</> Project 01: Networking

The goal of this project is to allow you to practice using low-level system calls related to networking along with object-oriented programming. To do this, you will create two new programs in Python:

1. `thor.py` : This is a basic HTTP client that will **hammer** a remote HTTP server by making multiple requests.
2. `spidey.py` : This is a basic HTTP server that supports directory listings, static files, and CGI scripts.

Once you have these programs, you will conduct an **experiment** using `thor.py` to test the latency and throughput of `spidey.py` .

For this assignment, you are to work in **groups** of `1` , `2` , or `3` and record your source material in the `project01` folder of your **project** Bitbucket repository and push your work by **11:59 PM Wednesday, April 20, 2016**.

</> Low-level Networking System Calls

For this project, you **must** use the **low-level** networking operations discussed in class: socket.socket, socket.bind, socket.listen, socket.connect, socket.accept, and socket.makefile.

This means that you **cannot** use the SocketServer framework or any other high-level networking libraries such as urllib.

Time Management and Incremental Development

This is a **big project**, which is why you have more time than usual and are allowed to work in groups. To complete this successfully, you will need to start **early** and work on it **incrementally**.

Activity 0: Readings + Bitbucket

Readings

The following readings provide a background into sockets and creating HTTP clients and servers in Python:

1. Socket Programming HOWTO

   This provides a short introduction into programming sockets in Python.

2. Let's Build A Web Server. Part 1, Part 2, and Part 3

   This is a series of articles that describe how to build a HTTP server in Python. It has much more information than you need (ie. we will not be implementing WSGI), but it provides a lot of illustrations and explanations. Read this to get an idea of what you will be doing, but don't get bogged down by the details.

3. Lecture 16 - Echo Client and Server

   This is an example of a echo client and server. The `simple_echo_client.py` and `simple_echo_server.py` versions demonstrate the core socket operations required to to implement this simple protocol, while the `echo_client.py` and `echo_server.py` demonstrate more complete versions of these programs by

incorporating object-oriented programming, error checking, logging, and command-line arguments.

Optional References:

1. TCP/IP Client and Server

   This is an overview of the features of the socket module in Python.

2. Python socket - network programming tutorial

   This is a tutorial on programming sockets in Python.

Code re-use

You may use the `echo_client.py` and `echo_server.py` scripts as the basis for `thor.py` and `spidey.py` respectively. In fact, you are encouraged to do so, but you may also choose to write them in anyway you wish as long as you only low-level system calls for sockets.

Bitbucket

Because you will be working in groups, one member of your group is to **fork** the following projects repository on Bitbucket. Once you have **forked** it, you should modify the `README.md` to include the name of the group members and their **netids**.

For this project, the projects repository contains a `project01/www` directory that can server as the `DOCROOT` for the `spidey.py` HTTP server.

Repository Access

Make sure that your repository is **private** and gives **CSE-20189-SP16** at least **write** permissions to your repository.

To facilitate collaboration, the owner of the repository should also give team members **write** access as well.

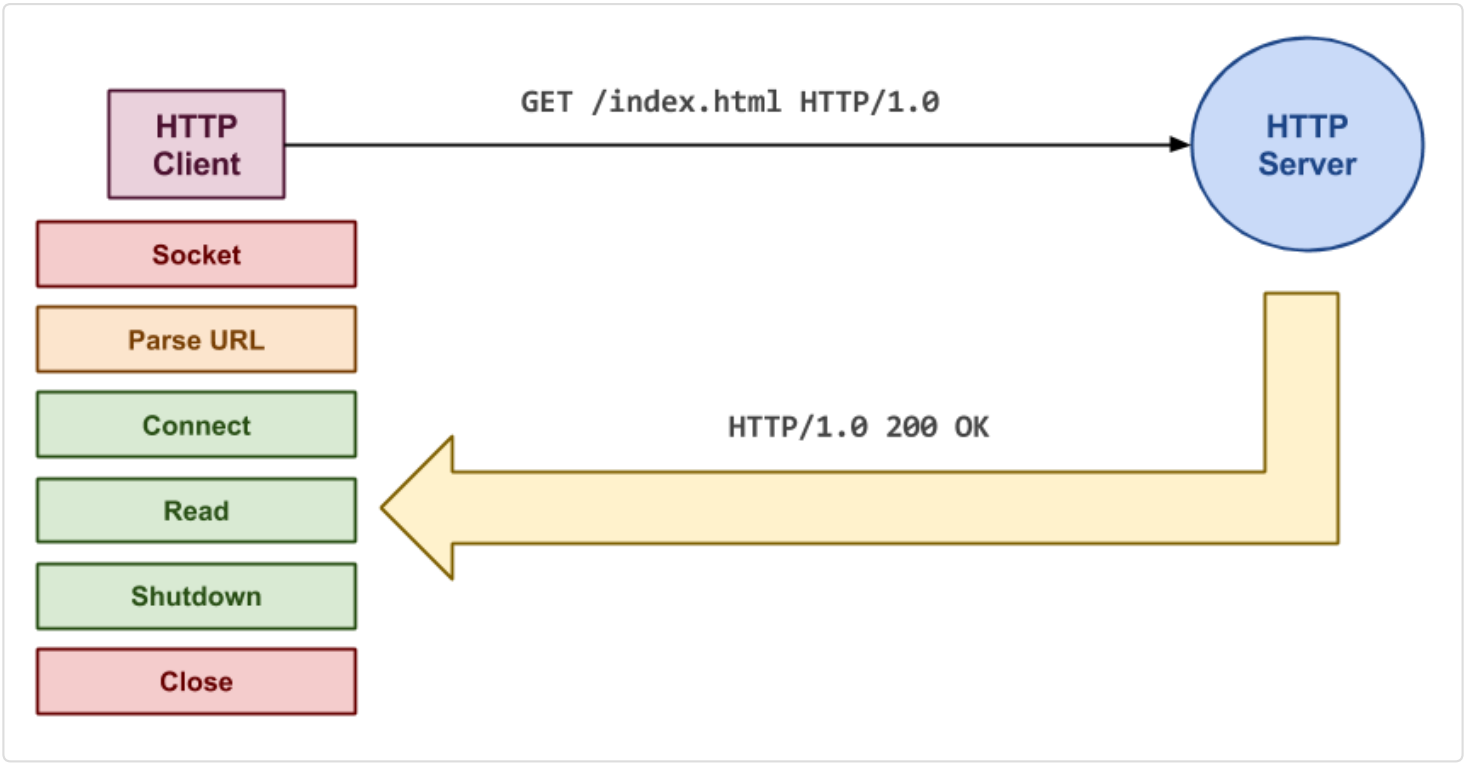
Activity 1: Thor

The first program is `thor.py`, which is a basic HTTP client similar to curl or wget that supports the following features:

1. Performs HTTP **GET** requests.
2. Performs multiple requests per process.
3. Supports utilizing multiple processes.

An example of `thor.py` can be found on the **student** machines at:

```
/afs/nd.edu/user15/pbui/pub/bin/thor
```



Usage

Given a `URL`, `thor.py` uses the HTTP protocol to fetch the contents of the `URL` and dumps them to `stdout`. The `-r` sets the number of HTTP request to be made per process (default is `1`), while `-p` sets the number of processes (default is `1`). The `-v` flag sets the logging level to DEBUG.

Help Message

```
# Display help message
$ ./thor.py
Usage: thor.py [-r REQUESTS -p PROCESSES -v] URL

Options:

    -h           Show this help message
    -v           Set logging to DEBUG level

    -r REQUESTS  Number of requests per process (default is 1)
    -p PROCESSES Number of processes (default is 1)
```

Single Verbose Request

```
# Perform single request with debugging enabled
$ ./thor.py -v example.com
[2016-04-10 14:25:12] URL:  example.com
[2016-04-10 14:25:12] HOST: example.com
[2016-04-10 14:25:12] PORT: 80
[2016-04-10 14:25:12] PATH: /
[2016-04-10 14:25:12] Connected to 93.184.216.34:80...
[2016-04-10 14:25:12] Handle
[2016-04-10 14:25:12] Sending request...
[2016-04-10 14:25:12] Receiving response...
Accept-Ranges: bytes
Cache-Control: max-age=604800
Content-Type: text/html
Date: Sun, 10 Apr 2016 18:25:12 GMT
Etag: "359670651+gzip"
Expires: Sun, 17 Apr 2016 18:25:12 GMT
Last-Modified: Fri, 09 Aug 2013 23:54:35 GMT
Server: ECS (mdw/1275)
Vary: Accept-Encoding
X-Cache: HIT
x-ec-custom-error: 1
Content-Length: 1270
Connection: close

<!doctype html>
<html>
<head>
    <title>Example Domain</title>

    <meta charset="utf-8" />
    <meta http-equiv="Content-type" content="text/html; charset=utf-8" />
    <meta name="viewport" content="width=device-width, initial-scale=1" />
    <style type="text/css">
    body {
        background-color: #f0f0f2;
        margin: 0;
        padding: 0;
        font-family: "Open Sans", "Helvetica Neue", Helvetica, Arial, sans-serif;

    }
    div {
        width: 600px;
        margin: 5em auto;
        padding: 50px;
        background-color: #fff;
        border-radius: 1em;
    }
    a:link, a:visited {
        color: #38488f;
        text-decoration: none;
    }
    @media (max-width: 700px) {
        body {
            background-color: #fff;
        }
        div {
            width: auto;
            margin: 0 auto;
            border-radius: 0;
```

```
            padding: 1em;
        }
    }
    </style>
</head>

<body>
<div>
    <h1>Example Domain</h1>
    <p>This domain is established to be used for illustrative examples in documents. Y
    domain in examples without prior coordination or asking for permission.</p>
    <p><a href="http://www.iana.org/domains/example">More information...</a></p>
</div>
</body>
</html>
[2016-04-10 14:25:12] Finish
[2016-04-10 14:25:12]  14863 | Elapsed time: 0.02 seconds
[2016-04-10 14:25:12]  14863 | Average elapsed time: 0.02 seconds
[2016-04-10 14:25:12] Process 14863 terminated with exit status 0
```

Multiple Verbose Requests with multiple processes

```
# Hammer time with 10 processes doing 10 requests each
$ ./thor.py -v -p 10 -r 10 example.com 2>&1 > /dev/null | grep Average
[2016-04-10 14:31:58]  15124 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15119 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15122 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15121 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15118 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15127 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15123 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15120 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15126 | Average elapsed time: 0.02 seconds
[2016-04-10 14:31:58]  15125 | Average elapsed time: 0.02 seconds
```

HTTP

Wikipedia has a decent overview of HTTP or the Hypertext Transfer Protocol. A basic client/server session looks like this:

```
# HTTP Client request
GET /index.html HTTP/1.0
Host: www.example.com

# HTTP Server Response
HTTP/1.0 200 OK
Date: Mon, 23 May 2005 22:38:34 GMT
Server: Apache/1.3.3.7 (Unix) (Red-Hat/Linux)
Last-Modified: Wed, 08 Jan 2003 23:11:55 GMT
ETag: "3f80f-1b6-3e1cb03b"
Content-Type: text/html; charset=UTF-8
Content-Length: 138
Accept-Ranges: bytes
Connection: close

<html>
<head>
<title>An Example Page</title>
</head>
<body>
Hello World, this is a very simple HTML document.
</body>
</html>
```

To implement the [client], we suggest that you build off the `echo_client.py` example. Using this as a base, you will need to create a custom `HTTPClient` class that derives from the `TCPClient` class.

Client Request

Given the URL, `http://www.example.com/index.html`, the client will connect to the host `www.example.com` at `port 80` and send the text:

```
GET /index.html HTTP/1.0<CRLF>
Host: www.example.com<cr><CRLF>
<CRLF>
```

Above, the `<CRLF>` represent the carriage return and line feed character because the HTTP standard requires that each line end with `\r\n`. To signal the end of the client request, the client must send an empty line as shown above.

Your `thor.py` should accept URLs in the following format:

```
http://www.example.com
www.example.com
www.example.com/
www.example.com:80/
www.example.com:80/index.html
www.example.com/index.html
www.example.com/index.html?name=value
```

Server Response

Once the server receives the request, it will return a response consisting of some headers followed by an empty line and then the contents of the resource requested.

Your `thor.py` should simply dump the server response to `STDOUT`.

The gory details of HTTP can be found in the HTTP 1.0 RFC 1945.

Hints

1. Use `echo_client.py` as a base for your implementation.
2. Use nc, curl, and wget to explore how HTTP requests are performed.
3. Your core control flow should look like this:

```
# Pseudo-code of core control flow
for process in PROCESS:
    for request in REQUESTS:
        client = HTTPClient(URL)
        client.run()
```

4. To support multiple processes, you should os.fork the specified number of `PROCESSES`, perform the specified number of `REQUESTS`, and then perform the necessary number of os.waits to cleanup the child processes.
5. You should create a `HTTPClient` class similar to the `EchoClient` in the `echo_client.py` example. You will have to create your own **contructor** since the `HTTPClient` takes a URL rather than the `address` and `port`:

```
# HTTPClient class
class HTTPClient(TCPClient):
    def __init__(self, url):
        TCPClient.__init__(self, None, None) # Initialize base class
```

6. The trickiest part of this program will probably be parsing the URL. As shown above, you need to be able to support a wide variety of URLs. I recommend heavily using the str.split method to slice and dice the provided URL. Here is an example:

```
# Parsing URL
self.url = url.split('://')[-1]

if '/' not in self.url:
    self.path = '/'
else:
    self.path = '/' + self.url.split('/', 1)[-1]
```

   In addition to the `path` you will want to determine the `host`, `address`, and `port` of the HTTP server from the given URL.

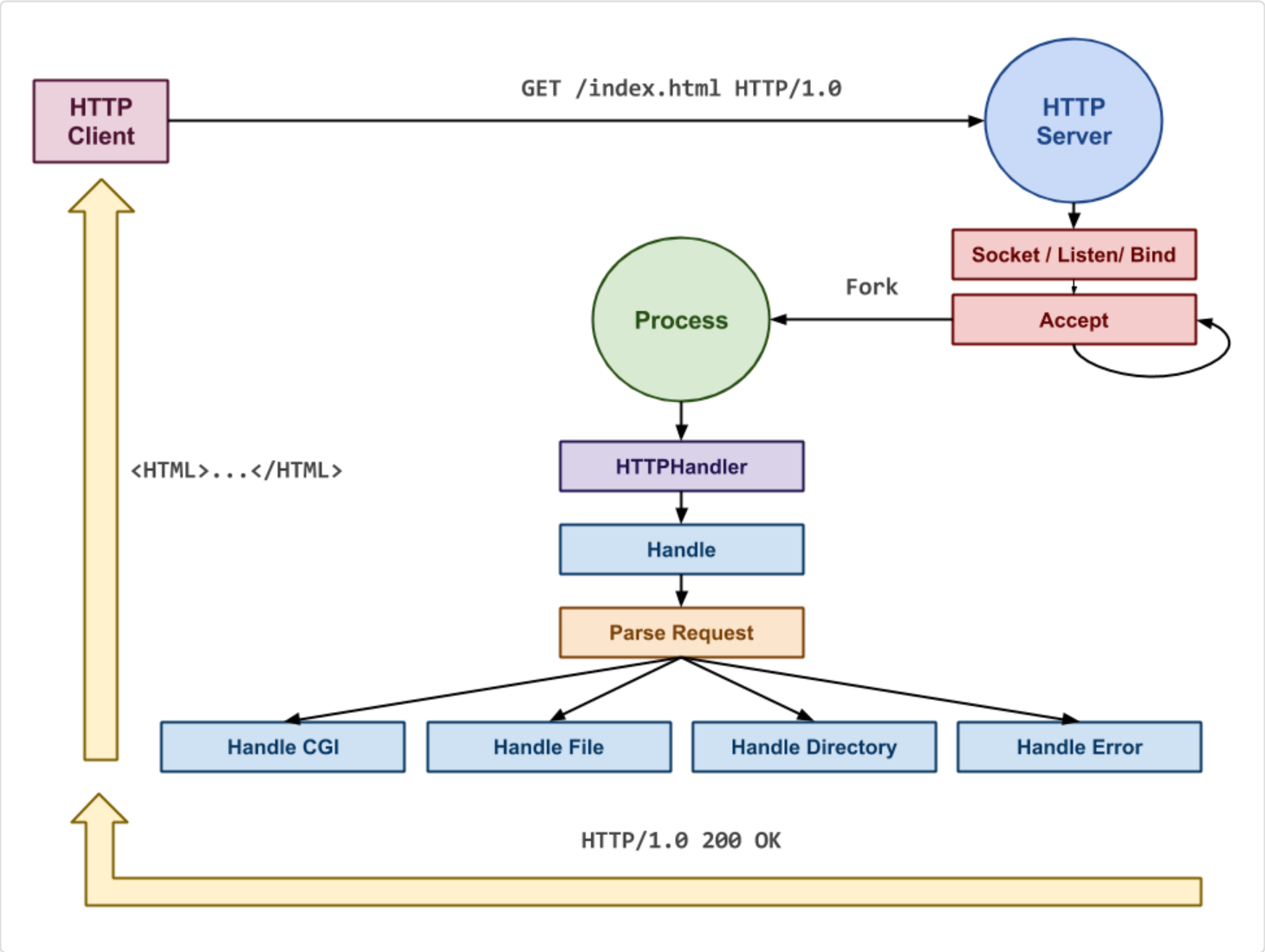
   Alternatively, you can use regular expressions and matching to extract groups using the re module.
7. If the user provides a domain name instead of an ip address, then you will need to use socket.gethostbyname to determine the `address` of the server.
8. The core logic of the `HTTPClient.handle` method is to write the HTTP request to the server as demonstrated above, and then read the response from the server and dump it to `STDOUT`.
9. To measure the time for each request, you can use the time.time function to get the start and end times.
10. You should handle errors gracefully and use the logging module to print debugging messages.

Activity 2: Spidey

The second program is `spidey.py`, which is a basic HTTP server similar to Apache or NGINX that supports the following features:

1. Executing in either single connection mode or forking mode
2. Displaying directory listings
3. Serving static files
4. Running CGI scripts
5. Showing error messages

An example of `spidey.py` in action can be found at: xavier.h4x0r.space:9234.



Usage

When executed, `spidey.py` opens a socket on the `PORT` specified by the `-p` flag (default is `9234`) and handles HTTP requests for files in the `DOCROOT` directory specified by the `-d` flag (default is current directory). If `-f` is specified, then `spidey.py` will for a child process for each incoming client request. The `-v` flag sets the logging level to DEBUG.

Help Message

```
# Display help message
$ ./spidey.py -h
Usage: spidey.py [-d DOCROOT -p PORT -f -v]

Options:

    -h         Show this help message
    -f         Enable forking mode
    -v         Set logging to DEBUG level

    -d DOCROOT Set root directory (default is current directory)
    -p PORT    TCP Port to listen to (default is 9234)
```

Verbose Single Connection Mode

```
# Serve content one connection at a time with debugging enabled
$ ./spidey -v
[2016-04-10 16:28:55] Listening on 0.0.0.0:9234...
[2016-04-10 16:29:01] Accepted connection from 10.63.11.140:59770
[2016-04-10 16:29:01] 10.63.11.140:59770 | Connect
[2016-04-10 16:29:01] 10.63.11.140:59770 | Parsing ['GET', '/', 'HTTP/1.1']
[2016-04-10 16:29:01] 10.63.11.140:59770 | Handle Directory
[2016-04-10 16:29:01] 10.63.11.140:59770 | Finish
[2016-04-10 16:29:01] Accepted connection from 10.63.11.140:59772
[2016-04-10 16:29:01] 10.63.11.140:59772 | Connect
[2016-04-10 16:29:01] 10.63.11.140:59772 | Parsing ['GET', '/favicon.ico', 'HTTP/1.1']
[2016-04-10 16:29:01] 10.63.11.140:59772 | Handle Error
[2016-04-10 16:29:01] 10.63.11.140:59772 | Finish
[2016-04-10 16:29:03] Accepted connection from 10.63.11.140:59774
[2016-04-10 16:29:03] 10.63.11.140:59774 | Connect
[2016-04-10 16:29:03] 10.63.11.140:59774 | Parsing ['GET', '/asdf', 'HTTP/1.1']
[2016-04-10 16:29:03] 10.63.11.140:59774 | Handle Error
[2016-04-10 16:29:03] 10.63.11.140:59774 | Finish
[2016-04-10 16:29:03] Accepted connection from 10.63.11.140:59776
[2016-04-10 16:29:03] 10.63.11.140:59776 | Connect
[2016-04-10 16:29:27] 10.63.11.140:59776 | Finish
```

Verbose Forking Mode with DOCROOT

```
# Serve content concurrently via forking from specified directory with debugging enabl
$ ./spidey -v -f -d www
[2016-04-10 16:35:58] Listening on 0.0.0.0:9234...
[2016-04-10 16:36:04] Accepted connection from 10.63.11.140:59822
[2016-04-10 16:36:04] 10.63.11.140:59822 | Connect
[2016-04-10 16:36:04] 10.63.11.140:59822 | Parsing ['GET', '/', 'HTTP/1.1']
[2016-04-10 16:36:04] 10.63.11.140:59822 | Handle Directory
[2016-04-10 16:36:04] 10.63.11.140:59822 | Finish
[2016-04-10 16:36:07] Accepted connection from 10.63.11.140:59834
[2016-04-10 16:36:07] 10.63.11.140:59834 | Connect
[2016-04-10 16:36:07] 10.63.11.140:59834 | Parsing ['GET', '/songs', 'HTTP/1.1']
[2016-04-10 16:36:07] 10.63.11.140:59834 | Handle Directory
[2016-04-10 16:36:07] 10.63.11.140:59834 | Finish
```

HTTP

As noted above, HTTP works in a **request** and **response** communication model. To implement the server, we suggest that you build off the `echo_server.py` example. Using this as a base, you will need to create a custom `HTTPHandler` that derives from the `BaseHandler` class.

Client Request

Once a connection is established, then the `HTTPHandler.handle` method should call an internal `_parse_request` method that reads and parses the HTTP request. For instance, given the following HTTP request:

```
GET /cgi-bin/env.sh?name=value HTTP/1.1
Host: xavier.h4x0r.space:9234
Connection: keep-alive
Cache-Control: max-age=0
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;q=0.8
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (X11; Linux x86_64) AppleWebKit/537.36 (KHTML, like Gecko) Chr
Accept-Encoding: gzip, deflate, sdch
Accept-Language: en-US,en;q=0.8
```

This information should get parsed and exported to the process environment (ie. os.environ) in the following manner:

1. The first line contains request with information for `REQUEST_METHOD`, `REQUEST_URI`, and `QUERY_STRING`.

   ```
   QUERY_STRING=name=value
   REQUEST_METHOD=GET
   REQUEST_URI=/cgi-bin/env.sh
   ```

2. All of the lines after the request are the HTTP headers, which should be parsed by splitting the key and value, capitalizing the key, replacing `-` with `_`, and prefixing the key with `HTTP_`. For instance, the key, value pairs above should get translated into:

   ```
   HTTP_ACCEPT_ENCODING=gzip, deflate, sdch
   HTTP_ACCEPT_LANGUAGE=en-US,en;q=0.8
   HTTP_ACCEPT=text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;
   HTTP_CONNECTION=keep-alive
   HTTP_HOST=xavier.h4x0r.space:9234
   HTTP_REFERER=http://xavier.h4x0r.space:9234/cgi-bin
   HTTP_UPGRADE_INSECURE_REQUESTS=1
   HTTP_USER_AGENT=Mozilla/5.0 (X11; Linux x86_64) AppleWebKit/537.36 (KHTML, like G
   ```

Likewise, the [TCP] connection address should be parsed into `REMOTE_ADDR`, `REMOTE_HOST` for the remote client's address, and `REMOTE_PORT` for the port they are using.

```
REMOTE_ADDR=10.63.11.140
REMOTE_HOST=10.63.11.140
REMOTE_PORT=60138
```

All of these pairs need to be exported to os.environ because the CGI scripts will read those variables in order to learn about the current request.

Once the HTTP request and headers have been parsed, the `HTTPClient.handle` method will need to then constructor the `uripath` of the request and then check what type of file it is and dispatch off of that:

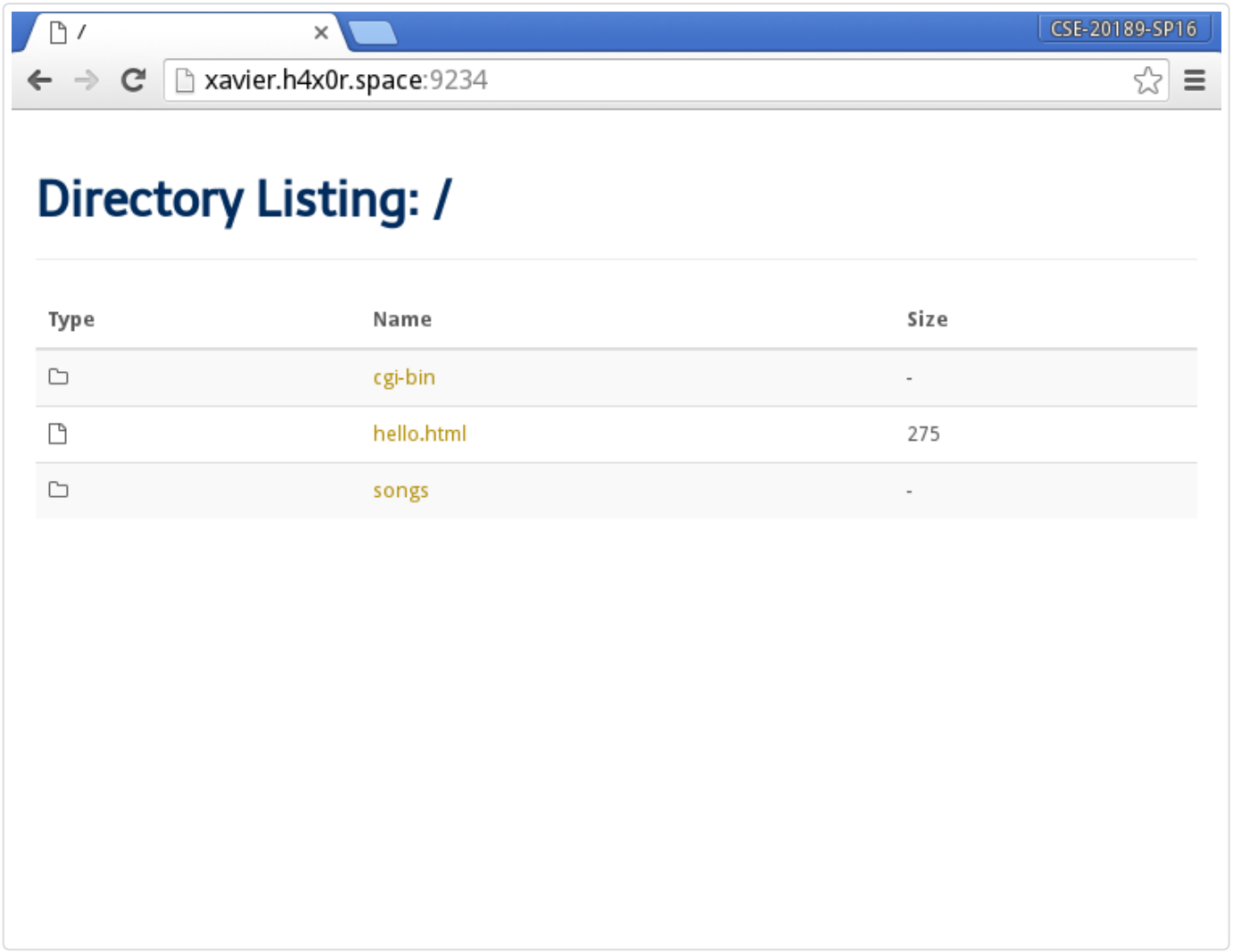
```
# HTTPClient.handle Pseudo-code
def handle(self):
    # Parse HTTP request and headers
    self._parse_request()

    # Build uripath by normalizing REQUEST_URI
    self.uripath = os.path.normpath(self.docroot + os.environ['REQUEST_URI'])

    # Check path existence and types and then dispatch
    if self.uripath does not exist or self.uripath does not start with self.docroot:
        self._handle_error(404) # 404 error
    elif self.uripath is a file and is executable
        self._handle_script()   # CGI script
    elif self.uripath is a file and is readable
        self._handle_file()     # Static file
    elif self.uripath is a directory and is readable
        self._handle_directory()# Directory listing
    else:
        self._handler_error(403)# 403 error
```

The reason why we need to construct the `uripath` is so we know how the requested `URL` maps to the local filesystem. To prevent a malicious user from being able to explore files outside the `DOCROOT`, we use os.path.normpath to normalize the paths and check that the resolved path starts with the `DOCROOT`.

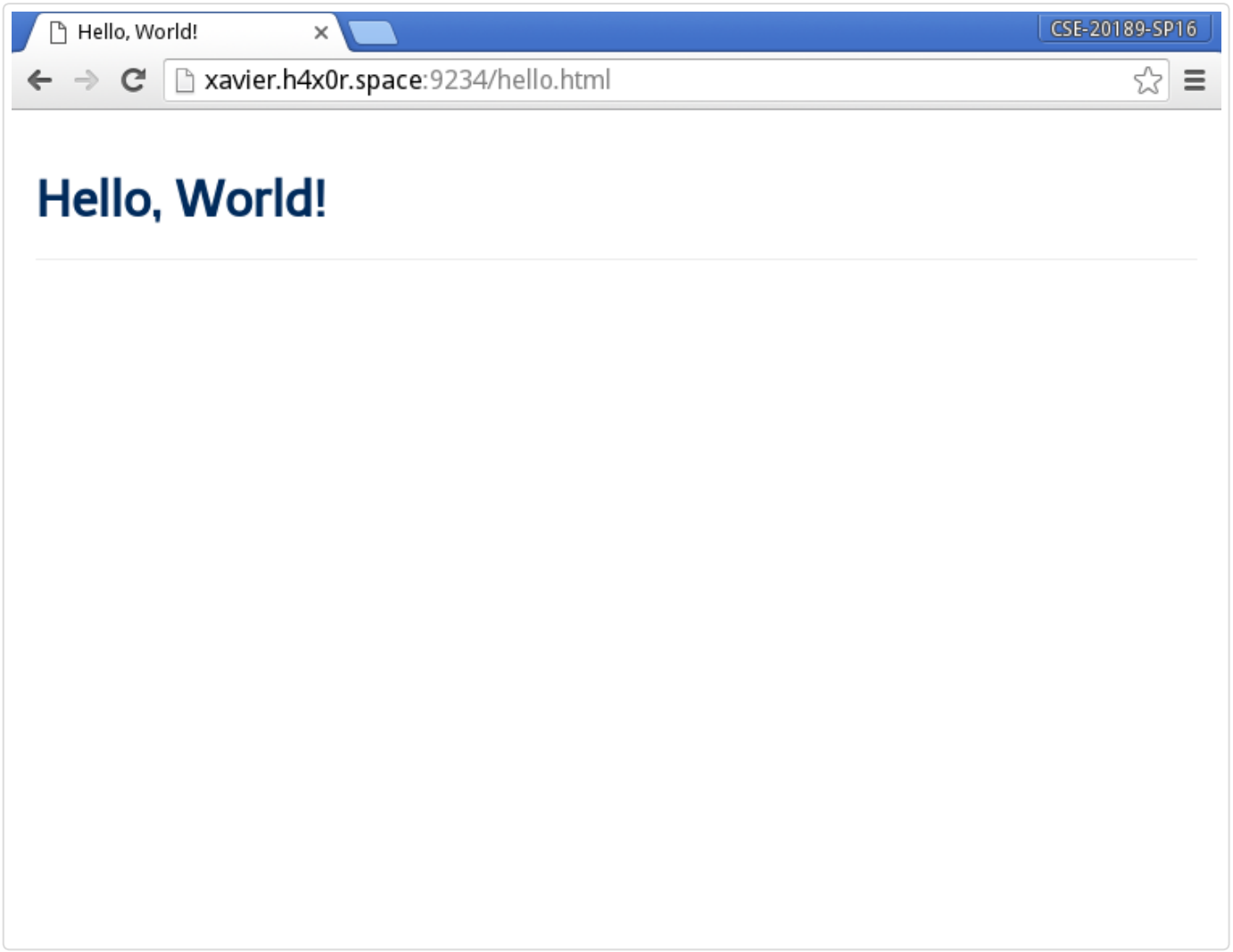
Server Response

As shown above, there are **four** different types of HTTP responses that `spidey.py` should support:

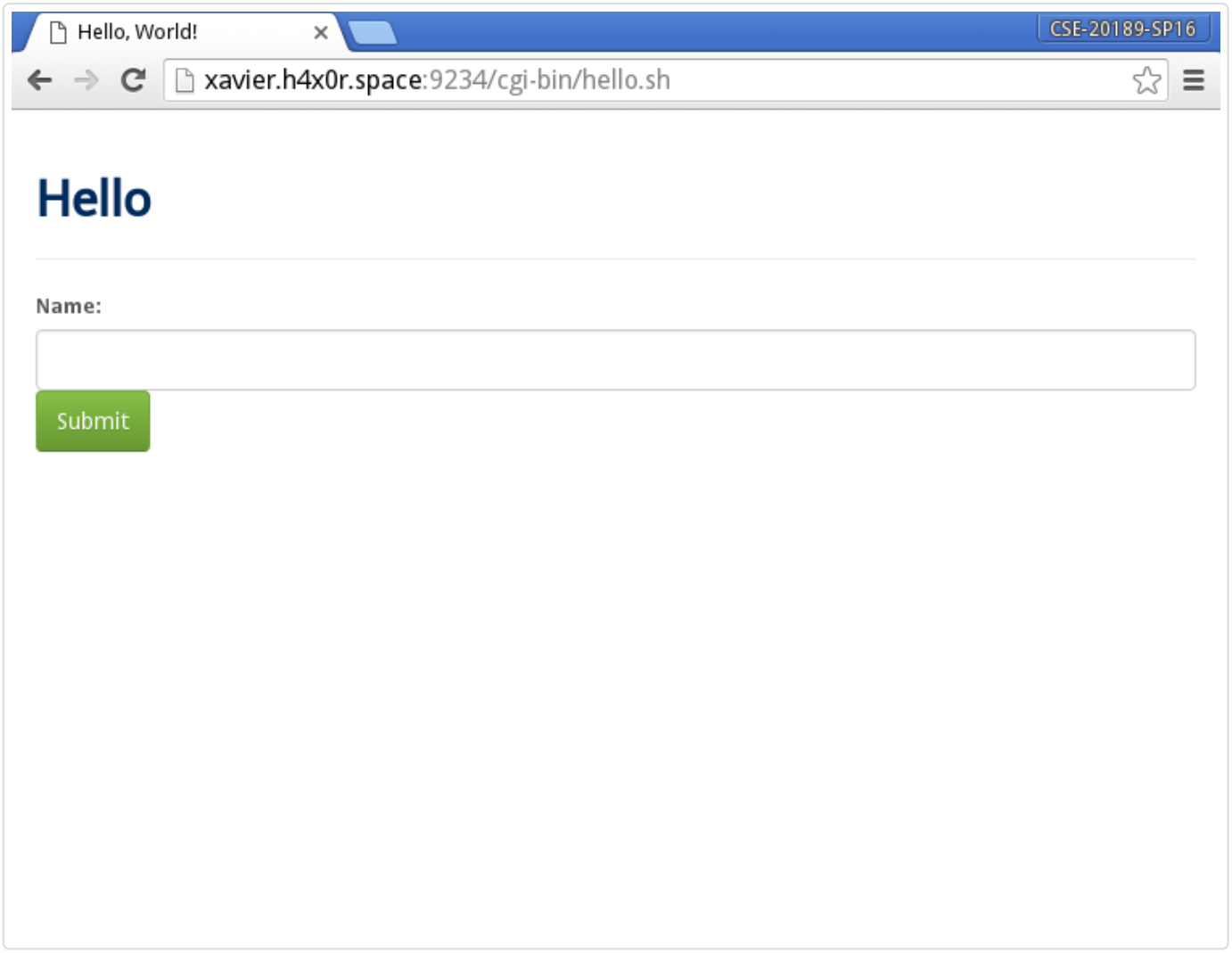
1. **Directory Listing**: This displays a listing of the entries in a directory. At the minimum it should show the name, size, and type of each entry.



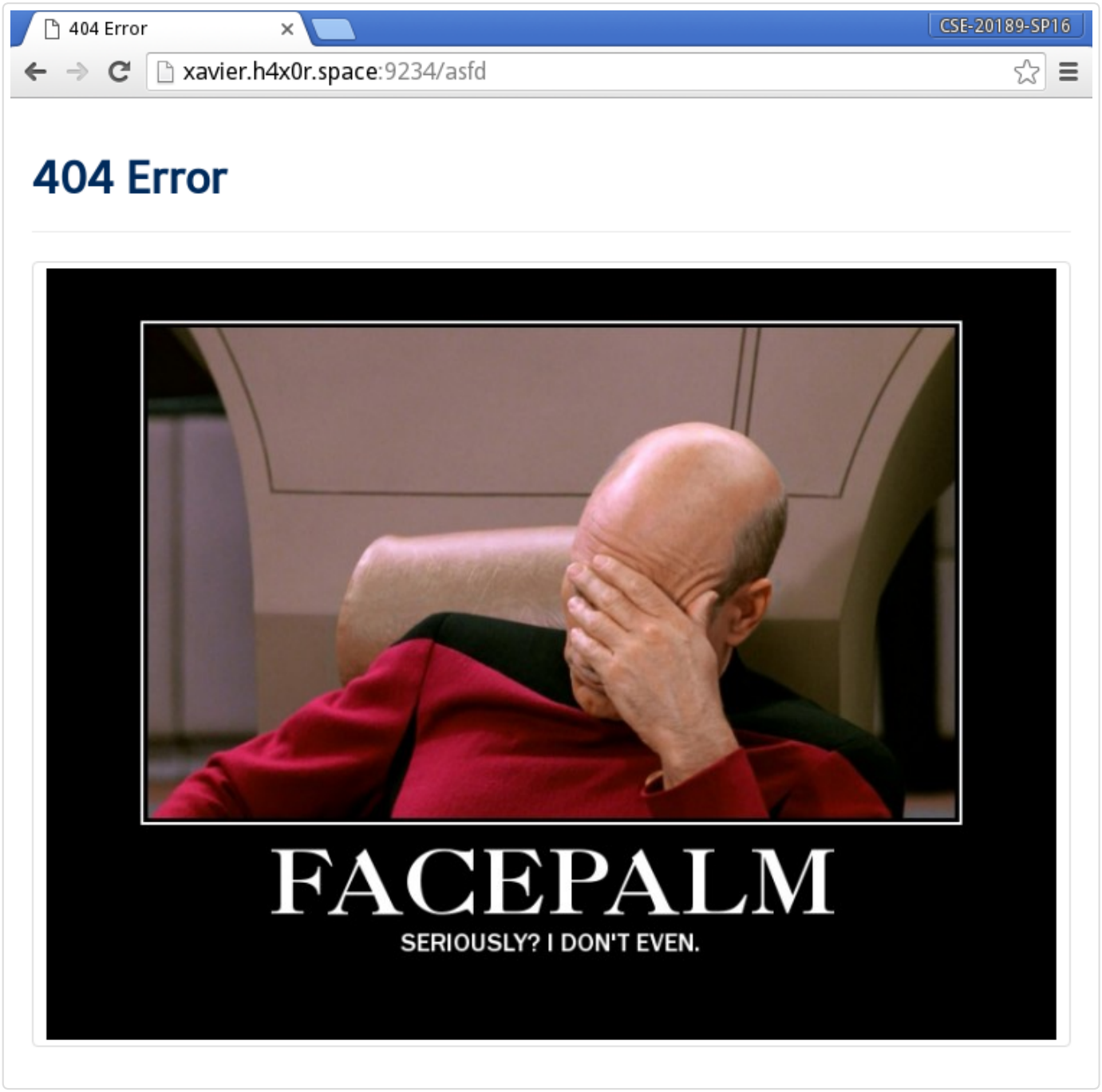
2. **Static File**: This opens the contents of the specified file and streams it back to the client via the socket:



3. **CGI Scripts**: This executes a script on the server and streams the results back to the client via the socket:



4. **Errors**: This displays a HTTP error and a funny picture:



Note: a valid HTTP response looks like this:

```
HTTP/1.0 200 OK
Content-Type: text/html

<html>
...
</html>
```

The first line contains the HTTP status code for the request. The second line instructs the client (i.e. web browser) what type of data to expect (i.e. mimetype). Each of these lines should be terminated with `\r\n`. Additionally, it is important that after the `Content-Type` line you include a blank line consisting of only `\r\n`. Most web clients will expect this blank line before parsing for the actual content.

Hints

1. Use `echo_server.py` as a base for your implementation.

2. You should create a `HTTPHandler` class similar to the `EchoHandler` in the `echo_server.py` . You will have to create your own **constructor** since the `BaseHandler` does not set a `docroot` instance variable:

```
# HTTPHandler class
class HTTPHandler(BaseHandler):
      def __init__(self, fd, address, docroot=None):
            BaseHandler.__init__(self, fd, address)
```

3. To implement `HTTPHandler._parse_request` , you will once again want to heavily utilize str.split and other string utilities. For example:

```
# Set REMOTE_ADDR from address
os.environ['REMOTE_ADDR'] = self.address.split(':', 1)[0]

# Read stream and set REQUEST_METHOD
data = self.stream.readline().strip().split()
os.environ['REQUEST_METHOD'] = data[0]
```

   Alternatively, you can use regular expressions and matching to extract groups using the re module.

4. To implement `HTTPHandler._handle_file` you will need to determine the file's mimetype using the following

```
mimetype, _ = mimetypes.guess_type(self.uripath)
if mimetype is None:
    mimetype = 'application/octet-stream'
```

   This uses the mimetypes.guess_type function to guess the mimetype and if that fails, then it defaults to `application/octet-stream` .

   Once you know the mimetype, then you should write the HTTP response status to the socket, open the requested file in **binary mode**, and then read from the file and write to the socket until everything has been read from the file.

5. To implement `HTTPHandler._handle_directory` , you will need to construct a HTML page that lists the contents of the directory. To get the contents of the directory, you can use os.listdir and then use the sorted function to order the list.

   To sort the contents of the directory so that directories come before files, you will need to implement a custom comparison function and pass that into the sorted call.

6. To implement `HTTPHandler._handle_script` , you will need to use the os.popen command to execute the script and stream the output of the command to the socket:

```
# Pseudo-code
Set SIGCHLD to Default
for line in Popen(uripath):
    Write line to socket
Set SIGCHLD to Ignore
```

   The reason why we need to set `SIGCHLD` to the default handler is that os.popen needs to catch `SIGCHLD` (it interally **forks** and **execs**) otherwise we will get an exception. After the os.popen we revert back to ignoring our children.

7. To implement `HTTPHandler._handle_error` , you will need to construct a HTML page that displays the specified error code. I also recommend you insert a **jovial** picture for the visitor's amusement.

8. To support **forking** mode, you will need to modify the `run` method of the `TCPServer` class to have the following control flow:

```
# Pseudo-code
Bind and Listen on Socket

Ignore Children

while True:
    Accept Socket into client, address

    if not self.forking:
        self._handle(client, address)
    else:
        Fork

        if Process is Child:
            self._handle(client, address)
            os._exit(0)
        else:
            client.close()
```

   In this model, we **bind** and **listen** to the socket as normal. Rather than wait for each child, we will simply tell the OS that we wish to **ignore** them and let `init` adopt them.

   When we **accept** a connection, we will then check if we have **forking** enabled. If not, we do what we normally do. Otherwise, we **fork** and in the child process we handle the connection and then exit via os._exit. In the parent, we simply close the client connection.

Activity 3: Experiments

Once you have completed both `thor.py` and `spidey.py` , you are to conduct **expermients** that answer the following questions:

1. What is the average latency of `spidey.py` in single connection vs forking mode for: directory listings, static files, CGI scripts?
2. What is the average throughput of `spidey.py` in single connection vs forking mode for: small static files (`1KB`), medium static files (`1MB`), and large static files (`1GB`)?

For each question, you must determine how you want to explore the question and how you wish to use `thor.py` to test `spidey.py` .

You should create shell scripts to automate running your experiments multiple times to generate a reasonable amount of data.

Report

After you have conducted your **experiments** and collected your data, you are to generate a charts and diagrams using gnuplot and then use LaTeX to write a report that answers the following questions:

1. **Summary**:

   Summarize what was accomplished in the project (ie. what worked and what didn't work) and how the work was divided among the group members.

2. **Latency**:

Describe how your group went about measuring the average latency of the different types of requests. You should have at least one diagram that illustrates the results of your experiments.

3. **Throughput**:

   Describe how your group went about measuring the average throughput of the different file sizes. You should have at least one diagram that illustrates the results of your experiments.

4. **Analysis**:

   Discuss the results of your experiments and explain why you received the results you did. What are the advantages and disadvantages to the forking model?

5. **Conclusions**:

   Wrap up the report by describing what you learned from not only the experiments but also the lab assignment as a whole.

Guru Point (Point 1)

For extra credit, you are to extend your `spidey.py` web server to do any of the following:

Directory Listings

1. Display thumbnails for images.
2. Display HTML5 audio element for audio files.

CGI Scripts

1. Write a guest book script that allows users to add entries to a running message board.
2. Write a survey or personality test script.
3. Write a multiple-choice quiz script of the topic of your choice.

To receive credit, you must show a TA or the instructor your code and a demonstration of it in action.

Submission

To submit your assignment, please commit your work to the `project01` folder in your **projects** Bitbucket repository by **11:59 PM Wednesday, April 20, 2016**. Your `project01` folder should contain at least the following files:

- `README.md`
- `Makefile`
- `thor.py`
- `spidey.py`
- `report.tex`

You also should include any data you collected for the report, along with the scripts you used to run the experiments and process the data.