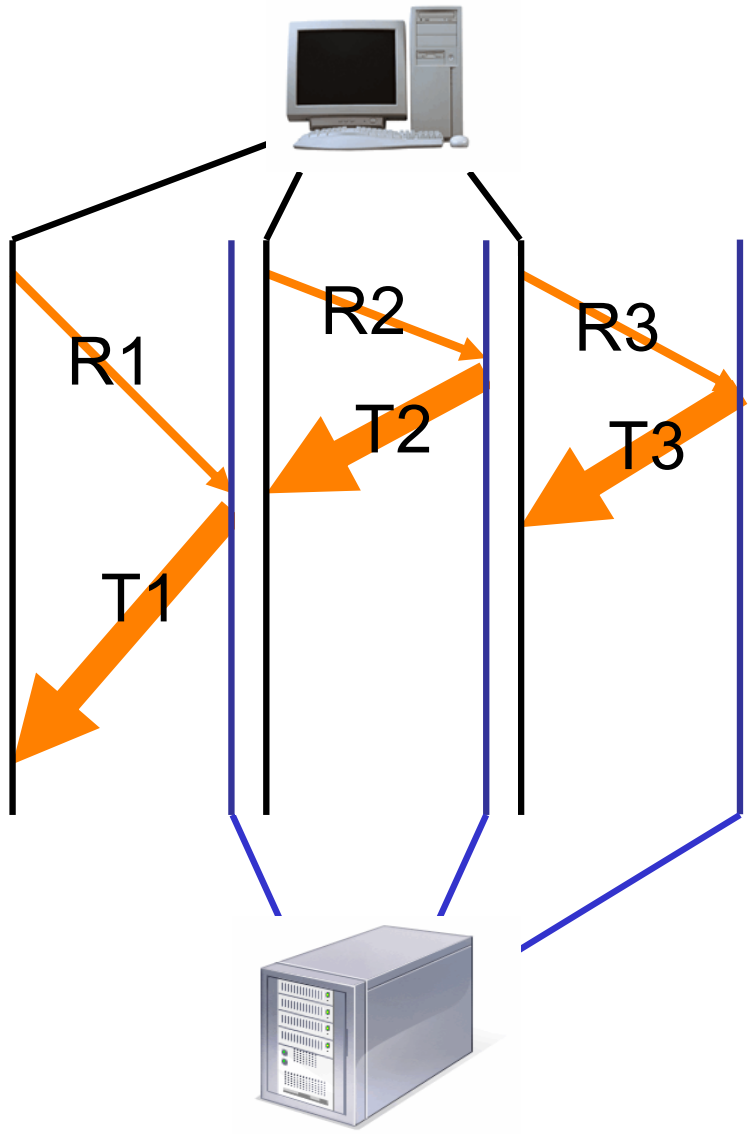


Improving HTTP Performance:

Concurrent Requests & Responses

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

Sever and the client would suffer from managing too many TCP connection.
That is costly



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

Persist over all the objects

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)

Example: pipeling means the client has already learn the total number of request. And they sent all the request at once. That save a lot of RTTs

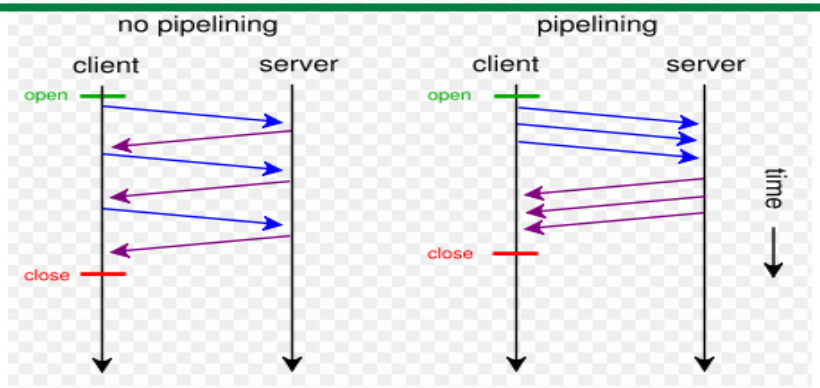
Persistent without pipelining:

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

Persistent with pipelining:

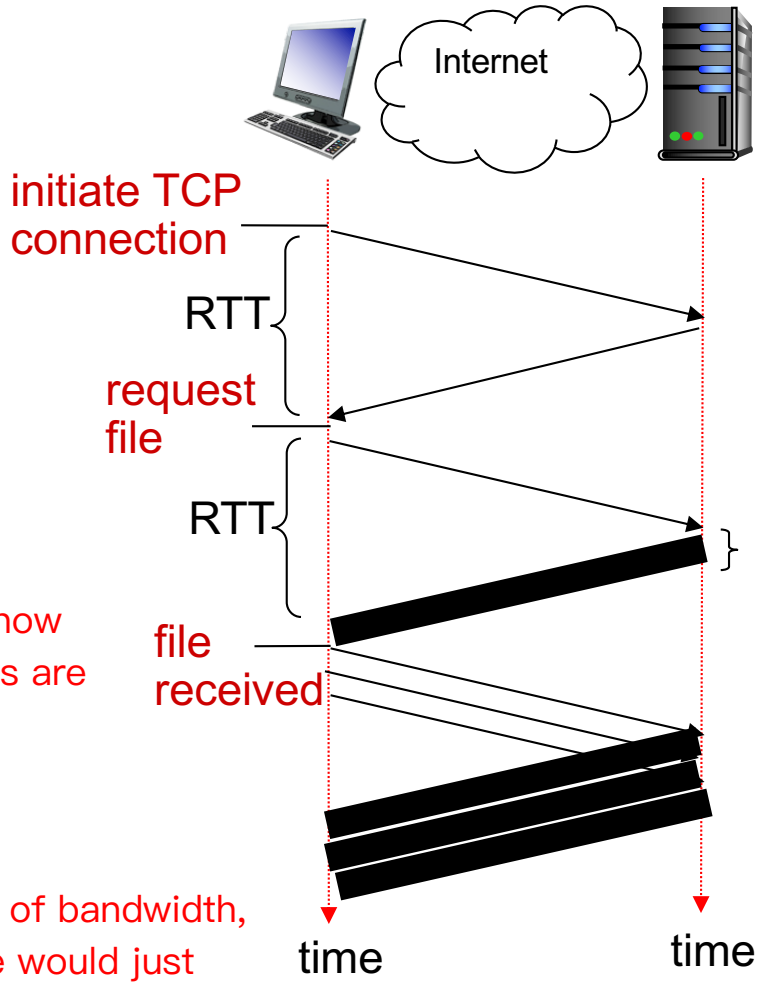
not a kind of parallel connection

- 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



3RTT + base file transmission + all files transmission

not a kind of parallel connection. This pipeling is focus on HTTP . It's a single TCP connection

To find out how many objects are there

The base file(including the indexes of all file)

This would not do with the loadind of bandwidth, All of mechanism mentioned above would just influence the RTT

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
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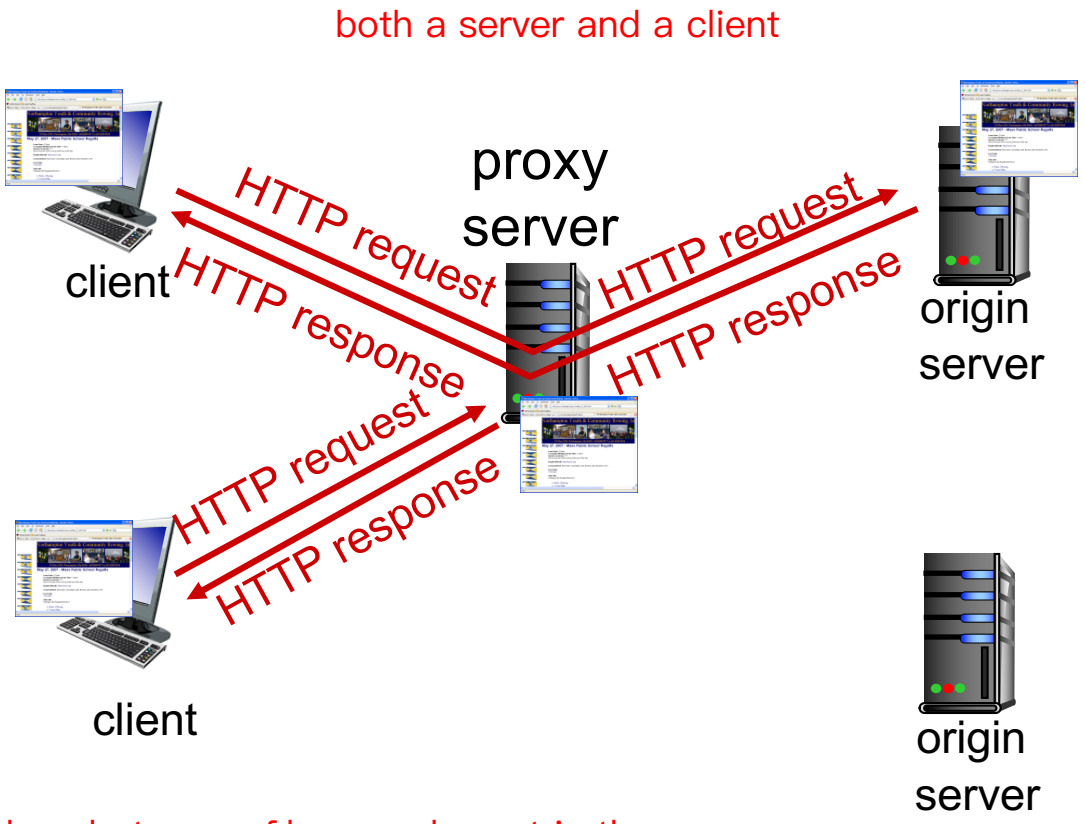
Improving HTTP Performance: Caching

- 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



The proxy server send file to the client from caches, but some files may be not in the Caches, so it send request to the origin server for those objects

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 (load on access router)
- RTT from access router to any origin server: 2 sec
- access link rate: 1.54 Mbps

15 requests per sencond

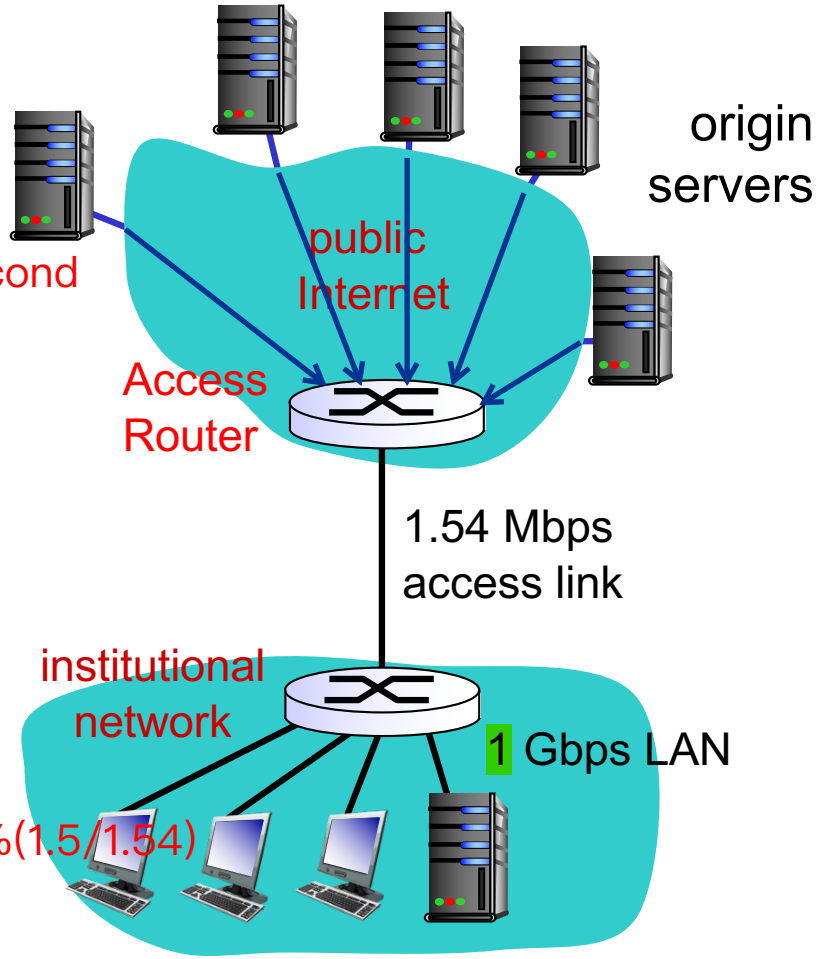
1.5 Mbps / 1 Gbps

consequences:

- LAN utilization: 0.15%
- access link utilization = ~~99%~~ 97.4%(1.5/1.54)
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + minutes + usecs

This is dominant

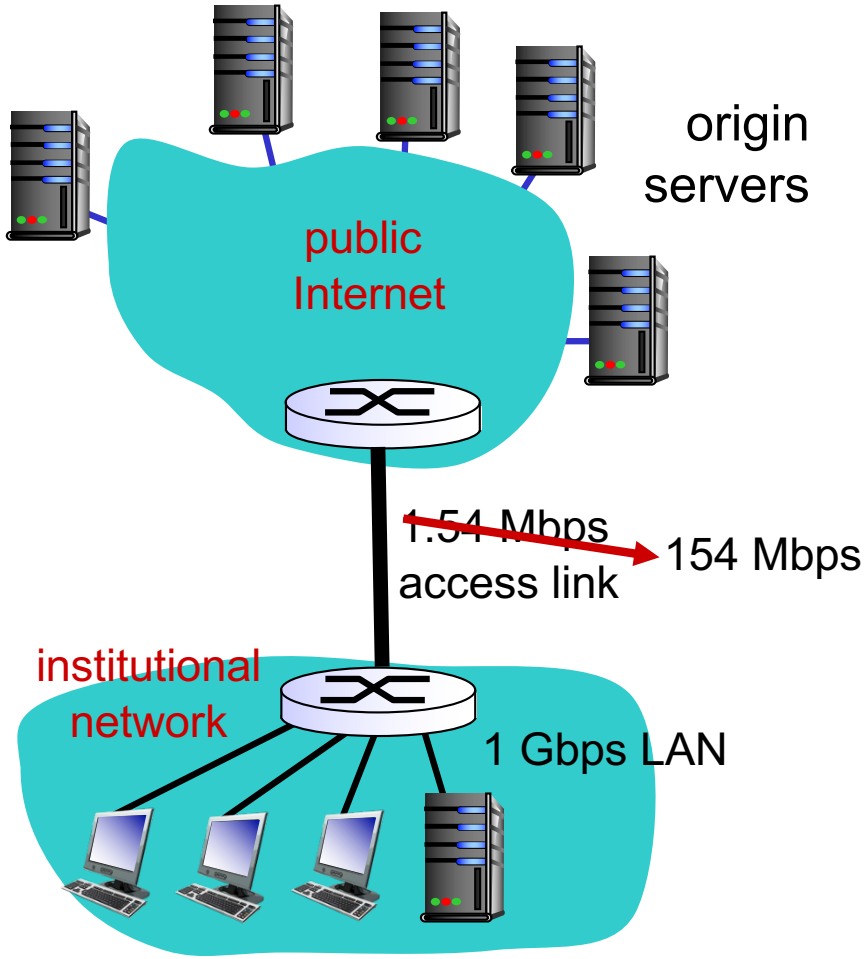
problem!



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



consequences:

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

Cost: increased access link speed (not cheap!)

Caching example: install local cache

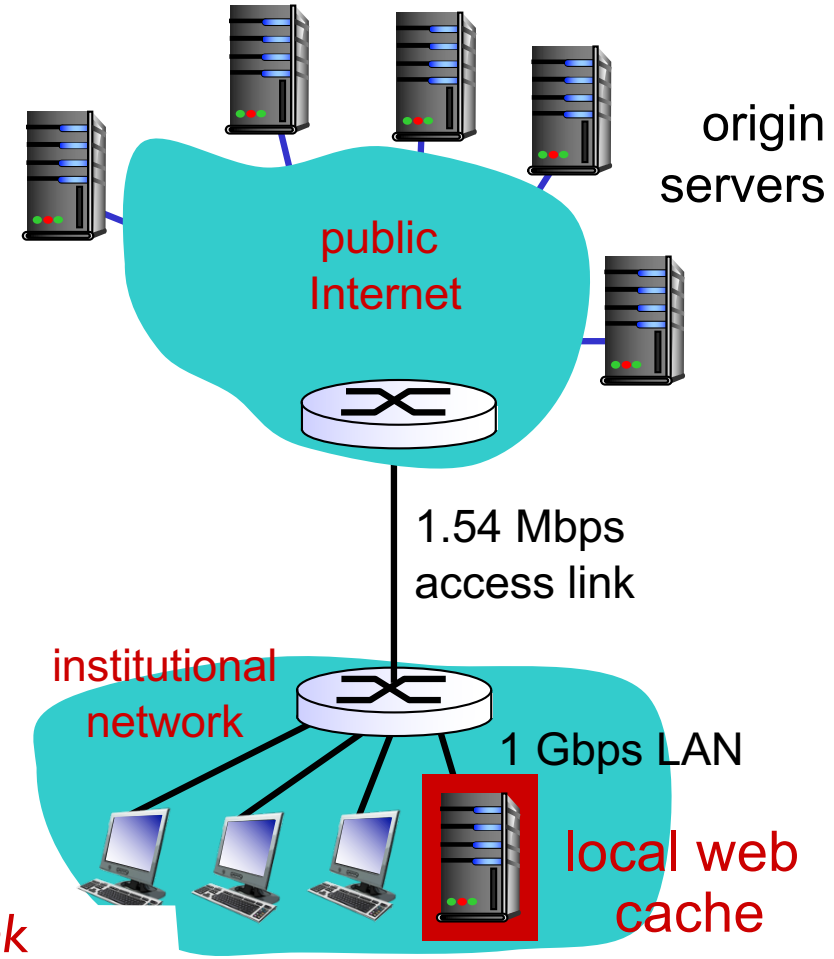
assumptions:

- avg object size: 100K bits
- avg request rate from browsers to origin servers: 15/sec
- avg data rate to browsers: 1.50 Mbps
- RTT from 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

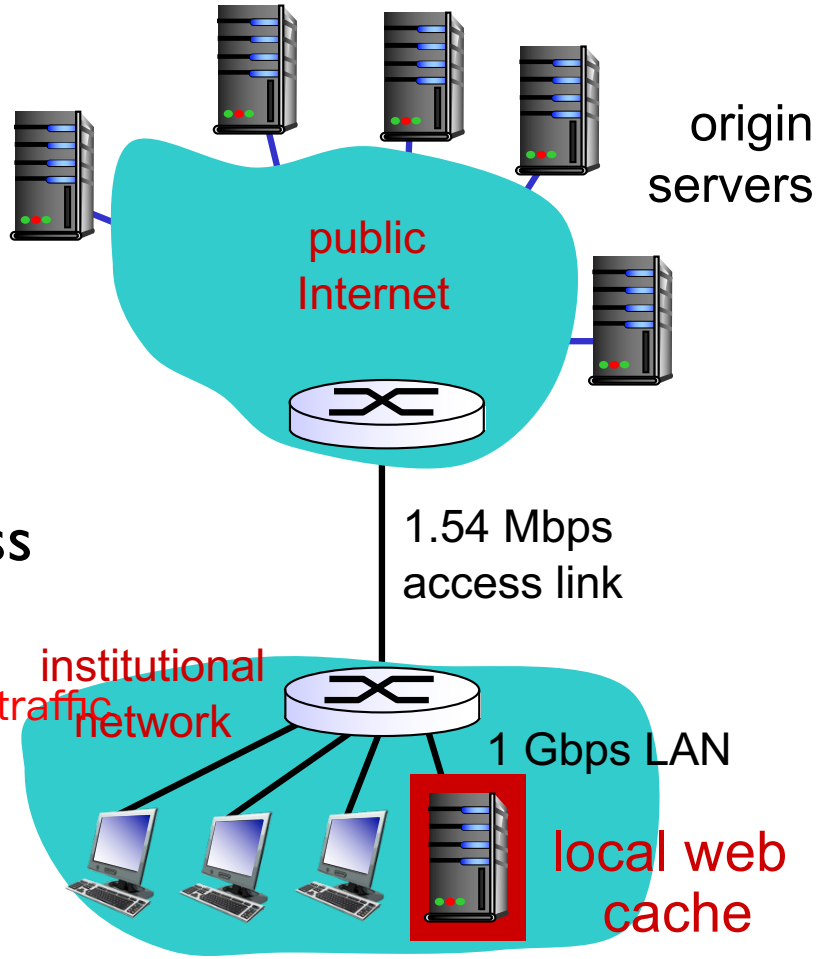
Calculating access link utilization, delay with cache:

- 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

Here is the point, it dramatically reduce the traffic

Hence the queueing would be reduced

- 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
  - less than with 154 Mbps link (and cheaper too!)



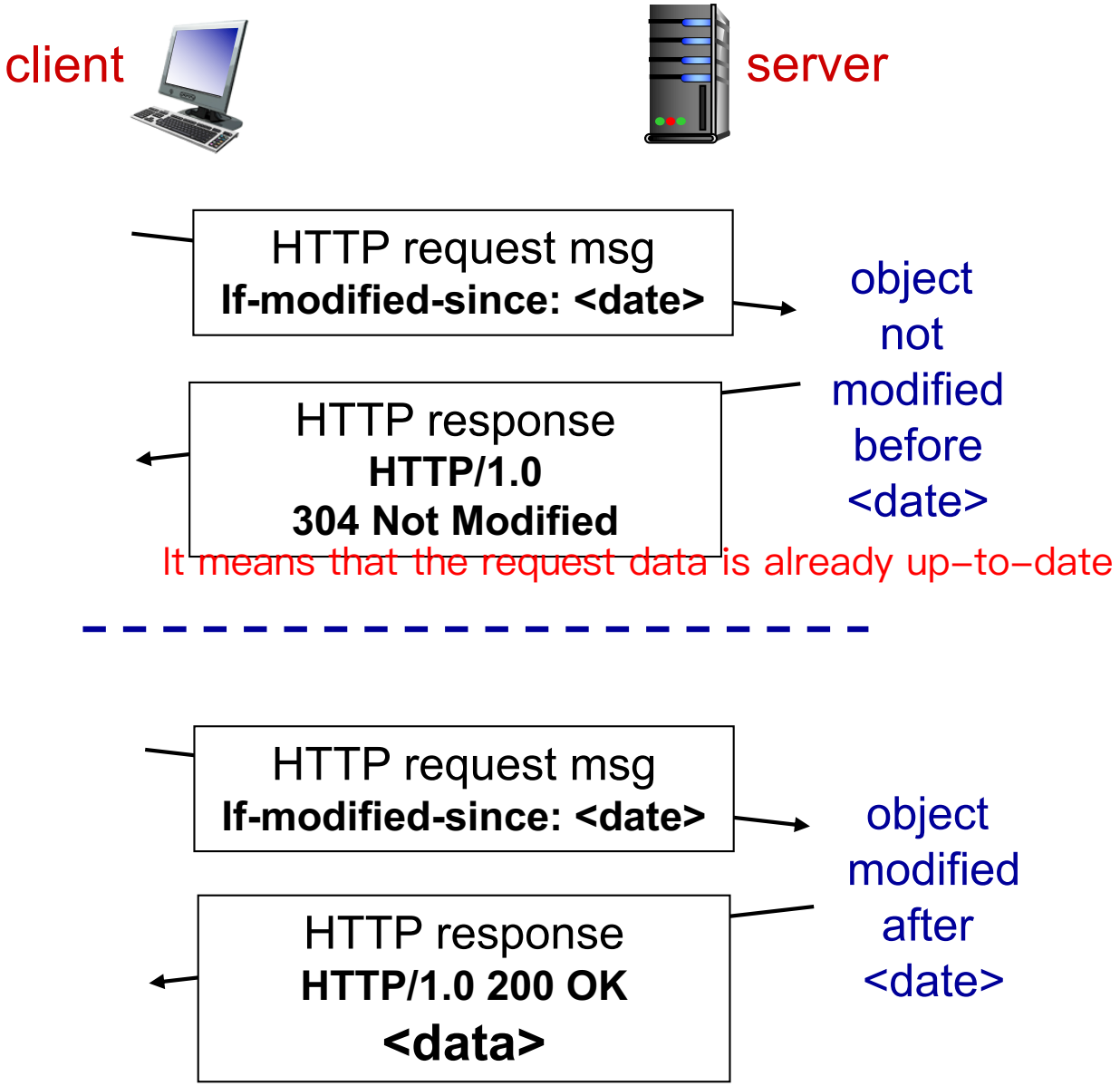
When the traffic is growing heavily, the queueing delay grow expontentially

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`



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

反响

- Replicate popular Web site across many machines
  - Spreads load on servers
  - Places content closer to clients
  - Helps when content isn't cacheable

Have multiple replication over different geological locations. So when it's being accessed, it would swithch to the closest one. Then the delay would be less

- 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.*

More on this later

Improving HTTP Performance: CDN

Content distribution network

- 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
  - 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

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)**?

D

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

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

For each object, construct a connection take D,
send a request and get the base file take D.
download the file take Si / 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. $3D + (S_0 + NS)/C$

E

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

D

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

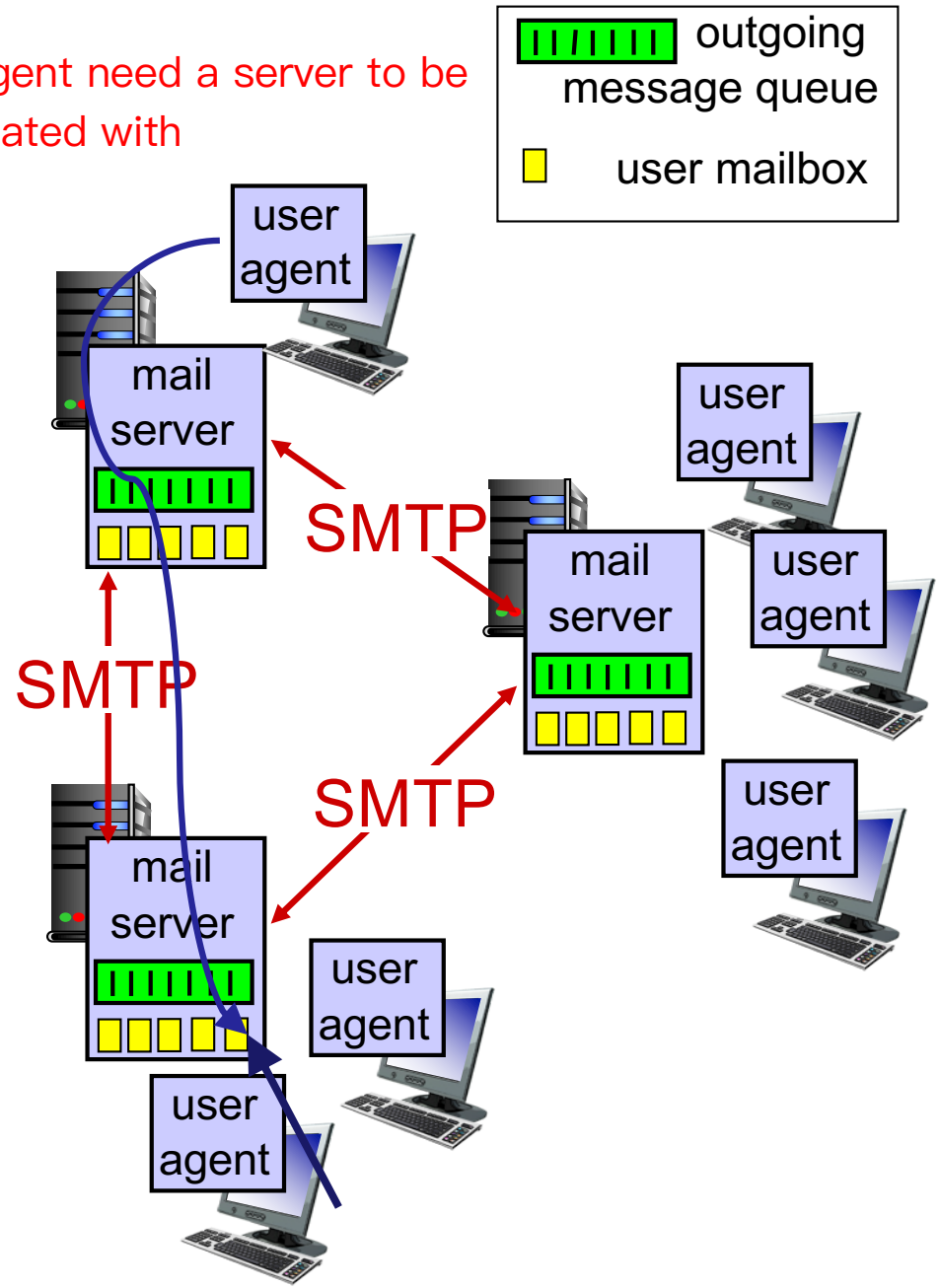
The agent need a server to be associated with

Three major components:

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

User Agent

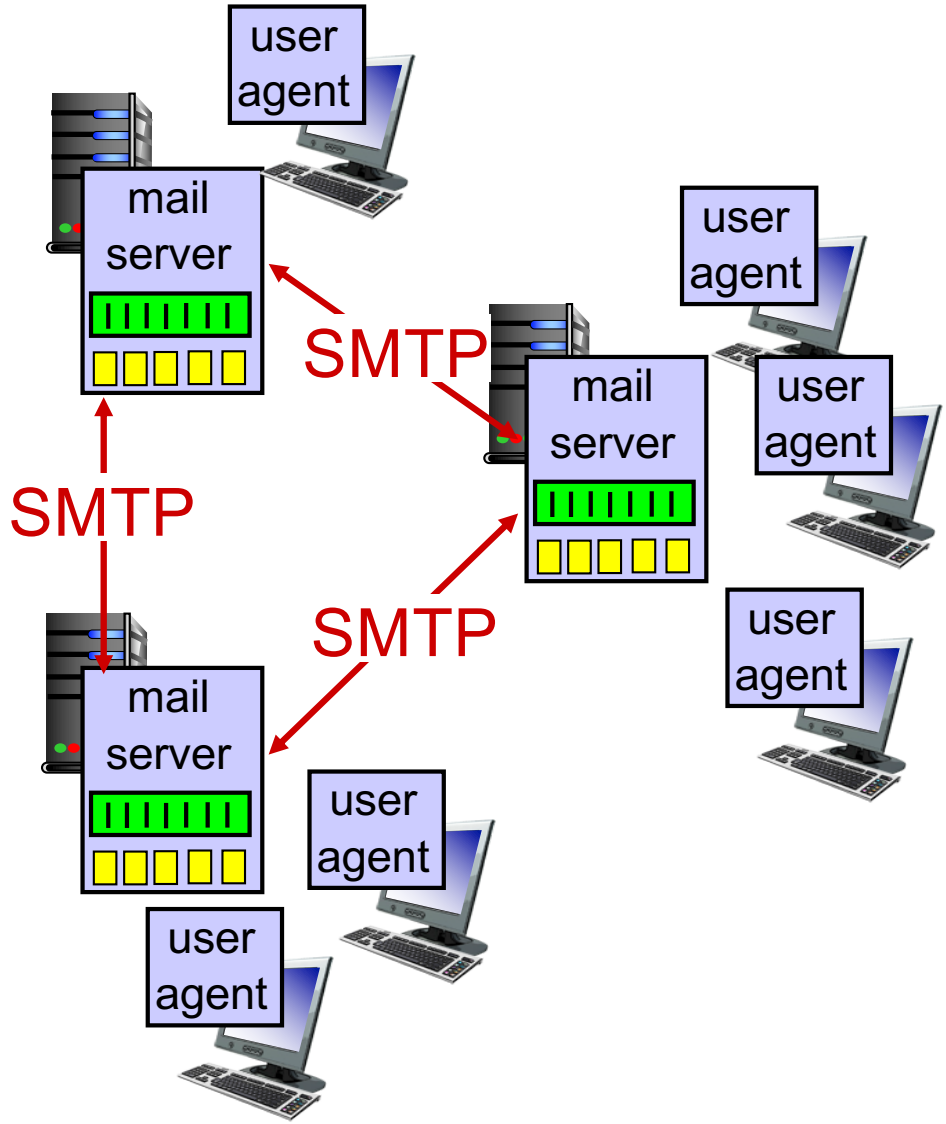
- a.k.a. "mail reader"
- composing, editing, reading mail messages
- e.g., Outlook, Thunderbird, iPhone mail client
- outgoing, incoming messages stored on server



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

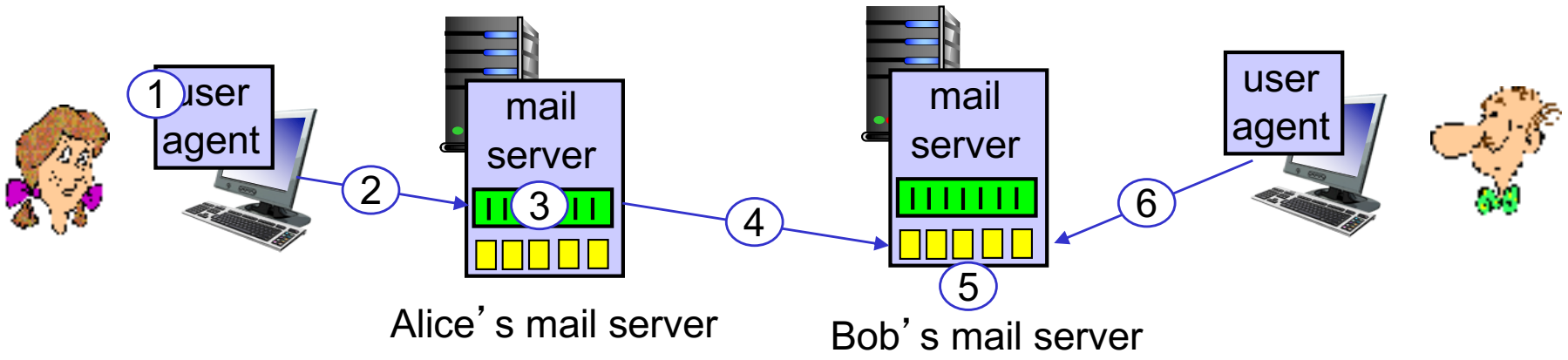


Electronic Mail: SMTP [RFC 2821]

- 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

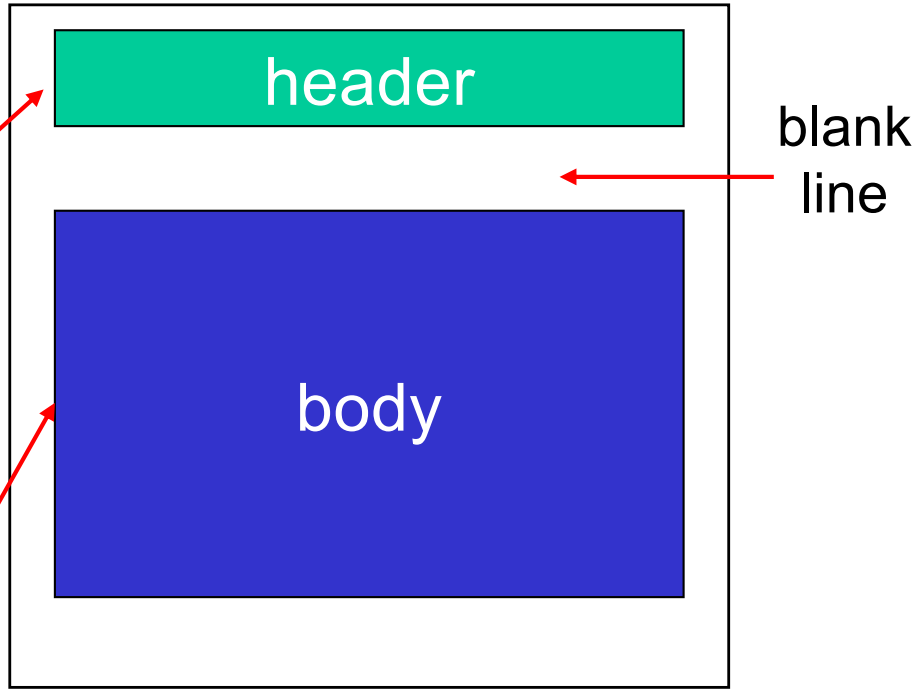
Mail message format

SMTP: protocol for exchanging email msgs

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

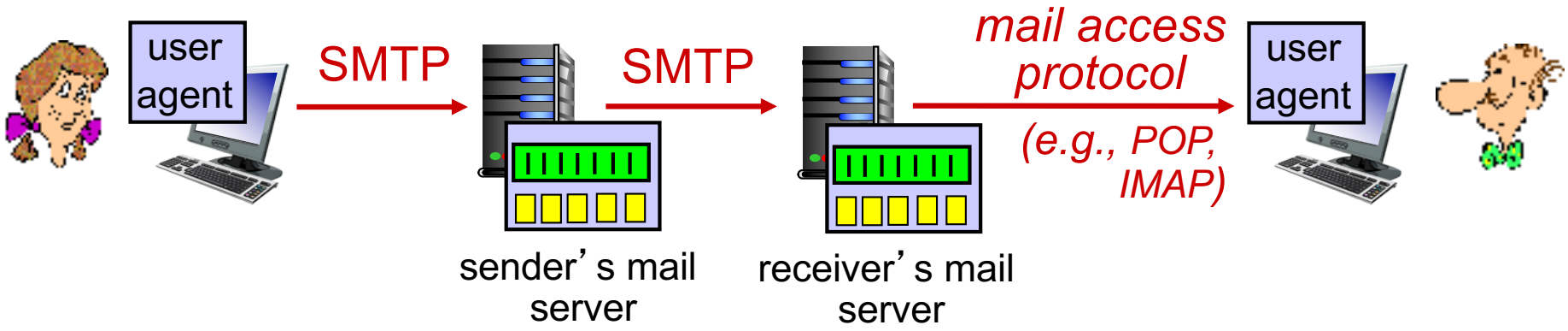
- header lines, e.g.,
  - To:
  - From:
  - Subject:

  different from SMTP MAIL FROM, RCPT TO: commands!
- Body: the "message"
  - ASCII characters only



Mail access protocols

We are not using SMTP here.
SMTP focus on email sending



- 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.

browsers

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

Quiz: SMTP

If the receiver's server is down for some reason,
Then the agent, who hold the server would take the responsibily
To ensure the mail is sent

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?

To take charge on their own part

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

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

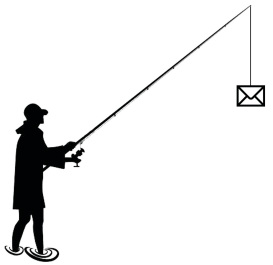
because as a server, it cannot be down, it has to run 24 /7

3. Why mail readers cannot use SMTP to download emails?

SMTP is a push

Without this series of mail servers, you would only be able to send emails to people whose email address domains matched your own – i.e., you could only send messages from one example.com account to another example.com account.

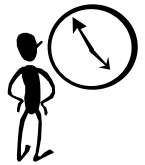
Phishing



- 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

Quiz: SMTP

1. 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?

2. Why do we have a separate Receiver's mail server?
   - Can't the recipient run the mail server on own end system?

3. Why mail readers cannot use SMTP to download emails?
   - Why separate mail access protocols, e.g., POP3, IMAP etc.?