Computer Networks

-The Application layer-

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W1 short test (1)

- Give examples of transmission media used for computer networks!
  - copper, coaxial, optical, etc.
- What is the client-server model, and how does communication take place?
  - It is a distributed framework, where the "client" explicitly requests information from a "server" hosting that information: 1. The client is sending a message over the network to the server 2. Client waits for reply 3. Server performs the requested work (sends reply)
- Give examples of fixed-wireless networks!
  - wireless in fixed locations: offices, homes that use WiFi without the mobility
- What are CDNs?
  - Many services use Content Delivery Networks to deliver content to users fast all around the world (e.g., Google, Netflix). It is a large collection of servers that are geo-distributed in a way that content is placed as close as possible to the users that are requesting it

W1 short test (2)

- What is the main difference between the IEEE 802.11 and IEEE 802.3 standards?
  - The IEEE 802.11 standard running from 11 Mbps to 7 Gbps is called WiFi, and the Ethernet (IEEE 802.3) is the most common wired LAN (generally faster, and lower latency).
- What is net neutrality, and what are its basic rules?
  - ISPs should provide equal quality of service to a given type of application traffic, regardless of who is sending that content: no blocking and throttling the connections, no paid prioritization, and transparency about the network practices concerning the other rules.

W2 summary (1)

- There are many different types of networks, in different sizes, for different goals
- The Internet is a collection of different networks that use common protocols and provide common services
- To join the Internet, the computer is connected to an ISP with a cable network, HFC, FTTH
  - device at the home end is the cable modem and the one at the cable headend is the CMTS
- The location where customer packets enter the ISP network for service the ISP's POP
  - the packet is routed over the backbone of the ISP, or handed over to another ISP, connected by an IXP

W2 summary (2)

- Network protocols often share a common set of design goals: reliability, resource allocation, evolvability, and security
- Most networks are organized as a stack of layers
- A service is a set of primitives that a layer provides to the above layer
- A protocol is a set of rules governing the format and meaning of the packets exchanged within a layer
- A set of layers and protocols is a network architecture, where a list of protocols used one per layer, is a protocol stack
- The OSI reference model is useful as a model of computer networks
- The TCP/IP reference model is useful for the representation of protocols
- Five layer model to discuss computer networks: Physical, (Data) Link, Network, Transport, Application

Agenda

- The Domain Name System (DNS)
- Electronic mail
- The World Wide Web
- Summary

The need of DNS

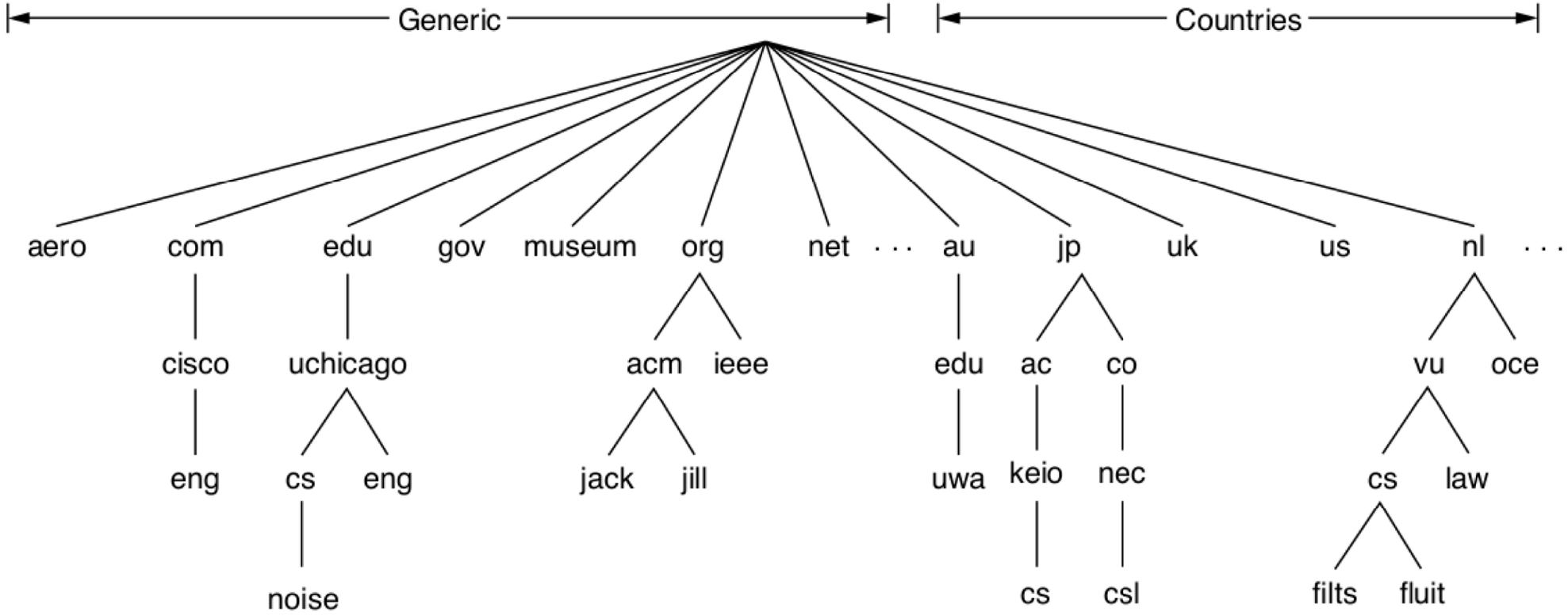
- Network addresses such as IP, are difficult to remember and brittle
- High-level, readable names decouple machine names from machine addresses
  - the human-readable domain names must be converted to IP addresses with the **DNS** (Domain Name System)
- First, a *host.txt* file listed all computer names and their IP addresses
- As the Internet grew, it needed a central management system to prevent host name conflicts
- DNS is a distributed database system that implements a hierarchical naming scheme
  - invented in 1983

The DNS lookup process

- The **stub resolver** process maps a name onto an IP address
- The stub resolver sends a query containing the name to a **local DNS resolver**
- Local DNS resolver performs a *recursive lookup* for the name against a set of DNS resolvers
- Local recursive resolver ultimately returns the corresponding IP address to the stub resolver
  - issues a sequence of queries to the respective name servers, and get the address from the **authorative name server**
- Stub resolver passes the result to the function that issued the query in the first place
  - query and response messages are sent as UDP packets
  - programs can use the IP address to communicate with the host corresponding to the DNS name that it had looked up

The DNS name space and hierarchy (1)

- The Internet is divided into over 250 **top-level domains**
  - each domain covers many hosts, and each domain is partitioned into subdomains
  - the domains constitute a namespace hierarchy



The DNS name space and hierarchy (2)

- The top-level domains are operated by companies called **registries**, appointed by **ICANN** (Internet Corporation for Assigned Names and Numbers), and **registrars** sell domain dames to users
  - e.g., Domain.com, GoDaddy, NameCheap, etc.
- The domain name a machine looks up is called a **FQDN** (Fully Qualified Domain Name), which starts with the most specific part of the domain name
  - each part of the hierarchy is separated by a dot (e.g., eng.cisco.com)
- Domain names are case-insensitive, with a max of 63 character long component names, with the full path name not exceeding 255 characters
- Each domain controls how it allocates the domains under it
  - e.g., in Japan, *ac.jp* is the equivalent of *edu*

DNS Queries and Responses

- A DNS client issues a query to a local recursive resolver, which performs an iterative query to ultimately resolve the query
- Another use for DNS queries is to look up domains in a **DNSBL** (DNS-based blacklist)
- There are multiple extensions of DNS queries, mainly because security concerns
- Every domain can have a set of **resource records**
  - when a resolver gives a domain name to DNS, it gets back the resource records associated with that name
  - the most common record is the IP address

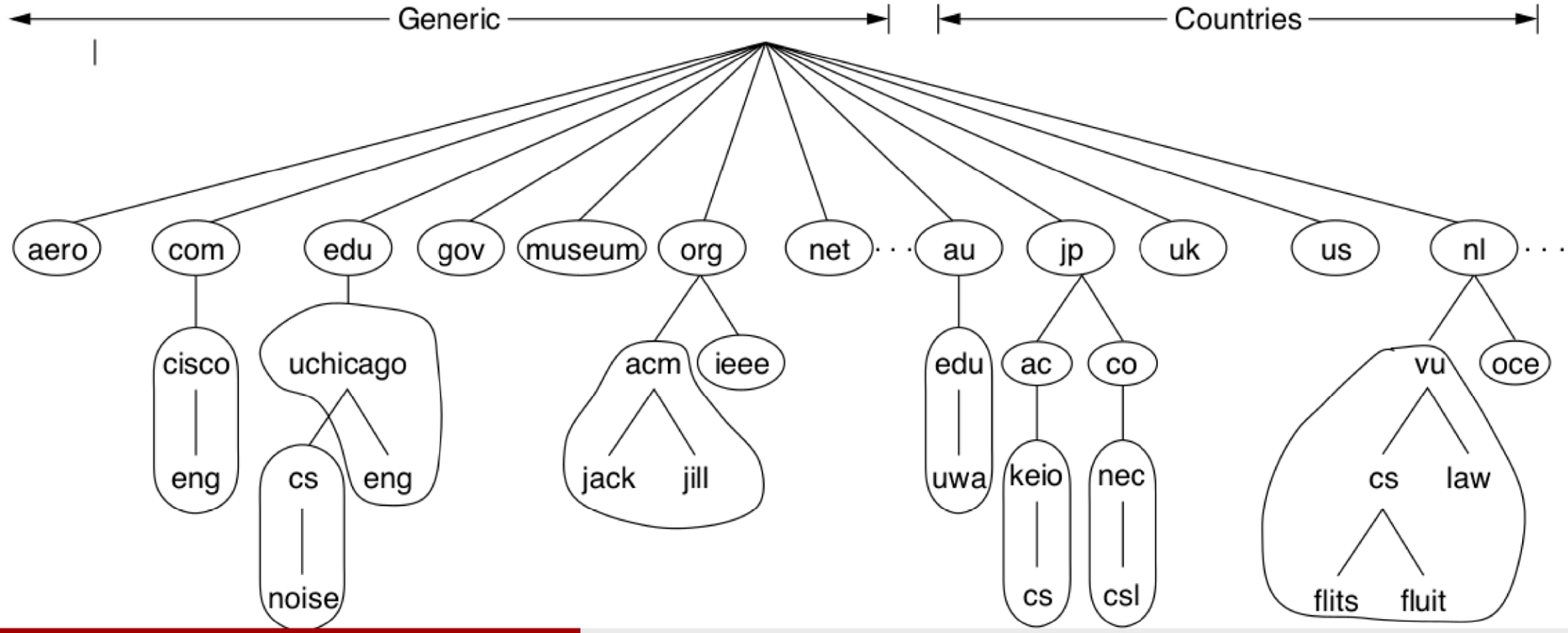
DNS records

Type	Meaning	Value
SOA	Start of authority	Parameters for this zone
A	IPv4 address of a host	32-Bit integer
AAAA	IPv6 address of a host	128-Bit integer
MX	Mail exchange	Priority, domain willing to accept email
NS	Name server	Name of a server for this domain
CNAME	Canonical name	Domain name
PTR	Pointer	Alias for an IP address
SPF	Sender policy framework	Text encoding of mail sending policy
SRV	Service	Host that provides it
TXT	Text	Descriptive ASCII text

- **DNSSEC** records allow responses from DNS name servers to carry digital signatures
  - the local or stub resolver can subsequently verify to ensure that the DNS records were not tampered with

DNS zones

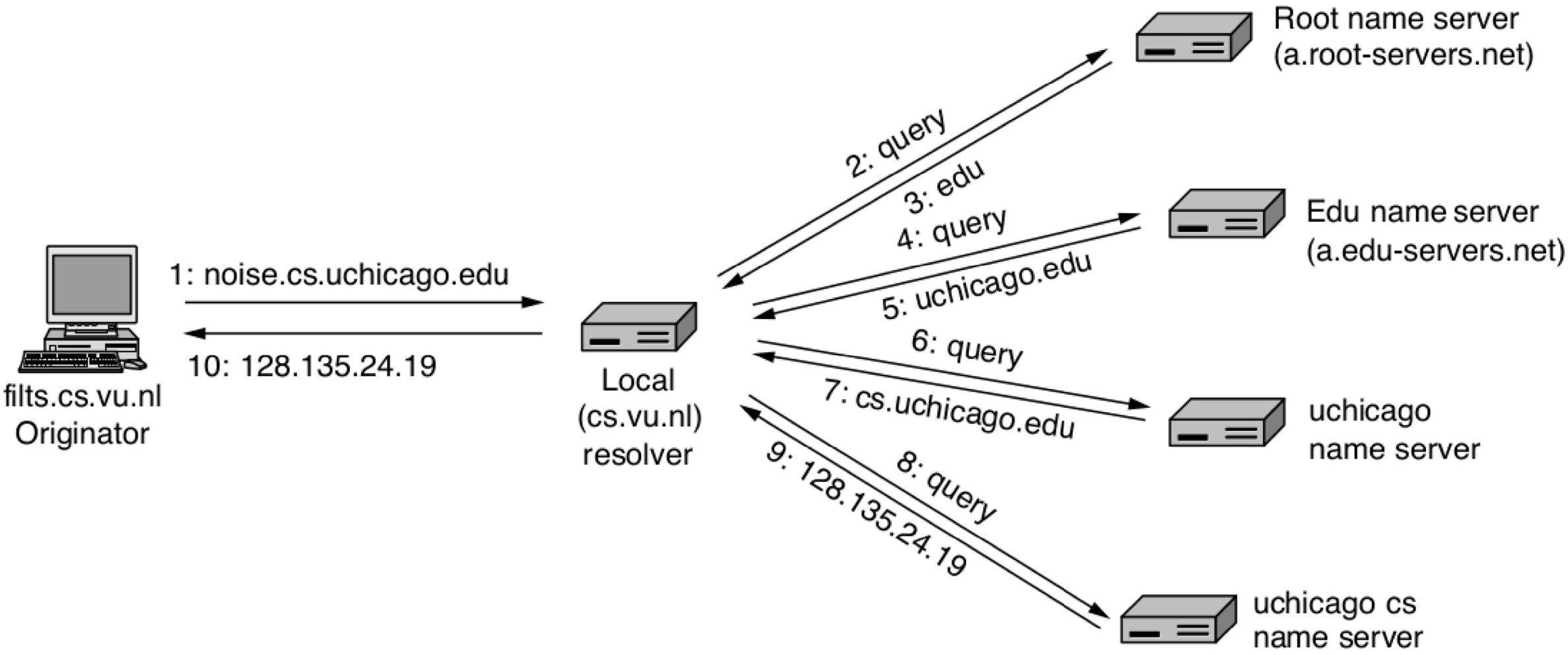
- In theory, a single name server could contain the entire DNS database and respond to all queries, but this is not practical
- The DNS name space is divided into non-overlapping **zones**
  - where the zone boundaries are placed is up to that zone's administrator



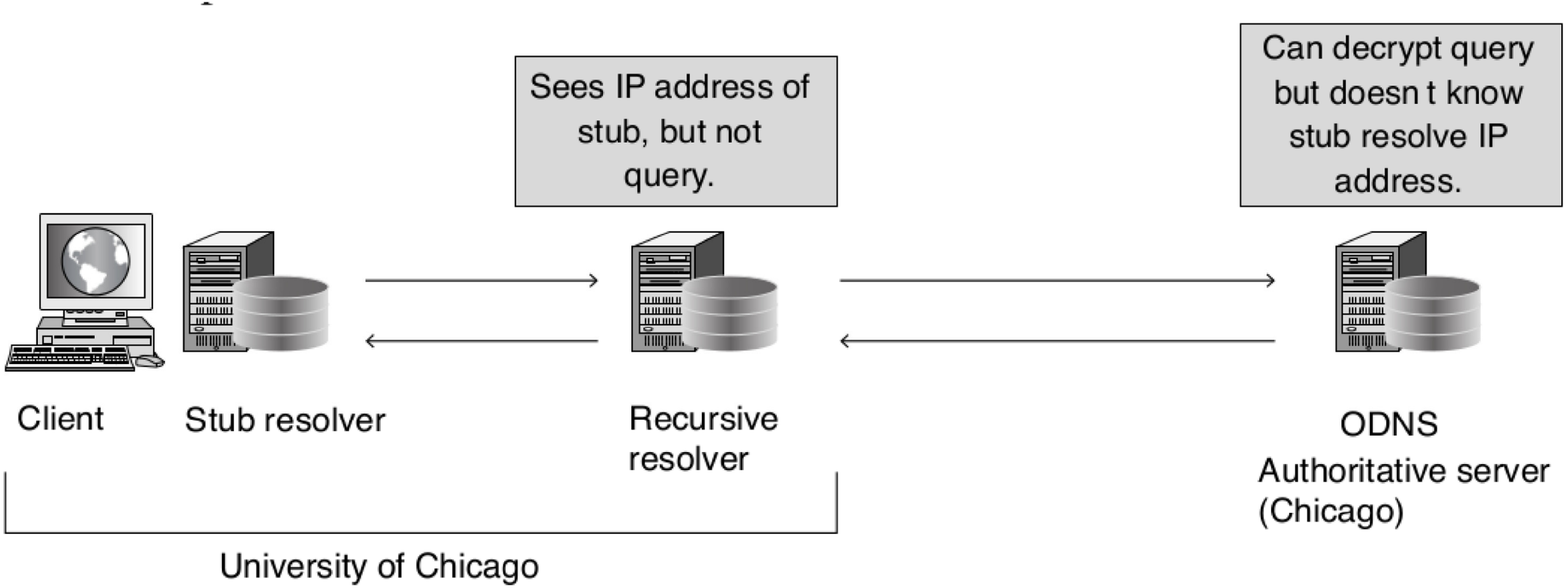
Name resolution (1)

- Each zone is associated with one or more name servers, hosts that hold the database for the zone
- **Name resolution** is the process of looking up a name a finding an address
  - when a resolver has a query about a domain name, it passes the query to a local name server
  - if the domain falls under the jurisdiction of the name server, it returns the authoritative resource records (always up-to-date, not like cached records)
  - if there is no cached info about the domain locally, the name servers starts a remote query

Name resolution (2)

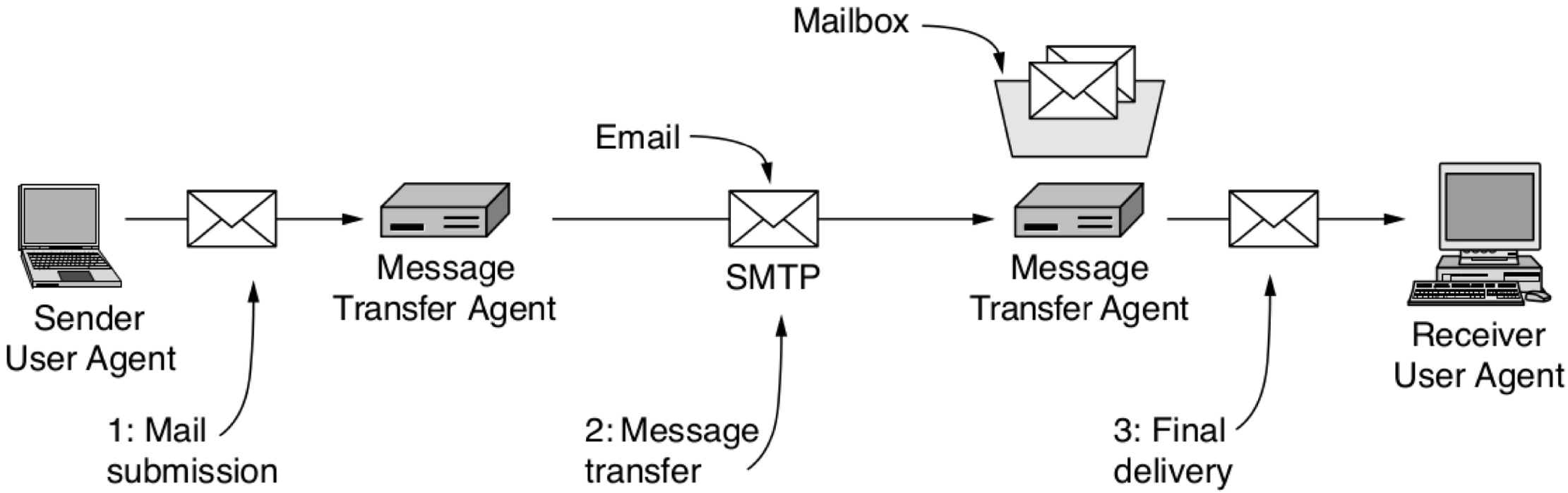


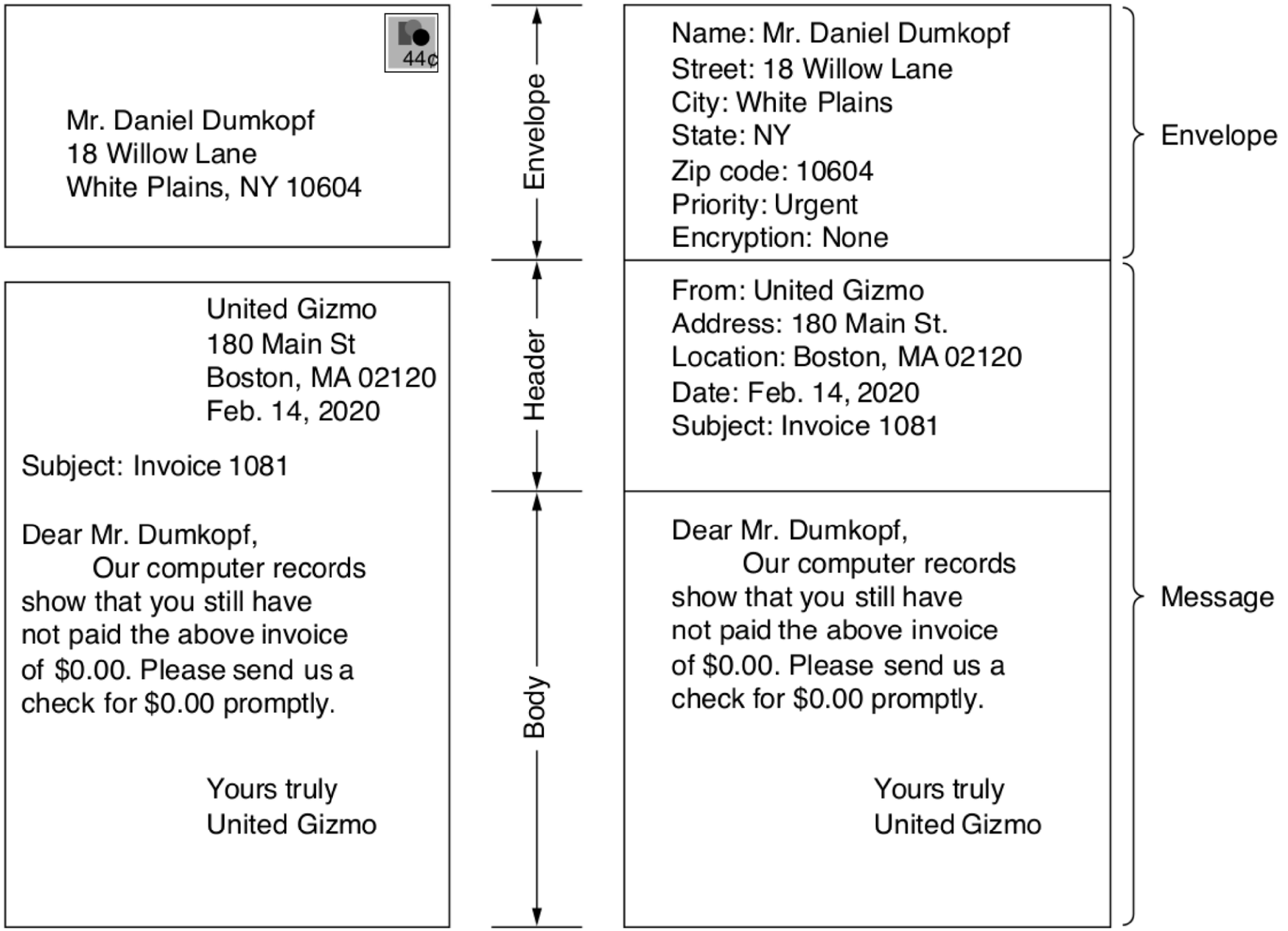
Oblivious DNS



Email system architecture

- The email architecture consists of two kinds of subsystems
  - **user agents** allow people to read and send email
  - **mail servers** or **message transfer agents** move messages from the source to the destination using SMTP (Simple Mail Transfer Protocol)

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Mr. Daniel Dumkopf
18 Willow Lane
White Plains, NY 10604
United Gizmo
180 Main St
Boston, MA 02120
Feb. 14, 2020
Subject: Invoice 1081
Dear Mr. Dumkopf,
Our computer records show that you still have not paid the above invoice of $0.00. Please send us a check for $0.00 promptly.
Yours truly
United Gizmo
Envelope
Header
Body
Name: Mr. Daniel Dumkopf
Street: 18 Willow Lane
City: White Plains
State: NY
Zip code: 10604
Priority: Urgent
Encryption: None
From: United Gizmo
Address: 180 Main St.
Location: Boston, MA 02120
Date: Feb. 14, 2020
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United Gizmo
Envelope
Message

Message formats: RFC 5322

- **RFC 5322** is the basic ASCII Internet message format

Header	Meaning
To:	Email address(es) of primary recipient(s)
Cc:	Email address(es) of secondary recipient(s)
Bcc:	Email address(es) for blind carbon copies
From:	Person or people who created the message
Sender:	Email address of the actual sender
Received:	Line added by each transfer agent along the route
Return-Path:	Can be used to identify a path back to the sender

Header	Meaning
Date:	The date and time the message was sent
Reply-To:	Email address to which replies should be sent
Message-Id:	Unique number for referencing this message later
In-Reply-To:	Message-Id of the message to which this is a reply
References:	Other relevant Message-Ids
Keywords:	User-chosen keywords
Subject:	Short summary of the message for the one-line display

Message formats: MIME

- **MIME** (Multipurpose Internet Mail Extensions): multimedia extensions to the basic format

Header	Meaning
MIME-Version:	Identifies the MIME version
Content-Description:	Human-readable string telling what is in the message
Content-Id:	Unique identifier
Content-Transfer-Encoding:	How the body is wrapped for transmission
Content-Type:	Type and format of the content

Type	Example subtypes	Description
text	plain, html, xml, css	Text in various formats
image	gif, jpeg, tiff	Pictures
audio	basic, mpeg, mp4	Sounds
video	mpeg, mp4, quicktime	Movies
font	otf, ttf Fonts for typesetting	
model	vrml	3D model
application	octet-stream, pdf, javascript, zip	Data produced by applications

Message transfer

- Emails are delivered by having the sending computer establish a TCP connection to port 25 of the receiving computer, and listening to this port is a mail server that speaks **SMTP** (Simple Mail Transfer Protocol)
- One of the main protocols used for the final delivery is **IMAP** (Internet Message Access Protocol), an improvement over **POP3** (Post Office Protocol ver. 3)
  - the mail server runs an IMAP server that listens to port 143
  - the user agent runs an IMAP client
  - the client connects to the server and begins to issue commands
- **Webmail** is an alternative to IMAP and SMTP for providing email service, using the Web as an interface (e.g., Gmail)

Web architecture

- The **World Wide Web** is an architectural framework for accessing linked content all over the Internet
  - since easy to use (e.g., graphical interface, etc.), it is very popular
  - began in 1989 at CERN to help large research teams to collaborate
- Fetching and rendering a *static* and *dynamic* **webpages** involves HTTP/HTTPS requests to many servers
  - one page pointing to another: **hyperlink**
  - **HTTP** (HyperText Transfer Protocol) is a text-based protocol, with the secure version being the **HTTPS**
  - each page is assigned an **URL** (Uniform Resource Locator) that is the page's worldwide name with three parts; protocol/scheme, DNS name, path for the specific page (e.g., https://fcc.gov/)

Client side

- Steps that occur when a link is selected:
  1. browser determines the URL
  2. browser asks DNS for the IP address of the server
  3. DNS replies
  4. browser makes a TCP connection
  5. sends HTTP request for the page
  6. server sends the page as HTTP response
  7. browser fetches other URLs as needed
  8. browser displays the page
  9. the TCP connections are released

Common URL protocols

Name	Used for	Example
http	Hypertext (HTML)	https://www.ee.uwa.edu/~rob/
https	Hypertext with security	https://www.bank.com/accounts/
ftp	FTP	ftp://ftp.cs.vu.nl/pub/minix/README
file	Local file	file:///usr/nathan/prog.c
mailto	Sending email	mailto:JohnUser@acm.org
rtsp	Streaming media	rtsp://youtube.com/montypython.mpg
sip	Multimedia calls	sip:eve@adversary.com
about	Browser information	about:plugins

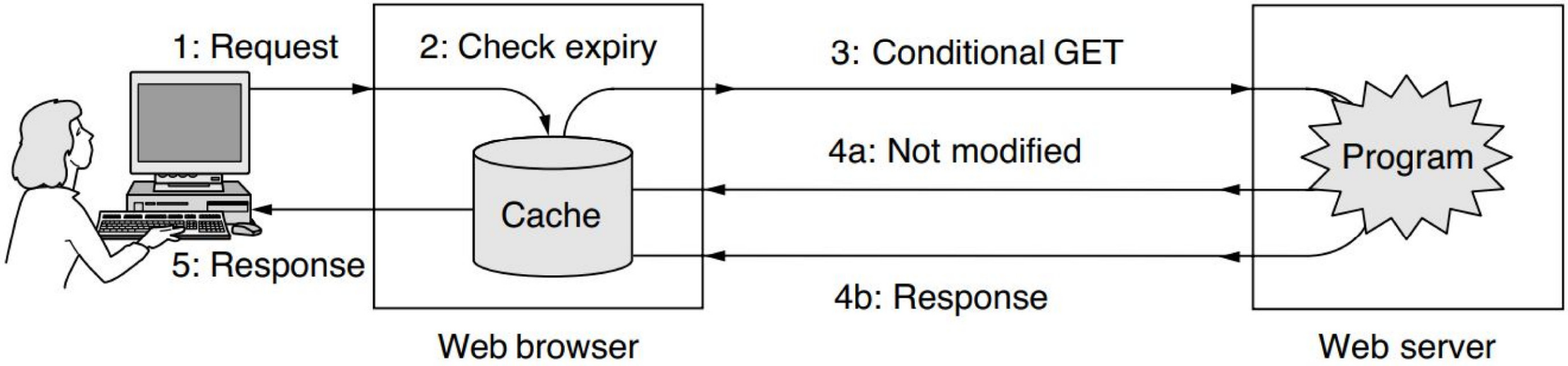
HTTP and HTTPS methods and status codes

- HTTP is a request-response protocol, running over TCP or UDP, with a variety of request methods
  - requests and responses may be followed by additional request and response headers (e.g., expires, set-cookie, etc.)
- HTTP/1, HTTP/2, HTTP/3

Method	Description
GET	Read a Web page
HEAD	Read a Web page's header
POST	Append to a Web page
PUT	Store a Web page
DELETE	Remove the Web page
TRACE	Echo the incoming request
CONNECT	Connect through a proxy
OPTIONS	Query options for a page

Code	Meaning	Examples
1xx	Information	100 = server agrees to handle client's request
2xx	Success	200 = request succeeded; 204 = no content present
3xx	Redirection	301 = page moved; 304 = cached page still valid
4xx	Client error	403 = forbidden page; 404 = page not found
5xx	Server error	500 = internal server error; 503 = try again later

HTTP caching



Server side

- Basic steps the server performs in its main loop:
  1. accept a TCP connection from a client (a browser)
  2. get the path to the page, which is the name of the file requested
  3. get the file (from disk)
  4. send the contents of the file to the client
  5. release the TCP connection
- For dynamic content, the third step may be replaced by the execution of a program that generates and returns the contents

W3 Summary (1)

- Human-readable domain names must be converted to IP addresses with the DNS
- Name resolution is the process of looking up a name a finding an address
- A DNS client issues a query to a local recursive resolver, which performs an iterative query to ultimately resolve the query
- The Internet is divided into top-level domains and many subdomains in a namespace hierarchy, involving non-overlapping zones
- The most common resource record 'A' is the IP address
- The email architecture consists of two kinds of subsystems: user agents and mail servers/message transfer agents speaking the SMTP
- RFC 5322 is the basic ASCII Internet message format
- MIME is about multimedia extensions to the basic format

W3 Summary (2)

- One of the main protocols used for the final email delivery is IMAP, an improvement over POP3
- Webmail is an alternative to IMAP and SMTP for providing email service, using the Web as an interface
- The World Wide Web is a popular architectural framework for accessing linked content all over the Internet
- HTTP/HTTPS is a request-response protocol with different request methods
- Fetching and rendering a static and dynamic pages involves HTTP/HTTPS requests to many servers
- Each page is assigned an URL that is the page's worldwide name with three parts
- There are several common URL protocols for a variety of purposes

W4-W6 topic

- Network layer and Transport layer (Network layer 1, Network layer 2/Transport layer 1, Transport layer 2)