Advanced Network Technologies

Applications

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- Delete if not required

Web caches (proxy server)

goal: satisfy client request without involving origin server

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

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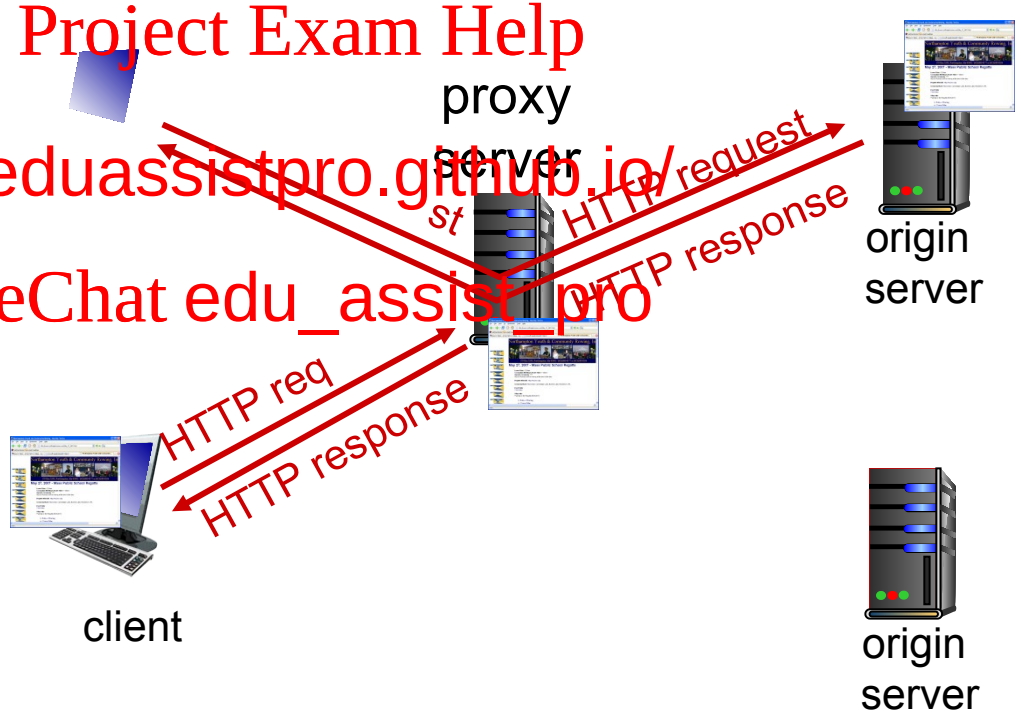

More about Web caching

› Q: Does the cache act as a client or a server?

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More about Web caching

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

why Web caching?

- reduce response time for client request
- affic on an
- i access link

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Caching example

assumptions:

- avg object size: 100K bits
- avg request rate from browsers to origin servers: 15/sec (1.5 Mbps service)
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54

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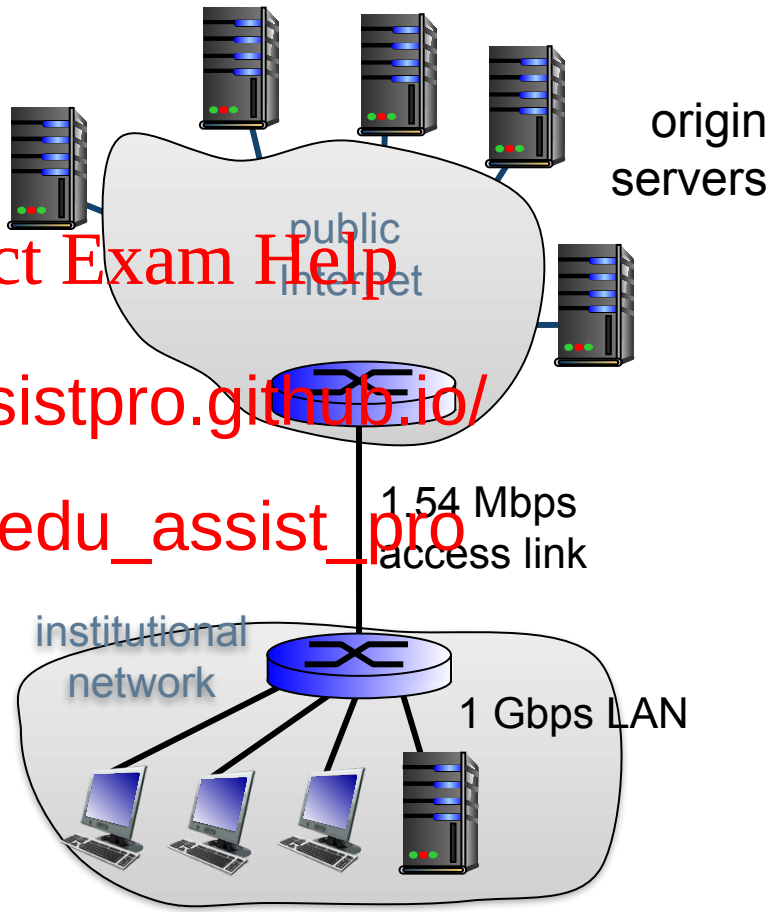

consequences:

- LAN utilization: 0.15%
- LANU = avg req rate * size / link bandwidth
- access link utilization = 99% *problem!*
- ALU = avg req rate * size / link bankwidth
- total delay = 2 sec + seconds + usecs

Q: what happens with fatter access link?

Caching example: fatter access link

assumptions:

- avg object size: 100K bits
- avg request rate from browsers to origin servers: 15/sec
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54

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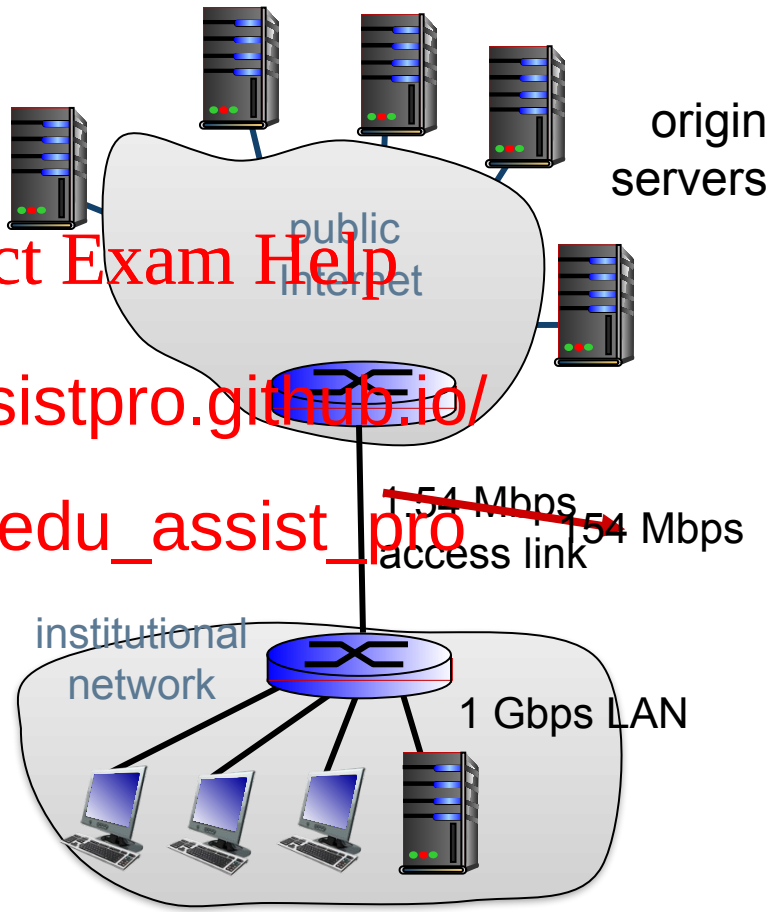
consequences:

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

msecs



Cost: increased access link speed (not cheap!)

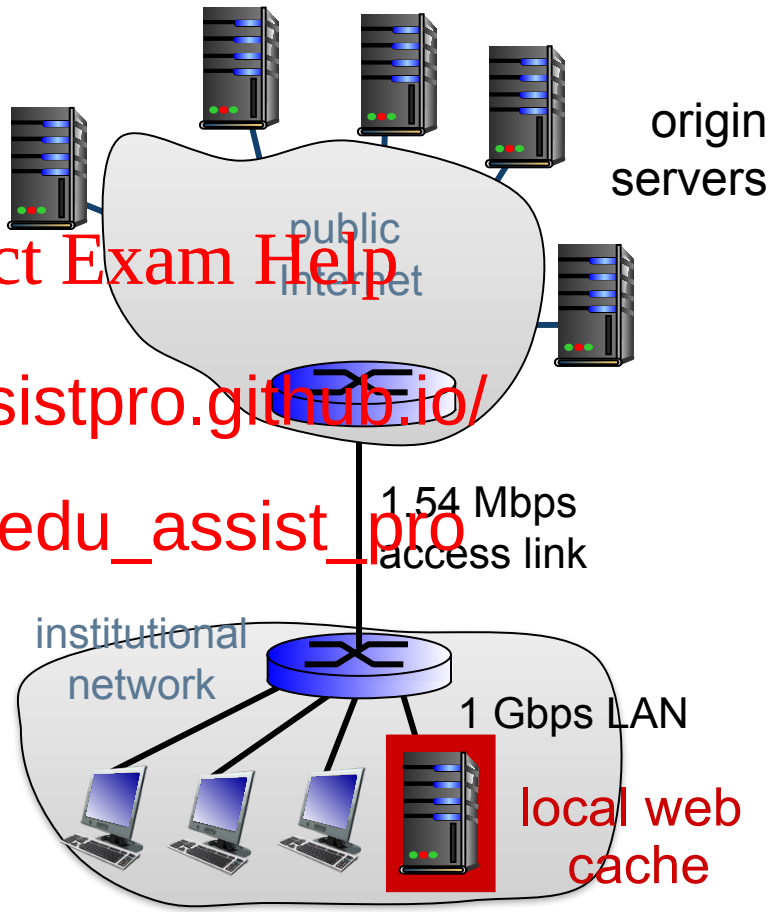
Caching example: install local cache

assumptions:

- avg object size: 100K bits
- avg request rate from browsers to origin servers: 15/sec
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54

consequences:

- LAN utilization: 0.15%
- access link utilization = 0%
- total delay = usecs



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Cost: web cache (cheap!)

Caching example: install local cache

Calculating access link utilization, delay with cache:

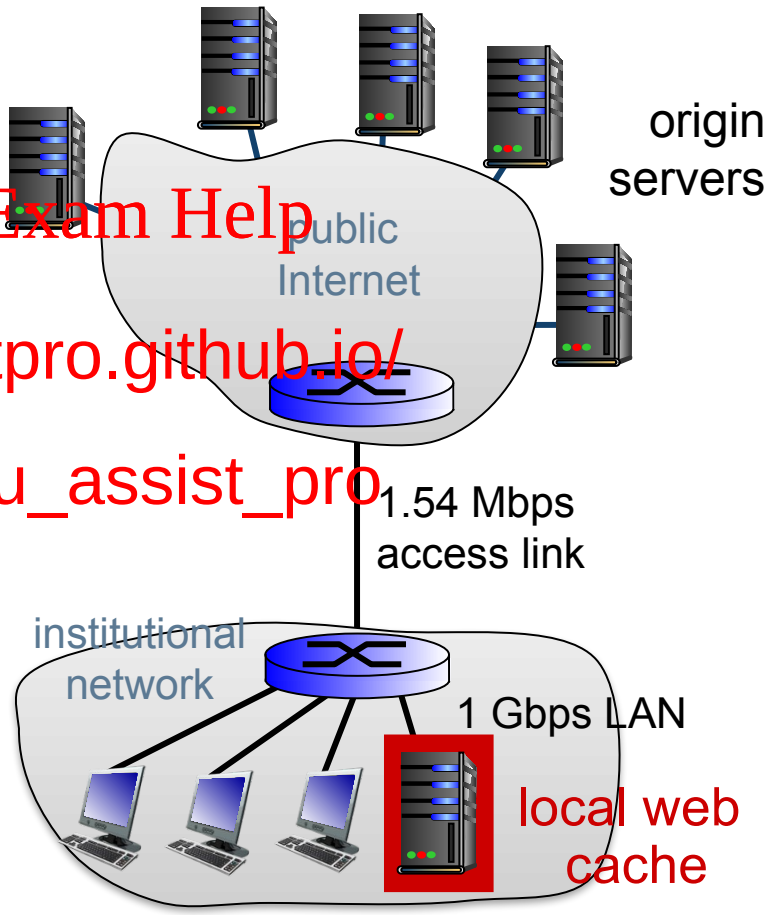
- suppose cache hit rate is 0.4
  - 40% requests satisfied at cache
  - 60% requests satisfied at origin
- access link utilizatio
  - 60% of requests use access link
- average total delay

= 0.6 * (delay from origin servers) +0.4 * (delay when satisfied at cache)

Link utilization is around 60%, queueing delay is small enough

= 0.6 (~2.x second) + 0.4 (~usecs)

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



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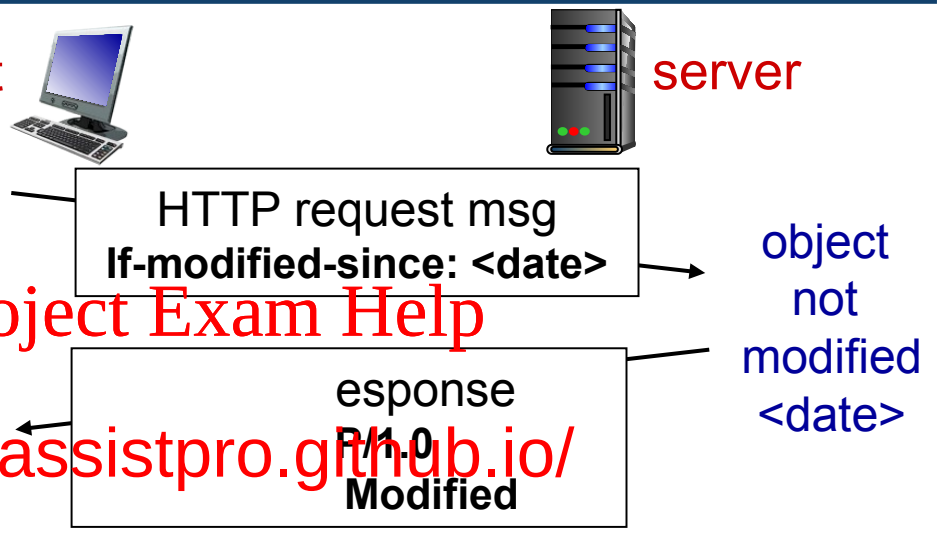
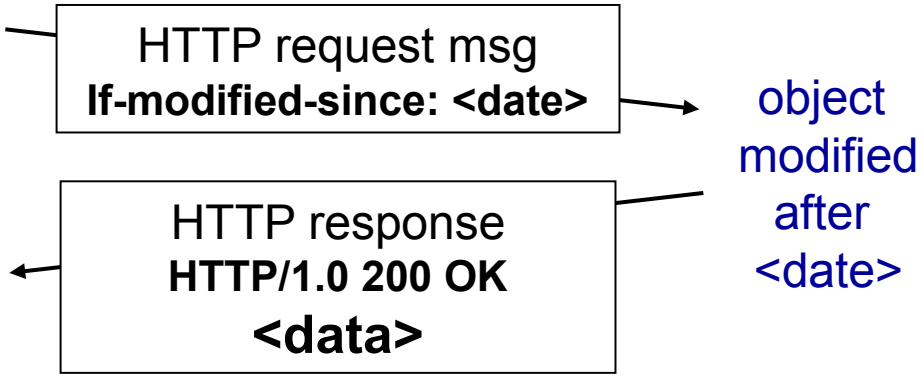
Conditional GET

- *Goal:* don't send object if client has up-to-date cached version
  - no object transmission delay
  - lower link utilization
- *client:* specify date of copy in HTTP reques

  `If-modified-since: <date>`
- *server:* response contains no object if cached copy is up-to-date:

  `HTTP/1.0 304 Not Modified`





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HTTP/2

Key goal: decreased delay in multi-object HTTP requests

HTTP1.1: introduced multiple, pipelined GETs over single TCP connection

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- server respond e-first-served scheduling) to

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- with FCFS, small object may ha r transmission (head-of-line (HOL) blocking) b bject(s)

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- loss recovery (retransmitting lost TCP segments) stalls object transmission

HTTP/2

Key goal: decreased delay in multi-object HTTP requests

HTTP/2: [RFC 7540, 2015] increased flexibility at *server* in sending object

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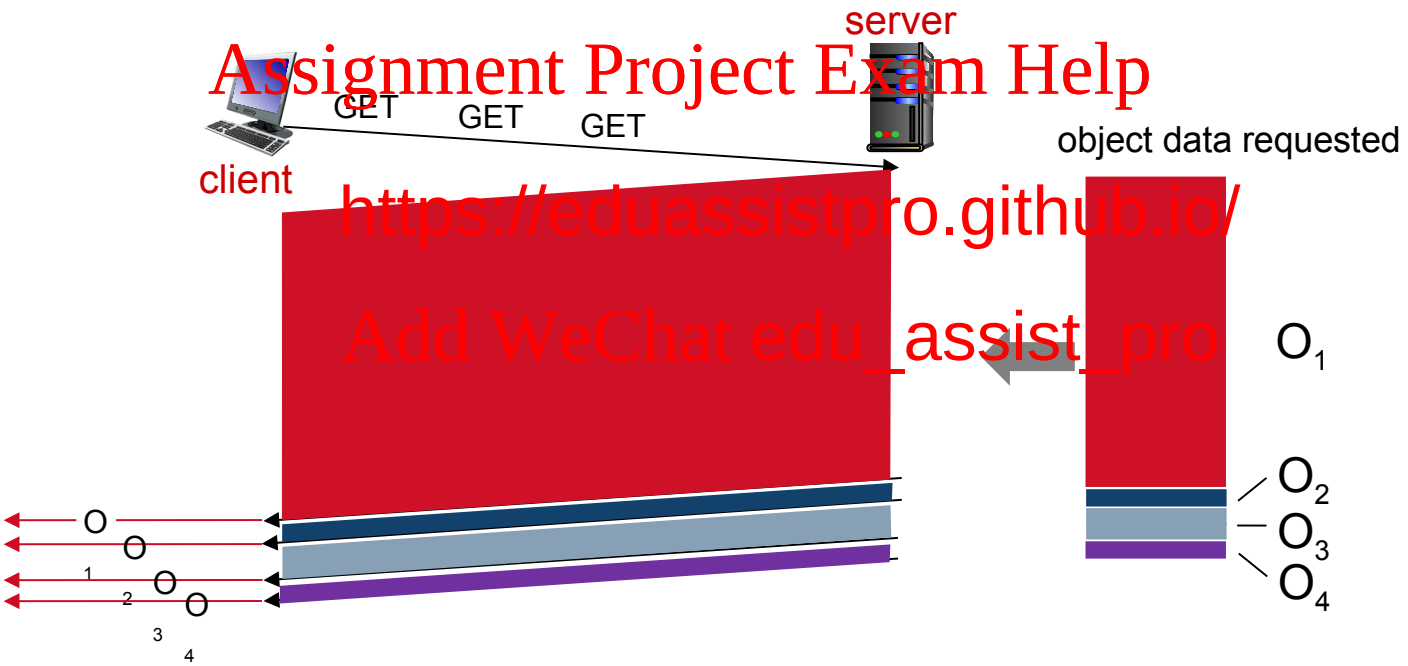
- methods, statu unchanged from HTTP 1.1
- transmission order of requested ed on client-specified object priority (not necessarily FCFS)
- *push* unrequested objects to client
- divide objects into frames, schedule frames to mitigate Head-of-line (HOL) blocking

HTTP/2: mitigating HOL blocking

HTTP 1.1: client requests 1 large object (e.g., video file, and 3 smaller objects)



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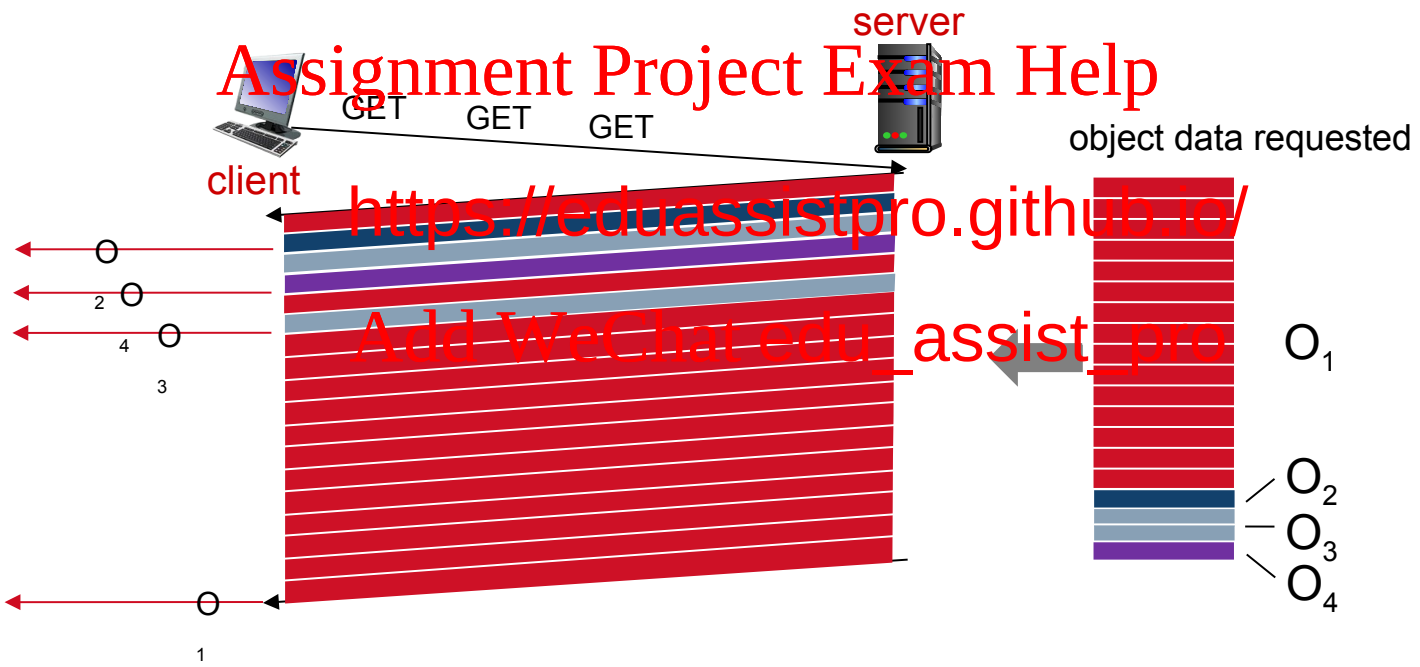
objects delivered in order requested: O_2, O_3, O_4 wait behind O_1

HTTP/2: mitigating HOL blocking

HTTP/2: objects divided into frames, frame transmission interleaved



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O_2, O_3, O_4 delivered quickly, O_1 slightly delayed

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HTTP/2 Streams and frames

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Client

Server

HTTP/2 Streams and frames

Frames:

- Basic HTTP/2 data unit, replacing HTTP/1.1 header and body format.
- HTTP/2 frame g (more efficient).
- Header frames, Data frames

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Streams

- Bidirectional channel where frames are transmitted
- Replacing HTTP/1.1 Request-Response mode

A single TCP connection to carry multiple streams

HTTP/2 push

The HTTP/2 Server Push mechanism allows the server to send resources proactively without waiting for a request, when it believes the client will need them.

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https://blog.golang.org/h2push

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Outline

- Web and HTTP (Done)
- FTP
- Email
- DNS
- P2P

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FTP

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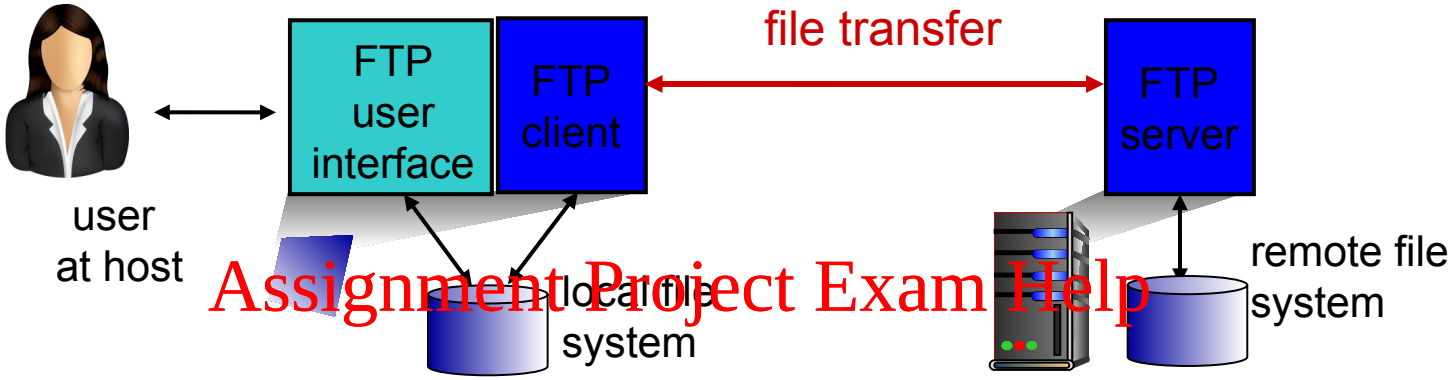
FTP: the file transfer protocol



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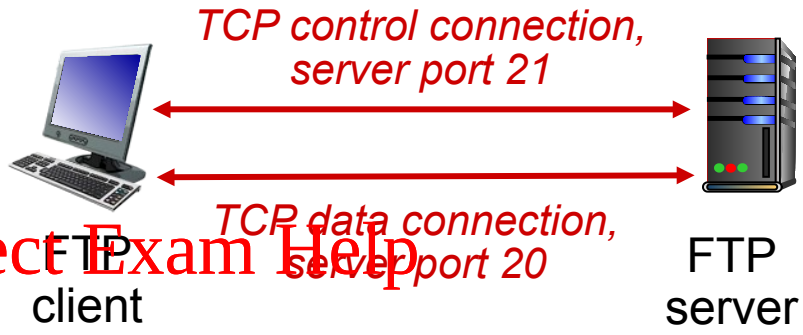
- transfer file to/from remote
- client/server model
  - *client:* side that initiates transfer (either to/from remote)
  - *server:* remote host
- ftp: RFC 959
- ftp server: port 21, 20

FTP: separate control, data connections

- FTP client contacts FTP server at port 21, using TCP
- client authorized over control connection
- client browses rem sends commands over control connection
- when server receives file transfer command, *server* opens 2nd TCP data connection (for file) *to* client
- after transferring one file, server closes data connection



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pens another TCP ection to transfer le

- control connection: *"out of band"*
- FTP server maintains "state": current directory, earlier authentication

FTP commands, responses

sample commands:

- sent as ASCII text over control channel
- **USER *username***
- **PASS *password***
- **LIST** return list of file in current directory
- **RETR filename** retrieves (gets) file
- **STOR filename** stores (puts) file onto remote host

sample return codes

- status code and phrase (as in HTTP)
- **331 Username OK, d required**
- **a conn open; starting**
- **425 Can't open data connection**
- **452 Error writing file**

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Email

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SMTP: Simple Mail Transfer Protocol

IMAP: Internet Message Access Protocol

POP3: Post Office Protocol 3

Electronic mail

Three major components:

- user agents (clients)
- mail servers
- simple mail transfer protocol: SMTP

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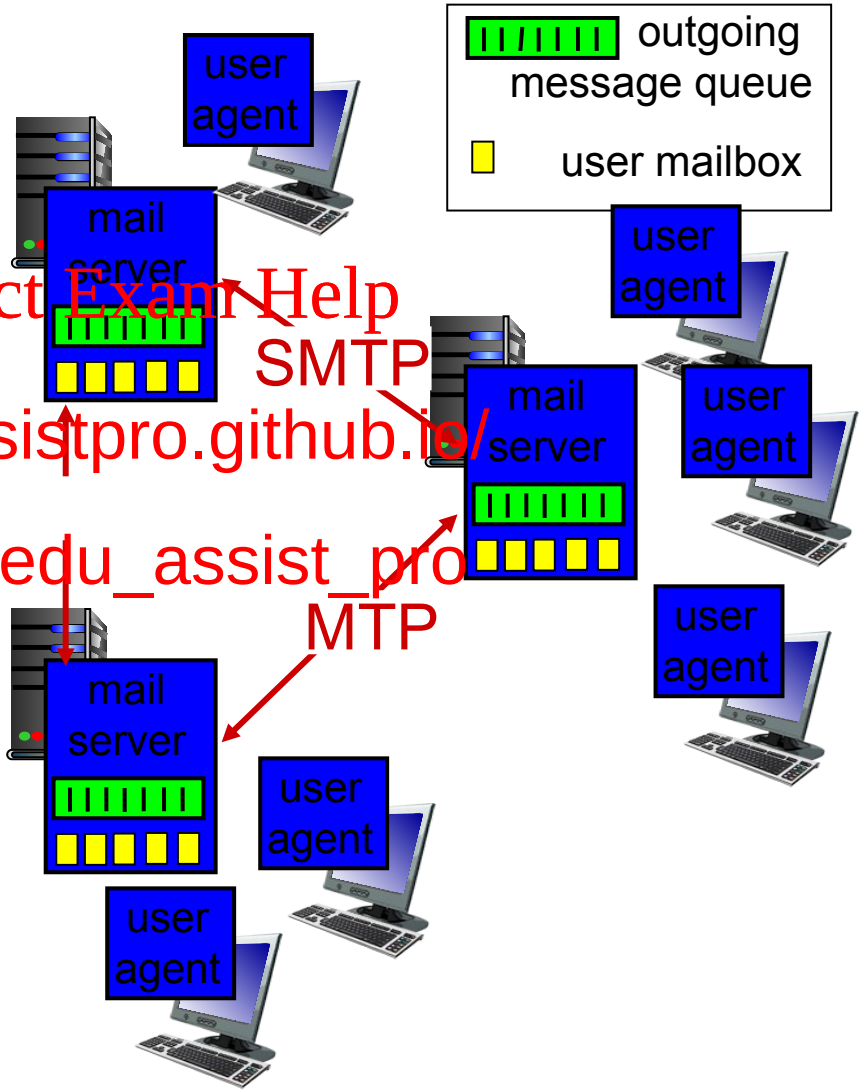
User Agent

- a.k.a. "mail reader"
- composing, editing, reading mail messages
- e.g., Outlook, Thunderbird, iPhone mail client



Electronic mail: mail servers

mail servers:

- *mailbox* contains incoming messages for user
- *message queue* of (to be sent) mail
- *SMTP protocol* to send email messages between mail servers
  - client: sending mail to server
  - "server": receiving mail from server

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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)
  - commands: ASCII text
  - response: status code and phrase
- messages must be in 7-bit ASCII
- Q: is SMTP stateful or stateless?
  - Stateful

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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 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

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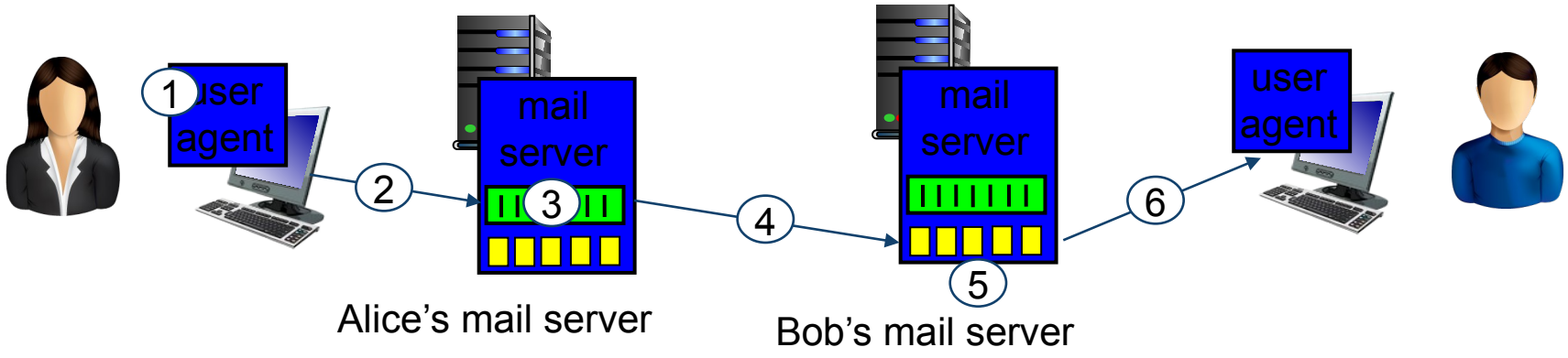

Sample SMTP interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250  Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
t ok    S: 250 bob@h
C: DATA
S: 354 Enter mail, end wit              line by itself
C: Do you like ketchup?
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

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SMTP: final words

- SMTP uses persistent connections
- SMTP requires message (header & body) t bit ASCII
- SMTP server uses `CRLF.CRLF` to determine end of message
  - Carriage return
  - Line feed

comparison with HTTP:

- HTTP: pull
- SMTP: push

SCII

sponse

in atus codes

- HTTP: each object encapsulated in its own response msg
- SMTP: multiple objects sent in one msg

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Mail message format

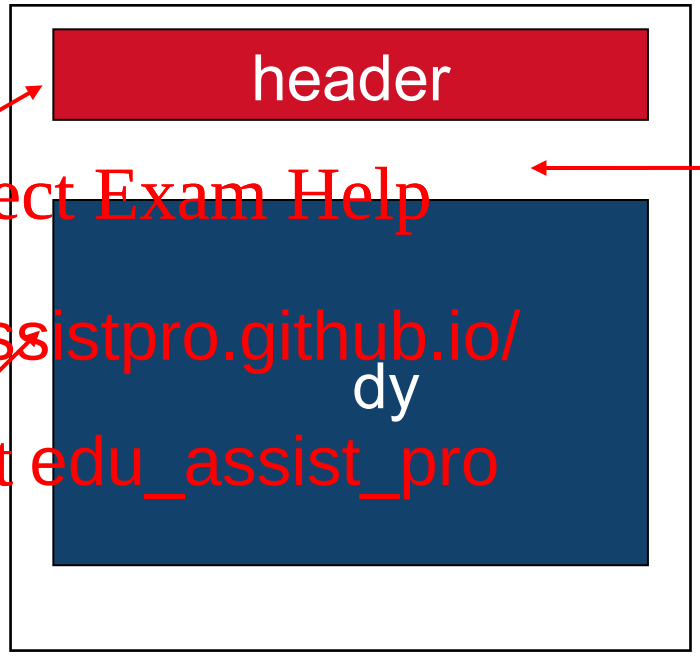
SMTP: protocol for exchanging email msgs

RFC 822: standard for text message format:

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

  different from SMTP MAIL FROM, RCPT TO: commands!

› Body: the "message"
  - ASCII characters only



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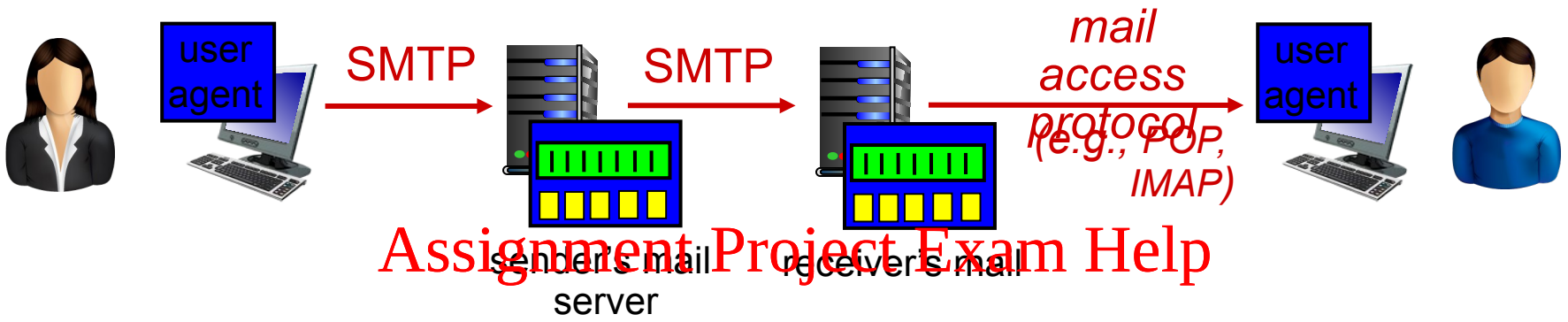
Mail access protocols



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- SMTP: delivery/storag
- mail access protocol: retrieval from sery
  - POP: Post Office Protocol [RFC 1939]: au nload
  - IMAP: Internet Mail Access Protocol [RFC 1730]: more features, including manipulation of stored msgs on server
  - HTTP: Using a browser to access a webmail `https://webmail.sydney.edu.au`

POP3 Protocol

authorization phase

- client commands:
  - **`user:`** declare username
  - **`pass:`** password
- server responses
  - **`+OK`**
  - **`-ERR`**

transaction phase, client:

- **`list:`** list message numbers
- **`retr:`** retrieve message by number
- **`dele:`** delete
- **`quit`**

```
S: +OK POP3 server ready
C: user bob
S: +OK
C: pass hungry
S: +OK user successfully logged on
C: list
                    ge 1 contents>
S: .
C: dele 1
C: retr 2
S: <message 1 contents>
S: .
C: dele 2
C: quit
S: +OK POP3 server signing off
```

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POP3 (more) and IMAP

more about POP3

- previous example uses POP3 "download and delete" mode
  - Bob cannot re-read e changes client
- POP3 "download-and-keep": copies of messages on different clients
- POP3 is stateless across sessions

IMAP

- keeps all messages in one place: at server
- to organize folders
- k ate across s
  - names of folders and mappings between message IDs and folder name

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DNS

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DNS: domain name system

Internet hosts, routers:

- IP address (32 bit) - used for addressing datagrams
- "name", e.g., www.yahoo.com - used by humans

people: many identi

- name, passport #

Q: how to map between IP address and name, and vice versa ?

Domain Name System:

› *distributed database* implemented in hierarchy of many *name servers*

n *application layer protocol:* hosts, r communicate to translation) (address/name

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DNS: services, structure

DNS services

- hostname to IP address translation
- host aliasing
  - canonical, alias na
- mail server aliasing
- load distribution
  - replicated Web servers: many IP addresses correspond to one name

why not centralize DNS?

- single point of failure
- distant centralized database
-

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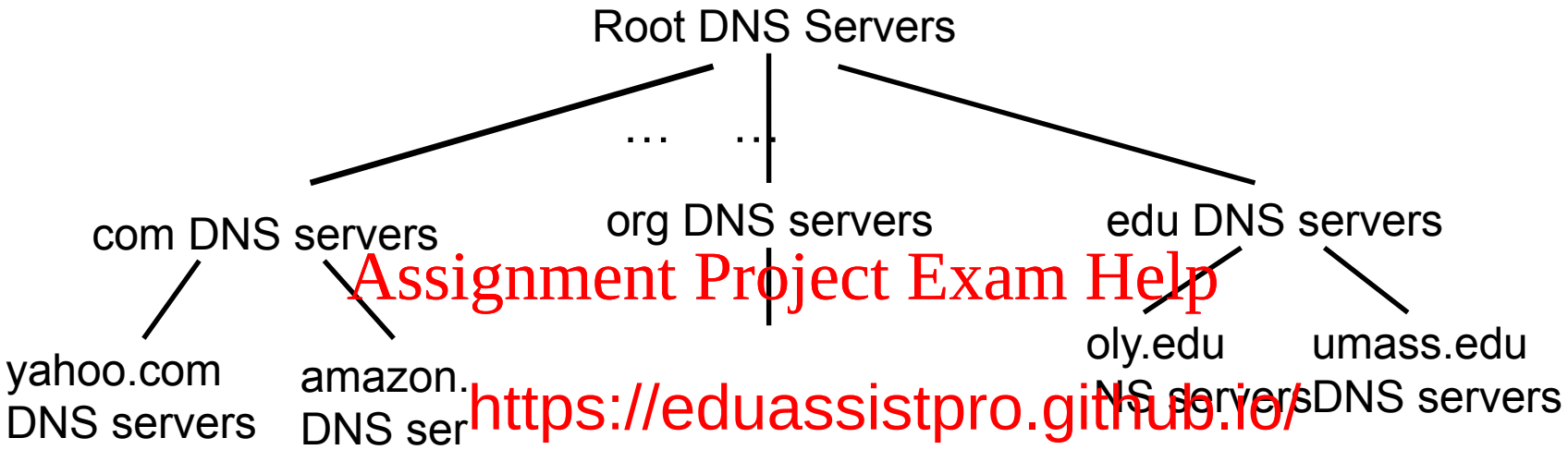
DNS: a distributed, hierarchical database



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client wants IP for www.amazon.com;

- client queries root server to find com DNS server
- client queries .com DNS server to get amazon.com DNS server
- client queries amazon.com DNS server to get IP address for www.amazon.com

DNS: root name servers

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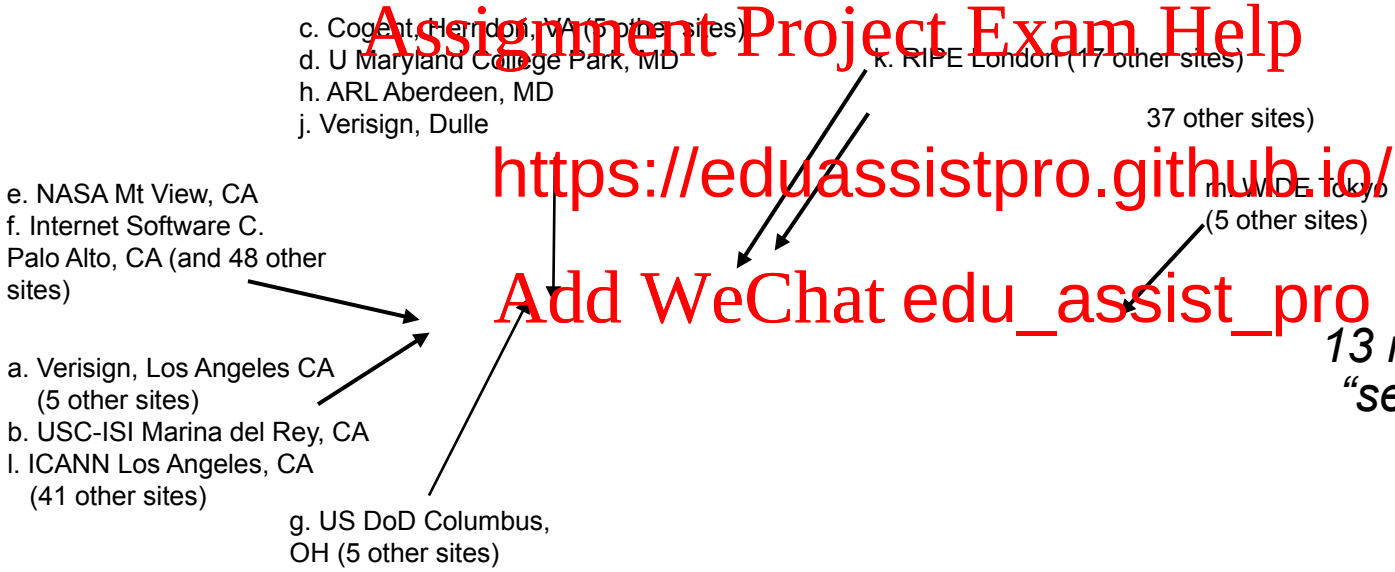

13 root name "servers" worldwide

TLD, authoritative servers

top-level domain (TLD) servers:

- responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, ca, jp
- Network Solutions maintains servers for .com TLD
- Educause for .edu TL

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authoritative DNS servers:

- organization's own DNS server(s), providi hostname to IP mappings for organization's named hosts
- can be maintained by organization or service provider

Local DNS name server

- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
  - also called "default name server"
- when host makes DNS query, query is sent to its local DNS server
  - has local cache of recent (but may be out of date!)
  - acts as proxy, forwards query into hierarchy

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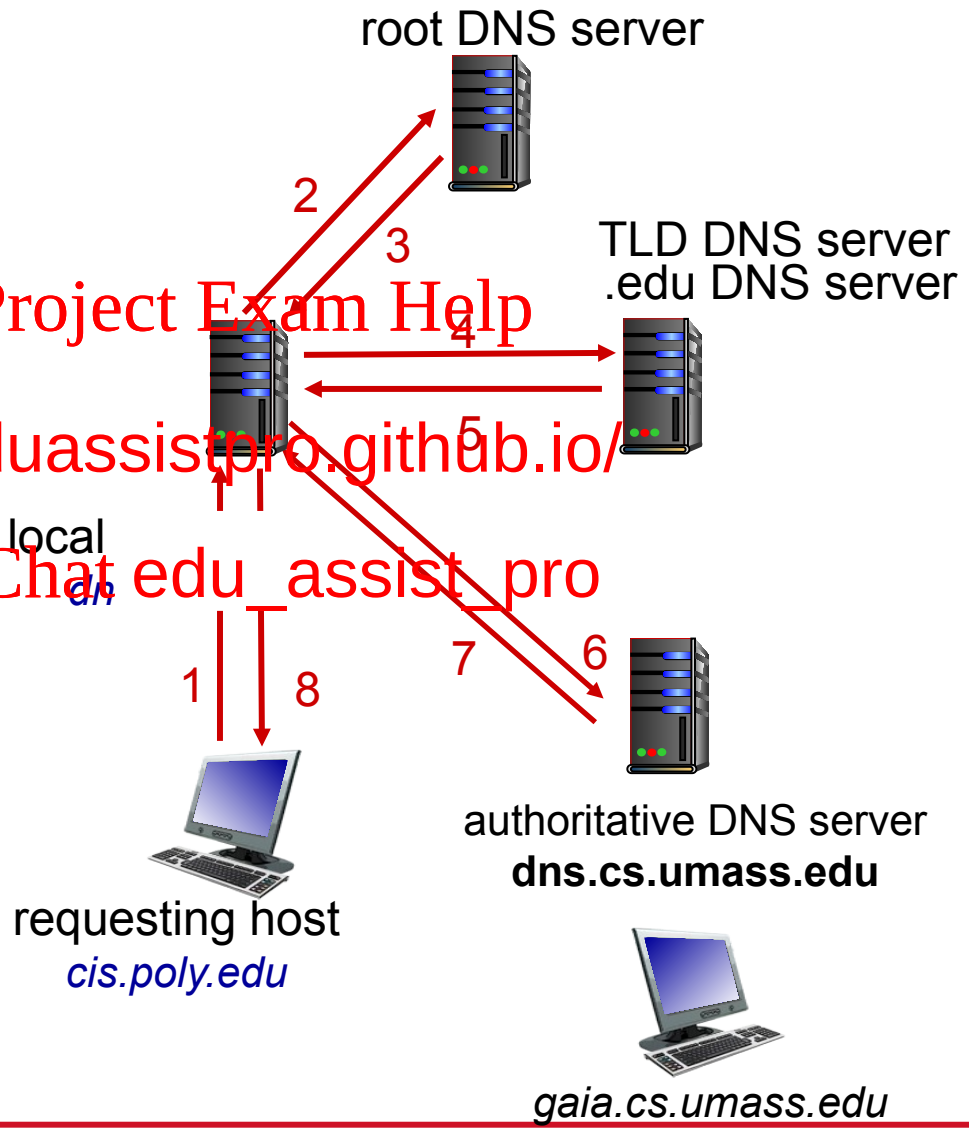
DNS name resolution example

- host at cis.poly.edu wants IP address for gaia.cs.umass.edu

iterated query:

- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"



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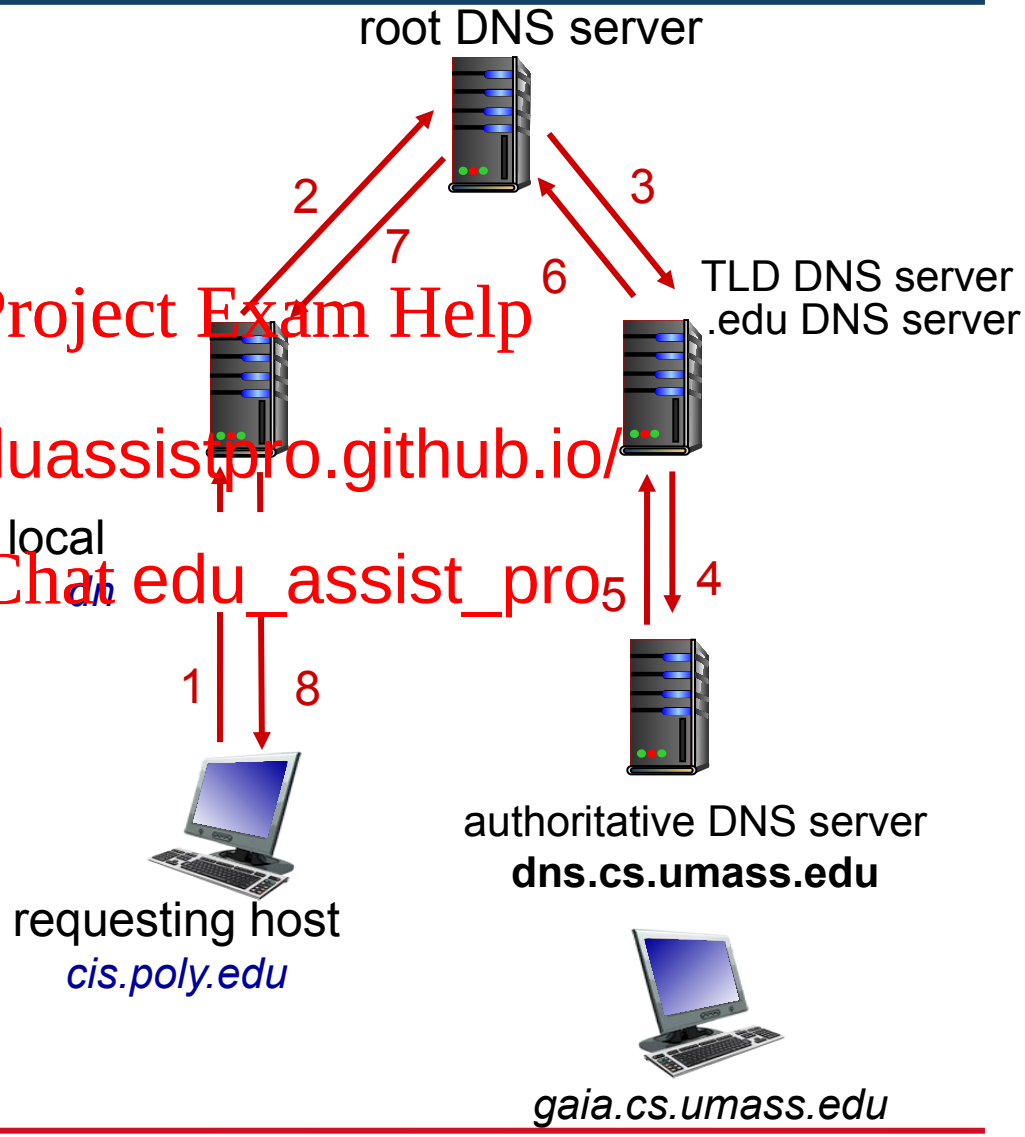
DNS name resolution example (cont'd)

recursive query:

- puts burden of name resolution on contacted name server
- heavy load at upper levels of hierarchy?



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DNS caching, updating records

- once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time (TTL)
- cached entries may be *out-of-date* (best effort name-to-address translation!)
  - if name host changes ternet-wide until all TTLs expire
- update/notify mechanisms proposed IE
  - RFC 2136

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DNS records

DNS: distributed db storing resource records (RR)

RR format: **`(name, value, type, ttl)`**

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type=A

- **`name`** is hostna
- **`value`** is IP add

type=NS

- **`name`** is domain (e.g., foo.com)
- **`value`** is hostname of authoritative name server for this domain

E

lias name for some
" (the r
`cm` is really
`t.backup2.ibm.com`

- **`value`** is canonical name

type=MX

- **`value`** is name of mailserver associated with **`name`**

Inserting records into DNS

- example: new startup "Network Utopia"
- register name networkuptopia.com at *DNS registrar* (e.g., Network Solutions)
  - provide names, IP addresses of authoritative name server
  - registrar inserts two RRs into .com TLD server:

NS) (networkutopia.co

(dns1.networkutop

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- create at authoritative server:

type A record for www.networkuptopia.com;

(www.networkutopia.com, 212.212.212.22, A)

(www.home.networkutopia.com, www.networkutopia.com, CNAME)

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Socket Programming

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Socket programming

goal: learn how to build client/server applications that communicate using sockets

socket: door between application process and end-end-transport protocol

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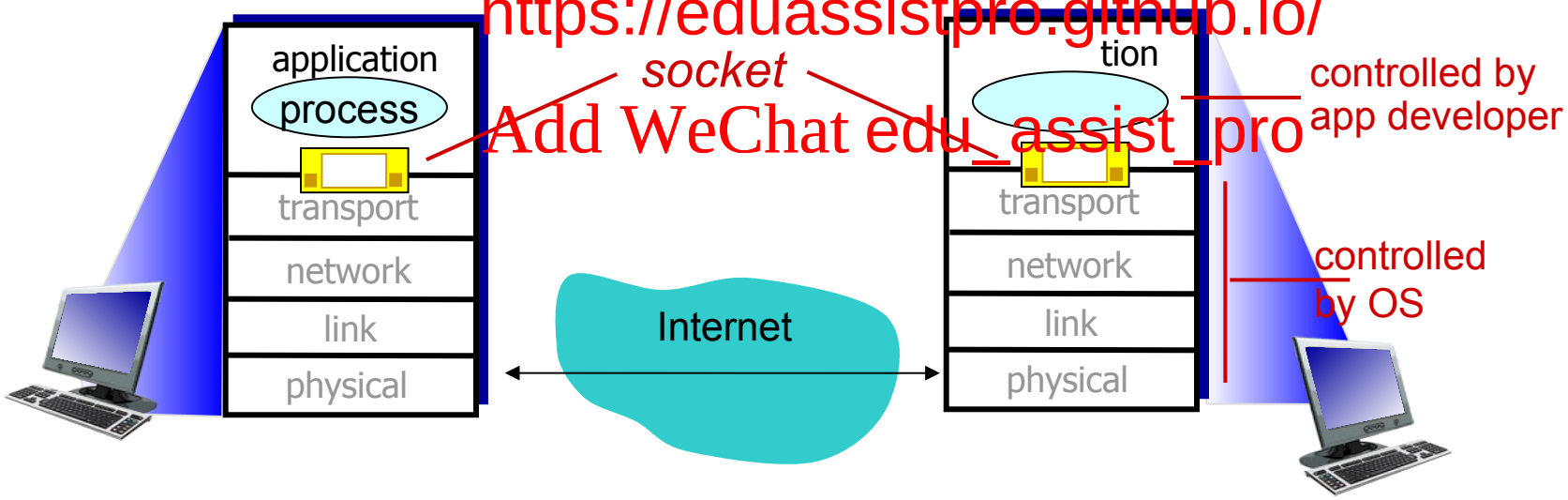

Two socket types for two transport services:

- *UDP:* unreliable datagram
- *TCP:* reliable, byte stream-oriented

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Application Examp

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1. Client reads a ta) from its keyboard and sends the dat rver.

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2. The server receives the dat erts characters to uppercase.
3. The server sends the modified data to the client.
4. The client receives the modified data and displays the line on its screen.

Socket programming with UDP

UDP: no "connection" between client & server

- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- receiver extracts sender IP address and port # from received packet

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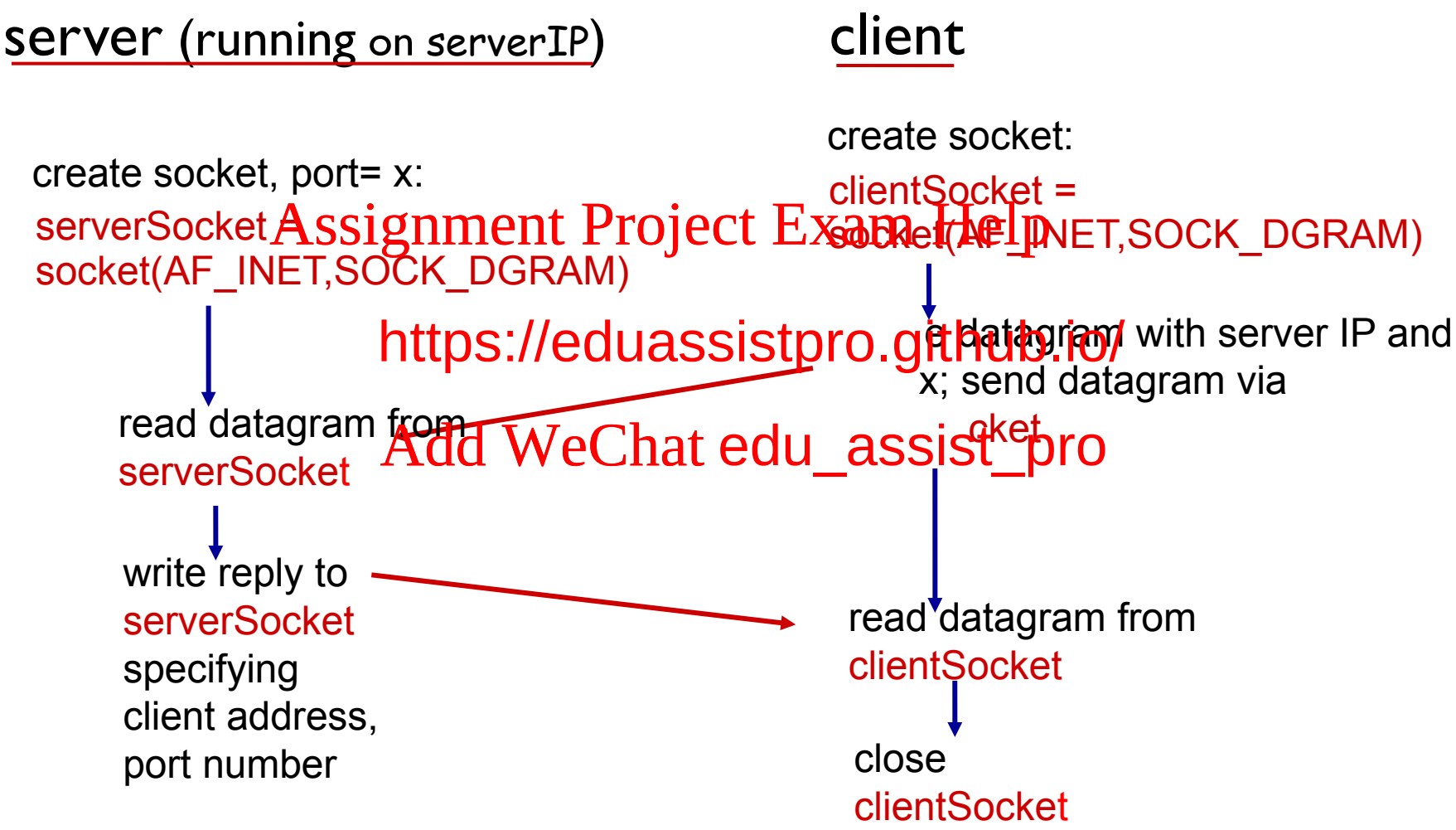
UDP: transmitted data may be lost or received out-of-order

Application viewpoint:

- UDP provides *unreliable* transfer of groups of bytes ("datagrams") between client and server

Client/server socket interaction: UDP



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UDP client

Python UDPClient

include Python's socket library

```
from socket import *
serverName = 'hostname'
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_DGRAM)
```

create UDP for server

get user keyboard input

```
message = input('Input lowercase sentence:')
message = message.encode('utf-8')
```

Attach server name, port to message; send into socket

```
clientSocket.sendto(message,(serverName, serverPort))
```

read reply characters from socket into string

```
modifiedMessage, serverAddress = clientSocket.recvfrom(2048)
```

print out received string and close socket

```
print (modifiedMessage.decode('utf-8'))
clientSocket.close()
```

convert from string to bytes
convert from bytes to string
New feature in Python 3

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UDP server

Python UDPServer

create UDP socket

bind socket to local port number 12000

loop forever

Read from UDP socket into message, getting client's address (client IP and port)

send upper case string back to this client

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_DGRAM)
                                    ort))
                                    /receive”
while 1:
    message, clientA                rSocket.recvfrom(2048)
     message=message.decode('utf-8')
    modifiedMessage = message.upper()
    serverSocket.sendto(modifiedMessage.encode('utf-8’),
clientAddress)
```

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Socket programming with TCP

client must contact server

- server process must first be running
- server must have created socket (door) that welcomes contact

client contacts server by:

- creating TCP socket, connecting server by specifying IP address, port number of server process
- *client connects:* client TCP establishes connection to server TCP

- when contacted by client, *server TCP creates new socket* for server process to communicate with that particular client

er to talk with
ients

numbers used to
ients

application viewpoint:

TCP provides reliable, in-order byte-stream transfer ("pipe") between client and server

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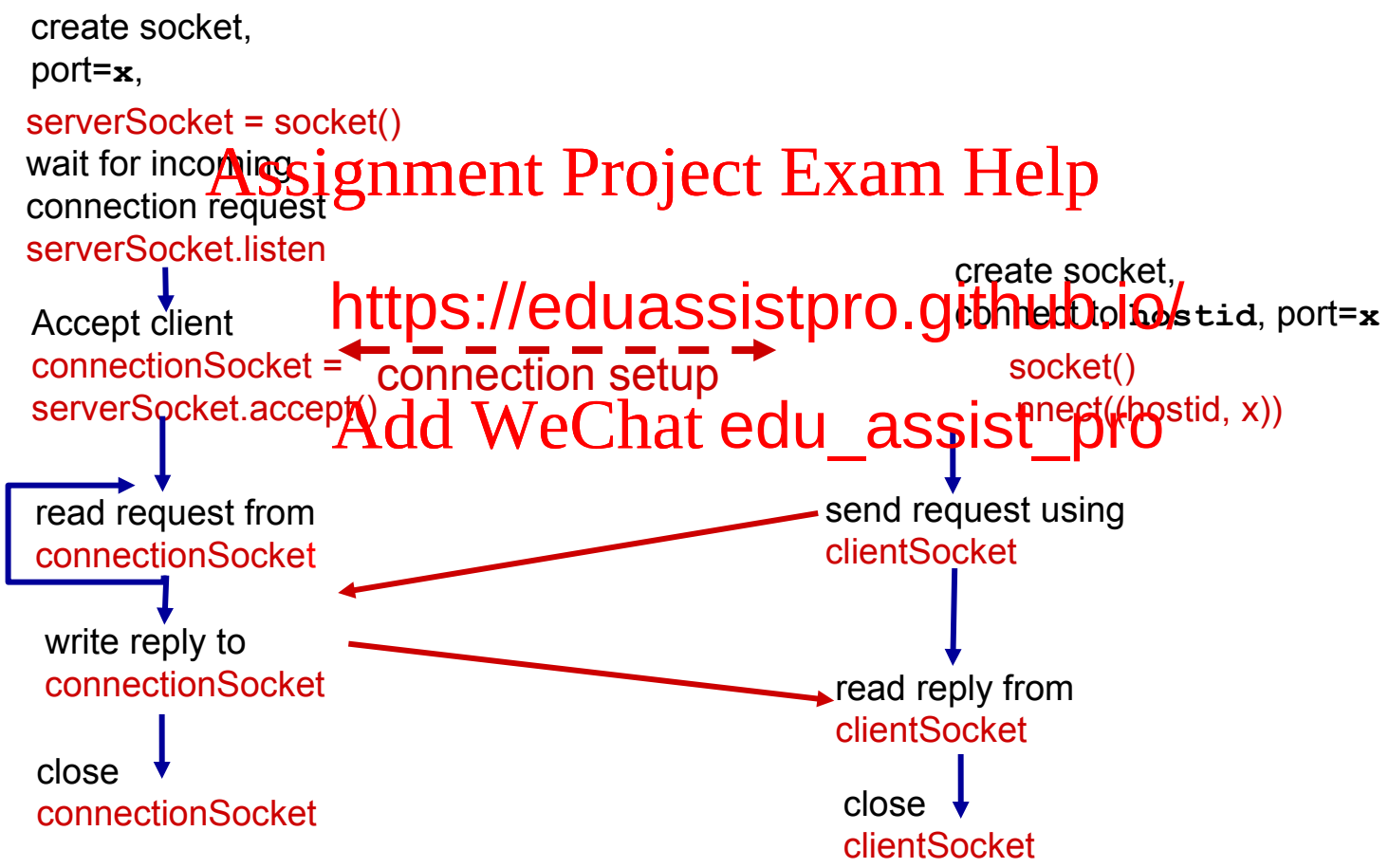
Client-server socket interaction TCP



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Python TCPClient

```
from socket import *
serverName = 'servername'
serverPort = 12000
clientSocket = so                                    EAM)
clientSocket.con                                     ))
sentence = input('Input lowercase
clientSocket.send(sentence.encod

modifiedSentence = clientSocket.recv(1024)
print ('From Server:', modifiedSentence.decode('utf-8'))
clientSocket.close()
```

create TCP socket for server, remote port 12000

No need to attach server name, port

Do not spe

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TCP server

Python TCPServer

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind(('',serverPort))
serverSocket.listen(1)
while 1:
    connectionSocket, addr = serverSocket.accept()
    sentence = connectionSocket.recv(1024)
    capitalizedSentence = sentence.decode('utf-8').upper().encode('utf-8')
    connectionSocket.send(capitalizedSentence)
    connectionSocket.close()
```

create TCP welcoming socket

server begins listening for incoming TCP requests

loop forever

server waits on accept() for incoming requests, new socket created on return

read bytes from socket (but not address as in UDP)

close connection to this client (but *not* welcoming socket)

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Peer-to-Peer

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Pure peer-to-peer model architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers are intermittently connected and cha addresses

examples:

- file distribution (BitTorrent)
- Streaming (Zattoo, KanKan)
- VoIP (Skype)

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File distribution: client-server vs. p2p

Question: how much time to distribute file (size *F*) from one server to *N* peers?

- peer upload/download capacity is limited resource

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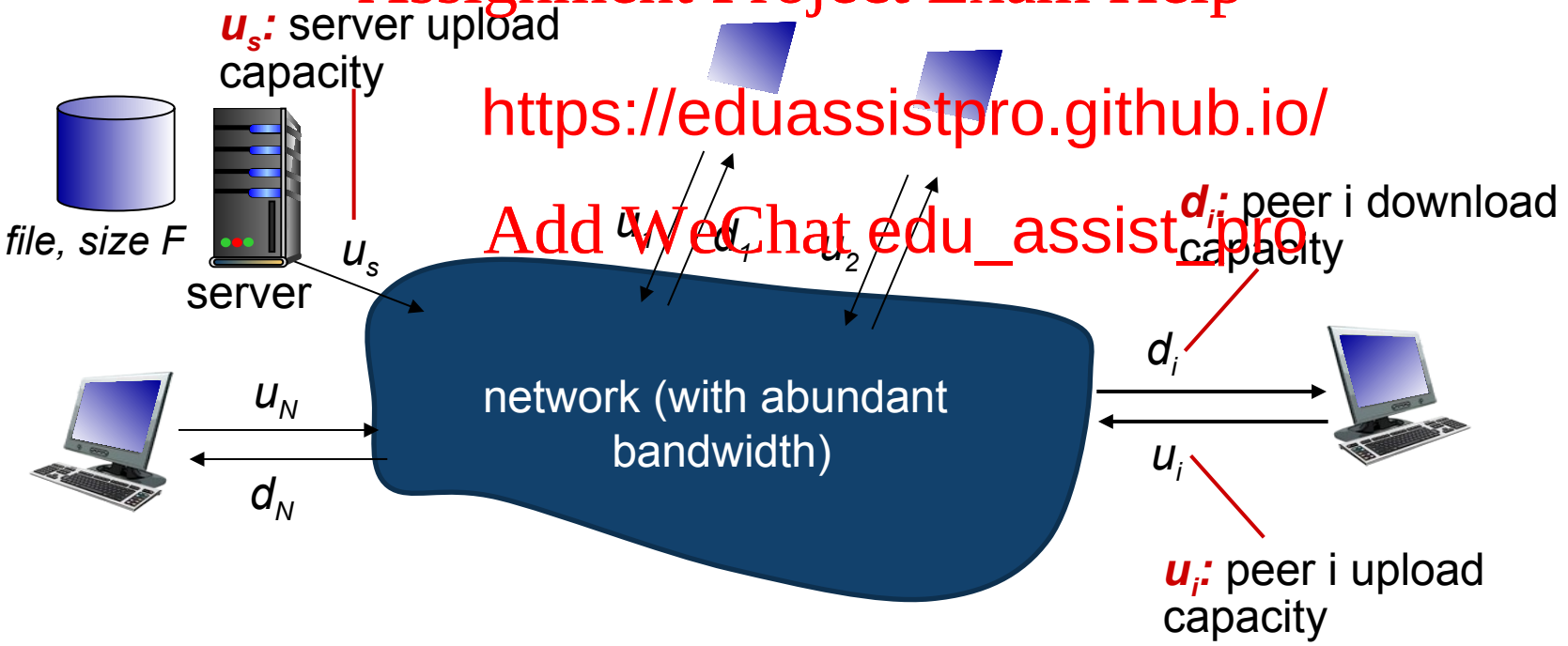
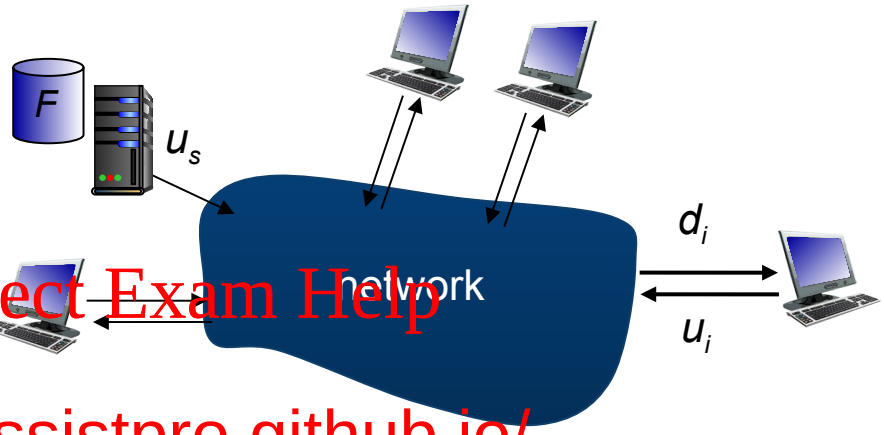


File distribution time: client-server

- *server transmission:* must sequentially send (upload) *N* file copies:
  - time to send one copy: F/u_s
  - time to send N copies:
- *client:* each client download file co
  - d_{min} = min client download rate
  - (worst case) client download time: F/d_{min}



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time to distribute F to N clients using client-server approach

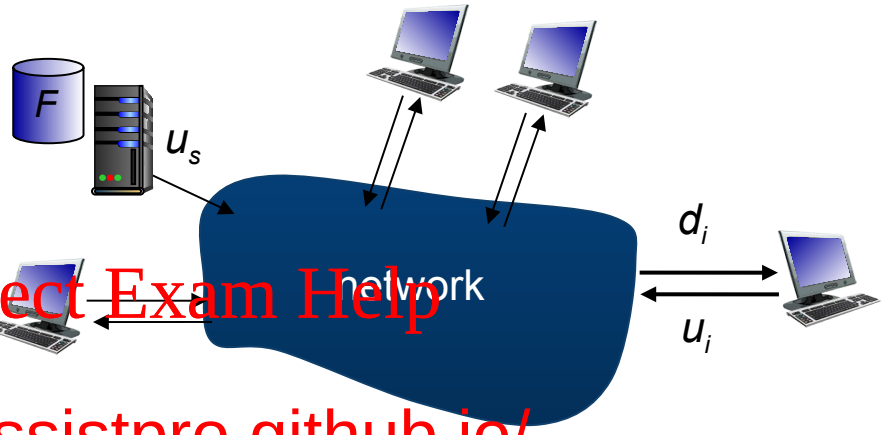
$$D_{c-s} > max\{NF/u_s, F/d_{min}\}$$

increases linearly in N

File distribution time: p2p

› *server transmission:* must upload at least one copy

- time to send one copy: F/u_s
  - *client:* each client must download file copy
    - client download ti
  - *clients:* as aggregat = upload NF bits
    - Max upload rate $u_s + \Sigma u_i$
    - $NF/(u_s + \Sigma u_i)$



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time to distribute F to N clients using P2P approach

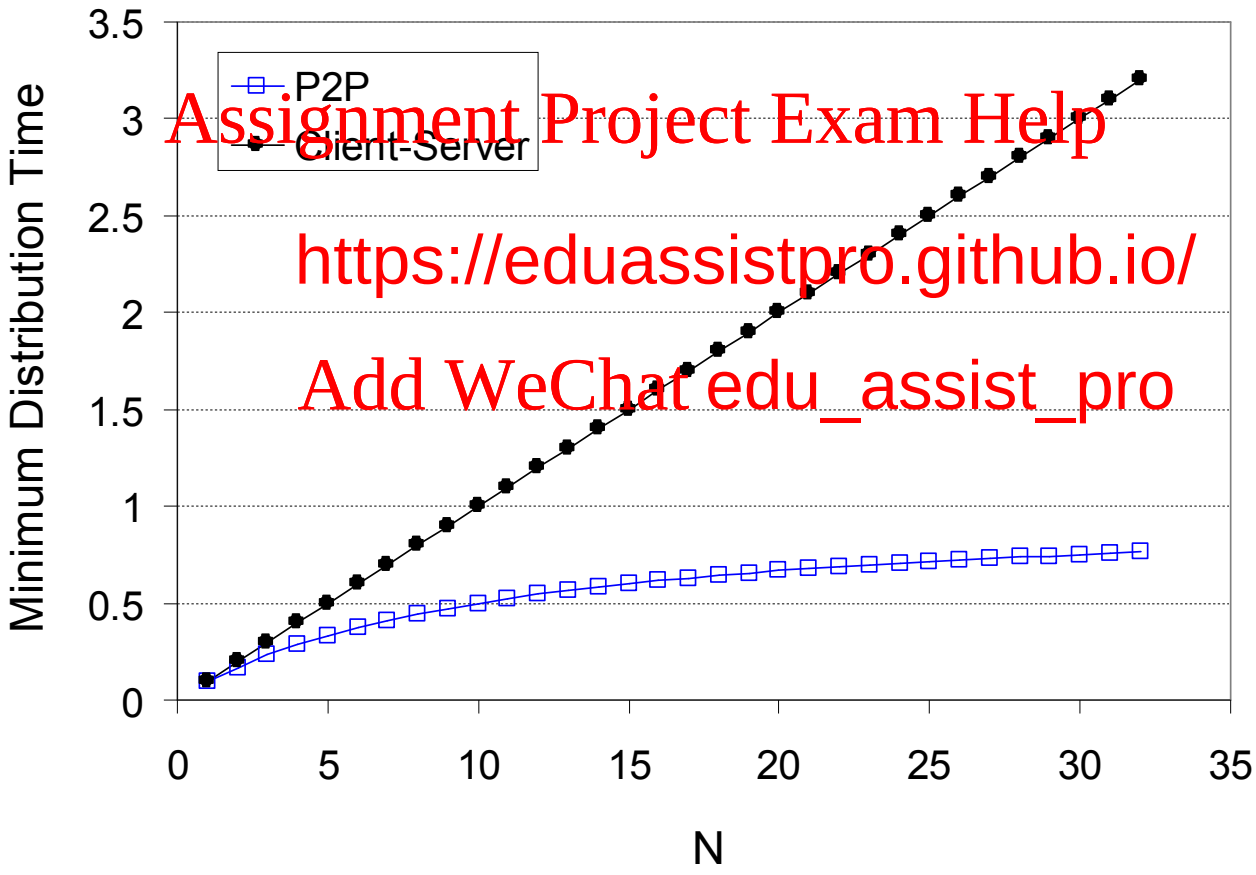
$$D_{P2P} > max\{F/u_s, F/d_{min}, NF/(u_s + \Sigma u_i)\}$$

increases linearly in N …

… but so does this, as each peer brings service capacity

Client-server vs. p2p

client upload rate = u, F/u = 1 hour, $u_s = 10u$, $d_{min} \geq u_s$



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P2P file distribution: BitTorrent

BitTorrent, a file sharing application

- 20% of European internet traffic in 2012.
- Used for Linux distribution, software patches, distributing movies
- Goal: quickly replicate large files to large number of clients

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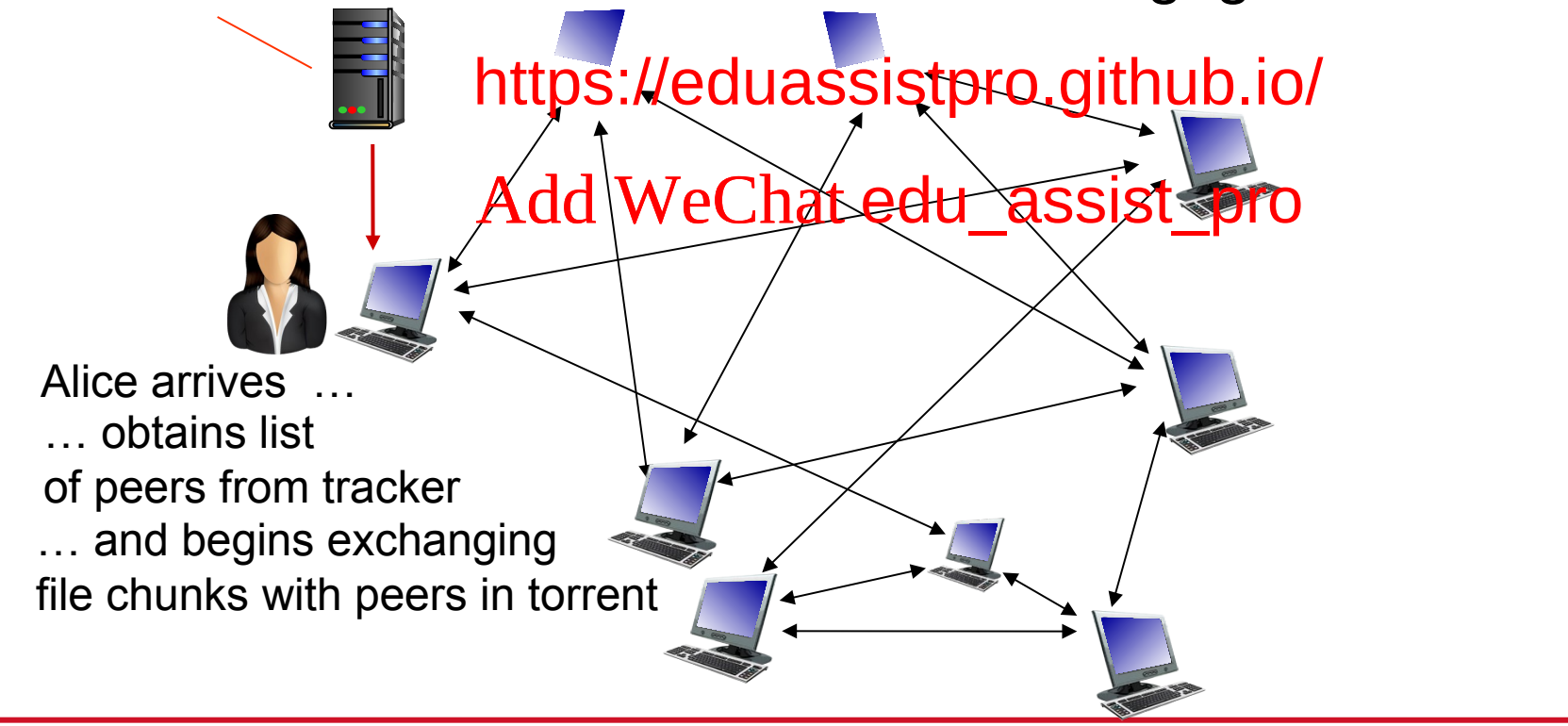
- Web server hosts a .torrent file (w/ file l tracker's URL…)
- A tracker tracks downloaders/owners of
- Files are divided into chunks (256kB-1MB)
- Downloaders download chunks from themselves (and owners)
- Tit-for-tat: the more one shares (server), the faster it can download (client)

P2P file distribution: BitTorrent

- file divided into 256KB chunks
- peers in torrent send/receive file chunks



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P2P file distribution: BitTorrent

- peer joining torrent:
  - has no chunks, but will accumulate them over time from other peers
  - registers with trac peers, connects t ("neighbors")

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- while downloading, peer uploads chunks to other peers
- peer may change peers with whom it exchanges chunks
- *churn:* peers may come and go
- once peer has entire file, it may (selfishly) leave or (altruistically) remain in torrent

BitTorrent: requesting, sending file chunks

requesting chunks:

- at any given time, different peers have different subsets of file chunks
- periodically, Alice a peer for list of chunks that they have
- Alice requests missing chunks from peers, rarest first

sending chunks: tit-for-tat

- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
  - rs are choked by Alice (do
  - e chunk
  - op 4 every10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

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BitTorrent: tit-for-tat

(1) Alice "optimistically unchokes" Bob

(2) Alice becomes one of Bob's top-four providers; Bob reciprocates

(3) Bob becomes one of Alice's top-four providers

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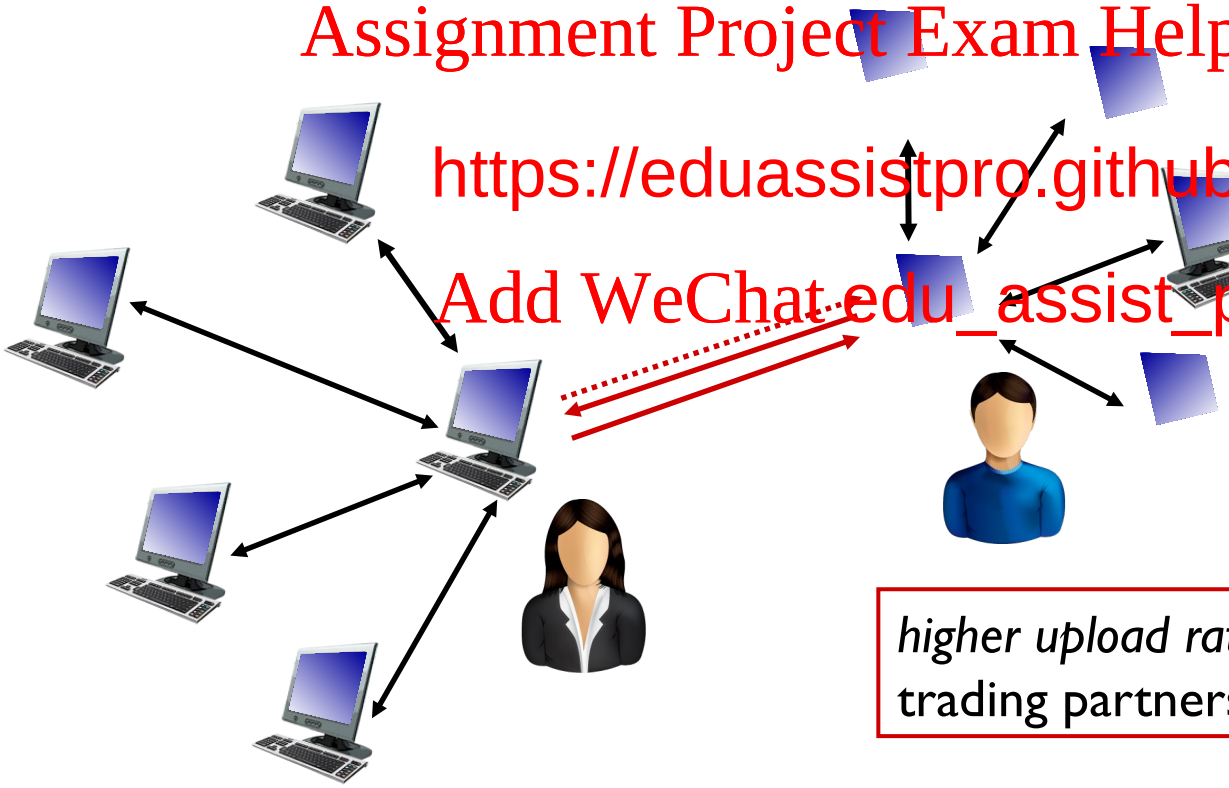

higher upload rate: find better trading partners, get file faster !