Computer Networking

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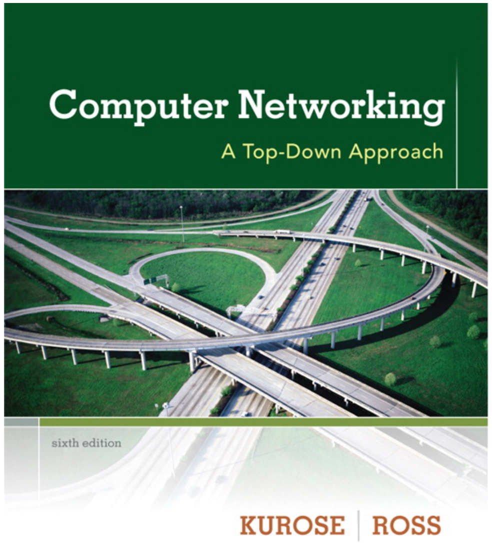
2017. Fall

Chapter 2
Application Layer



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Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

Assignments (ver6, CN):

- **ch2: 5, 6, 7, 8, 9, 10, 17, 19, 22, 26, 33**

Chapter 2: outline

2.1 principles of network applications

2.2 Web and HTTP

2.3 FTP

2.4 electronic mail

- SMTP, POP3, IMAP

2.5 DNS

2.6 P2P applications

2.7 socket programming with UDP and TCP

Chapter 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
  - FTP
  - SMTP / POP3 / IMAP
  - DNS
- creating network applications
  - socket API

Some network apps

- e-mail
- web
- text messaging
- remote login
- P2P file sharing
- multi-user network games
- streaming stored video (YouTube, Hulu, Netflix)
- voice over IP (e.g., Skype)
- real-time video conferencing
- social networking
- search
- …
- …

What APPs do you know?

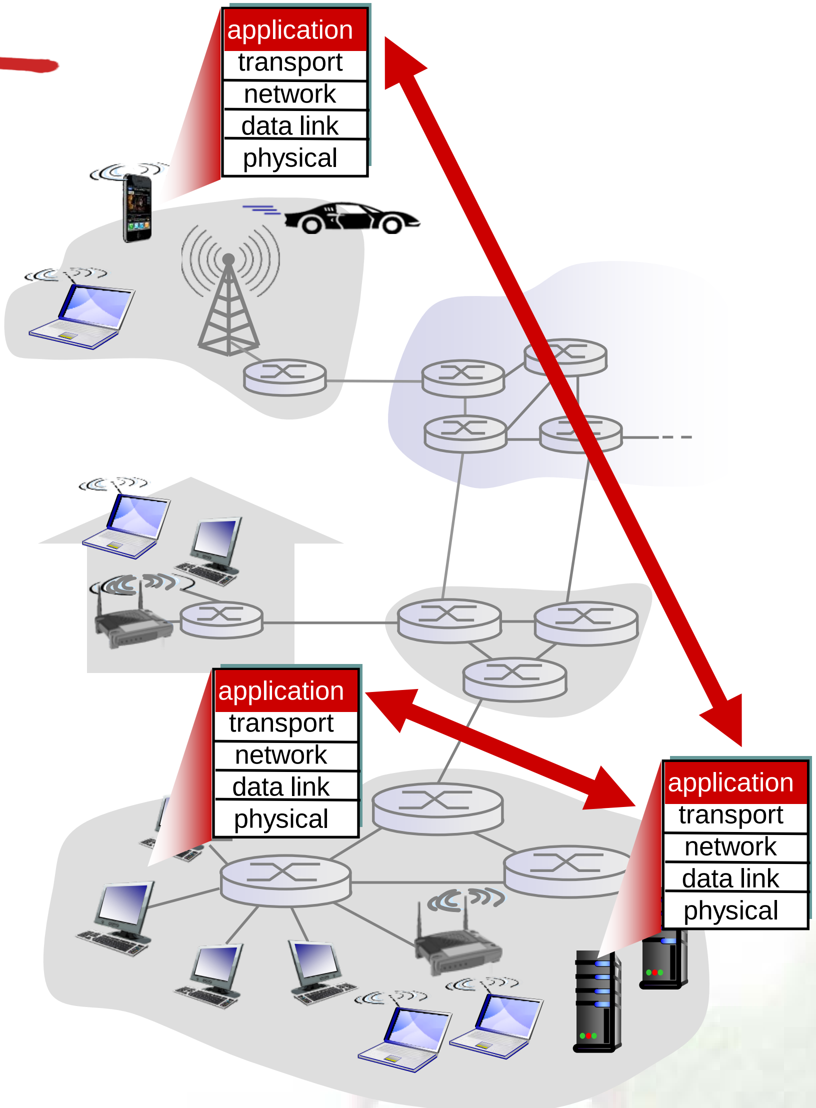
Creating a network app

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

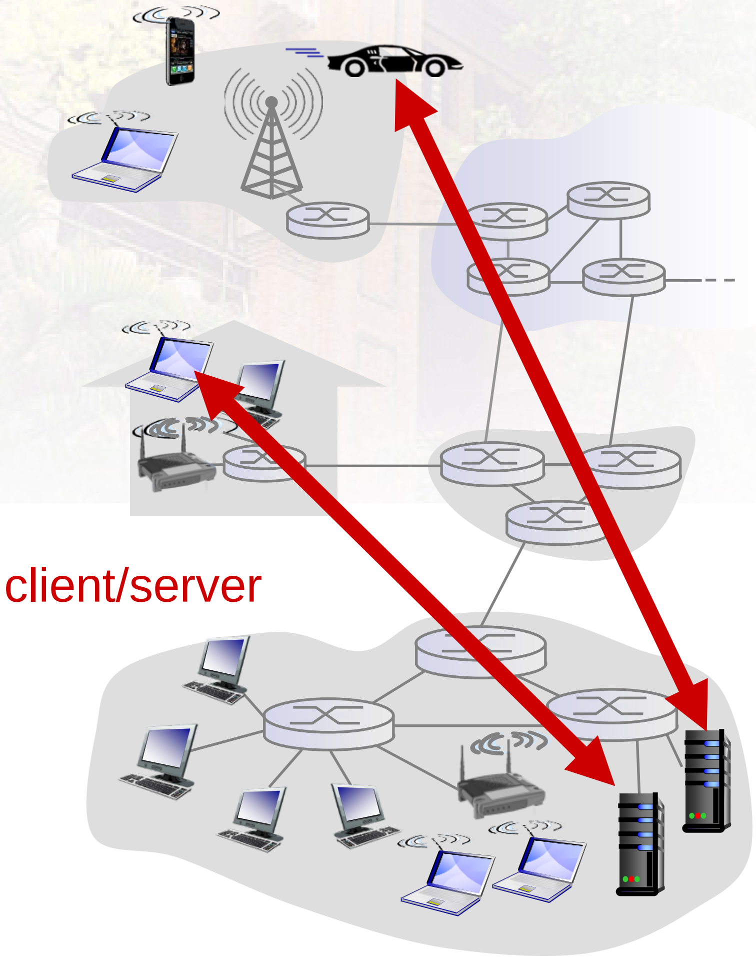


Application architectures

possible structure of applications:

- **client-server (C/S)**
- **peer-to-peer (P2P)**

Client-server architecture

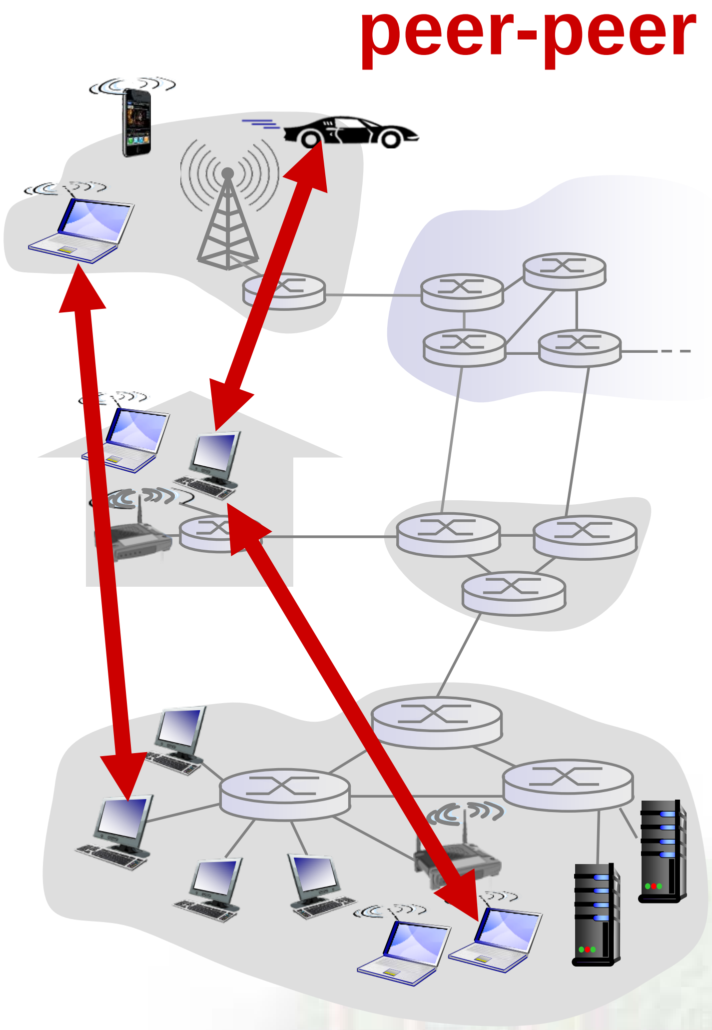


server:
- always-on host
- permanent IP address
- data centers for scaling

clients:
- communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do not communicate directly with each other

P2P architecture

- *no* always-on server
- arbitrary end systems directly communicate
- 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
- peers are intermittently connected and change IP addresses
  - complex management



Processes communicating

process: **program running within a host**

- **within same host, two processes communicate using inter-process communication (defined by OS)**

- **processes in different hosts communicate by exchanging messages**

clients, servers

client process: **process that *initiates* communication**

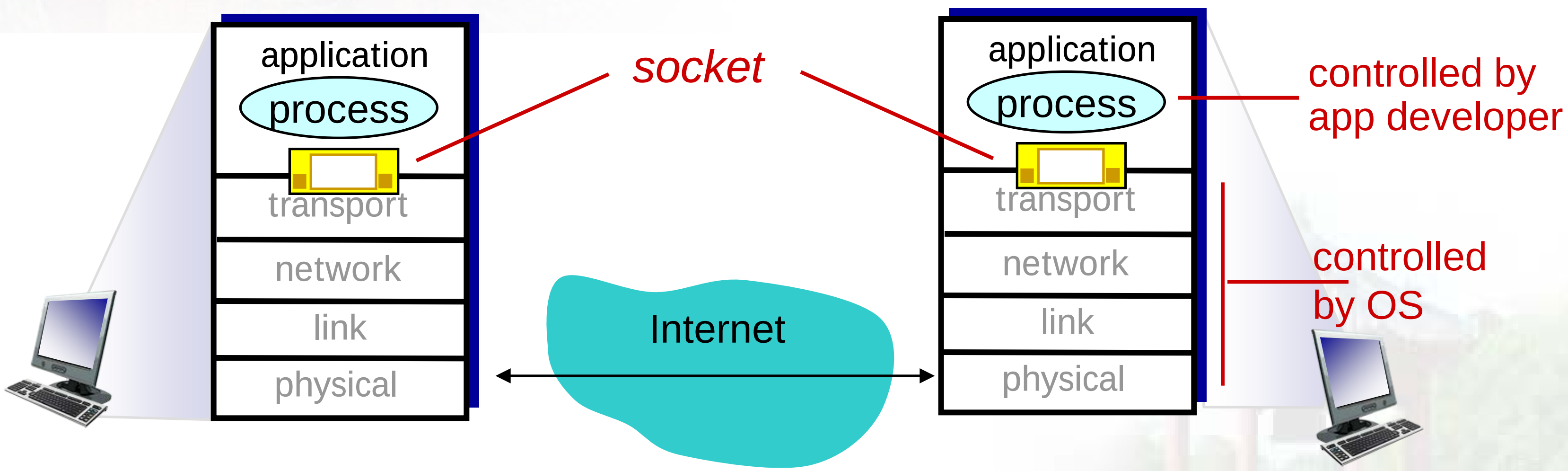
server process: **process that *waits to* be contacted**

- **aside: applications with P2P architectures have client processes & server processes**

Sockets

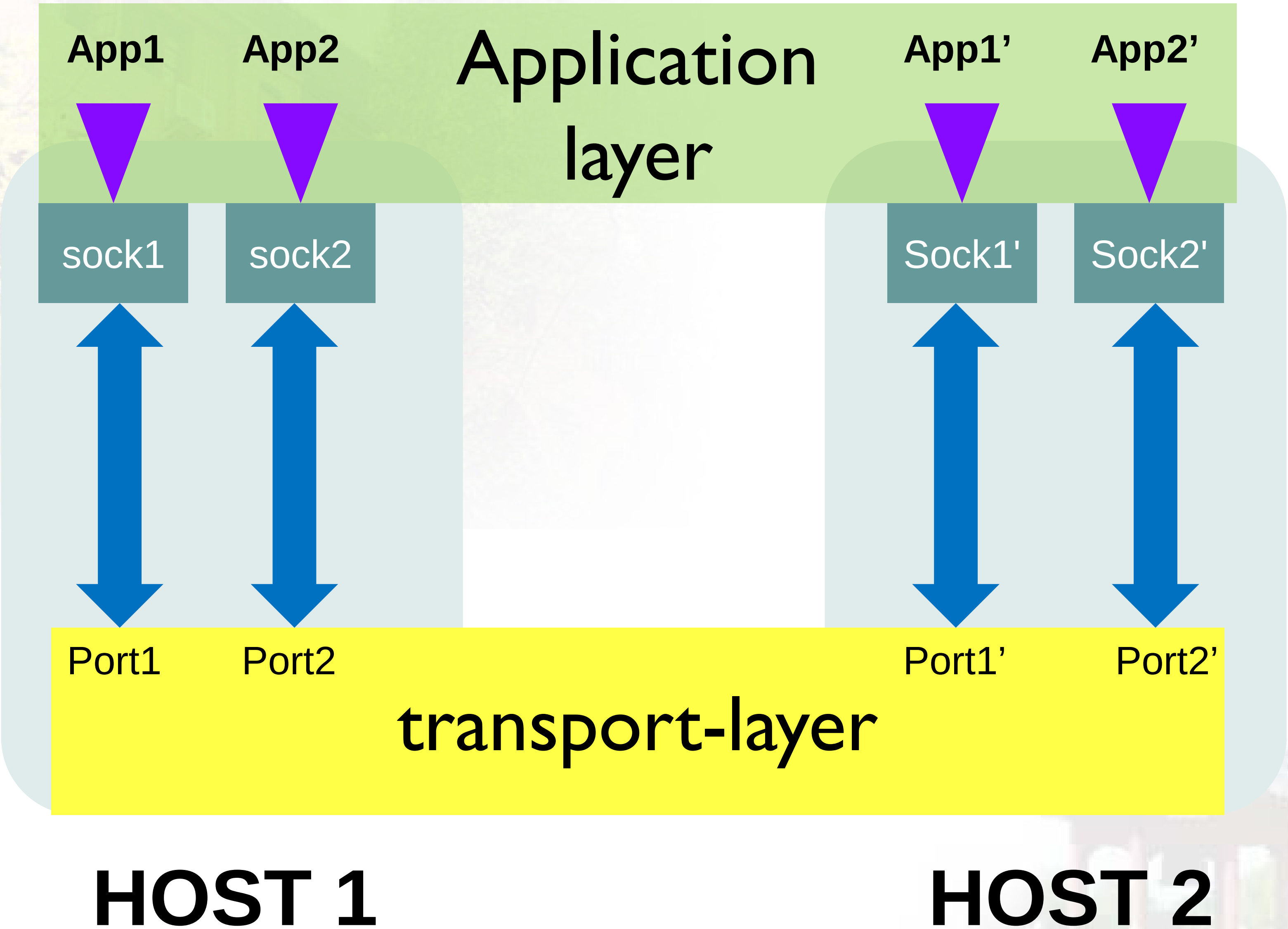
What is Socket?

- 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



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 gaia.cs.umass.edu web server:
  - IP address: 128.119.245.12
  - port number: 80
- more shortly…


App1
App2
Application layer
App1’
App2’
sock1
sock2
Sock1'
Sock2'
Port1
Port2
Port1’
Port2’
transport-layer
HOST 1
HOST 2

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, QQ

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: 5kbps-1Mbps video:10kbps-5Mbps	yes, 100's msec
stored audio/video	loss-tolerant	same as above	yes, few secs
interactive games	loss-tolerant	few kbps up	yes, 100's msec
text 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?

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

Securing TCP

TCP & UDP

- no encryption
- Clear-text passwords sent into socket traverse Internet in clear-text

SSL

- provides encrypted TCP connection
- data integrity
- end-point authentication

SSL is at app layer

- Apps use SSL libraries, which "talk" to TCP

SSL socket API

- Clear-text passwords sent into socket traverse Internet encrypted
- See Chapter 7

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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.,**

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

HTTP overview

http/1.1 (rfc2616)

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 connections

non-persistent HTTP

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

persistent HTTP

- **multiple objects can be sent over single TCP connection between client, server**

Non-persistent HTTP

suppose user enters URL:

`www.someSchool.edu/someDepartment/home.index`

(contains text, references to 10 jpeg images)

1a. HTTP client initiates TCP connection to HTTP server (process) at www.someSchool.edu on port 80

1b. HTTP server at host www.someSchool.edu waiting for TCP connection at port 80. "accepts" connection, notifying client

2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket. Message indicates that client wants object someDepartment/home.index

3. HTTP server receives request message, forms *response message* containing requested object, and sends message into its socket

time

Non-persistent HTTP (cont.)

4. HTTP server closes TCP connection.

5. HTTP client receives response message containing html file, displays html. Parsing html file, finds 10 referenced jpeg objects

6. Steps 1-5 repeated for **each** of 10 jpeg objects

time

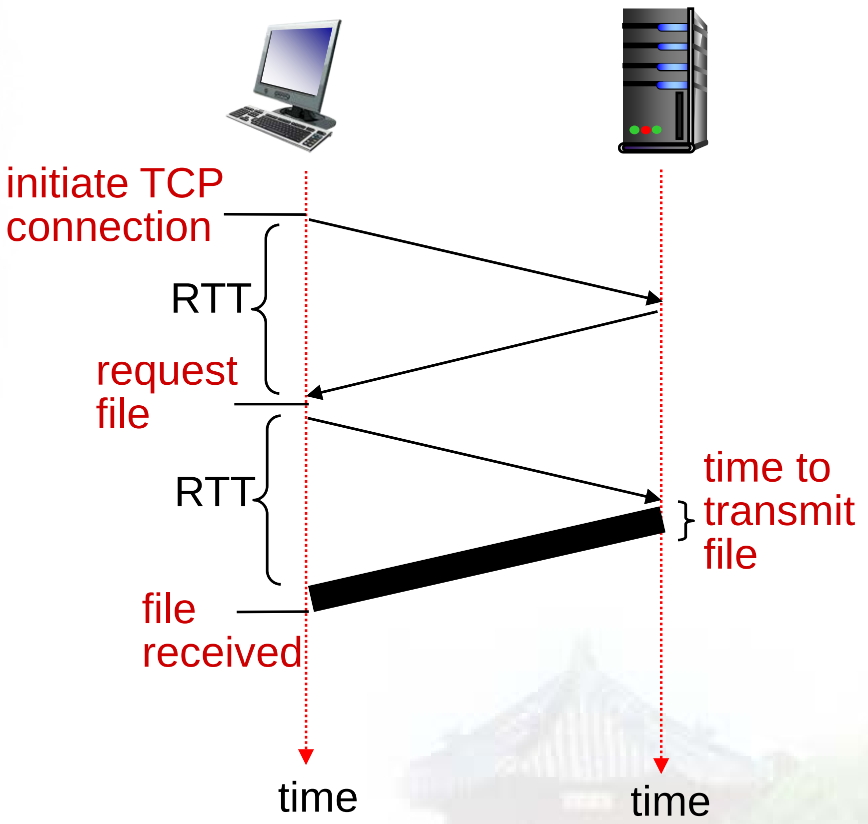
Non-persistent HTTP: response time

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



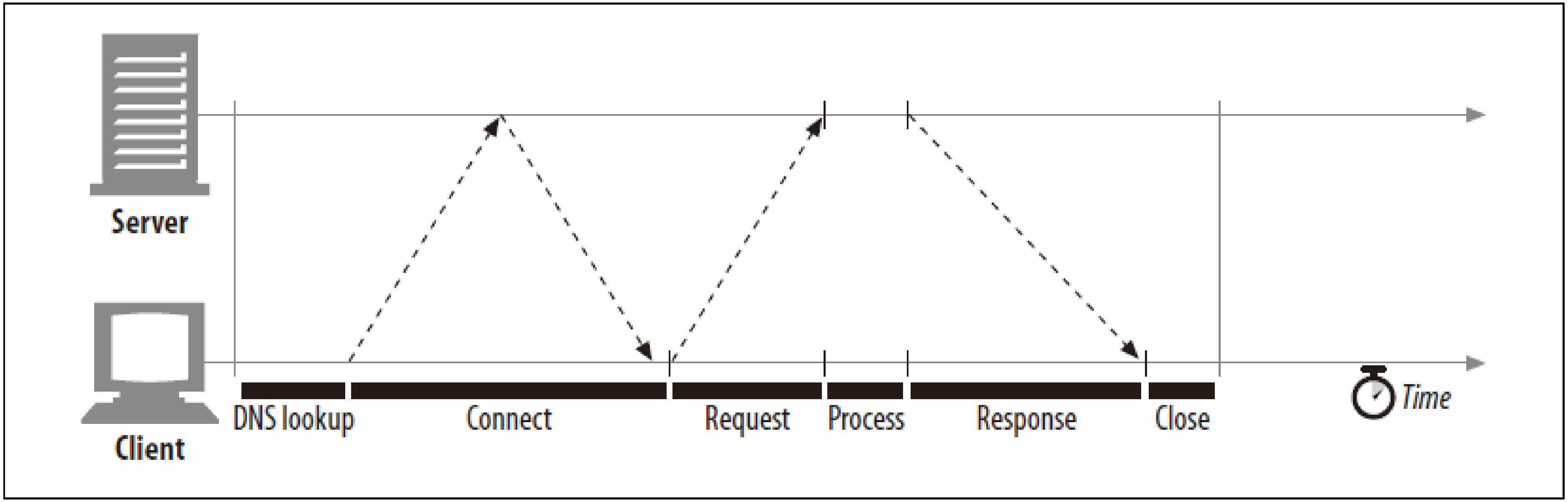
Persistent HTTP

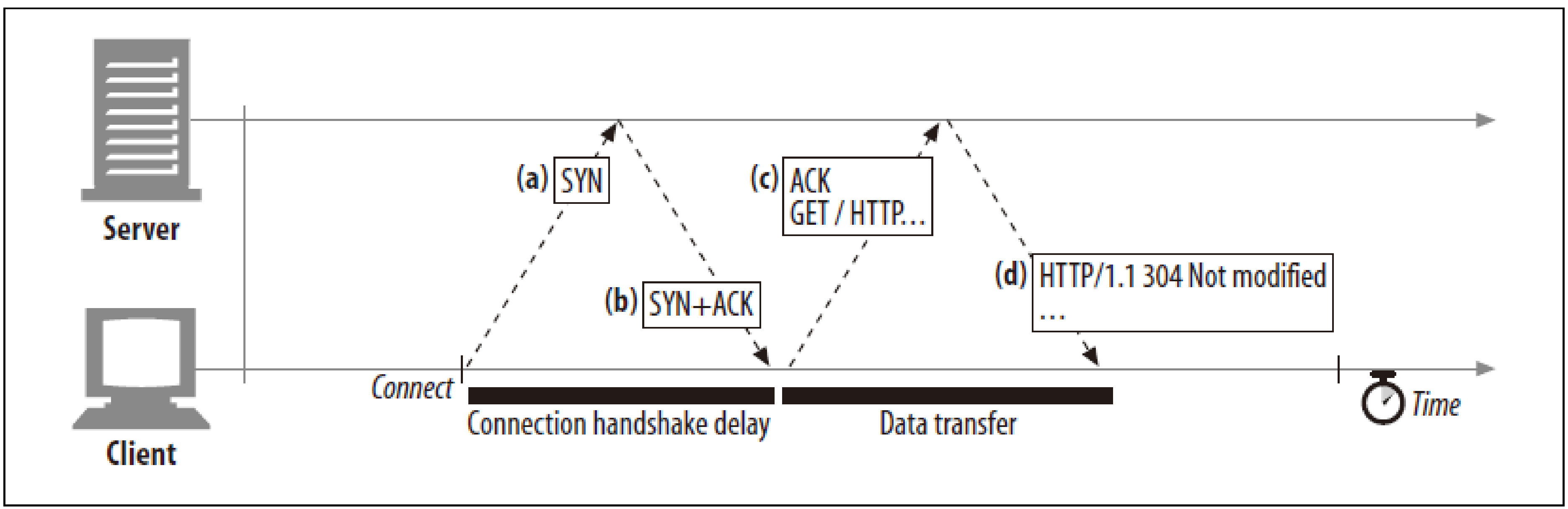
non-persistent HTTP issues:

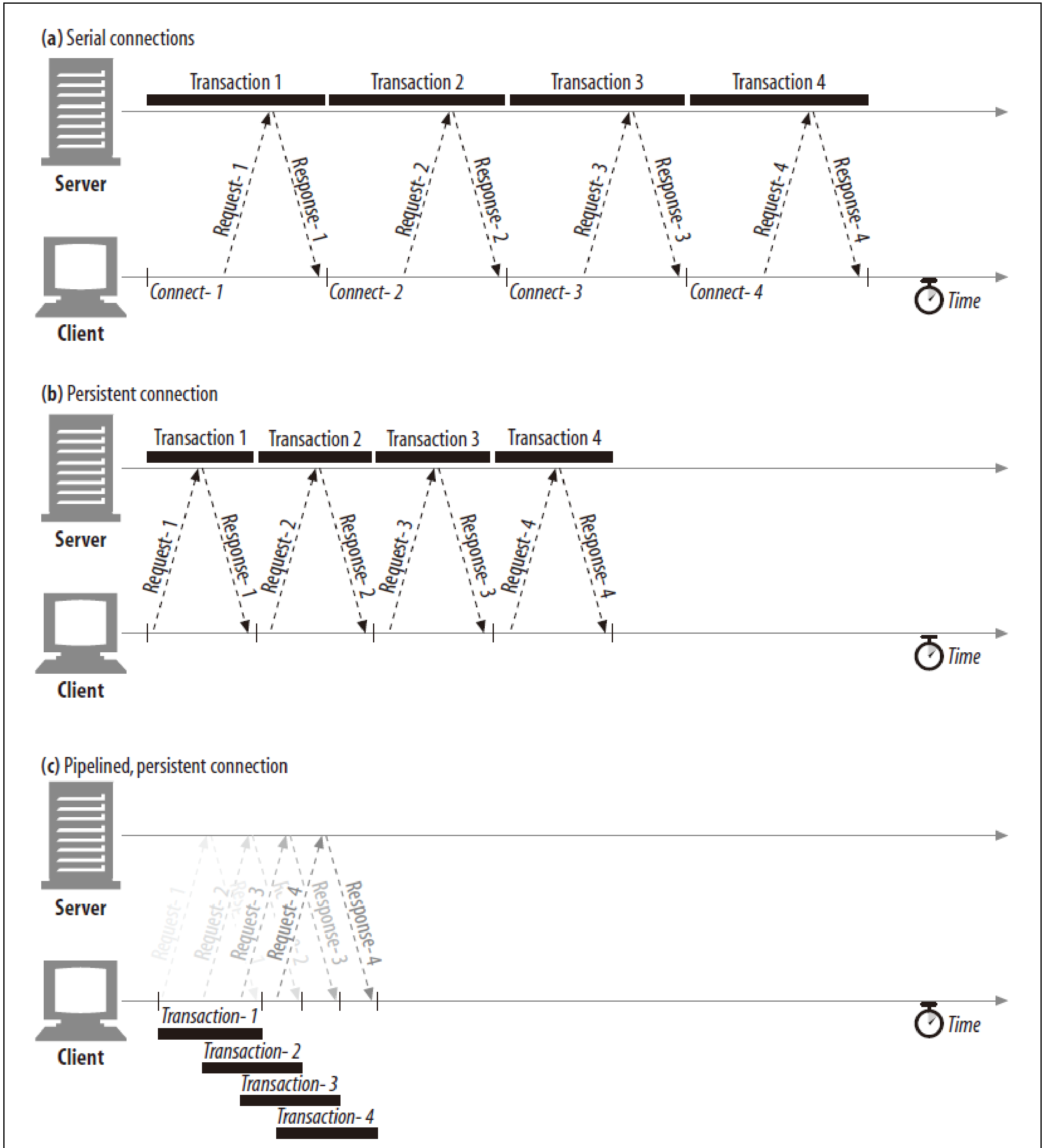
- requires 2 RTTs per object
- OS overhead for *each* TCP connection
- browsers often open parallel TCP connections to fetch referenced objects

persistent HTTP:

- server leaves connection open after sending response
- subsequent HTTP messages between same client/server sent over open connection
- client sends requests as soon as it encounters a referenced object
- as little as one RTT for all the referenced objects


Server
Client
DNS lookup
Connect
Request
Process
Response
Close
Time


Server
Client
(a) SYN
(b) SYN+ACK
(c) ACK
GET / HTTP...
(d) HTTP/1.1 304 Not modified
...
Connect
Connection handshake delay
Data transfer
Time


(a) Serial connections
Server
Client
Transaction 1
Transaction 2
Transaction 3
Transaction 4
Request- 1
Response- 1
Request- 2
Response- 2
Request- 3
Response- 3
Request- 4
Response- 4
Connect- 1
Connect- 2
Connect- 3
Connect- 4
Time
(b) Persistent connection
Server
Client
Transaction 1
Transaction 2
Transaction 3
Transaction 4
Request- 1
Response- 1
Request- 2
Response- 2
Request- 3
Response- 3
Request- 4
Response- 4
Time
(c) Pipelined, persistent connection
Server
Client
Request- 3
Request- 4
Response- 3
Response- 4
Transaction- 1
Transaction- 2
Transaction- 3
Transaction- 4
Time

Week 3

HTTP request message

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

carriage return character

line-feed character

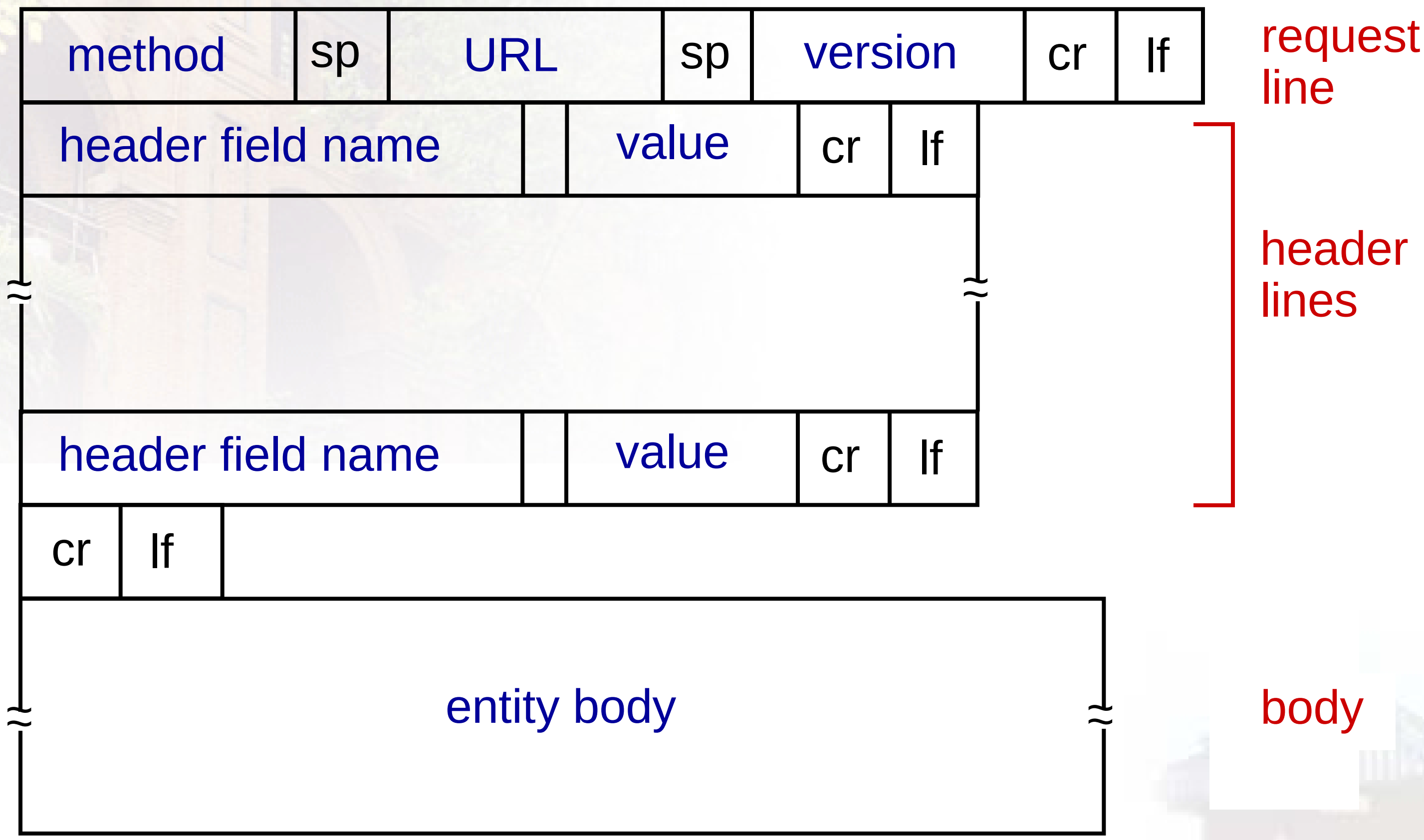
request line (GET, POST, HEAD commands)

```
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
```

header lines

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

HTTP request message: general format



Uploading form input

POST method:

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

URL method:

- uses GET method
- input is uploaded in URL field of request line: `www.somesite.com/animalsearch?monkeys&banana`

Method types

HTTP/1.0:

- GET
- POST
- 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

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`

Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet cis.poly.edu 80
```

opens TCP connection to port 80 (default HTTP server port) at cis.poly.edu. anything typed in sent to port 80 at cis.poly.edu

2. type in a GET HTTP request:

```
GET /~ross/ HTTP/1.1
Host: cis.poly.edu
```

by typing this in (hit carriage return twice), you send this minimal (but complete) GET request to HTTP server

3. look at response message sent by HTTP server!

(or use Wireshark to look at captured HTTP request/response)

User-server state: cookies

many Web sites use cookies

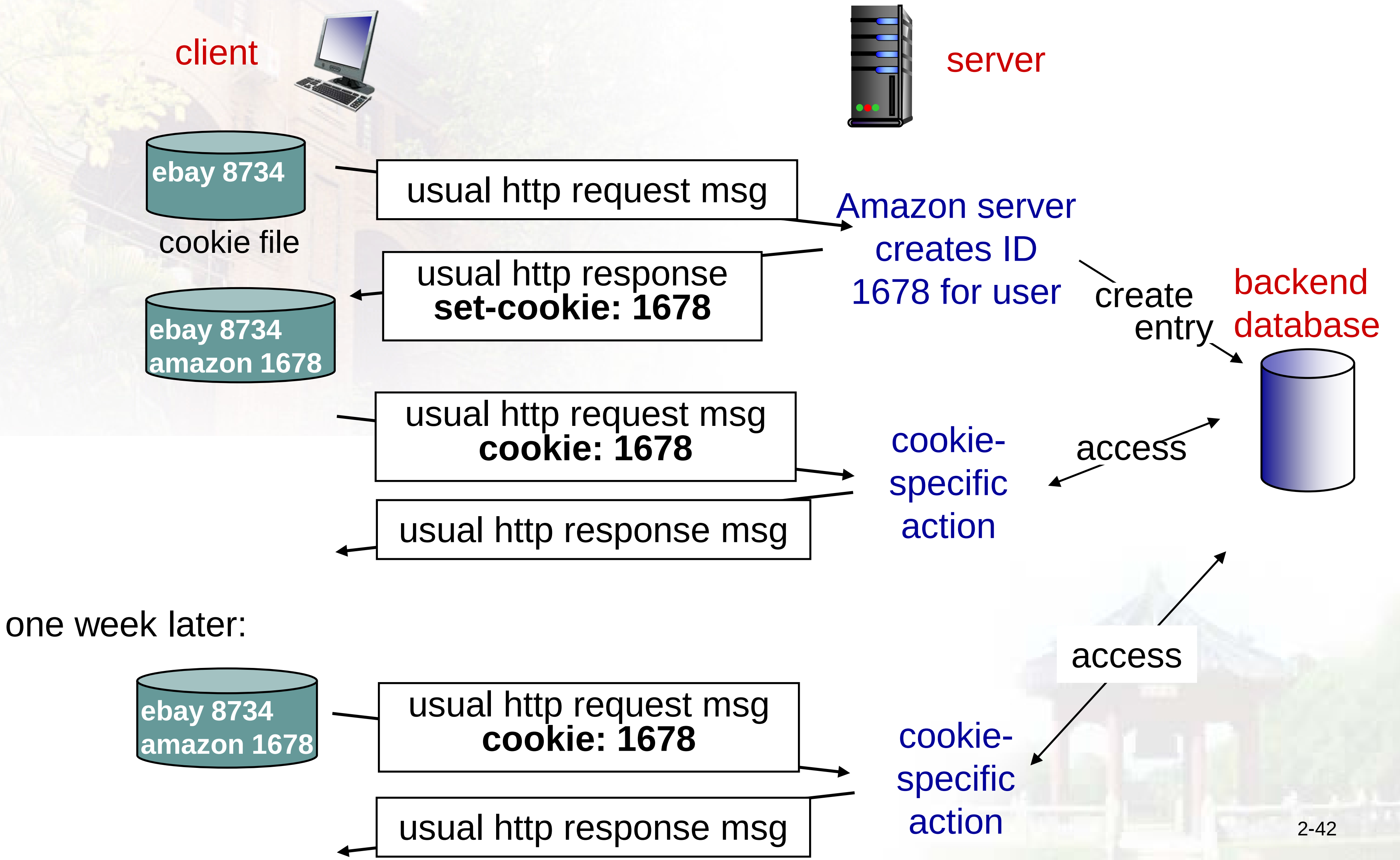
four components:

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.)



Cookies (continued)

what cookies can be used for:

- **authorization**
- **shopping carts**
- **recommendations**
- **user session state (Web e-mail)**

aside

cookies and privacy:

- cookies permit sites to learn a lot about you
- you may supply name and e-mail to sites

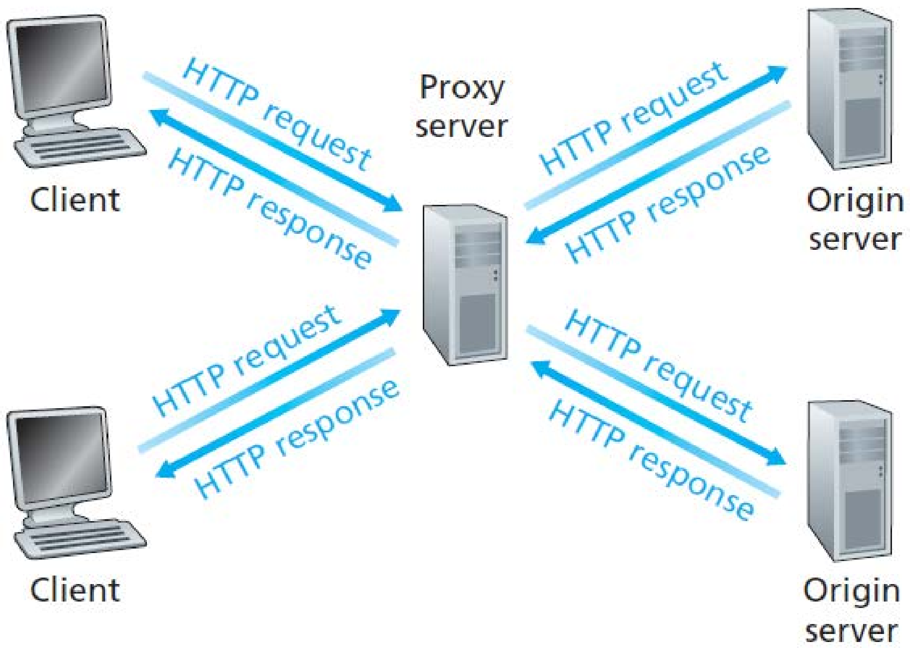
how to keep "state":

- protocol endpoints: maintain state at sender/receiver over multiple transactions
- cookies: http messages carry state

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 (so too does P2P file sharing)

Caching example:

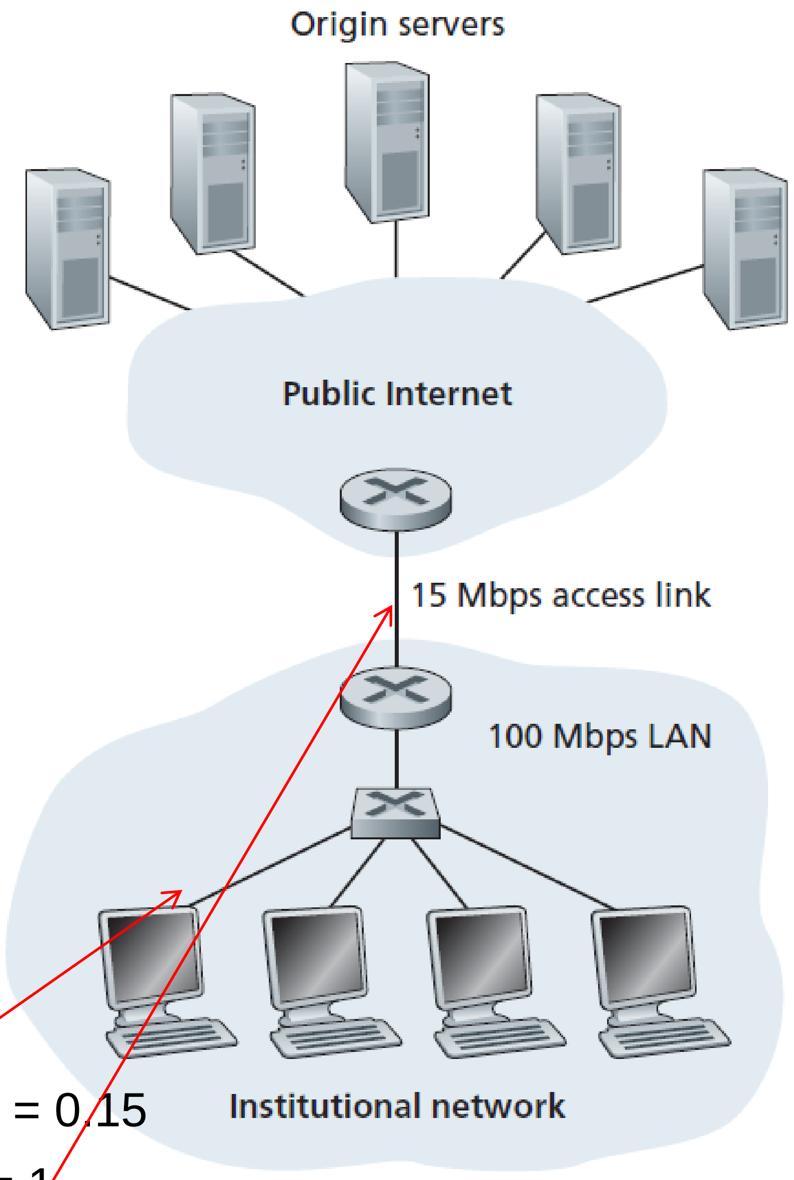
assumptions:

- avg object size: 1M bits
- avg request rate from browsers to origin servers:15/sec
- avg data rate to browsers: 15 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: 15 Mbps

consequences:

- LAN utilization: 15%
- access link utilization = 99%
- total delay = Internet delay + access delay + LAN delay
  = 2 **sec** + **minutes** + **usecs**

problem!



(15 requests/sec) (1 Mbits/request)/(100 Mbps) = 0.15

(15 requests/sec) (1 Mbits/request)/(15 Mbps) = 1

瓶颈在哪里？

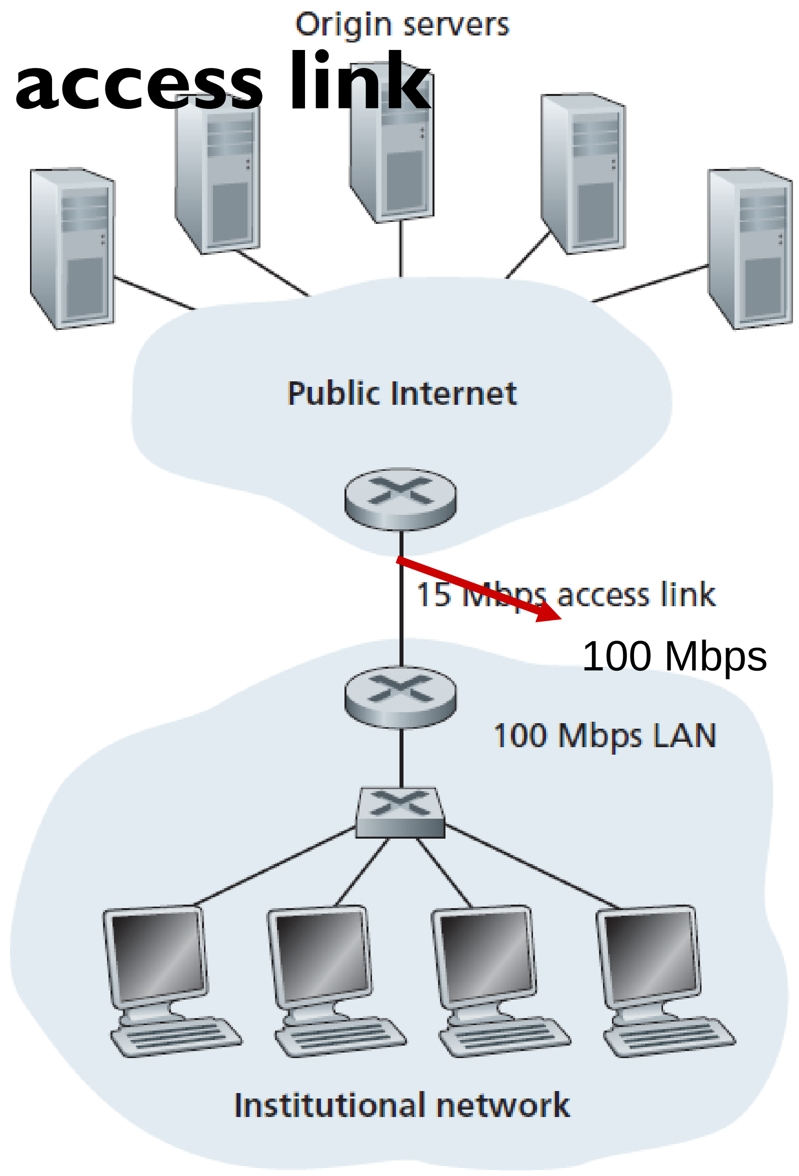
Caching example: fatter access link

assumptions:

- avg object size: 1M bits
- avg request rate from browsers to origin servers: 15/sec
- avg data rate to browsers: 15 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: ~~15 Mbps~~ 100Mbps

consequences:

- LAN utilization: 15%
- access link utilization = ~~99%~~ 15%
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + ~~minutes~~ msecs + usecs



Cost: increased access link speed (not cheap!)

Caching example: install local cache

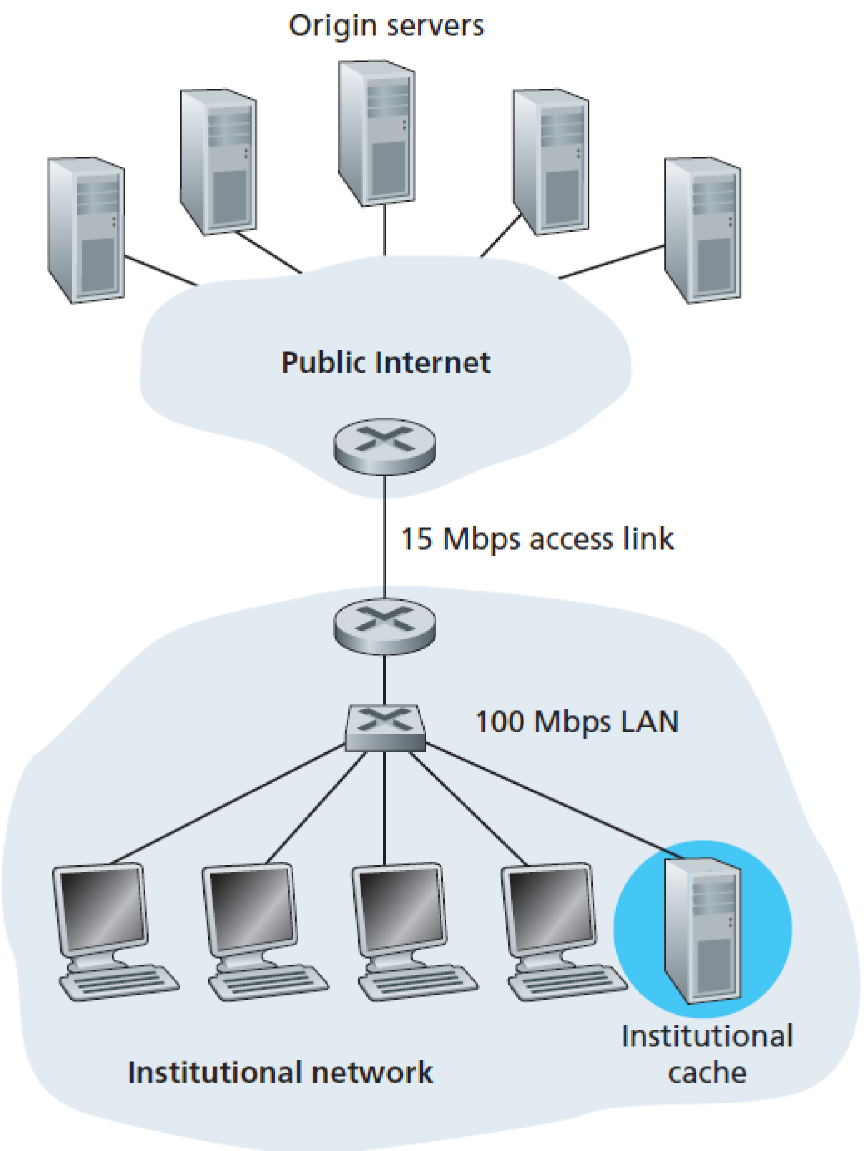
assumptions:
- avg object size: 1M bits
- avg request rate from browsers to origin servers:15/sec
- avg data rate to browsers: 15 Mbps
- RTT from institutional router to any origin server: 2 sec
- access link rate: 15 Mbps

consequences:
- LAN utilization: 15%
- access link utilization = 100%
- total delay = Internet delay + access delay + LAN delay
  = 2 sec + minutes + usecs ?

?

How to compute link utilization, delay?

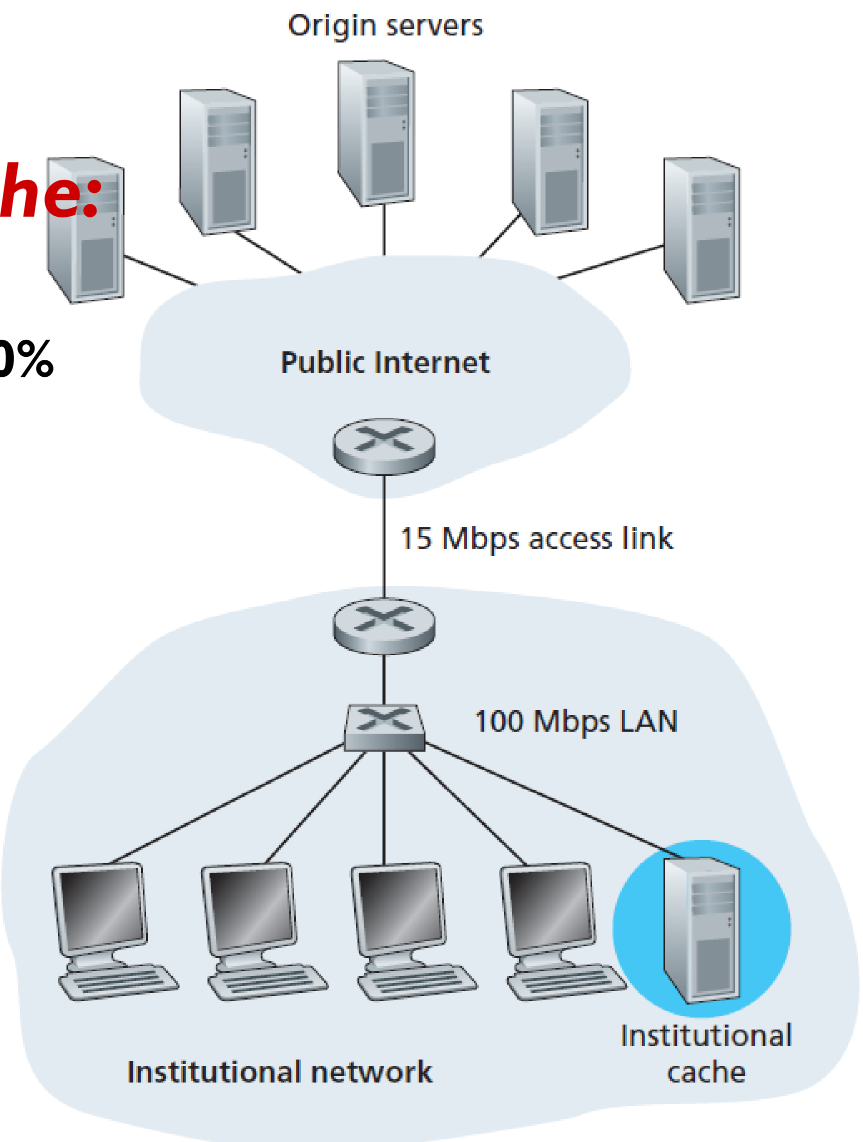
Cost: web cache (cheap!)



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*15 Mbps = 9 Mbps
  - utilization = 9/15 = 0.6

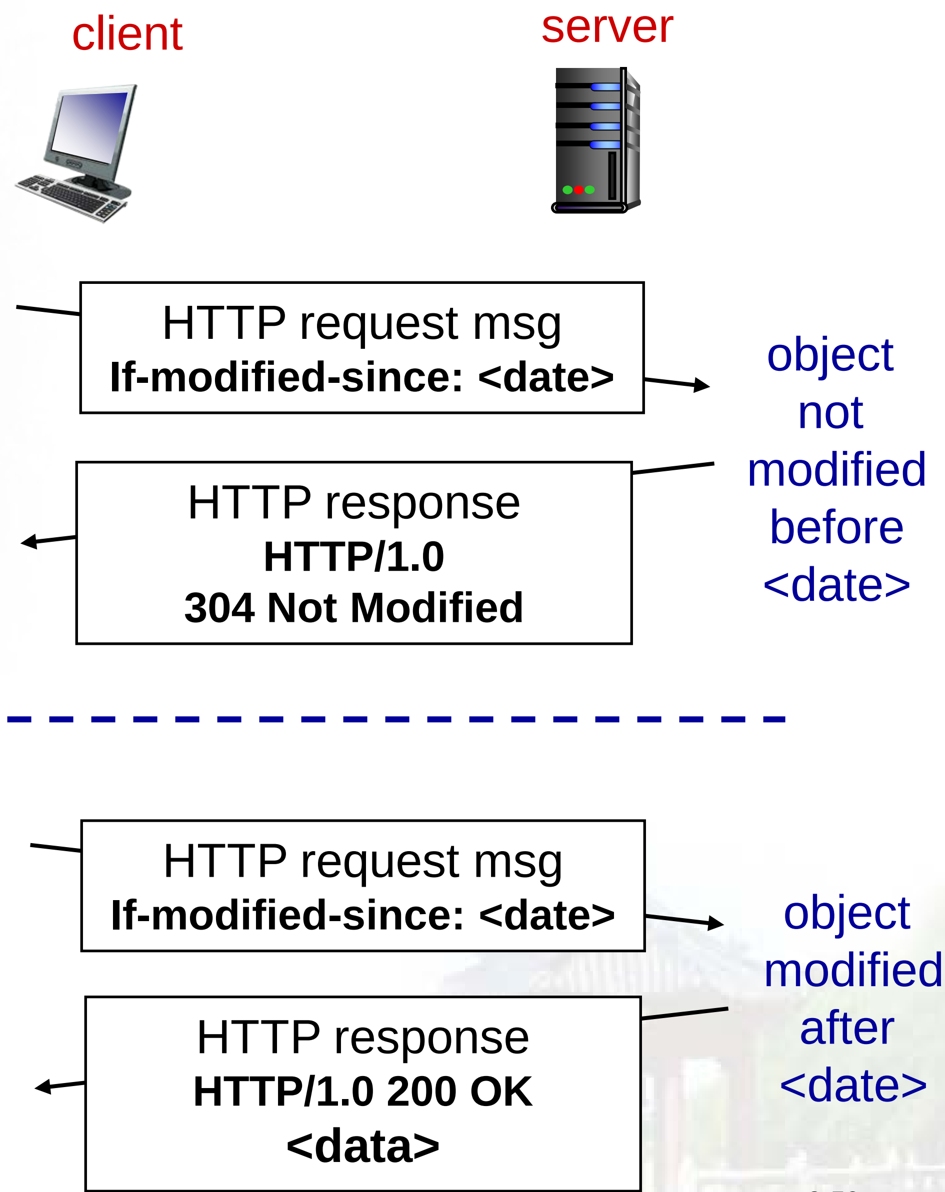
- total delay
  - = 0.6 * (delay from origin servers) +0.4 * (delay when satisfied at cache)
  - = 0.6 (2+0.01) + 0.4 (~msecs~0.01s)
  - = ~ 1.2 secs
  - less than with 100Mbps link (and cheaper too!)

Conditional GET

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

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

  `HTTP/1.0 304 Not Modified`



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- app architectures
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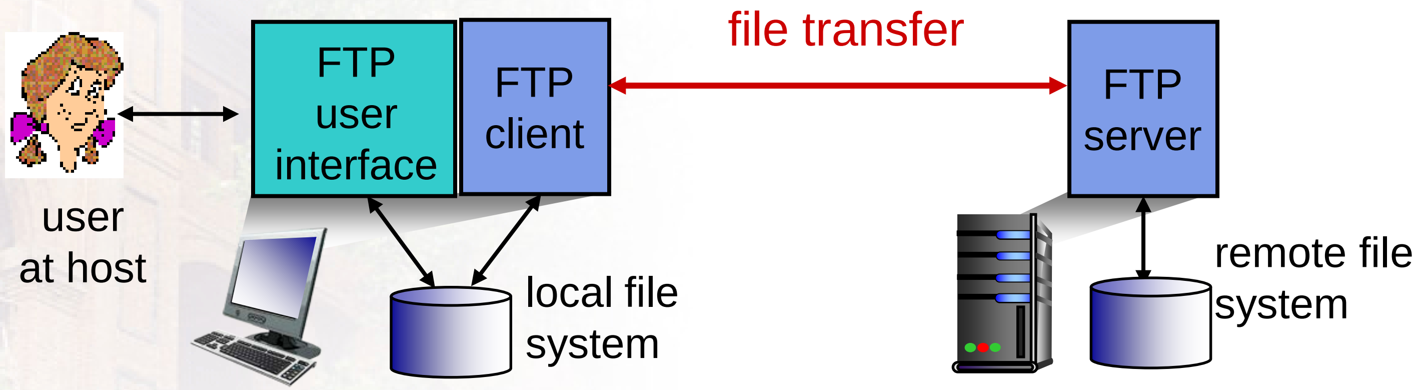
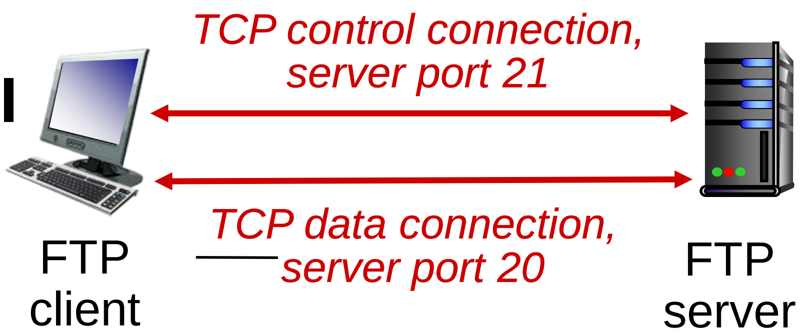
FTP: the file transfer protocol



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

FTP: separate control, data connections

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



- server opens another TCP data connection to transfer another file
- control connection: *"out of band"*
- FTP server maintains "state": current directory, earlier authentication

FTP commands, responses

sample commands:

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

sample return codes

- status code and phrase (as in HTTP)
- `331 Username OK, password required`
- `125 data connection already open; transfer starting`
- `425 Can't open data connection`
- `452 Error writing file`

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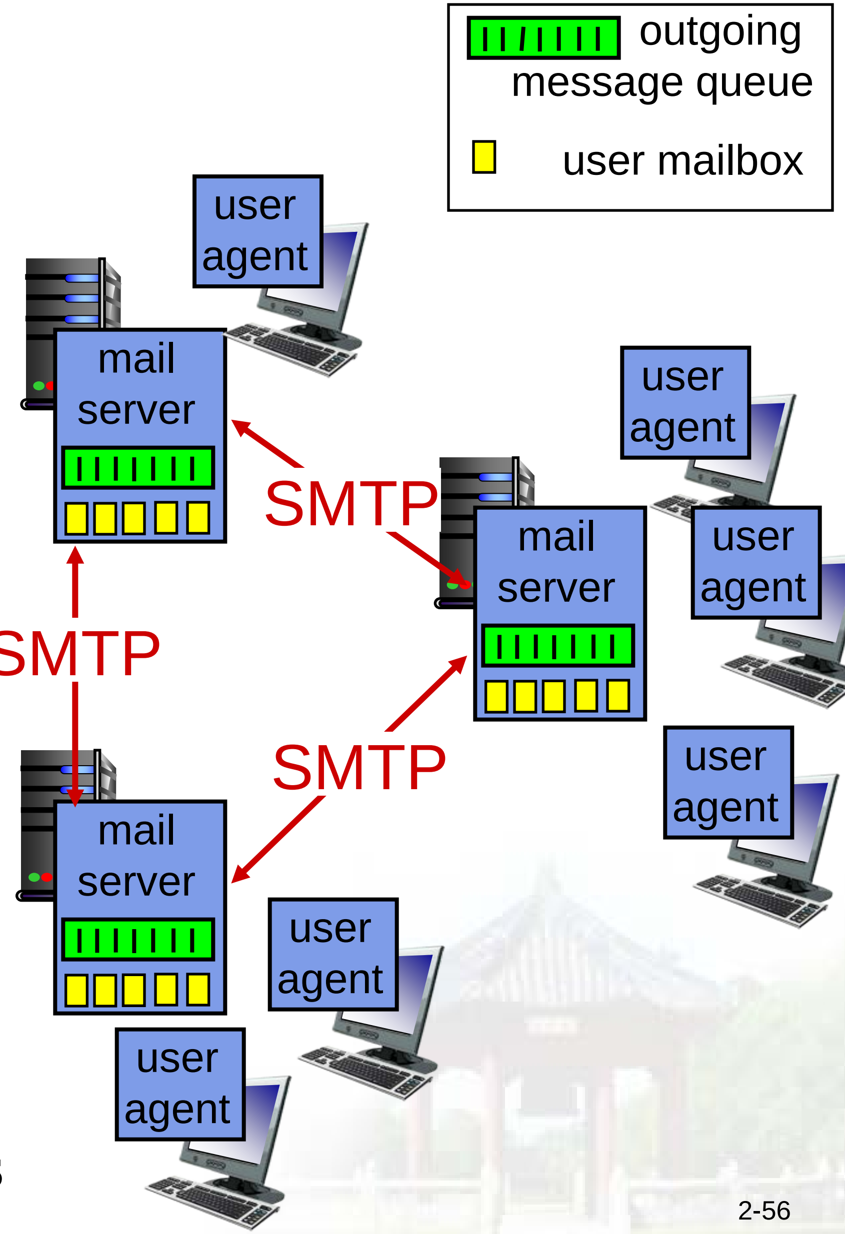
Electronic mail

Three major components:

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

User Agent

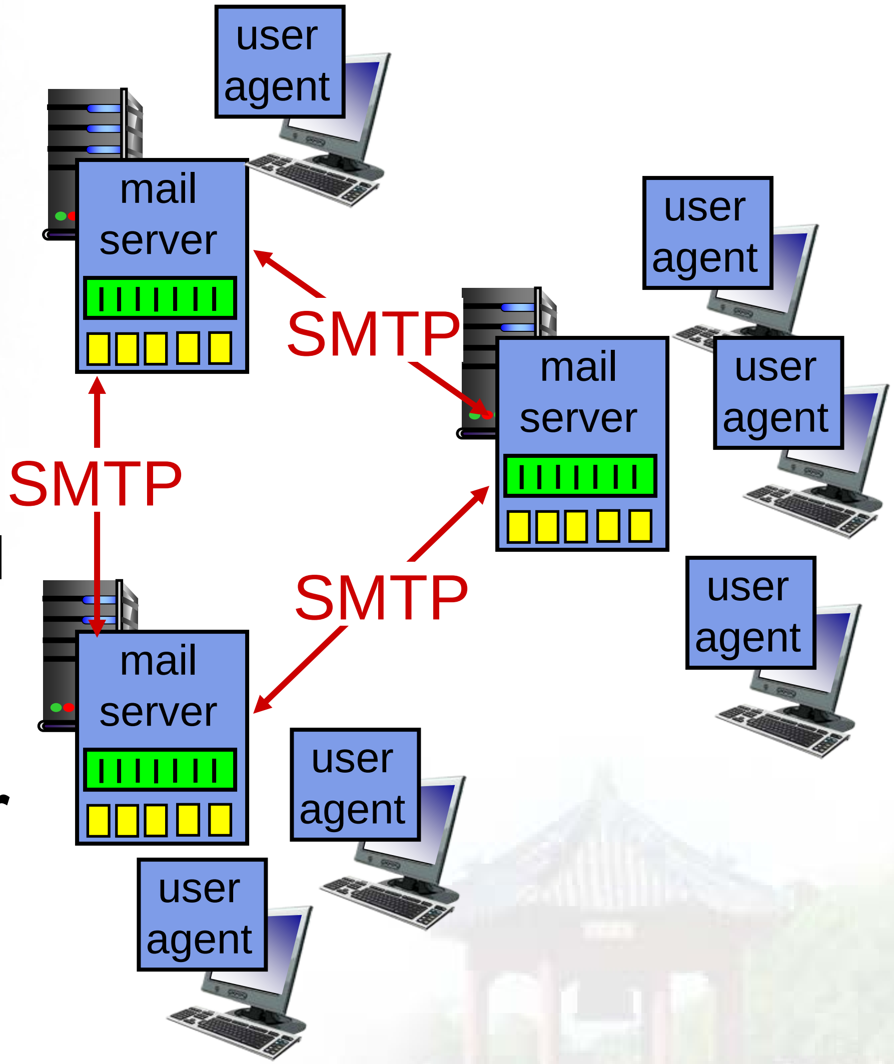
- **a.k.a. "mail reader"**
- **composing, editing, reading mail messages**
- **e.g., Outlook, Thunderbird, iPhone mail client**
- **outgoing, incoming messages stored on server**



Electronic mail: mail servers

mail servers:

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

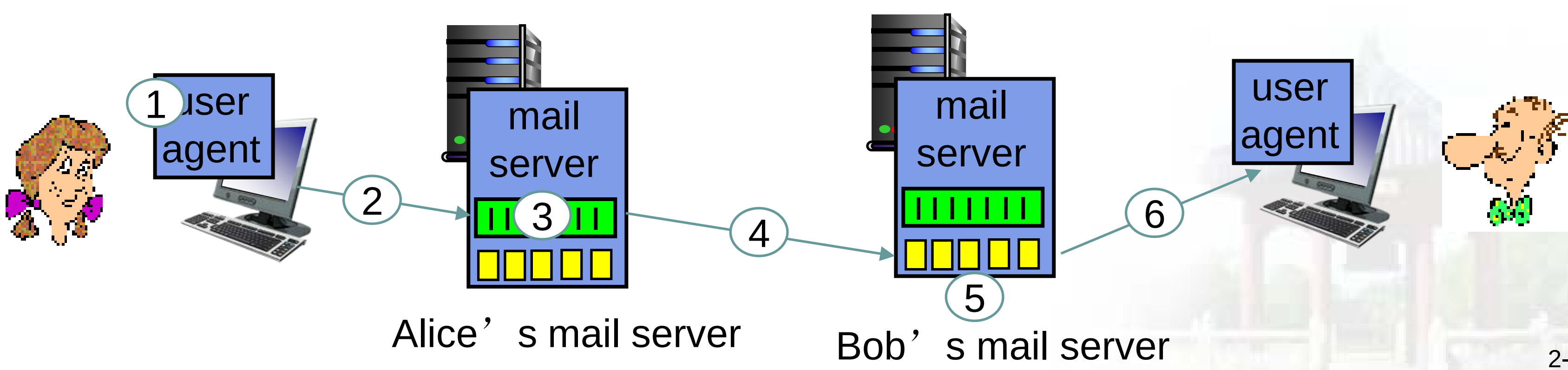


Electronic Mail: SMTP [RFC 2821]

- uses TCP to reliably transfer email message from client to server, port 25
- direct transfer: sending server to receiving server
- three phases of transfer
  - handshaking (greeting)
  - transfer of messages
  - closure
- command/response interaction (like HTTP, FTP)
  - **commands:** ASCII text
  - **response:** status code and phrase
- messages must be in 7-bit ASCI

Scenario: Alice sends message to Bob

1) Alice uses UA to compose message "to" `bob@someschool.edu`
2) Alice's UA sends message to her mail server; message placed in message queue
3) client side of SMTP opens TCP connection with Bob's mail server
4) SMTP client sends Alice's message over the TCP connection
5) Bob's mail server places the message in Bob's mailbox
6) Bob invokes his user agent to read message



Sample SMTP interaction

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

Try SMTP interaction for yourself:

- `telnet servername 25`
- see 220 reply from server
- enter **HELO, MAIL FROM, RCPT TO, DATA, QUIT** commands

above lets you send email without using email client (reader)

SMTP: final words

- SMTP uses persistent connections
- SMTP requires message (header & body) to be in 7-bit ASCII
- SMTP server uses `CRLF.CRLF` to determine end of message

comparison with HTTP:

- HTTP: pull
- SMTP: push
- both have ASCII command/response interaction, status codes
- HTTP: each object encapsulated in its own response msg
- SMTP: multiple objects sent in multipart msg

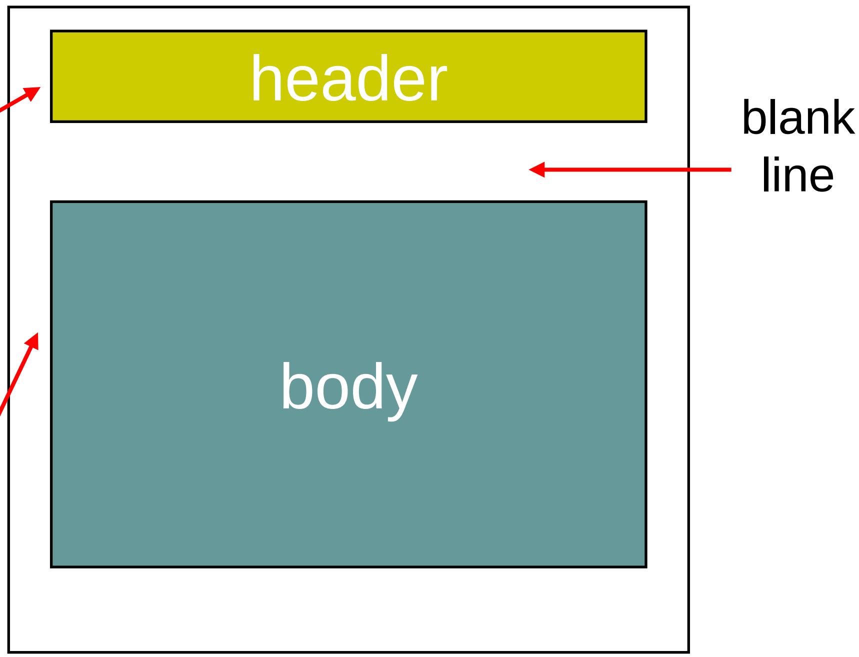
Mail message format

SMTP: protocol for exchanging email msgs

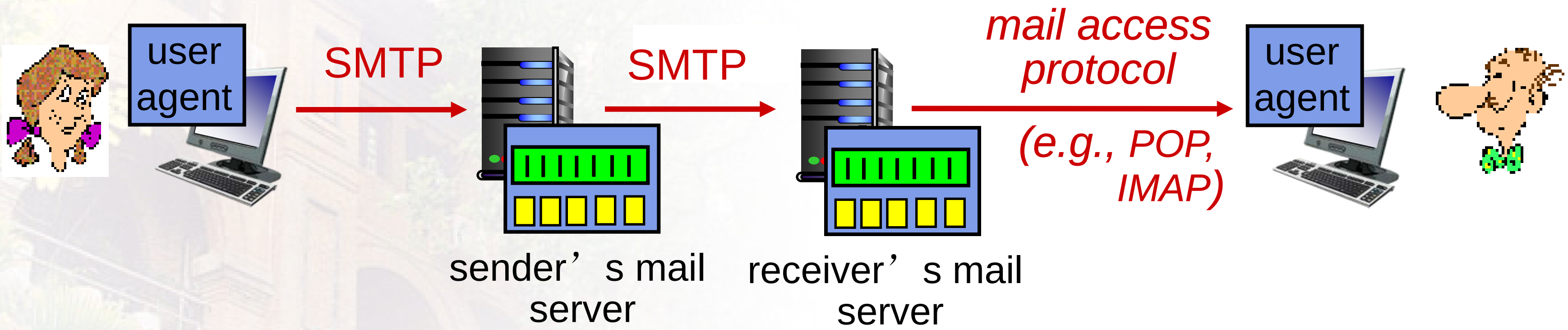
RFC 822: standard for text message format:

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

  different from SMTP MAIL FROM, RCPT TO: commands!
- Body: the "message"
  - ASCII characters only



Mail access protocols



- **SMTP: delivery/storage to receiver's server**
- **mail access protocol: retrieval from server**
  - **POP: Post Office Protocol [RFC 1939]: authorization, download**
  - **IMAP: Internet Mail Access Protocol [RFC 1730]: more features, including manipulation of stored msgs on server**
  - **HTTP: gmail, Hotmail, Yahoo! Mail, etc.**

POP3 protocol

authorization phase

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

transaction phase**, client:**

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

```
S: +OK POP3 server ready
C: user bob
S: +OK
C: pass hungry
S: +OK user successfully logged on
```

```
C: list
S: 1 498
S: 2 912
S: .
C: retr 1
S: <message 1 contents>
S: .
C: dele 1
C: retr 2
S: <message 1 contents>
S: .
C: dele 2
C: quit
S: +OK POP3 server signing off
```

POP3 (more) and IMAP

more about POP3

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

IMAP

- keeps all messages in one place: at server
- allows user to organize messages in folders
- keeps user state across sessions:
  - names of folders and mappings between message IDs and folder name

Chapter 2: outline

2.1 principles of network applications

- app architectures
- app requirements

2.2 Web and HTTP

2.3 FTP

2.4 electronic mail

- SMTP, POP3, IMAP

2.5 DNS

2.6 P2P applications

2.7 socket programming with UDP and TCP

DNS: domain name system

people: many identifiers:

- SSN, name, passport #

Internet hosts, routers:

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

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

Domain Name System:

- *distributed database* implemented in hierarchy of many *name servers*
- *application-layer protocol:* hosts, name servers communicate to *resolve* names (address/name translation)
  - note: core Internet function, implemented as application-layer protocol
  - complexity at network's "edge"

DNS: services, structure

DNS services

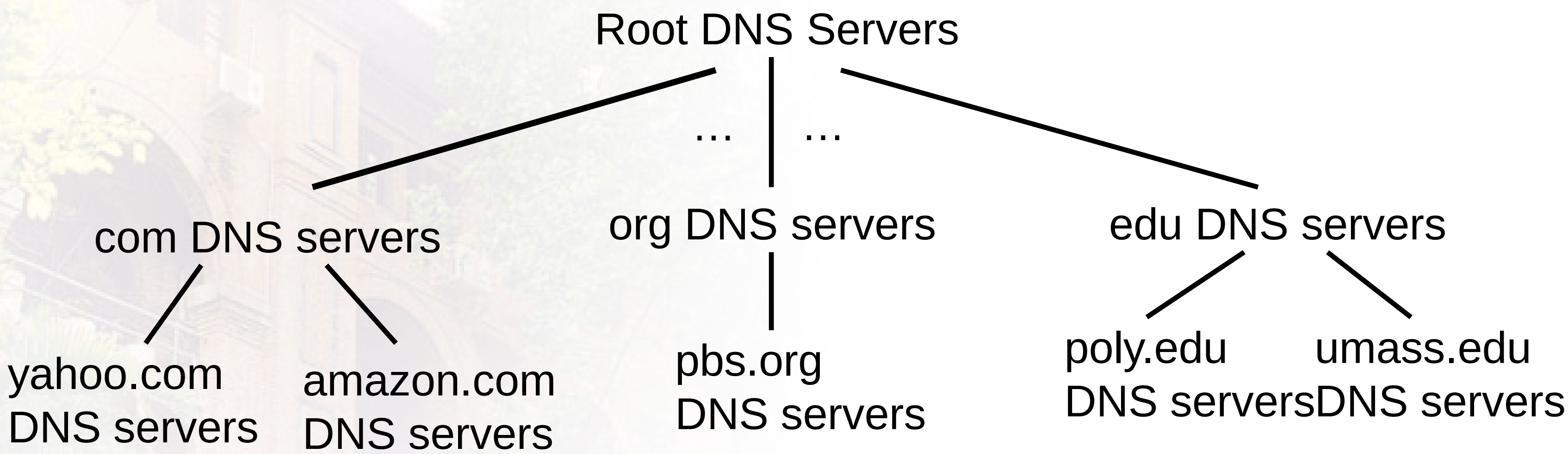
- hostname to IP address translation
- host aliasing
  - canonical, alias names
- mail server aliasing
- load distribution
  - replicated Web servers: many IP addresses correspond to one name

why not centralize DNS?

- single point of failure
- traffic volume
- distant centralized database
- maintenance

A: doesn't scale!

DNS: a distributed, hierarchical database

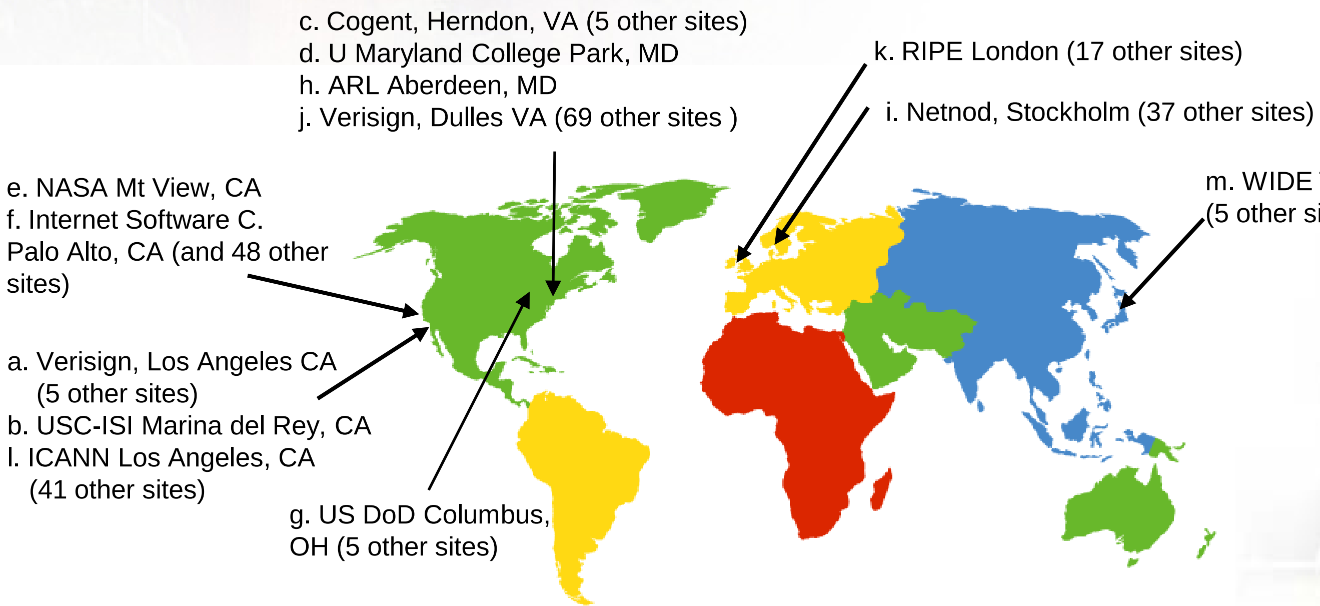


client wants IP for www.amazon.com; 1st approx:

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

DNS: root name servers

- contacted by local name server that can not resolve name
- root name server:
  - contacts authoritative name server if name mapping not known
  - gets mapping
  - returns mapping to local name server



13 root name "servers" worldwide

TLD, authoritative servers

top-level domain (TLD) servers:

.com DNS server

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

authoritative DNS servers:

amazon.com DNS server

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

Local DNS name server

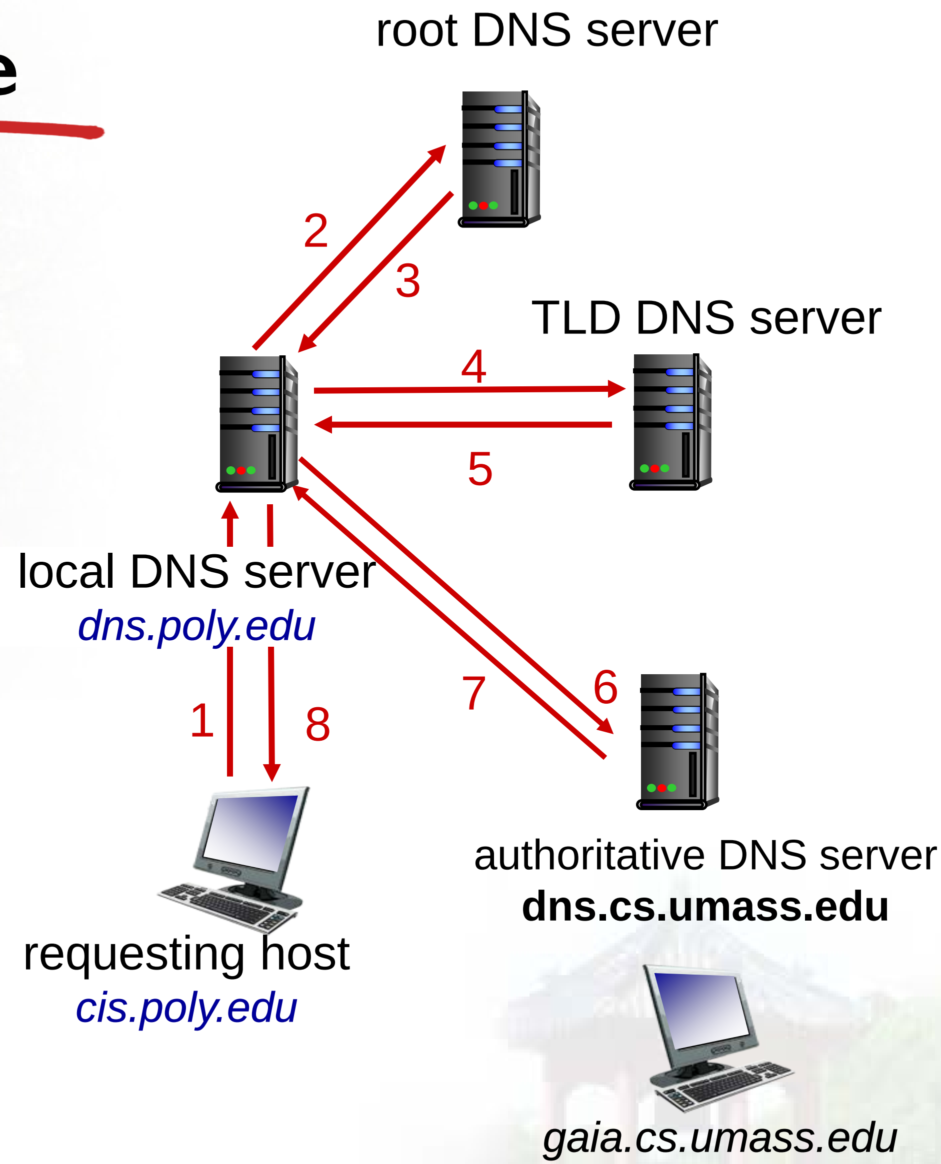
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
  - also called "default name server"
- when host makes DNS query, query is sent to its local DNS server
  - has local cache of recent name-to-address translation pairs (but may be out of date!)
  - acts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

DNS name resolution example

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

iterated query:

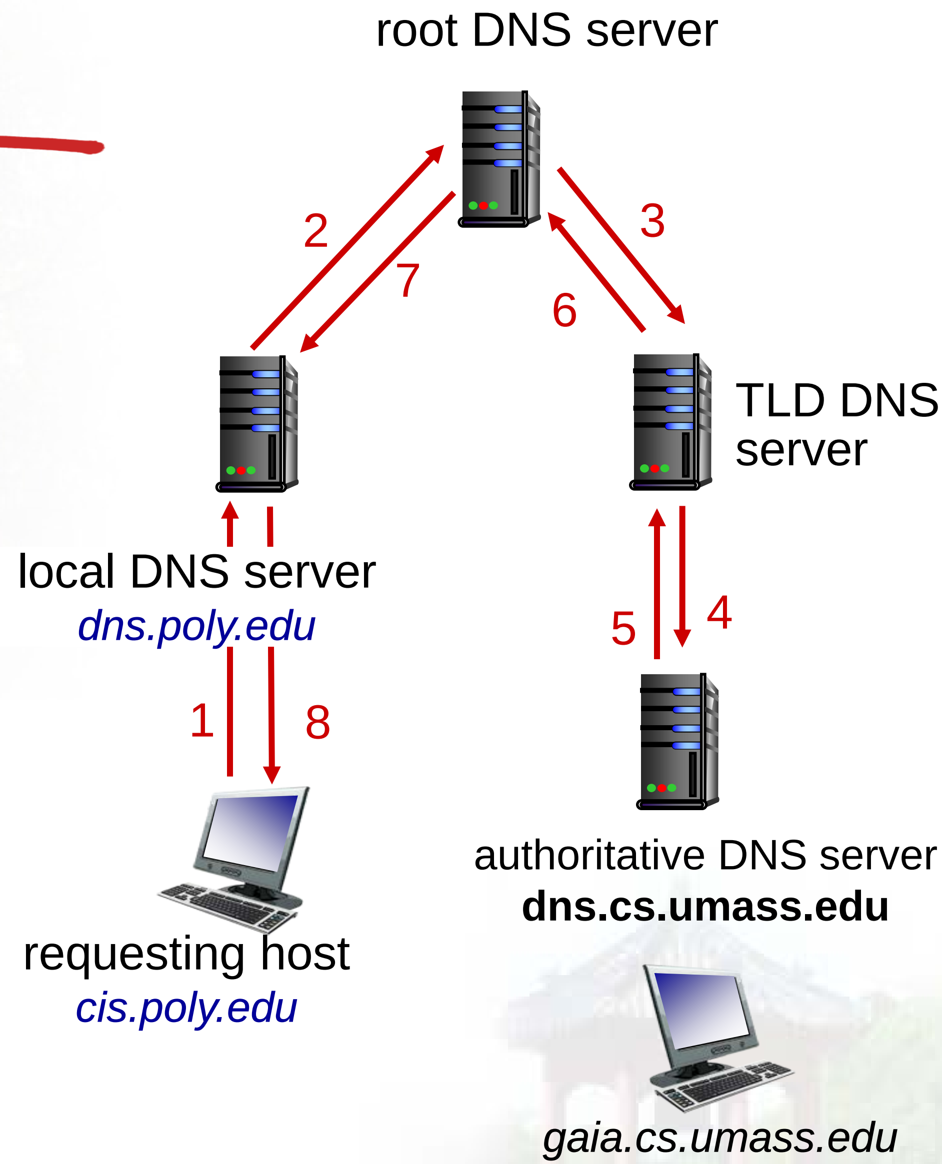
- contacted server **replies with NAME of server to contact**
- "I don't know this name, but ask this server"



DNS name resolution example

recursive query:

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



DNS: caching, updating records

- once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time (TTL)
  - TLD servers typically cached in local name servers
    - thus root name servers not often visited
- cached entries may be *out-of-date* (best effort name-to-address translation!)
  - if name host changes IP address, may not be known Internet-wide until all TTLs expire
- update/notify mechanisms proposed IETF standard
  - RFC 2136

DNS records

DNS: **distributed db storing resource records (RR)**

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

type=A
- **`name`** is hostname
- **`value`** is IP address

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

type=CNAME
- **`name`** is alias name for some "canonical" (the real) name
- **`www.ibm.com`** is really **`servereast.backup2.ibm.com`**
- **`value`** is canonical name

type=MX
- **`value`** is name of mailserver associated with **`name`**

DNS protocol, messages

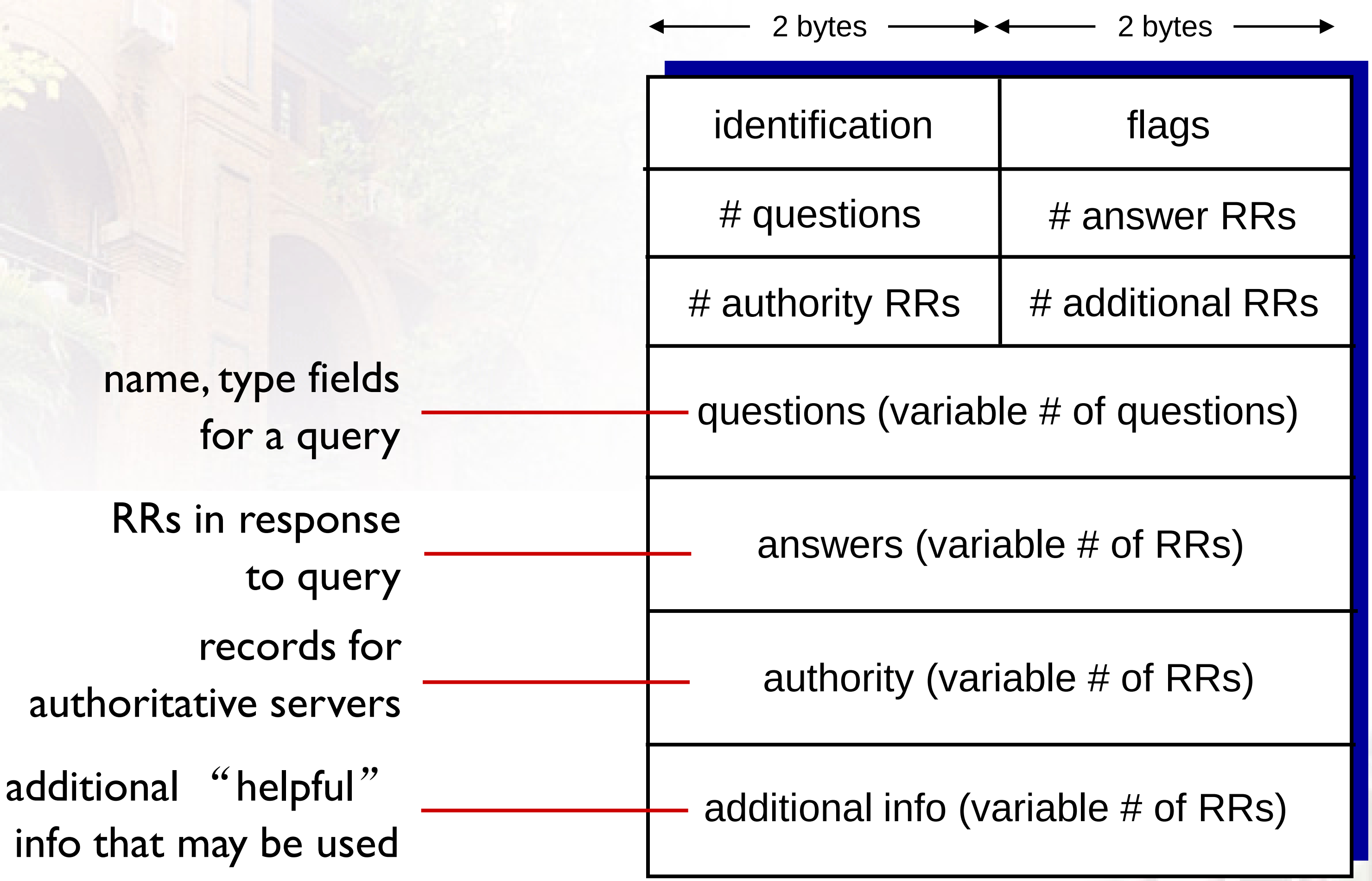
- ***query*** **and** ***reply*** **messages, both with same** ***message format***

msg header

- identification: 16 bit # for query, reply to query uses same #
- flags:
  - query or reply
  - recursion desired
  - recursion available
  - reply is authoritative

<table>
<tr><th>← 2 bytes →</th><th>← 2 bytes →</th></tr>
<tr><td>identification</td><td>flags</td></tr>
<tr><td># questions</td><td># answer RRs</td></tr>
<tr><td># authority RRs</td><td># additional RRs</td></tr>
<tr><td colspan="2">questions (variable # of questions)</td></tr>
<tr><td colspan="2">answers (variable # of RRs)</td></tr>
<tr><td colspan="2">authority (variable # of RRs)</td></tr>
<tr><td colspan="2">additional info (variable # of RRs)</td></tr>
</table>

DNS protocol, messages



Inserting records into DNS

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

```
(networkutopia.com, dns1.networkutopia.com, NS)
(dns1.networkutopia.com, 212.212.212.1, A)
```

- create authoritative server type A record for www.networkuptopia.com; type MX record for networkutopia.com

Attacking DNS

DDoS attacks

- Bombard root servers with traffic
  - Not successful to date
  - Traffic Filtering
  - Local DNS servers cache IPs of TLD servers, allowing root server bypass
- Bombard TLD servers
  - Potentially more dangerous

Redirect attacks

- Man-in-middle
  - Intercept queries
- DNS poisoning
  - Send bogus relies to DNS server, which caches

Exploit DNS for DDoS

- Send queries with spoofed source address: target IP
- Requires amplification

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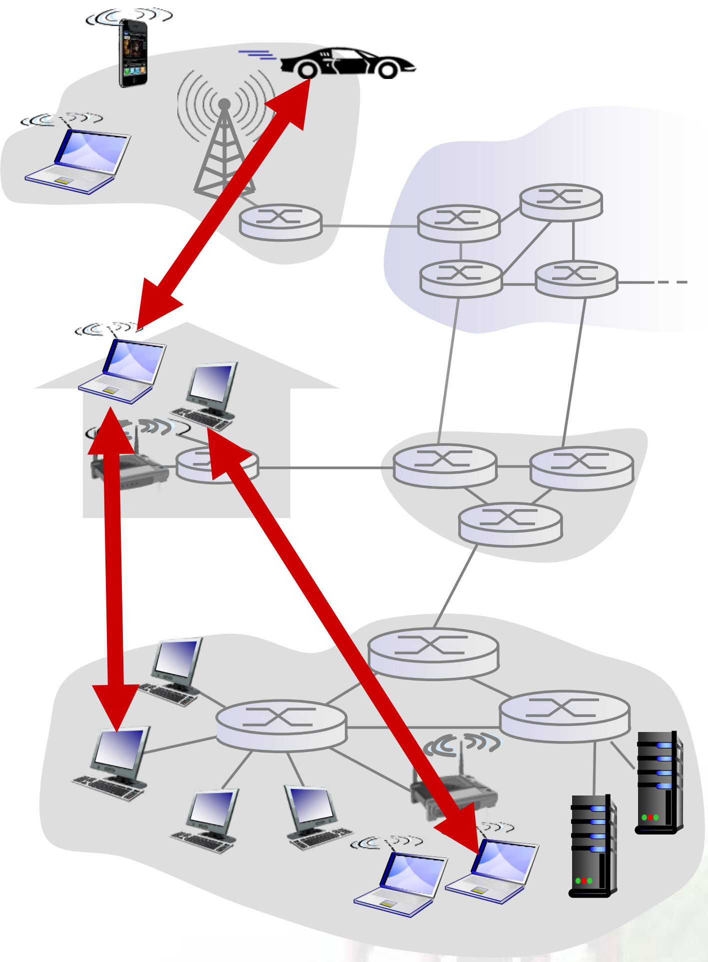
2.7 socket programming with UDP and TCP

Pure P2P architecture

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

examples:

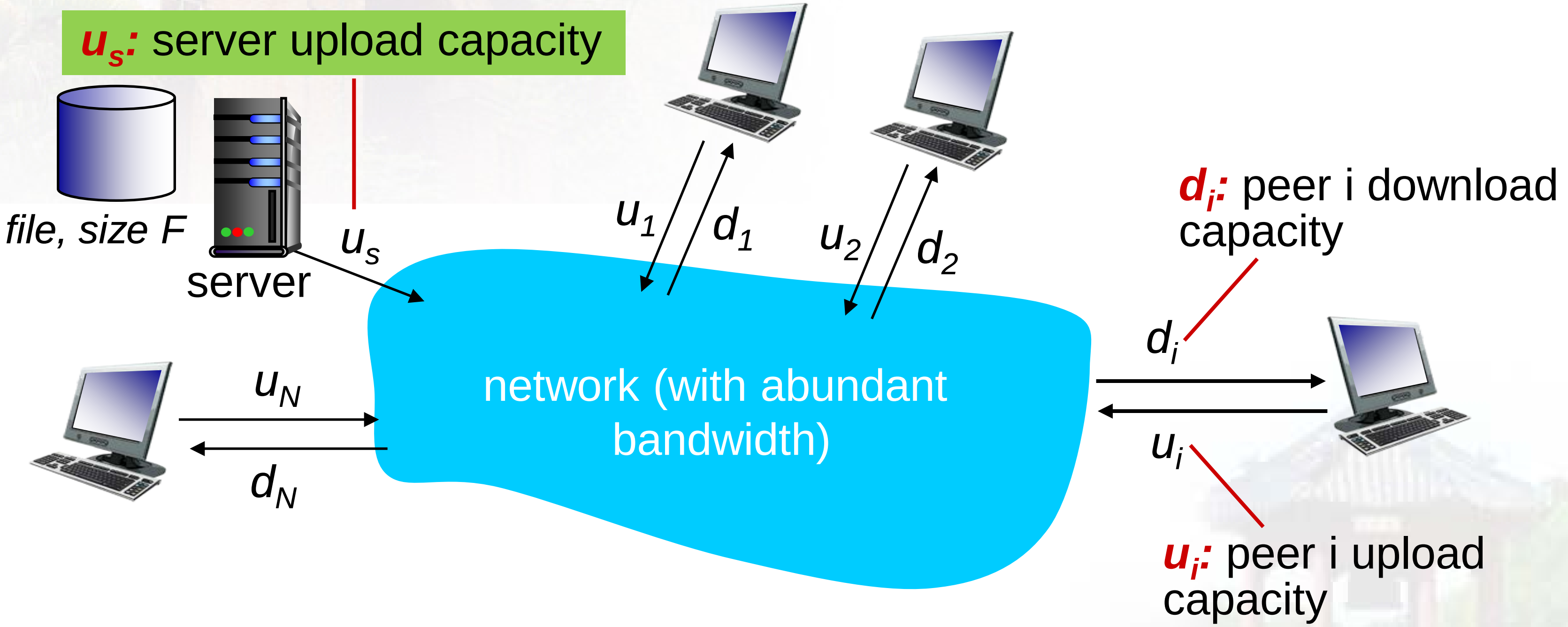
- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)



File distribution: client-server vs P2P

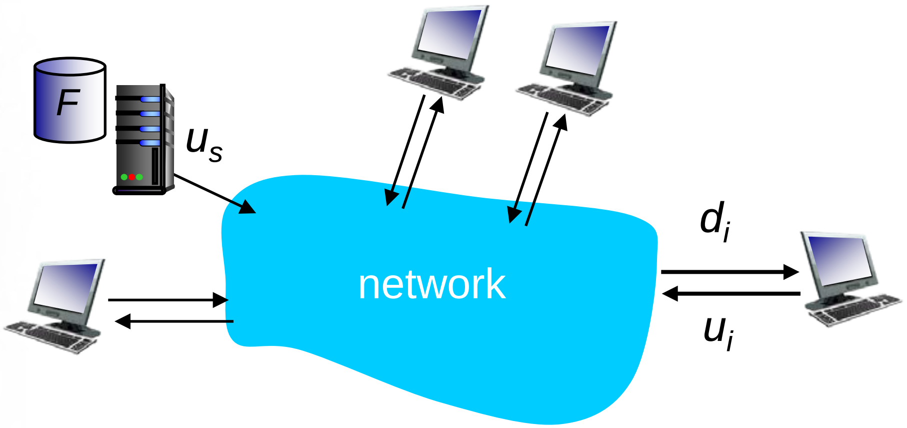
Question: **how much time to distribute file (size *F*) from *one server to N peers*?**

- **peer upload/download capacity is limited resource**



File distribution time: client-server

- ***server transmission:*** **must sequentially send (upload) *N* file copies:**
  - **time to send one copy: F/u_s**
  - **time to send N copies: NF/u_s**



- *client:* each client must download file copy
  - d_{min} = min client download rate
  - min client download time: F/d_{min}

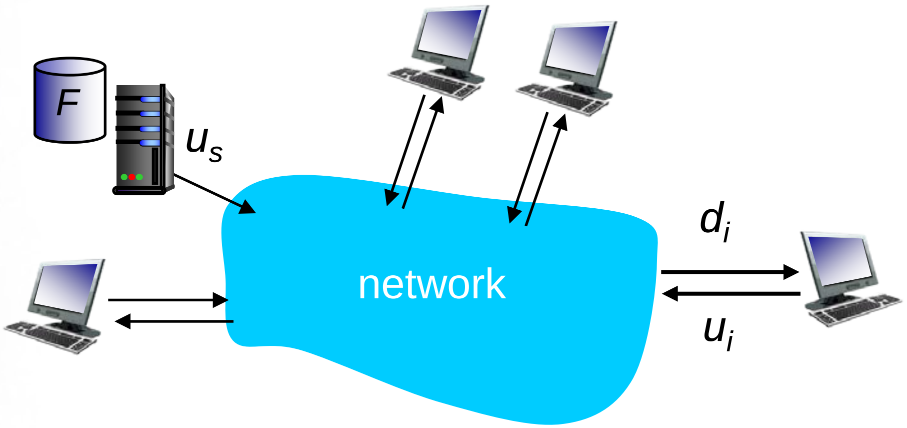
time to distribute F to N clients using client-server approach

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

increases linearly in N

File distribution time: P2P

- ***server transmission:*** **must upload at least one copy**
  - **time to send one copy: F/u_s**



- *client:* each client must download file copy
  - min client download time: F/d_{min}

- *clients:* as aggregate must download *NF* bits
  - max upload rate (limting max download rate) is $u_s + \Sigma u_i$

time to distribute F to N clients using P2P approach

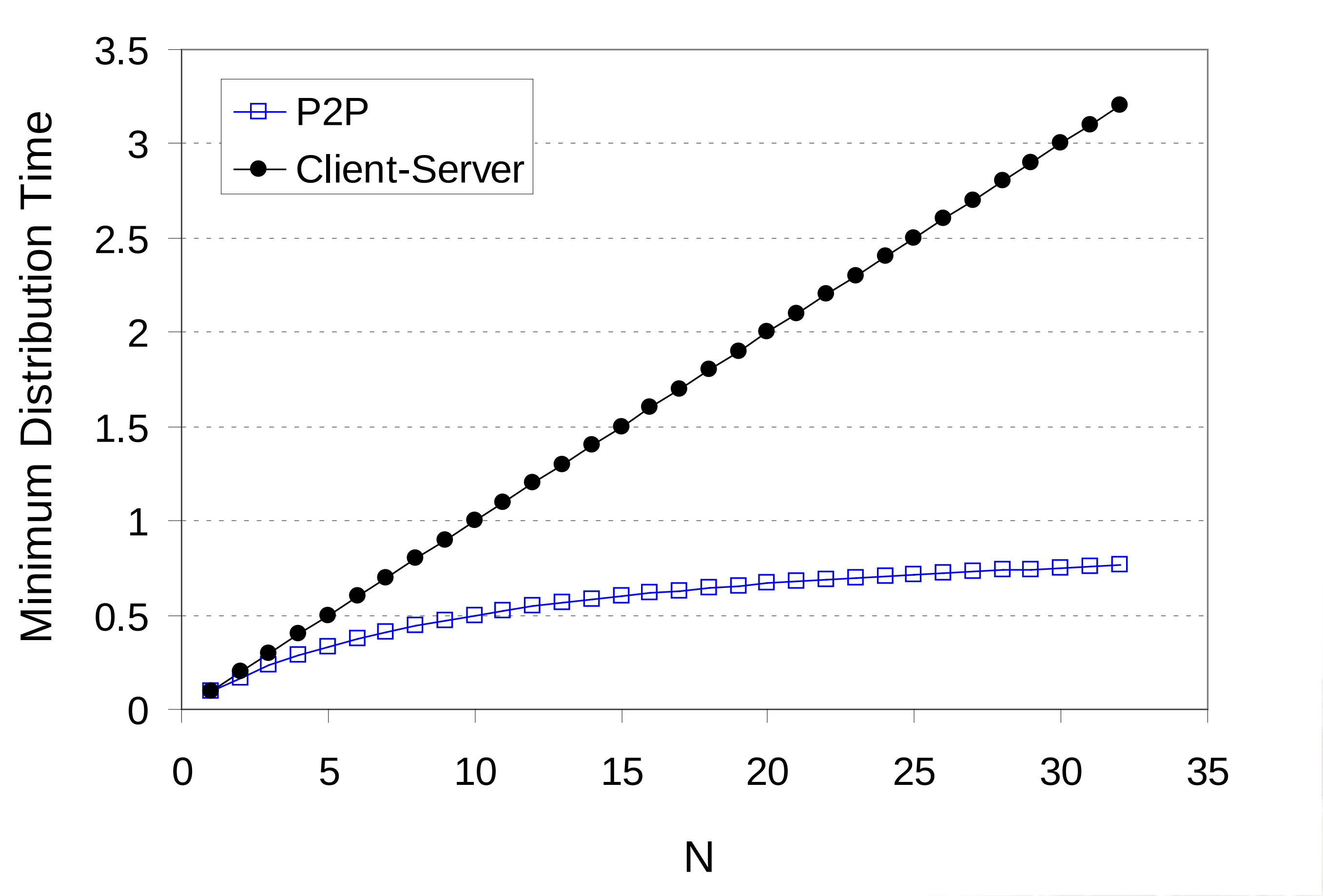
$$D_{P2P} \geq max\{F/u_{s,},F/d_{min,},NF/(u_s + \Sigma u_i)\}$$

increases linearly in *N* …

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

Client-server vs. P2P: example

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

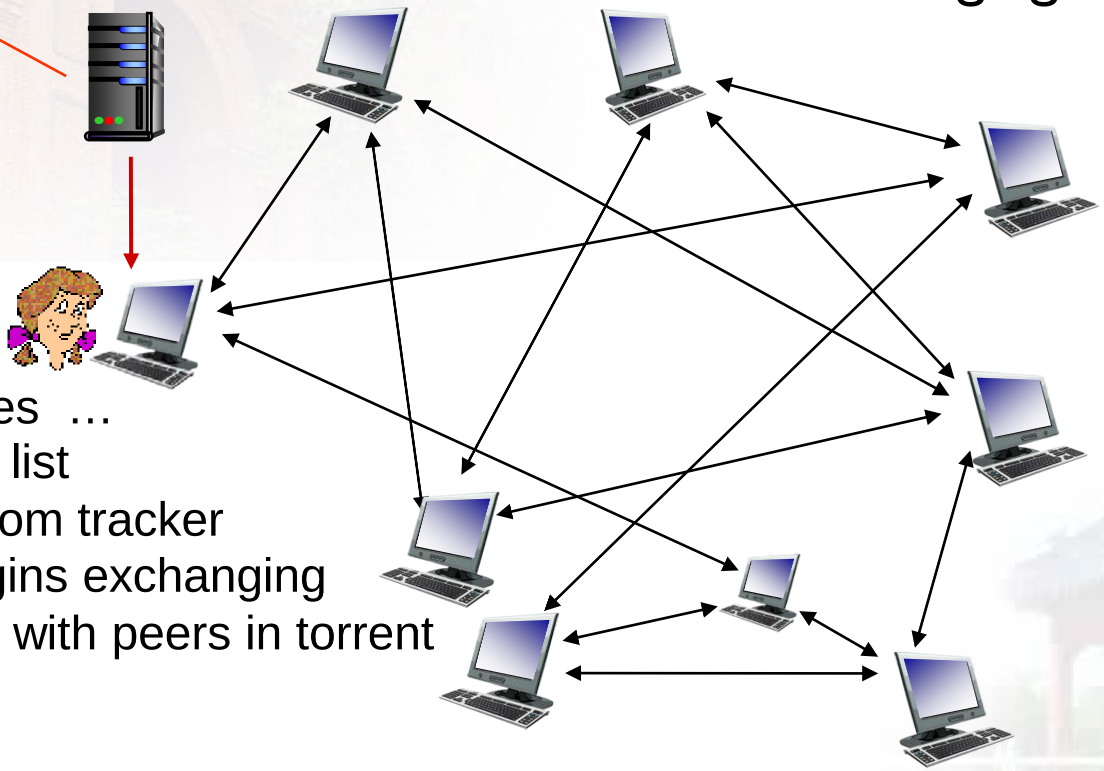


P2P file distribution: BitTorrent

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

tracker: tracks peers participating in torrent

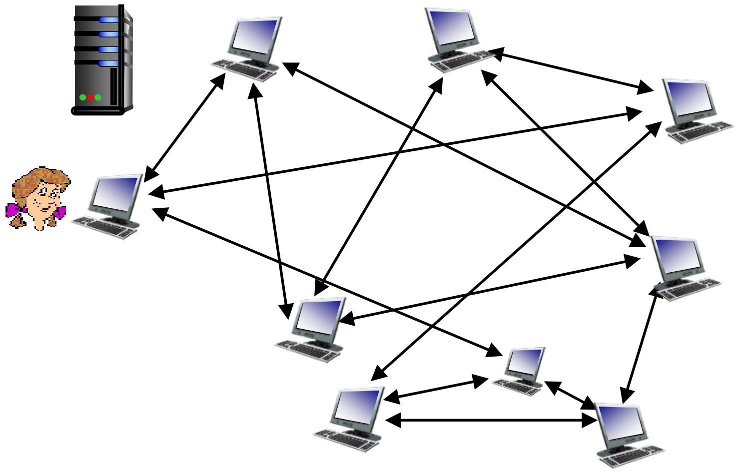
torrent: group of peers exchanging chunks of a file



Alice arrives …
… obtains list
of peers from tracker
… and begins exchanging
file chunks with peers in torrent

P2P file distribution: BitTorrent

- **peer joining torrent:**
  - **has no chunks, but will accumulate them over time from other peers**
  - **registers with tracker to get list of peers, connects to subset of peers ("neighbors")**



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

BitTorrent: requesting, sending file chunks

requesting chunks:

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

sending chunks: tit-for-tat

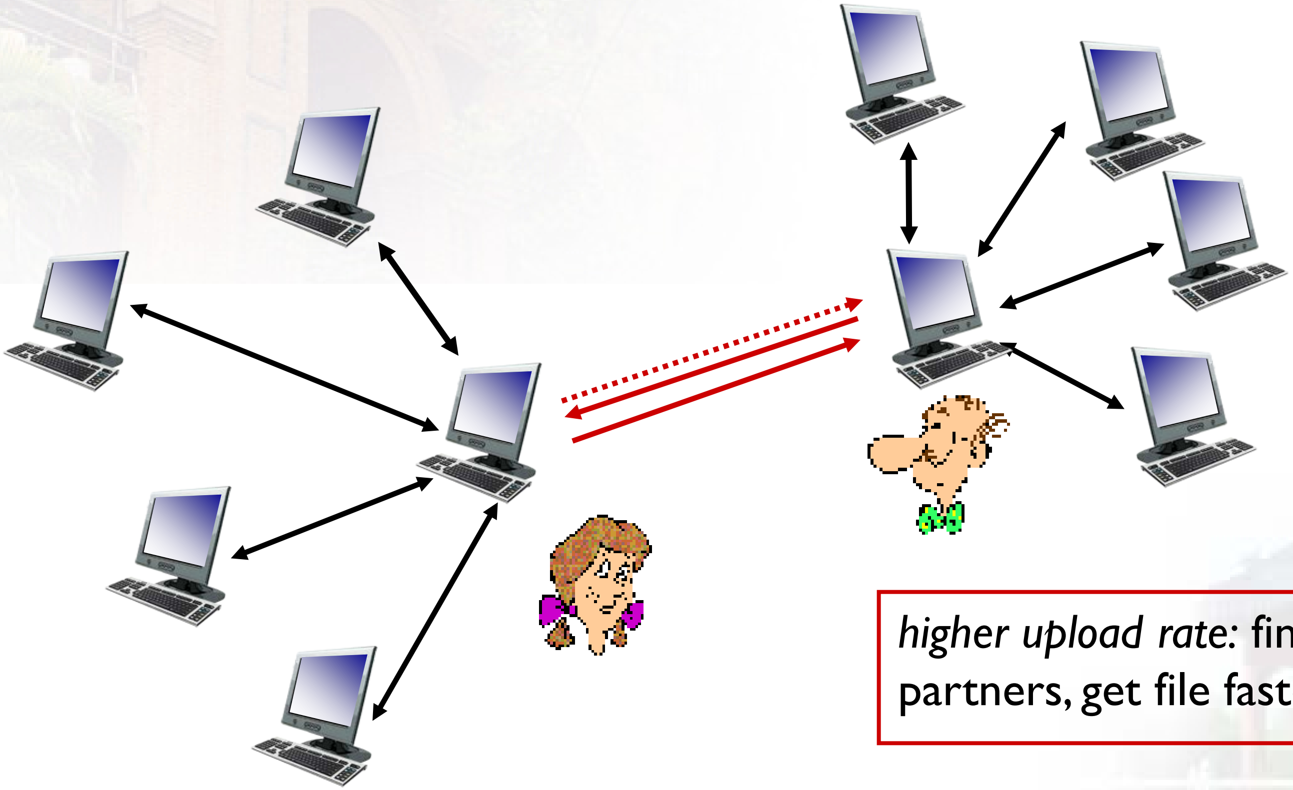
- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
  - other peers are choked by Alice (do not receive chunks from her)
  - re-evaluate top 4 every10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
  - newly chosen peer may join top 4

BitTorrent: tit-for-tat

(1) Alice "optimistically unchokes" Bob

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

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



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

Distributed Hash Table (DHT)

- Hash table
- DHT paradigm
- Circular DHT and overlay networks
- Peer churn

Simple Database

Simple database with (key, value) pairs:

- key: human name; value: social security #

Key	Value
John Washington	132-54-3570
Diana Louise Jones	761-55-3791
Xiaoming Liu	385-41-0902
Rakesh Gopal	441-89-1956
Linda Cohen	217-66-5609
…….	………
Lisa Kobayashi	177-23-0199

- key: movie title; value: IP address

Hash Table

- More convenient to store and search on numerical representation of key
- key = hash(original key)

Original Key	Key	Value
John Washington	8962458	132-54-3570
Diana Louise Jones	7800356	761-55-3791
Xiaoming Liu	1567109	385-41-0902
Rakesh Gopal	2360012	441-89-1956
Linda Cohen	5430938	217-66-5609
…….		………
Lisa Kobayashi	9290124	177-23-0199

Distributed Hash Table (DHT)

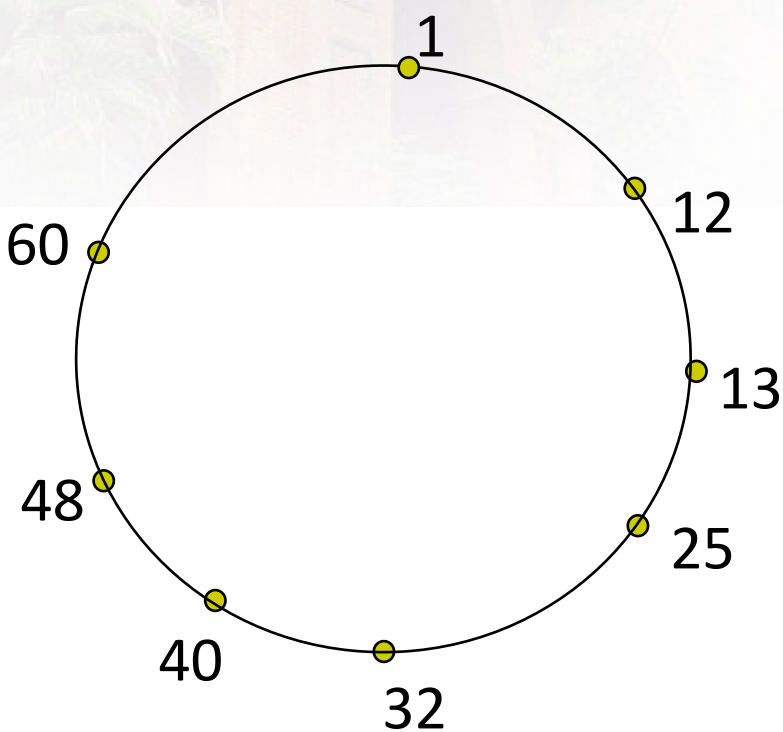
- **Distribute (key, value) pairs over millions of peers**
  - **pairs are evenly distributed over peers**
- **Any peer can query database with a key**
  - **database returns value for the key**
  - **To resolve query, small number of messages exchanged among peers**
- **Each peer only knows about a small number of other peers**
- **Robust to peers coming and going (churn)**

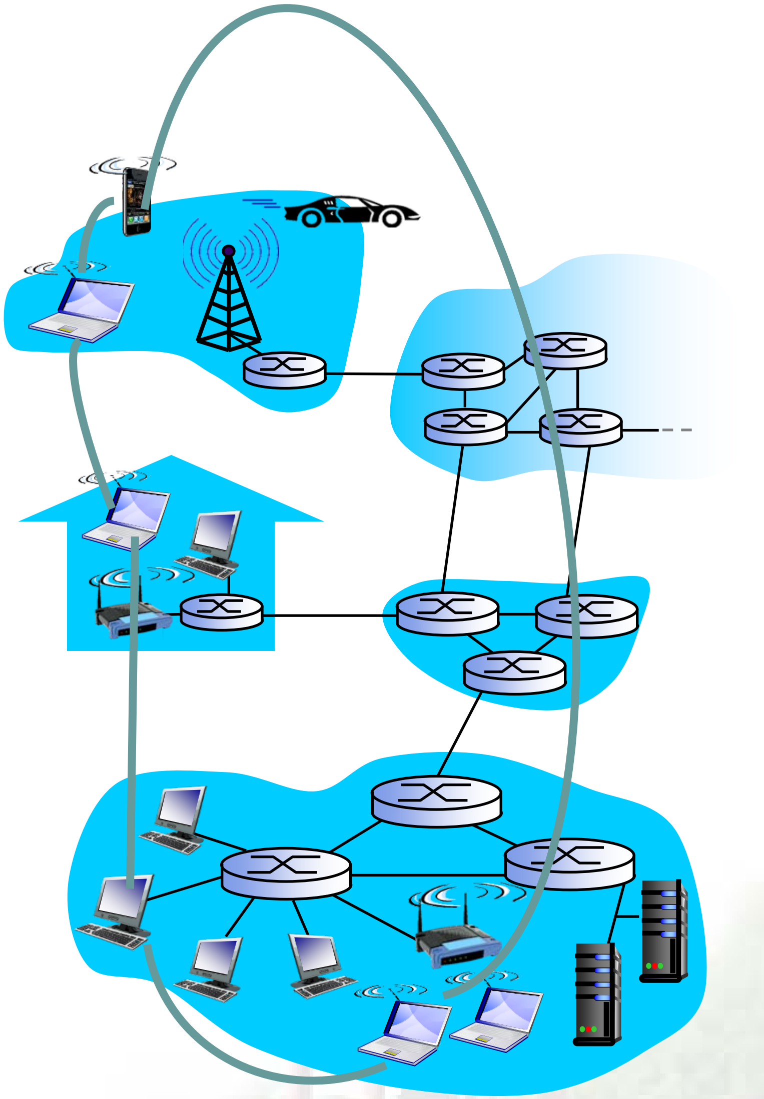
Assign key-value pairs to peers

- rule: assign key-value pair to the peer that has the *closest* ID.
- convention: closest is the *immediate successor* of the key.
- e.g., ID space {0,1,2,3,…,63}
- suppose 8 peers: 1,12,13,25,32,40,48,60
  - If key = 51, then assigned to peer 60
  - If key = 60, then assigned to peer 60
  - If key = 61, then assigned to peer 1

Circular DHT

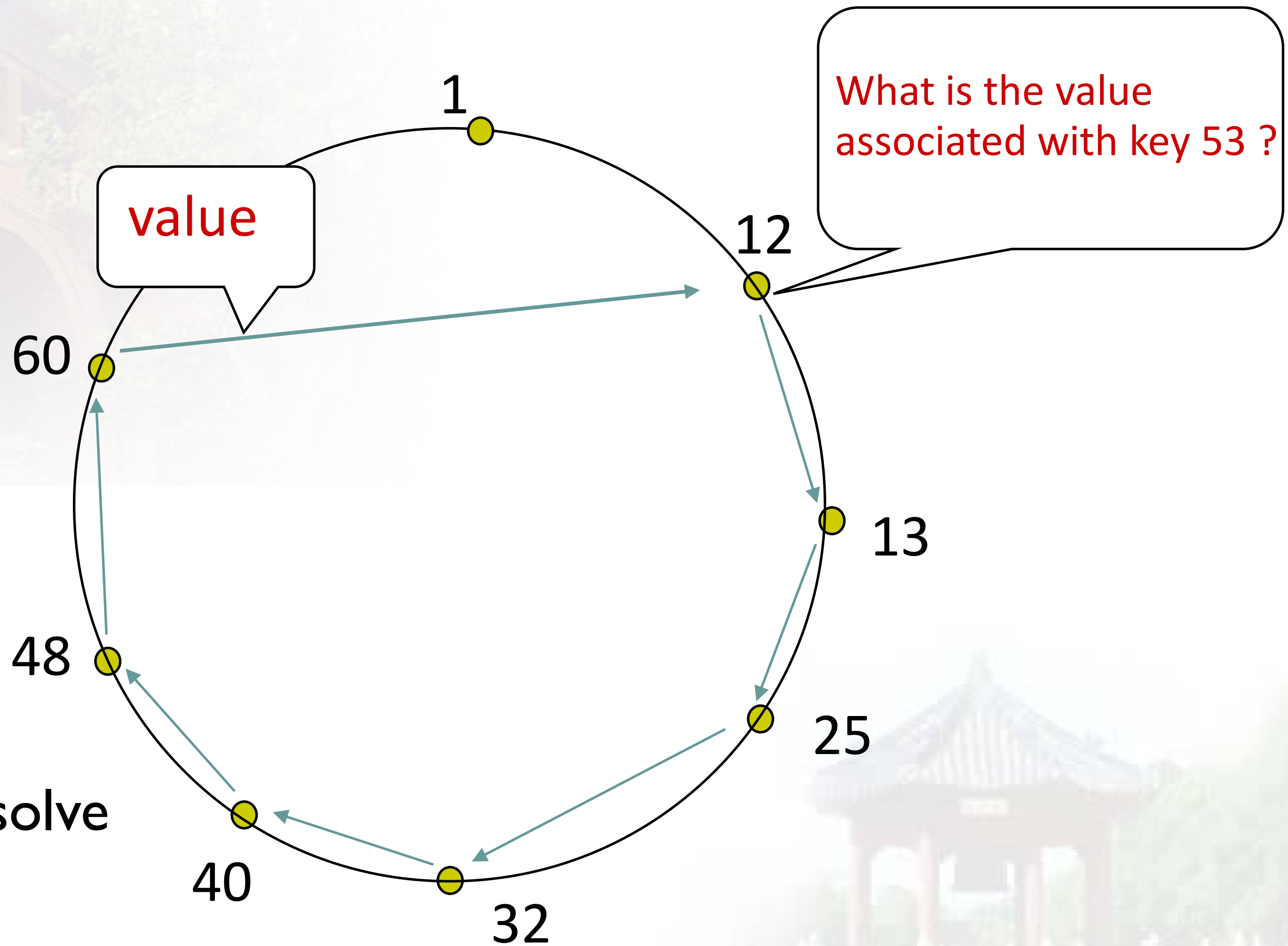
- **each peer *only* aware of immediate successor and predecessor.**





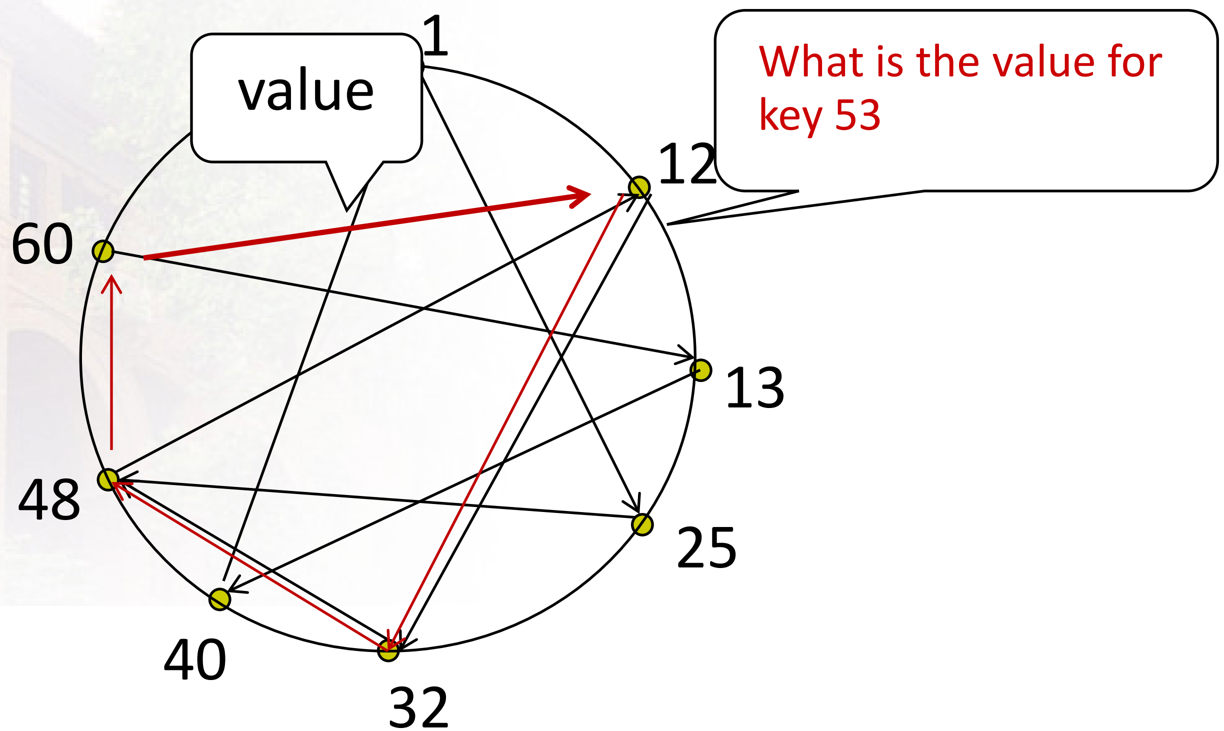
"overlay network"

Resolving a query



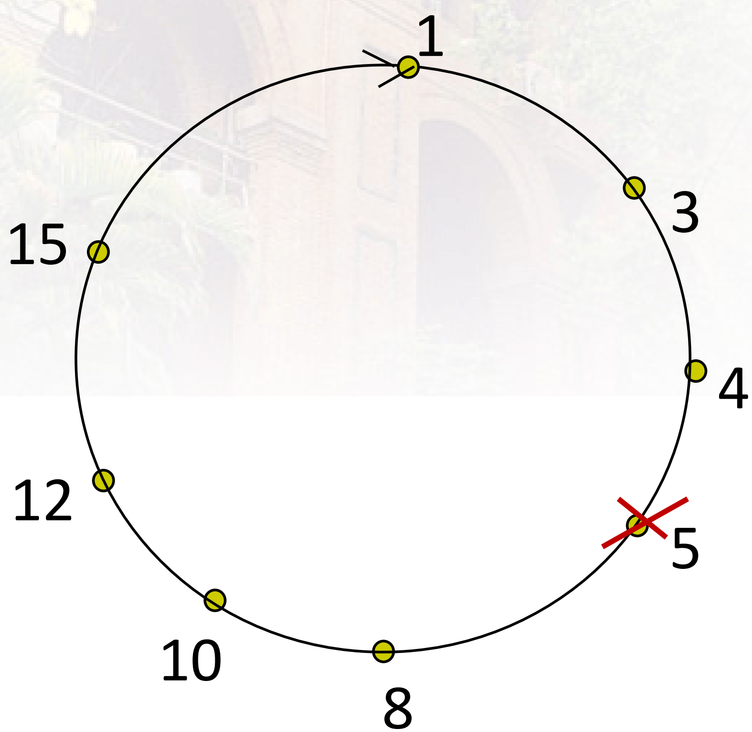
O(*N*) messages
on avgerage to resolve
query, when there
are *N* peers

Circular DHT with shortcuts



- **each peer keeps track of IP addresses of predecessor, successor, short cuts.**
- **reduced from 6 to 3 messages.**
- **possible to design shortcuts with *O(log N)* neighbors, *O(log N)* messages in query**

Peer churn

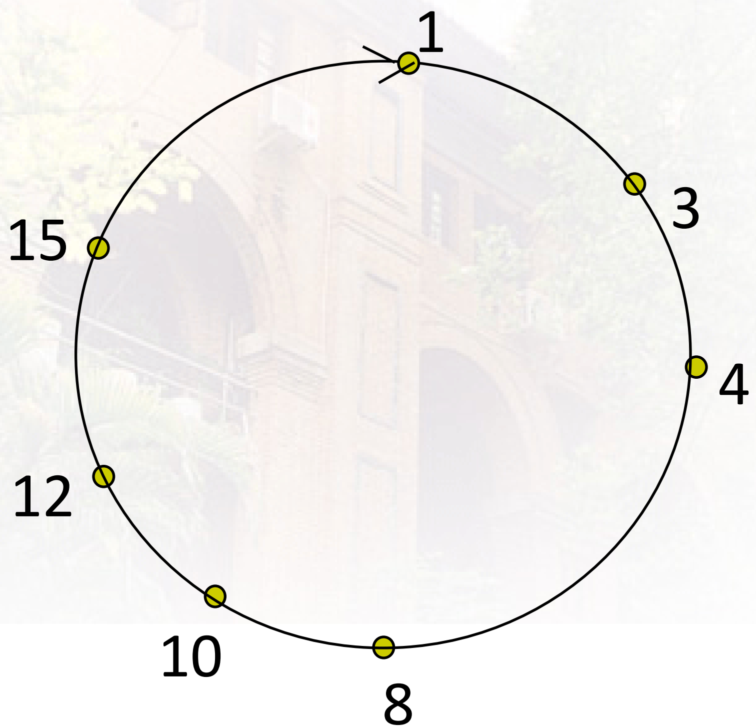


handling peer churn:

- peers may come and go (churn)
- each peer knows address of its two successors
- each peer periodically pings its two successors to check aliveness
- if immediate successor leaves, choose next successor as new immediate successor

example: peer 5 abruptly leaves

Peer churn



handling peer churn:

- peers may come and go (churn)
- each peer knows address of its two successors
- each peer periodically pings its two successors to check aliveness
- if immediate successor leaves, choose next successor as new immediate successor

example: peer 5 abruptly leaves

- **peer 4 detects peer 5's departure; makes 8 its immediate successor**
- **4 asks 8 who its immediate successor is; makes 8's immediate successor its second successor.**

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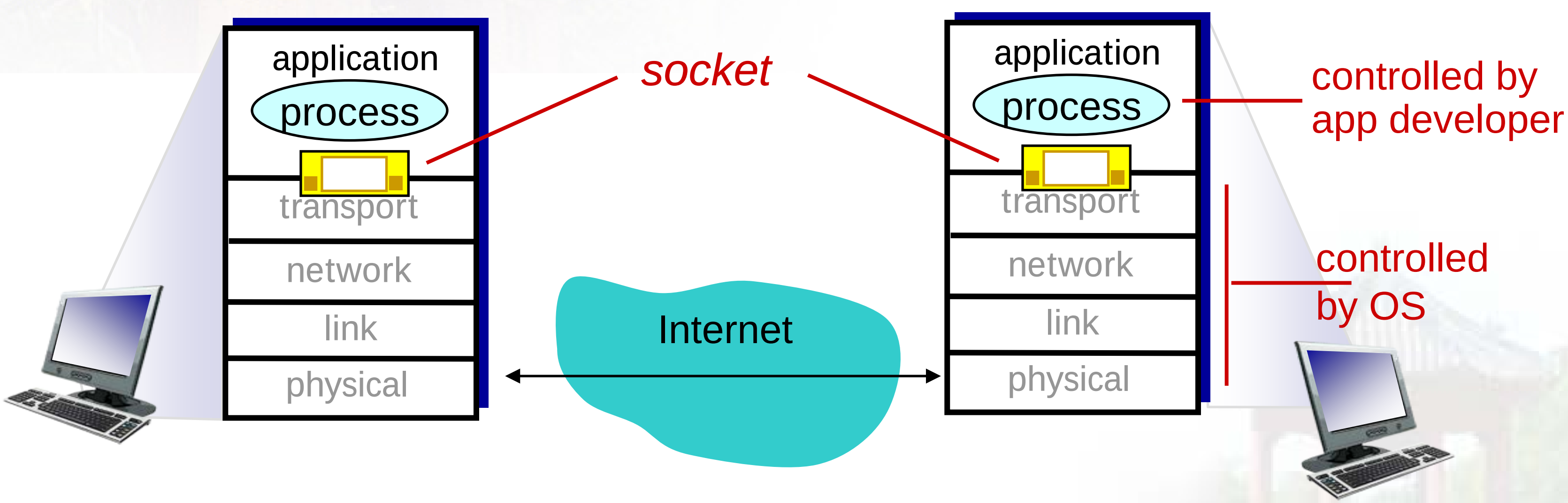
Socket programming

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

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



Socket programming

Two socket types for two transport services:

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

Application Example:

1. Client reads a line of characters (data) from its keyboard and sends the data to the server.
2. The server receives the data and converts characters to uppercase.
3. The server sends the modified data to the client.
4. The client receives the modified data and displays the line on its screen.

Socket programming *with UDP*

UDP: no "connection" between client & server

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

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

Application viewpoint:

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

Client/server socket interaction: UDP

server (running on serverIP)

create socket, port= x:

serverSocket =
socket(AF_INET,SOCK_DGRAM)

read datagram from
serverSocket

write reply to
serverSocket
specifying
client address,
port number

client

create socket:

clientSocket =
socket(AF_INET,SOCK_DGRAM)

Create datagram with server IP and
port=x; send datagram via
clientSocket

read datagram from
clientSocket

close
clientSocket

Example app: UDP client

Python UDPClient

include Python's socket library

create UDP socket for server

get user keyboard input

Attach server name, port to message; send into socket

read reply characters from socket into string

print out received string and close socket

```
from socket import *
serverName = ‘hostname’
serverPort = 12000
clientSocket = socket(socket.AF_INET,
                      socket.SOCK_DGRAM)
message = raw_input(’Input lowercase sentence:’)
clientSocket.sendto(message,(serverName, serverPort))
modifiedMessage, serverAddress =
                      clientSocket.recvfrom(2048)
print modifiedMessage
clientSocket.close()
```

Example app: UDP server

Python UDPServer

create UDP socket

bind socket to local port number 12000

loop forever

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

send upper case string back to this client

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET, SOCK_DGRAM)
serverSocket.bind(('', serverPort))
print "The server is ready to receive"
while 1:
    message, clientAddress = serverSocket.recvfrom(2048)
    modifiedMessage = message.upper()
    serverSocket.sendto(modifiedMessage, clientAddress)
```

Socket programming *with TCP*

client must contact server

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

client contacts server by:

- Creating TCP socket, specifying IP address, port number of server process
- ***when client creates socket:*** client TCP establishes connection to server TCP

- when contacted by client, ***server TCP creates new socket*** for server process to communicate with that particular client
  - allows server to talk with multiple clients
  - source port numbers used to distinguish clients (more in Chap 3)

application viewpoint:

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

Client/server socket interaction: TCP

server (running on **hostid**)

create socket,
port=**x**, for incoming
request:
serverSocket = socket()

wait for incoming
connection request
connectionSocket =
serverSocket.accept()

TCP
connection setup

read request from
connectionSocket

write reply to
connectionSocket

close
connectionSocket

client

create socket,
connect to **hostid**, port=**x**
clientSocket = socket()

send request using
clientSocket

read reply from
clientSocket

close
clientSocket

Example app: TCP client

Python TCPClient

create TCP socket for server, remote port 12000

No need to attach server name, port

```
from socket import *
serverName = ’servername’
serverPort = 12000
clientSocket = socket(AF_INET, SOCK_STREAM)
clientSocket.connect((serverName,serverPort))
sentence = raw_input(‘Input lowercase sentence:’)
clientSocket.send(sentence)
modifiedSentence = clientSocket.recv(1024)
print ‘From Server:’, modifiedSentence
clientSocket.close()
```

Example app: TCP server

Python TCPServer

create TCP welcoming socket

server begins listening for incoming TCP requests

loop forever

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

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

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

```
from socket import *
serverPort = 12000
serverSocket = socket(AF_INET,SOCK_STREAM)
serverSocket.bind((‘’,serverPort))
serverSocket.listen(1)
print ‘The server is ready to receive’
while 1:
    connectionSocket, addr = serverSocket.accept()

    sentence = connectionSocket.recv(1024)
    capitalizedSentence = sentence.upper()
    connectionSocket.send(capitalizedSentence)
    connectionSocket.close()
```

Chapter 2: summary

our study of network apps now complete!

- **application architectures**
  - **client-server**
  - **P2P**
- **application service requirements:**
  - **reliability, bandwidth, delay**
- **Internet transport service model**
  - **connection-oriented, reliable: TCP**
  - **unreliable, datagrams: UDP**

- specific protocols:
  - HTTP
  - FTP
  - SMTP, POP, IMAP
  - DNS
  - P2P: BitTorrent, DHT
- socket programming: TCP, UDP sockets

Chapter 2: summary

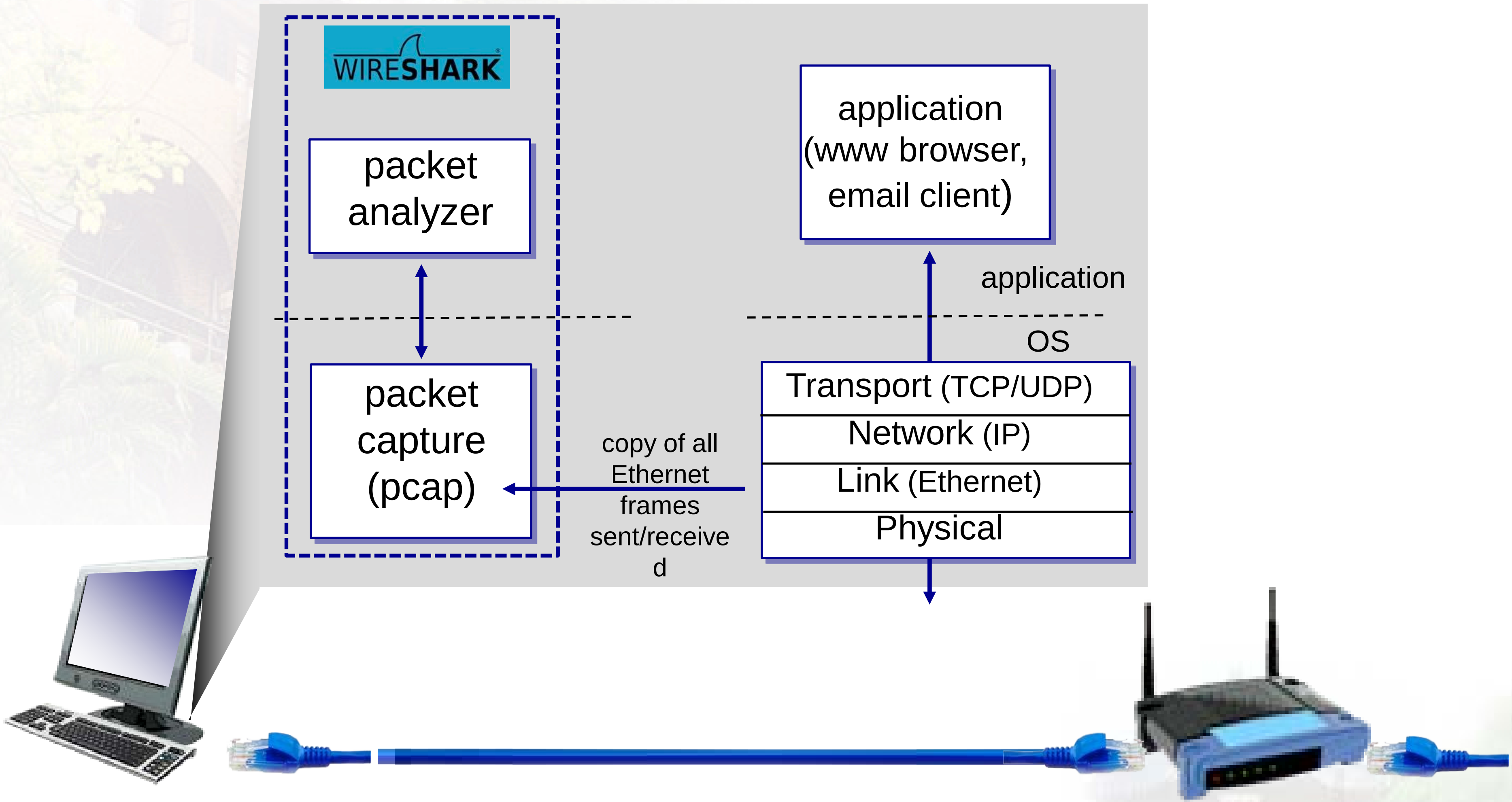
most importantly: learned about protocols!

- **typical request/reply message exchange:**
  - **client requests info or service**
  - **server responds with data, status code**
- **message formats:**
  - **headers: fields giving info about data**
  - **data: info being communicated**

important themes:

- control vs. data msgs
  - in-band, out-of-band
- centralized vs. decentralized
- stateless vs. stateful
- reliable vs. unreliable msg transfer
- "complexity at network edge"

Chapter 2
Additional Slides



WIRESHARK
packet analyzer
packet capture (pcap)
copy of all Ethernet frames sent/receive d
application (www browser, email client)
application
OS
Transport (TCP/UDP)
Network (IP)
Link (Ethernet)
Physical

Quiz for Chapter 2

- Many Web sites use cookies. List the four components
- What's iterated query and recursive query?
- What's the difference between HTTP and FTP, besides their default port number and protocol commands and return codes?
- How to insert records into DNS? How do people get IP address of your Web site?
- What's "optimistically unchoke" in P2P networks?
- What‘s the POP3 modes and their weakness?

- How do they connect to each other when both Alice and Bob are behind “NATs"?
- What's the difference between TCP and UDP socket programming?
- UDP service:
  - - unreliable data transfer between sending and receiving process
  - - does not provide: connection setup, reliability, flow control, congestion control, timing, throughput guarantee, or security
  - Q: why bother? Why is there a UDP?
- What's the goal of web caches (proxy server), how it works?

- **Why Web caching? What's it's advantage?**
- **What's a Torrent in BitTorrent? How many torrent does Alice need to join when she wants to download 3 files?**
- **Why not centralize DNS?**
- **A user requests a web page that consists of some text and 4 images. For this page, the client will send ______ HTTP request messages and ______ HTTP response messages.**
- **To receive messages, process must have identifier. What's the identifier?**
  - **IP? Port? IP+Port? Domain name?**

- **What transport service does an app need?**
  - **Data loss? Timing? Throughput? Security?**
- **Users write programs that run on (different) end systems, communicate over network. No need to write software for network-core devices.**
  - **True ? Or False?**

The End of Chapter 2