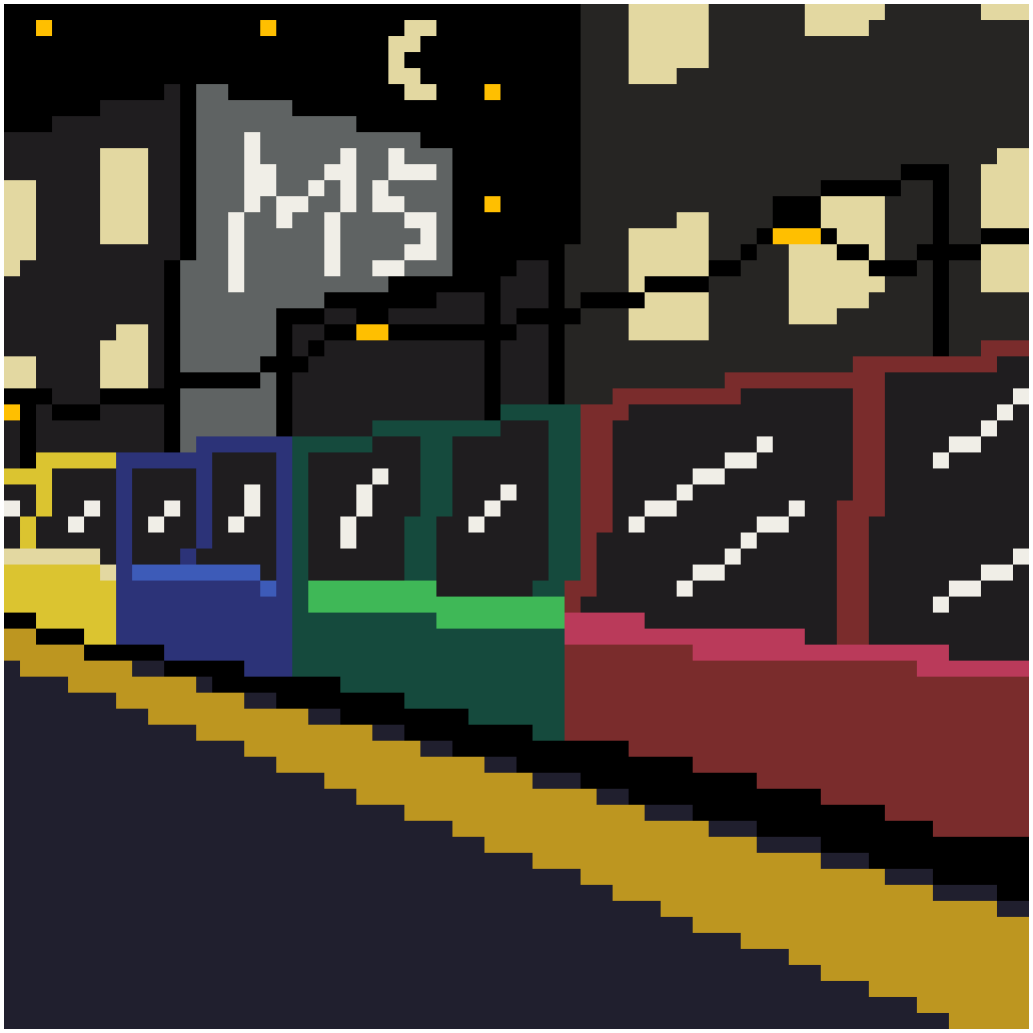
CS 15 Project 1: A Metro Simulator



Contents

Introduction

The Green Line has come to Tufts! In this assignment, you will create a program that simulates action on the Green Line. Your program will monitor a train as it travels a simplified course of the Green Line Extension, and will manage `Passenger`s as they board and depart at specified stops along the way.

The primary, high-level tasks for this assignment are as follows:

- Create an interactive front-end simulation that works with both files and the command line
- Design and develop an object-oriented approach to solving the back-end logic for the simulation
- Seamlessly connect the front-end and back-end systems

A few words of caution: The training wheels are off! There are some requirements (see below) for your implementation, but we have given you considerably more freedom to architect your solution to this problem than in previous assignments. This is a double-edged sword! To succeed, it would be wise to read the following spec thoroughly and to start designing a solution as early as possible. This will give you time to go to office hours to discuss your plan with the course staff before you start coding. This program can be done with less code than the previous assignment **if** you have designed your program well.

Deliverables There are multiple phases of deliverables for this assignment:

- **Week one:**
  - Design checkoff.
  - The code for your `Passenger` and `PassengerQueue` classes.
- **Week two:** Your final `MetroSim` program.

Continue reading to learn more about these deliverables!

Simulation Overview

Data Abstraction

Your design choices will be of chief importance in this project. It is **your responsibility** to plan out how you will build and utilize various components of the simulation. These components include:

- `Passenger`s, which must contain:
  - an `id`
  - a `starting station`
  - an `ending station`
- `PassengerQueue`s, which contain `Passenger`s who are waiting to board or depart from trains.
- A list of `Station`s.
- the `Train`, which carries `Passenger`s between `Station`s.

While it may not be obvious at first how to model these components, we will give you some guidelines to help you establish the architecture of your `MetroSim` program. We don't require every item in the list to be its own class, so it will be up to you to decide how each component is to be modeled. **However, we do require that you represent the `Train` as a list of `PassengerQueue` objects, where each `PassengerQueue` represents a train station**. But more on that later.

Note: You may find yourself confused. This is okay! You might want to refresh your memory about abstraction, classes in `C++`, etc. We strongly suggest that you head over to the reference page, where there is a lot of great material on these topics. Also, there is a lot of information in the upcoming sections which should help clarify the points above. Head back here after reading through the document to begin designing your solution.

User Interface

Also critical to this project is the implementation of the user-facing (front-end) interface. That is to say, the user will interface with this program through the command-line, and it is your responsibility to implement the logic for that interface correctly. More detail will be provided later, but here is a brief overview of how the program will work:

- The user will start `MetroSim`, and provide (among other things), a list of stations. This list will be in a file which `MetroSim` will process.
- Once you have initialized the simulation based on the provided material, `MetroSim` will process a series of commands, which will be fed to the program in one of two ways:
  1. By a file (provided at the program's start along with the station list)
  2. Through standard input, aka `std::cin`, which is the default if no file is provided.
- Every command will perform one of the following operations:
  - Add a passenger to the simulation
  - Move a train to the next stop
  - End the simulation
- After every command, `MetroSim` will (1) print an updated view of the train and `Station`s to `std::cout`, and (2) print a list of passengers that have left the train to a file specified by the user at the start of the program.
- When either no more input can be read from a file, or the user inputs the `m f` command, the simulation terminates successfully (and with no memory leaks!!).

Program Details

Program Design

Note: you should carefully consider your design and implementation plan before writing any code. In fact, we require you to come to office hours to review your design and implementation plan before writing any code (continue reading for details).

The Passenger

We have provided you with the interface for a `Passenger` object (within `Passenger.h`). You must use this `Passenger` interface, and *you may not modify the contents of* `Passenger.h` besides the header comment.

You must implement the `print` function for the `Passenger` interface within the provided implementation file (`Passenger.cpp`). The `Passenger` `print` function should format output as follows:

```
[PASSENGER_ID, ARRIVAL->DEPARTURE]
```

where

- `PASSENGER_ID` is the `Passenger`'s `ID` (each `Passenger` receives a unique consecutive id number, starting at 1).
- `ARRIVAL` and `DEPARTURE` are the station numbers of the arrival and departure stations, respectively.

Note: The format in which you print must match the above line exactly. Note that there is a space between ARRIVAL and the preceding comma, and that when each passenger is printed, there should be no additional whitespace outside the square brackets. Also note that any boxes surrounding output text in this document are **not** to be included in your output - they are just here to help highlight the text.

The PassengerQueue

You're required to write a `PassengerQueue` class from scratch that implements *exactly* the following interface:

- `Passenger PassengerQueue::front()`

  Returns, but does not remove, the element at the front of the queue. You may throw an error if this function is called on an empty queue, but you are not required to do so.

- `void PassengerQueue::dequeue()`

  Removes the element at the front of the queue. You may throw an error if this function is called on an empty queue, but you are not required to do so.

- `void PassengerQueue::enqueue(const Passenger &passenger)`

  Inserts a new passenger at the end of the queue.

- `int PassengerQueue::size()`

  Returns the number of elements in the queue.

- `void PassengerQueue::print(std::ostream &output)`

  Prints each `Passenger` in the `PassengerQueue` to the given output stream from front to back, with no spaces in between and no trailing newline. For example:

```
[1, 1->2][2, 1->3][3, 2->3][4, 2->3]
```

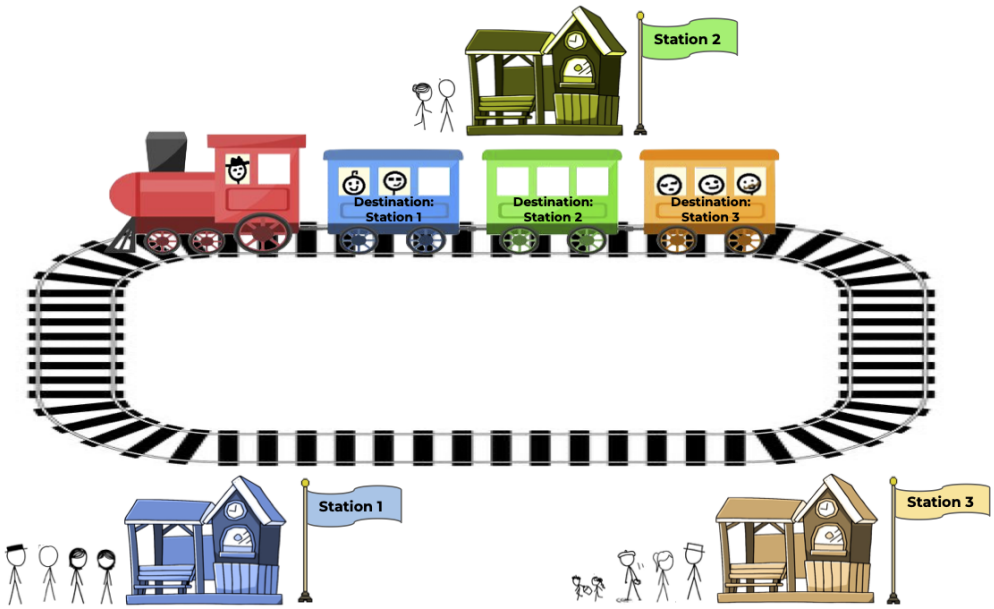
Make sure your `PassengerQueue` interface matches the interface listed above *exactly*. You may not add any other public functions. You must use either `std::vector` or `std::list` to implement this class.

Note: By default, `C++` will define a nullary constructor and the Big Three for you.

The code for your `Passenger` and `PassengerQueue` classes will be due at the end of week one, along with your design checkoff.

The Train and The Stations

As stated in the program overview, you are required to implement your train as a **list of** `PassengerQueue` instances (each element of the list is a `PassengerQueue`). Upon boarding the train, each passenger is organized into a `PassengerQueue` based on their destination. See the image below for a visual representation of the `Train`.



You may find that you will need to represent "lists" of various data types. For this, we require that you use `std::vector` or `std::list`, since it will greatly reduce how much code you'll need to write/rework, although you may need to do a little reading before you get started.

The `std::vector` and `std::list` documentation on `https://www.cplusplus.com` is a great resource. If you feel that this reference is too verbose for your taste, feel free to seek out additional resources. As always, any material that you use (including reused code from this class) should be noted in the **Acknowledgements** section of your `README`.

Program Flow

Running From the Command Line

You will write a program called `MetroSim` that accepts either 2 or 3 command-line arguments (in addition to the program name), like this:

```
./MetroSim stationsFile outputFile [commandsFile]
```

where:

- `stationsFile` is an input file containing names of the `Station`s, one per line
- `outputFile` is the file to send simulator output to
- `commandsFile` (optional) is a second input file containing commands to execute. If this parameter is not given, then you should read input from `std::cin`. Note: it's a common convention to denote optional parameters by putting them in square brackets.

If the program is invoked with a different number of parameters you should quit execution by returning `EXIT_FAILURE` after printing the following message to `std::cerr`:

```
Usage: ./MetroSim stationsFile outputFile [commandsFile]
```

Initialization

In the initialization phase you will open the `stationsFile` and process any `Station`s you find. The `stationsFile` is in plain text, with one `Station` name per line. You may assume the `stationsFile` has at least two `Station`s, and each `Station`'s name is a string of at least one character. `Station` names may be more than one word, e. g., "South Station".

Note: do not worry about malformed files. We will not test your program with empty `Station` files or files with duplicate `Station` names, etc. Just program assuming any input files are correctly formatted. You **do**, however, have to handle cases in which a file cannot be opened (see below for the specific message and behavior).

After you have finished processing the `stationsFile`, print the `Station`s you have just read (output specifications are below). Remember to place the `Train` at the first `Station`. Initially, there are no `Passengers` in the `Train` or at any `Station`.

If your program cannot open any of the provided file(s), you should quit by returning `EXIT_FAILURE` and print the following error message to `std::cerr`

```
Error: could not open file FILENAME
```

where FILENAME is the name of the file that could not be opened.

We have given you sample Station and command files (stations.txt and test_commands.txt, respectively). We will test your code with others, and you should make other similar files for your own testing, e.g., on a shorter list of Stations or with a sequence of commands that causes particular code in your program to run for test purposes.

Controlling the Simulation

MetroSim will accept input from either a commandsFile that contains a list of commands, or from std::cin if no commandsFile was given.

Commands are case sensitive. You may assume input data is valid. (e.g., a Passenger will never want to go to a Station with a negative number, etc...). Your program can do anything in such cases (segfault, quit, be angry, etc.).

Your program will prompt on std::cout for a command by printing the text "Command? "), and then will read a command in and process it. Your code will handle the following commands:

- p ARRIVAL DEPARTURE
  - The command p ARRIVAL DEPARTURE adds a new Passenger to the simulation who boards at the ARRIVAL Station and departs at the DEPARTURE Station. ARRIVAL and DEPARTURE are specified by a number (note that the first Station is Station 0).
  - Passengers are enqueued at the ARRIVAL Station.
  - Passengers should get consecutive IDs assigned in the order they arrive starting with the number 1 (not 0). I. e., the first Passenger to ever arrive will have ID 1, the second one ID 2, and so on.
- m m (metro move)
  - The command m m moves the Train from the current Station to the next one in the line. The train should move to the first Station if it is currently at the last Station.
  - As the train leaves a Station, all Passengers at the departing Station will get on the train, regardless of which Station the Passengers are going to. They board in the same order as they arrived at that Station.
  - When the Train arrives at a Station, any Passengers whose final destination is that Station will exit the Train and the Station—you can remove them from your simulator. Exiting passengers *will not* be included in the next state of the simulation printed to std::cout (i.e., passengers exit *then* we print the state), however, their exit will be logged in the output file...
  - For each Passenger that exits at a Station, the following line should be written to the output file (**not** std::cout), followed by a single newline:

    ```
    Passenger ID left train at station STATION_NAME
    ```

    replacing ID and STATION_NAME with that Passenger's ID and the Station's name, respectively.
  - Note: You may notice that the list of Stations is circular; that is, when the train reaches the bottom of the list, it returns to the top. We recognize that you have recently learned about a particular circular data structure, but it's up to you to determine whether it's

necessary to use. Be sure to consider the use cases of the data structures you implement and whether they apply to the program you build. (Feel free to check in with a TA if you're confused about this note!)

- `m f` (metro finish)
  - The command `m f` should terminate the simulation, as described in the **Ending the Simulation** section.

Printing the State of the Simulation

You should print the state of the simulation (described below) after each command that runs, according to the following format:

1. Print the text "Passengers on the train:" followed by a space, followed by a curly brackets enclosed list of passengers on the train, followed by a newline.
2. For each station on the train line, print:
   (a) `TRAIN:` followed by a space if the train is currently at that `Station`, otherwise print seven spaces.
   (b) The `Station` number enclosed in square brackets, followed by a space.
   (c) The `Station` name, followed by a space
   (d) A curly brackets enclosed list of the passengers currently waiting at the `Station`, followed by a newline.

Whenever you print a `Passenger`, you should follow the format described in **The Passenger** section above.

Example output for train line with 4 `Station`s, where the `Train` is currently at `Station` 1:

```
Passengers on the train: {[1, 0->2][2, 0->3]}
      [0] station_0 {}
TRAIN: [1] station_1 {}
      [2] station_2 {[3, 2->3][4, 2->3]}
      [3] station_3 {}
```

Note that `Passenger`s on the `Train` are in **ascending** order based on the **destination** `Station`. If there's a tie, the `Passenger` that boarded the train first will precede the `Passenger` that boarded afterwards.

You can assume that each `Station`'s name has at least one character, and that there will be at least two `Station`s provided.

Note: follow the format exactly, including spaces. We strongly encourage you to run the `diff` command to compare the output of your solution with that of the reference implementation. Refer to the **Testing** section for more information.

Ending the Simulation

If your program runs out of commands in the input (end of file is reached) or the command `m f` is given, your program should print the following text to `std::cout`, followed by a single newline and terminate:

```
Thanks for playing MetroSim. Have a nice day!
```

Always remember to deallocate all previously heap-allocated memory and close all previously opened files before your program terminates!

Special Note: File Input vs. std::cin

When you look at your program's output, be aware that it will look differently depending on whether the input comes from `std::cin` or from a commands file. When a user types at the terminal, there will be a newline when they press "enter" to enter input, but no newline will be there if you take input from a file. See the examples below.

std::cin Example

```
Command? m m
Passengers on the train:
```

File Input Example

```
Command? Passengers on the train:
```

We are aware of this difference (indeed, you will notice that `the_MetroSim` behaves that way). This difference is expected, and you will not need any code to try to "correct" this.

Getting Started

You can get the starter files by running the following command:

```
/comp/15/files/proj_metrosim/setup
```

Note that you should **not** manually run `cp`, but rather run the above program. The files will be copied for you.

The Reference Implementation

After running the above command, you will have access to a reference implementation of the program named `the_MetroSim`. We **strongly** encourage you to play around with it both to learn what is expected of your program and to test your your program. We will be comparing your program's output to the reference, so be sure that you are adhering to the output format. If the `diff` command reports any differences between the output of your implementation and the reference implementation, then you will lose points on the functional correctness portion of your implementation assessment. Refer to the **Testing** section in this document for more information.

The setup script makes a link to the reference implementation rather than your own copy. You use it exactly the same as you would use any other program, but this will guarantee you always use

the most recent version.

Design Checkoff (Required)

First, complete the required design checkoff questions given in the starter file `metro_design_checkoff.txt`, and submit your answers on Gradescope under the assignment "MetroSim Design Checkoff."

You must submit this file prior to meeting with a TA.

Then, go to office hours and talk to a TA about your plan. You should be prepared to discuss the answers you submitted. You are welcome to bring other materials as well, though you are not required to: drawings, pseudocode, etc.

The design checkoff helps twofold: you plan out your project and get your brain working on it in the background, and you also get design feedback before it's too late. TAs will check off your design, but reserve the right to not check off your design if they believe your design was not thoroughly mapped out enough.

Please sign up for a design check off on the form linked here.

Note: it is completely okay to deviate from this initial plan. In fact, we encourage you to continue to evaluate the structure of your solution and fine-tune it as you go – that's what programmers do in the real world, anyway. The purpose of this check-off is more to help you establish a game plan, as well as clear up any misconceptions you may have.

Phase One (Required)

For phase one of this project, you must complete the implementations of `Passenger` and `PassengerQueue`, and you must thoroughly test these classes. See the course calendar for the due date.

Testing

Test thoroughly and incrementally. You should be sure that your `PassengerQueue` behaves as intended before you start implementing your `MetroSim`. Your program will have many components—it will be *significantly* easier to debug issues if you test components as you implement them, rather than implementing everything then testing at the end.

Use the unit testing skills that you have developed in the first assignment. You can place all tests in the file `unit_tests.h`, which we provide for you. Just make sure to `#include` any corresponding `.h` files needed for the tests, and to update the dependencies for the `unit_test` rule in the Makefile (see Makefile section, below).

We also note that you are not *required* to use our `unit_test` framework. Alternatively, you can create your own testing file, with its own `main()` function that calls out to testing functions. Then, you'll have to compile your code with the testing `main` function instead of the simulator `main`. The choice of how to test your program is up to you—but either way, you must test your program!

Note that many functions within your `MetroSim` implementation will likely be private; this means that you cannot test them directly from a testing function in another file. You have two options:

1. Test private functions indirectly via public functions.
2. Temporarily make the private functions public to test them, and then make them private once you have tested them (make sure you don't forget to make them private again!).

After you have written and debugged the `PassengerQueue` class and other classes, and you have an implementation of `MetroSim` that you think works as expected, the best way to test your results will be to compare the output from your implementation with the output from the reference implementation. Your output and the reference implementation's output must match **exactly**. Here are some tips to help you compare your implementation to the reference:

- Redirecting the standard output stream (`std::cout`) to a file using the `>` symbol on the command line.

  In the following example, we run `MetroSim` with `stations.txt` as the stations file, `output.txt` as the output file, and `commands.txt` as the commands file. Any output that `MetroSim` sends to `std::cout` will be saved in `stdout.txt`.

```
./MetroSim stations.txt output.txt commands.txt > stdout.txt
```

- Redirecting the contents of a file into the standard input stream (`std::cin`) using the `<` symbol on the command line.

  In the following example, we run `MetroSim` with `stations.txt` as the stations file, `output.txt` as the output file. We are **not** passing `commands.txt` as a command-line parameter; rather, we are sending the contents of the `commands.txt` file to `std::cin` of the `MetroSim` program.

```
./MetroSim stations.txt output.txt < commands.txt
```

- Redirecting both the standard output (`std::cout`) and standard input (std::cin) streams.

```
./MetroSim stations.txt output.txt < commands.txt > stdout.txt
```

  With the above example, any time that `MetroSim` tries to read from `std::cin`, it is actually reading from `commands.txt`. Any output that `MetroSim` sends to `std::cout` is saved in `stdout.txt`.

- Using `diff` command to compare the contents of two files.

  It is highly recommended that you compare your output files with that of the demo using `diff`. So, for instance, if, given the same inputs, the reference implementation produced `stdout_demo.txt` and your implementation produced `stdout_personal.txt`, you could compare them with the following command:

```
diff stdout_demo.txt stdout_personal.txt
```

It can be difficult sometimes to understand the output of `diff`. Here is one reference that may help:
`https://linuxize.com/post/diff-command-in-linux/`.

Makefile

Since you are in charge of the structure of your implementation, we cannot know exactly what files you will have. This means you will need to update the given `Makefile` to build your program correctly.

The `Makefile` we provide you with already includes:

- A `MetroSim` rule, with some listed dependencies, and *no recipe* (yet!)
- A rule for building `PassengerQueue.o`
- A `unit_test` rule, with some dependencies already added, which will be used by the `unit_test` program
- A `clean` rule which removes object code, temporary files, and an executable named `a.out` (if one exists)

You will need to update the `Makefile` with the following:

- Every `.cpp` file will need a corresponding `.o` rule in the Makefile. This includes `MetroSim.cpp`, `main.cpp`, `Passenger.cpp`, and any new `.cpp` files that you write. You can use the given `PassengerQueue.o` rule as guidance.
- The dependencies for the `MetroSim` and `unit_test` rules must be updated with the new `.o` files as needed.
- You need to write the recipe for the `MetroSim` rule, which links all of the necessary .o files together

We have added `TODO` comments throughout your Makefile, corresponding to the updates listed above. You must make these updates!

README

With your code files you will also submit a `README` file. You can format your `README` however you like. However it should have the following sections:

A The title of the homework and the author's name (you)

B The purpose of the program

C Acknowledgements for any help you received

D The files that you provided and a short description of what each file is and its purpose

E How to compile and run your program

F An "architectural overview" i.e., a description of how your various program modules relate. For example, how you represent various structures in your implementation (e.g stations, trains).

G An outline of the data structures and algorithms that you used. Given that this is a data structures class, you need to always discuss the **ADT** that you used and the **data structure** that you used to implement it and justify why you used it. Please discuss the features of the data structure and also include (with some justification/explanation) two other situations/circumstances/problems where you could utilize it. The **algorithm** overview is always relevant. Please pick a couple interesting/complex algorithms to discuss in the `README`.

H Details and an explanation of how you tested the various parts of assignment and the program as a whole. You may reference the testing files that you submitted to aid in your explanation.

I Tell us how much time you spent, in total, on this assignment in hours.

Each of the sections should be clearly delineated and begin with a section heading describing the content of the section. You should not only have the section letter used in the outline above.

Submitting

Be sure your files have header comments, and that those header comments include your name, the assignment, the date, and acknowledgements for any help you received (if not already credited in the `README` file).

For phase 0, submit your complete `metro_design_checkoff.txt` file to the assignment "MetroSim Design Checkoff" on Gradescope.

For phase 1, you will need to submit the following files:

```
Passenger.h, Passenger.cpp
PassengerQueue.h, PassengerQueue.cpp
unit_tests.h
README
```

You should only include other C++ files if your solution to `PassengerQueue` depends on them. Do not submit `MetroSim.cpp` for example. You must submit them using Gradescope to the assignment `proj_metrosim_phase1`. Submit these files directly, do not try to submit them in a folder. The `README` doesn't have to be the final `README`. Just document anything that you feel we should know about your `Passenger`, `PassengerQueue`, or the submission in general.

For the final submission, we don't know exactly what files your final program will comprise. You will need to submit at least the following files:

```
PassengerQueue.h, PassengerQueue.cpp
Passenger.h, Passenger.cpp
MetroSim.h, MetroSim.cpp
main.cpp
(... any other C++ source files)
(... any testing files)
unit_tests.h
Makefile
README
```

You must also submit:

- Any unit tests you write for your program. This may be done in a file called `unit_tests.h`, using the `unit_test` framework that we have used on past assignments. Alternatively, you can create your own testing `main` functions, e.g., submit a file called `MetroSim_tests.cpp` with a `main` function that calls out to tests. Whatever testing files you use, you must submit them!
- Any command files (excluding the command file provided).

You must submit them using Gradescope to the assignment `proj_metrosim`. Note, you only need to include testing input files. For example, input stations or commands files you used. You do not need to include output files of any kind (`stdout`, `stderr`, or the output files you log passenger departures to).

Before submitting your work, please make sure your code and documentation (including sections of the README) conform to the course style guide.

Be sure your program builds correctly using the commands `make` and `make MetroSim`, because we will use those commands to build your program in testing. Be sure to include every file required to compile your code, along with any tests, and your `Makefile` and `README`. You don't have to give us the reference implementation. A useful test is to make a submission directory, copy all your files in there, then run make and see if the program builds. Test it, then submit everything.