

Computer Networks and Applications

COMP 3331/COMP 9331

Week 2

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Introduction(Protocol Layering, Security)

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Application Layer (Principles, Web)

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

I. Introduction: roadmap

I.1 what is the Internet?

I.2 network edge

- end systems, access networks, links

I.3 network core

- packet switching, circuit switching, network structure

I.4 delay, loss, throughput in networks

I.5 protocol layers, service models

I.6 networks under attack: security

I.7 history

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Self study

Three (networking) design steps

- ❖ Break down the problem into tasks
- ❖ Organize these tasks
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- ❖ Decide who does what
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Tasks in Networking

❖ What does it take to send packets across?

❖ Simplistic decomposition:

- Task 1: send along a single wire

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- Task 2: stitch these together to go across 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 packets get to the destination process
- ❖ Do something with the data

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Resulting Modules

- ❖ Bits / Packets on wire (Physical)
- ❖ Delivery packets within local network (Datalink)
- ❖ Deliver packets across global network (Network)
- ❖ Ensure that packets get to the dst process.
(Transport)
- ❖ Do something with the data (Application)

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

Dear John,

» Aide:

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» Puts letter in envelope with CEO

Your days are numbered. B's full name

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» Takes to FedEx

--Pat

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- ❖ 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

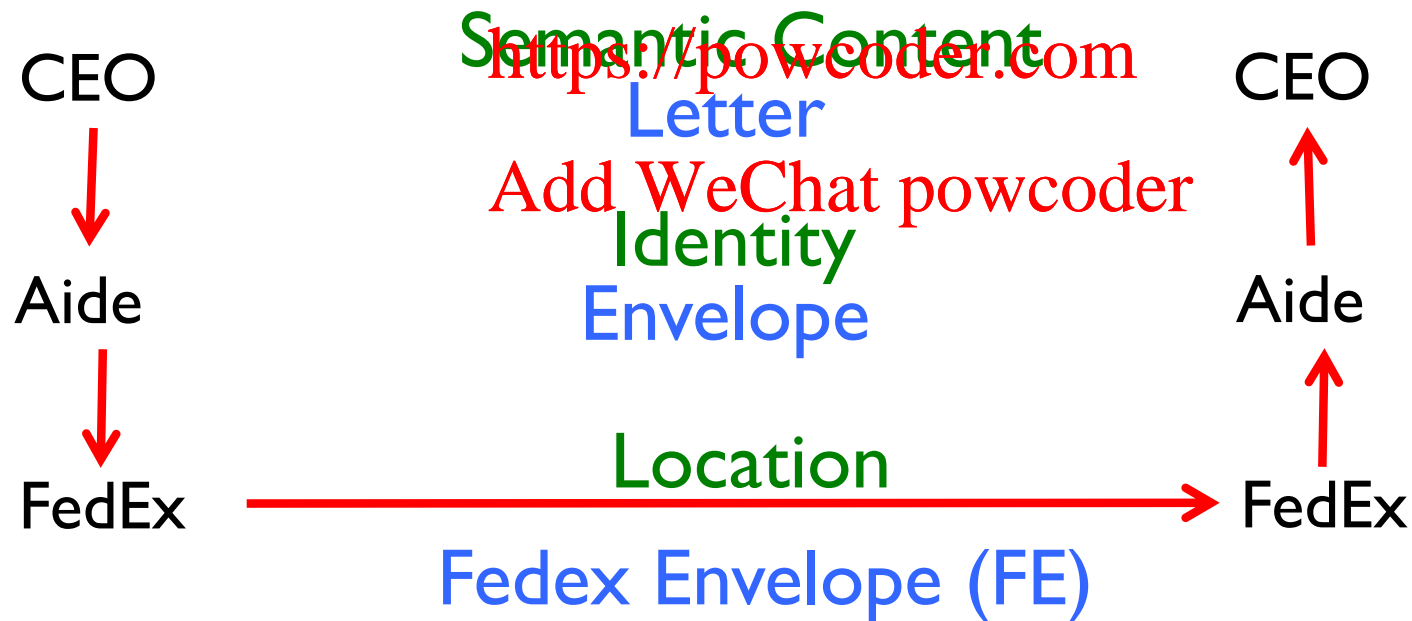
The Path of the Letter

“Peers” on each side understand the same things

No one else needs to (abstraction)

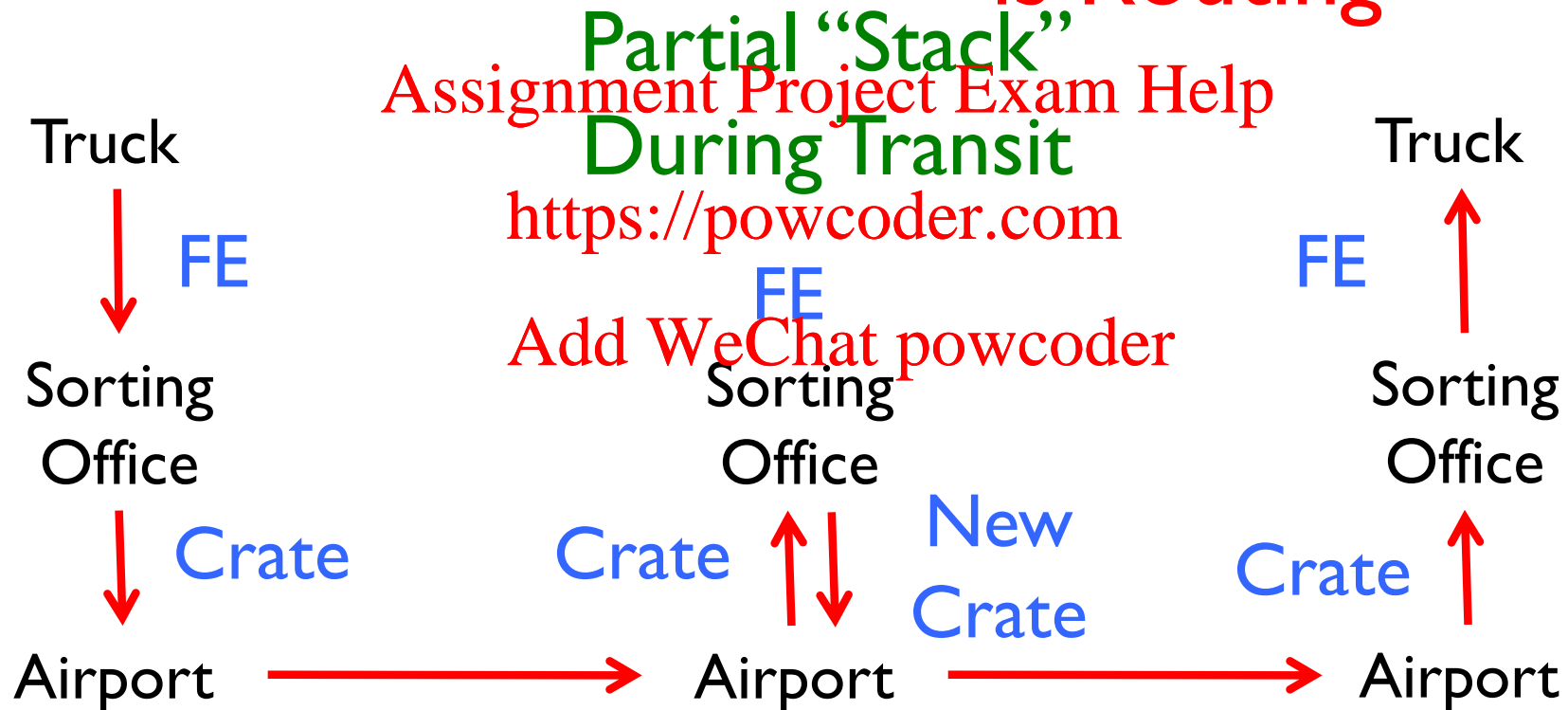
Lowest level has most packaging

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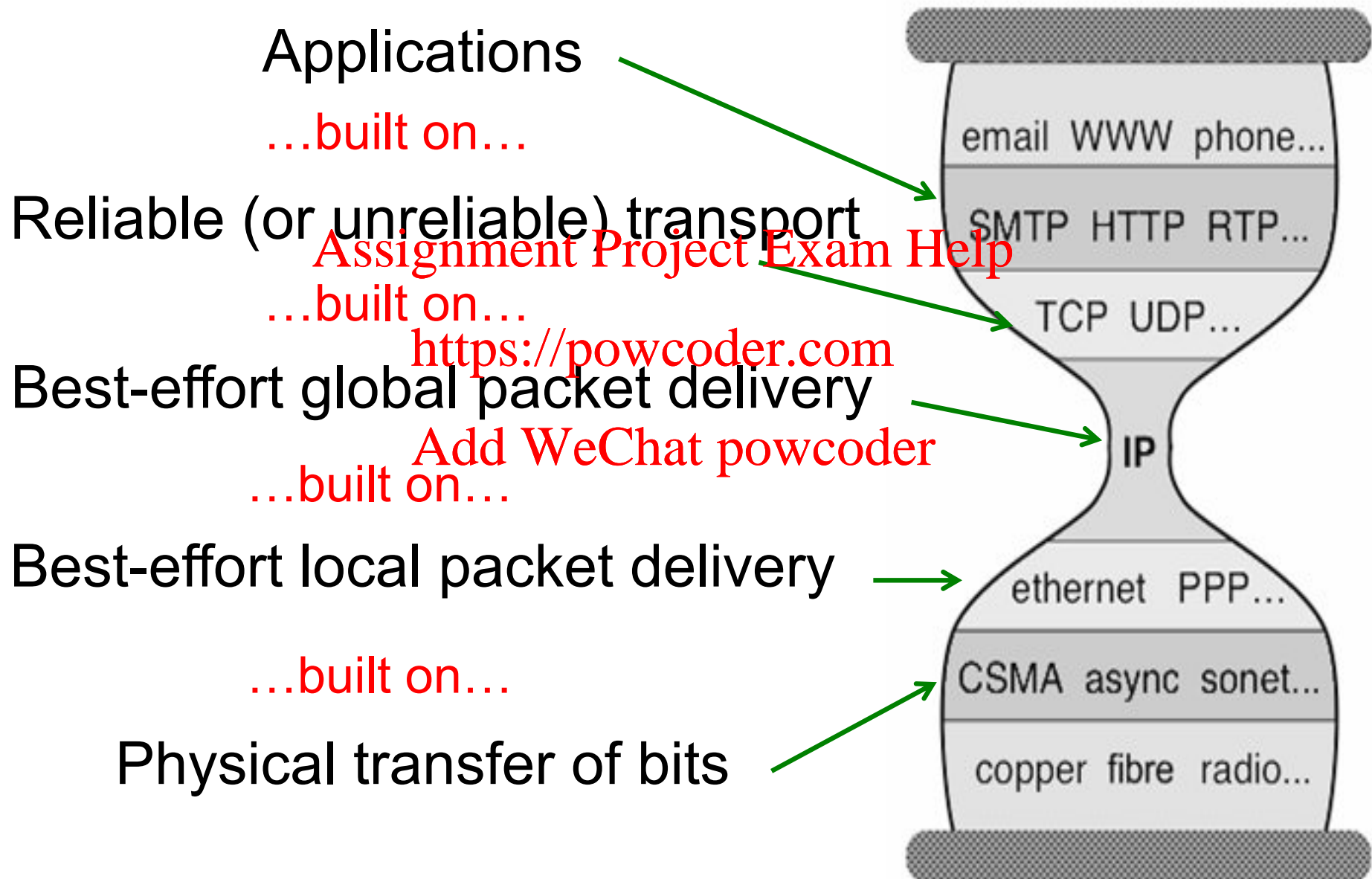
The Path Through FedEx

Higher “Stack” at Ends Highest Level of “Transit Stack” is Routing



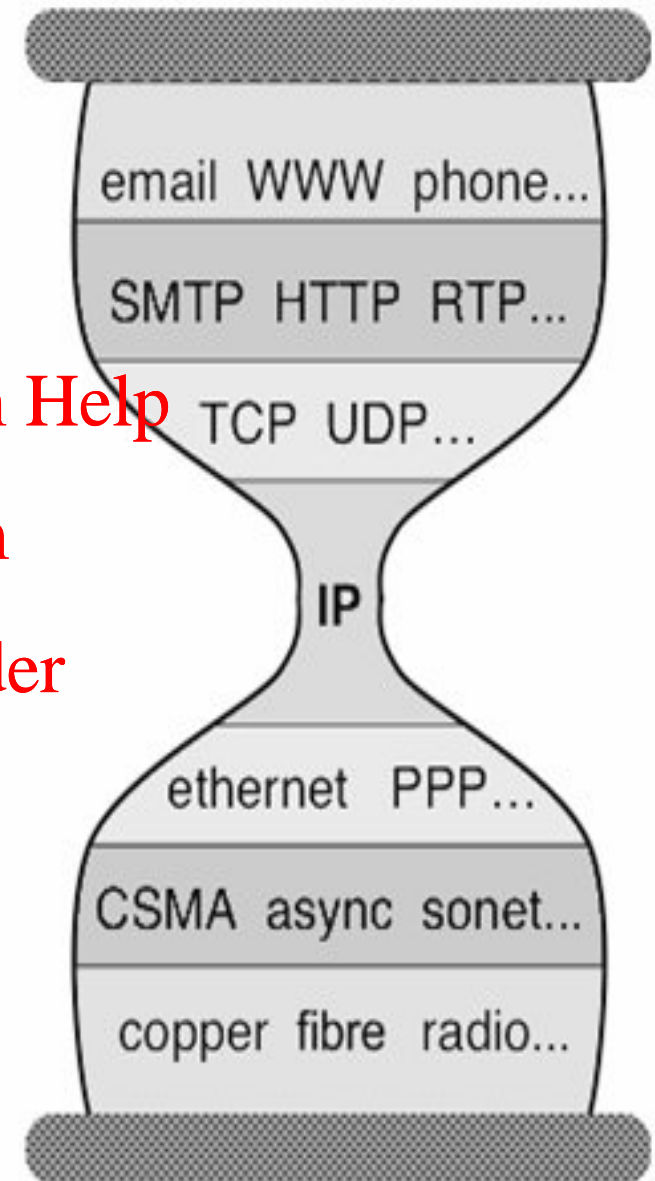
Deepest Packaging (Envelope+FE+Crate)
at the Lowest Level of Transport

In the context of the Internet



Internet protocol stack

- ❖ **application:** supporting network applications
 - FTP, SMTP, HTTP, Skype, ..
- ❖ **transport:** process-process data transfer
 - TCP, UDP <https://powcoder.com>
- ❖ **network:** routing of datagrams from source to destination
 - IP, routing protocols
- ❖ **link:** data transfer between neighboring network elements
 - Ethernet, 802.11 (WiFi), PPP
- ❖ **physical:** bits “on the wire”



Three Observations

❖ Each layer:

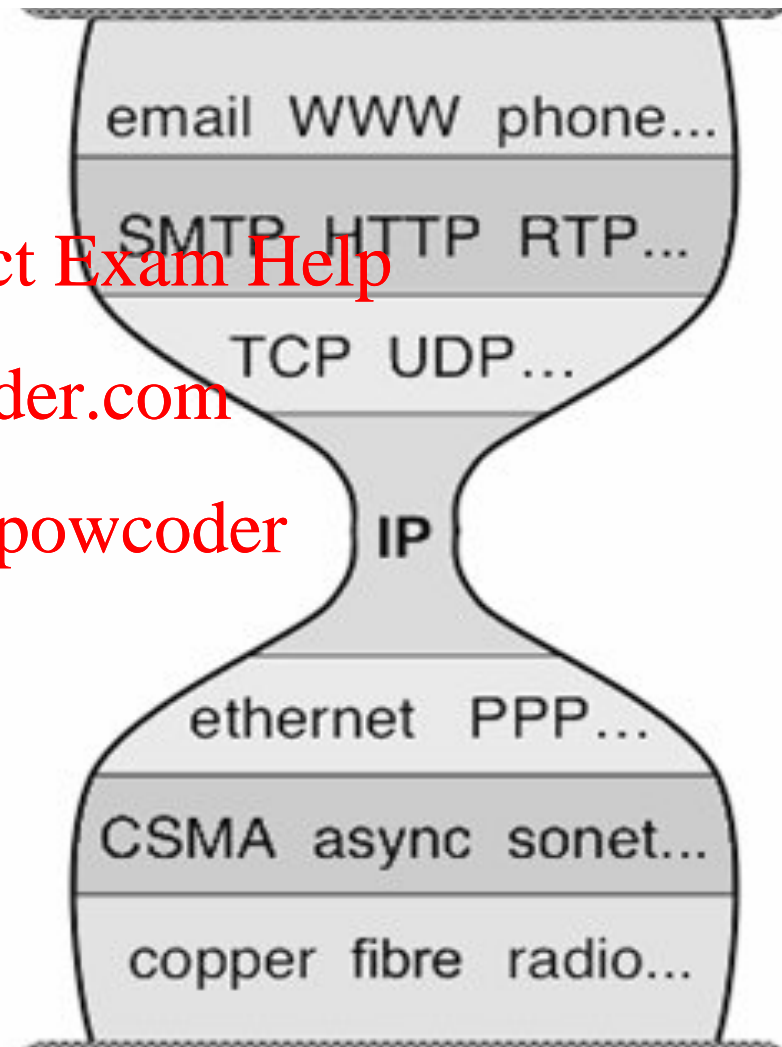
- Depends on layer below
- Supports layer above
- Independent of others

❖ Multiple versions in layer

- 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?

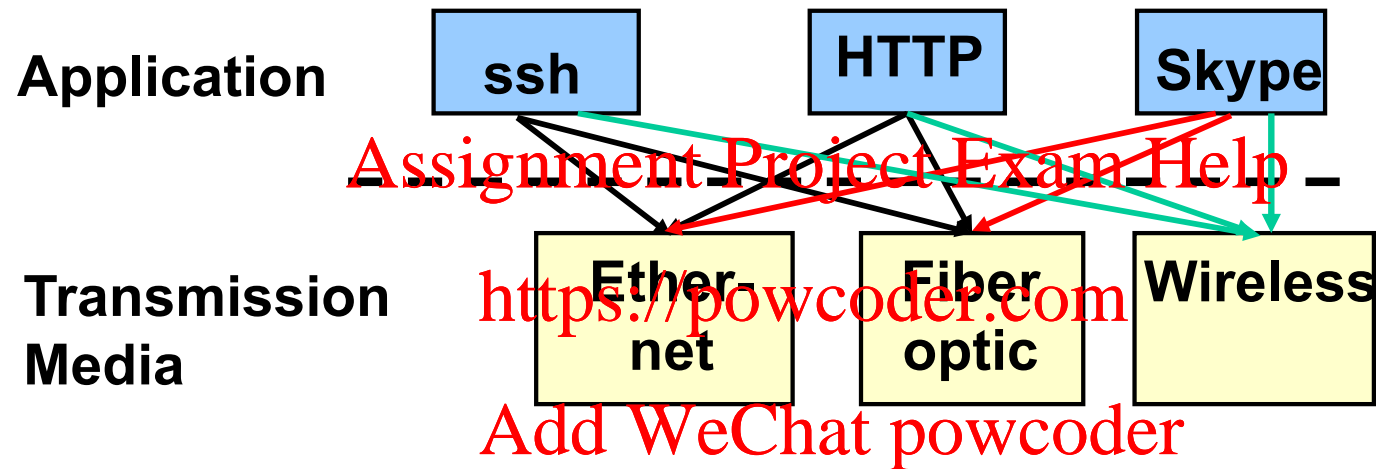


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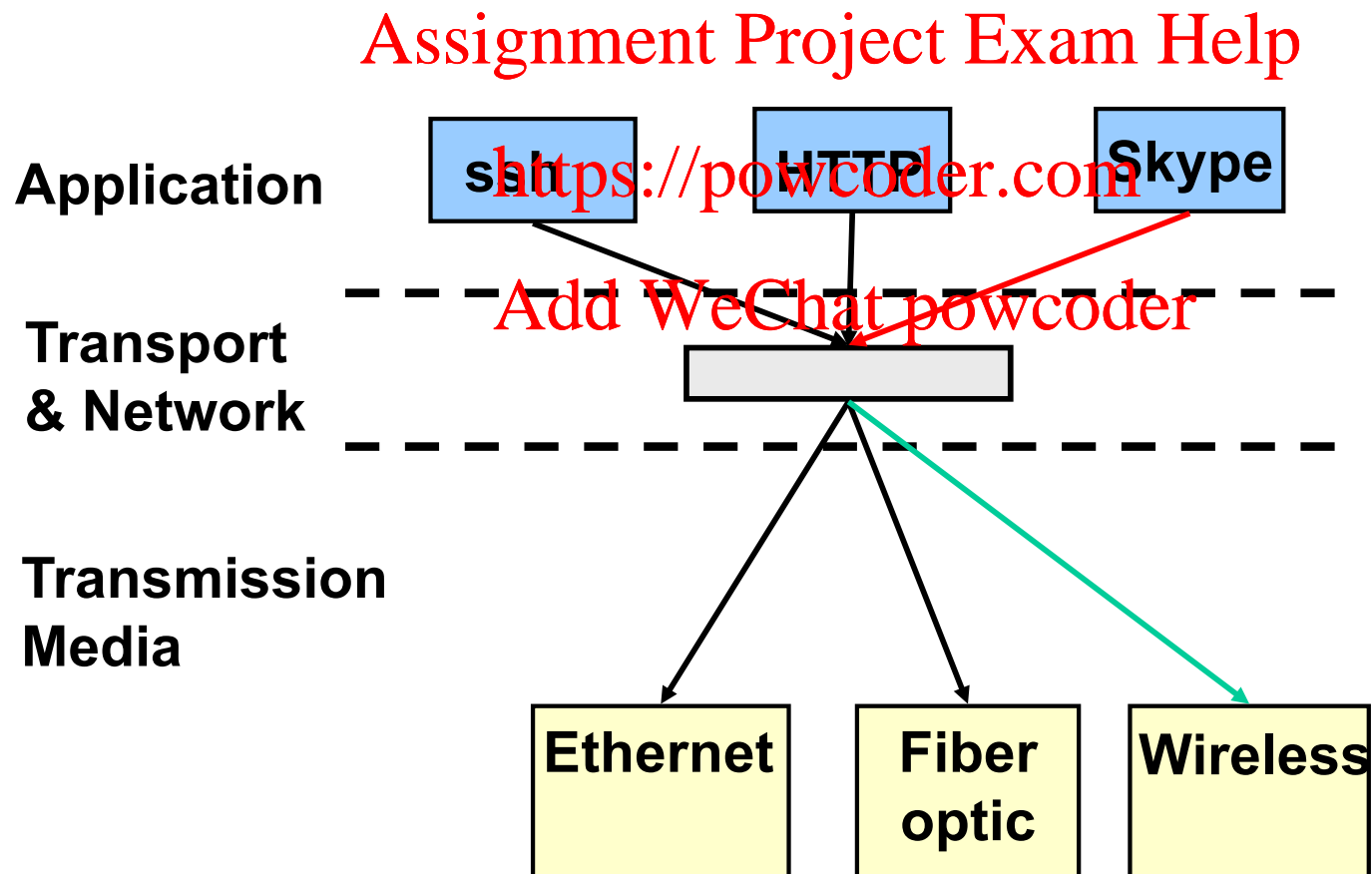
An Example: No Layering



- ❖ 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 loss due to corruption vs. congestion
- ❖ Headers start to get really big
 - E.g., typically TCP + IP + Ethernet headers 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

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- ❖ But we need to implement layers across machines
 - Hosts
 - Routers
 - Switches

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- ❖ What gets implemented where?

What Gets Implemented on Host?

- ❖ Bits arrive on wire, must make it up to application
 - ❖ Therefore, all layers must exist at host!
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What Gets Implemented on Router?

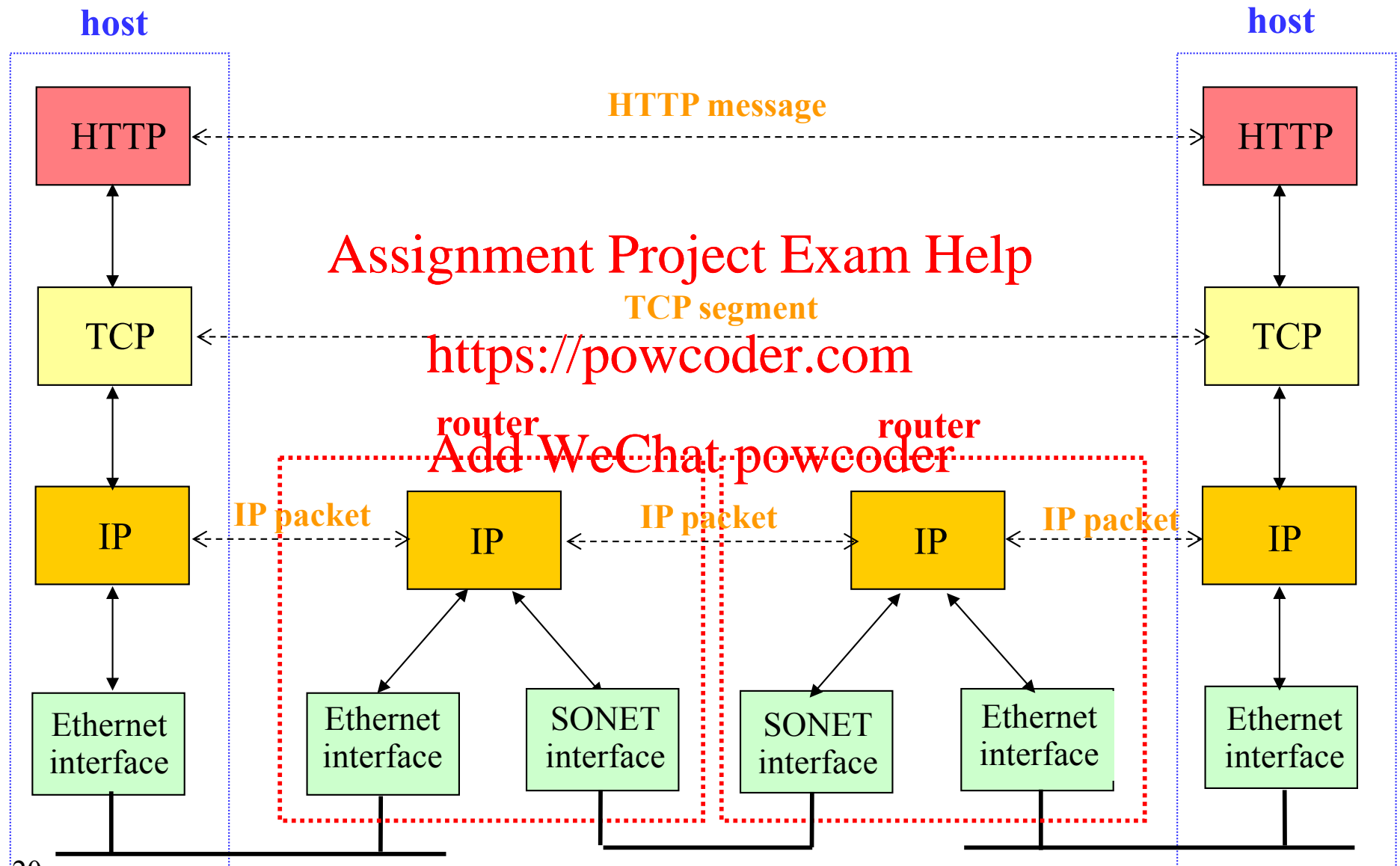
- ❖ Bits arrive on wire
 - Physical layer necessary
- ❖ Packets must be delivered to next-hop
 - datalink layer necessary
- ❖ Routers participate in global delivery
 - Network layer necessary
- ❖ Routers don't support reliable delivery
 - Transport layer (and above) **not** supported

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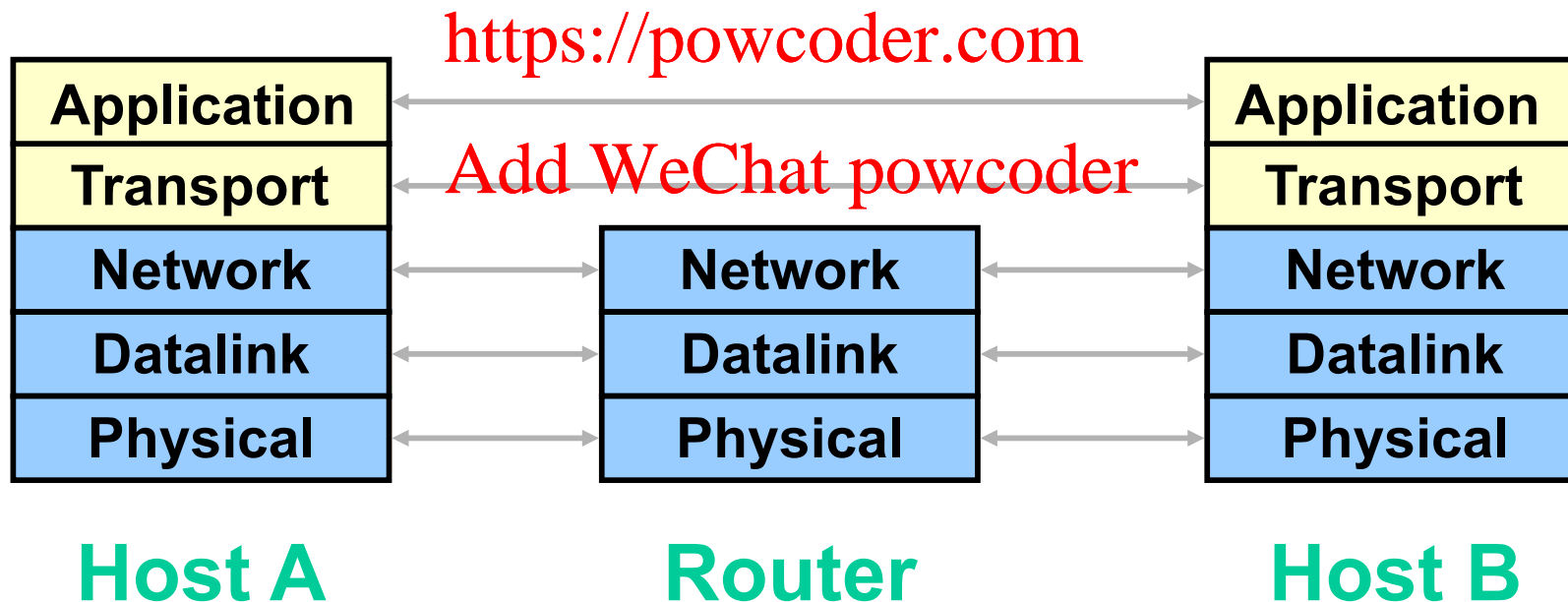
Internet Layered Architecture



Logical Communication

- ❖ Layers interacts with peer's corresponding layer

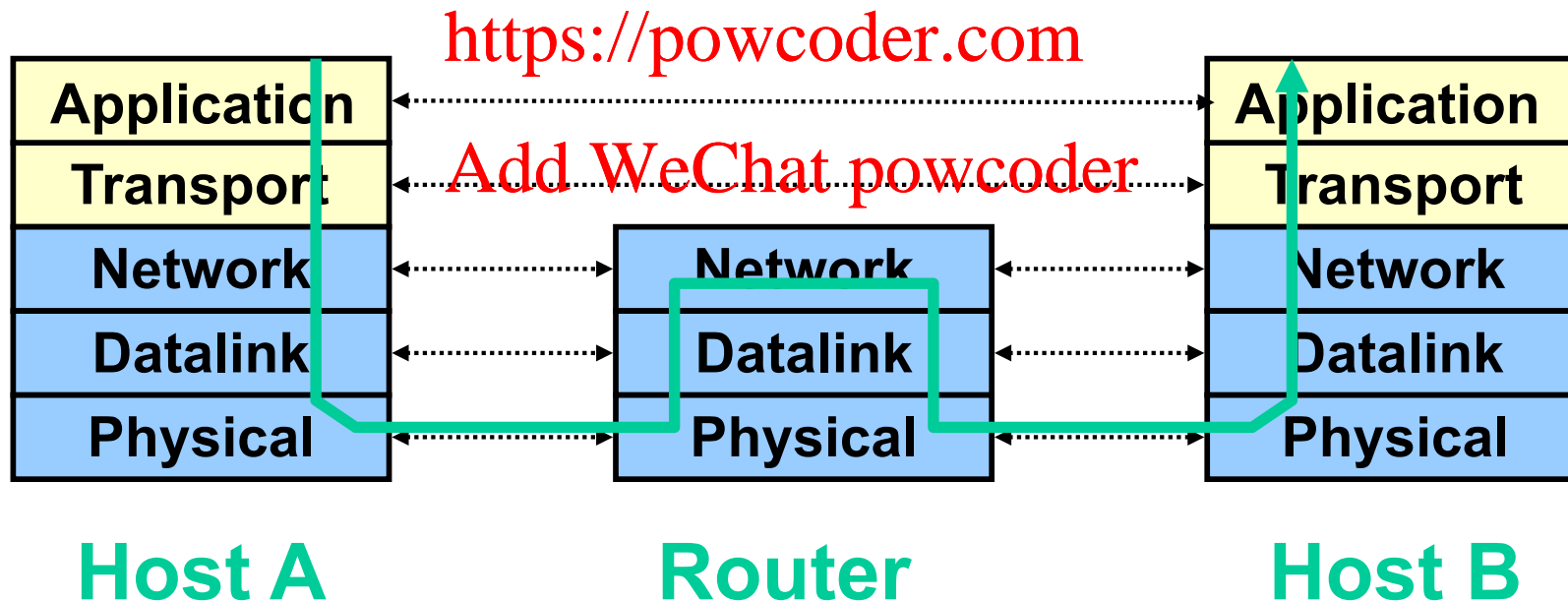
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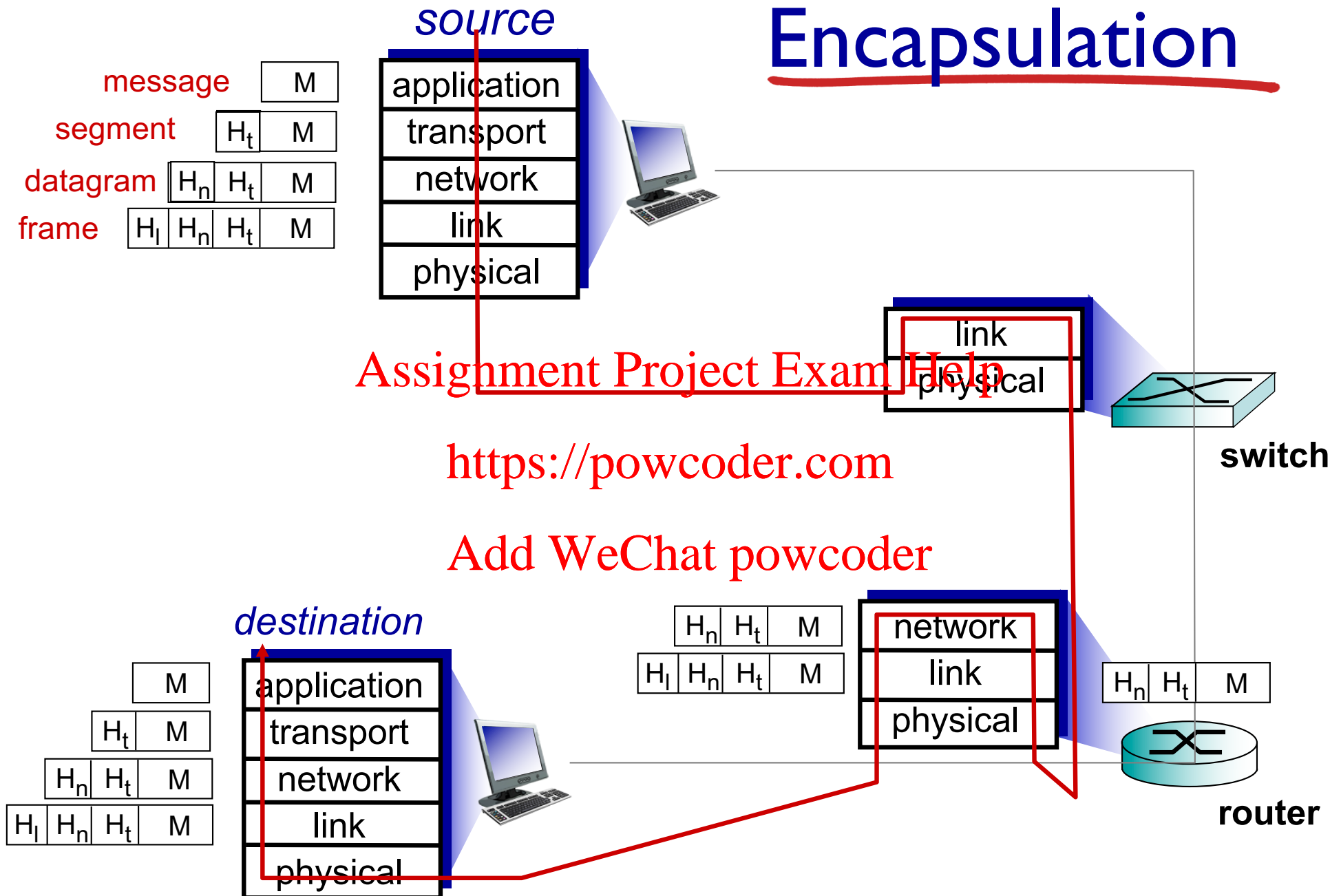
Physical Communication

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

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Encapsulation



I. Introduction: roadmap

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I.5 protocol layers, service models

I.6 networks under attack: security

I.7 history

Self study

Introduction: summary

covered a “ton” of material!

- ❖ Internet overview
- ❖ what's a protocol?
- ❖ network edge, core, access network
 - packet-switching versus 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 follow!

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2. Application Layer: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic mail

- SMTP, POP3, IMAP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

2.7 socket programming with UDP and TCP

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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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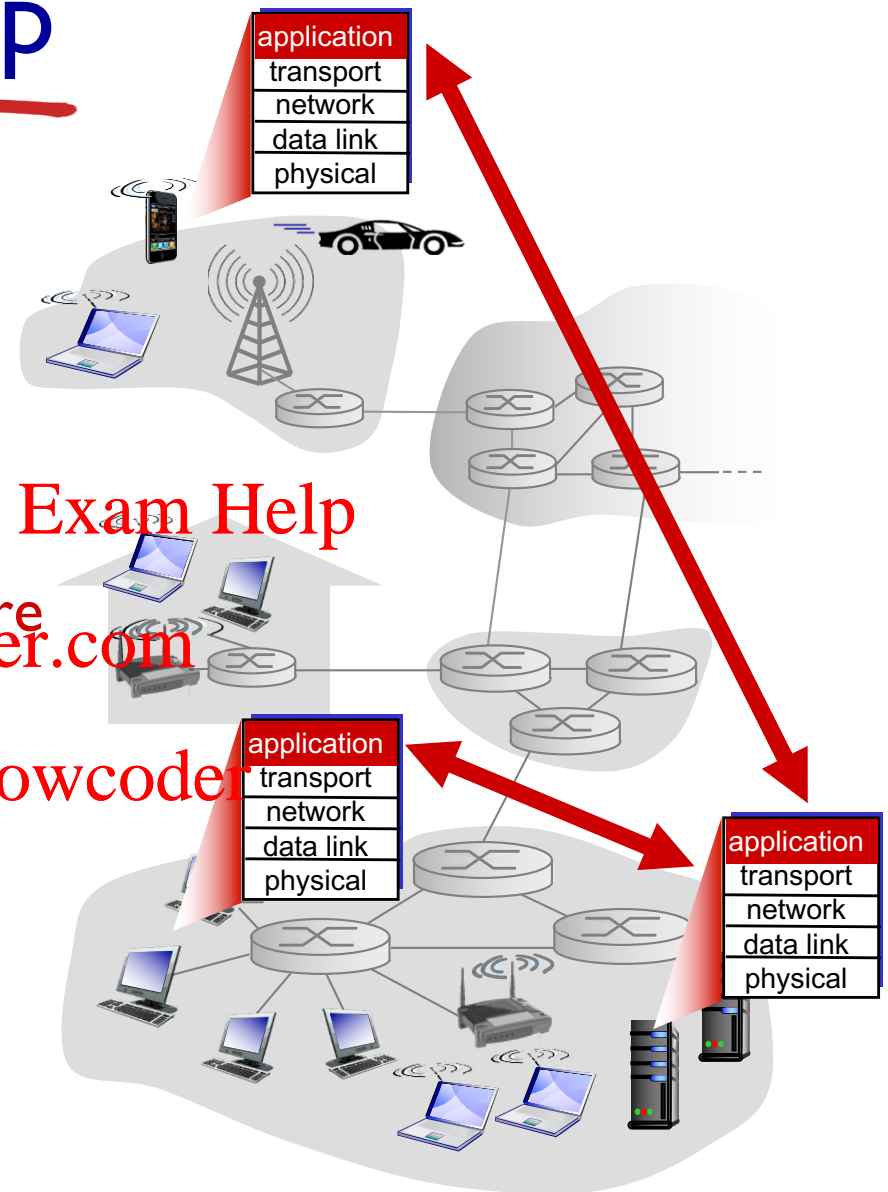
Creating a network app

Write programs that:

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

No need to write software for network-core devices

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



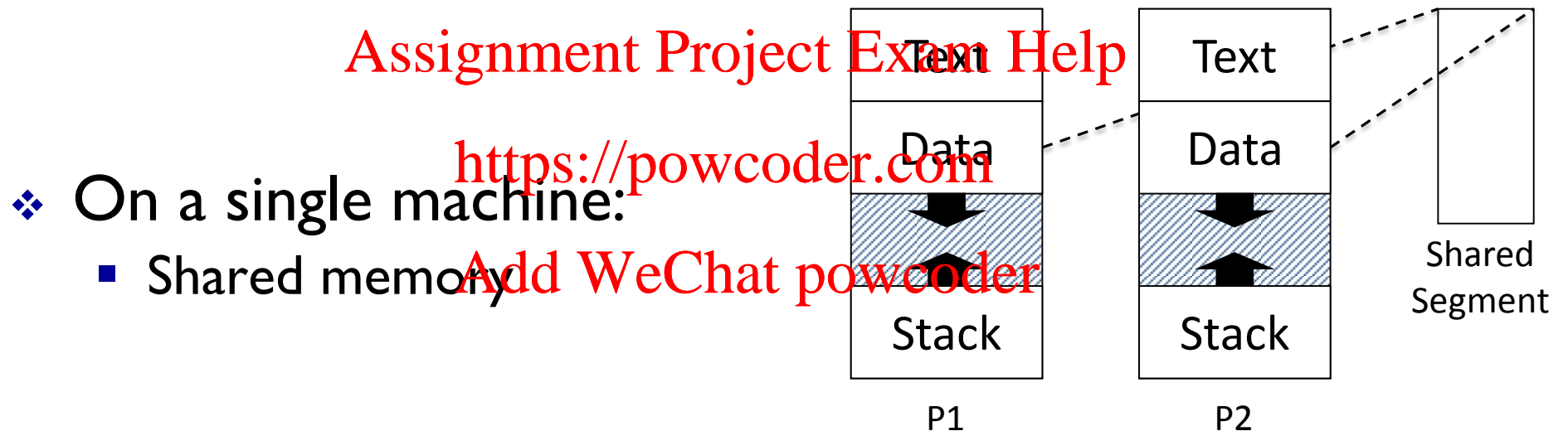
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Interprocess Communication (IPC)

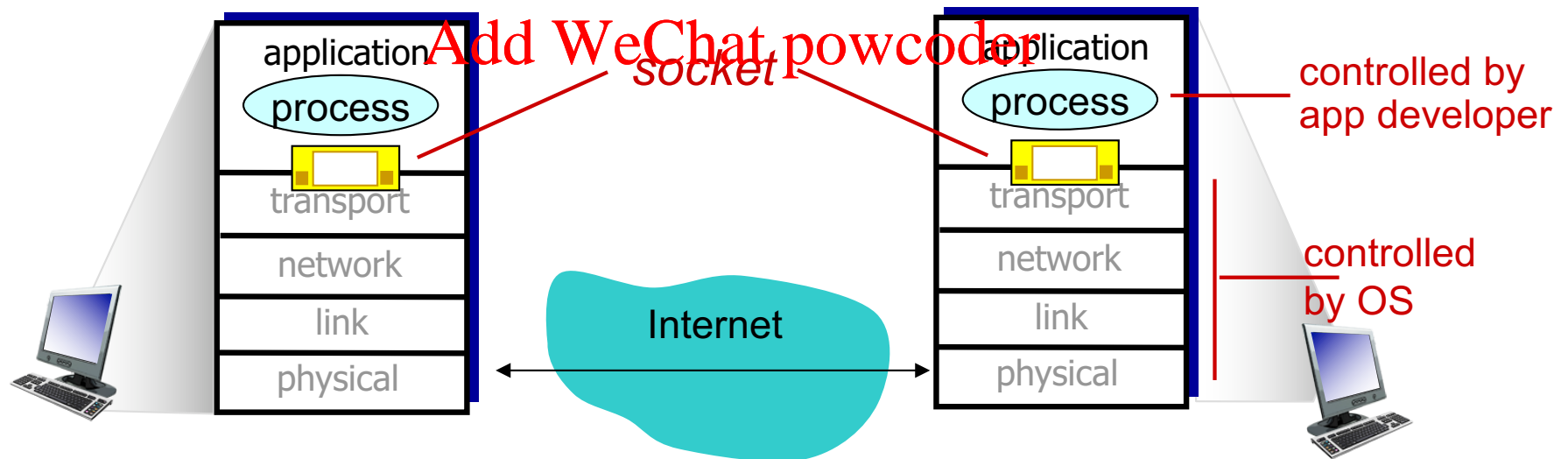
- ❖ Processes talk to each other through Inter-process communication (IPC)



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

Sockets

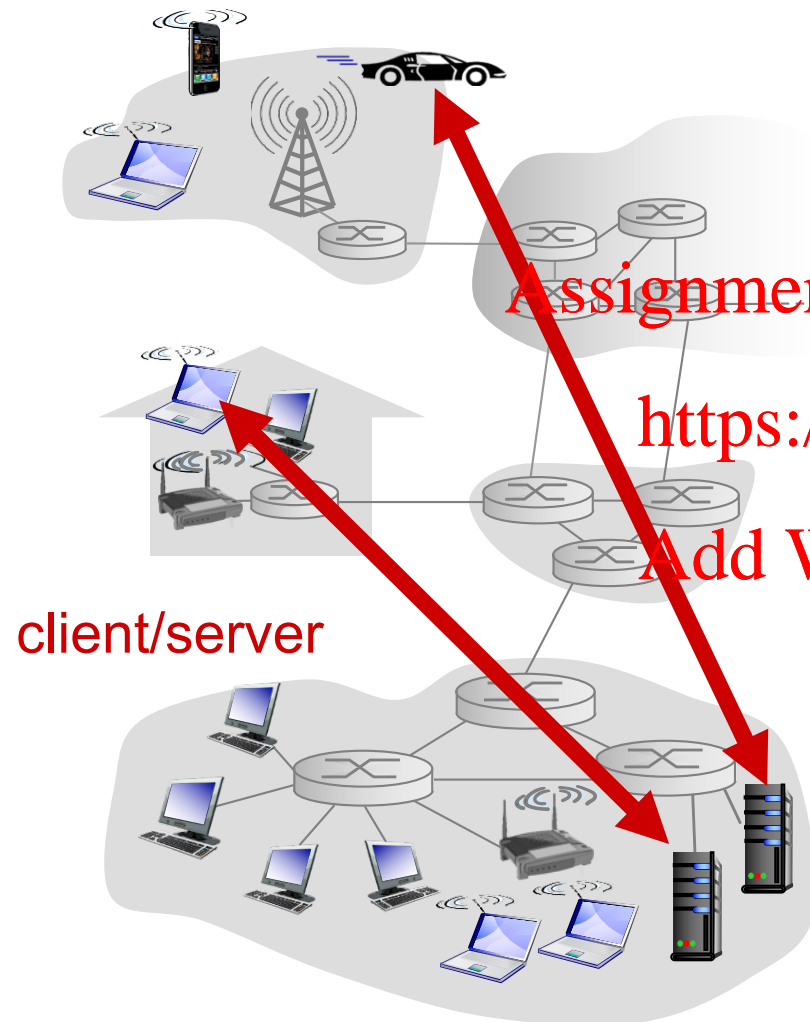
- ❖ process sends/receives messages to/from its **socket**
- ❖ socket analogous to door
 - sending process shoves message out door
 - sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process
- ❖ Application has a few options, OS handles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



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

Client-server architecture



client/server

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

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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

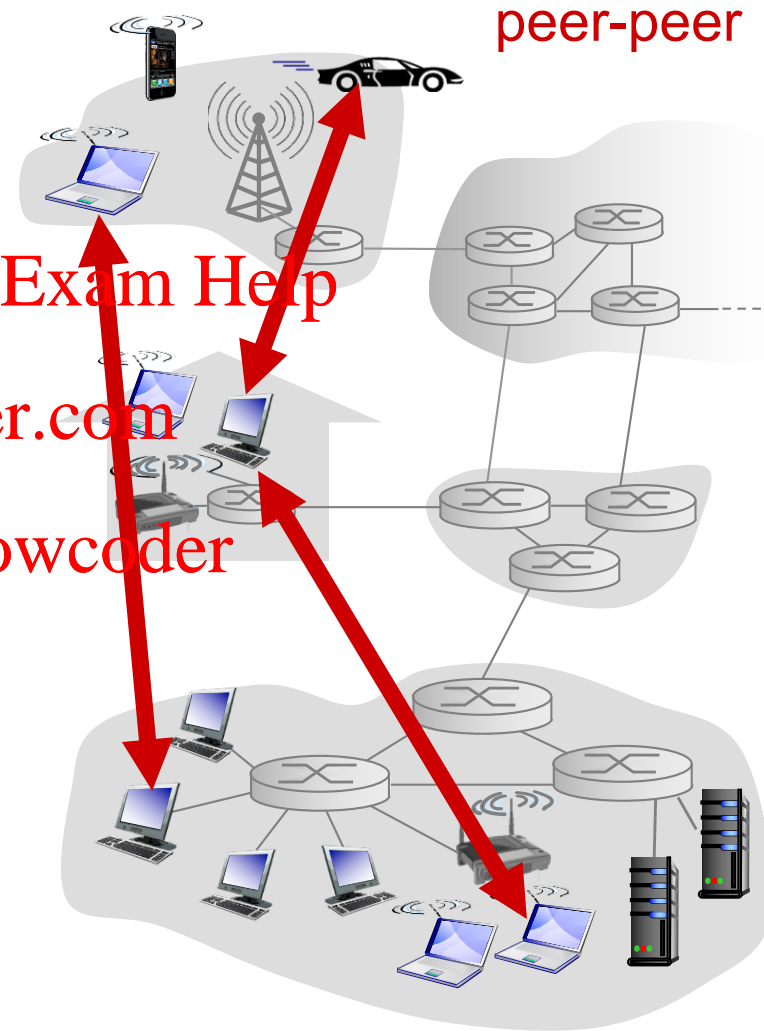
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P2P architecture

- ❖ *no* always-on server
 - No permanent rendezvous involved
- ❖ arbitrary end systems (peers) directly communicate
- ❖ Symmetric responsibility (unlike client/server)
- ❖ Often used for:
 - File sharing (BitTorrent)
 - Games
 - Video distribution, video chat
 - In general: “distributed systems”



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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

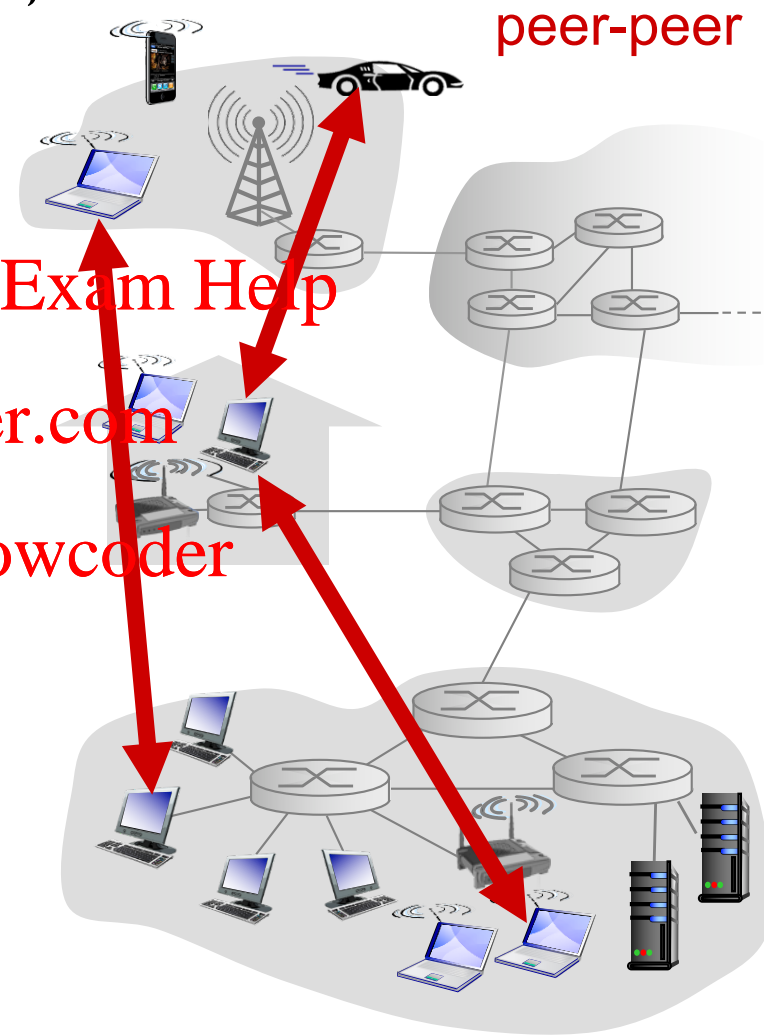
+ Reliability: redundancy, fault tolerance

+ Geographic distribution

- Fundamental problems of decentralized control

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

- Distributed algorithms are complex



App-layer protocol defines

- ❖ types of messages exchanged,
 - e.g., request, response
 - ❖ message syntax:
 - what fields in messages & how fields are delineated
 - ❖ message semantics
 - meaning of information in fields
 - ❖ rules for when and how processes send & respond to messages
- open protocols:
- ❖ defined in RFCs
 - ❖ allows for interoperability
- proprietary protocols:
- ❖ e.g., Skype
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What transport service does an app need?

data integrity

- ❖ some apps (e.g., file transfer, web transactions) require 100% reliable data transfer
- ❖ other apps (e.g., audio) can tolerate some loss

timing

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

throughput

- ❖ some apps (e.g., multimedia) require minimum amount of throughput to be “effective”
- ❖ other apps (“elastic apps”) make use of whatever throughput they get

security

- ❖ encryption, data integrity, ...

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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 msec
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 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	HTTP [RFC 2616]	TCP
file transfer	FTP [RFC 959]	TCP
streaming multimedia	HTTP (e.g., YouTube), RTP [RFC 1889]	TCP 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 requirements

2.2 Web and HTTP

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The Web – Precursor



Ted Nelson

❖ 1967, Ted Nelson, Xanadu:

- A world-wide publishing network that would allow information to be stored not as separate files but as connected literature
 - Owners of documents would be automatically paid via electronic means for the virtual copying of their documents
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- ## ❖ Coined the term “Hypertext”

The Web – History



Tim Berners-Lee

- ❖ World Wide Web (WWW): a distributed database of “pages” linked through **Hypertext Transport Protocol**

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- First HTTP implementation - 1990
 - Tim Berners-Lee at CERN

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- HTTP/0.9 – 1991
 - Simple GET command for the Web
- HTTP/1.0 – 1992
 - Client/Server information, simple caching
- HTTP/1.1 – 1996
- HTTP2.0 - 2015

<http://info.cern.ch/hypertext/WWW/TheProject.html>

Web and HTTP

First, a review...

- ❖ *web page* consists of *objects*
- ❖ object can be HTML file, JPEG image, Java applet, audio file,...
- ❖ web page consists of *base HTML file* which includes *several referenced objects*
- ❖ each object is addressable by a *URL*, e.g.,

`www.someschool.edu/someDept/pic.gif`

host name

path name

Uniform Resource Locator (URL)

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

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

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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.unsw.edu.au/~salilk/papers/journals/TMC2012.pdf>

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- ❖ Extend to program executions as well...

- 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 model
 - **client:** browser that requests, receives, (using HTTP protocol) and "displays" Web objects
 - **server:** Web server sends (using HTTP protocol) objects in response to requests



HTTP overview (continued)

uses TCP:

- ❖ client initiates TCP connection (creates socket) to server port 80
- ❖ server accepts TCP connection from client
- ❖ HTTP messages (application-layer protocol messages) exchanged between browser (HTTP client) and Web server (HTTP server)
- ❖ TCP connection closed

HTTP is “stateless”

- ❖ server maintains no information about past client requests

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

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```
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\n
Date: Sun, 26 Sep 2010 20:09:20 GMT\r\n
Server: Apache/2.0.52 (CentOS)\r\n
Last-Modified: Tue, 30 Oct 2007 17:00:02
GMT\r\n
ETag: "17dc6-a5c-bf/16880"\r\n
Accept-Ranges: bytes\r\n
Content-Length: 2652\r\n
Keep-Alive: timeout=10, max=100\r\n
Connection: Keep-Alive\r\n
Content-Type: text/html; charset=ISO-8859-
1\r\n
\r\n
data data data data data ...

HTTP response status codes

- ❖ status code appears in 1st line in server-to-client response message.
- ❖ some sample codes:

200 OK

- request succeeded, requested object later in this msg

301 Moved Permanently

- requested object moved, new location specified later in this msg (Location:)

400 Bad Request

- request msg not understood by server

404 Not Found

- requested document not found on this server

505 HTTP Version Not Supported

451 Unavailable for Legal Reasons

429 Too Many Requests

418 I'm a Teapot

HTTP is all text

- ❖ 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

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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

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when initial HTTP requests arrives at site, site creates:

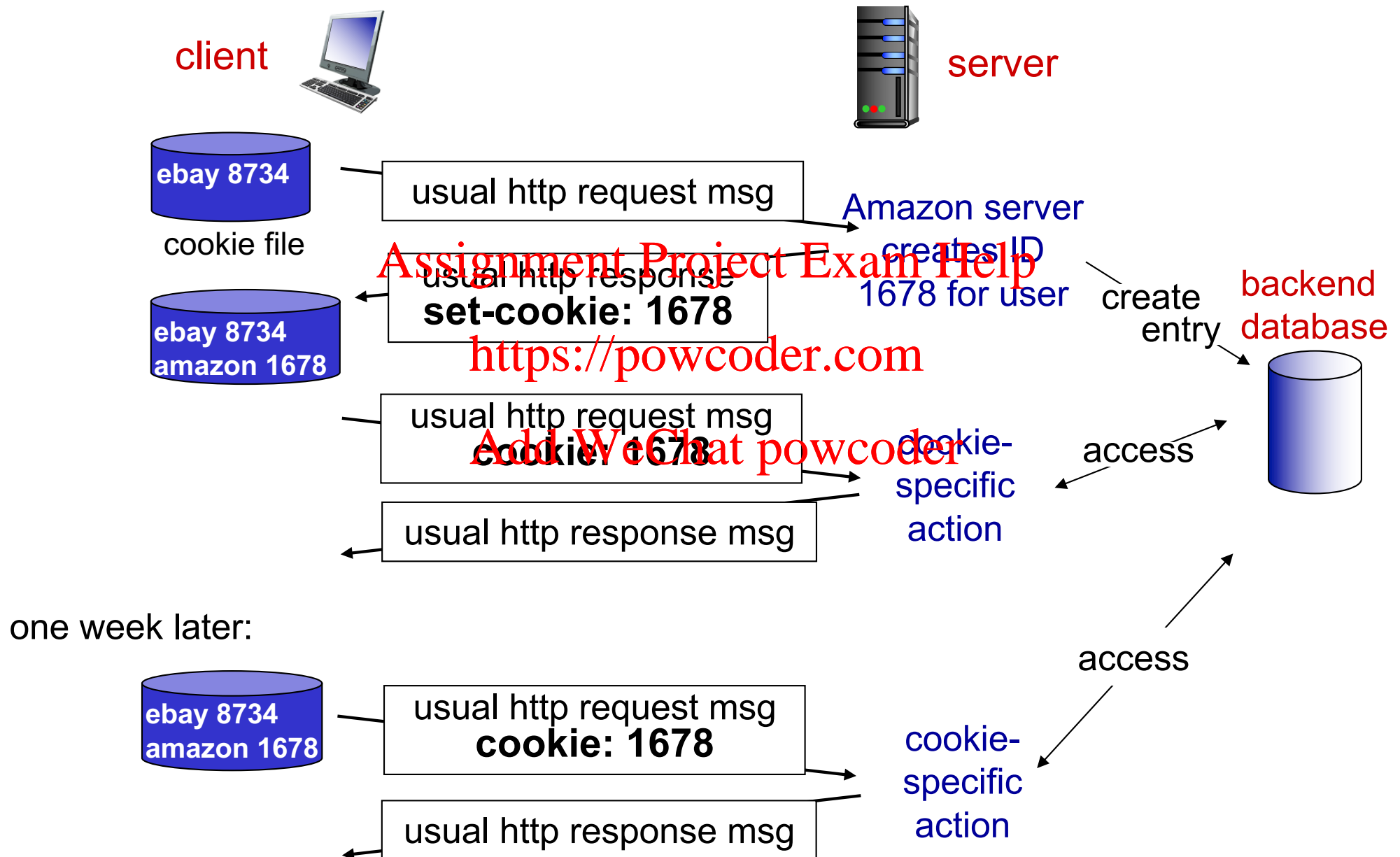
■ unique ID

■ entry in backend database for ID

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Cookies: keeping “state” (cont.)



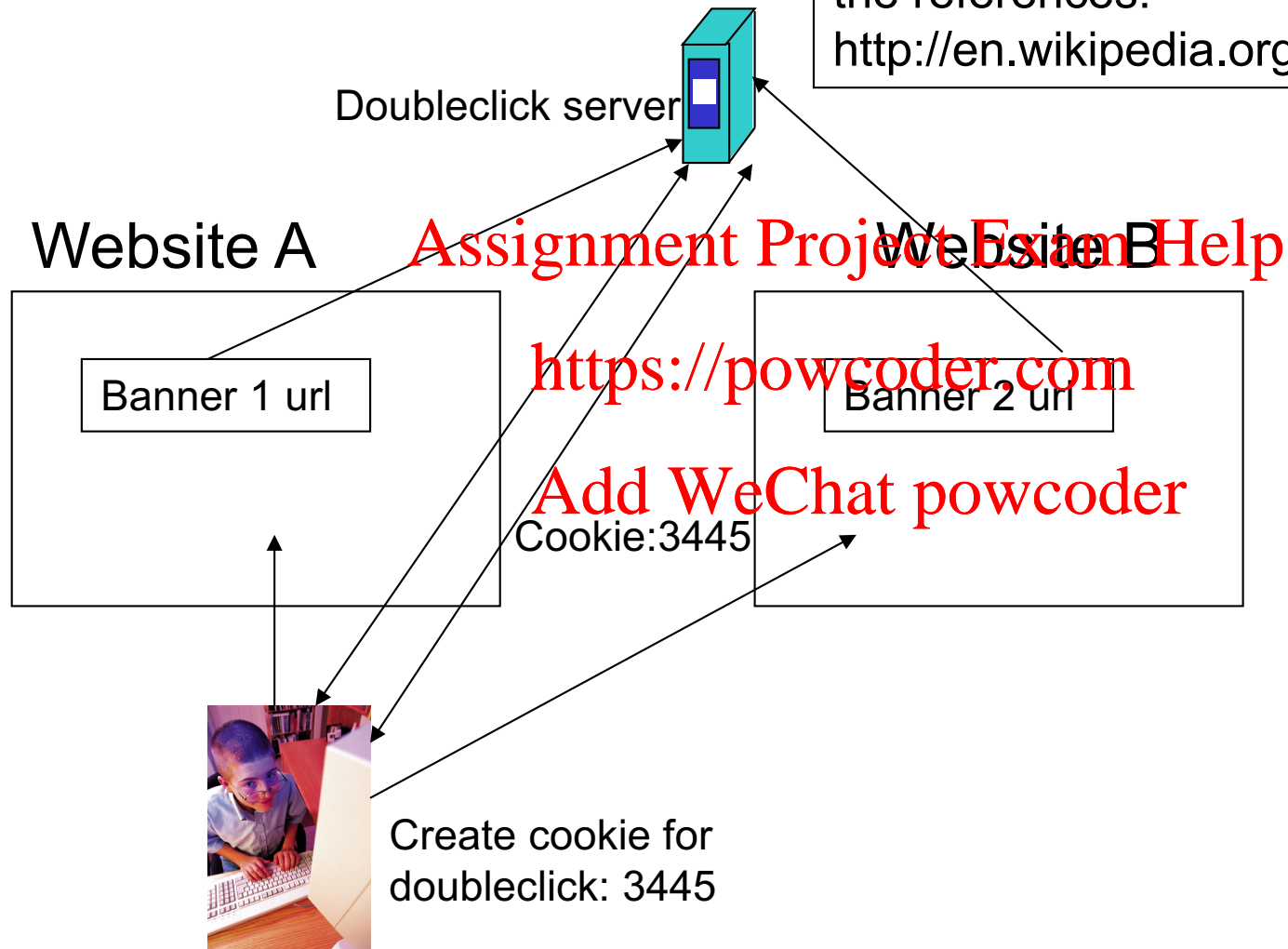
The Dark Side of Cookies

- ❖ Cookies permit sites to learn a lot about you
- ❖ You may supply name and e-mail to sites (and more)
- ❖ 3rd party cookies (from ad networks, etc.) can follow you across multiple sites
 - Ever visit a website, and the next day ALL your ads are from them ?
 - Check your browser's cookie file (cookies.txt, cookies.plist)
 - Do you see a website that you have never visited
- ❖ You COULD turn them off
 - But good luck doing anything on the Internet !!

Third party cookies

For more, check the following link and follow the references:

http://en.wikipedia.org/wiki/HTTP_cookie



Performance of HTTP

- Page Load Time (PLT) as the metric
 - From click until user sees page
 - Key measure of web performance
- Depends on many factors such as
 - page content/structure,
 - protocols involved and
 - Network bandwidth and RTT

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Performance Goals

❖ User

- fast downloads
- high availability

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❖ Content provider

- happy users (hence above)
- cost-effective infrastructure

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❖ Network (secondary)

- avoid overload

Solutions?

Improve HTTP to
achieve faster
downloads

❖ User

- fast downloads
- high availability

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❖ Content provider

- happy users (hence labore)
- cost-effective infrastructure

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❖ Network (secondary)

- avoid overload

Solutions?

❖ User

- fast downloads
- high availability

Improve HTTP to
achieve faster
downloads

❖ Content provider

- happy users (hence lab on)
- cost-effective delivery infrastructure

Caching and Replication

❖ Network (secondary)

- avoid overload

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Solutions?

❖ User

- fast downloads
- high availability

Improve HTTP to
achieve faster
downloads

❖ Content provider

- happy users (hence more)
- cost-effective delivery infrastructure

Caching and Replication

❖ Network (secondary)

- avoid overload

Exploit economies of scale
(Webhosting, CDNs, datacenters)

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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

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HTTP Performance

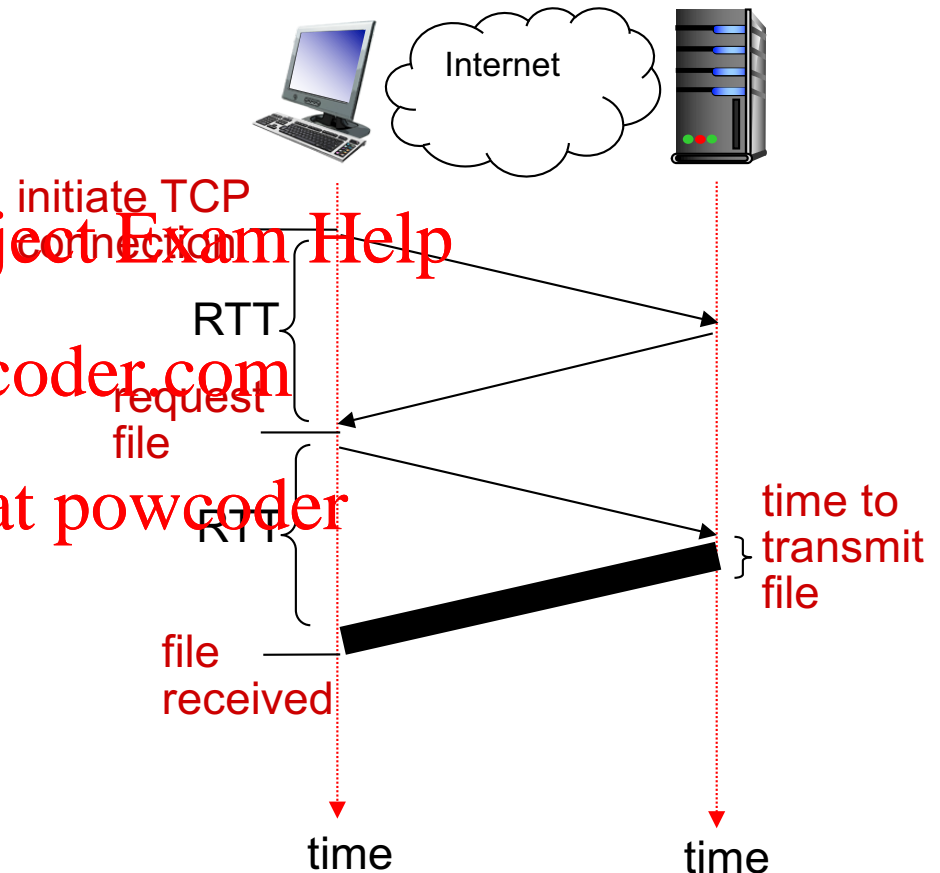
- ❖ Most Web pages have multiple objects
 - e.g., HTML file and a bunch of embedded images
 - ❖ How do you retrieve those objects (naively)?
 - *One item at a time*
 - ❖ New TCP connection per (small) object!
- non-persistent HTTP*
- ❖ at most one object sent over TCP connection
 - connection then closed
 - ❖ 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

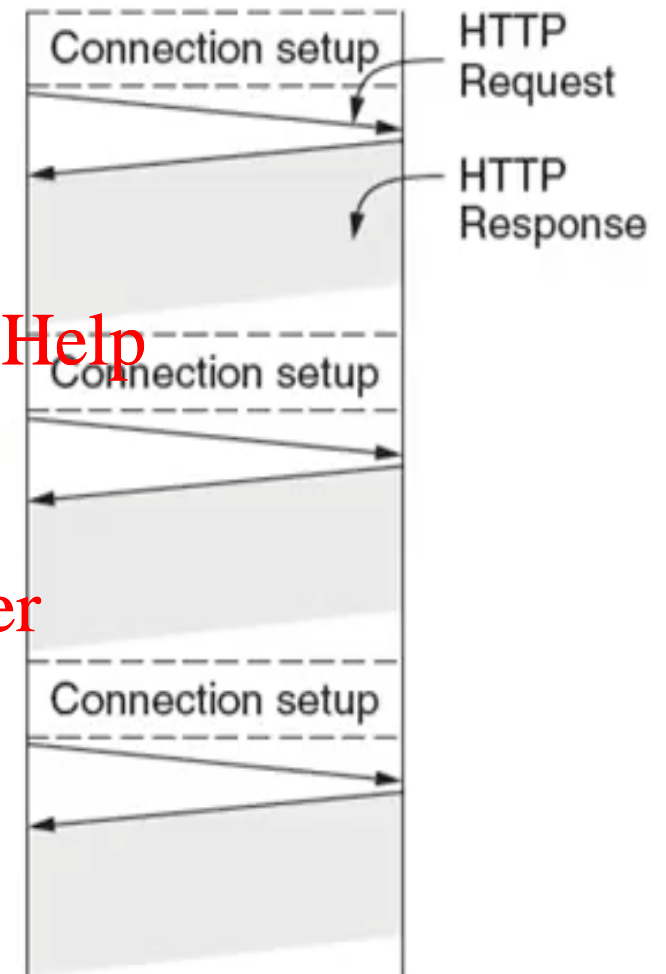
HTTP response time:

- ❖ 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 request/responses even when resources are located on different servers
- Multiple TCP slow-start phases (more in lecture on TCP)



Improving HTTP Performance:

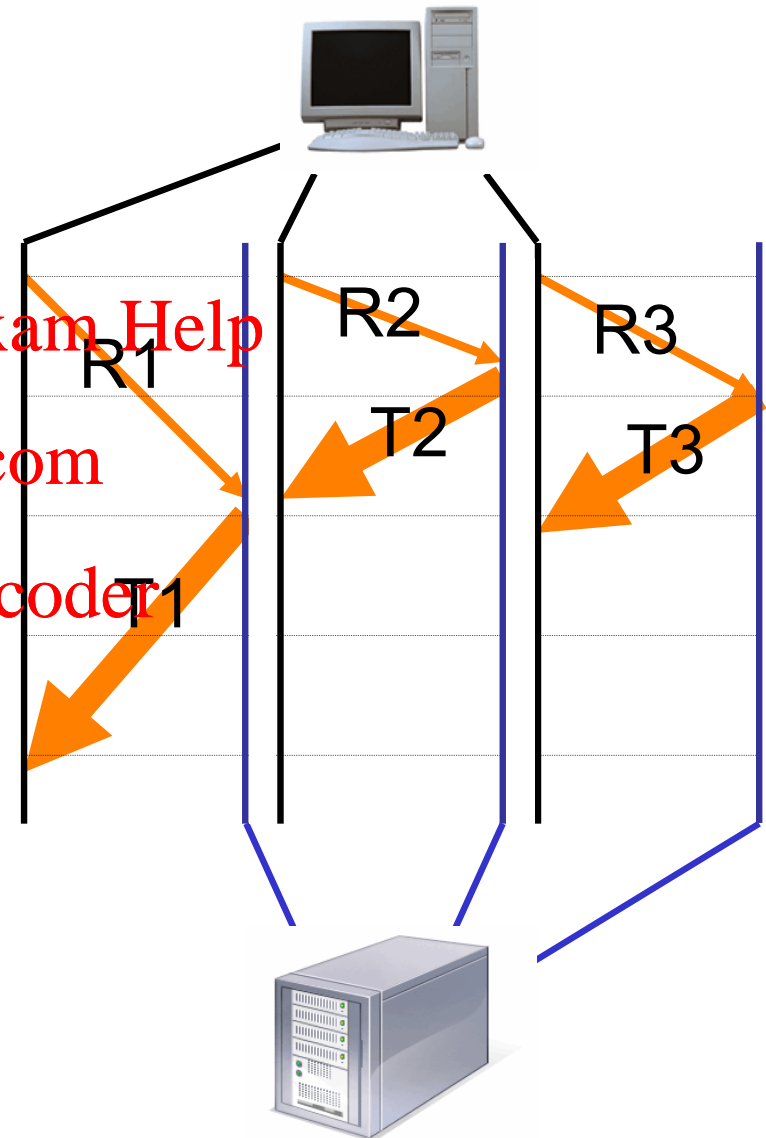
Concurrent Requests & Responses

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

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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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Persistent HTTP

Persistent HTTP

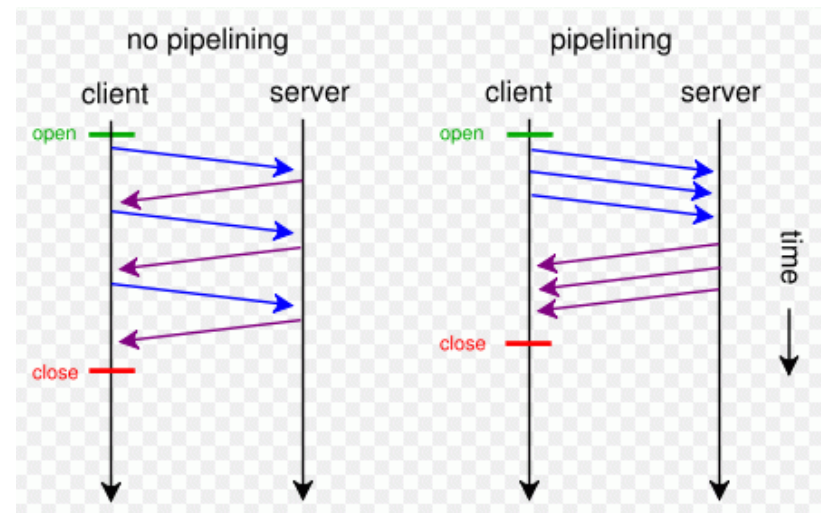
- ❖ server leaves TCP connection open after sending response
- ❖ subsequent HTTP messages between same client/server are sent over the same TCP connection
- ❖ Allow TCP to learn more accurate RTT estimate (APPARENT LATER IN THE COURSE)
- ❖ Allow TCP congestion window to increase (APPARENT LATER)
- ❖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

Persistent without pipelining:

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

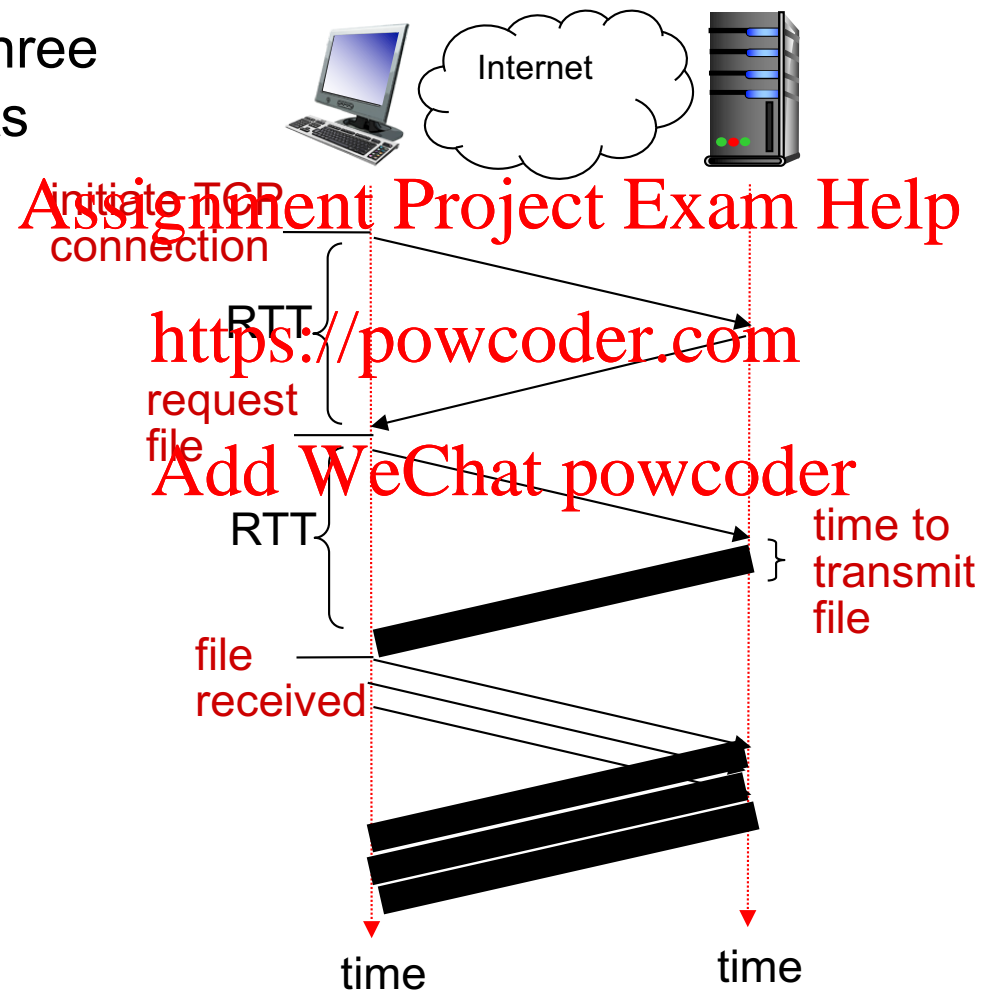
Persistent with pipelining:

- ❖ default 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

Website with one
index page and three
embedded objects



Improving HTTP Performance: Caching

❖ Why does caching work?

- Exploits *locality of reference*

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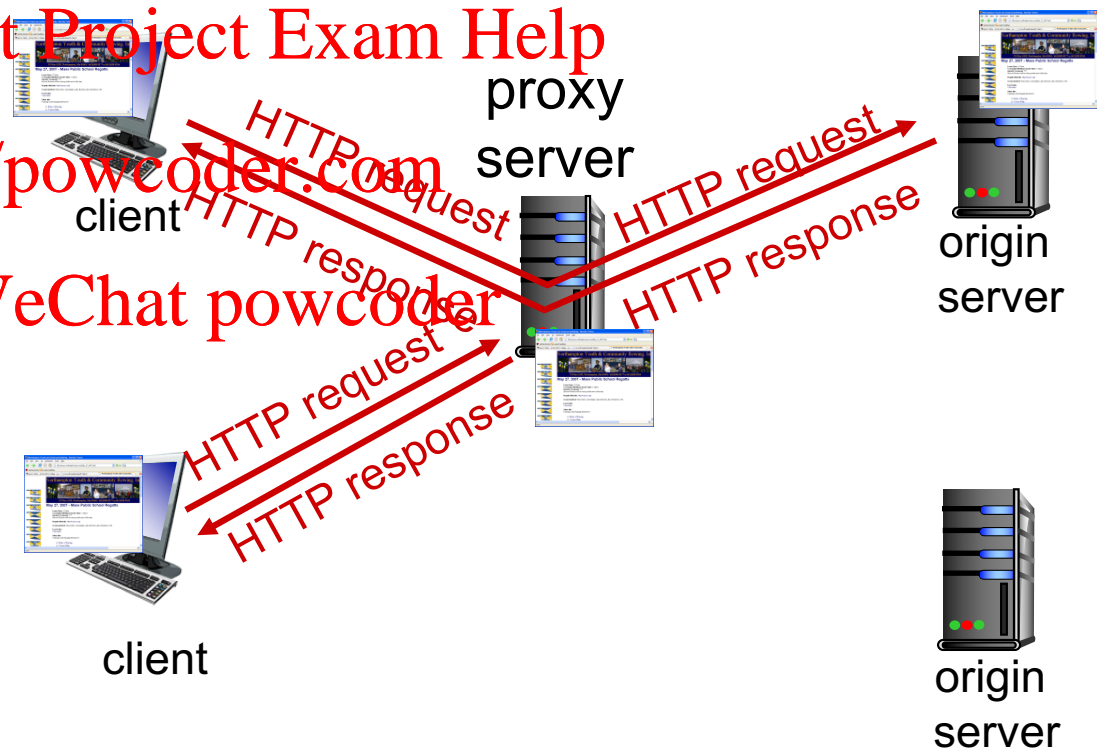
❖ How well does caching work?

- Very well, up to a limit
- Large overlap in content
- But many unique requests

Web caches (proxy server)

goal: satisfy client request without involving origin server

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



More about Web caching

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

why Web caching?

- ❖ reduce response time for client request
- ❖ reduce traffic on an institution's access link
- ❖ Internet dense with caches: enables “poor” content providers to effectively deliver content

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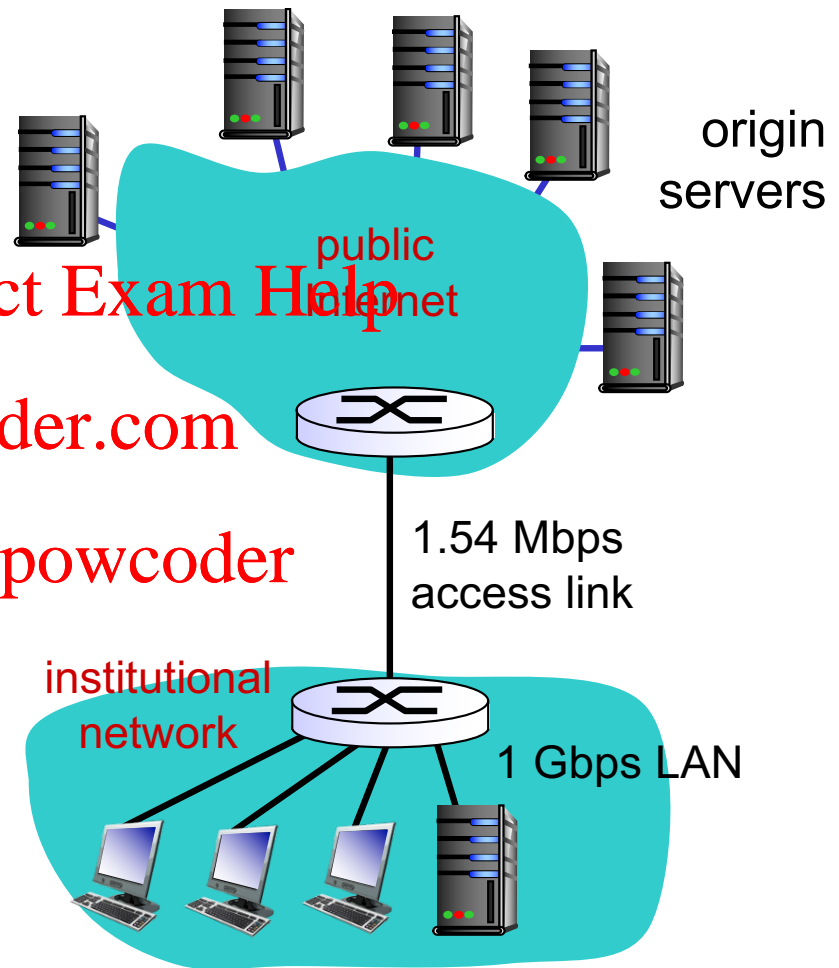
Caching example:

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 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

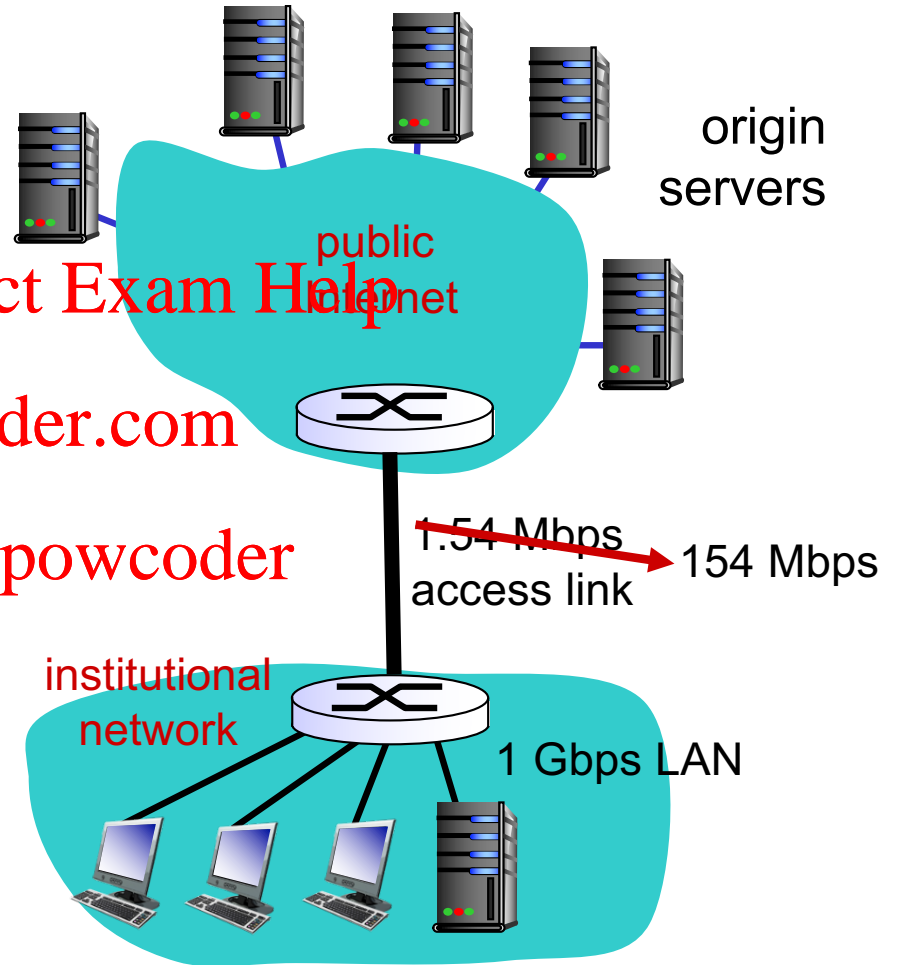
assumptions:

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

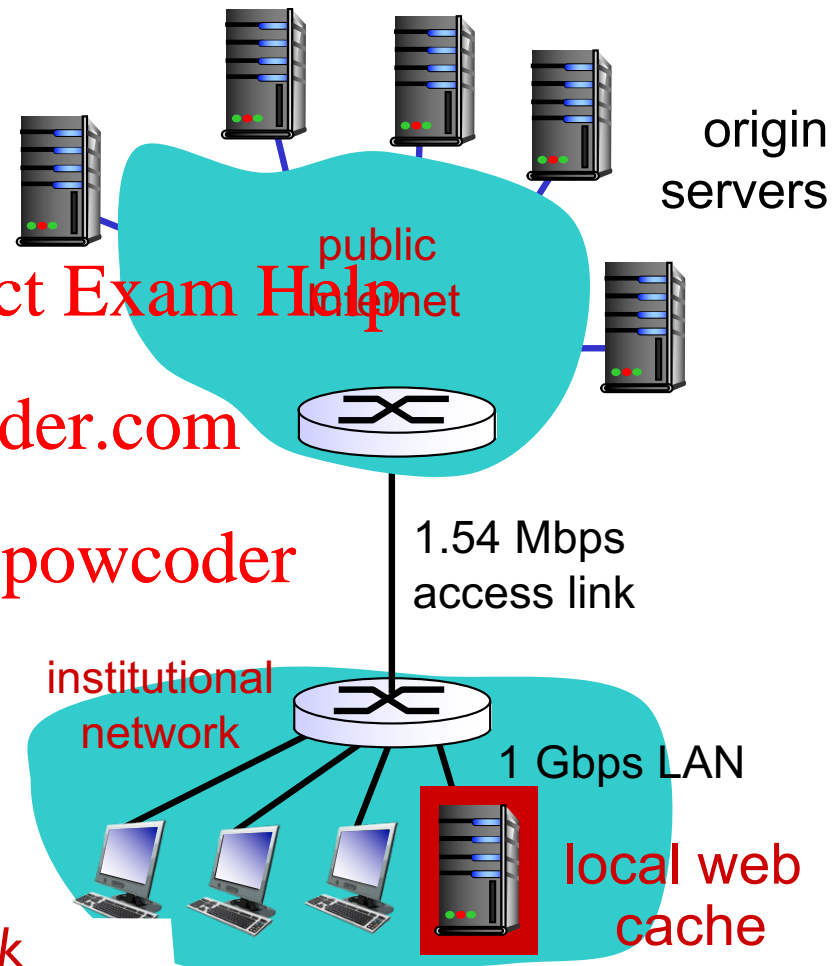
assumptions:

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

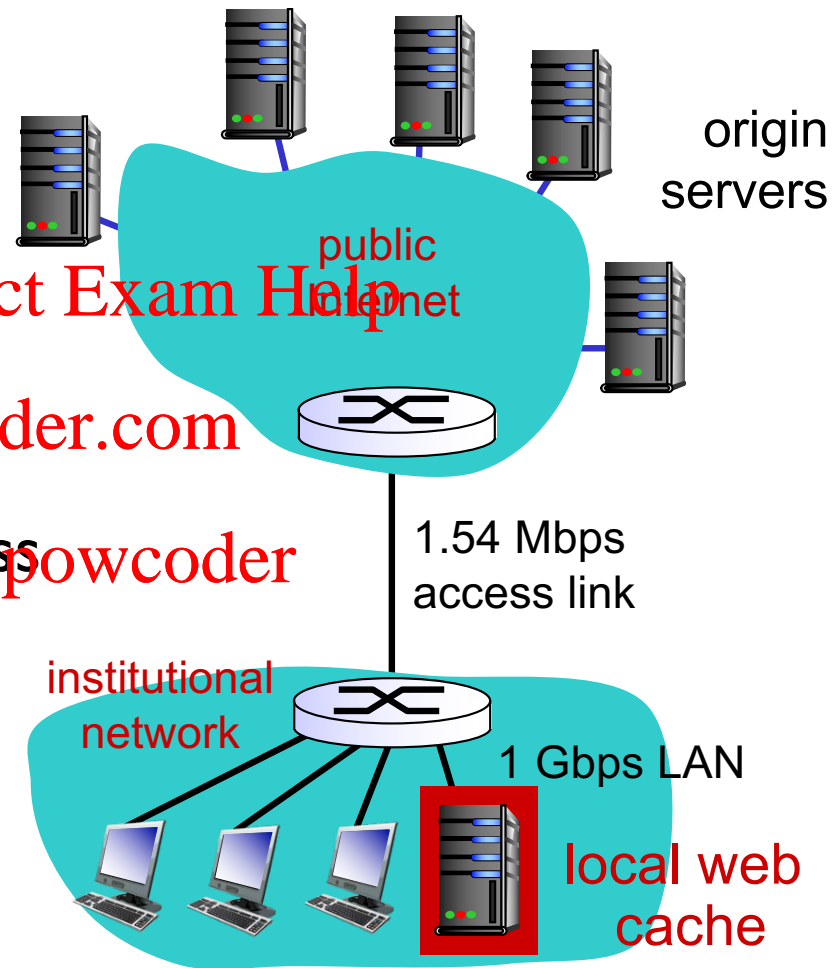
Cost: web cache (cheap!)



Caching example: install local cache

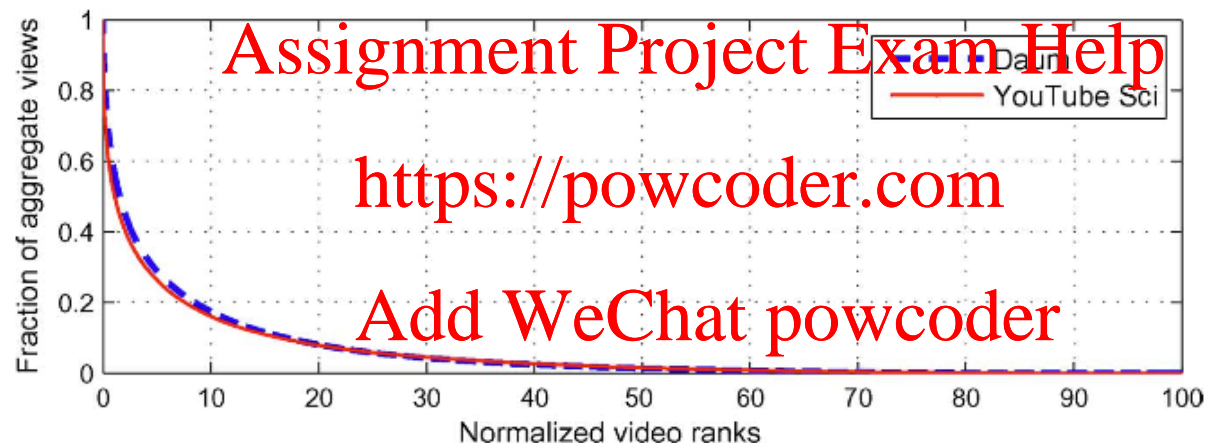
Calculating access link utilization, delay with cache:

- ❖ suppose cache hit rate is 0.4
 - 40% requests satisfied at cache, 60% requests satisfied at origin
- ❖ access link utilization:
 - 60% of requests use access link
- ❖ data rate to browsers 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!)



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>

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>`

object
not
modified
before
<date>

HTTP response
`HTTP/1.0
304 Not Modified`

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

object
modified
after
<date>

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

Example Cache Check Request

GET / HTTP/1.1

Accept: */*

Accept-Language: en-us

Accept-Encoding: gzip, deflate

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

If-None-Match: "7a11f-10ed-3a75ae4a"

User-Agent: Mozilla/4.0 (compatible; MSIE 5.5; Windows NT 5.0)

Host: www.intel-iris.net

Connection: Keep-Alive

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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"

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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

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- ❖ Problem:

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

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- ❖ 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
- ❖ Integrate forward and reverse caching functionality
- ❖ Large-scale distributed storage infrastructure (usually) administered by one entity
 - e.g., Akamai has servers in 20,000+ locations
- ❖ Combination of (pull) caching and (push) replication
 - **Pull:** Direct result of clients' requests
 - **Push:** Expectation of high access rate
- ❖ Also do some processing
 - Handle *dynamic* web pages
 - *Transcoding*
 - *Maybe do some security function – watermark IP*

What about HTTPS?



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

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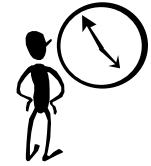
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What's on the horizon: HTTP/2

- ❖ Google SPDY (speedy) -> HTTP/2: (RFC 7540 May 2015)
- ❖ Better content structure
- ❖ Improvements
 - Servers can **push** content and thus reduce overhead of an additional request cycle
 - Fully multiplexed
 - Requests and responses are sliced in smaller chunks called frames, frames are tagged with an ID that connects data to the request/response
 - overcomes Head-of-line blocking in HTTP 1.1
 - Prioritisation of the order in which objects should be sent (e.g. CSS files may be given higher priority)
 - Data compression of HTTP headers
 - Some headers such as cookies can be very long
 - Repetitive information

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

Summary



- ❖ Completed Introduction (Chapter 1)

- Solve Sample Problem Set

- ❖ Application Layer (Chapter 2)

- Principles of Network Applications
- HTTP

Reading Exercise
Chapter 2: 2.4 – 2.7

- ❖ Next Week: Application Layer (contd.)

- E-mail
- P2P
- DNS
- Socket Programming

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