Computer Networks and Applications

COMP 3331/COMP 9331

Week 2

Introduction(Protocol Layering, 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 core
- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks
1.5 protocol layers, service models
1.6 networks under attack: security
1.7 history

Three (networking) design steps

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

Tasks in Networking

- What does it take to send packets across country?
- Simplistic decomposition:
  - Task 1: send along a single wire

  - Task 2: stitch these together to go across country

- This gives idea of what I mean by decomposition

Tasks in Networking (bottom up)

- Bits on wire
- Packets on wire
- Deliver packets within local network
- Deliver packets across global network
- Ensure that packets get to the destination
- Do something with the data

Resulting Modules

- Bits on wire (Physical)
- Packets on wire (Physical)
- Delivery packets within local network (Datalink)
- Deliver packets across global network (Network)
- Ensure that packets get to the dst. (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
    - » Aide:
      - » Puts letter in envelope with CEO B's full name
      - » Takes to FedEx

```
Dear John,

Your days are numbered.

            --Pat
```

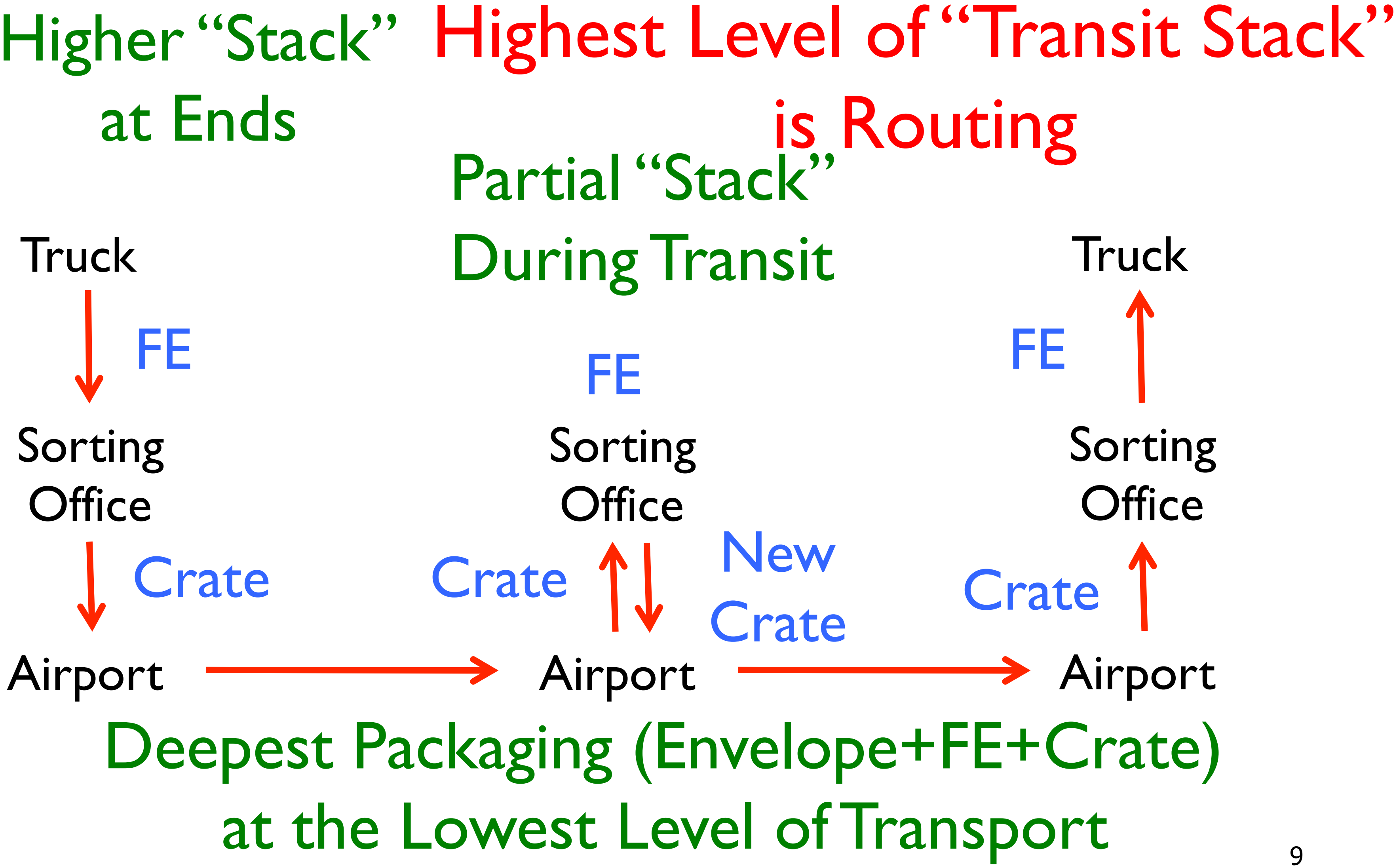
- FedEx Office
  - Puts letter in larger envelope
  - Puts name and street address on FedEx envelope
  - Puts package on FedEx delivery truck
- FedEx delivers to other company

The Path of the Letter

"Peers" on each side understand the same things
No one else needs to (abstraction)
Lowest level has most packaging

CEO	Semantic Content Letter	CEO
↓		↑
Aide	Identity Envelope	Aide
↓		↑
FedEx	Location → Fedex Envelope (FE)	FedEx

The Path Through FedEx



In the context of the Internet

Applications

…built on…

Reliable (or unreliable) transport

…built on…

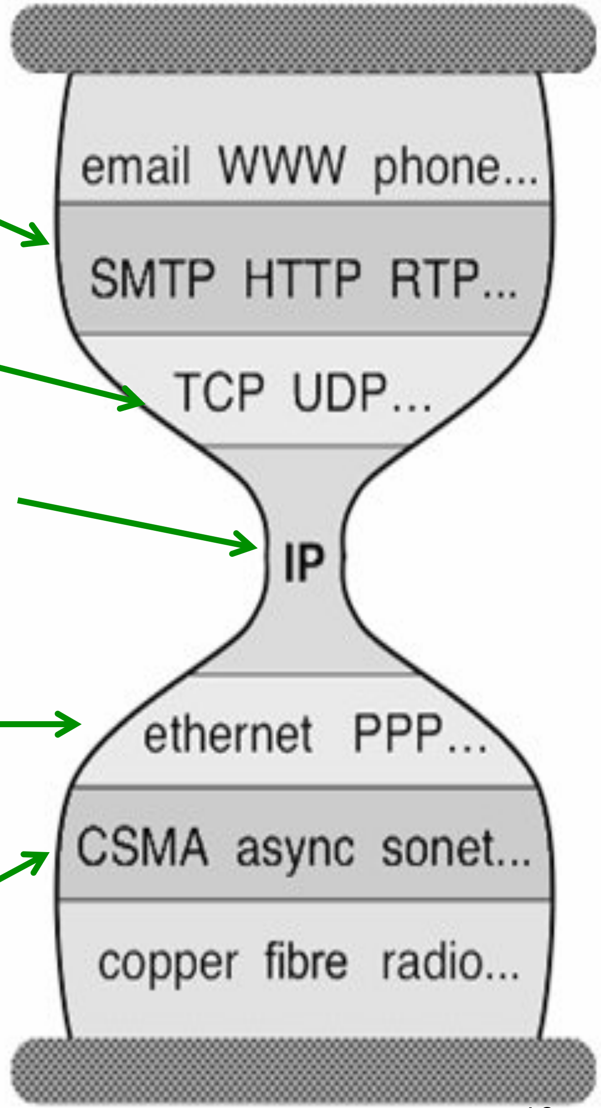
Best-effort global packet delivery

…built on…

Best-effort local packet delivery

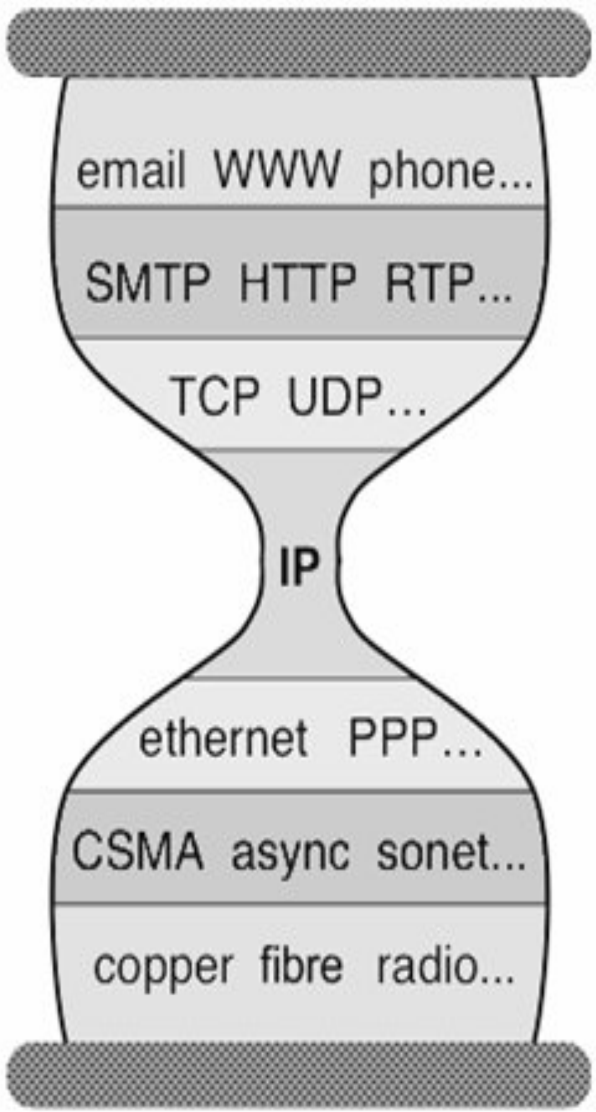
…built on…

Physical transfer of bits



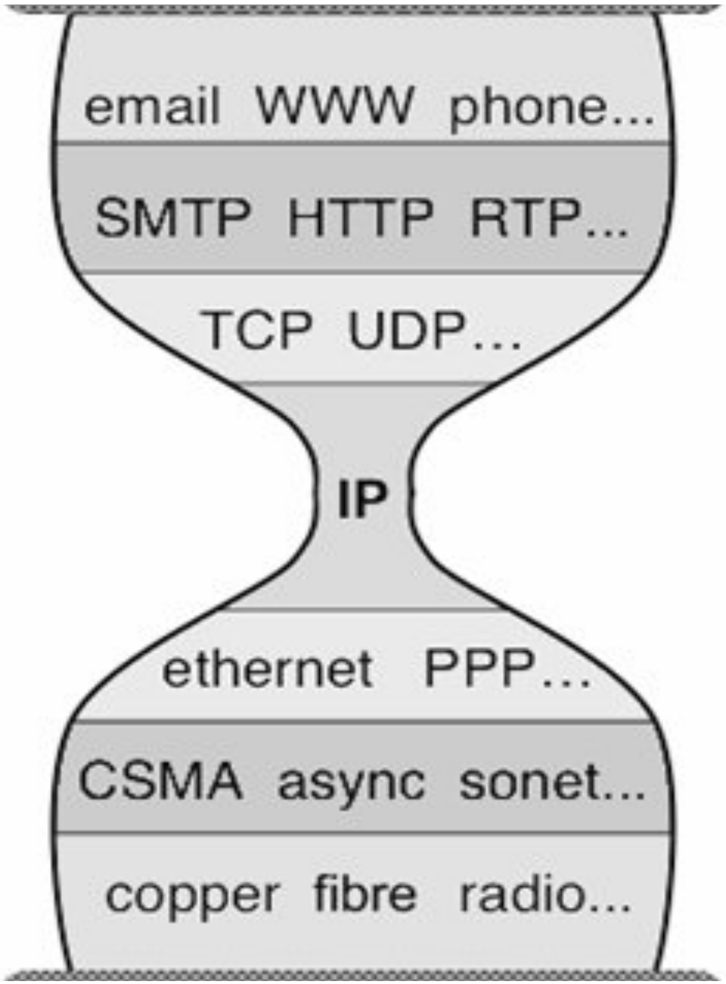
Internet protocol stack

- *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

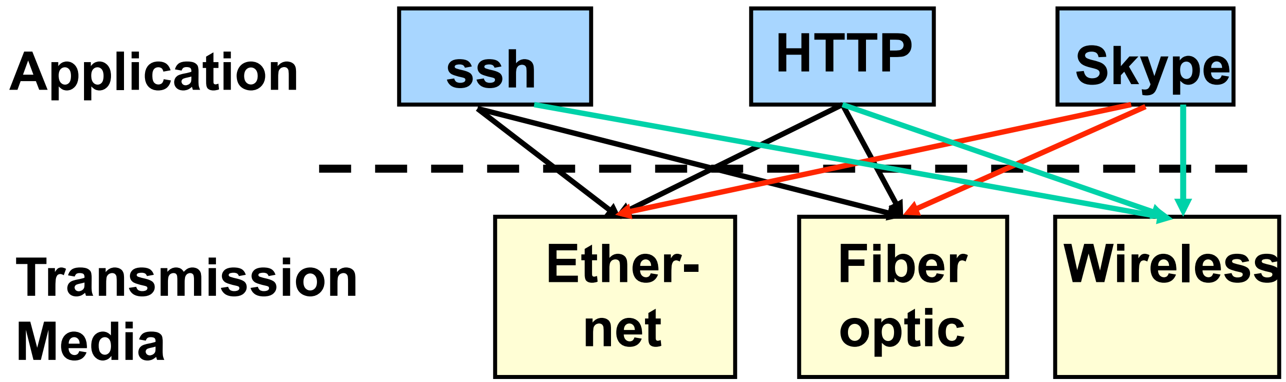
- Each layer:
  - Depends on layer below
  - Supports layer above
  - Independent of others
- Multiple versions in layer
  - Interfaces differ somewhat
  - Components pick which lower-level protocol to use
- But only one IP layer
  - Unifying protocol



Quiz: What are the benefits of layering?

-
-
-

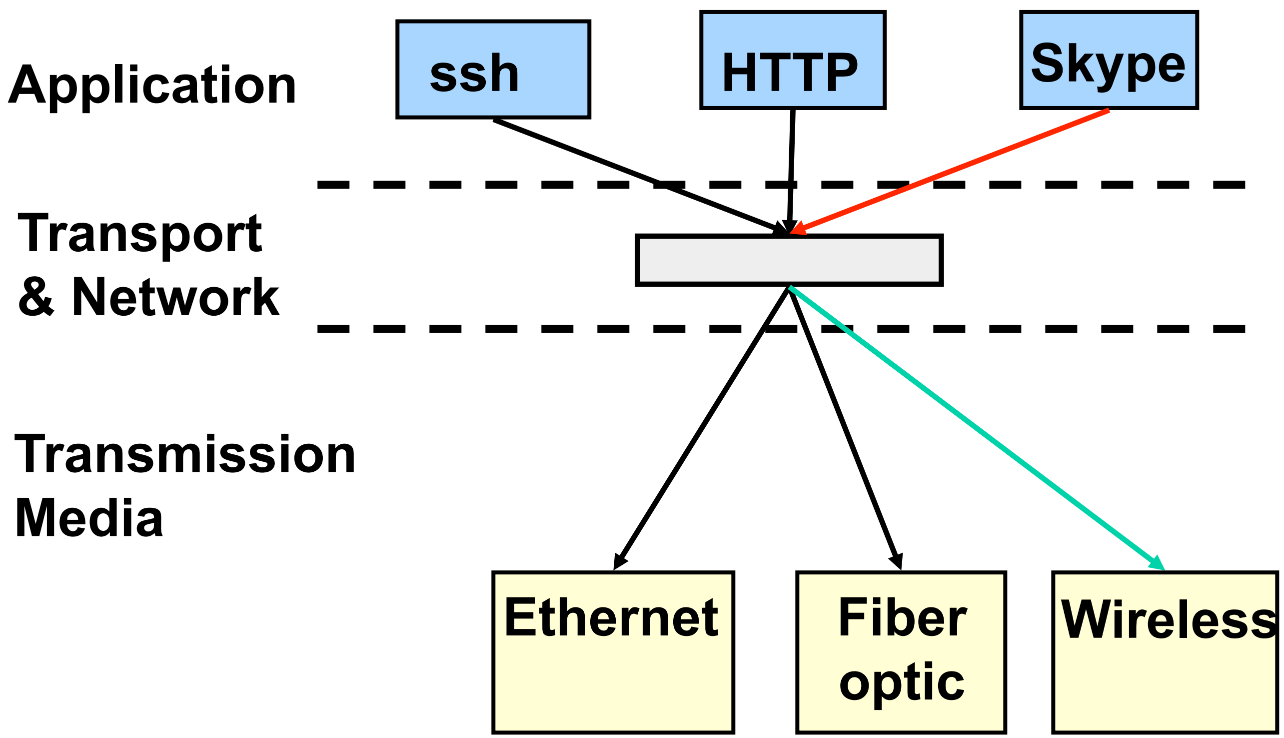
An Example: No Layering



- 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
- But we need to implement layers across machines
  - Hosts
  - Routers
  - Switches
- What gets implemented where?

What Gets Implemented on Host?

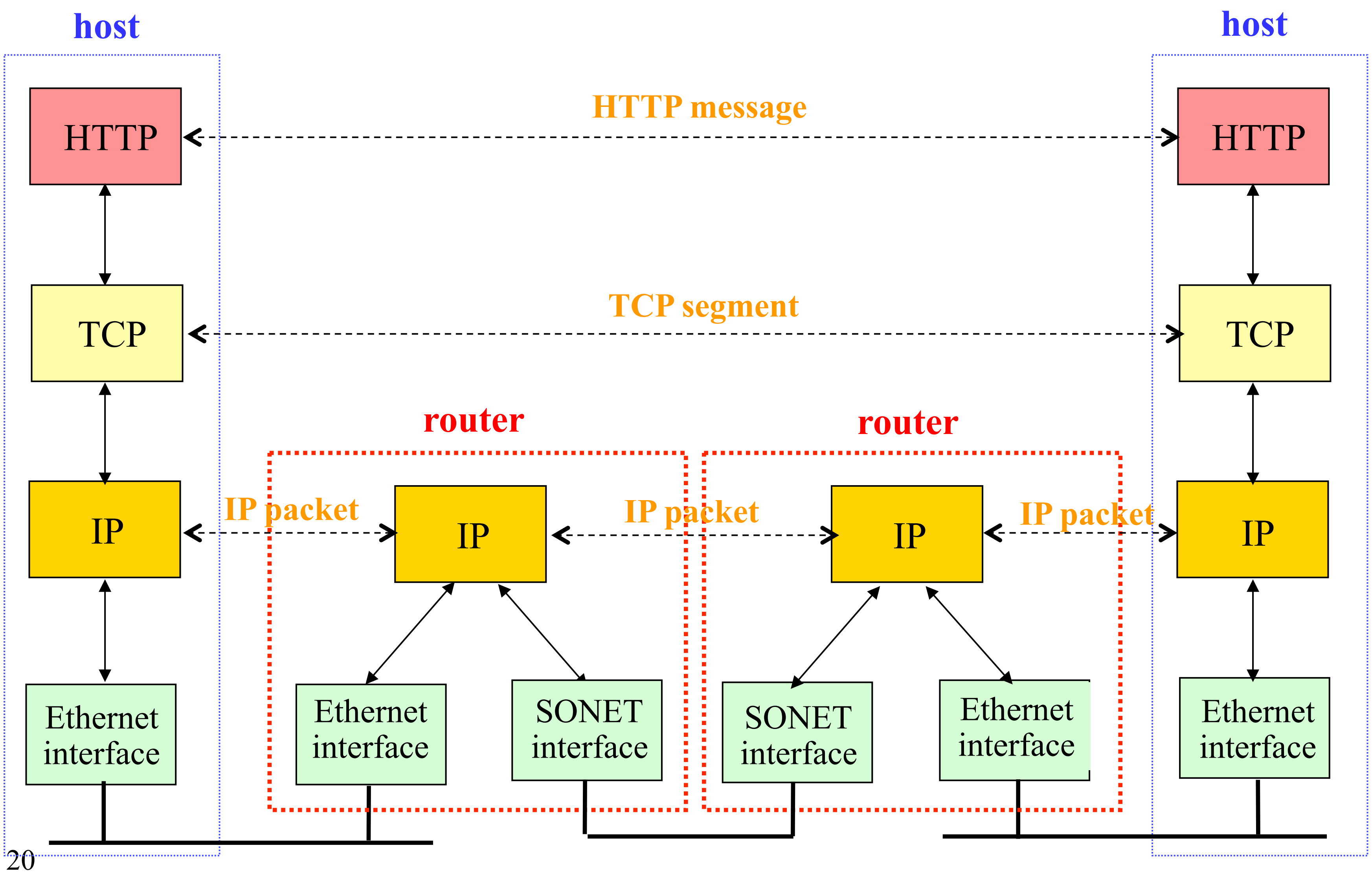
- Bits arrive on wire, must make it up to application

- Therefore, all layers must exist at host!

What Gets Implemented on Router?

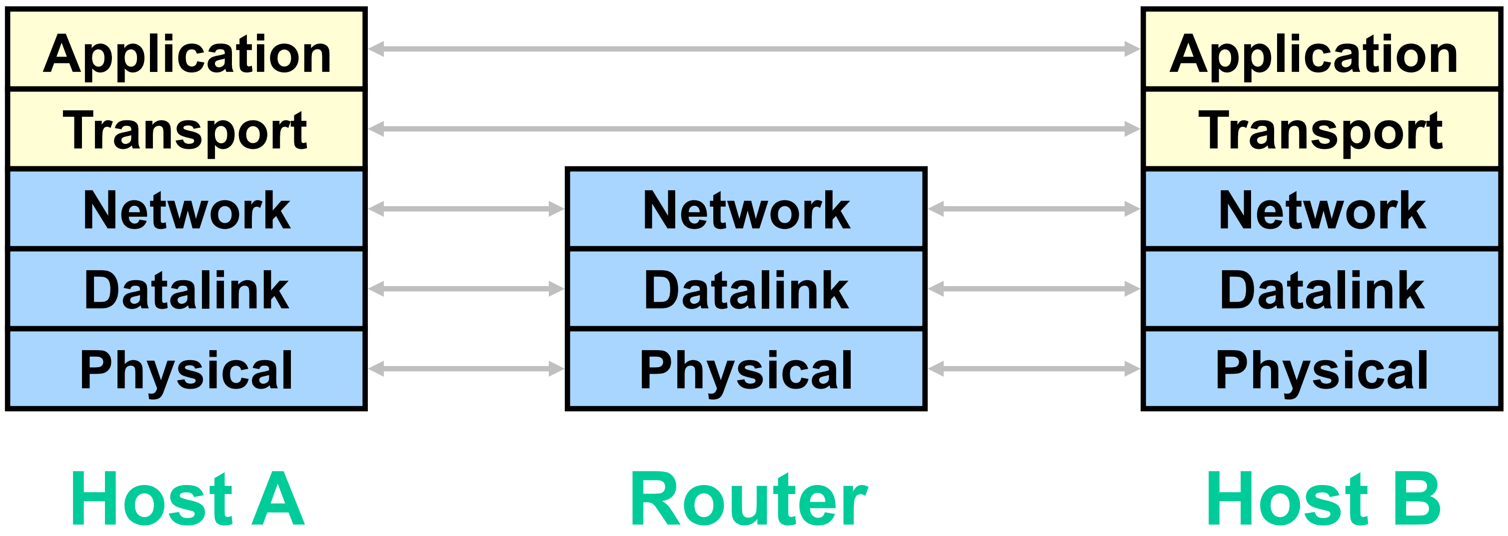
- Bits arrive on wire
  - Physical layer necessary
- Packets must be delivered to next-hop
  - datalink layer necessary
- Routers participate in global delivery
  - Network layer necessary
- Routers don’t support reliable delivery
  - Transport layer (and above) ***<u>not</u>*** supported

Internet Layered Architecture



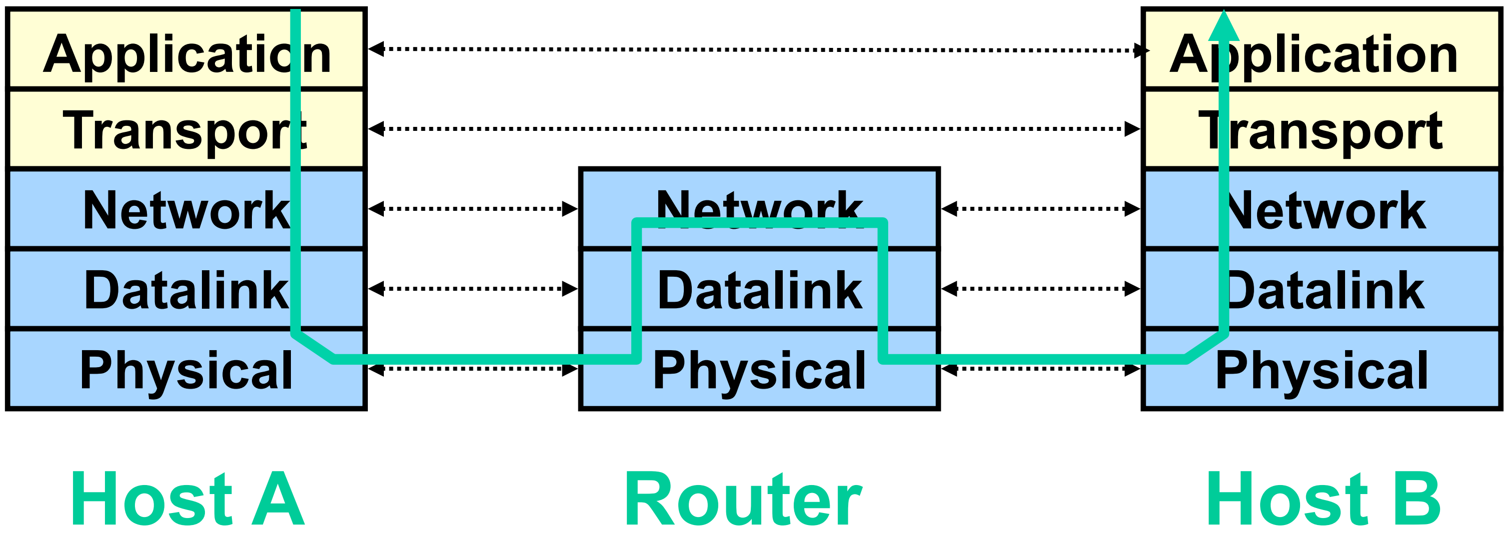
Logical Communication

- Layers interacts with peer's corresponding layer

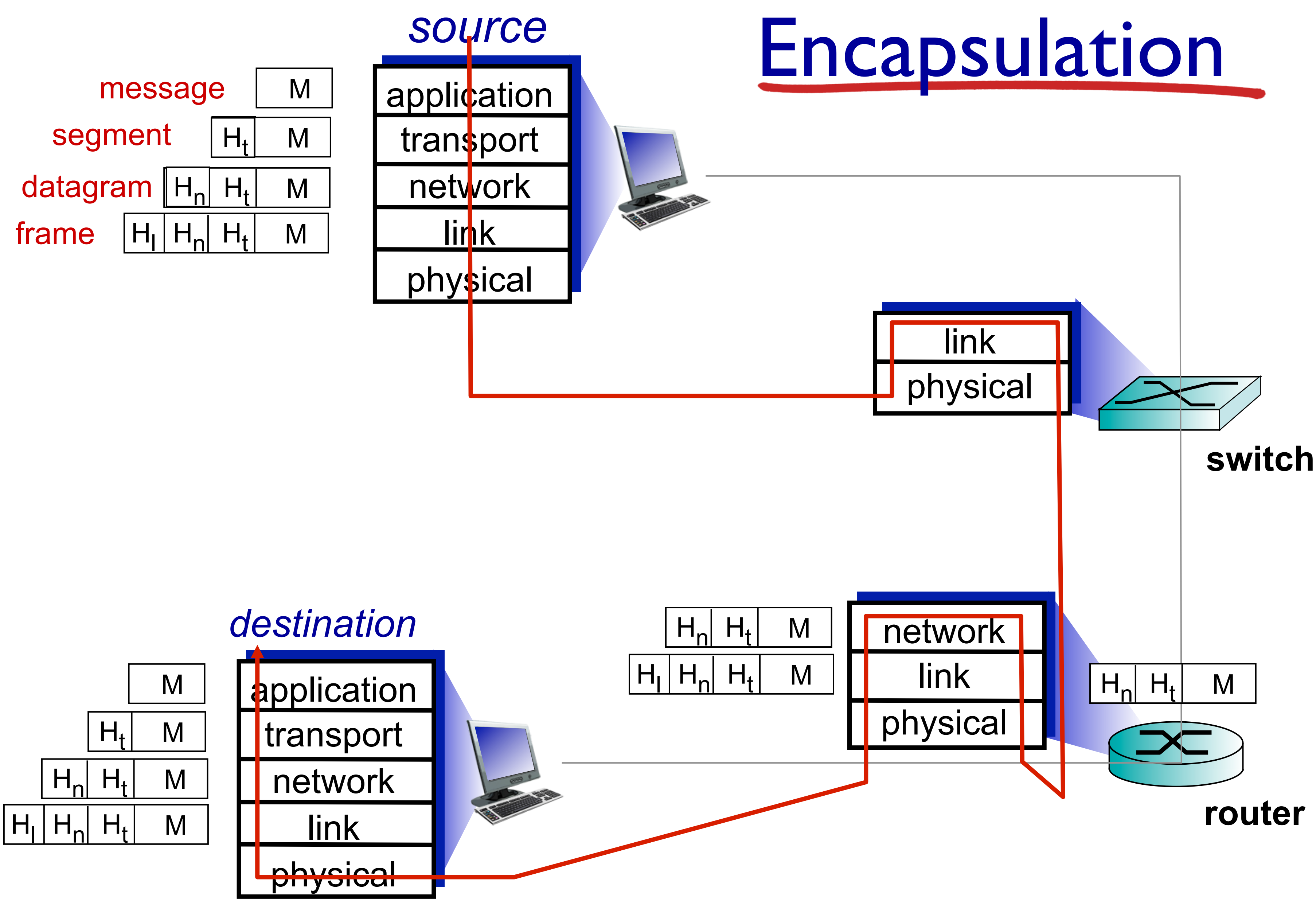


Physical Communication

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



Encapsulation



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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-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!*

2. Application Layer: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 electronic mail
- SMTP, POP3, IMAP

2.4 DNS

2.5 P2P applications

2.6 video streaming and content distribution networks (CDNs)

2.7 socket programming with UDP and TCP

2. Application layer

our goals:

- conceptual, implementation aspects of network application protocols
  - transport-layer service models
  - client-server paradigm
  - peer-to-peer paradigm
- learn about protocols by examining popular application-level protocols
  - HTTP
  - SMTP / POP3 / IMAP
  - DNS
  - Video streaming
- creating network applications
  - socket API

Quiz: Can you name a few networked applications?

Creating a network app

write programs that:

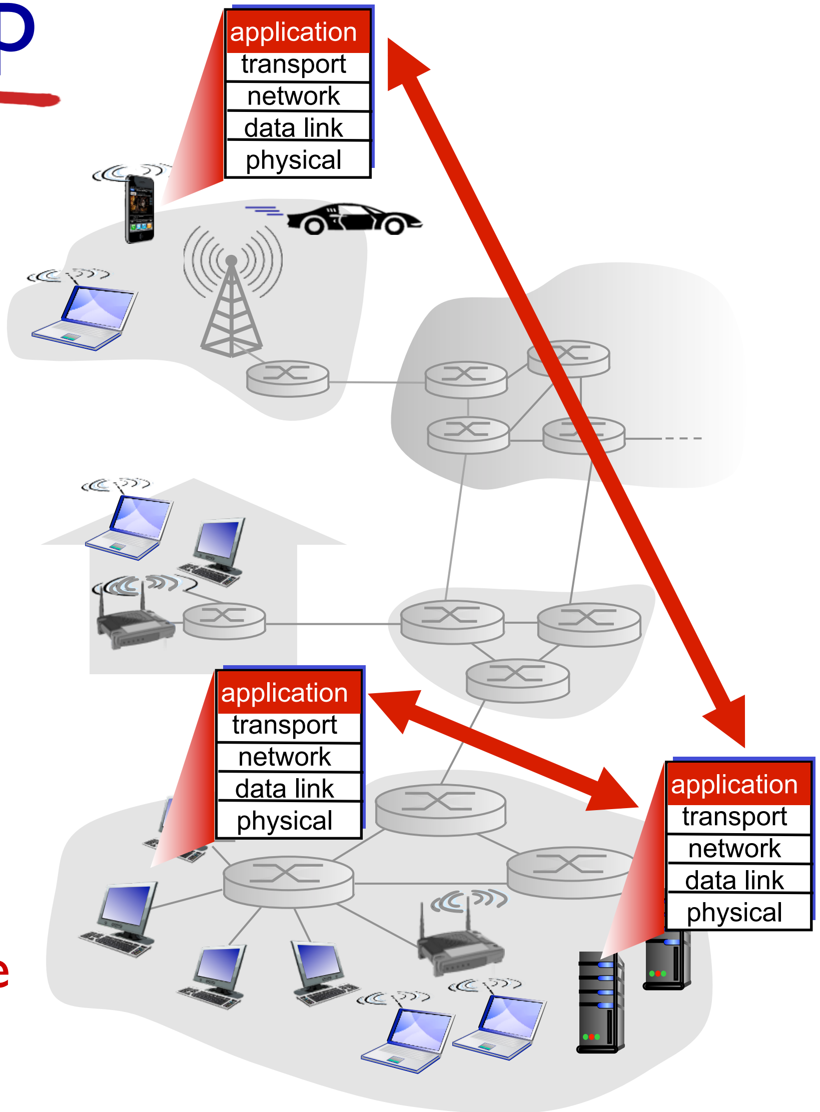
- run on (different) *end systems*
- communicate over network
- e.g., web server software communicates with browser software

Varying degrees of integration

- Loose: email, web browsing
- Medium: chat, Skype, remote file systems
- Tight: process migration, distributed file systems

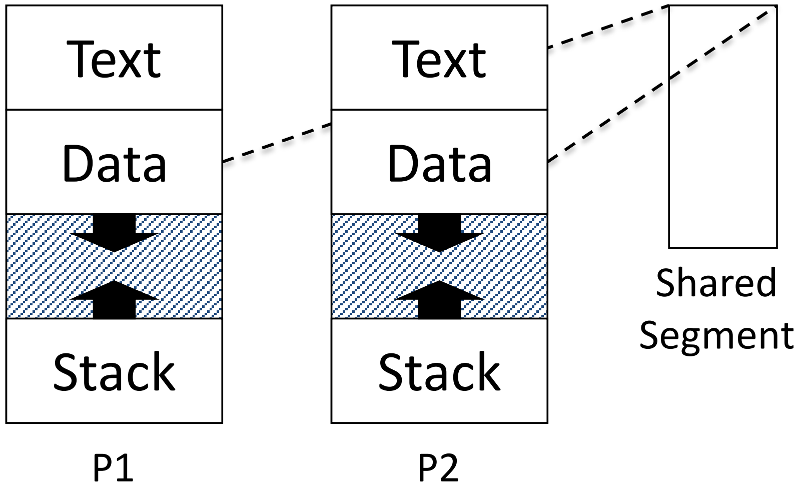
no need to write software for network-core devices

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



Interprocess Communication (IPC)

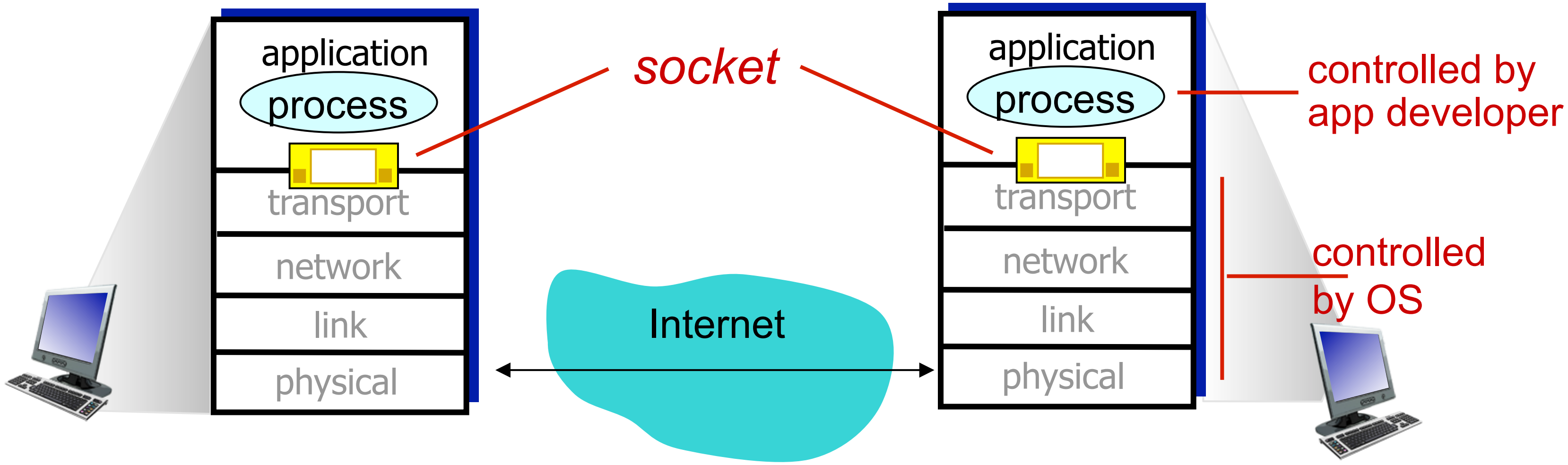
- Processes talk to each other through Inter-process communication (IPC)



- On a single machine:
  - Shared memory
- Across machines:
  - We need other abstractions (message passing)

Sockets

- 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

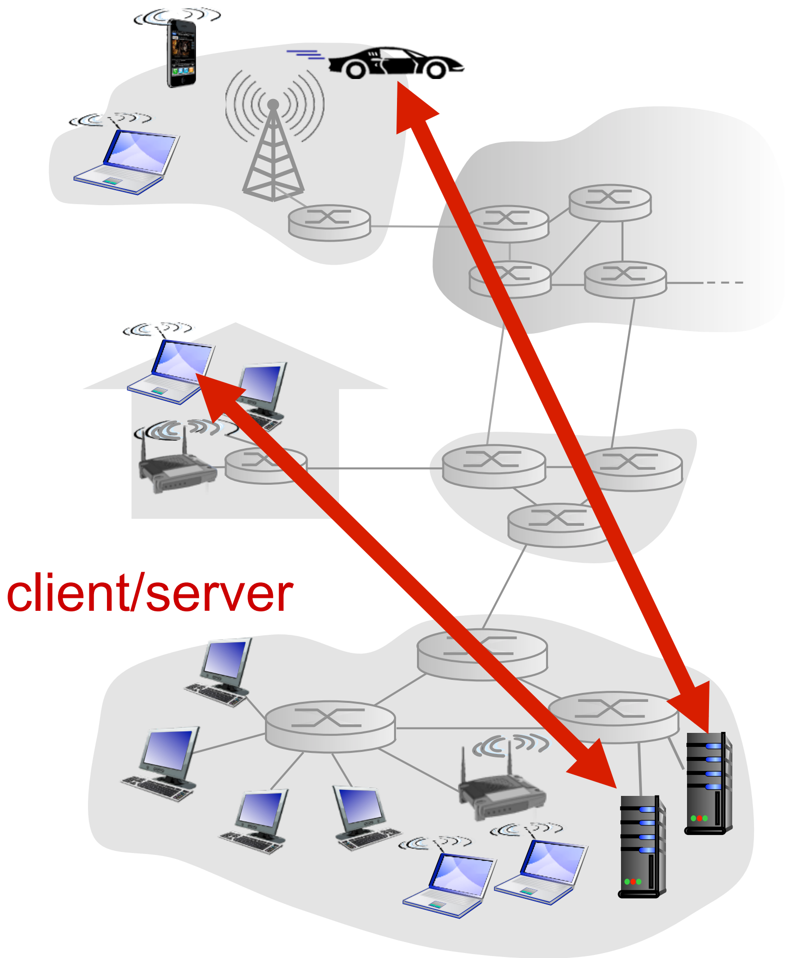


Addressing processes

- 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
- more on this in 2 weeks

Client-server architecture



server:

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

clients:

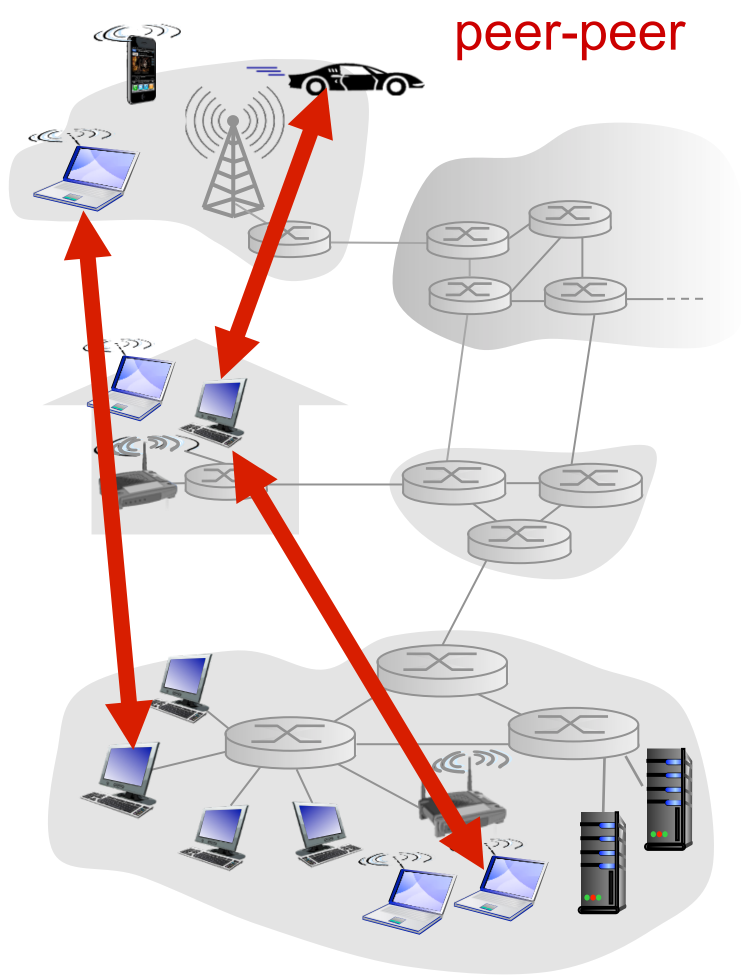
- Short-lived process that makes requests
- “User-side” of application
- Initiates the communication

Client versus Server

- Server
  - Always-on host
  - Permanent IP address (rendezvous location)
  - Static port conventions (http: 80, email: 25, ssh: 22)
  - Data centres for scaling
  - May communicate with other servers to respond
- Client
  - May be intermittently connected
  - May have dynamic IP addresses
  - Do not communicate directly with each other

P2P architecture

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

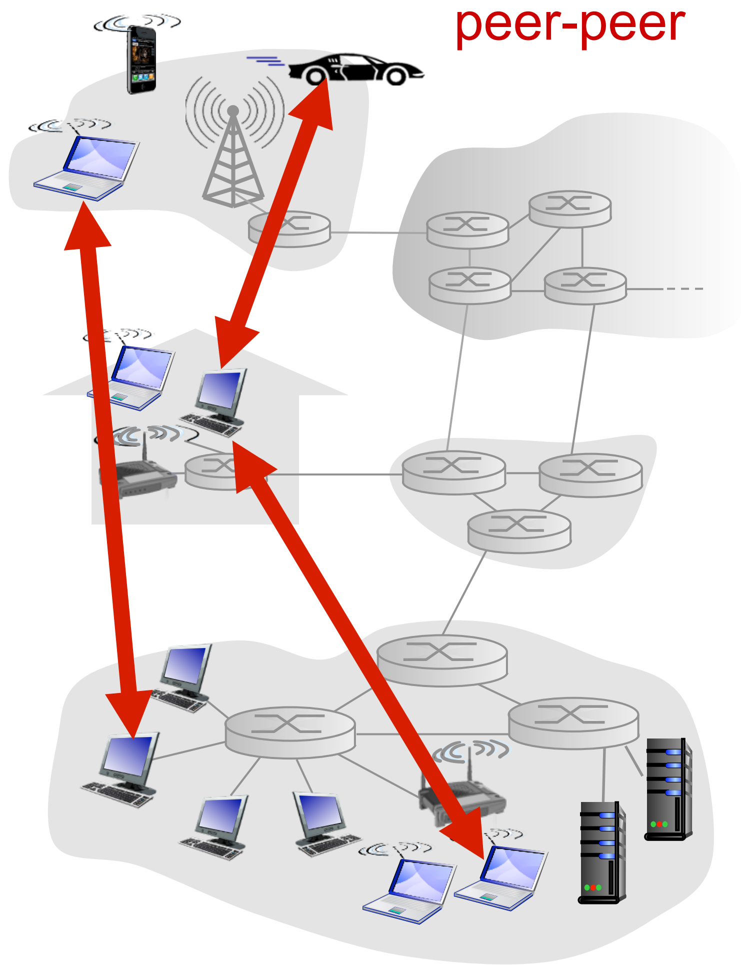


P2P architecture: Pros and Cons

+ peers request service from other peers, provide service in return to other peers
  - *self scalability* – new peers bring new service capacity, as well as new service demands
+ Speed: parallelism, less contention
+ Reliability: redundancy, fault tolerance
+ Geographic distribution

-Fundamental problems of decentralized control
  - State uncertainty: no shared memory or clock
  - Action uncertainty: mutually conflicting decisions

-Distributed algorithms are complex



App-layer protocol defines

- types of messages exchanged,
  - e.g., request, response
- message syntax:
  - what fields in messages & how fields are delineated
- message semantics
  - meaning of information in fields
- rules for when and how processes send & respond to messages

open protocols:

- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

proprietary protocols:

- e.g., Skype

What transport service does an app need?

data integrity

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

timing

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

throughput

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

security

- encryption, data integrity, …

Transport service requirements: common apps

application	data loss	throughput	time sensitive
file transfer	no loss	elastic	no
e-mail	no loss	elastic	no
Web documents	no loss	elastic	no
real-time audio/video	loss-tolerant	audio: 50kbps-1Mbps video:100kbps-5Mbps	yes, 100's msec
stored audio/video	loss-tolerant	same as above	yes, few 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:* 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, orconnection setup,

Q: why bother? Why is there a UDP?

NOTE: More on transport in Weeks 5 and 6

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
- Coined the term "Hypertext"

The Web – History

Tim Berners-Lee

- World Wide Web (WWW): a distributed database of "pages" linked through Hypertext Transport Protocol (HTTP)
  - First HTTP implementation - 1990
    - Tim Berners-Lee at CERN
  - HTTP/0.9 – 1991
    - Simple GET command for the Web
  - HTTP/1.0 –1992
    - Client/Server information, simple caching
  - HTTP/1.1 - 1996

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.,

$$\underbrace{\texttt{www.someschool.edu}}_{\text{host name}}\texttt{/}\underbrace{\texttt{someDept/pic.gif}}_{\text{path name}}$$

Uniform Resource Locator (URL)

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

- *protocol*: http, ftp, https, smtp, rtsp, *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

Uniform Resource Locator (URL)

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

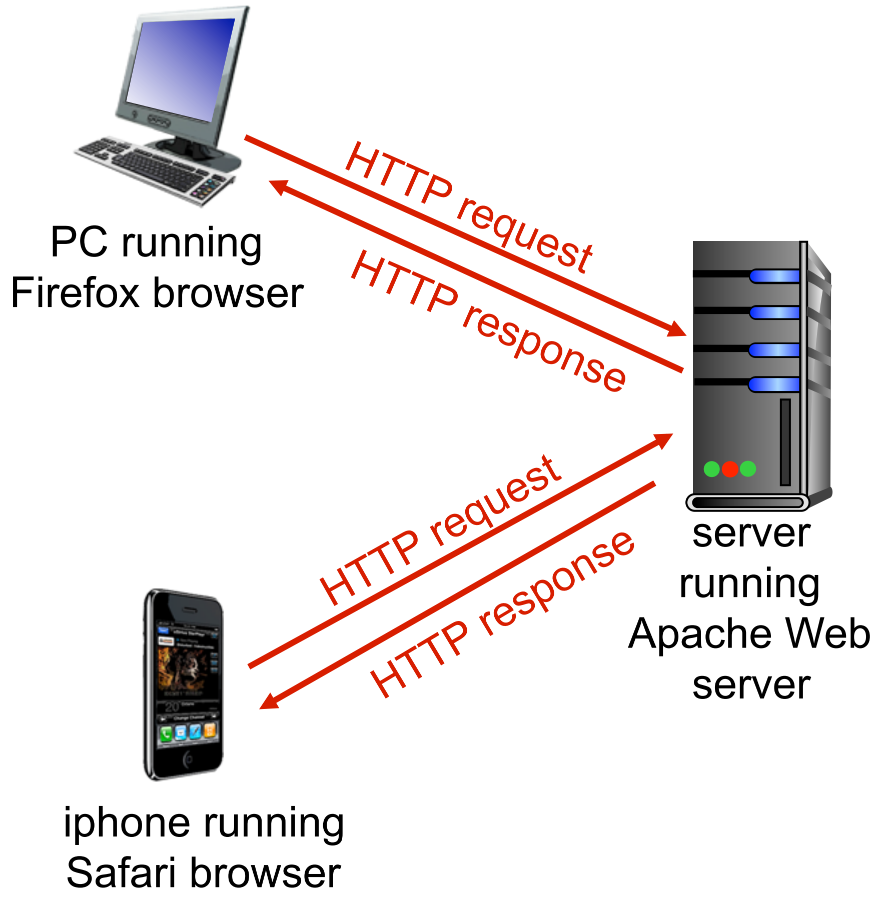
- Extend the idea of hierarchical hostnames to include anything in a file system
  - http://www.cse.unsw.edu.au/~salilk/papers/journals/TMC2012.pdf

- 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

aside

protocols that maintain "state" are complex!

- past history (state) must be maintained
- if server/client crashes, their views of "state" may be inconsistent, must be reconciled

HTTP request message

- two types of HTTP messages: *request, response*
- HTTP request message:
  - ASCII (human-readable format)

carriage return character

line-feed character

request line
(GET, POST,
HEAD commands)

header
lines

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

```
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
```

HTTP response message

status line
(protocol
status code
status phrase)

header
lines

data, e.g.,
requested
HTML file

```
HTTP/1.1 200 OK\r\n
Date: Sun, 26 Sep 2010 20:09:20 GMT\r\n
Server: Apache/2.0.52 (CentOS)\r\n
Last-Modified: Tue, 30 Oct 2007 17:00:02 GMT
   \r\n
ETag: "17dc6-a5c-bf716880"\r\n
Accept-Ranges: bytes\r\n
Content-Length: 2652\r\n
Keep-Alive: timeout=10, max=100\r\n
Connection: Keep-Alive\r\n
Content-Type: text/html;
   charset=ISO-8859-1\r\n
\r\n
data data data data data ...
```

HTTP response status codes

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

`200 OK`

- request succeeded, requested object later in this msg

`301 Moved Permanently`

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

`400 Bad Request`

- request msg not understood by server

`404 Not Found`

- requested document not found on this server

`505 HTTP Version Not Supported`

`451 Unavailable for Legal Reasons`

`429 Too Many Requests`

`418 I'm a Teapot`

HTTP is all text

- Makes the protocol simple
  - Easy to delineate messages (\r\n)
  - (relatively) human-readable
  - No issues about encoding or formatting data
  - Variable length data
- Not the most efficient
  - Many protocols use binary fields
    - *Sending "12345678" as a string is 8 bytes*
    - *As an integer, 12345678 needs only 4 bytes*
  - Headers may come in any order
  - Requires string parsing/processing

Request Method types ("verbs")

HTTP/1.0:

- GET
  - Request page
- POST
  - Uploads user response to a form
- HEAD
  - asks server to leave requested object out of response

HTTP/1.1:

- GET, POST, HEAD
- PUT
  - uploads file in entity body to path specified in URL field
- DELETE
  - deletes file specified in the URL field
- TRACE, OPTIONS, CONNECT, PATCH
  - For persistent connections

Uploading form input

POST method:

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

Get (in-URL) method:

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

```
www.somesite.com/animalsearch?monkeys&banana
```

User-server state: cookies

many Web sites use cookies

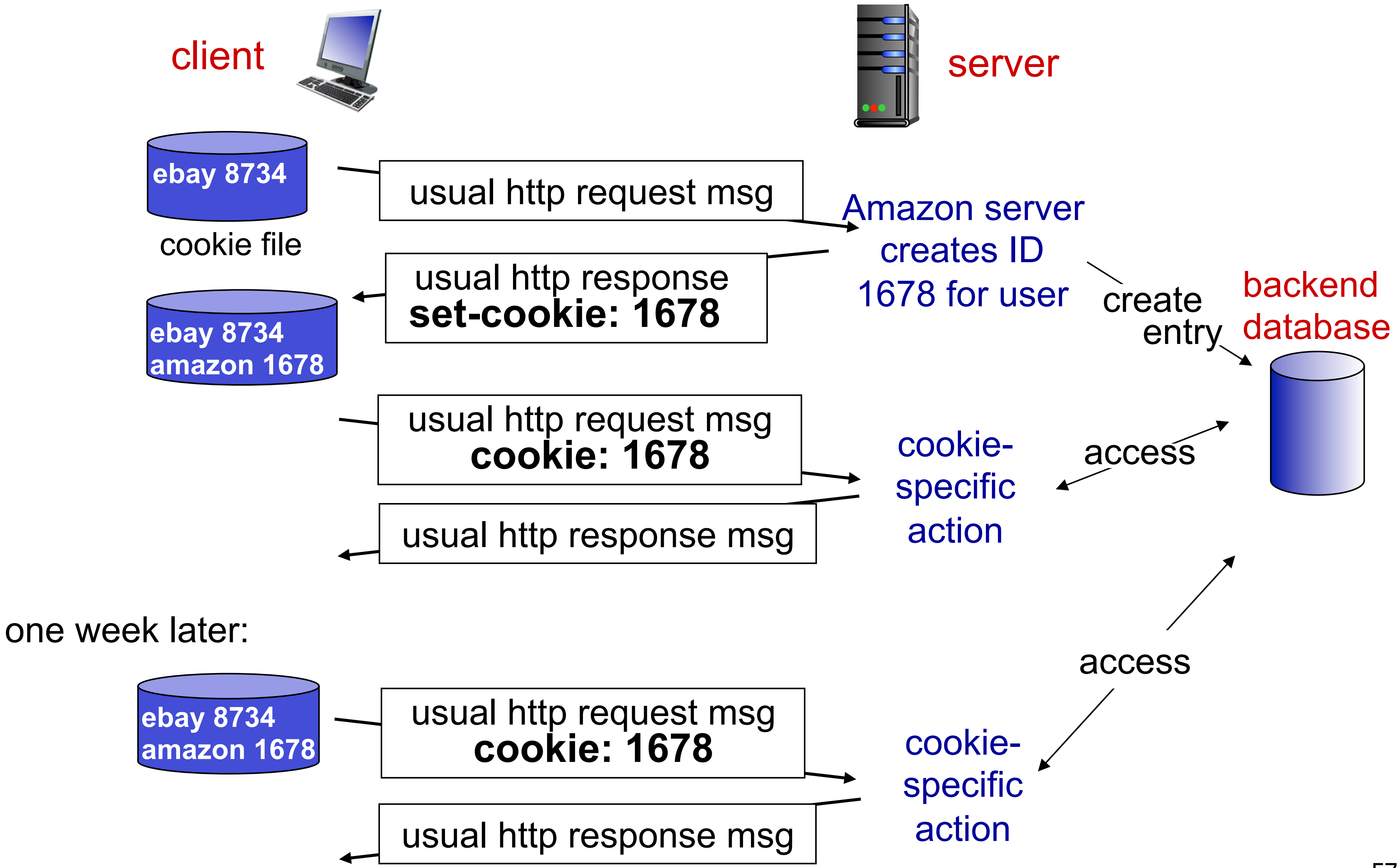
four components:

1) cookie header line of HTTP *response* message
2) cookie header line in next HTTP *request* message
3) cookie file kept on user's host, managed by user's browser
4) back-end database at Web site

example:

- Susan always access Internet from PC
- visits specific e-commerce site for first time
- when initial HTTP requests arrives at site, site creates:
  - unique ID
  - entry in backend database for ID

Cookies: keeping "state" (cont.)

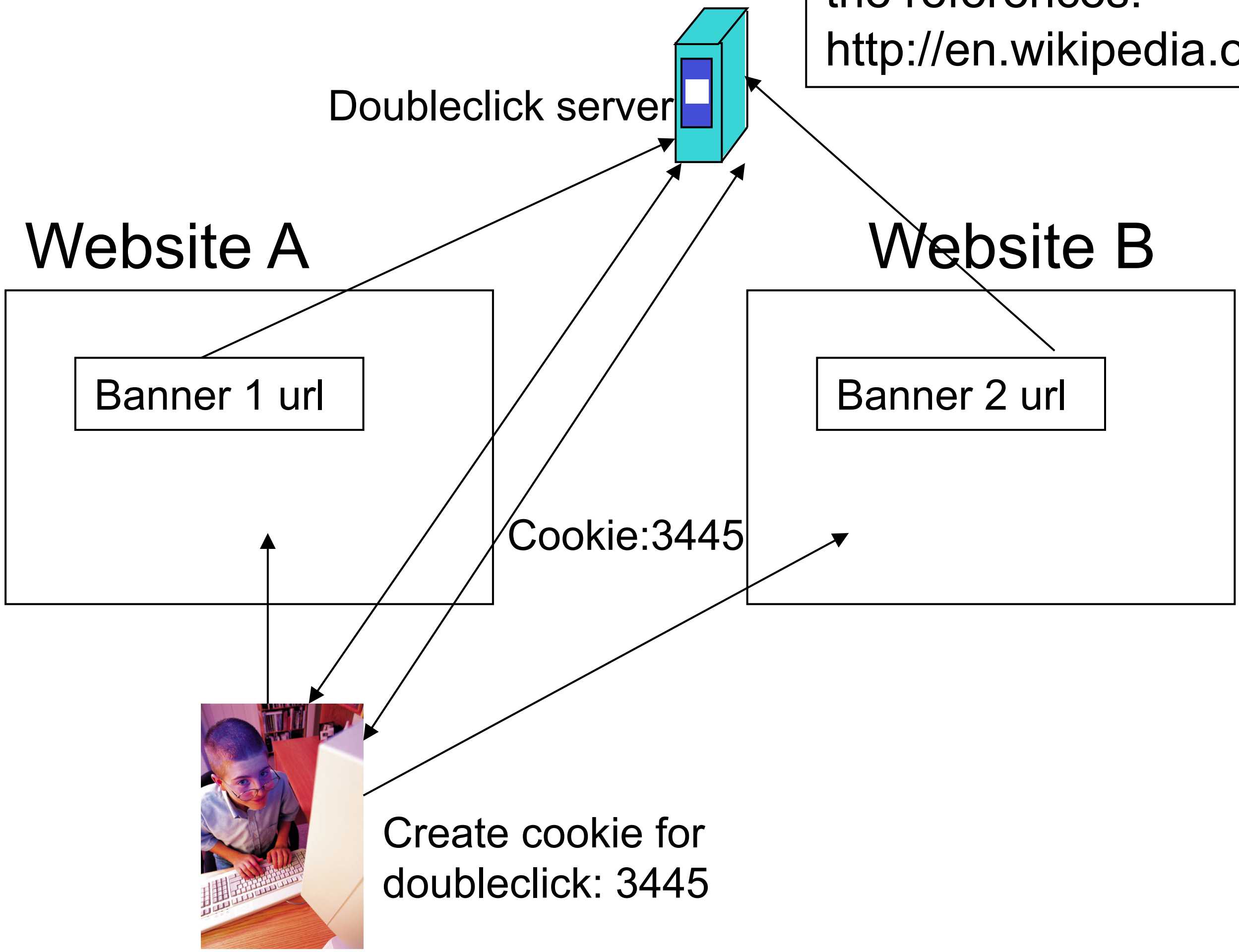


The Dark Side of Cookies

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

Third party cookies

For more, check the following link and follow the references: http://en.wikipedia.org/wiki/HTTP_cookie



Performance Goals

- User
  - fast downloads
  - high availability

- Content provider
  - happy users (hence, above)
  - cost-effective infrastructure

- Network (secondary)
  - avoid overload

Solutions?

Improve HTTP to achieve faster downloads

- User
  - fast downloads
  - high availability
- Content provider
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Solutions?

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- User
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Caching and Replication

Solutions?

- User
  - fast downloads
  - high availability

Improve HTTP to compensate for TCP's weak spots

- Content provider
  - happy users (hence, above)
  - cost-effective delivery infrastructure

Caching and Replication

- Network (secondary)
  - avoid overload

Exploit economies of scale (Webhosting, CDNs, datacenters)

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

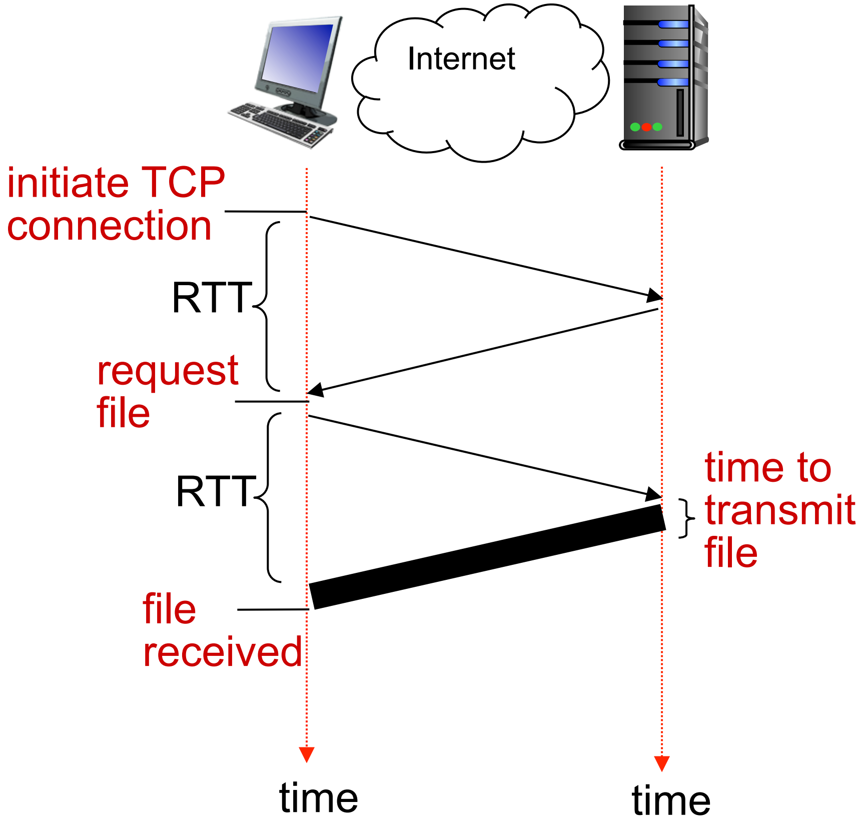
Non-persistent HTTP: response time

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 =

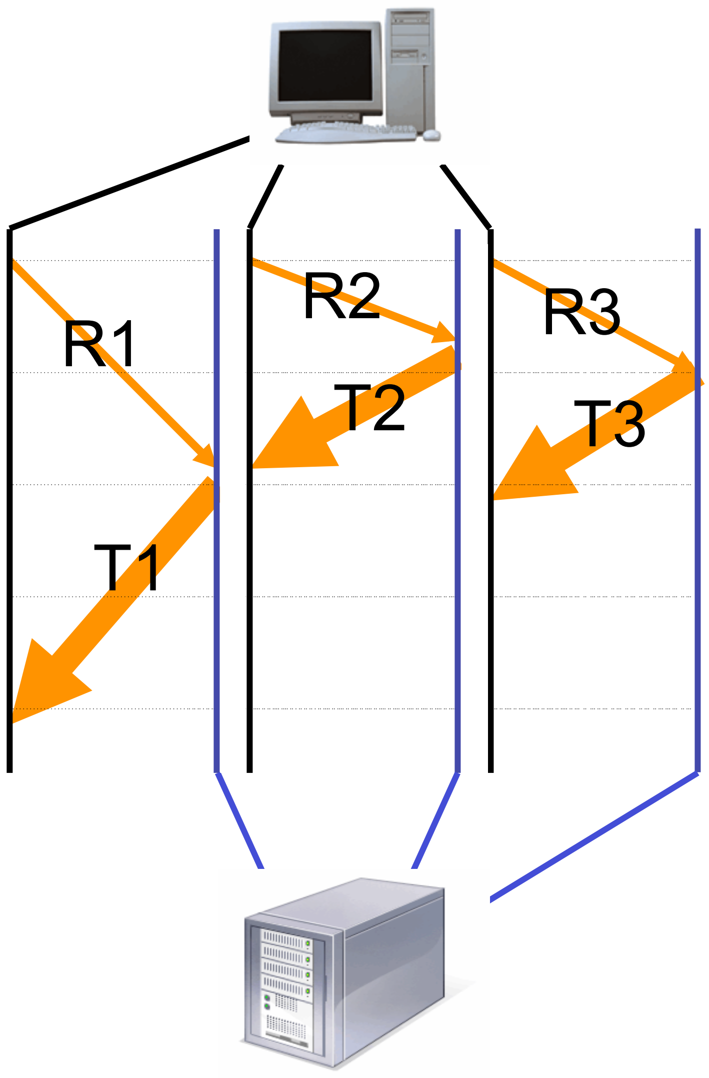
  2RTT+ file transmission time



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

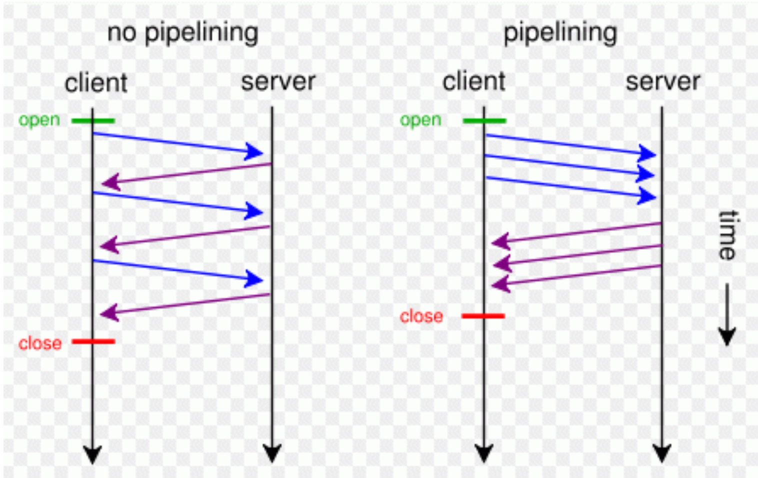
- server leaves TCP connection open after sending response
- subsequent HTTP messages between same client/server are sent over the same TCP connection
- Allow TCP to learn more accurate RTT estimate (APPARENT LATER IN THE COURSE)
- Allow TCP congestion window to increase (APPARENT LATER)
- i.e., leverage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

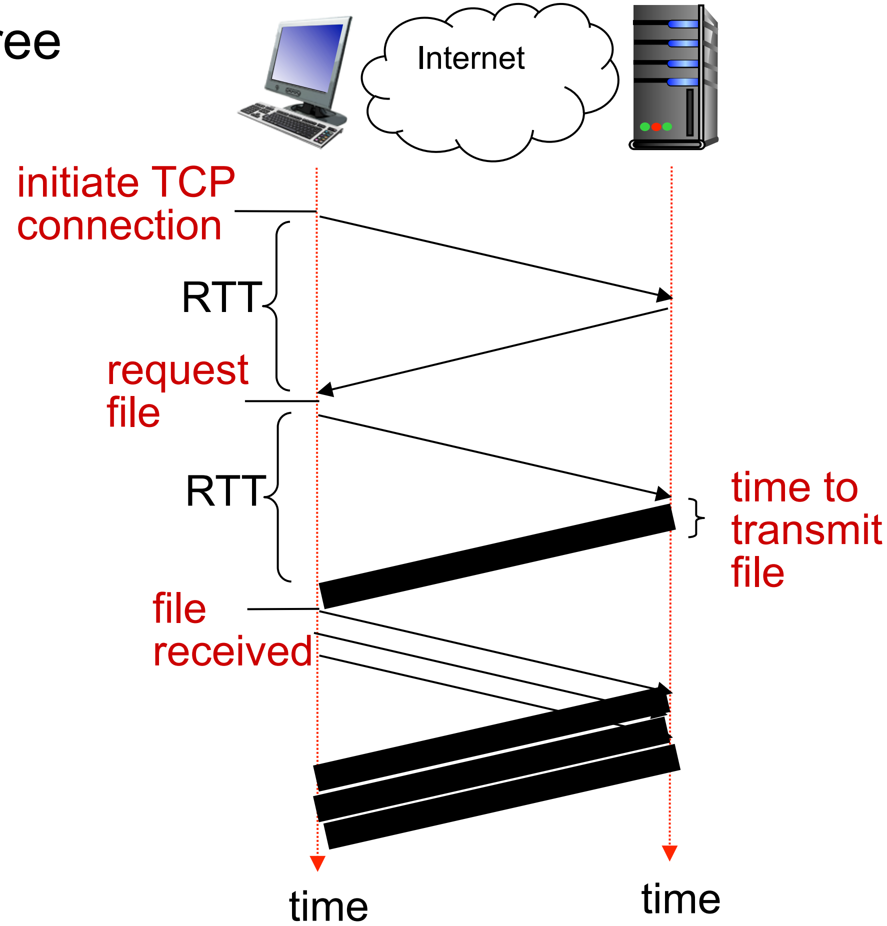
Persistent with pipelining:

- 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



HTTP Response Time Example

- Usually index.html is downloaded first. Upon inspecting index.html, the clients download all the objects referenced in index.html
- Q. For an index file containing 2 objects, what is the response time for (a) non-persistent HTTP, (b) Persistent HTTP without pipelining, and (c) Persistent HTTP with pipelining?
- A.
  - 2xRTT + some additional file transmission delay to get the index file (1xRTT for opening TCP connection and 1xRTT for downloading index)
  - For non-persistent, each object costs 2xRTT
  - For persistent without pipelining, each object costs 1xRTT
  - For persistent with pipelining, all object downloaded in 1xRTT
  - (a) 2+2x2 = 6xRTT + some file tx delay
  - (b) 2+2 = 4xRTT + some file tx delay
  - (c) 2+1 = 3xRTT+ some file tx delay

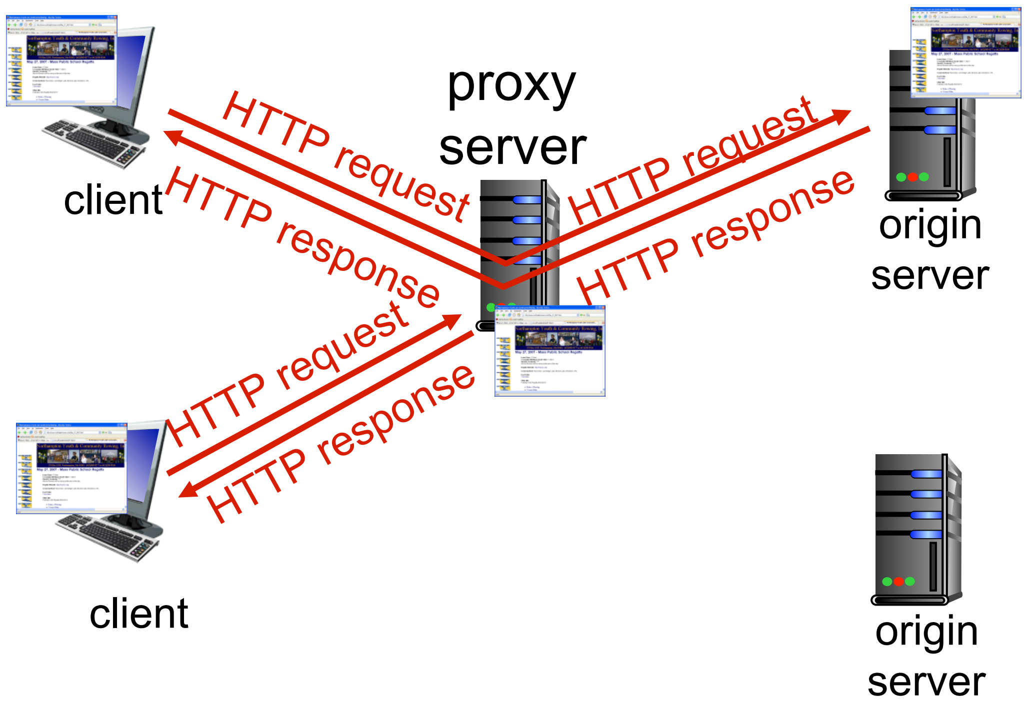
Improving HTTP Performance: Caching

- Why does caching work?
  - Exploits *locality of reference*
- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content
  - But many unique requests

Web caches (proxy server)

goal: satisfy client request without involving origin server

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



More about Web caching

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

why Web caching?

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

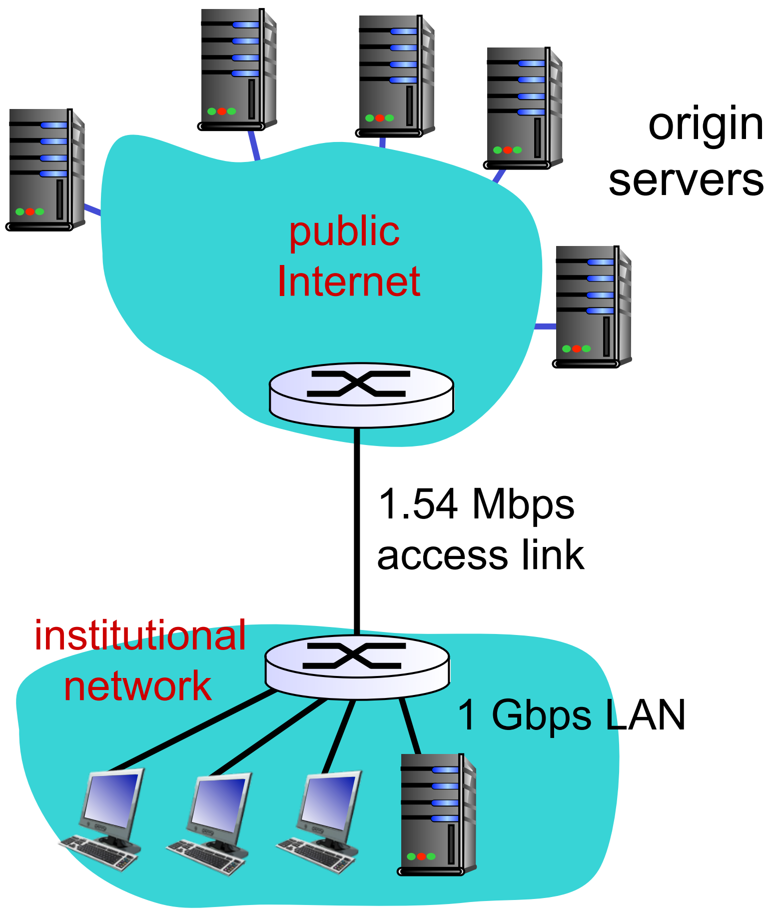
Caching example:

assumptions:

- avg object size: 100K bits
- avg request rate from browsers to origin servers:15/sec
- avg data rate to browsers: 1.50 Mbps (100Kx15)
- RTT from institutional router to any origin server: 2 sec
- access link rate: 1.54 Mbps

consequences:

- LAN utilization: 15%
- access link utilization = 97.4% *problem!*
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + minutes + usecs



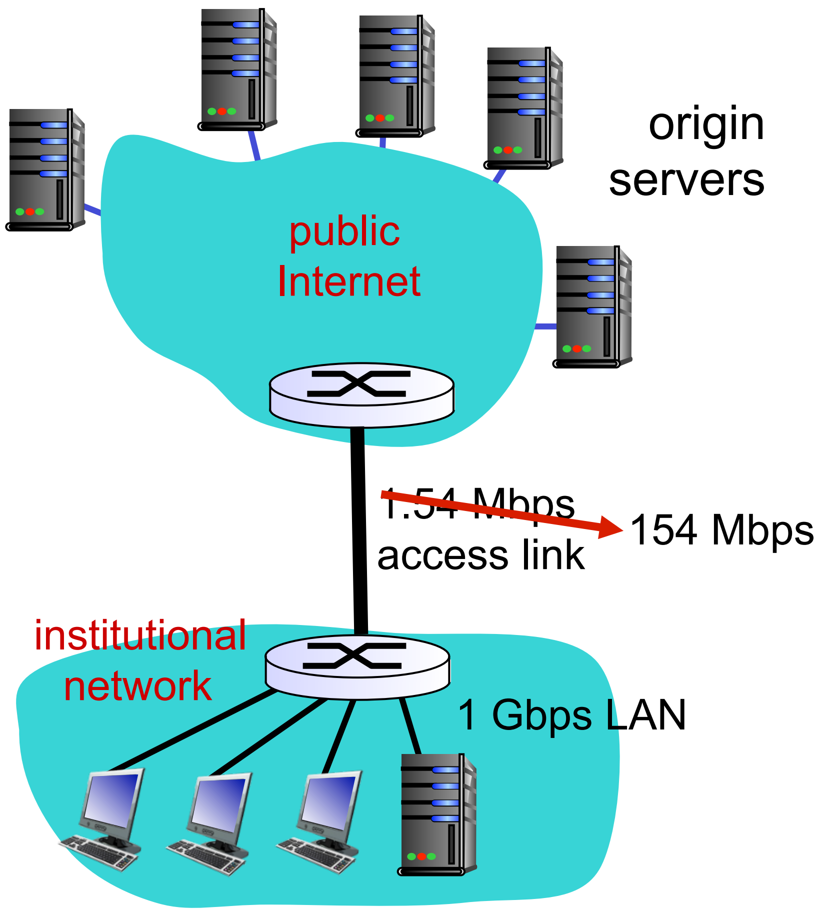
Caching example: fatter access link

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: 15%   0.99%
- access link utilization = ~~97.4%~~
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + ~~minutes~~ + usecs
  msecs



Cost: increased access link speed (not cheap!)

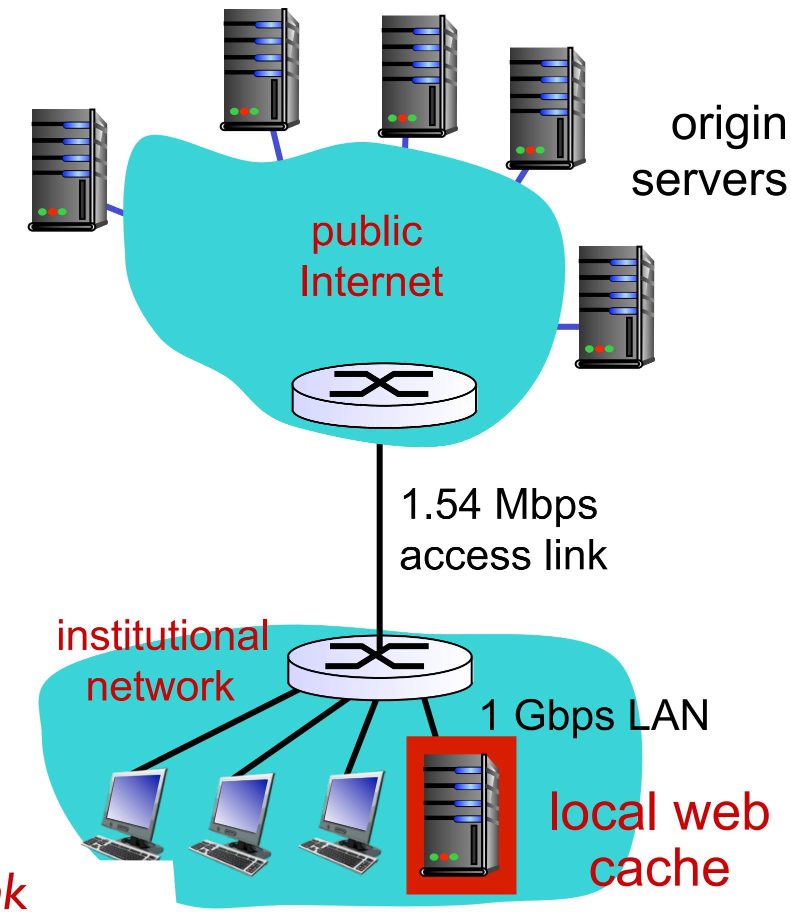
Caching example: install local cache

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?

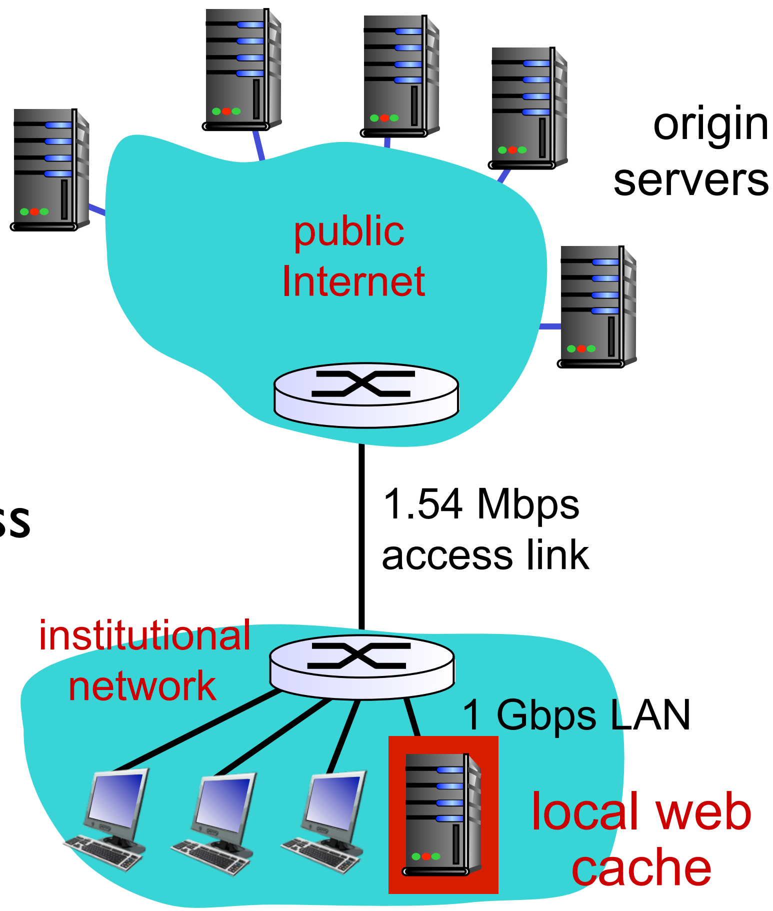
Cost: web cache (cheap!)



Caching example: install local cache

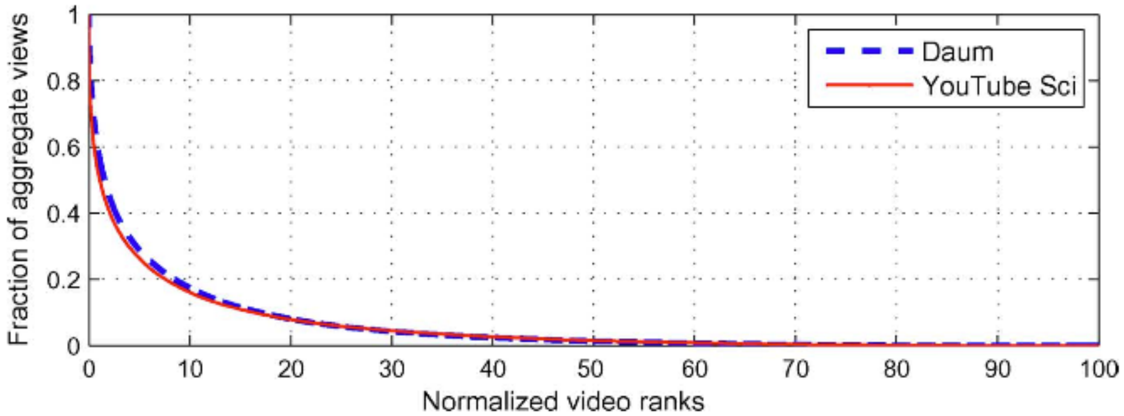
Calculating access link utilization, delay with cache:

- 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 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

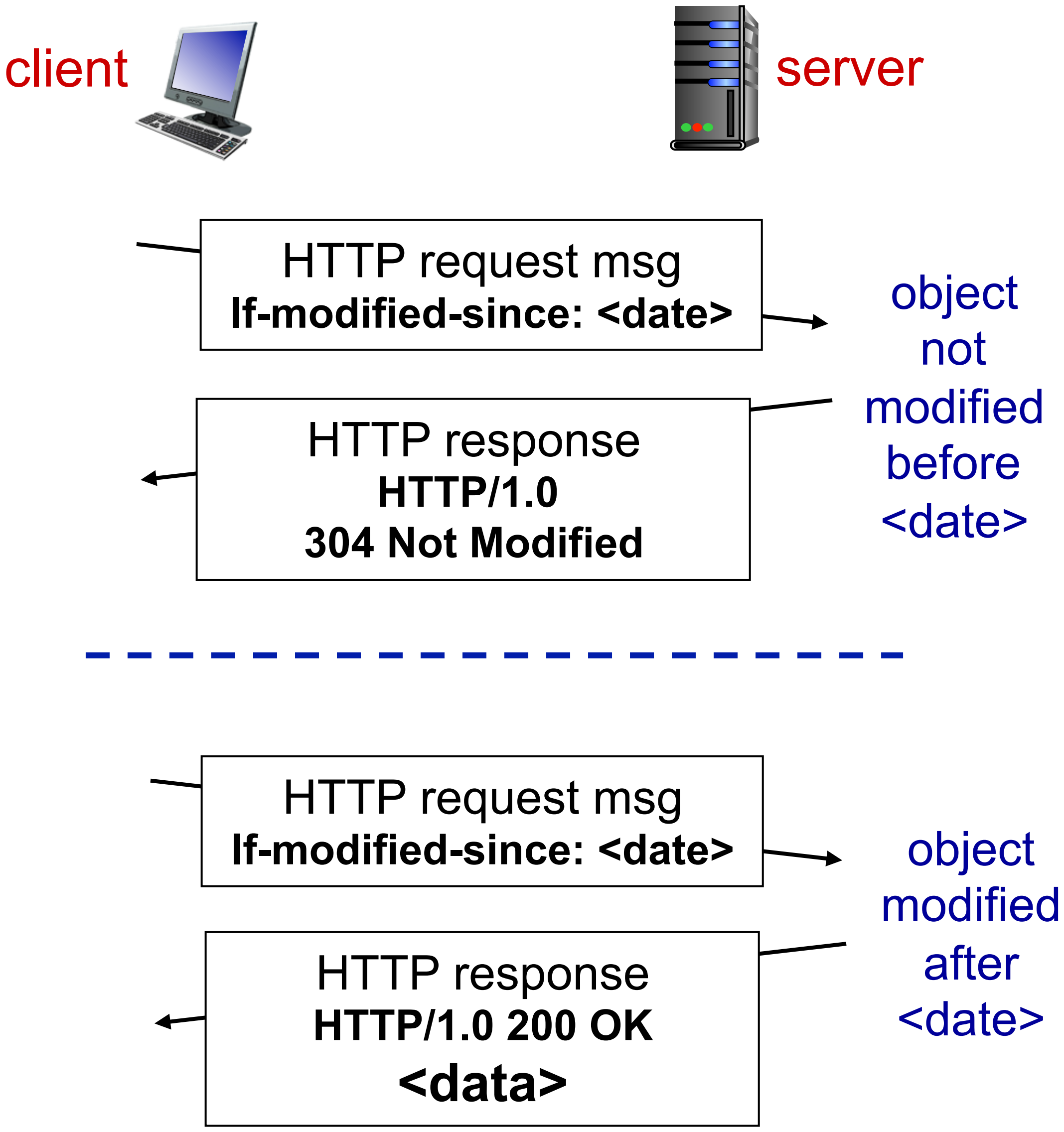
Conditional GET

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

```
If-modified-since:
  <date>
```

- *server:* response contains no object if cached copy is up-to-date:

```
HTTP/1.0 304 Not
  Modified
```



Example Cache Check Request

```
GET / HTTP/1.1
Accept: */*
Accept-Language: en-us
Accept-Encoding: gzip, deflate
If-Modified-Since: Mon, 29 Jan 2001 17:54:18 GMT
If-None-Match: "7a11f-10ed-3a75ae4a"
User-Agent: Mozilla/4.0 (compatible; MSIE 5.5; Windows NT
   5.0)
Host: www.intel-iris.net
Connection: Keep-Alive
```

Example Cache Check Response

```
HTTP/1.1 304 Not Modified
Date: Tue, 27 Mar 2001 03:50:51 GMT
Server: Apache/1.3.14 (Unix)  (Red-Hat/Linux) mod_ssl/2.7.1
   OpenSSL/0.9.5a DAV/1.0.2 PHP/4.0.1pl2 mod_perl/1.24
Connection: Keep-Alive
Keep-Alive: timeout=15, max=100
ETag: "7a11f-10ed-3a75ae4a"
```

Improving HTTP Performance: Replication

- 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 particular replica
    - Balance load across server replicas
    - Pair clients with nearby servers
  - Expensive

- Common solution:
  - DNS returns different addresses based on client's geo location, server load, *etc.*

More on this later

Improving HTTP Performance: CDN

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

What about HTTPS?

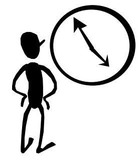
- HTTP is insecure
- HTTP basic authentication: password sent using base64 encoding (can be readily converted to plaintext)
- HTTPS: HTTP over a connection encrypted by Transport Layer Security (TLS)
- Provides:
  - Authentication
  - Bidirectional encryption
- Widely used in place of plain vanilla HTTP

What's on the horizon: HTTP/2

- Standardised in May 2015: RFC 7540
- Improvements
  - Severs can **push** content and thus reduce overhead of an additional request cycle
  - Fully multiplexed
    - Requests and responses are sliced in smaller chunks called frames, frames are tagged with and 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)
- Completed Application Layer (Chapter 2)
  - Principles of Network Applications
  - HTTP
- Next Week: Application Layer (contd.)
  - E-mail
  - P2P
  - DNS
  - Socket Programming