Cloud Computing Concepts (C3), Part 1
Programming Assignment (Machine Programming or MP) for C3 Part 1 (also for use in CS425 Coursera section)
Name: Membership Protocol
2022

Important Dates

Released: Week 1 of C3 Part 1
Due: End of Week 6 of C3 Part 1

1 What is this MP about?

This MP is about implementing a membership protocol similar to one we discussed in class. Since it is infeasible to run thousand cluster nodes (peers) over a real network, we are providing you with an implementation of an emulated network layer (EmulNet). Your membership protocol implementation will sit above EmulNet in a peer- to-peer (P2P) layer, but below an App layer. Think of this like a 3 layer protocol stack with Application, P2P, and EmulNet as the three layers (from top to bottom). More details are below.

Your protocol must satisfy: i) Completeness all the time: every non-faulty process must detect every node join, failure, and leave, ii) Accuracy of failure detection when there are no message losses and message delays are small. When there are message losses, completeness must be satisfied and accuracy must be high. It must achieve all of these even under simultaneous multiple failures.

You can choose to implement any of the membership protocols we learnt in class – all to all heartbeating, or gossip-style heartbeating, or SWIM-style membership. We recommend either gossip or SWIM, since you will learn the most this way.

The template code is written in C++. It is one of the most commonly used languages in industry for writing systems code. For this, you will need at least C++11 (gcc version 4.7 and onwards).

On Course Week 6 (CS 425 version; position in the Cloud Computing Concepts course may vary), you'll find two pages related to MP1. One item is where you can generate "submission tokens" and view your grading results. The other page allows you to launch an online programming environment. These pages also have attached an extra zip file containing the starter template code, in case you want to try working offline instead.

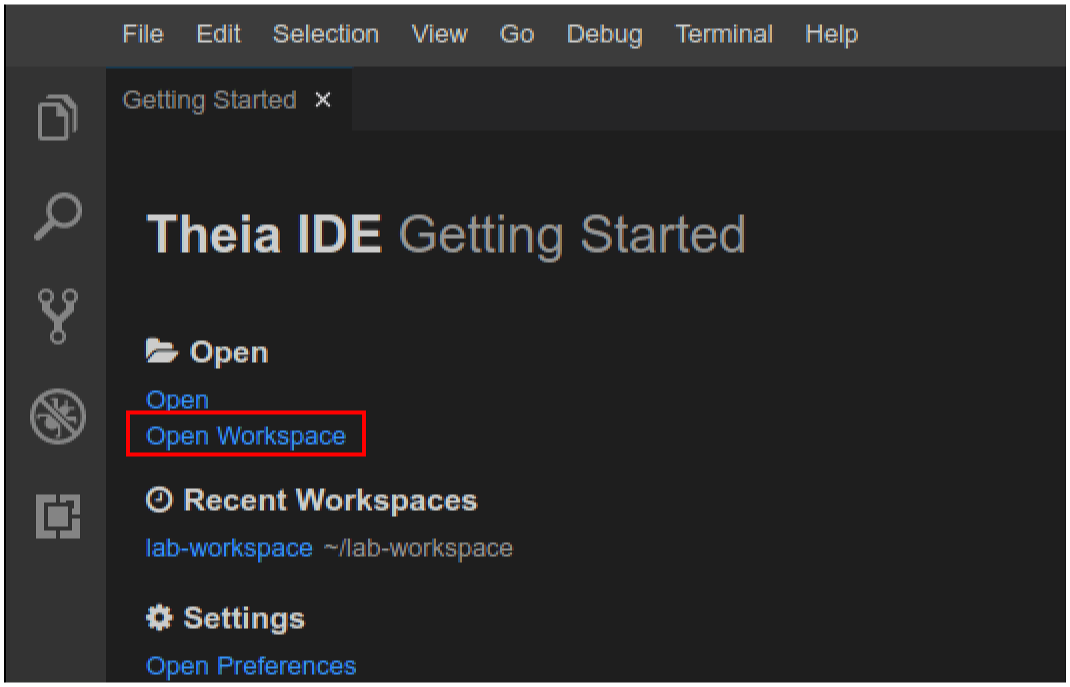
We will be providing you with the autograder scripts (unit tests) that you can use to test that your program passes all requirements (Section 6).

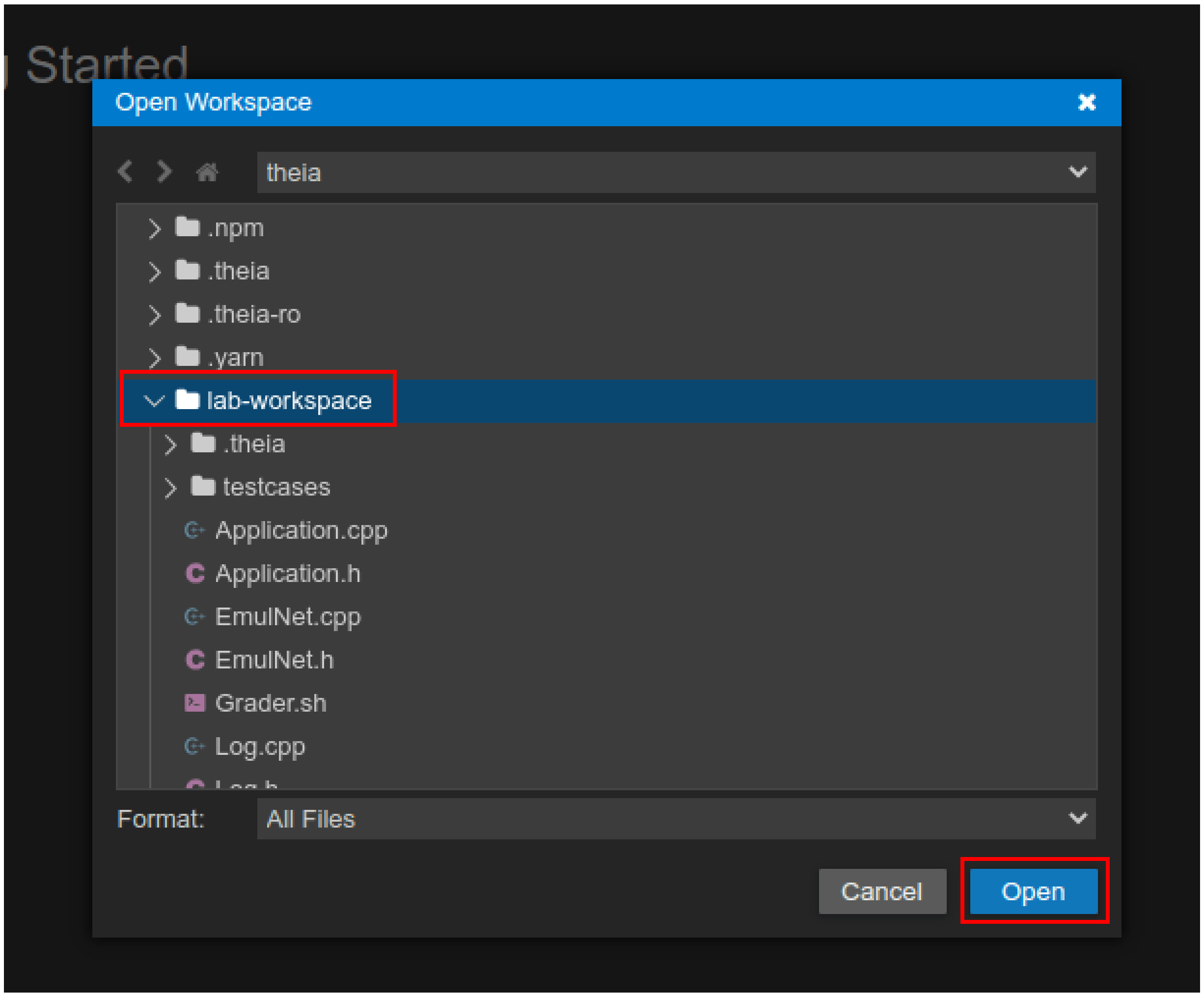
1.1 Theia IDE Workspace

(Beginning Fall 2020) An embedded workspace is provided on the Coursera site for those taking a Coursera section of the course. This workspace provides an IDE similar to (an open-source variant of) VS Code. The starter files and submission script are already present in the environment when you open it, but if the workspace loads in a state with no panels or files visible, you may need to manually reload the workspace and open the file editor pane.

A separate, illustrated document introducing Theia will also be attached to the assignment item on Coursera. Here is a brief overview. Some programming assignments will be split into two items on Coursera: one where you can copy a “submission token” key for use in a later step, as well as view your submission results; and a separate “Ungraded Lab” item, which will allow you to launch the Theia IDE workspace and actually work on the project. Although the Lab may be labeled “Ungraded,” there is indeed a way to submit your work for a grade there. We have provided a script, submit.py, which will ask for your email address and the temporary submission token, in order to submit the assignment instantly.

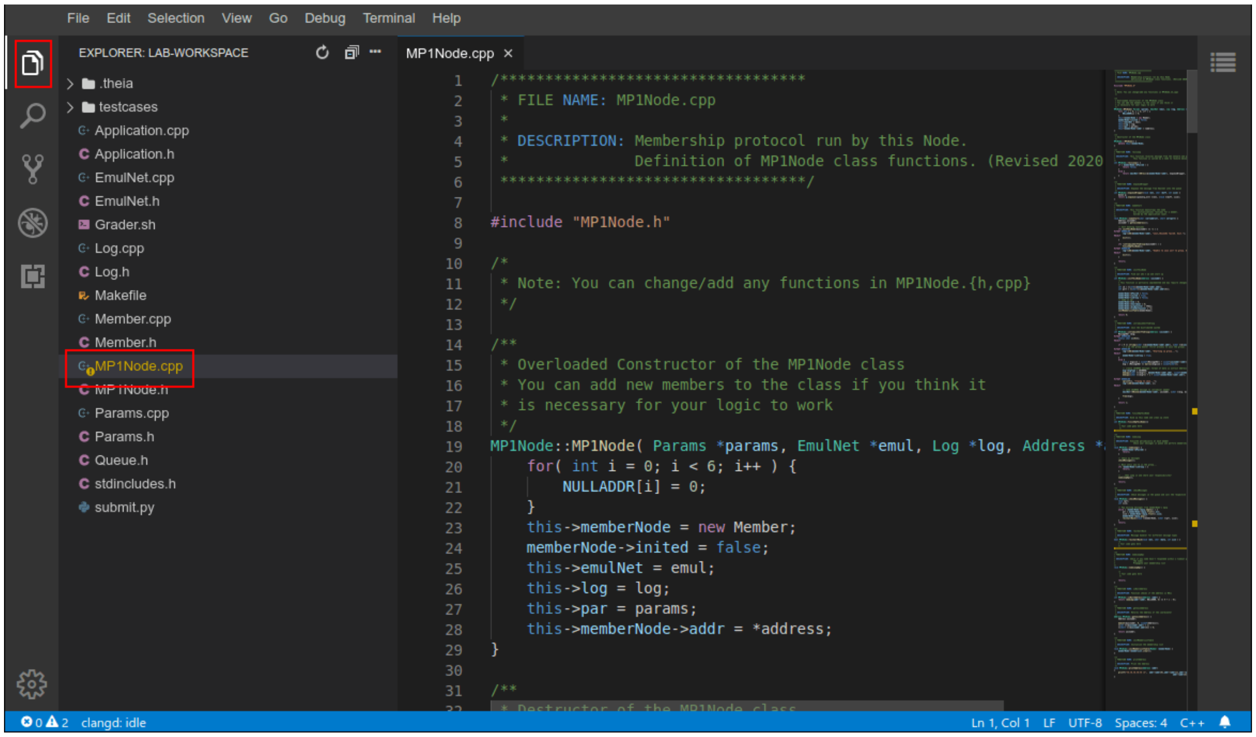
When you first open Theia, it may appear empty. Just click “Open Workspace”. This will open another panel where you can highlight “lab-workspace” and then click “Open.”





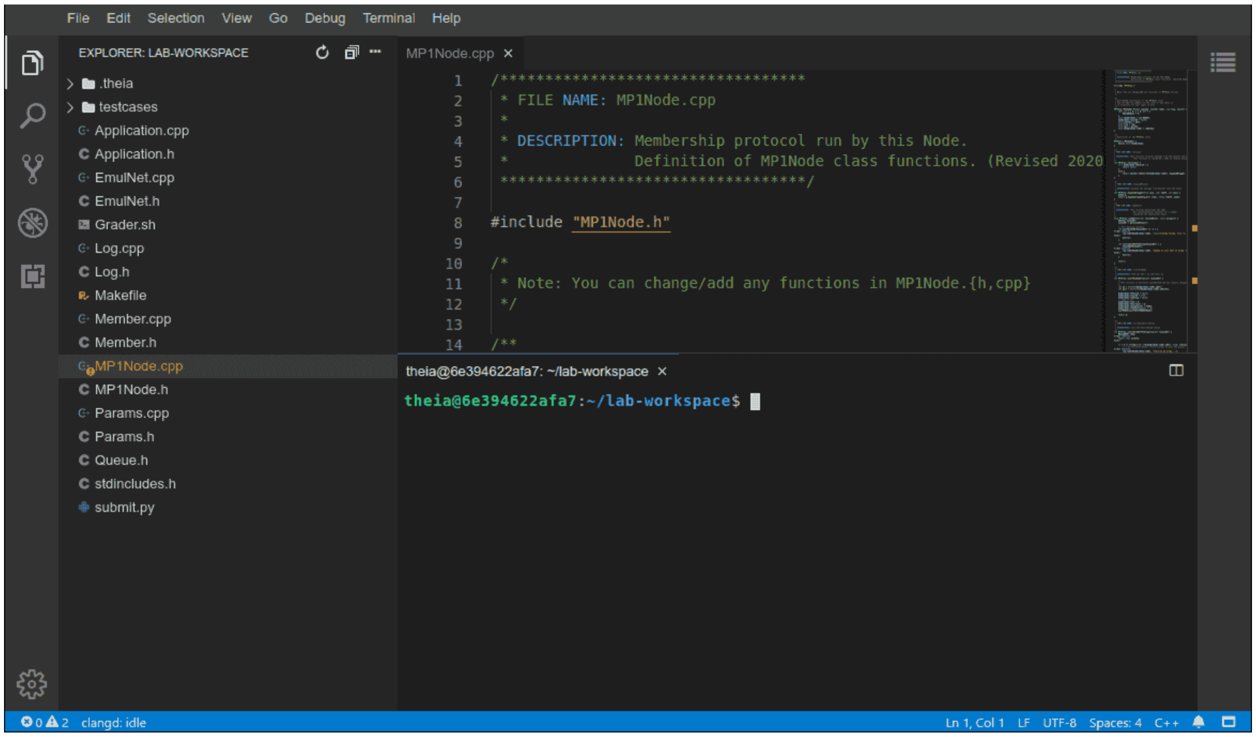
It’s **very important** that you use the lab-workspace folder to do your work. This folder will be specially backed up and preserved in the cloud in between your sessions. If you try to use a different folder in the filesystem to work on your project, you may lose your work.

Once you’ve opened “lab-workspace” as your workspace, then at this point, the starter files have loaded in the background. However, you need to open some viewing panes to see them. Click the file explorer icon in the upper left corner to view a file list, then click a filename to open it for editing.



```
/**********************************
 * FILE NAME: MP1Node.cpp
 *
 * DESCRIPTION: Membership protocol run by this Node.
 *              Definition of MP1Node class functions. (Revised 2020
 **********************************/

#include "MP1Node.h"

/*
 * Note: You can change/add any functions in MP1Node.{h,cpp}
 */

/**
 * Overloaded Constructor of the MP1Node class
 * You can add new members to the class if you think it
 * is necessary for your logic to work
 */
MP1Node::MP1Node( Params *params, EmulNet *emul, Log *log, Address *
    for( int i = 0; i < 6; i++ ) {
        NULLADDR[i] = 0;
    }
    this->memberNode = new Member;
    memberNode->inited = false;
    this->emulNet = emul;
    this->log = log;
    this->par = params;
    this->memberNode->addr = *address;
}

/**
 * Destructor of the MP1Node class
```

You can also open a Bash terminal using Terminal > New Terminal. At this point you'll be ready to work.



```
/**********************************
 * FILE NAME: MP1Node.cpp
 *
 * DESCRIPTION: Membership protocol run by this Node.
 *              Definition of MP1Node class functions. (Revised 2020
 **********************************/

#include "MP1Node.h"

/*
 * Note: You can change/add any functions in MP1Node.{h,cpp}
 */

/**
```

```
theia@6e394622afa7:~/lab-workspace$
```

1.2 Backing Up Your Work

As we mentioned above, it's important for you to work on your MP under the **~/lab-workspace** directory to make sure your files are automatically saved online between sessions. (Note that "~/lab-workspace" is a shorthand notation for the directory "/home/theia/lab-workspace" in the filesystem.) Your files will be saved to the cloud every few minutes, and you should be able to resume from where you left off by returning to the lab. If you worry you might lose your files, or you want to take them offline, then you can download them from the workspace. First, open the Theia terminal, and then type:

```
cd ~/lab-workspace
make clean
zip -r backup.zip *
```

This will clean up the temporary workspace files and bundle everything into a zip file, which you will see in the file list. Then, you can right-click on the backup.zip file and choose Download.

Instructions for testing and submitting your code are given later in this document.

1.3 Academic Integrity

All work in this MP must be individual, i.e., no groups. You can talk with others about the MP specification and concepts surrounding the MP, but you can neither discuss solutions or code, nor share code. We might check your code to find similarities in structure and ideas. You will also learn the most if you do this work individually!

2 The Three Layers

The three layer implementation framework we are providing will allow you to run multiple copies of peers within one process running a single-threaded simulation engine. Here is how the three layers work.

2.1 Emulated Network: EmulNet

EmulNet provides the following functions that your membership protocol above should use:

- void *ENinit(Address *myaddr, short port);
- int ENsend(Address *myaddr, Address *toaddr, string data);
- int ENsend(Address *myaddr, Address *toaddr, char *data, int size);
- int ENrecv(Address *myaddr, int (* enq)(void *, char *, int), struct timeval *t, int times, void *queue);
- int ENcleanup();

ENinit is called once by each node (peer) to initialize its own address (myaddr). ENsend and ENrecv are called by a peer respectively to send and receive waiting messages. ENrecv enqueues a received message using a function specified through a pointer enqueue(). The third and fourth parameters (t and times) are unused for now. You can assume that ENsend and ENrecv are reliable (when there are no message losses in the underlying network). ENcleanup is called at the end of the simulator run to clean up the EmulNet implementation. These functions are provided so that they can later be easily mapped onto implementations that use TCP sockets.

Please do not modify the files EmulNet.cpp,h given to you. We will replace it with our own implementations during testing. You should only use the above functions to access the EmulNet layer, and should not access the EmulNet data structures directly.

2.2 Application: Application

This layer drives the simulation. Files Application.{cpp,h} contain code for this. Look at the main() function. This runs in synchronous periods (globaltime variable). During each period, some peers may be started up, and some caused to crash-stop. Most importantly, for each peer that is alive, the function nodeLoop() is called. nodeLoop() is implemented in the P2P layer (MP1Node.{cpp,h}) and basically receives all messages that were sent for this peer in the last period, as well as checks whether the application has any new waiting requests.

Please do not modify these files Application.cpp,h given to you.

2.3 P2P Layer

The functionality for this layer is pretty limited at this time. Files MP1Node.{cpp,h} contain code for this. This is the layer responsible for implementing the membership protocol. As such this is where your code should be implemented. You can very well imagine the P2P layer can be extended to provide functionalities like file insert, lookup, remove etc.

3 What does the Code do currently?

As given to you, the code prints out debugging messages into dbg.log (format is node address [globaltime] message). You can turn debugging on or off by commenting out the #DEFINE DEBUGLOG in stdincludes.h.

Two message types are currently defined for the P2P layer (MP1Node.cpp implementation) - JOINREQ and JOINREP. Currently, JOINREQ messages are received by the introducer. The introducer is the first peer to join the system(for Linux, this is typically 1.0.0.0:0, due to the big-endianness). The best place to start your implementation is to have the introducer reply to a JOINREQ with a JOINREP message. The next section lists all the functionalities you have to implement.

4 What do I Implement?

All your code will go into the P2P layer in file MP1Node.{cpp,h}. Do not make changes to any other file other than MP1Node.cpp,h as they will be replaced.

You will need to of course implement nodeLoopOps(), and the recvCallBack() functions. Both functions are invoked by nodeLoop() to periodically perform protocol routines. Specifically, they should have functionalities loosely described below, which means you have considerable flexibility in choosing implementation details, except that your final submission should work with the other files unchanged. We will be implementing a membership protocol. Here are the functionalities your implementation must have:

- Introduction: Each new peer contacts a well-known peer (the introducer) to join the group. This is implemented through JOINREQ and JOINREP messages. Currently, JOINREQ messages reach the introducer, but JOINREP messages are not implemented. JOINREP messages should specify the cluster member list. The introducer does not need to maintain a list of all peers currently in the system; a partial list of fixed size can be maintained.
- Membership: You need to implement a membership protocol that satisfies completeness all the time (for joins and failures), and accuracy when there are no message delays or losses (high accuracy when there are losses or delays). We recommend implementing either gossip-style heartbeating or SWIM-style membership, although all to all heartbeating would be fine too (though you'd learn less). See lecture slides for more details.

Some of the things that you will probably need to modify are the class/struct member and enum MsgTypes in Mp1Node.h. You need to handle the new message types in separate Process functions similar to JOINREQ/JOINREP for this.

4.1 Logging

Logging your events is critical as the grader scripts (Section 6) look at the logs.

Log.{cpp,h} has a LOG() function that prints out node status into a file named dbg.log. Also it implements two functions logNodeAdd and logNodeRemove. Whenever a process adds or removes a member from its membership list, make sure you use logNodeAdd and logNodeRemove to log these respectively. The grader scripts will look for these log entries when running the tests. These functions take two address parameters - pass the address of the recording process as the first parameter and the address of the process getting added/removed as second parameter.

5 What are these Other Files?

Params.{cpp,h} contains the setparams() function that initializes several parameters at the simulator start, including the number of peers in the system(EN_GPSZ), and the global time variable globaltime, etc.

The remaining files Member.cpp,h list some necessary definitions and declarations -- see descriptions in the files. Avoid modifying these files.

Why is the Code Structure So Involved? There are two reasons. Firstly, think about the issues involved in converting this into a real application. All EN*() functions can be easily replaced with a different set that sends and receives messages through sockets. Then, once the periodic functionalities (e.g., nodeLoop()) are replaced with a thread that wakes up periodically, and appropriate conversions are made for calling the other functions nodeStart() and recvLoop(), your implementation can be made to run over a real network!

Secondly, this structure allows us to debug (and even measure the performance through traces) the membership protocol easily and on a single host machine. Compare this with the debugging challenge for several hundred processes running on a real network. Once the simulation engine works, you can convert the implementation easily into one for a real network, and it will work.

6 How do I Test my Code?

6.1 Testing

To compile the code, run make.
To execute the program, from the program directory run: ./Application testcases/<test_name>.conf. The conf files contain information about the parameters used by your application:

```
MAX_NNB: val
SINGLE_FAILURE: val
DROP_MSG: val
MSG_DROP_PROB: val
```

where MAX_NNB represents the max number of neighbors, SINGLE_FAILURE is a one bit 1/0 variable that sets single/multi failure scenarios, MSG_DROP_PROB represents the message drop probability (between 0 and 1) and MSG_DROP is a one bit 1/0 variable that decides if messages will be dropped or not.

There is a tester script Tester.sh. It tests your implementation of membership protocol in 3 scenarios and grades each of them on 3 separate metrics. The scenarios are –

1. Single node failure
2. Multiple node failure
3. Single node failure under a lossy network.

The grader tests the following things – i) whether all nodes joined the peer group correctly, ii) whether all nodes detected the failed node (completeness) and iii) whether the correct failed node was detected (accuracy). Each of these is represented as configuration files inside the testcase folder.

6.2 Grading

The MP is worth a total of 90 points. When you run the grader it tells you whether you passed all the tests (out of 90). You should add code into the requisite portions so that your code passes all tests on the Coursera grading platform.

6.3 Submission Instructions

Use the test runner (i.e., Tester.sh) provided to you in the code template to test your solution locally in your computer as many times as you want. Make sure you are using at least C++11 (gcc version 4.7 and onwards).

- ❏ How do I run the grader on my computer ?
  ```
  $ bash ./Tester.sh
  ```

Once you are satisfied with your solution, use the submission script (submit.py) provided to you in the code template to submit your solution to coursera.

- ❏ How do I submit to coursera ?

  ```
  $ python3 submit.py
  ```

  Before you submit, make sure you back up all your files and work in a different directory. The script will prompt for login details. Login ID is the email address you use with Coursera. It will also ask you to enter a submission token. This is the single-use key you can generate on the Coursera instructions page for this assignment. (This is NOT your own Coursera account password!) You will need to generate a fresh submission token on the instructions page each time you wish to resubmit the assignment for grading.

  You can also check the score of your submission on the coursera programming assignments web page. The page for the particular programming assignment has a tab called “My submission” that lists a log of submissions and results. Please note that it takes a while (sometimes a few hours) for your submission to be graded. Please be patient! If you make multiple submissions, then the submission with the highest score will be considered for grading.