Poll Everywhere

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Which concept did you find the most difficult in the context of Homework 3?

A. The index file layout

B. C++ Classes & Inheritance

C. C++ STL

D. Query Processor Algorithm

E. GDB/Valgrind

F. Style considerations

G. Prefer not to say

Systems Programming
Hypertext Transfer Protocol

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Relevant Course Information

- Exercise 16 due Wednesday (3/4)
  - Server-side programming
  - Can use ex15 client solution to send messages to ex16 server
- Homework 4 due next Thursday (3/12)
  - Can still use 2 late days for HW4 (hard deadline of 3/15)
  - Part of section this week will cover tools for debugging HW4
- Final Exam in just over two weeks (Wednesday, 3/18)
  - Final review session on Friday (3/13) 4:30–6:20 PM
  - Locations KNE 110 & KNE 120
  - Ed post with forthcoming details (NOT cumulative)
  - Practice finals and solutions on course website

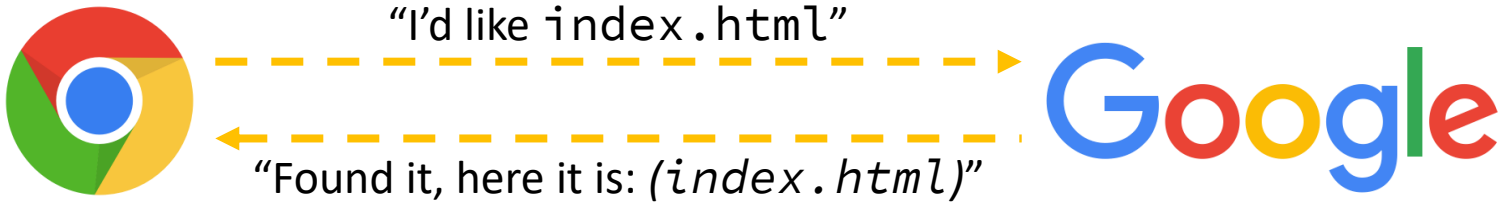
Homework 4 Summary & Demo

- Build a Multithreaded Web Server (333gle)
  - You will host the querying service that you built in your previous homework on a web server
- Running your server
  - `./http333d <port> <static files> <unit indices>`
  - Static files are the files on disk corresponding to our index files
  - You (and others on the Husky VPN) can access it via browser now!
- Implementation
  - Using network protocols to communicate between client/server
  - Handling some additional security flaws
  - Multithreading is already implemented for you

Client and Server Communication

- Lecture 21 (Client-side and Server-side Networking) has already shown how to do this in C/C++
  - `sendreceive.cc` and `server_accept_rw_close.cc`

- This is what actually happens on the web!
  - Clients establish a stable TCP connection the server
  - Lots of bytes are interchanged/processed between each other



Case Study of Protocols: HTTP

- A **protocol** defines a set of rules governing the *format* and *exchange* of messages in a computing system
  - Syntax: The formatting or grammar of the system
  - Semantics: What messages are being exchanged
  - Allows everyone be on the same page of communication

- **H**yper**t**ext **T**ransfer **P**rotocol: Request/Response Protocol
  - HTTP defines how we should send information between a client and a server
  - A **request** will send a message to the server (about anything)
  - A **response** will process and respond to that message
  - And it's human-readable!

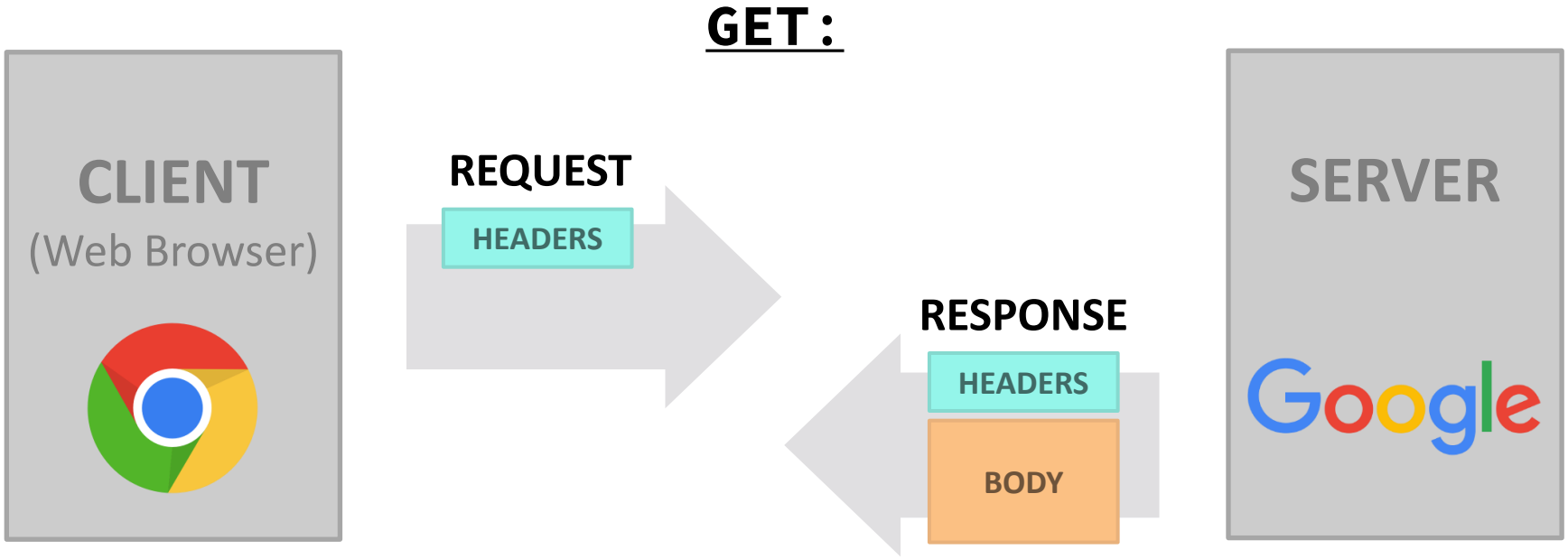
Requests: Client Sending Messages

- A client wants to talk to a server about something
  - Initiates a conversation (establish or using existing connection)
  - Generally, this is for retrieving a resource, using **Uniform Resource Identifier (URI)**

- Standard Syntax:
  - `[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]`

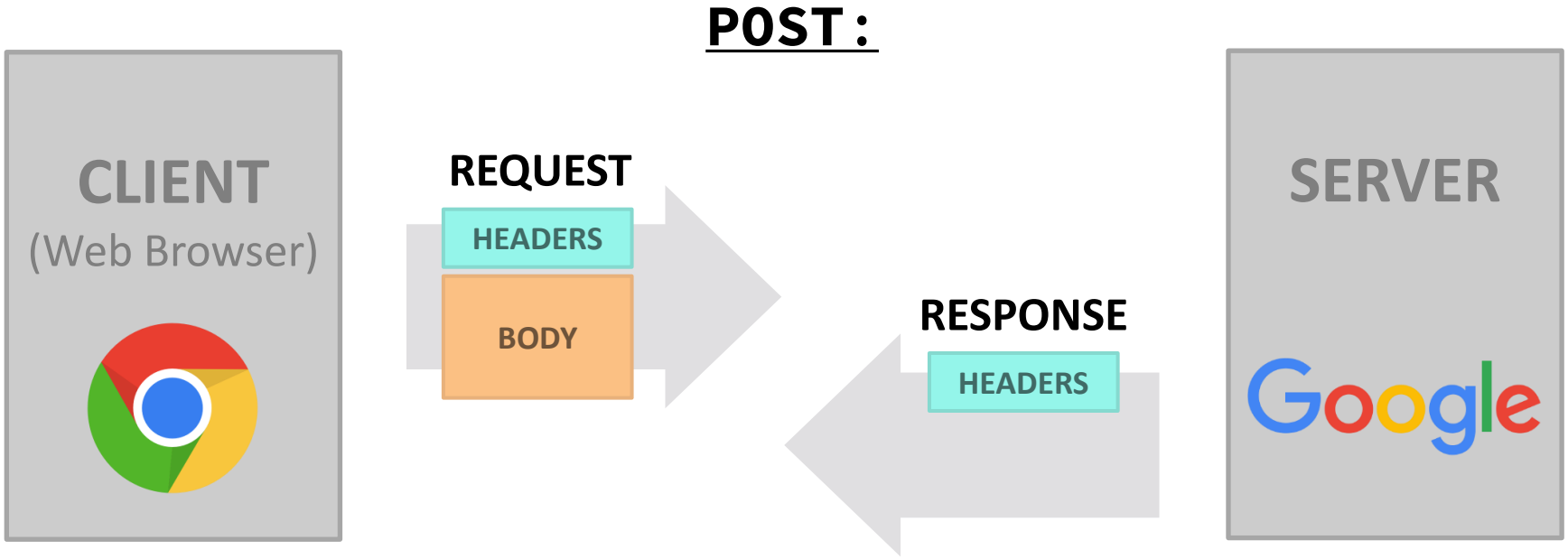
HTTP Methods (1/4)

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



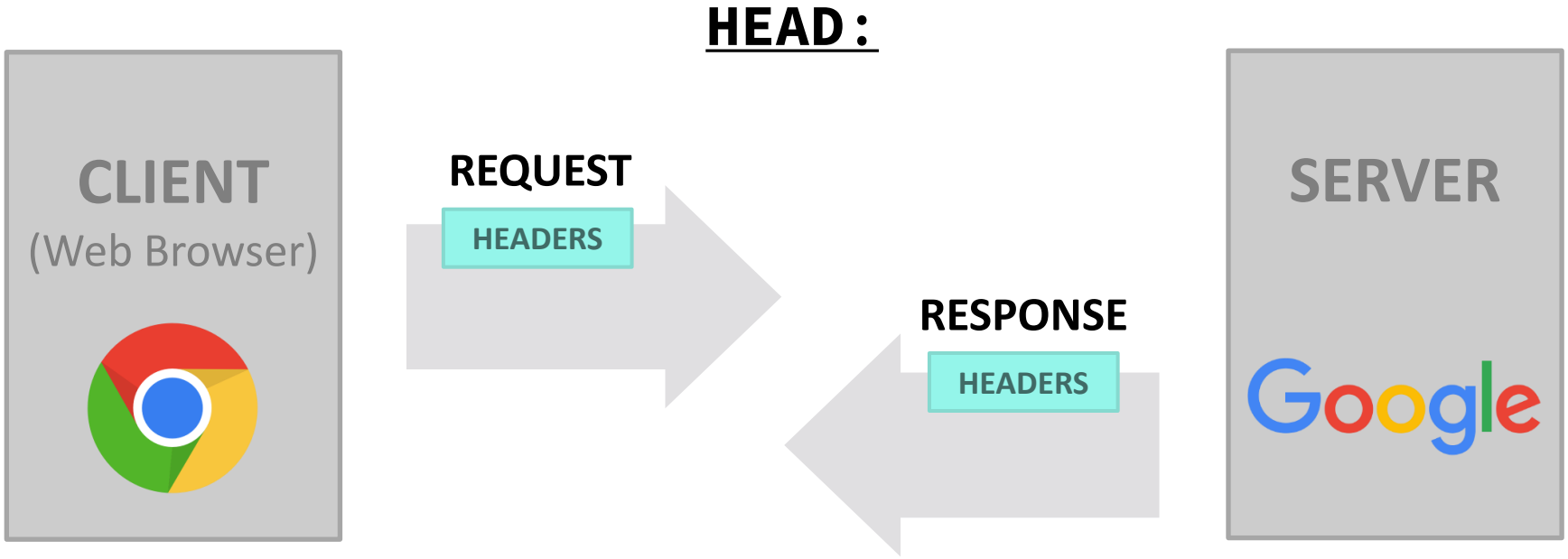
HTTP Methods (2/4)

- There are three commonly-used HTTP methods:
  - GET: "Please send me the named resource"
  - **POST**: "I'd like to submit data to you" (*e.g.*, file upload)



HTTP Methods (3/4)

- There are three commonly-used HTTP methods:
  - 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 (4/4)

- There are three commonly-used HTTP methods:
  - `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`, `...`
    - For instance: `TRACE` – "show any proxies or caches in between me and the server"
  - https://developer.mozilla.org/en-US/docs/Web/HTTP/Methods

Client Headers

- The client can provide one 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.rfc-editor.org/rfc/rfc2616.html#section-5.3

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
Cookie:
SESS0c8e598bbe17200b27e1d0a18f9a42bb=5c18d7ed6d369d56b69a1
c0aa441d
...
```

- Demo: Use nc to see a real HTTP request

Response: Server Responding

- A server parses and sends a response to a user
  - Indicate how the server processed the request (accepted or not)
  - Send requested resource back to the client

- 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]

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"

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://developer.mozilla.org/en-US/docs/Web/HTTP/Headers
  - https://developer.mozilla.org/en-US/docs/Web/HTTP/Basics_of_HTTP/MIME_types

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
Content-Length: 82
Content-Type: text/html
...
<html><body>
<font color="chartreuse" size="18pt">Awesome!!</font>
</body></html>
```

- Demo: Use `nc -C` to see real HTTP responses

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Which statements are FALSE about the HTTP/1.1 Protocol?

A. HTTP/1.1 is a flexible and efficient protocol

B. A client always sends a message first before the server

C. An HTTP Request can only request one resource at a time

D. An HTTP Response needs to have a response body

E. We're not really sure…

HTTP/1.1 Protocol

Extra (non-testable) material

- HTTP / 1.1 (1997) – The protocols accepted by **all current browsers and servers**
  - Built after HTTP/0.9 (1991) and HTTP/1.0 (1996)
  - Better performance, richer caching features, better support for multihomed servers, and much more
- "Chunked Transfer-Encoding" – Send responses in multiple pieces (`Transfer-Encoding: chunked`)
  - https://en.wikipedia.org/wiki/List_of_HTTP_header_fields#transfer-encoding-response-header
- Persistent Connections: TCP connections can handle multiple requests (`Connection: keep-alive`)

Improvements: HTTP/2 and HTTP/3

Extra (non-testable) material

- Human-readable text protocols can only go so far
- HTTP/2 (2015) was a push to optimize HTTP/1.1
  - Built off Google Project SPDY which aimed to reduce latency
  - Compressed headers and message body
  - Many larger companies quickly transitioned
  - https://en.wikipedia.org/wiki/HTTP/2
- HTTP/3 (2022) builds even more on HTTP/2
  - Mainly using UDP-based protocol called QUIC (holds a standard connection like TCP)
  - https://en.wikipedia.org/wiki/HTTP/3

Slow to Change: HTTP Protocols

Extra (non-testable) material

- HTTP/1.1 is still used today (1996 – Present)
  - ~15% of requests still use HTTP/1.1 in 2024 (2 years ago)
    - https://almanac.httparchive.org/en/2024/http#fig-2
  - Down from ~43% of requests 7 years ago
    - https://almanac.httparchive.org/en/2019/http#fig-3
- Why is the transition taking so long?
  - Lack of knowledge about HTTP/2+
  - A good portion of web servers are still using HTTP/1.1
  - It takes engineering work to support a new HTTP protocol
  - HTTP/1.1 is human readable
  - Amongst more…

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