p4-web

EECS 280 Project 4: Web

Due 8:00pm Tuesday November 14, 2023. You may work alone or with a partner (partnership guidelines).

Fall 2023 release.

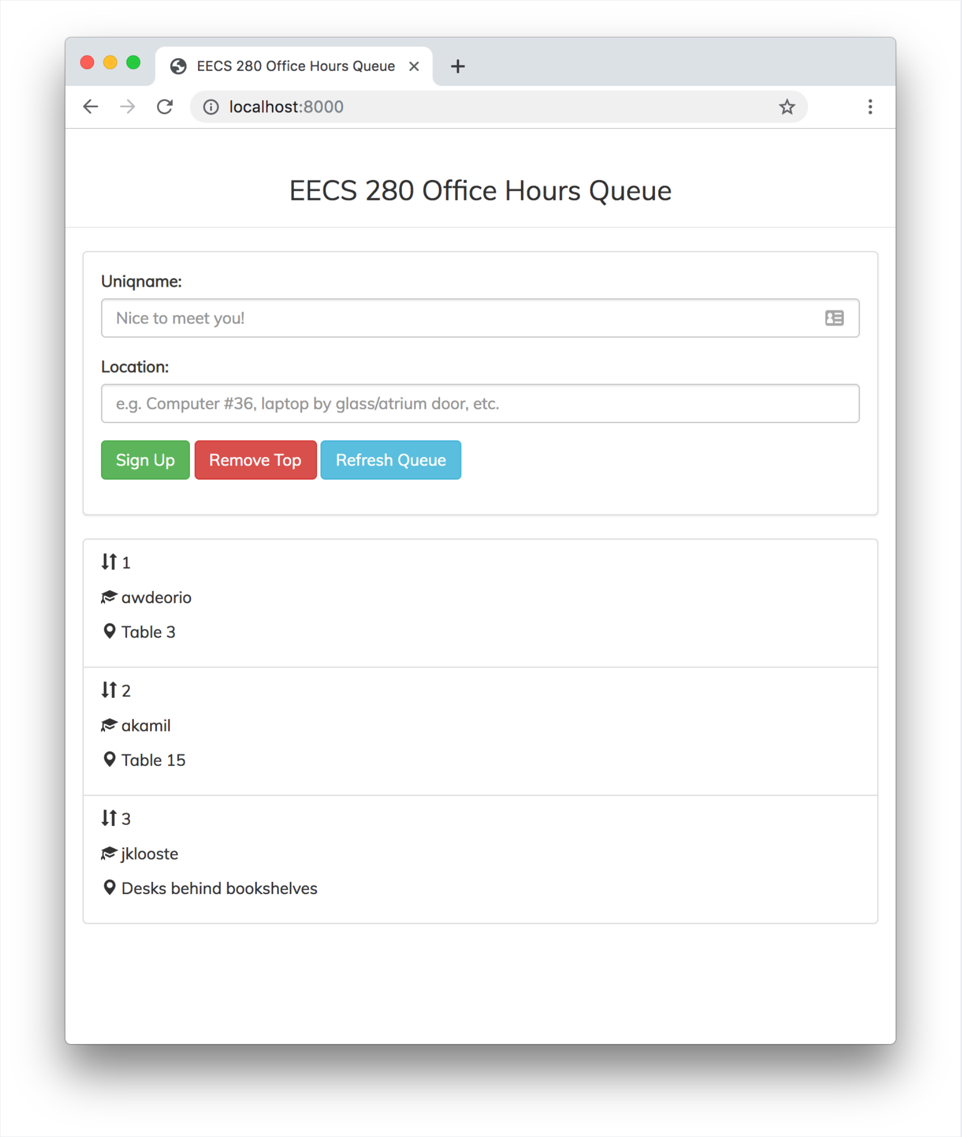
ℹ **IMPORTANT**
For **Fall 2023**, the driver portion of the project that implements the web API (`api.cpp`) is **OPTIONAL** and is **NOT GRADED** on the autograder. The `List.hpp` and `List_tests.cpp` files are all that is required. You are still welcome to do the whole project if you like, or to return to it on your own after the course has finished.

Introduction

Build a web server for an office hours queue.

The learning goals of this project include Container ADTs, Dynamic Memory, The Big Three, Linked Lists, and Iterators. You will gain experience with `new` and `delete`, constructors and destructors, and the `list` data structure.

When you're done, you'll have a working web application accessible through your browser.



EECS 280 Office Hours Queue

Uniqname:

Nice to meet you!

Location:

e.g. Computer #36, laptop by glass/atrium door, etc.

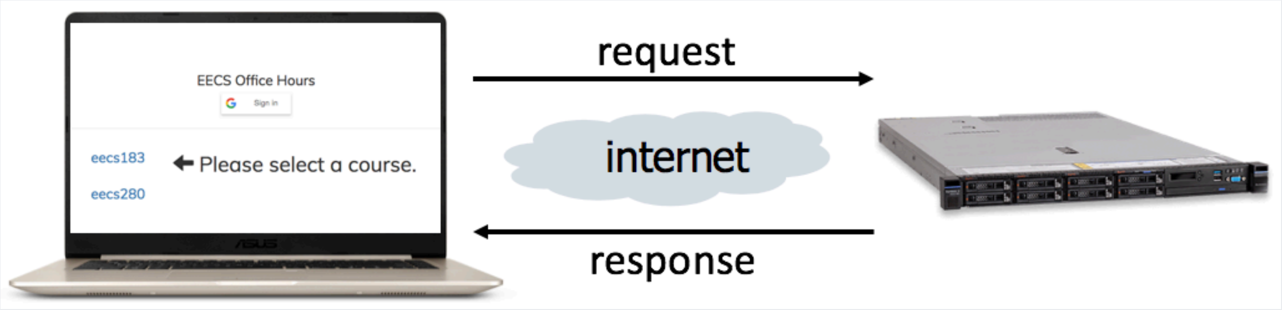
1
awdeorio
Table 3

2
akamil
Table 15

3
jklooste
Desks behind bookshelves

Web app background

When you browse to a web site like our EECS 280 office hours queue http://eecsoh.org, your computer makes a *request* and a server returns a *response*.



Simple web pages

Your web browser makes a request when you visit a page. First, it connects to the `eecsoh.org` server, then requests the `/index.html` page (“no filename” is a shortcut for `index.html`).

```
GET / HTTP/1.1
```

The `eecsoh.org` server responds with plain text in HTML format. Your browser *renders* the HTML, adding colors, formatting and images.

```
HTTP/1.1 200 OK

<html>
  <body>
    EECS Office Hours
    ...
  </body>
</html>
```

HTTP

HTTP is the protocol that describes what requests and responses should look like. Both are plain text sent from one computer to another computer through the internet. Let’s take a second look at the previous example in more detail.

The request contains an action (`GET`), a path (`/eecsoh/`), a version (`HTTP/1.1`) and some headers (`Host: localhost`). Headers are key/value pairs separated by a colon.

```
GET /eecsoh/ HTTP/1.1
Host: localhost
```

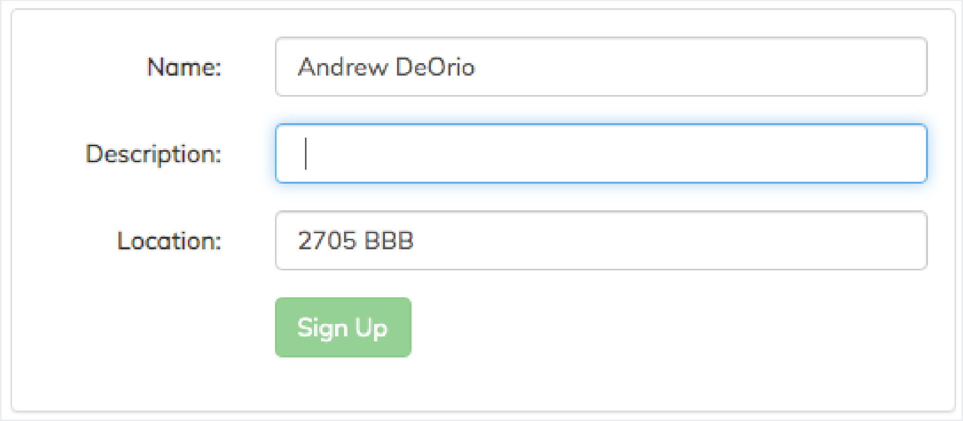
The response contains a version (`HTTP/1.1`), a status code (`200`), status description (`OK`), some headers (`Content-Type ...` and `Content-Length ...`), and a body (`<html> ... </html>`).

```
HTTP/1.1 200 OK
Content-Type: text/html; charset=utf-8
Content-Length: 3316

<html>
  <body>
    EECS Office Hours
    ...
  </body>
</html>
```

Web 2.0 applications

Web 2.0 applications like the EECS 280 office hours queue interact with the user. Let’s take a look at what happens when you click the “Sign Up” button.



Name: Andrew DeOrio

Description:

Location: 2705 BBB

First, the client’s web browser sends an HTTP request to the server. The request might look like this. Notice that the request includes a body with the information entered by the client. The information is in a machine-readable format called JSON.

```
POST /api/queue/tail/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 59

{
    "uniqname": "awdeorio",
    "location": "2705 BBB"
}
```

Next, the server receives the request sent by the client. The server acts on the request.

1. *Deserialize* the JSON data, converting it into a data structure
2. Modify an internal data structure, possibly a list
3. Create a response data structure
4. *Serialize* the response data structure, converting it to JSON
5. Send the response to the client

The response to the client might look like this.

```
HTTP/1.1 201 Created
Content-Type: application/json; charset=utf-8
Content-Length: 78

{
    "location": "2705 BBB",
    "position": 1,
    "uniqname": "awdeorio"
}
```

Finally, the client receives the response and updates the web page, showing the up-to-date queue in this example.

A server that responds to requests with data instead of HTML is called a REST API (REpresentational State Transfer). REST APIs return data in a machine-readable format like JSON.

Our tutorial Working with JSON provides many more details about the JSON format.

Setup

Set up your visual debugger and version control, then submit to the autograder.

Visual debugger

During setup, name your project `p4-web`. Use this starter files link: `https://eecs280staff.github.io/p4-web/starter-files.tar.gz`

VS Code | Visual Studio | Xcode

If you created a `main.cpp` while following the setup tutorial, rename it to `api.cpp`. Otherwise, create a new file `api.cpp`. You should end up with a folder with starter files that look like this. You may have already renamed files like `List.hpp.starter` to `List.hpp`.

```
$ ls
List.hpp                public_error01.in           test03.in
List_compile_check.cpp  public_error01.out.correct  test03.out.correct
List_public_test.cpp    server.py                   test04.in
List_tests.cpp          test01.in                   test04.out.correct
Makefile                test01.out.correct          test05.in
index.html              test02.in                   test05.out.correct
json.hpp                test02.out.correct          unit_test_framework.hpp
```

Here’s a short description of each starter file.

File(s)	Description
`List.hpp.starter`	Starter code for the `List`.
`List_tests.cpp`	Your `List` unit tests.

File(s)	Description
`List_compile_check.cpp`	Compile check test for `List`
`List_public_test.cpp`	A very small test case for `List` .

`test01.in`
`test01.out.correct`
`test02.in`
`test02.out.correct`
`test03.in`
`test03.out.correct`
`test04.in`
`test04.out.correct`
`test05.in`
`test05.out.correct`
	Simple test cases for the server program.

`Makefile`	Helper commands for building.
`json.hpp`	Library for working with JSON.
`unit_test_framework.hpp`	A simple unit-testing framework.
`server.py`	Python wrapper script for running the office hours queue server.
`index.html`	HTML for the office hours queue.

Version control

Set up version control using the Version control tutorial.

After you’re done, you should have a local repository with a “clean” status and your local repository should be connected to a remote GitHub repository.

```
$ git status
On branch main
Your branch is up-to-date with 'origin/main'.

nothing to commit, working tree clean
$ git remote -v
origin  https://github.com/awdeorio/p4-web.git (fetch)
origin  https://githubcom/awdeorio/p4-web.git (push)
```

You should have a `.gitignore` file (instructions).

```
$ head .gitignore
# This is a sample .gitignore file that's useful for C++ projects.
...
```

Group registration

Register your partnership (or working alone) on the Autograder. Then, submit the code you have.

Linked list

Implement your doubly linked list in `List.hpp`. `List.hpp.starter` provides prototypes for each function. Because `List` is a *templated* container, function implementations go in `List.hpp`. There is no `List.cpp`.

While the `List` from lecture was singly linked, this `List` is doubly linked. This `List` also contains an iterator interface.

Do not modify the public interface of the `List` class. Implement a doubly-linked list. No arrays or vectors, etc. Manage memory allocation so that there are no memory leaks (Leak checking tutorial).

Compile and run the provided compile check and `List` tests.

```
$ make List_compile_check.exe
$ make List_public_test.exe
$ ./List_public_test.exe
```

Write tests for `List` in `List_tests.cpp` using the Unit Test Framework. You'll submit these tests to the autograder. See the Unit Test Grading section.

```
$ make List_tests.exe
$ ./List_tests.exe
```

Pro-tip: Getting an error about `typename`? Take a look at our reference on Typename.

Setup

Rename these files (VS Code (macOS), VS Code (Windows), Visual Studio, Xcode, CLI):

- `List.hpp.starter` -> `List.hpp`
- `List_tests.cpp.starter` -> `List_tests.cpp`

Edit `List.hpp`, adding a function stub for each function prototype in `List.hpp`. Here's an example.

```
template<typename T>
bool List<T>::empty() const {
  assert(false);
}
```

The List tests should compile and run. The public tests will fail until you implement the functions. The file for your test cases (`List_tests.cpp`) will pass because it initially only contains `ASSERT_TRUE(true)`.

```
$ make List_public_test.exe
$ ./List_public_test.exe
$ make List_tests.exe
$ ./List_tests.exe
```

At this point, we haven't written the List Iterator, so `List_compile_check.exe` won't compile. You'll need to take a look at the lecture about iterators and write your own tests. After you do, use the provided compile check like this:

```
$ make List_compile_check.exe
```

Configure your IDE to debug either the public tests or your own tests.

	Public tests	Your own tests
VS Code (macOS)	Set program name to: `${workspaceFolder}/List_public_test.exe`	Set program name to: `${workspaceFolder}/List_test`
VS Code (Windows)	Set program name to: `${workspaceFolder}/List_public_test.exe`	Set program name to: `${workspaceFolder}/List_test`
Xcode	Include compile sources: `List_public_test.cpp`, `List.hpp`	Include compile sources: `List_tests.cpp`, `List.hpp`

	Public tests	Your own tests
Visual Studio	Exclude files from the build: • Include `List_public_test.cpp` • Exclude `List_compile_check.cpp` , `List_tests.cpp` , `api.cpp` , `main.cpp` (if present)	Exclude files from the build: • Include `List_tests.cpp` • Exclude `List_compile_check.cpp` , `List_public_test.cpp` , `api.cpp` , `main.cpp` (if pres

Queue REST API (Optional)

IMPORTANT
For **Fall 2023**, the driver portion of the project that implements the web API (`api.cpp`) is **OPTIONAL** and is **NOT GRADED** on the autograder. The `List.hpp` and `List_tests.cpp` files are all that is required. You are still welcome to do the whole project if you like, or to return to it on your own after the course has finished.

The top-level application is an office hours queue REST API that reads requests from stdin (`cin`) and writes responses to stdout (`cout`). Requests and responses are formatted using a simplified subset of real HTTP.

Write the program in `api.cpp` . Run it with one of our provided input files.

```
$ make api.exe
$ ./api.exe < test01.in
HTTP/1.1 200 OK
Content-Type: application/json; charset=utf-8
Content-Length: 160

{
    "queue_head_url": "http://localhost/queue/head/",
    "queue_list_url": "http://localhost/queue/",
    "queue_tail_url": "http://localhost/queue/tail/"
}
```

Setup

Make sure you have created `api.cpp`. (VS Code (macOS), VS Code (Windows), Visual Studio, Xcode, CLI).

Add “hello world” code if you haven’t already.

```
#include <iostream>
using namespace std;

int main() {
  cout << "Hello World!\n";
}
```

The API program should compile and run.

```
$ make api.exe
$ ./api.exe
Hello World!
```

Configure your IDE to debug the API program.

VS Code (macOS)	Set program name to: `${workspaceFolder}/api.exe`
VS Code (Windows)	Set program name to: `${workspaceFolder}/api.exe`
Xcode	Include compile sources: `api.cpp`
Visual Studio	Exclude files from the build: • Include `api.cpp` • Exclude `List_compile_check.cpp`, `List_public_test.cpp`, `List_tests.cpp`, `main.cpp` (if present)

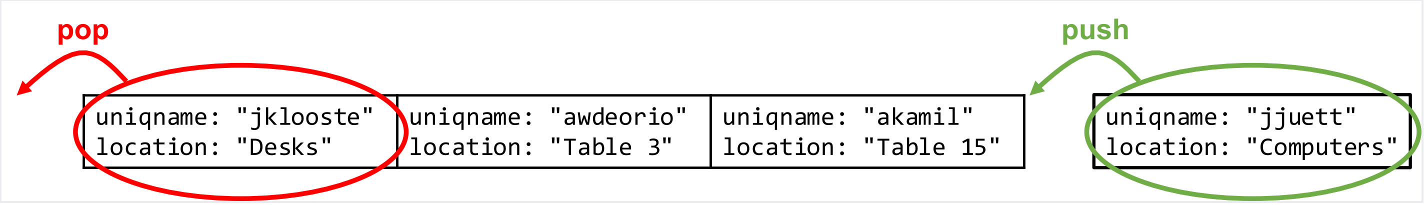
Set up input redirection (VS Code (macOS), VS Code (Windows), XCode, Visual Studio) to read `test01.in`.

To compile and run the API program with one test:

```
$ make api.exe
$ ./api.exe < test01.in
```

Libraries

A *queue* contains items stored in first-in-first-out order: the first item to be added is also the first one to be removed. Queues are commonly implemented using a linked list. A linked list allows insertion and removal at both ends, allowing items to be added at one end and removed at the other. This is in contrast to a vector, which only allows insertion and removal at one end.



Use the standard library `list` so you can get started on this project right away. Later, you'll implement your own linked list that works just like the STL.

The REST API will implement the requests summarized in this table. The following sections provide more detail.

Request	Description
`GET /api/`	Read routes
`GET /api/queue/`	Read all queue positions
`GET /api/queue/head/`	Read first queue position
`POST /api/queue/tail/`	Create last queue position
`DELETE /api/queue/head/`	Delete first queue position

Design

Use a linked `list` containing a `struct` or `class` to store your queue. Don't use `json` objects to store your queue or the data in your queue.

Here's an outline of how to structure your solution.

1. Read a request with `cin`
   - To read data, create a temporary `json` object and use `cin` (Reading JSON from a stream)
2. Read or write the `list` data structure
3. Write a response with `cout`
   - To write data, create a temporary `json` object and use `cout` (Writing JSON to a stream)

Your code should be structured in such a way that your program will `return 0` if it fails to read the beginning of a request from cin (i.e. it fails to read one of “GET /api/”, “POST /api/queue/tail/”, etc. because of some error, including end of file). NOTE: Your code should not `return` from main if it encounters an error as described in Error handling.

Pro-tip: Here’s how the instructors started their solution.

```
#include <list>

struct Student {
  // ...
};

class OHQueue {
public:
  void run() {
    while(/* Read request with cin */) {
      // Read or write queue member variable
      // Write response with cout
    }
  }

private:
  std::list<Student> queue;
};

int main() {
  OHQueue ohqueue;
  OHQueue.run();
}
```

Sample browser session

The following is an example of a browser session that adds three people to an empty queue and then retrieves the full queue.

The browser starts by sending a `POST` request to the `/api/queue/tail` path to add a student. The request body includes the student’s uniqname and location.

```
POST /api/queue/tail/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
```

```
Content-Length: 58

{
    "uniqname": "awdeorio",
    "location": "Table 3"
}
```

The server returns the following response, indicating success:

```
HTTP/1.1 201 Created
Content-Type: application/json; charset=utf-8
Content-Length: 77

{
    "location": "Table 3",
    "position": 1,
    "uniqname": "awdeorio"
}
```

The browser sends a second `POST` request to add another student:

```
POST /api/queue/tail/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 57

{
    "uniqname": "akamil",
    "location": "Table 15"
}
```

The server responds:

```
HTTP/1.1 201 Created
Content-Type: application/json; charset=utf-8
Content-Length: 76

{
    "location": "Table 15",
    "position": 2,
    "uniqname": "akamil"
}
```

The browser adds one more student to the queue:

```
POST /api/queue/tail/ HTTP/1.1
```

```
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 75

{
    "uniqname": "jklooste",
    "location": "Desks behind bookshelves"
}
```

The server response:

```
HTTP/1.1 201 Created
Content-Type: application/json; charset=utf-8
Content-Length: 94

{
    "location": "Desks behind bookshelves",
    "position": 3,
    "uniqname": "jklooste"
}
```

The browser now sends a `GET` request to the `/api/queue/` path to obtain the entire queue:

```
GET /api/queue/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

The server responds with the contents of the queue in order:

```
HTTP/1.1 200 OK
Content-Type: application/json; charset=utf-8
Content-Length: 412

{
    "count": 3,
    "results": [
        {
            "location": "Table 3",
            "position": 1,
            "uniqname": "awdeorio"
        },
        {
            "location": "Table 15",
            "position": 2,
            "uniqname": "akamil"
        },
        {
            "location": "Desks behind bookshelves",
            "position": 3,
            "uniqname": "jklooste"
        }
    ]
}
```

The requests for this example are in the file `test02.in`, and the responses are in `test02.out.correct`.

Request format

Every request has the same format. The only parts that change are the method (`GET` in this example), the path (`/api/` in this example), the content length (`0` here) and the body (empty here).

The content length in a request is the number of bytes in the body. Two newlines between the headers and the body are not included in the content length. Each body is followed a newline, which is included in the content length.

In this example, the two newlines separating the headers and the body are present, but the body is empty. That is why you see a blank line at the end and `Content-Length: 0`.

```
GET /api/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

Response format

Every response has the same format. The only parts that change are the response code (`200` in this example), the content length (`160`) and the body. The body is everything inside the curly braces `{ ... }` followed by a trailing newline.

```
HTTP/1.1 200 OK
Content-Type: application/json; charset=utf-8
Content-Length: 160

{
    "queue_head_url": "http://localhost/queue/head/",
    "queue_list_url": "http://localhost/queue/",
    "queue_tail_url": "http://localhost/queue/tail/"
}
```

Your implementation must order key-value pairs alphabetically by key. Use the process in Writing JSON to a stream to ensure that the ordering is correct.

The content length in a response is the number of bytes in the body. Two newlines between the headers and the body are not included in the content length. Each body is followed a newline, which is included in the content length.

> **Pro-tip:** Compute the content length like the example in Writing JSON to a stream.

Error handling

You don’t need to handle these errors. In other words, your implementation can assume that these things are correct:

- Requests are properly formatted
- HTTP method is one of `GET`, `DELETE`, or `POST`
- `Content-Length` of a request is correct
- All `GET` and `DELETE` requests will have a `Content-Length: 0`
- If `Content-Length: 0`, there will be no JSON body

You must handle the following errors:

- HTTP path is not valid. The path must exactly match one of `/api/`, `/api/queue/`, `/api/queue/head/`, or `/api/queue/tail/`, including the slashes.
- HTTP method is not appropriate for the path. For example, `POST /api/`.

If one of the errors above occurs, read the remainder of the request, including any headers or body. Then, return the following response after reading the entire request. Note that there is a blank line after `Content-Length: 0`.

```
HTTP/1.1 400 Bad Request
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

`GET /api/`

The `/api/` route accepts a `GET` request and returns a list of URLs supported by this REST API. It always returns the same data. See the examples in Request format and Response format for the input and output for this path.

Run the unit test.

```
$ make api.exe
$ ./api.exe < test01.in > test01.out
$ diff test01.out test01.out.correct
```

Pro-tip: Debug output differences using `diff -y -B`, which shows differences side-by-side and ignores whitespace. We'll use the `less` pager so we can scroll through the long terminal output. Press `q` to quit.

```
$ ./api.exe < test01.in > test01.out
$ diff -y -B test01.out test01.out.correct | less  # q to quit
```

`POST /api/queue/tail/`

The `/api/queue/tail/` route accepts a `POST` request and creates one new person on the queue. As a simplification, we do not check if a person is already on the queue, thus the same uniqname may appear multiple times.

Example request

```
POST /api/queue/tail/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 58

{
    "uniqname": "jackgood",
    "location": "Table 5"
}
```

Example response

```
HTTP/1.1 201 Created
Content-Type: application/json; charset=utf-8
Content-Length: 77

{
    "location": "Table 5",
    "position": 1,
    "uniqname": "jackgood"
}
```

Run the unit test.

```
$ make api.exe
$ ./api.exe < test04.in > test04.out
$ diff test04.out test04.out.correct
```

`GET /api/queue/head/`

The `/api/queue/head` route accepts a `GET` request and returns the person at the head of the queue. Fields are in the order shown by the example, and the person at the head of the queue always has position 1. If the queue is empty, return a `400` error.

Example request

```
GET /api/queue/head/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

Example response

```
HTTP/1.1 200 OK
Content-Type: application/json; charset=utf-8
Content-Length: 77

{
    "location": "Table 3",
    "position": 1,
    "uniqname": "awdeorio"
}
```

Run the unit test.

```
$ make api.exe
$ ./api.exe < test03.in > test03.out
$ diff test03.out test03.out.correct
```

`GET /api/queue/`

The `/api/queue/` route accepts a `GET` request and returns a list of everyone on the queue, including `location`, `position` and `uniqname` in that order. The list is ordered by position, which always starts with 1 for the person currently at the head of the queue.

Example request

```
GET /api/queue/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

Example response

```
HTTP/1.1 200 OK
Content-Type: application/json; charset=utf-8
Content-Length: 412

{
    "count": 3,
    "results": [
        {
            "location": "Table 3",
            "position": 1,
            "uniqname": "awdeorio"
        },
        {
            "location": "Table 15",
            "position": 2,
            "uniqname": "akamil"
        },
        {
            "location": "Desks behind bookshelves",
            "position": 3,
            "uniqname": "jklooste"
        }
    ]
}
```

If the queue is empty, the response should be:

```
HTTP/1.1 200 OK
Content-Type: application/json; charset=utf-8
Content-Length: 40

```

```
{
    "count": 0,
    "results": null
}
```

Run the unit test.

```
$ make api.exe
$ ./api.exe < test02.in > test02.out
$ diff test02.out test02.out.correct
```

`DELETE /api/queue/head/`

The `/api/queue/head/` route accepts a `DELETE` request and removes the person at the head of the queue.

Example request

```
DELETE /api/queue/head/ HTTP/1.1
Host: localhost
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

Example response

```
HTTP/1.1 204 No Content
Content-Type: application/json; charset=utf-8
Content-Length: 0

```

If the queue is empty, return a `400` error.

Run the unit test.

```
$ make api.exe
$ ./api.exe < test05.in > test05.out
$ diff test05.out test05.out.correct
```

Real web server (Optional)

Once you have a working solution for the office hours queue API as specified, you have a working back-end for a real office hours queue web server!

First, make sure your API passes all the unit tests.

```
$ make test-api
```

Build and start the server. You might need to install Python 3 with `brew install python3` (macOS) or `apt-get install python3` (WSL or Linux).

```
$ make api.exe
$ python3 server.py
Starting server on localhost:8000
```

In a web browser, navigate to http://localhost:8000/index.html. You should see a web page. A shortcut is http://localhost:8000.

Now try http://localhost:8000/api/. You should see JSON data.

Your browser is sending a GET request over the network. Let’s try it using the command line using a second terminal.

```
$ curl localhost:8000/api/
{
    "queue_head_url": "http://localhost/queue/head/",
    "queue_list_url": "http://localhost/queue/",
    "queue_tail_url": "http://localhost/queue/tail/"
}
```

The `server.py` script listens for incoming network requests. If the client request path starts with `/api`, it copies the request to the stdin of `api.exe` and copies the stdout of `api.exe` back to the client. Otherwise, `server.py` copies a file to the client over the network (e.g., `index.html`).

Visual Studio Note: If you are working on Windows and use Visual Studio (not to be confused with Visual Studio Code), compile `api.exe` from the Ubuntu (WSL) terminal (`make api.exe`), just for this demo. This avoids a problem with Windows vs. Linux line endings when running `server.py`.

API Tests

Run all the API tests.

```
$ make test-api
```

Submission and grading

Submit these files to the autograder.

- `List.hpp`
- `List_tests.cpp`

This project will be autograded for correctness, comprehensiveness of your test cases, and programming style. See the style checking tutorial for the criteria and how to check your style automatically on CAEN.

Testing

Check for memory leaks using the Leak checking tutorial.

Run all the unit tests and system tests. This includes the public tests we provided and the unit tests that you wrote.

```
$ make test
```

> **Pro-tip:** Run commands in parallel with `make -j`.
>
> ```
> $ make -j4 test
> ```

Unit Test Grading

We will autograde your `List` unit tests.

Your unit tests must use the unit test framework.

A test suite must complete less than 5 seconds and contain 50 or fewer `TEST()` items. One test suite is one `_tests.cpp` file.

To grade your unit tests, we use a set of intentionally buggy instructor solutions. You get points for catching the bugs.

1. We compile and run your unit tests with a **correct solution**.
   - Tests that pass are **valid**.
   - Tests that fail are **invalid**, they falsely report a bug.
2. We compile and run all of your **valid** tests against each **buggy solution**.
   - If any of your tests fail, you caught the bug.
   - You earn points for each bug that you catch.

Requirements and restrictions

It is our goal for you to gain practice with good C++ code, classes, and dynamic memory.

DO	DO NOT
Modify .cpp files and `List.hpp`	Modify other `.hpp` files
For `List`, make helper member functions private	Modify the public interface of `List`
Use these libraries: `<iostream>`, `<string>`, `<cassert>`, `<sstream>`, `<utility>`	Use other libraries
Use `<list>` (and optionally `<algorithm>`) in `api.cpp`	Use `<algorithm>`, `<list>`, or other containers in `List.hpp`
`#include` a library to use its functions	Assume that the compiler will find the library for you (some do, some don't)
Use C++ strings	Use C-strings
Send all output to standard out (AKA stdout) by using `cout`	Send any output to standard error (AKA stderr) by using `cerr`
Pass large structs or classes by reference	Pass large structs or classes by value
Pass by const reference when appropriate	"I don't think I'll modify it …"
Use the Address Sanitizer to check for memory errors	"It's probably fine…"

Acknowledgments

Original project written by Andrew DeOrio awdeorio@umich.edu, winter 2019.