Application Layer

Goals:

- Conceptual aspects of network application protocols
  - Client server paradigm
  - Service models
- Review protocols by examining popular application-level protocols
  - HTTP
  - DNS

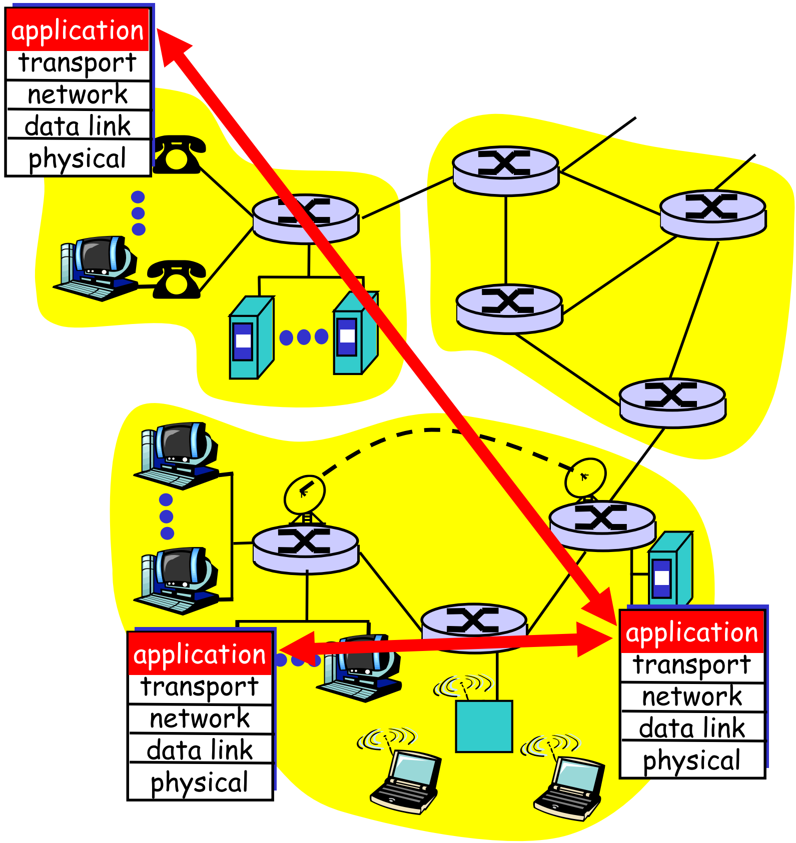
Applications and Application-Layer Protocols

Application: communicating, distributed processes

- Running in network hosts in "user space"
- Exchange messages to implement app
- E.g., email, file transfer, the Web

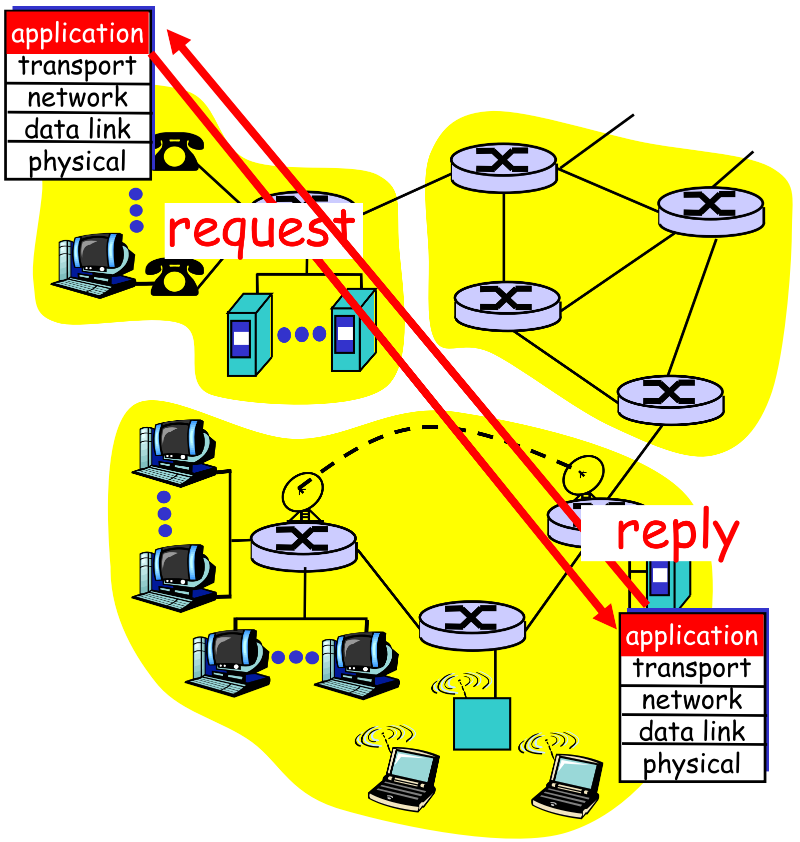
Application-layer protocols

- One "piece" of an app
- Define messages exchanged by apps and actions taken
- User services provided by lower layer protocols



Client-Server Paradigm

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



Client:

- Initiates contact with server ("speaks first")
- Typically requests service from server,
- E.g., request WWW page, send email

Server:

- Provides requested service to client
- E.g., sends requested WWW page, receives/stores received email

Services Provided by Internet Transport Protocols

TCP service:

- *Connection-oriented:* setup required between client, server
- *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

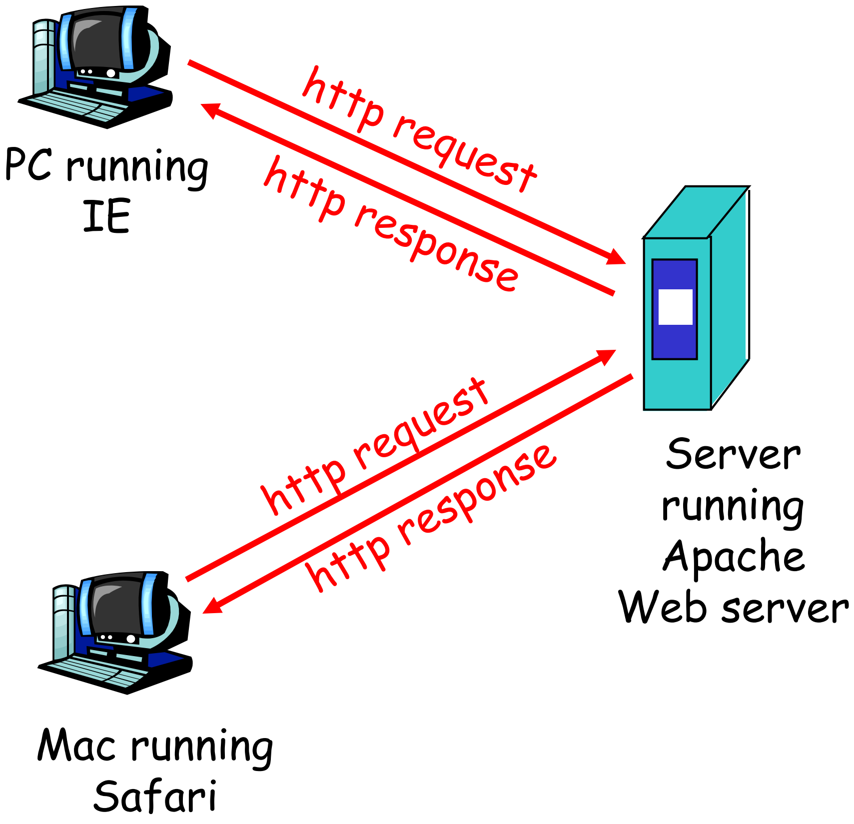
UDP service:

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

The HTTP Protocol

HTTP: Hypertext transfer protocol

- Application layer protocol for the Web
- Client/server model
  - *Client:* browser that requests, receives, “displays” web objects
  - *Server:* Web server sends objects in response to requests
- Also used as part of many other application layer protocol



HTTP Development Timeline

Mar 1990	CERN labs document proposing Web
Jan 1992	HTTP/0.9 specification
Dec 1992	Proposal to add MIME to HTTP
Feb 1993	UDI (Universal Document Identifier) Network
Mar 1993	HTTP/1.0 first draft
Jun 1993	HTML (1.0 Specification)
Oct 1993	URL specification
Nov 1993	HTTP/1.0 second draft
Mar 1994	URI in WWW
May 1996	HTTP/1.0 Informational, RFC 1945
Jan 1997	HTTP/1.1 Proposed Standard, RFC 2068
Jun 1999	HTTP/1.1 Draft Standard, RFC 2616
2001	HTTP/1.1 Formal Standard
…ongoing	HTTP/2 Drafts and Standardization

The HTTP Protocol: Basics

HTTP: TCP transport service

- 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 Message Format: Request

- Two types of http messages: *Request, response*
- http request message:
  - ASCII (human-readable format)

request line
(GET, POST,
HEAD commands)

header
lines

Carriage return,
line feed
indicates end
of message

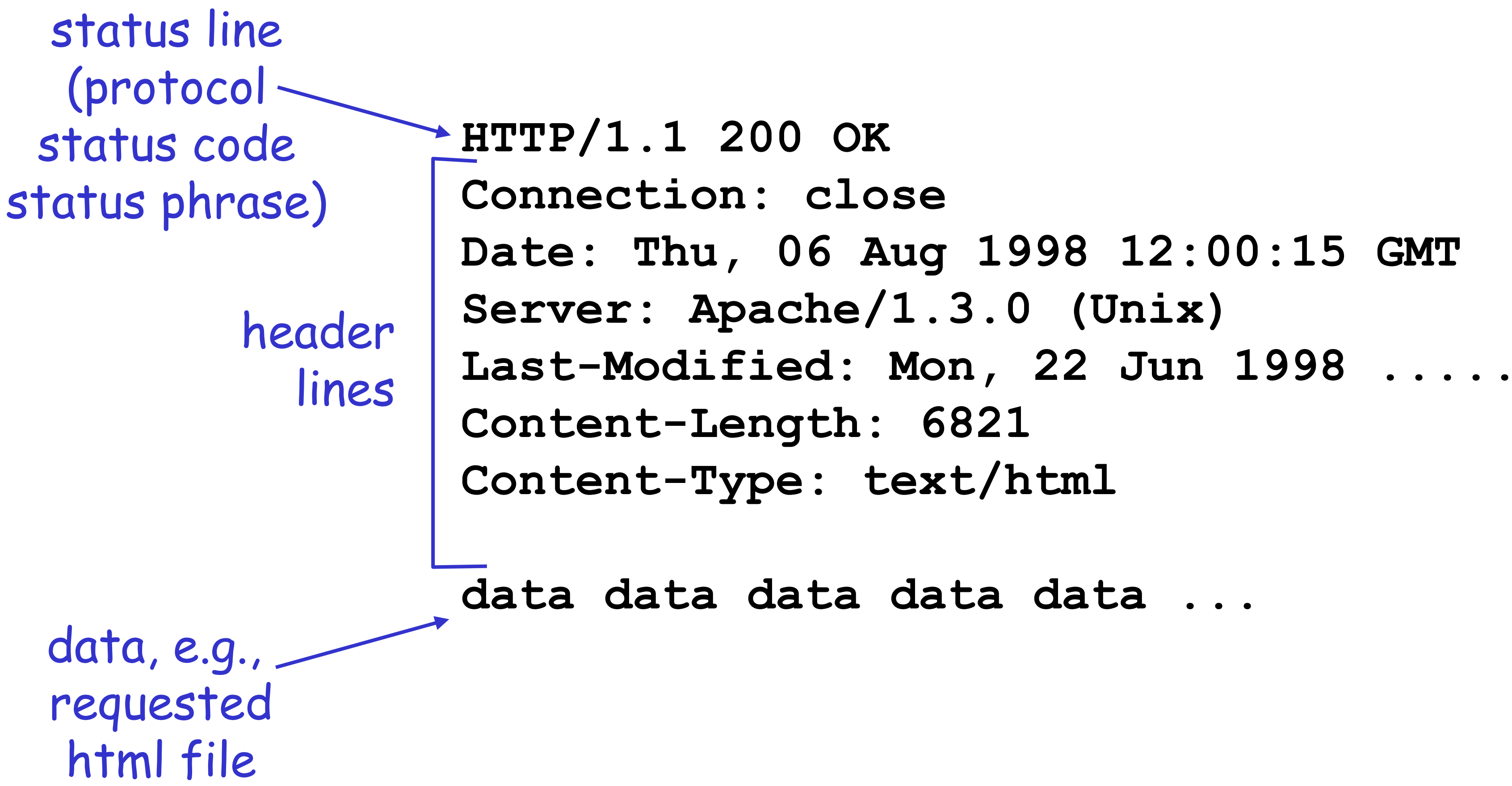
```
GET /somedir/page.html HTTP/1.1
Connection: close
User-agent: Mozilla/4.0
Accept: text/html, image/gif,image/jpeg
Accept-language:fr

```

(extra carriage return, line feed)

HTTP Request Methods

- Methods
  - GET
  - HEAD
  - POST
  - PUT
  - Delete

HTTP Message Format: Response



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`

The HTTP Protocol: Connections

- Non-persistent connection:
  One object in each TCP connection
  - Some browsers create multiple TCP connections *simultaneously* – one per object
- Persistent connection:
  Multiple objects transferred within one TCP connection
- Pipelined persistent connections:
  Multiple requests issued without waiting for response
  Responses are in order of the requests
- Persistent connection with out-of-order delivery (SPDY):
  Multiple requests issued. Server can return the objects in arbitrary order. Typically according to server priority. In addition the server may send additional objects.

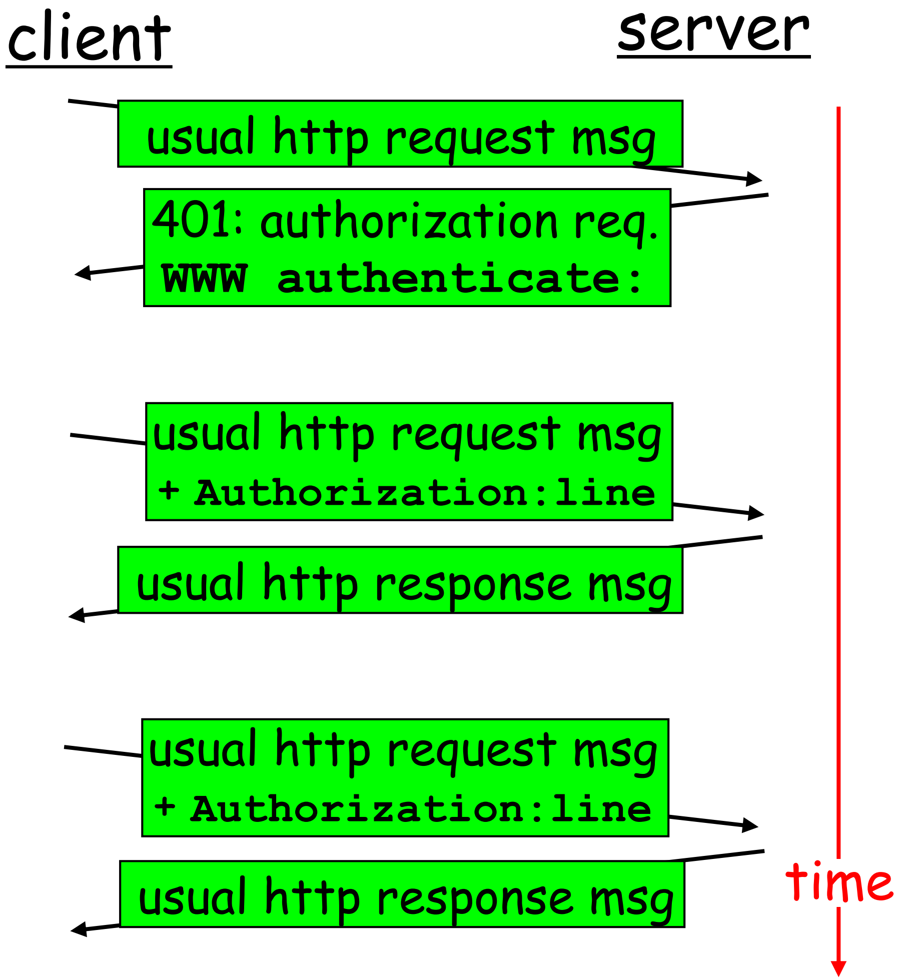
User-Server Interaction: Authentication

Authentication goal: Control access to server documents

- Stateless: Client must present authorization in each request
- Authorization: Typically name, password
  - `Authorization:` header line in request
  - If no authorization, server refuses access, sends

    `WWW authenticate:`

    header line in response



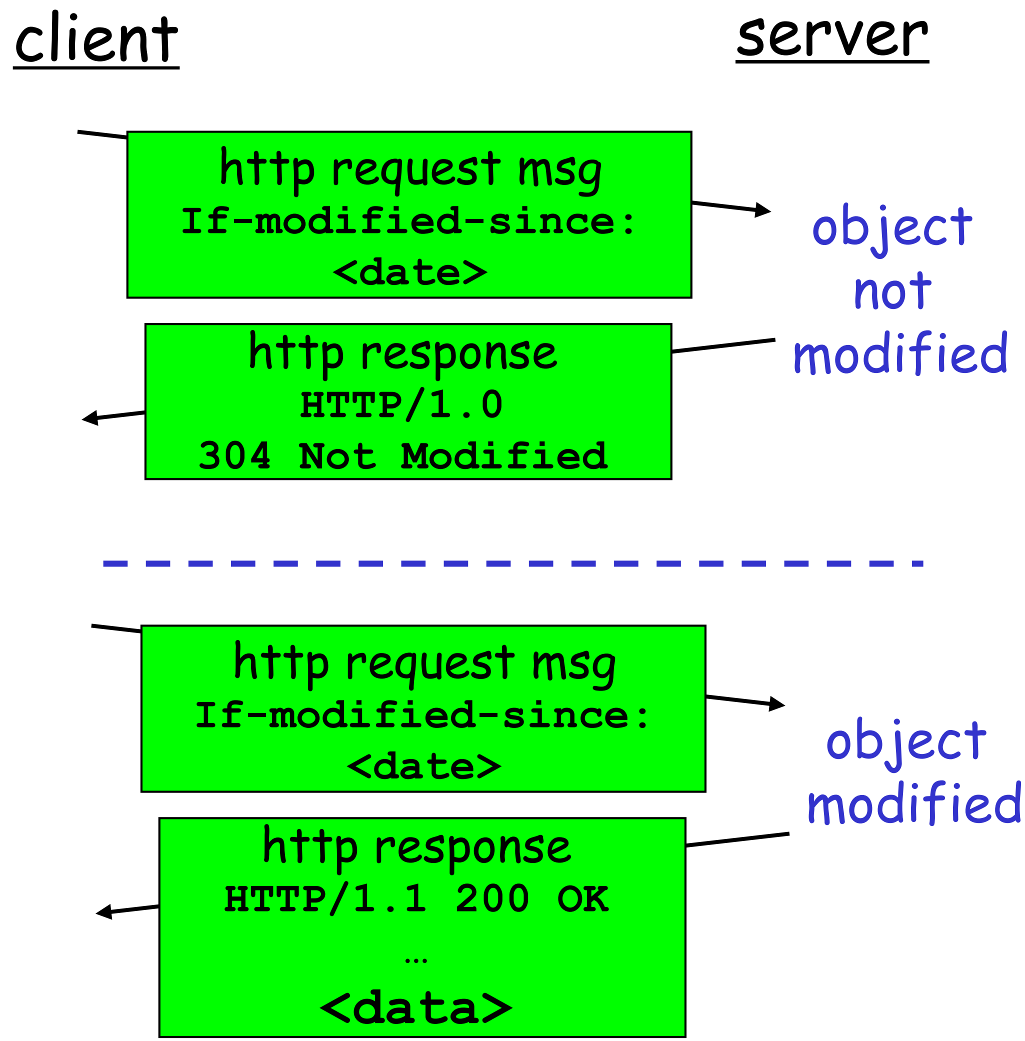
User-Server interaction: Conditional GET

- Goal: Don't send object if client has up-to-date stored (cached) version
- Client: Specify date of cached copy in http request

  If-modified-since: <date>

- Server: Response contains no object if cached copy up-to-date:

  HTTP/1.0 304 Not Modified



User-Side State: Cookies

Most Web sites use cookies

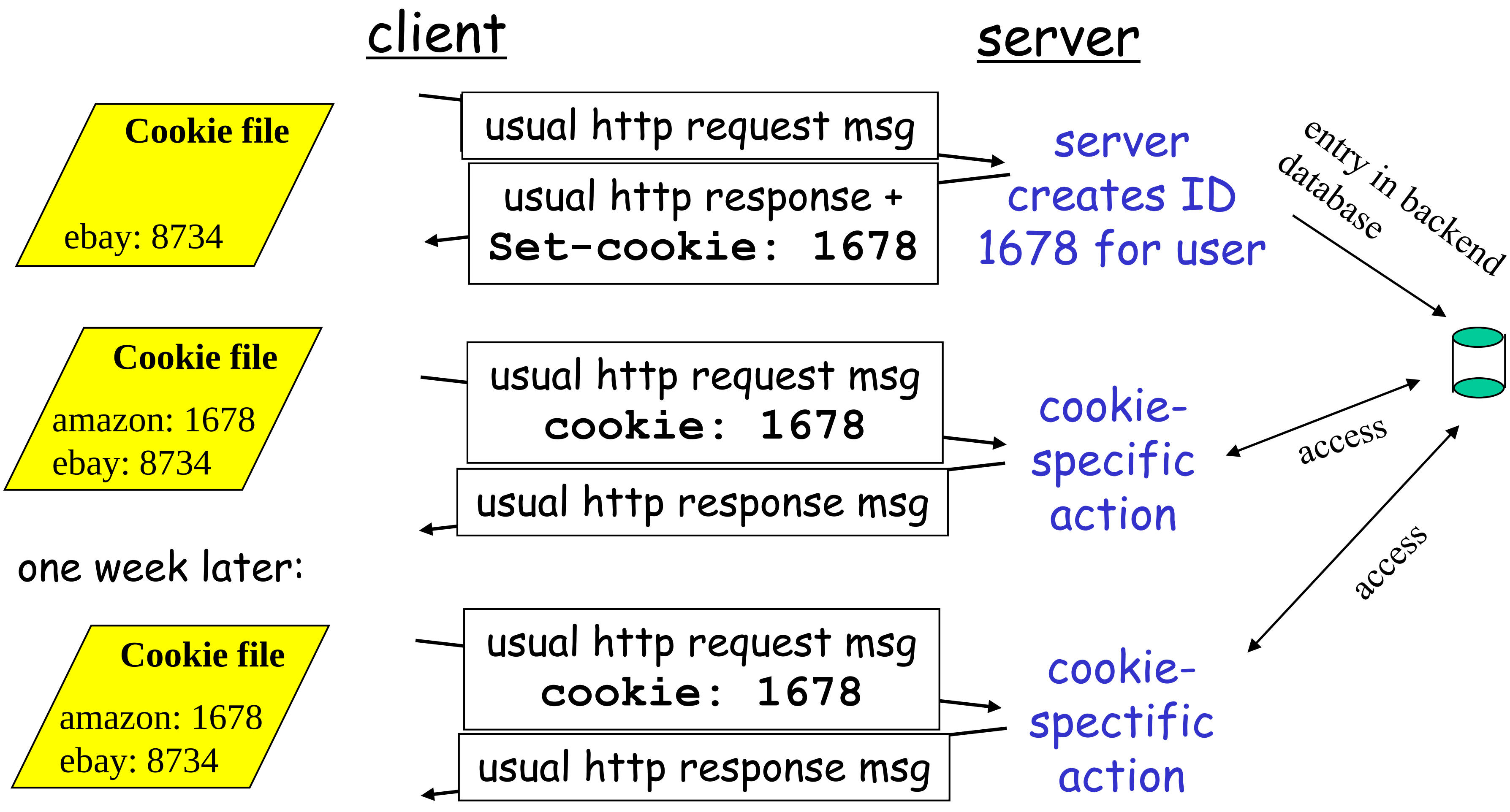
Four components:

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

Example:

- Susan access Internet always from same PC
- She visits a specific e-commerce site for first time
- When initial HTTP requests arrives at site, site creates a unique ID and creates an entry in backend database for ID

Cookies: Keeping State



Cookies: Keeping State (2)

What cookies can bring:

- Authorization
- Shopping carts
- Recommendations
- User session state (e.g. for Web e-mail)

aside

Cookies and privacy:

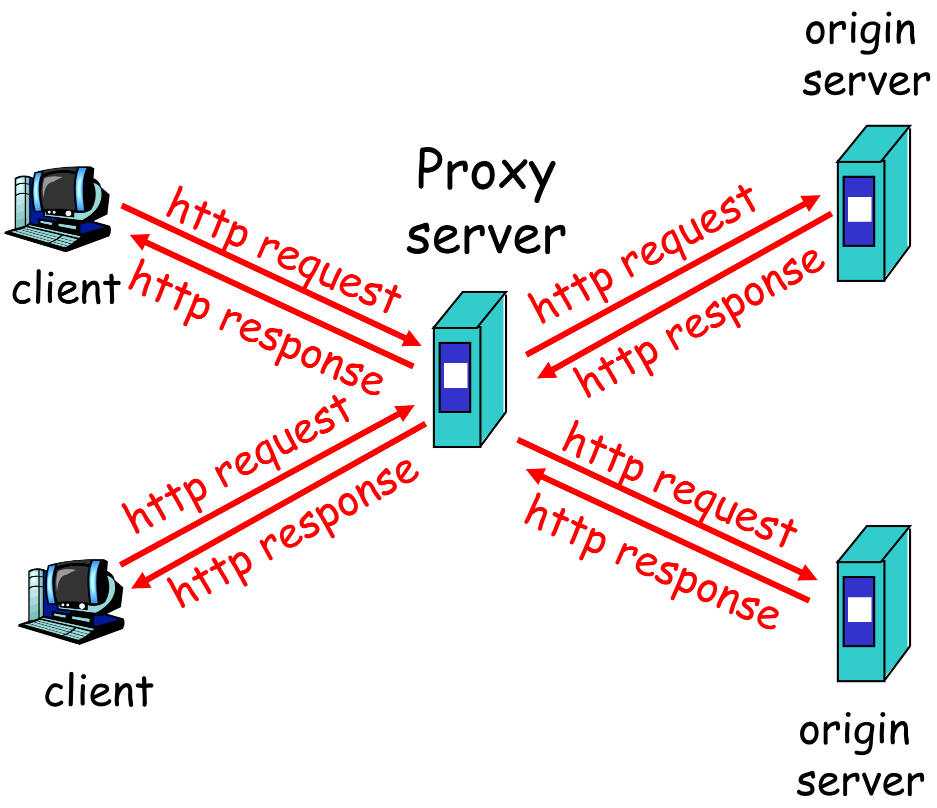
- Cookies permit sites to learn a lot about you
- You may supply name and e-mail to sites
- Search engines use redirection & cookies to learn even more
- Advertising companies obtain info across sites

- Users can even be tracked if cookies are turned of

Web Caches (Proxy Servers)

Goal: Satisfy client request without involving origin server

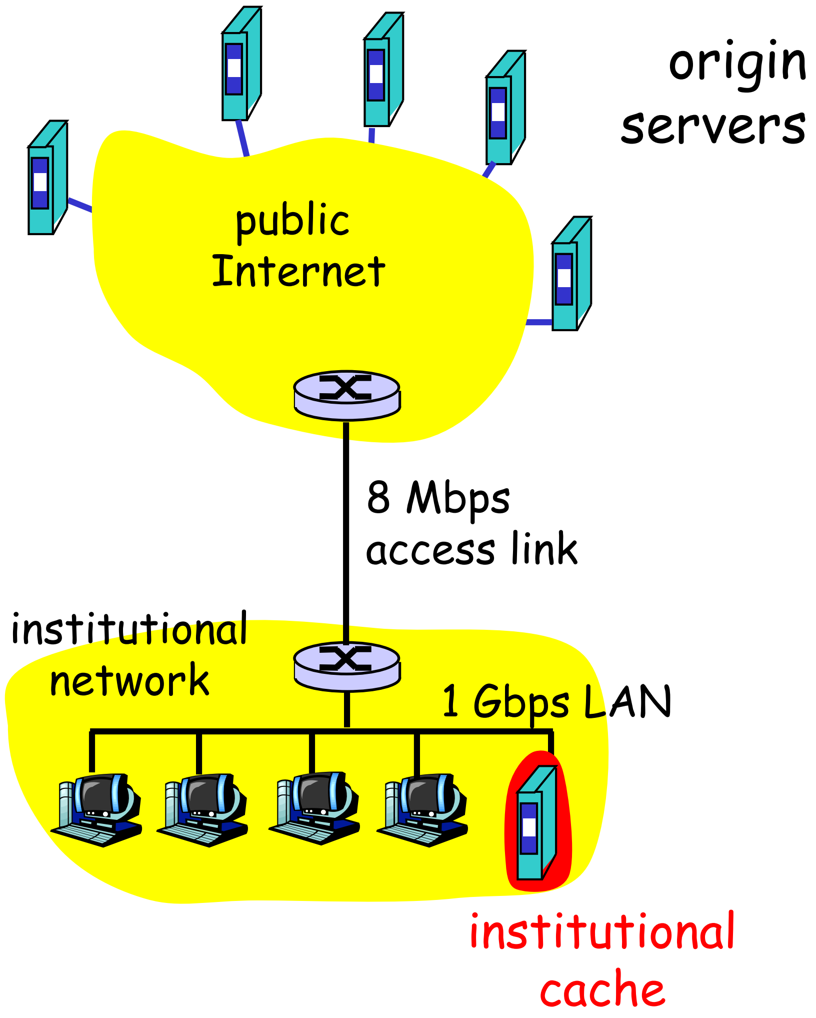
- User sets browser: WWW accesses via web cache
- Client sends all http requests to web cache
  - If object at web cache, web cache immediately returns object in http response
  - Else requests object from origin server, then returns http response to client



Why Web Caching?

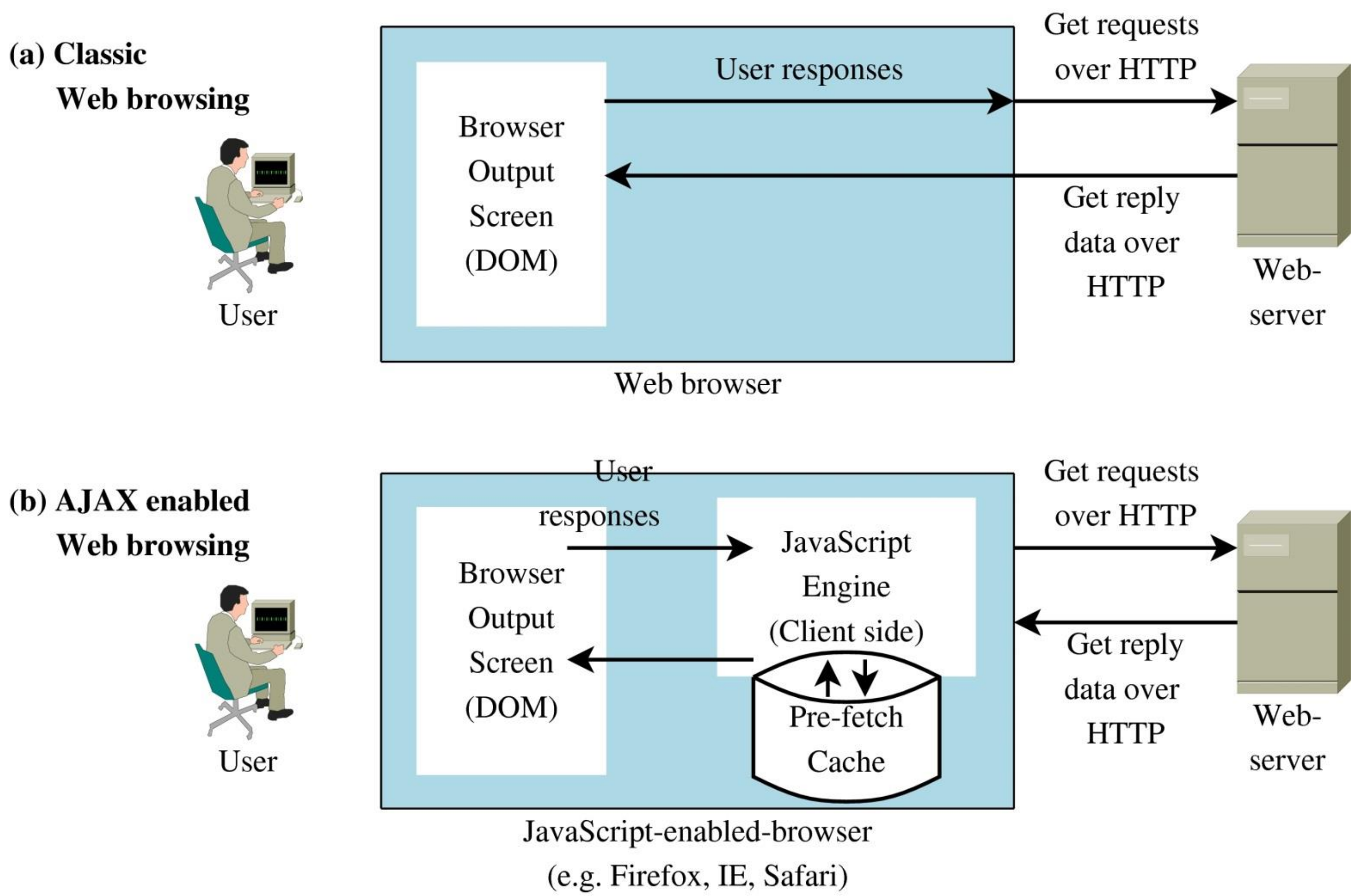
Assume: Cache is "close" to client (e.g., in same network)

- Smaller response time: cache "closer" to client
- Decrease traffic to distant servers
  - Link out of institutional/local ISP network often bottleneck



Web 2.0: E.g., AJAX Enabled Apps

- E.g.: Google Maps: A canonical AJAX application

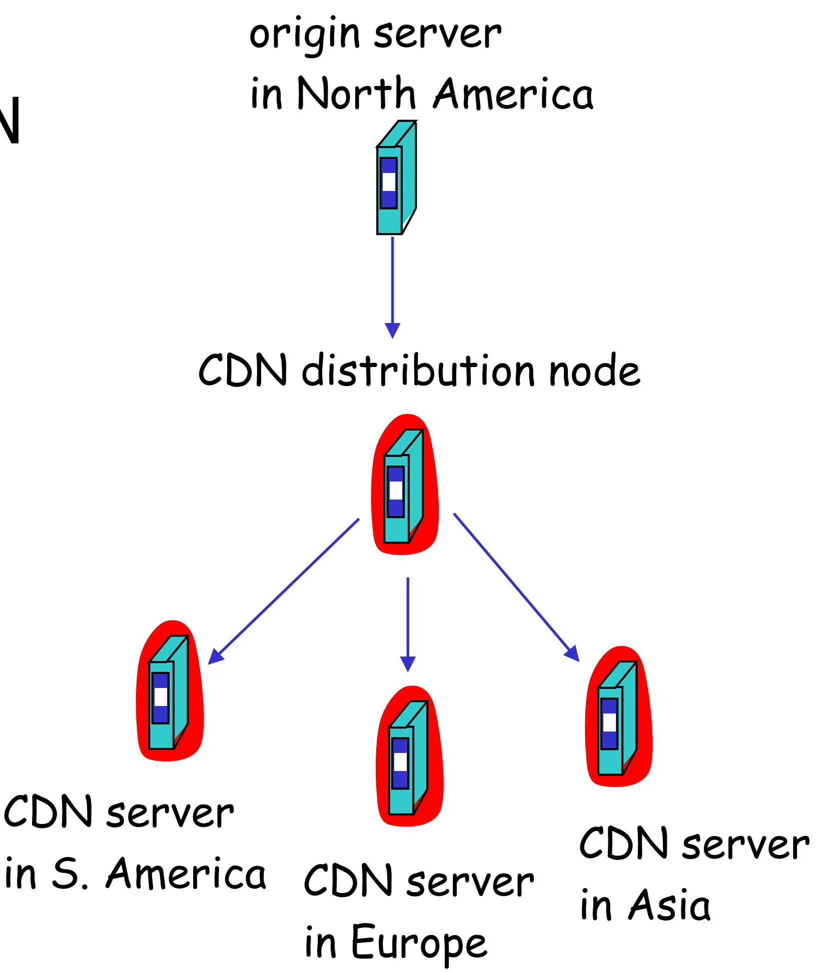


Content Distribution Networks (CDNs)

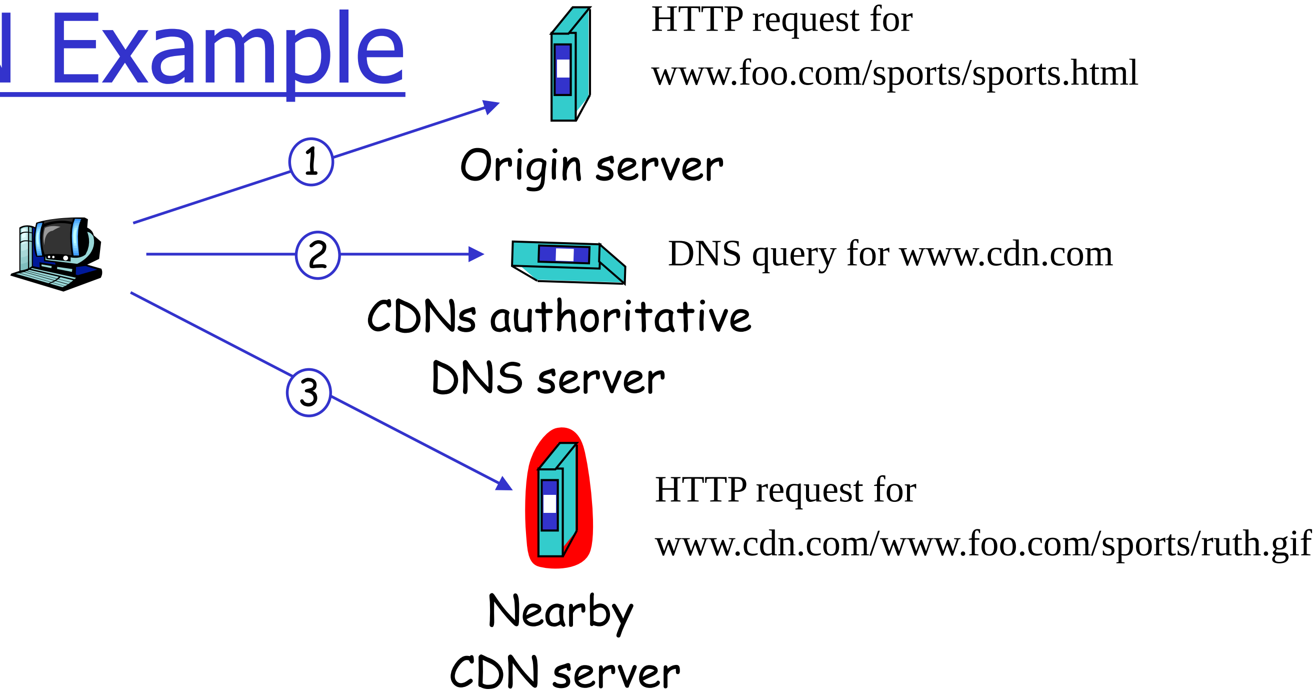
Content providers are the CDN customers.

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



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

DNS: Domain Name System

People: many identifiers:

- SSN, name, Passport #

Internet hosts, routers:

- IP address (32/128 bit) – used for addressing datagrams
- “name”, e.g., gaia.cs.umass.edu – used by humans

Q: How to map between IP addresses and name?

- Domain Name System (DNS)

  RFC1034/RFC1035, RFC3007

DNS: Domain Name System

Domain Name System:

- *Distributed database:* Implemented in hierarchy of many *name servers*
- *Application-layer protocol:* Host, routers, name servers communicate to *resolve* names (address/name translation)
  - 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

Does not *scale!*

DNS Name Servers (2)

No server has all name-to-IP address mappings

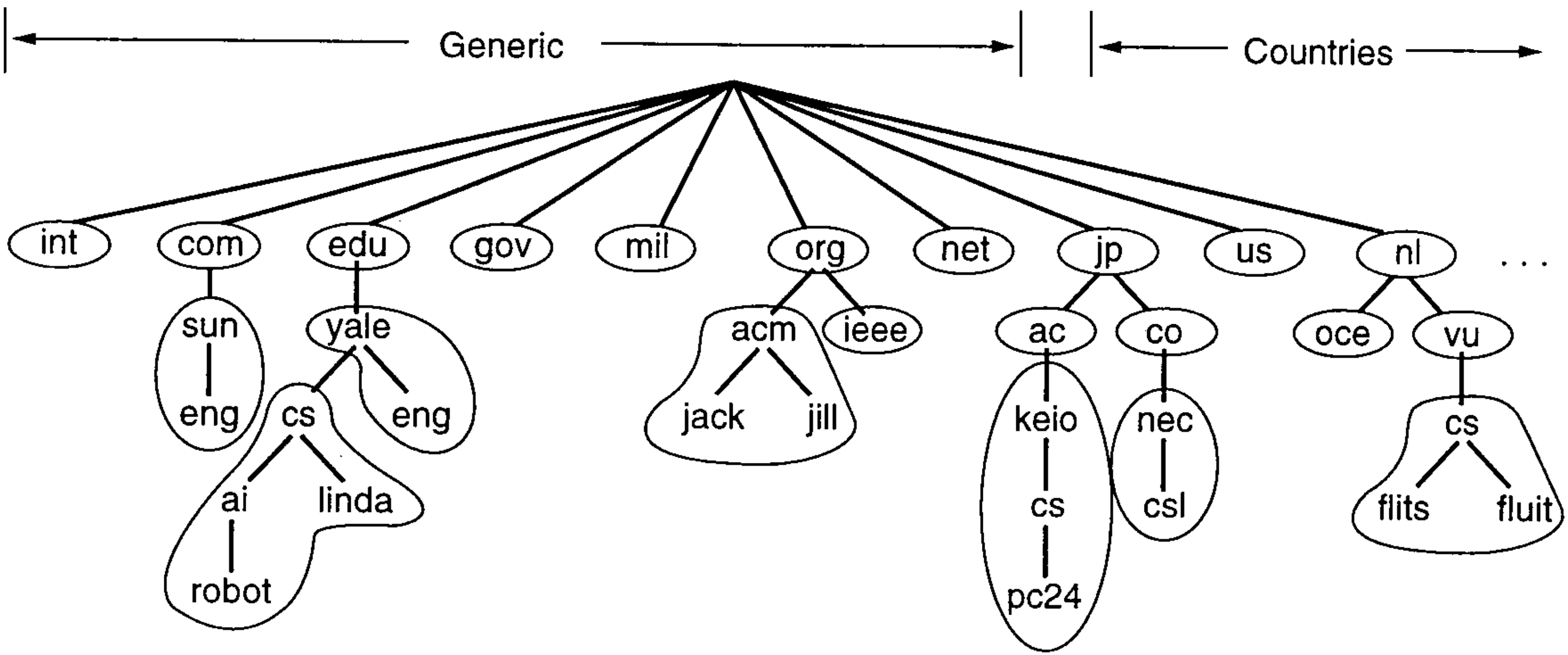
Local name servers:

- Each ISP, company has *local (default) name server*
- Host DNS query first goes to local name server

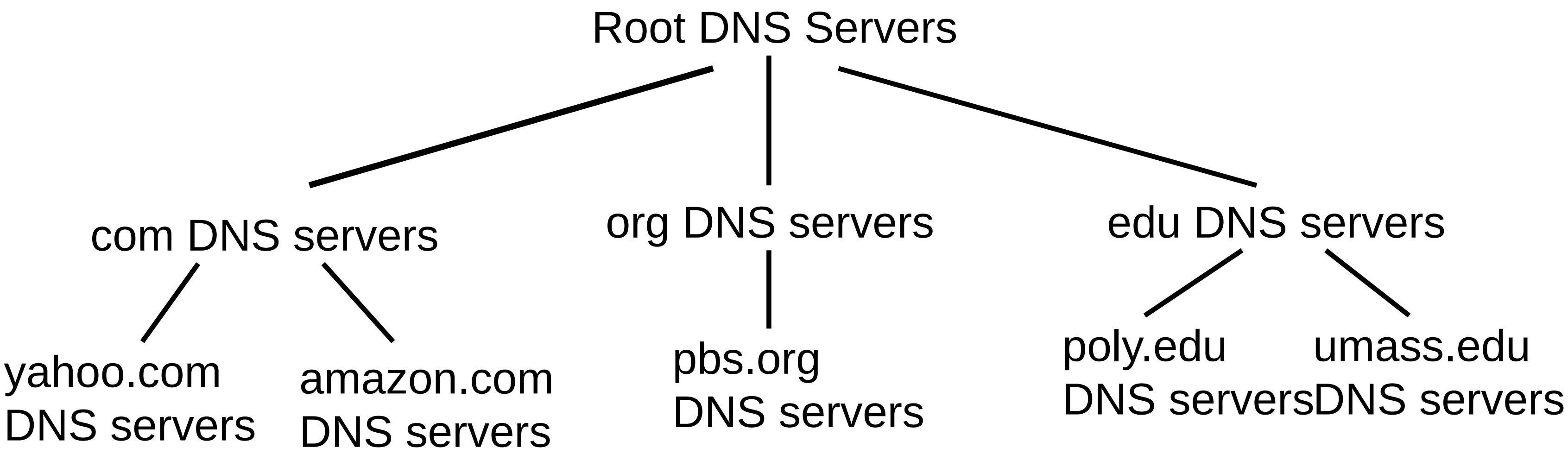
Authoritative name server:

- For a host: stores that host's IP address, name
- Can perform name/address translation for that host's name

DNS: Hierarchical Naming Tree



Distributed, Hierarchical Database

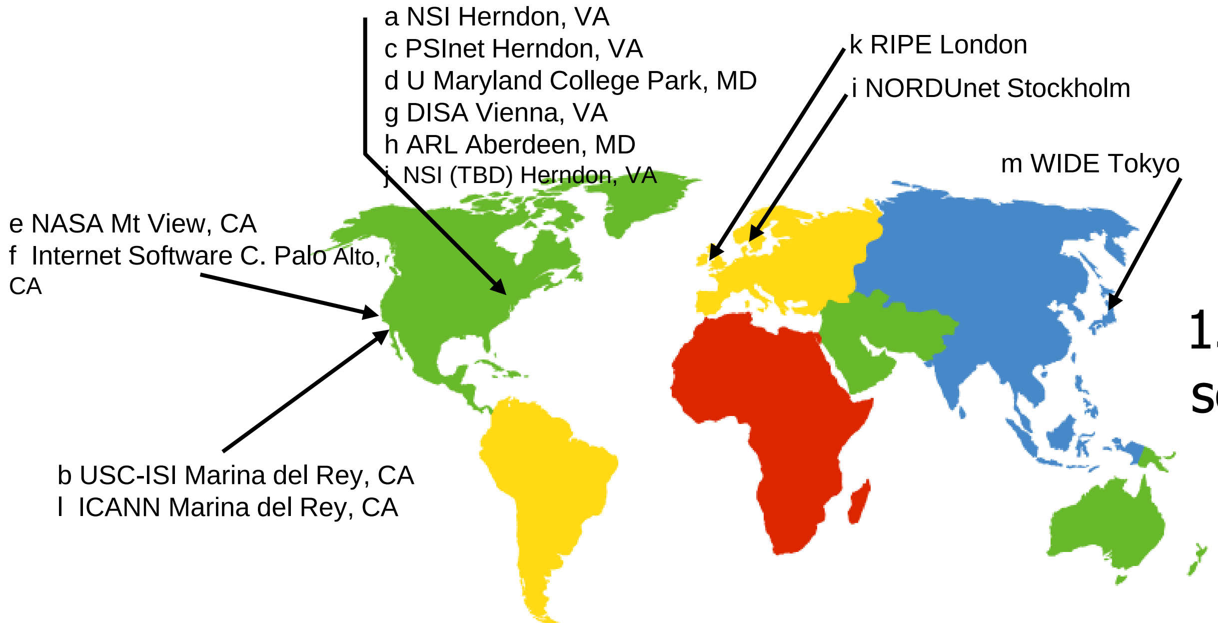


Client wants IP for www.amazon.com; 1st approx:

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

DNS: Root Name Servers

- Contacted by local name server that can not resolve name
- Root name server:
  - Contacts authoritative name server if name mapping not known
  - Gets mapping
  - Returns mapping to local name server
  - Most use anycast addressing



13 root name servers worldwide

TLD and authoritative servers

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

Local Name Server (Recursor)

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

DNS Records

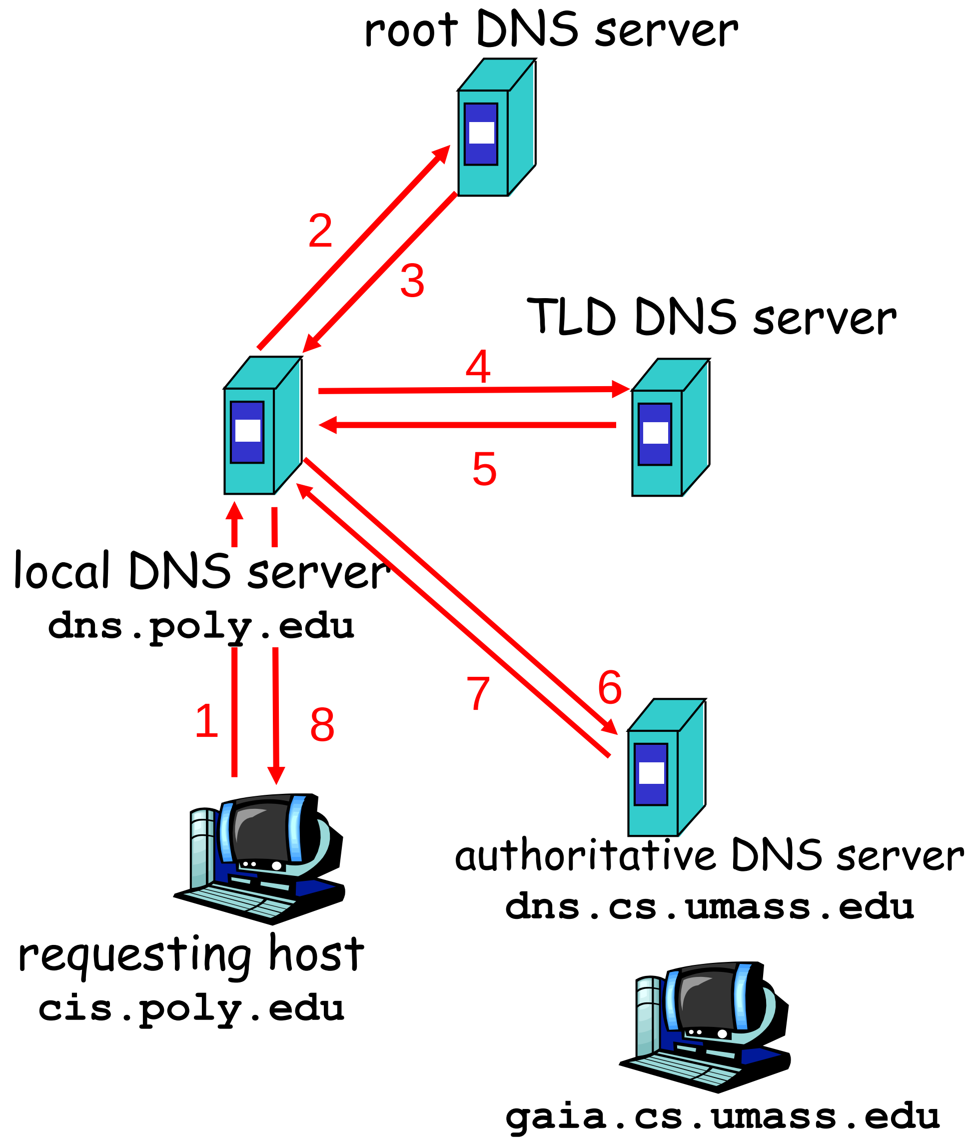
DNS: Distributed db storing resource records (RR)

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
  - for alias
- Type=MX
  - for mail
- Type=AAAA
  - for IPv6

Example

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



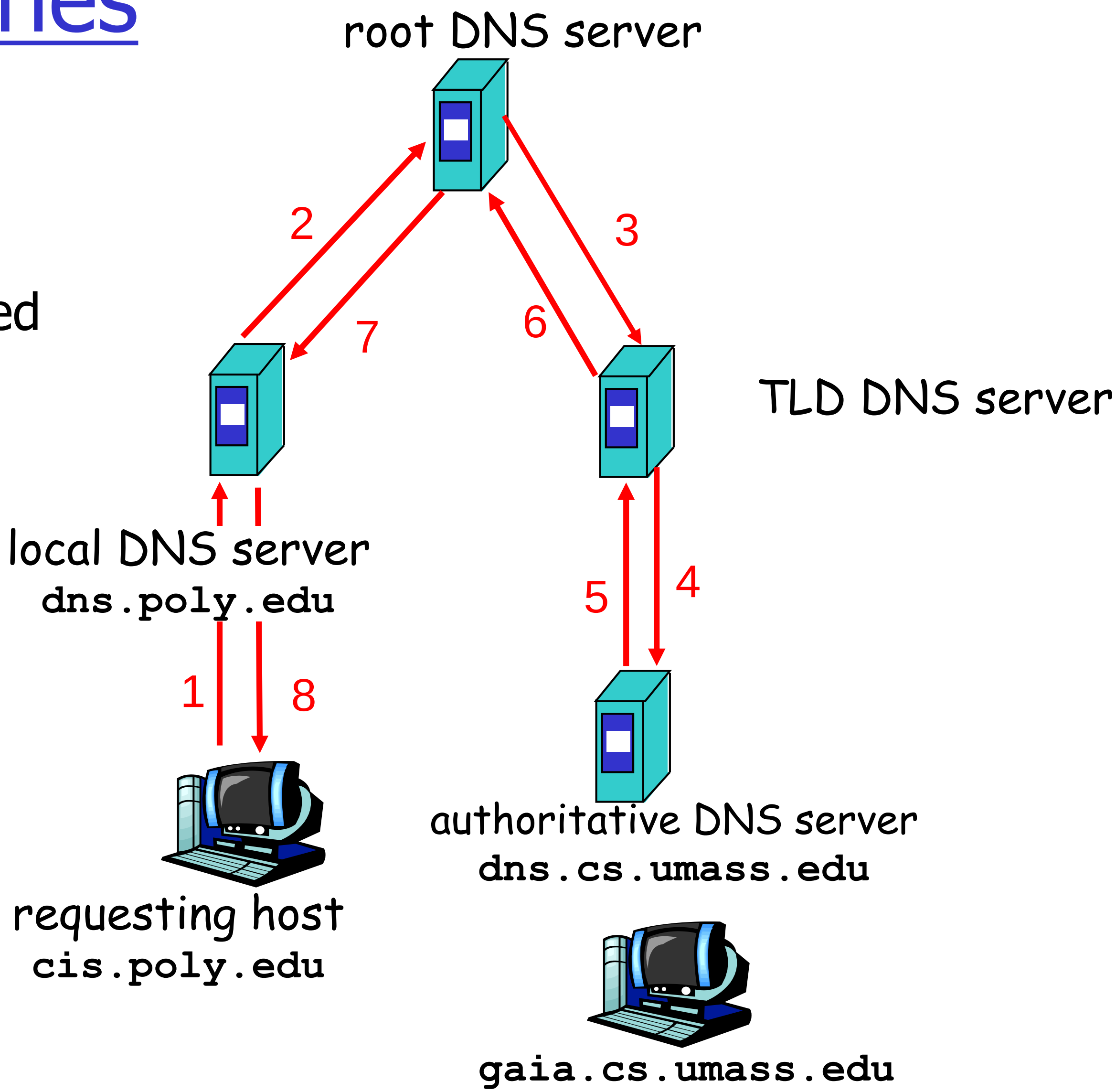
Recursive queries

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: Iterative Queries

Recursive query:

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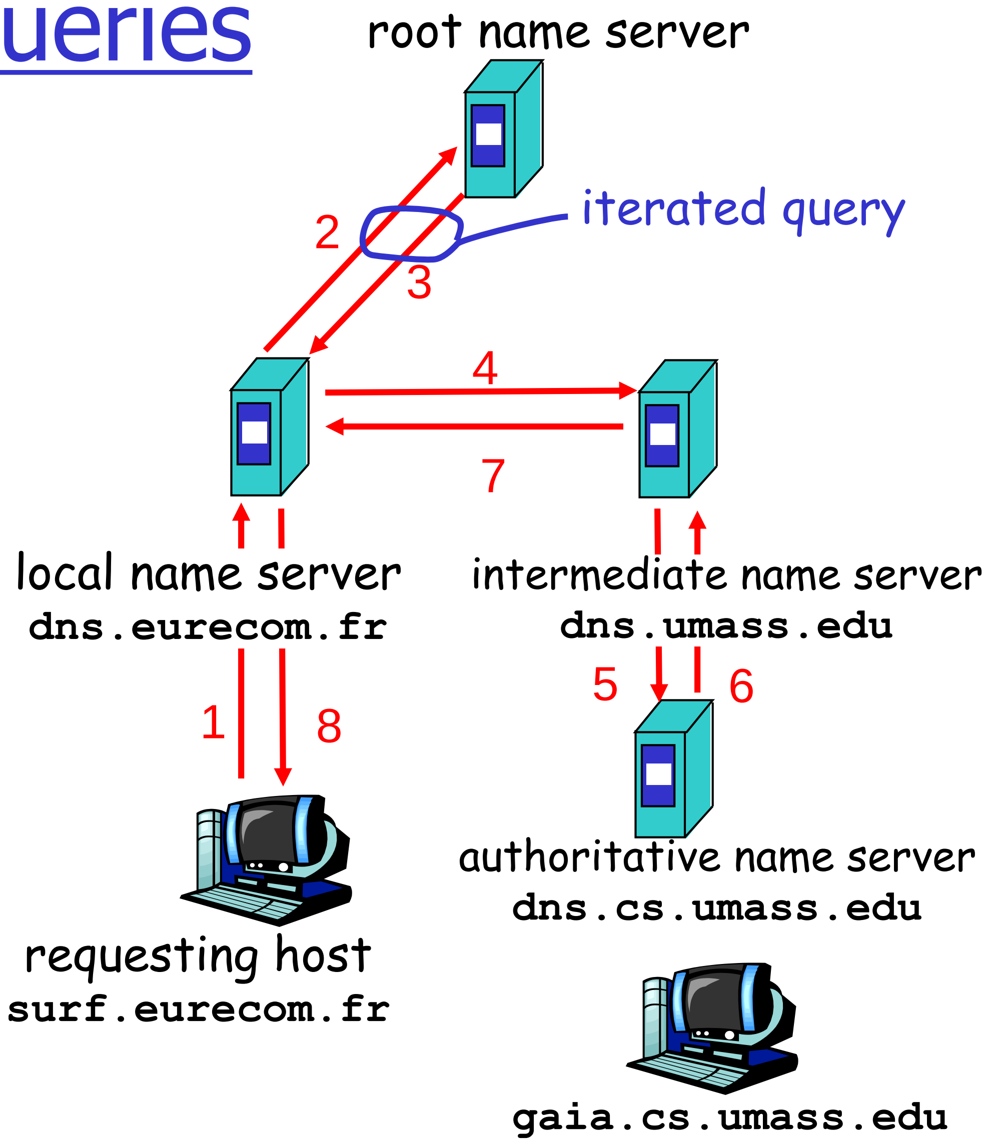
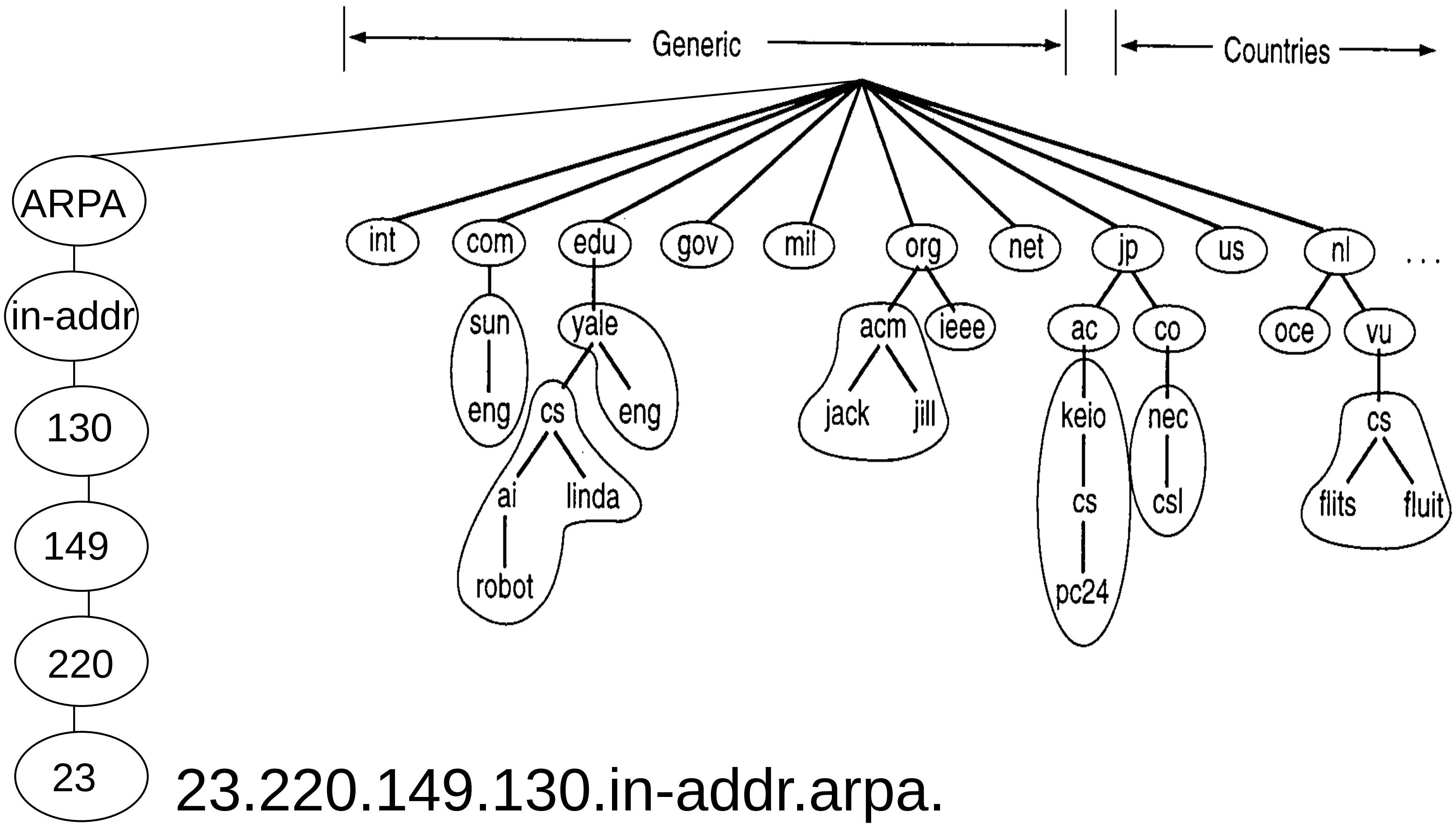


Mapping IP Address to Names

- Special domains: in-addr.arpa. / ip6.arpa.



23.220.149.130.in-addr.arpa.

1.a.c.6.d.c.5.8.0.5.6.8.0.6.d.c.1.0.0.0.9.b.6.9.0.7.4.0.1.0.0.2.ip6.arpa.