Chapter 6 Application Layer

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Chapter 6: Application layer

- 6.1 Principles of network applications
- 6.2 Web and HTTP
- 6.3 FTP
- 6.4 Electronic Mail
  - SMTP, POP3, IMAP
- 6.5 DNS
- 6.6 P2P file sharing
- 6.7 Socket programming with TCP
- 6.8 Socket programming with UDP

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
- programming network applications
  - socket API

Some network apps

- E-mail
- Web
- Instant messaging
- Remote login
- P2P file sharing
- Multi-user network games
- Streaming stored video clips
- Internet telephone
- Real-time video conference
- Massive parallel computing
-
-
-

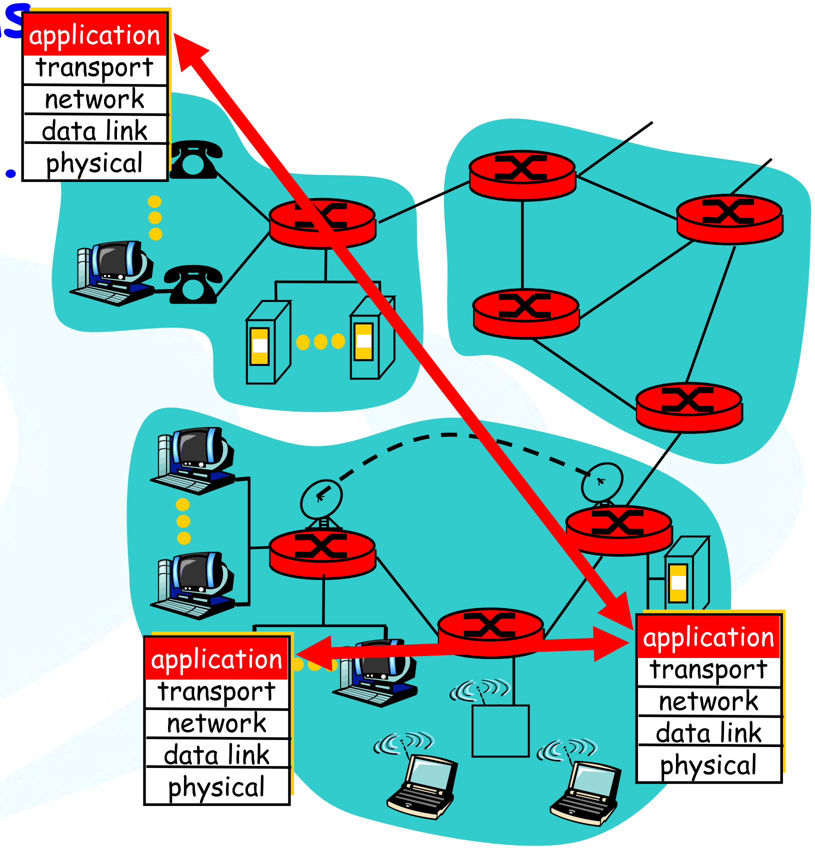
Creating a network app

Write programs that

- run on different end systems and
- communicate over a network.
- e.g., Web: Web server software communicates with browser software

little software written for devices in network core

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

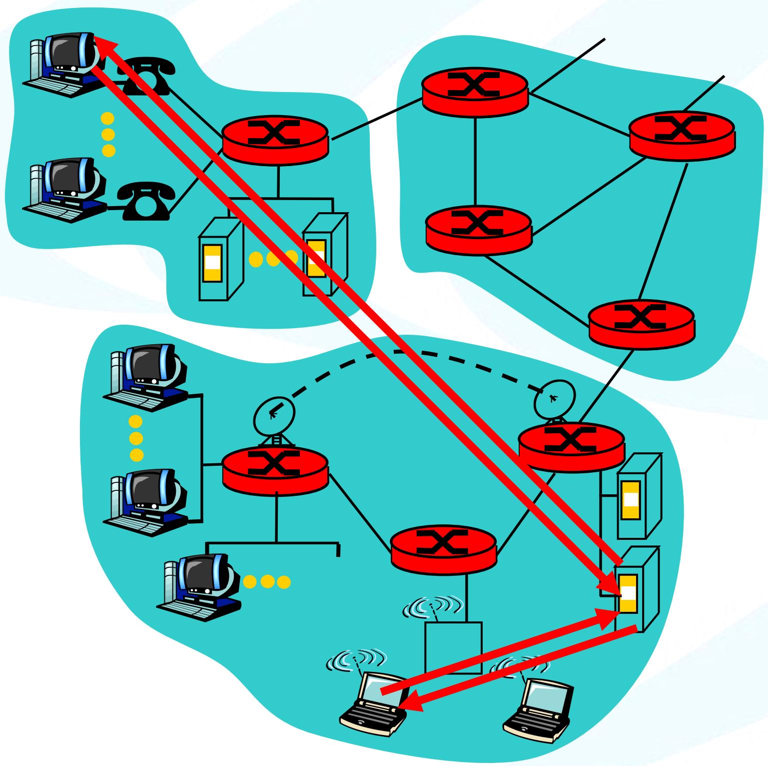


6.1 Principles of network applications

Application architectures

- Client-server
- Peer-to-peer (P2P)
- Hybrid of client-server and P2P

Client-server architecture

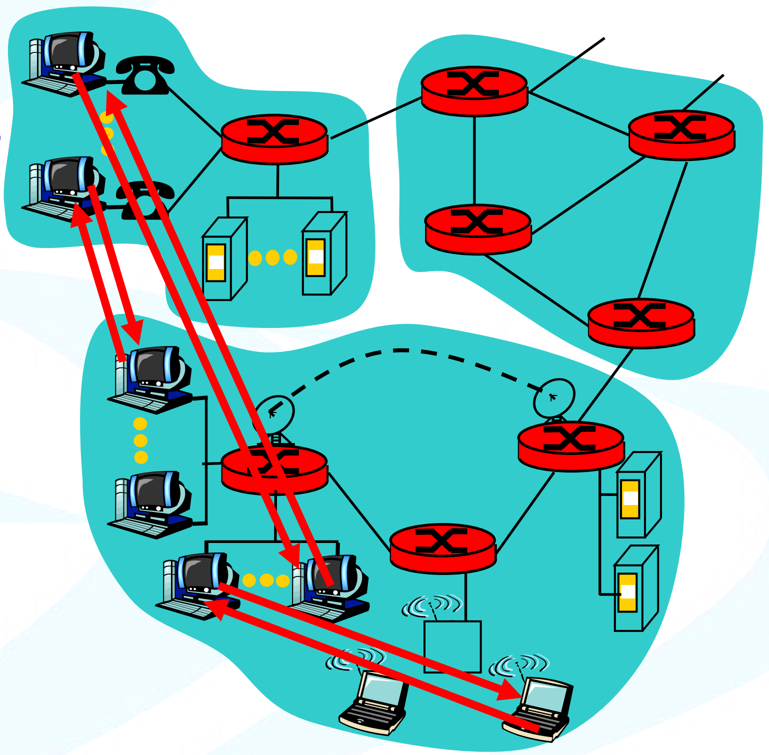


server:
- always-on host
- permanent IP address
- server farms for scaling

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

Pure P2P architecture

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



Highly scalable
But difficult to manage

Hybrid of client-server and P2P

Napster
- File transfer P2P
- File search centralized:
  - Peers register content at central server
  - Peers query same central server to locate content

Instant messaging
- Chatting between two users is P2P
- Presence detection/location centralized:
  - User registers its IP address with central server when it comes online
  - User contacts central server to find IP addresses of buddies

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**

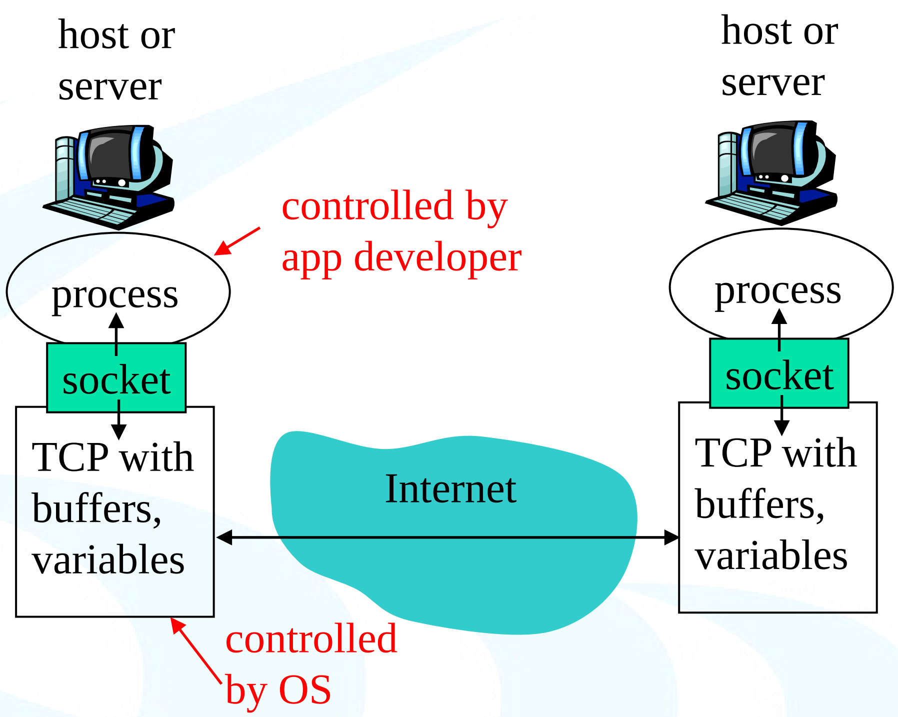
Client process: process that initiates communication

Server process: process that waits to be contacted

- Note: applications with P2P architectures have client processes & server processes

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 which brings message to socket at receiving process



- **API: (1) choice of transport protocol; (2) ability to fix a few parameters (lots more on this later)**

Addressing processes

- For a process to receive messages, it must have an identifier
- A host has a unique32-bit IP address
- Q: does the IP address of the host on which the process runs suffice for identifying the process?
- Answer: No, many processes can be running on same host
- Identifier includes both the IP address and port numbers associated with the process on the host.
- Example port numbers:
  - HTTP server: 80
  - Mail server: 25
- More on this later

App-layer protocol defines

- Types of messages exchanged, e.g., request & response messages
- Syntax of message types: what fields in messages & how fields are delineated
- Semantics of the fields, i.e., meaning of information in fields
- Rules for when and how processes send & respond to messages

Public-domain protocols:
- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

Proprietary protocols:
- e.g., KaZaA

What transport service does an app need?

Data loss

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

Timing

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

Bandwidth

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

Transport service requirements of common apps

Application	Data loss	Bandwidth	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
instant messaging	no loss	elastic	yes and no

Internet transport protocols services

TCP service:

- *connection-oriented:* setup required between client and server processes
- *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 bandwidth guarantees

UDP service:

- unreliable data transfer between sending and receiving process
- does not provide: connection setup, reliability, flow control, congestion control, timing, or bandwidth guarantee

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	proprietary (e.g. RealNetworks)	TCP or UDP
Internet telephony	proprietary (e.g., Vonage,Dialpad)	typically UDP

6.2 Web and HTTP

Web and HTTP

First some jargon

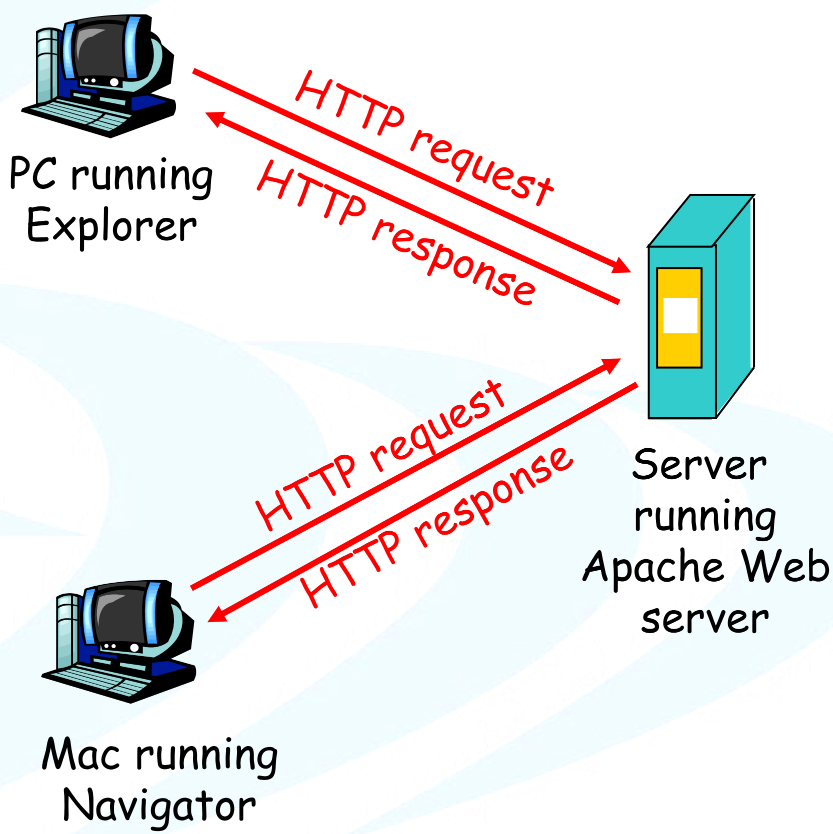
- Web page consists of objects
- Object can be HTML file, JPEG image, Java applet, audio file,…
- Web page consists of base HTML-file which includes several referenced objects
- Each object is addressable by a URL
- Example URL:

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

HTTP overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server model
  - *client:* browser that requests, receives, "displays" Web objects
  - *server:* Web server sends objects in response to requests
- HTTP 1.0: RFC 1945
- HTTP 1.1: RFC 2068



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

time

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

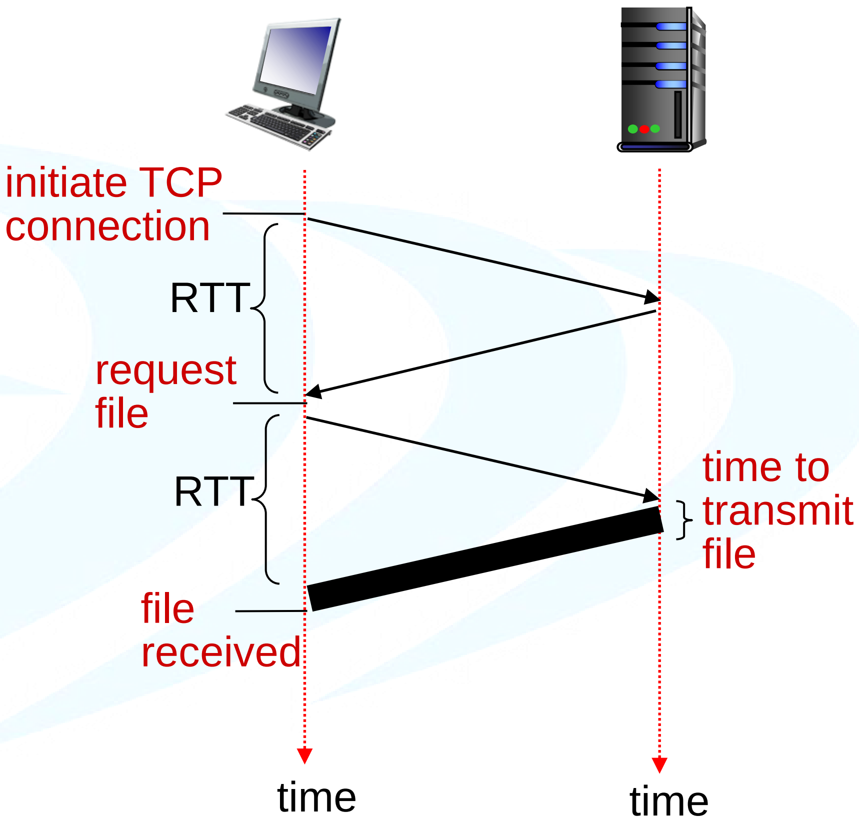
Non-persistent HTTP: response time

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**

HTTP request message

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

request line (GET, POST, HEAD commands)

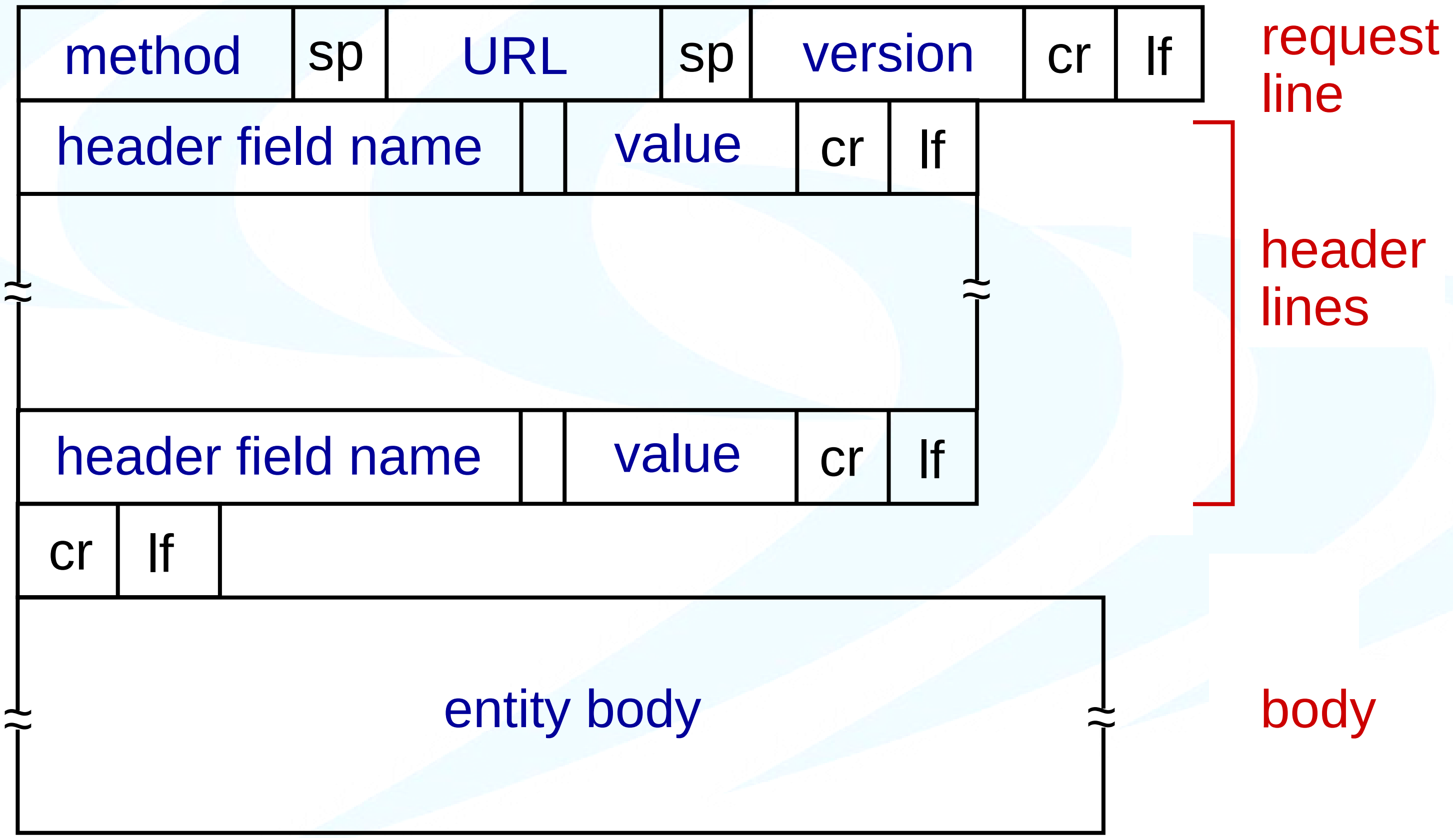
```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language:fr
```

header lines

(extra carriage return, line feed)

Carriage return, line feed indicates end of message

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
Connection close
Date: Thu, 06 Aug 1998 12:00:15 GMT
Server: Apache/1.3.0 (Unix)
Last-Modified: Mon, 22 Jun 1998 …...
Content-Length: 6821
Content-Type: text/html

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

User-server state: cookies

Many major Web sites use cookies

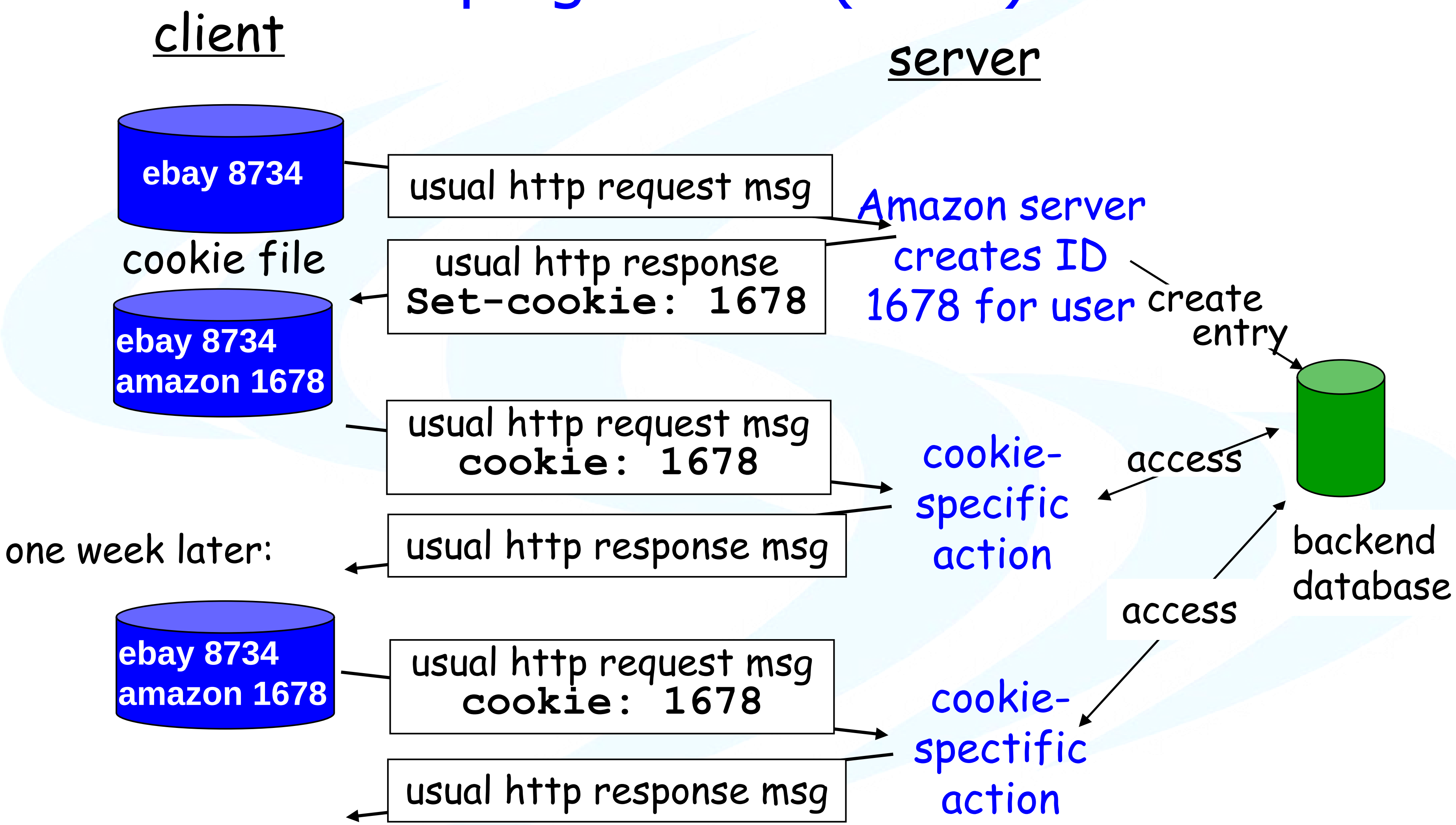
Four components:

1) cookie header line of HTTP *response* message
2) cookie header line in 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 access Internet always from same PC
- She visits a specific e-commerce site for first time
- When initial HTTP requests arrives at site, site creates a unique ID and creates an 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

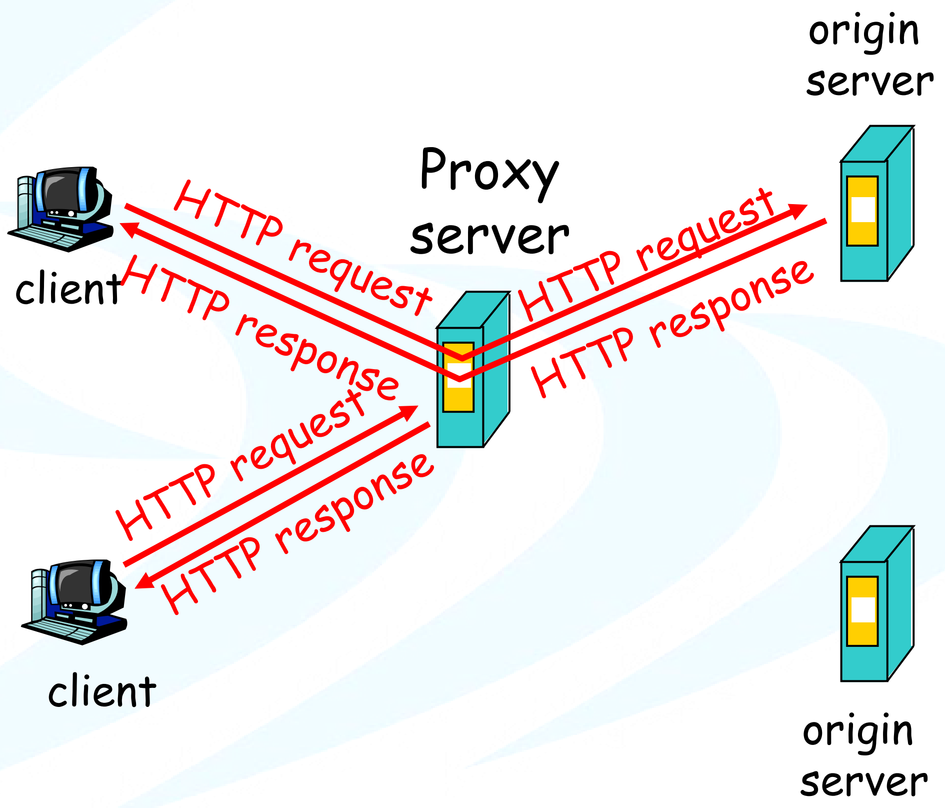
How to keep "state":

- 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)

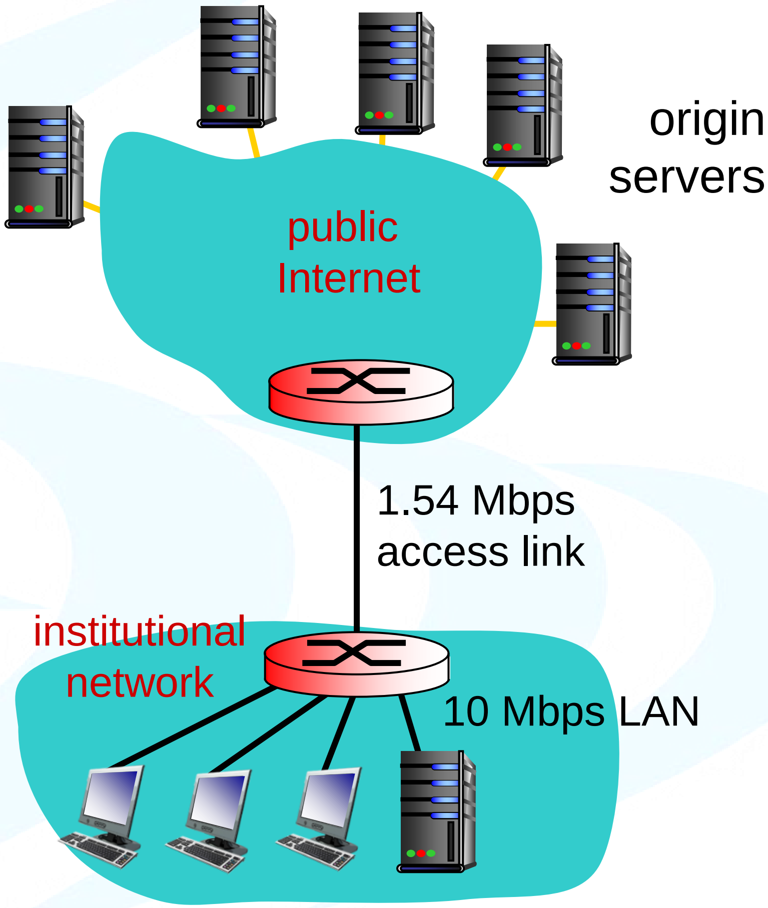
Caching example:

assumptions:

- avg object size: 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: *problem!*

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



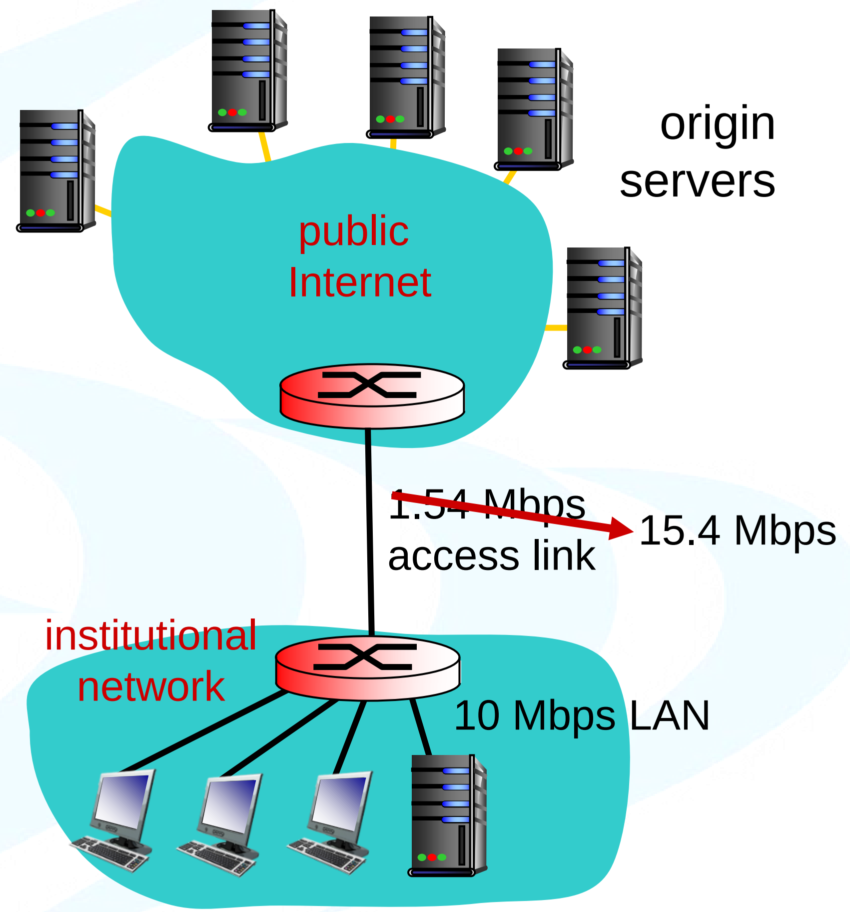
Caching example: fatter access link

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~~ 15.4 Mbps

consequences:

- LAN utilization: 15%
- access link utilization = ~~99%~~ 9.9%
- 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

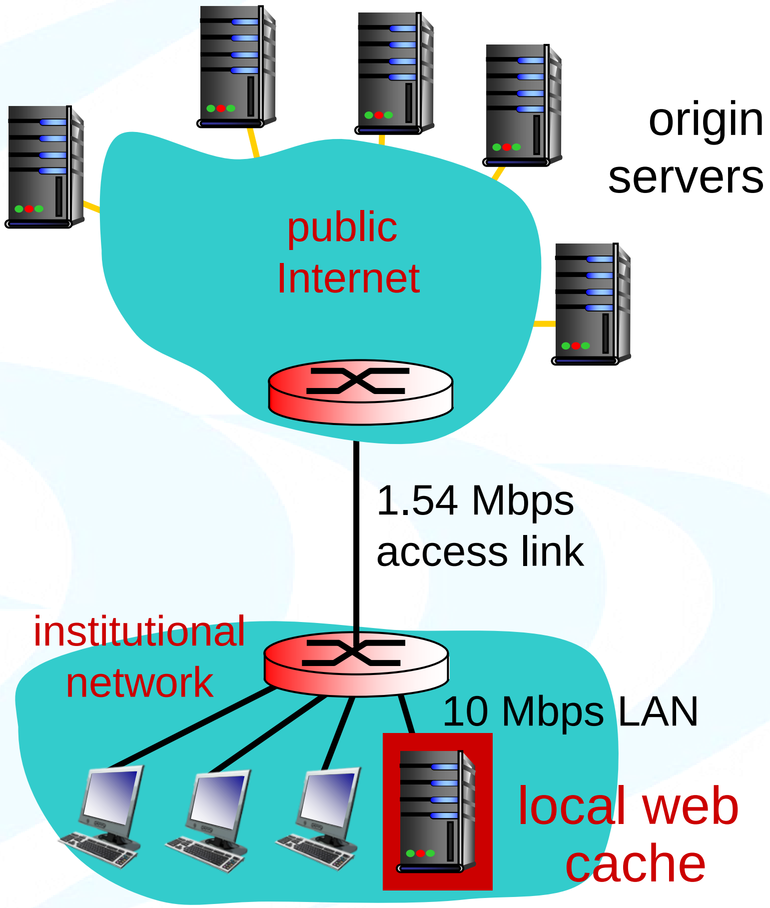
assumptions:

- 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:

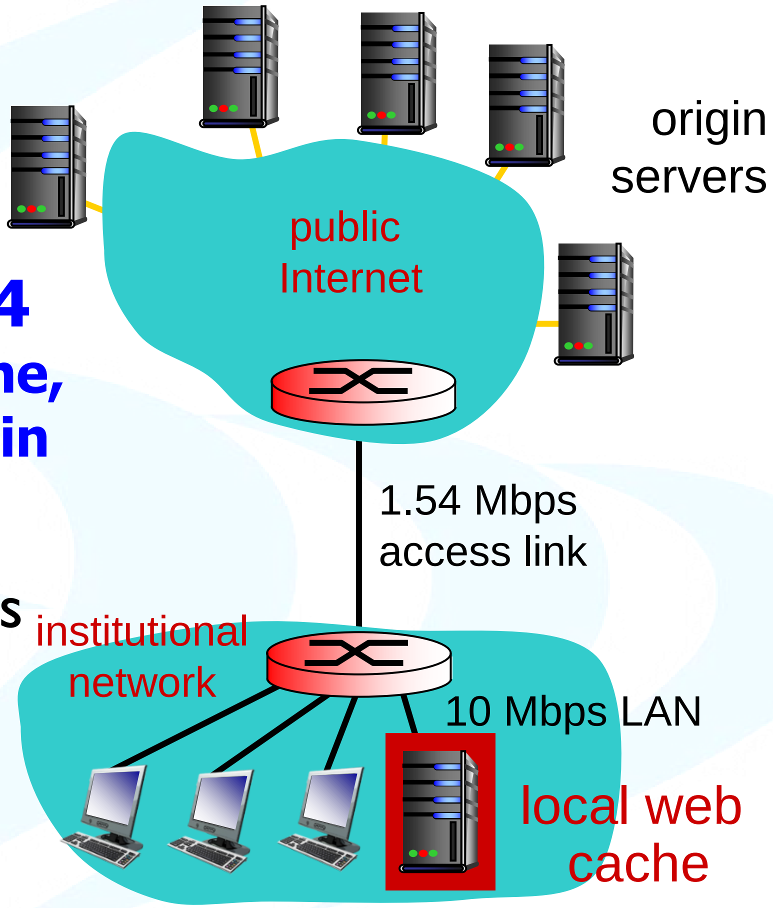
- LAN utilization: 15%
- access link utilization = ?
- total delay = ?

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**

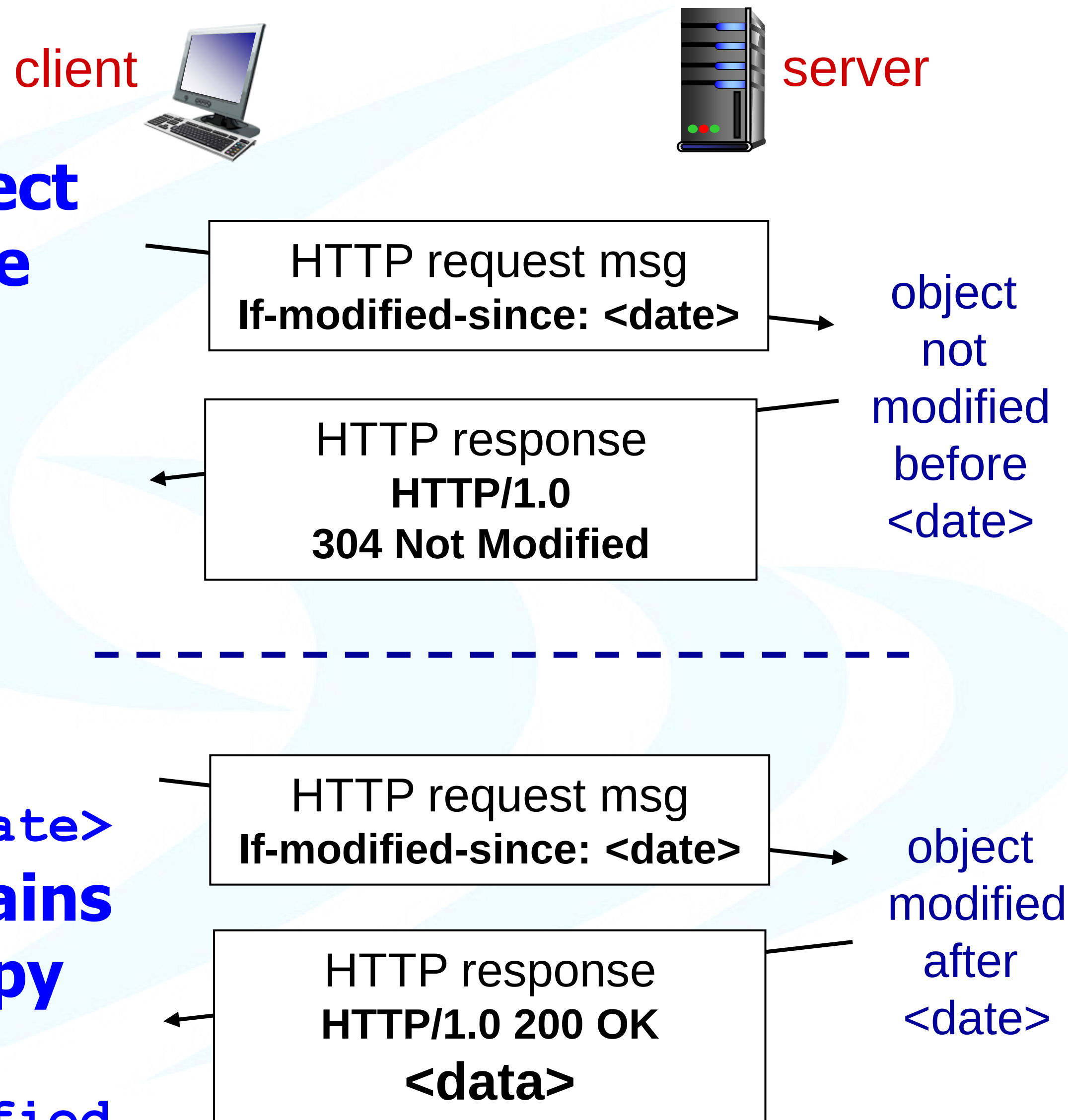
- access link utilization:
  - 60% of requests use access link
- data rate to browsers over access link
  = 0.6*1.50 Mbps = .9 Mbps
  - utilization = 0.9/1.54 = .58
- total delay
  - = 0.6 * (delay from origin servers) +0.4 * (delay when satisfied at cache)
  - = 0.6 (2.01) + 0.4 (~msecs) = ~ 1.2 secs
  - less than with 15.4 Mbps 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

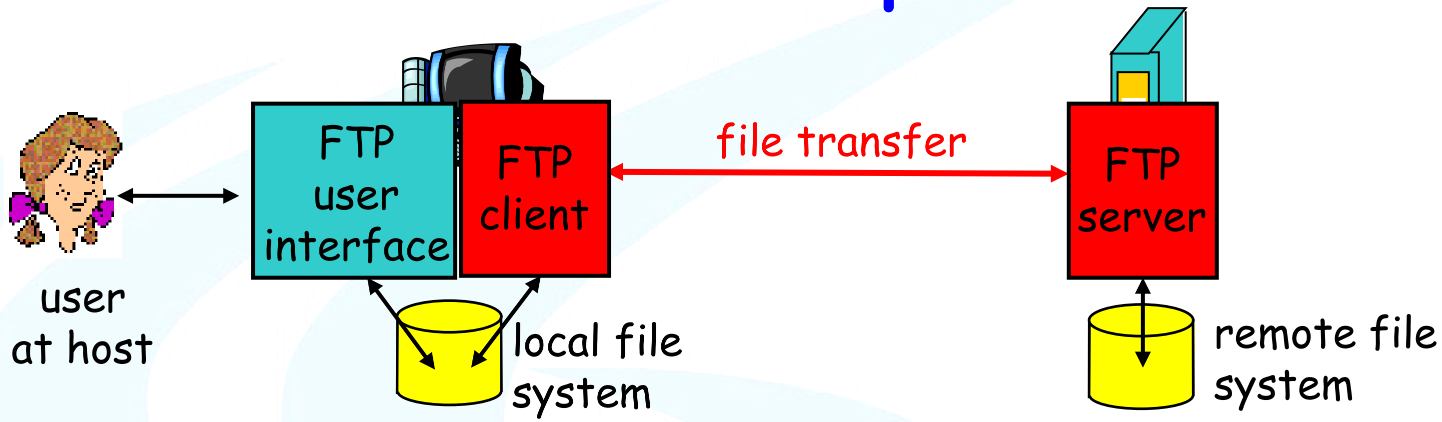
  `If-modified-since: <date>`
- *server:* response contains no object if cached copy is up-to-date:

  `HTTP/1.0 304 Not Modified`



6.3 FTP

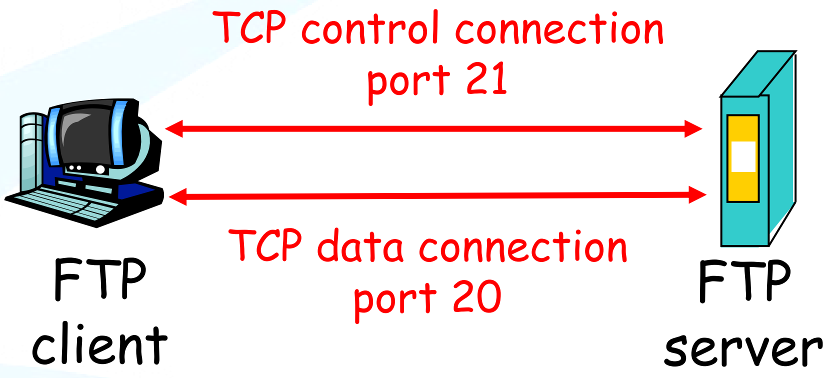
FTP: the file transfer protocol



- 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, specifying TCP as transport protocol
- Client obtains authorization over control connection
- Client browses remote directory by sending commands over control connection.
- When server receives a command for a file transfer, the server opens a TCP data connection to client
- After transferring one file, server closes connection.



- Server opens a second 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

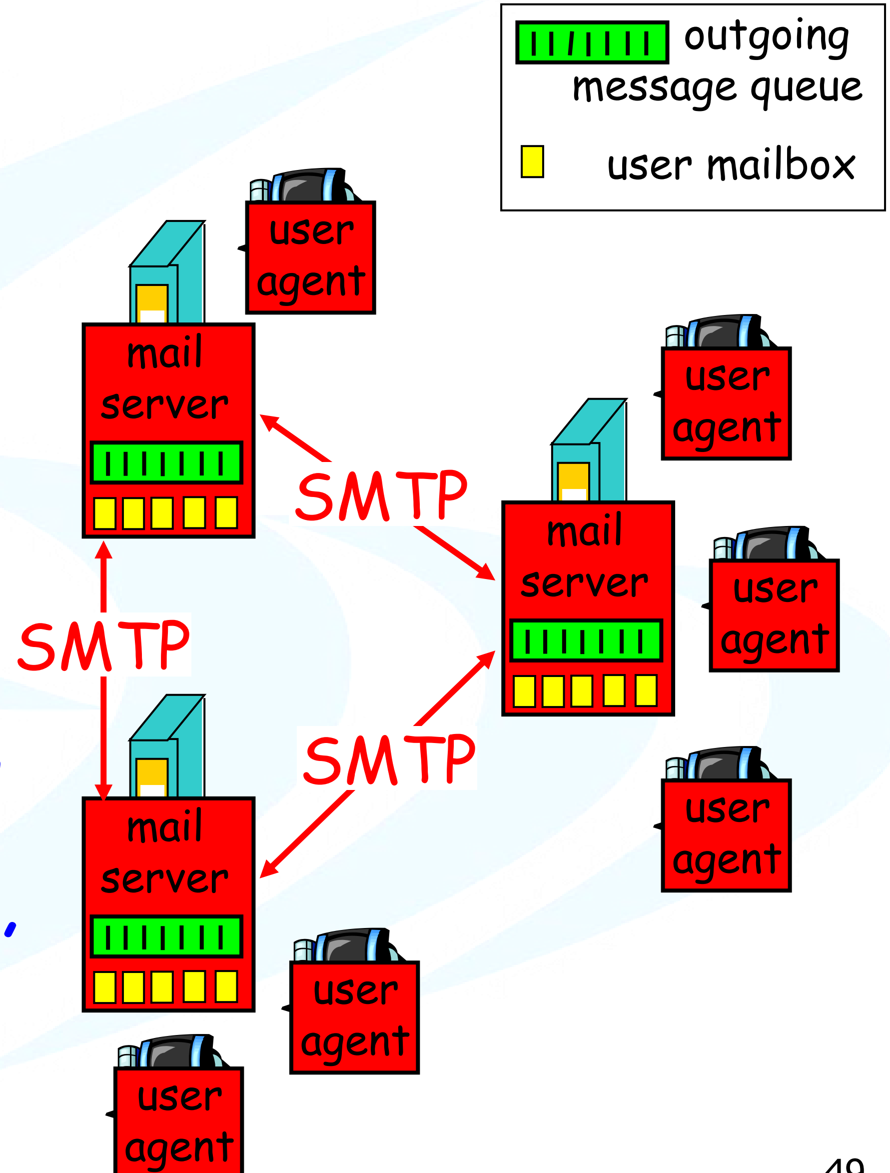
6.4 Electronic Mail
SMTP, POP3, IMAP

Electronic Mail

Three major components:
- user agents
- mail servers
- simple mail transfer protocol: SMTP

- User Agent

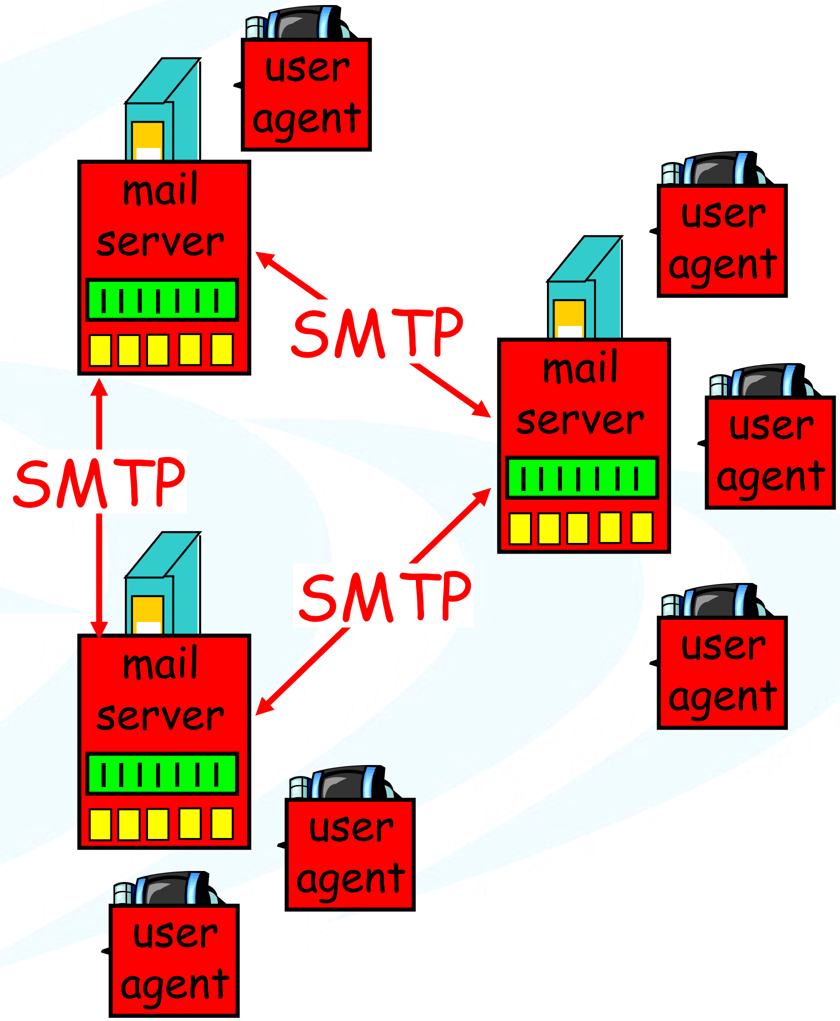
- a.k.a. "mail reader"
- composing, editing, reading mail messages
- e.g., Eudora, Outlook, elm, Netscape Messenger
- outgoing, incoming messages stored on server



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

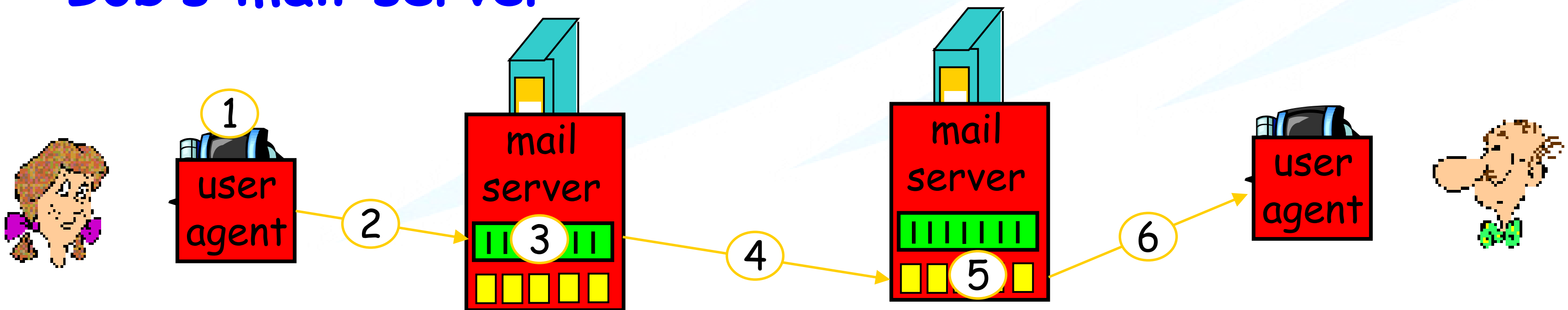


Electronic Mail: SMTP [RFC 2821, RFC5321]

- 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
  - commands: ASCII text
  - response: status code and phrase
- messages must be in 7-bit ASCII

Scenario: Alice sends message to Bob

1) Alice uses UA to compose message and "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 message**
- **SMTP: multiple objects sent in multipart message**

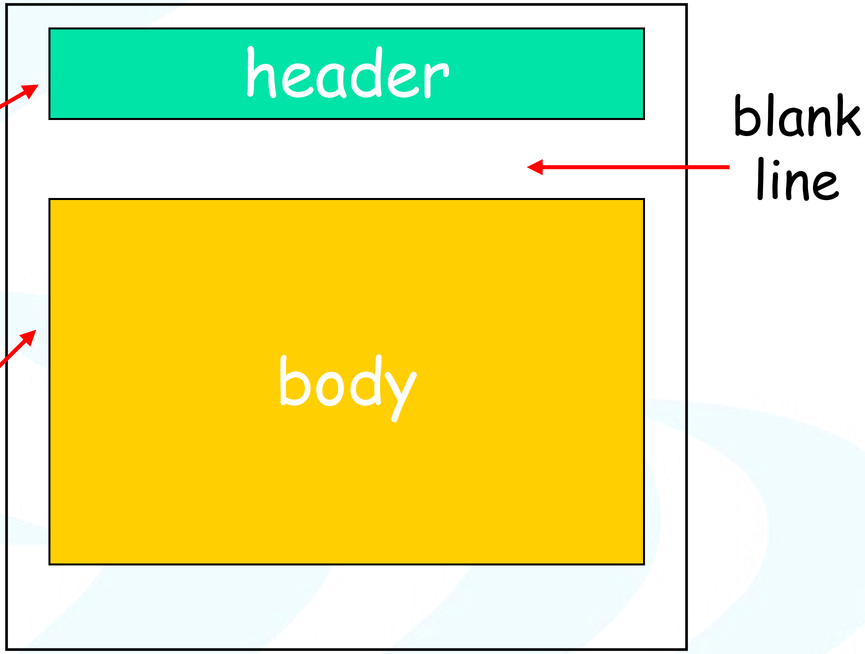
Mail message format

SMTP: protocol for exchanging email msgs

RFC 5322: standard for text message format:

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

  different from SMTP commands!
- body
  - the "message", ASCII characters only



Message format: multimedia extensions

- **MIME: multimedia mail extension, RFC 2045, 2056**
- **additional lines in msg header declare MIME content type**

MIME version

method used to encode data

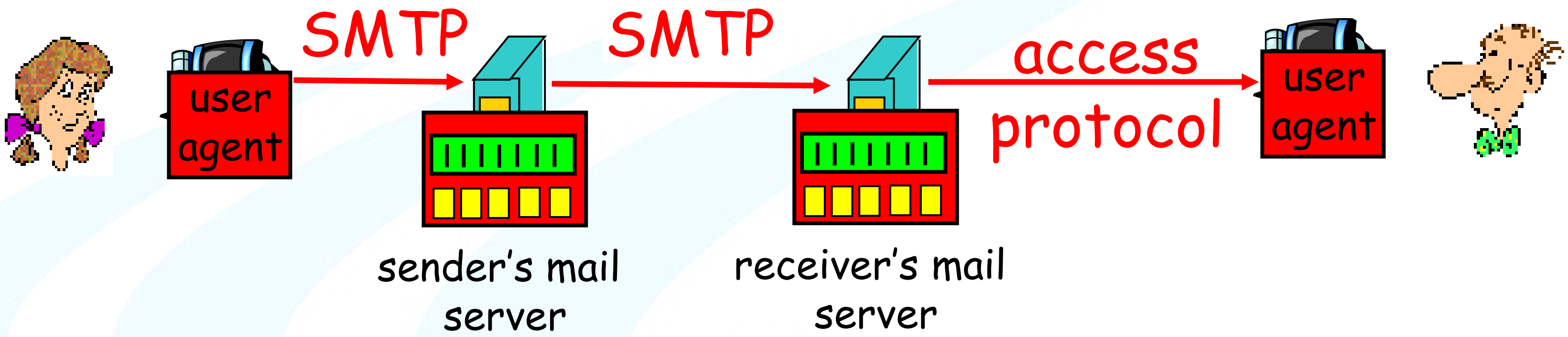
multimedia data type, subtype, parameter declaration

encoded data

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
```

Mail access protocols



- SMTP: delivery/storage to receiver's server
- Mail access protocol: retrieval from server
  - POP: Post Office Protocol [RFC 1939]
    - authorization (agent <-->server) and download
  - IMAP: Internet Mail Access Protocol [RFC 1730]
    - more features (more complex)
    - manipulation of stored msgs on server
  - HTTP: 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 “download and delete” mode.
- Bob cannot re-read e-mail if he changes client
- “Download-and-keep”: copies of messages on different clients
- POP3 is stateless across sessions

IMAP

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

6.5 DNS

DNS: Domain Name System

People: many identifiers:

- SSN, name, passport #

Internet hosts, routers:

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

Q: map between IP addresses and name ?

Domain Name System:

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

DNS services

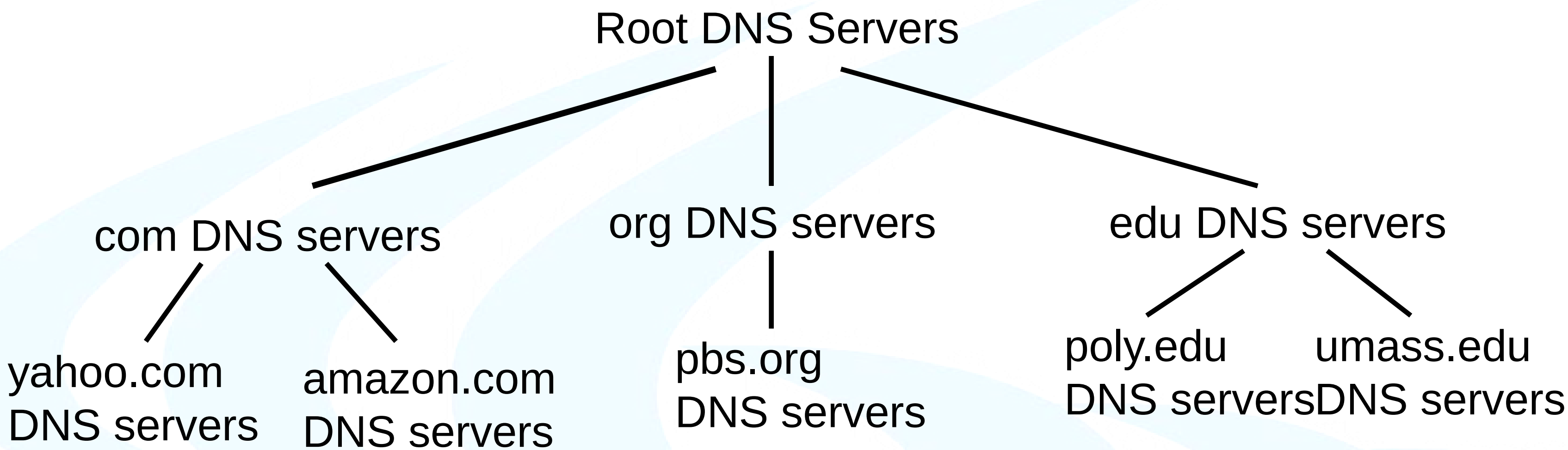
- Hostname to IP address translation
- Host aliasing
  - Canonical and alias names
- Mail server aliasing
- Load distribution
  - Replicated Web servers: set of IP addresses for one canonical name

Why not centralize DNS?

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

doesn't *scale!*

Distributed, Hierarchical Database

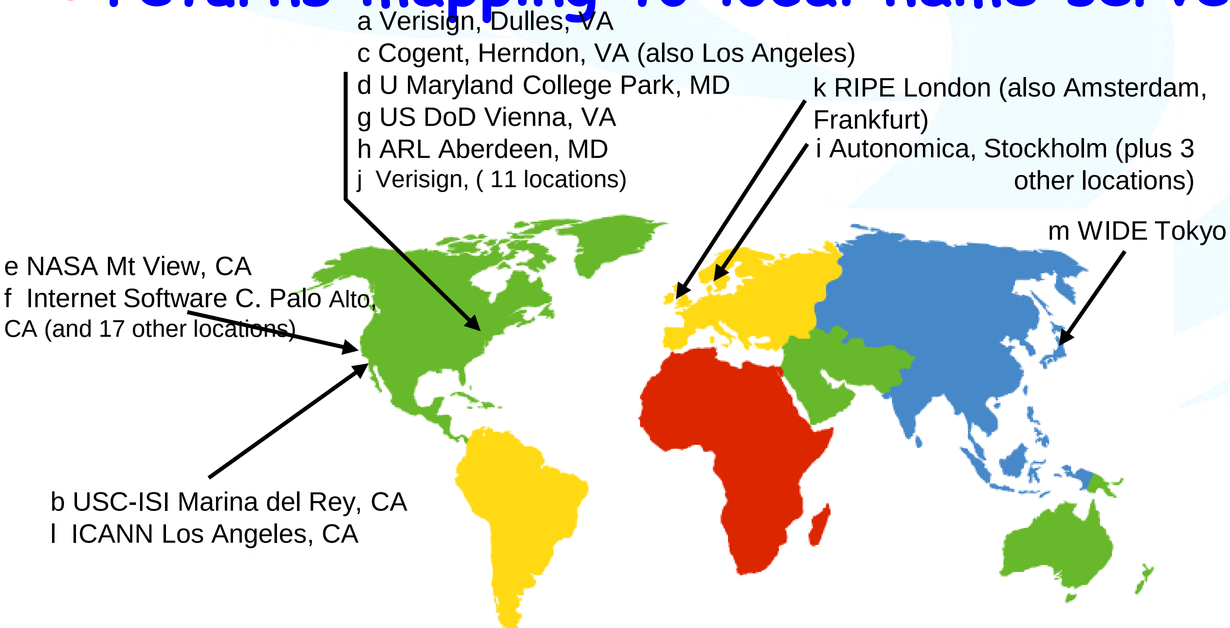


Client wants IP for www.amazon.com; 1st approx:

- Client queries a 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 and Authoritative Servers

- Top-level domain (TLD) servers: responsible for com, org, net, edu, etc, and all top-level country domains uk, fr, ca, jp.
  - Network solutions maintains servers for com TLD
  - Educause for edu TLD
- Authoritative DNS servers: organization's DNS servers, providing authoritative hostname to IP mappings for organization's servers (e.g., Web and mail).
  - Can be maintained by organization or service provider

Local Name Server

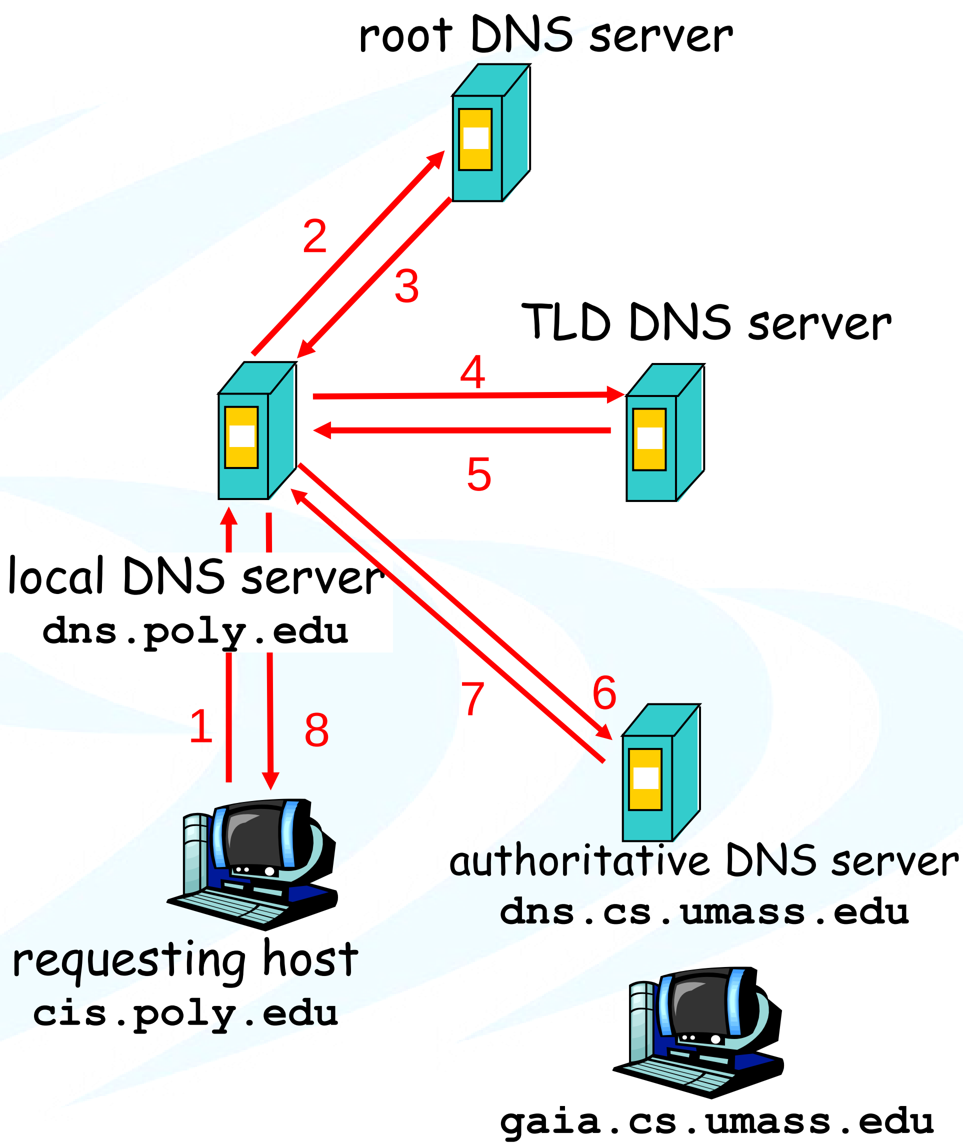
- Does not strictly belong to hierarchy
- Each ISP (residential ISP, company, university) has one.
  - Also called “default name server”
- When a host makes a DNS query, query is sent to its local DNS server
  - Acts as a proxy, forwards query into hierarchy.

Example

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

iterated query:

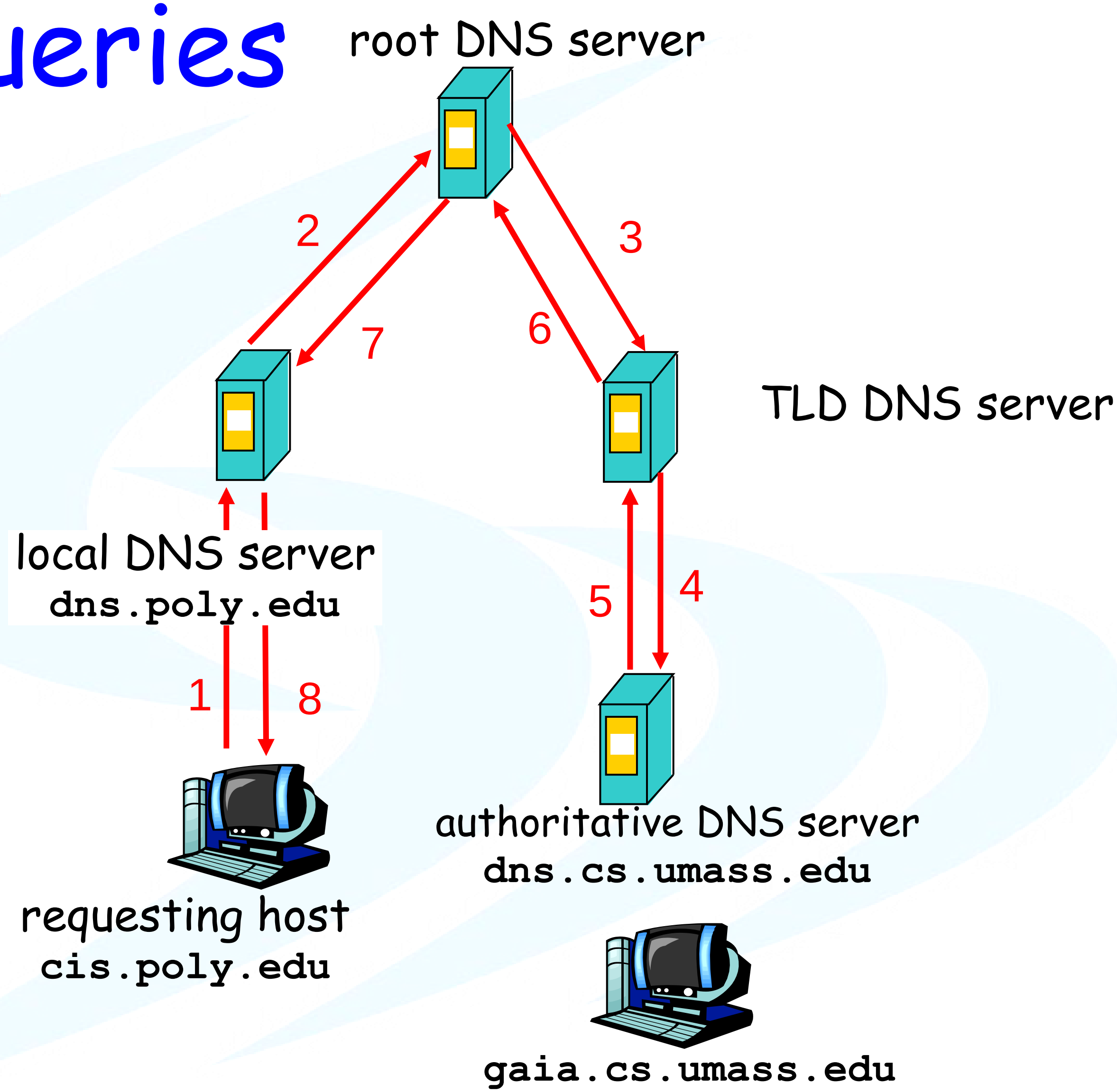
- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"



Recursive queries

recursive query:

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



DNS: caching and updating records

- once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time
  - TLD servers typically cached in local name servers
    - Thus root name servers not often visited
- update/notify mechanisms under design by IETF
  - RFC 2136
  - http://www.ietf.org/html.charters/dnsind-charter.html

DNS服务器： DNS7.HICHINA.COM DNS8.HICHINA.COM

记录类型	主机记录	解析线路	记录值	MX优先级	TTL
A	offlinedownloadstorage	默认	219.216.110.88	--	10分钟
A	vm.team	默认	219.216.110.88	--	10分钟
A	mongodb.team	默认	219.216.110.88	--	10分钟

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

A	offlinedownl	默认	219.216.110.88

搭建网站：要将域名指向主机服务商提供的IP地址，请选择「A记录」；要将域名指向主机服务商提供的另一个
建立邮箱：需要设置「MX记录」，根据邮箱服务商提供的MX记录填写。

A记录：将域名指向一个IPv4地址（例如：10.10.10.10），需要增加A记录
CNAME记录：如果将域名指向一个域名，实现与被指向域名相同的访问效果，需要增加CNAME记录
MX记录：建立电子邮箱服务，将指向邮件服务器地址，需要设置MX记录
NS记录：域名解析服务器记录，如果要将子域名指定某个域名服务器来解析，需要设置NS记录
TXT记录：可任意填写（可为空），通常用做SPF记录（反垃圾邮件）使用
AAAA记录：将主机名（或域名）指向一个IPv6地址（例如：ff03:0:0:0:0:0:0:c1），需要添加AAAA记录
SRV记录：记录了哪台计算机提供了哪个服务。格式为：服务的名字.协议的类型（例如：_example-server._tc
显性URL：将域名指向一个http（s)协议地址，访问域名时，自动跳转至目标地址（例如：将www.net.cn显性
隐性URL：与显性URL类似，但隐性转发会隐藏真实的目标地址（例如：将www.net.cn隐性转发到www.hichi

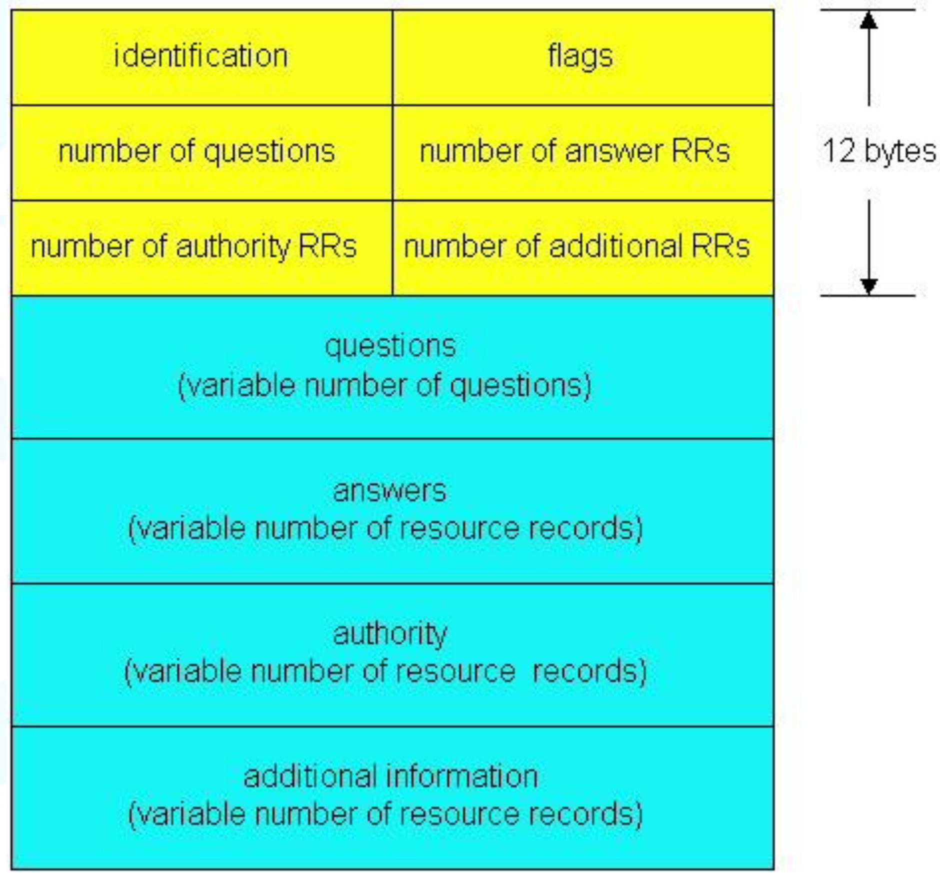
CNAME	smtp	默认	smtp.mxhichina.com
CNAME	mail	默认	mail.mxhichina.com
CNAME	pop3	默认	pop3.mxhichina.com
MX	@	默认	mxw.mxhichina.com
MX	@	默认	mxn.mxhichina.com

DNS protocol, messages

DNS protocol : *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



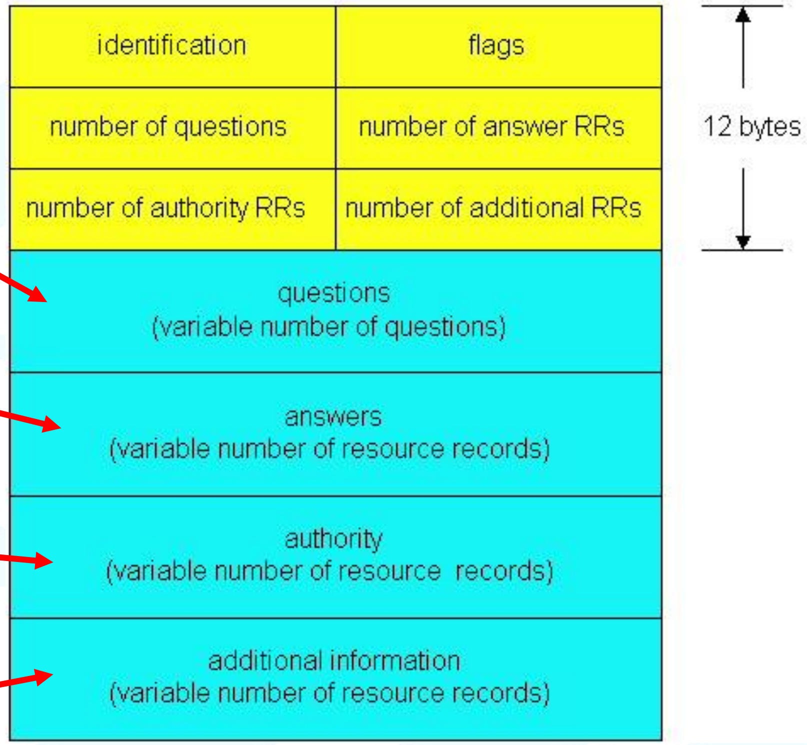
DNS protocol, messages

Name, type fields for a query

RRs in response to query

records for authoritative servers

additional "helpful" info that may be used



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
- How do people get IP address of your Web site?

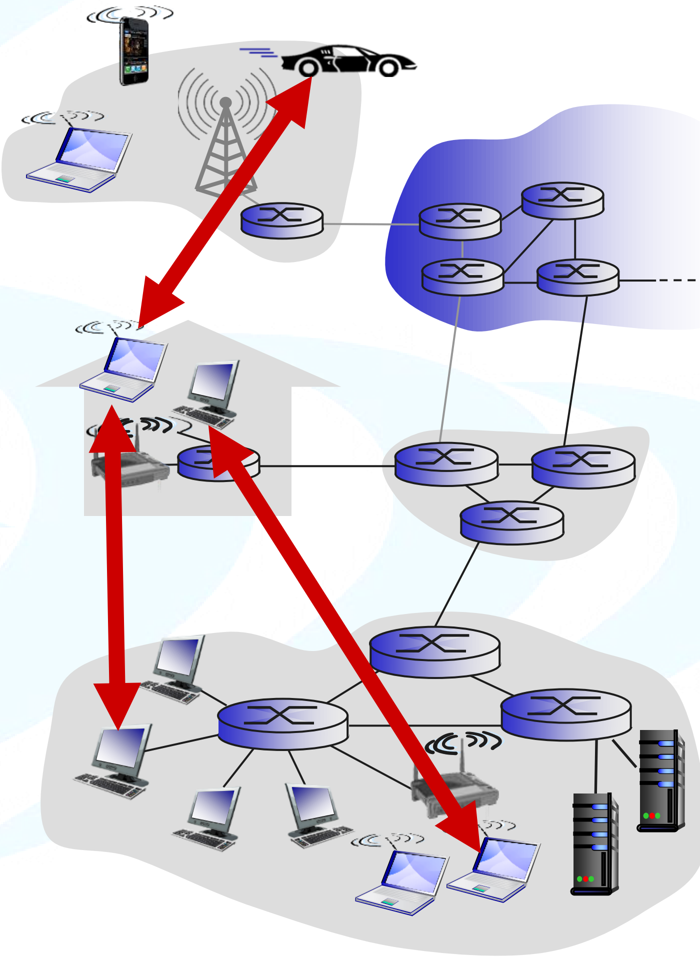
6.6 P2P Applications

Pure P2P architecture

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

examples:

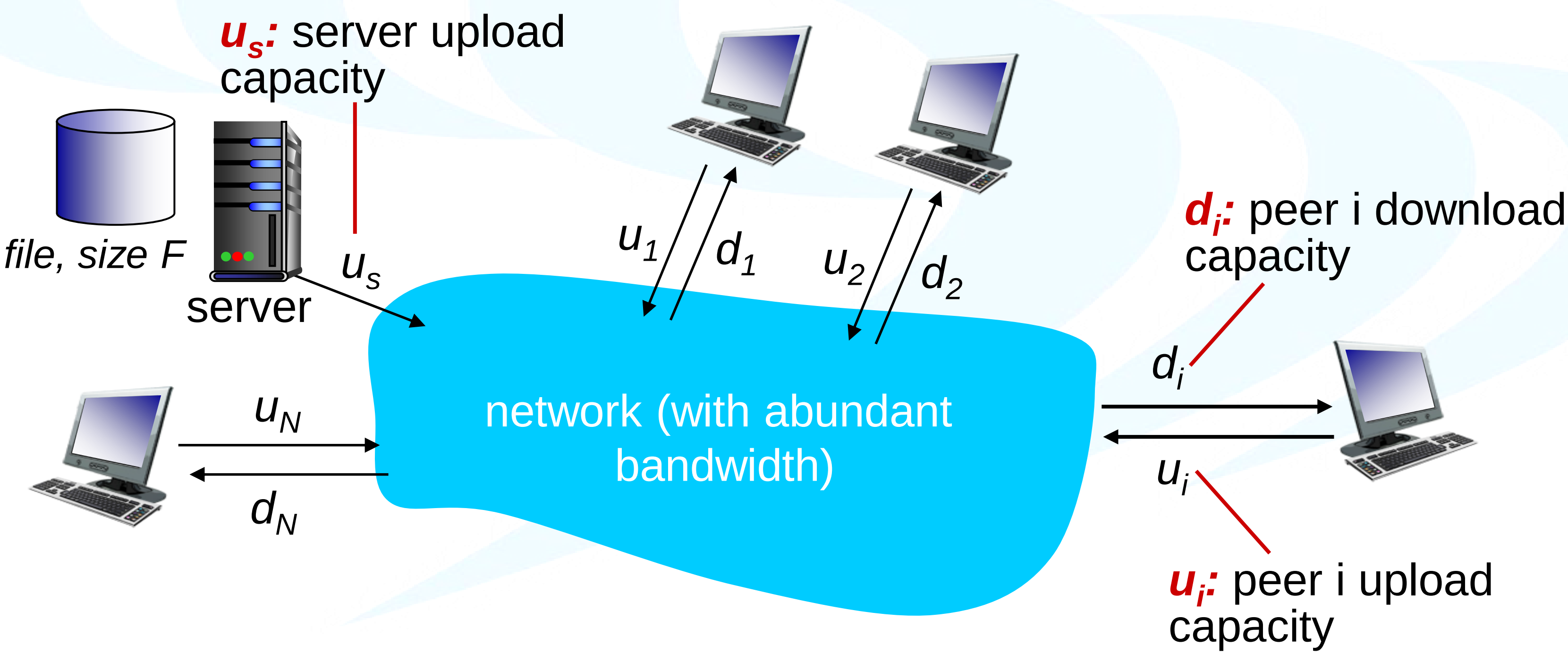
- file distribution (BitTorrent)
- Streaming (KanKan)
- VoIP (Skype)



File distribution: client-server vs P2P

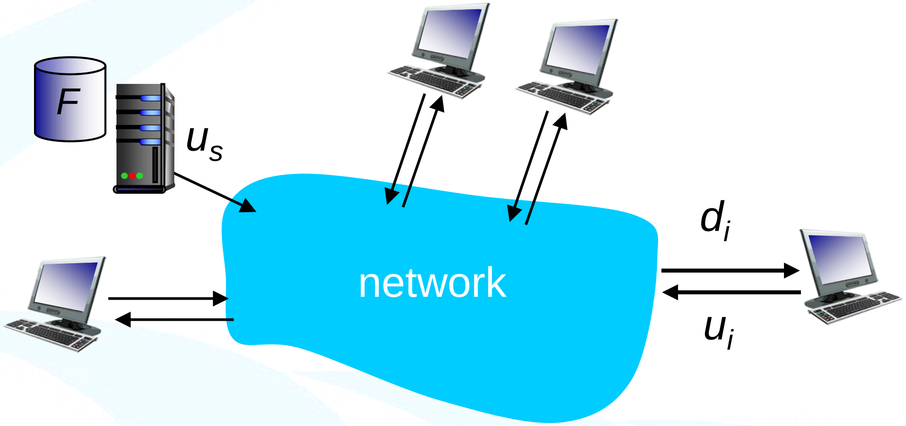
Question: **how much time to distribute file (size *F*) from one server to *N peers*?**

- **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}



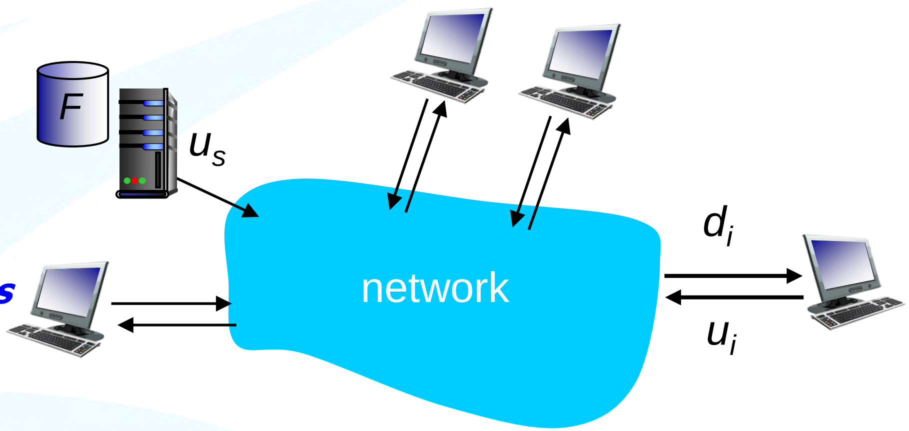
time to distribute F to N clients using client-server approach

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

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 (limiting max download rate) is $u_s + \Sigma u_i$

time to distribute F to N clients using P2P approach

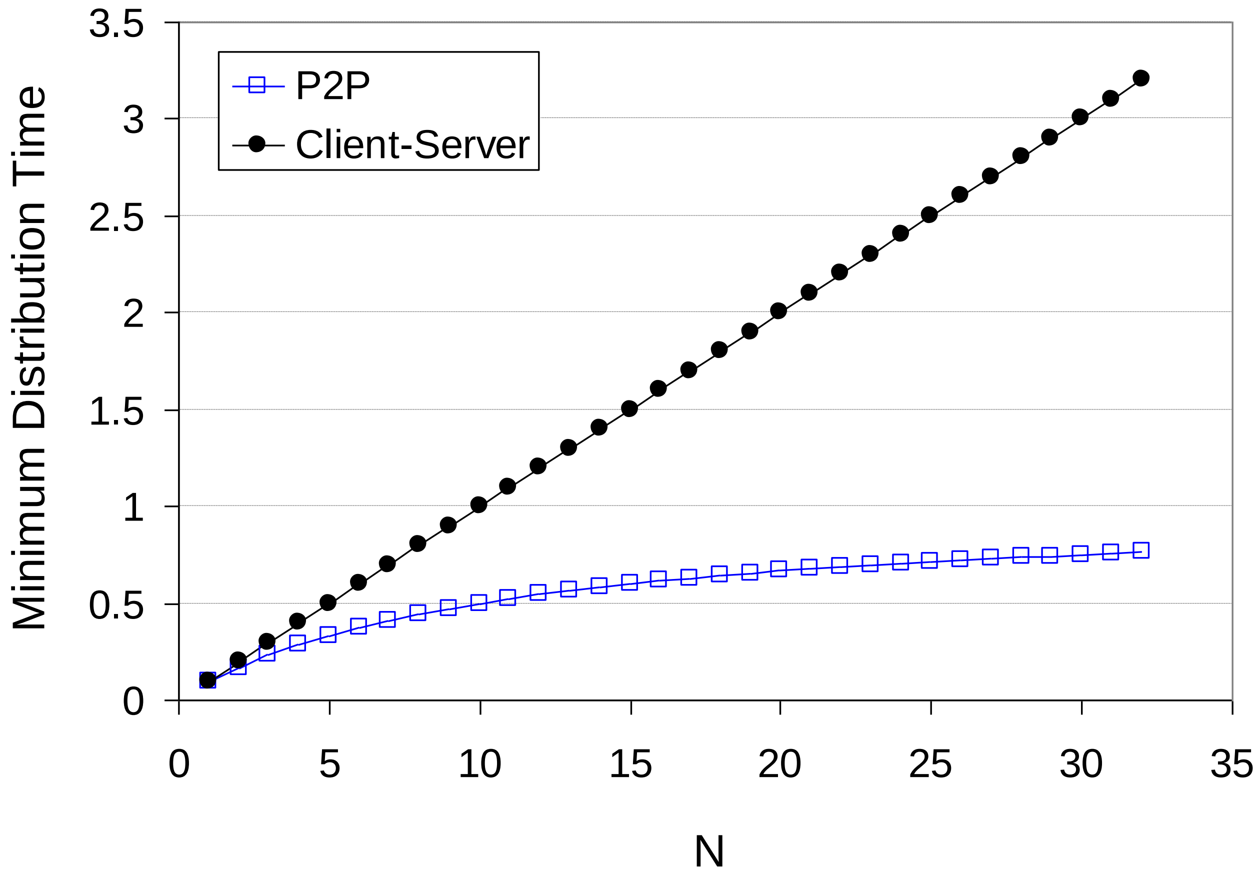
$$D_{P2P} \geq \max\{F/u_s, F/d_{min}, NF/(u_s + \Sigma u_i)\}$$

increases linearly in *N* …

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

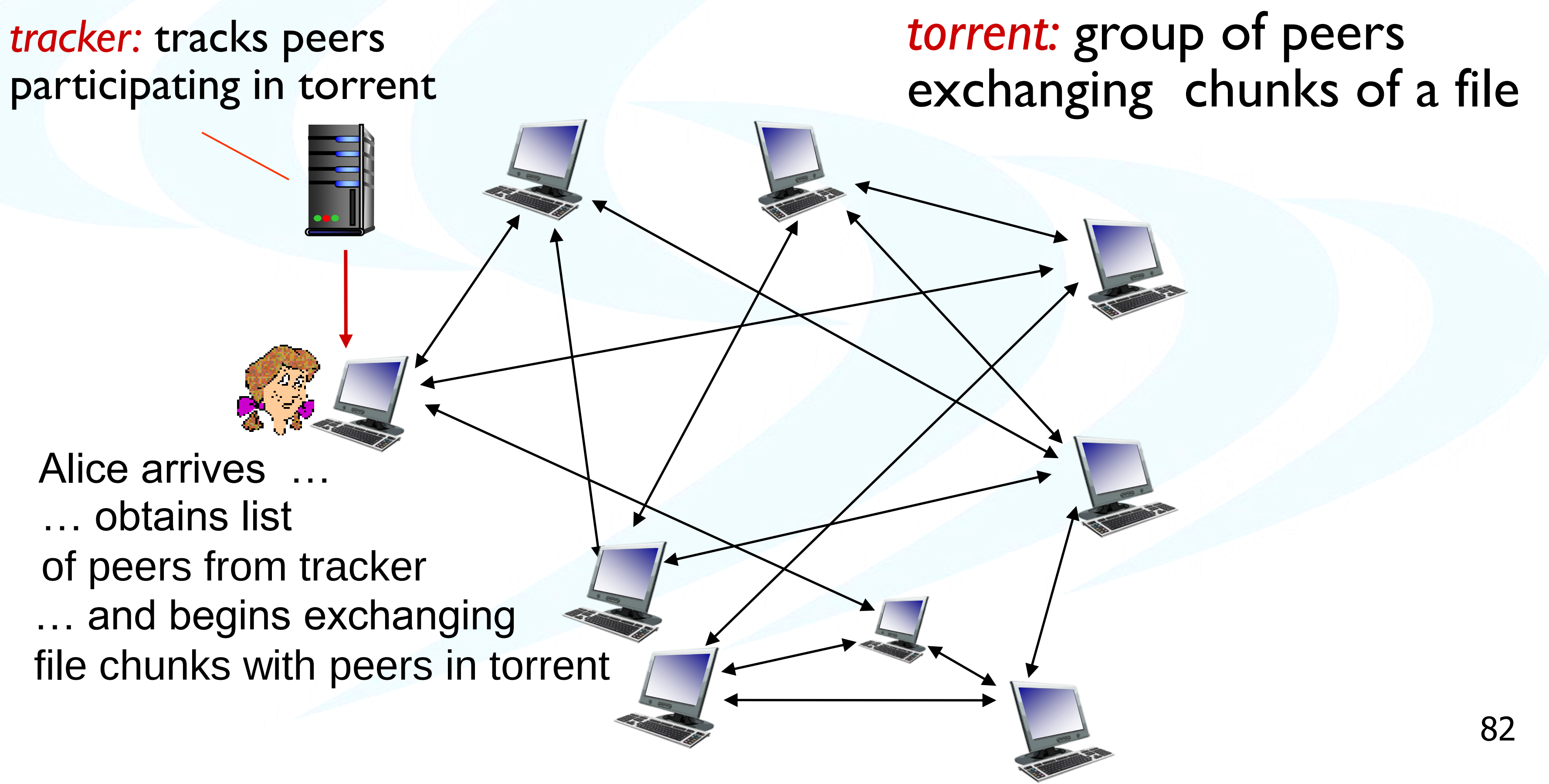
Client-server vs. P2P: example

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



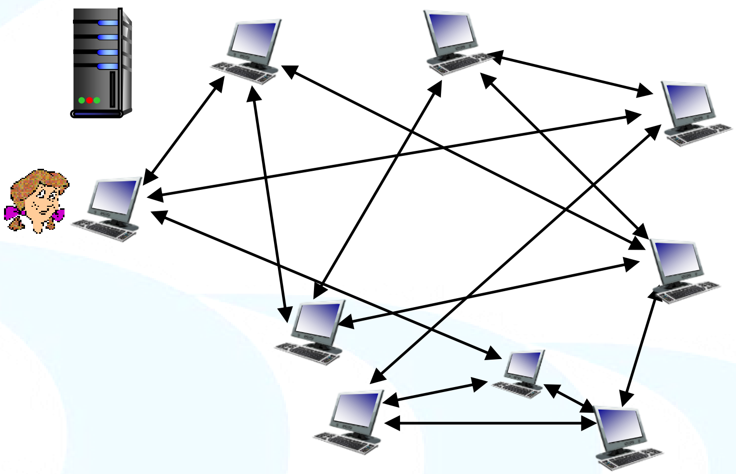
P2P file distribution: BitTorrent

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



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

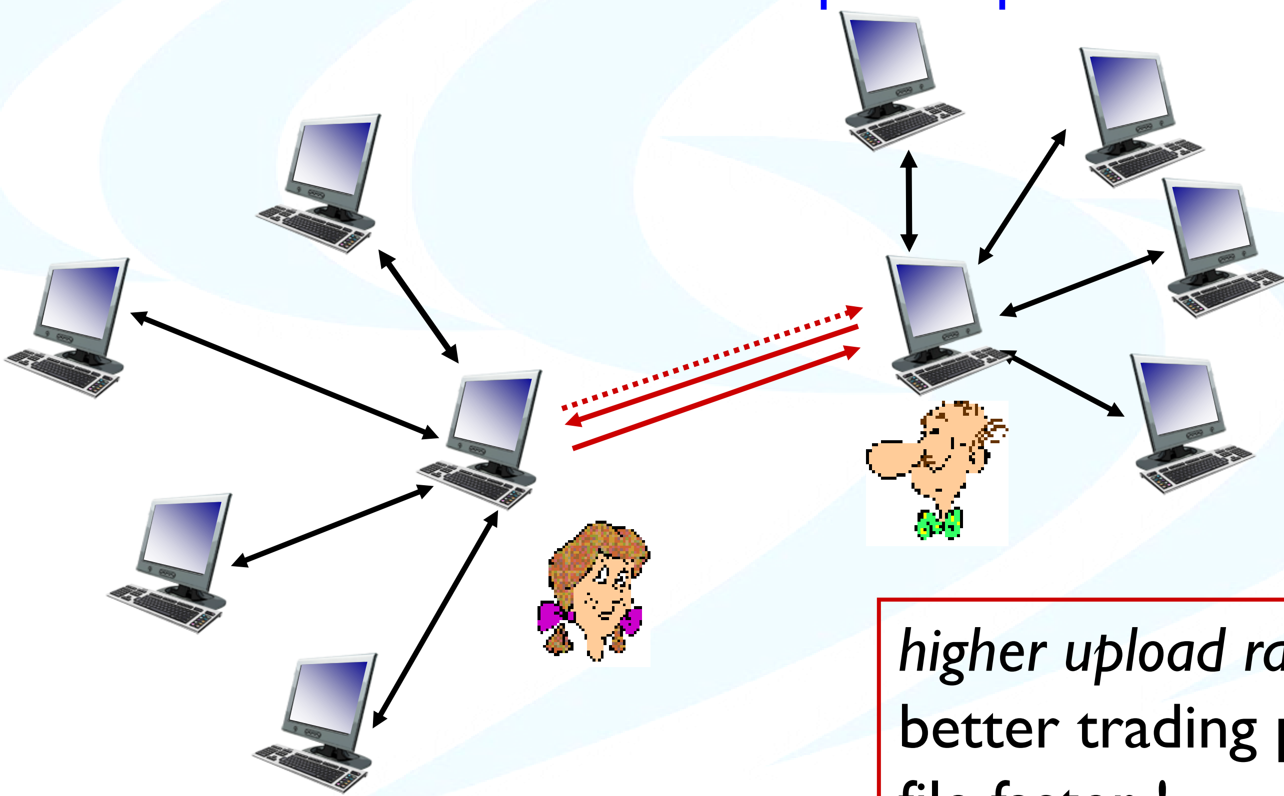
- Alice sends chunks to those four peers currently sending her chunks *at highest rate*
  - other peers are choked by Alice (do not receive chunks from her)
  - re-evaluate top 4 every10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - "optimistically unchoke" this peer
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

P2P file sharing

Example

- Alice runs P2P client application on her notebook computer
- Intermittently connects to Internet; gets new IP address for each connection
- Asks for "Hey Jude"
- Application displays other peers that have copy of Hey Jude.
- Alice chooses one of the peers, Bob.
- File is copied from Bob's PC to Alice's notebook: HTTP
- While Alice downloads, other users uploading from Alice.
- Alice's peer is both a Web client and a transient Web server.

All peers are servers = highly scalable!

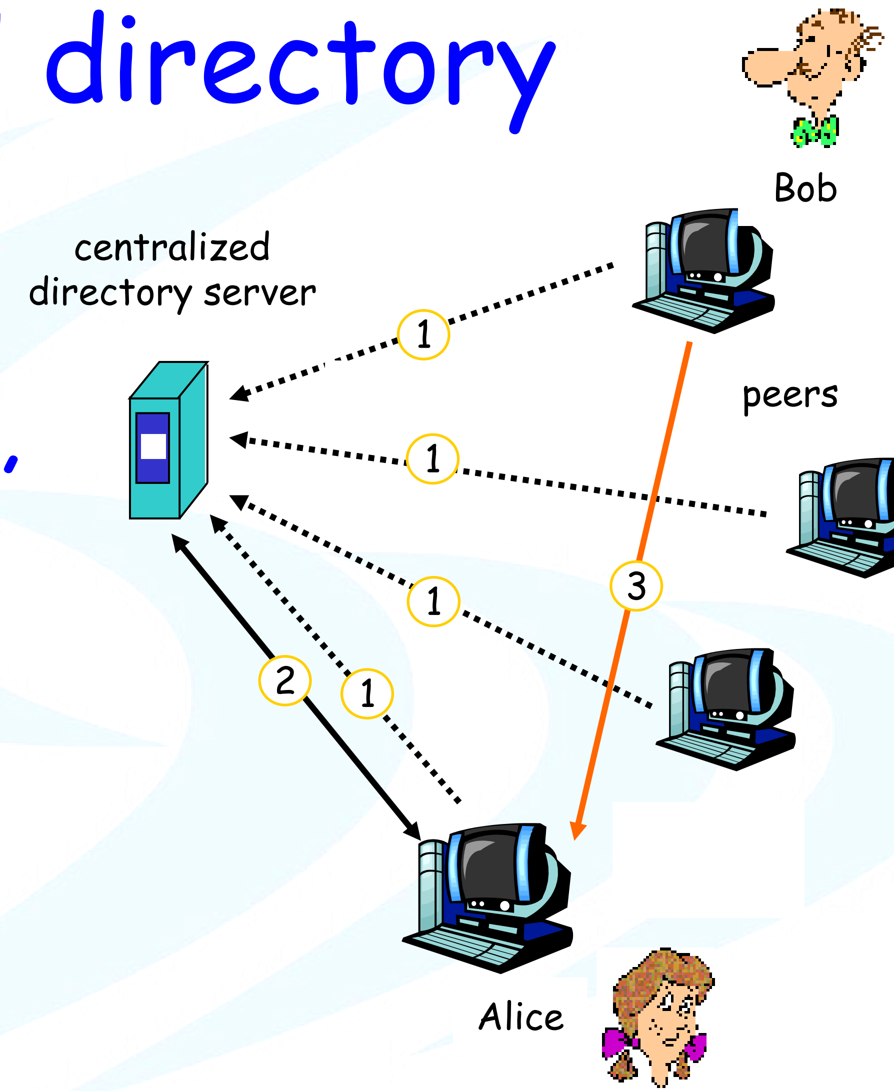
P2P: centralized directory

original "Napster" design

1) when peer connects, it informs central server:
- IP address
- content

2) Alice queries for "Hey Jude"

3) Alice requests file from Bob



P2P: problems with centralized directory

- Single point of failure
- Performance bottleneck
- Copyright infringement

file transfer is decentralized, but locating content is highly centralized

Query flooding: Gnutella

- fully distributed
  - no central server
- public domain protocol
- many Gnutella clients implementing protocol

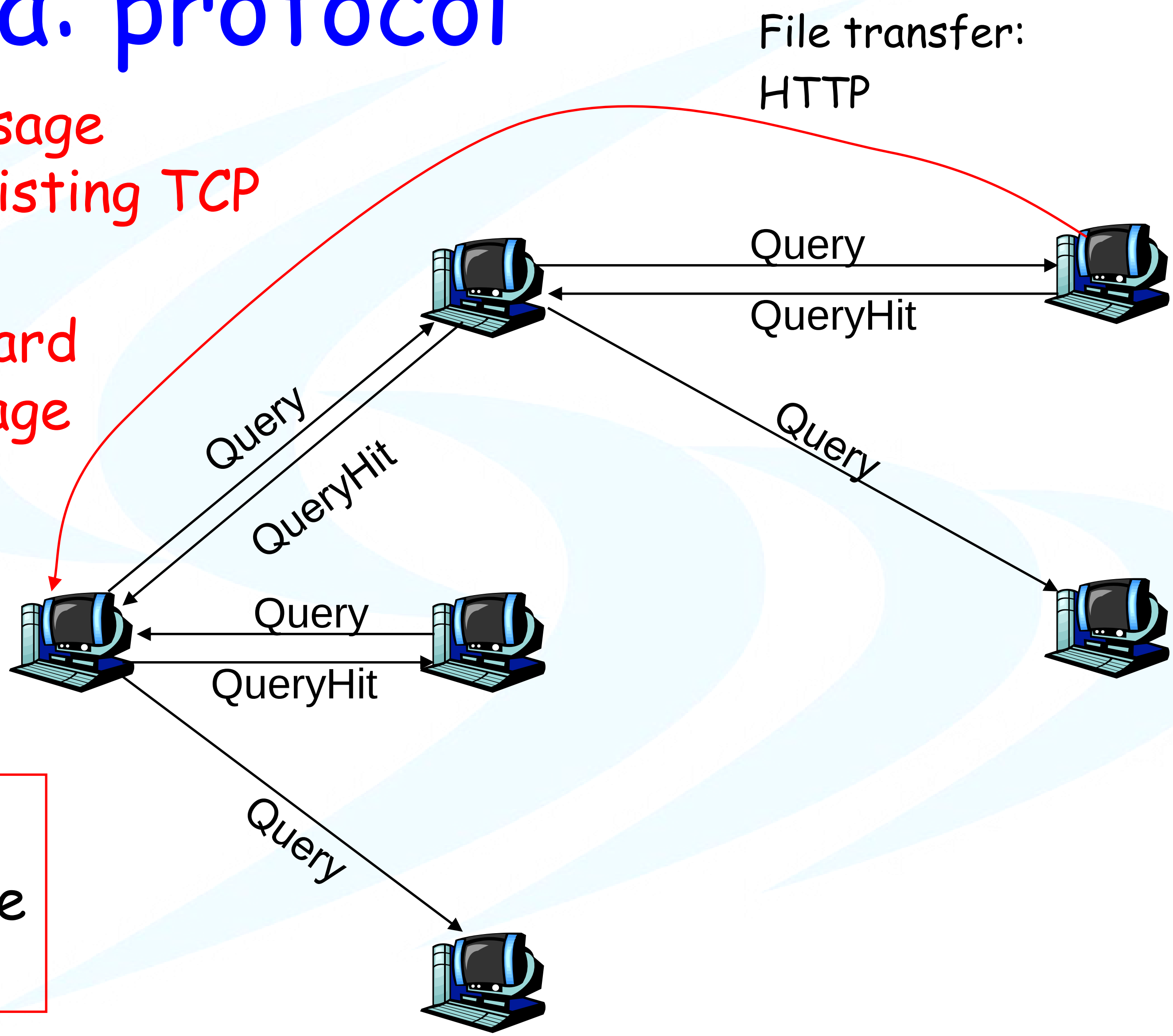
overlay network: graph

- edge between peer X and Y if there's a TCP connection
- all active peers and edges is overlay net
- Edge is not a physical link
- Given peer will typically be connected with < 10 overlay neighbors

Gnutella: protocol

- Query message sent over existing TCP connections
- peers forward Query message
- QueryHit sent over reverse path

Scalability: limited scope flooding



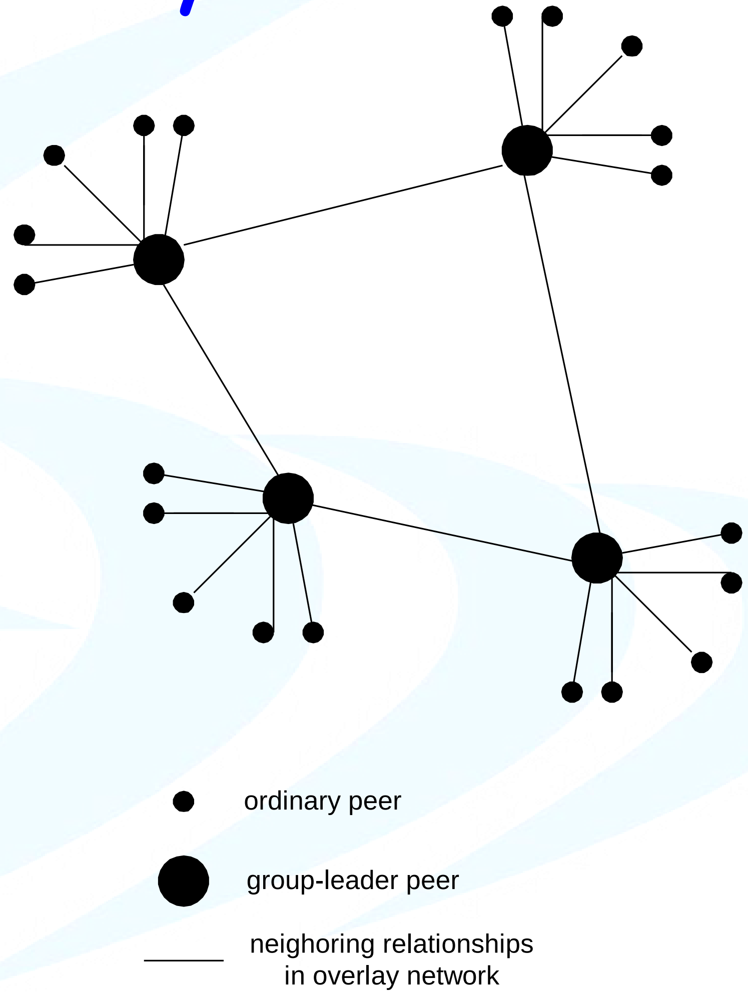
Gnutella: Peer joining

1. Joining peer X must find some other peer in Gnutella network: use list of candidate peers
2. X sequentially attempts to make TCP with peers on list until connection setup with Y
3. X sends Ping message to Y; Y forwards Ping message.
4. All peers receiving Ping message respond with Pong message
5. X receives many Pong messages. It can then setup additional TCP connections

Peer leaving: see homework problem!

Exploiting heterogeneity: KaZaA

- Each peer is either a group leader or assigned to a group leader.
  - TCP connection between peer and its group leader.
  - TCP connections between some pairs of group leaders.
- Group leader tracks the content in all its children.



KaZaA: Querying

- Each file has a hash and a descriptor
- Client sends keyword query to its group leader
- Group leader responds with matches:
  - For each match: metadata, hash, IP address
- If group leader forwards query to other group leaders, they respond with matches
- Client then selects files for downloading
  - HTTP requests using hash as identifier sent to peers holding desired file

6.7 Socket programming with TCP

Socket programming

Goal: learn how to build client/server application that communicate using sockets

Socket API

- introduced in BSD4.1 UNIX, 1981
- explicitly created, used, released by apps
- client/server paradigm
- two types of transport service via socket API:
  - unreliable datagram
  - reliable, byte stream-oriented

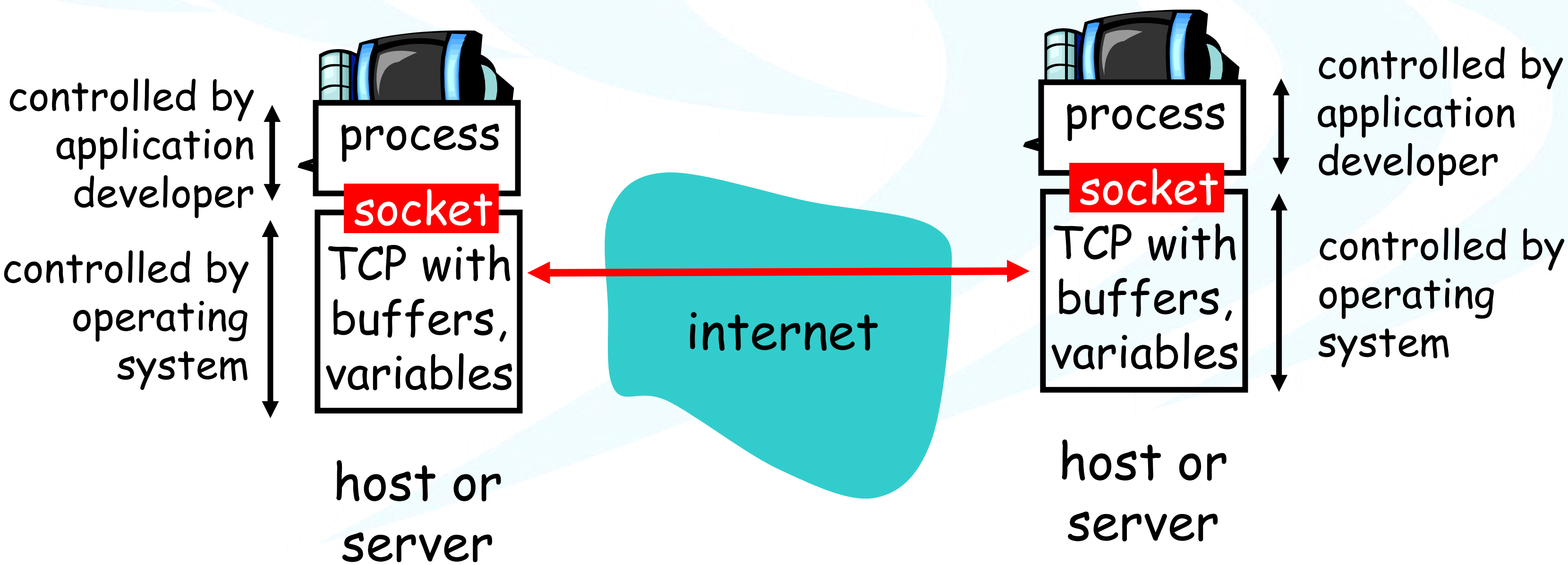
socket

a *host-local*, *application-created*, *OS-controlled* interface (a "door") into which application process can both send and receive messages to/from another application process

Socket-programming using TCP

Socket: a door between application process and end-end-transport protocol (UCP or TCP)

TCP service: reliable transfer of bytes from one process to another



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 client-local 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 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 transfer of bytes ("pipe") between client and server

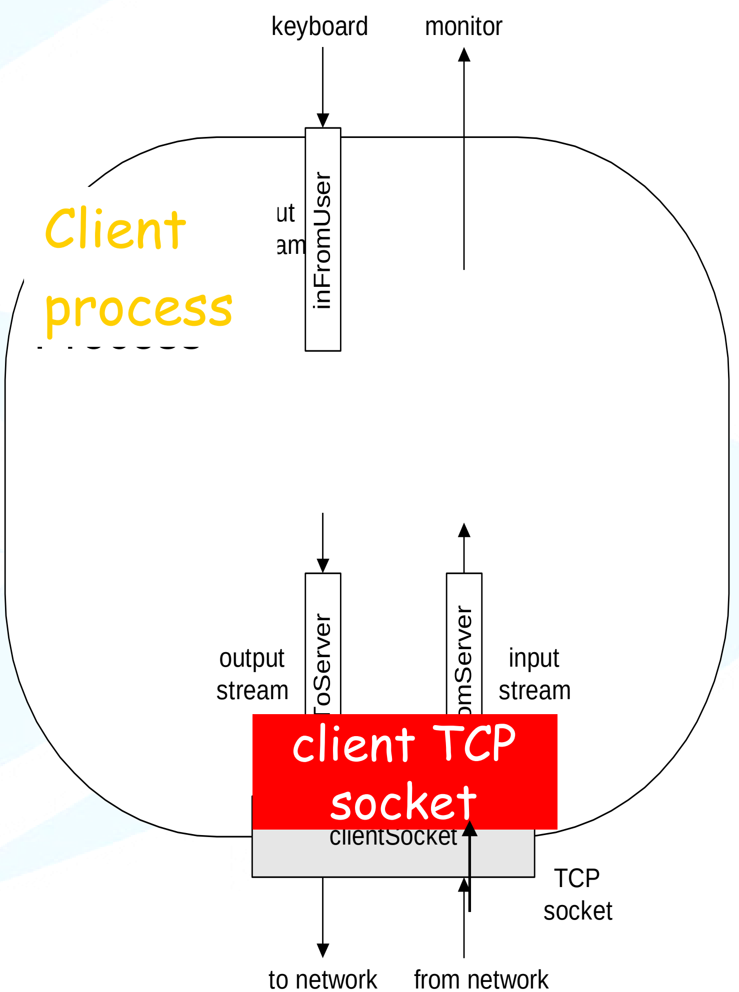
Stream jargon

- A stream is a sequence of characters that flow into or out of a process.
- An input stream is attached to some input source for the process, e.g., keyboard or socket.
- An output stream is attached to an output source, e.g., monitor or socket.

Socket programming with TCP

Example client-server app:

1) client reads line from standard input (inFromUser stream) , sends to server via socket (outToServer stream)
2) server reads line from socket
3) server converts line to uppercase, sends back to client
4) client reads, prints modified line from socket (inFromServer stream)



Client/server socket interaction: TCP

Server (running on `hostid`)

create socket,
port=`x`, for
incoming request:
welcomeSocket =
ServerSocket()

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

read request from
connectionSocket

write reply to
connectionSocket

close
connectionSocket

TCP
connection setup

Client

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

send request using
clientSocket

read reply from
clientSocket

close
clientSocket

Example: Java client (TCP)

```
import java.io.*;
import java.net.*;
class TCPClient {

    public static void main(String argv[]) throws Exception
    {
        String sentence;
        String modifiedSentence;

        BufferedReader inFromUser =
          new BufferedReader(new InputStreamReader(System.in));

        Socket clientSocket = new Socket("hostname", 6789);

        DataOutputStream outToServer =
          new DataOutputStream(clientSocket.getOutputStream());
```

Create input stream

Create client socket, connect to server

Create output stream attached to socket

Example: Java client (TCP), cont.

Create input stream attached to socket

```
        BufferedReader inFromServer =
          new BufferedReader(new
          InputStreamReader(clientSocket.getInputStream()));

        sentence = inFromUser.readLine();
```

Send line to server

```
        outToServer.writeBytes(sentence + '\n');
```

Read line from server

```
        modifiedSentence = inFromServer.readLine();

        System.out.println("FROM SERVER: " + modifiedSentence);

        clientSocket.close();

    }
}
```

Example: Java server (TCP)

```
import java.io.*;
import java.net.*;

class TCPServer {

  public static void main(String argv[]) throws Exception
    {
      String clientSentence;
      String capitalizedSentence;

      ServerSocket welcomeSocket = new ServerSocket(6789);

      while(true) {

          Socket connectionSocket = welcomeSocket.accept();

         BufferedReader inFromClient =
           new BufferedReader(new
           InputStreamReader(connectionSocket.getInputStream()));
```

Create welcoming socket at port 6789

Wait, on welcoming socket for contact by client

Create input stream, attached to socket

Example: Java server (TCP), cont

Create output stream, attached to socket

Read in line from socket

Write out line to socket

```
DataOutputStream  outToClient =
  new DataOutputStream(connectionSocket.getOutputStream());

clientSentence = inFromClient.readLine();

capitalizedSentence = clientSentence.toUpperCase() + '\n';

outToClient.writeBytes(capitalizedSentence);
         }
     }
}
```

End of while loop, loop back and wait for another client connection

6.8 Socket programming with UDP

Socket programming *with UDP*

UDP: no "connection" between client and server

- no handshaking
- sender explicitly attaches IP address and port of destination to each packet
- server must extract IP address, port of sender from received packet

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

application viewpoint

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

Client/server socket interaction: UDP

Server (running on `hostid`)

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

read request from
serverSocket

write reply to
serverSocket
specifying client
host address,
port number

Client

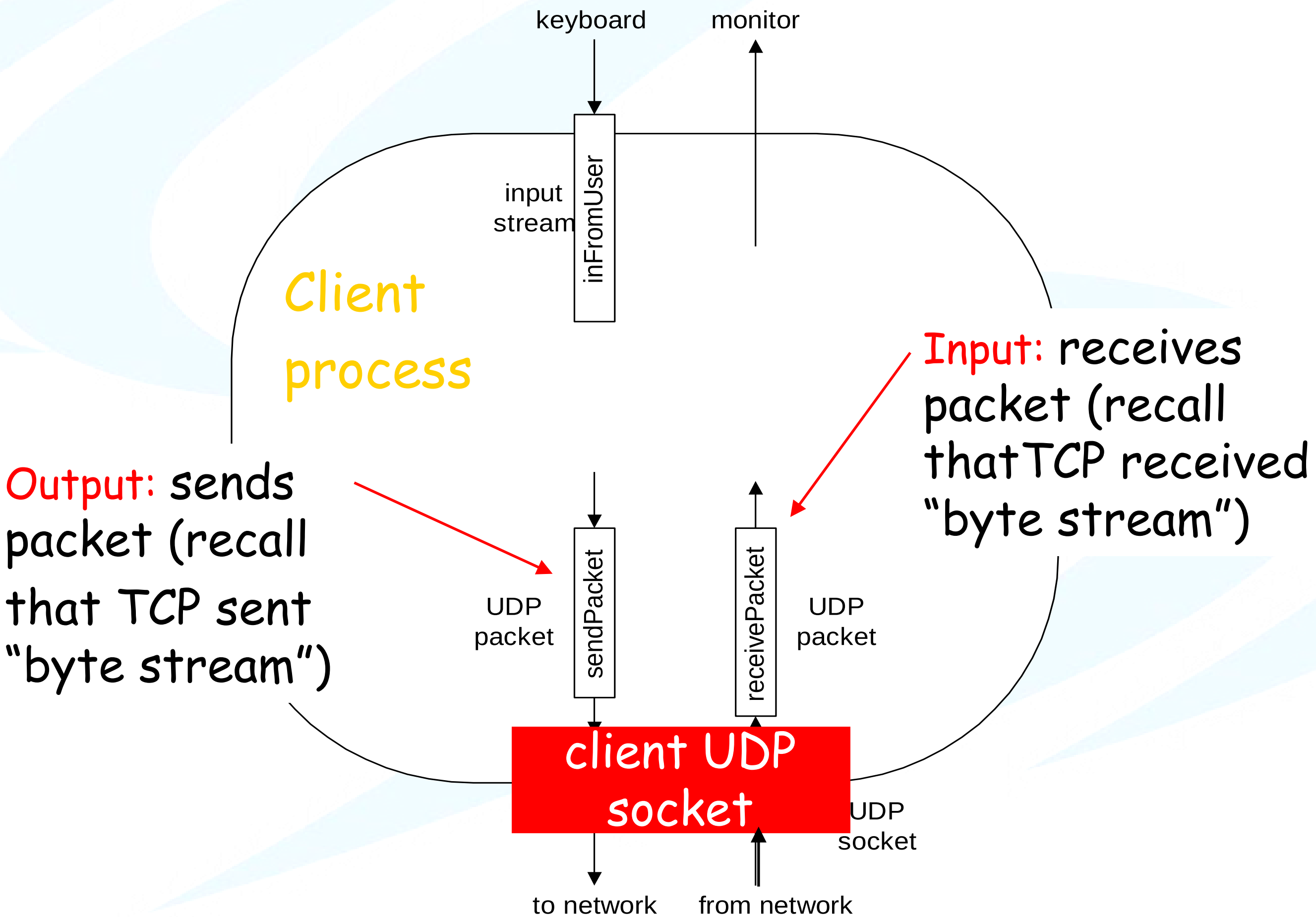
create socket,
clientSocket =
DatagramSocket()

Create, address (`hostid, port=x,`
send datagram request
using clientSocket

read reply from
clientSocket

close
clientSocket

Example: Java client (UDP)



Example: Java client (UDP)

```
import java.io.*;
import java.net.*;

class UDPClient {
    public static void main(String args[]) throws Exception
    {

      BufferedReader inFromUser =
        new BufferedReader(new InputStreamReader(System.in));

      DatagramSocket clientSocket = new DatagramSocket();

      InetAddress IPAddress = InetAddress.getByName("hostname");

      byte[] sendData = new byte[1024];
      byte[] receiveData = new byte[1024];

      String sentence = inFromUser.readLine();

      sendData = sentence.getBytes();
```

Create input stream

Create client socket

Translate hostname to IP address using DNS

Example: Java client (UDP), cont.

Create datagram with data-to-send, length, IP addr, port

Send datagram to server

Read datagram from server

```
DatagramPacket sendPacket =
   new DatagramPacket(sendData, sendData.length, IPAddress, 9876);

clientSocket.send(sendPacket);

DatagramPacket receivePacket =
   new DatagramPacket(receiveData, receiveData.length);

clientSocket.receive(receivePacket);

String modifiedSentence =
    new String(receivePacket.getData());

System.out.println("FROM SERVER:" + modifiedSentence);
clientSocket.close();
}
}
```

Example: Java server (UDP)

Create datagram socket at port 9876

Create space for received datagram

Receive datagram

```
import java.io.*;
import java.net.*;

class UDPServer {
  public static void main(String args[]) throws Exception
    {

      DatagramSocket serverSocket = new DatagramSocket(9876);

      byte[] receiveData = new byte[1024];
      byte[] sendData  = new byte[1024];

      while(true)
        {

          DatagramPacket receivePacket =
             new DatagramPacket(receiveData, receiveData.length);

           serverSocket.receive(receivePacket);
```

Example: Java server (UDP), cont

```
String sentence = new String(receivePacket.getData());

InetAddress IPAddress = receivePacket.getAddress();

int port = receivePacket.getPort();

        String capitalizedSentence = sentence.toUpperCase();

sendData = capitalizedSentence.getBytes();

DatagramPacket sendPacket =
  new DatagramPacket(sendData, sendData.length, IPAddress,
               port);

serverSocket.send(sendPacket);
  }
 }
}
```

Get IP addr port #, of sender

Create datagram to send to client

Write out datagram to socket

End of while loop, loop back and wait for another datagram

Chapter 6: Summary

our study of network apps now complete!

- application architectures
  - client-server
  - P2P
  - hybrid
- 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, Skype
- socket programming