Application Layer

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Adapted in part from J. Kurose (Umass)

- **Conceptual + implementation aspects of network application protocols**
  - **client server paradigm**
  - **service models**
- **Specific protocols:**
  - **http, ftp, smtp, pop, dns**
- **Sockets**

Recap: Reference Models

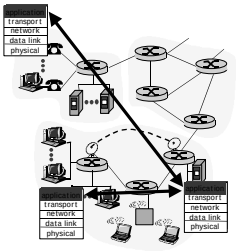
TCP/IP Model	TCP/IP Protocols			OSI Ref Model
Application	FTP	Telnet	HTTP	Application
				Presentation
Transport	TCP		UDP	Session
				Transport
Internetwork	IP			Network
Host to Network	Ether net	Packe Radio	Point-to-Point	Datalink
				Physical

"Top-down" approach means we will first learn the application layer and then learn about lower layers

Applications and app-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**



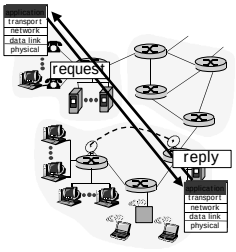
Network applications: some jargon

- **A process is a program that is running within a host.**
- **Within the same host, two processes communicate with interprocess communication defined by the OS.**
- **Processes running in different hosts communicate with an application-layer protocol**
- **A user agent is an interface between the user and the network application.**
  - **Web:browser**
  - **E-mail: mail reader**
  - **streaming audio/video: media player**

Client-server paradigm

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

Client:
- **initiates contact with server ("speaks first")**
- **typically requests service from server,**
- **for Web, client is implemented in browser; for e-mail, in mail reader**

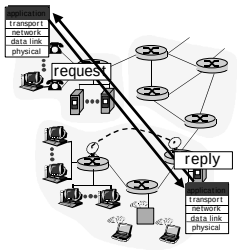


Client-server paradigm

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

Server:

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



Application-layer protocols

API: application programming interface

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

Q: 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**

What Transport Service does an App need?

Data loss

- **some apps (e.g., audio) can tolerate some loss**
- **other apps (e.g., file transfer, telnet) 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 apps

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

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 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**

Q: why bother? Why is there a UDP?

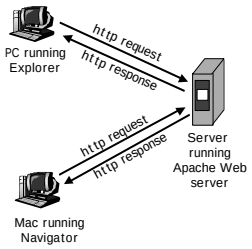
Internet apps: their protocols and transport protocols

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. RealNetworks)	TCP or UDP
remote file server	NSF	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, "displays" Web objects**
  - ***server:*** **Web server sends objects in response to requests**
- **http1.0: RFC 1945**
- **http1.1: RFC 2068**



The http protocol: more

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.School.edu/Department/home.index (contains text, references to 10 jpeg images)

1a. http client *initiates* TCP connection to http server (process) at www.School.edu. Port 80 is default for http server.

1b. http server at host www.School.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

3. http server receives request message, forms *response message* containing requested object (Department/home.index), sends message into socket

time

http example (cont.)

time

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

4. http server closes TCP connection.

Non-persistent and persistent connections

Non-persistent

- **HTTP/1.0**
- **server parses request, responds, and closes TCP connection**
- **2 RTTs to fetch each object**
- **Each object transfer suffers from slow start**

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 and less slow start.**

But most 1.0 browsers use parallel TCP connections.

http message format: request

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

request line (GET, POST, HEAD commands)

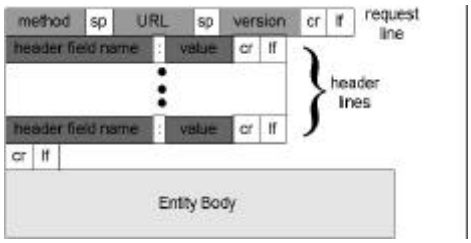
header lines

```
GET /somedir/page.html HTTP/1.0
User-agent: Mozilla/4.0
Accept: text/html, image/gif,image/jpeg
Accept-language:fr
```

(extra carriage return, line feed)

Carriage return, line feed indicates end of message

http *request* message: general format



http message format: *response*

status line (protocol status code status phrase)

header lines

data, e.g., requested html file

```
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 ...
```


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

Trying out http (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet www.eurecom.fr 80
```

Opens TCP connection to port 80 (default http server port) at www.eurecom.fr. Anything typed in sent to port 80 at www.eurecom.fr

2. Type in a GET http request:

```
GET /~ross/index.html HTTP/1.0
```

By typing this in (hit carriage return twice), you send this minimal (but complete) GET request to http server

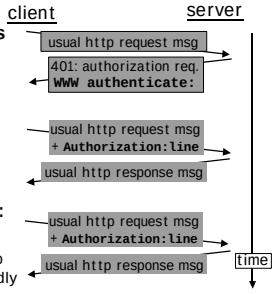
3. Look at response message sent by http server!

User-server interaction: *authentication*

Authentication goal: control access to server

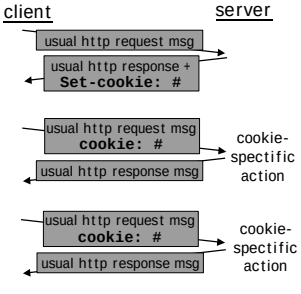
- **stateless: client presents authorization in each request**
- **authorization: typically name, password**
  - `authorization:` **header line in request**
  - **Sends header line** `WWW authenticate:` **if unauthorized**

Browser caches name & password so that user does not have to repeatedly enter it.



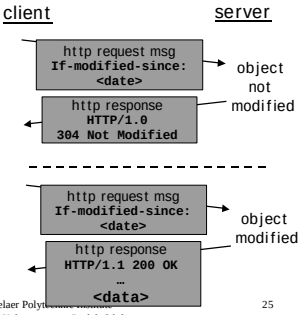
User-server interaction: cookies

- **server sends "*cookie*" to client in response msg**
  `Set-cookie: 1678453`
- **client presents cookie in later requests**
  `cookie: 1678453`
- **server matches presented-cookie with server-stored info**
  - **authentication**
  - **remembering user preferences**



User-server interaction: *conditional* GET

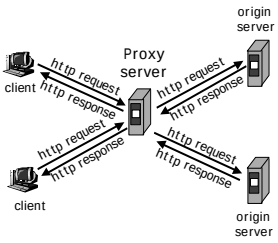
- **Goal: don't send object if client has up-to-date stored (cached) version**
- **client: specify date of cached copy in http request**
  `If-modified-since: <date>`
- **server: response contains no object if cached copy up-to-date:**
  `HTTP/1.0 304 Not Modified`



Web Caches (proxy server)

Goal: satisfy client request without involving origin server

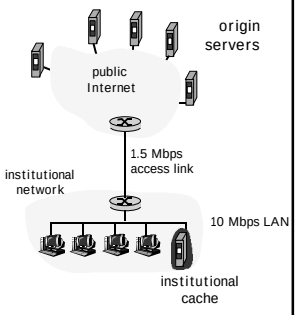
- **user sets browser: Web accesses via web cache**
- **client sends all http requests to web cache**
  - **if object at web cache, web cache immediately returns object in http response**
  - **else requests object from origin server, then returns http response to client**



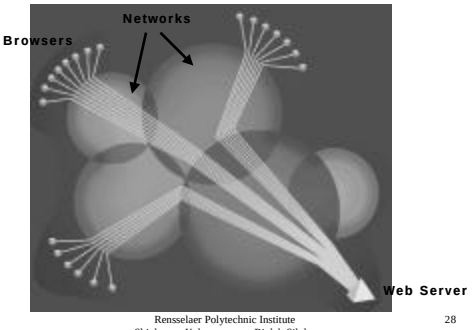
Why Web Caching?

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

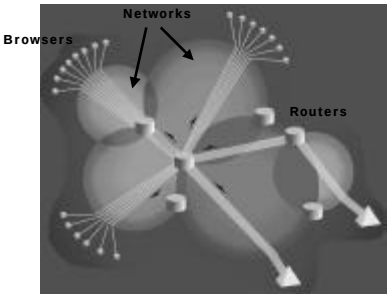
- **smaller response time: cache "closer" to client**
- **decrease traffic to distant servers**
  - **link out of institutional/local ISP network often bottleneck**



Content Delivery: motivation

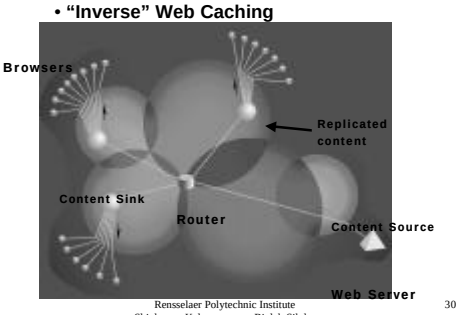


Content Delivery: congestion

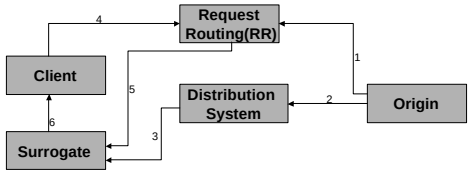


Content Delivery: idea

- **Reduces load on server**
- **Avoids network congestion**
- **"Inverse" Web Caching**

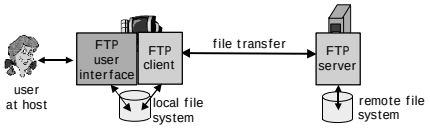


CDN: Architectural Layout



- Publisher informs RR of Content Availability.
- Content Pushed to Distribution System.
- Client Requests Content, Requested redirected to RR.
- RR finds the most suitable Surrogate
- Surrogate services client request.

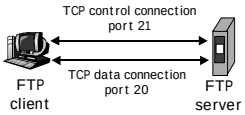
ftp: the file transfer protocol



- 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, 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, responses

Sample commands:

- sent as ASCII text over control channel
- `USER` *`username`*
- `PASS` *`password`*
- `LIST` returns list of file 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`

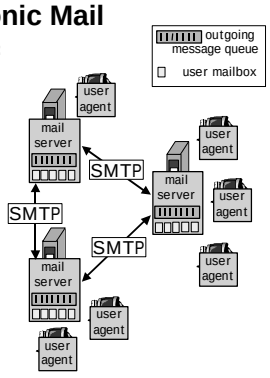
Electronic Mail

Three major components:

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

User Agent

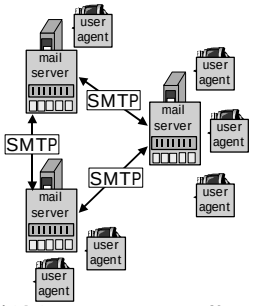
- a.k.a. "mail reader"
- composing, editing, reading mail messages
- e.g., Eudora, Outlook, elm, Netscape Messenger
- outgoing, incoming messages stored on server



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



Electronic Mail: smtp [RFC 821]

- uses tcp to reliably transfer email msg 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
```


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 email client (reader)

smtp: final words

- smtp uses persistent connections
- smtp requires that message (header & body) be in 7-bit ascii
- certain character strings are not permitted in message (e.g., `CRLF.CRLF`). Thus message has to be encoded (usually into either base-64 or quoted printable)
- smtp server uses `CRLF.CRLF` to determine end of message

Comparison with http

- http: pull
- email: push
- both have ASCII command/response interaction, status codes
- http: each object is encapsulated in its own response message
- smtp: multiple objects message sent in a multipart message

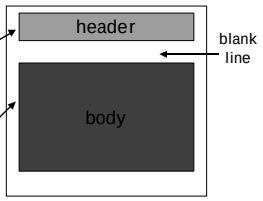
Mail message format

smtp: protocol for exchanging email msgs

RFC 822: standard for text message format:

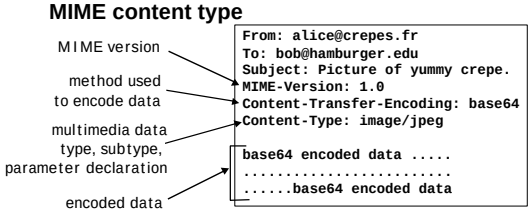
- header lines, e.g.,
  - To:
  - From:
  - Subject:

  different from smtp commands!
- body
  - the "message", ASCII characters only



Message format: multimedia extensions

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



MIME types

`Content-Type: type/subtype; parameters`

Text
- example subtypes: `plain, html`

Image
- example subtypes: `jpeg, gif`

Audio
- exampe 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

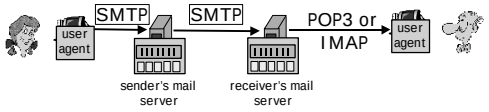
```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Type: multipart/mixed; boundary=98766789

--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--
```


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 1730]
    - more features (more complex)
    - manipulation of stored msgs on server
  - HTTP: Hotmail , Yahoo! Mail, etc.

POP3 protocol

authorization phase
- **client commands:**
  - `user:` **declare username**
  - `pass:` **password**
- **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
```


DNS: Domain Name System

People: many identifiers:
- **SSN, name, Passport #**

Internet hosts, routers:
- **IP address (32 bit) - used for addressing datagrams**
- **"name", e.g., gaia.cs.umass.edu - used by humans**

Q: map between IP addresses and name ?

Domain Name System:
- ***distributed database* implemented in hierarchy of many *name servers***
- ***application-layer protocol* host, routers, name servers to communicate to *resolve* names (address/name translation)**
  - **note: 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**

doesn't *scale!*

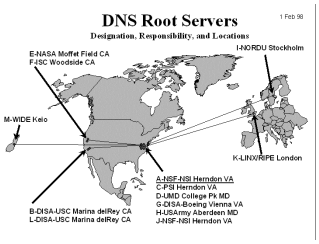
- **no server has all name-to-IP address mappings**

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

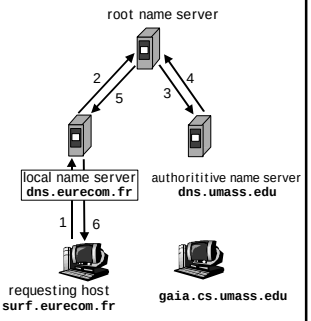
- **contacted by local name server that can not resolve name**
- **root name server:**
  - **contacts authoritative name server if name mapping not known**
  - **gets mapping**
  - **returns mapping to local name server**
- **~ dozen root name servers worldwide**



Simple DNS example

host `surf.eurecom.fr` **wants IP address of** `gaia.cs.umass.edu`

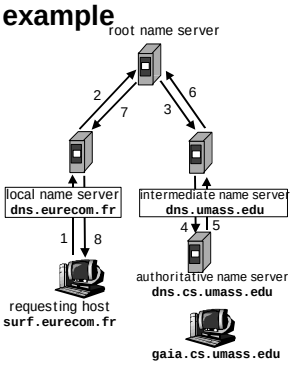
1. **Contacts its local DNS server,** `dns.eurecom.fr`
2. `dns.eurecom.fr` **contacts root name server, if necessary**
3. **root name server contacts authoritative name server,** `dns.umass.edu`, **if necessary**



DNS example

Root name server:

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



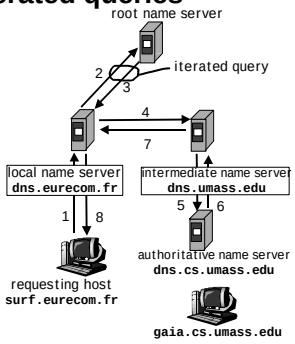
DNS: iterated queries

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 records

DNS: distributed db storing resource records (RR)

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

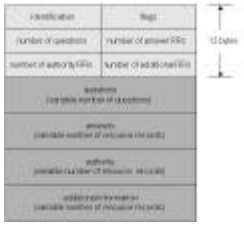
- **Type=A**
  - `name` **is hostname**
  - `value` **is IP address**
- **Type=NS**
  - `name` **is domain (e.g. foo.com)**
  - `value` **is IP address of authoritative name server for this domain**
- **Type=CNAME**
  - `name` **is an alias name for some "cannonical" (the real) name**
  - `value` **is cannonical name**
- **Type=MX**
  - `value` **is hostname of mailserver associated with** `name`

DNS protocol, messages

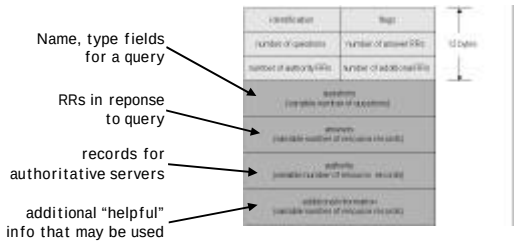
DNS protocol : *query* and *reply* messages, both with same *message format*

msg header

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



DNS protocol, messages



Sockets

Goal: learn models of client/server application that communicate using sockets

Socket API

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

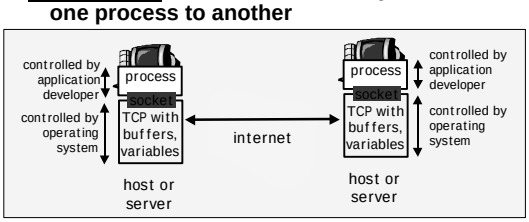
socket

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

TCP sockets

Socket: a door between application process and end-end-transport protocol (UCP or TCP)

TCP service: reliable transfer of bytes from one process to another



TCP sockets

Client must contact server

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

Client contacts server by:

- **creating client-local TCP socket**
- **specifying IP address, 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

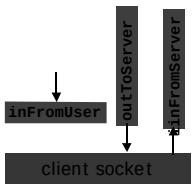
TCP Sockets

Example client-server app:

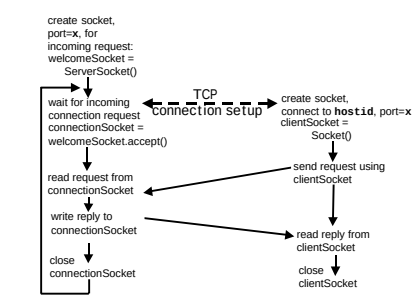
- **client reads line from standard input (`inFromUser` stream) , sends to server via socket (`outToServer` stream)**
- **server reads line from socket**
- **server converts line to uppercase, sends back to client**
- **client reads, prints modified line from socket (`inFromServer` stream)**

Input stream: sequence of bytes into process

Output stream: sequence of bytes out of process



Client/server socket interaction: TCP



UDP Sockets

UDP: no "connection" between client and server

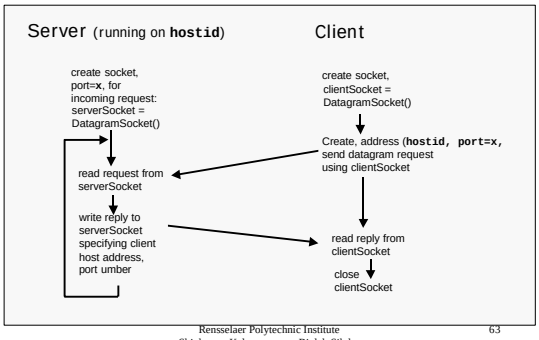
- **no handshaking**
- **sender explicitly attaches IP address and port of destination**
- **server must extract IP address, port of sender from received datagram**

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

application viewpoint

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

Client/server socket interaction: UDP



Application Layer: Summary

Our study of network apps now complete!

- **application service requirements:**
  - **reliability, bandwidth, delay**
- **client-server paradigm**
- **Internet transport service model**
  - **connection-oriented, reliable: TCP**
  - **unreliable, datagrams: UDP**
- **specific protocols:**
  - **http**
  - **ftp**
  - **smtp, pop3**
  - **dns**
- **sockets**
  - **client/server implementation**
  - **using tcp, udp sockets**

Application Layer: Summary

<u>Most importantly:</u> learned about *<u>protocols</u>*

- **typical *request/reply* message exchange:**
  - **client requests info or service**
  - **server responds with data, status code**
- **message *formats*:**
  - **headers: fields giving info about data**
  - **data: info being communicated**
- **control vs. data msgs**
  - **in-based, out-of-band**
- **centralized vs. decentralized**
- **stateless vs. stateful**
- **reliable vs. unreliable msg transfer**
- **"complexity at network edge"**
- **security: authentication**