HW 2: HTTP Server

CS 162

Due: March 5, 2019

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1 Introduction

The Hypertext Transport Protocol (HTTP) is the most commonly used application protocol on the Internet today. Like many network protocols, HTTP uses a client-server model. An HTTP client opens a network connection to an HTTP server and sends an HTTP request message. Then, the server replies with an HTTP response message, which usually contains some resource (file, text, binary data) that was requested by the client.

In this assignment, you will implement an HTTP server that handles HTTP GET requests. You will provide functionality through the use of HTTP response headers, add support for HTTP error codes, create directory listings with HTML, and create a HTTP proxy. The request and response headers must comply with the HTTP 1.0 protocol found here[1].

1.1 Getting Started

Log in to your VM and grab the skeleton code from the staff repository:

```
$ cd ~/code/personal
$ git pull staff master
$ cd hw2
```

1.2 Setup Details

The CS 162 Vagrant VM is set up with a special host-only network that will allow your host computer (e.g. your laptop) to connect directly to your VM. The IP address of your VM is `192.168.162.162`.

You should be able to run `ping 192.168.162.162` from your host computer (e.g. your laptop) and receive ping replies from the VM. If you are unable to ping the VM, you can try setting up port forwarding in Vagrant instead (more information here[2]).

[1] http://www.w3.org/Protocols/HTTP/1.0/spec.html
[2] https://docs.vagrantup.com/v2/networking/forwarded_ports.html

2 Background

2.1 Structure of HTTP Request

The format of a HTTP request message is:

- an HTTP request line (containing a method, a query string, and the HTTP protocol version)
- zero or more HTTP header lines
- a blank line (i.e. a CRLF by itself)

The line ending used in HTTP requests is CRLF, which is represented as `\r\n` in C.

Below is an example HTTP request message sent by the Google Chrome browser to a HTTP web server running on localhost (127.0.0.1) on port 8000 (the CRLF's are written out using their escape sequences):

```
GET /hello.html HTTP/1.0\r\n
Host: 127.0.0.1:8000\r\n
Connection: keep-alive\r\n
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;q=0.8\r\n
User-Agent: Chrome/45.0.2454.93\r\n
Accept-Encoding: gzip,deflate,sdch\r\n
Accept-Language: en-US,en;q=0.8\r\n
\r\n
```

Header lines provide information about the request[3]. Here are some HTTP request header types:

- **Host**: contains the hostname part of the URL of the HTTP request (e.g. `inst.eecs.berkeley.edu` or `127.0.0.1:8000`)
- **User-Agent**: identifies the HTTP client program, takes the form "Program-name/x.xx", where x.xx is the version of the program. In the above example, the Google Chrome browser sets User-Agent as `Chrome/45.0.2454.93`.

[3] For a deeper understanding, open the web developer view on your web browser and look at the headers sent when you request any webpage

2.2 Structure of HTTP Response

The format of a HTTP response message is:

- an HTTP response status line (containing the HTTP protocol version, the status code, and a description of the status code)
- zero or more HTTP header lines
- a blank line (i.e. a CRLF by itself)
- the content requested by the HTTP request

The line ending used in HTTP requests is CRLF, which is represented as `\r\n` in C.

Here is a example HTTP response with a status code of 200 and an HTML file attached to the response (the CRLF's are written out using their escape sequences):

```
HTTP/1.0 200 OK\r\n
Content-Type: text/html\r\n
Content-Length: 128\r\n
\r\n
<html>\n
<body>\n
<h1>Hello World</h1>\n
<p>\n
Let's see if this works\n
</p>\n
</body>\n
</html>\n
```

Typical status lines might be `HTTP/1.0 200 OK` (as in our example above), `HTTP/1.0 404 Not Found`, etc.

The status code is a three-digit integer, and the first digit identifies the general category of response:

- 1xx indicates an informational message only
- 2xx indicates success
- 3xx redirects the client to another URL
- 4xx indicates an error in the client
- 5xx indicates an error in the server

Header lines provide information about the response. Here are some HTTP response header types:

- **Content-Type**: the MIME type of the data attached to the response, such as `text/html` or `text/plain`
- **Content-Length**: the number of bytes in the body of the response

3 Your Assignment

3.1 HTTP Webserver Outline

From a network standpoint, your basic HTTP web server should implement the following:

1. Create a listening socket and bind it to a port
2. Wait a client to connect to the port
3. Accept the client and obtain a new connection socket
4. Read in and parse the HTTP request
5. Do **one** of two things: (determined by command line arguments)
   - Serve a file from the local file system, or yield a 404 Not Found
   - Proxy the request to another HTTP server.

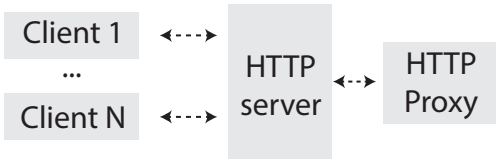


Figure 1: when using a proxy, the http server serves requests by streaming them to a remote http server (proxy). responses from the proxy are sent back to clients.

   The httpserver will be in **either** file mode or proxy mode. It does not do both things at the same time.
6. Send the appropriate HTTP response header and attached file/document back to the client (or an error message)

The skeleton code already implements steps 1-4. **Your deliverables are to implement step 5, step 6, and additionally a thread pool for serving multiple HTTP requests concurrently.** `libhttp.c/h` will help you with steps 5 and 6, and `wq.c/h` will help you with the thread pool.

3.2 Usage ./httpserver

Here is the usage string for httpserver. The argument parsing step has been implemented for you:

```
$ ./httpserver --help
Usage: ./httpserver --files files/ --port 8000 [--num-threads 5]
       ./httpserver --proxy inst.eecs.berkeley.edu:80 --port 8000 [--num-threads 5]
```

The available options are:

- `--files` — Selects a directory from which to serve files. You should be serving files from the hw2/ folder (e.g. if you are currently cd'ed into the hw2/ folder, you should just use "`--files files/`".
- `--proxy` — Selects an "upstream" http server to proxy. The argument can have a port number after a colon (e.g. inst.eecs.berkeley.edu:80). If a port number is not specified, port 80 is the default.
- `--port` — Selects which port the http server listens on for incoming connections. Use in both files mode and proxy mode. (This is different from the proxy port.)

- `--num-threads` — Indicates the number of threads in your thread pool that are able to concurrently serve client requests. This argument is initially unused and it is up to you to use it properly.

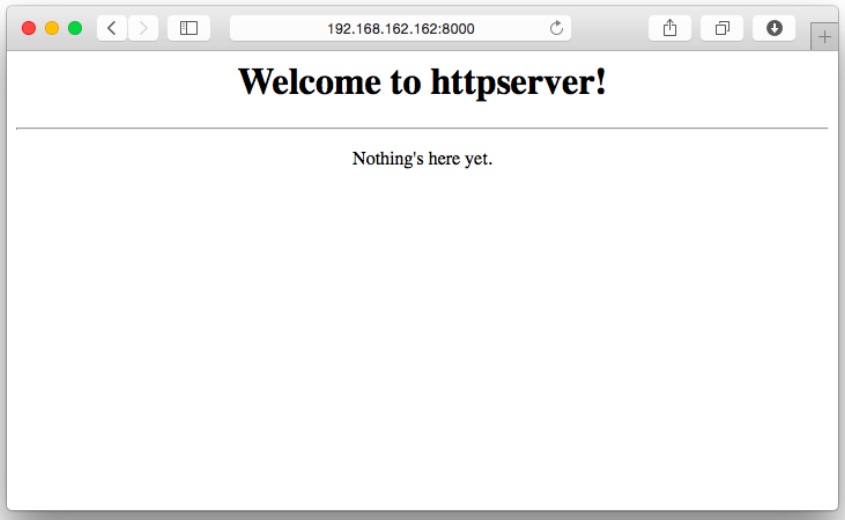
You should not specify both `--files` and `--proxy` at the same time, or the later option will override any earlier one. The `--proxy` option can also take an IP address.

Initially, the `--num-threads` argument is unused and optional. It is your task to use it for implementing your thread pool — your final solution must use the argument properly. It is ok to eventually remove single-threaded functionality and make the `--num-threads` argument required.

If you want to use a port number between 0 and 1023, you will need to run your http server as root. These ports are the "reserved" ports, and they can only be bound by the root user. You can do this by running "`sudo ./httpserver --files files/`".

3.3 Accessing the http server

Check that your http server works by opening your web browser and going to http://192.168.162.162:8000/.



You can also send HTTP requests with the `curl` program, which is installed on your VM. An example of how to use curl is:

```
$ curl -v http://192.168.162.162:8000/
```

You can also open a connection to your HTTP server directly over a network socket using netcat (nc), and type out your HTTP request (or pipe it from a file):

```
$ nc -v 192.168.162.162 8000
Connection to 192.168.162.162 8000 port [tcp/*] succeeded!
(Now, type out your HTTP request here.)
```

3.4 Common error messages

3.4.1 Failed to bind on socket: Address already in use

This means you have an httpserver running in the background. This can happen if your code leaks processes that hold on to their sockets, or if you disconnected from your VM and never shut down your httpserver. You can fix this by running "`pkill -9 httpserver`". If that doesn't work, you can specify a different port by running "`httpserver --files files/ --port 8001`", or you can reboot your VM with "`vagrant reload`".

3.4.2 Failed to bind on socket: Permission denied

If you use a port number that is less than 1024, you may receive this error. Only the root user can use the "well-known" ports (numbers 1 to 1023), so you should choose a higher port number (1024 to 65535).

3.5 Your Assignment

1. Implement `handle_files_request(int fd)` to handle HTTP GET requests for files. This function takes in the connection socket fd obtained in step 3 of the outline above. Your handler should:

   - Use the value of the `--files` command line argument, which contains the path where the files are. (This is stored in the global variable `char *server_files_directory`)
   - If the HTTP request's path corresponds to a file, respond with a 200 OK and the full contents of the file. (e.g. if `GET /index.html` is requested, and a file named `index.html` exists in the files directory) You should also be able to handle requests to files in subdirectories of the files directory (e.g. `GET /images/hero.jpg`)

     Hints:

     – Look in `libhttp.h` for a bunch of useful helper functions! An example of their usage is provided in the skeleton code and some documentation can be found in the appendix.
     – Make sure you set the correct `Content-Type` HTTP header. A helper function in `libhttp.h` will return the MIME type of a file. (This is really the only header you need to implement to get images/documents to display properly.)
     – Also make sure you set the correct `Content-Length` HTTP header. The value of this header should be the size of the HTTP response body, measured in bytes. For example, `Content-Length: 7810`.
     – HTTP request paths **always begin with a `/`**, even if you are requesting the home page (e.g. `http://inst.eecs.berkeley.edu/` would have a request path of `/`).
   - If the HTTP request's path corresponds to a directory and the directory contains an `index.html` file, respond with a 200 OK and the full contents of the index.html file. (You may not assume that directory requests will have a trailing slash in the query string.)

     Hints:

     – To tell the difference between files and directories, you may find the **stat()** function and the **S_ISDIR** or **S_ISREG** macros useful
     – You do not need to handle file system objects other than files and directories (e.g. you do not need to handle symbolic links, pipes, special files)
     – Make helper functions to re-use similar code when you can. It will make your code easier to debug!
   - If the request corresponds to a directory and the directory does not contain an `index.html` file, respond with an HTML page containing links to all of the immediate children of the directory (similar to `ls -1`), **as well as a link to the parent directory**. (A link to the parent directory looks like `<a href="../">Parent directory</a>`)

     Hints:

     – To list the contents of a directory, good functions to use are `opendir()` and `readdir()`
     – Links in HTTP can use relative paths or absolute paths. It is just like how `cd usr/` and `cd /usr/` do two entirely different things.
     – You don't need to worry about extra slashes in your links (e.g. `//files///a.jpg` is perfectly fine). Both the file system and your web browser are tolerant of it.
     – Don't forget to set the `Content-Type` header.
   - Otherwise, return a 404 Not Found response (the HTTP body is optional). There are many things that can go wrong during an HTTP request, but we only expect you to support the 404 Not Found error message for a non-existent file.
   - You only need to handle one HTTP request/response per connection when serving files. You do not need to implement connection keep-alive or pipelining for this section.

2. Implement a fixed-sized thread pool for handling multiple client request concurrently.

   - Use the `pthreads` thread library that we've discussed in section. The section handout is a good resource.
   - Your thread pool should be able to concurrently serve exactly `--num-threads` clients and no more. Note that we typically use `--num-threads + 1` threads in our program: the original thread is responsible for `accept()`-ing client connections in a while loop and dispatching the associated requests to be handled by the threads in the thread pool.
   - Begin by looking at the functions in `wq.c/h`.
     - The original thread (i.e. the thread you started the `httpserver` program with) should `wq_push` the client socket file descriptors received from `accept` into the `wq_t work_queue` declared at the top of `httpserver.c` and defined in `wq.c/h`.
     - Then, threads in the thread pool should use `wq_pop` to get the next client socket file descriptor to handle.
     - Most of the functionality of the work queue is written to you in `wq.c`. However, the skeleton implementation of `wq_pop` is non-blocking (it should be), and neither `wq_pop` nor `wq_push` are thread-safe. Your task is fix this.
   - In addition to implementing the blocking work queue, you'll need to make your server spawn `--num-threads` new threads which will sit in a loop and:
     - Make blocking calls to `wq_pop` for the next client socket file descriptor.
     - After succefully popping a to-be-served client socket fd, call the appropriate `request_handler` to handle the client request.

   Hints:

   - Get man page documentation for the appropriate synchronization primatives by running the following command:
     `$ sudo apt-get install glibc-doc`.
   - Read the man pages (or use Google-fu) for `pthread_cond_init` and `pthread_mutex_init`. You'll need both of these synchronization primitives.

3. Implement `handle_proxy_request(int fd)` to proxy HTTP requests to another HTTP server.

   We've already handled the connection setup code for you. You should read and understand it, but you don't need to modify it. In short, here is what we have done:

   - We use the value of the `--proxy` command line argument, which contains the address and port number of the upstream HTTP server. (These two values are stored in the global variables `char *server_proxy_hostname` and `int server_proxy_port`.
   - We do a DNS lookup of the server_proxy_hostname, which will look up the IP address of the hostname (check out gethostbyname2()).
   - We create a network socket and connect it to the IP address that we get from DNS. Check out socket() and connect().
   - htons() is used to set the socket's port number (integers in memory are little-endian, whereas network stuff expects big-endian). Also note that HTTP is a `SOCK_STREAM` protocol.

   Now comes your part! Here is what you need to take care of:

   - Wait for new data on both sockets (the HTTP client fd, and the upstream HTTP server fd). When data arrives, you should immediately read it to a buffer and then write it to the other socket. You are essentially maintaining 2-way communication between the HTTP client and the upstream HTTP server. **Your proxy must support multiple requests/responses.**
     Hints:

  - This is more tricky than writing to a file or reading from stdin, since you do not know which side of the 2-way stream will write data first, or whether they will write more data after receiving a response. In proxy mode, you will find that multiple HTTP request/responses are sent within the same connection, unlike your HTTP server which only needs to support one request/response per connection.
  - You should again use pthreads for this task. Consider using two threads to facilitate the two-way communication, one from A to B and the other from B to A. It is ok to use multiple threads to serve a single client proxy request, as long as your implementation can still only serve exactly `--num-threads` clients and no more.
  - You'll need to use `client_socket_fd`.
  - **Do not use** `select()`, `fcntl()`, or the like. We used to recommended this approach in previous semesters but we've found this method to be too confusing.
- If either of the sockets closes, communication cannot continue, so you should close the other socket and exit the child process.

3.6 Submission

To submit and push to autograder, first commit your changes, then do:

```
git push personal master
```

Within 30 minutes you should receive an email from the autograder. (If you haven't received an email within half an hour, please notify the instructors via a private post on Piazza.)

A Function reference: libhttp

We have provided some helper functions to deal with the details of the HTTP protocol. They are included in the skeleton as `libhttp.c` and `libhttp.h`. These functions only implement a small fraction of the entire HTTP protocol, but they are more than enough for this assignment.

A.1 Example usage

Reading a HTTP request from a socket `fd` only involves a single function call.

```
// Returns NULL if an error was encountered.
struct http_request *request = http_request_parse(fd);
```

Sending a HTTP response is a multi-step process. First, you should send the HTTP status line using `http_start_response`. Then, you can send any number of headers with `http_send_header`. After all the headers are sent, you MUST call `http_end_headers` (even if you didn't send a single header). Finally, you can use `http_send_string` (for null-terminated C strings) or `http_send_data` (for binary data) to send your data.

```
http_start_response(fd, 200);
http_send_header(fd, "Content-type", http_get_mime_type("index.html"));
http_send_header(fd, "Server", "httpserver/1.0");
http_end_headers(fd);
http_send_string(fd, "<html><body><a href='/'>Home</a></body></html>");
http_send_data(fd, "<html><body><a href='/'>Home</a></body></html>", 47);
close(fd);
```

A.2 Request object

A `http_request` struct pointer is returned by `http_request_parse`. This struct contains just two members:

```
struct http_request {
  char *method;
  char *path;
};
```

A.3 Functions

- `struct http_request *http_request_parse(int fd)`
  Returns a pointer to a `http_request` struct containing the HTTP method and the path that of a request that is read from the socket. This function will return `NULL` if the request is invalid. This function will block until data is available on `fd`.
- `void http_start_response(int fd, int status_code)`
  Writes the HTTP status line to `fd` to start the HTTP response. For example, when `status_code` is `200`, the function will produce `HTTP/1.0 200 OK\r\n`
- `void http_send_header(int fd, char *key, char *value)`
  Writes a HTTP response header line to `fd`. For example, if `key` is equal to `"Content-Type"` and the `value` is equal to `"text/html"` this function will write `Content-Type: text/html\r\n`
- `void http_end_headers(int fd)`
  Writes a CRLF (`\r\n`) to `fd` to indicate the end of the HTTP response headers.

- `void http_send_string(int fd, char *data)`
  Alias for `http_send_data(fd, data, strlen(data))`.
- `void http_send_data(int fd, char *data, size_t size)`
  Sends `data` to `fd`. If `data` is too large to be written all at once, this function will call `write()` in a loop to send the data one piece at a time.
- `char *http_get_mime_type(char *file_name)`
  Returns a string for the correct `Content-Type` based on `file_name`.