

COMP 6461

Computer Networks & Protocols

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Lecture 4a

Application Layer (Part 3)

Application layer: overview

- Principles of network applications
- video streaming and content distribution networks
- Web and HTTP
- **E-mail, SMTP, IMAP**
- The Domain Name System DNS
- P2P applications
- socket programming with UDP and TCP

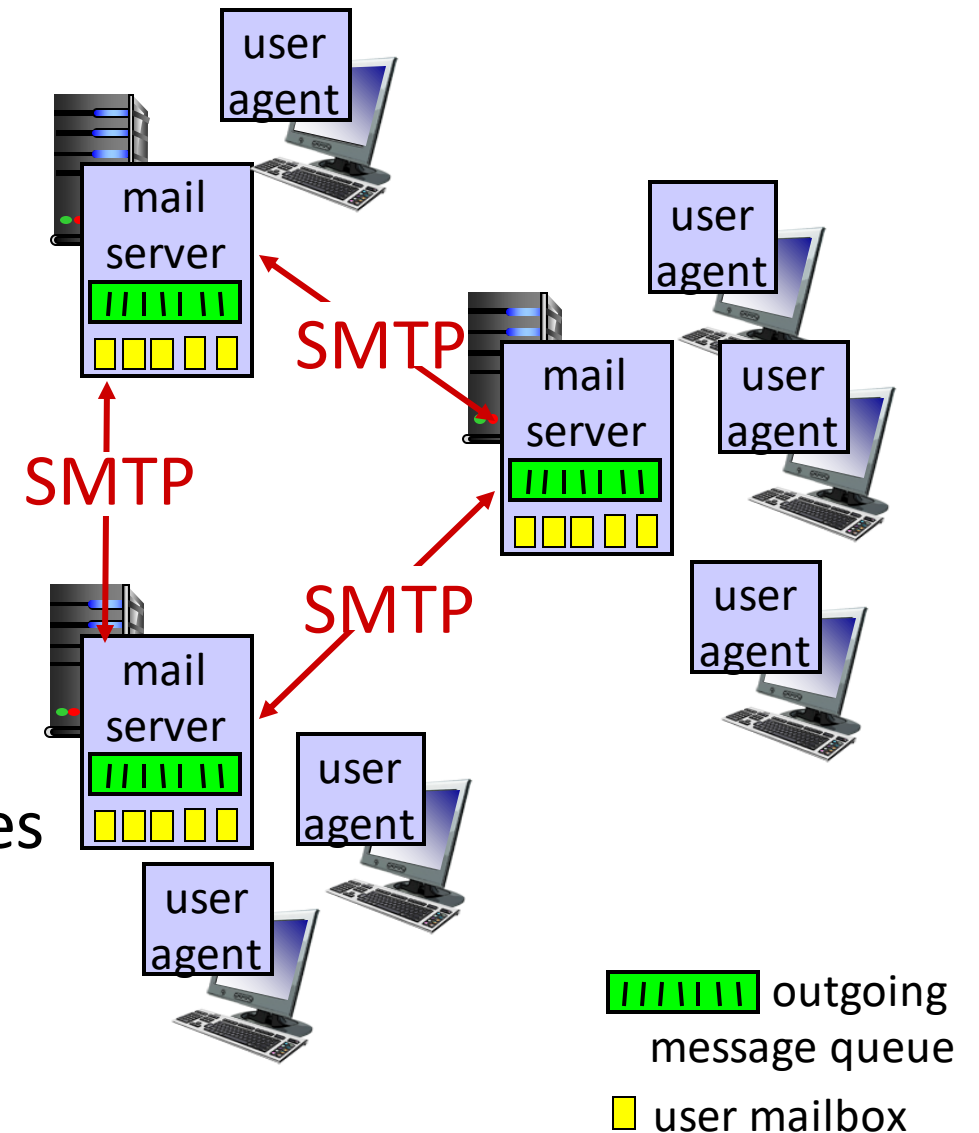
E-mail

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., Outlook, iPhone mail client
- outgoing, incoming messages stored on server



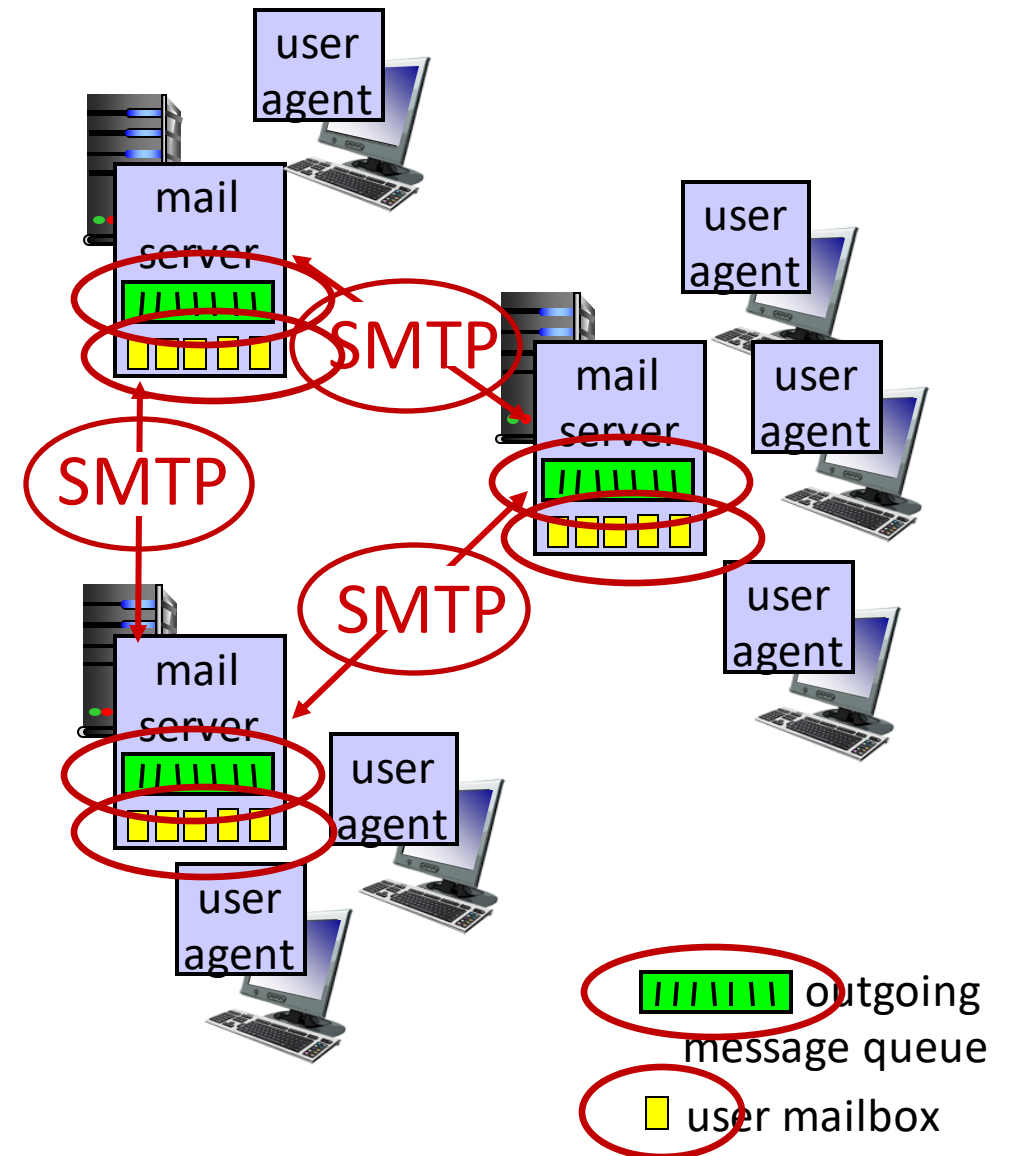
E-mail: mail servers

mail servers:

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

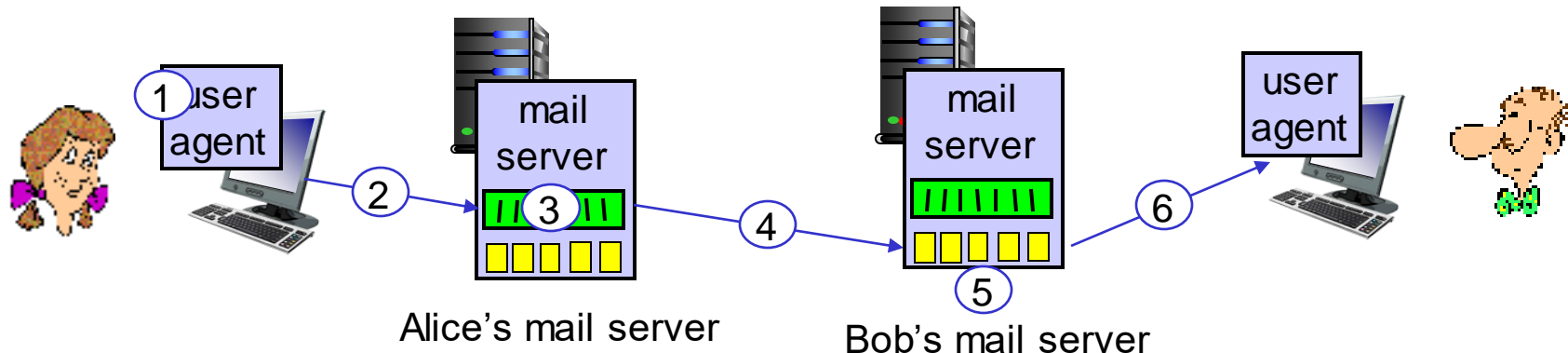
SMTP protocol between mail servers to send email messages

- **client**: sending mail server
- **“server”**: receiving mail server



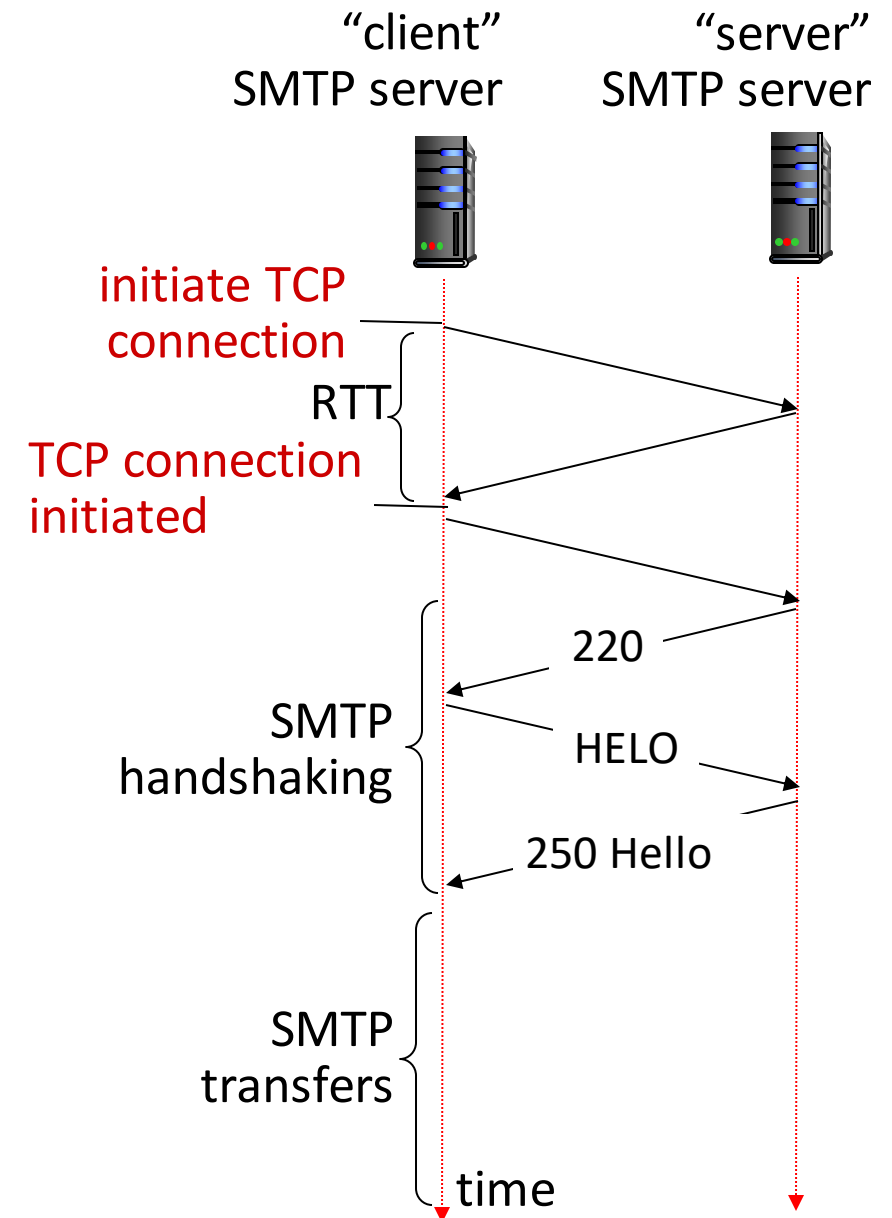
Scenario: Alice sends e-mail to Bob

- 1) Alice uses UA to compose e-mail message "to" bob@some school.edu
- 2) Alice's UA sends message to her mail server using SMTP; message placed in message queue
- 3) client side of SMTP at mail server opens TCP connection with Bob's mail server
- 4) SMTP client sends Alice's message over the TCP connection to Bob's mail server
- 5) Bob's mail server places the message in Bob's mailbox
- 6) Bob's invokes his user agent to read Alice's message



SMTP RFC (5321)

- uses TCP to reliably transfer email message from client (mail server initiating connection) to server, port 25
 - direct transfer: sending server (acting like client) to receiving server
- three phases of transfer
 - SMTP handshaking (greeting)
 - SMTP transfer of messages
 - SMTP closure
- command/response interaction (like HTTP)
 - **commands**: ASCII text
 - **response**: status code and phrase



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
```


SMTP: observations

comparison with HTTP:

- HTTP: client pull
- SMTP: client push
- both have ASCII command/response interaction, status codes
- HTTP: each object encapsulated in its own response message
- SMTP: multiple objects sent in multipart message
- SMTP uses persistent connections
- SMTP requires message (header & body) to be in 7-bit ASCII
- SMTP server uses CRLF.CRLF to determine end of message

Mail message format

SMTP: protocol for exchanging e-mail messages, defined in RFC 5321 (like RFC 7231 defines HTTP)

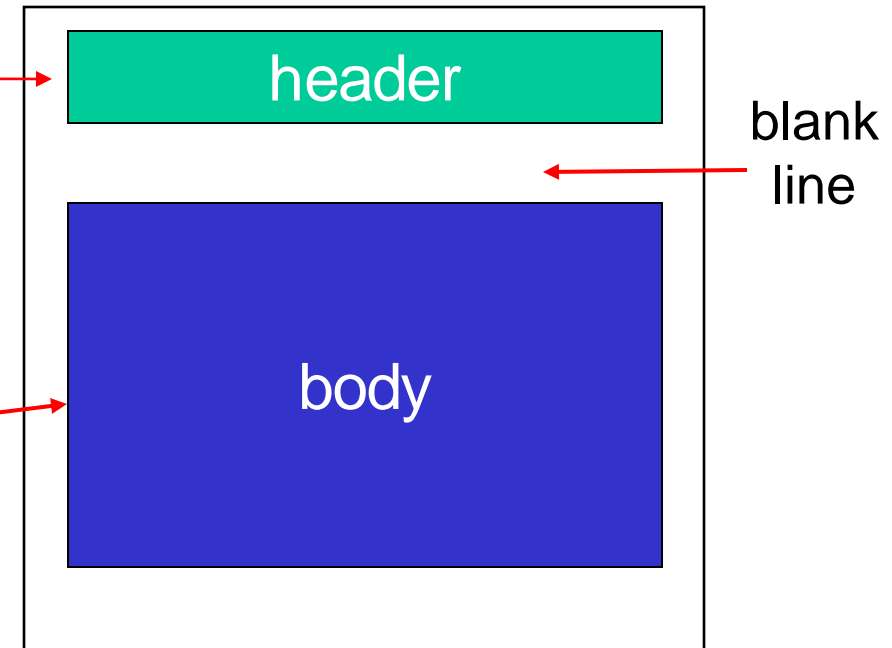
RFC 2822 defines *syntax* for e-mail message itself (like HTML defines syntax for web documents)

- header lines, e.g.,

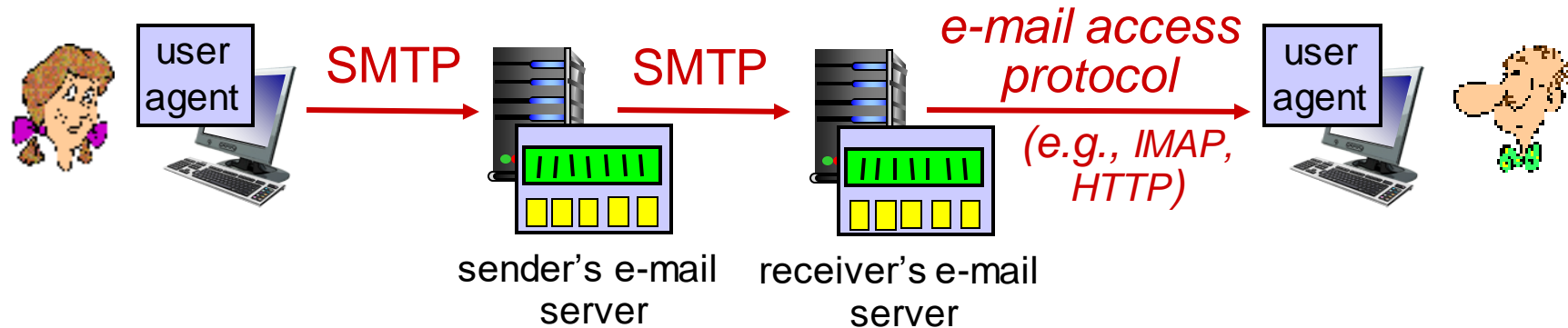
- To:
- From:
- Subject:

these lines, within the body of the email message area different from SMTP MAIL FROM:, RCPT TO: commands!

- Body: the “message” , ASCII characters only



Retrieving email: mail access protocols



- **SMTP:** delivery/storage of e-mail messages to receiver's server
- mail access protocol: retrieval from server
 - **IMAP:** Internet Mail Access Protocol [RFC 3501]: messages stored on server, IMAP provides retrieval, deletion, folders of stored messages on server
- **HTTP:** gmail, Hotmail, Yahoo!Mail, etc. provides web-based interface on top of SMTP (to send), IMAP (or POP) to retrieve e-mail messages

Application Layer: Overview

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- The Domain Name System
DNS
- P2P applications
- socket programming with UDP and TCP

DNS: Domain Name System

people: many identifiers:

- SSN, name, passport #

Internet hosts, routers:

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

Q: how to map between IP address and name, and vice versa ?

Domain Name System (DNS):

- *distributed database* implemented in hierarchy of many *name servers*
- *application-layer protocol*: hosts, DNS servers communicate to *resolve* names (address/name translation)
 - *note*: core Internet function, implemented as application-layer protocol
 - complexity at network’s “edge”

DNS: services, structure

DNS services:

- hostname-to-IP-address translation
- host aliasing
- mail server aliasing
- load distribution
- replicated web servers: many IP addresses correspond to one name

Q: Why not centralize DNS?

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

A: doesn't scale!

- Comcast DNS servers alone: 600B DNS queries/day
- Akamai DNS servers alone: 2.2T DNS queries/day

Thinking about the DNS

humongous distributed database:

- ~ billion records, each simple

handle many *trillions* of queries/day:

- many more reads than writes.
- *performance matters*: almost every Internet communication interaction with DNS - msec count!

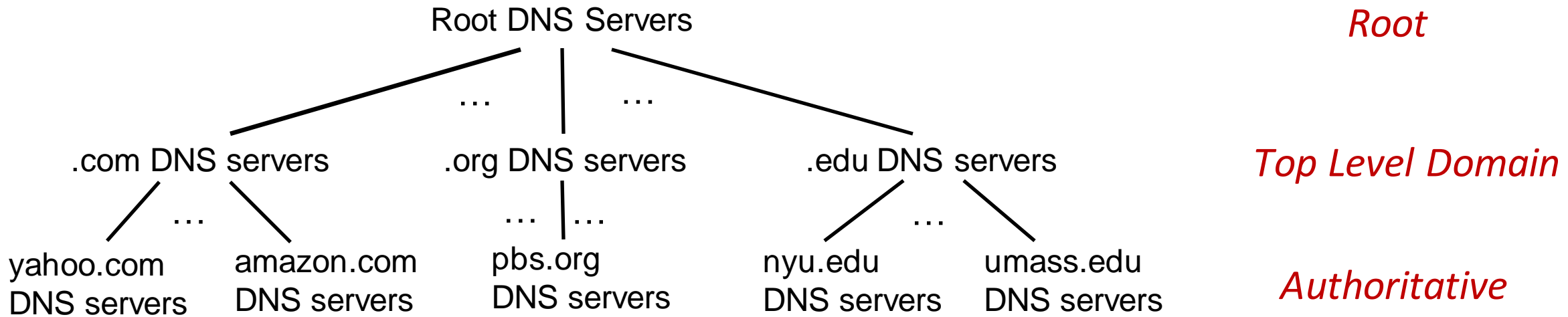
organizationally , physically decentralized:

- millions of different organizations responsible for their records

“bulletproof”: reliability, security



DNS: a distributed, hierarchical database

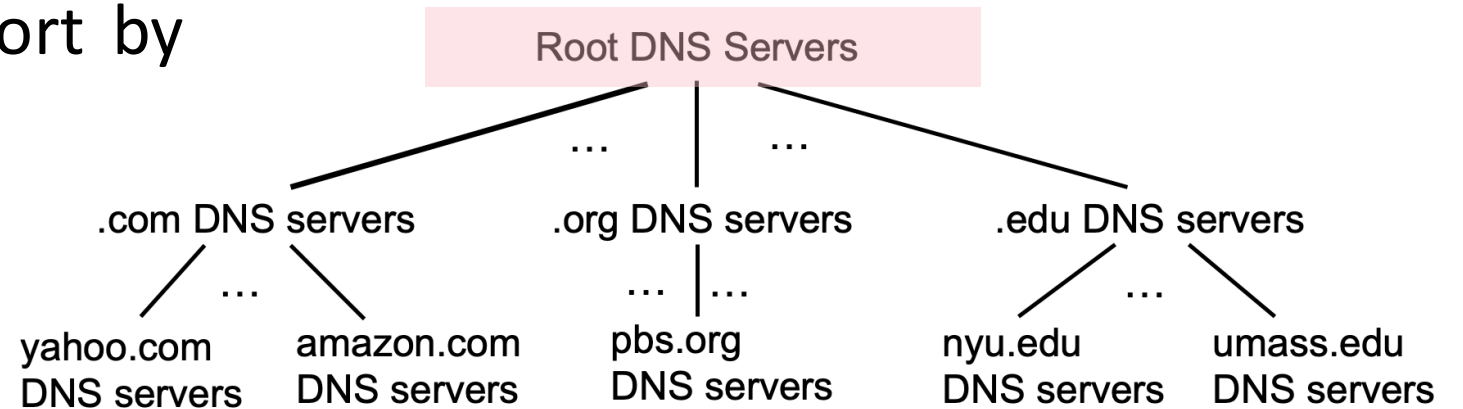


Client wants IP address for `www.amazon.com`; 1st approximation:

- client queries root server to find .com DNS server
- client queries .com DNS server to get amazon.com DNS server
- client queries amazon.com DNS server to get IP address for `www.amazon.com`

DNS: root name servers

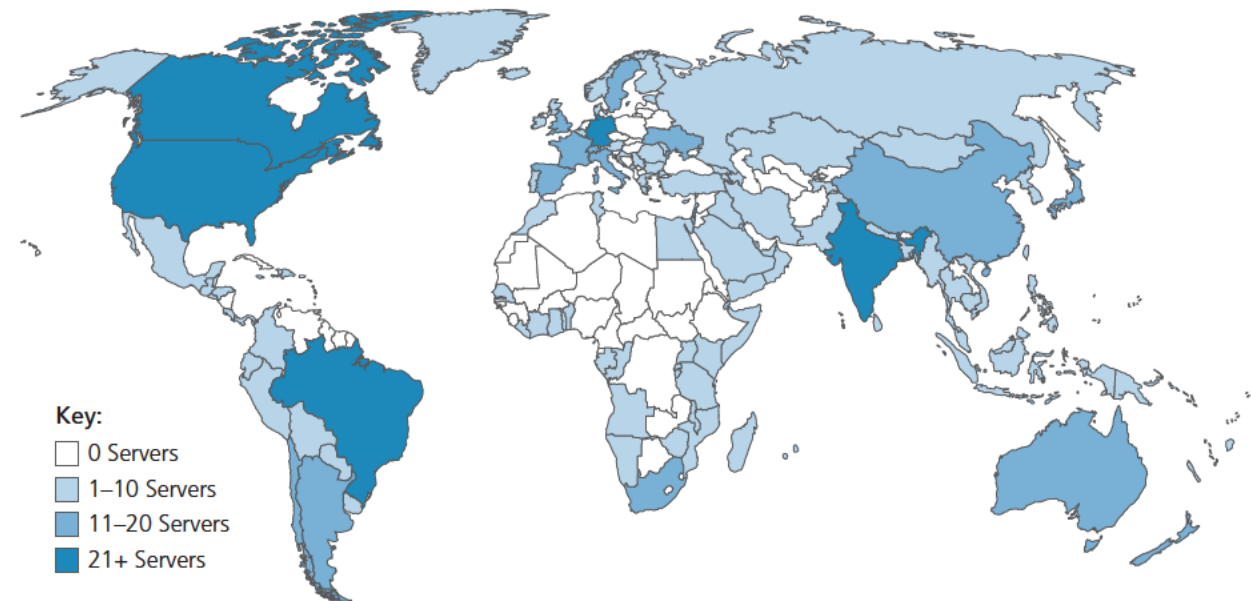
- official, contact-of-last-resort by name servers that can not resolve name



DNS: root name servers

- official, contact-of-last-resort by name servers that can not resolve name
- *incredibly important* Internet function
 - Internet couldn't function without it!
 - DNSSEC – provides security (authentication, message integrity)
- ICANN (Internet Corporation for Assigned Names and Numbers) manages root DNS domain

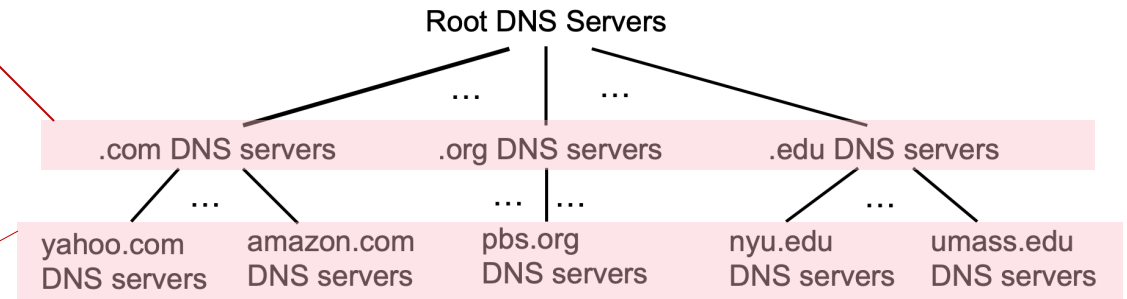
13 logical root name “servers”
worldwide each “server” replicated
many times (~200 servers in US)



Top-Level Domain, and authoritative servers

Top-Level Domain (TLD) servers:

- responsible for .com, .org, .net, .edu, .aero, .jobs, .museums, and all top-level country domains, e.g.: .cn, .uk, .fr, .ca, .jp
- Network Solutions: authoritative registry for .com, .net TLD
- Educause: .edu TLD



authoritative DNS servers:

- organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
- can be maintained by organization or service provider

Local DNS name servers

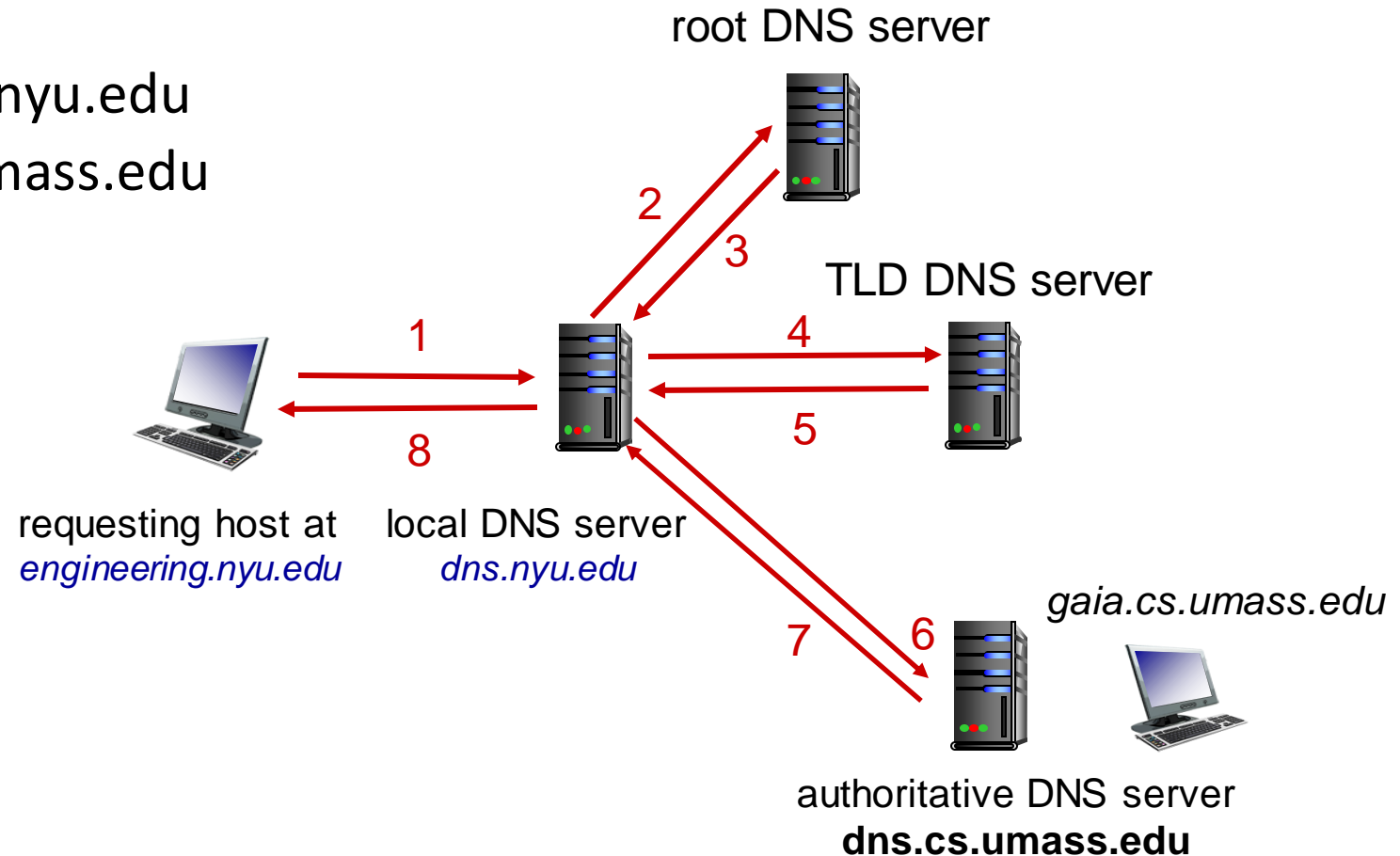
- when host makes DNS query, its sent to its *local DNS server*
 - Local DNS server returns reply, answering:
 - form its local cache of recent name-to-address translation pair (possible out of data)
 - forwarding request into DNS hierarchy for resolution
- each ISP has local DNS name server; to find yours:
 - MacOS: `scutil --dns`
 - Windows: `>ipconfig /all`

DNS name resolution: iterated query

Example: host at `engineering.nyu.edu` wants IP address for `gaia.cs.umass.edu`

Iterated query:

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

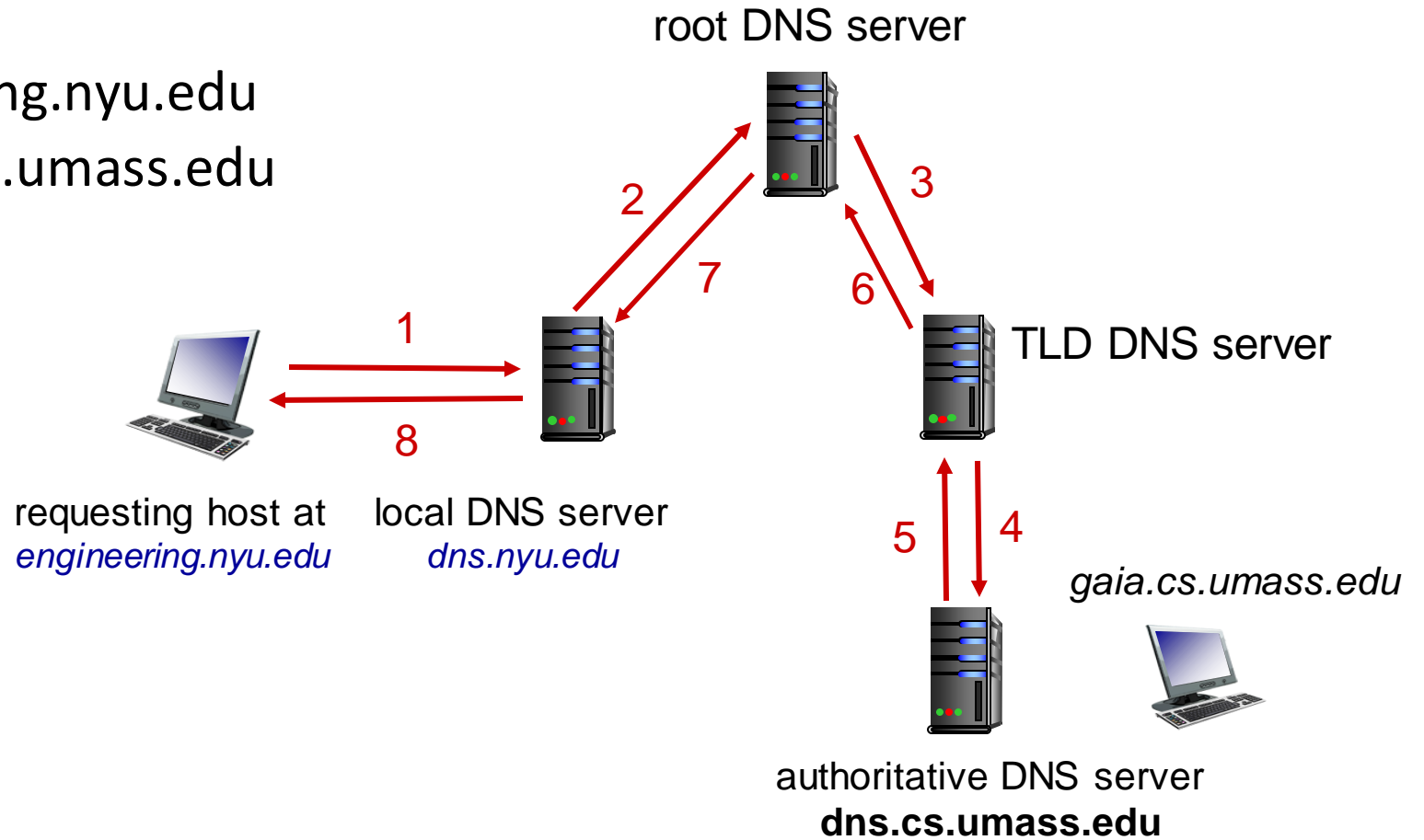


DNS name resolution: recursive query

Example: host at `engineering.nyu.edu` wants IP address for `gaia.cs.umass.edu`

Recursive query:

- puts burden of name resolution on contacted name server
- heavy load at upper levels of hierarchy?



Caching DNS Information

- once (any) name server learns mapping, it *cached* mapping, and *immediately* returns a cached mapping in response to a query
 - caching improves response time
 - cache entries timeout (disappear) after some time (TTL)
 - TLD servers typically cached in local name servers
- cached entries may be *out-of-date*
 - if named host changes IP address, may not be known Internet-wide until all TTLs expire!
 - *best-effort name-to-address translation!*

DNS records

DNS: distributed database 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 hostname 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

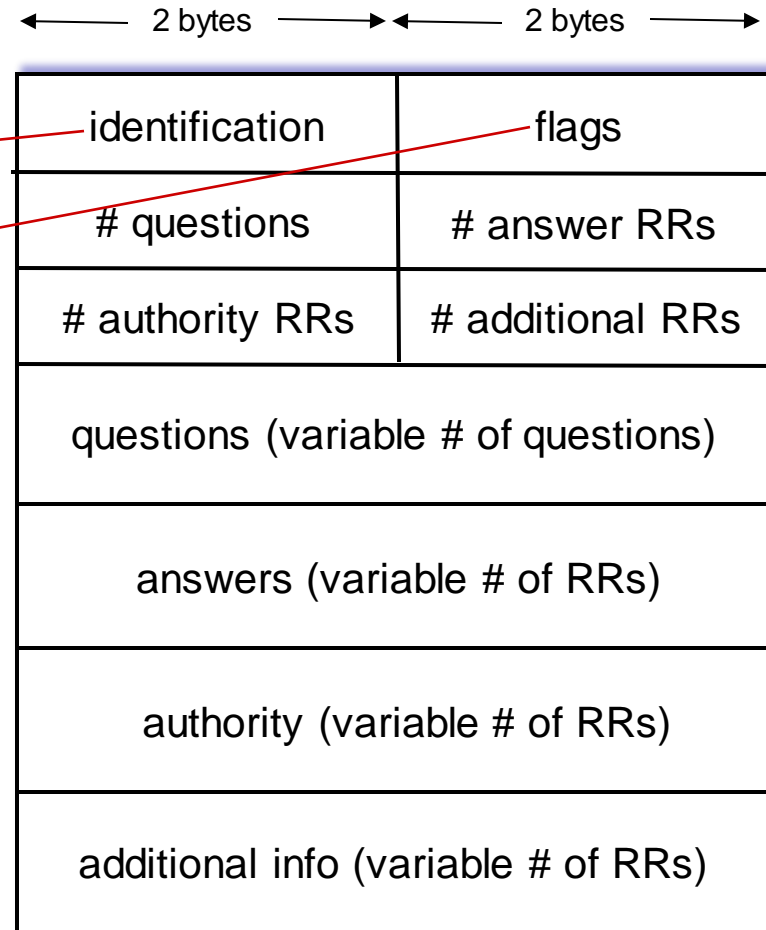
- **value** is name of mailserver associated with **name**

DNS protocol messages

DNS *query* and *reply* messages, both have same *format*:

message header:

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



DNS protocol messages

DNS *query* and *reply* messages, both have same *format*:

← 2 bytes → ← 2 bytes →

identification	flags
# questions	# answer RRs
# authority RRs	# additional RRs
questions (variable # of questions)	
answers (variable # of RRs)	
authority (variable # of RRs)	
additional info (variable # of RRs)	

name, type fields for a query

RRs in response to query

records for authoritative servers

additional “helpful” info that may
be used

Getting your info into the DNS

- example: new startup “Network Utopia”
- register name networkutopia.com at *DNS registrar* (e.g., Network Solutions)
 - provide names, IP addresses of authoritative name server (primary and secondary)
 - registrar inserts two RRs into .com TLD server:
(networkutopia.com, dns1.networkutopia.com, NS)
(dns1.networkutopia.com, 212.212.212.1, A)
- create authoritative server type A record for www.networkutopia.com;
type MX record for networkutopia.com

DNS security

DDoS attacks

- bombard root servers with traffic
 - not successful to date
 - traffic filtering
 - local DNS servers cache IPs of TLD servers, allowing root server bypass
- bombard TLD servers
 - potentially more dangerous

redirect attacks

- man-in-middle
 - Intercept queries
- DNS poisoning
 - Send bogus replies to DNS server, which caches

exploit DNS for DDoS

- send queries with spoofed source address: target IP
- requires amplification