# Application layer: overview

Our goals:

- conceptual *and* implementation aspects of application-layer protocols
  - transport-layer service models
  - client-server paradigm
  - peer-to-peer paradigm
- learn about protocols by examining popular application-layer protocols
  - HTTP
  - SMTP, IMAP
  - DNS
- programming network applications
  - socket API

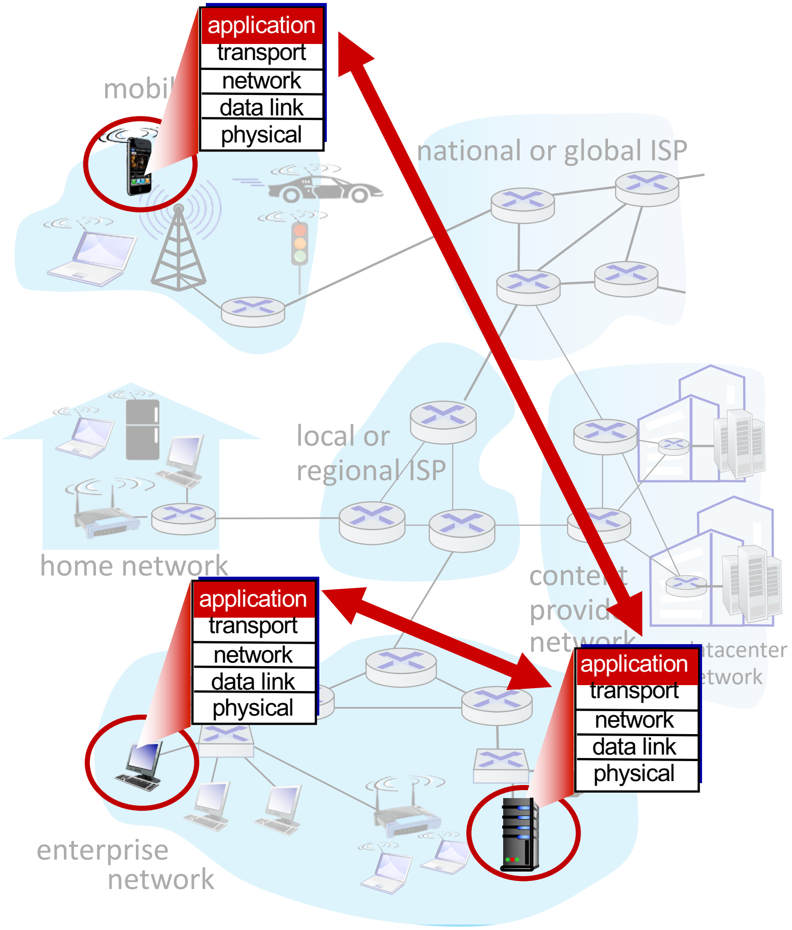
# Creating a network app

write programs that:

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

no need to write software for network-core devices

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



# Client-server paradigm

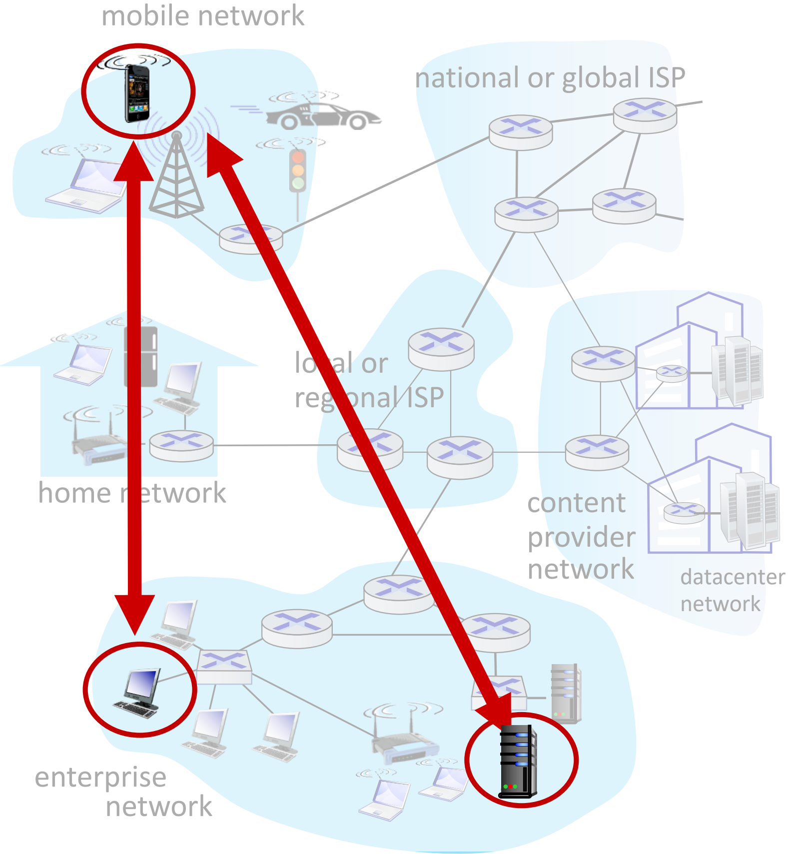
server:

- always-on host
- permanent IP address
- often in data centers, for scaling

clients:

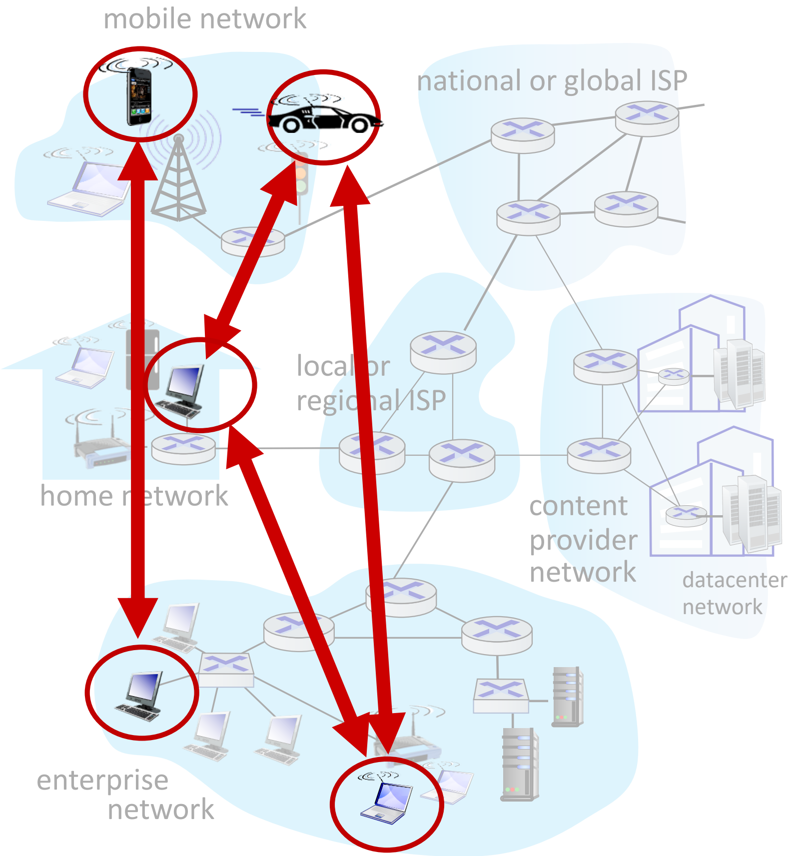
- contact, communicate with server
- may be intermittently connected
- may have dynamic IP addresses
- do *not* communicate directly with each other

- examples: HTTP, IMAP, FTP



# Peer-peer architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers request service from other peers, provide service in return to other peers
  - *self scalability* – new peers bring new service capacity, as well as new service demands
- peers are intermittently connected and change IP addresses
  - complex management
- example: P2P file sharing



# Processes communicating

*process:* program running within a host

- within same host, two processes communicate using inter-process communication (defined by OS)
- processes in different hosts communicate by exchanging messages

clients, servers

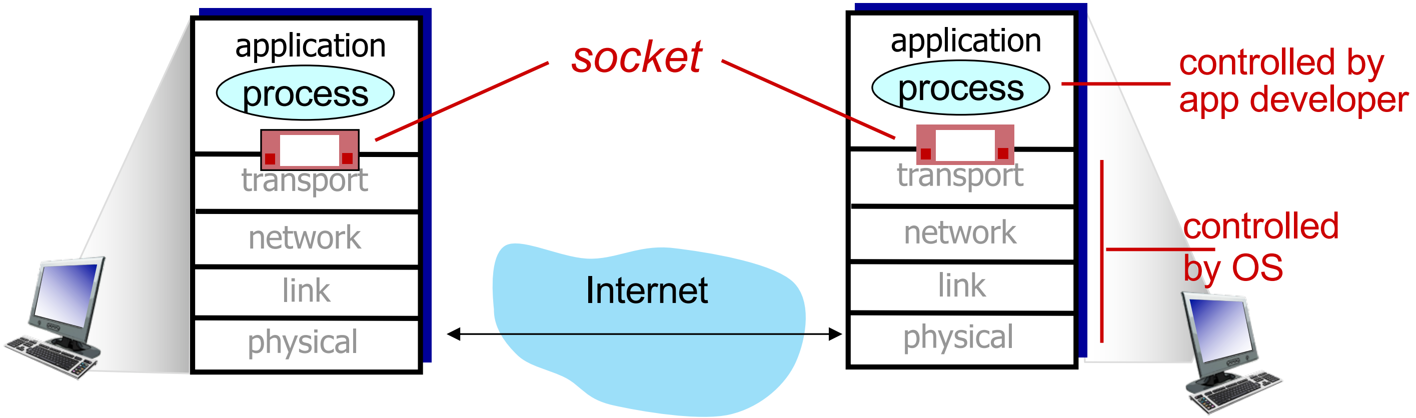
*client process:* process that initiates communication

*server process:* process that waits to be contacted

- 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 to deliver message to socket at receiving process
  - two sockets involved: one on each side



# Addressing processes

- to receive messages, process must have *identifier*
- host device has unique 32-bit IP address
- *Q:* does IP address of host on which process runs suffice for identifying the process?
    - *A:* no, *many* processes can be running on same host

- *identifier* includes both IP address and port numbers associated with process on host.
- example port numbers:
    - HTTP server: 80
    - mail server: 25
- to send HTTP message to gaia.cs.umass.edu web server:
    - IP address: 128.119.245.12
    - port number: 80

# An application-layer protocol defines:

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

open protocols:

- defined in RFCs, everyone has access to protocol definition
- allows for interoperability
- e.g., HTTP, SMTP

proprietary protocols:

- e.g., Skype

# Internet transport protocols services

*TCP service:*

- *reliable transport* between sending and receiving process
- *flow control:* sender won't overwhelm receiver
- *congestion control:* throttle sender when network overloaded
- *does not provide:* timing, minimum throughput guarantee, security
- *connection-oriented:* setup required between client and server processes

*UDP service:*

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

# Socket programming with UDP

UDP: no “connection” between client & server

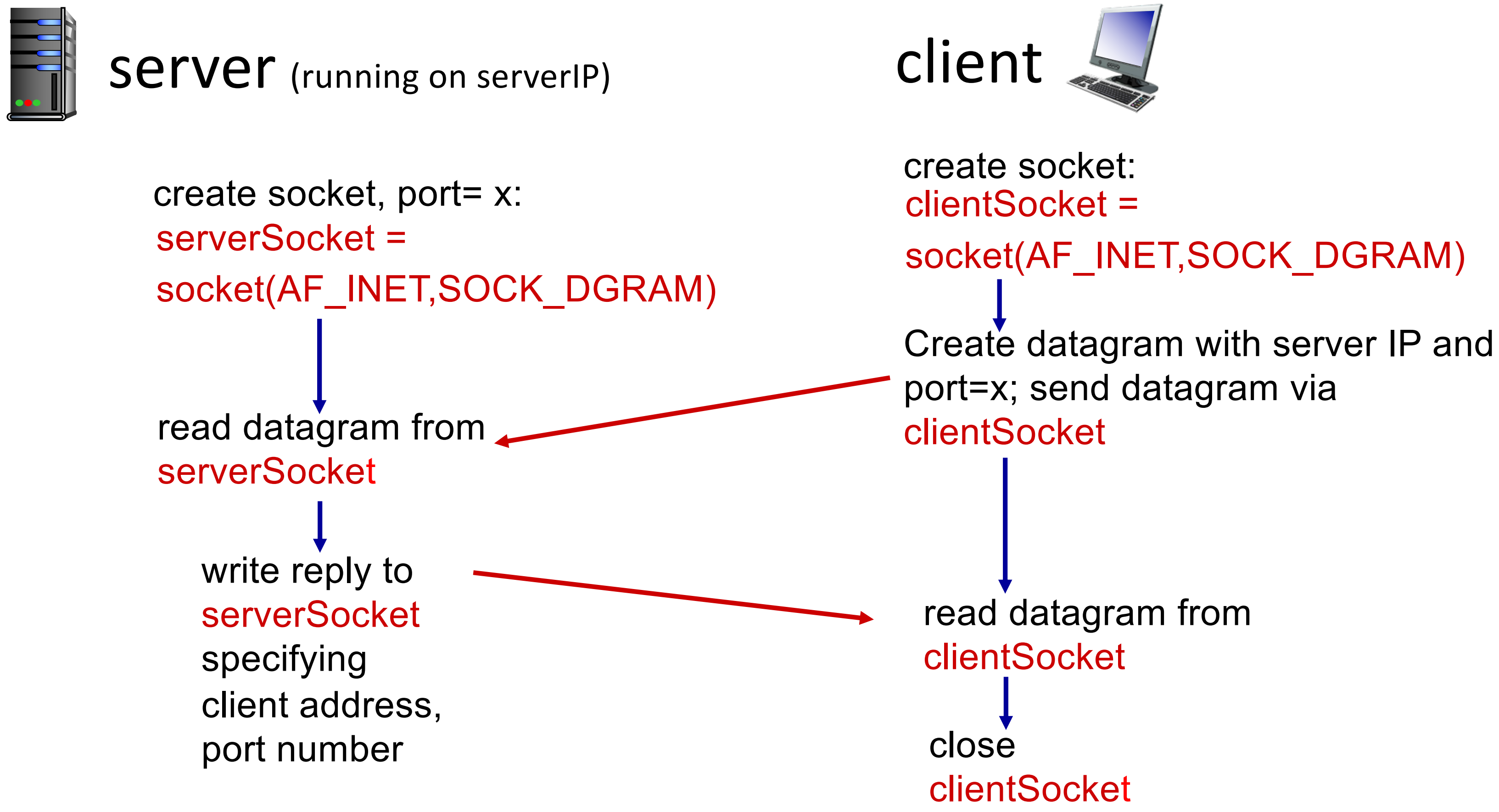
- no handshaking before sending data
- sender explicitly attaches IP destination address and port # to each packet
- receiver extracts sender IP address and port# from received packet

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

Application viewpoint:

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

# Client/server socket interaction: UDP



server (running on serverIP)

create socket, port= x:
serverSocket =
socket(AF_INET,SOCK_DGRAM)

read datagram from
serverSocket

write reply to
serverSocket
specifying
client address,
port number

client

create socket:
clientSocket =
socket(AF_INET,SOCK_DGRAM)

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

read datagram from
clientSocket

close
clientSocket

# Example app: UDP client

*Python UDPClient*

include Python’s socket library →

```
from socket import *
serverName = ‘hostname’
serverPort = 12000
```

create UDP socket for server →

```
clientSocket = socket(AF_INET,
                      SOCK_DGRAM)
```

get user keyboard input →

```
message = raw_input(’Input lowercase sentence:’)
```

attach server name, port to message; send into socket →

```
clientSocket.sendto(message.encode(),
                    (serverName, serverPort))
```

read reply characters from socket into string →

```
modifiedMessage, serverAddress =
                    clientSocket.recvfrom(2048)
```

print out received string and close socket →

```
print modifiedMessage.decode()
clientSocket.close()
```

# Example app: UDP server

*Python UDPServer*

create UDP socket →

bind socket to local port number 12000 →

loop forever →

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

send upper case string back to this client →

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

# Internet transport protocols services

| **application** | **application layer protocol** | **transport protocol** |
|---|---|---|
| file transfer/download | FTP [RFC 959] | TCP |
| e-mail | SMTP [RFC 5321] | TCP |
| Web documents | HTTP 1.1 [RFC 7320] | TCP |
| Internet telephony | SIP [RFC 3261], RTP [RFC 3550], or proprietary | TCP or UDP |
| streaming audio/video | HTTP [RFC 7320], DASH | TCP |
| interactive games | WOW, FPS (proprietary) | UDP or TCP |

# IP addresses: how to get one?

That’s actually two questions:

1. Q: How does a *host* get IP address within its network (host part of address)?
2. Q: How does a *network* get IP address for itself (network part of address)

How does *host* get IP address?

- hard-coded by sysadmin in config file (e.g., /etc/rc.config in UNIX)
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
    - “plug-and-play”

# DHCP: Dynamic Host Configuration Protocol

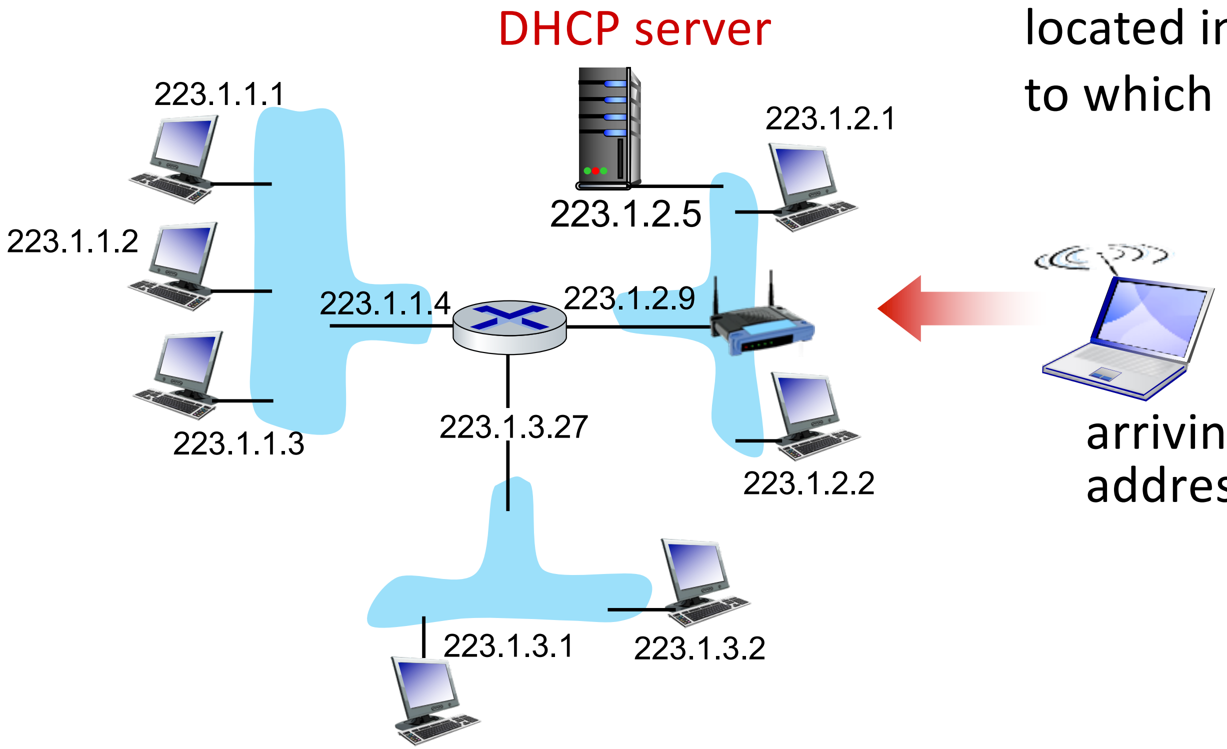
goal: host *dynamically* obtains IP address from network server when it "joins" network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/on)
- support for mobile users who join/leave network

## DHCP overview:

- host broadcasts DHCP discover msg [optional]
- DHCP server responds with DHCP offer msg [optional]
- host requests IP address: DHCP request msg
- DHCP server sends address: DHCP ack msg

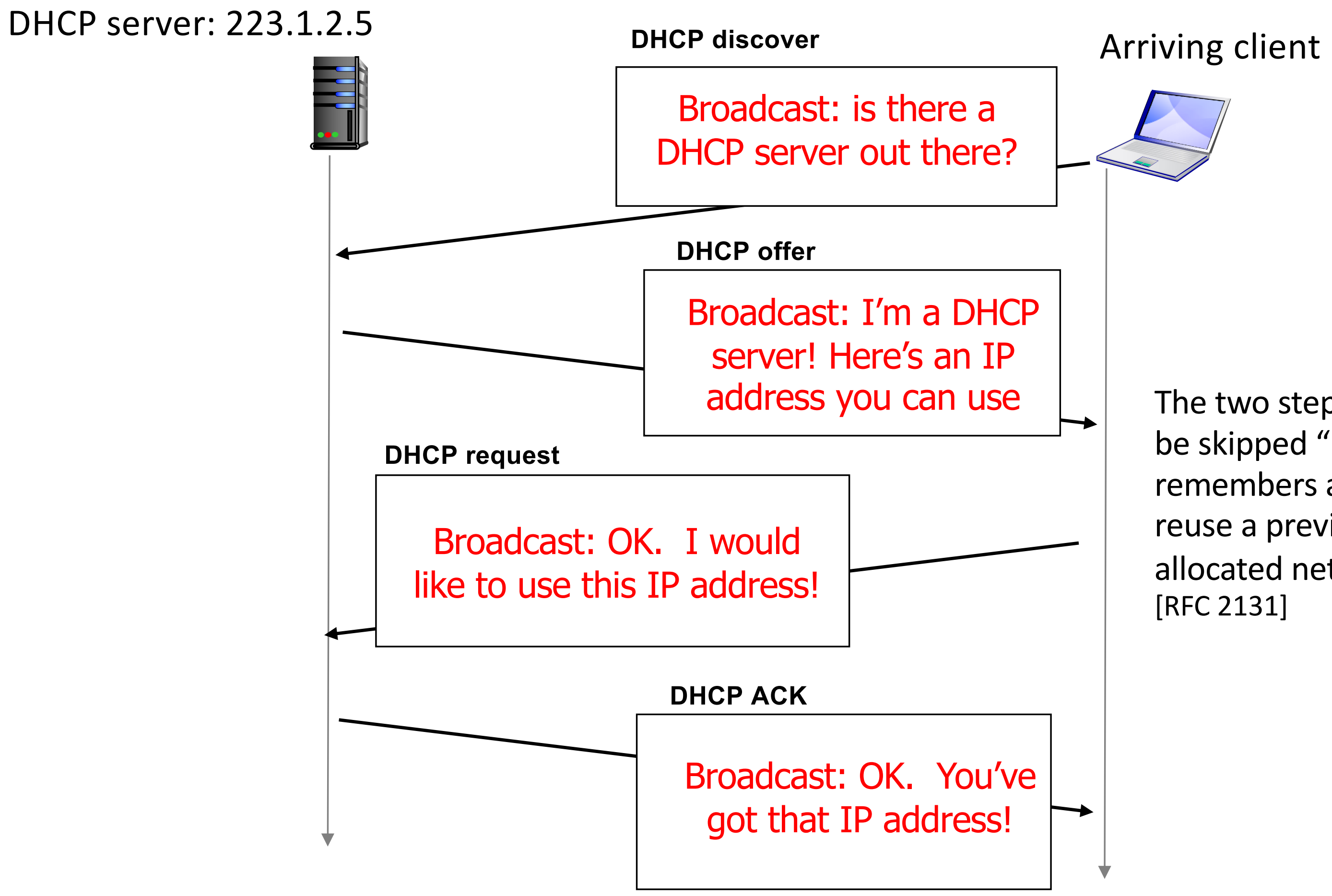
# DHCP client-server scenario



Typically, DHCP server will be co-located in router, serving all subnets to which router is attached

arriving DHCP client needs address in this network

# DHCP client-server scenario



DHCP server: 223.1.2.5

Arriving client

**DHCP discover**

Broadcast: is there a DHCP server out there?

**DHCP offer**

Broadcast: I'm a DHCP server! Here's an IP address you can use

**DHCP request**

Broadcast: OK. I would like to use this IP address!

**DHCP ACK**

Broadcast: OK. You've got that IP address!

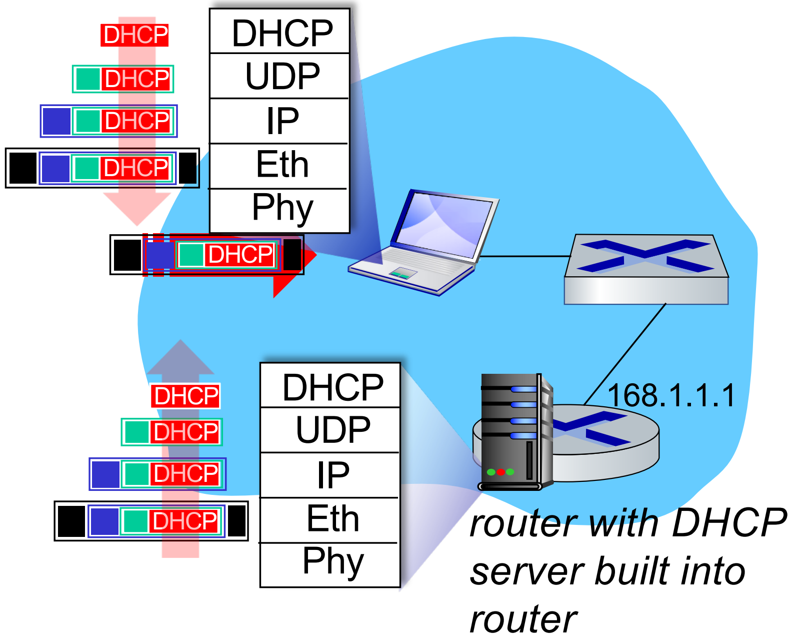
The two steps above can be skipped "if a client remembers and wishes to reuse a previously allocated network address" [RFC 2131]

# DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

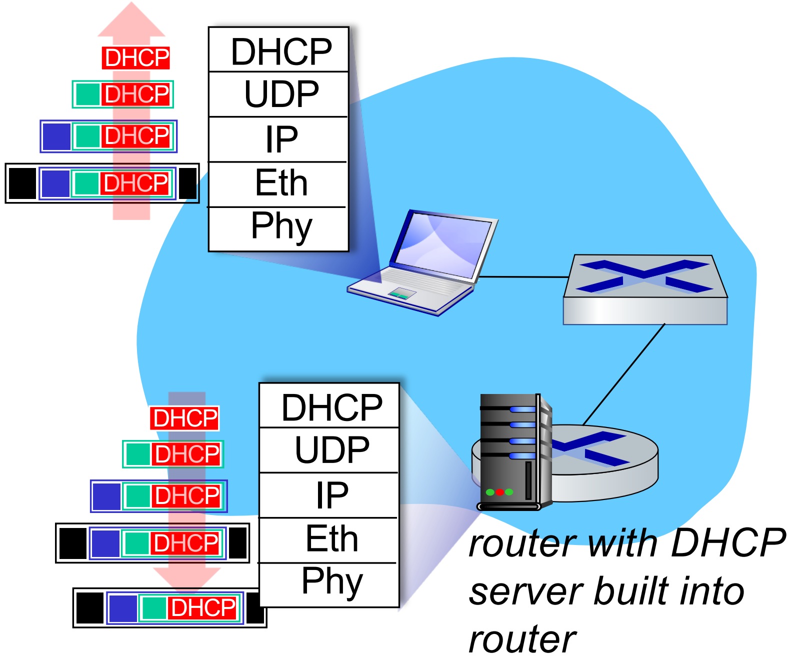
# DHCP: example



*router with DHCP server built into router*

- Connecting laptop will use DHCP to get IP address, address of first-hop router, address of DNS server.
- DHCP REQUEST message encapsulated in UDP, encapsulated in IP, encapsulated in Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet demux'ed to IP demux'ed, UDP demux'ed to DHCP

# DHCP: example



*router with DHCP server built into router*

- DCP server formulates DHCP ACK containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server
- encapsulated DHCP server reply forwarded to client, demuxing up to DHCP at client
- client now knows its IP address, name and IP address of DNS server, IP address of its first-hop router

# IP addresses: how to get one?

*Q:* how does *network* get subnet part of IP address?

*A:* gets allocated portion of its provider ISP's address space

|  |  |  |
|---|---|---|
| ISP's block | 11001000 00010111 00010000 00000000 | 200.23.16.0/20 |

ISP can then allocate out its address space in 8 blocks:

|  |  |  |
|---|---|---|
| Organization 0 | 11001000 00010111 00010000 00000000 | 200.23.16.0/23 |
| Organization 1 | 11001000 00010111 00010010 00000000 | 200.23.18.0/23 |
| Organization 2 | 11001000 00010111 00010100 00000000 | 200.23.20.0/23 |
| ... | ….. …. | …. |
| Organization 7 | 11001000 00010111 00011110 00000000 | 200.23.30.0/23 |

# DNS: Domain Name System

*people:* many identifiers:

- SSN, name, passport #

*Internet hosts, routers:*

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

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

*Domain Name System:*

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

# DNS: services, structure

## DNS services

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

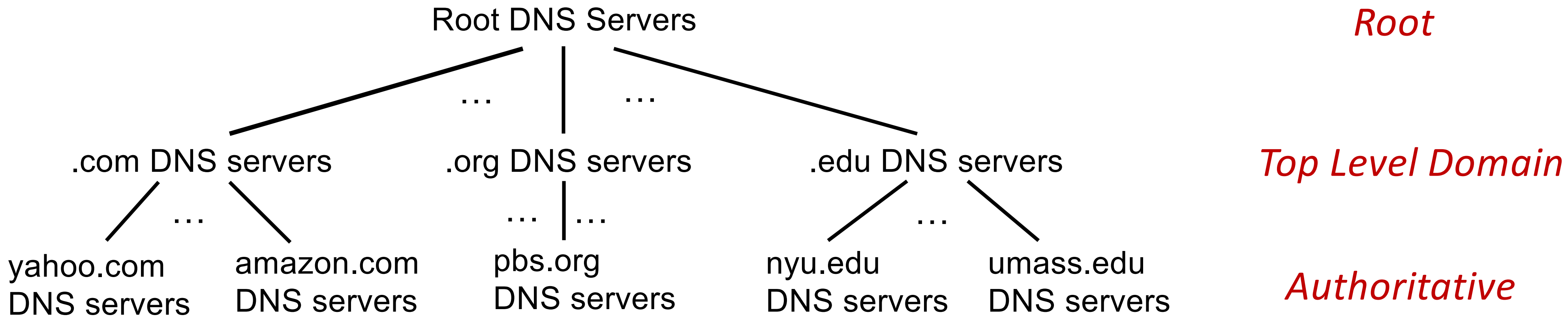
## *Q: Why not centralize DNS?*

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

## *A: doesn‘t scale!*

- Comcast DNS servers alone: 600 Billion (milliards) DNS queries per day

# DNS: a distributed, hierarchical database



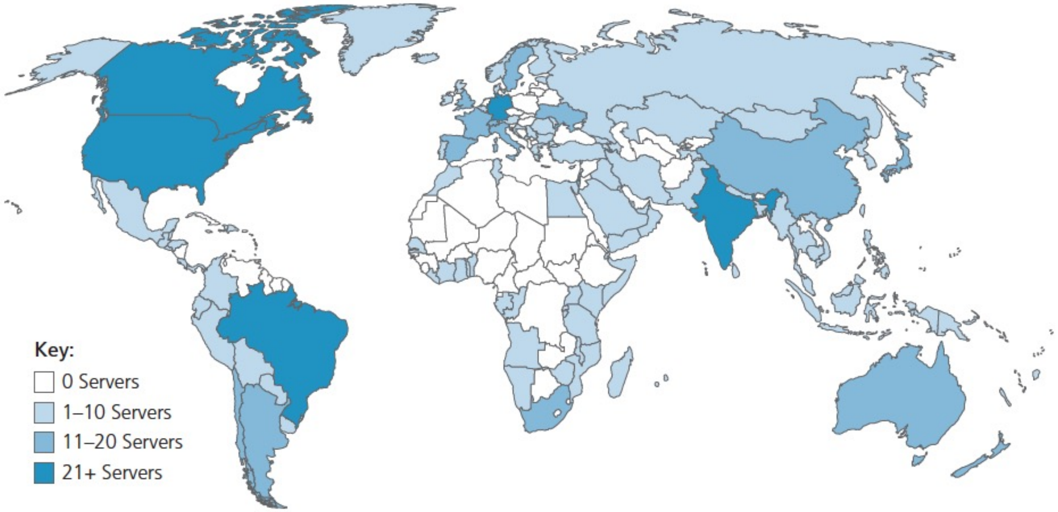
Client wants IP address for www.amazon.com; 1st approximation:

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

# DNS: root name servers

- official, contact-of-last-resort by name servers that can not resolve name
- *incredibly important* Internet function
  - Internet couldn't function without it!
  - DNSSEC – provides security (authentication and message integrity)
- ICANN (Internet Corporation for Assigned Names and Numbers) manages root DNS domain

13 logical root name "servers" worldwide each "server" replicated many times (~200 servers in US)



# TLD: authoritative servers

## Top-Level Domain (TLD) servers:

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

## Authoritative DNS servers:

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

# Local DNS name servers

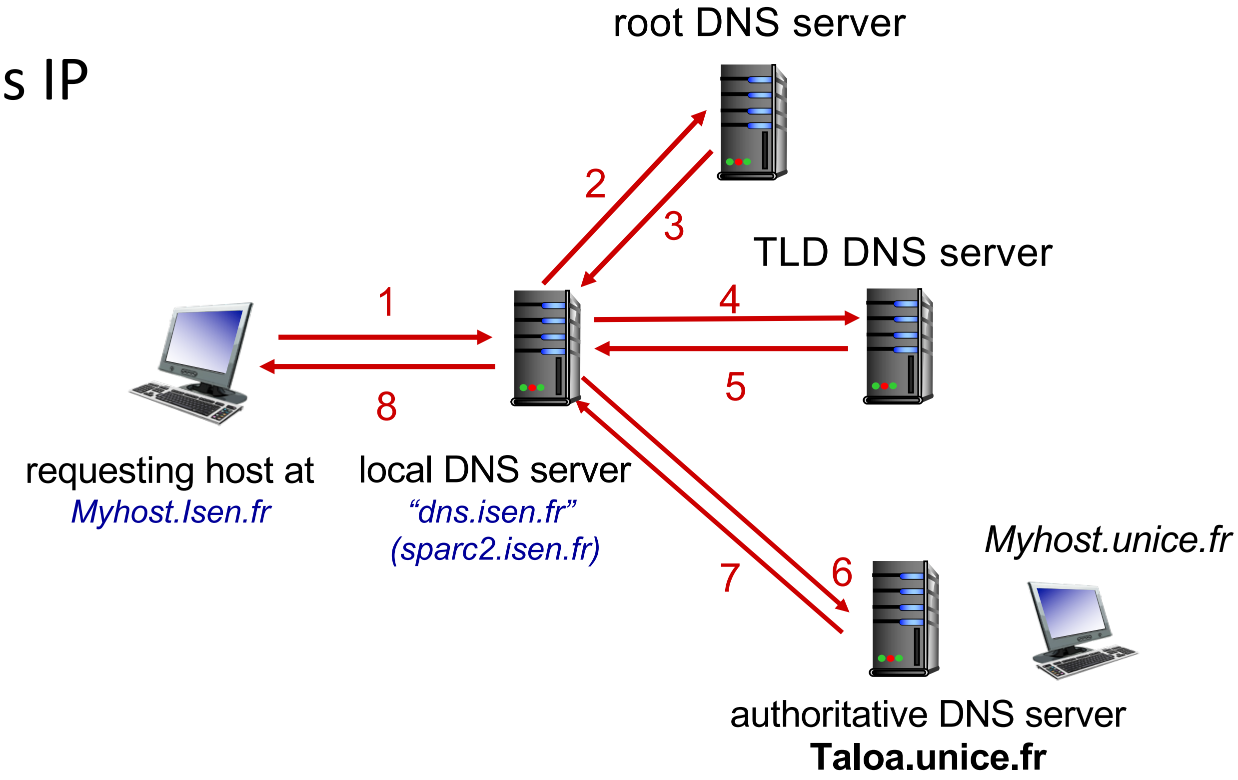
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
  - also called “default name server”
- when host makes DNS query, query is sent to its local DNS server
  - has local cache of recent name-to-address translation pairs (but may be out of date!)
  - acts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

# DNS name resolution: iterated query

Example: host at isen.fr wants IP address for unice.fr

Iterated query:

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

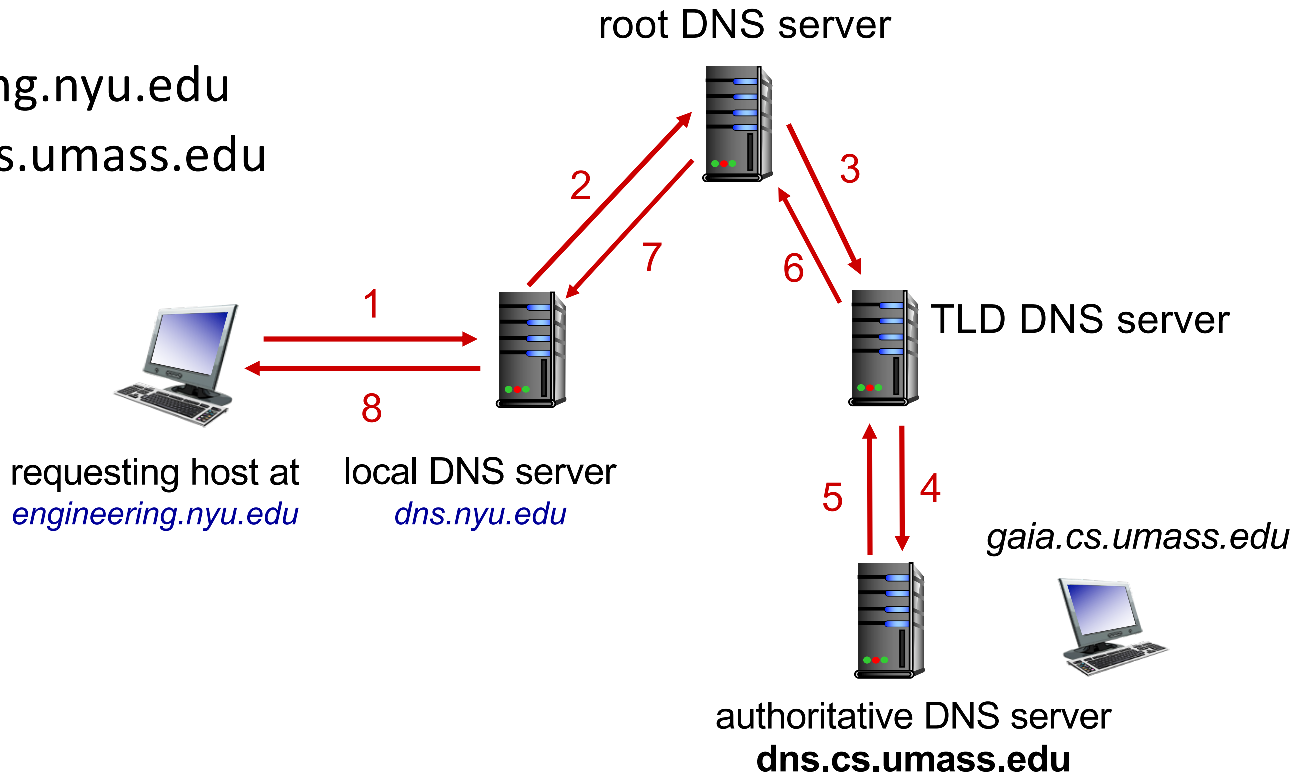


# DNS name resolution: recursive query

Example: host at engineering.nyu.edu wants IP address for gaia.cs.umass.edu

Recursive query:

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



# Caching, Updating DNS Records

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

# DNS records

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

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

## type=A

- `name` is hostname
- `value` is IP address

## type=NS

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

## type=CNAME

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

## type=MX

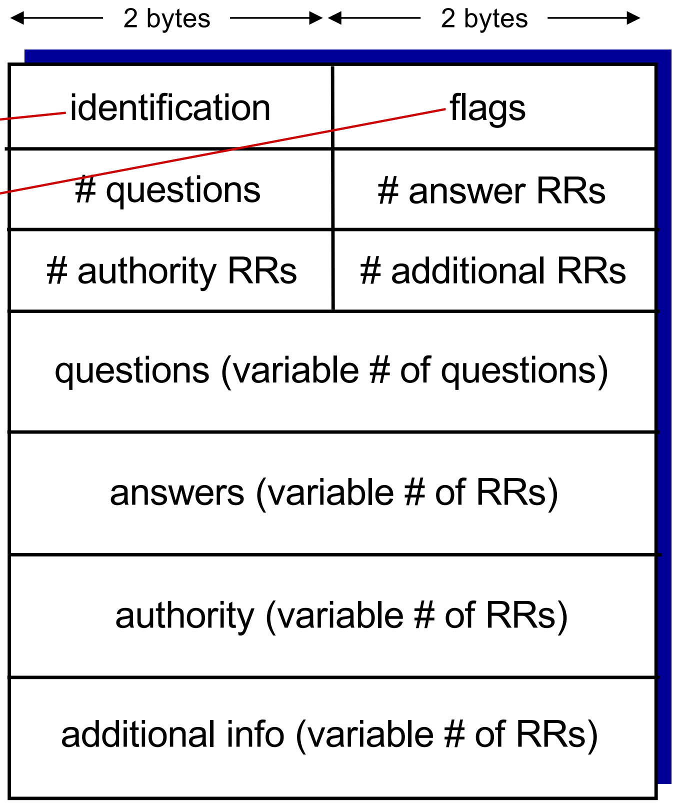
- `value` is name of mailserver associated with `name`

# DNS protocol messages

DNS *query* and *reply* messages, both have same *format:*

message header:

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



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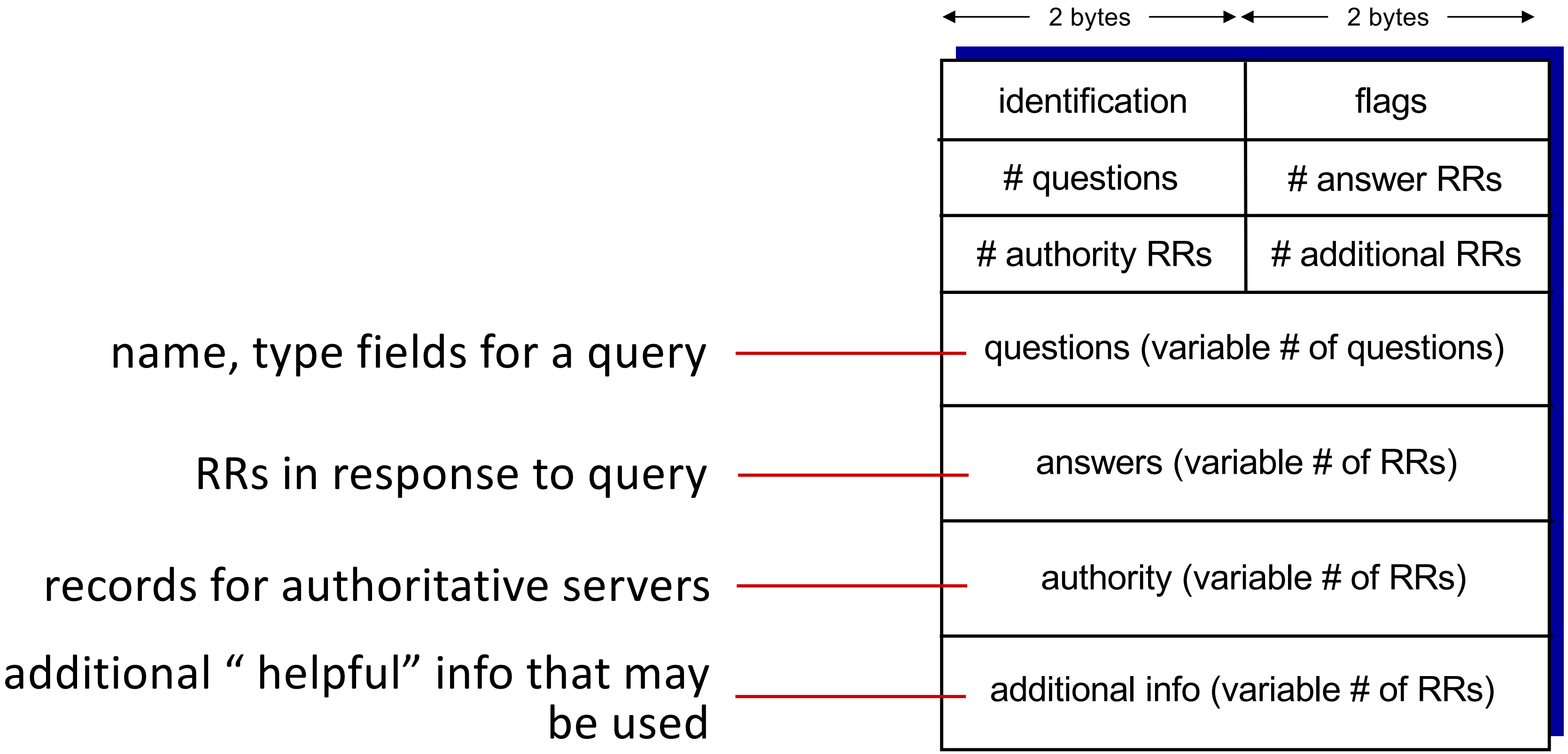
DNS *query* and *reply* messages, both have same *format:*



# 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 NS, A RRs into .com TLD server:

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

    `(dns1.networkutopia.com, 212.212.212.1, A)`
- create authoritative server locally with IP address `212.212.212.1`
  - type A record for www.networkuptopia.com
  - type MX record for networkutopia.com

# DNS security

## DDoS attacks

- bombard root servers with traffic
  - not successful to date
  - traffic filtering
  - local DNS servers cache IPs of TLD servers, allowing root server bypass
- bombard TLD servers
  - potentially more dangerous

## Redirect attacks

- man-in-middle
  - intercept DNS queries
- DNS poisoning
  - send bogus relies to DNS server, which caches

## Exploit DNS for DDoS

- send queries with spoofed source address: target IP
- requires amplification

DNSSEC
[RFC 4033]

# Example of www.unice.fr

Look at list of root servers : https://www.iana.org/domains/root

Gives you the 13 root servers
get lower, you see that the .fr DNS servers ar D.NIC.Fr, …

Nslookup on a DNS server

Whois to know the DNS server used (and lot more)

# Web and HTTP

*First, a quick review…*

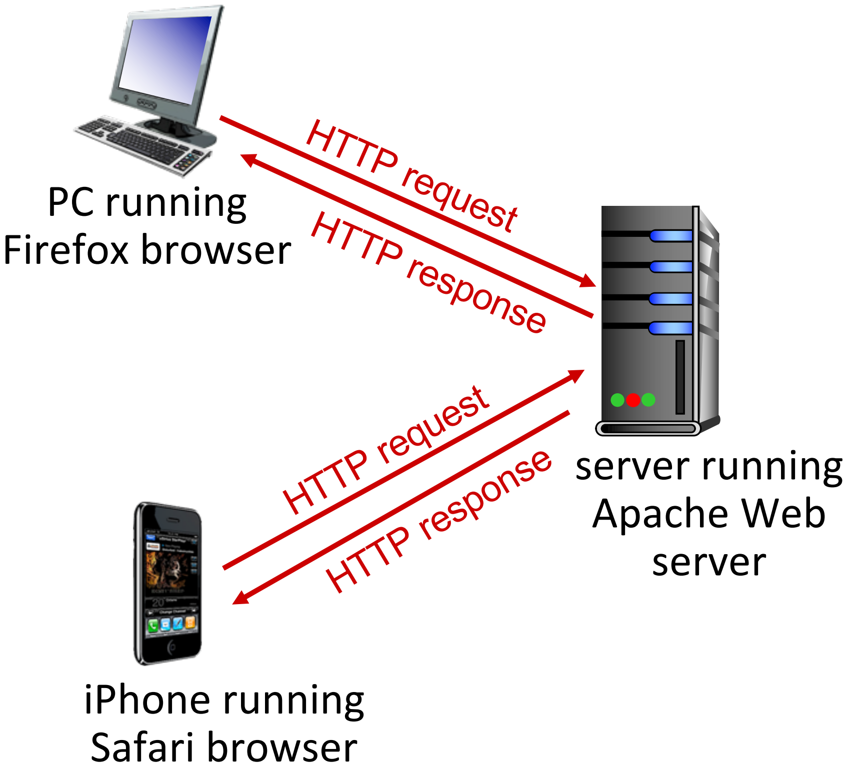
- web page consists of *objects,* each of which can be stored on different Web servers
- object can be HTML file, JPEG image, Java applet, audio file,…
- web page consists of *base HTML-file* which includes *several referenced objects, each* addressable by a *URL,* e.g.,

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

# HTTP overview

**HTTP: hypertext transfer protocol**

- Web's application layer protocol
- client/server model:
  - *client:* browser that requests, receives, (using HTTP protocol) and "displays" Web objects
  - *server:* Web server sends (using HTTP protocol) objects in response to requests



# HTTP overview (continued)

*HTTP 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: two types

*Non-persistent HTTP*

1. TCP connection opened
2. at most one object sent over TCP connection
3. TCP connection closed

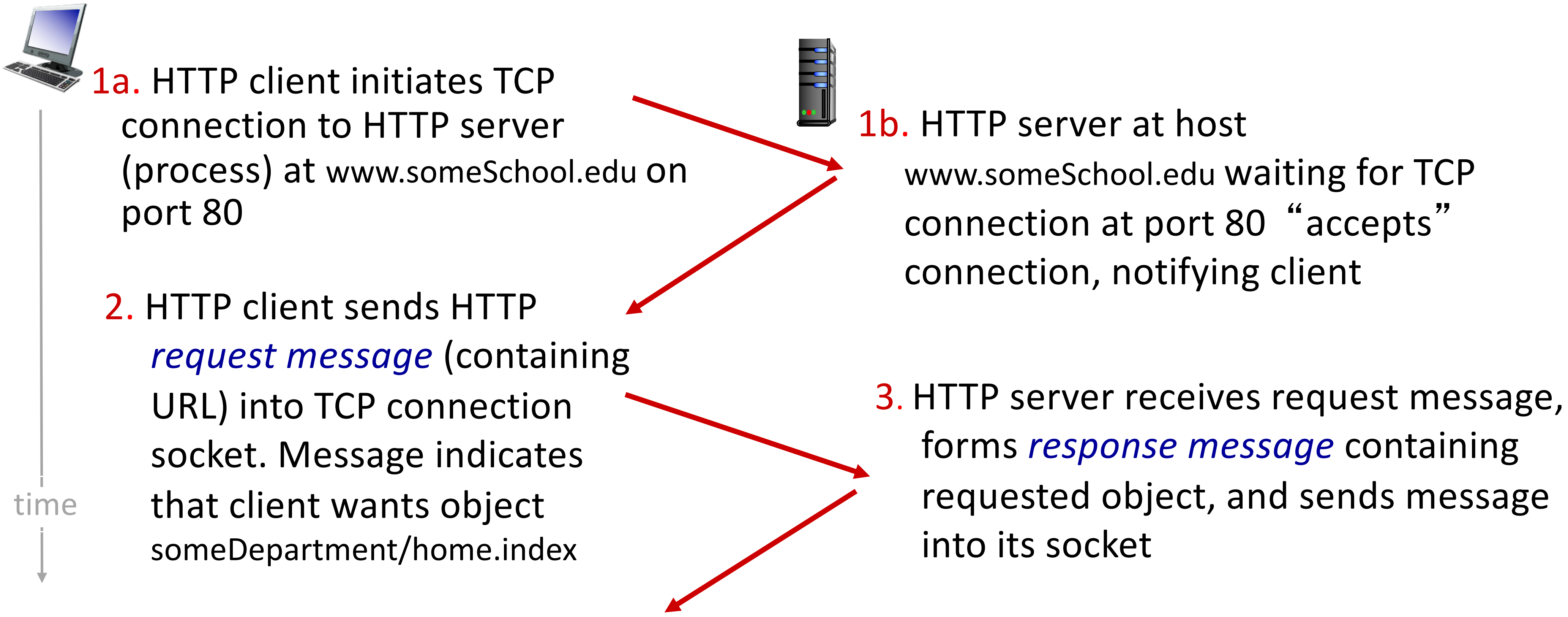
downloading multiple objects required multiple connections

*Persistent HTTP*

- TCP connection opened to a server
- multiple objects can be sent over *single* TCP connection between client, and that server
- TCP connection closed

# Non-persistent HTTP: example

User enters URL: **`www.someSchool.edu/someDepartment/home.index`**
(containing 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

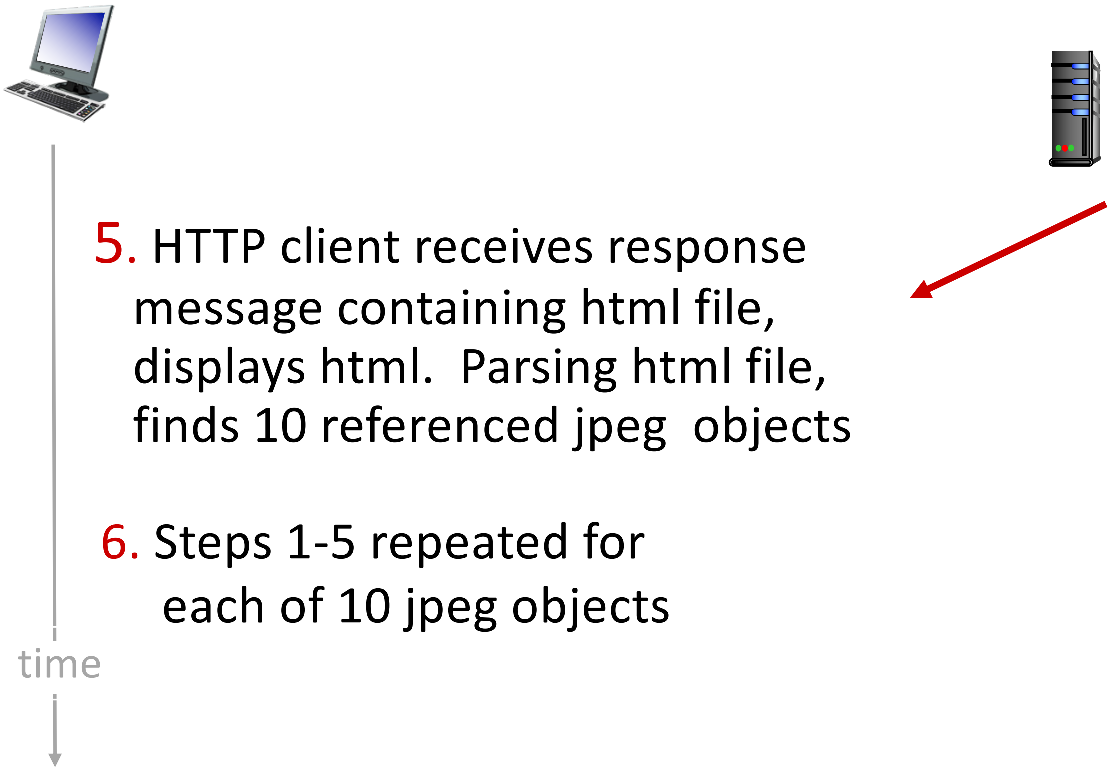
2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket. Message indicates that client wants object someDepartment/home.index

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

# Non-persistent HTTP: example (cont.)

User enters URL: **`www.someSchool.edu/someDepartment/home.index`**

(containing text, references to 10 jpeg images)



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

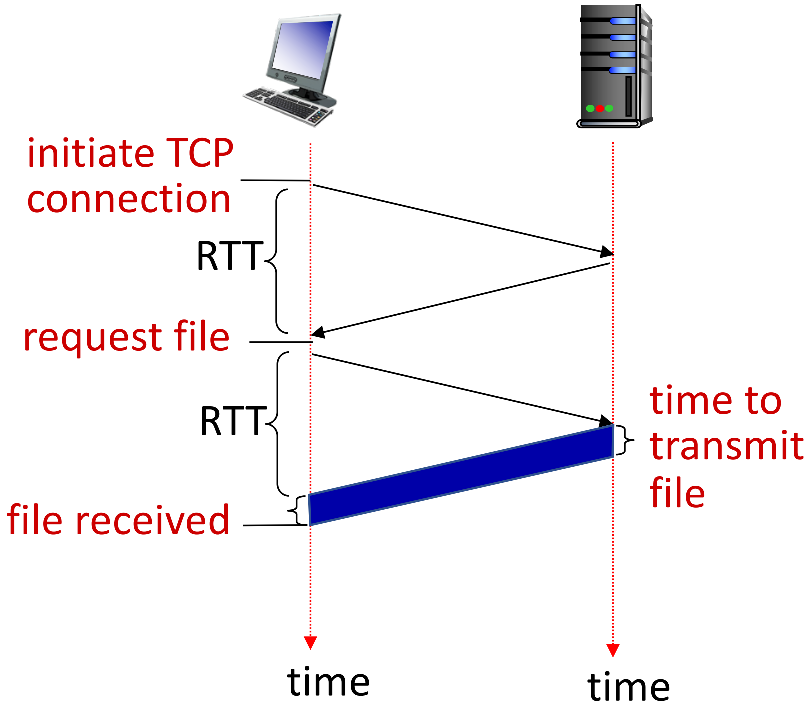
6. Steps 1-5 repeated for each of 10 jpeg objects

# Non-persistent HTTP: response time

**RTT (definition):** time for a small packet to travel from client to server and back

**HTTP response time (per object):**

- one RTT to initiate TCP connection
- one RTT for HTTP request and first few bytes of HTTP response to return
- obect/file transmission time



*Non-persistent HTTP response time = 2RTT+ file transmission time*

# Persistent HTTP (HTTP 1.1)

*Non-persistent HTTP issues:*

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

*Persistent HTTP (HTTP1.1):*

- 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 (cutting response time in half)

# HTTP request message

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

carriage return character

line-feed character

request line (GET, POST, HEAD commands)

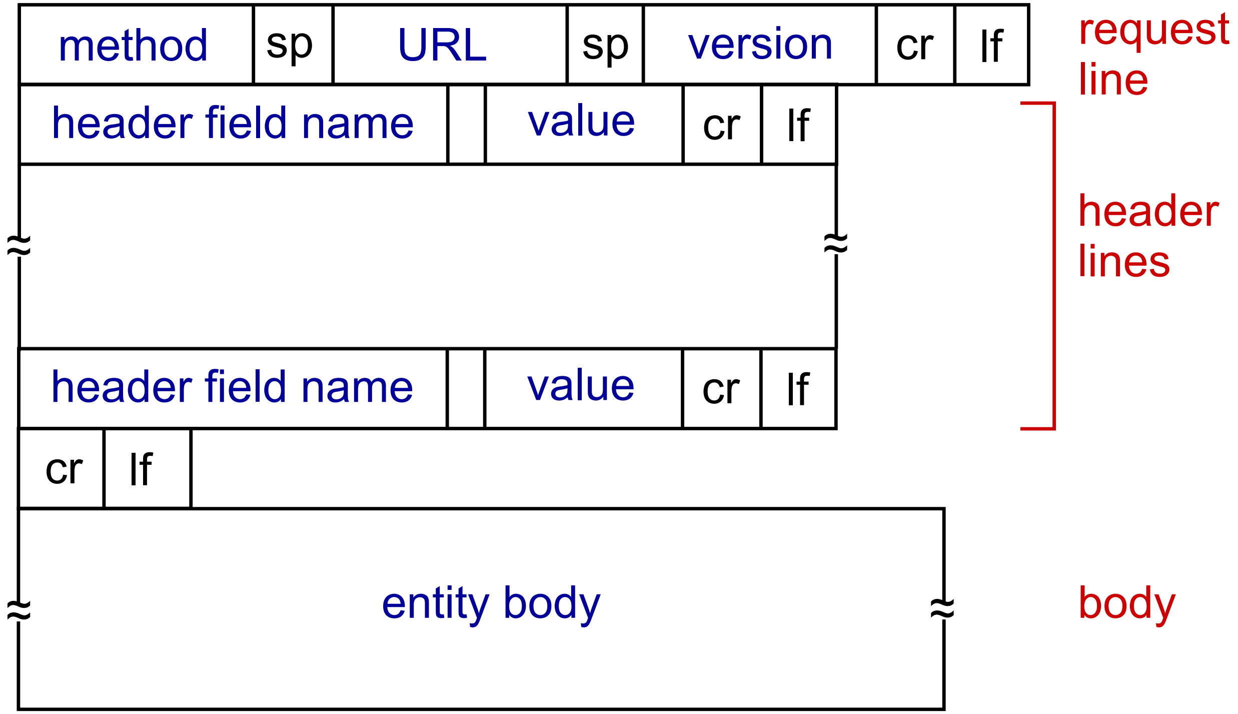
header lines

```
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
```

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

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

# HTTP request message: general format



# Other HTTP request messages

## POST method:

- web page often includes form input
- user input sent from client to server in entity body of HTTP POST request message

## GET method (for sending data to server):

- include user data in URL field of HTTP GET request message (following a ‘?’):

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

## HEAD method:

- requests headers (only) that would be returned *if* specified URL were requested with an HTTP GET method.

## PUT method:

- uploads new file (object) to server
- completely replaces file that exists at specified URL with content in entity body of POST HTTP request message

# 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 ...
```

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

# 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 message

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

  400 Bad Request
  - request msg not understood by server

  404 Not Found
  - requested document not found on this server

  505 HTTP Version Not Supported

# Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet www.i3s.unice.fr 80
```

- opens TCP connection to port 80 (default HTTP server port) at www.i3s.unice.fr .
- anything typed in will be sent to port 80 at `www.i3s.unice.fr`

2. type in a GET HTTP request:

```
GET /~deneire/ HTTP/1.1
Host: www.i3s.unice.fr
```

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

3. look at response message sent by HTTP server!

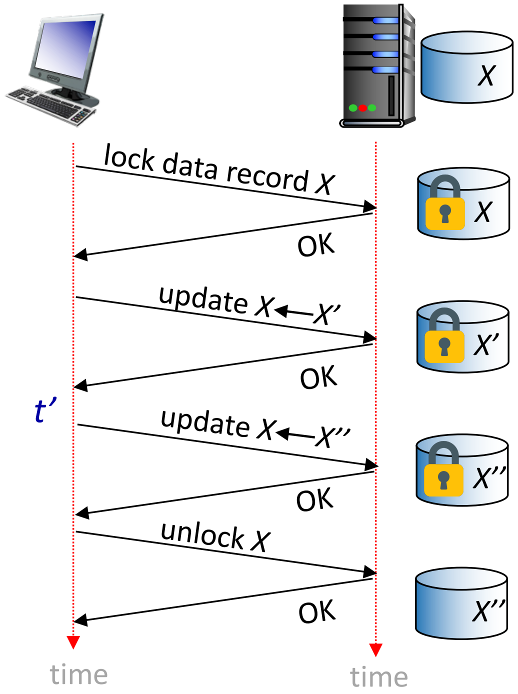
(or use Wireshark to look at captured HTTP request/response)

# Maintaining user/server state: cookies

Recall: HTTP GET/response interaction is *stateless*

- no notion of multi-step exchanges of HTTP messages to complete a Web "transaction"
  - no need for client/server to track "state" of multi-step exchange
  - all HTTP requests are independent of each other
  - no need for client/server to "recover" from a partially-completed-but-never-completely-completed transaction

a stateful protocol: client makes two changes to X, or none at all



*Q:* what happens if network connection or client crashes at *t'* ?

# Maintaining user/server state: cookies

Web sites and client browser use *cookies* to maintain some state between transactions

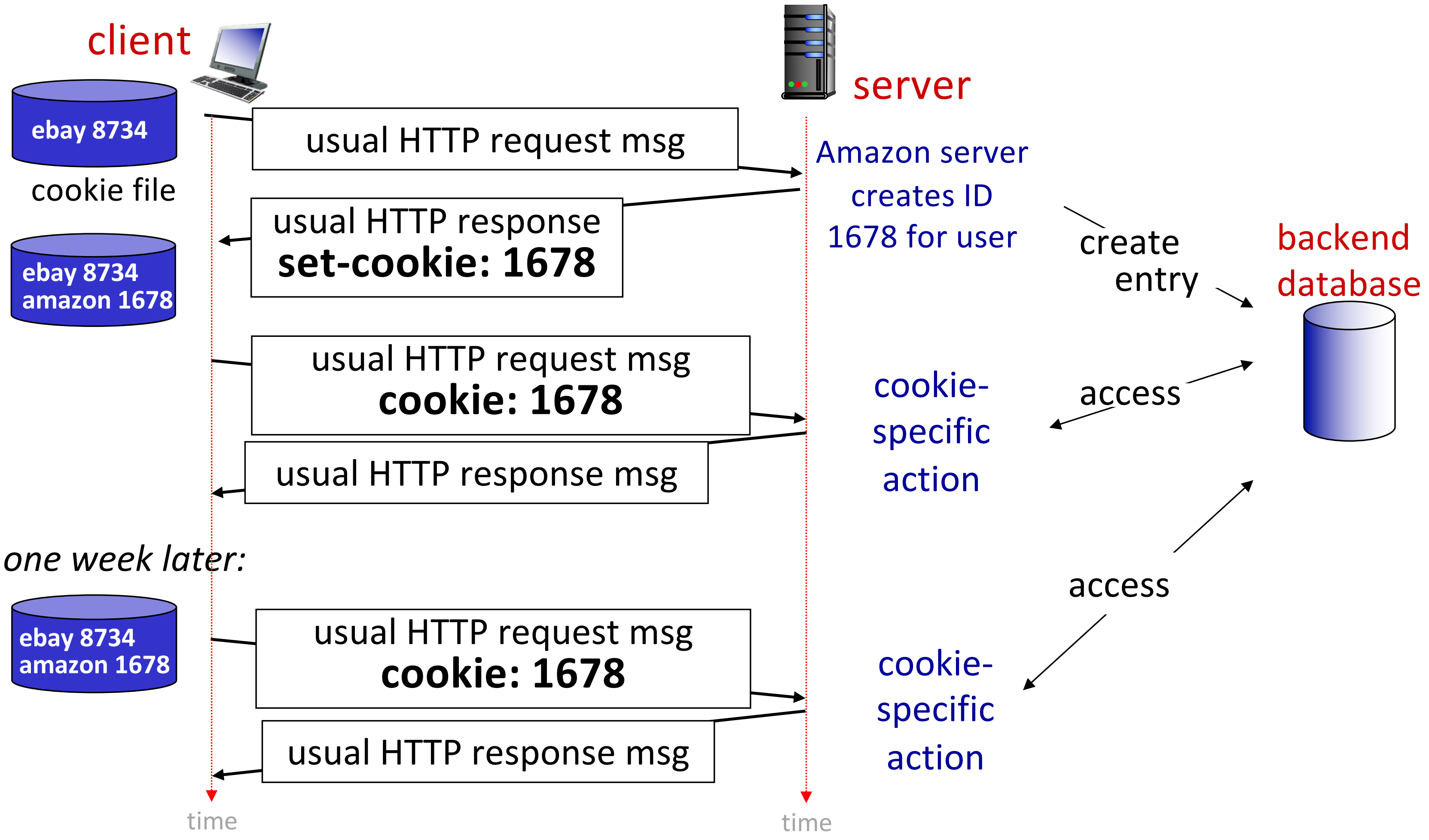
*four components:*

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

Example:

- Susan uses browser on laptop, visits specific e-commerce site for first time
- when initial HTTP requests arrives at site, site creates:
  - unique ID (aka "cookie")
  - entry in backend database for ID
- subsequent HTTP requests from Susan to this site will contain cookie ID value, allowing site to "identify" Susan

# Maintaining user/server state: cookies



# HTTP cookies: comments

*What cookies can be used for:*

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

*Challenge: How to keep state:*

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

aside

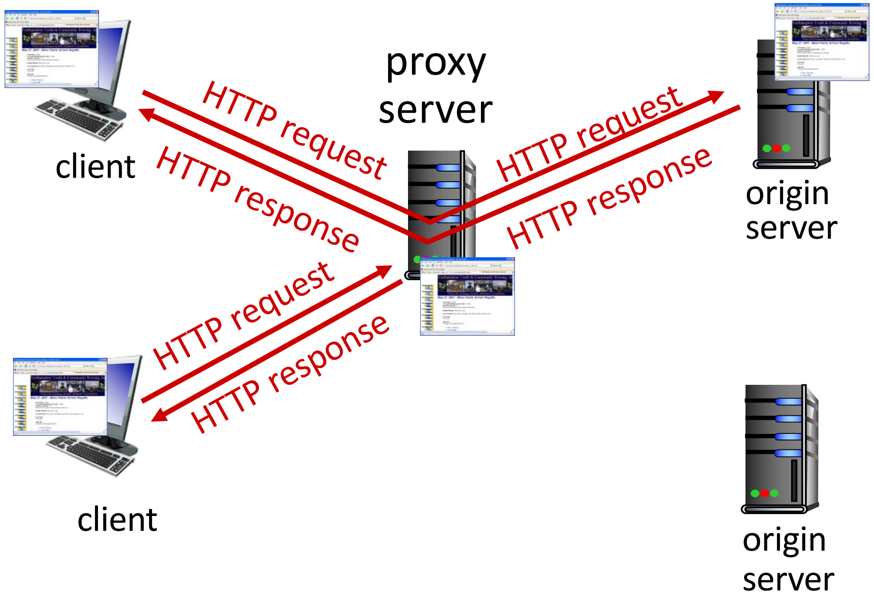
*cookies and privacy:*

- cookies permit sites to *learn* a lot about you on their site.
- third party persistent cookies (tracking cookies) allow common identity (cookie value) to be tracked across multiple web sites

# Web caches (proxy servers)

*Goal:* satisfy client request without involving origin server

- user configures browser to point to a *Web cache*
- browser sends all HTTP requests to cache
  - *if* object in cache: cache returns object to client
  - *else* cache requests object from origin server, caches received object, then returns object to client



# Web caches (proxy servers)

- Web 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
  - cache is closer to client
- reduce traffic on an institution's access link
- Internet is dense with caches
  - enables "poor" content providers to more effectively deliver content

# Caching example

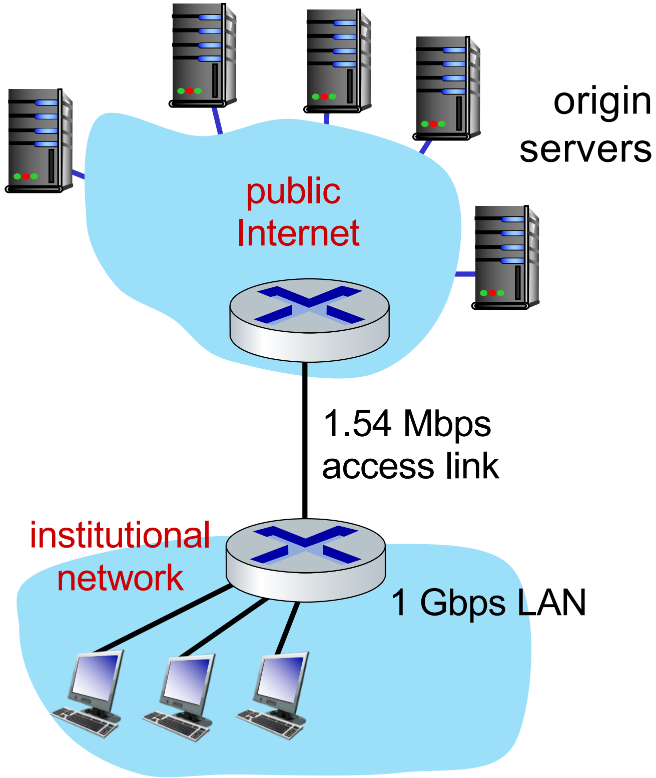
*Scenario:*

- access link rate: 1.54 Mbps
- RTT from institutional router to server: 2 sec
- Web object size: 100K bits
- Average request rate from browsers to origin servers: 15/sec
    - average data rate to browsers: 1.50 Mbps

*Performance:*

- LAN utilization: .0015
- access link utilization = .97
- end-end delay = Internet delay + access link delay + LAN delay
  = 2 sec + minutes + usecs

*problem:* large delays at high utilization!



# Caching example: buy a faster access link

*Scenario:* 154 Mbps

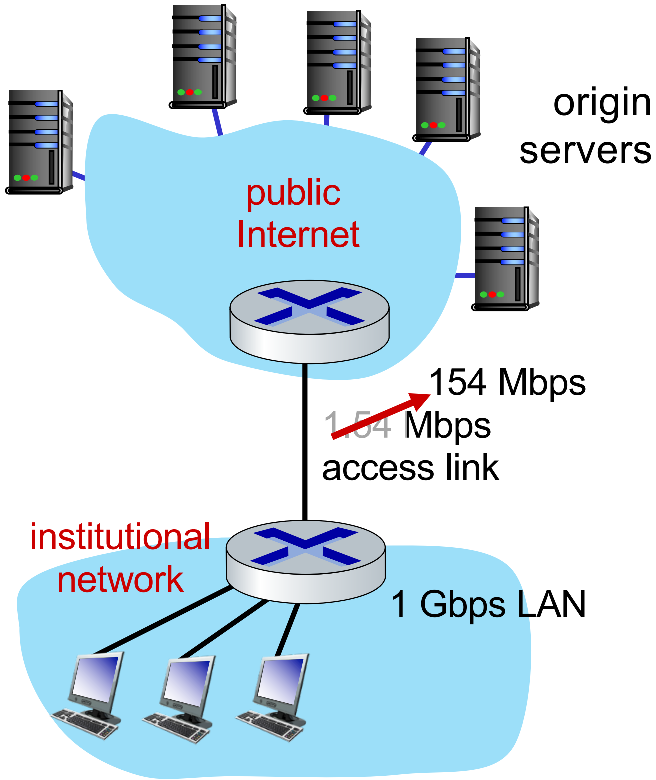
- access link rate: ~~1.54~~ Mbps
- RTT from institutional router to server: 2 sec
- Web object size: 100K bits
- Avg request rate from browsers to origin servers: 15/sec
    - avg data rate to browsers: 1.50 Mbps

*Performance:*

- LAN utilization: .0015
- access link utilization = ~~.97~~ → .0097
- end-end delay = Internet delay + access link delay + LAN delay

  = 2 sec + ~~minutes~~ + usecs

*Cost:* faster access link (expensive!) msecs



# Caching example: install a web cache

*Scenario:*

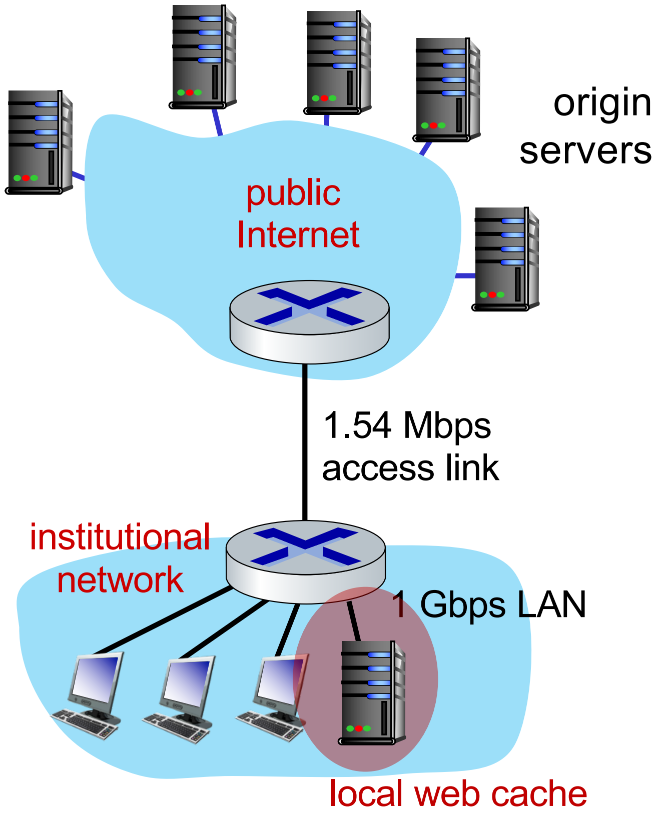
- access link rate: 1.54 Mbps
- RTT from institutional router to server: 2 sec
- Web object size: 100K bits
- Avg request rate from browsers to origin servers: 15/sec
  - avg data rate to browsers: 1.50 Mbps

*Performance:*

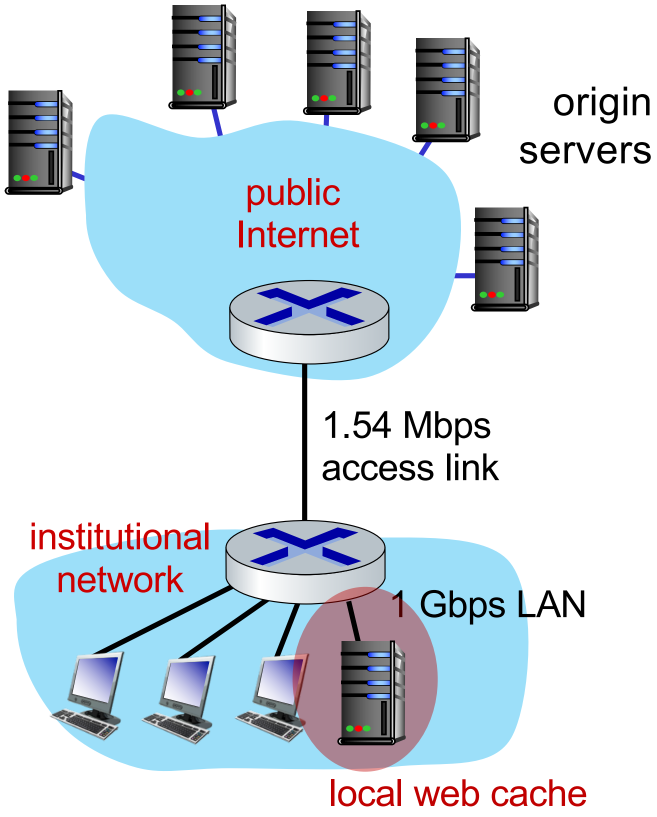
- LAN utilization: .?
- access link utilization = ?
- average end-end delay = ?

*How to compute link utilization, delay?*

*Cost:* web cache (cheap!)



# Caching example: install a web cache



## Calculating access link utilization, end-end delay with cache:

- suppose cache hit rate is 0.4: 40% requests satisfied at cache, 60% requests satisfied at origin
- access link: 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
- average end-end delay

  = 0.6 * (delay from origin servers)

  + 0.4 * (delay when satisfied at cache)

  = 0.6 (2.01) + 0.4 (~msecs) = ~ 1.2 secs

*lower average end-end delay than with 154 Mbps link (and cheaper too!)*

# Conditional GET

*Goal:* don’t send object if cache has up-to-date cached version

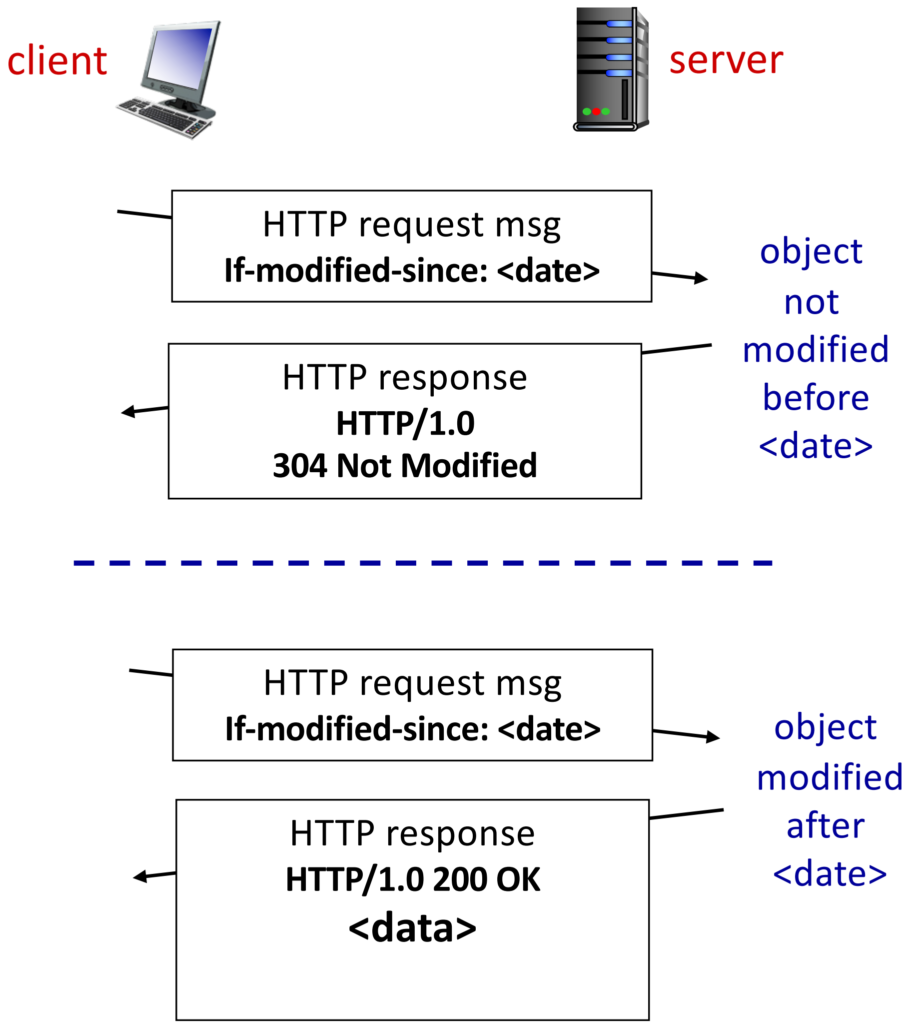
- no object transmission delay
- lower link utilization

- *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**



client

server

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

HTTP response
**HTTP/1.0**
**304 Not Modified**

object not modified before <date>

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

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

object modified after <date>

# HTTP/2

*Key goal:* decreased delay in multi-object HTTP requests

*HTTP1.1:* introduced multiple, pipelined GETs over single TCP connection

- server responds *in-order* (FCFS: first-come-first-served scheduling) to GET requests
- with FCFS, small object may have to wait for transmission (head-of-line (HOL) blocking) behind large object(s)
- loss recovery (retransmitting lost TCP segments) stalls object transmission

# HTTP/2

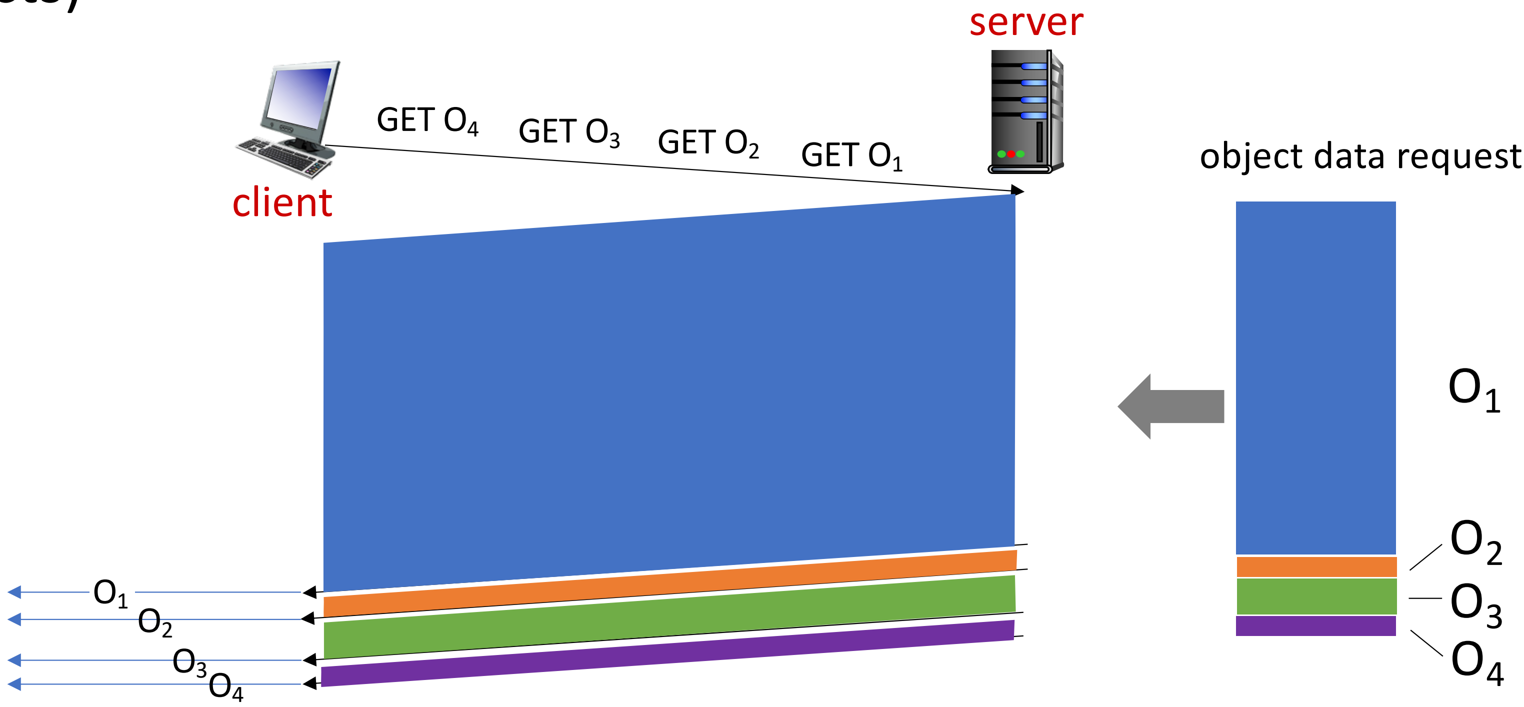
*Key goal:* decreased delay in multi-object HTTP requests

*HTTP/2:* [RFC 7540, 2015] increased flexibility at *server* in sending objects to client:

- methods, status codes, most header fields unchanged from HTTP 1.1
- transmission order of requested objects based on client-specified object priority (not necessarily FCFS)
- *push* unrequested objects to client
- divide objects into frames, schedule frames to mitigate HOL blocking

# HTTP/2: mitigating HOL blocking

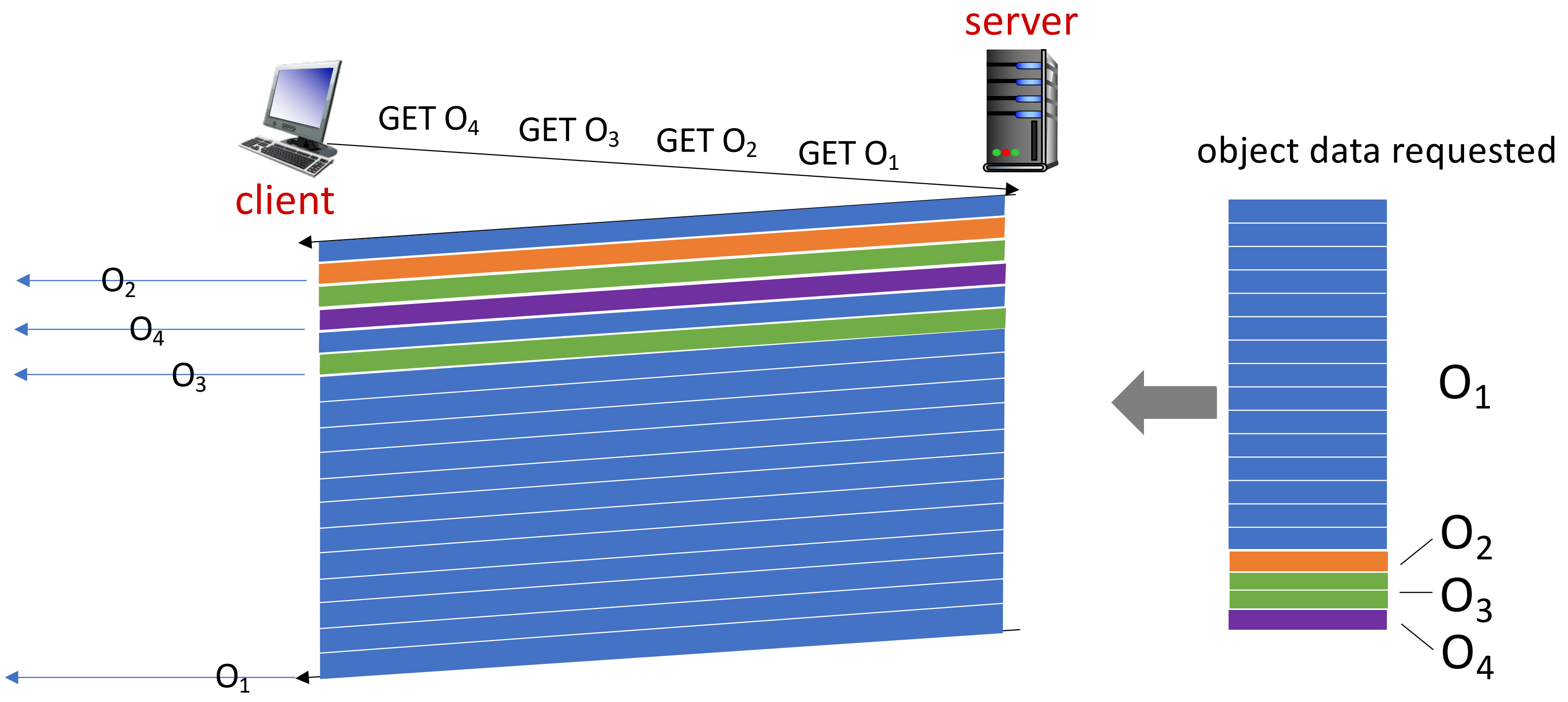
HTTP 1.1: client requests 1 large object (e.g., video file, and 3 smaller objects)



*objects delivered in order requested: $O_2$, $O_3$, $O_4$ wait behind $O_1$*

# HTTP/2: mitigating HOL blocking

HTTP/2: objects divided into frames, frame transmission interleaved



*$O_2$, $O_3$, $O_4$ delivered quickly, $O_1$ slightly delayed*

# HTTP/2 to HTTP/3

*Key goal:* decreased delay in multi-object HTTP requests

HTTP/2 over single TCP connection means:

- recovery from packet loss still stalls all object transmissions
  - as in HTTP 1.1, browsers have incentive to open multiple parallel TCP connections to reduce stalling, increase overall throughput
- no security over vanilla TCP connection
- HTTP/3: adds security , per object error- and congestion-control (more pipelining) over UDP

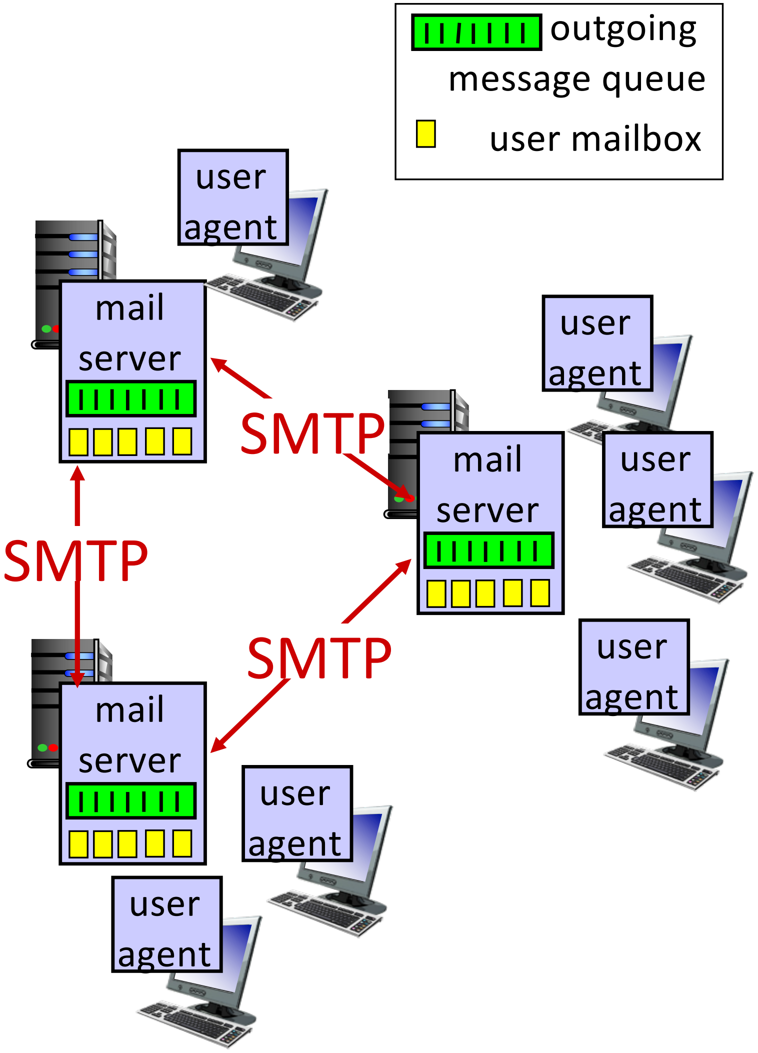
# E-mail

## Three major components:

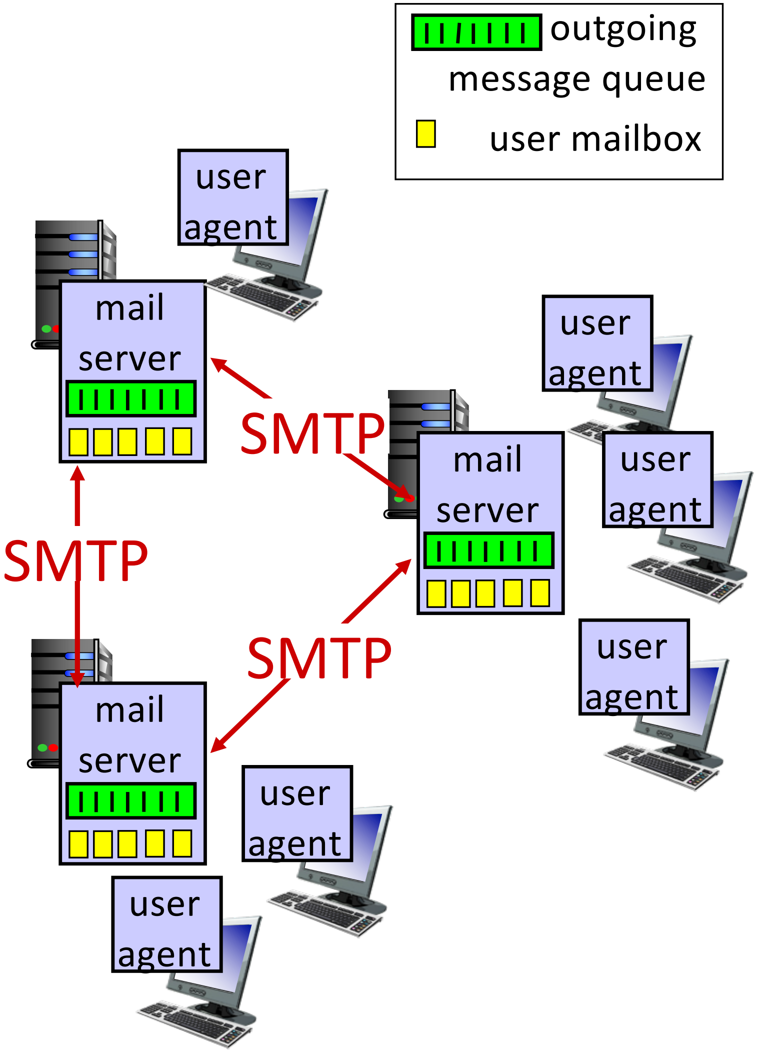
- user agents
- mail servers
- simple mail transfer protocol: SMTP

## User Agent

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



# E-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

# E-mail: the RFC (5321)

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

# Scenario: Alice sends e-mail to Bob

1) Alice uses UA to compose e-mail message "to" bob@someschool.edu

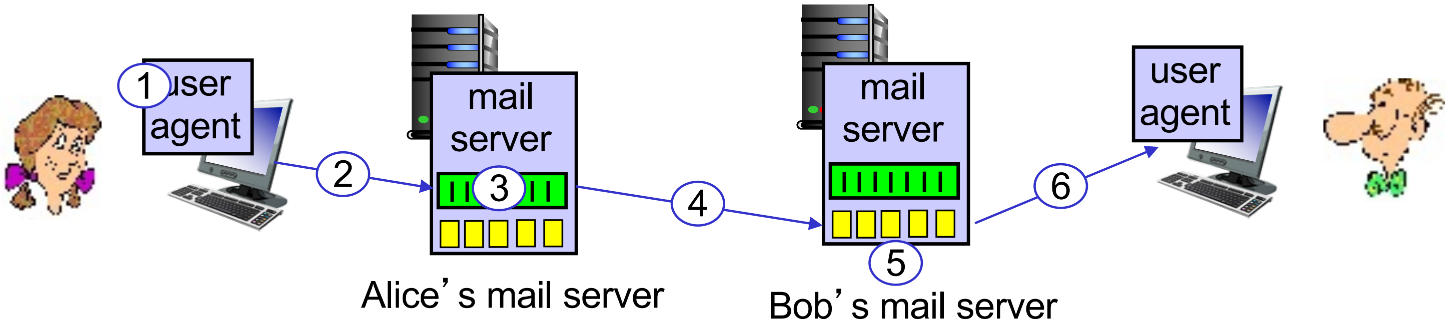
2) Alice's UA sends message to her mail server; message placed in message queue

3) client side of SMTP opens TCP connection with Bob's mail server

4) SMTP client sends Alice's message over the TCP connection

5) Bob's mail server places the message in Bob's mailbox

6) Bob invokes his user agent to read message



# Sample SMTP interaction

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

# Try SMTP interaction for yourself:

telnet <servername> 25

- see 220 reply from server
- enter HELO, MAIL FROM:, RCPT TO:, DATA, QUIT commands

above lets you send email without using e-mail client (reader)

*Note: this will only work if <servername> allows telnet connections to port 25 (this is becoming increasingly rare because of security concerns)*

# SMTP: closing observations

*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

- 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

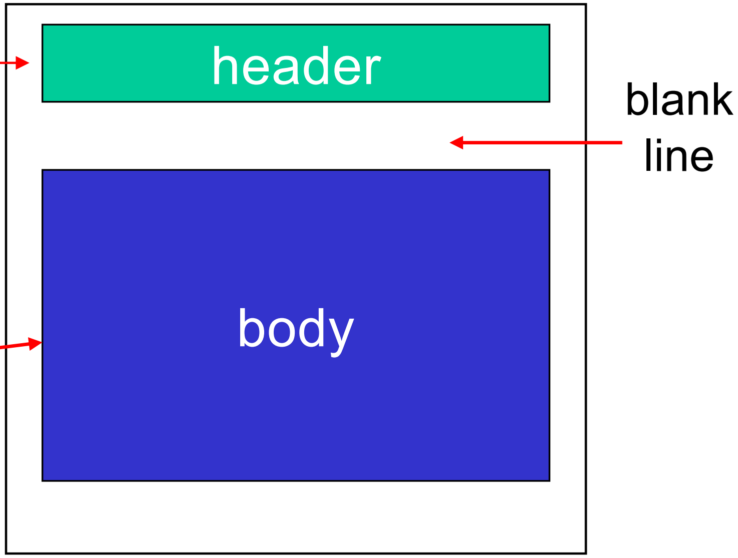
# Mail message format

SMTP: protocol for exchanging e-mail messages, defined in RFC 531 (like HTTP)

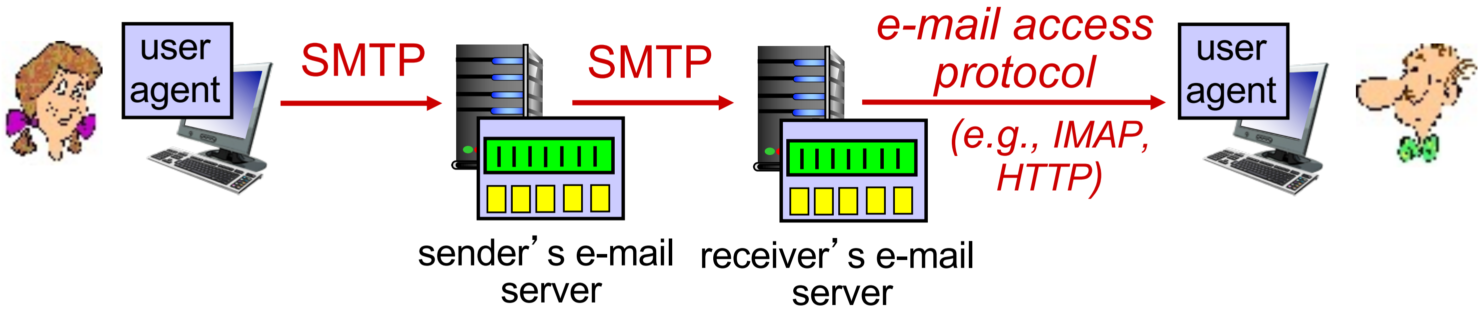
RFC 822 defines *syntax* for e-mail message itself (like HTML)

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

  these lines, within the body of the email message area different from SMTP MAIL FROM:, RCPT TO: commands!
- Body: the “message” , ASCII characters only



# Mail access protocols



- SMTP: delivery/storage of e-mail messages to receiver's server
- mail access protocol: retrieval from server
  - IMAP: Internet Mail Access Protocol [RFC 3501]: messages stored on server, IMAP provides retrieval, deletion, folders of stored messages on server
- HTTP: gmail, Hotmail, Yahoo!Mail, etc. provides web-based interface on top of STMP (to send), IMAP (or POP) to retrieve e-mail messages

# Test sur le mailer de free

Il faut se connecter sur une machine qui a Free comme FAI :

```
ssh invite1@deneire.hd.free.fr
mdp invite1
```

```
telnet smtp.free.fr 25
```

Il faut »s'authentifier » EHLO deneire.hd.free.fr

Puis jouer avec
SMTP MAIL FROM:, RCPT TO: …

Du coup, vous pouvez m'envoyer un mail en vous faisant passer pour "n'importe qui"