Computer Networks and Applications

COMP 3331/COMP 9331

Week 2

Introduction(Networking, Security) & Application Layer (Principles, Web)

Reading Guide: Chapter 1, Sections 1.5 - 1.7
Chapter 2, Sections 2.1 – 2.2

1. Introduction: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network

- packet s , network structure

1.4 delay, loss, throughput rks

1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

Self study

Three (networking) design steps

- Break down the problem into tasks
- Organize these tasks
- Decide who

Tasks in Networking

- What does it take to send packets across?
- Simplistic decomposition:
  - Task 1: sen
  - Task 2: stitch these togeth ross country/globe

- This gives idea of what I mean by decomposition

Tasks in Networking (bottom up)

- Bits /Packets on wire
- Deliver packets within local network
- Deliver packets across global network
- Ensure that process estination
- Do something with the d

Resulting Modules

- Bits / Packets on wire (Physical)
- Delivery packets within local network (Datalink)
- Deliver packets across global network (Network)
- Ensure that p process. (Transport)
- Do something with the dat tion)

This is decomposition…

Now, how do we organize these tasks?

Inspiration…

- CEO A writes letter to CEO B
  - Folds letter and hands it to administrative aide
    - » Aide:
      - » Puts letter in envelope with CEO

```
Dear John,

Your days are numbe

          --Pat
```

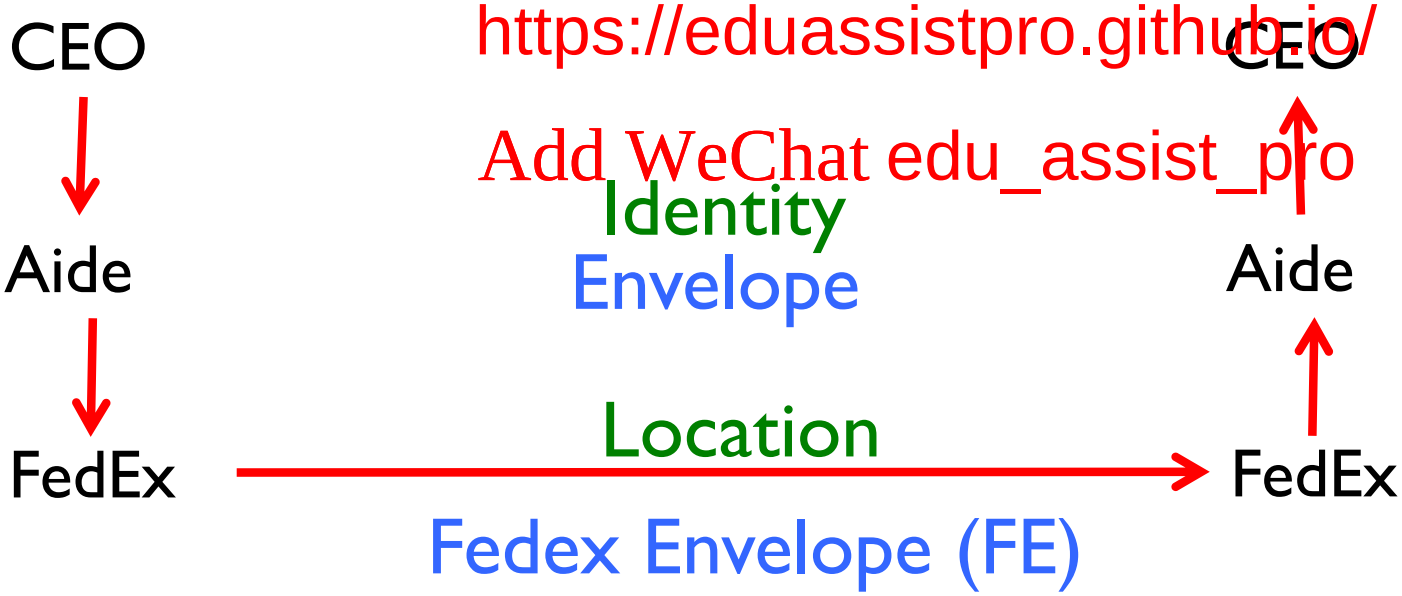

- FedEx Office
  - Puts letter in larger envelope
  - Puts name and street address on FedEx envelope
  - Puts package on FedEx delivery truck
- FedEx delivers to other company

The Path of the Letter

"Peers" on each side understand the same things

No one else needs to (abstraction)

Lowest level has most packaging

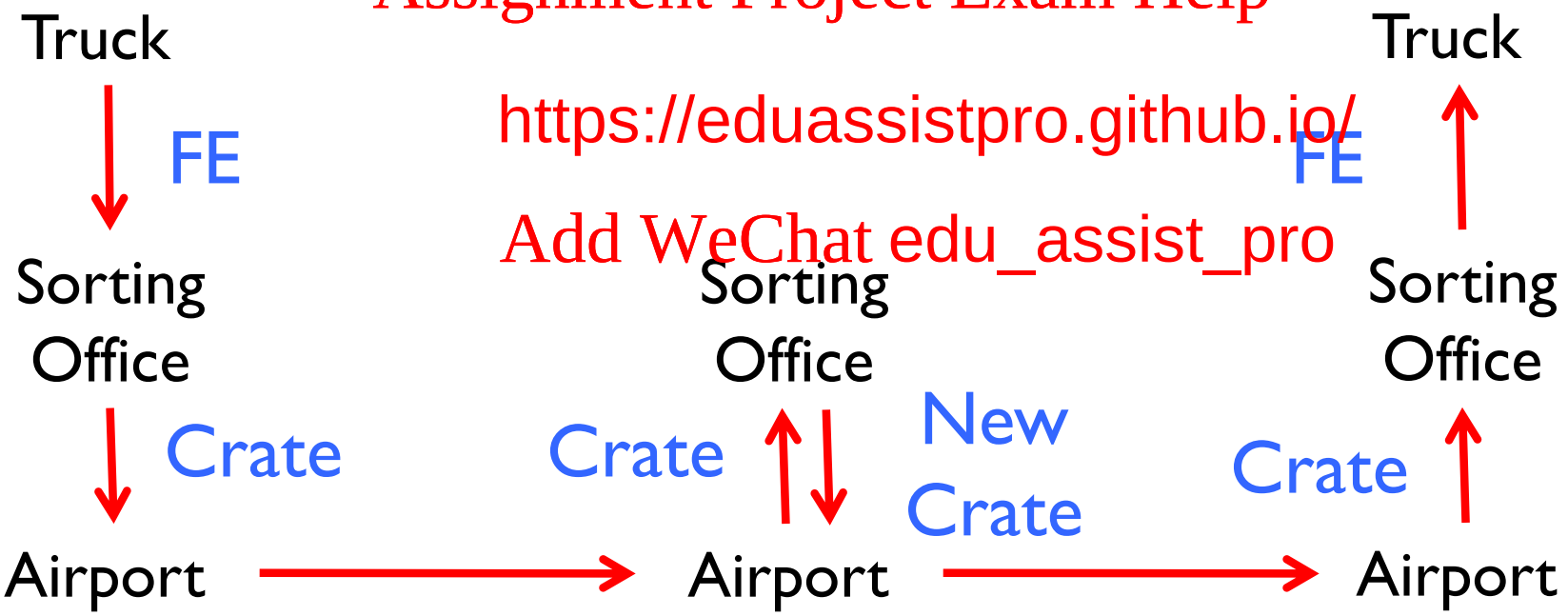


The Path Through FedEx

Higher "Stack" at Ends

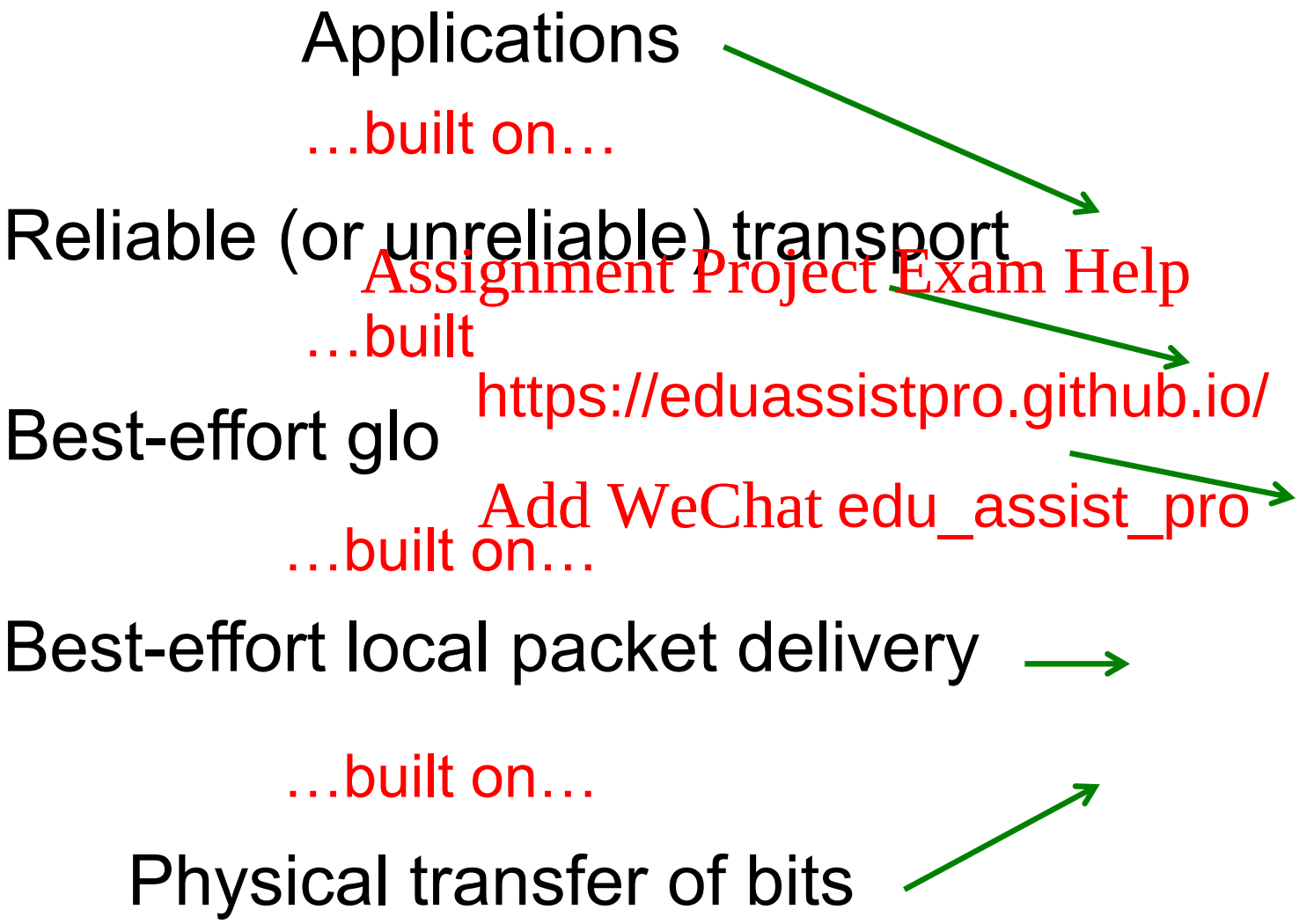
Highest Level of "Transit Stack" is Routing

Partial "Stack"



Deepest Packaging (Envelope+FE+Crate) at the Lowest Level of Transport

In the context of the Internet



Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP, Skype, ..
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *physical:* bits "on the wire"

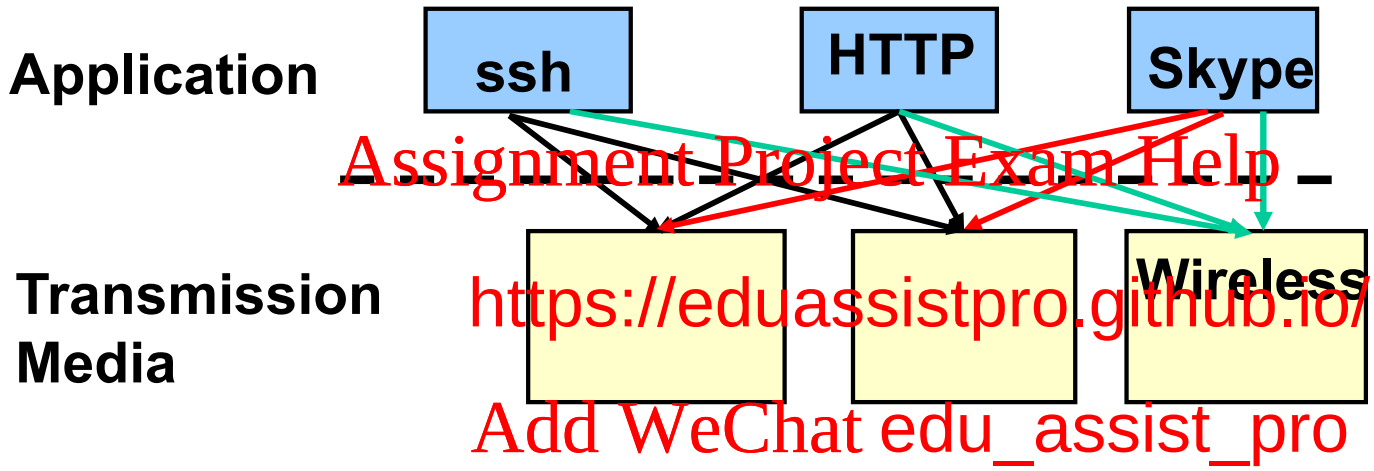
Three Observations

- Each layer:
  - Depends on layer below
  - Supports layer above
  - Independent of others
- Multiple versions
  - Interfaces differ somewhat
  - Components pick which lower level protocol to use
- But only one IP layer
  - Unifying protocol

Quiz: What are the benefits of layering?

-
-
-

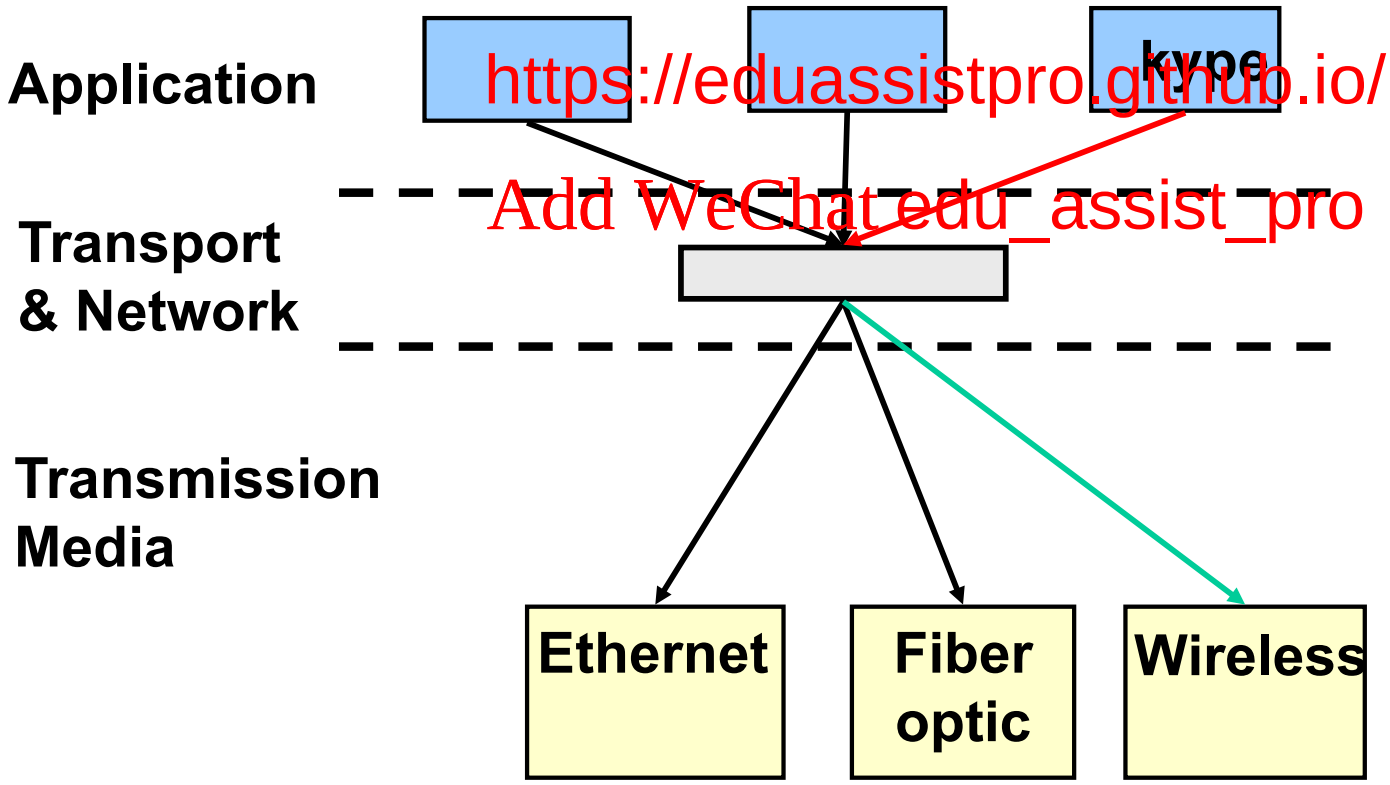
An Example: No Layering



- No layering: each new application has to be re-implemented for every network technology !

An Example: Benefit of Layering

- Introducing an intermediate layer provides a common abstraction for various network technologies



Is Layering Harmful?

- Layer N may duplicate lower level functionality
  - E.g., error recovery to retransmit lost data
- Information hiding may hurt performance
  - E.g. packet lo congestion
- Headers start
  - E.g., typically TCP + IP + Et ers add up to 54 bytes
- Layer violations when the gains too great to resist
  - E.g., TCP-over-wireless
- Layer violations when network doesn't trust ends
  - E.g., Firewalls

Distributing Layers Across Network

- Layers are simple if only on a single machine
  - Just stack of modules interacting with those above/below
- But we need to cross machines
  - Hosts
  - Routers
  - Switches
- What gets implemented where?

What Gets Implemented on Host?

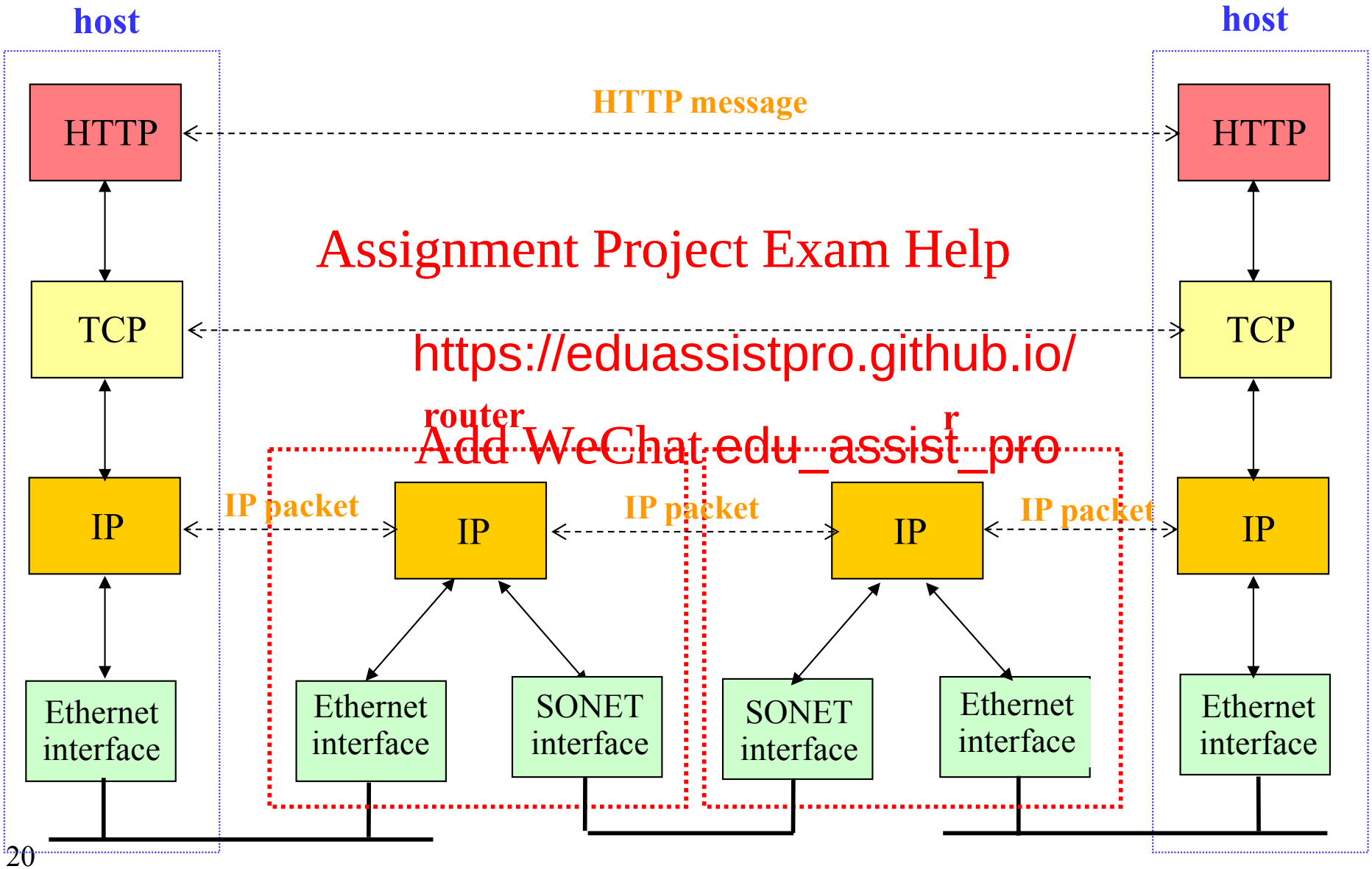
- Bits arrive on wire, must make it up to application

- Therefore, al at host!

What Gets Implemented on Router?

- Bits arrive on wire
  - Physical layer necessary
- Packets must hop
  - datalink layer
- Routers participate in glob
  - Network layer necessary
- Routers don't support reliable delivery
  - Transport layer (and above) ***not*** supported

Internet Layered Architecture



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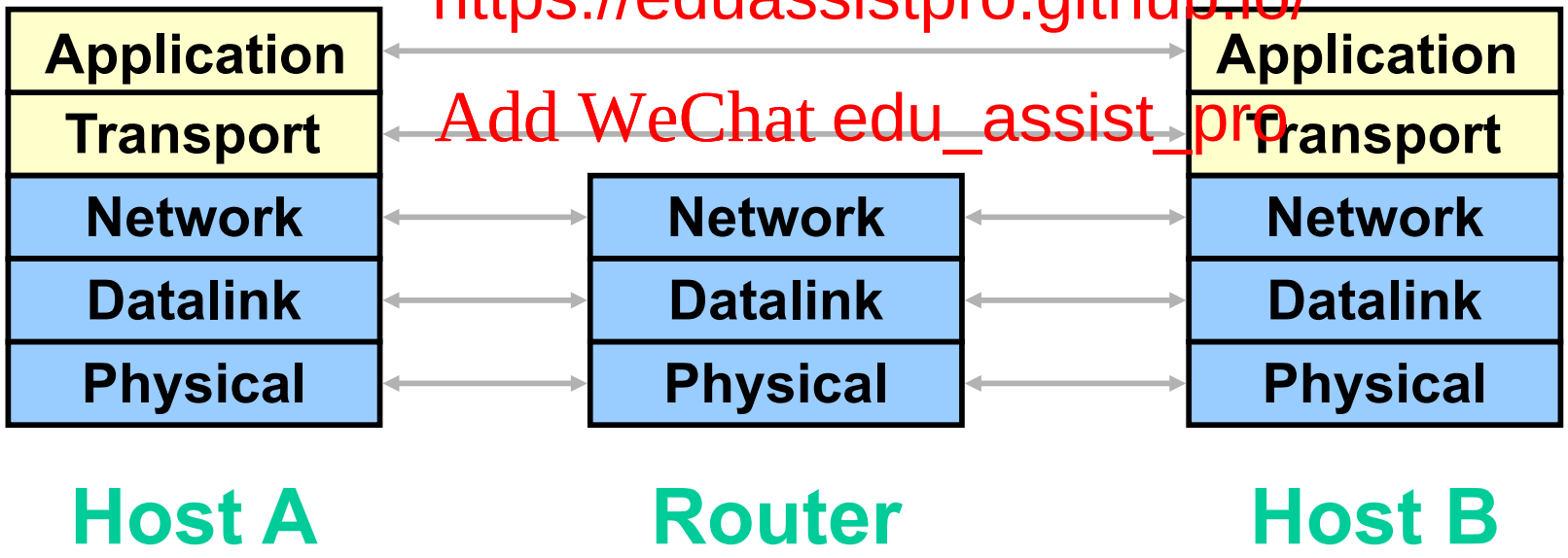
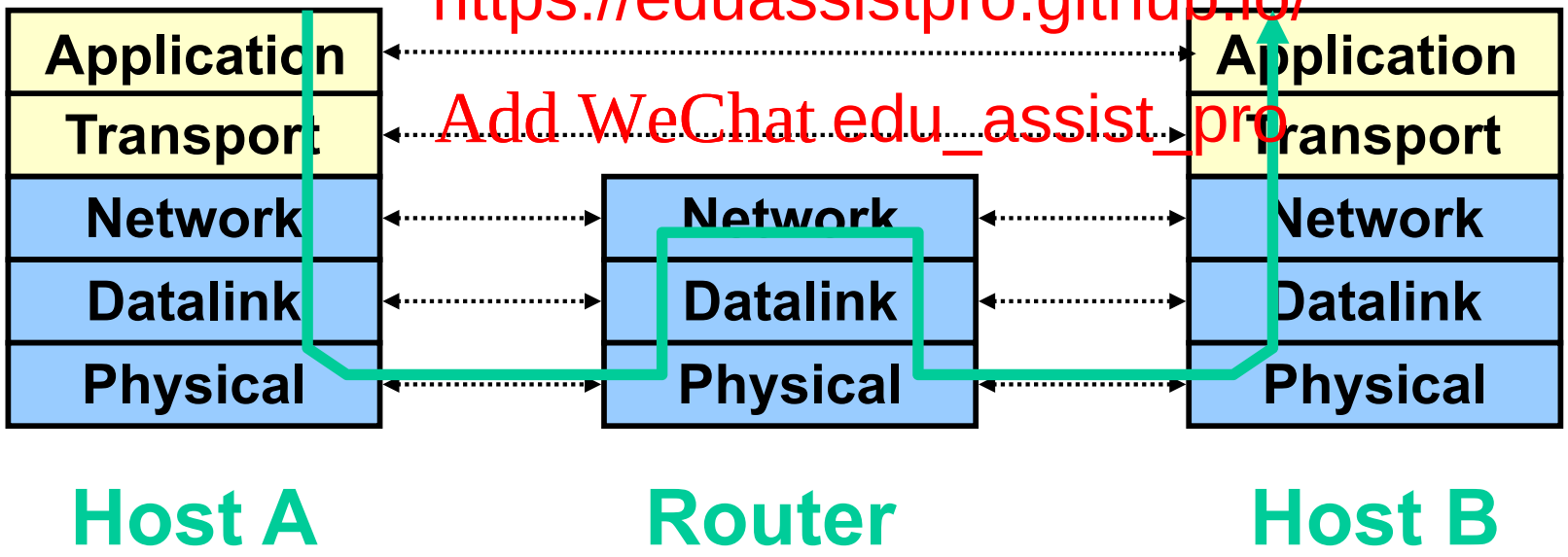
Logical Communication

- Layers interacts with peer's corresponding layer

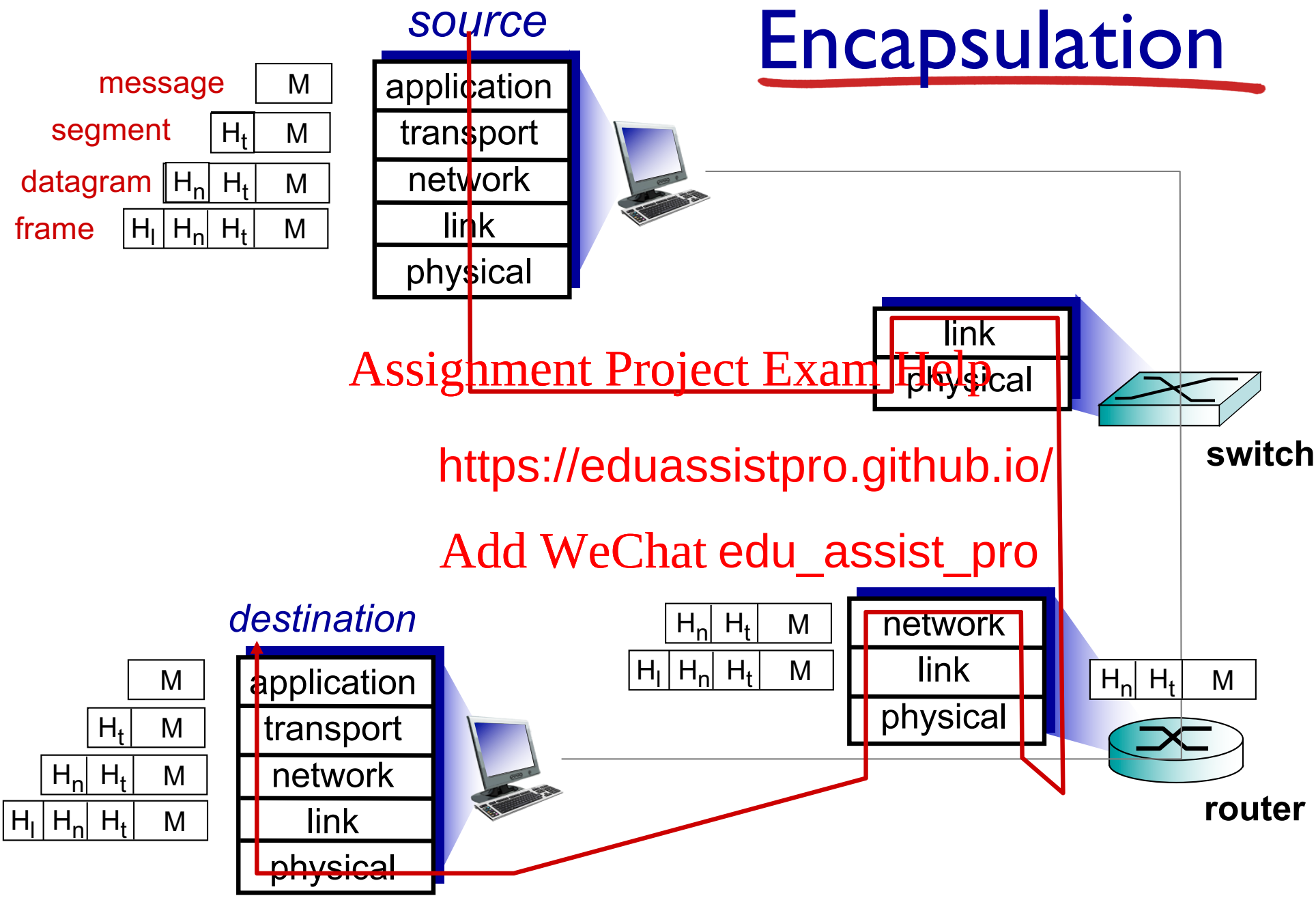


Physical Communication

- Communication goes down to physical network
- Then from network peer to peer
- Then up to relevant layer



Encapsulation



1. Introduction: roadmap

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- end systems, access networks, links

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- packet swi , network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

Self study

Introduction: summary

covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switc
    circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

you now have:

- context, overview, "feel" of networking
- more depth, detail *to ow!*

2. Application Layer: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic m

- SMTP, POP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution orks (CDNs)

et programming DP and TCP

2. Application layer

our goals:

- conceptual, implementation aspects of network application protocols
  - transport-lay service mode
  - client-server paradigm
  - peer-to-peer paradigm
- learn about protocols by examining popular application-level protocols
  - HTTP / POP3 / IMAP
  - network s
  - socket API

Creating a network app

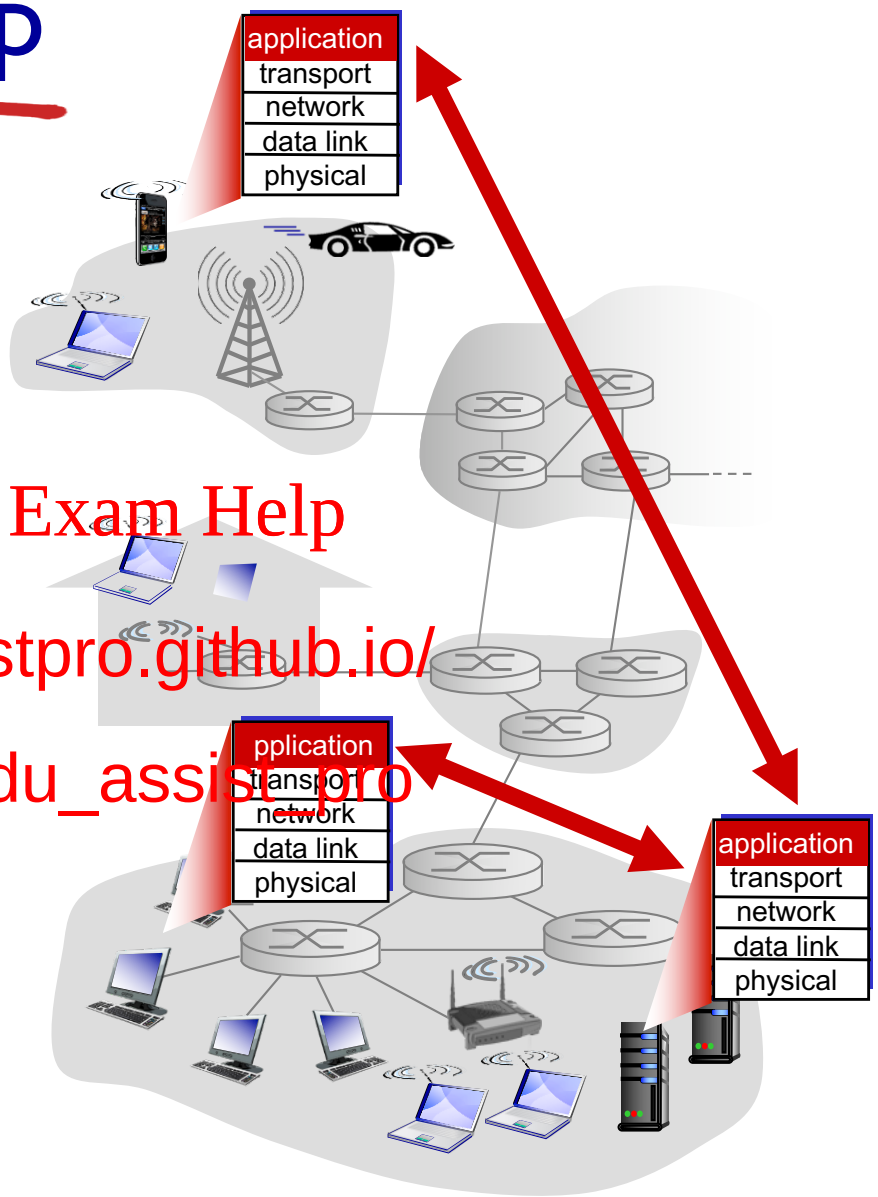
Write programs that:

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

No need to write softwar devices

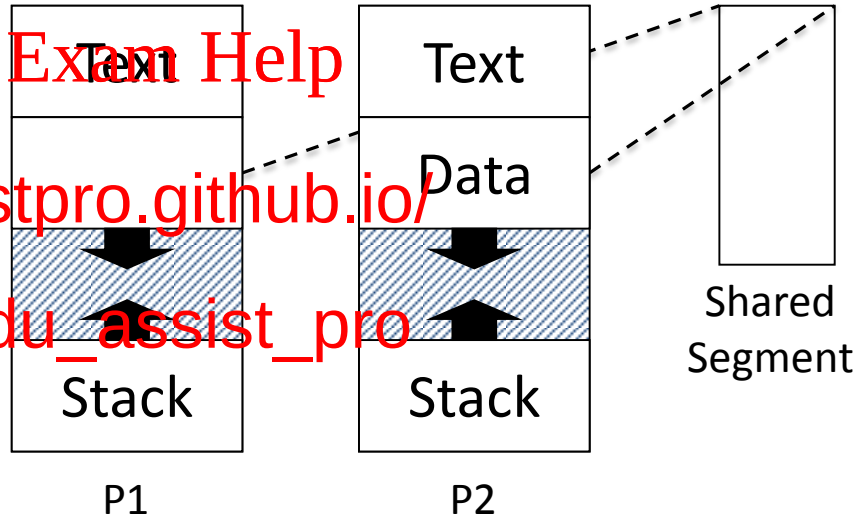
- network-core devices do not run user applications

- applications on end systems allows for rapid app development, propagation



Interprocess Communication (IPC)

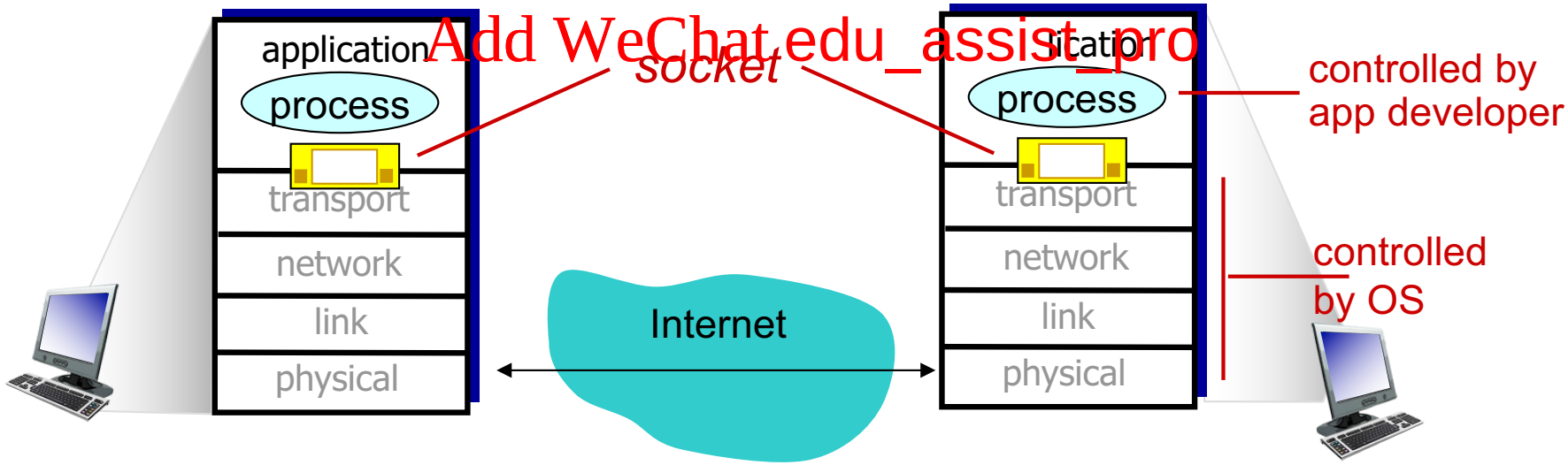
- Processes talk to each other through Inter-process communication (IPC)
- On a single m
  - Shared memory



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

Sockets

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

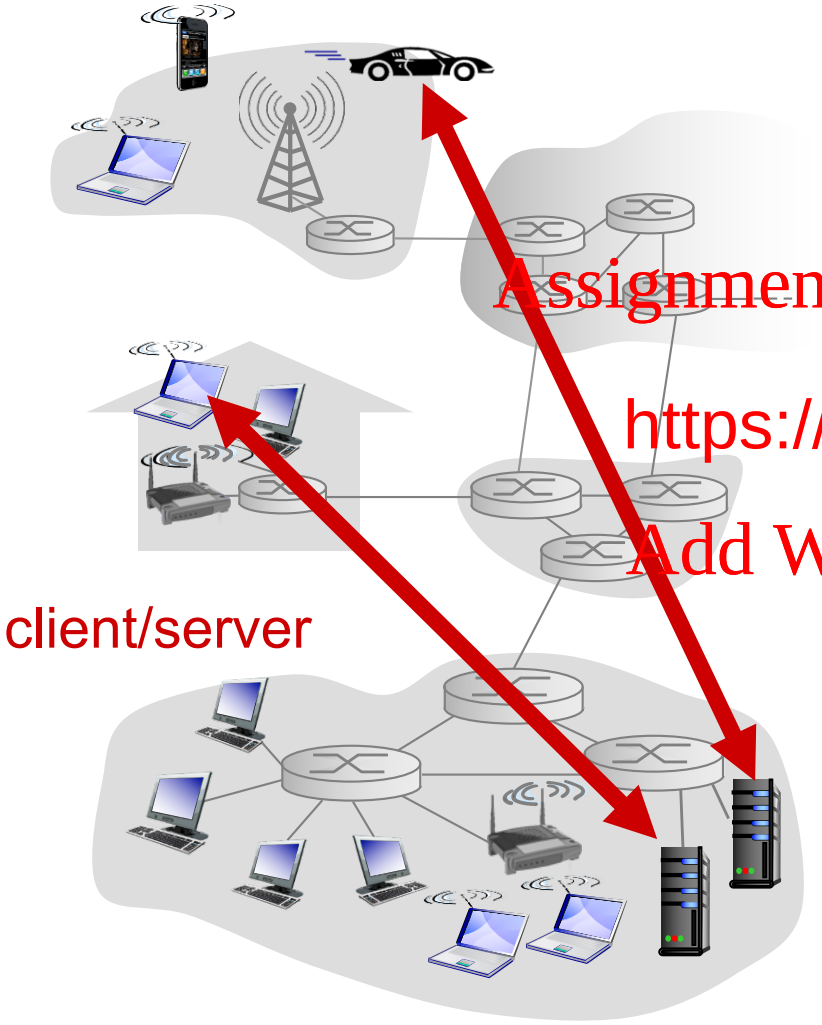


Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- *Q:* does IP address of host on which proces suffice for identif 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:
  - P server: 80
  - l server: 25
  - HTTP message to .edu.au web server:
    - IP address: 129.94.242.51
    - port number: 80

Client-server architecture



server:

- Exports well-defined request/response interface
- long-lived process that waits for requests

iving request, carries

clie

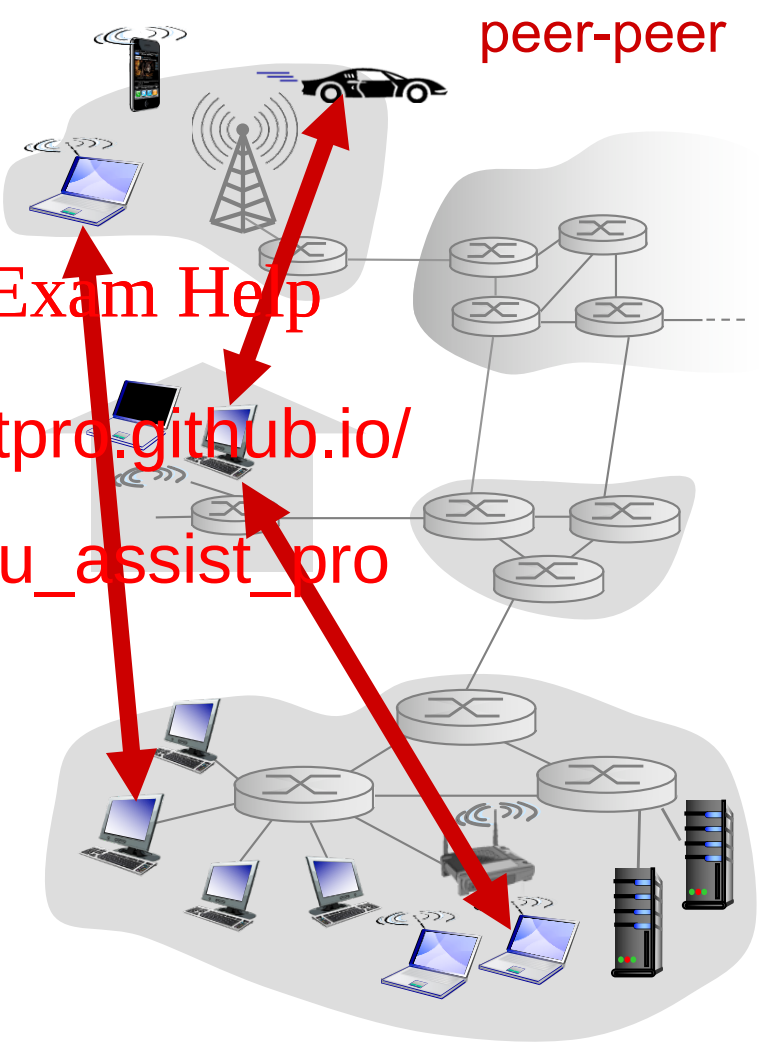
- Short-lived process that makes requests
- "User-side" of application
- Initiates the communication

Client versus Server

- Server
  - Always-on host
  - Permanent IP address (rendezvous location)
  - Static port con (http: 80, email ssh:22)
  - Data centres for scaling
  - May communicate with other servers to respond
- Client
  - May be intermittently connected
  - May have dynamic IP sses
  - o cate with each other

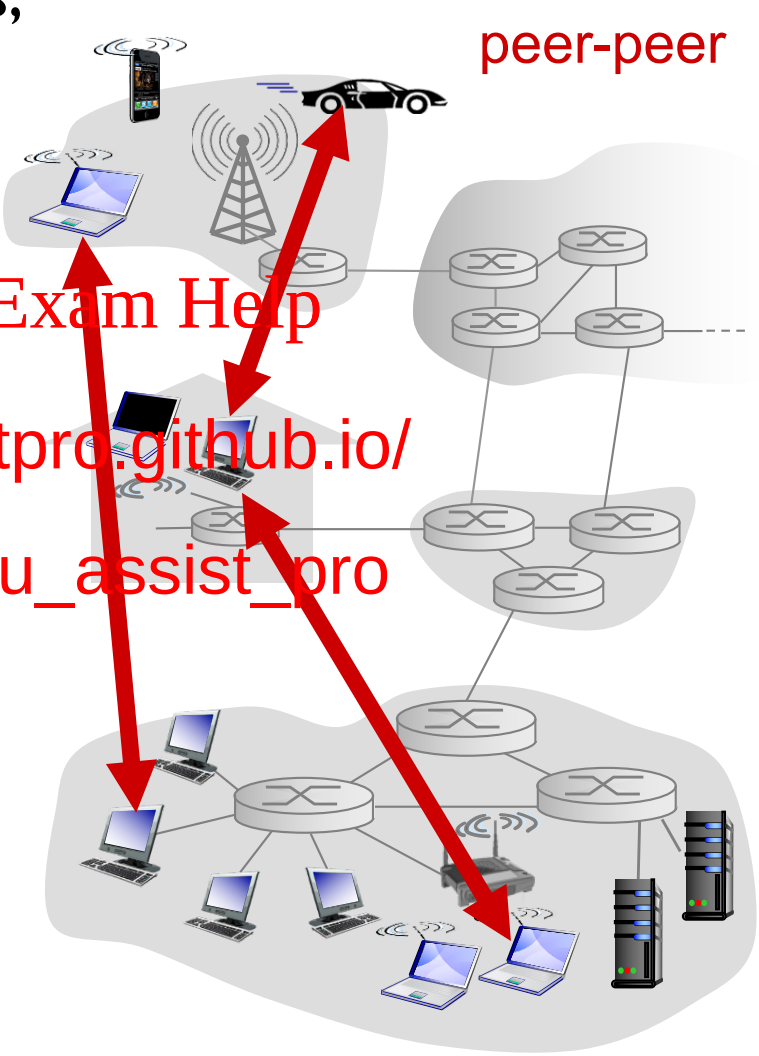
P2P architecture

- *no* always-on server
  - No permanent rendezvous involved
- arbitrary end systems (peers) directly communicate
- Symmetric respo (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: redundanc
+ Geographic distributi



- 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 & how fields 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

ary protocols:

kype

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 los

throughput

- some apps (e.g., multimedia) require minimum amount of throughput to be "
  ctive
- r apps ("elastic apps") ever
  input they get

timing

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

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
real-time audio/video	l	s-1Mbps vid 5Mbps	yes, 100’s msec
stored audio/video	loss-tolerant	sa	yes, few msecs
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:* send overwhelm rece
- *congestion control* 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

provide:
y, flow control,
n control,
oughput
guarantee, security,
orconnection setup,

Q: why bother? Why is there a UDP?

NOTE: More on transport in Weeks 4 and 5

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		TCP
file transfer		TCP
streaming multimedia	HTTP (e.g., RTP [RFC 18	CP or UDP
Internet telephony	SIP, RTP, proprietary (e.g., Skype)	TCP or UDP

2. Application Layer: outline

2.1 principles of network applications
- app architectures
- app require

2.2 Web and H

2.3 electronic mail
- SMTP, POP3, IMAP

2.4 DNS

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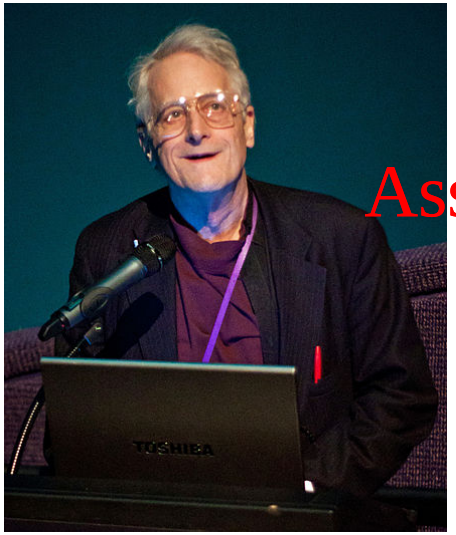
DP and TCP

The Web – Precursor

Self study



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 documents would be automatically aid via electronic means tual copying of their documents
- Coined the term "Hypertext"

The Web – History

Self study

Tim Berners-Lee

- World Wide Web (WWW): a distributed database of "pages" linked through Hypertext Transport Protocol (HTTP)

mentation - 1990 at CERN

- HTTP/0

  - 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

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 pr tp: 80 https: 443
- *directory path*: hiera
- *resource*: Identifies the desired resou

Uniform Resource Locator (URL)

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

- Extend the idea of hierarchical hostnames to include anything in a file system
  - http://www.cse.u ls/TMC2012.pdf
- Extend to program executions as we
  - http://us.f413.mail.yahoo.com/ym/ShowLetter?box=%40B%40Bulk&MsgId=2604_1744106_29699_1123_1261_0_28917_3552_1289957100&Search=&Nhead=f&YY=31454&order=down&sort=date&pos=0&view=a&head=b
  - Server side processing can be incorporated in the name

HTTP overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server mo
  - *client:* browse requests, rec (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 T connection from
- 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

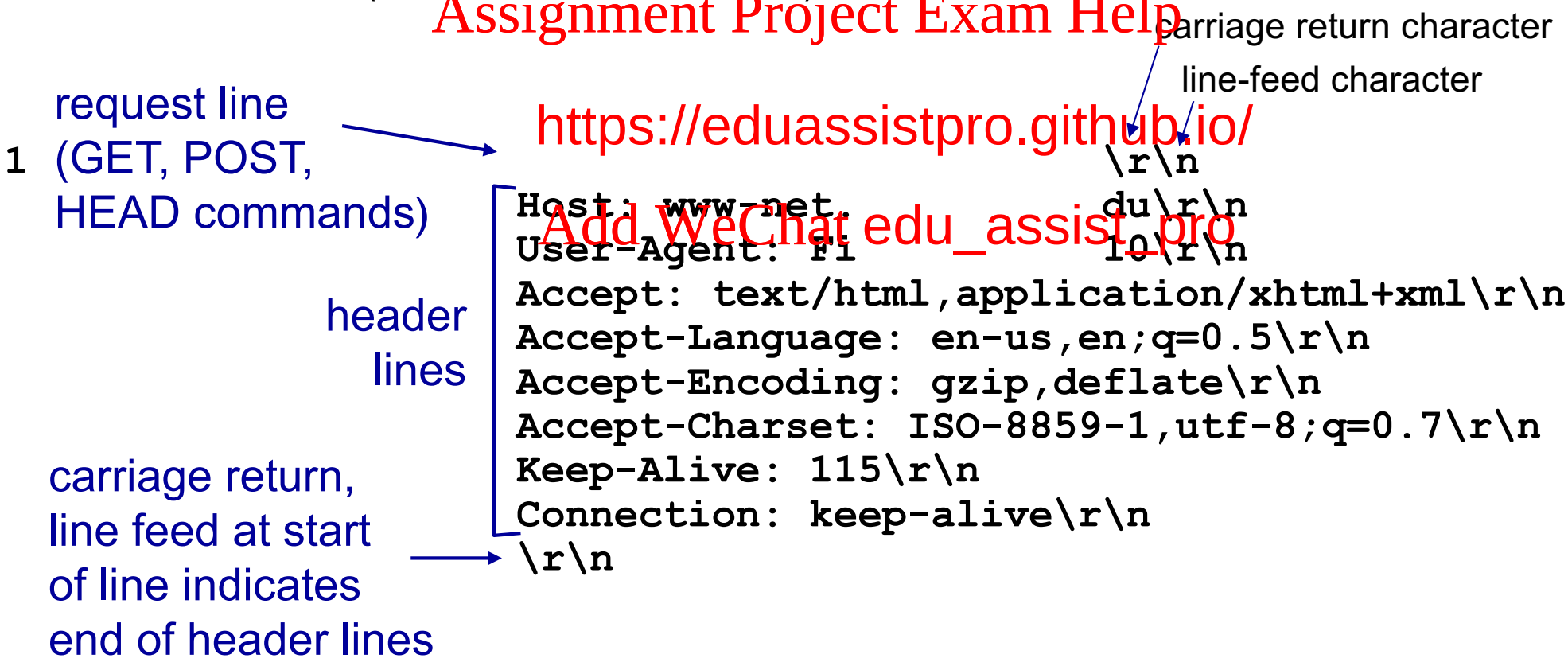
aside

Is that 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
   GM
ETag:                                 1\r\n
Accept-Ranges: byt
Content-Length: 26
Keep-Alive: timeou                  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 ob cified later in this msg (Location:)

400 Bad Request

- request msg not understood b

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 ab ing data
  - Variable leng
- Not the most efficient
  - Many protocols use binary f
    - 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 re form
- HEAD
  - asks server to leave requested object out of response

HTTP/1.1:

- GET, POST, HEAD
- PUT
  - uploads file in entity body h specified in URL
- DELETE
  - ile 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)

- 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

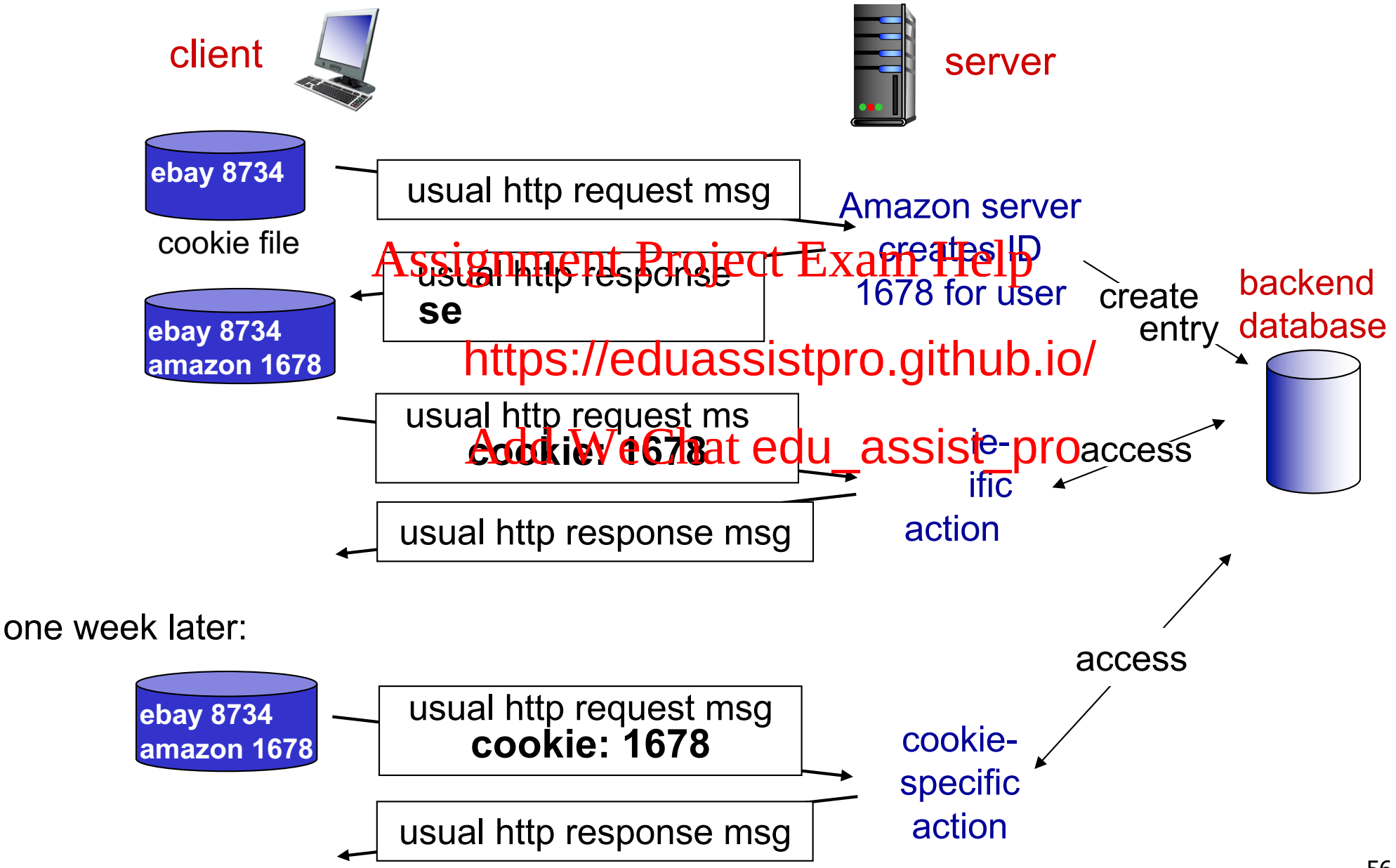
four components:

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 rst time
  ial HTTP requests t site, si ID
  - entry in backend database for ID

Cookies: keeping "state" (cont.)

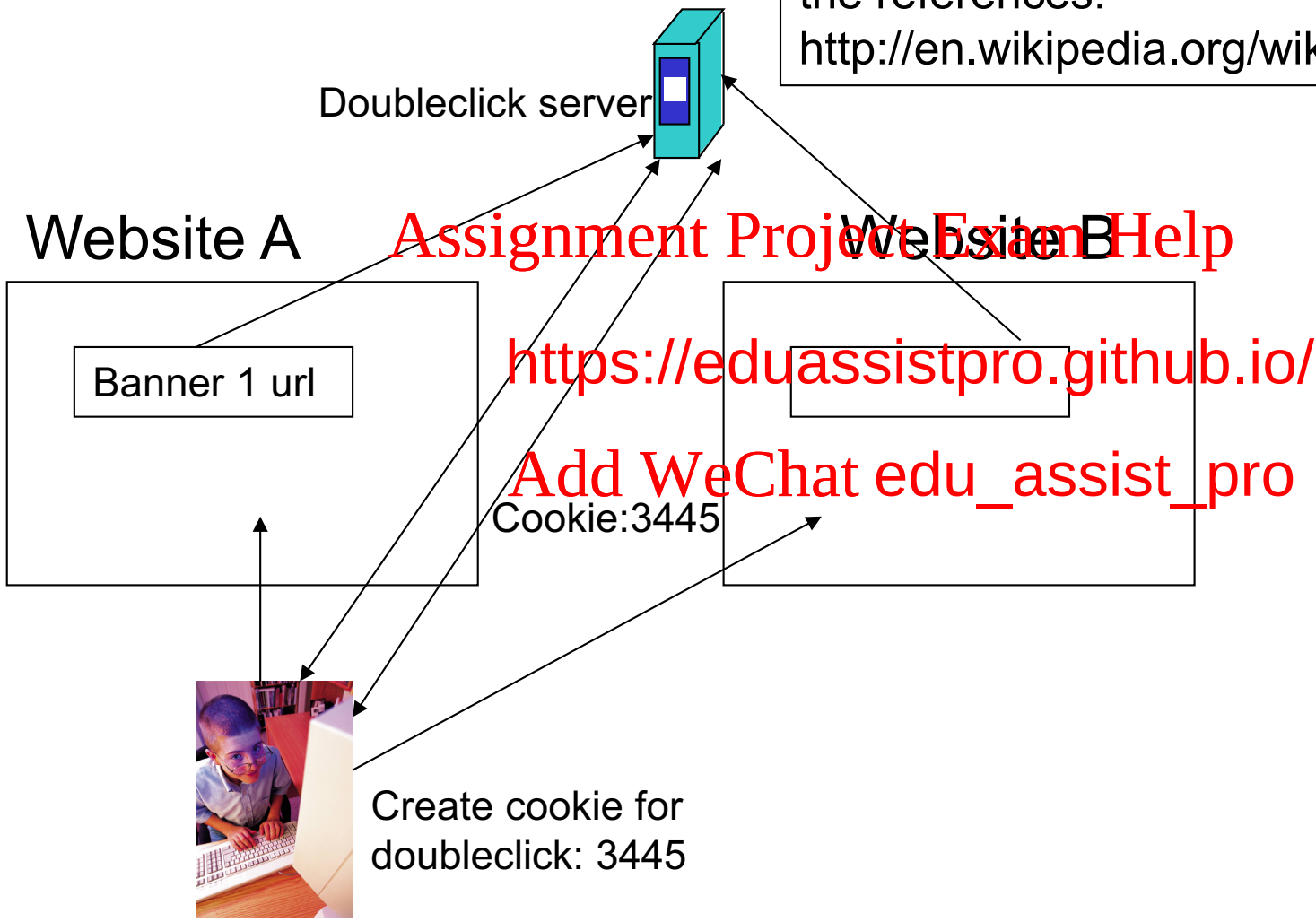


The Dark Side of Cookies

- Cookies permit sites to learn a lot about you
- You may supply name and e-mail to sites (and more)
- 3rd party cookies (ads) can follow you across multiple sites
  - Ever visit a website, and the next d 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
  - page content
  - protocols involved and
  - Network bandwidth and RT

Performance Goals

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

Solutions?

Improve HTTP to achieve faster downloads

- User
  - fast downloads
  - high availability
- Content prov
  - happy users (headache)
  - cost-effective infrastructure
- Network (secondary)
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Solutions?

Improve HTTP to achieve faster downloads

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  - happy users (low latency)
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aching and Replication

Solutions?

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- User
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- Content prov
  - happy users (low latency)
  - cost-effective delivery infrastructure
- Network (secondary)
  - avoid overload

aching 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 co
- Change HTTP to avoid re nsfers 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*
- New TCP co) object!

non-persistent HTTP

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

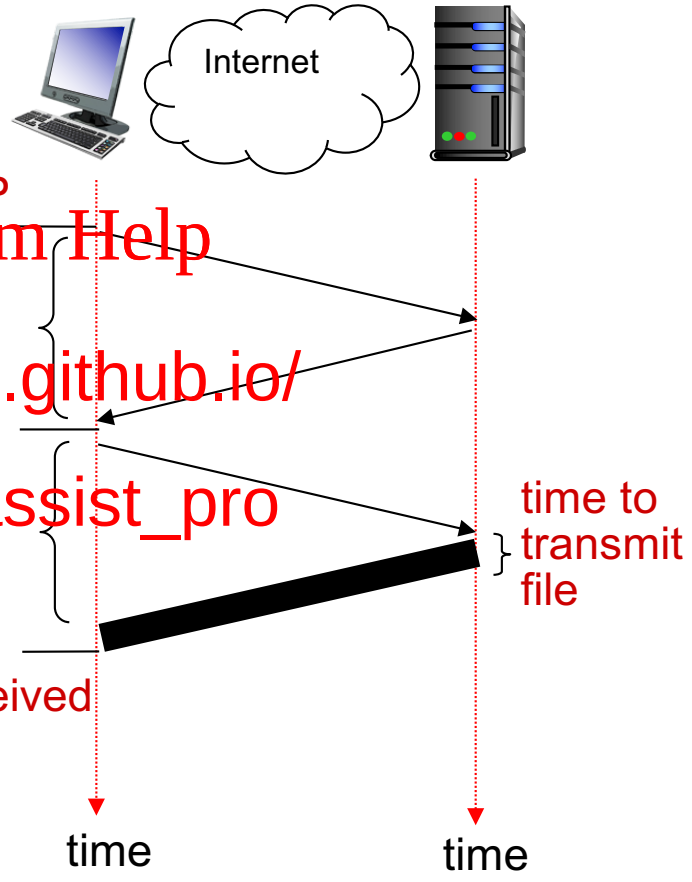
Non-persistent HTTP: response time

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

HTTP response time:

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

  2RTT+ file transmission time



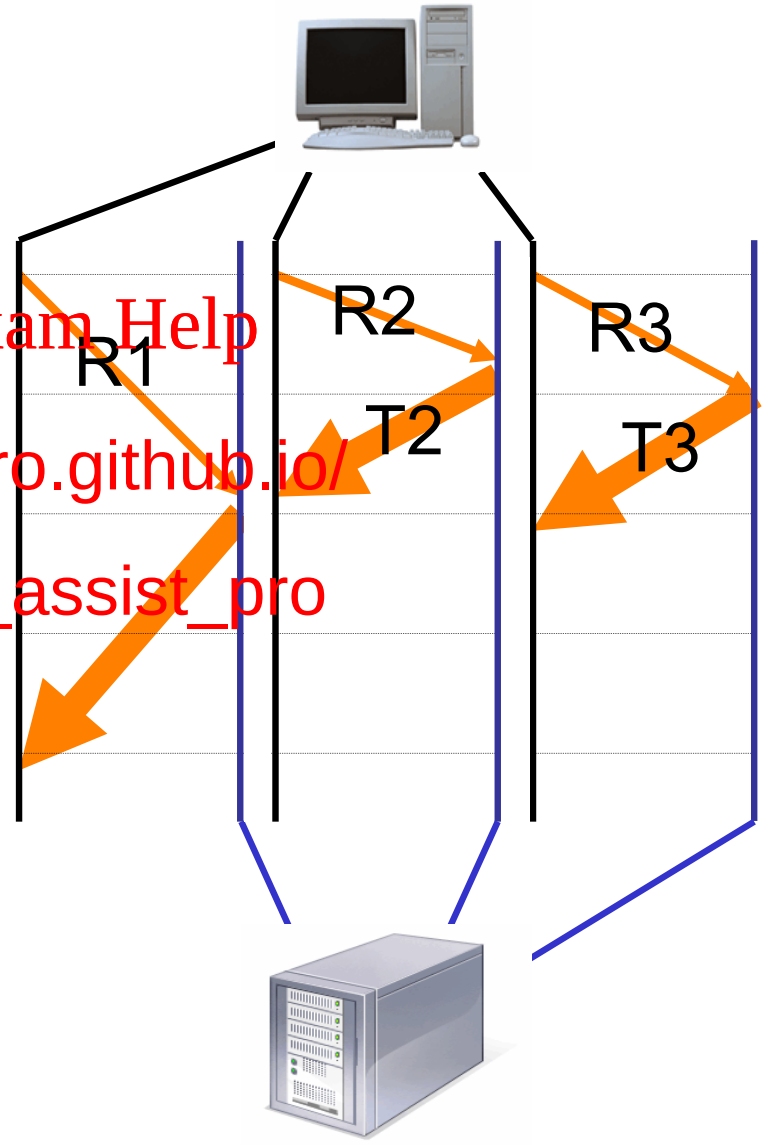
HTTP/1.0

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

Improving HTTP Performance:

Concurrent Requests & Responses

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



Quiz: Parallel HTTP Connections

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

Persistent HTTP

Persistent HTTP

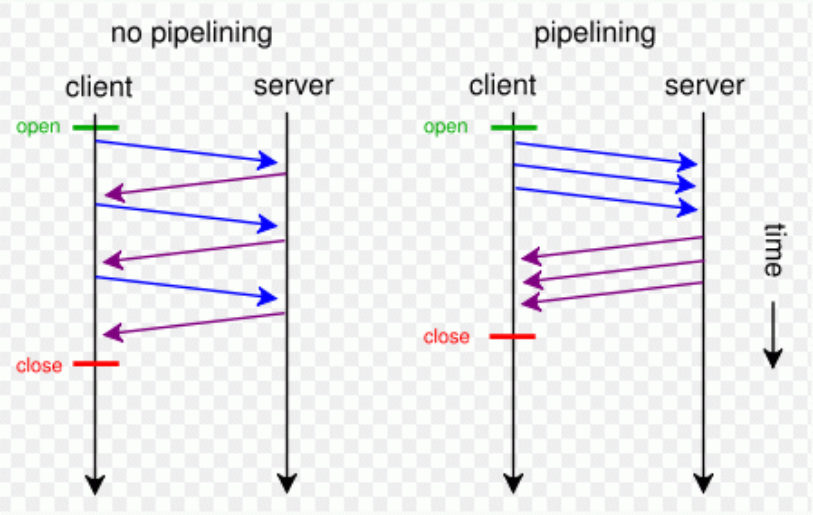
- server leaves TCP connection open after sending response
- subsequent HTTP messages between same client/server are sent over the same TCP connection
- Allow TCP to learn m RTT estimate (APPAR IN THE COURSE)
- Allow TCP congestion window to increase (APPARENT LATER)
- i.e., leverage previously discovered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

Persistent without pipelining:

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

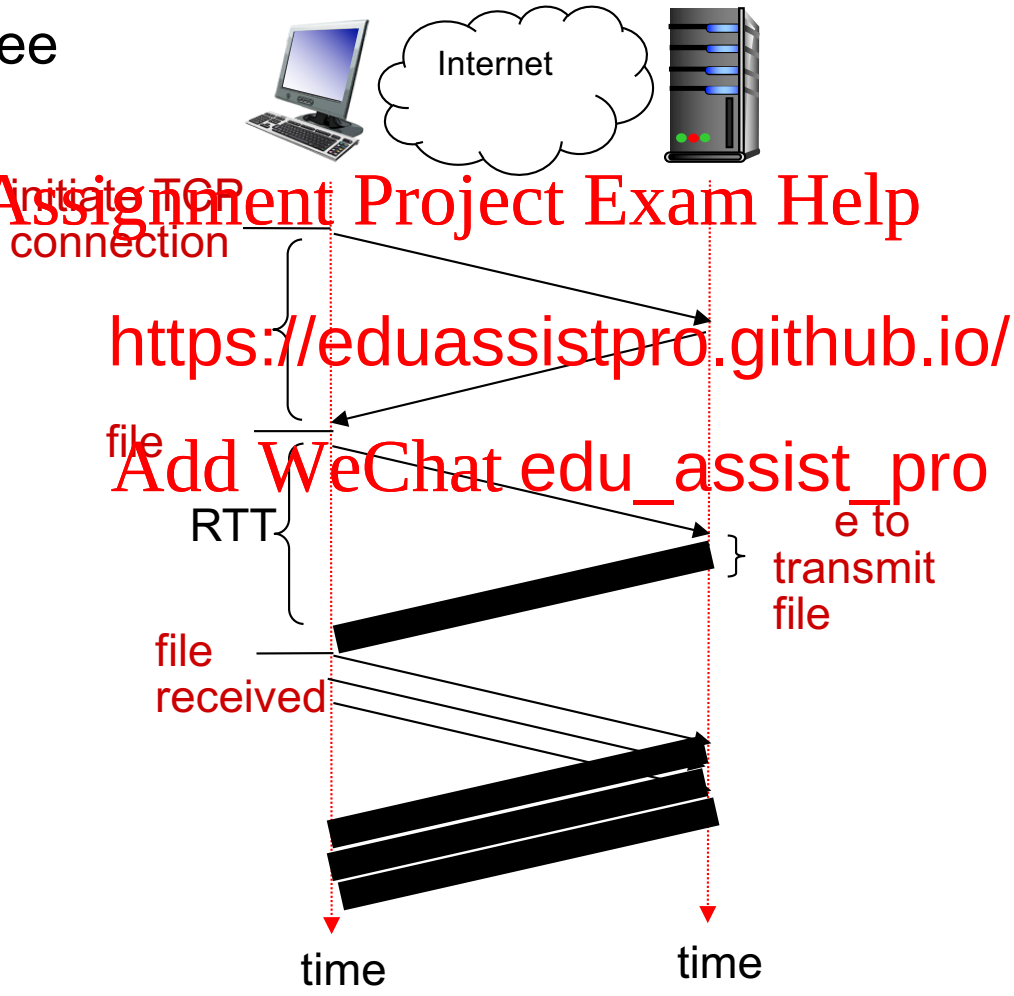
Persistent with pipelining:

- TTP/1.1 requests as soon as it eferenced object
- RTT for all the referenced objects



HTTP 1.1: response time

Website with one index page and three embedded objects



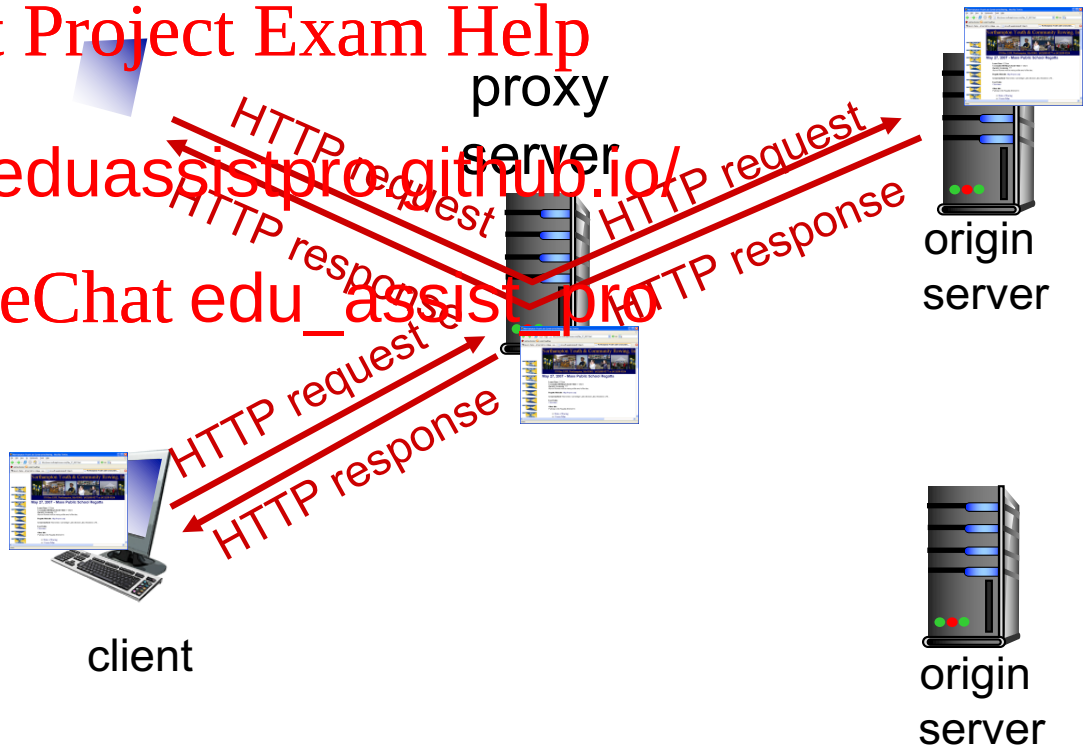
Improving HTTP Performance: Caching

- Why does caching work?
  - Exploits *locality of reference*
- How well does caching
  - 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 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
- typically cach installed by ISP (university, company, residential ISP)

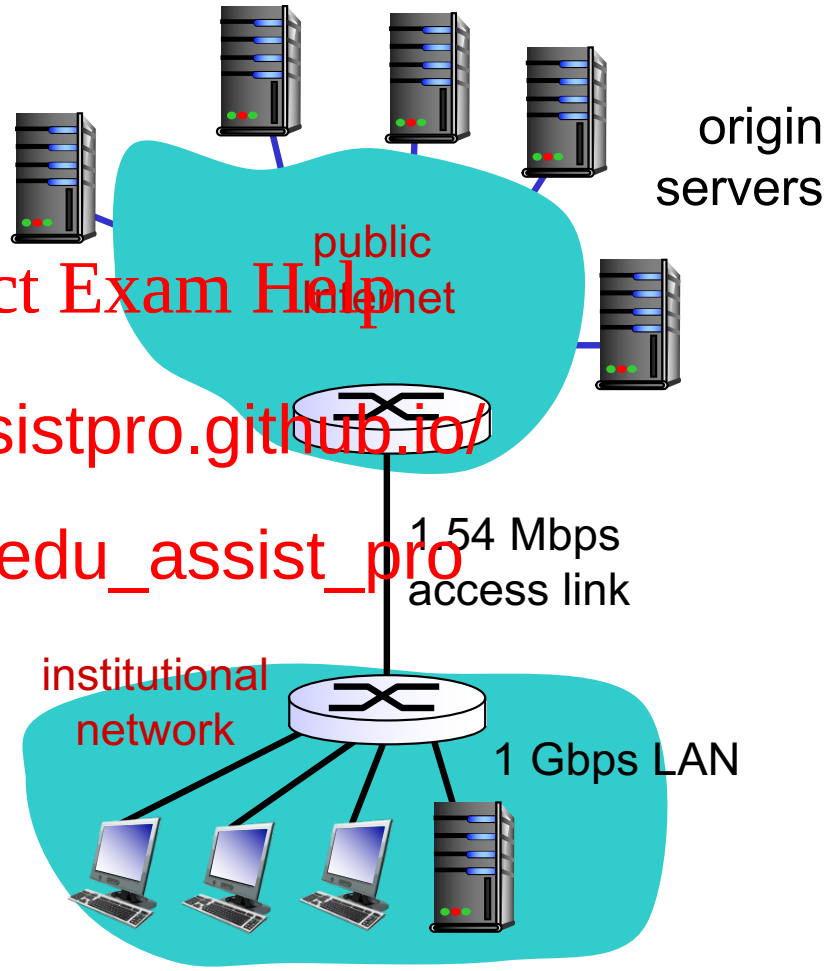
why Web caching?

- reduce response time for client request
- traffic on an ion's access link
- dense with nables "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 b Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54 Mbps



consequences:

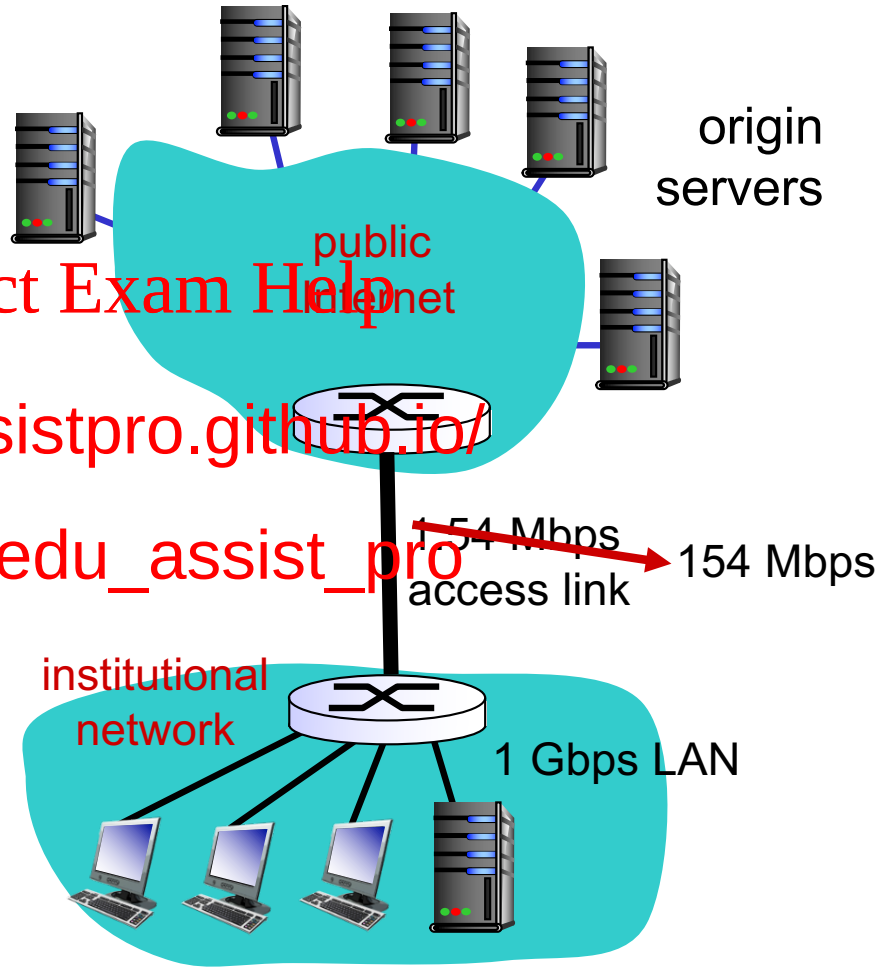
- LAN utilization: 0.15% *problem!*
- access link utilization = 99%
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + minutes + usecs

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 b Mbps
- RTT from institu to any origin server: 2 sec
- access link rate: 1.54 Mbps

154 Mbps



consequences:

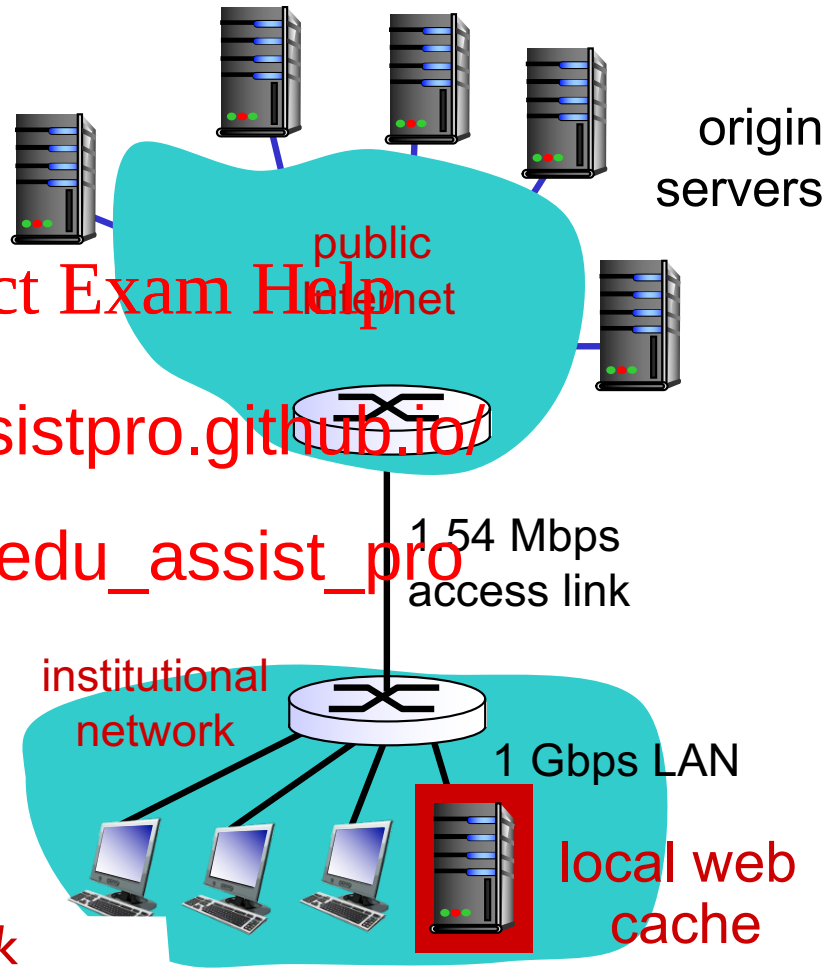
- LAN utilization: 0.15% 0.99%
- access link utilization = 99%
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + minutes + usecs
  msecs

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



consequences:

- LAN utilization: ?
- access link utilization = ?
- total delay = ?

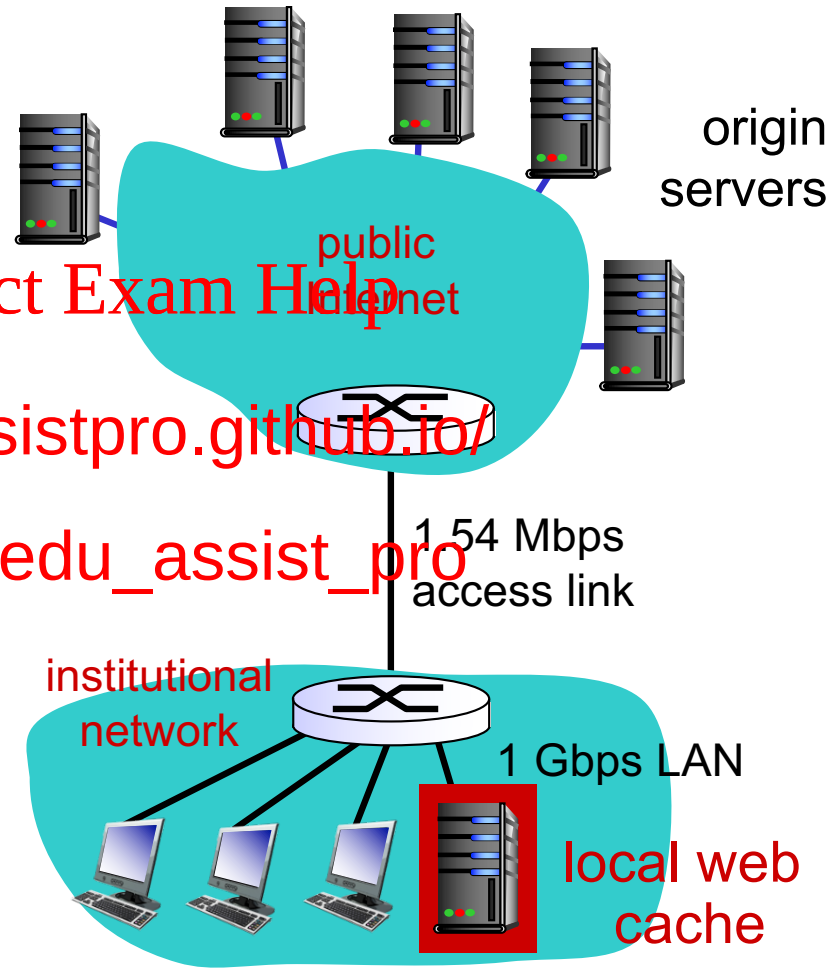
How to compute link utilization, delay?

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 utilizat
  - 60% of requests us
- data rate to browsers over access link = 0.6*1.50 Mbps = .9 Mbps
  - utilization = 0.9/1.54 = .58
- total delay
  - = 0.6 * (delay from origin servers) +0.4 * (delay when satisfied at cache)
  - = 0.6 (2.01) + 0.4 (~msecs)
  - = ~ 1.2 secs
  - less than with 154 Mbps link (and cheaper too!)



But what is the likelihood of cache hits?

- Distribution of web object requests generally follows a Zipf-like distribution
- *The probability that a document will be referenced k requests after it was last referenced is roughly proportional to 1/k* . That is, web traces exhibit excellent **temporal locality**.

Video content exhibits similar properties: 10% of the top popular videos account for nearly 80% of views, while the remaining 90% of videos account for total 20% of requests.

Paper – http://yongyeol.com/papers/cha-video-2009.pdf

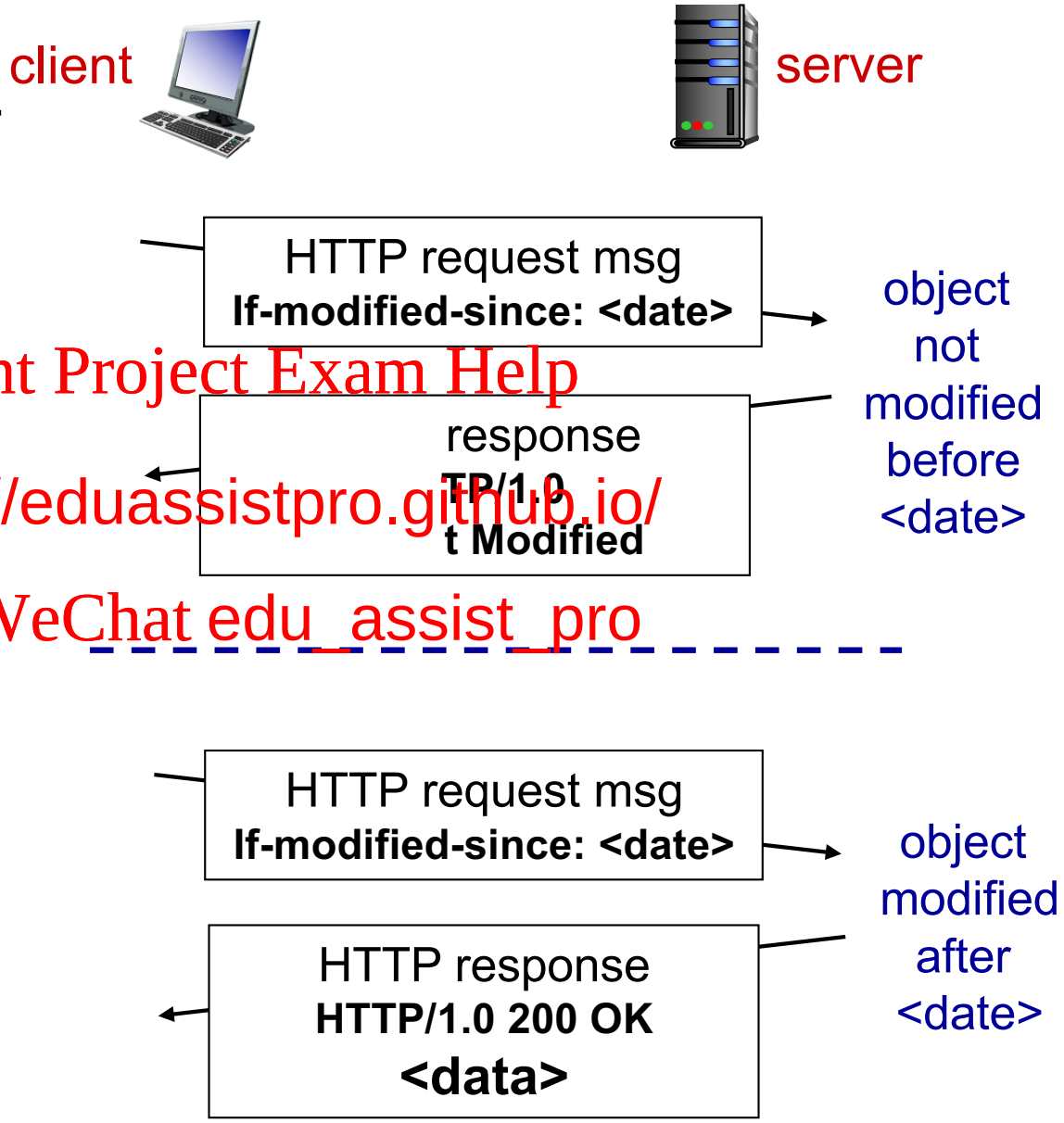
Paper – "Web Caching and Zipf-like Distributions: Evidence and Implications"
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.34.8742&rep=rep1&type=pdf

Conditional GET

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

Example Cache Check Response

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 particul
    - Balance load across server replica
    - 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

- Caching and replication as a service
- Integrate forward and reverse caching functionality
- Large-scale distributed storage infrastructure (usually) administered b
  - *e.g.,* Akamai + locations
- Combination of (pull) caching) replication
  - **Pull:** Direct result of clien s
  - **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?

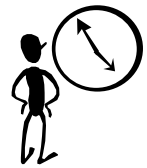
- HTTP is insecure
- HTTP basic authentication: password sent using base64 encoding (can be readily converted to plaintext)
- HTTPS: HTTP encrypted by Transport Layer Security (T
- Provides:
  - Authentication
  - Bidirectional encryption
- Widely used in place of plain vanilla HTTP

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 multiplexe
    - Requests and chunks called frames, frames are tagged with an ID tha 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

Summary



- Completed Introduction (Chapter 1)
  - Solve Sample Problem Set
- Application Layer (Chapter 2)
  - Principles of Network Applications
  - HTTP
- Next Week: App
  - E-mail
  - P2P
  - DNS
  - Socket Programming

Reading Exercise
Chapter 2: 2.4 – 2.7