Lecture 7: Application Layer
DNS, Email

COMP 332, Spring 2024

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Acknowledgements: materials adapted from Computer Networking: A Top Down Approach 7th edition: ©1996-2016, J.F Kurose and K.W. Ross, All Rights Reserved as well as from slides by Abraham Matta at Boston University and some material from Computer Networks by Tannenbaum and Wetherall.

Today

Announcements

- hwk 3 due Wednesday

Domain names

- overview

Domain Name System

- name resolution
- protocol
- dig and wireshark
- attacks

Electronic Mail

Domain Name System

OVERVIEW

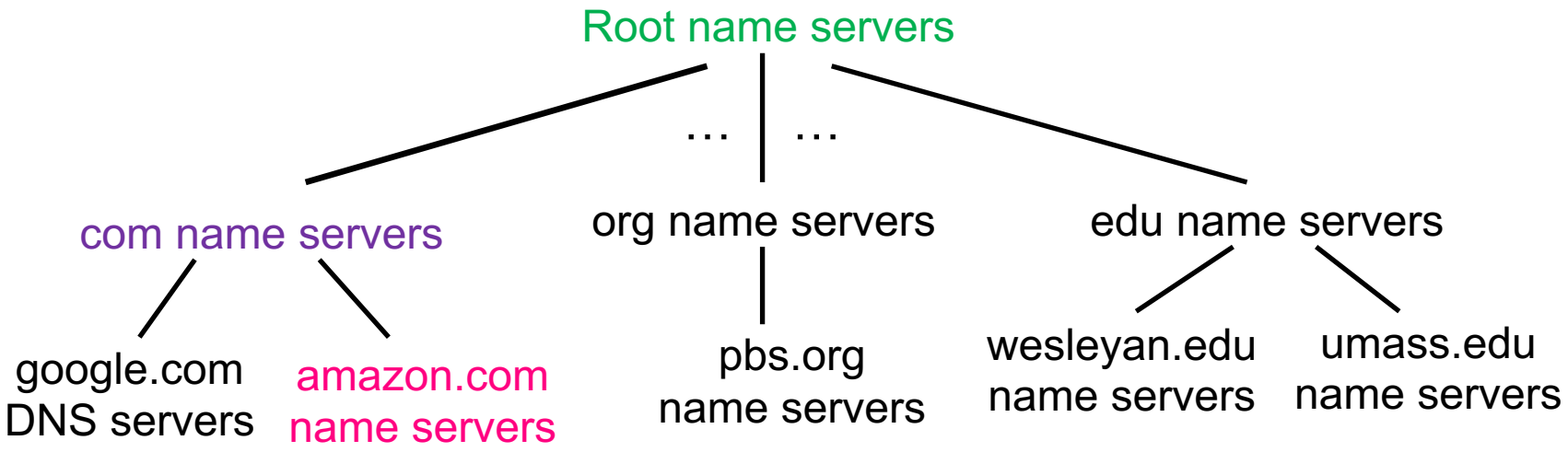
DNS comprises 2 components

1st component: application layer protocol

- translates between identifiers
  - hostnames ⇔ IP addresses
- used by other application layer protocols
  - HTTP, SMTP, …
- runs primarily over UDP (port 53)

Core Internet function implemented as application layer protocol, with complexity at network edge

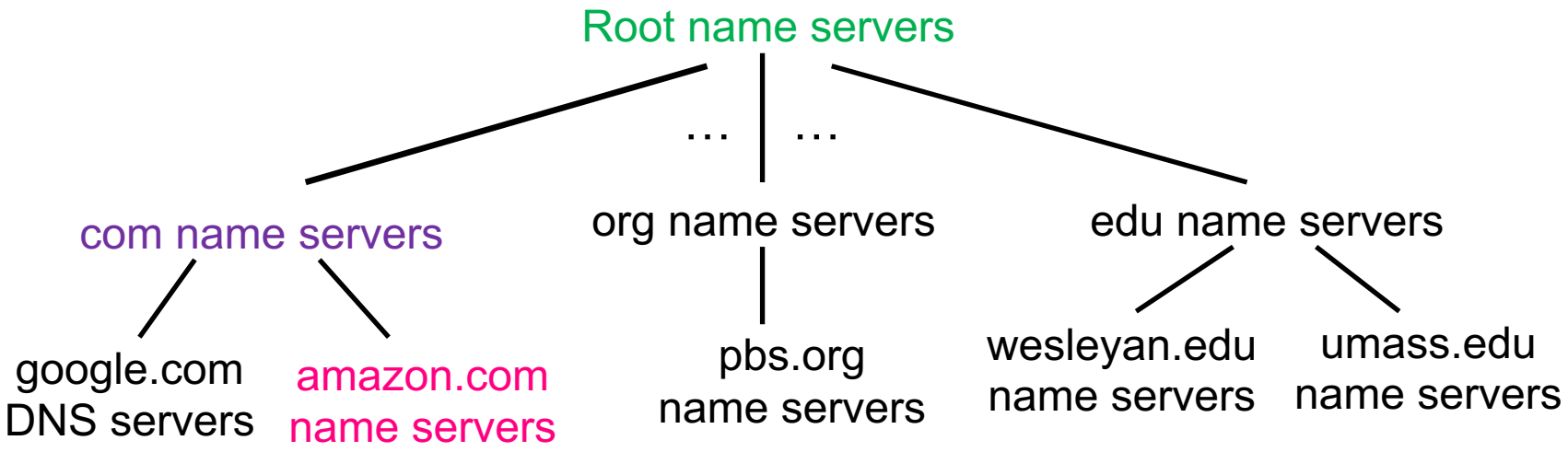
DNS comprises 2 components



2nd component: distributed hierarchical database

- organized to follow name hierarchy
  - fixes namespace issues and ownership
- distributed across many name servers
  - for scalability
- no name server has all mappings (resource records)
  - for scalability, updatability, freshness

DNS comprises 2 components



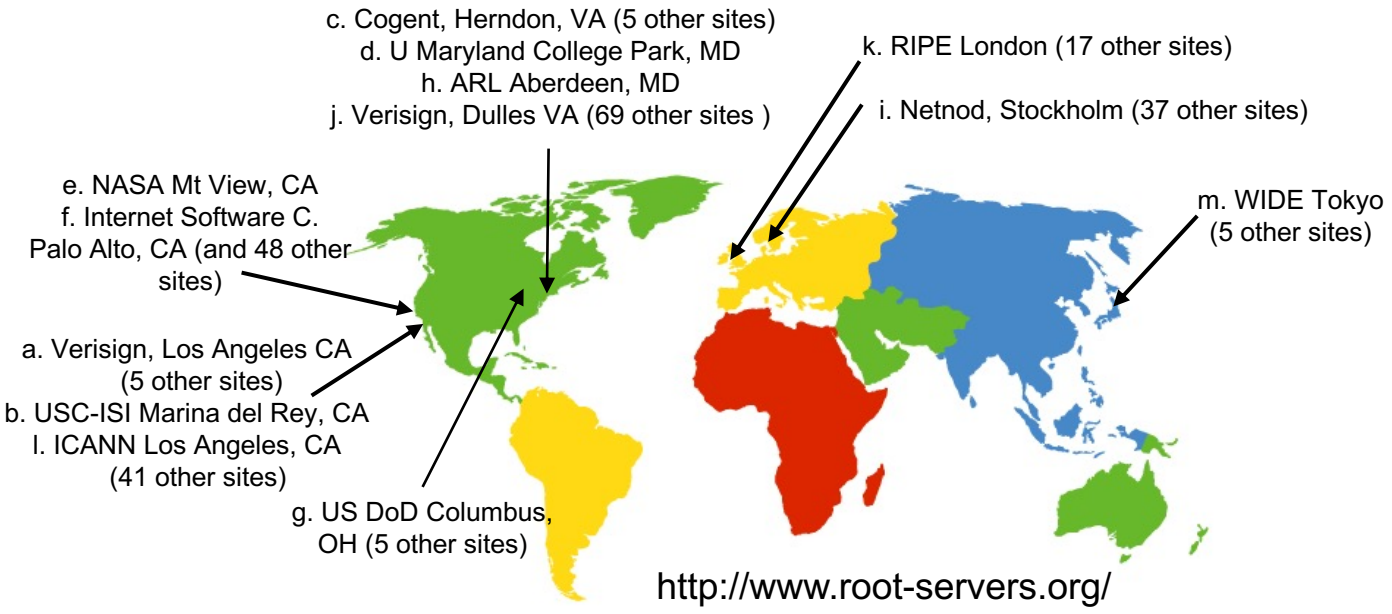
Client wants IP for www.amazon.com

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

Root name servers

13 logical name servers, [a-m].root-servers.net

- know all Top Level Domain (TLD) name servers and their IP addr
- each root server replicated many times (933 currently)
- contact authoritative name server if name mapping not known

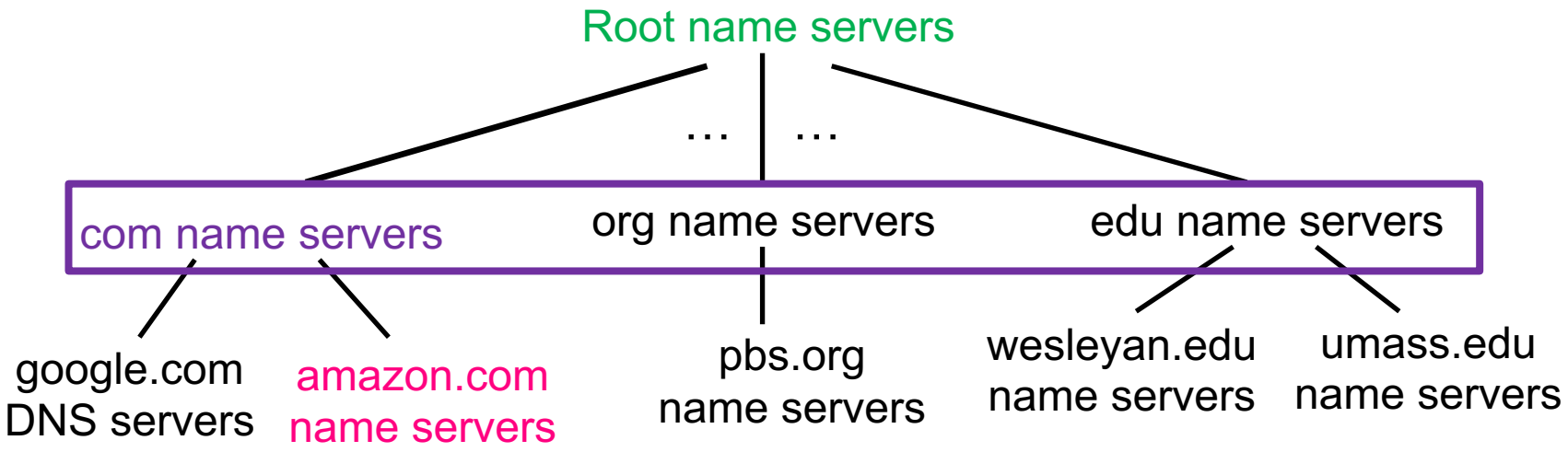


Robust distributed infrastructure

dig

```
> dig

; <<>> DiG 9.8.3-P1 <<>>
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 27061
;; flags: qr rd ra; QUERY: 1, ANSWER: 13, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;.                              IN      NS

;; ANSWER SECTION:
.                       35480   IN      NS      d.root-servers.net.
.                       35480   IN      NS      k.root-servers.net.
.                       35480   IN      NS      m.root-servers.net.
.                       35480   IN      NS      h.root-servers.net.
.                       35480   IN      NS      i.root-servers.net.
.                       35480   IN      NS      a.root-servers.net.
.                       35480   IN      NS      e.root-servers.net.
.                       35480   IN      NS      l.root-servers.net.
.                       35480   IN      NS      c.root-servers.net.
.                       35480   IN      NS      j.root-servers.net.
.                       35480   IN      NS      g.root-servers.net.
.                       35480   IN      NS      f.root-servers.net.
.                       35480   IN      NS      b.root-servers.net.

;; Query time: 28 msec
```

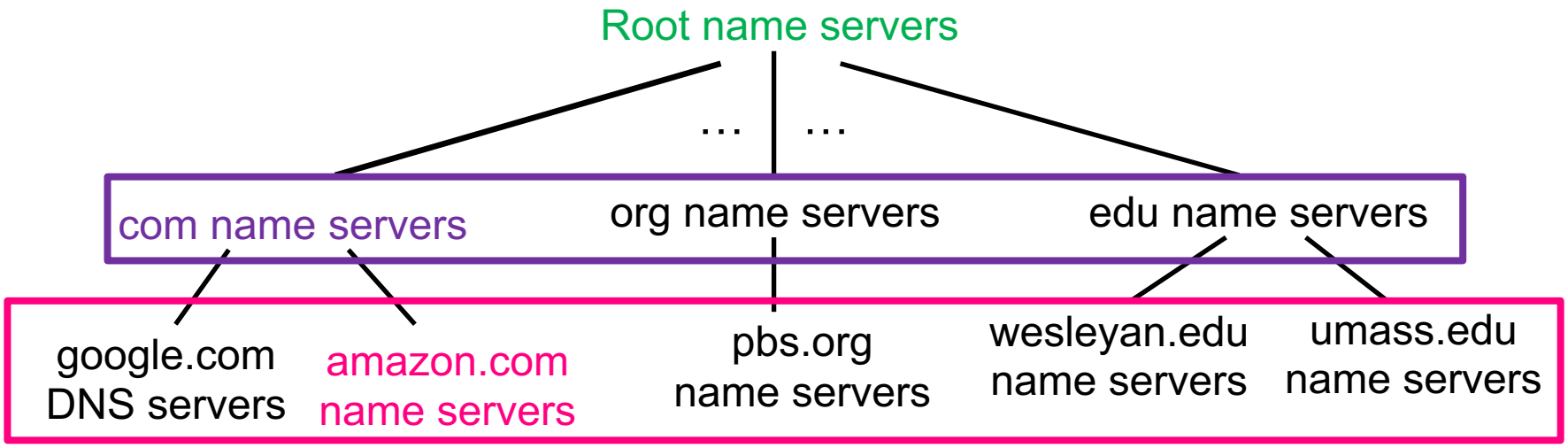
Top-level domain servers



Top-level domain (TLD) servers

- know authoritative name servers and their IP addresses for (sub)-domains in their zone
- responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g., uk, fr, ca, jp
- Verisign maintains servers for .com, .edu TLDs, among others

Authoritative servers



Authoritative servers

- know IP addresses for all hosts in organization's domain
- organization's own name server(s)
- provides authoritative hostname to IP mappings for org's named hosts
- maintained by organization or service provider

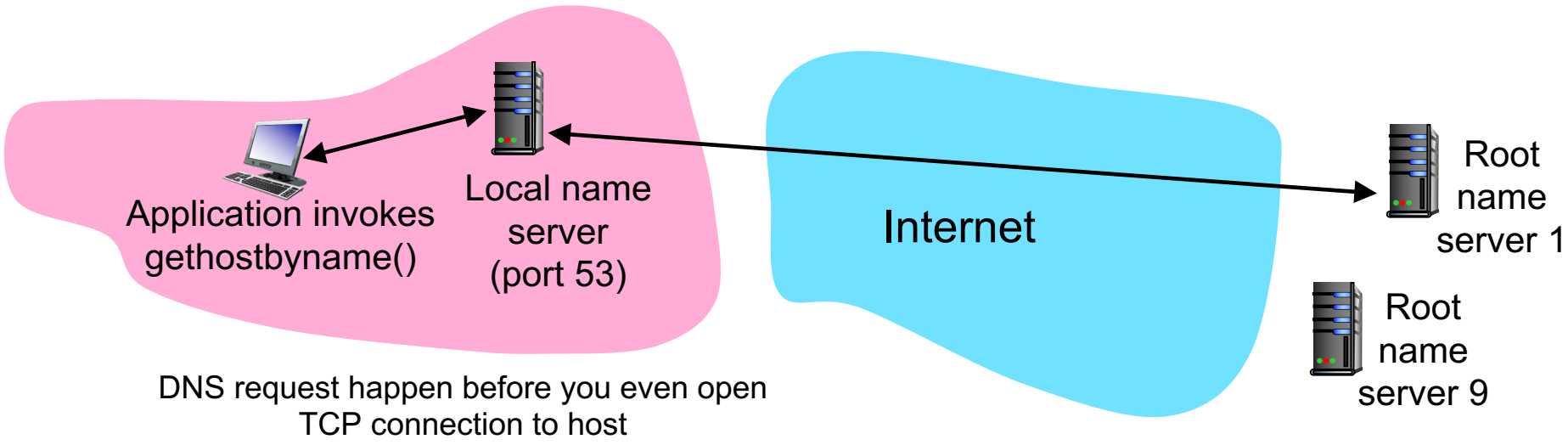
Local name server

When host makes DNS query, sent 1st to its local name server

- has local cache of recent name-to-address translation pairs
  - but may be out of date!
- acts as proxy, forwards query into hierarchy if it cannot resolve

Each ISP (residential, company, university, …) has one

- hosts get IP address of local name server from DHCP or manual config



DNS request happen before you even open TCP connection to host

Domain Name System

NAME RESOLUTION

Resolving non-local names

No single name server has complete information

If local name server can't resolve address

- contacts root name server

13 root name servers world-wide

- each has addresses of name servers for all TLD name servers
  - e.g., wesleyan.edu, ibm.com

What happens?

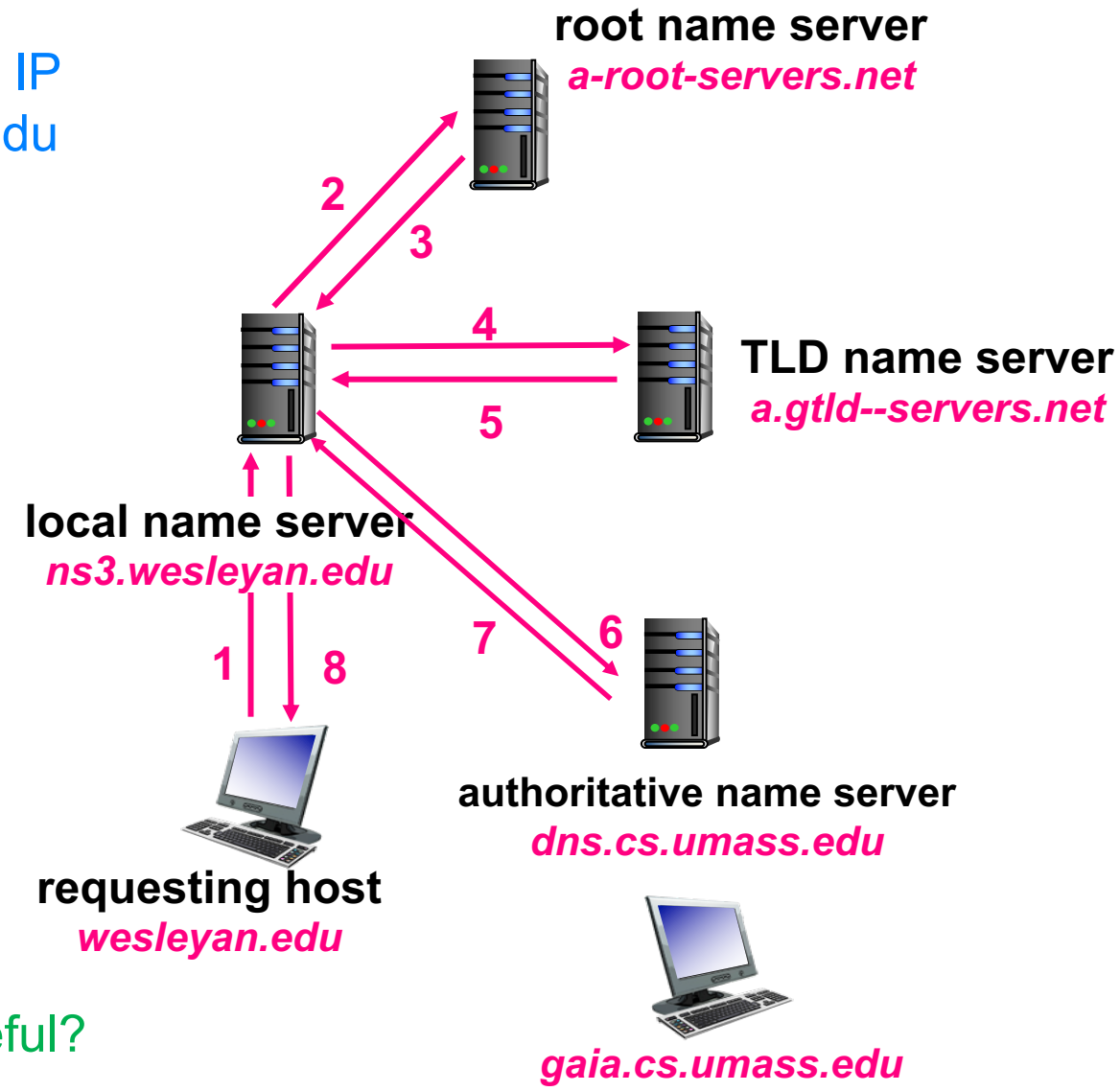
- contact root server
  - returns IP address of name server which should be contacted next
- contact TLD name server
  - may itself return a pointer to another name server
- iterative process of following name server pointers

Iterative name resolution

Host at wesleyan.edu wants IP address for gaia.cs.umass.edu

Iterated query

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



Q: why is iterated query useful?

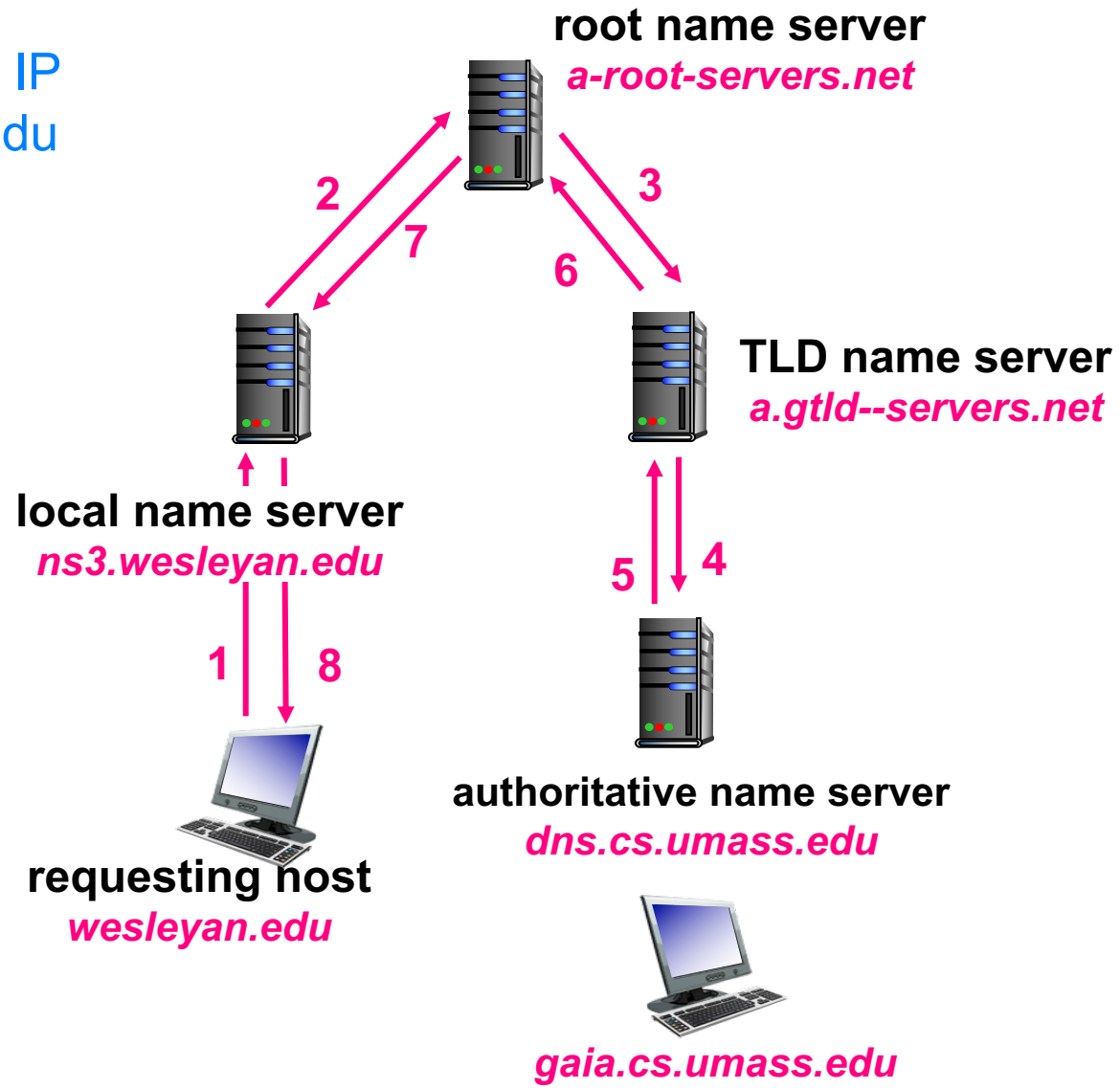
Reduces load on other servers

Recursive name resolution

Host at wesleyan.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
- "Let me ask about that name for you"



Q: why is this useful?

Reduces load on requesting server

Domain Name System

PROTOCOL

DNS resource records (RR)

DNS is distributed database

- returns RRs in response to queries

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

What you pass to index in on

What is returned

type=A/AAAA

- name is hostname
- value is IPv4 address (IPv6 for AAAA)

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
- value is canonical name
- www.ibm.com is really servereast.backup2.ibm.com or ibm.com is really www.ibm.com

type=MX

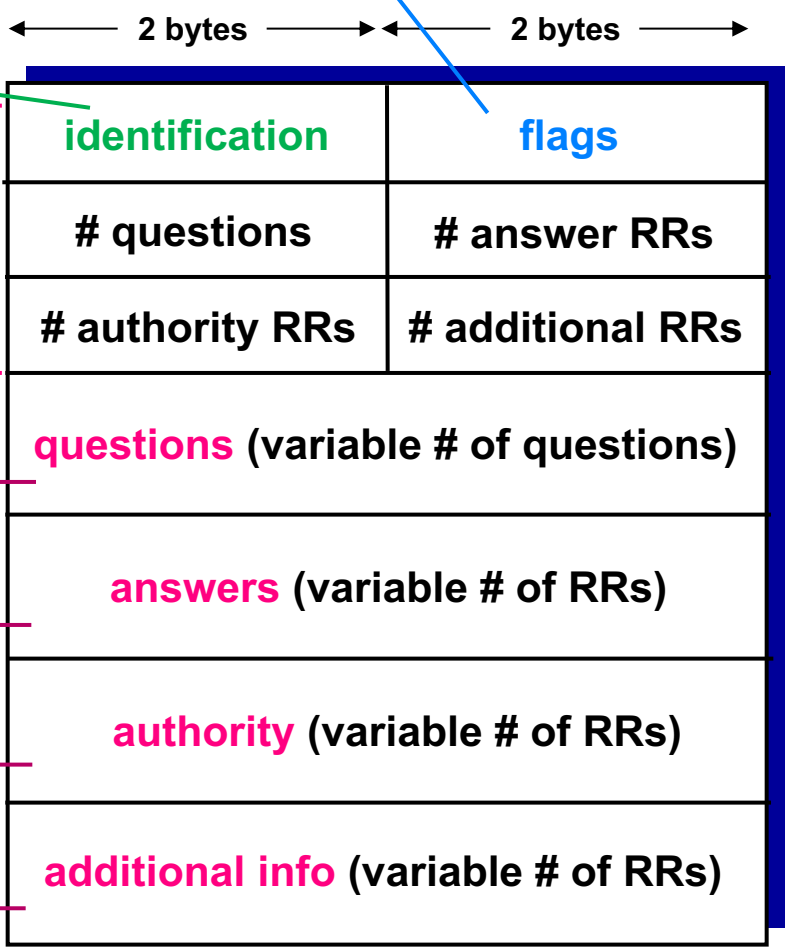
- value is name of mailserver associated with name

DNS protocol message format

Format of messages exchanged with DNS servers

flags
- query or reply
- recursion desired
- recursion available
- reply is authoritative

identification: 16 bit # for query, reply to query uses same #



message header

name, type fields for a query

RRs in response to query

records for authoritative servers

info that may be helpful (e.g., IP address of mail server)

Inserting records into DNS

Example

- new startup “Network Utopia”

Register name networkuptopia.com at DNS registrar

- e.g., Network Solutions, delegated by ICANN
- need to provide registrar with names and IP addresses of your authoritative name server (primary and secondary)
- registrar inserts two RRs into .com TLD (top-level) server

```
(networkutopia.com, dns1.networkutopia.com, NS)
(dns1.networkutopia.com, 212.212.212.1, A)
```

Create

- authoritative server Type A record for www.networkuptopia.com
- type MX record for networkutopia.com

Caching and updating records

Once (any) name server learns mapping, it caches mapping

- cache entries timeout (disappear) after some time (TTL)
- marked as "non-authoritative" mapping with address of authoritative server
- TLD servers typically cached in local name servers
  - thus root name servers not often visited

Cached entries may be out-of-date (best effort)

- if host changes IP address
  - may not be known Internet-wide until all TTLs expire

DNS Propagation

New domain names can take up to 72 hours to be accessible.

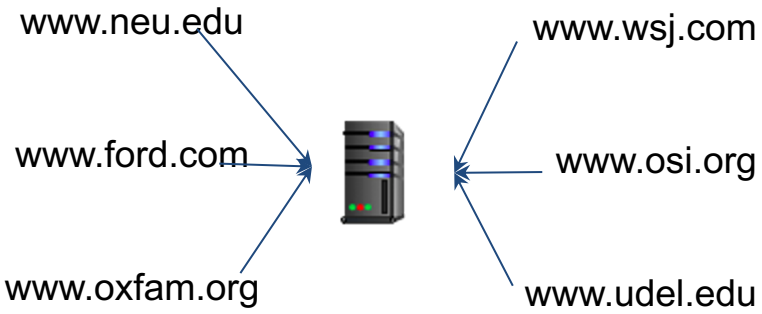
Why?

- new domain names require
  - authoritative server for domain and TLD name server to be updated
- name servers in hierarchy cache Root and TLD information

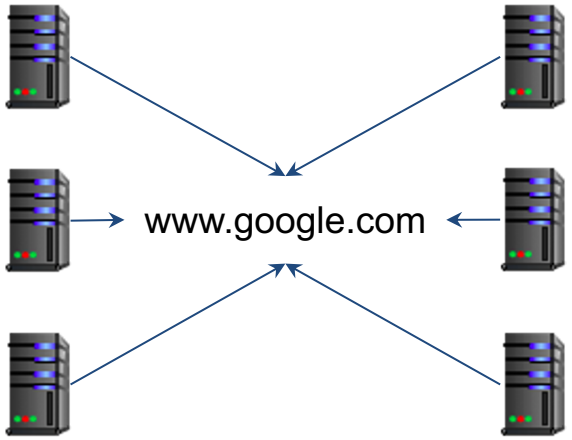
```
dig 2001:558:feed::1

; <<>> DiG 9.10.6 <<>> 2001:558:feed::1
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NXDOMAIN, id: 22662
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 1, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 512
;; QUESTION SECTION:
;2001:558:feed::1.              IN      A

;; AUTHORITY SECTION:
                    7395    IN      SOA     a.root-servers.net. nstld.verisign-grs.com.
```

DNS Aliasing and Load Balancing

One machine (IP address) can have multiple domain names



One domain name can point to multiple hosts (IP addresses)



CDNs use these properties to deliver content at scale while offering geographic, ISP, end system , … differentiation.

Domain Name System

DIG AND WIRESHARK

dig inria.fr

```
> dig inria.fr

; <<>> DiG 9.10.6 <<>> inria.fr
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 32537
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;inria.fr.                      IN      A

;; ANSWER SECTION:
inria.fr.               300     IN      A       128.93.162.83

;; Query time: 1397 msec
;; SERVER: 129.133.52.12#53(129.133.52.12)
;; WHEN: Thu Feb 16 19:56:55 EST 2023
;; MSG SIZE  rcvd: 53
```

Wireshark for dig inria.fr query

```
▶ Frame 27: 68 bytes on wire (544 bits), 68 bytes captured (544 bits) on interface 0
▶ Ethernet II, Src: 78:4f:43:73:43:26 (78:4f:43:73:43:26), Dst: 129.133.176.1 (3c:8a:b0:1e:18:01)
▶ Internet Protocol Version 4, Src: 129.133.187.174, Dst: 129.133.52.12
▶ User Datagram Protocol, Src Port: 51519 (51519), Dst Port: 53 (53)
▼ Domain Name System (query)
    [Response In: 28]
    Transaction ID: 0x2d1f
  ▶ Flags: 0x0100 Standard query
    Questions: 1
    Answer RRs: 0
    Authority RRs: 0
    Additional RRs: 0
  ▼ Queries
    ▼ inria.fr: type A, class IN
        Name: inria.fr
        [Name Length: 8]
        [Label Count: 2]
        Type: A (Host Address) (1)
        Class: IN (0x0001)
```

Wireshark for dig inria.fr response

```
▶ Frame 28: 84 bytes on wire (672 bits), 84 bytes captured (672 bits) on interface 0
▶ Ethernet II, Src: 129.133.176.1 (3c:8a:b0:1c:18:01), Dst: 78:4f:43:73:43:26 (78:4f:43:73:43:26)
▶ Internet Protocol Version 4, Src: 129.133.52.12, Dst: 129.133.187.174
▶ User Datagram Protocol, Src Port: 53 (53), Dst Port: 51519 (51519)
▼ Domain Name System (response)
    [Request In: 27]
    [Time: 0.007877000 seconds]
    Transaction ID: 0x2d1f
  ▶ Flags: 0x8180 Standard query response, No error
    Questions: 1
    Answer RRs: 1
    Authority RRs: 0
    Additional RRs: 0
  ▼ Queries
    ▼ inria.fr: type A, class IN
        Name: inria.fr
        [Name Length: 8]
        [Label Count: 2]
        Type: A (Host Address) (1)
        Class: IN (0x0001)
  ▼ Answers
    ▼ inria.fr: type A, class IN, addr 128.93.162.84
        Name: inria.fr
        Type: A (Host Address) (1)
        Class: IN (0x0001)
        Time to live: 7169
        Data length: 4
        Address: 128.93.162.84
```

What really happens when you type URL?

1. DNS query
   - sent to get ip address for hostname over UDP
2. TCP socket opened to ip address
3. HTTP msgs sent over TCP socket
4. TCP socket shutdown

Load inria.fr webpage

129.133.188.34	129.133.52.11	DNS	68	Standard query 0xe8ca A inria.fr
129.133.52.11	129.133.188.34	DNS	84	Standard query response 0xe8ca A 128.93.162.84
129.133.188.34	129.133.52.11	DNS	68	Standard query 0x67ba AAAA inria.fr
JuniperN_1e:18:01	Broadcast	ARP	64	Gratuitous ARP for 129.133.176.1 (Request) [ETHERN
129.133.52.11	129.133.188.34	DNS	119	Standard query response 0x67ba
129.133.188.34	128.93.162.84	TCP	74	33302 > http [SYN] Seq=0 Win=29200 Len=0 MSS=1460
128.93.162.84	129.133.188.34	TCP	74	http > 33302 [SYN, ACK] Seq=0 Ack=1 Win=14480 Len=
129.133.188.34	128.93.162.84	TCP	66	33302 > http [ACK] Seq=1 Ack=1 Win=29312 Len=0 TSv
129.133.188.34	128.93.162.84	HTTP	382	GET / HTTP/1.1
128.93.162.84	129.133.188.34	TCP	66	http > 33302 [ACK] Seq=1 Ack=317 Win=15616 Len=0 T
128.93.162.84	129.133.188.34	HTTP	558	HTTP/1.1 301 Moved Permanently (text/html)
129.133.188.34	128.93.162.84	TCP	66	33302 > http [ACK] Seq=317 Ack=493 Win=30336 Len=0
129.133.188.34	128.93.162.84	TCP	66	33302 > http [FIN, ACK] Seq=317 Ack=493 Win=30336
128.93.162.84	129.133.188.34	TCP	66	http > 33302 [FIN, ACK] Seq=493 Ack=317 Win=15616
129.133.188.34	128.93.162.84	TCP	66	33302 > http [ACK] Seq=318 Ack=494 Win=30336 Len=0
129.133.188.34	129.133.52.11	DNS	72	Standard query 0x52a5 A www.inria.fr
129.133.188.34	129.133.52.11	DNS	72	Standard query 0x1f32 AAAA www.inria.fr
128.93.162.84	129.133.188.34	TCP	66	http > 33302 [ACK] Seq=494 Ack=318 Win=15616 Len=0
129.133.52.11	129.133.188.34	DNS	142	Standard query response 0x1f32 CNAME ezp3.inria.f
129.133.52.11	129.133.188.34	DNS	107	Standard query response 0x52a5 CNAME ezp3.inria.f
129.133.188.34	128.93.162.84	TCP	74	36018 > https [SYN] Seq=0 Win=29200 Len=0 MSS=1460
128.93.162.84	129.133.188.34	TCP	74	https > 36018 [SYN, ACK] Seq=0 Ack=1 Win=14480 Len
129.133.188.34	128.93.162.84	TCP	66	36018 > https [ACK] Seq=1 Ack=1 Win=29312 Len=0 TS
129.133.188.34	128.93.162.84	TLSv1.2	255	Client Hello
128.93.162.84	129.133.188.34	TCP	66	https > 36018 [ACK] Seq=1 Ack=190 Win=15616 Len=0

Domain Name System

VULNERABILITIES

DNS is the root of trust to the web

What can happen if DNS is compromised?

- when you enter bankofamerica.com you expect to go to BoA site

How can DNS be compromised?

- Distributed Denial-of-Service (DDoS) attacks
  - bombard root servers with traffic
    - not successful to date, e.g., due to 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, malware on host / subvert DHCP server (home routers) to issue bogus DNS server
  - DNS poisoning
    - send bogus replies to DNS server, which caches
- Exploit DNS for DDoS
  - send queries with spoofed source address: target IP
  - requires amplification

Turkey hijacks DNS to enable censorship

BGPMON Now part of OpenDNS

HOME BLOG ABOUT US PRODUCTS AND SERVICES CLIENT PORTAL

Turkey Hijacking IP addresses for popular Global DNS providers

Posted by Andree Toonk - March 29, 2014 - Hijack, News and Updates - 26 Comments

At BGPmon we see numerous BGP hijacks every single day, some are interesting because of the size and scale of the hijack or as we've seen today because of the targeted hijacked prefixes. It all started last weekend when the Turkish president ordered the censorship of twitter.com. This started with a block of twitter by returning false twitter IP addresses by Turk Telekom DNS servers. Soon users in Turkey discovered that changing DNS providers to Google DNS or OpenDNS was a good method of bypassing the censorship. But as of around 9am UTC today (Saturday March 29) this changed when Turk Telekom started to hijack the IP address for popular free and open DNS providers such as Google's 8.8.8.8, OpenDNS' 208.67.222.222 and Level3's 4.2.2.2. **BGP hijack** Using the Turk Telekom looking glass we can see that AS9121 (Turk Telekom) has specific /32 routes for these IP addresses. Since this is the most specific route possible for an IPv4 address, this route will always be selected and the result is that traffic for this IP address is sent to this new bogus route.

```
show router bgp routes 8.8.8.8
```

Electronic Mail

OVERVIEW

Inventor of Email

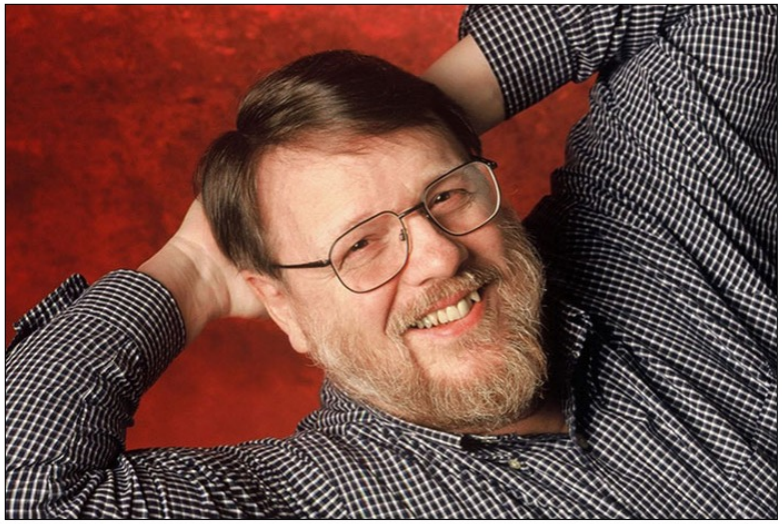
Ray Tomlinson at Raytheon BBN Technologies

Raytheon

VISIT: CYBER | WHO WE ARE | WHAT WE DO | GL

THE FATHER OF EMAIL

REMEMBERING RAYTHEON ENGINEER RAY TOMLINSON 1941-2016



Engineer Ray Tomlinson sent the first network email in 1971, choosing the '@' symbol to separate the name of the sender from the address of the host computer.

Share

In 1971, in a windowless room in Cambridge, Massachusetts, a bearded computer scientist named Ray Tomlinson was hunched before two massive computers, struggling to send the world's first email.

He had been programming and debugging for hours, trying fruitlessly to get a message from one cabinet-sized computer to another.

Now he tried again, banging out his name on a teletype keyboard: TOMLINSON. He followed that with an @ symbol – a little-used key he had chosen as a separator – and then the name of the other computer.

Tomlinson rolled his chair over to the second computer's teletype and banged out TYPE MAILBOX on the keyboard.

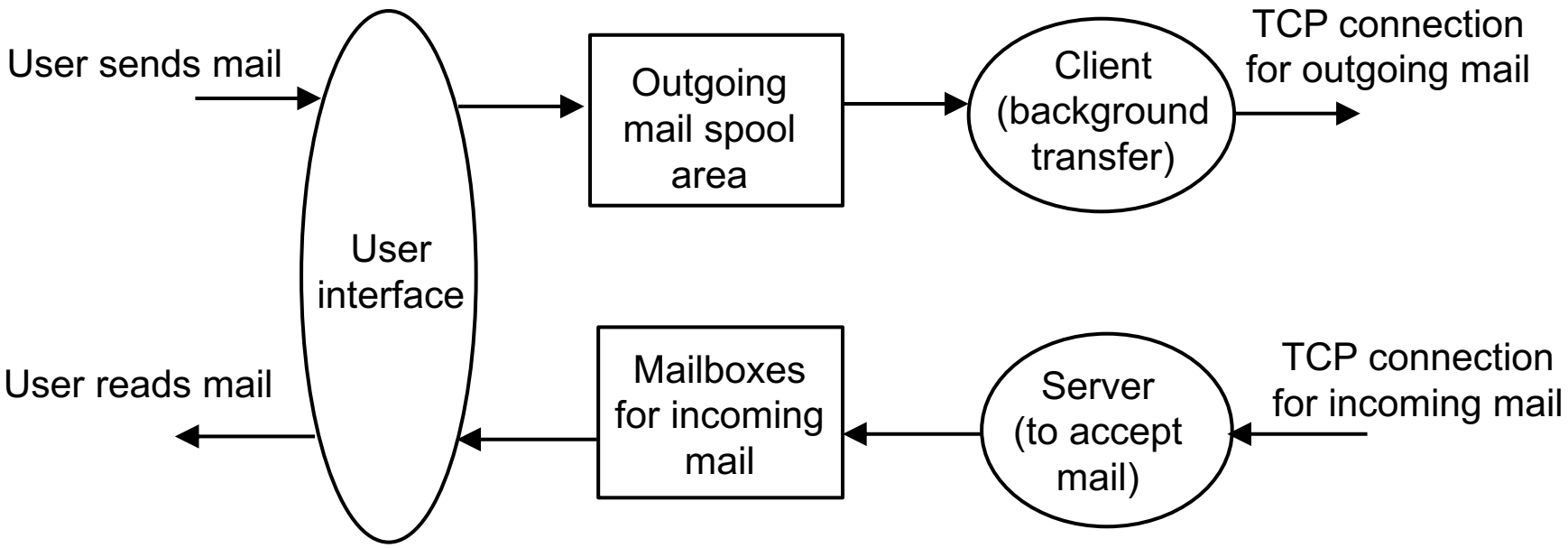
For a moment there was silence. And then with a rattle, the teletype came alive. History's first email had arrived.

"The mail was sitting there just like it is today when you check your inbox," Tomlinson said.

Tomlinson, a principal engineer at Raytheon BBN Technologies, passed away on March 5, 2016. He was 74 years old.

Inducted into the Internet Hall of Fame in 2012 for his invention of modern email, Tomlinson made the historic choice to separate the name of his message's recipient from the name of the host computer using the "@" symbol, creating one of the most universally recognized digital icons on the planet. In 2011, he was ranked No. 4 on the list of the top 150 MIT-

Overview



Uses client-server communication

- not interactive: transfer of msgs occurs in background ("spooling'")

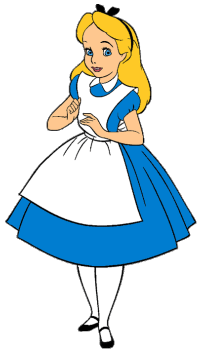
Reliable service

- uses TCP

Major components of electronic mail (email)

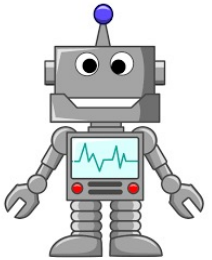
User-agents aka mail reader (what you use)

- composing, editing, reading mail messages
- e.g., Outlook, Thunderbird, iPhone mail client, Gmail
- incoming/outgoing messages stored on mail server
- client-server communication with mail server



Alice

Alice's User Agent



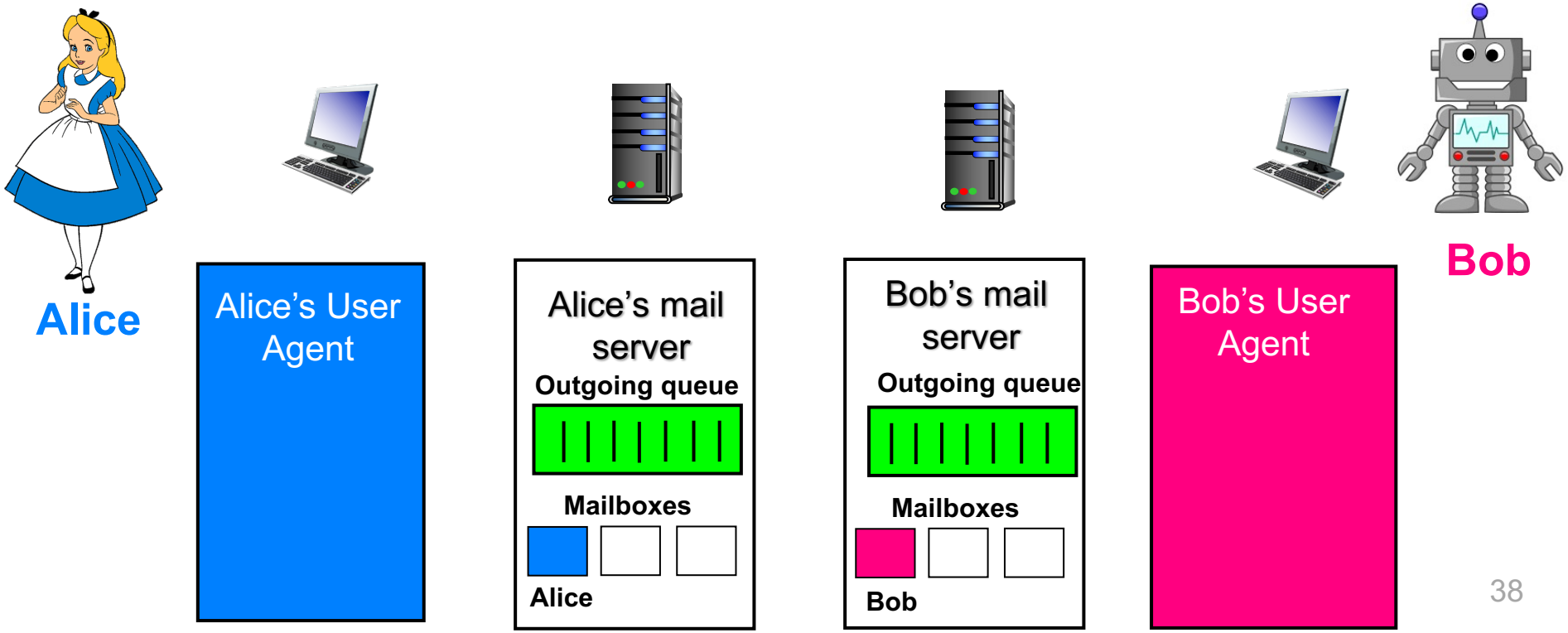
Bob

Bob's User Agent

Major components of electronic mail (email)

Mail servers

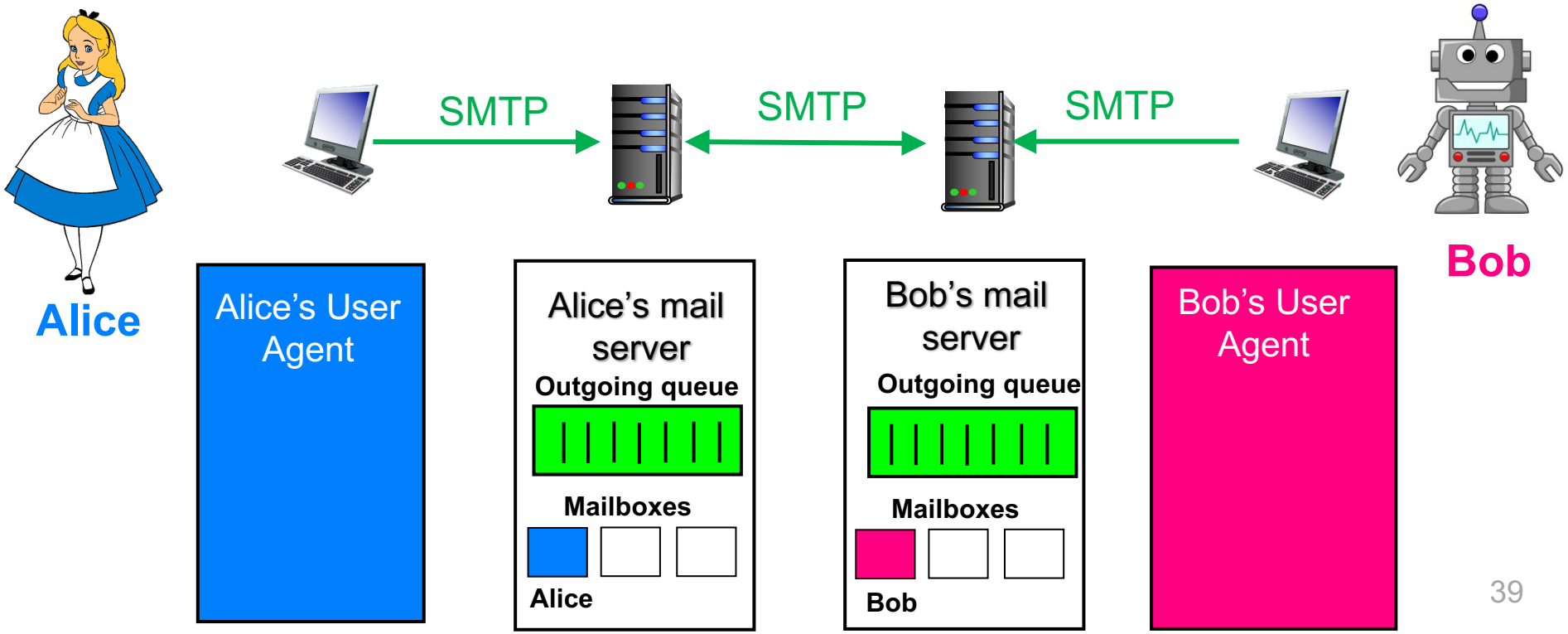
- mailbox for each user: holds user's incoming messages
- outgoing message queue: holds messages to be sent
  - messages held in queue until successfully delivered
  - reattempts done every 30 min or so. If undeliverable, user notified



Major components of electronic mail (email)

SMTP (simple mail transfer protocol) [RFC 2821]

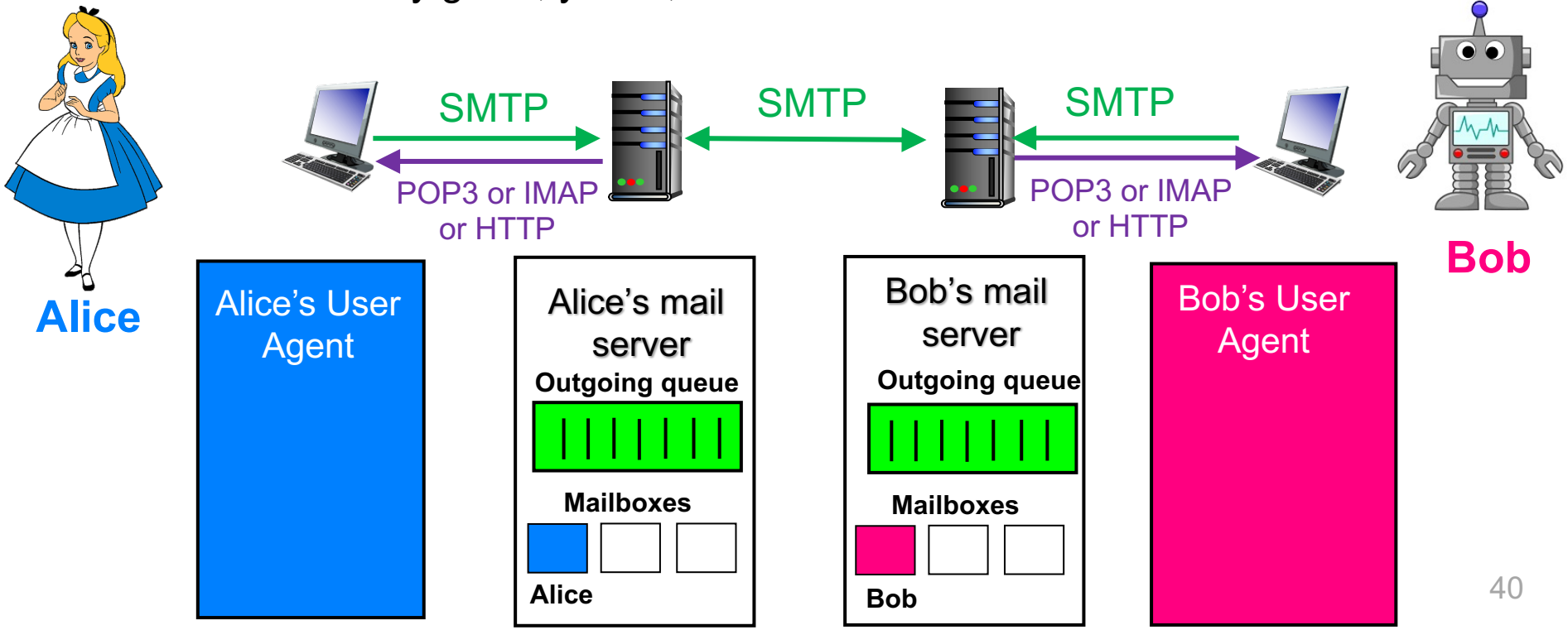
- **transfers msgs**: from user agent to mail server and between mail servers
- persistent connection, TCP port 25, SSL encrypted uses port 465
- p2p comm among mail servers, client-server with user-agents
  - user agent does not run server side of SMTP (would need to always be on)
  - mail server runs both client and server sides



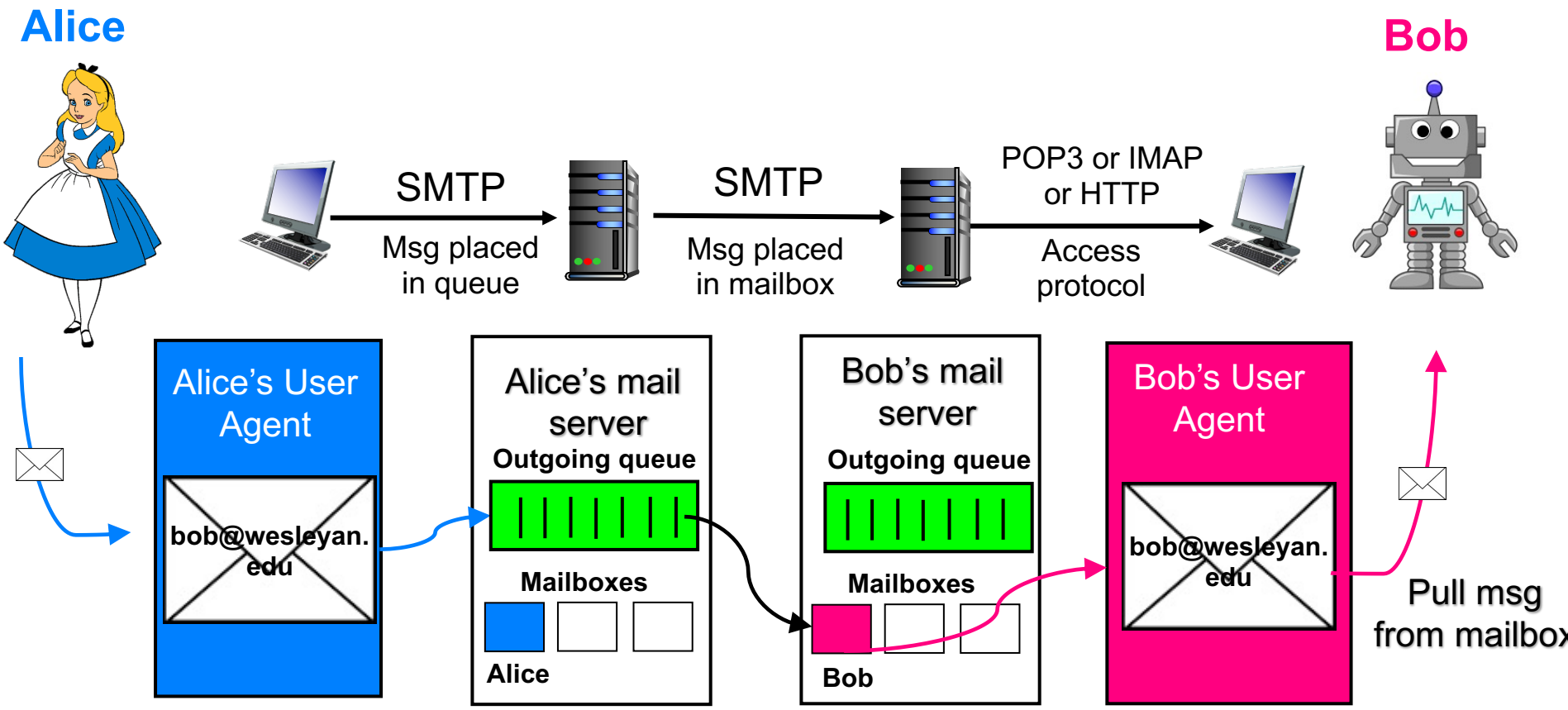
Major components of electronic mail (email)

Mail access protocols for user agent to retrieve mail

- POP3: Post Office Protocol [RFC 1939]
  - basic: downloads email, deletes from server, emails stored on computer
- IMAP: Internet Mail Access Protocol [RFC 1730]
  - more complex, recommended over POP3
    - manipulate msgs stored on server, email stored on server, use multiple computers
- HTTP: used by gmail, yahoo, etc …



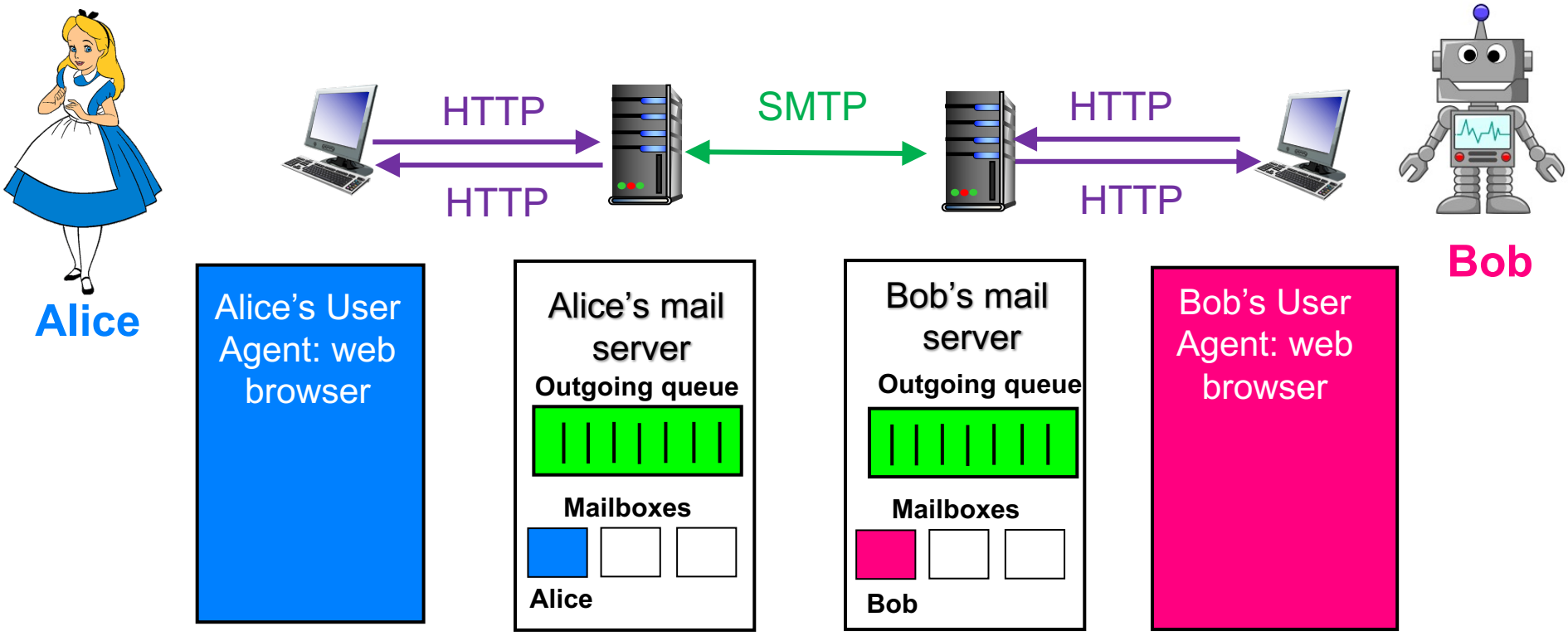
What happens when Alice sends email to Bob?



Q: What happens before any mail protocol communication?

TCP handshake

Webmail



HTTP is used for communication between Client and mail server

SMTP is used for communication between mail servers

Look at complete email header

Show raw source in gmail or wesleyan email