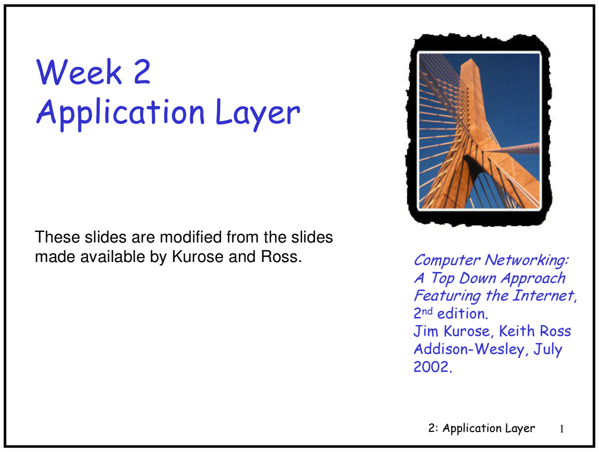
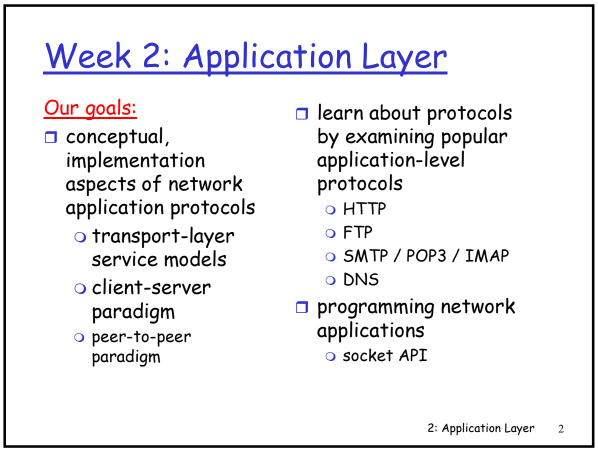


Week 2
Application Layer

These slides are modified from the slides made available by Kurose and Ross.

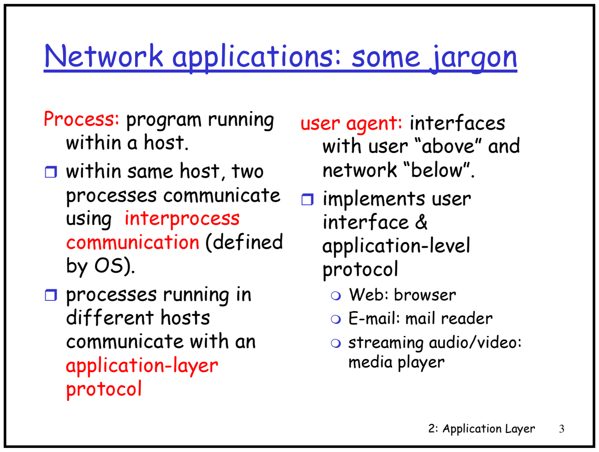
Computer Networking: A Top Down Approach Featuring the Internet, 2nd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2002.



Week 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
- programming network applications
  - socket API



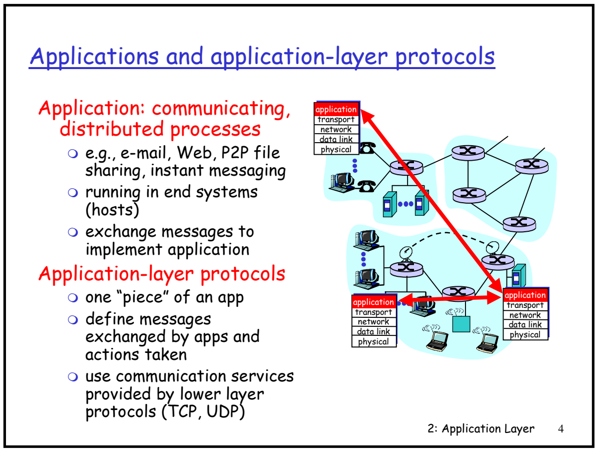
Network applications: some jargon

Process: program running within a host.

- within same host, two processes communicate using interprocess communication (defined by OS).
- processes running in different hosts communicate with an application-layer protocol

user agent: interfaces with user "above" and network "below".

- implements user interface & application-level protocol
  - Web: browser
  - E-mail: mail reader
  - streaming audio/video: media player



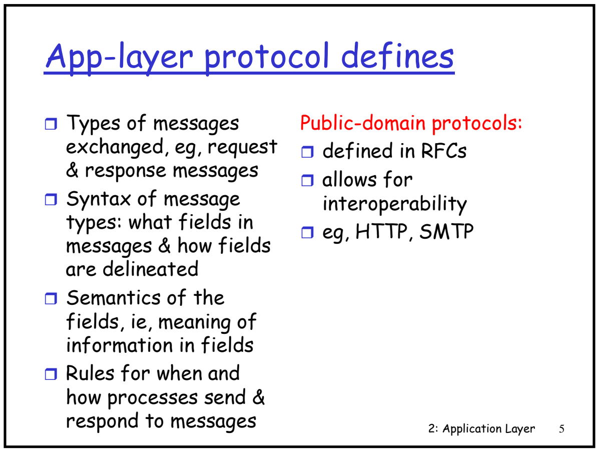
Applications and application-layer protocols

Application: communicating, distributed processes

- e.g., e-mail, Web, P2P file sharing, instant messaging
- running in end systems (hosts)
- exchange messages to implement application

Application-layer protocols

- one "piece" of an app
- define messages exchanged by apps and actions taken
- use communication services provided by lower layer protocols (TCP, UDP)

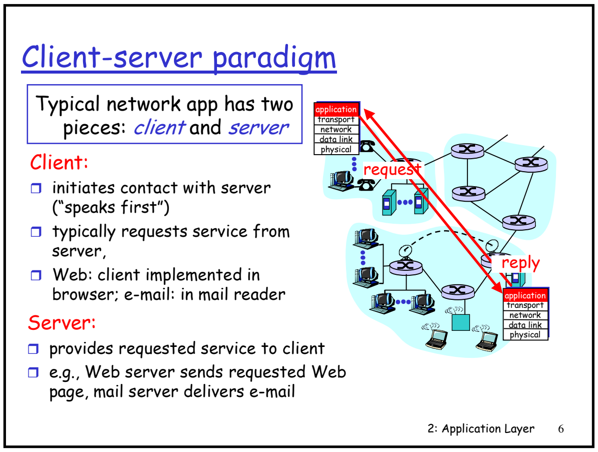


App-layer protocol defines

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

Public-domain protocols:

- defined in RFCs
- allows for interoperability
- eg, HTTP, SMTP



Client-server paradigm

Typical network app has two pieces: *client* and *server*

Client:

- initiates contact with server ("speaks first")
- typically requests service from server,
- Web: client implemented in browser; e-mail: in mail reader

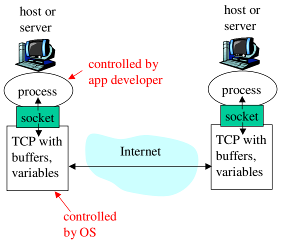
Server:

- provides requested service to client
- e.g., Web server sends requested Web page, mail server delivers e-mail

application
transport
network
data link
physical
request
reply
application
transport
network
data link
physical

Processes communicating across network

- process sends/receives messages to/from its socket
- socket analogous to door
  - sending process shoves message out door
  - sending process asssumes transport infrastructure on other side of door which brings message to socket at receiving process


host or server
host or server
controlled by app developer
process
process
socket
socket
TCP with buffers, variables
Internet
TCP with buffers, variables
controlled by OS

- 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
- Every host has a unique 32-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

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 providing:* 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., Dialpad)	typically UDP

Web and HTTP

First some jargon

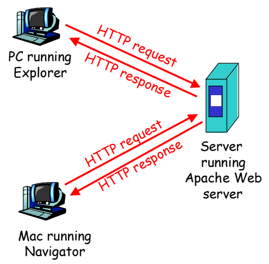
- Web page consists of objects
- Object can be HTML file, JPEG image, Java applet, audio file,…
- Web page consists of base HTML-file which includes several referenced objects
- Each object is addressable by a URL
- Example URL:

$$\underbrace{\texttt{www.cs.rit.edu}}_{\text{host name}}\underbrace{\texttt{/somecourse/pic.gif}}_{\text{path name}}$$

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

Nonpersistent HTTP

- At most one object is sent over a TCP connection.
- HTTP/1.0 uses nonpersistent HTTP

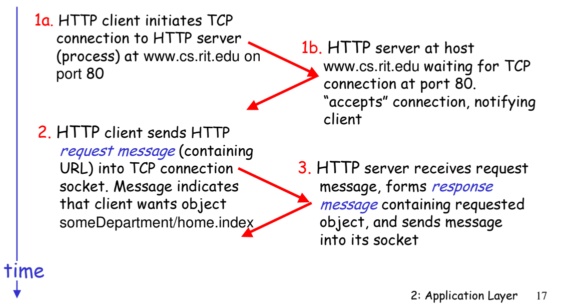
Persistent HTTP

- Multiple objects can be sent over single TCP connection between client and server.
- HTTP/1.1 uses persistent connections in default mode

Nonpersistent HTTP

Suppose user enters URL
`www.cs.rit.edu/someDepartment/home.index`

(contains text, references to 10 jpeg images)



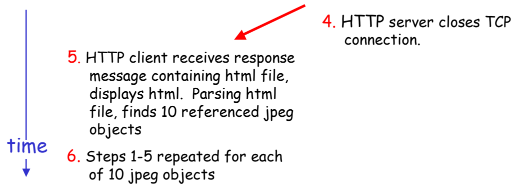
1a. HTTP client initiates TCP connection to HTTP server (process) at www.cs.rit.edu on port 80

1b. HTTP server at host www.cs.rit.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

Nonpersistent 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

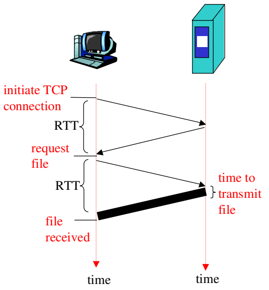
Response time modeling

Definition of RTT: time to send a small packet to travel from client to server and back.

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

total = 2RTT+transmit time



Persistent HTTP

Nonpersistent HTTP issues:

- requires 2 RTTs per object
- OS must work and allocate host resources for each TCP connection
- but 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 are sent over connection

Persistent without pipelining:

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

Persistent with pipelining:

- default in HTTP/1.1
- client sends requests as soon as it encounters a referenced object
- as little as one RTT for all the referenced objects

HTTP request message

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

request line (GET, POST, HEAD commands)

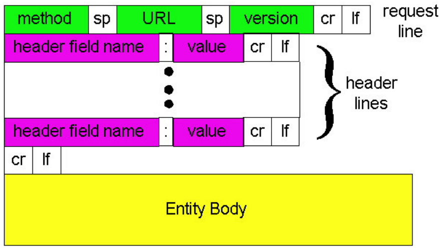
```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language:fr
```

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

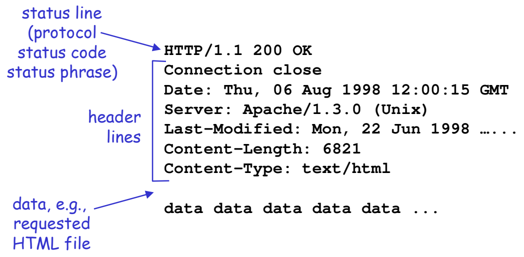
HTTP/1.0

- 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

In first line in server->client response message.
A few sample codes:

200 OK
- request succeeded, requested object later in this message

301 Moved Permanently
- requested object moved, new location specified later in this message (Location:)

400 Bad Request
- request message not understood by server

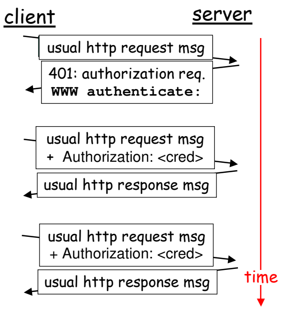
404 Not Found
- requested document not found on this server

505 HTTP Version Not Supported

User-server interaction: authorization

Authorization : control access to server content

- authorization credentials: typically name, password
- stateless: client must present authorization in *each* request
  - authorization: header line in each request
  - if no authorization: header, server refuses access, sends
    `WWW authenticate:`
    header line in response



Cookies: keeping "state"

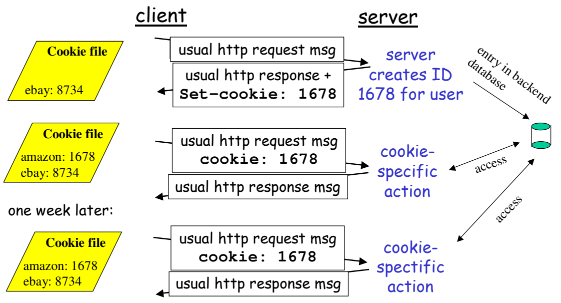
Many major Web sites use cookies

Four components:

1) cookie header line in the HTTP response message
2) cookie header line in HTTP request message
3) cookie file kept on user's host and 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.)

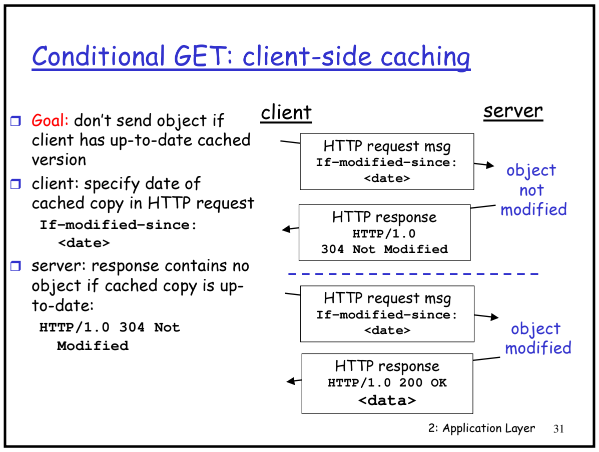


Cookies (continued)

What cookies can bring:
- 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
- search engines use redirection & cookies to learn yet more
- advertising companies obtain info across sites



Conditional GET: client-side caching

- Goal: don't send object if client has up-to-date cached version
- client: specify date of cached copy in HTTP request
  `If-modified-since: <date>`
- server: response contains no object if cached copy is up-to-date:
  `HTTP/1.0 304 Not Modified`

client

server

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

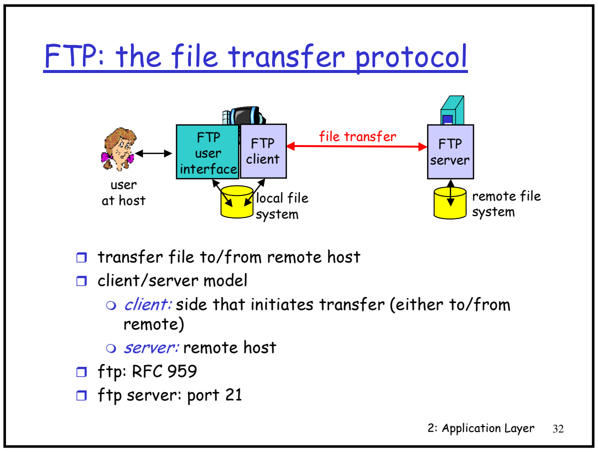
object not modified

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

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

object modified

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



FTP: the file transfer protocol

user at host

FTP user interface

FTP client

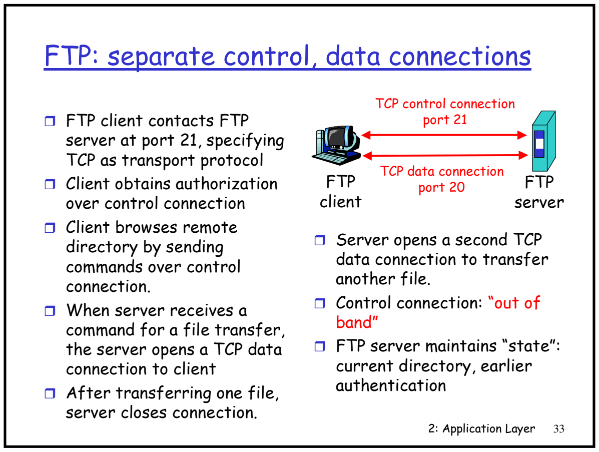
file transfer

FTP server

local file system

remote file system

- 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.

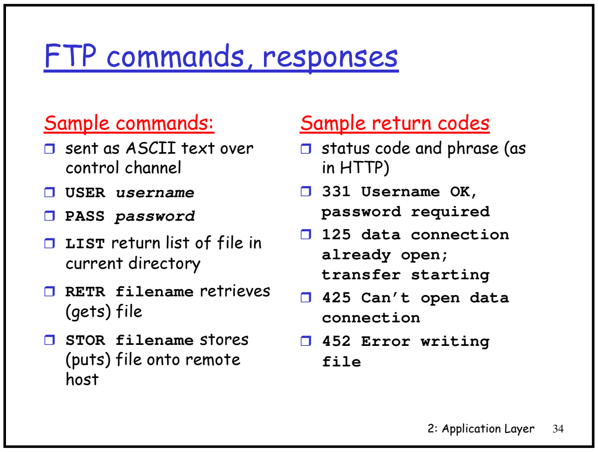
TCP control connection port 21

TCP data connection port 20

FTP client

FTP server

- Server opens a second TCP data connection to transfer another file.
- Control connection: "out of band"
- FTP server maintains "state": current directory, earlier authentication



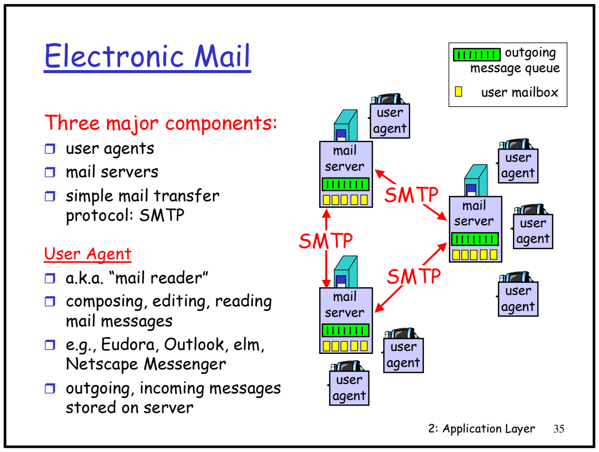
FTP commands, responses

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`



Electronic Mail

🟩 outgoing message queue

🟨 user mailbox

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

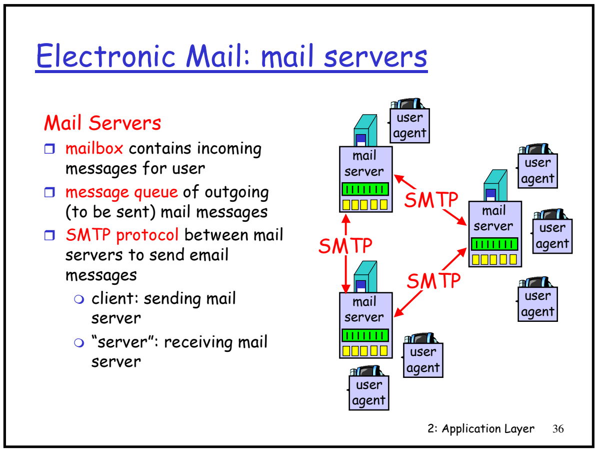
user agent

mail server

SMTP

SMTP

SMTP



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

user agent

mail server

SMTP

SMTP

SMTP

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

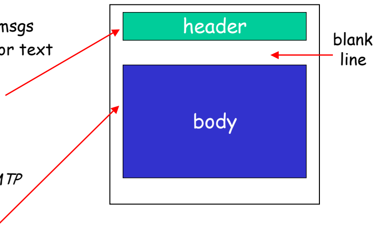
Mail message format

SMTP: protocol for exchanging email msgs

RFC 822: standard for text message format:

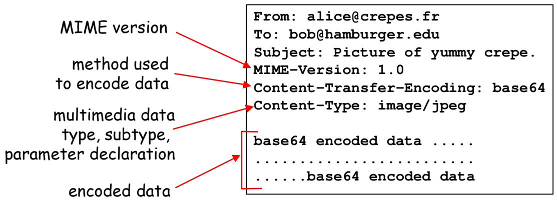
- header lines, e.g.,
  - To:
  - From:
  - Subject:

  different from SMTP 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
```

MIME types

`Content-Type: type/subtype; parameters`

Text

- example subtypes: `plain`, `html`

Image

- example subtypes: `jpeg`, `gif`

Audio

- exampe subtypes: `basic` (8-bit mu-law encoded), `32kadpcm` (32 kbps coding)

Video

- example subtypes: `mpeg`, `quicktime`

Application

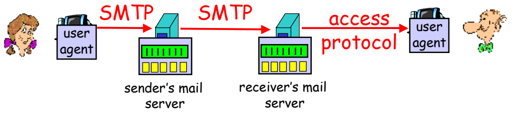
- other data that must be processed by reader before "viewable"
- example subtypes: `msword, octet-stream`

Multipart Type

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary=StartOfNextPart

--StartOfNextPart
Dear Bob, Please find a picture of a crepe.
--StartOfNextPart
Content-Transfer-Encoding: base64
Content-Type: image/jpeg
base64 encoded data .....
.........................
......base64 encoded data
--StartOfNextPart
Do you want the reciple?
```

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.

DNS: Domain Name System

People: many identifiers:
- SSN, name, passport #

Internet hosts, routers:
- IP address (32 bit) - used for addressing datagrams
- "name", e.g., gaia.cs.umass.edu - 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 name servers

Why not centralize DNS?
- single point of failure
- traffic volume
- distant centralized database
- maintenance

doesn't *scale!*

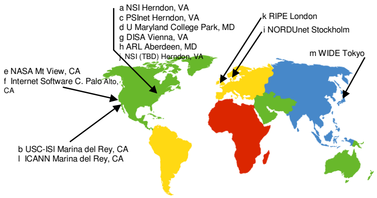
- no server has all name-to-IP address mappings

local name servers:
- each ISP, company has *local (default) name server*
- host DNS query first goes to local name server

authoritative name server:
- for a host: stores that host's IP address, name
- can perform name/address translation for that host's name

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

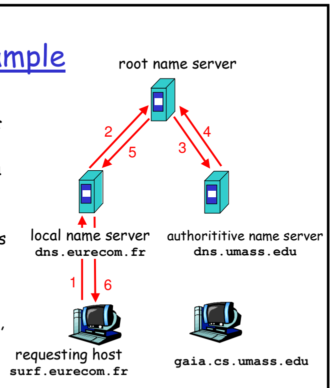


13 root name servers worldwide

Simple DNS example

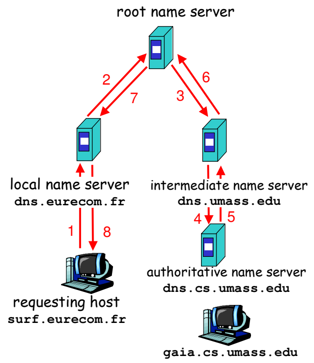
host **surf.eurecom.fr** wants IP address of **gaia.cs.umass.edu**

1. contacts its local DNS server, **dns.eurecom.fr**
2. **dns.eurecom.fr** contacts root name server, if necessary
3. root name server contacts authoritative name server, **dns.umass.edu**, if necessary



DNS example

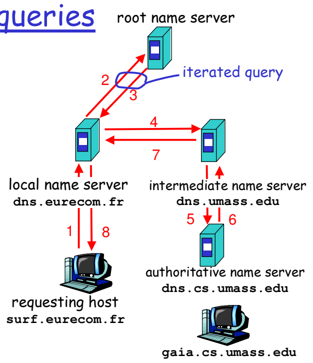
Root name server:
- may not know authoritative name server
- may know *intermediate name server:* who to contact to find authoritative name server



DNS: iterated queries

recursive query:
- puts burden of name resolution on contacted name server
- heavy load?

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



DNS: caching and updating records

- once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time
- update/notify mechanisms under design by IETF
  - RFC 2136
  - http://www.ietf.org/html.charters/dnsind-charter.html

DNS records

DNS: distributed db storing resource records (RR)

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

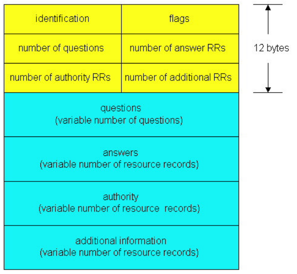
- Type=A
  - **name** is hostname
  - **value** is IP address
- Type=NS
  - **name** is domain (e.g. foo.com)
  - **value** is IP address of authoritative name server for this domain
- Type=CNAME
  - **name** is alias name for some "cannonical" (the real) name
    `www.ibm.com` is really
    `servereast.backup2.ibm.com`
  - **value** is cannonical name
- Type=MX
  - **value** is name of mailserver associated with **name**

DNS protocol, messages

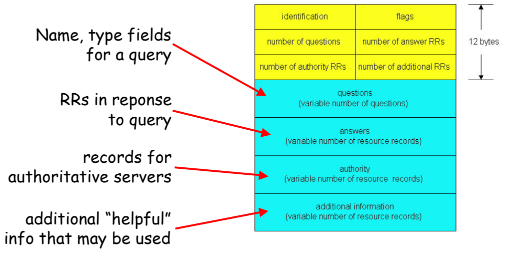
DNS protocol : *query* and *reply* messages, both with same *message format*

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



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

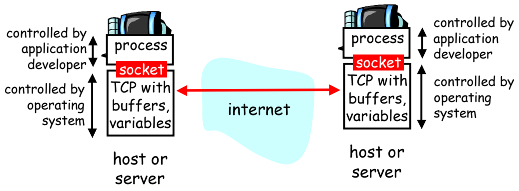
socket

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 (UDP 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

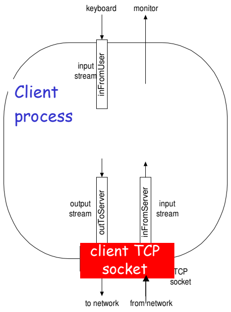
Stream jargon

- 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, eg, keyboard or socket.
- An output stream is attached to an output source, eg, monitor or socket.

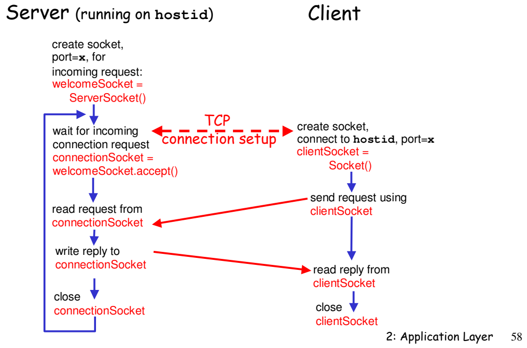
Socket programming with TCP

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`)

Client

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

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

TCP connection setup

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

send request using clientSocket

read request from connectionSocket

write reply to connectionSocket

read reply from clientSocket

close connectionSocket

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;
```

Create input stream

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

Create client socket, connect to server

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

Create output stream attached to socket

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

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;
```

Create welcoming socket at port 6789

```
      ServerSocket welcomeSocket = new ServerSocket(6789);

      while(true) {
```

Wait, on welcoming socket for contact by client

```
         Socket connectionSocket = welcomeSocket.accept();
```

Create input stream, attached to socket

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

Example: Java server (TCP), cont

Create output stream, attached to socket

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

Read in line from socket

```
clientSentence = inFromClient.readLine();

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

Write out line to socket

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

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

Socket programming *with UDP*

UDP: no "connection" between client and server

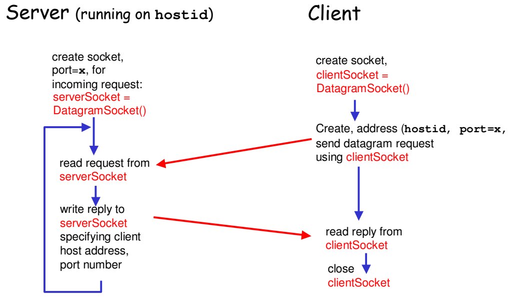
- no handshaking
- sender explicitly attaches IP address and port of destination to each packet
- server must extract IP address, port of sender from received packet

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

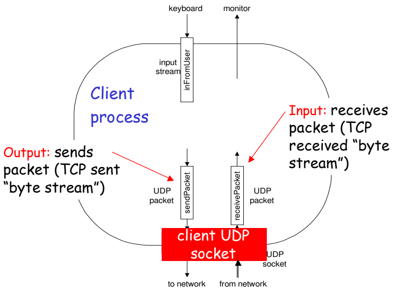
application viewpoint

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

Client/server socket interaction: UDP


Server (running on hostid)
Client
create socket, port=x, for incoming request: serverSocket = DatagramSocket()
create socket, clientSocket = DatagramSocket()
Create, address (hostid, port=x, send datagram request using clientSocket
read request from serverSocket
write reply to serverSocket specifying client host address, port number
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
   {
```

Create input stream

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

Create client socket

```
     DatagramSocket clientSocket = new DatagramSocket();
```

Translate hostname to IP address using DNS

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

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

     String sentence = inFromUser.readLine();
     sendData = sentence.getBytes();
```

Example: Java client (UDP), cont.

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

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

Send datagram to server

```
clientSocket.send(sendPacket);

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

Read datagram from server

```
clientSocket.receive(receivePacket);

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

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

Example: Java server (UDP)

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

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

Create datagram socket at port 9876

```
      DatagramSocket serverSocket = new DatagramSocket(9876);

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

      while(true)
        {
```

Create space for received datagram

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

Receive datagram

```
           serverSocket.receive(receivePacket);
```

Example: Java server (UDP), cont

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

Get IP addr port #, of sender

```
InetAddress IPAddress = receivePacket.getAddress();

int port = receivePacket.getPort();

        String capitalizedSentence = sentence.toUpperCase();

sendData = capitalizedSentence.getBytes();
```

Create datagram to send to client

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

Write out datagram to socket

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

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

Building a simple Web server

- handles one HTTP request
- accepts the request
- parses header
- obtains requested file from server's file system
- creates HTTP response message:
  - header lines + file
- sends response to client
- after creating server, you can request file using a browser (eg IE explorer)
- see text for details

Socket programming: references

C-language tutorial (audio/slides):

- "Unix Network Programming" (J. Kurose),

http://manic.cs.umass.edu/~amldemo/courseware/intro.

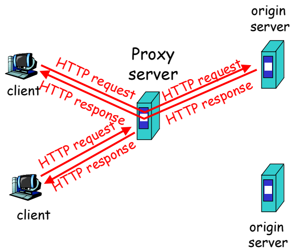
Java-tutorials:

- "All About Sockets" (Sun tutorial), http://www.javaworld.com/javaworld/jw-12-1996/jw-12-sockets.html
- "Socket Programming in Java: a tutorial," http://www.javaworld.com/javaworld/jw-12-1996/jw-12-sockets.html

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



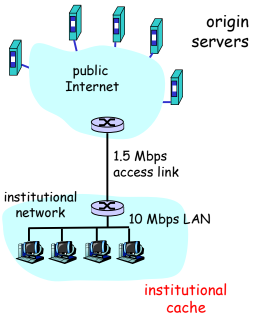
More about Web caching

- Cache acts as both client and server
- Cache can do up-to-date check using `If-modified-since` HTTP header
  - Issue: should cache take risk and deliver cached object without checking?
  - Heuristics are used.
- Typically cache is installed by ISP (university, company, residential ISP)

Why Web caching?

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

Caching example (1)



Assumptions

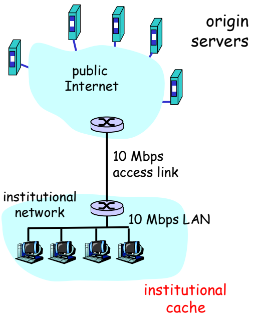
- average object size = 100,000 bits
- avg. request rate from institution's browser to origin serves = 15/sec
- delay from institutional router to any origin server and back to router = 2 sec

Consequences

- utilization on LAN = 15%
- utilization on access link = 100%
- total delay = Internet delay + access delay + LAN delay

= 2 sec + minutes + milliseconds

Caching example (2)



Possible solution

- increase bandwidth of access link to, say, 10 Mbps

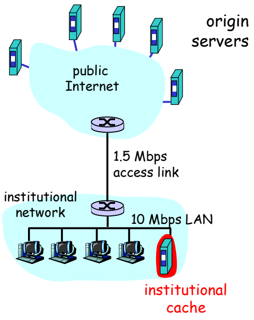
Consequences

- utilization on LAN = 15%
- utilization on access link = 15%
- Total delay = Internet delay + access delay + LAN delay

= 2 sec + msecs + msecs

- often a costly upgrade

Caching example (3)



Install cache

- suppose hit rate is .4

Consequence

- 40% requests will be satisfied almost immediately
- 60% requests satisfied by origin server
- utilization of access link reduced to 60%, resulting in negligible delays (say 10 msec)
- total delay = Internet delay + access delay + LAN delay

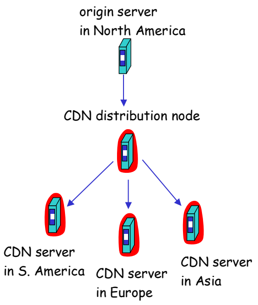
= .6*2 sec + .6*.01 secs + milliseconds < 1.3 secs

Content distribution networks (CDNs)

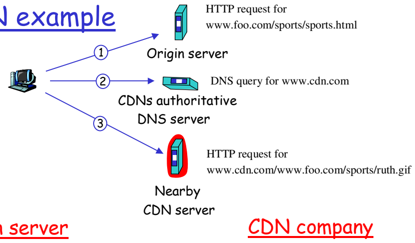
- The content providers are the CDN customers.

Content replication

- CDN company installs hundreds of CDN servers throughout Internet
  - in lower-tier ISPs, close to users
- CDN replicates its customers' content in CDN servers. When provider updates content, CDN updates servers



CDN example


HTTP request for www.foo.com/sports/sports.html
1
Origin server
2
DNS query for www.cdn.com
CDNs authoritative DNS server
3
HTTP request for www.cdn.com/www.foo.com/sports/ruth.gif
Nearby CDN server

origin server

- www.foo.com
- distributes HTML
- Replaces:

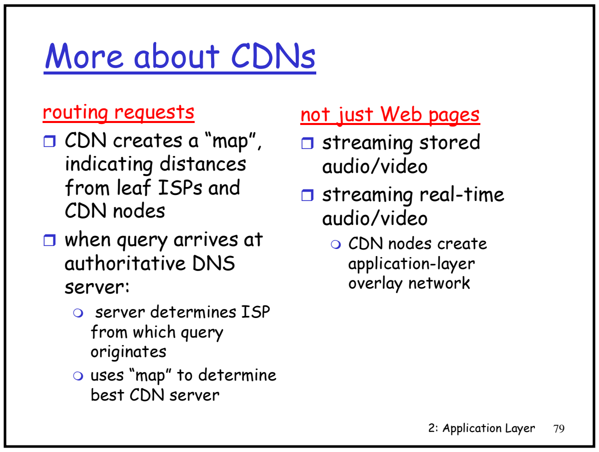
http://www.foo.com/sports.ruth.gif

with

http://www.cdn.com/www.foo.com/sports/ruth.gif

CDN company

- cdn.com
- distributes gif files
- uses its authoritative DNS server to route redirect requests



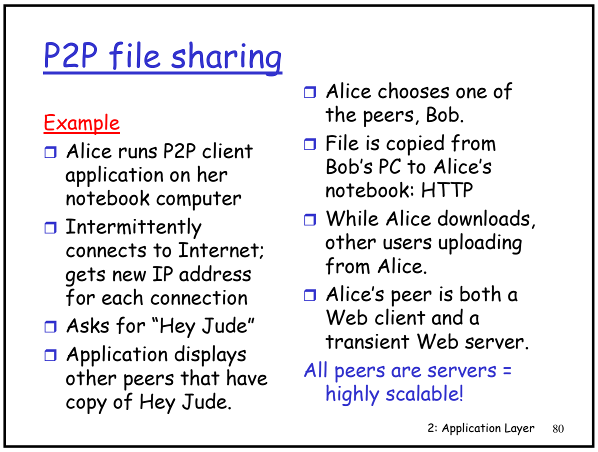
More about CDNs

routing requests

- CDN creates a "map", indicating distances from leaf ISPs and CDN nodes
- when query arrives at authoritative DNS server:
  - server determines ISP from which query originates
  - uses "map" to determine best CDN server

not just Web pages

- streaming stored audio/video
- streaming real-time audio/video
  - CDN nodes create application-layer overlay network

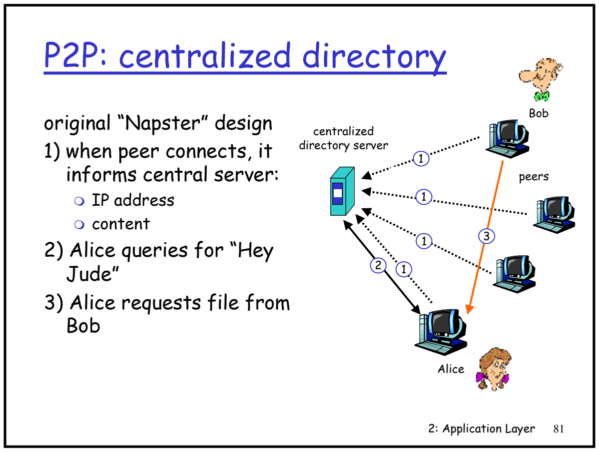


P2P file sharing

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.

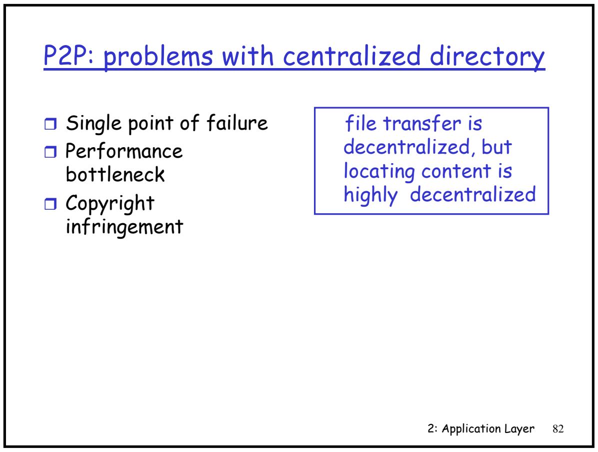
All peers are servers = highly scalable!



P2P: centralized directory

original "Napster" design

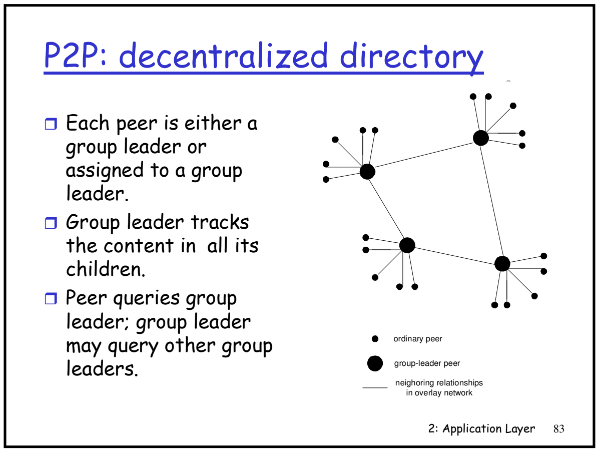
1) when peer connects, it informs central server:
   - IP address
   - content
2) Alice queries for "Hey Jude"
3) Alice requests file from Bob



P2P: problems with centralized directory

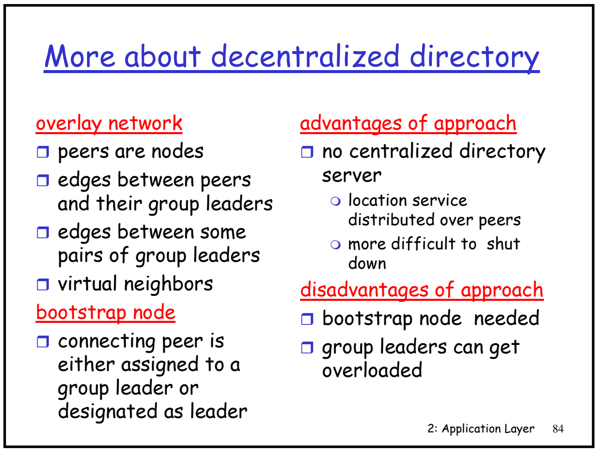
- Single point of failure
- Performance bottleneck
- Copyright infringement

file transfer is decentralized, but locating content is highly decentralized



P2P: decentralized directory

- Each peer is either a group leader or assigned to a group leader.
- Group leader tracks the content in all its children.
- Peer queries group leader; group leader may query other group leaders.



More about decentralized directory

overlay network

- peers are nodes
- edges between peers and their group leaders
- edges between some pairs of group leaders
- virtual neighbors

bootstrap node

- connecting peer is either assigned to a group leader or designated as leader

advantages of approach

- no centralized directory server
  - location service distributed over peers
  - more difficult to shut down

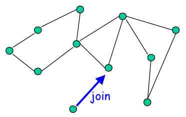
disadvantages of approach

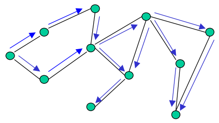
- bootstrap node needed
- group leaders can get overloaded

P2P: Query flooding

- Gnutella
- no hierarchy
- use bootstrap node to learn about others
- join message

- Send query to neighbors
- Neighbors forward query
- If queried peer has object, it sends message back to querying peer





P2P: more on query flooding

Pros

- peers have similar responsibilities: no group leaders
- highly decentralized
- no peer maintains directory info

Cons

- excessive query traffic
- query radius: may not have content when present
- bootstrap node
- maintenance of overlay network