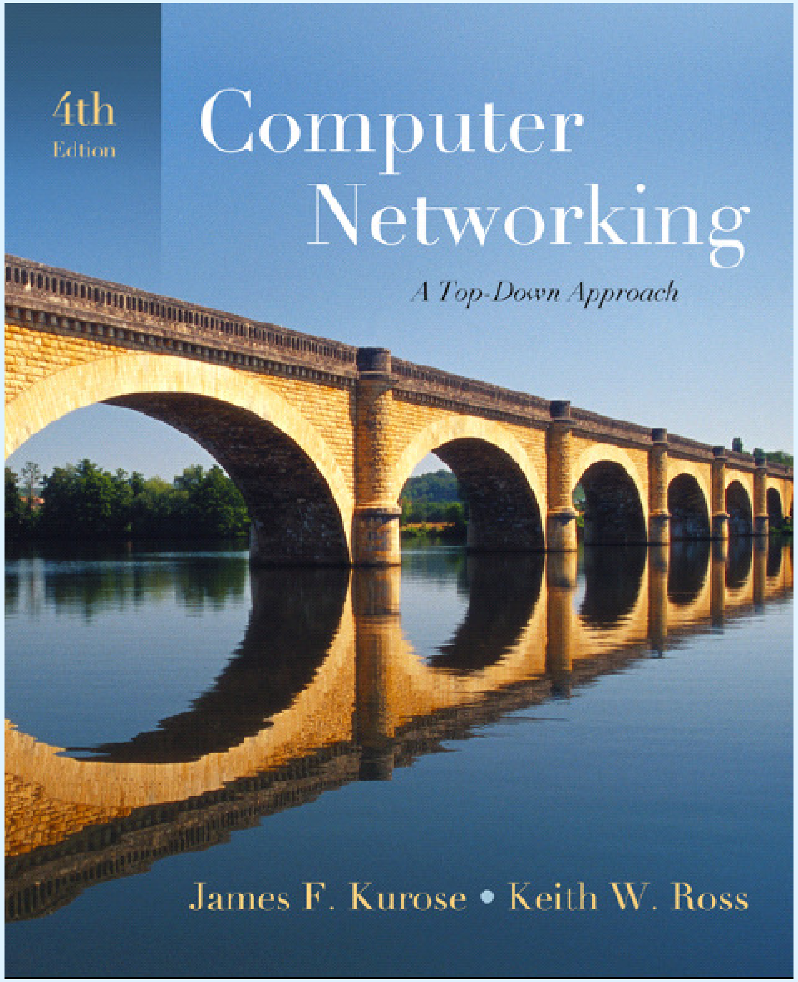
Application layer

Bildspelet omfattar till stor del bilder som hör till följande bok:



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Computer Networking: A Top Down Approach , 4th edition.
Jim Kurose, Keith Ross, Addison-Wesley, July 2007.

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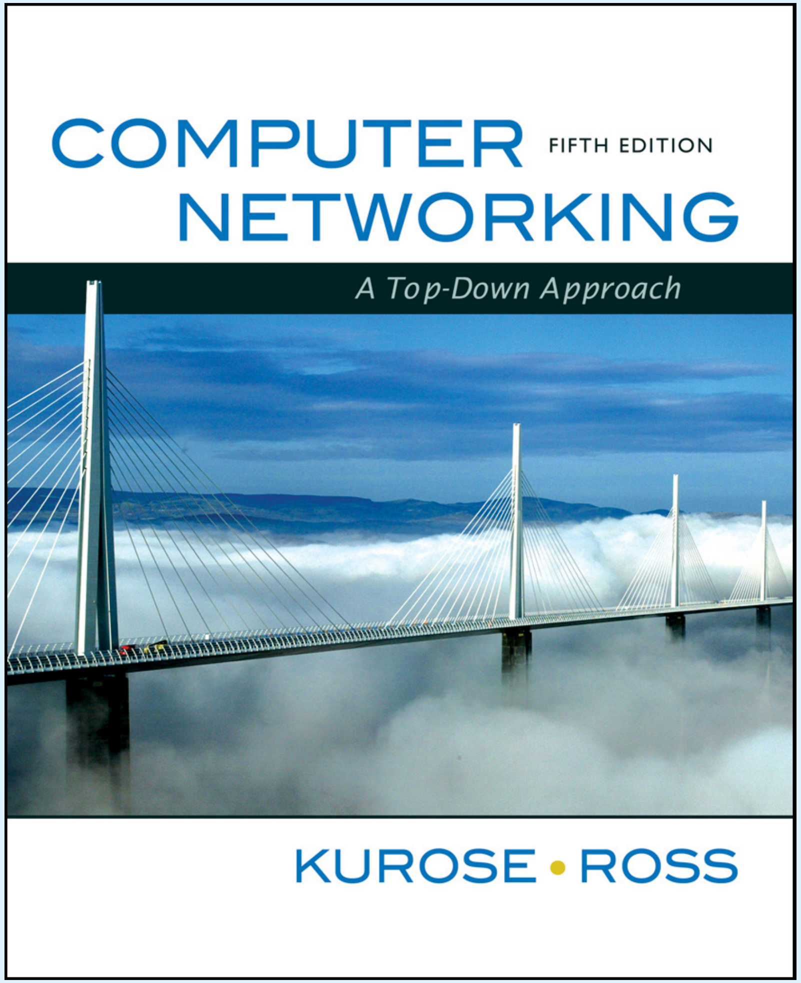

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Jim Kurose, Keith Ross, Addison-Wesley, April 2009.

App-layer protocol defines

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

Public-domain protocols:

- defined in RFCs
- allows for interoperability
- e.g., HTTP, SMTP

Proprietary protocols:

- e.g., Skype

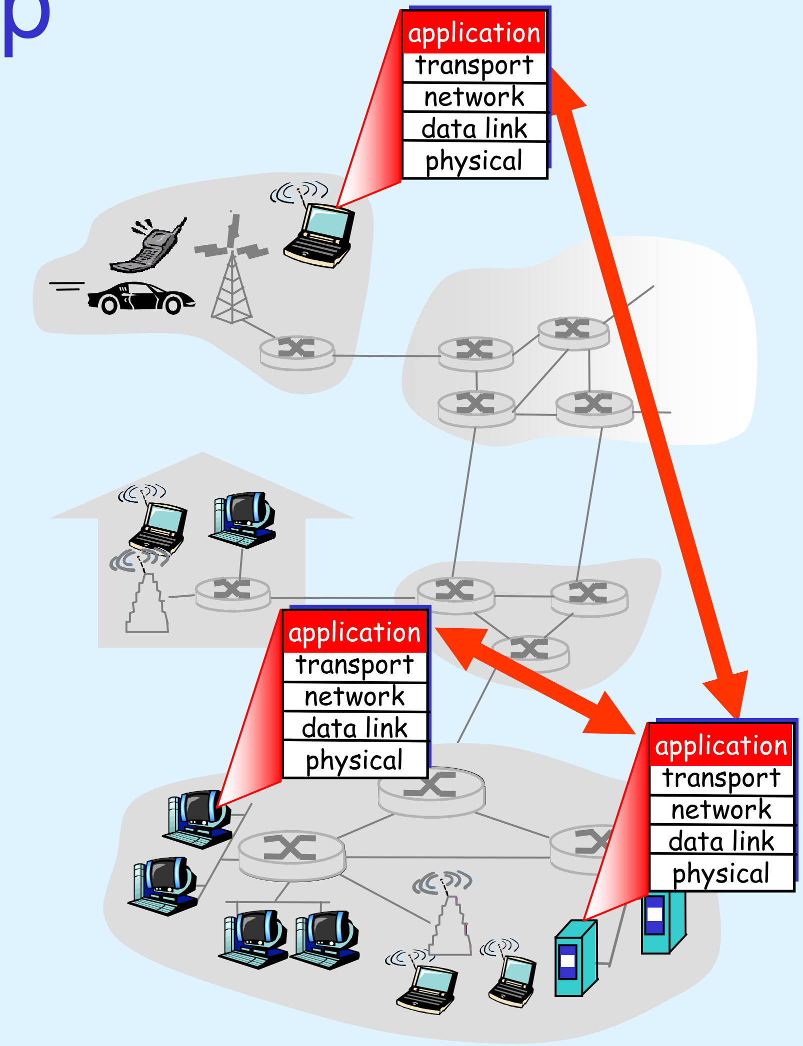
Creating a network app

write programs that

- run on (different) *end systems*

little software written for devices in network core

- network core devices do not run user applications



Processes communicating

Process: program running within a host.

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

Client process: process that initiates communication

Server process: process that waits to be contacted

- Note: applications with P2P architectures have client processes & server processes

Adressering av applikationsprogram

- Värden adresseras med dess IP-adress
- Applikationsprogrammet i värden adresseras genom sitt applikationsprotokoll
- Applikationsprotokollet adressera av sin SAP, dvs. porten
- Porten finns i gränssnittet mellan transportskiktet och applikationsskiktet

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	no loss	elastic	no
real-time audio/video	loss-tolerant	audio: 5kbps-1Mbps video:10kbps-5Mbps	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
instant messaging	no loss	elastic	yes and no

Internet transport protocols services

TCP service:

- *connection-oriented:* setup required between client and server processes
- *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:

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

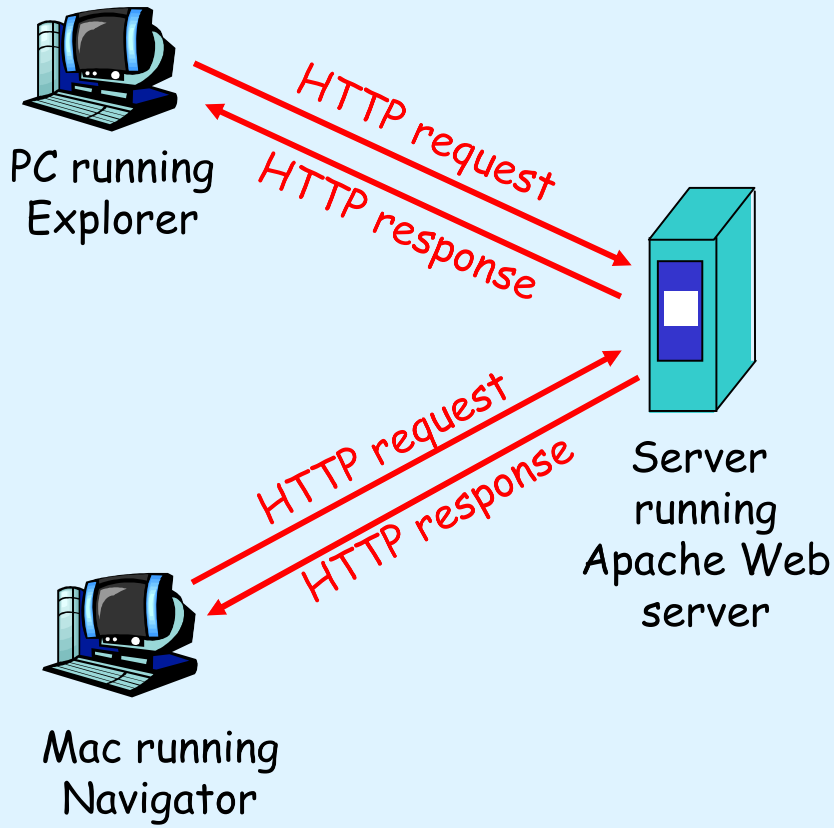
Web and HTTP

- Web page consists of base HTML-file which includes several referenced objects
- Each object is addressable by a URL

HTTP overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server model
- HTTP 1.0: RFC 1945
- HTTP 1.1: RFC 2068



HTTP overview (continued)

Uses TCP:

- client initiates TCP connection (creates socket) to server, port 80
- server accepts TCP connection from client
- HTTP messages exchanged between browser (HTTP client) and Web server (HTTP server)
- TCP connection closed

HTTP is "stateless"

- server maintains no information about past client requests

aside

Protocols that maintain "state" are complex!

- past history (state) must be maintained
- if server/client crashes, their views of "state" may be inconsistent, must be reconciled

HTTP connections

Nonpersistent HTTP

- At most one object is sent over a TCP connection.
- HTTP/1.0 uses nonpersistent HTTP

Persistent HTTP

- Multiple objects can be sent over single TCP connection between client and server.
- HTTP/1.1 uses persistent connections in default mode

Persistent HTTP

<u>Nonpersistent HTTP issues:</u>

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

<u>Persistent HTTP</u>

- server leaves connection open after sending response
- subsequent HTTP messages between same client/server sent over open connection

<u>Persistent ***without*** pipelining:</u>

- client issues new request only when previous response has been received
- one RTT for each referenced object

<u>Persistent ***with*** pipelining:</u>

- default in HTTP/1.1
- client sends requests as soon as it encounters a referenced object
- as little as one RTT for all the referenced objects

HTTP request message

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

request line (GET, POST, HEAD commands)

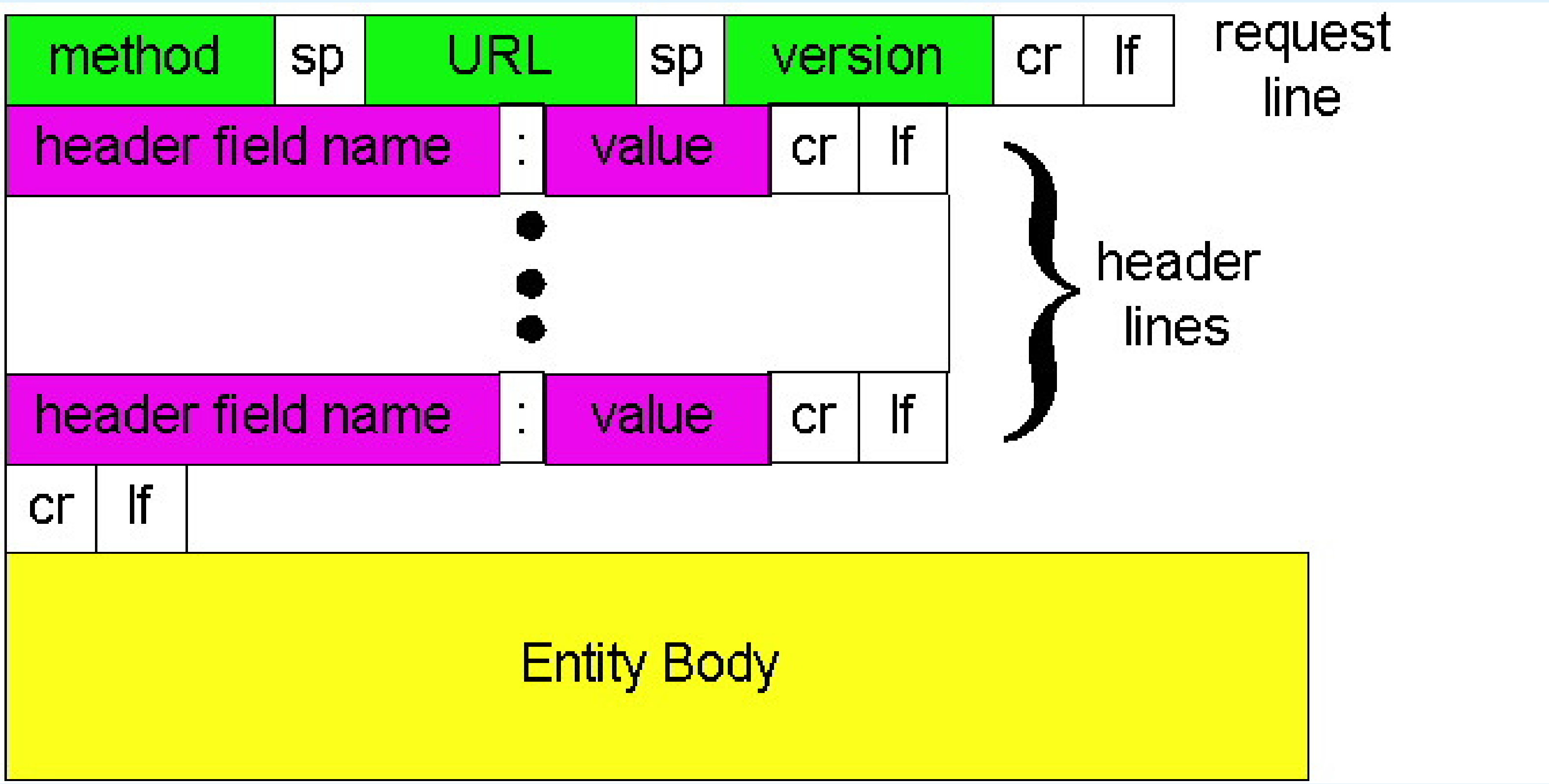
```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
User-agent: Mozilla/4.0
Connection: close
Accept-language:fr
```

header lines

Blank line (extra carriage return, line feed)

Carriage return, line feed indicates end of message

HTTP request message: general format



Uploading form input

Post method:

- Web page often includes form input
- Input is uploaded to server in entity body

GET method:

- Uses the URL
- Input is uploaded in URL field of request line:

Method types

HTTP/1.0

- GET
- POST
- HEAD
  - asks server to leave requested object out of response

HTTP/1.1

- GET, POST, HEAD
- PUT
  - uploads file in entity body to path specified in URL field
- DELETE
  - deletes file specified in the URL field

HTTP response message

status line
(protocol
status code
status phrase)

header
lines

data, e.g.,
requested
HTML file

```
HTTP/1.1 200 OK
Connection close
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

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`

HTTP-Exempel (1)

1. På kommandprompten
   telnet basen.oru.se 80 [Enter]

2. Skriv "i blindo" i telnet
   HEAD /datorkom/tomten.html HTTP/1.1 [Enter]

3. Skriv "i blindo" i telnet
   Host: basen.oru.se [Enter] [Enter]

"I blindo" eftersom
set localecho
avbryter kommunikationen.

HTTP-Exempel (2)

Telnet basen.oru.se

```
HTTP/1.1 200 OK
Vary: accept-encoding
Server: Roxen/5.2.200-r2
Accept-Ranges: bytes
Last-Modified: Fri, 13 Feb 2015 12:55:48 GMT
Date: Wed, 23 Sep 2015 12:36:00 GMT
Connection: keep-alive
Content-Type: text/html
Content-Length: 476
ETag: "32bab6fdb6d2e270c527eff196aab255"
```

Cookies (continued)

What cookies can bring:

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

User-server state: cookies

Many major Web sites use cookies

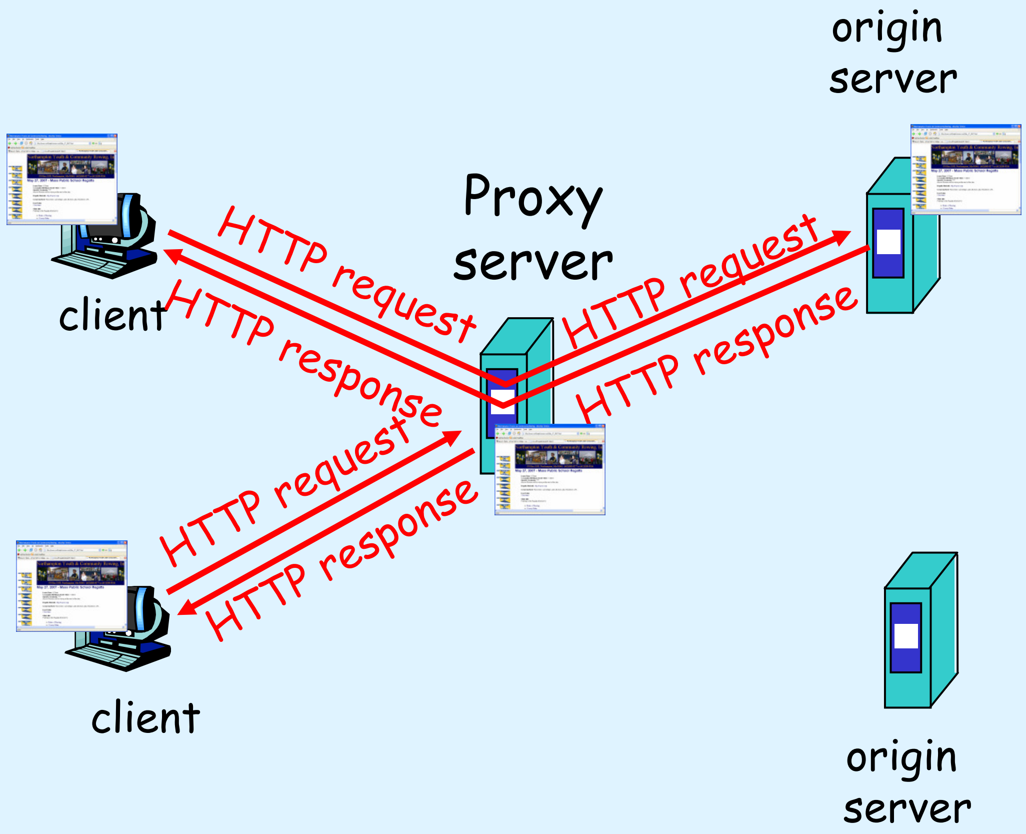
<u>Four components:</u>

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

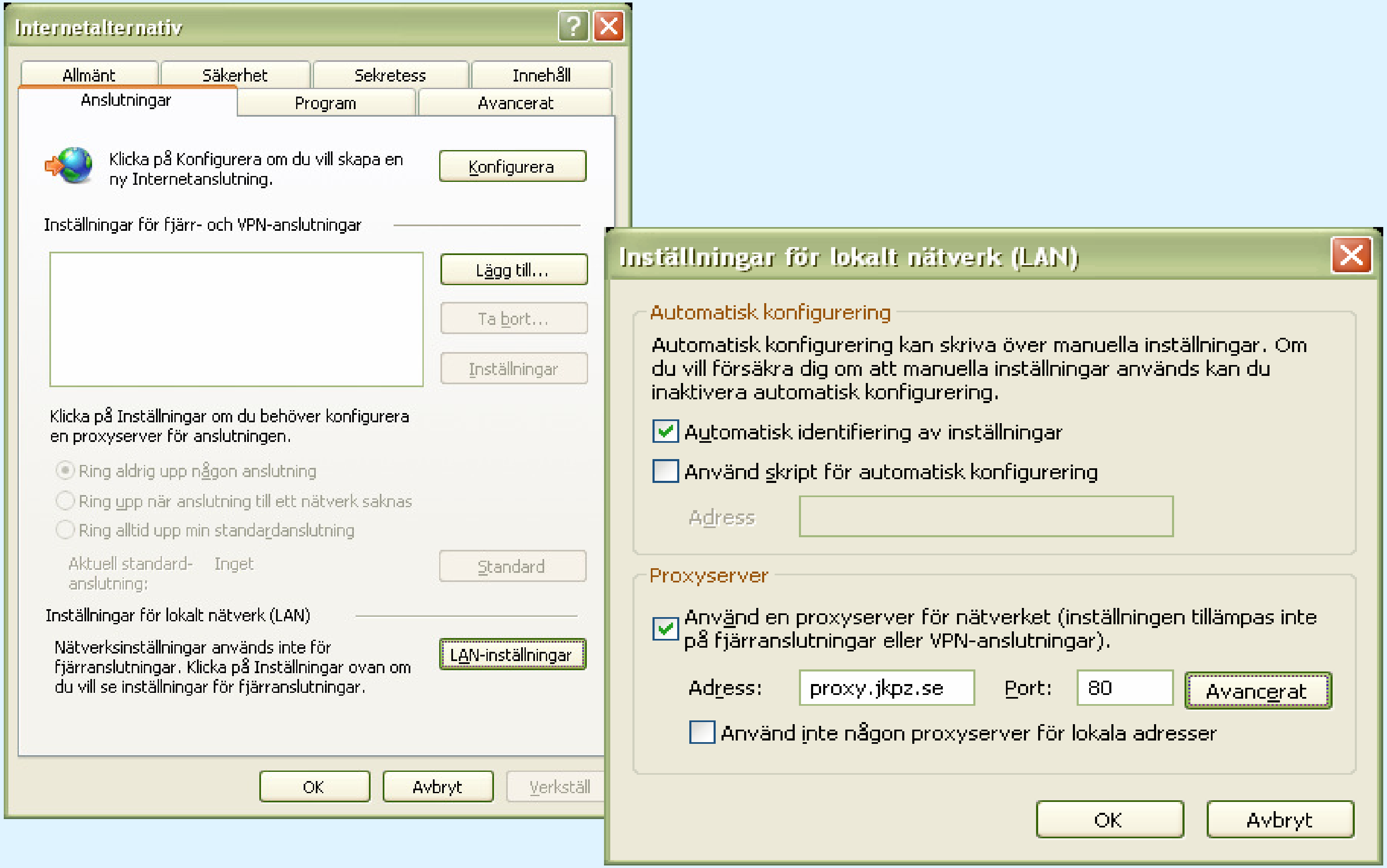
Web caches (proxy server)

Goal: satisfy client request without involving origin server

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



Proxyinställning i IE



More about Web caching

- cache acts as both client and server
- typically cache is installed by ISP (university, company, residential ISP)

Why Web caching?

- reduce response time for client request
- reduce traffic on an institution's access link.
- Internet dense with caches: enables "poor" content providers to effectively deliver content (but so does P2P file sharing)

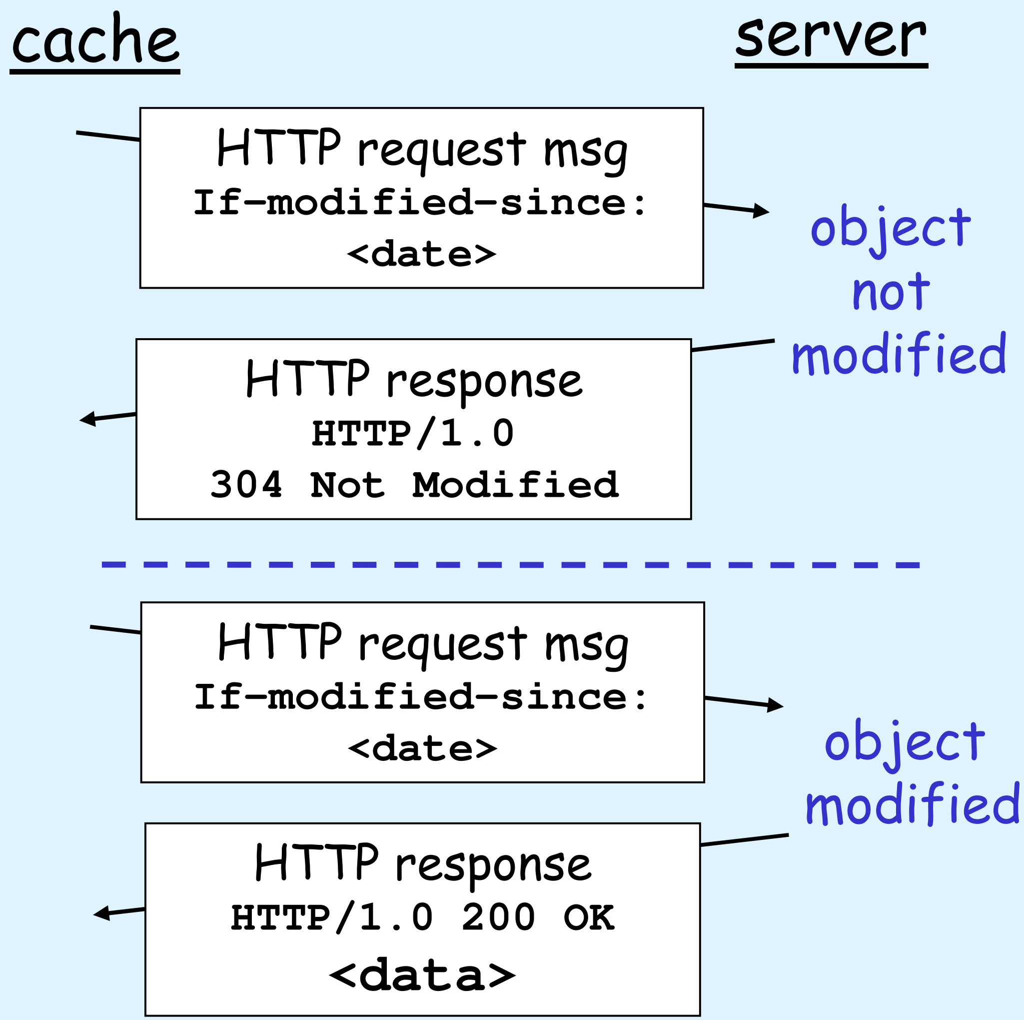
Conditional GET

- **Goal:** don't send object if cache has up-to-date cached version
- cache: specify date of cached copy in HTTP request

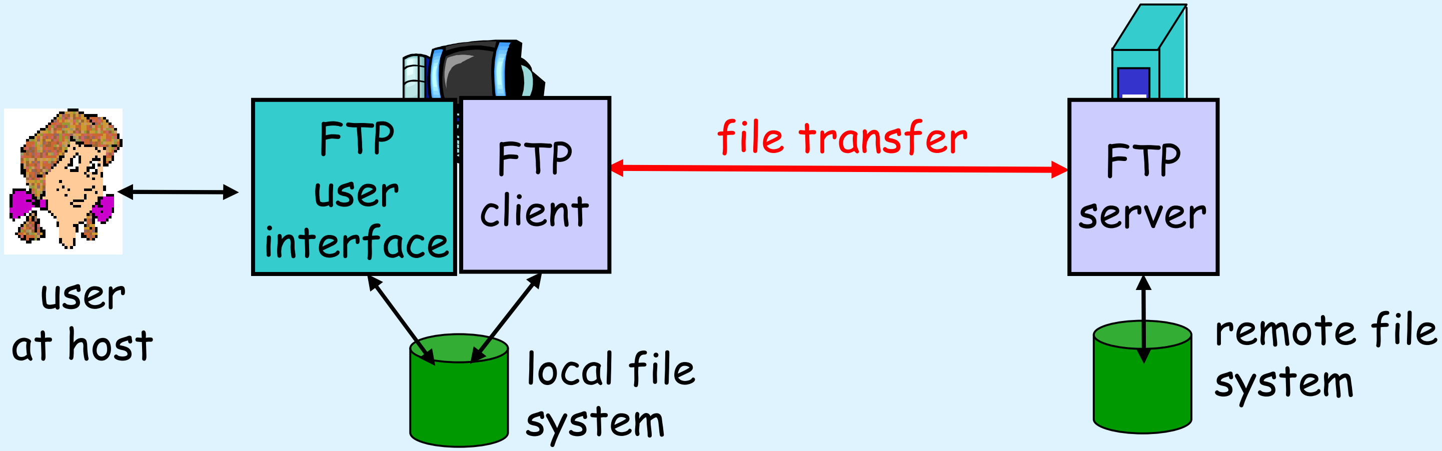
`If-modified-since: <date>`

- server: response contains no object if cached copy is up-to-date:

`HTTP/1.0 304 Not Modified`



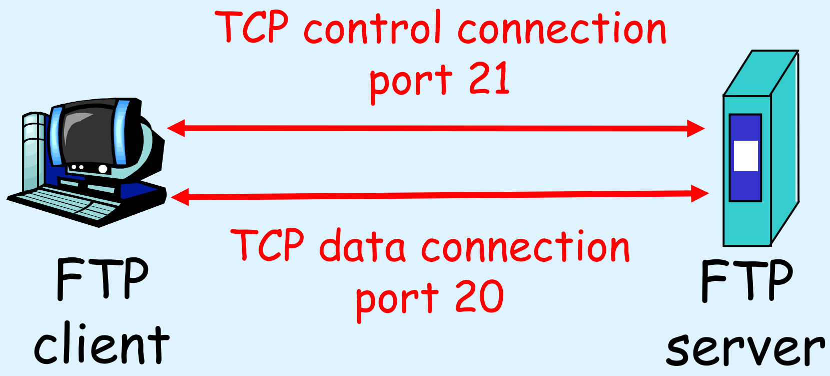
FTP: the file transfer protocol



- 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: separate control, data connections

- FTP client contacts FTP server at port 21, TCP is transport protocol
- client authorized over control connection
- client browses remote directory by sending commands over control connection.
- when server receives file transfer command, server opens *2nd* TCP connection (for file) to client
- after transferring one file, server closes data connection.



- server opens another TCP data connection to transfer another file.
- control connection: "out of band"
- 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** return list of file in current directory
- **RETR filename** retrieves (gets) file
- **STOR filename** stores (puts) file onto remote host

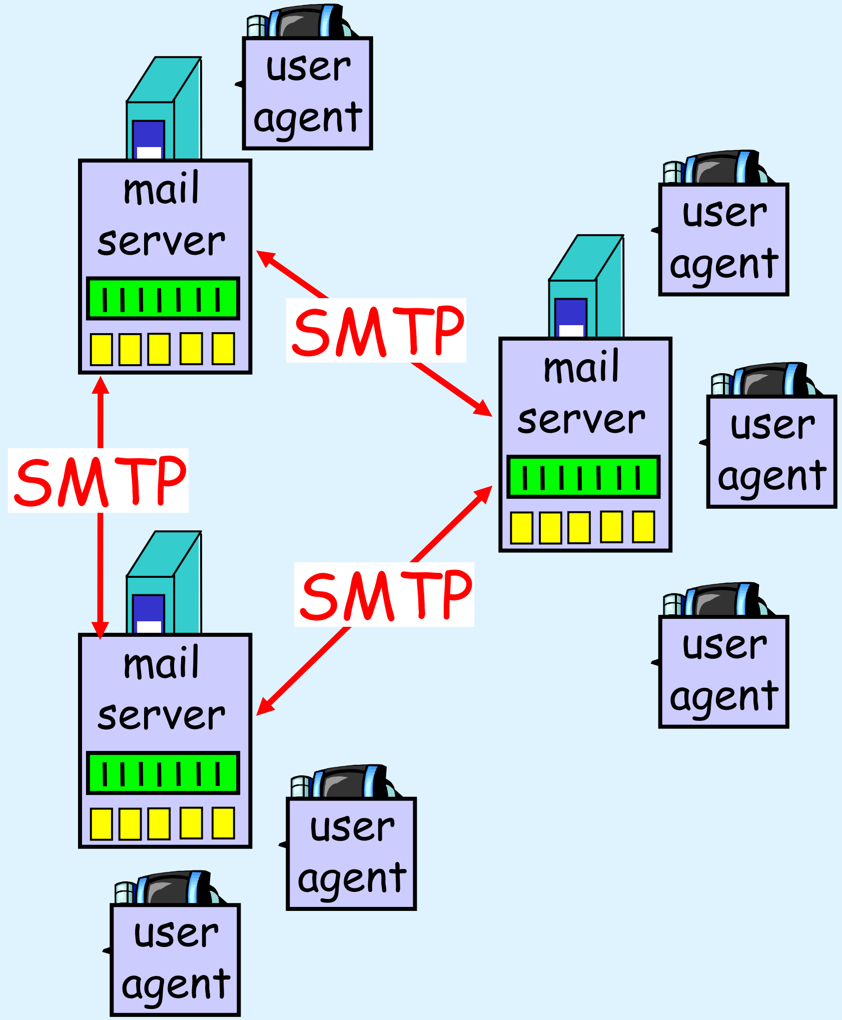
Sample return codes

- 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: mail servers

Mail Servers

- mailbox contains incoming messages for user
- message queue of outgoing (to be sent) mail messages
- SMTP protocol between mail servers to send email messages
  - client: sending mail server
  - "server": receiving mail server



Electronic Mail: SMTP [RFC 2821]

- 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

Message format: multimedia extensions

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

MIME version

method used to encode data

multimedia data type, subtype, parameter declaration

encoded data

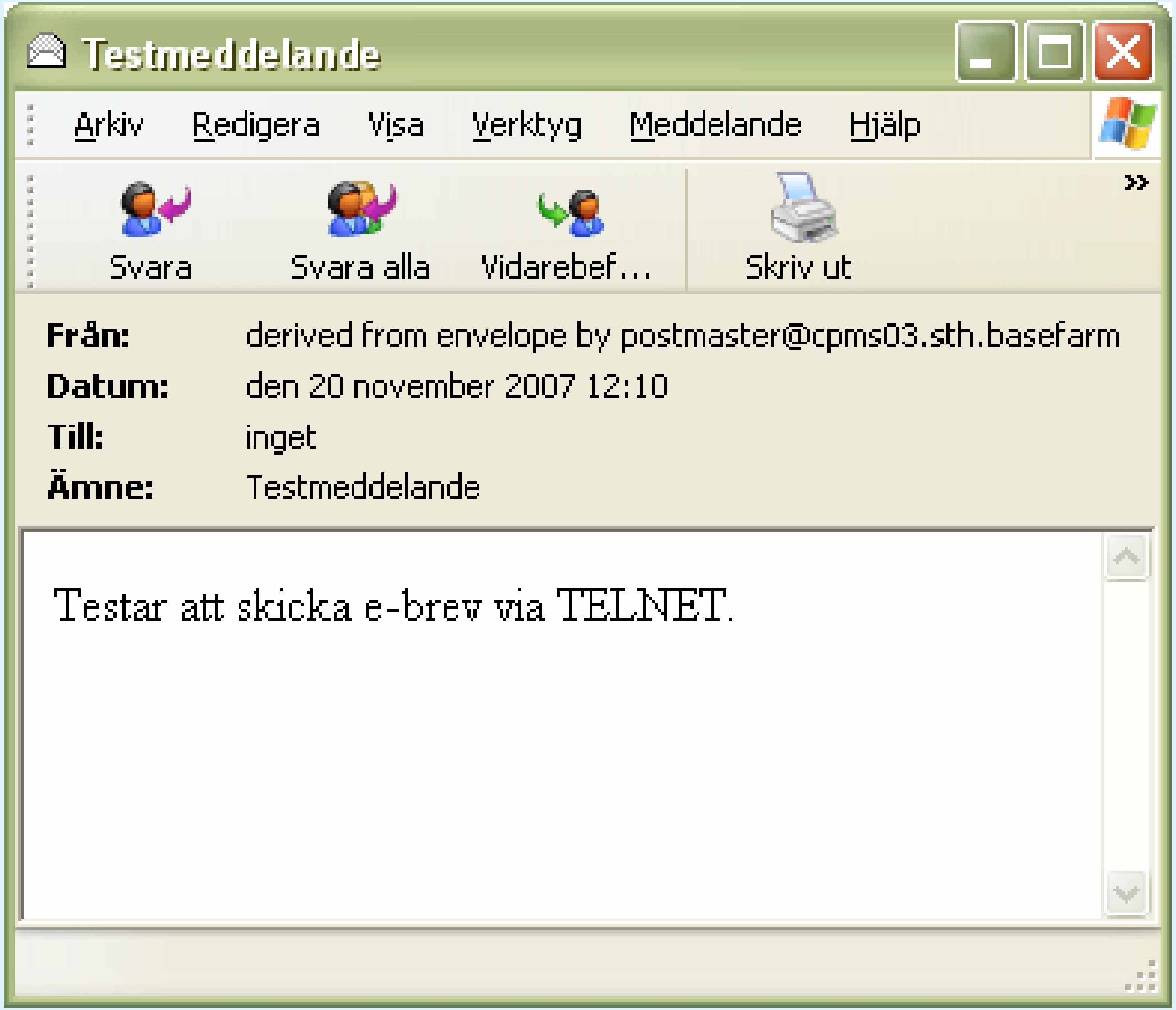
```
From: alice@crepes.fr
To: bob@hamburger.edu
Subject: Picture of yummy crepe.
MIME-Version: 1.0
Content-Transfer-Encoding: base64
Content-Type: image/jpeg

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

Try SMTP interaction for yourself:

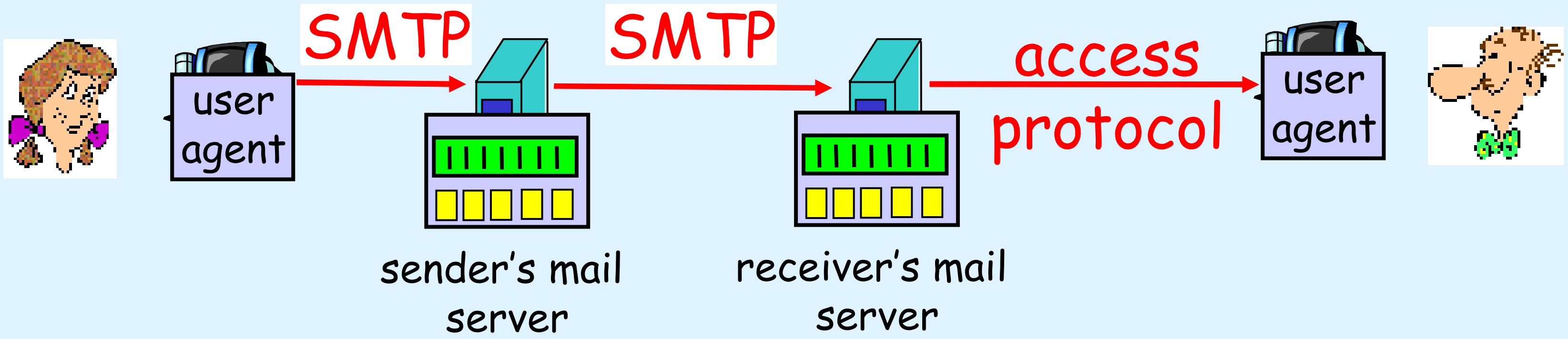
1. **`telnet servername 25`**
2. see 220 reply from server
3. enter HELO, MAIL FROM, RCPT TO, DATA, QUIT commands

Kommandotolken

```
220 ch-smtp01.sth.basefarm.net ESMTP Exim 4.68 Tue, 20 Nov 2007 12:07:03 +0100
HELO comhem.se
250 ch-smtp01.sth.basefarm.net Hello c83-253-64-85.bredband.comhem.se [83.253.64
.85]
MAIL FROM: jack.pencz@comhem.se
250 OK
RCPT TO: jack.pencz@comhem.se
250 Accepted
DATA
354 Please start mail input.
Subject: Testmeddelande

Testar att skicka e-brev via TELNET.
.
250 Mail queued for delivery.
QUIT
221 Closing connection. Good bye.


Anslutningen till värddatorn bröts.

C:\Documents and Settings\Ägaren>
```


Testmeddelande
Arkiv Redigera Visa Verktyg Meddelande Hjälp
Svara
Svara alla
Vidarebef...
Skriv ut
Från: derived from envelope by postmaster@cpms03.sth.basefarm
Datum: den 20 november 2007 12:10
Till: inget
Ämne: Testmeddelande
Testar att skicka e-brev via TELNET.

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: gmail, Hotmail, Yahoo! Mail, etc.

DNS

DNS services

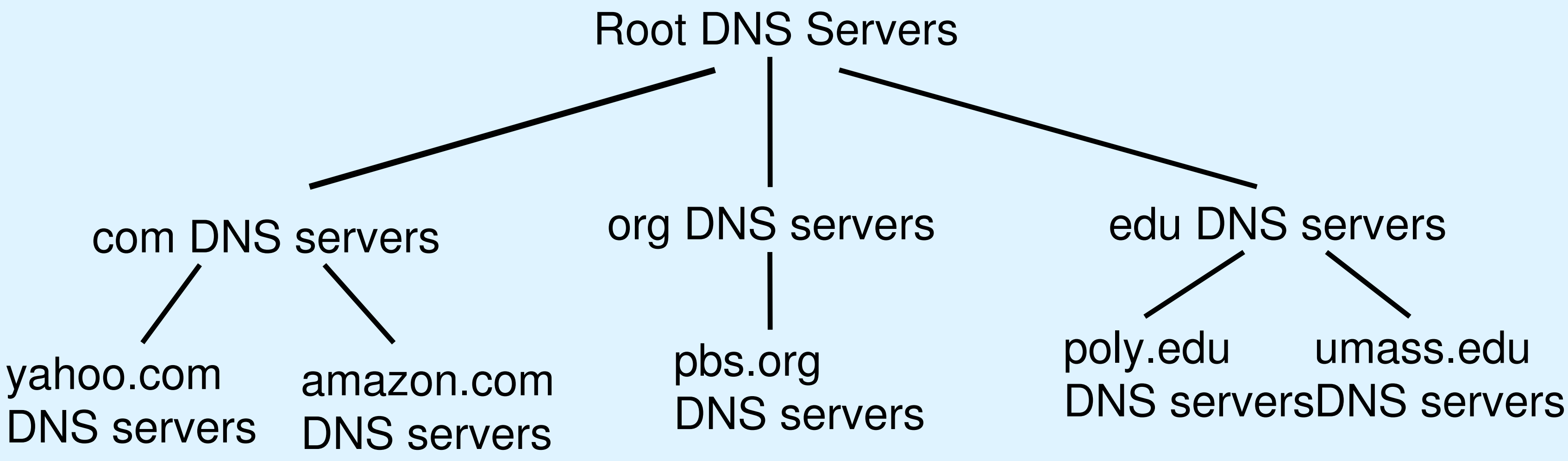
- hostname to IP address translation
- host aliasing
  - Canonical, alias names
- mail server aliasing
- load distribution
  - replicated Web servers: set of IP addresses for one canonical name

Why not centralize DNS?

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

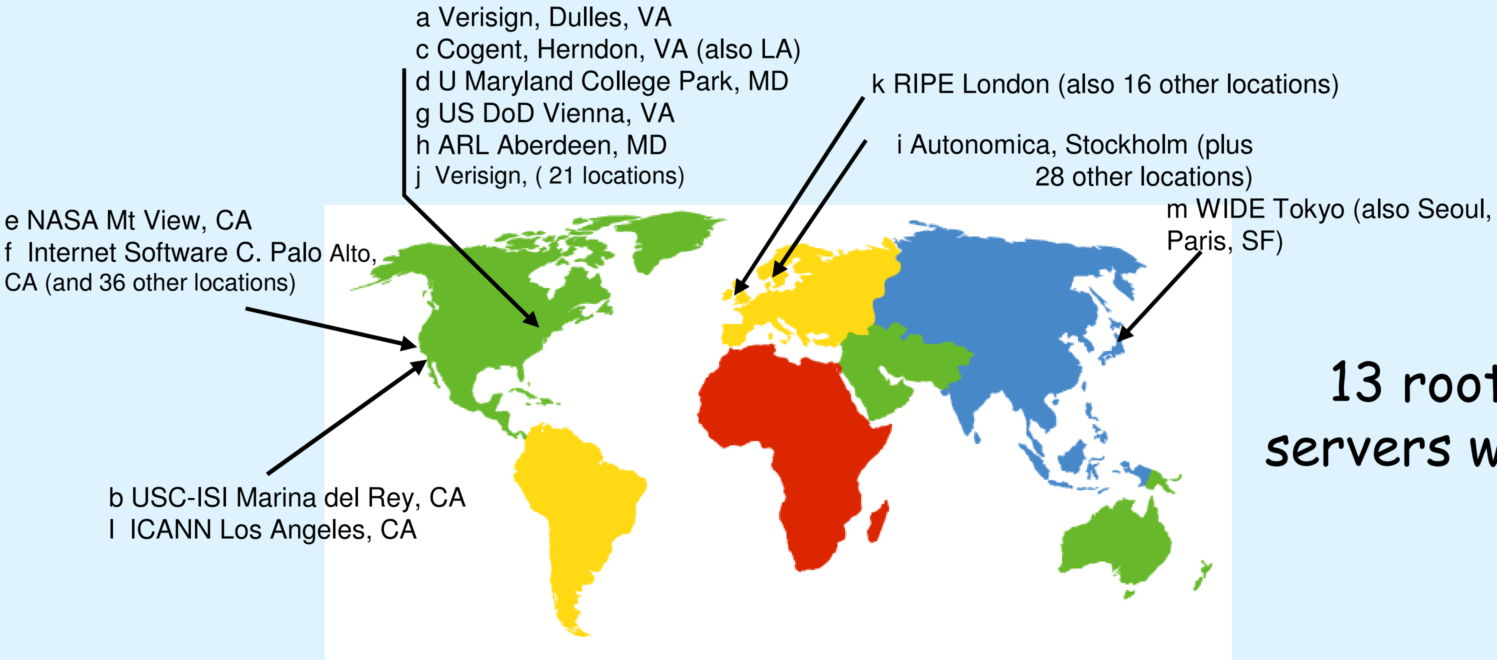
doesn't *scale!*

Distributed, Hierarchical Database



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



13 root name servers worldwide

TLD and Authoritative Servers

- **Top-level domain (TLD) servers:**
  - responsible for com, org, net, edu, etc, and all top-level country domains uk, fr, ca, jp.
- **Authoritative DNS servers:**
  - organization's DNS servers, providing authoritative hostname to IP mappings for organization's servers (e.g., Web, mail).
  - can be maintained by organization or service provider

Local Name Server

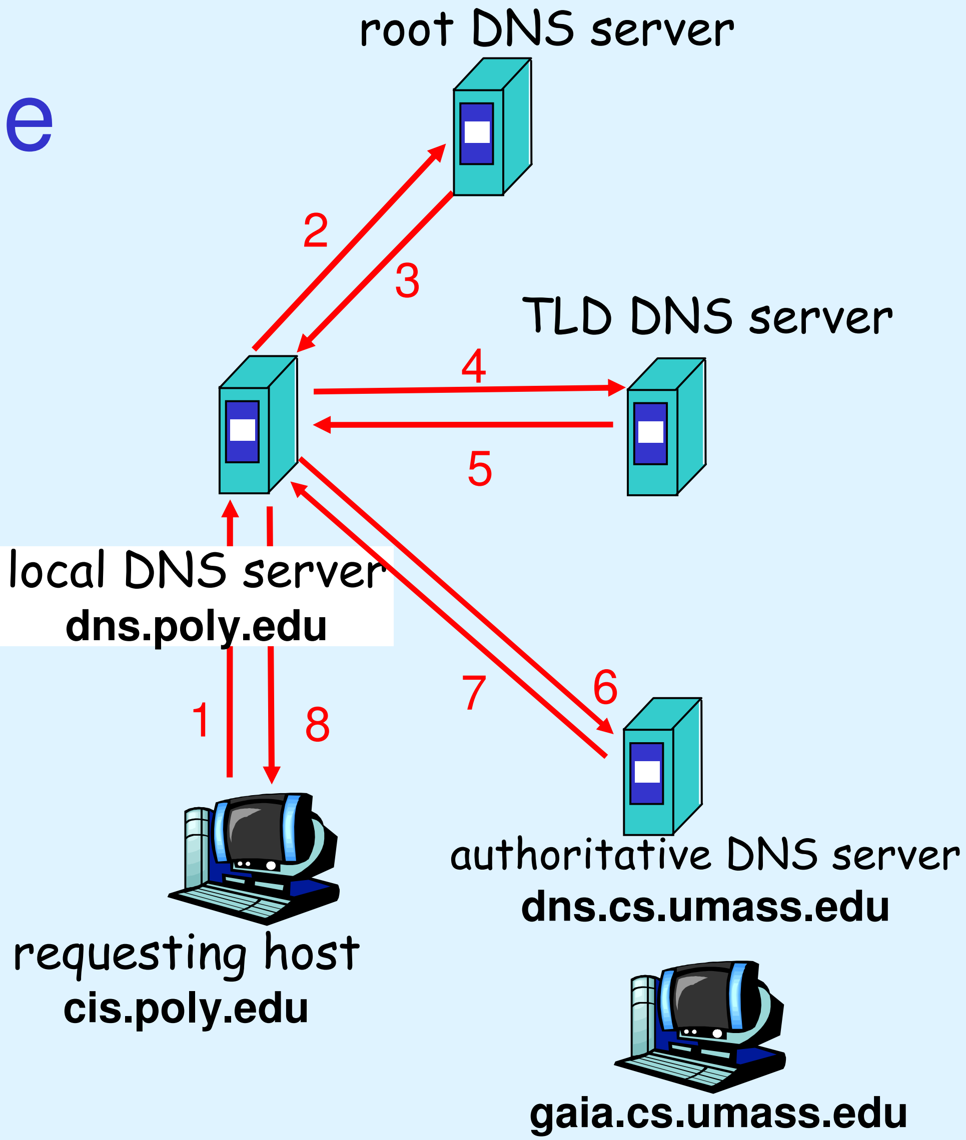
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one.
  - also called "default name server"
- when host makes DNS query, query is sent to its local DNS server
  - acts as proxy, forwards query into hierarchy

DNS name resolution example

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

<u>iterated query:</u>

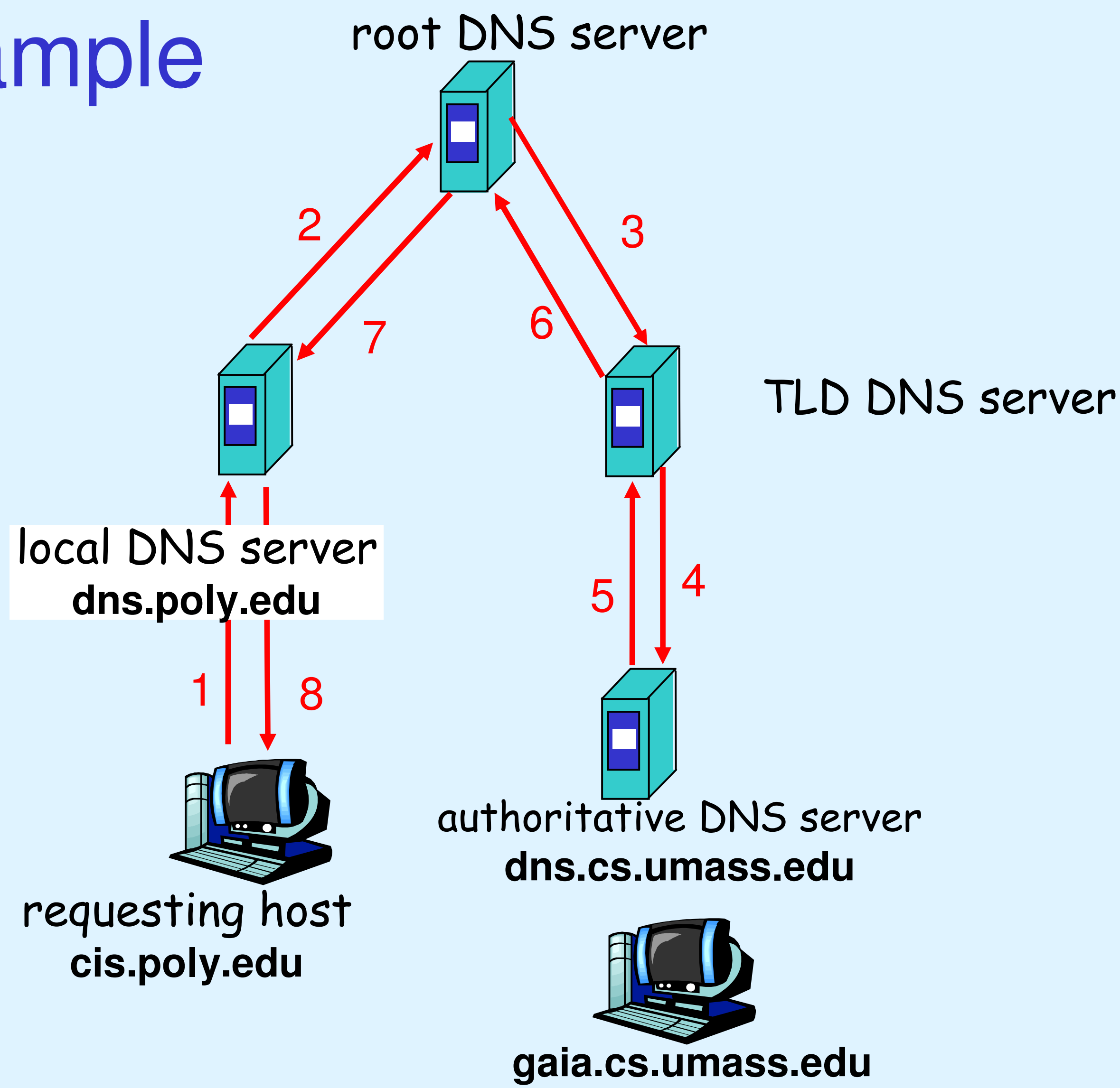
- contacted server replies with name of server to contact
- "I don't know this name, but ask this server"



DNS name resolution example

<u>recursive query:</u>

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

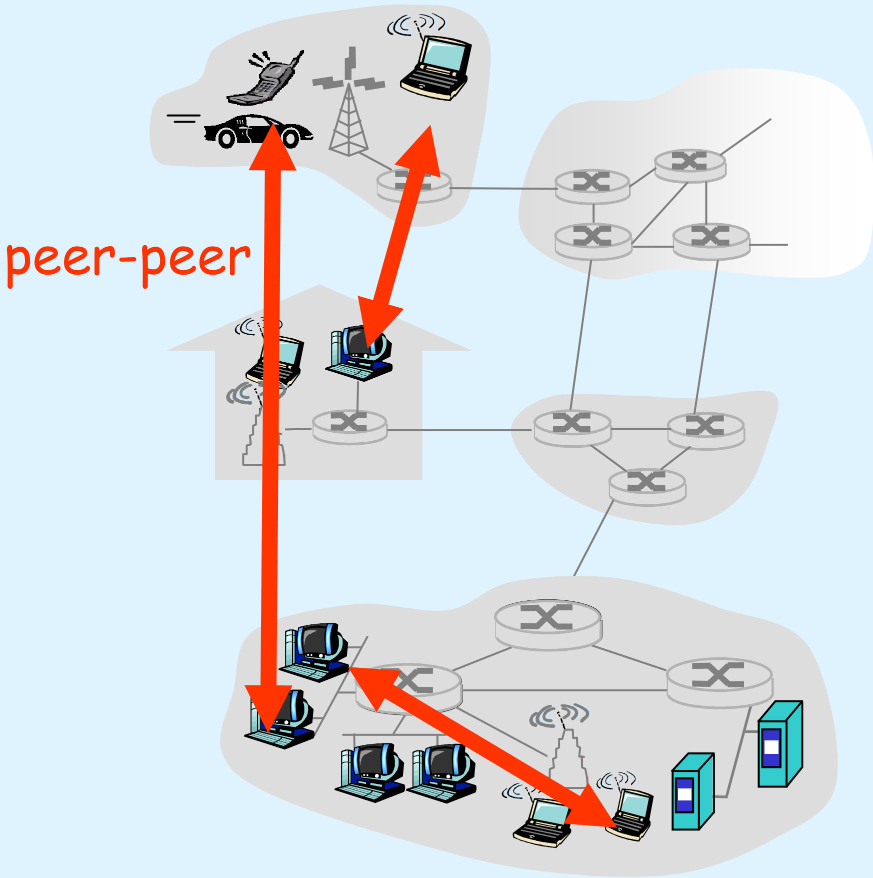


DNS: caching and updating records

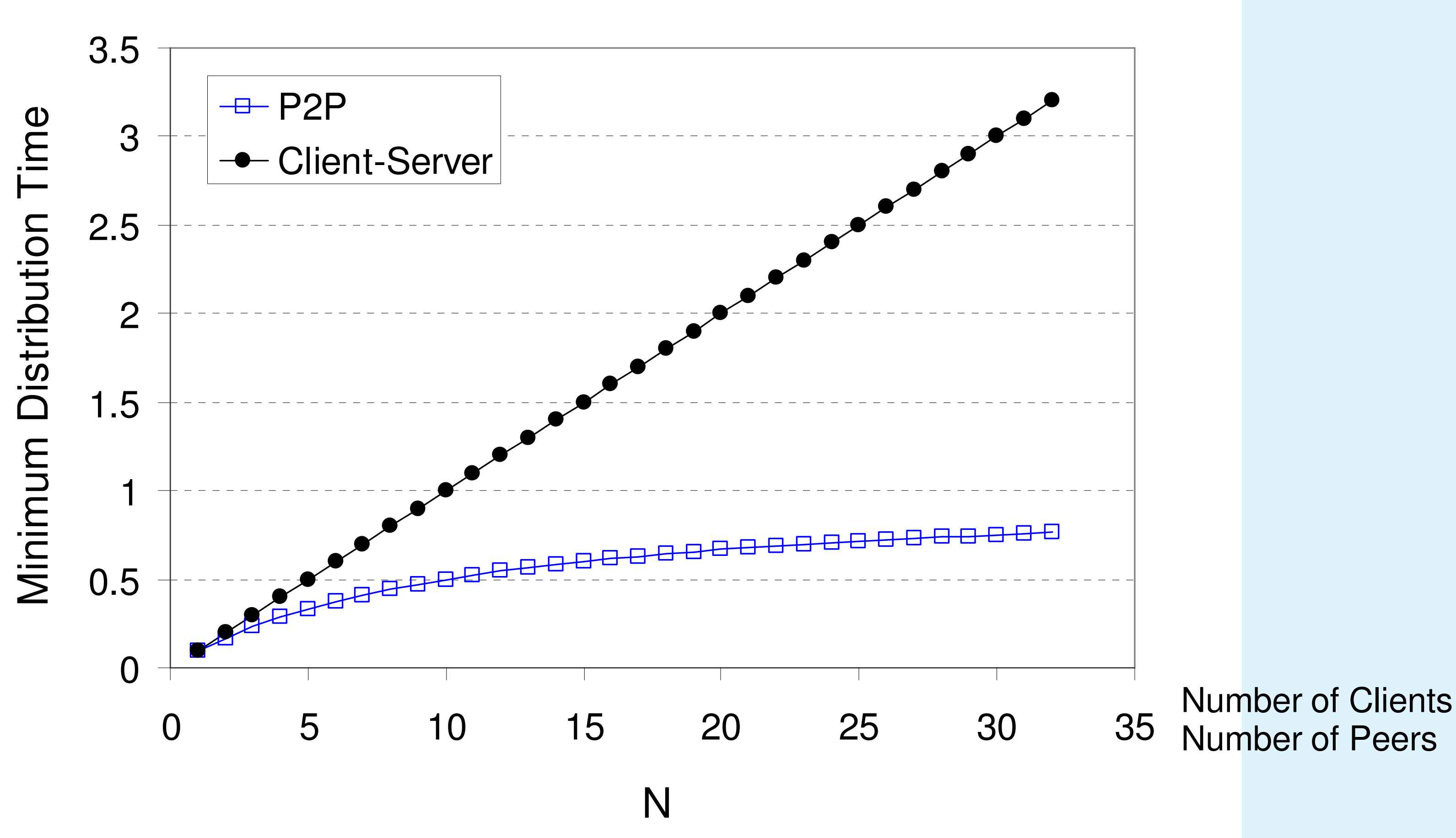
- once (any) name server learns mapping, it *caches* mapping
  - cache entries timeout (disappear) after some time
  - TLD servers typically cached in local name servers
    - Thus root name servers not often visited

Pure P2P architecture

- *No* always-on server
- Arbitrary end-systems directly communicate
- Peers are intermittently connected and change IP addresses

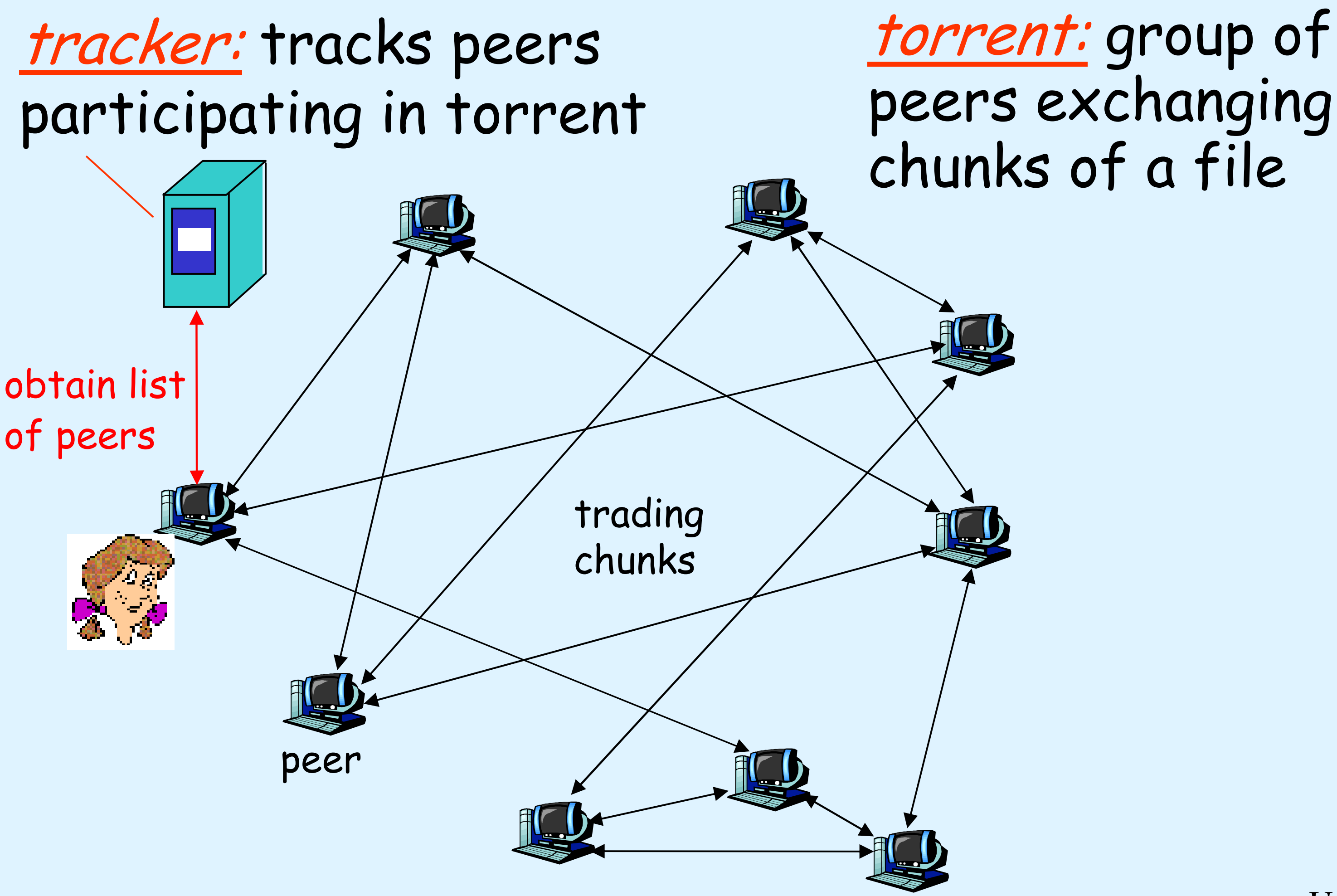


Server-client vs. P2P: example

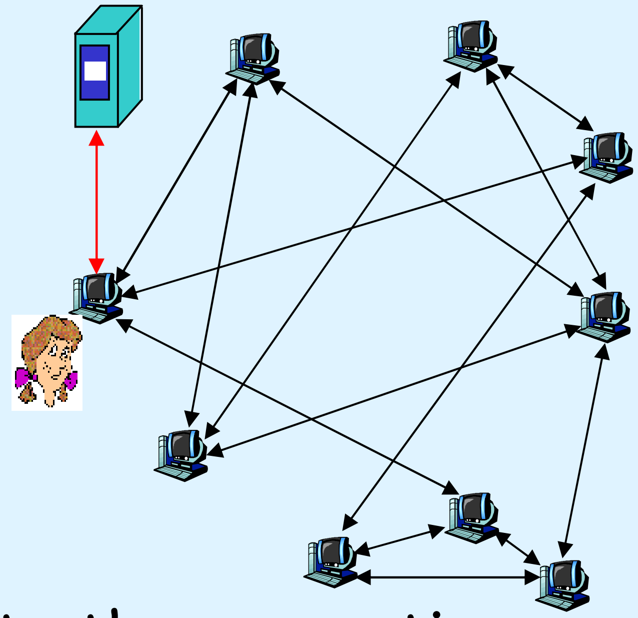


File distribution: BitTorrent

- P2P file distribution



BitTorrent (1)



- Peer joining torrent:
- File divided into 256 KB *chunks*.
  - –has no chunks, but will accumulate them over time
  - –registers with tracker to get list of peers, connects to subset of peers (“neighbors”)
- While downloading, peer uploads chunks to other peers.
- Peers may come and go
- Once peer has entire file, it may (selfishly) leave or (altruistically) remain

BitTorrent (2)

Pulling Chunks

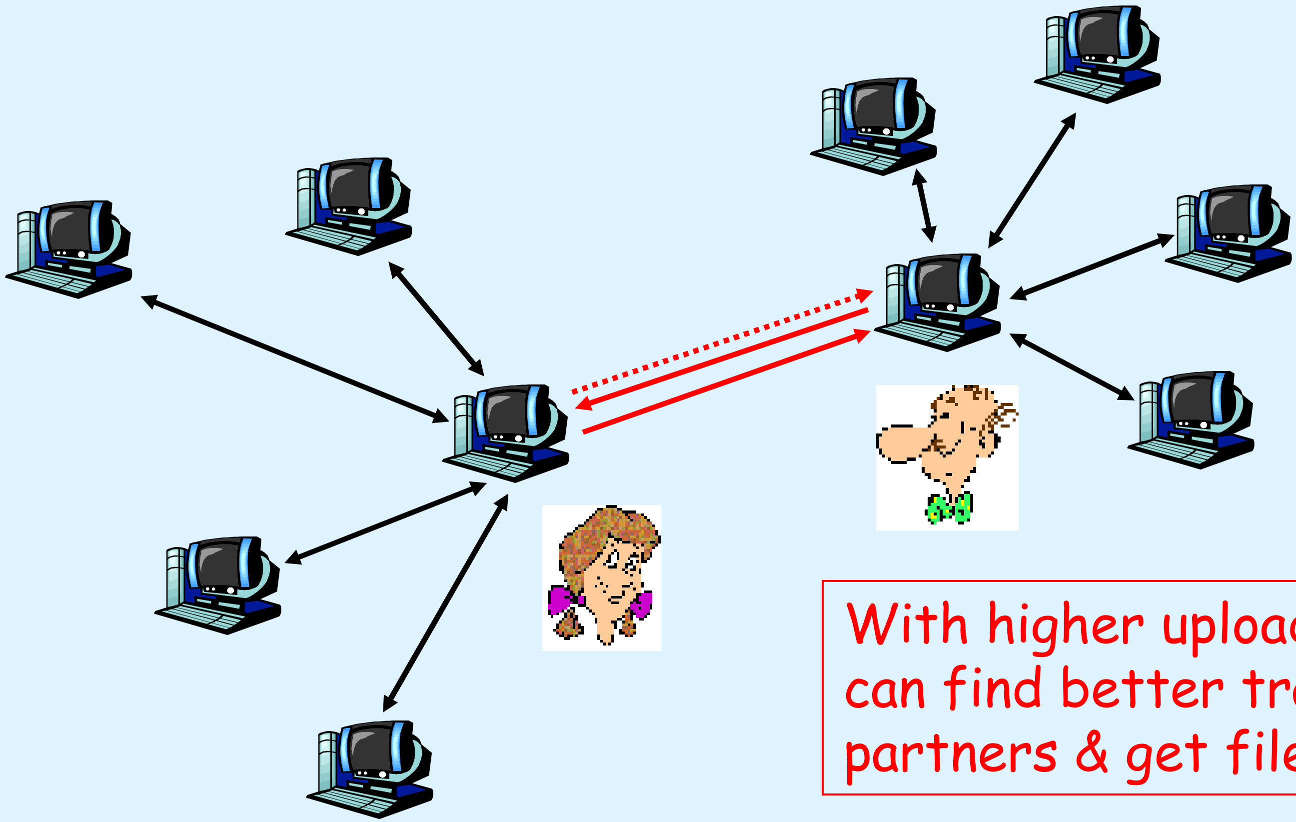
- At any given time, different peers have different subsets of file chunks
- Periodically, a peer (Alice) asks each neighbor for list of chunks that they have.
- Alice sends requests for her missing chunks
  - –rarest first

Sending Chunks: tit-for-tat

- Alice sends chunks to four neighbors currently sending her chunks *at the highest rate*
  - re-evaluate top 4 every 10 secs
- every 30 secs: randomly select another peer, starts sending chunks
  - newly chosen peer may join top 4
  - "optimistically unchoke"

BitTorrent: Tit-for-tat

(1) Alice “optimistically unchokes” Bob
(2) Alice becomes one of Bob’s top-four providers; Bob reciprocates
(3) Bob becomes one of Alice’s top-four providers



With higher upload rate, can find better trading partners & get file faster!

Distributed Hash Table (DHT)

- DHT = distributed P2P database
- Database has (key, value) pairs;
  key: ss number; value: human name
  key: content type; value: IP address
- Peers query DB with key
  DB returns values that match the key
- Peers can also insert (key, value) peers

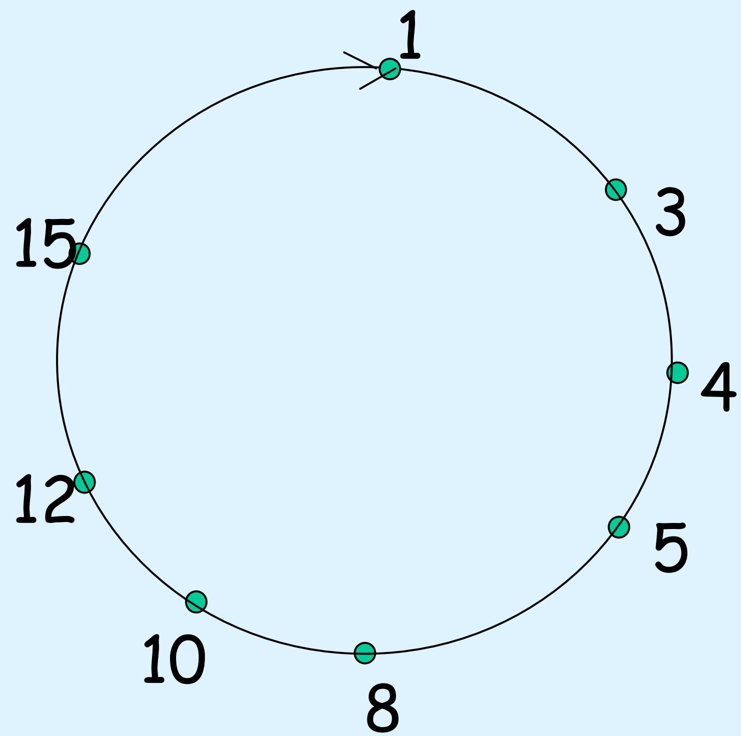
DHT Identifiers

- Assign integer identifier to each peer in range $[0, 2^n-1]$.
- Each identifier can be represented by n bits.
- Require each key to be an integer in same range.
- To get integer keys, hash original key, eg, key = H("Led Zeppelin IV")
- This is why they call it a distributed "hash" table.

How to assign keys to peers?

- Central issue:
  - Assigning (key, value) pairs to peers.
- Rule: assign key to the peer that has the closest ID.
- Convention in lecture: closest is the immediate successor of the key.
- Ex: $n = 4$; peers: 1,3,4,5,8,10,12,15;
  key = 13, then successor peer = 15
  key = 15, then successor peer = 1

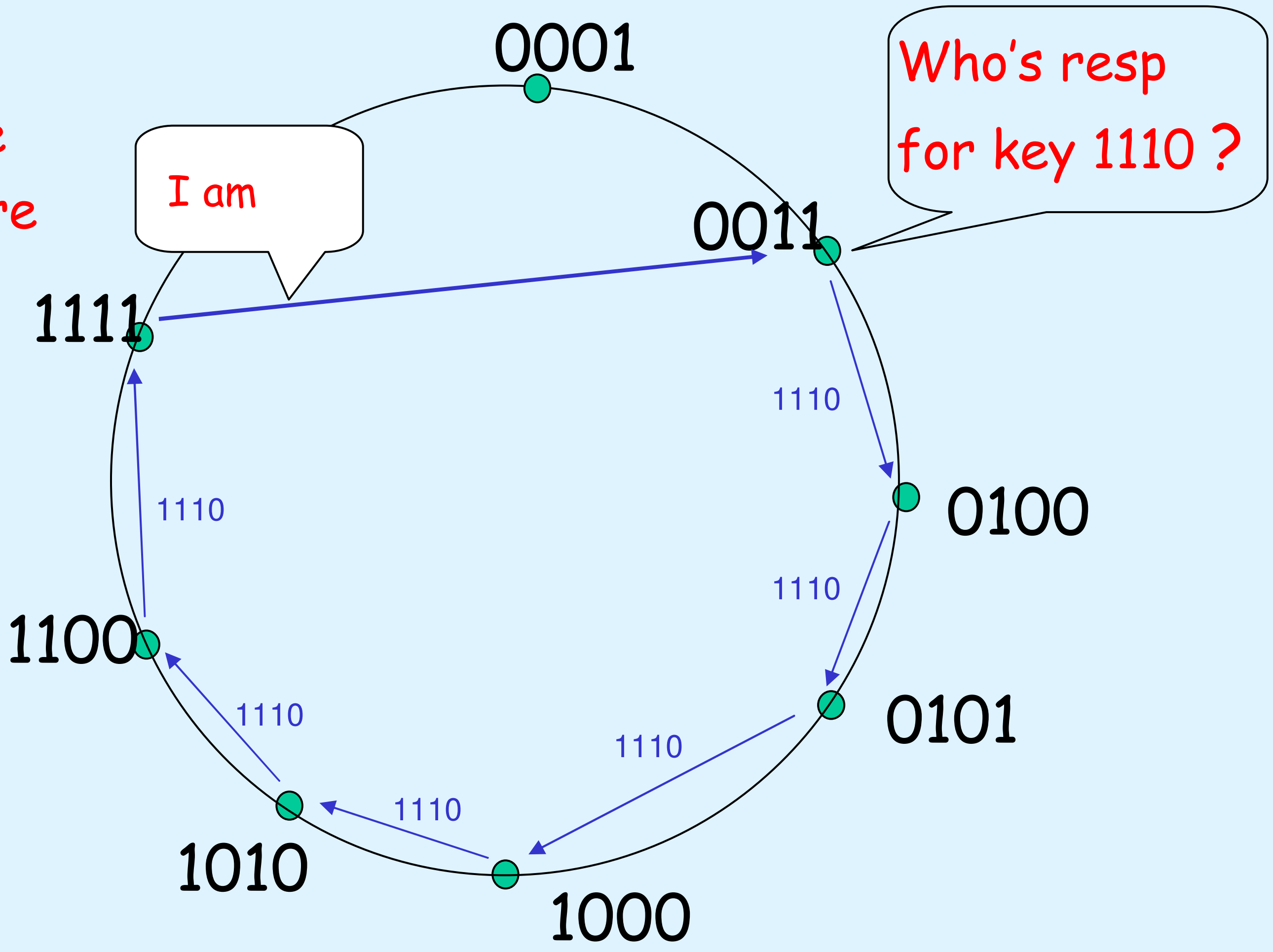
Circular DHT (1)



- Each peer *only* aware of immediate successor and predecessor.
- "Overlay network"

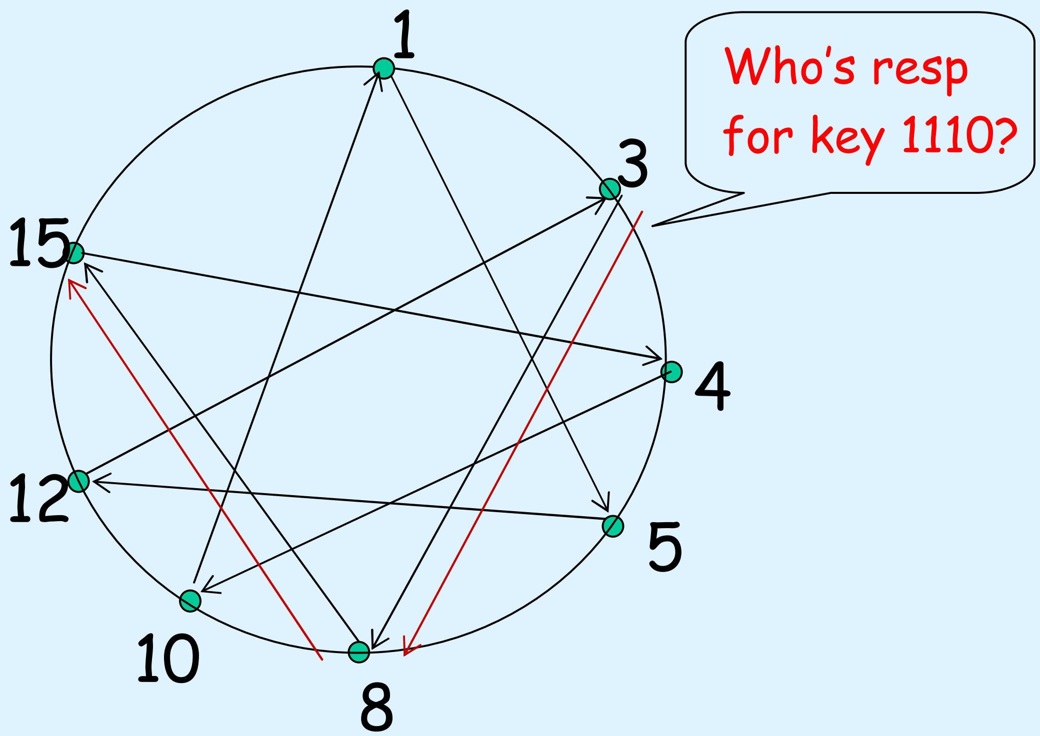
Circle DHT (2)

$O(N)$ messages on avg to resolve query, when there are N peers



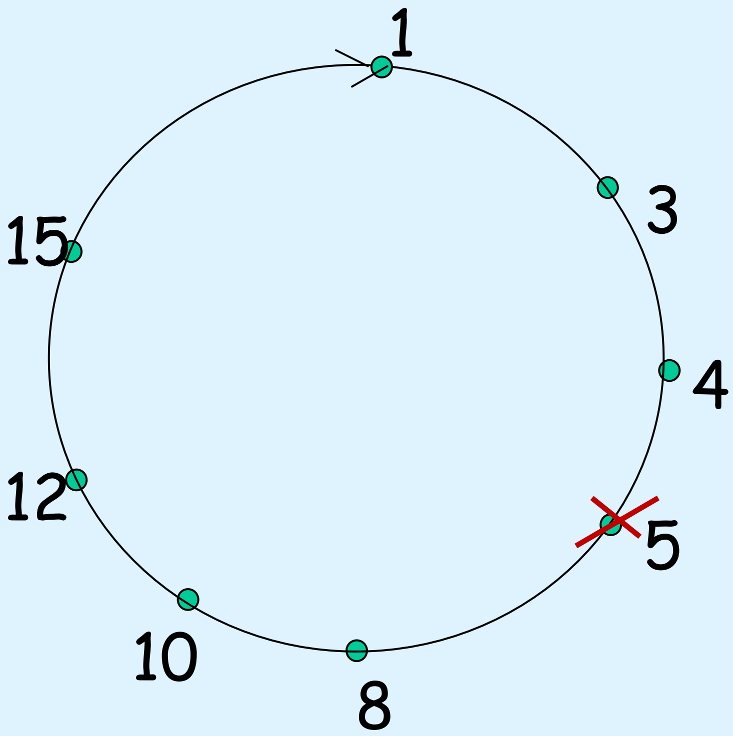
Define closest as closest successor

Circular DHT with Shortcuts



- Each peer keeps track of IP addresses of predecessor, successor, short cuts.
- Reduced from 6 to 2 messages.
- Possible to design shortcuts so $O(\log N)$ neighbors, $O(\log N)$ messages in query

Peer Churn

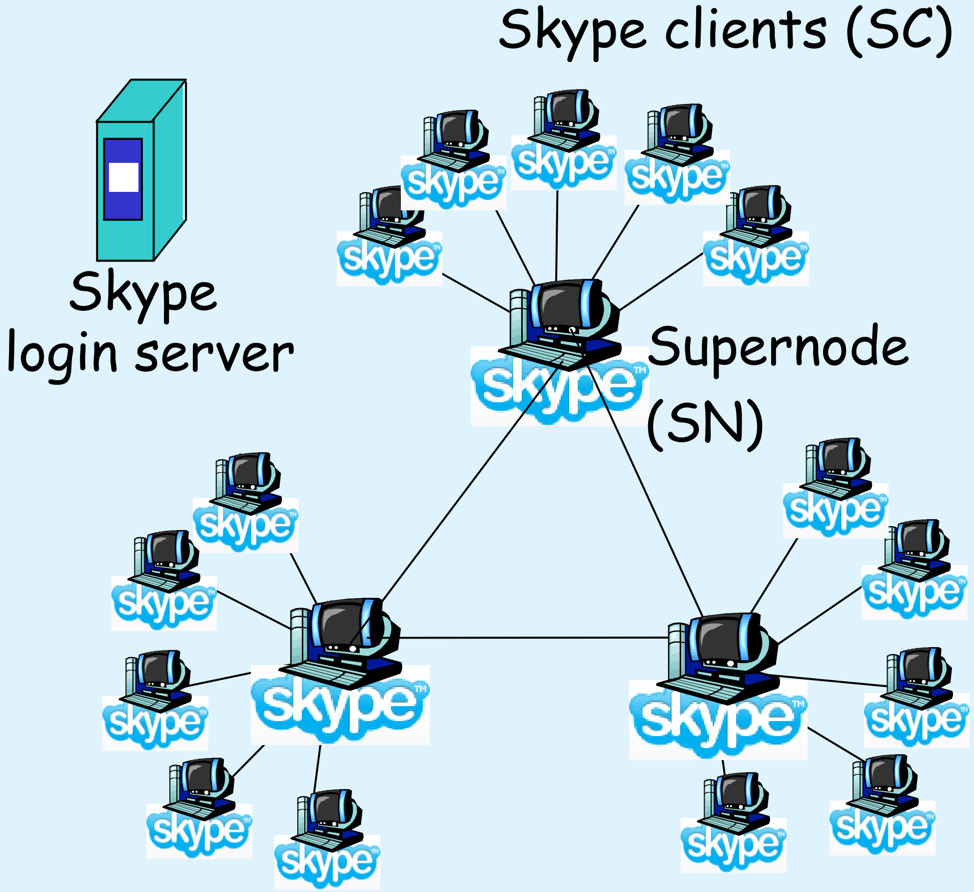


- To handle peer churn, require each peer to know the IP address of its two successors.
- Each peer periodically pings its two successors to see if they are still alive.

1. Peer 5 abruptly leaves
2. Peer 4 detects; makes 8 its immediate successor; asks 8 who its immediate successor is; makes 8's immediate successor its second successor.
3. What if peer 13 wants to join?

P2P Case study: Skype

- Inherently P2P: pairs of users communicate.
- Proprietary application-layer protocol (inferred via reverse engineering)
- Hierarchical overlay with SNs
- Index maps usernames to IP addresses; distributed over SNs

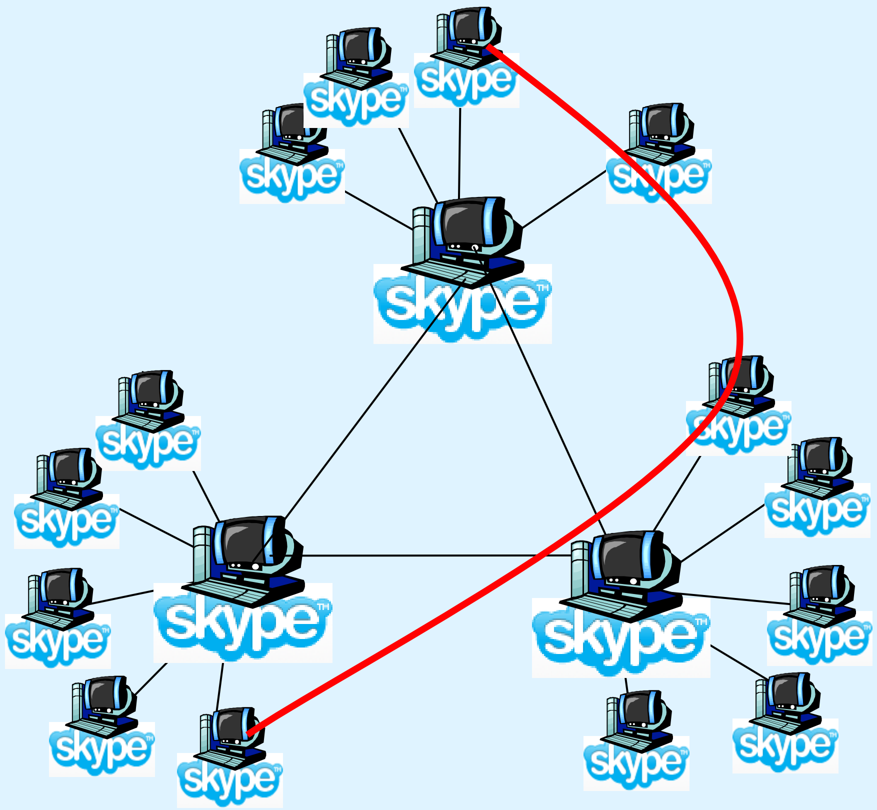


Peers as relays

- Problem when both Alice and Bob are behind "NATs".
- NAT prevents an outside peer from initiating a call to insider peer

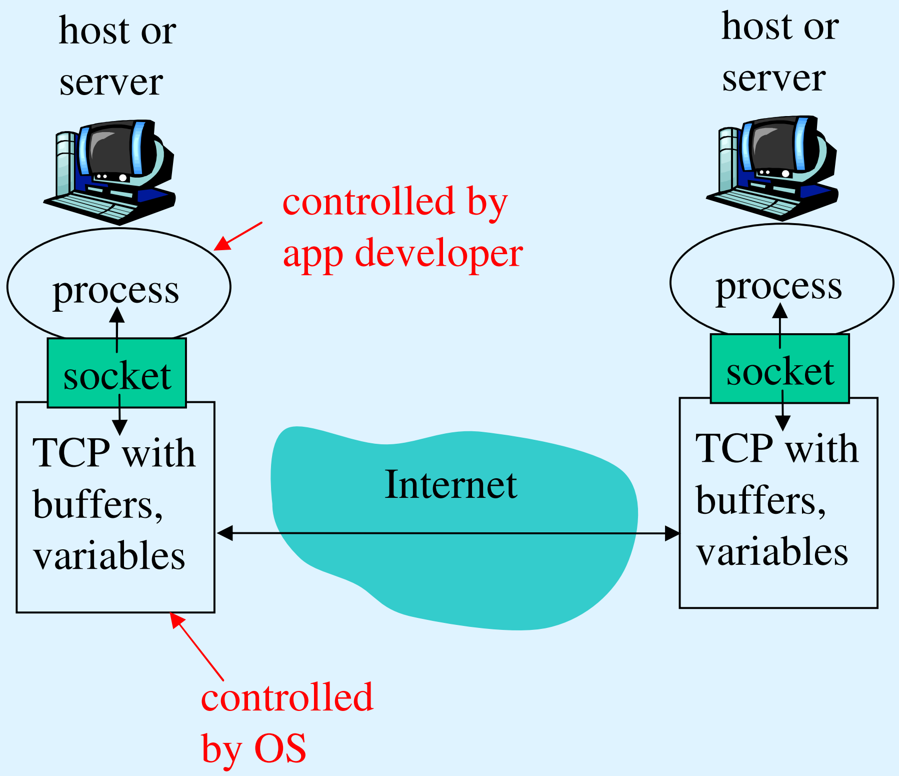
Solution:

1. Using Alice's and Bob's SNs, Relay is chosen
2. Each peer initiates session with relay.
3. Peers can now communicate through NATs via relay



Sockets

- process sends/receives messages to/from its socket
- socket analogous to door
  - sending process shoves message out door
  - sending process relies on transport infrastructure on other side of door which brings message to socket at receiving process



- API: (1) choice of transport protocol: TCP or UDP
  (2) ability to fix a few parameters, e.g. address