INF3190 – Application Layer
DNS, Web, Mail

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Application layer

in the TCP/IP stack

Introduction

What is it?

Internet view

- everything above the socket interface is application layer function

=> all functions of OSI layers 5 and 6 are Internet application layer

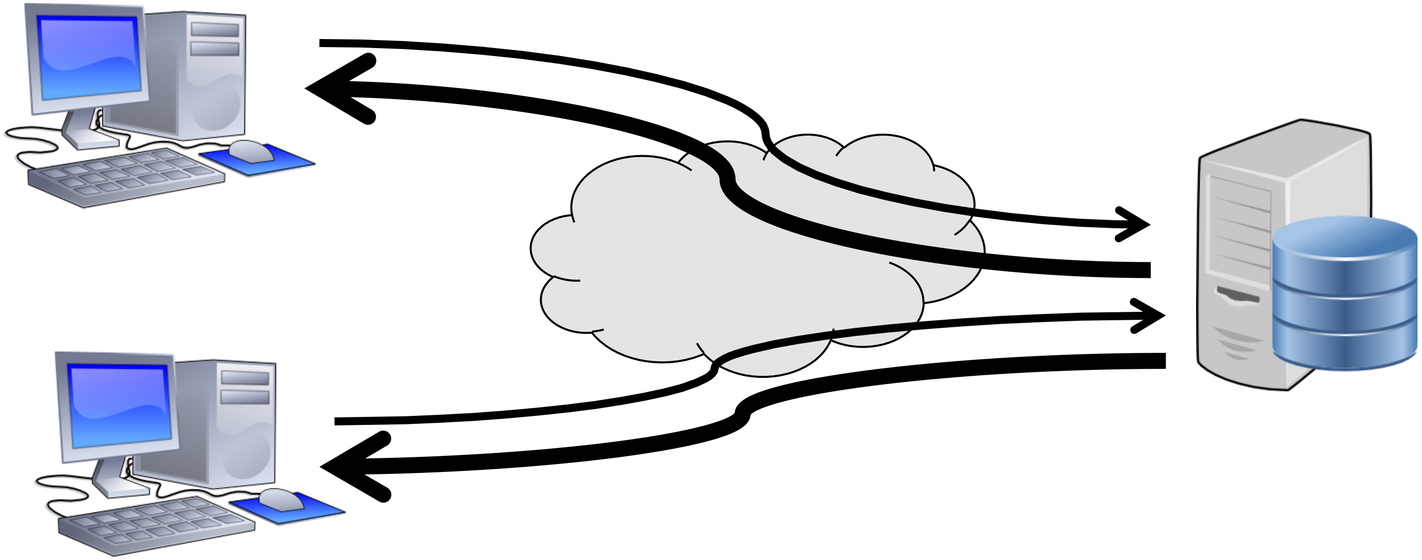
We still need (many of) those OSI functions

- long-term session maintenance, reconnections, session migration
- protocol translation
- today's Internet world has protocols for this
  (official standards (de jure) and de facto)
  - SMTP + (POP3 or IMAP)
  - HTTP, SHTTP, QUIC
  - (RTSP or SIP) + RTP/RTCP
  - MPEG DASH, Apple HLS, ~~Microsoft Smooth Streaming~~
  - DCE / CORBA

Client-Server

- Traditional communication model, easily comprehensible abstraction
  - Clients request service (initiate connection)
  - Servers provide service (answer requests)

- Examples: Web Client/Server, Mail Client/Server, FTP Client/Server



Peer-to-Peer

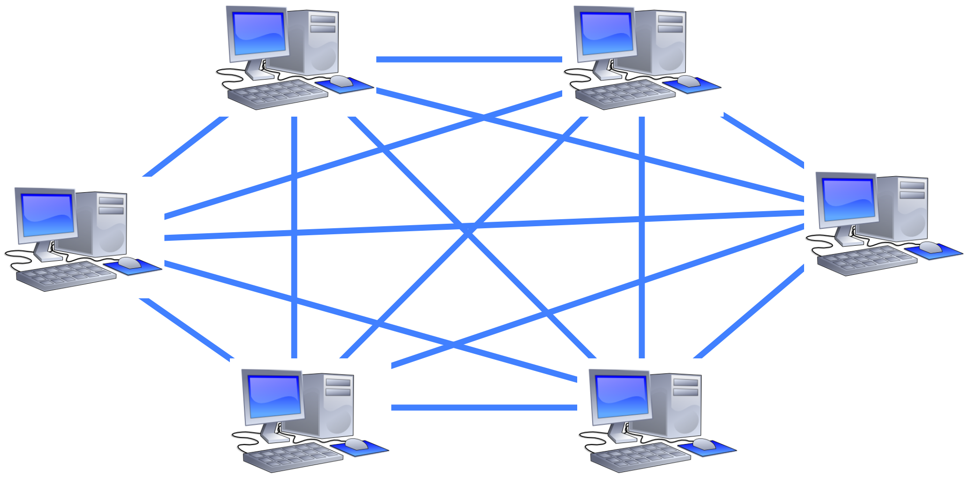
Recognized application-layer paradigm since 2000s

First clearly visible application: Napster

- file sharing (mostly for music)
- ruled illegal
- followed by others: Gnutella, Kazaa, BitTorrent, Freenet
- later picked up by research: CAN, Chord, Tapestry, Kademlia, Pastry
- idea: avoid control and/or censorship

Famous services

- video streaming: PPTV, P2PTV
- distributed computing: SETI@home



Old tech. that is like P2P but not recognized:

- Telephony
- Usenet news
- IP Routing

Actually, P2P = original Internet model

- all nodes are equal
- all nodes can address each other
- ownership is distributed

The presentation problem

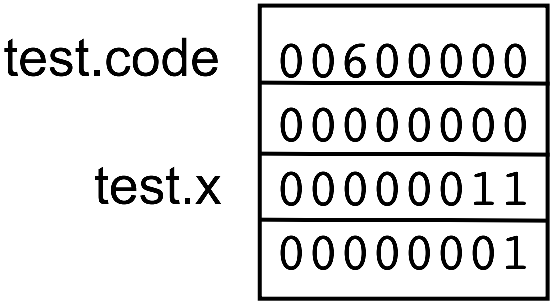
Q: Does perfect memory-to-memory copy solve "the communication problem"?

A: Not always!

```
struct Test
{
   char code;
   int x;
}

Test test;

test.x = 273;
test.code='a'
```



test.code

00600000

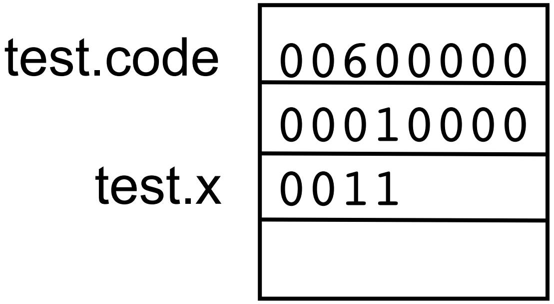
00000000

test.x

00000011

00000001

host 2 format
e.g. Intel DOS
not packed
little endian



test.code

00600000

00010000

test.x

0011

host 2 format
e.g. ARM Linux
packed
big endian

Problem: Different data format, storage conventions

Solving the presentation problem

1. Translate local-host format to host-independent format
2. Transmit data in host-independent format
3. Translate host-independent format to remote-host format

Old Style

- cross-platform standardized binary encoding of data structures
  - OSI host-independent format: “Abstract Syntax Notation One” (ASN.1) defines “Basic Encoding Rules” (BER)
  - XDR: „external data representation“, belonged to NFS

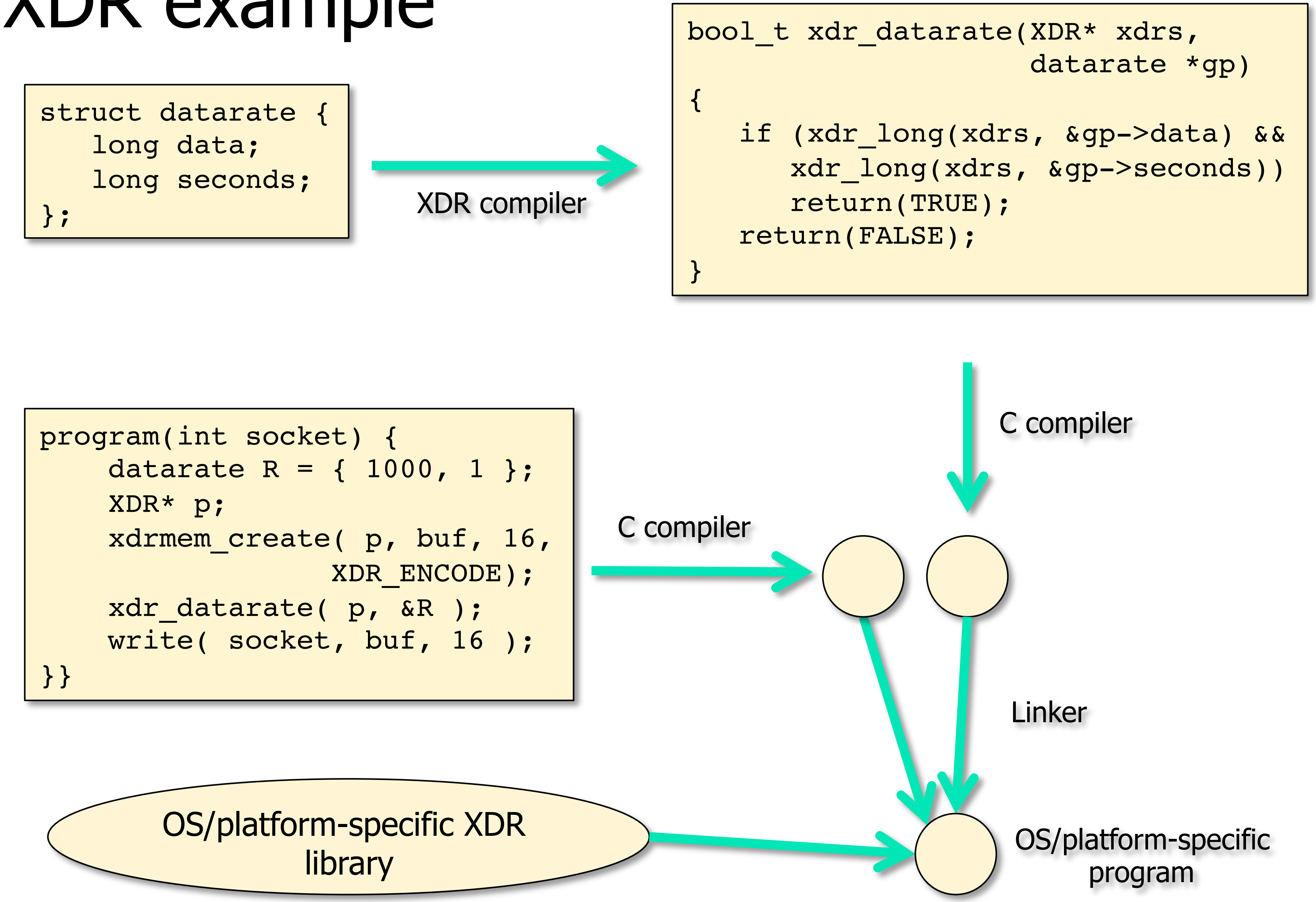
- compensate for platform differences
- assume single data interpretation
- space-saving

Current Style

- encoding everything as text
  - XML: „extensible markup language“
  - REST: „representational state transfer”

- convey data in platform-independent manner
- local styling and interpretation
- readable and debuggable

XDR example



```
struct datarate {
   long data;
   long seconds;
};
```

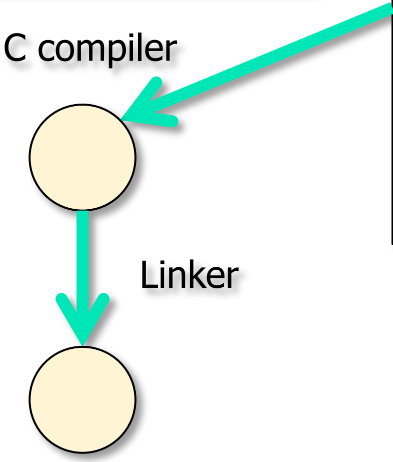
```
bool_t xdr_datarate(XDR* xdrs,
                    datarate *gp)
{
   if (xdr_long(xdrs, &gp->data) &&
      xdr_long(xdrs, &gp->seconds))
      return(TRUE);
   return(FALSE);
}
```

```
program(int socket) {
    datarate R = { 1000, 1 };
    XDR* p;
    xdrmem_create( p, buf, 16,
                 XDR_ENCODE);
    xdr_datarate( p, &R );
    write( socket, buf, 16 );
}}
```

REST example

```
struct datarate {
   long data;
   long seconds;
};
```

```
void sendfunction( int socket, datarate* gp ) {
  char buf[1000];
  sprintf(buf, “POST https://peer.nowhere.com”
     “/1/classes/datarate HTTP/1.1\n”
     ...
     “’{\”data\":\”%d\”,\”seconds\":\”%d\”}’/n”
     “https://peer.nowhere.com/1/classes”
     “/datarate”,
     gp->data, gp->seconds );
}
```



sent over the network at run-time:

```
POST https://peer.nowhere.com/1/classes/datarate HTTP/1.1
  ...
  X-Parse-Application-Id: Datarate-Setter
  X-Parse-REST-API-Key: JASD3476D
  Content-Type: application/json

  ’{”data":1000,”seconds":”1”}’
  https://peer.nowhere.com/1/classes/datarate
```

Solving the presentation problem

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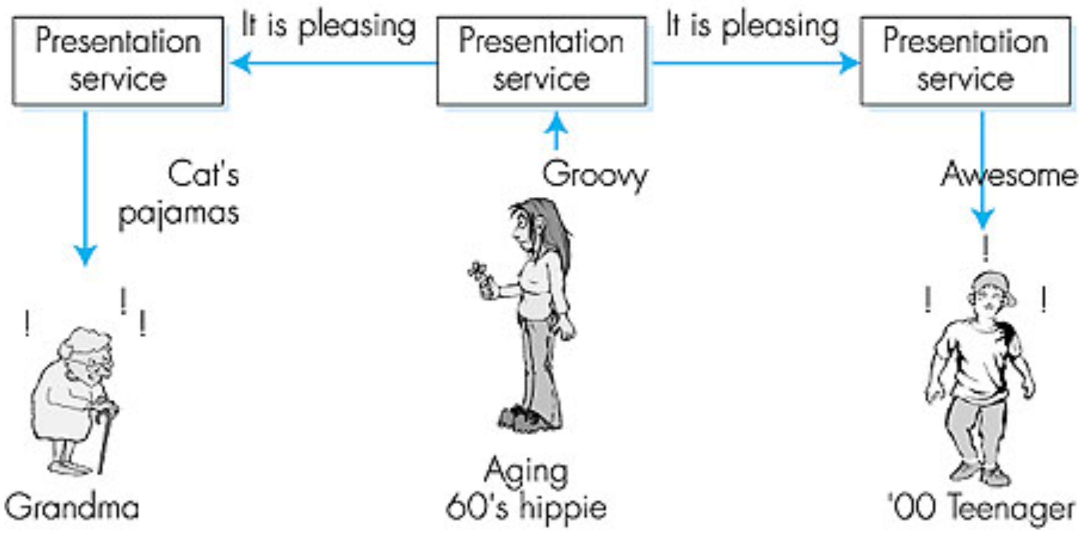


OSI host-independent format: "Abstract Syntax Notation One" (ASN.1) defines "Basic Encoding Rules" (BER)

Application layer

in the TCP/IP stack

DNS

Domain Name System

How to connect to a remote computer?

Connect to <hostname,port>

- e.g. `telnet 127.0.0.1 23`
  talking to my own machine
  obviously: used all the time, esp. since DHCP screws up your other addresses

- or `wget http://173.194.39.31:80/`
  talking to one of Google's machines
  possible to remember

- or `ssh 9.228.93.3`
  trying to talk to a desktop that had this address in 1995
  impossible to remember unless you've typed it 100 times a day

- If you want short names, write them into /etc/hosts
- originally globally maintained by SRI, changes re-distributed by email and ftp (no more, ancient history)

How to connect to a remote computer?

Use “reasonable” names

- e.g.
```
ssh login.ifi.uio.no
wget www.google.com
```

- not only easier to remember
- reflects also organisation structures

- although the hierarchical structure may not fulfill all purposes
- somewhat related to physical network structure, at least locally

Domain Name System (DNS)

DNS at a High-Level

Domain Name System

Hierarchical namespace

As opposed to original, flat namespace

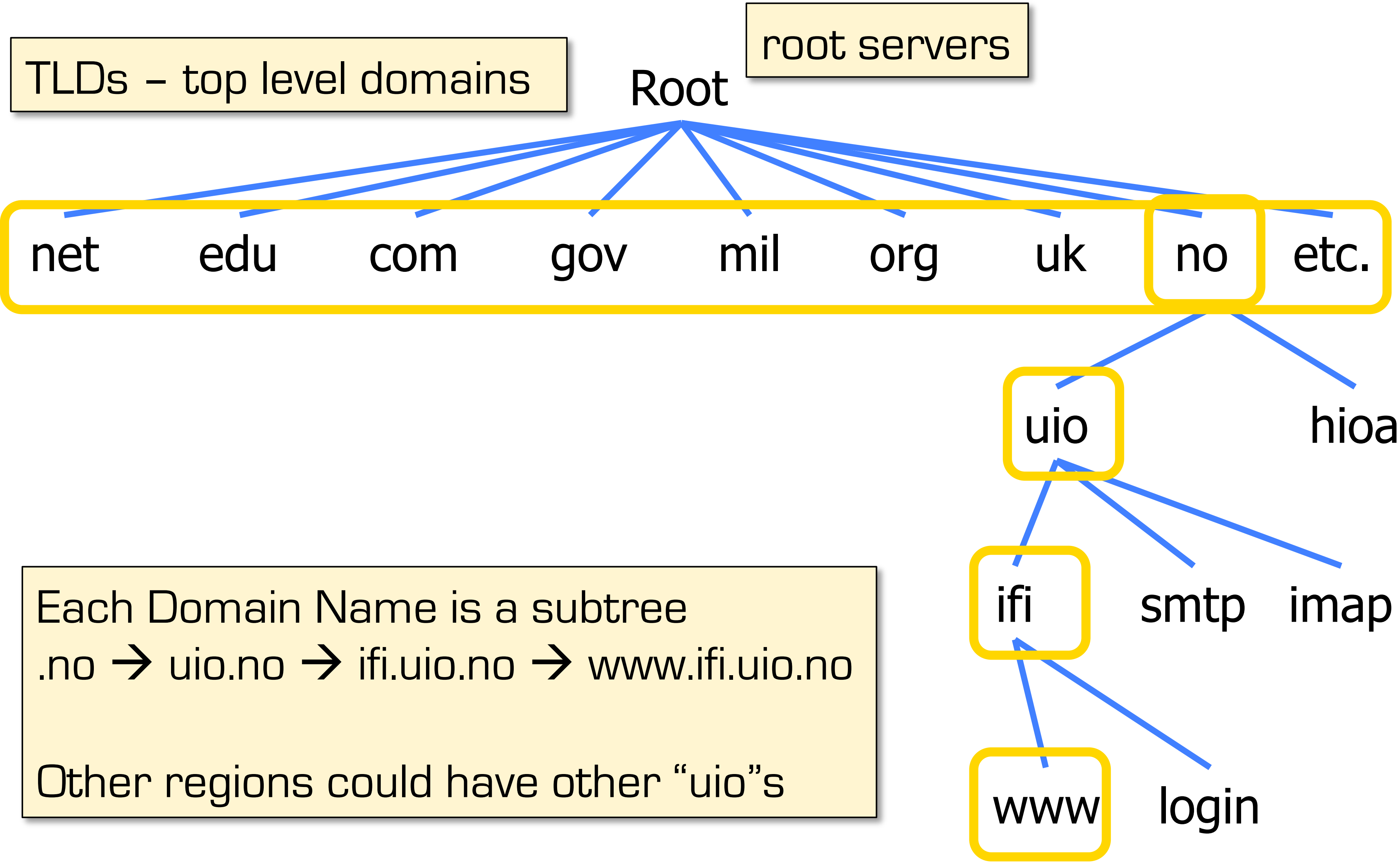
e.g. .com → google.com → mail.google.com

Distributed database

Simple client/server architecture

- UDP or TCP port 53
- servers must use TCP nowadays
- clients using TCP are mostly rejected
  - reduces server load
  - is a security problem

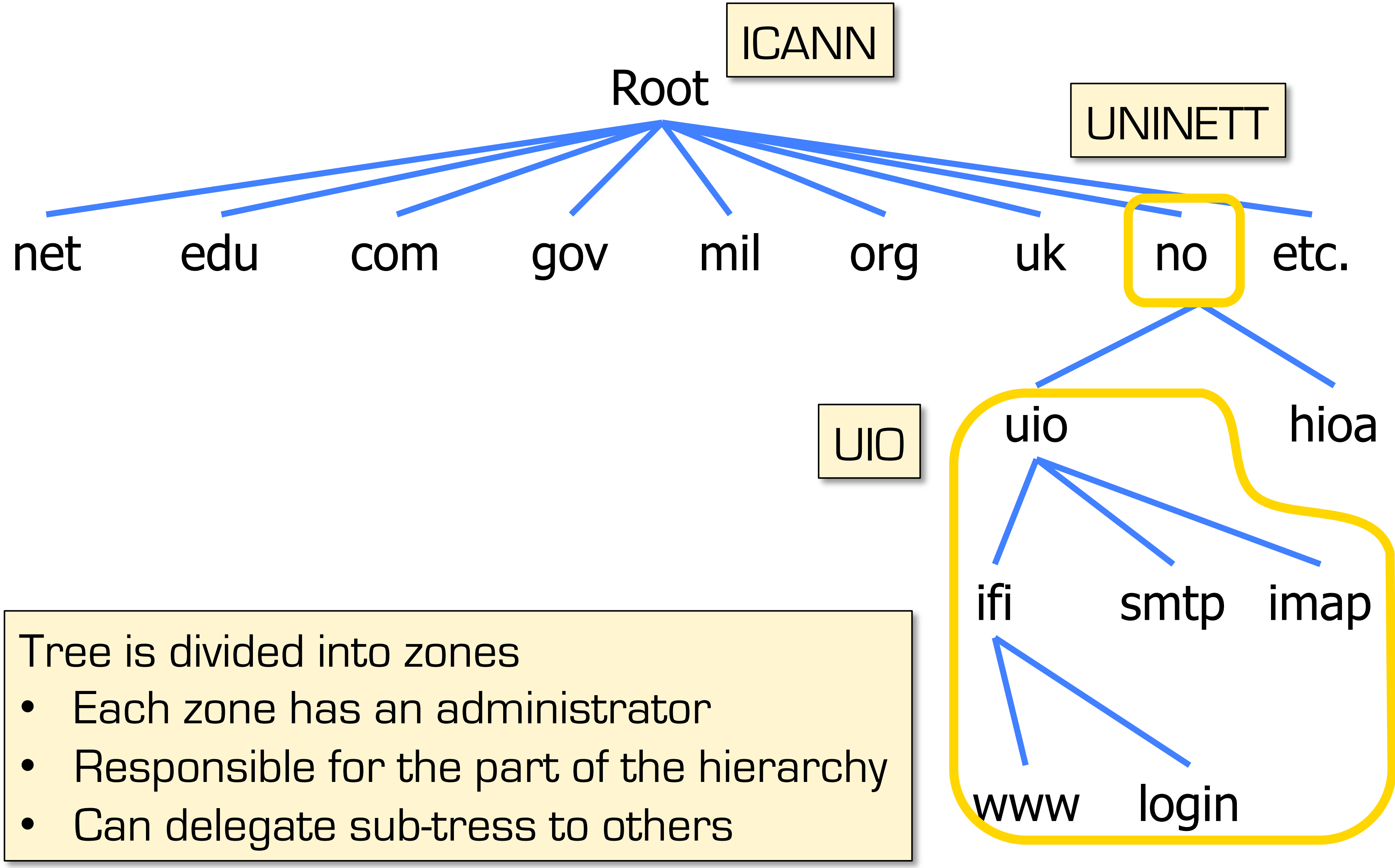
Naming Hierarchy



Each Domain Name is a subtree
.no → uio.no → ifi.uio.no → www.ifi.uio.no

Other regions could have other "uio"s

Hierarchical Administration



Tree is divided into zones

- Each zone has an administrator
- Responsible for the part of the hierarchy
- Can delegate sub-tress to others

Server Hierarchy

Functions of each DNS server

- Authority over a portion of the hierarchy
  - No need to store all DNS names
- Store all the records for hosts/domains in its zone
  - **Must** be replicated for robustness (at least 2 servers)
- Know the addresses of the root servers
  - Resolve queries for unknown names

Root servers know about all TLDs

Root Name Servers

Responsible for the Root Zone File

- Lists the TLDs and who controls them

```
com.            172800 IN     NS     a.gtld-servers.net.
com.            172800 IN     NS     b.gtld-servers.net.
com.            172800 IN     NS     c.gtld-servers.net.
```

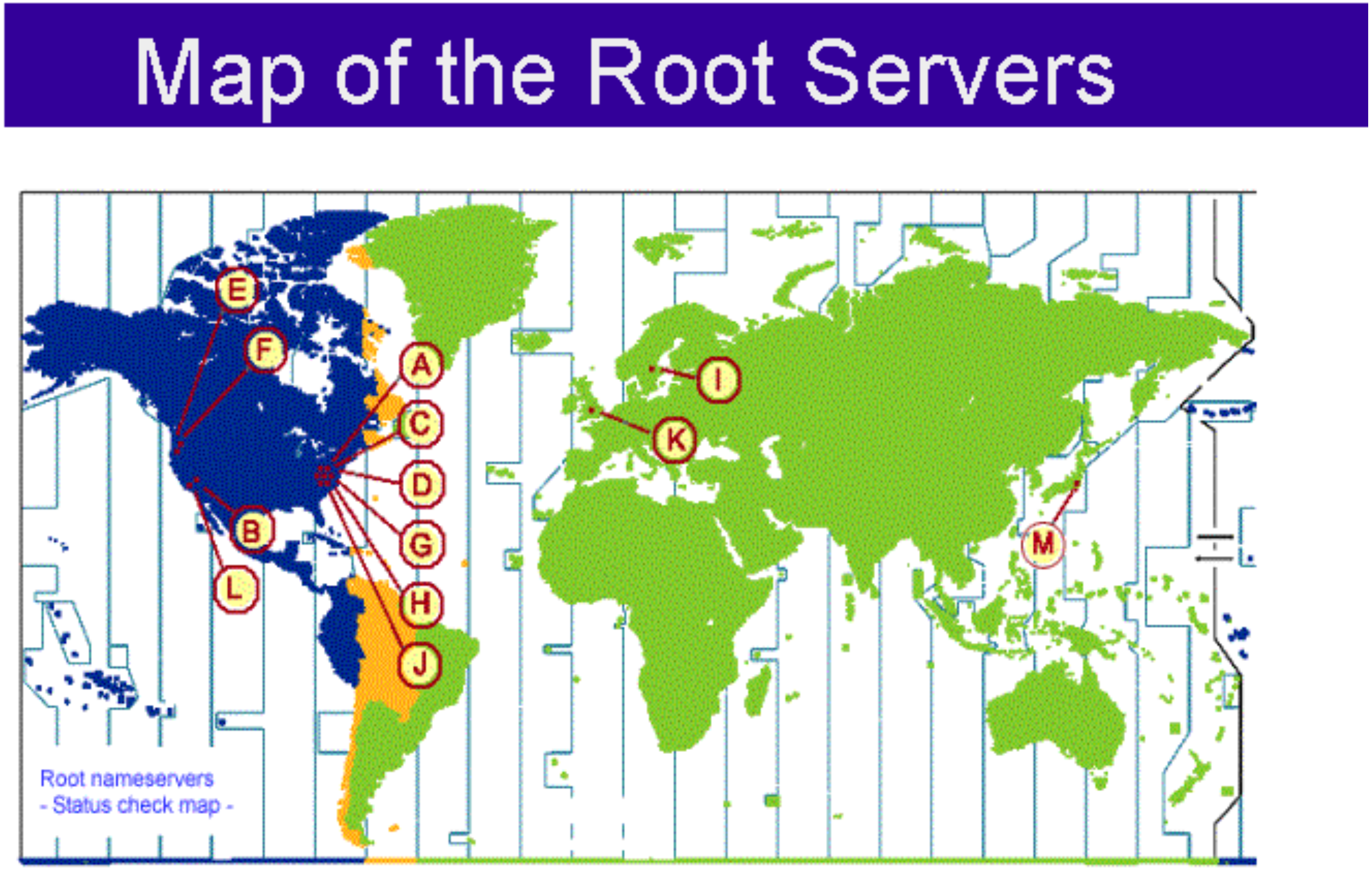
Administered by ICANN

- 13 root servers, labeled A→M
- 6 are anycasted, i.e. they are globally replicated

Contacted when names cannot be resolved

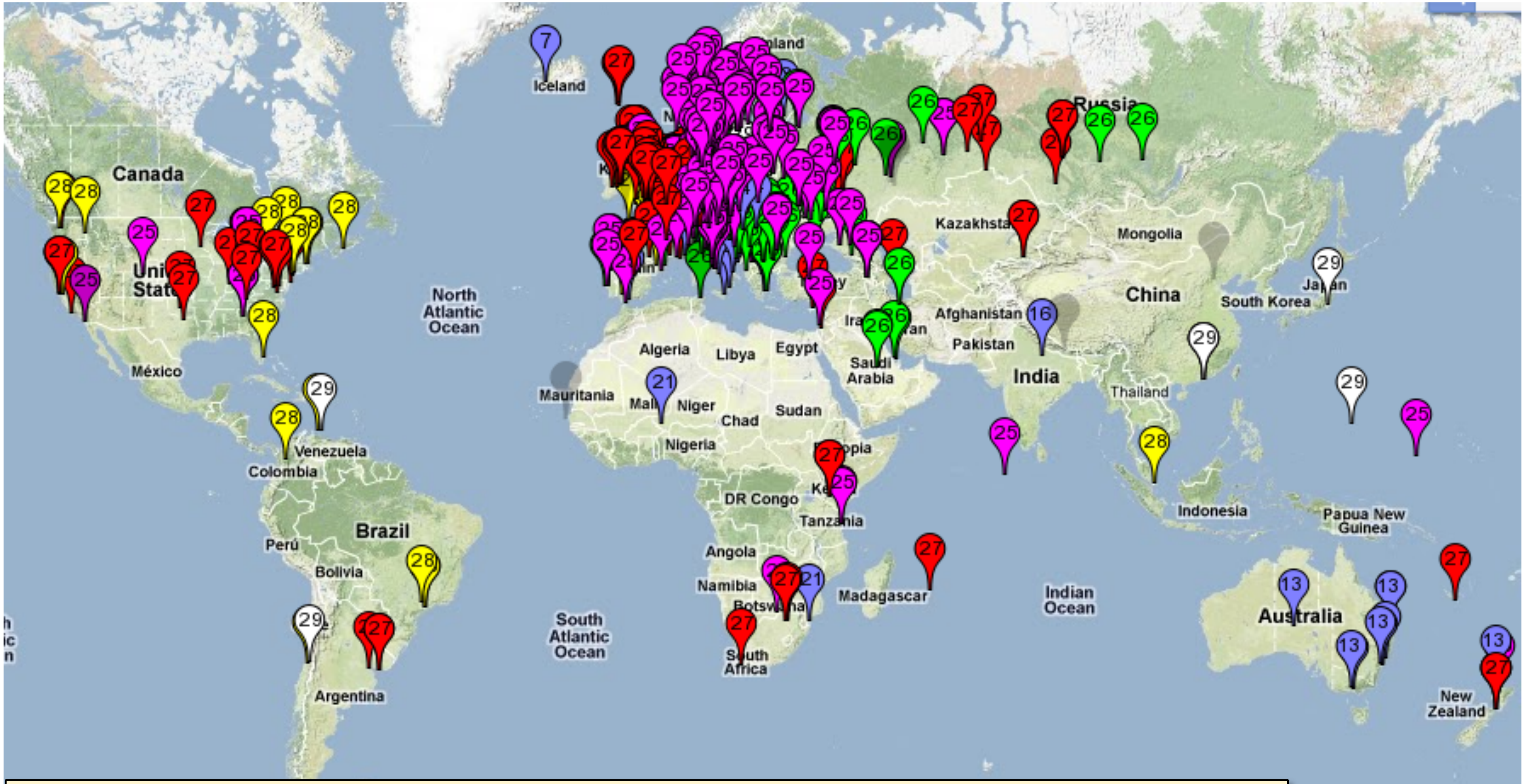
- In practice, most systems cache this information
- DDoS attacks designed to reach root
- infrastructure bugs (e.g. old Telenor modems converted IPv6 lookup into broken IPv4 lookup)

ICANN



from: http://www.icann.org/en/news/correspondence/roberts-testimony-14feb01-en.htm

Map of the Roots



k-root (Europe) is an anycast root node
This is RIPE's map of probing which of the 6 k-root copies get accessed

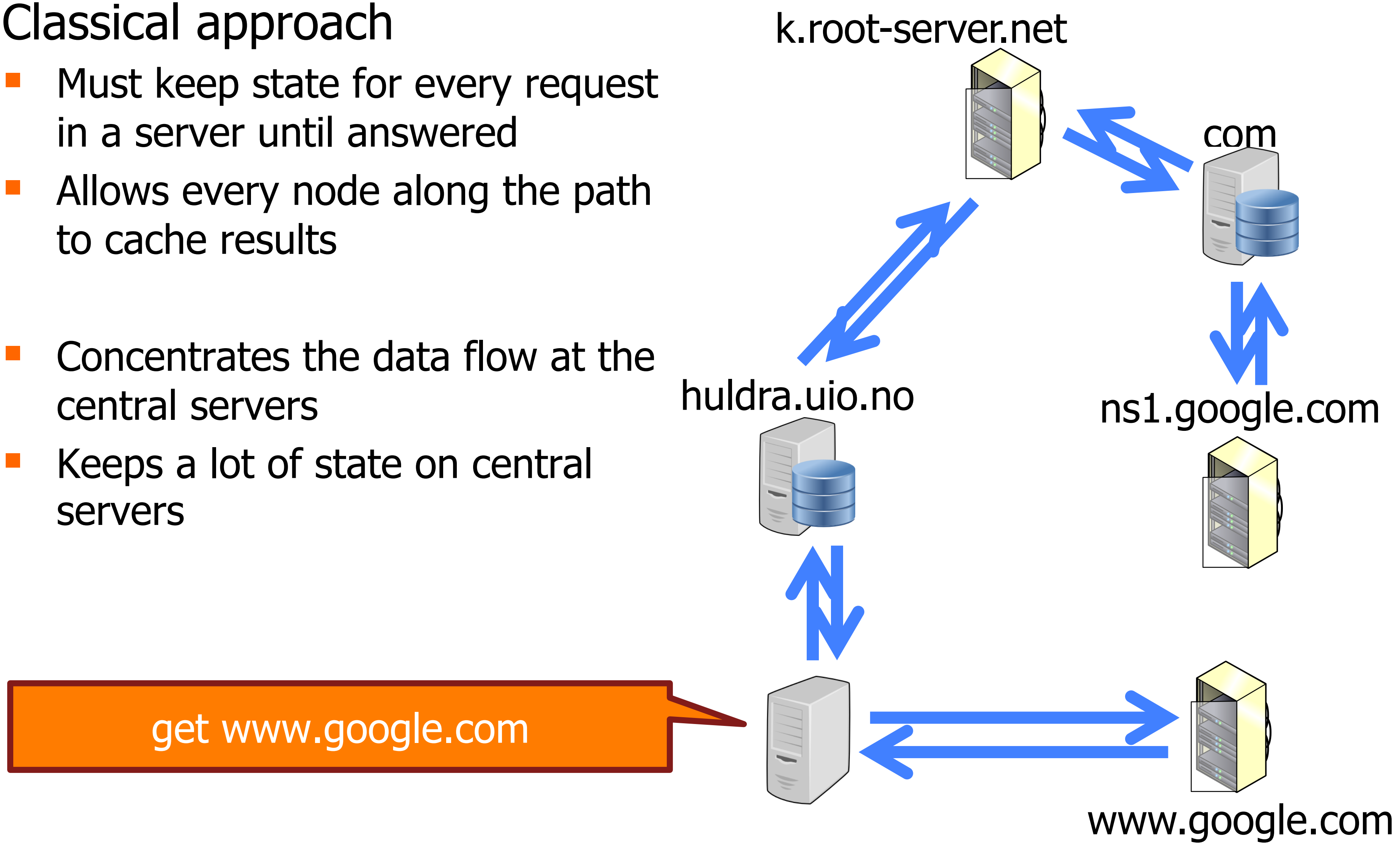
from https://labs.ripe.net/Members/kistel/dns-measurements-with-ripe-atlas-data

Recursive DNS Query

Classical approach

- Must keep state for every request in a server until answered
- Allows every node along the path to cache results

- Concentrates the data flow at the central servers
- Keeps a lot of state on central servers

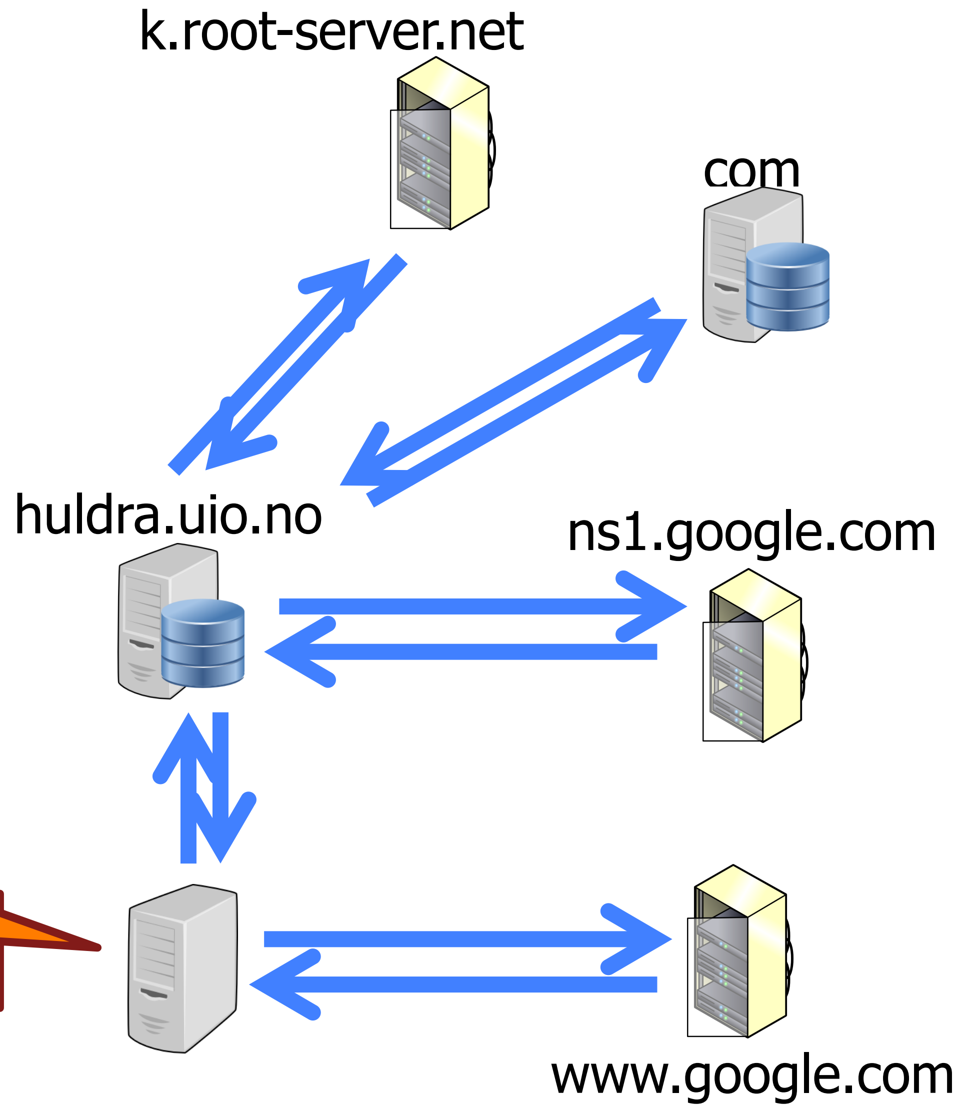


Iterated DNS Query

Newer approach

- Redirects request
- Keep state only at local server (or some servers) until answered

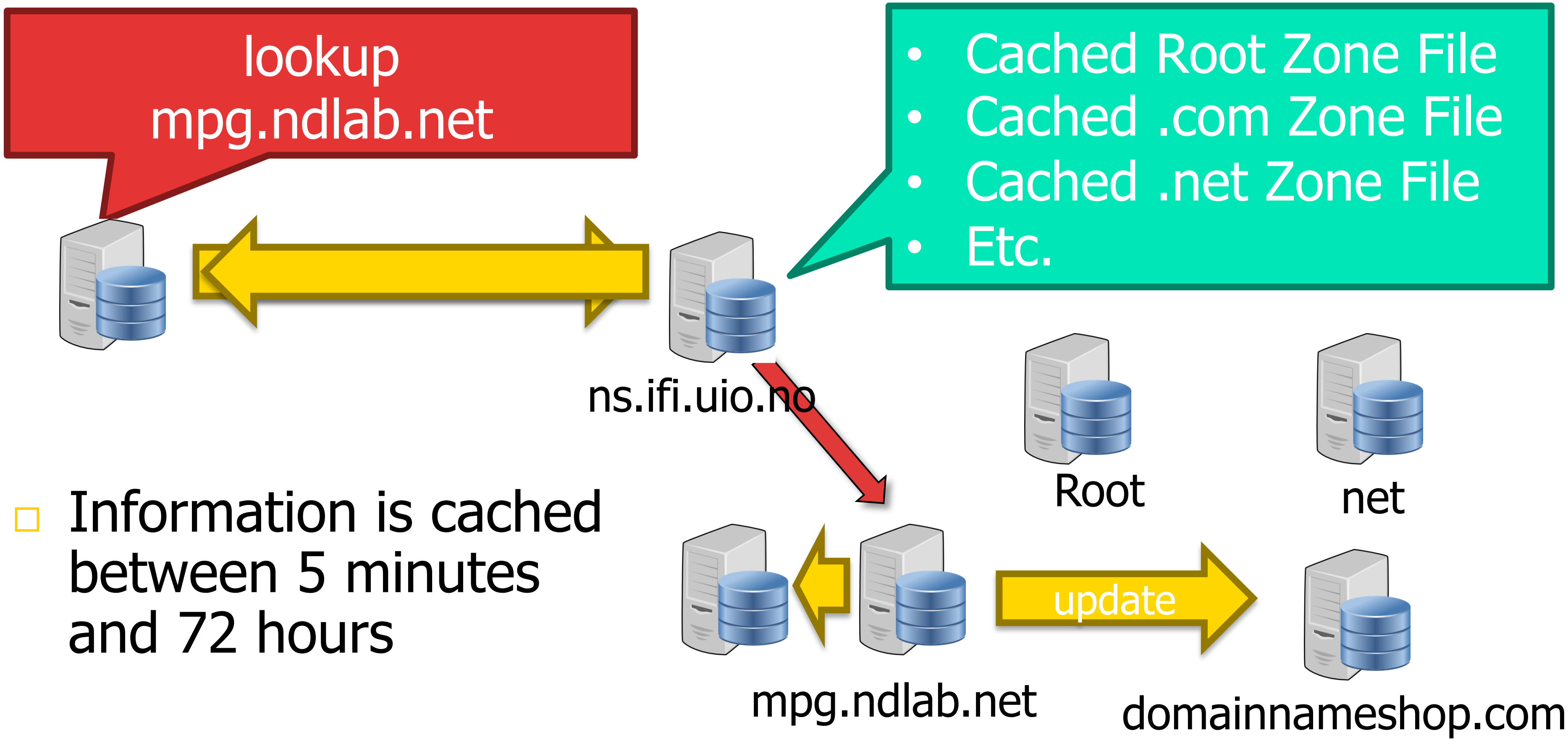
- Allows few nodes to cache results
- Halves number of requests at central servers
- Avoids state on central servers entirely



get www.google.com

Caching vs. Freshness

- Caching reduces DNS resolution latency
- Caching reduces server load
- Caching delays updates



- Information is cached between 5 minutes and 72 hours

DNS as Indirection Service

- DNS gives us very powerful capabilities
  - Not only easier for humans to reference machines!

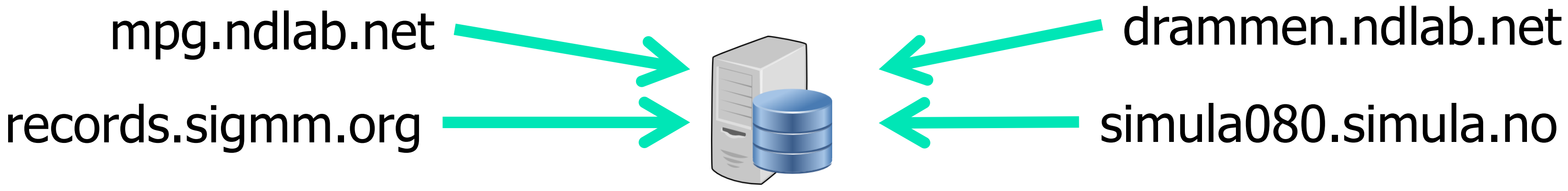
- Changing the IPs of machines becomes trivial
  - e.g. you want to move your web server to a new host
  - Just change the DNS record!

  - Dynamic DNS

  - Zoned DNS

Aliasing and Load Balancing

One machine can have many aliases



mpg.ndlab.net

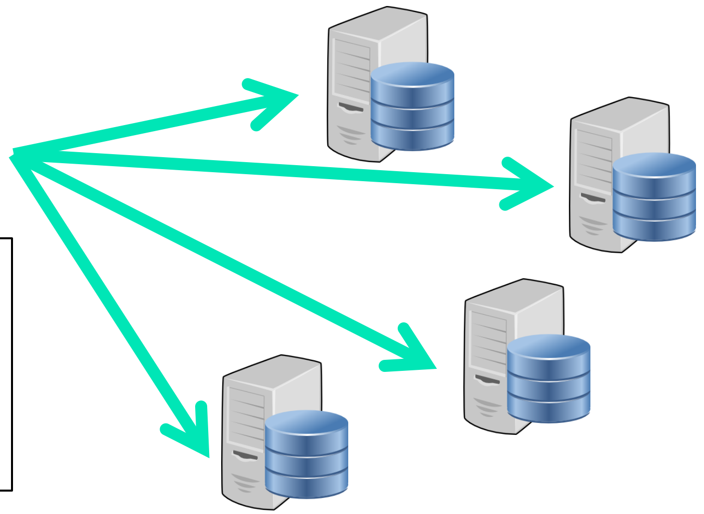
records.sigmm.org

drammen.ndlab.net

simula080.simula.no

One domain can map to multiple machines

www.google.com



That includes k.root-server.net
and
login.ifi.uio.no

Content Delivery Networks

DNS allows zoning

e.g. Netflix (and Google) addresses depend
on the origin of your connection
geography, ISP, …

addresses can also depend on server load
minimal 5-minutes allows Netflix
to direct people to other servers every 5 minutes

Content Delivery Networks

DNS allows zoning

e.g. Netflix (and Google) addresses depend on the origin of your connection geography, ISP, …

“Small problem” with this technique
- modern to use external ***resolvers***
- e.g. ***ALL*** Chrome DNS lookups seem to originate from 8.8.8.8 (an address owned by Google)

Consequences
- user stays more anonymous
- Netflix and others make wrong decisions

addresses can also depend on server load
minimal 5-minutes allows Netflix
to direct people to other servers every 5 minutes

add-ons

- is DNS essential: not really
- where are the root servers located – map!
- resolver: internal and external
- DNS prefetcher
- DNS resolve latency
- alternatives to DNS – P2P
- you get to the best YouTube server because the DNS resolver that you talk to is closest to you
  - this is no longer true when you use an external resolver, such as Chrome's built-in connection to an external resolver
  - benefit: anonymity
  - problem: e.g. Akamai load balancing

Application layer

in the TCP/IP stack

HTTP

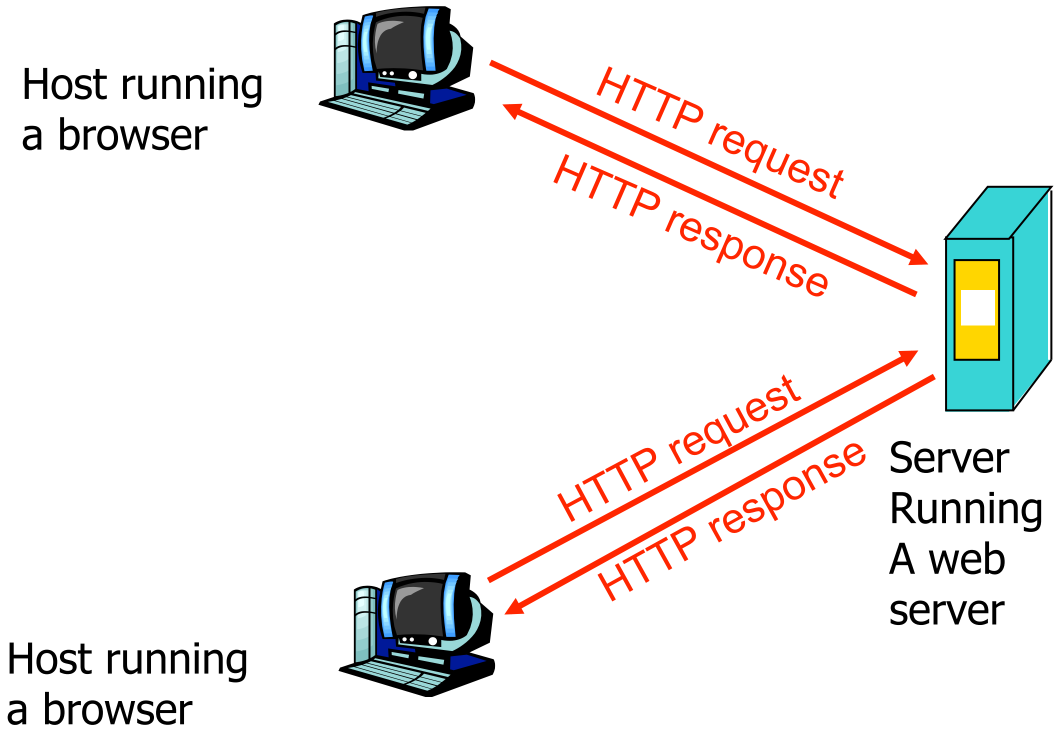
Hypertext Transfer Protocol

The Web: the HTTP protocol

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

- Three major versions
- HTTP/1.0 (1990)
- HTTP/1.1 (1999)
- HTTP/2 (2015)



The HTTP protocol

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 example

Suppose user enters URL www.mn.uio.no/ifi/index.html

1a. HTTP client initiates TCP connection to HTTP server (process) at www.mn.uio.no. Port 80 is default for HTTP server.

1b. HTTP server at host www.mn.uio.no waiting for TCP connection at port 80. "accepts" connection, notifying client

2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket

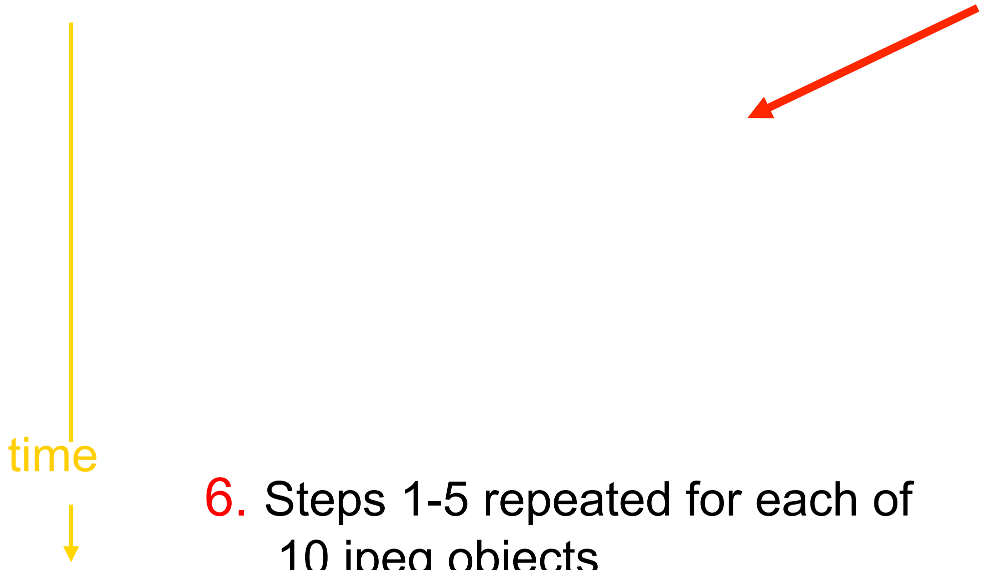
3. HTTP server receives request message, forms *response message* containing requested object (ifi/index.html), sends message into socket

time

(now let's say index.html contains text, references to 10 JPEG images)

HTTP example (cont.)

5. HTTP client receives response message containing HTML file, displays HTML. Parsing HTML file, finds 10 referenced JPEG objects



4. HTTP server closes TCP connection.

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

Non-persistent, persistent connections

Non-persistent

- HTTP/1.0: server parses request, responds, closes TCP connection
- 2 RTTs to fetch object
  - TCP connection
  - object request/transfer
- each transfer suffers from TCP's initially slow sending rate
- many browsers open multiple parallel connections

Persistent

- default for HTTP/1.1
- on same TCP connection: server, parses request, responds, parses new request,..
- client sends requests for all referenced objects as soon as it receives base HTML
- fewer RTTs, less slow start

Persistent with pipelining

- request multiple objects in one go (even fewer RTTs)
- answers arrive one after each other in order of requests

HTTP/1.x message format: request

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

request line
(GET, POST,
HEAD commands)

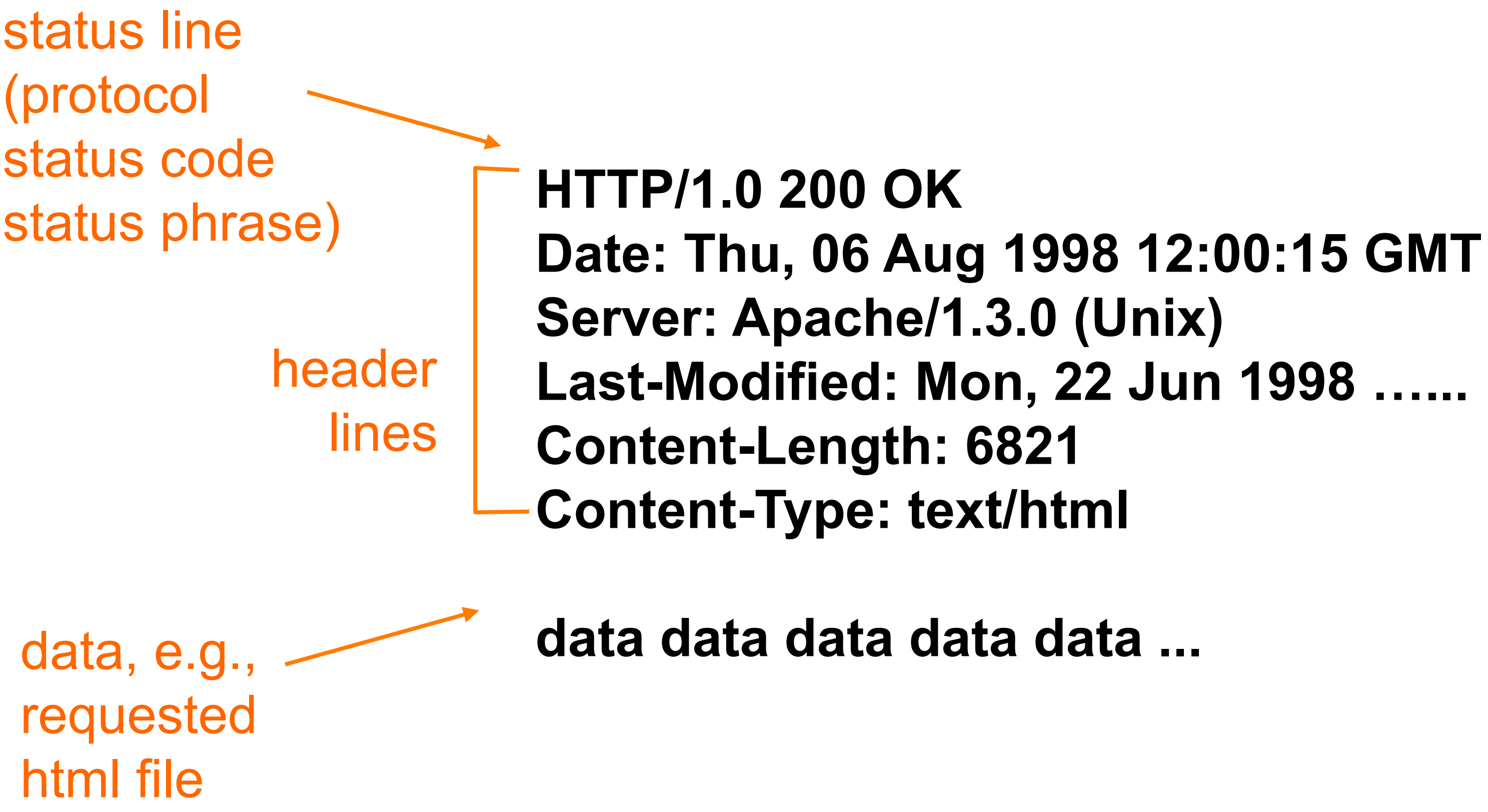
header
lines

```
GET /ifi/index.html HTTP/1.0
User-agent: Mozilla/4.0
Accept: text/html, image/gif,image/jpeg
Accept-language:no

(extra carriage return, line feed)
```

Carriage return,
line feed
indicates end
of message

HTTP/1.x message format: response



status line
(protocol
status code
status phrase)

header
lines

```
HTTP/1.0 200 OK
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 ...
```

data, e.g.,
requested
html file

HTTP/1.x response status code examples

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

Trying out HTTP/1.x (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet www.aftenposten.no 80
```

Opens TCP connection to port 80 (default HTTP server port) at www.aftenposten.no. Anything typed in will be sent via this connection.

2. Type in a GET request:

```
GET / HTTP/1.1
```

By typing this in (hit carriage return once), you send this minimal (but complete) GET request for the root document to the HTTP server

3. Quickly: type in the host header:

```
Host: www.aftenposten.no
```

Servers can be multi-homed (multiple different web sites on physical server), and so the client must specify which host it wants. Else, a server would often return an error message.

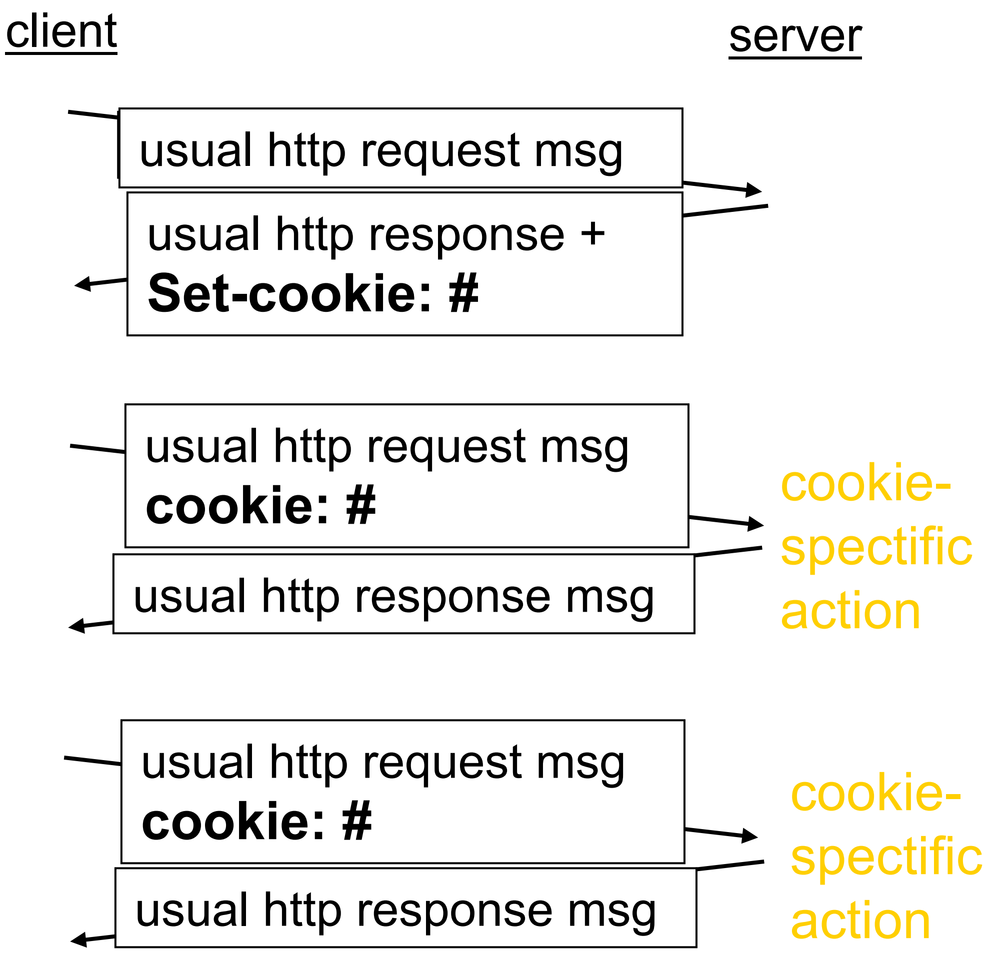
4. Hit carriage return twice and see the result

Cookies: keeping "state"

- server-generated # , server-remembered #, later used for:
  - authentication
  - remembering user preferences, previous choices
- server sends "cookie" to client in response msg

  Set-cookie: 1678453
- client presents cookie in later requests

  cookie: 1678453

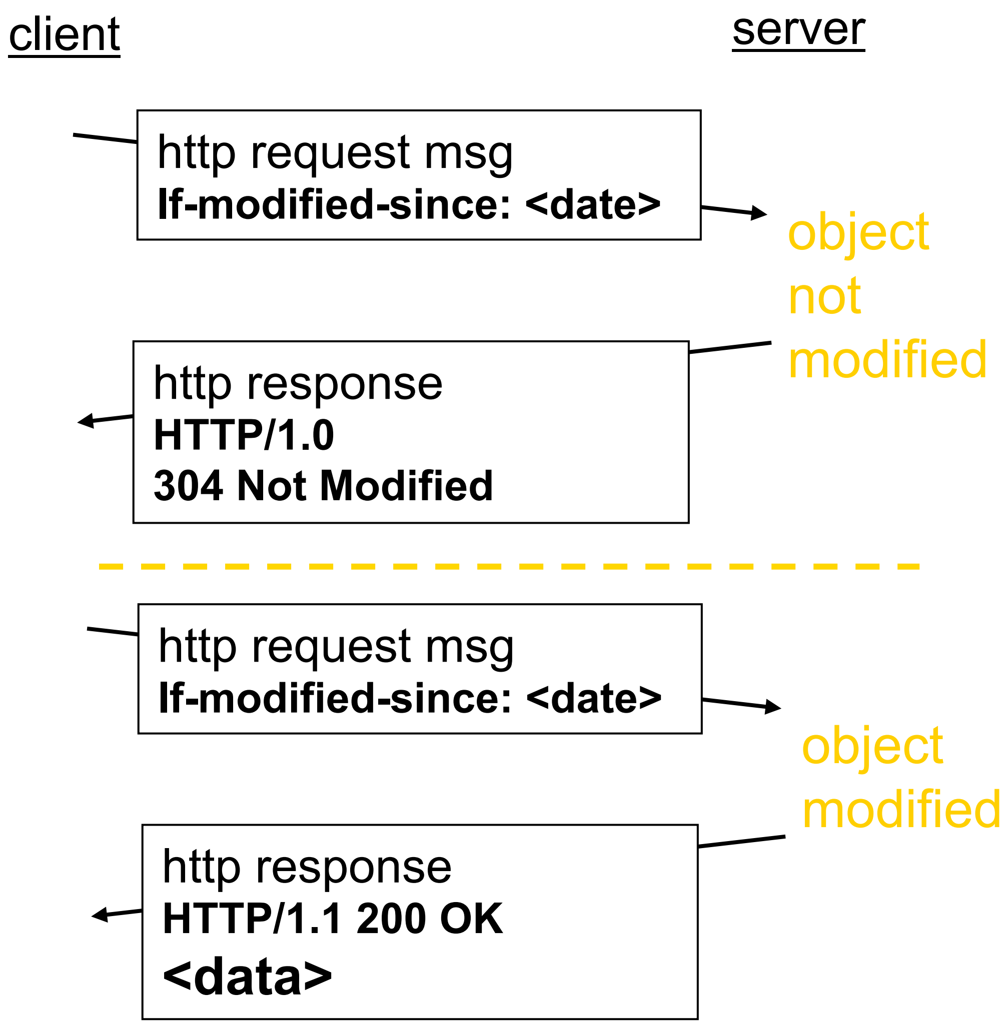


Conditional GET: client-side caching

- 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:

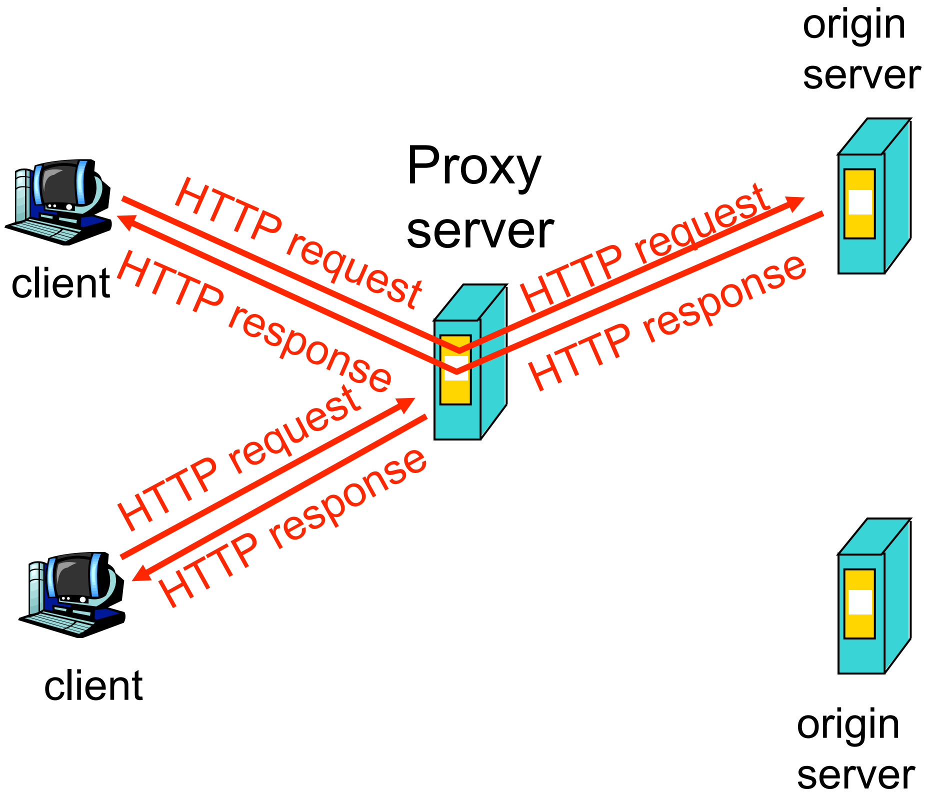
  HTTP/1.0 304 Not Modified



Web Caches (proxy server)

Goal: satisfy client request without involving origin server

- user sets browser: Web accesses via web cache
- client sends all HTTP requests to web cache
  - object in web cache: web cache returns object
  - else web cache requests object from origin server, then returns object to client



Assumption: cache is closer to client (e.g. same network) => faster, less “long-distance” traffic

Big changes in HTTP/2

- textual protocol → binary protocol
- supports header compression
- ordered and blocking → multiplexed
  - can therefore use one connection for parallelism
- client pull only -> client pull and server push

Changes in HTTP/2

textual protocol

can be written manually

can be read when intercepted

easy to add (and ignore) proprietary extensions

very talkative

binary protocol

saves space

less data to write and parse

exactly specified

hard to extended

uncompressed header

required in 1.0

avoidance eases transition to 1.1

compressed header

adds a lookup table

may save space

info like: *cookies, referer, stream dependencies, weighting, priorities, client identification, …*

Changes in HTTP/2

ordered and blocking

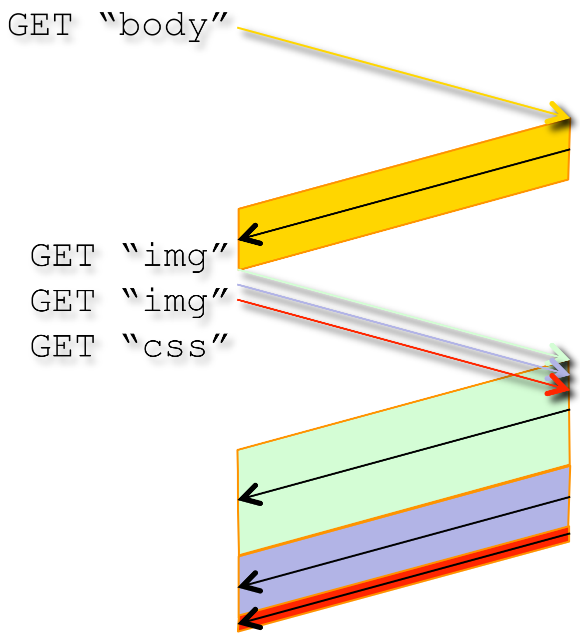
speed-up by using several parallel TCP connections (1.x)

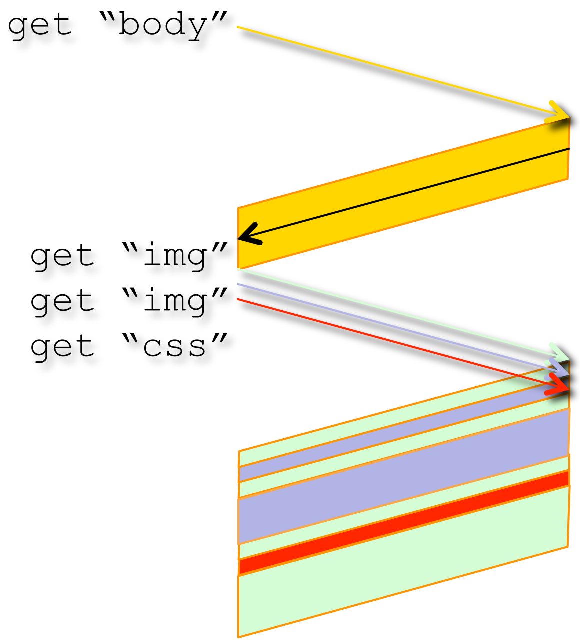
speed-up by using pipelining (1.1)

multiplexed

send all requests at once

server chooses order (e.g. send advertising inlays first) and can mix messages





app-layer flow control per subflow

Changes in HTTP/2

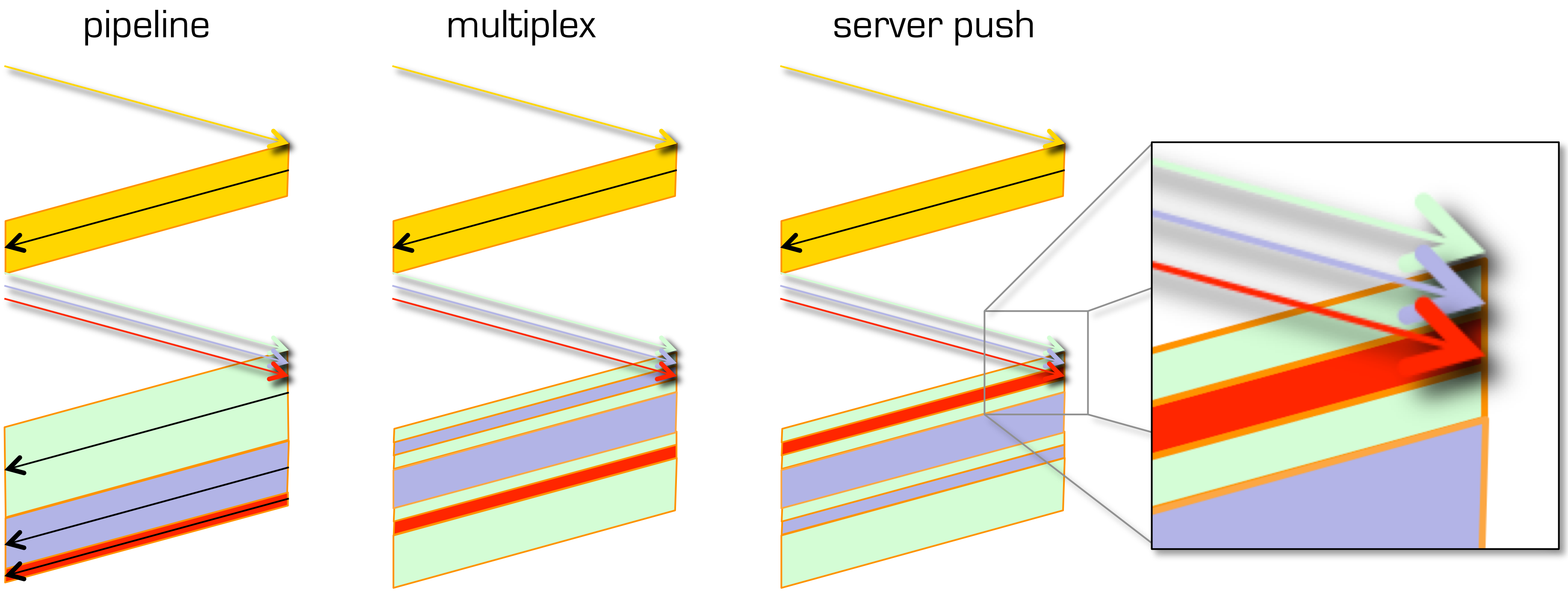
client pull

assumption: server is stateless

→

client pull + server push

assumption: server knows best



Application layer

in the TCP/IP stack

SMTP and MIME

Simple mail transfer protocol

Multipurpose Internet mail extensions

Electronic Mail

- Major components
  - “mail clients”
    Message User Agents (MUAs)
  - “mail servers”
    Message Submission / Transfer / Delivery Agents (MSA, MTA, MDA)
    - often realized as one component called
      Message Handling Service (MHS)

- MUA
  - a.k.a. “mail reader”
  - composing, editing, reading mail messages
  - outgoing, incoming messages stored on server

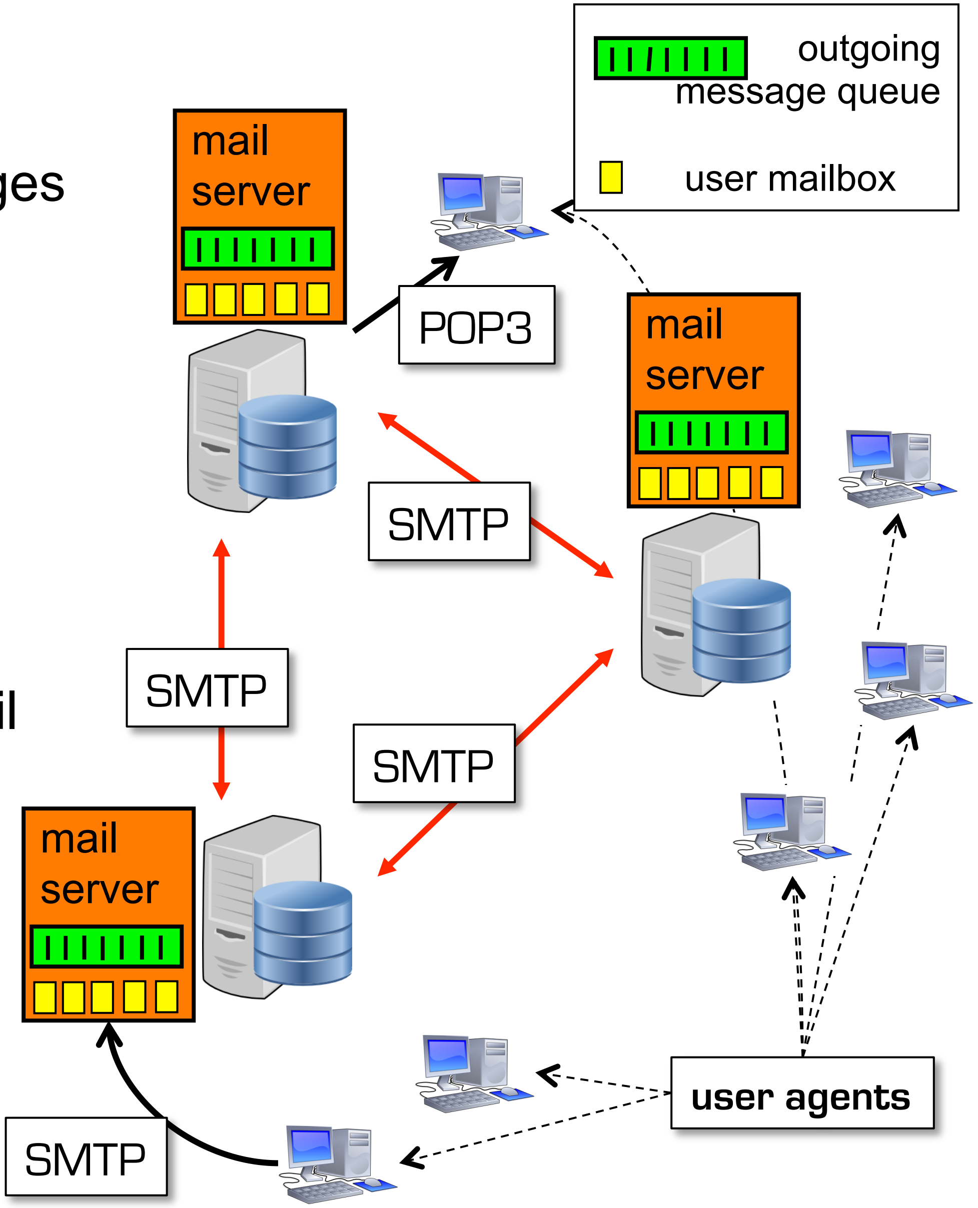
Electronic Mail: mail servers

Mail Servers

- *mailbox* contains incoming messages (yet to be read) for user
- *message queue* of outgoing (to be sent) mail messages

Simple Mail Transfer Protocol (SMTP)

- between mail servers to send email messages
- client: sending mail server
- server: receiving mail server



Electronic Mail: 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

- messages must be in 7-bit ASCII

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
```

Handmade SMTP

```
telnet servername 25
```

see 220 reply from server

enter HELO, MAIL FROM, RCPT TO, DATA, QUIT commands

above lets you send email without using email client (reader)

SMTP: final words

SMTP uses persistent connections

SMTP requires message (header & body) to be in 7-bit ASCII

Certain character strings not permitted in msg (e.g., `CRLF.CRLF`). Thus msg has to be encoded (usually into either base-64 or quoted printable)

SMTP server uses `CRLF.CRLF` to determine end of message (no length header)

Comparison with HTTP/1.x:

- HTTP: pull
- STMP: push
  - until final server!
  - until recently: reading mails on final server itself using NFS
- both have ASCII command/ response interaction, status codes
- HTTP
  - each object encapsulated in its own response msg
- SMTP
  - originally the same
  - now: multiple objects sent in multipart msg

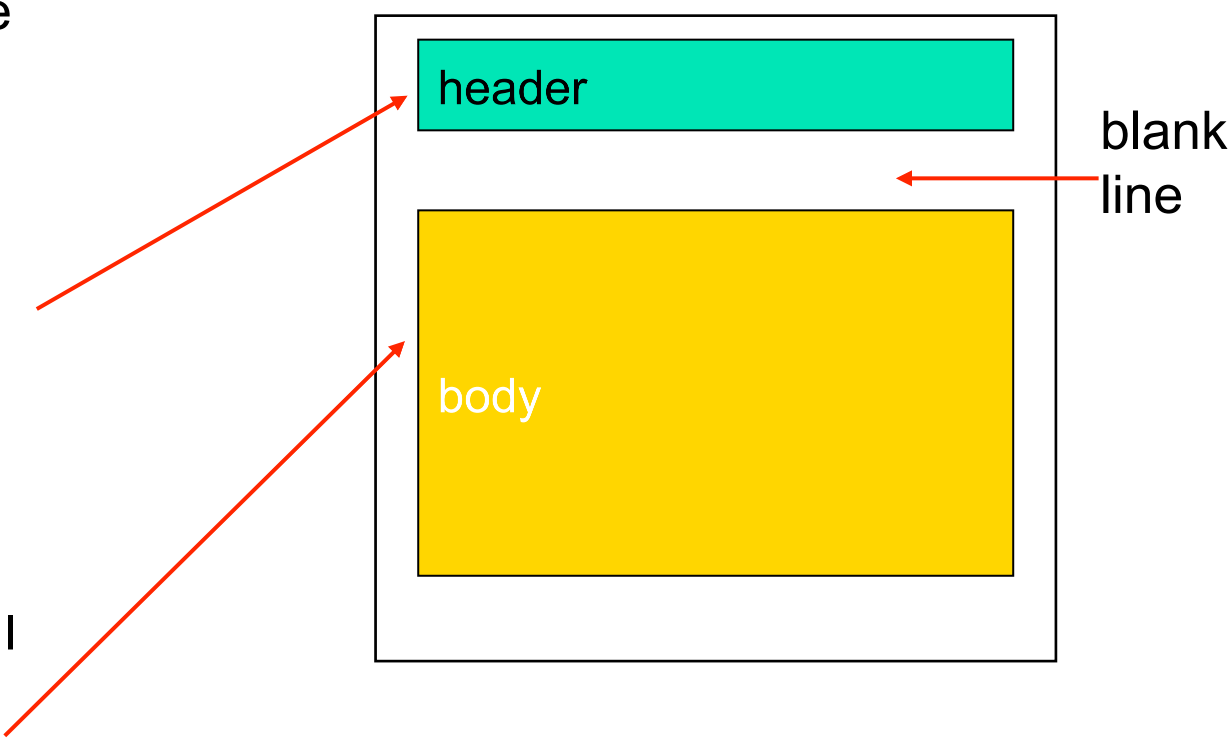
Mail message format

SMTP: protocol for exchanging email msgs

Standard for text message format:

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

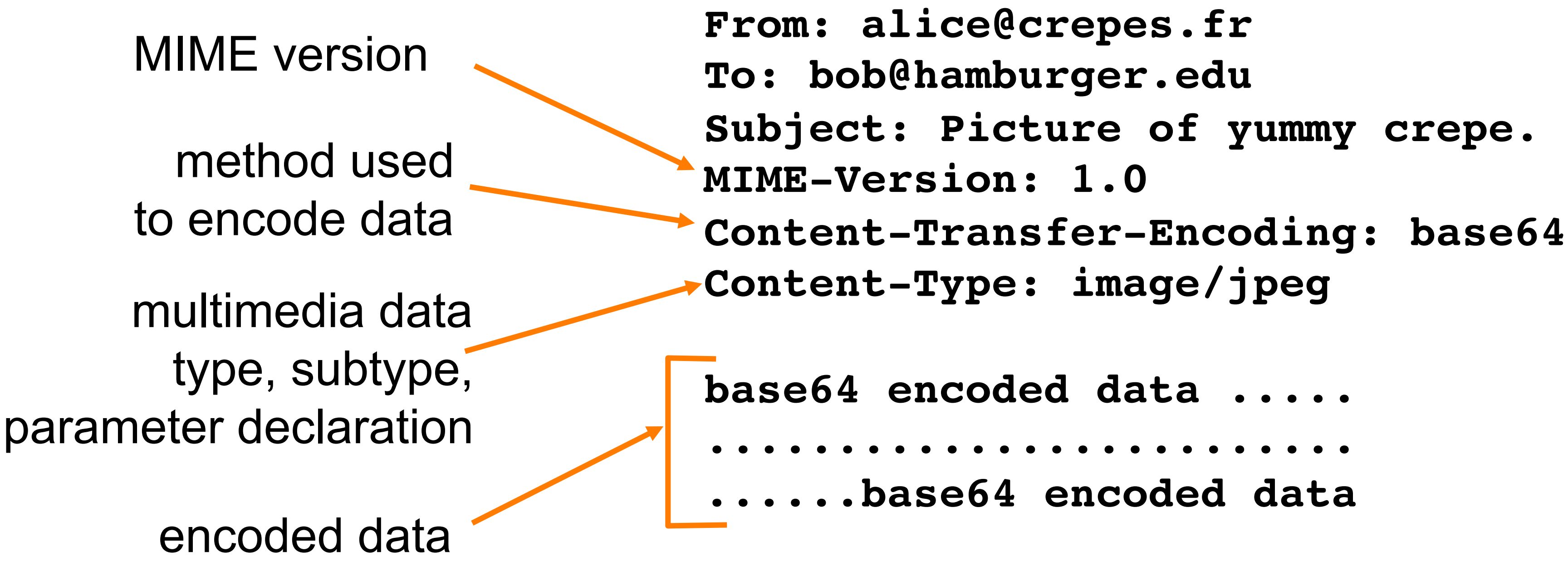
  different from SMTP commands!
- body
  - the “message”, ASCII characters only



Message format: multimedia extensions

MIME: multipurpose Internet mail extension

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
```

"classical" mail may indicate:
Content-type: text/ascii
but 7-bit ASCII text is still the default

MIME types

`Content-Type: type/subtype; parameters`

Text

- example subtypes: **plain, html**

Image

- example subtypes: **jpeg, gif**

Audio

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

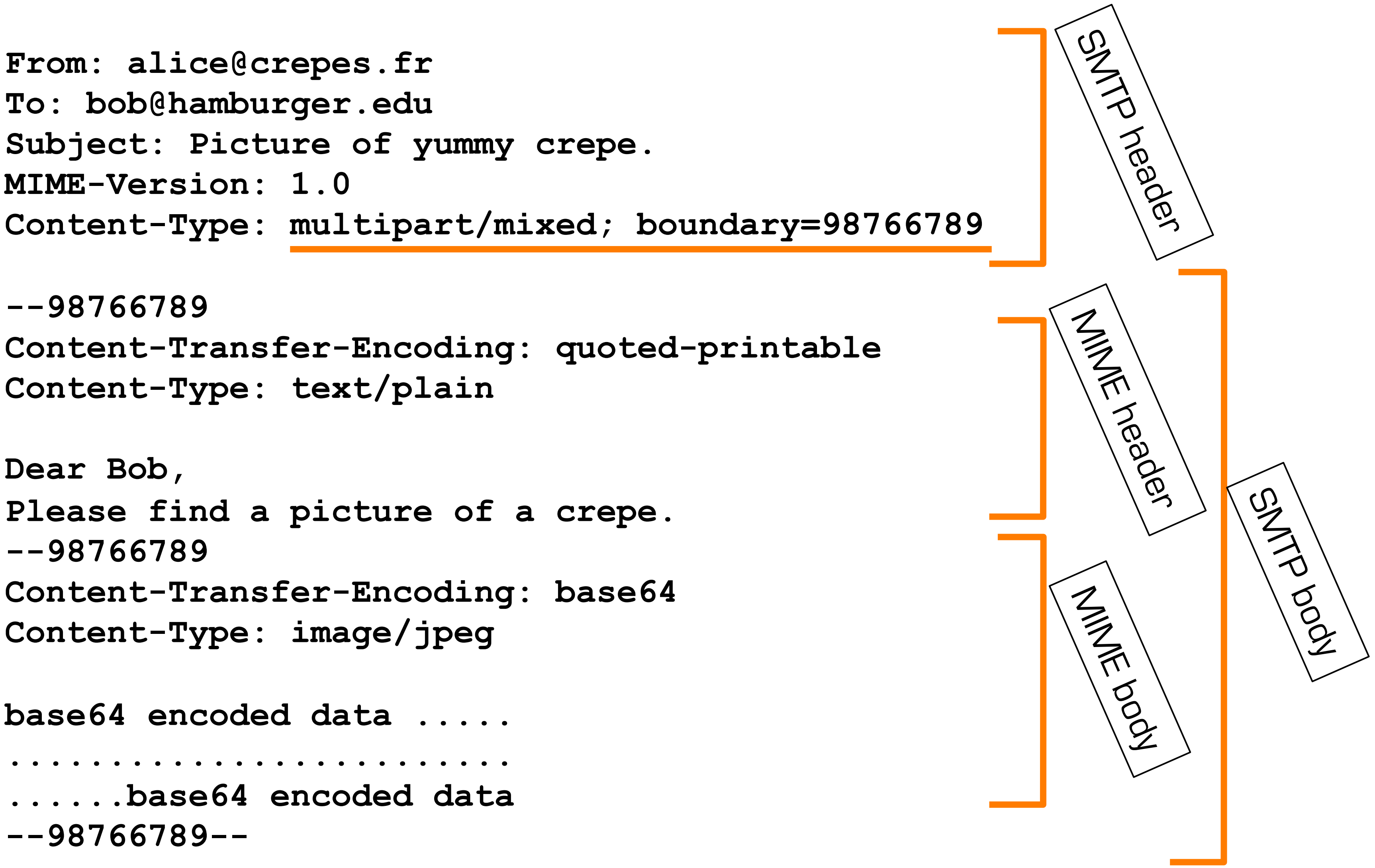
Video

- 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=98766789

--98766789
Content-Transfer-Encoding: quoted-printable
Content-Type: text/plain

Dear Bob,
Please find a picture of a crepe.
--98766789
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
--98766789--
```

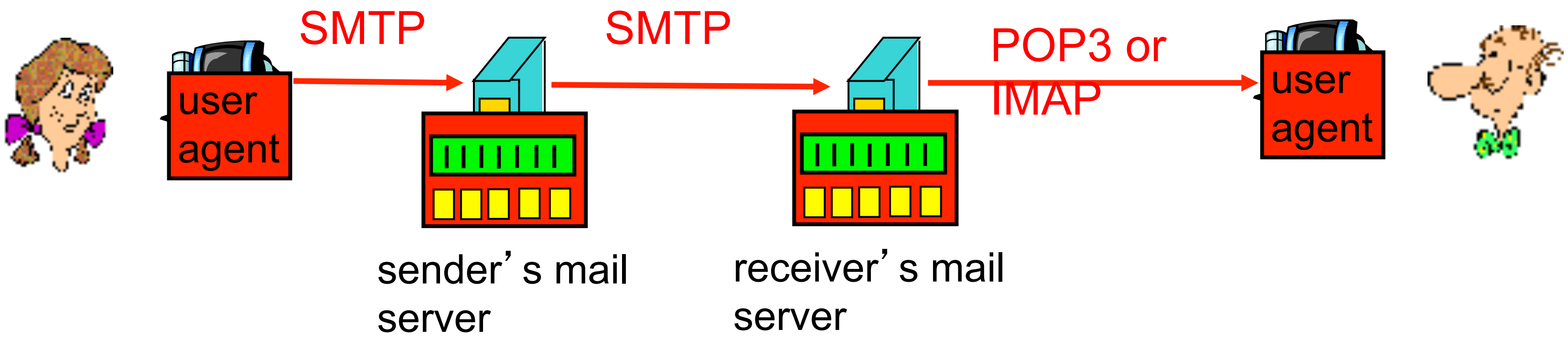
SMTP header

MIME header

MIME body

SMTP body

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 messages on server
  - HTTP: Hotmail , Yahoo! Mail, etc.

POP3 protocol

authorization phase

- client commands:
  - **`user`**: declare username
  - **`pass`**: password (plain text!)
- server responses
  - **`+OK`**
  - **`-ERR`**

transaction phase, client:

- **`list`**: list message numbers
- **`retr`**: retrieve message by number
- **`dele`**: delete
- **`quit`**

```
S:  +OK POP3 server ready
C:  user alice
S:  +OK
C:  pass hungry
S:  +OK user successfully logged on
```

```
C:  list
S:  1 498
S:  2 912
S:  .
C:  retr 1
S:  <message 1 contents>
S:  .
C:  dele 1
C:  retr 2
S:  <message 1 contents>
S:  .
C:  dele 2
C:  quit
S:  +OK POP3 server signing off
```

IMAP protocol example (from RFC3501)

```
C: <open connection>
S:   * OK IMAP4rev1 Service Ready
C:   a001 login mrc secret
S:   a001 OK LOGIN completed
C:   a002 select inbox
S:   * 18 EXISTS
S:   * FLAGS (\Answered \Flagged \Deleted \Seen \Draft)
S:   * 2 RECENT
S:   * OK [UNSEEN 17] Message 17 is the first unseen message
S:   * OK [UIDVALIDITY 3857529045] UIDs valid
S:   a002 OK [READ-WRITE] SELECT completed
C:   a003 fetch 12 full
S:   * 12 FETCH (FLAGS (\Seen) INTERNALDATE "17-Jul-1996
02:44:25 -0700"
     RFC822.SIZE 4286 ENVELOPE ("Wed, 17 Jul 1996 02:23:25
-0700 (PDT)"
     "IMAP4rev1 WG mtg summary and minutes"
     (("Terry Gray" NIL "gray" "cac.washington.edu"))
     (("Terry Gray" NIL "gray" "cac.washington.edu"))
     (("Terry Gray" NIL "gray" "cac.washington.edu"))
     ((NIL NIL "imap" "cac.washington.edu"))
     ((NIL NIL "minutes" "CNRI.Reston.VA.US")
     ("John Klensin" NIL "KLENSIN" "MIT.EDU")) NIL NIL
     "<B27397-0100000@cac.washington.edu>")
     BODY ("TEXT" "PLAIN" ("CHARSET" "US-ASCII") NIL NIL
"7BIT" 3028
     92))
S:   a003 OK FETCH completed
C:   a004 fetch 12 body[header]
S:   * 12 FETCH (BODY[HEADER] {342}
S:   Date: Wed, 17 Jul 1996 02:23:25 -0700 (PDT)
S:   From: Terry Gray <gray@cac.washington.edu>
S:   Subject: IMAP4rev1 WG mtg summary and minutes
S:   To: imap@cac.washington.edu
S:   cc: minutes@CNRI.Reston.VA.US, John Klensin
<KLENSIN@MIT.EDU>
S:   Message-Id: <B27397-0100000@cac.washington.edu>
S:   MIME-Version: 1.0
S:   Content-Type: TEXT/PLAIN; CHARSET=US-ASCII
S:
S:   )
S:   a004 OK FETCH completed
C    a005 store 12 +flags \deleted
S:   * 12 FETCH (FLAGS (\Seen \Deleted))
S:   a005 OK +FLAGS completed
C:   a006 logout
S:   * BYE IMAP4rev1 server terminating connection
S:   a006 OK LOGOUT completed
```

Summary

- First peek at structure of distributed applications
- Presentation Layer functions
- Domain Name Systems
  - with note on CDNs
- HTTP
- SMTP
  - and an example for POP3 and IMAP