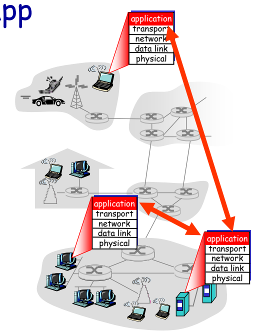
Application Layer

- e-mail
- web
- instant messaging
- remote login
- P2P file sharing
- multi-user network games
- streaming stored video (YouTube)
- voice over IP
- real-time video conferencing
- cloud computing
- …
- …
-

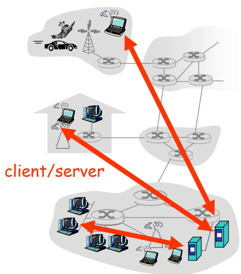
Creating a network app

Write programs that
- run on (different) *end systems*
- communicate over network
- e.g., web server - browser

No need to write software for network-core devices



Client-server architecture

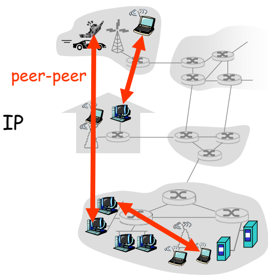


server:
- always-on
- permanent IP address
- server farms for scaling

clients:
- communicate with server
- not always connected
- dynamic IP addresses
- do not communicate directly with each other

Pure P2P architecture

- *no* always-on server
- end systems directly communicate
- peers are not always connected and change IP addresses



Hybrid of client-server and P2P

Skype
- voice-over-IP P2P application
- server: finding address of remote party
- client-client speech: direct

Processes communicating

process: program running within a host.

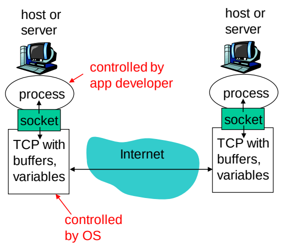
- processes communicate by exchanging messages

client process: process that initiates communication

server process: process that waits to be contacted

Sockets

- process sends/receives messages to/from its socket
- socket analogous to door



Addressing processes

- a process must have an *identifier*
- host device has unique IP address
- *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

App-layer protocol defines

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

public-domain protocols:
- defined in RFCs
  e.g., HTTP, SMTP

proprietary protocols:
- e.g., Skype

What transport service does an app need?

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

Timing
- some apps (e.g., Internet telephony, interactive games) require low delay

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

…

Transport protocol services

TCP:
- *connection-oriented:* setup required between client and server processes
- *reliable transport*
- *flow control*
- *congestion control*
- *does not provide:* timing, minimum throughput guarantees

UDP:
- unreliable data transfer between sending and receiving process

Web and HTTP

- web page consists of objects
- object can be HTML file, JPEG image, audio file,…
- web page consists of base HTML-file with referenced objects
- each object is addressable by a URL
- example URL:

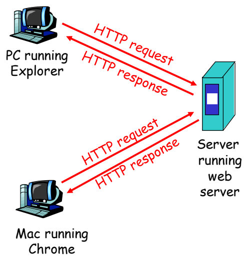
`www.someschool.edu/someDept/pic.gif`

host name — path name

HTTP overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server model
  - *client:* browser
  - *server:* Web server



HTTP overview

Uses TCP:

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

HTTP is "stateless"

- server keeps no information about past client requests

> protocols that maintain "state" are complex!
> - past history (state) must be maintained
> - if server/client crashes, their views of "state" may be inconsistent

HTTP connections

non-persistent HTTP

- at most one object sent over TCP connection.

persistent HTTP

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

HTTP request message

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

request line (GET, POST, HEAD commands)

header lines

carriage return character

line-feed character

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

```
GET /index.html HTTP/1.1\r\n
Host: www-net.cs.umass.edu\r\n
User-Agent: Firefox/3.6.10\r\n
Accept: text/html,application/xhtml+xml\r\n
Accept-Language: en-us,en;q=0.5\r\n
Accept-Encoding: gzip,deflate\r\n
Accept-Charset: ISO-8859-1,utf-8;q=0.7\r\n
Keep-Alive: 115\r\n
Connection: keep-alive\r\n
\r\n
```


HTTP response message

status line (protocol status code status phrase)

header lines

data, e.g., requested HTML file

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


HTTP response status codes

- status code appears in 1st line in server->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 Web sites use cookies

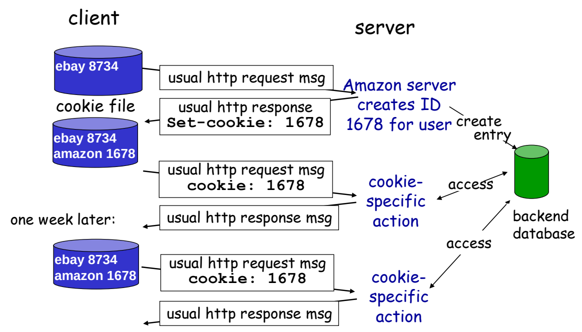
four components:

1) cookie header line of HTTP *response* message
2) cookie header line in HTTP *request* message
3) cookie file kept on 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

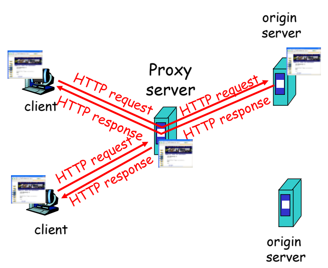
Cookies: keeping "state" (cont.)



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

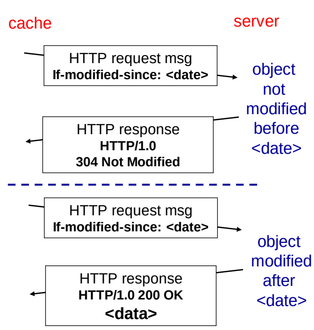
- cache acts as both client and server
- typically cache is installed by ISP (university, company, residential ISP)

why Web caching?

- reduce response time for client request
- reduce traffic on an institution's access link

Conditional GET

- Goal: don't send object if cache has up-to-date cached version
- cache: specify date of cached copy in HTTP request
- server: response contains no object if cached copy is up-to-date:



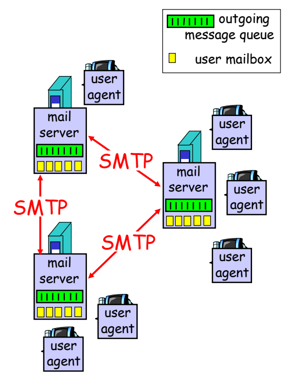
Email

Three major components:

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

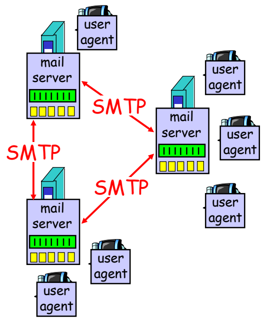
User Agent

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



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



SMTP

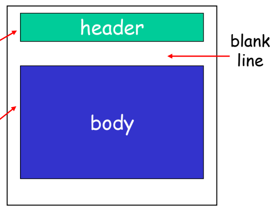
- uses TCP to reliably transfer email message from client to server, port 25
- direct transfer: sending server to receiving server
- three phases of transfer
  - handshaking (greeting)
  - transfer of messages
  - closure
- command/response interaction
  - commands: ASCII text
  - response: status code and phrase

Mail message format

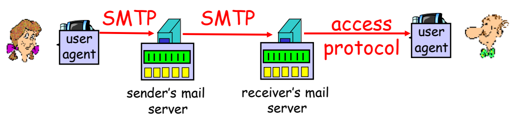
SMTP: protocol for exchanging email msgs

RFC 822: standard for text message format:

- header lines, e.g.,
  - To:
  - From:
  - Subject:
- body
  - the "message"



Mail access protocols



- SMTP: delivery/storage to receiver's server
- mail access protocol: retrieval from server
  - POP: Post Office Protocol
    - authorization (agent <-->server) and download
  - IMAP: Internet Mail Access Protocol
    - more features (more complex)
    - manipulation of stored msgs on server
  - HTTP: gmail, Hotmail, Yahoo! Mail, etc.

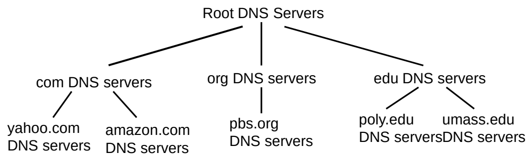
DNS

DNS services
- hostname to IP address translation
- 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

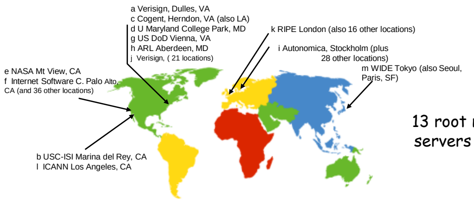
doesn't *scale!*

Distributed, Hierarchical Database



client wants IP for www.amazon.com:
- 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



13 root name servers worldwide

TLD and Authoritative Servers

Top-level domain (TLD) servers:

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

Authoritative DNS servers:

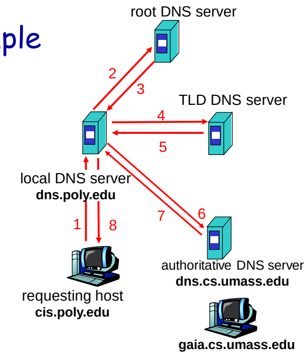
- organization's DNS servers, hostname to IP mappings for organization's servers
- can be maintained by organization or service provider

DNS name resolution example

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

iterated query:

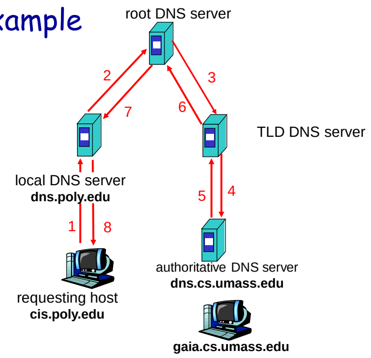
- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"



DNS name resolution example

recursive query:

- puts burden of name resolution on contacted name server

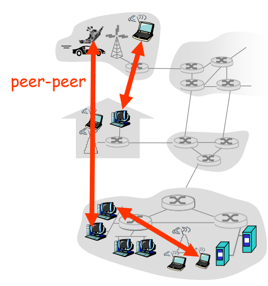


DNS: caching and updating records

- 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

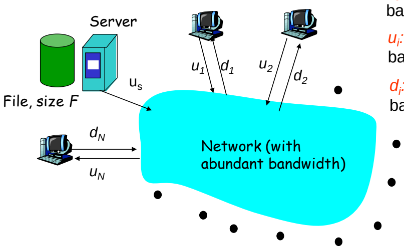
Pure P2P architecture

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



File Distribution: Server-Client vs P2P

Question : How much time to distribute file from one server to N peers?

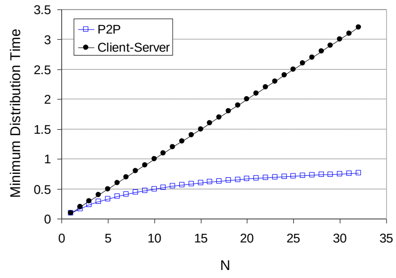


u_s: server upload bandwidth

u_i: peer i upload bandwidth

d_i: peer i download bandwidth

Server-client vs. P2P: example

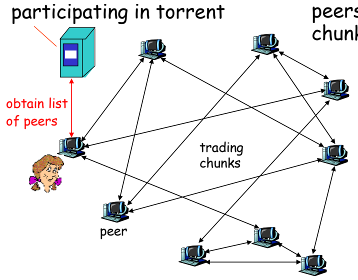


File distribution: BitTorrent

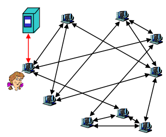
P2P file distribution

tracker: tracks peers participating in torrent

torrent: group of peers exchanging chunks of a file



BitTorrent



- file divided into 256KB *chunks*.
- peer joining torrent:
  - has no chunks, but will accumulate them over time
  - registers with tracker to get list of peers, connects to subset of peers ("neighbors")
- while downloading, peer uploads chunks to other peers.
- peers may come and go
- once peer has entire file, it may (selfishly) leave or (altruistically) remain

BitTorrent

Pulling Chunks

- at any given time, different peers have different subsets of file chunks
- periodically, a peer (Alice) asks each neighbor for list of chunks that they have.
- Alice sends requests for her missing chunks
  - rarest first

Sending Chunks: tit-for-tat

- Alice sends chunks to four neighbors currently sending her chunks *at the highest rate*
  - re-evaluate top 4 every 10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - newly chosen peer may join top 4