Chapter 2
APPLICATIONS

Distributed
Computing
Group

Computer Networks

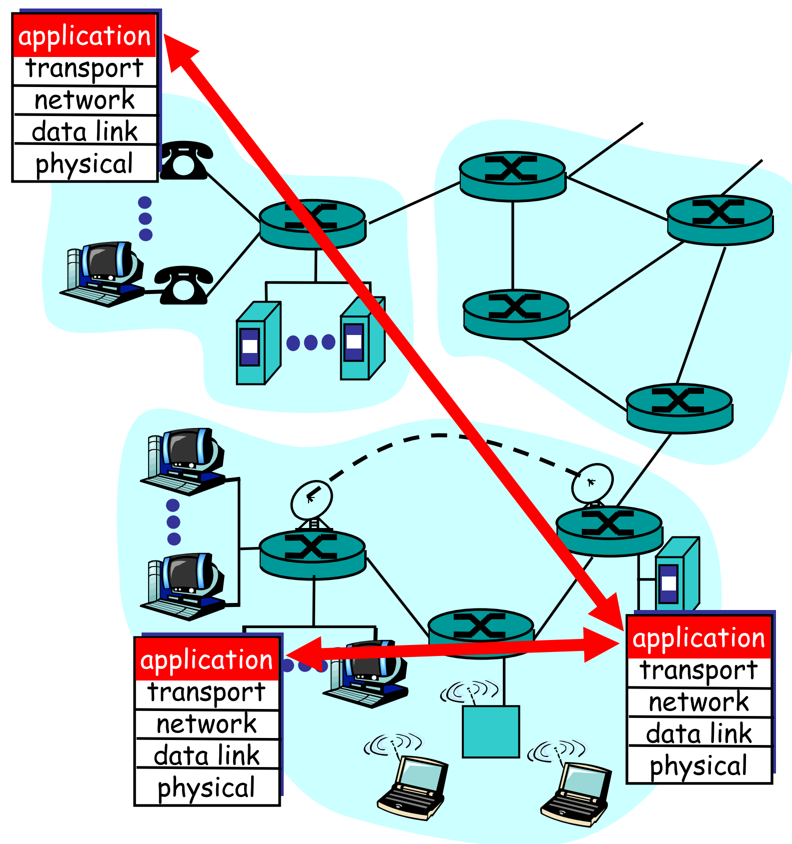
Summer 2006

Overview

- Learn specific application layer protocols
  - http, ftp, smtp, pop, dns, etc.
- How to program network applications?
- Socket API for Java and Eiffel
- Goals
  - learn about protocols by examining popular application-level protocols
  - conceptual and implementation aspects of network application protocols
  - client-server paradigm
  - service models

Applications vs. Application-Layer Protocols

- Application: communicating, distributed process
  - running in network hosts in "user space"
  - exchange messages to implement application
  - e.g. email, ftp, web
- Application-layer protocol
  - one part of application
  - define messages exchanged by applications and actions taken
  - use communication services provided by transport layer protocols (TCP, UDP)

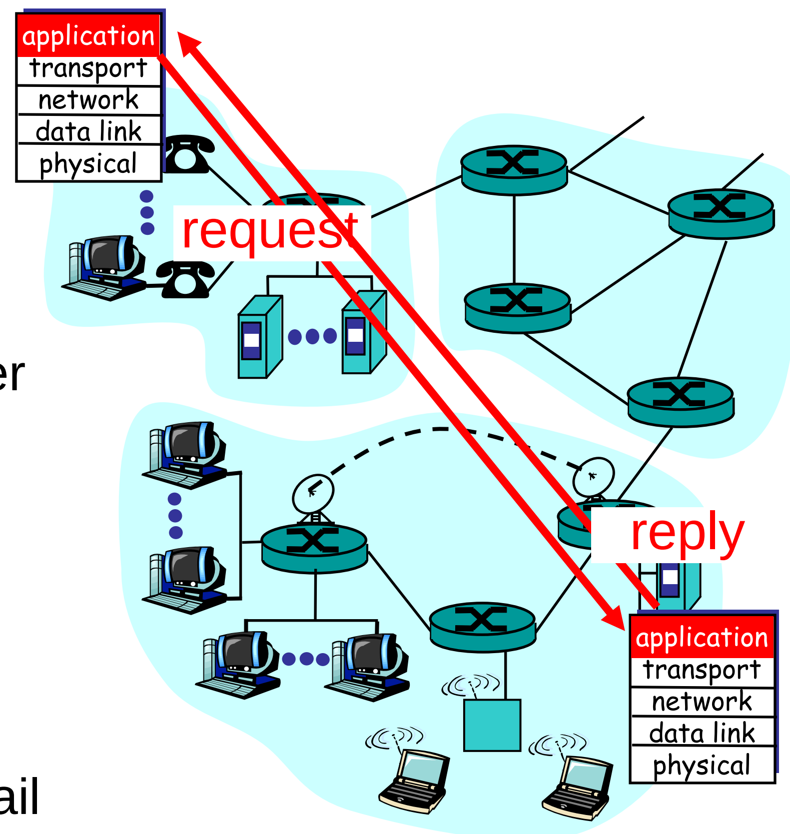


Network applications: some jargon

- Process: program running within a host
  - within same host, two processes communicate using interprocess communication (defined by Operating System).
  - processes running on different hosts communicate with an application-layer protocol through messages
- User agent: software process, interfacing with user “above” and network “below”
  - implements application-level protocol
  - Examples
    - Web: browser
    - E-mail: mail reader
    - streaming audio/video: media player

Client-server paradigm

Typical network app has two parts: Client and Server



Client

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

Server

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

API: Application Programming Interface

- Defines interface between application and transport layers
- socket: Internet API
- two processes communicate by sending data into socket, reading data out of socket

- How does a process identify the other process with which it wants to communicate?
  - IP address of host running other process
  - "port number": allows receiving host to determine to which local process the message should be delivered
  - lots more on this later…

What transport service does an application 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 to be "effective"

Bandwidth

- some apps (e.g. multimedia) require minimum amount of bandwidth to be "effective"
- other apps ("elastic apps") make use of whatever bandwidth they get

Transport service requirements of common applications

Application	Data loss	Bandwidth	Time Sensitive
file transfer	no loss	elastic	no
e-mail	no loss	elastic	no
Web documents	loss-tolerant	elastic	no
real-time audio/video	loss-tolerant	audio: 5Kb-1Mb video:10Kb-5Mb	yes, 100's msec
stored audio/video	loss-tolerant	same as above	yes, few secs
interactive games	loss-tolerant	few Kbps up	yes, 100's msec
financial apps	no loss	elastic	yes and no

Internet transport protocols services

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 provide 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
- Why bother? Why is there a UDP service at all?!?

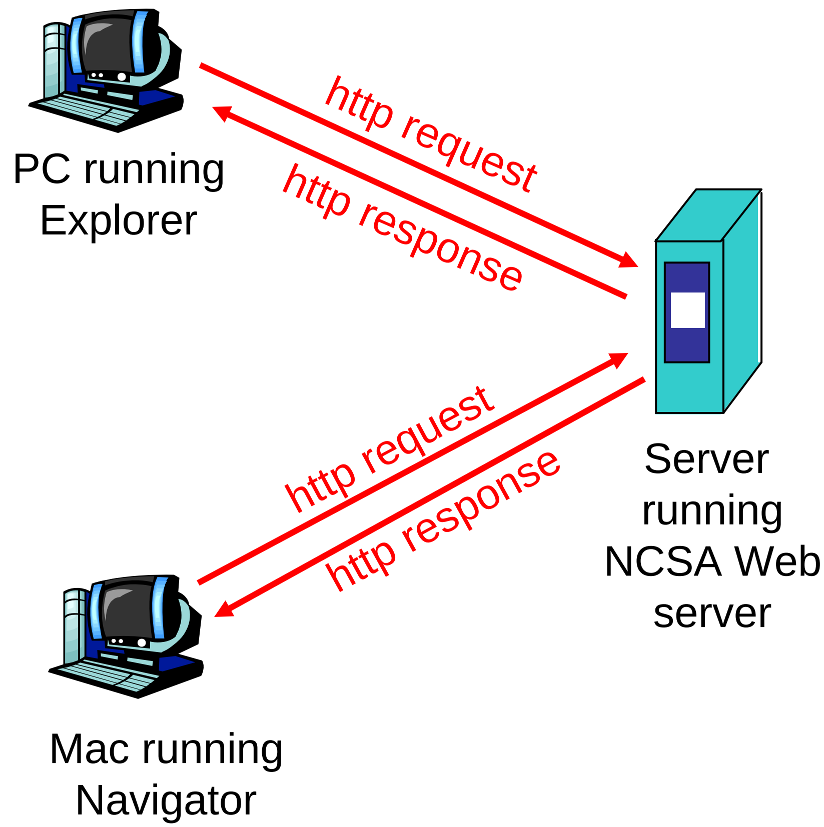
Internet apps: application, transport protocols

Application	Application layer protocol	Underlying transport protocol
e-mail	smtp [RFC 821]	TCP
remote terminal access	telnet [RFC 854]	TCP
Web	http [RFC 2068]	TCP
file transfer	ftp [RFC 959]	TCP
streaming multimedia	proprietary (e.g. Quicktime)	TCP or UDP
remote file server	NFS	TCP or UDP
Internet telephony	proprietary (e.g. Vocaltec)	typically UDP

The Web: The http protocol

http: hypertext transfer protocol

- Web's application layer protocol
- client/server model
  - *client:* browser that requests, receives, and "displays" Web objects
  - *server:* Web server sends objects in response to requests
- http 1.0: RFC 1945
- http 1.1: RFC 2616



More on the http protocol

- 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

Example for http

Suppose user enters URL www.inf.ethz.ch/education/index.html
(assume that web page contains text, references to 10 jpeg images)

1. http client initiates TCP connection to http server (process) at www.inf.ethz.ch. Port 80 is default for http server.

2. http server at host www.inf.ethz.ch waiting for TCP connection at port 80, “accepts” connection, notifies client

3. http client sends http request message (containing URL) into TCP connection socket

4. http server receives request message, forms *response message* containing requested object (index.html in directory education), sends message into socket

time

Example for http (continued)

5. http server closes TCP connection

6. http client receives response message containing html file, displays html. Parsing html file, finds 10 referenced jpeg pictures

Then…

Steps 1-6 repeated for each of the 10 jpeg objects

time

Non-persistent vs. persistent connections

Non-persistent

- http/1.0
- server parses request, responds, closes TCP connection
- 2 RTTs (round-trip-time) 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

http message format: request

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

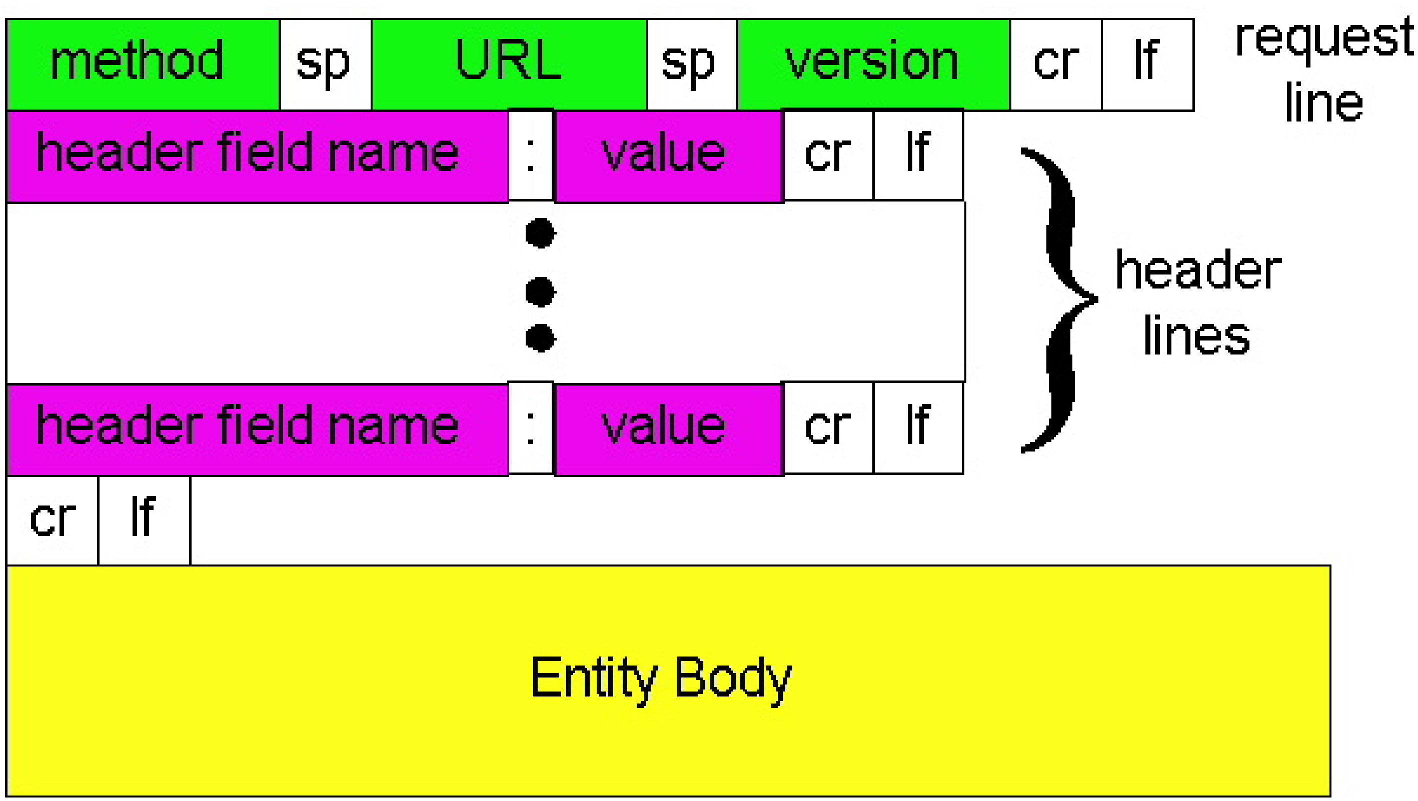
request line
(GET, POST,
HEAD commands)

```
GET /somedir/page.html HTTP/1.1
Host: www.servername.com
User-agent: Mozilla/4.0
Accept-language: de

(extra carriage return, line feed)
```

header
lines

Carriage return
and line feed
indicate end
of message

http request message: the general format



http message format: response

status line (protocol status code status phrase)

header lines

data, e.g. requested html file

```
HTTP/1.1 200 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 ...
```

http response status codes

First line of 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

Be your own http client

1. Telnet to your favorite Web server:
   telnet www.sbb.ch 80

- Opens TCP connection to port 80 (default http server port) at www.sbb.ch.

2. Type in a GET http request:
   GET /index.htm HTTP/1.0

- Anything typed in sent to port 80 at www.sbb.ch
- By typing this (hit carriage return twice), you send this minimal (but complete) GET request to http server

3. Check out response message sent by http server…

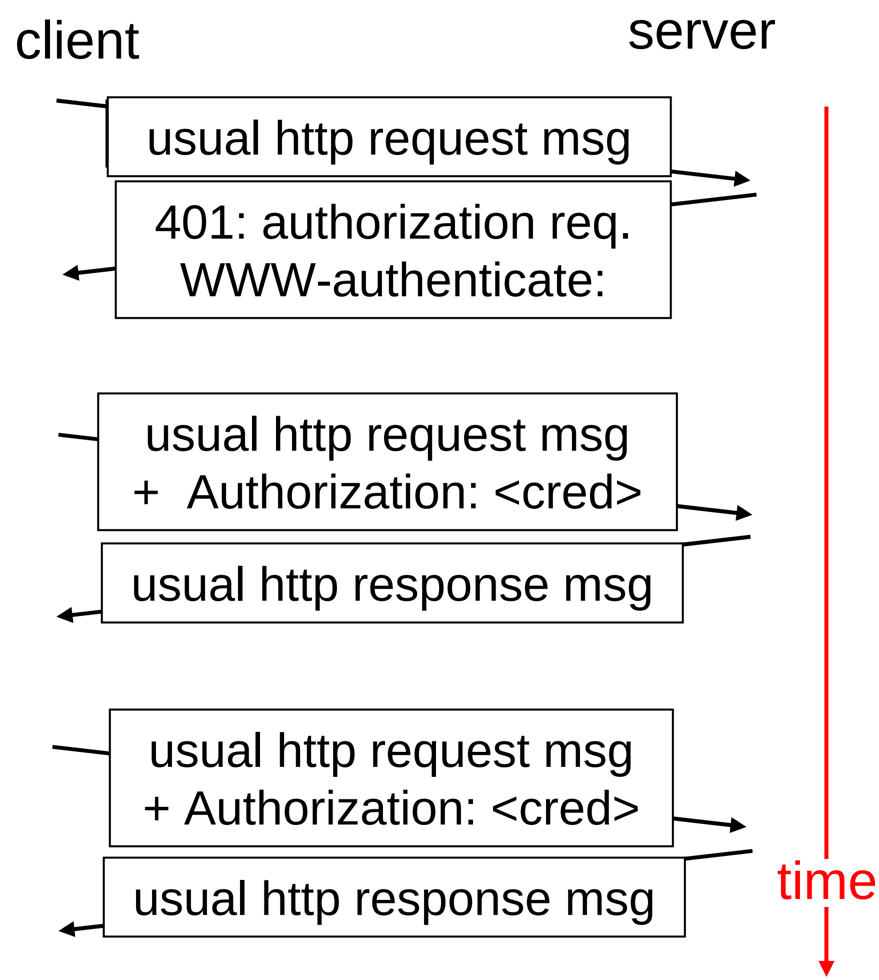
Could you check the SBB timetable from within your own application?!?

User-server interaction: authentication

- Authentication: control access to server content
- authorization credentials: typically name and password
- stateless: client must present authorization in *each* request
  - authorization: header line in each request
  - if no authorization: header, server refuses access, sends

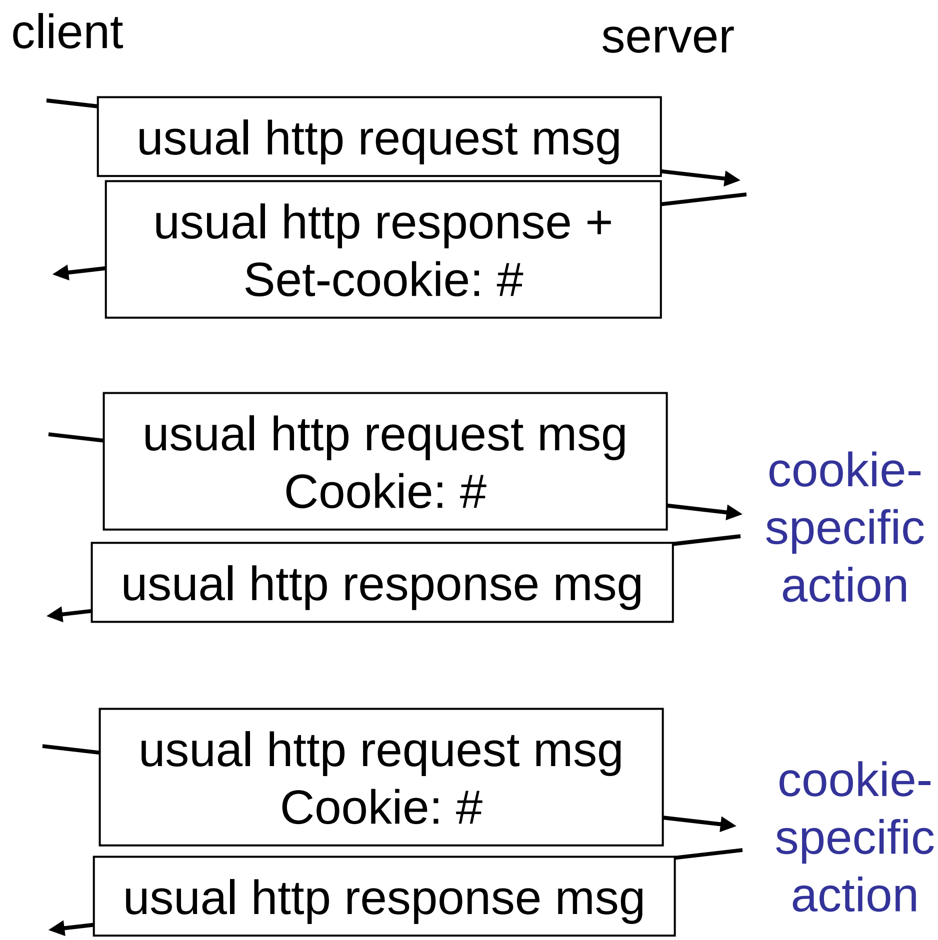
    `WWW authenticate:`

    header line in response



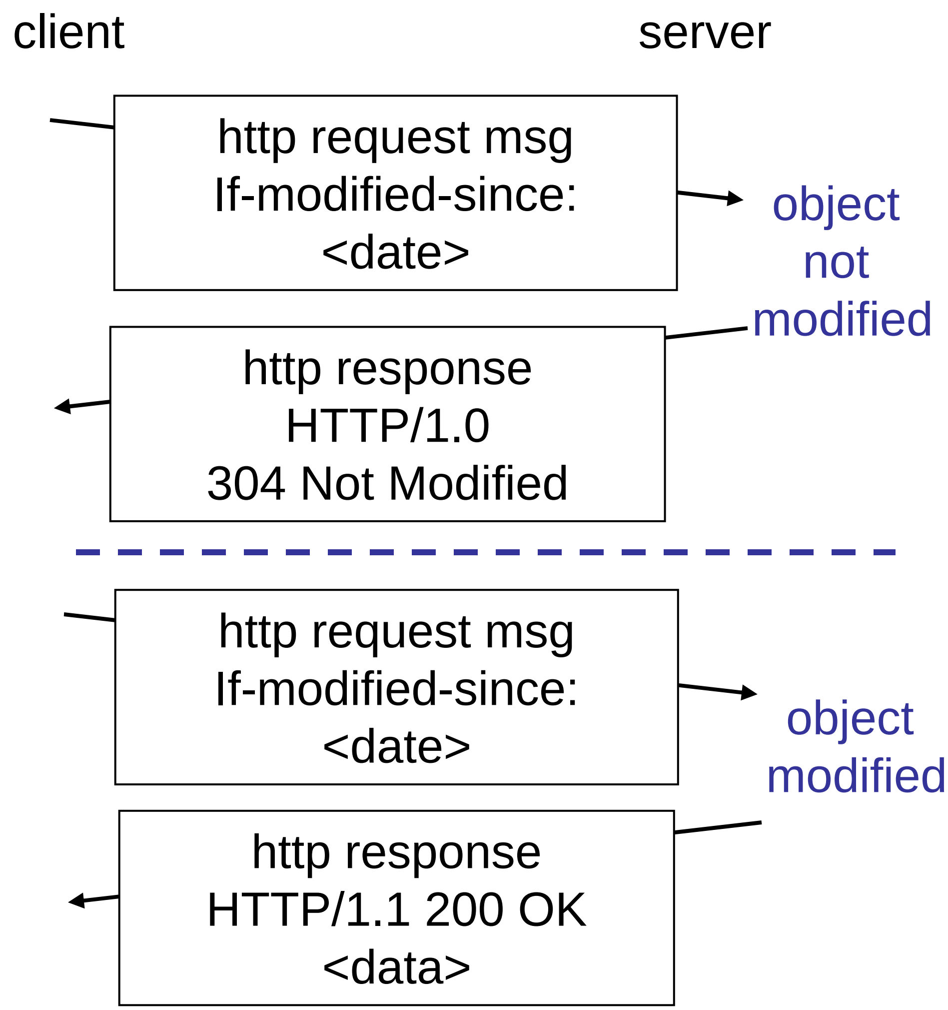
Cookies: keeping "state"

- server-generated # , server-remembered #, later used for
  - authentication
  - remembering user preferences
  - remembering previous choices
  - (…privacy?)
- server sends "cookie" to client in response msg
  `Set-cookie: 1678453`
- client presents cookie in later requests
  `Cookie: 1678453`



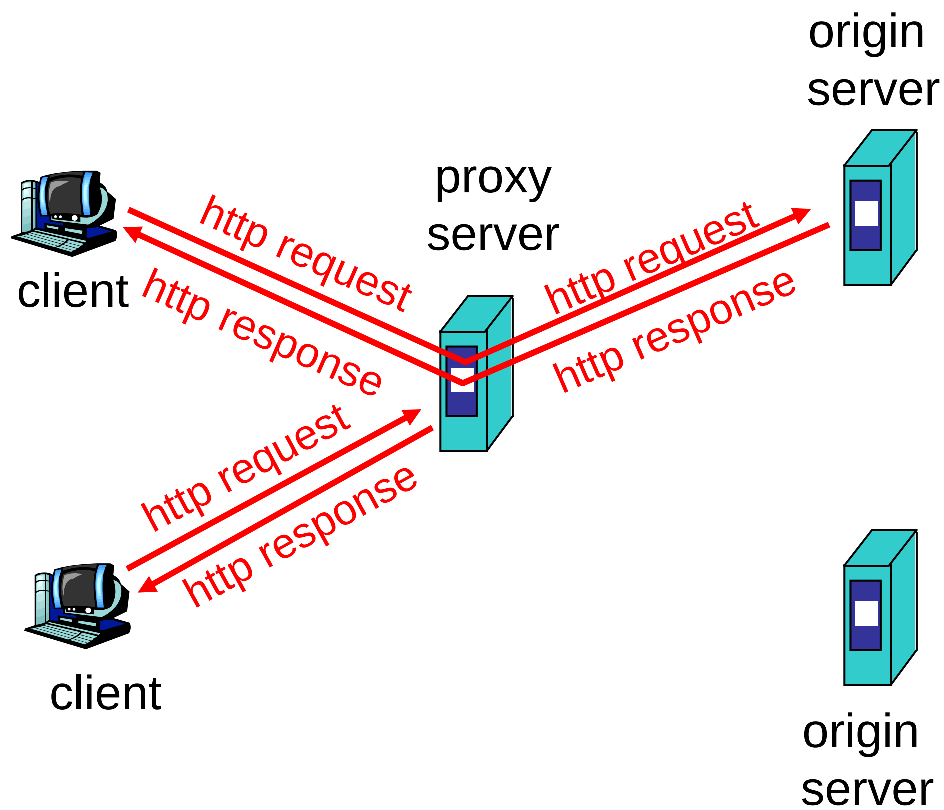
Conditional GET: client-side caching

- 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`



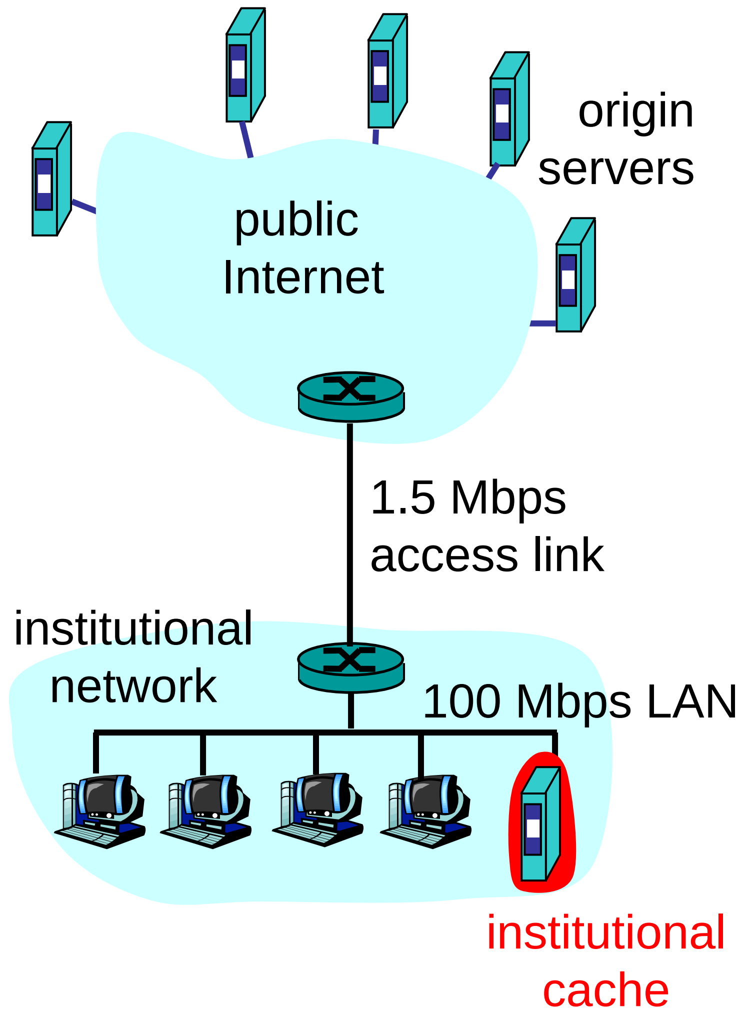
Web Caches (a.k.a. proxy server)

- 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



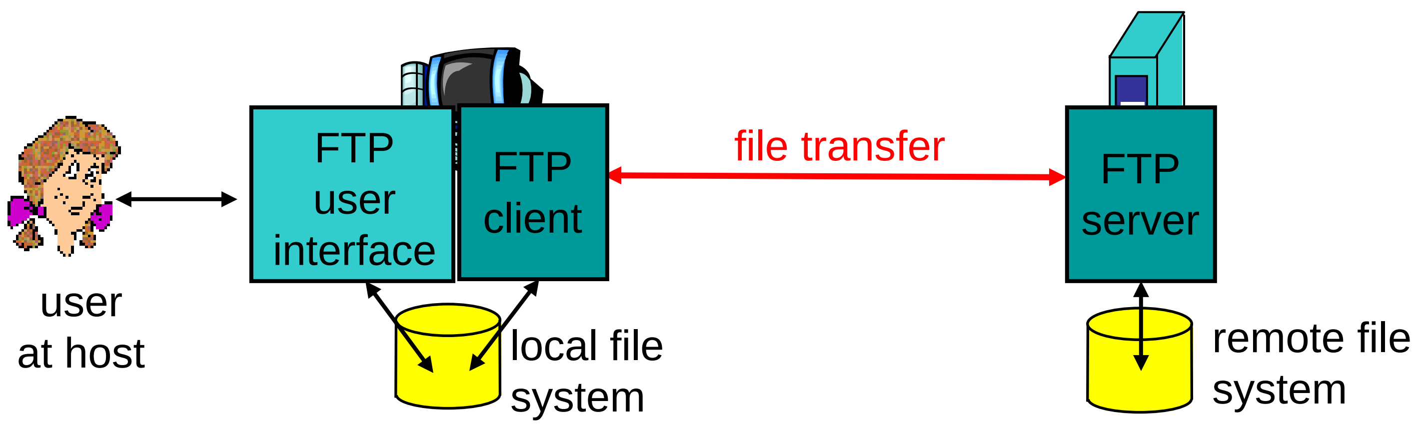
Why Web Caching?

- Assumption: 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 is often a bottleneck



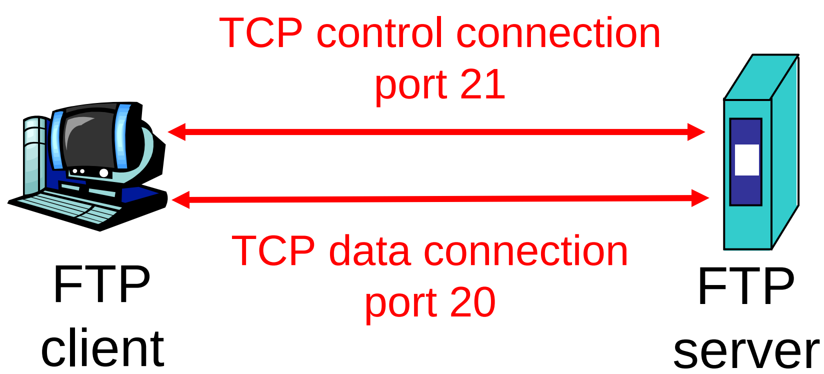
ftp: The file transfer protocol

- transfer file to/from remote host
- client/server model
  - client: side that initiates transfer (either to/from remote)
  - server: remote host
- ftp: RFC 959
- ftp server: port 21



ftp: separate control and data connections

- ftp client contacts ftp server at port 21, specifying TCP as transport protocol
- two parallel TCP connections opened
  - control: exchange commands, responses between client, server. "out of band control"
  - data: file data to/from server
- ftp server maintains "state": current directory, earlier authentication



ftp commands and responses

Sample commands

- sent as ASCII text over control channel
- **`USER`** ***`username`***
- **`PASS`** ***`password`***
- **`LIST`** returns list of files in current directory
- **`RETR filename`** retrieves (gets) file
- **`STOR filename`** stores (puts) file onto remote host

Sample return codes

- status code and phrase (as in http)
- **`331 Username OK, password required`**
- **`125 data connection already open; transfer starting`**
- **`425 Can’t open data connection`**
- **`452 Error writing file`**

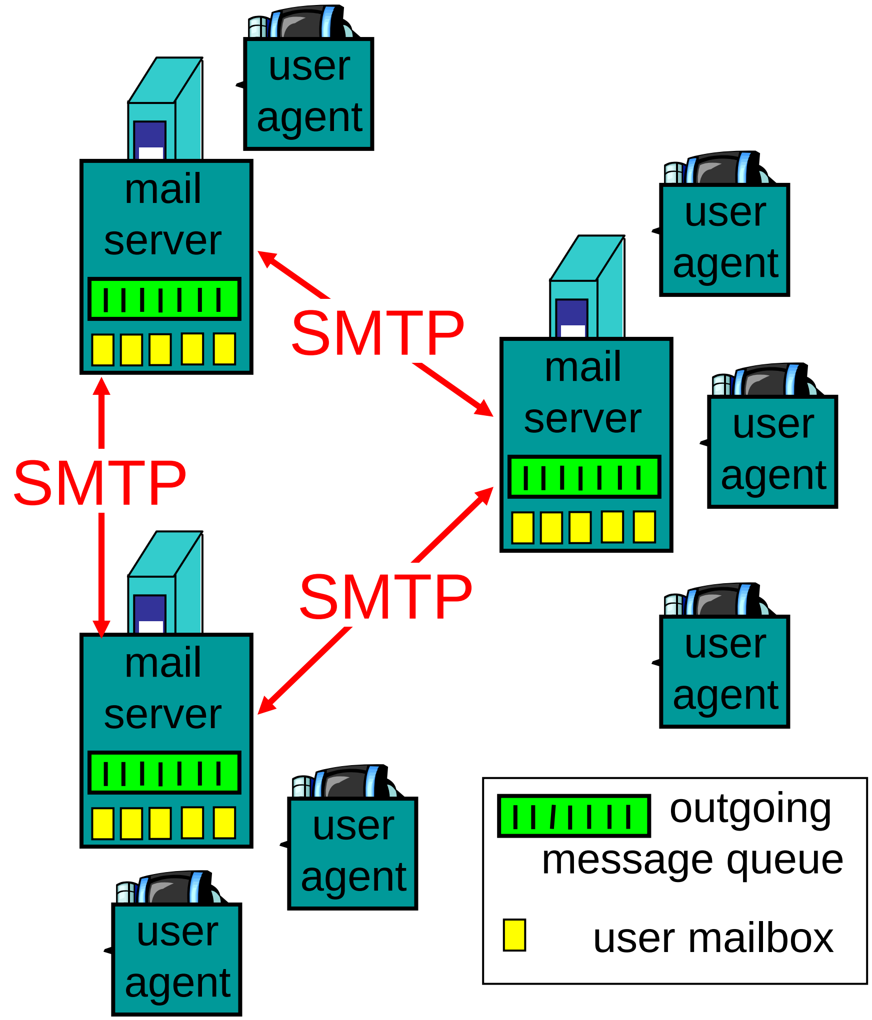
Electronic Mail

Three major components

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

User Agent

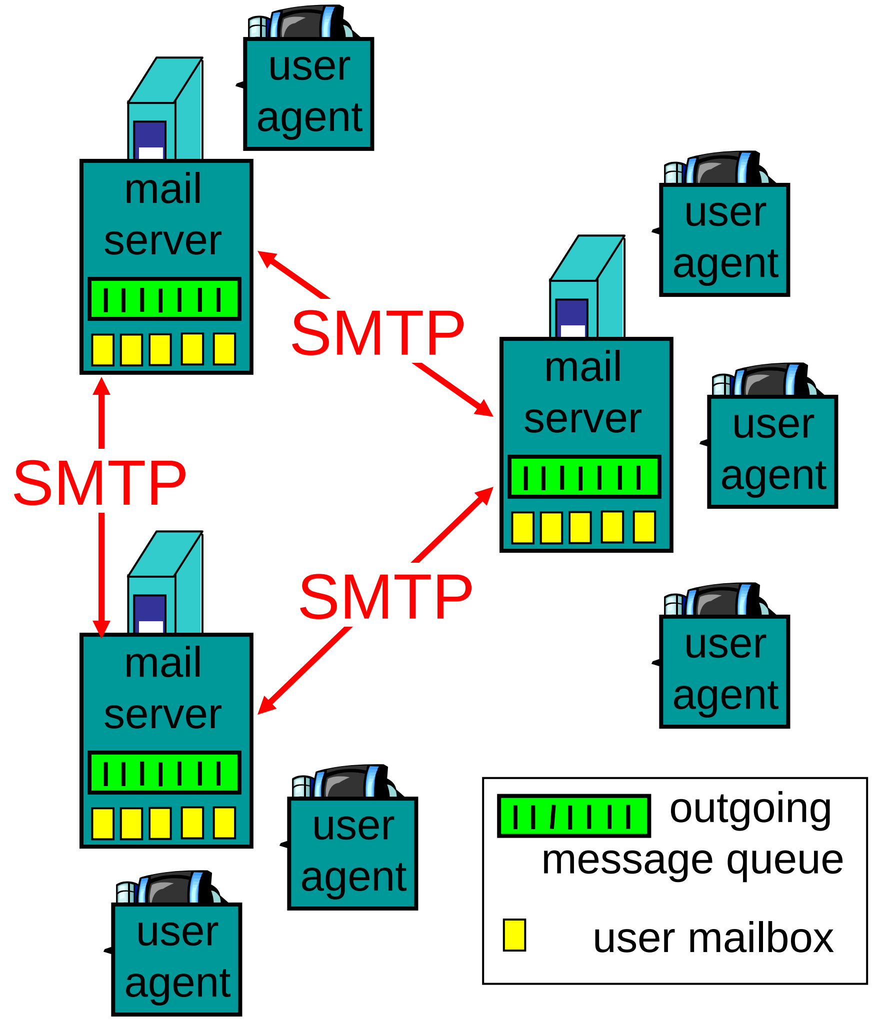
- a.k.a. "mail reader"
- composing, editing, reading mail messages
- Examples: Outlook, Netscape Messenger, elm, Eudora
- outgoing, incoming messages stored on server



Electronic Mail: mail servers

- mailbox contains incoming messages (yet to be read) 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

- Why not sending directly?



Electronic Mail: SMTP

- uses TCP to reliably transfer email message from client to server, on port 25
- direct transfer: sending server to receiving server
- three phases of transfer
  - handshake (greeting)
  - transfer of messages
  - closure
- command/response interaction
  - commands: ASCII text
  - response: status code and phrase
- SMTP: RFC 821

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
```

You can be your own smtp client: telnet to a mail server you know (**`telnet mail.inf.ethz.ch 25`**) and play with the protocol…

smtp: more details

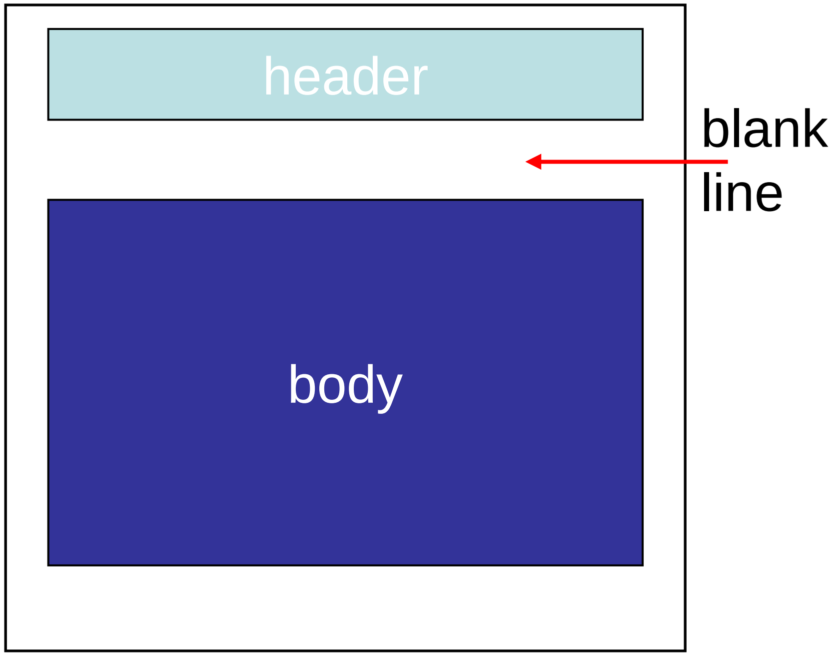
- smtp uses persistent connections
- smtp requires message (header & body) to be in 7-bit ASCII
- certain character strings not permitted in msg (e.g., **`CRLF.CRLF`**, which is used to determine the end of a message by the server).
- Thus msg has to be encoded (usually into either base-64 or quoted printable)

Comparison with http

- http: pull
- email: push
- both have ASCII command/response interaction and status codes
- http: each object encapsulated in its own response msg (1.0), or by use of content-length field (1.1)
- smtp: multiple objects sent in multipart msg (as we will see on the next slides)

Mail message format

- smtp: protocol for exchanging email msgs
- RFC 822: standard for text message format:
- header lines, e.g.
  - To:
  - From:
  - Subject:
  - (!) Caution: these are not smtp commands! They are like the header of a letter, whereas smtp commands are like the address on the envelope
- body
  - the "message"
  - ASCII characters only



Message format: multimedia extensions

- MIME: multimedia mail extension, RFC 2045, 2056
- additional lines in message header declare MIME content type

MIME version

method used to encode data

multimedia data type, subtype, parameter declaration

encoded data

```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

base64 encoded data .....
.........................
......base64 encoded data
```

MIME types

`Content-Type: type/subtype; parameters`

Text

- example subtypes: **`plain, enriched, 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

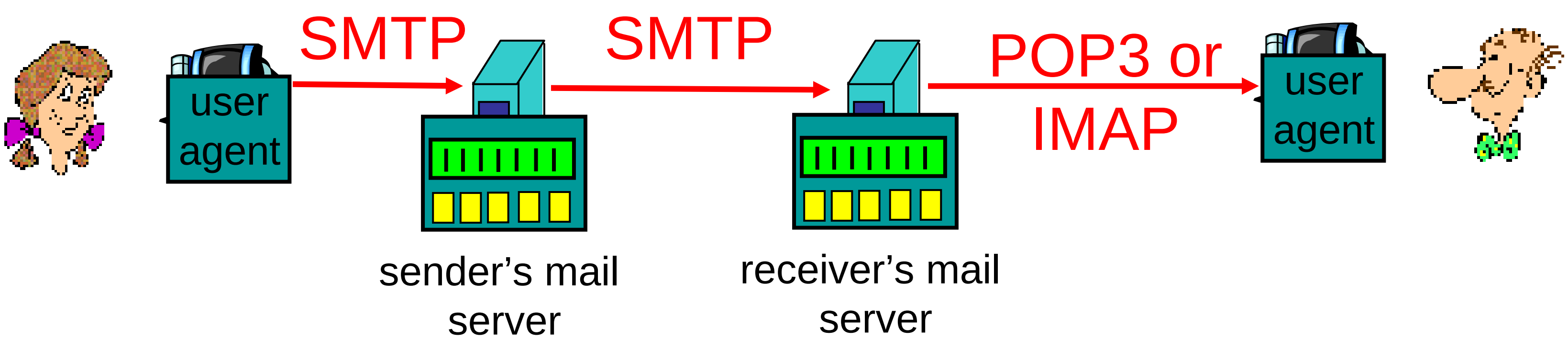
- other data that must be processed by reader before “viewable”
- example subtypes: **`msword, octet-stream`**

MIME 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--
```

Mail access protocols

- SMTP: delivery/storage to receiver's server
- Mail access protocol: retrieval from server
  – POP: Post Office Protocol [RFC 1939]
    - authorization (agent <-->server) and download
  – IMAP: Internet Mail Access Protocol [RFC 2060]
    - 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
- server responses
  - +OK
  - -ERR

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

Transaction phase

- client commands
  - list: list message numbers
  - retr: retrieve message by number
  - dele: delete
  - quit

```
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
```

DNS: Domain Name System

People have many identifiers

- passport number, AHV number, student number, name, etc.

Internet hosts, routers

- IP address (129.132.130.152); used for addressing datagrams
- Name (photek.ethz.ch); used by humans

- We need a map from names to IP addresses (and vice versa?)

Domain Name System

- *distributed database* implemented in hierarchy of many *name servers*
- *application-layer protocol* host, routers, name servers to communicate to *resolve* names (name/address translation)
  – note: is a core Internet function, but only 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

…it does not *scale!*

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

local name servers

– each ISP, company has *local (default) name server*

– host DNS query first goes to local name server

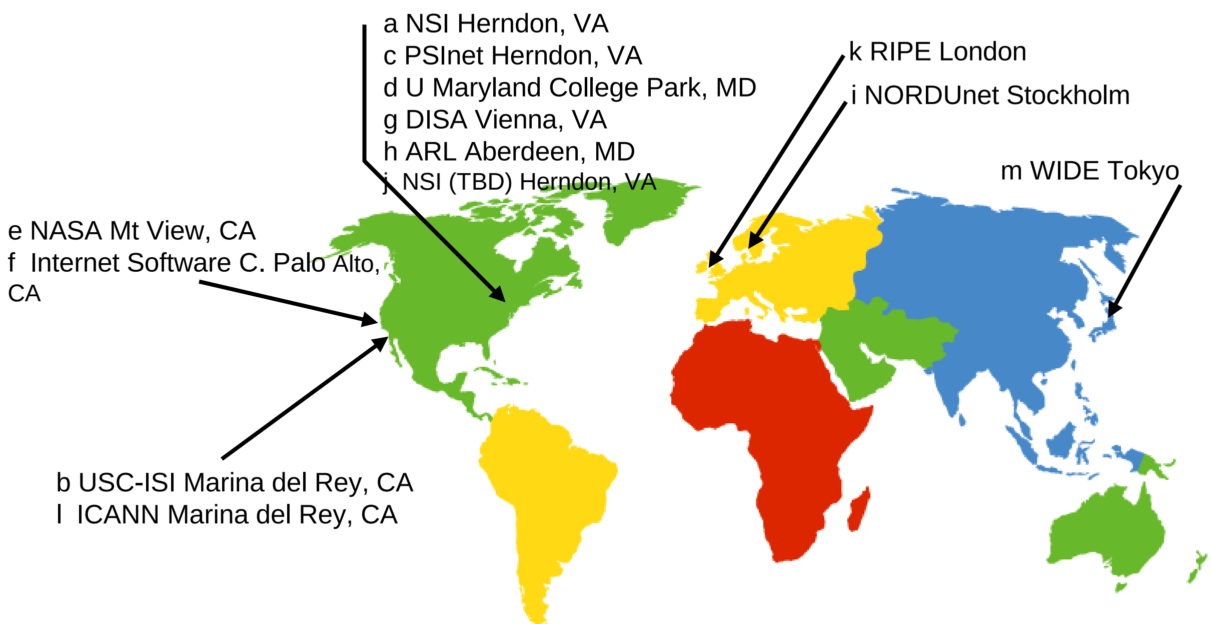
authoritative name server

– for a host: stores that host's IP address, name

– can perform name/address translation for that host's name

DNS: Root name servers

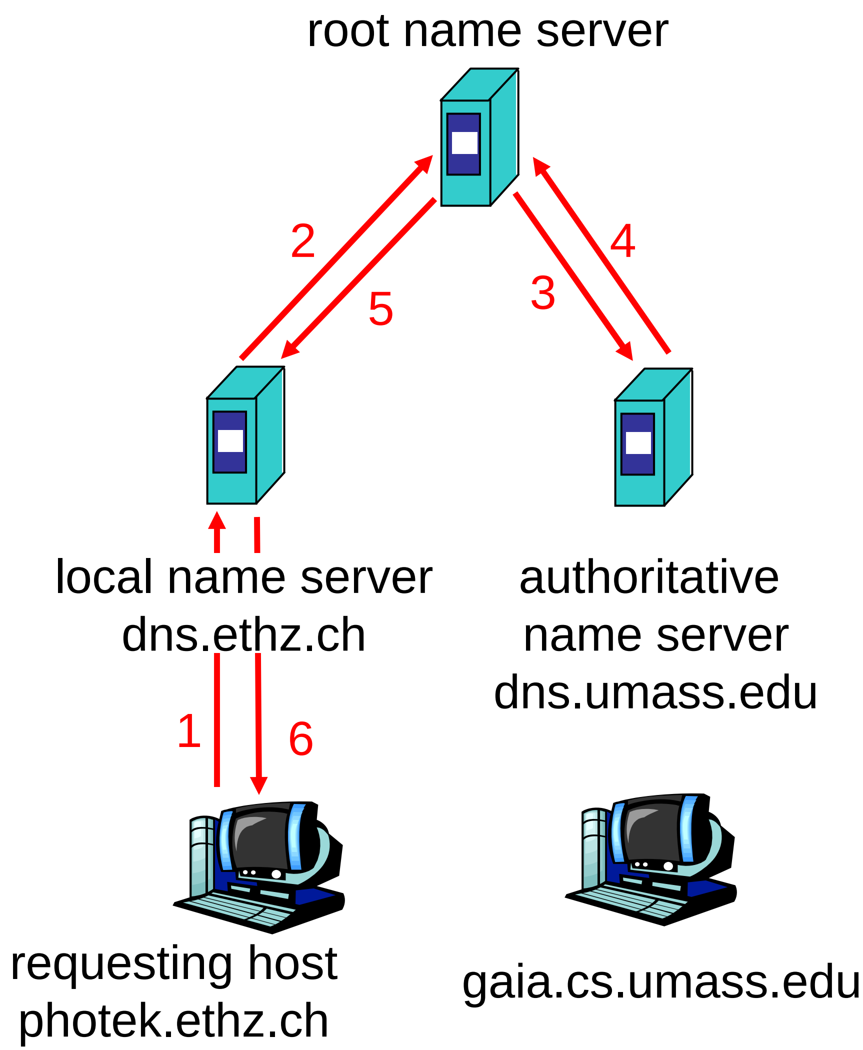
- contacted by local name server that cannot resolve name
- root name server
  - contacts authoritative name server if name mapping not known
  - gets mapping
  - returns mapping to local name server
  - currently 13 root name servers worldwide



Simple DNS example

- host photek.ethz.ch wants IP address of gaia.cs.umass.edu

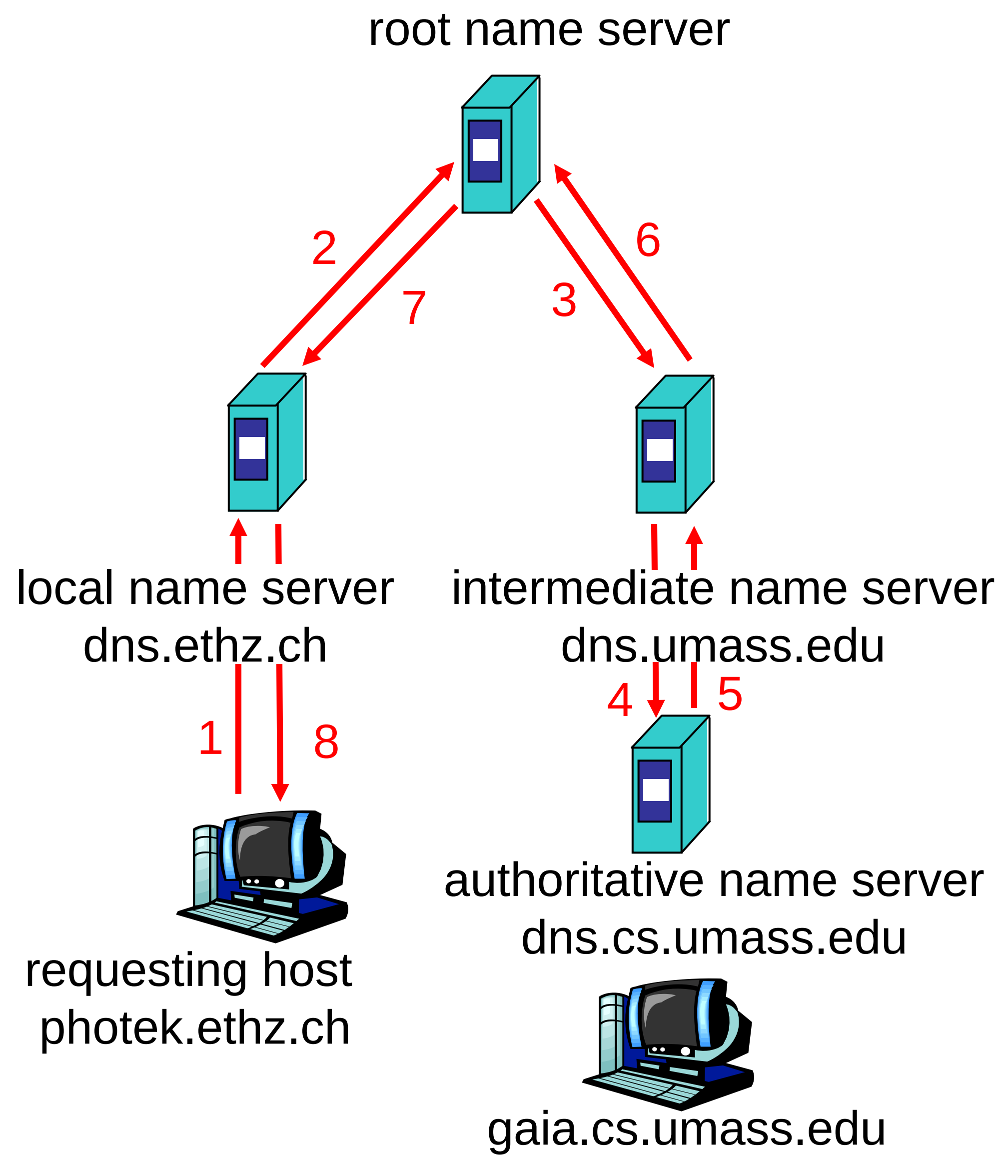
1. contact local DNS server, dns.ethz.ch
2. dns.ethz.ch contacts root name server, if necessary
3. root name server contacts authoritative name server, dns.umass.edu, if necessary



DNS extended example

Root name server:

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



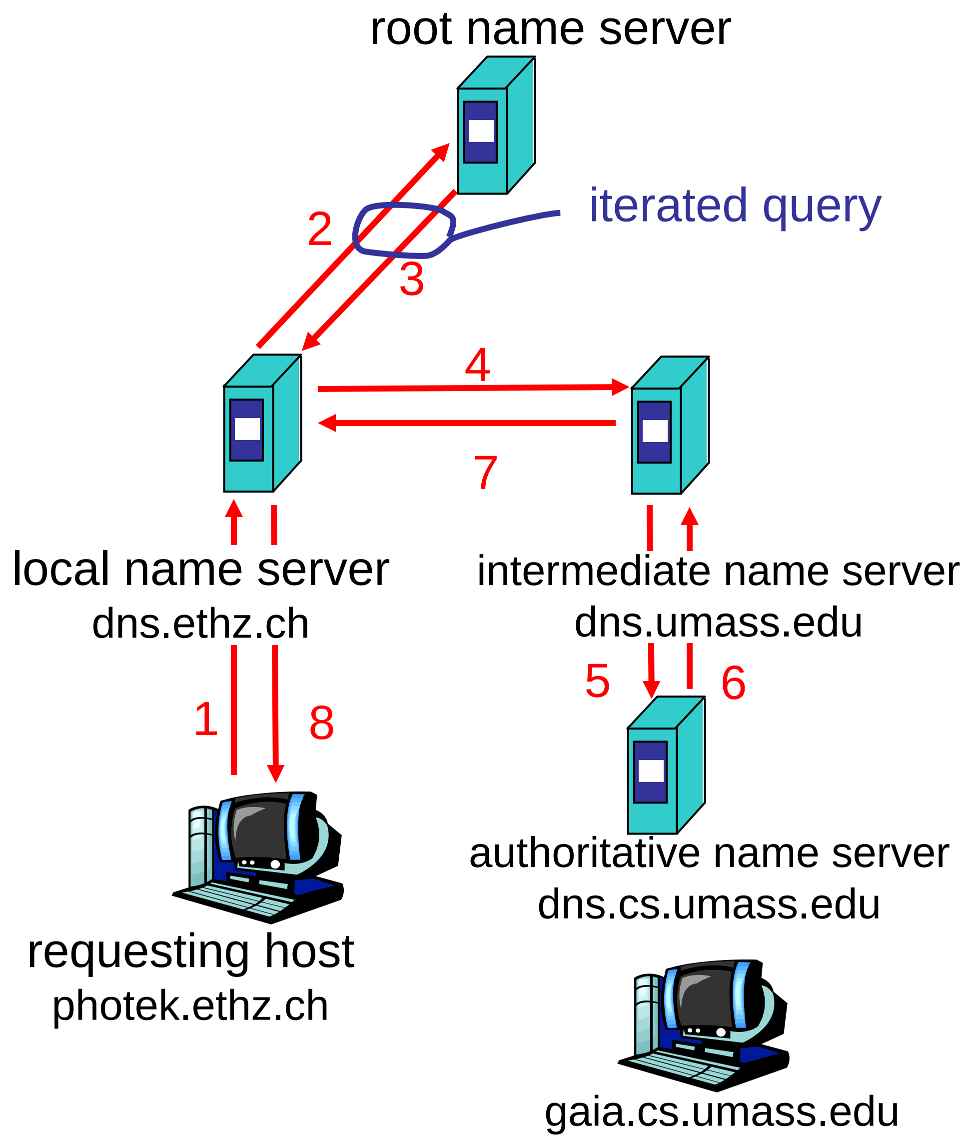
DNS Iterated queries

Recursive query

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

Iterated query

- contacted server replies with name of server to contact
- “I don’t know this name, but ask this server”



DNS: Caching and updating records

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

DNS resource records

DNS: distributed database storing resource records (RR)

RR format: **(name, ttl, class, type, value)**

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

Example of DNS lookup

```
host -v dcg.ethz.ch
Trying "dcg.ethz.ch"
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 27554
;; flags: qr aa rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 3,
   ADDITIONAL: 3

;; QUESTION SECTION:
;dcg.ethz.ch.                    IN      ANY

;; ANSWER SECTION:
dcg.ethz.ch.            86400    IN      CNAME   dcg.inf.ethz.ch.

;; AUTHORITY SECTION:
ethz.ch.                3600000  IN      NS      dns1.ethz.ch.
ethz.ch.                3600000  IN      NS      dns2.ethz.ch.
ethz.ch.                3600000  IN      NS      dns3.ethz.ch.

;; ADDITIONAL SECTION:
dns1.ethz.ch.           86400    IN      A       129.132.98.12
dns2.ethz.ch.           86400    IN      A       129.132.250.220
dns3.ethz.ch.           86400    IN      A       129.132.250.2
```

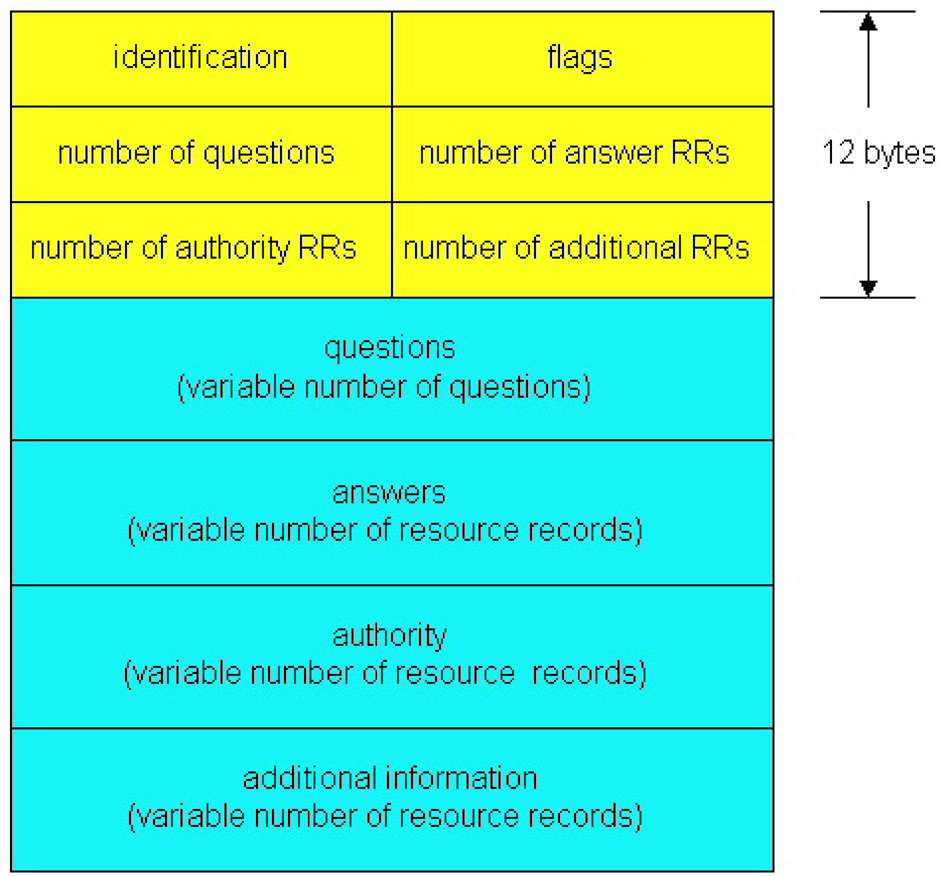
DNS protocol, messages

DNS protocol

- *query* and *reply* messages, both with same *message format*

msg header

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



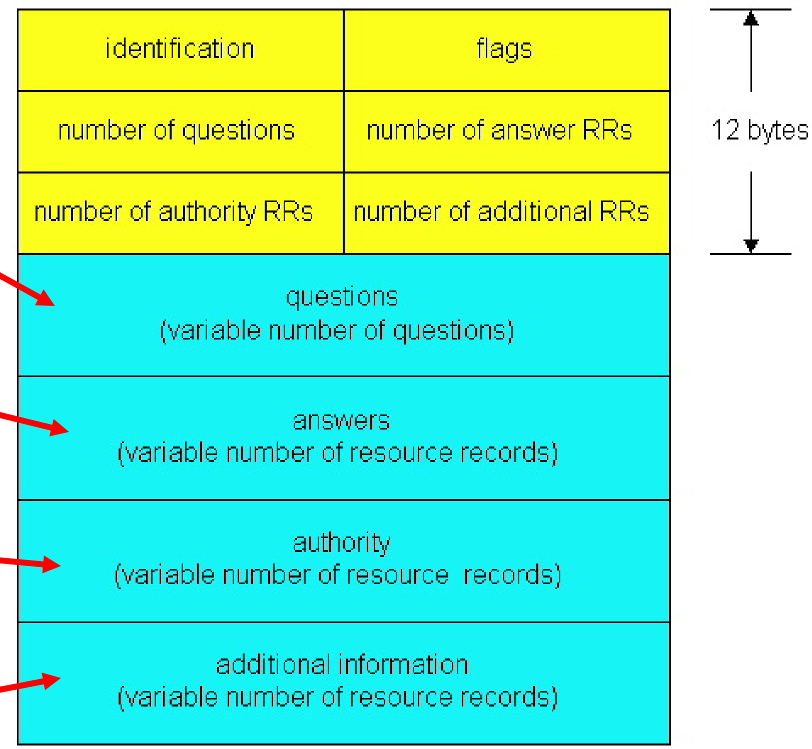
DNS protocol, messages

Name, type fields
for a query

RRs in response
to query

records for
authoritative servers

additional “helpful”
info that may be used



Socket programming

Goal

- Learn building client/server applications that communicate using sockets, the standard application programming interface

Socket API

- introduced in BSD4.1 UNIX, 1981
- explicitly created, used, released by applications
- client/server paradigm
- two types of transport service via socket API
  - unreliable datagram
  - reliable, byte stream-oriented

socket

a *host-local*, *application-created/owned*, *OS-controlled* interface (a “door”) into which application process can both send and receive messages to/from another (remote or local) application process

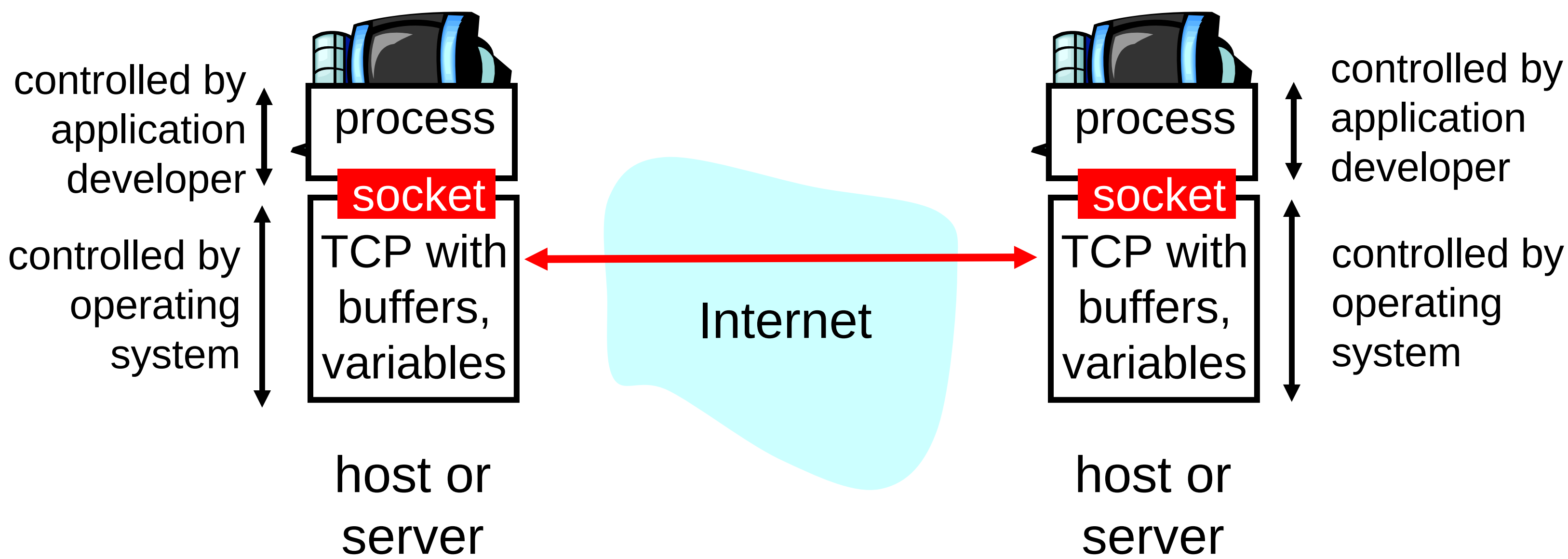
Socket programming with TCP

Socket

- a door between application process and end-end-transport protocol (UDP or TCP)

TCP service

- reliable transfer of *bytes* from one process to another



Socket programming with TCP

Client must contact server

- server process must first be running already
- server must have created socket ("door") that welcomes client's contact

Client contacts server by

- creating client-local TCP socket
- specifying IP address and port number of server process

- When client creates socket: client TCP establishes connection to server TCP
- When contacted by client, server TCP creates new socket for server process to communicate with client
  - allows server to talk with multiple clients

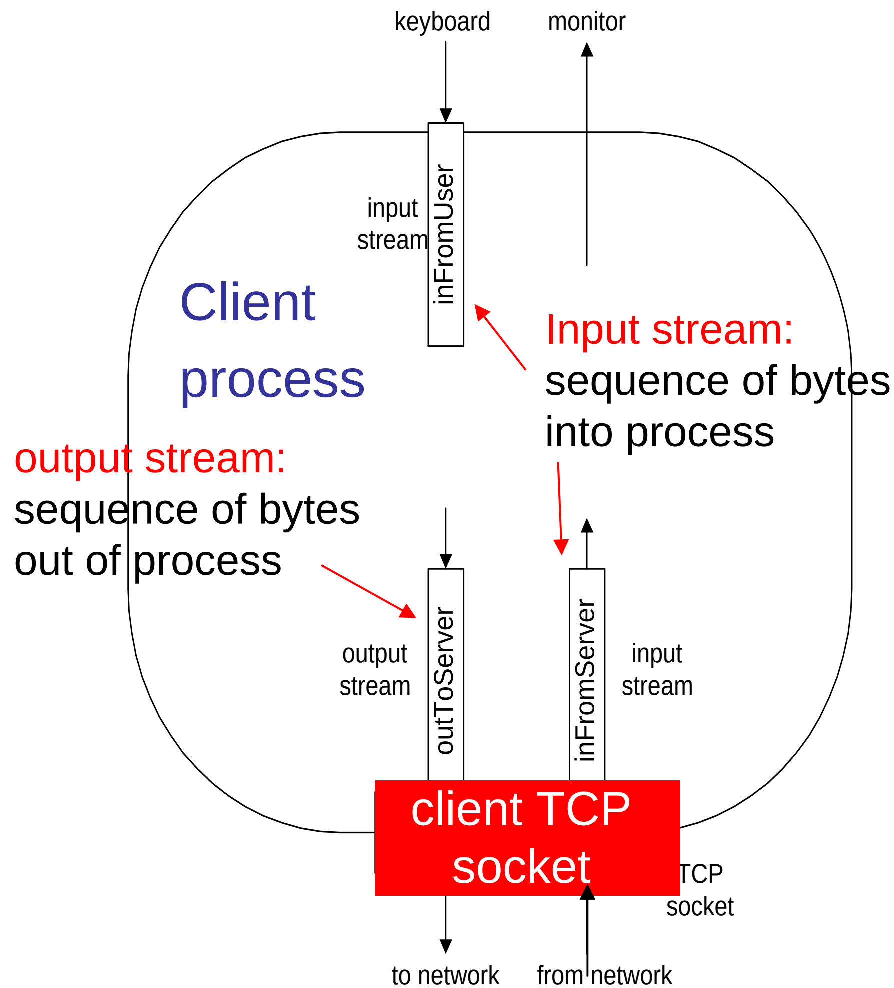
application viewpoint

TCP provides reliable, in-order transfer of bytes ("pipe") between client and server

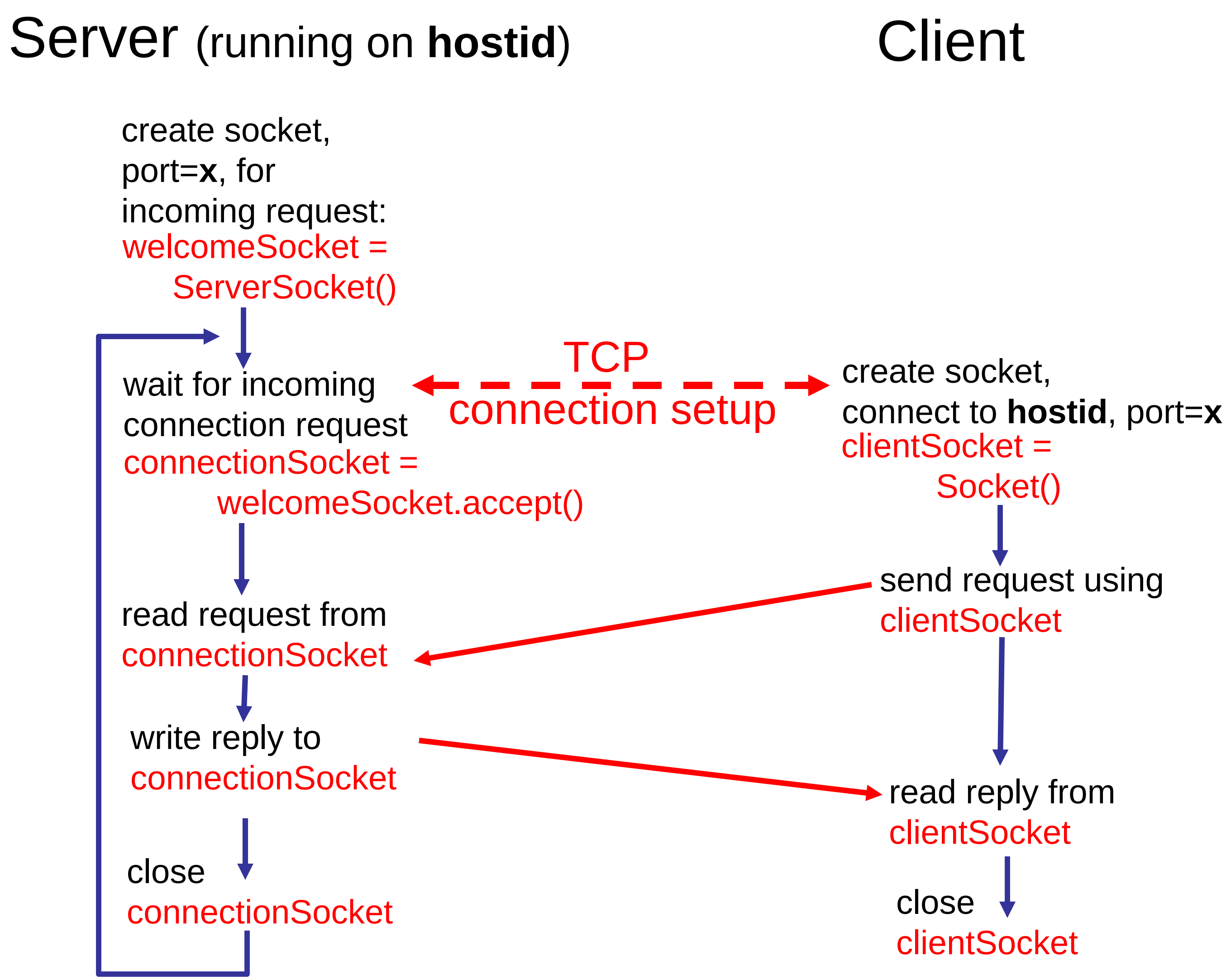
Socket programming with TCP (Java)

Example client-server application

- client reads line from standard input (**`inFromUser`** stream), sends to server via socket (**`outToServer`** stream)
- server reads line from socket
- server converts line to uppercase, sends back to client
- client reads and prints modified line from socket (**`inFromServer`** stream)



Client/server socket interaction with TCP (Java)



Example: Java client (TCP)

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

class TCPClient {
    public static void main(String argv[]) throws Exception
    {
        String sentence;
        String modifiedSentence;
```

Create input stream

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

Create client socket, connect to server

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

Create output stream attached to socket

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

Example: Java client (TCP), continued

Create input stream attached to socket

```
BufferedReader inFromServer =
  new BufferedReader(new
  InputStreamReader(clientSocket.getInputStream()));

sentence = inFromUser.readLine();
```

Send line to server

```
outToServer.writeBytes(sentence + '\n');
```

Read line from server

```
modifiedSentence = inFromServer.readLine();

System.out.println("FROM SERVER: " + modifiedSentence);

clientSocket.close();

    }
}
```

Example: Java server (TCP)

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

class TCPServer {

  public static void main(String argv[]) throws Exception
   {
     String clientSentence;
     String capitalizedSentence;

     ServerSocket welcomeSocket = new ServerSocket(6789);

     while(true) {

        Socket connectionSocket = welcomeSocket.accept();

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

Create welcoming socket at port 6789

Wait on welcoming socket for contact by client

Create input stream, attached to socket

Example: Java server (TCP), continued

Create output stream, attached to socket

Read in line from socket

Write out line to socket

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

clientSentence = inFromClient.readLine();

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

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

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

Problem: One client can block other clients

Problem can be solved with threads:

```
ServerSocket welcomeSocket = new ServerSocket(6789);
while(true) {
        Socket connectionSocket = welcomeSocket.accept();
        ServerThread thread = new ServerThread(connectionSocket);
        thread.start();
}

public class ServerThread extends Thread {
        /* Handles connection socket */
        /* “More or less” code of old server loop */
}
```

Alternative solution: Client opens socket *after* reading input line

Socket programming with UDP

Remember: UDP: no “connection” between client and server

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

application viewpoint

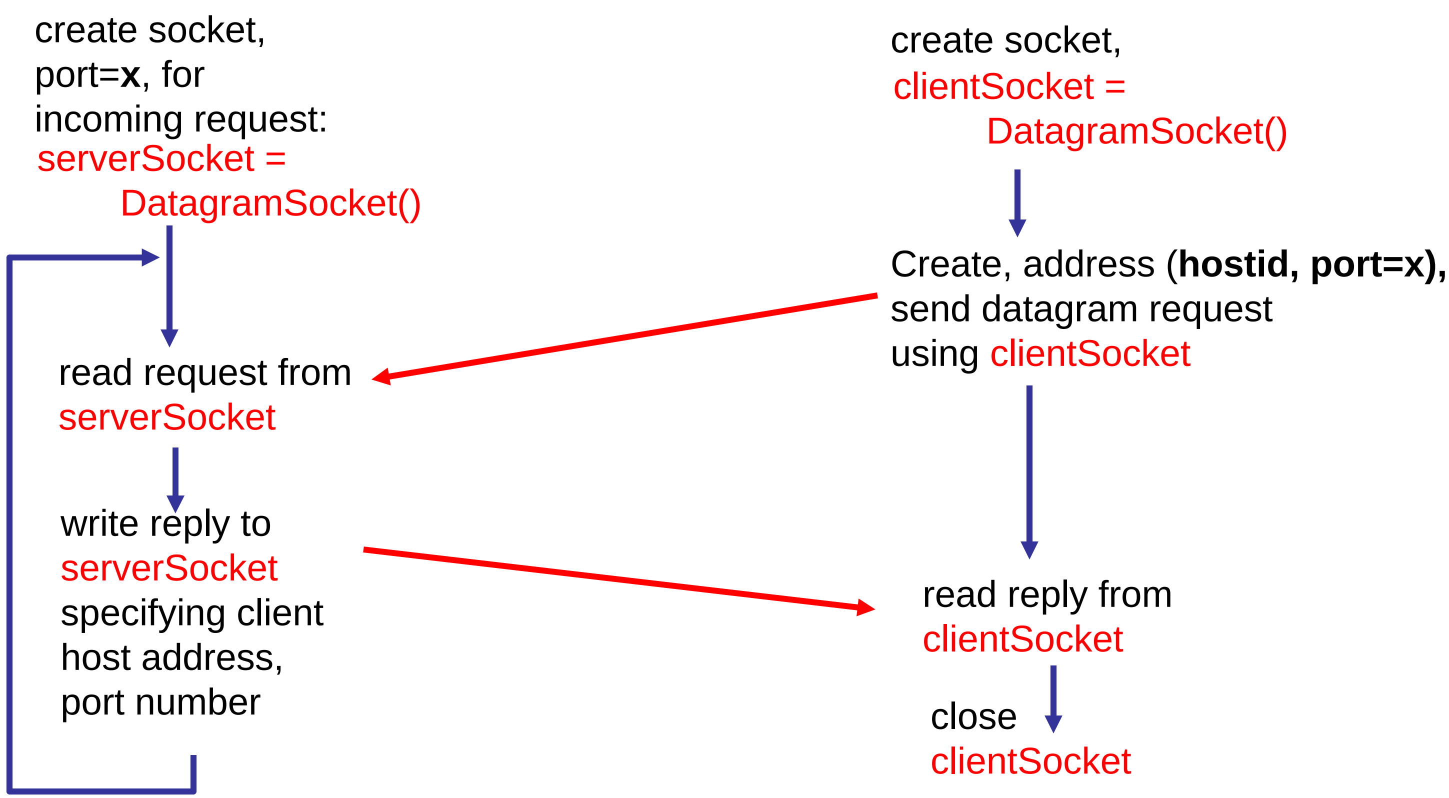
UDP provides unreliable transfer of groups of bytes (“datagrams”) between client and server

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

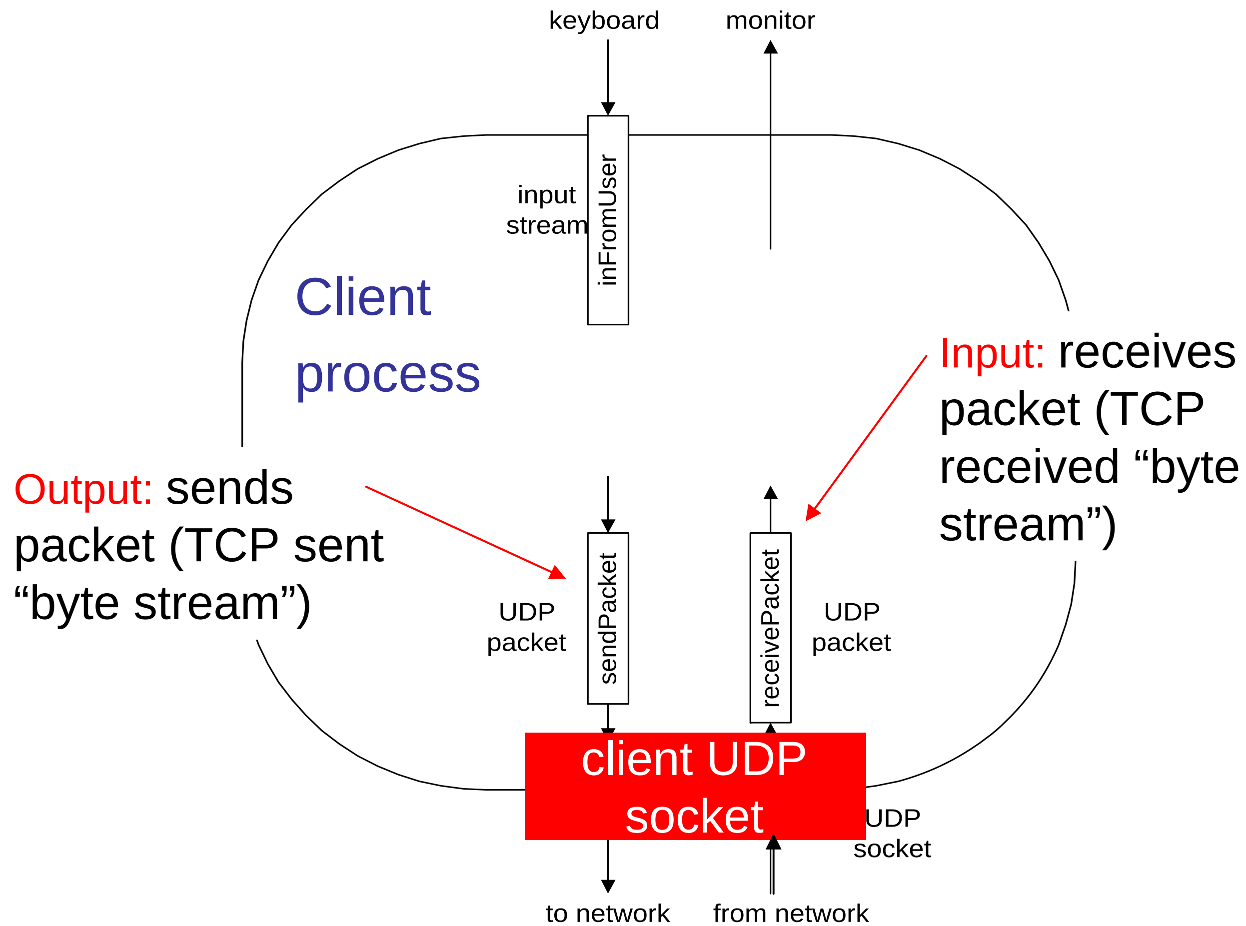
Client/server socket interaction: UDP (Java)

Server (running on **hostid**)

Client



Example: Java client (UDP)



Example: Java client (UDP)

Create input stream

Create client socket

Translate hostname to IP Address using DNS

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

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

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

      DatagramSocket clientSocket = new DatagramSocket();

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

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

      String sentence = inFromUser.readLine();

      sendData = sentence.getBytes();
```

Example: Java client (UDP), continued

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

Send datagram to server

Read datagram from server

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

clientSocket.send(sendPacket);

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

clientSocket.receive(receivePacket);

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

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

}
```

Example: Java server (UDP)

Create datagram socket at port 9876

Create space for received datagram

Receive datagram

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

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

      DatagramSocket serverSocket = new DatagramSocket(9876);

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

      while(true)
        {

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

          serverSocket.receive(receivePacket);
```

Example: Java server (UDP), continued

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

Get IP addr port #, of sender

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

int port = receivePacket.getPort();

        String capitalizedSentence = sentence.toUpperCase();

sendData = capitalizedSentence.getBytes();
```

Create datagram to send to client

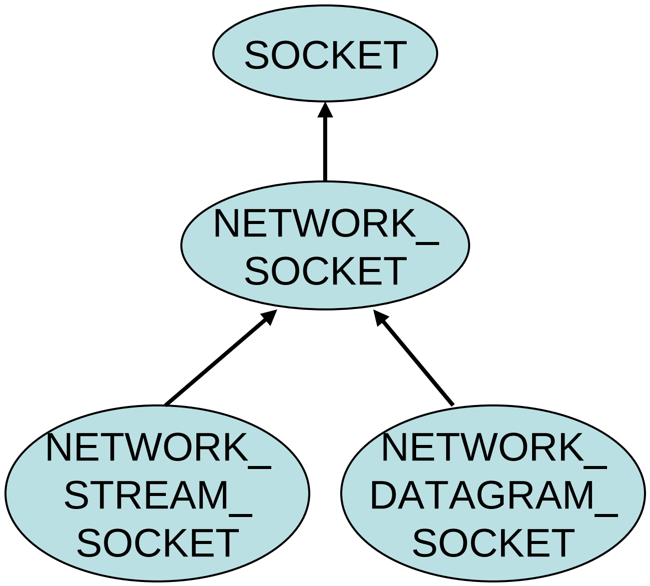
```
DatagramPacket sendPacket =
  new DatagramPacket(sendData, sendData.length, IPAddress,
              port);
```

Write out datagram to socket

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

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

EiffelNet: Sockets and communication modes



- Two modes of socket communication:
  - stream communication
  - datagram communication
- Stream socket:
  - provided by the STREAM_classes
  - provides sequenced communication without any loss or duplication of data
  - *synchronous*: the sending system waits until it has established a connection to the receiving system and transmitted the data
- Datagram socket:
  - provided by the DATAGRAM_classes
  - *asynchronous*: the sending system emits its data and does not wait for an acknowledgment
  - efficient, but it does not guarantee sequencing, reliability or non-duplication

Example: Eiffel Server (TCP - stream socket)

```
class  OUR_SERVER
inherit
          SOCKET_RESOURCES
          STORABLE
create
          make
feature
          soc1, soc2: NETWORK_STREAM_SOCKET
          make (argv: ARRAY [STRING])  is
            local
                count: INTEGER
            do
                if argv.count /= 2 then
                    io.error.putstring ("Usage: ")
                    io.error.putstring (argv.item (0))
                    io.error.putstring ("portnumber")
                else
                    create soc1.make_server_by_port (argv.item (1).to_integer)
                    from
                        soc1.listen (5)
                        count := 0
                      until
                        count := 5
                    loop
                        process
                        count := count + 1
                   end
                   soc1.cleanup
                end
              rescue  soc1.cleanup
              end
```

CLIENT:

1) Sends to the server a list of strings
5) Receives the result from the server and print it

SERVER:

2) Receives the corresponding object structure
3) Appends to it another string
4) Returns the result to the client

Accepts communication with the client and exchange messages

Create server socket on ‘portnumber’

Listen on socket for at most ‘5’ connections

- Accepts communication with the client
- Receives a message from the client
- Extends the message
- Sends the message back to the client

Closes the open socket and frees the corresponding resources

Example: Eiffel Server (TCP - stream socket), continued

Receives a message from the client, extend it, and send it back.

```
process is
    local
        our_new_list: OUR_MESSAGE
    do
        soc1.accept
        soc2 ?= soc1.accepted
        our_new_list ?= retrieved (soc2)

        from
            our_new_list.start
        until
            our_new_list.after
        loop
            io.putstring (our_new_list.item)
            our_new_list.forth
            io.new_line
        end

        our_new_list.extend ("Server message. %N")
        our_new_list.general_store (soc2)
        soc2.close
    end
end
```

- the server obtains access to the server
- *accept* - ensures synchronization to with the client
- *accept* - creates a new socket which is accesible through the attribute *accepted*
- the *accepted* value is assigned to *soc2* - this makes *soc1* available to accept connections with other clients

The message exchanged between server and client is a linked list of strings

```
class OUR_MESSAGE

inherit
        LINKED_LIST
[STRING]
        STORABLE
        undefine
            is_equal, copy
        end

create
        make
end
```

Extends the message received from the client

Sends the extended message back to the client

Closes the socket

Example: Eiffel Client (TCP - stream socket)

```
class OUR_CLIENT
inherit
        NETWORK_CLIENT
            redefine
                received
            end
create
        make_client
feature
        our_list: OUR_MESSAGE
        received: OUR_MESSAGE

        make_client (argv: ARRAY [STRING]) is
            -- Build list, send it, receive modified list, and
print it.
            do
                if argv.count /= 3 then
                  io.error.putstring ("Usage: ")
                  io.error.putstring (argv.item (0))
                  io.error.putstring ("hostname portnumber")
              else
                  make (argv.item (2).to_integer, argv.item (1))
                  build_list
                  send (our_list)
                  receive
                  process_received
                  cleanup
              end
             rescue
              cleanup
             end
        ...
```

- The message exchanged between server and client
- 1. Creates a socket and setup the communication
- 2. Builds the list of strings
- 3. Sends the list of strings to the server
- 4. Receives the message from the server
- 5. Prints the content of the received message
- 6. Closes the open socket and free the corresponding resources

Example: Eiffel Client (TCP - stream socket), continued

```
         build_list is
          do
                create our_list.make
                our_list.extend ("This ")
                our_list.extend ("is ")
                our_list.extend (“a")
                our_list.extend ("test.")
          end

         process_received is
          do
                if received = Void then
                      io.putstring ("No list received.")
                else
                      from received.start until received.after loop
                            io.putstring (received.item)
                            received.forth
                      end
                end
          end
end
```

Builds the list of strings ‘our_list’ for transmission to the server

Prints the content of the received message in sequence

Example: Eiffel Server (UDP - datagram socket)

```
class OUR_DATAGRAM_SERVER
create
        make
feature
        make (argv: ARRAY [STRING]) is
            local
                soc: NETWORK_DATAGRAM_SOCKET
              ps: MEDIUM_POLLER
              readcomm: DATAGRAM_READER
              writecomm: SERVER_DATAGRAM_WRITER
            do
              if argv.count /= 2 then
                  io.error.putstring ("Usage: ")
                  io.error.putstring (argv.item (0))
                  io.error.putstring (" portnumber")
              else
                  create soc.make_bound (argv.item (1).to_integer)
                  create ps.make

                  create readcomm.make (soc)
                  ps.put_read_command (readcomm)
                  create writecomm.make (soc)
                  ps.put_write_command (writecomm)
                  . . .
```

1. Creates read and write commands
2. Attach them to a poller
3. Set up the poller for execution

Creates a network datagram socket bound to a local address with a specific port

Creates poller with multi-event polling

1. Creates a read command which it attaches to the socket
2. Enters the read command into the poller
3. Creates a write command which it attaches to the socket
4. Enters the write command into the poller

Example: Eiffel Server (UDP - datagram socket), continued

```
        . . .
            ps.make_read_only
              ps.execute (15, 20000)
            ps.make_write_only
            ps.execute (15, 20000)
            soc.close
        end
    rescue
        if not soc.is_closed then
            soc.close
        end
    end
end
```

1. Sets up the poller to accept read commands only and then executes the poller -- enable the server to get the read event triggered by the client's write command

2. Reverses the poller's set up to write-only, and then executes the poller

Monitors the sockets for the corresponding events and executes the command associated with each event that will be received

Example: Eiffel Client (UDP - datagram socket)

```
class  OUR_DATAGRAM_CLIENT

create
        make
feature
        make (argv: ARRAY [STRING])  is
            local
                soc: NETWORK_DATAGRAM_SOCKET
              ps: MEDIUM_POLLER
              readcomm: DATAGRAM_READER
              writecomm: CLIENT_DATAGRAM_WRITER
            do
              if argv.count /= 3 then
                    io.error.putstring ("Usage: ")
                    io.error.putstring (argv.item (0))
                    io.error.putstring ("hostname portnumber")
              else
                    create soc.make_targeted_to_hostname
                                  (argv.item (1), argv.item
(2).to_integer)
                    create ps.make

                    create readcomm.make (soc)
                    ps.put_read_command (readcomm)
                    create writecomm.make (soc)
                    ps.put_write_command (writecomm)
                    . . .
```

1. Create read and write commands
2. Attach them to a poller
3. Set up the poller for execution

Command executed in case of a read event

Command executed by the client when the socket “is ready for writing”

Create a datagram socket connected to ‘hostname’ and ‘port’

Creates poller with multi-event polling

1. Creates a read command which it attaches to the socket
2. Enters the read command into the poller
3. Creates a write command which it attaches to the socket
4. Enters the write command into the poller

Example: Eiffel Client (UDP - datagram socket), continued

```
                ...
                ps.make_write_only
                ps.execute (15, 20000)
                ps.make_read_only
                ps.execute (15, 20000)
                soc.close
            end
        rescue
            if not soc.is_closed then
                soc.close
            end
end
```

1. Sets up the poller to write commands only and then executes the poller

2. Reverses the poller's set up to accept read commands only, and then executes the poller -- enables the client to get the read event triggered by the server's write command

Monitors the sockets for the corresponding events and executes the command associated with each event that will be received

Example: Eiffel Command class (UDP - datagram socket)

```
class OUR_DATAGRAM_READER

inherit
        POLL_COMMAND
        redefine
                active_medium
        end

create
        make
feature
        active_medium:
NETWORK_DATAGRAM_SOCKET

        execute (arg: ANY) is
            local
                rec_pack: DATAGRAM_PACKET
              i: INTEGER
            do
              rec_pack := active_medium.received (10, 0)
              io.putint (rec_pack.packet_number)
              from i := 0 until i > 9 loop
                   io.putchar (rec_pack.element (i))
                   i := i + 1
              end
            end
end
```

Commands and events:

- Each system specify certain communication events that it wants to monitor, and certain commands to be executed on occurrence of the specified events
- The commands are objects, instances of the class POLL_COMMAND
- The class POLL_COMMAND has the procedure *execute* which executes the current command

Command classes:

- OUR_DATAGRAM_READER – represents operations that must be triggered in the case of a read event
- CLIENT_DATAGRAM_WRITER – command executed by the client when the socket "is ready for writing"
- SERVER_DATAGRAM_WRITER – command executed by the server when the socket "is ready for writing"

Receive a packet of size 10 characters

Prints the packet number of the packet

Prints all the caracters from the packet

Example: Eiffel Command class (UDP - datagram socket), cont

```
class CLIENT_DATAGRAM_WRITER
inherit
        POLL_COMMAND
        redefine
                active_medium
        end

create
        make
feature
        active_medium:
NETWORK_DATAGRAM_SOCKET

        execute (arg: ANY) is
            local
                sen_pack: DATAGRAM_PACKET
                char: CHARACTER
            do
                -- Make packet with 10 characters 'a' to
'j'
                -- in succesive positions
                create sen_pack.make (10)
                from char := 'a' until char > 'j' loop
                    sen_pack.put_element (char |-| 'a')
                    char := char.next
                end
                sen_pack.set_packet_number (1)
                active_medium.send (sen_pack, 0)
            end
end
```

Command executed by the client when the socket "is ready for writing"

```
class SERVER_DATAGRAM_WRITER
inherit
        POLL_COMMAND
        redefine
                active_medium
        end

create
        make
feature
        active_medium:
NETWORK_DATAGRAM_SOCKET

        execute (arg: ANY) is
            local
                sen_pack: DATAGRAM_PACKET
                i: INTEGER
            do
                -- Make packet with 10 characters 'a' in
                -- succesive positions
                create sen_pack.make (10)
                from i := 0 until i > 9 loop
                    sen_pack.put_element ('a', i)
                    i := i + 1
                end
                sen_pack.set_packet_number (2)
                active_medium.send (sen_pack, 0)
            end
end
```

Command executed by the server when the socket "is ready for writing"