Hypertext Transport Protocol
CSE 333

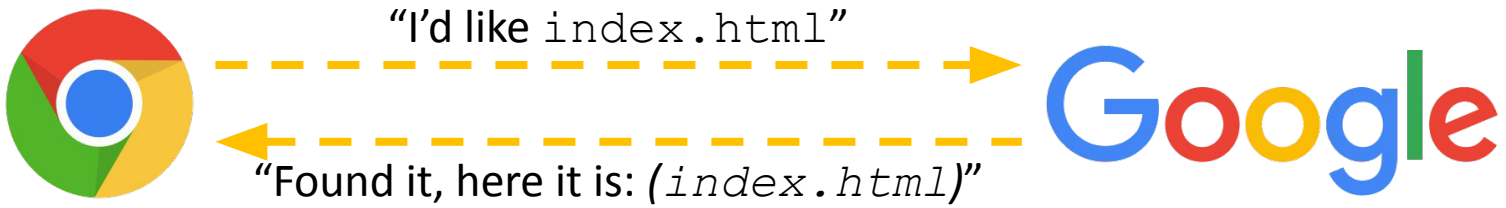
Instructor: Alex Sanchez-Stern

Teaching Assistants:
Audrey Seo
Deeksha Vatwani
Derek de Leuw
Katie Gilchrist

Administrivia

- Ex15 due this morning
- Ex16 due **Wednesday, August 13th**
  - Server-side programming using material from Friday
- Learning isn't supposed to be miserable, ask for help!
  - In particular, the staff knows a lot of debugging techniques that will make your lives easier and be useful in the long term

HTTP Basics



- A widely used **application-level** protocol
- The client sends a request for a web object over a connection and the server replies with the object's contents
- We have to figure out how to let the client and server communicate their intentions to each other clearly
  - We have to define a *protocol*

Protocols

- A protocol is a set of rules governing the format and exchange of messages in a computing system
  - What messages can a client exchange with a server?
    - What is the syntax of a message?
    - What do the messages mean?
  - What sequence of messages are allowed?
    - What are allowed replies to a message?
    - How are errors conveyed?
- A protocol is (roughly) the network equivalent of an API

HTTP: Hypertext Transport Protocol

- A request / response protocol
  - A client (web browser) sends a request to a web server
  - The server processes the request and sends a response
- Typically, a **request** asks a server to retrieve a resource
  - A *resource* is an object or document, named by a Uniform Resource Locator (**URL**)
- A **response** indicates whether or not the server succeeded
  - If so, it provides the content of the requested response

- https://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol

HTTP Requests

- General form:
  - `[METHOD] [request-uri] HTTP/[version]\r\n`
    `[headerfield1]: [fieldvalue1]\r\n`
    `[headerfield2]: [fieldvalue2]\r\n`
    `[...]`
    `[headerfieldN]: [fieldvalueN]\r\n`
    `\r\n`
    `[request body, if any]`

- Demo: use `nc` as a server to see a real request

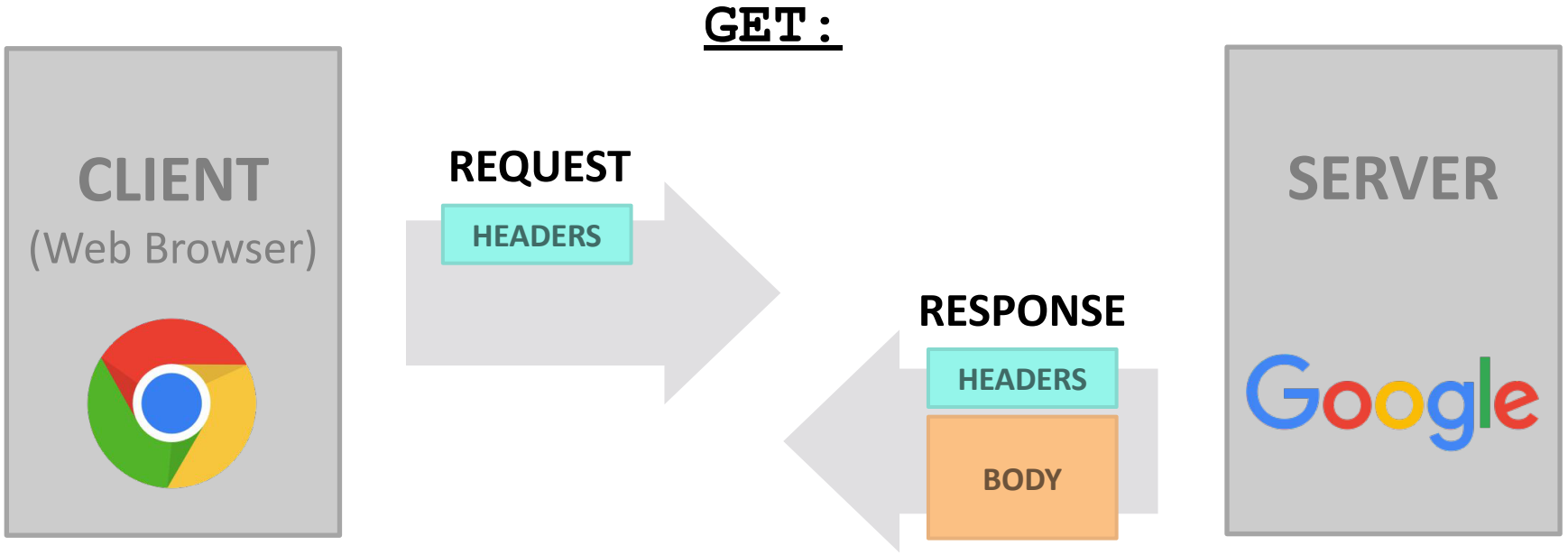
A Real Request

```
GET / HTTP/1.1
Host: attu.cs.washington.edu:3333
Connection: keep-alive
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36
(KHTML, like Gecko) Chrome/66.0.3359.181 Safari/537.36
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,
image/apng,*/*;q=0.8
DNT: 1
Accept-Encoding: gzip, deflate
Accept-Language: en-US,en;q=0.9
Cookie:
SESS0c8e598bbe17200b27e1d0a18f9a42bb=5c18d7ed6d369d56b69a1c0aa441d7 8f;
SESSd47cbe79be51e625cab059451de75072=d137dbe7bbe1e90149797dcd89c639b1;
_sdsat_DMC_or_CCODE=null; _sdsat_utm_source=; _sdsat_utm_medium=;
_sdsat_ut m_term=; _sdsat_utm_content=; adblock=blocked;
s_fid=50771A3AC73B3FFF-3F18A ABD559FFB5D; s_cc=true;
prev_page=science.%3A%2Fcontent%2F347%2F6219%2F262% 2Ftab-pdf;
ist_usr_page=1; sat_ppv=79; ajs_anonymous_id=%229225b8cf-6637-49
c8-8568-ecb53cfc760c%22; ajs_user_id=null; ajs_group_id=null;
__utma=208078.07.216184303.1491952757.1496310296.1;
```

. . .

HTTP Methods

- There are three commonly-used HTTP methods:
  - **`GET`**: "Please send me the named resource"



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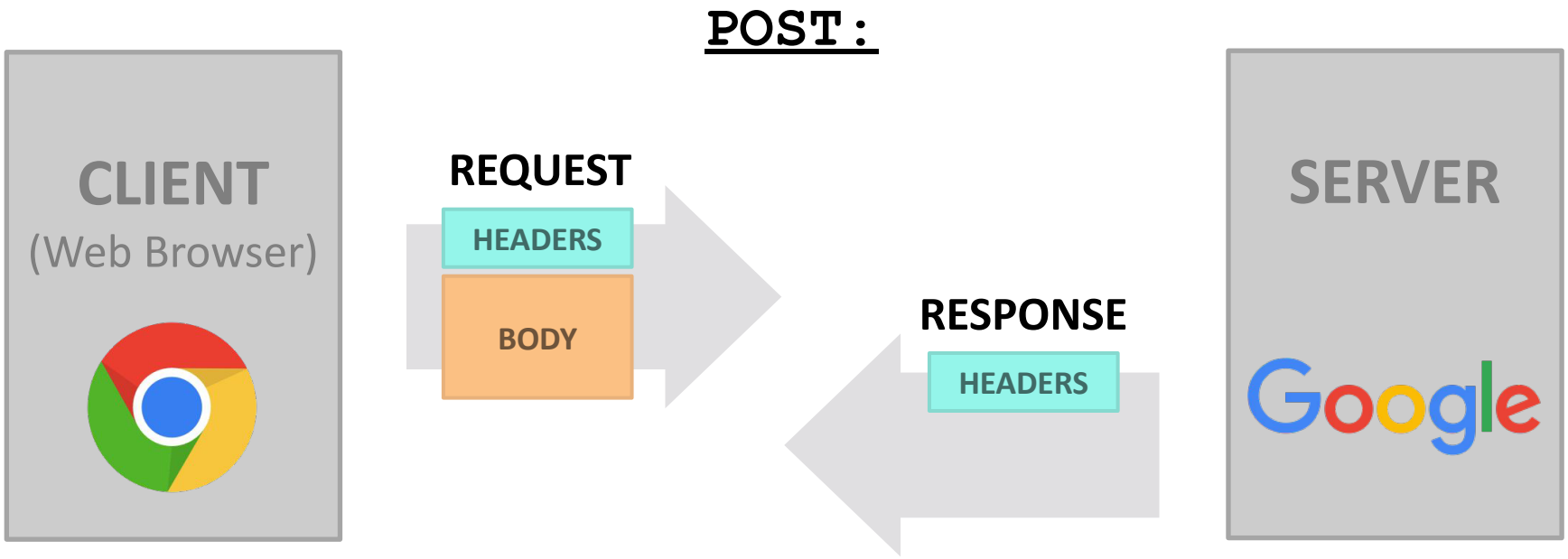
  - **`POST`**: "I'd like to submit data to you" (*e.g.* file upload)



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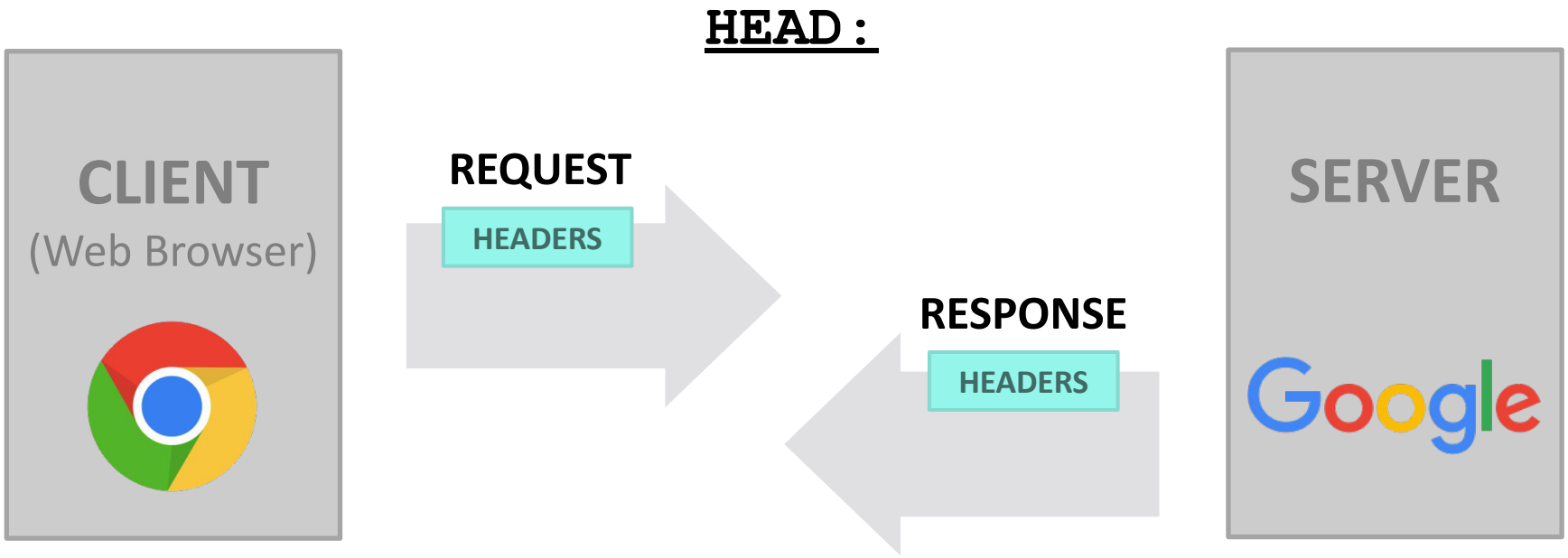
  - **`HEAD`**: "Send me the headers for the named resource"



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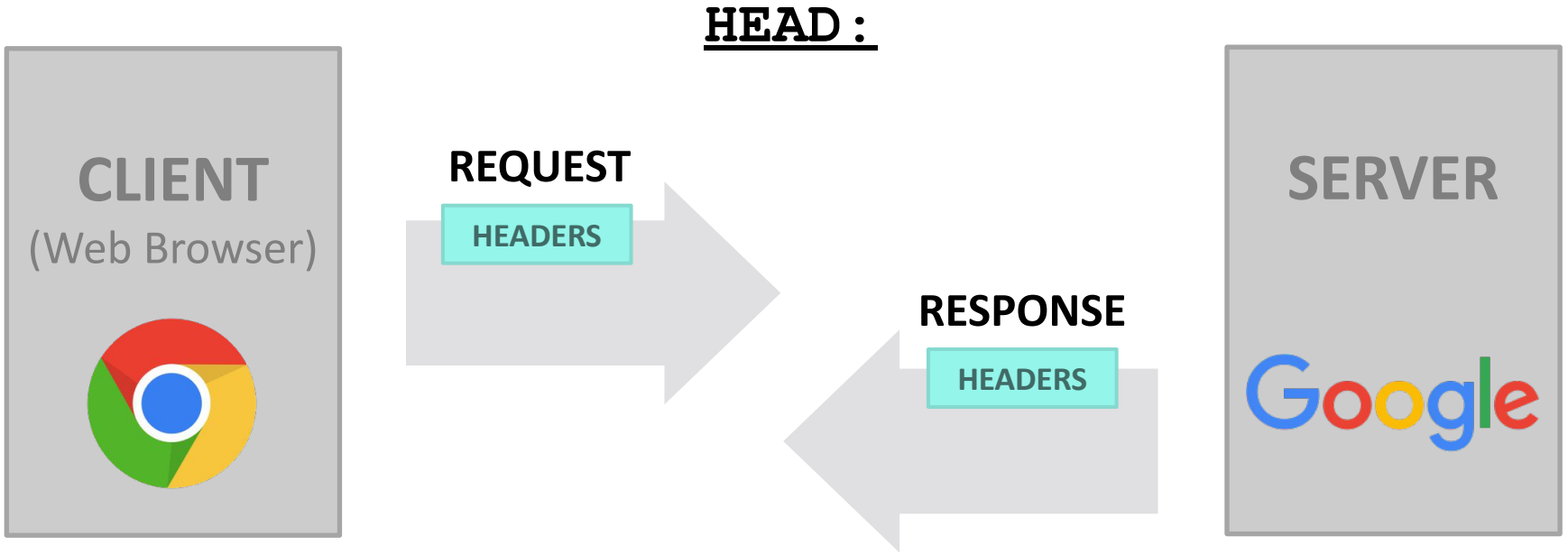
  - `GET`: "Please send me the named resource"
  - `POST`: "I'd like to submit data to you" (*e.g.* file upload)
  - **`HEAD`**: "Send me the headers for the named resource"
    - Doesn't send resource; often to check if cached copy is still valid



HTTP Methods

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  - `GET`: "Please send me the named resource"
  - `POST`: "I'd like to submit data to you" (*e.g.* file upload)
  - `HEAD`: "Send me the headers for the named resource"
    - Doesn't send resource; often to check if cached copy is still valid
- Other methods exist, but are much less common:
  - `PUT`, `DELETE`, `TRACE`, `OPTIONS`, `CONNECT`, `PATCH`, `...`
    - Eg: `TRACE` is "show any proxies or caches in between me and the server"

HTTP Versions

- All current browsers and servers "speak" HTTP/1.1
  - Version 1.1 of the HTTP protocol
    - https://www.w3.org/Protocols/rfc2616/rfc2616.html
  - Standardized in 1997 and meant to fix shortcomings of HTTP/1.0
    - Better performance, richer caching features, better support for multihomed servers, and much more
- HTTP/2 standardized mid 2010's (published in 2015)
  - Allows for higher performance but doesn't change the basic web request/response model
  - Will coexist with HTTP/1.1 for a long time
- HTTP/3 standardized in 2023

Client Headers

- The client can provide zero or more request "headers"
  - These provide information to the server or modify how the server should process the request
- You'll encounter many in practice
  - `Host:` the DNS name of the server
  - `User-Agent:` an identifying string naming the browser
  - `Accept:` the content types the client prefers or can accept
  - `Cookie:` an HTTP cookie previously set by the server
  - https://www.w3.org/Protocols/rfc2616/rfc2616-sec5.html

HTTP Responses

- General form:
  - `HTTP/[version] [status code] [reason]\r\n`
    `[headerfield1]: [fieldvalue1]\r\n`
    `[headerfield2]: [fieldvalue2]\r\n`
    `[...]`
    `[headerfieldN]: [fieldvalueN]\r\n`
    `\r\n`
    `[response body, if any]`

Most servers will accept \n newlines also, but \r\n is the standard, so use -C to make sure nc does that.

- Demo: use `nc` as a client to see a real response

A Real Response

```
HTTP/1.1 200 OK
Date: Mon, 21 May 2018 07:58:46 GMT
Server: Apache/2.2.32 (Unix) mod_ssl/2.2.32 OpenSSL/1.0.1e-fips
mod_pubcookie/3.3.4a mod_uwa/3.2.1 Phusion_Passenger/3.0.11
Last-Modified: Mon, 21 May 2018 07:58:05 GMT
ETag: "2299e1ef-52-56cb2a9615625"
Accept-Ranges: bytes
Content-Length: 82
Vary: Accept-Encoding,User-Agent
Connection: close
Content-Type: text/html
Set-Cookie:
bbbbbbbbbbbbbbb=DBMLFDMJCGAOILMBPIIAAIFLGBAKOJNNMCJIKKBKCDMDEJHMPONHCILPI
BLADEAKCIABMEEPAOPMMKAOLHOKJMIGMIDKIHNCANAPHMFMBLBABPFENPDANJAPIBOIOOOD;
HttpOnly

<html><body>
<font color="chartreuse" size="18pt">Awesome!!</font>
</body></html>
```

Status Codes and Reason

- *Code*: numeric outcome of the request – easy for computers to interpret
  - A 3-digit integer with the 1st digit indicating a response category
    - `1xx`: Informational message
    - `2xx`: Success
    - `3xx`: Redirect to a different URL
    - `4xx`: Error in the client's request
    - `5xx`: Error experienced by the server
- *Reason*: human-readable explanation
  - *e.g.* "OK" or "Moved Temporarily"

Common Statuses

- `HTTP/1.1 200 OK`
  - The request succeeded and the requested object is sent
- `HTTP/1.1 404 Not Found`
  - The requested object was not found
- `HTTP/1.1 301 Moved Permanently`
  - The object exists, but its name has changed
    - The new URL is given as the "`Location:`" header value
- `HTTP/1.1 500 Server Error`
  - The server had some kind of unexpected error

Server Headers

- The server can provide zero or more response "headers"
  - These provide information to the client or modify how the client should process the response
- You'll encounter many in practice
  - `Server:` a string identifying the server software
  - `Content-Type:` the type of the requested object
  - `Content-Length:` size of requested object
  - `Last-Modified:` a date indicating the last time the request object was modified
  - https://www.w3.org/Protocols/rfc2616/rfc2616-sec6.html

Cool HTTP/1.1 Features

- "Chunked Transfer-Encoding"
  - A server might not know how big a response object is
    - *e.g.* dynamically-generated content in response to a query or other user input
  - How do you send Content-Length?
    - Could wait until you've finished generating the response, but that's not great in terms of *latency* – we want to start sending the response right away
  - Chunked message body: response is a series of chunks

Cool HTTP/1.1 Features

- Persistent connections
  - Establishing a TCP connection is costly
    - Multiple network round trips to set up the TCP connection
    - TCP has a feature called "slow start"; slowly grows the rate at which a TCP connection transmits to avoid overwhelming networks
  - A web page consists of multiple objects and a client probably visits several pages on the same server
    - Bad idea: separate TCP connection for each object
    - Better idea: single TCP connection, multiple requests

20 years later…

- World has changed since HTTP/1.1 was adopted
  - Web pages were a few hundred KB with a few dozen objects on each page, now several MB each with hundreds of objects (JS, graphics, …) & multiple domains per page
  - Much larger ecosystem of devices (phones especially)

- Many hacks used to make HTTP/1.1 performance tolerable
  - Multiple TCP sockets from browser to server
  - Caching tricks; JS/CSS ordering and loading tricks; cookie hacks
  - Compression/image optimizations; splitting/sharding requests
  - etc., etc. …

HTTP/2

- HTTP/2 standardized in 2015
  - Supported by all major browsers and servers since ~2015
  - Doesn't change the basic web request/response model
  - Will coexist with HTTP/1.1 for a long time

HTTP/2

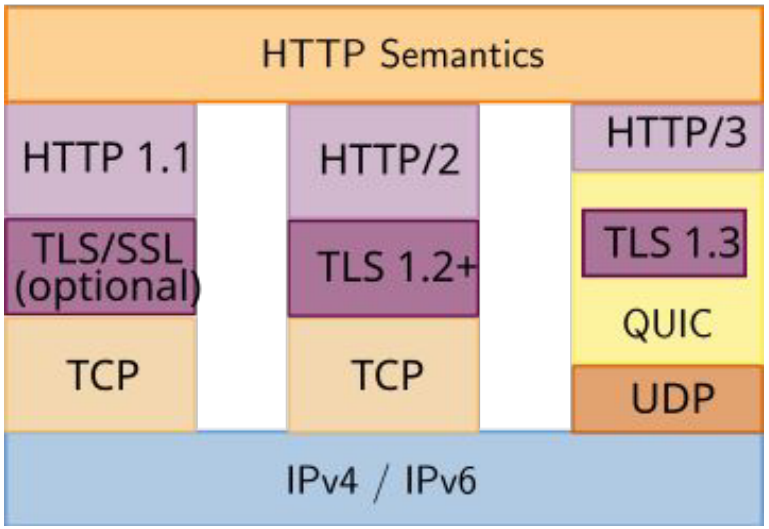
- Based on Google SPDY
  - Binary protocol - easier parsing by machines (harder for humans); sizes in headers, not discovered as requests are processed; …
    - But same core request/response model (GET, POST, OK, …)
  - Multiple data steams multiplexed on single TCP connections
  - Header compression, server push, object priorities, more…
- All existing implementations incorporate TLS encryption (https)

Another 10 years later…

- Websites are made up of **many** resources now
- Many of those resources come from different servers
- Almost all web traffic is encrypted (HTTPS)
- Devices switch networks often (cellular to wifi, etc)
- TCP starts to be a bottleneck
  - Initial connection involves many steps, especially when TLS is added on top
  - Multiple resources sharing a connection means that one dropped packet can block everything

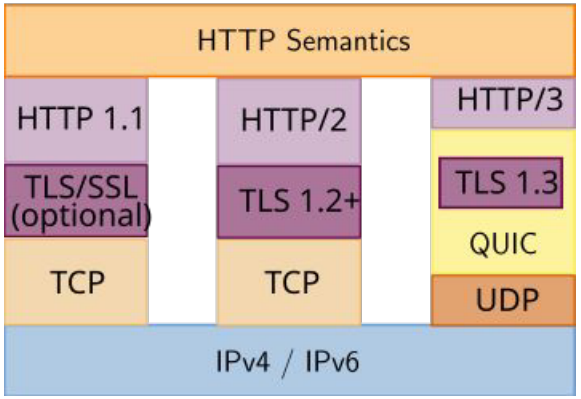
HTTP/3

- Up to 4x faster!
- Replaces TCP with QUIC, a UDP-based protocol
- In the works for a long time (first parts in 2012)



HTTP/3

- Faster encryption
  - Brings encryption into the initial handshake for fewer round-trips
  - Each packet is encrypted individually, so that you don't have to wait for more data to decrypt
- Less blocking
  - Packet recovery is **per-stream**
  - If a packets gets lost when retrieving one file, other files downloads can keep going while the first is retransmitted
- Faster network switching



Extra Exercise #1

- Write a program that:
  - Creates a listening socket that accepts connections from clients
  - Reads a line of text from the client
  - Parses the line of text as a DNS name
  - Connects to that DNS name on port 80
  - Writes a valid HTTP request for "/"
    - ```
      GET / HTTP/1.1\r\n
      Host: <DNS name>\r\n
      Connection: close\r\n
      \r\n
      ```
  - Reads the reply and returns it to the client
      ```