

# Computer Networks and Applications

COMP 3331/COMP 9331

Week 2  
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Application Layer (Principles, Web,  
Email)

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

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

2.7 socket programming with UDP and TCP

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## 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

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# Creating a network app

Write programs that:

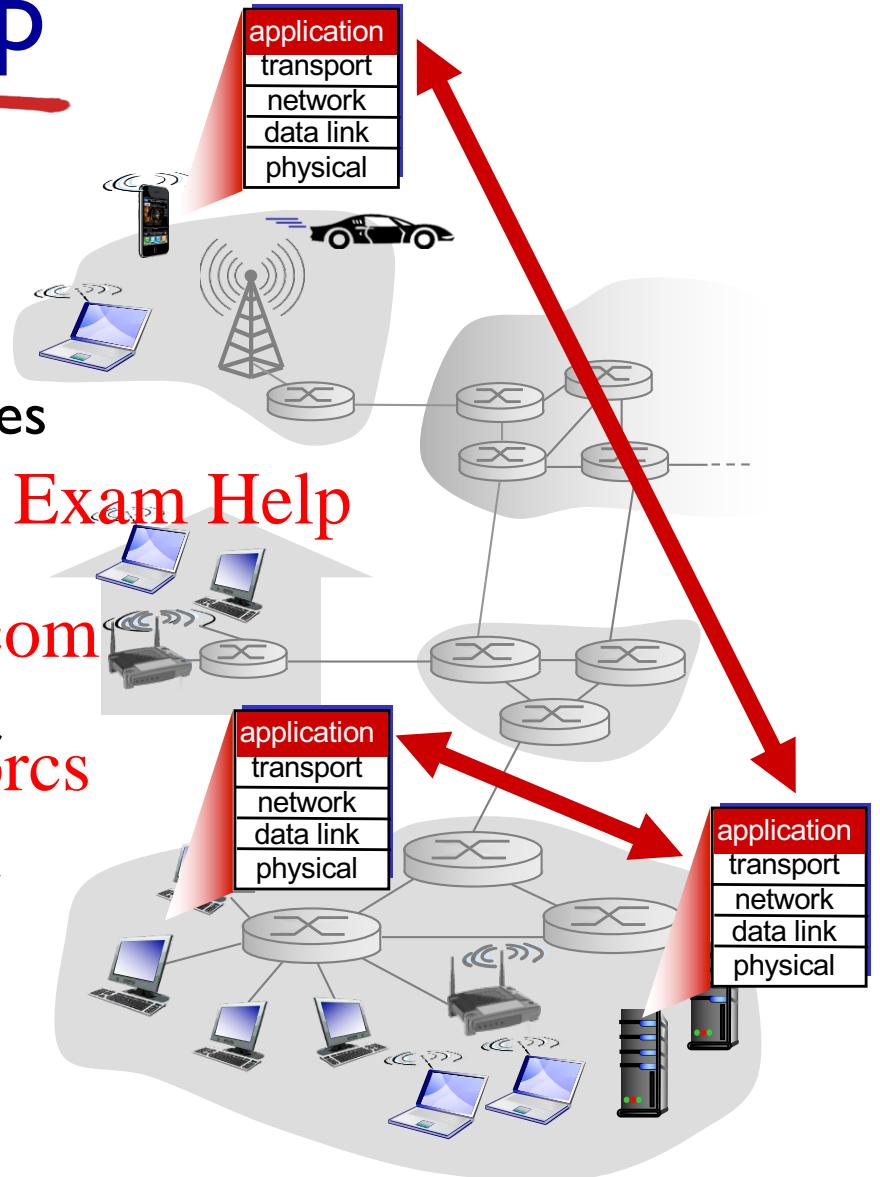
- ❖ run on (different) end systems
- ❖ communicate over network
- ❖ e.g., web server software communicates with browser software

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No need to write software for network-core devices  
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- ❖ network-core devices do not run user applications
- ❖ applications on end systems allows for rapid app development

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# Interprocess Communication (IPC)

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

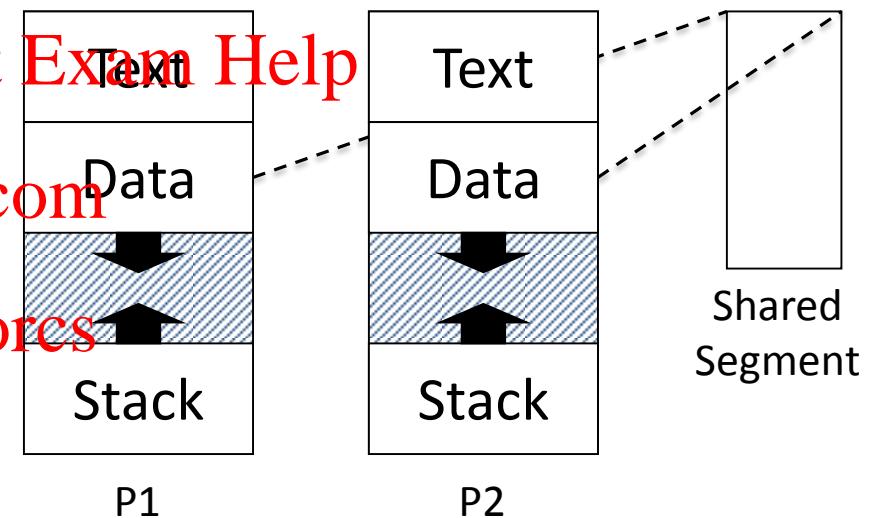
- ❖ On a single machine:

- Shared memory

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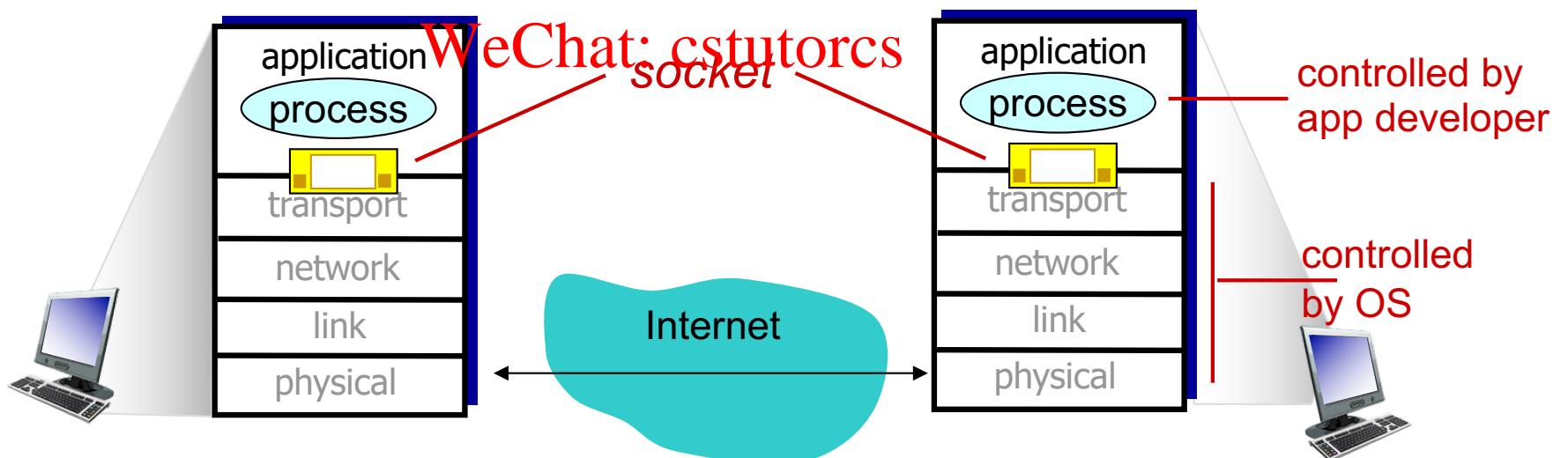


- ❖ Across machines:

- We need other abstractions (message passing)

# Sockets

- ❖ process sends/receives messages to/from its **socket**
- ❖ socket analogous to door
  - sending process shoves message out through the 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  
<https://cstutorcs.com>



# Addressing processes

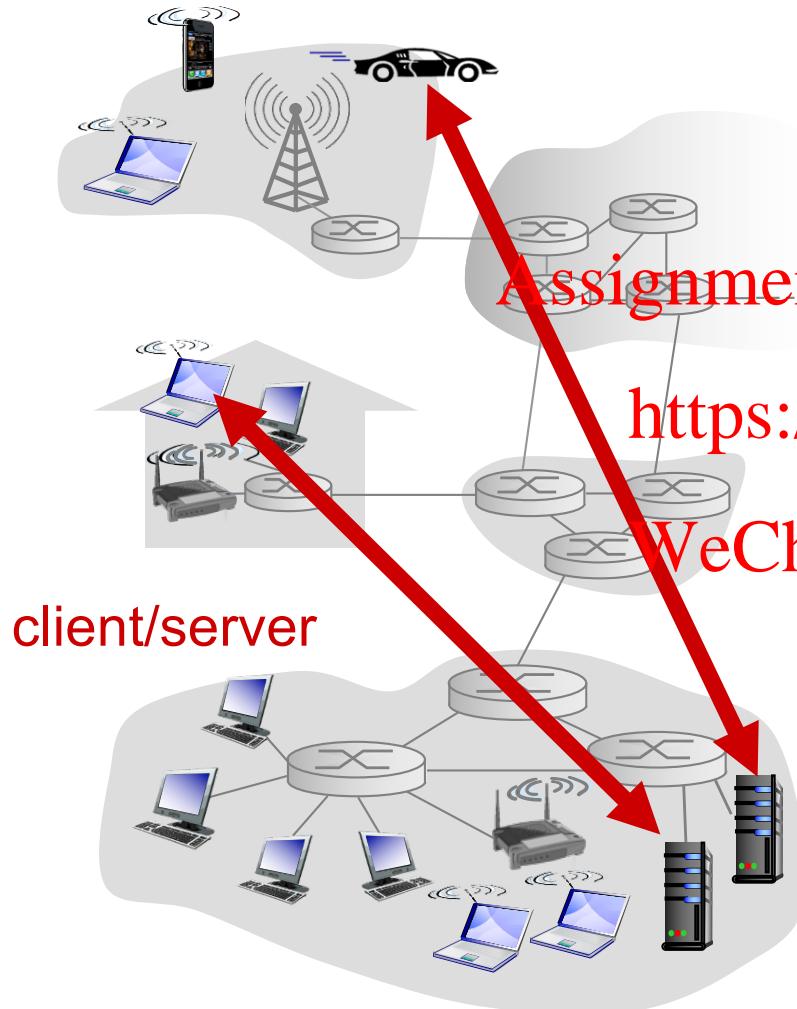
- ❖ to receive messages, process must have *identifier*
- ❖ host device has unique 32-bit IP address
- ❖ Q: does IP address of host on which process runs suffice for identifying the process?
  - A: no, many processes can be running on same host
- ❖ *identifier* includes both IP address and port numbers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

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# 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

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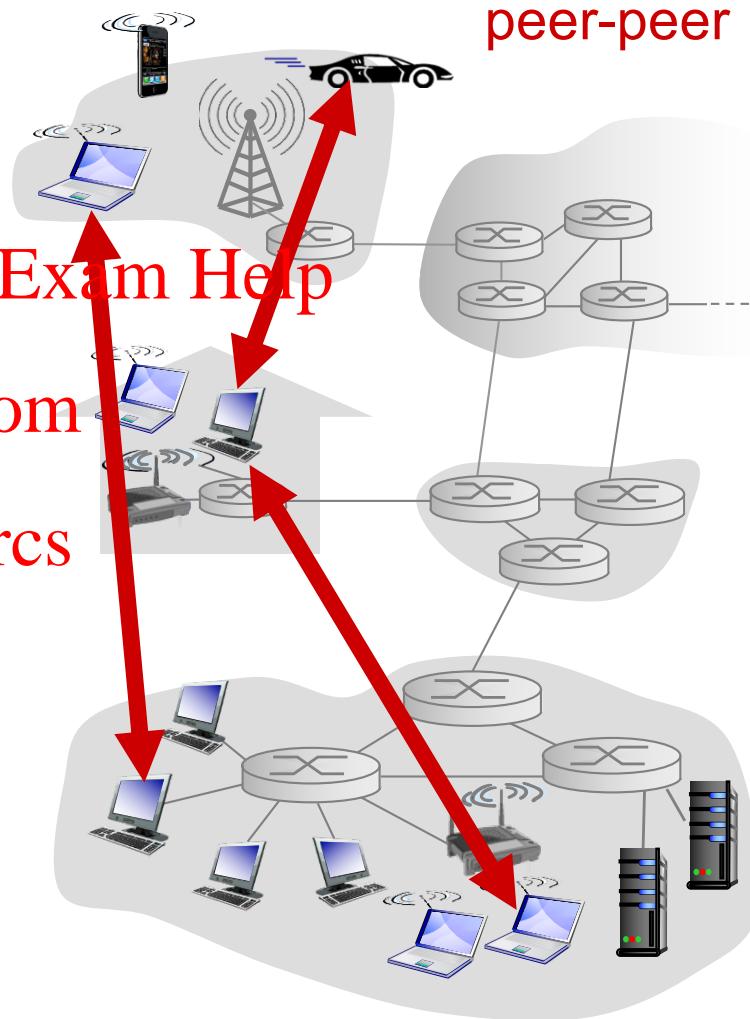
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# P2P architecture

- ❖ 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
  - Blockchain and cryptocurrencies
  - Video distribution, video chat
  - In general: “distributed systems”

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# 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

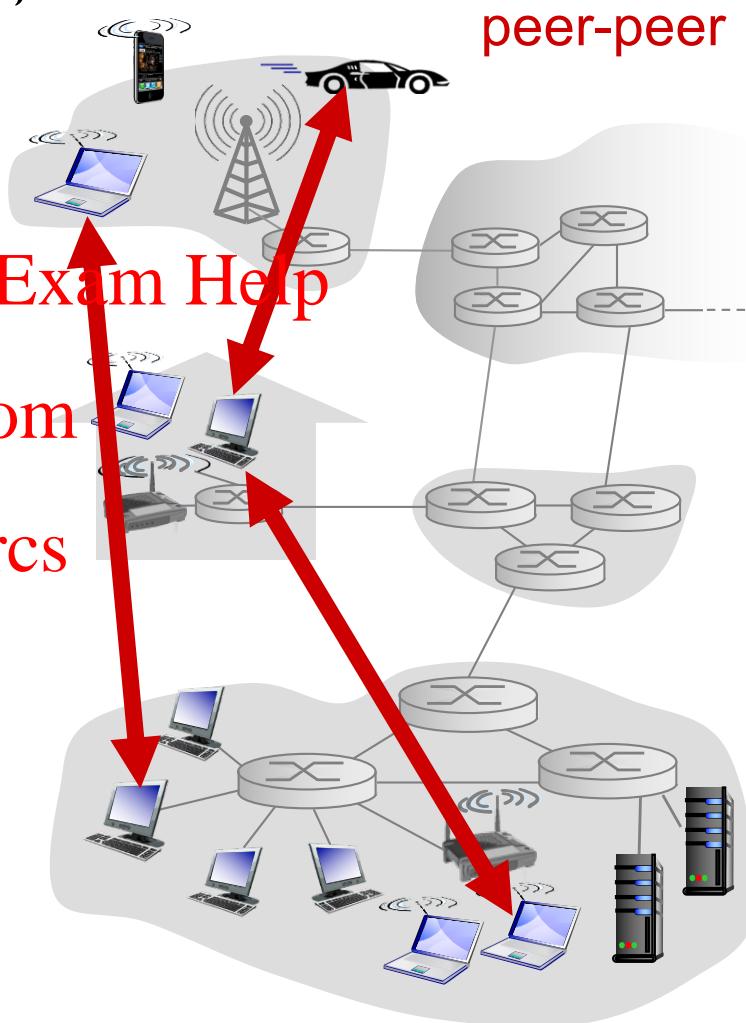
-Fundamental problems of decentralized control

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

-Distributed algorithms are complex

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# App-layer protocol defines

- ❖ types of messages exchanged,
    - e.g., request, response
  - ❖ message syntax
    - what fields in messages & how fields are delineated
  - ❖ message semantics
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- ❖ open protocols:
    - ❖ defined in RFCs
    - ❖ allows for interoperability
      - e.g., HTTP, SMTP, WebRTC
  - ❖ proprietary protocols:
    - ❖ e.g., Skype, Teams, Zoom

# 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

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## 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

## 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

application	application layer protocol	underlying transport protocol
e-mail	SMTP [RFC 2821]	TCP
remote terminal access	Telnet [RFC 854]	TCP
Web	HTTP [RFC 2616]	TCP
file transfer	FTP [RFC 959] <a href="https://tutorcs.com">https://tutorcs.com</a> <a href="#">WeChat: cstutorcs</a>	TCP
streaming multimedia	HTTP (e.g., YouTube), RTP [RFC 1889] <a href="#">WeChat: cstutorcs</a>	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  
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- C. TCP provides reliability while UDP does not  
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- D. Neither TCP nor UDP provides reliability

**Answer: C**

Open a browser and type: **www.zeetings.com/salil**

## 2. Application Layer: outline

### 2.1 principles of network applications

- app architectures
- app requirements

### 2.5 P2P applications

### 2.6 video streaming and content distribution networks (CDNs)

### 2.2 Web and HTTP

### 2.7 socket programming with UDP and TCP

### 2.3 electronic mail

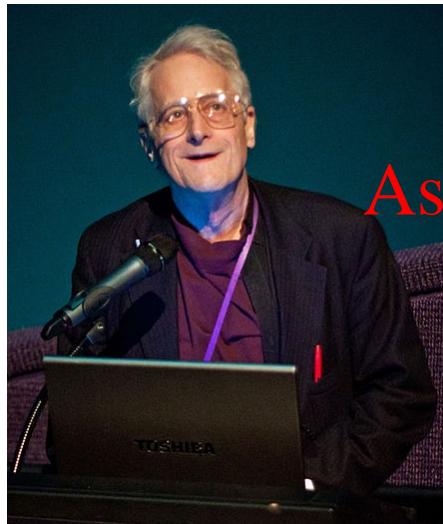
- SMTP

### 2.4 DNS

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# The Web – Precursor

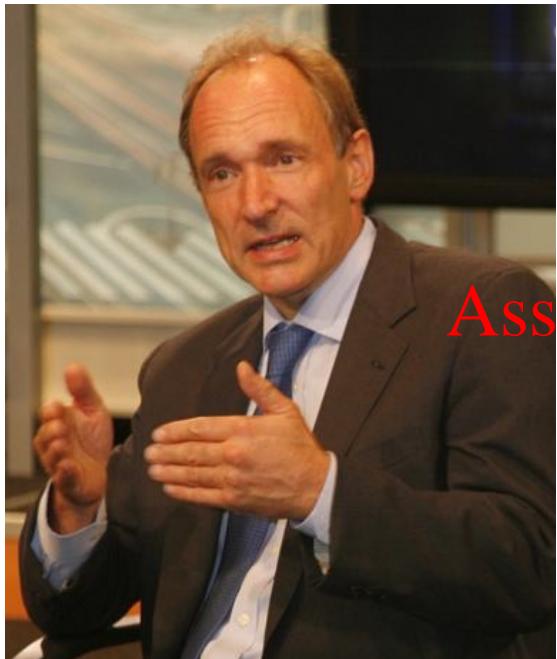


Ted Nelson

- ❖ 1967, Ted Nelson, Xanadu:
  - A world-wide publishing network that would allow information to be stored not as separate files but as connected literature  
<https://tutorcs.com>
  - Owners of documents would be automatically paid via electronic means for the virtual copying of their documents
- ❖ WeChat: cstutorcs  
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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  
<https://tutorcs.com>
    - 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>

# 2020 This Is What Happens In An Internet Minute



# Web and HTTP

*First, a review...*

- ❖ **web page** consists of **objects**
- ❖ object can be HTML file, JPEG image, Java applet, audio file, ...  
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- ❖ web page consists of ~~lists of~~ ~~base~~ ~~HTML-file~~ which includes **several referenced objects**  
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- ❖ 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>      Assignment Project Exam Help
    <title>Hyperlink Example</title>
  </head>
  <body>        WeChat: cstutorcs
    <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:** browses <https://tutorcs.com> 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

*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)

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request line  
(GET, POST,  
HEAD commands)

header  
lines

carriage return,  
line feed at start  
of line indicates  
end of header lines

```
https://tutorcs.com
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: <https://tutorcs.com>)

## **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
- ❖ Non-text content needs to be encoded

# 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

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# Uploading form input

## POST method:

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

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## Get (in-URL) method:

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

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`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

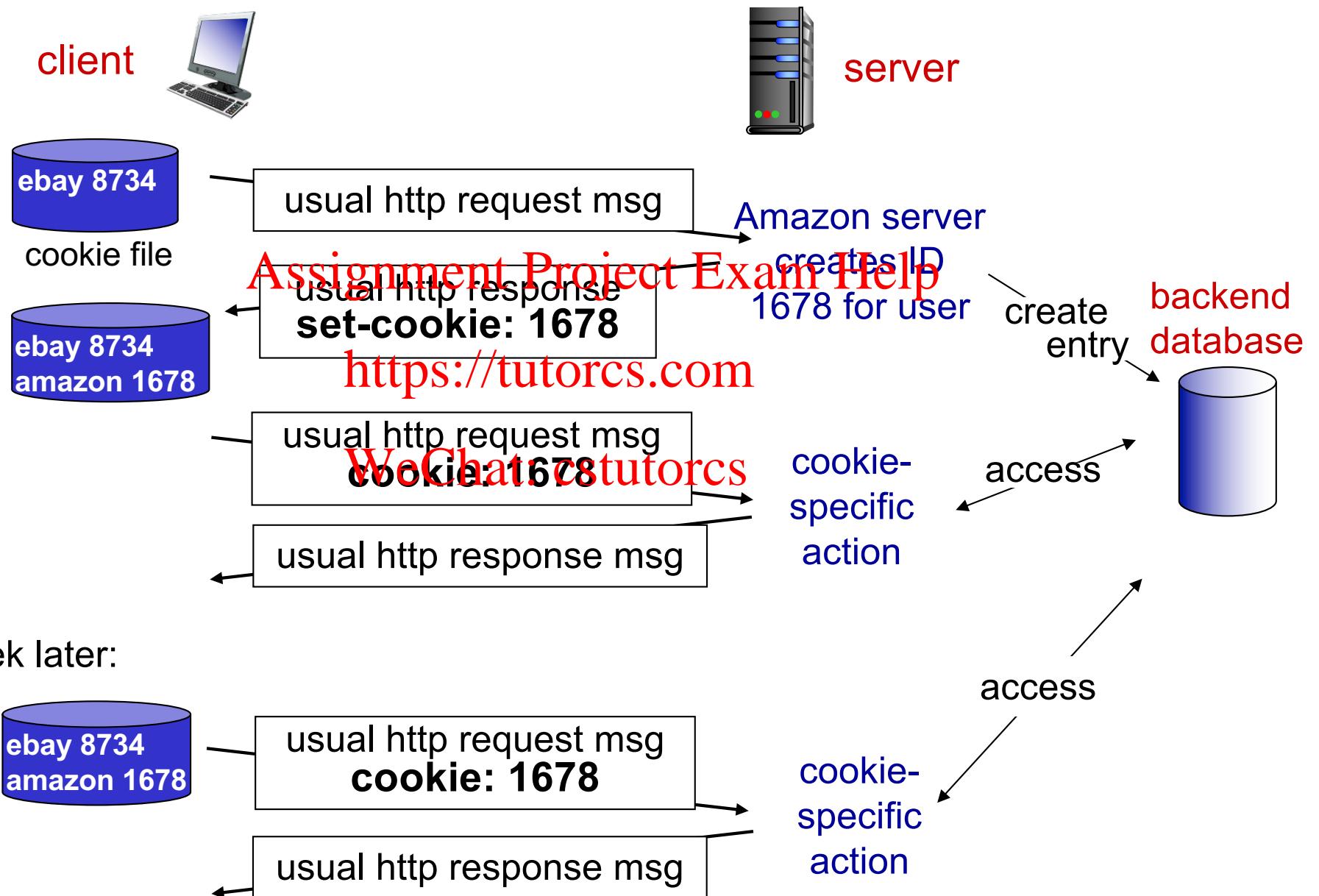
**example:**

- ❖ 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

HTTP is stateless  
It does not save the clients request



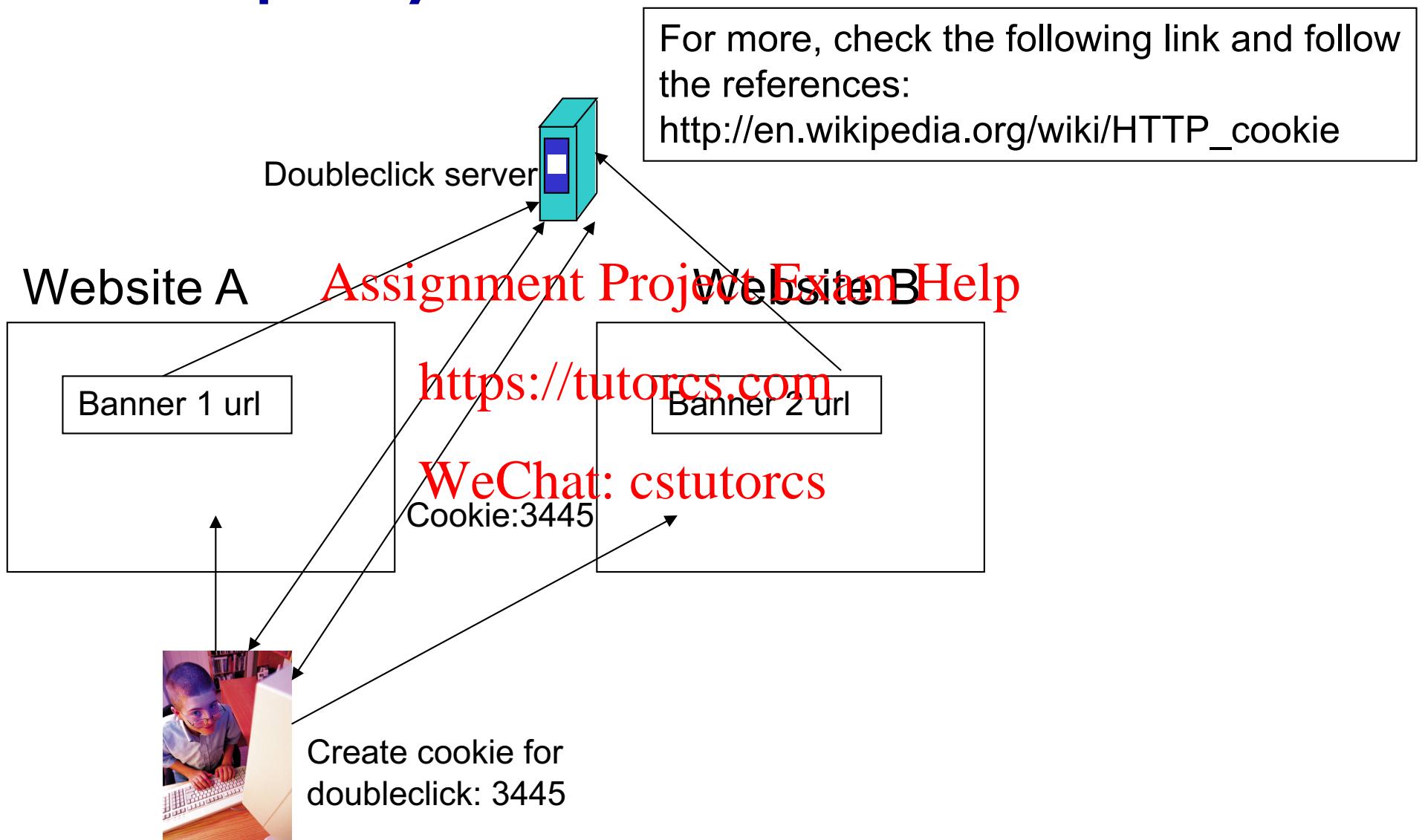
# Cookies: keeping “state” (cont.)



# 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)  
*Assignment Project Exam Help*
- ❖ 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



In practice the banner can be a single pixel (invisible to the user)

# 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 (~~WeChat: above~~ <https://tutorcs.com>)
  - cost-effective infrastructure
- ❖ Network (secondary)
  - avoid overload

# Solutions?

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- ❖ User
  - fast downloads
  - high availability
- ❖ Content provider
  - happy users (~~WeChat: cstutorcs~~)
  - cost-effective infrastructure
- ❖ Network (secondary)
  - avoid overload

Improve HTTP to  
achieve faster  
downloads

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# Solutions?

- ❖ User

- fast downloads
- high availability

Improve HTTP to  
achieve faster  
downloads

- ❖ Content provider

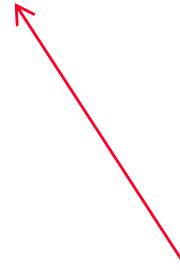
- happy users (~~WeChat: cstutorcs~~)
- cost-effective delivery infrastructure

<https://tutorcs.com> Caching and Replication

- ❖ Network (secondary)

- avoid overload

# Solutions?

- ❖ User
    - fast downloads
    - high availability
  - ❖ Content provider
    - happy users (~~WeChat: cstutorcs~~)
    - cost-effective delivery infrastructure
  - ❖ Network (secondary)
    - avoid overload
- Improve HTTP to achieve faster downloads
- <https://tutorcs.com> 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!

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*non-persistent HTTP*

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

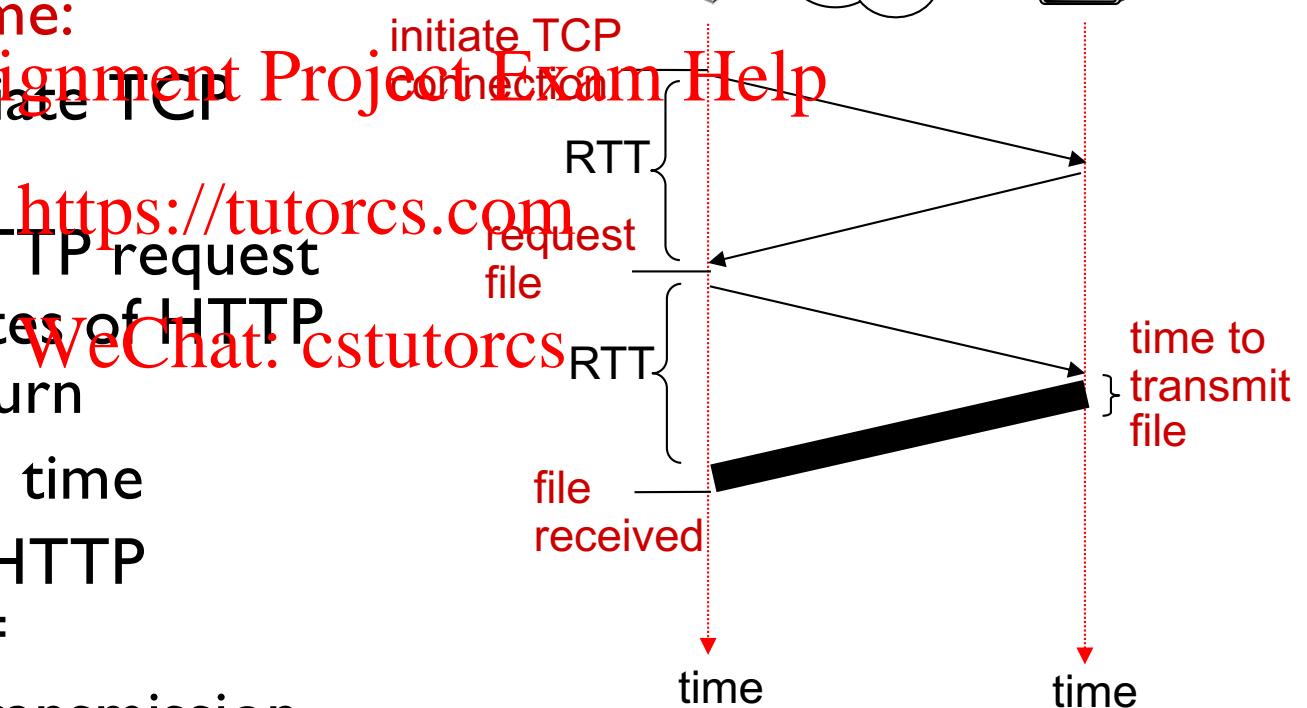
# Non-persistent HTTP: response time

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

HTTP response time:

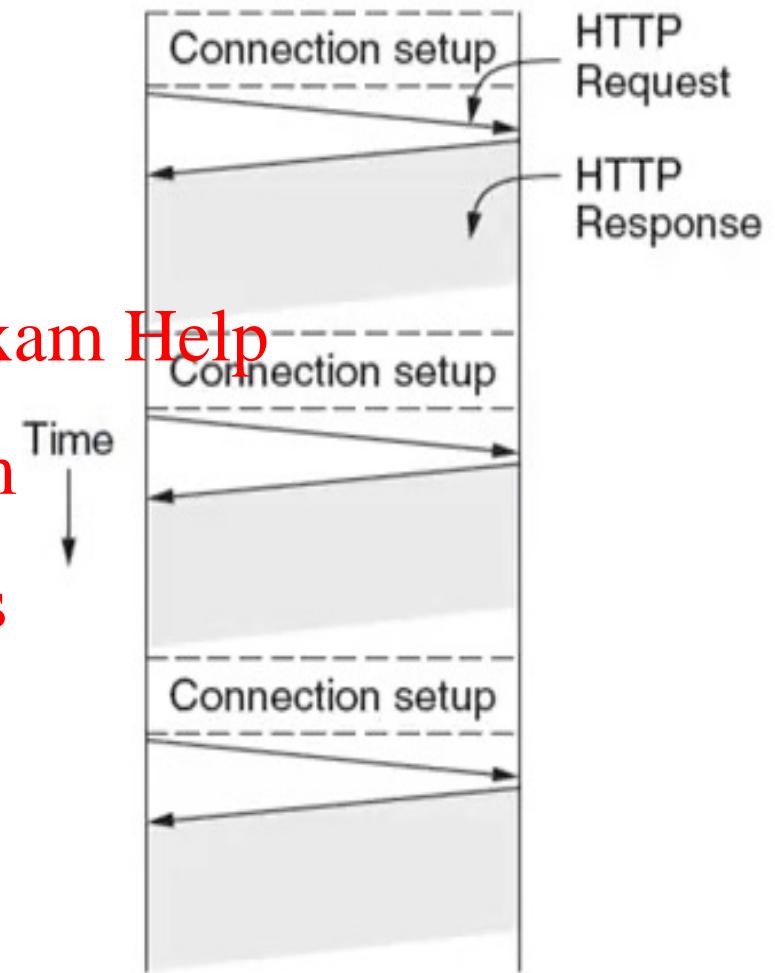
- ❖ one RTT to initiate TCP connection
- ❖ one RTT for HTTP request and first few bytes of HTTP response to return
- ❖ file transmission time
- ❖ non-persistent HTTP response time =

$$2\text{RTT} + \text{file transmission time}$$



# 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 requests even when resources are located on different servers
- Multiple TCP slow-start phases (more in lecture on TCP)

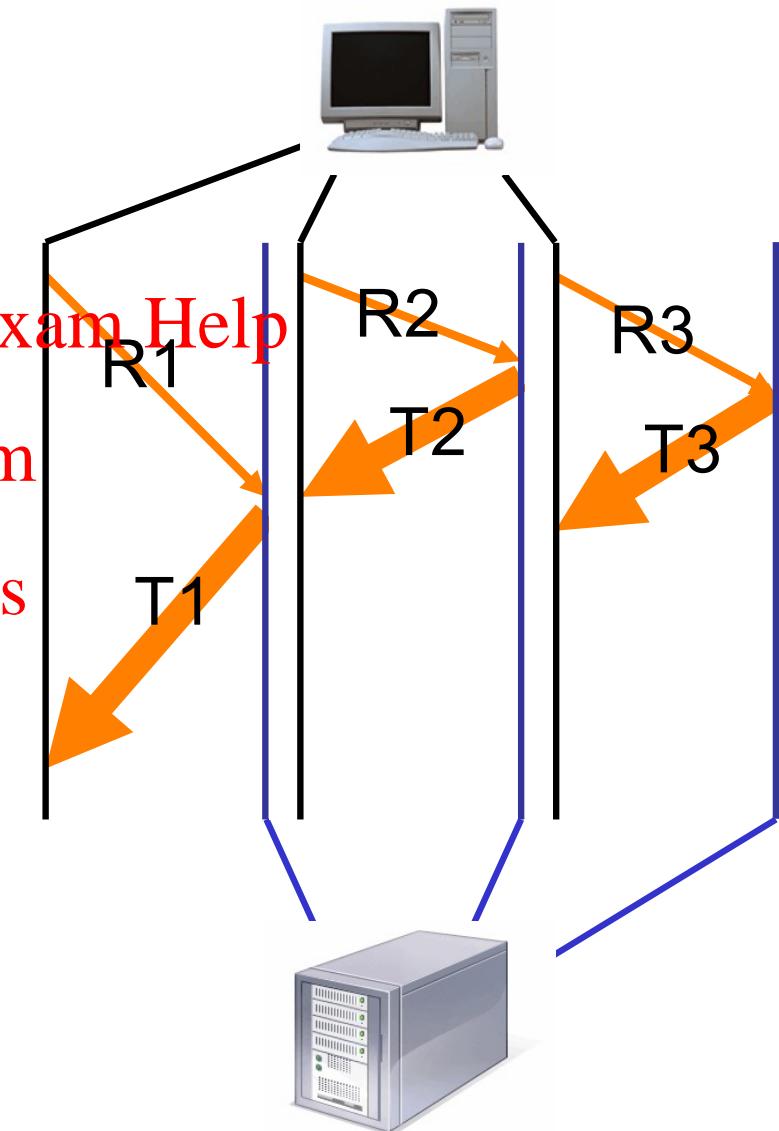


# Improving HTTP Performance: Concurrent Requests & Responses

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

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# 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?  
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- ❖ Answer: Extra load on the server for managing parallel connections

Open a browser and type: [www.zeetings.com/salil](http://www.zeetings.com/salil)

# 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)**

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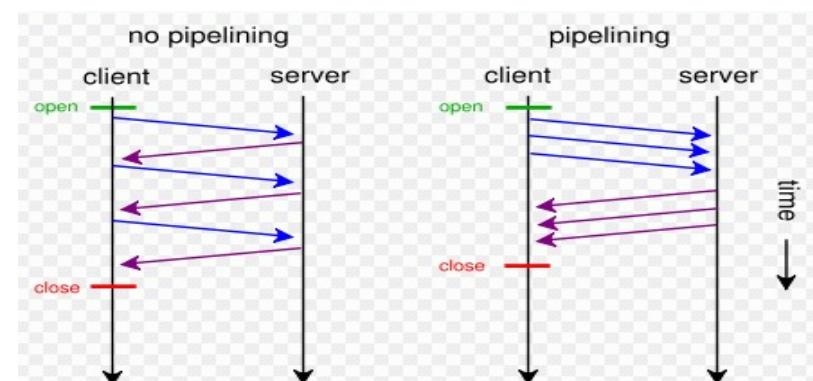
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## Persistent without pipelining:

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

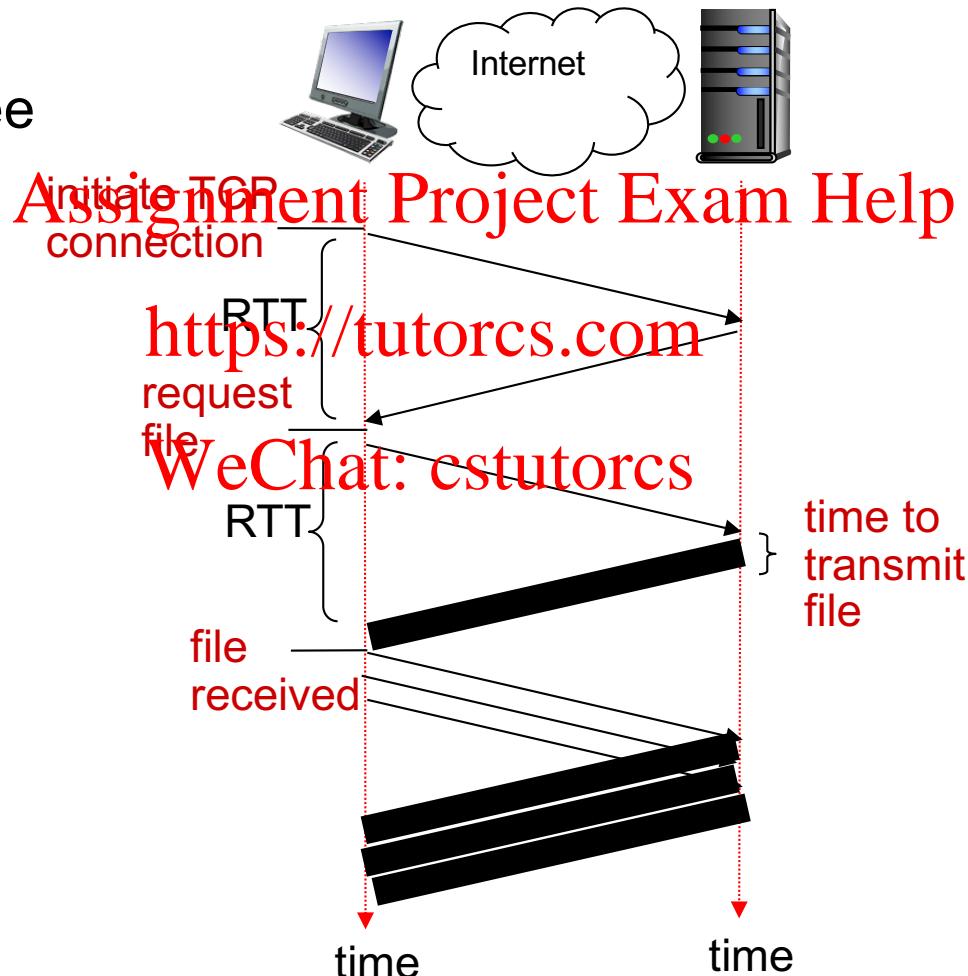
## Persistent with pipelining:

- ❖ 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

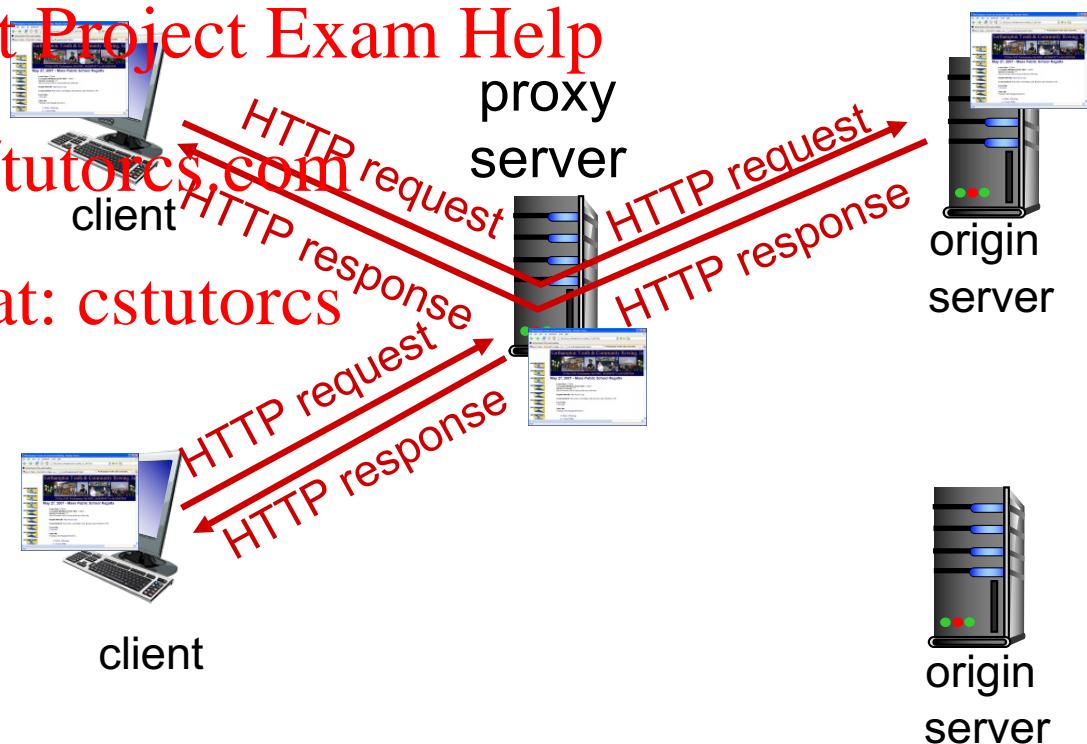
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- Why does caching work?
  - Exploit *locality of reference*
- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests
- Trend: increase in dynamic content
  - For example, customization of web pages
  - Reduces benefits of caching
  - Some exceptions, for example, video content

# 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

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# Caching example:

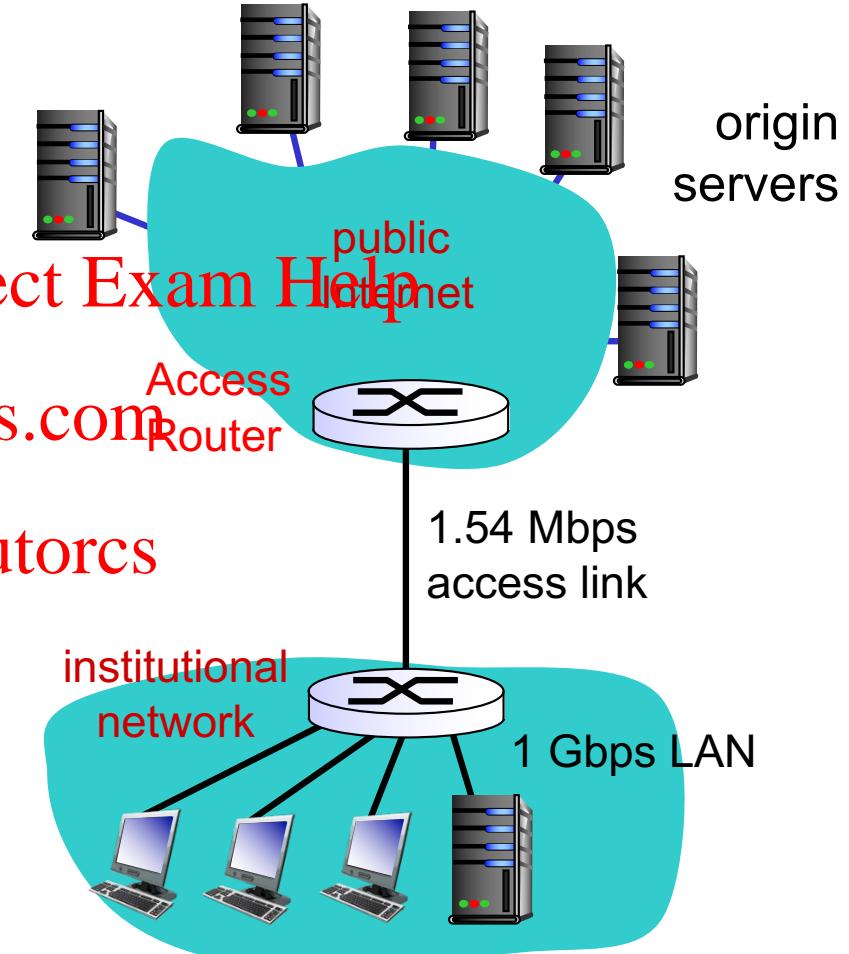
## *assumptions:*

- ❖ 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

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## *consequences:*

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

*problem!*

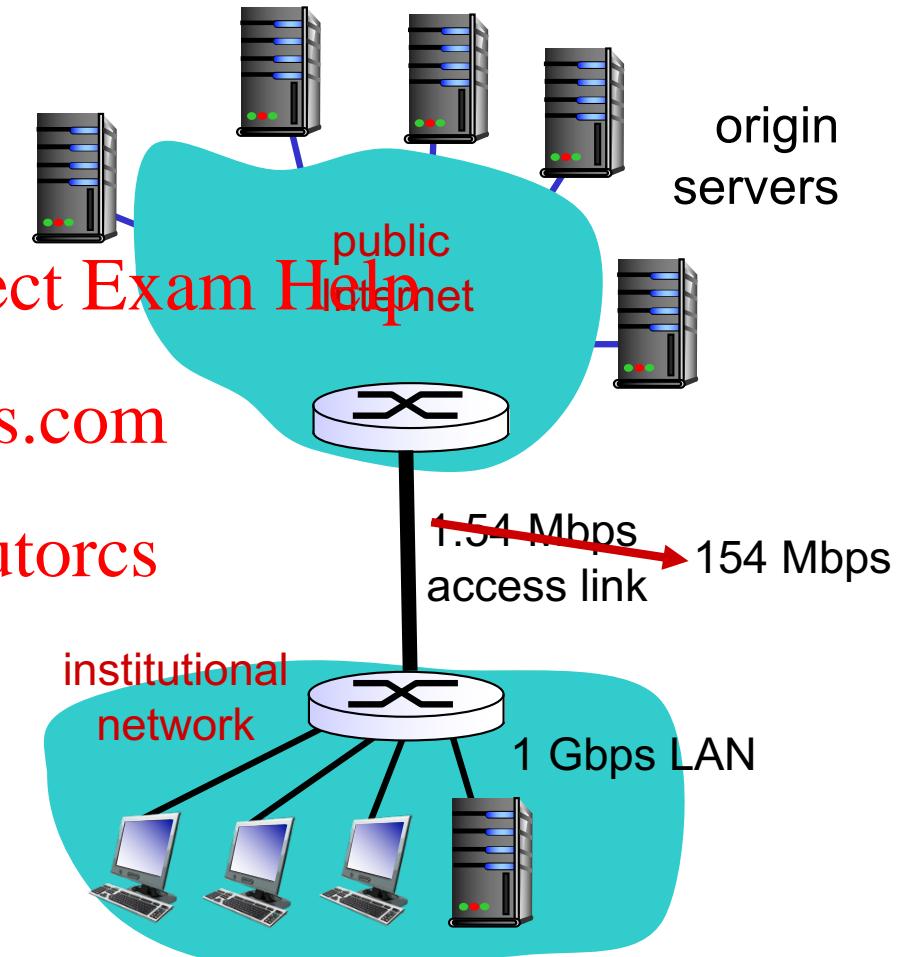
# Caching example: fatter access link

## 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

## *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

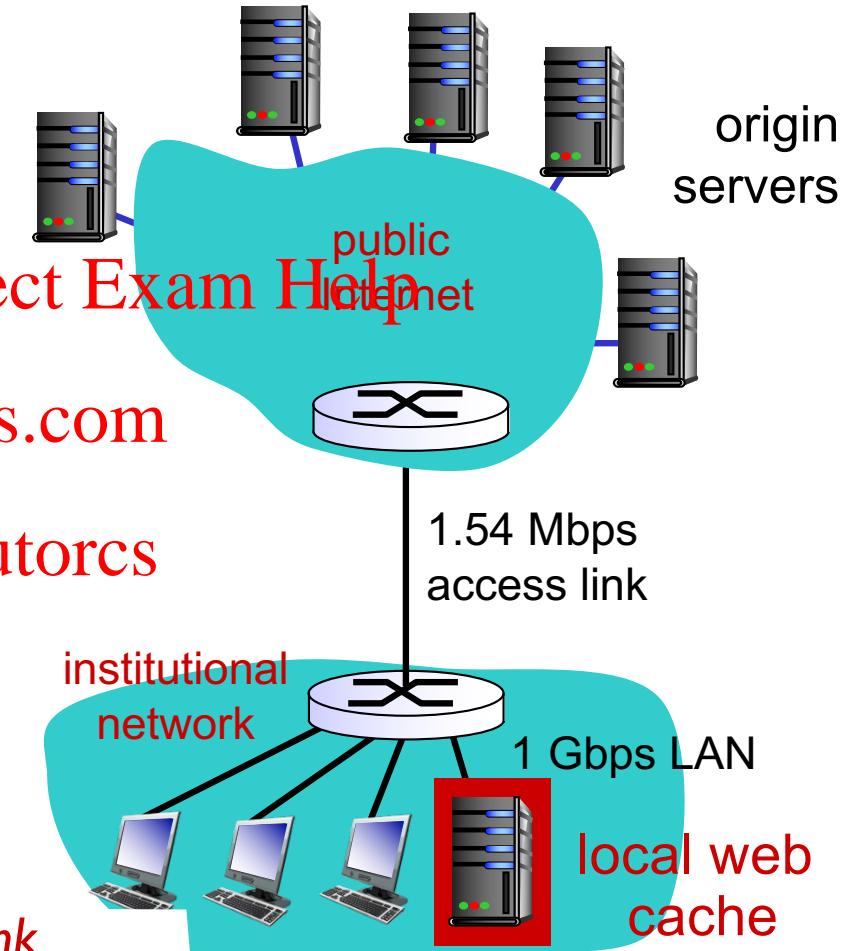
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## *consequences:*

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

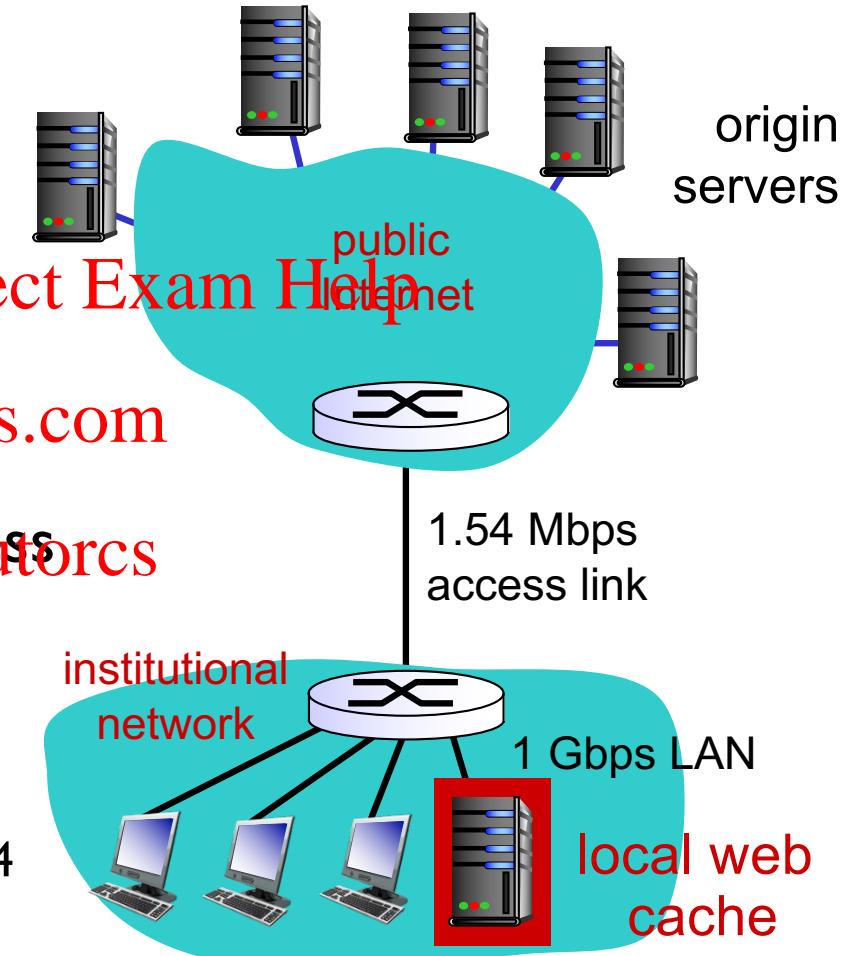


*Cost:* web cache (cheap!)

# 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 <https://tutorcs.com>
  - 60% of requests use access link
- ❖ data rate to browser 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

HTTP request msg  
**If-modified-since: <date>**

HTTP response  
https://tutorcs.com    HTTP/1.0  
**304 Not Modified**

object  
not  
modified  
before  
<date>

HTTP request msg  
**If-modified-since: <date>**

HTTP response  
HTTP/1.0 200 OK  
**<data>**

object  
modified  
after  
<date>

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# Example Cache Check Request

GET / HTTP/1.1

Accept: \*/\*

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Accept-Language: en-us

Accept-Encoding: gzip, deflate

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

If-None-Match: "7a11f10ed-3a75ae4a"

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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"

Etag: Usually used for dynamic content. The value is often a cryptographic hash of the content.

# 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 a 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
- 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

# What about HTTPS?

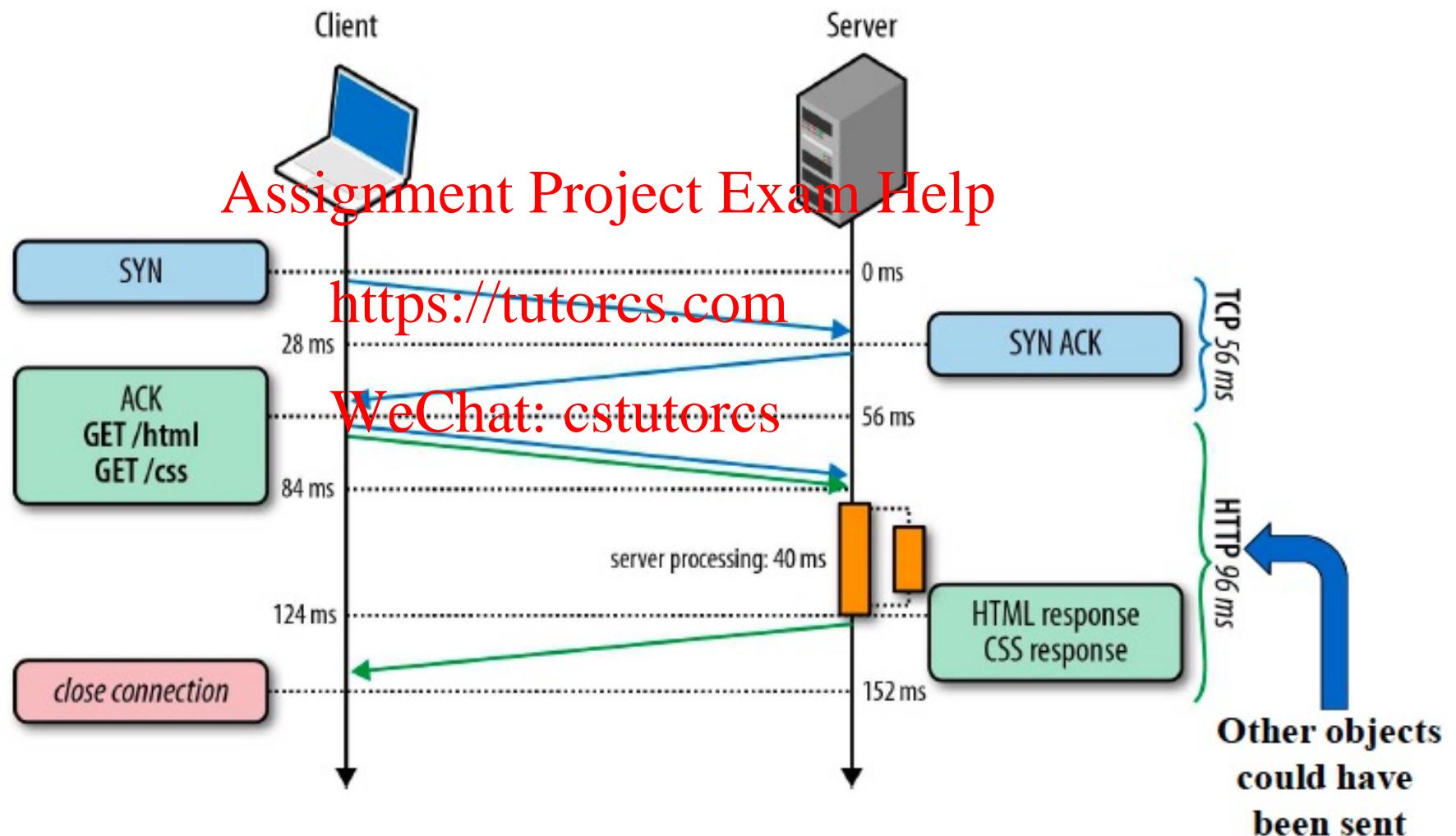
- HTTP is insecure
- HTTP basic authentication: password sent using base64 encoding (can be readily converted to plaintext)
- HTTPS: HTTP over a connection encrypted by Transport Layer Security (TLS)
- Provides:
  - Authentication
  - Bidirectional encryption
- Widely used in place of plain vanilla HTTP



# Issues with HTTP

- Head of line blocking: “slow” objects delay later requests
  - Example objects from remote storage vs from local memory
- Browsers often open multiple TCP connections for parallel transfers
  - Increases throughput and reduces impact of HOL blocking
  - Increases load on servers and network
- HTTP headers are big
  - Overheads higher for small objects
- Objects have dependencies, different priorities
  - Javascript vs images
  - Extra RTTs for “dependent” objects

# Head of Line Blocking Example



# What's on the horizon: HTTP/2

---

- Google SPDY (speedy) -> HTTP/2: (RFC 7540 May 2015)
- Binary instead of text
  - Efficient to parse, more compact and much less error-prone
- Responses are multiplexed over a single TCP connection
  - Server can send response data whenever it is ready
  - “Fast” objects can bypass “slow” objects – avoid HOL blocking
  - Fewer handshakes, more traffic (helps congestion control)
- Multiplexing uses prioritized flow-controlled schemes
  - Urgent responses can bypass non-critical responses
- Single TCP connection
- HTTP headers are compressed
- Push feature allows server to push embedded objects to the client without waiting for request
  - Saves RTT

More details: <https://http2.github.io/faq/>  
Demo: <http://www.http2demo.io>



## 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)?

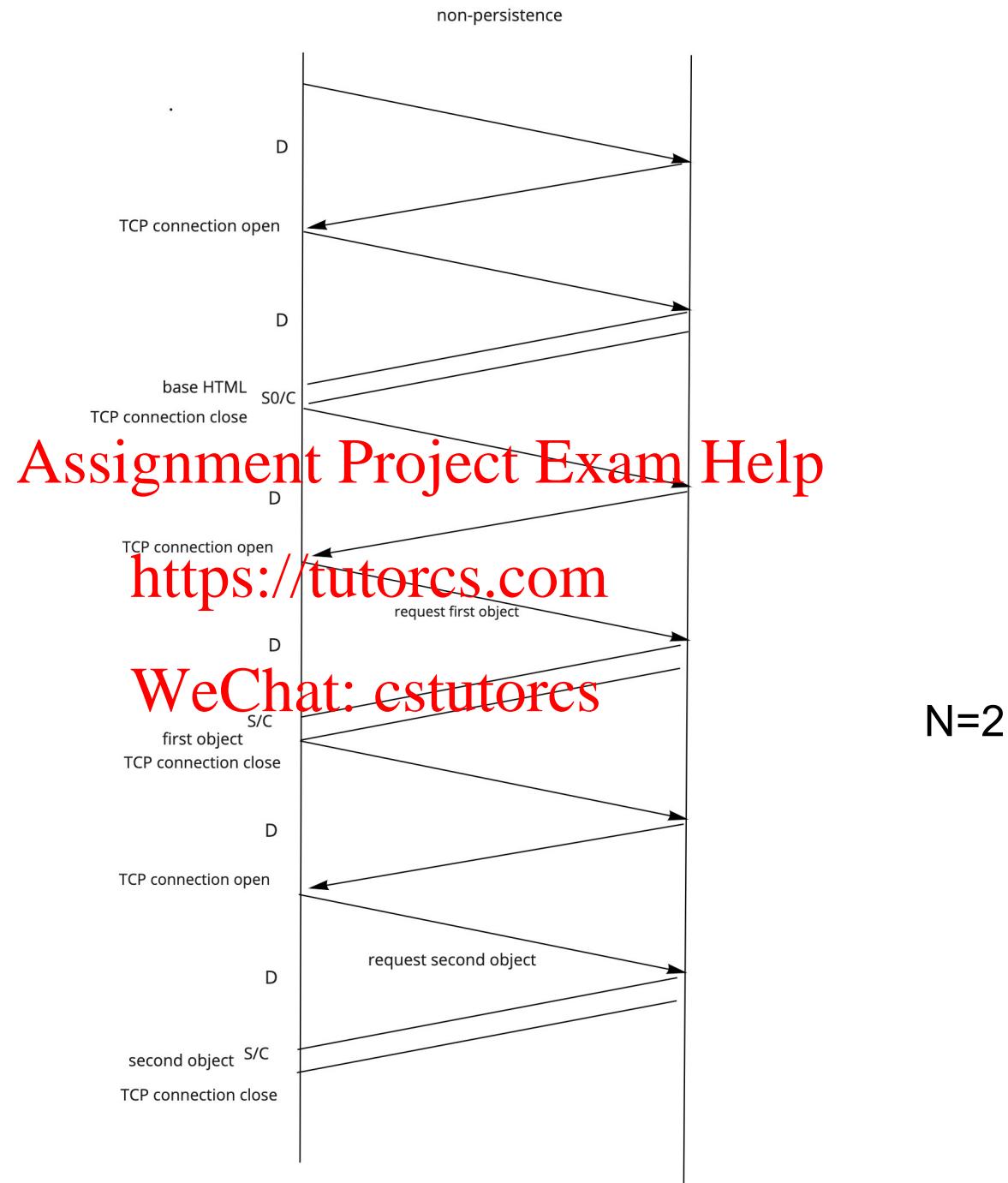
**Assignment Project Exam Help**

- A.  $D + (S_0 + NS)/C$  <https://tutorcs.com>
- B.  $2D + (S_0 + NS)/C$  WeChat: cstutorcs
- C.  $N(D + S/C)$
- D.  $2D + S_0/C + N(2D + S/C)$
- E.  $2D + S_0/C + N(D + S/C)$

**Answer: D**

(see picture on next slide)

Open a browser and type: [www.zeetings.com/salil](http://www.zeetings.com/salil)



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<https://tutorcs.com>

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N=2



## Quiz: HTTP (2)

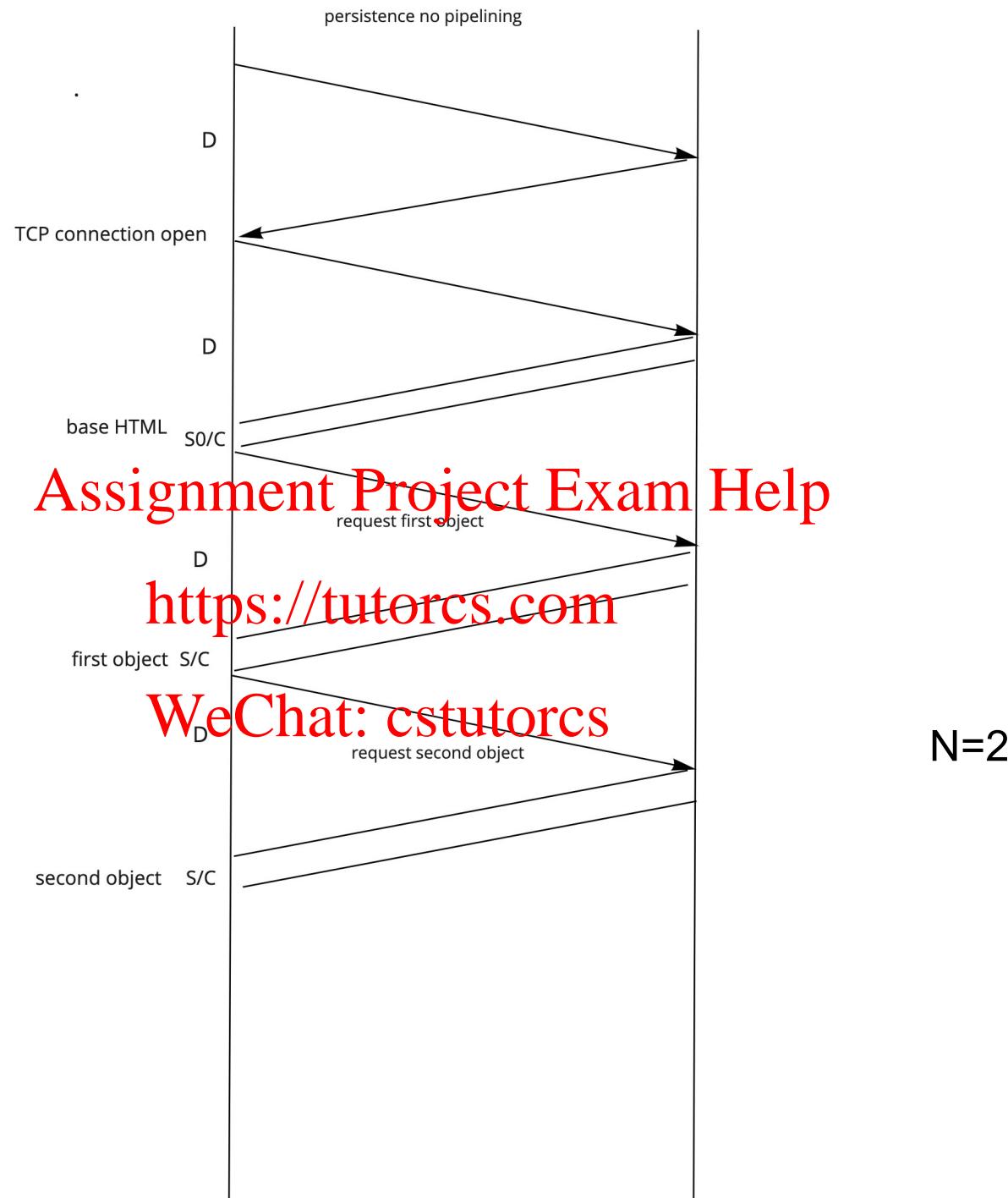
Consider an HTML page with a base file of size  $S_0$  bits and  $N$  inline objects each of size  $S$  bits. Assume a client fetching the page across a link of capacity  $C$  bits/s and RTT of  $D$ . How long does it take to download the page using **persistent HTTP (without parallelism or pipelining)?**

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- A.  $2D + (S_0 + NS)/C$  <https://tutorcs.com>
- B.  $3D + (S_0 + NS)/C$  WeChat: cstutorcs
- C.  $N(D + S/C)$
- D.  $2D + S_0/C + N(2D + S/C)$
- E.  $2D + S_0/C + N(D + S/C)$

**Answer: E**  
(see picture on next slide)

Open a browser and type: [www.zeetings.com/salil](http://www.zeetings.com/salil)





## 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?

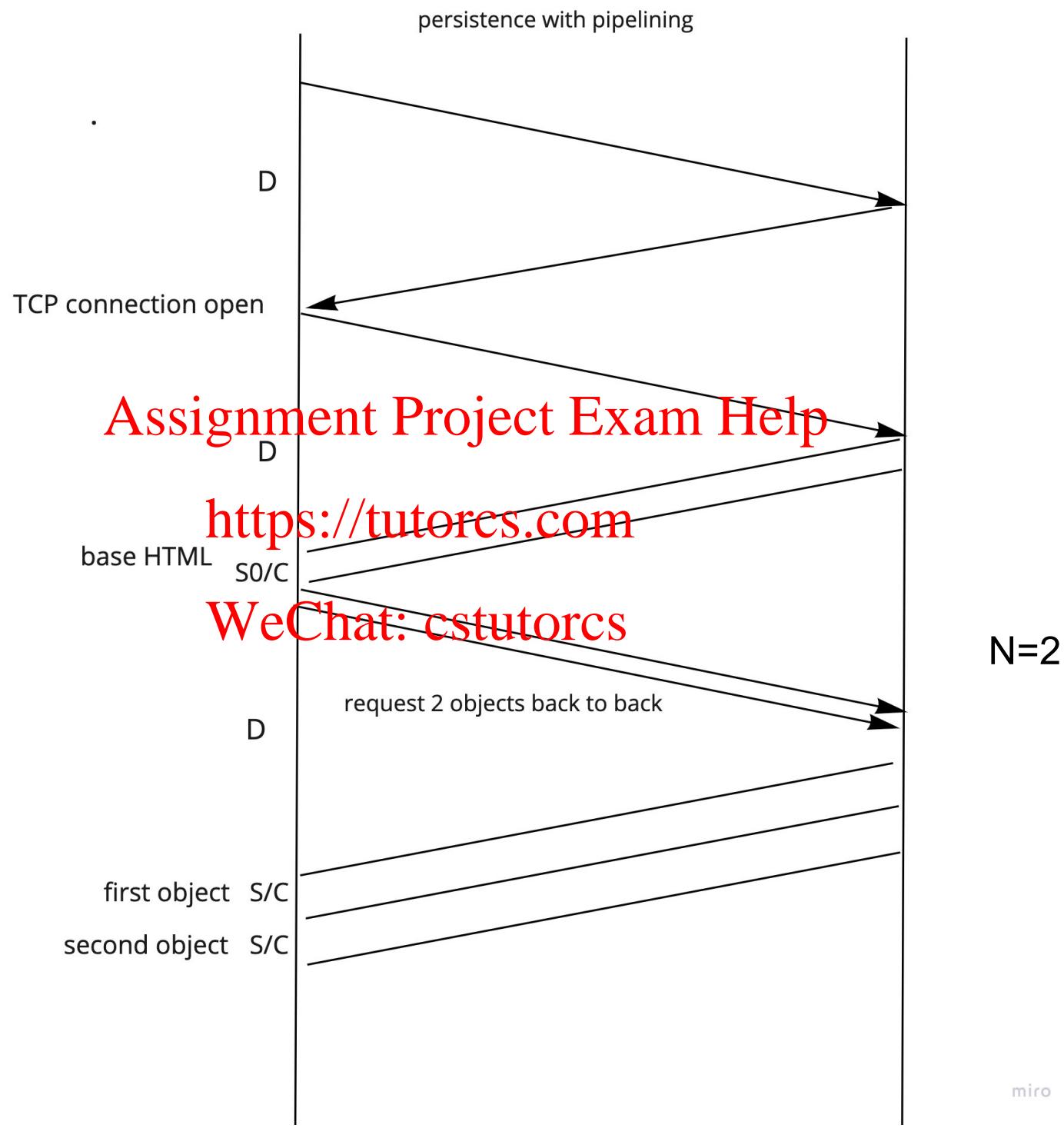
**Assignment Project Exam Help**

- A.  $2D + (S_0 + NS)/C$  <https://tutorcs.com>
- B.  $4D + (S_0 + NS)/C$  WeChat: cstutorcs
- C.  $N(D + S/C)$
- D.  $3D + S_0/C + NS/C$
- E.  $2D + S_0/C + N(D + S/C)$

**Answer: D**

(see picture on next slide)

Open a browser and type: [www.zeetings.com/salil](http://www.zeetings.com/salil)



# Application Layer: outline

## 2.1 principles of network applications

- app architectures
- app requirements

## 2.2 Web and HTTTP

## 2.3 electronic mail

- SMTP

## 2.4 DNS

## 2.5 P2P applications

## 2.6 video streaming and content distribution networks (CDNs)

## 2.7 socket programming with UDP and TCP

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# Electronic mail

*Three major components:*

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

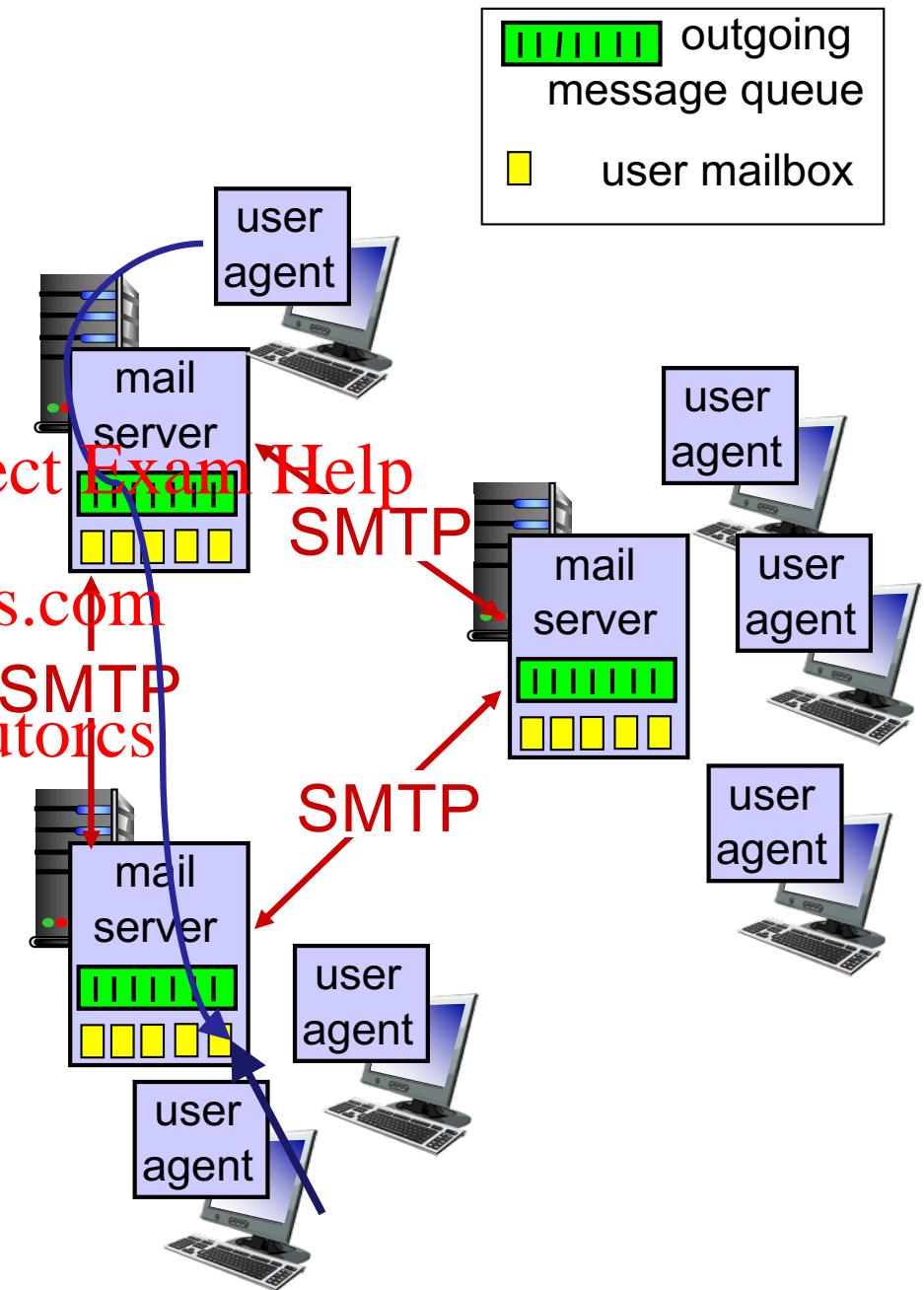
## User Agent

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

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<https://tutorcs.com>

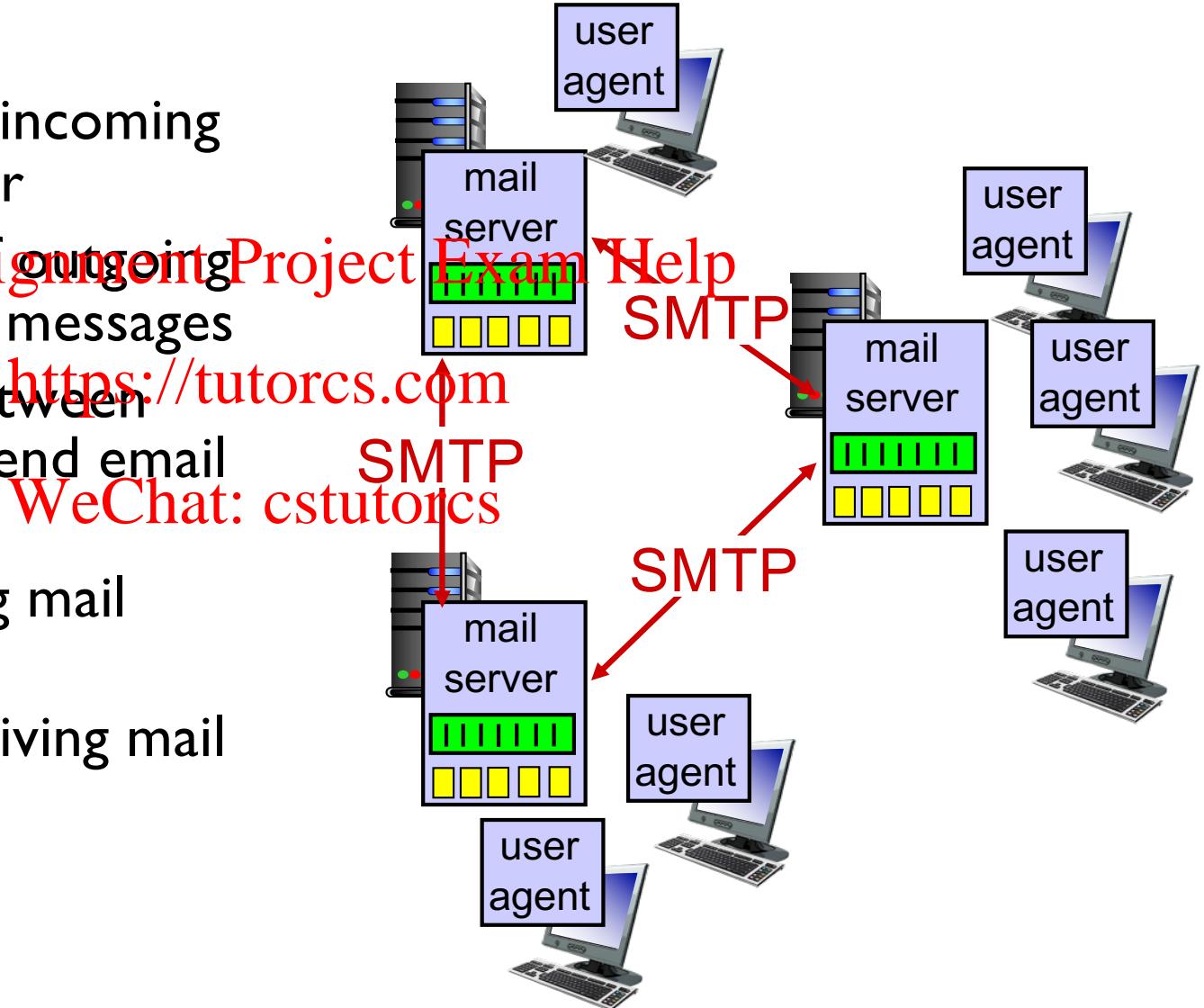
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# Electronic mail: mail servers

## 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

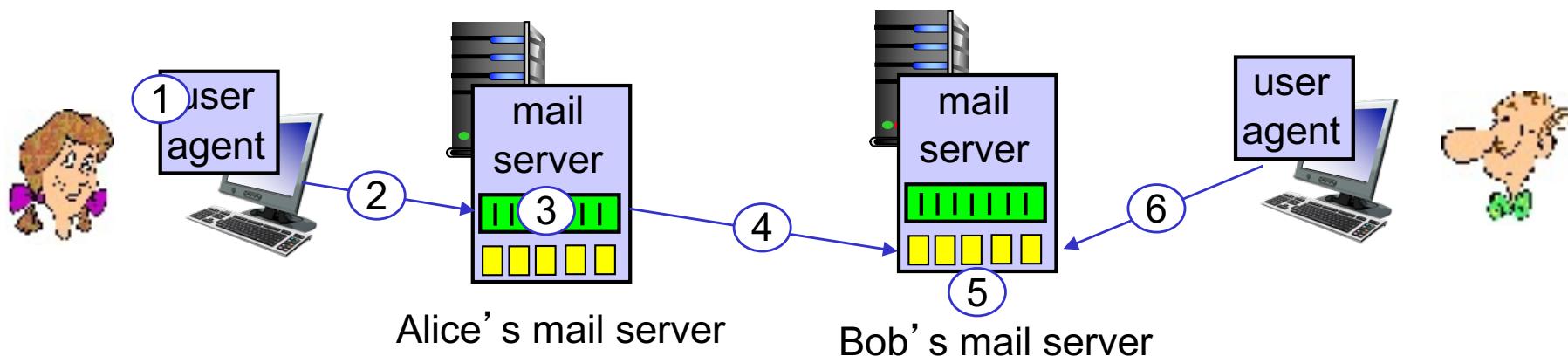


# Electronic Mail: SMTP [RFC 2821]

- ❖ uses TCP to reliably transfer email message from client to server, port 25
- ❖ direct transfer: sending server to receiving server [Assignment Project Exam Help](#)
- ❖ three phases of transfer <https://tutorcs.com>
  - 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. **Assignment Project Exam Help** placed in message queue
  - 3) client side of SMTP <https://tutorcs.com> 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
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# Sample SMTP interaction

S: 220 hamburger.edu  
C: HELO crepes.fr  
S: 250 Hello crepes.fr, pleased to meet you  
C: MAIL FROM:~~Assignment Project Exam Help~~  
S: 250 alice@crepes.fr... Sender ok  
C: RCPT TO: <~~bob@hamburger.edu~~  
S: 250 bob@hamburger.edu ... Recipient ok  
C: DATA ~~WeChat: cstutorcs~~  
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

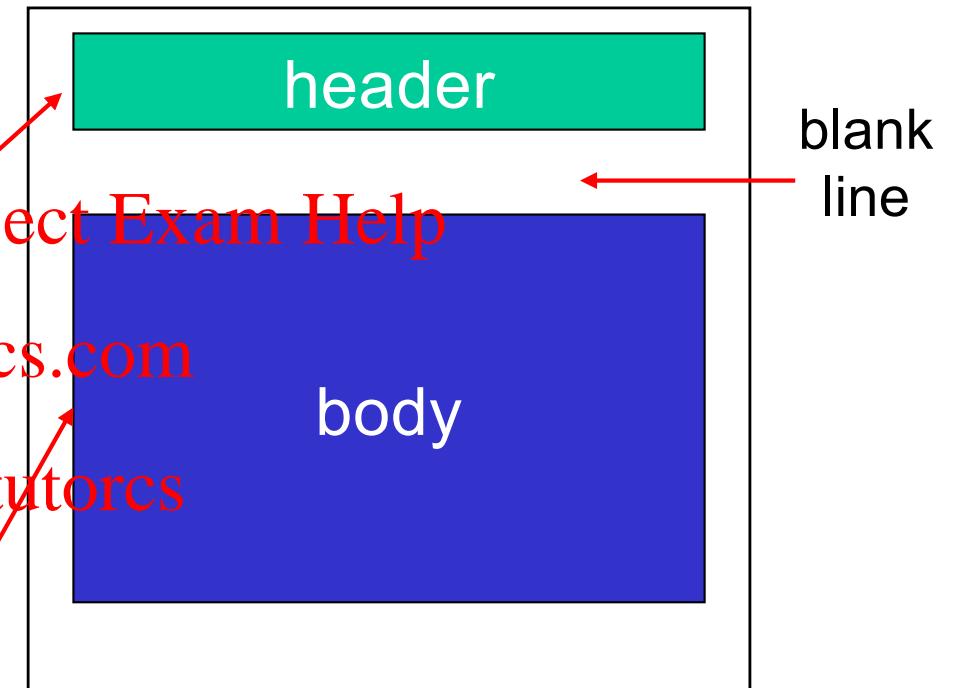
RFC 5322 (822,2822):  
standard for text message  
format (Internet Message  
Format, IMF): <https://tutorcs.com>

- ❖ header lines, e.g.

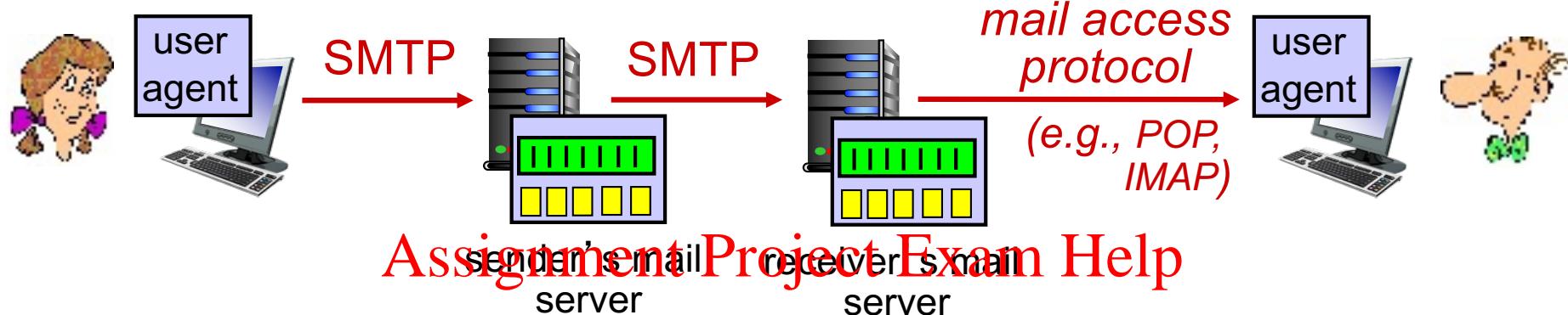
- To:
  - From:
  - Subject:

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

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



# Mail access protocols



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- ❖ **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?

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**ANSWER: TO ENSURE THAT THE MAIL CAN BE DELIVERED  
IF THE RECEIVER'S ~~MAIL SERVER~~ <https://tutorcs.com> IS DOWN MOMENTARILY**

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**Open a browser and type: [www.zeetings.com/salil](http://www.zeetings.com/salil)**

# Quiz: SMTP

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

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

ANSWER: THE RECIPIENT MAY NOT BE ALWAYS CONNECTED

<https://tutorcs.com>

WeChat: cstutorcs

Open a browser and type: [www.zeetings.com/salil](http://www.zeetings.com/salil)

# Summary

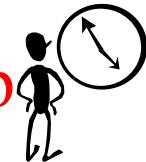
- ❖ Application Layer (Chapter 2)

- Principles of Network Applications
- HTTP
- E-mail

- ❖ Next:

- DNS
- P2P

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<https://tutorcs.com>

Reading Exercise for next week

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**I HAVE A HTTP JOKE**

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<https://tutorcs.com>

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**BUT IF I POST IT HERE, YOU WON'T GET IT**

[makeameme.org](http://makeameme.org)