

Project #3: TCP Socket Programming

ECE 650 – Spring 2025

Due: Thursday, Feb 27, 2025 at 11:59 pm

General Instructions

1. You will work individually on this project.
2. The code for this assignment should be developed and tested in a **UNIX-based** environment, specifically the Duke Linux environment available at login.oit.duke.edu.
3. You must follow this assignment spec carefully, and turn in everything that is asked (and in the proper formats, as described). Due to the large class size, this is required to make grading more efficient. For this assignment, testing will be automated. If you do not follow exact instructions for your submission materials (file names, program output, etc.) points will be deducted.
4. You have a chance to preview your program results tested by our auto-grader if you submit your homework on Gradescope 2 days before the due date. The autograder will release your score 48 hours before the deadline. The pre-release is just a feedback for you and isn't meant to help you debug, so please do not ask your TA for what test cases you have failed.

Note: This assignment includes a programming portion (this document) and a written portion (separate document). Be sure to submit both!

1 Overview

In this assignment you will develop a pair of programs that will interact to model a game, which is described below. The game is simple, but the assignment will give you hands-on practice with creating a multi-process application, processing command line arguments, setting up and monitoring network communication channels between the processes (using **TCP sockets**), and reading/writing information between processes across sockets.

The game that will be modeled is called *hot potato*, in which there are some number of players who quickly toss a potato from one player to another until, at a random point, the game ends and the player holding the potato is “it”. The object is to not be the one holding the potato at the end of the game. In this assignment, you will create a ring of “player” processes that will pass the potato around. Thus, each player process has a left neighbor and a right neighbor. Also, there will be a “ringmaster” process that will start each game, report the results, and shut down the game.

The game that you will work on follows the following process:

1. To begin, the ringmaster creates a “potato” object initialized with some number of hops and sends the potato to a randomly selected player.
2. Each time a player receives the potato, the player will decrement the number of hops and append the player’s ID (which is the id number assigned to each player as described in the Communication Mechanism section below) to the potato. Then, this player who is holding the potato will choose next step based on the remaining number of hops as bellow:
 - a. If the remaining number of hops is greater than zero, the player will randomly select a neighbor and send the potato to that neighbor.
 - b. The game ends when the hop counter reaches zero. **The player holding the potato sends it to the ringmaster, indicating the end of the game.** The ringmaster prints a trace of the game to the screen (using the player identities that are appended to the potato), and shuts the game down (by sending a message to each player to indicate they may shut down as the game is over).

The assignment is to create one ringmaster process and some number of player processes, then play a game and terminate all the processes gracefully. You may explicitly create each process from an interactive shell; however, the player processes must exit cleanly at the end of the game in response to commands from the ringmaster.

Based on the description above, the **ringmaster** side will be responsible for the following:

1. Establish **N network socket connections with N number of players** and provide relevant information to each player (see Communication Mechanism section below for details)
2. Create a “potato” object as described above
3. Randomly select a player and send the “potato” to the selected player
4. At the end of the game (when the ringmaster receive the potato from the player who is “it”), **print a trace of the potato to the screen**

5. Shut the game down by sending a message to each player

The **player** side will be responsible for the following:

1. Establish three network socket connections for communication:
 - a. with the player to the left
 - b. with the player to the right
 - c. with the ringmaster

Keep in mind that the player needs to behave as a client when connecting to the ringmaster. In order for the players to connect to their neighboring players, you can decide which side will act as the server and which side will act as the client.

2. Keep listening to the three channels as “potato” can arrive on any of these three channels. Note that commands and important information may also be received from the ringmaster.
3. Properly handle everything received based on game rules.

2 Communication Mechanism

In this assignment, you will use TCP sockets as the mechanism for communication between the ringmaster and player processes. Your programs must use exactly the command line arguments described here. The ringmaster program is invoked as shown below, where `num_players` must be greater than 1 and `num_hops` must be greater than or equal to zero and less than or equal to 512 (make sure to validate your command line arguments!).

Note that here **zero is a valid number of hops**. In this case, the game must create the ring of processes. **After the ring is created, the ringmaster immediately shuts down the game.**

The server program is invoked as:

```
ringmaster <port_num> <num_players> <num_hops>
(example: ./ringmaster 1234 3 100)
```

The player program is invoked as:

```
player <machine_name> <port_num>
(example: ./player vcm-xxxx.vm.duke.edu 1234)
```

where `machine_name` is the machine name (e.g. login-teer-03.oit.duke.edu) where the ringmaster process is running and `port_num` is the port number given to the ringmaster process which it uses to open a socket for player connections. If there are N players, each player will have an ID of 0, 1, 2, to $N-1$.

A player's ID and other information that each player will need to connect to their left and right neighbor can be provided by the ringmaster as part of setting up the game. The players are connected in the ring such that the left neighbor of player i is player $i-1$ and the right neighbor is player $i+1$. Player 0 is the right neighbor of player $N-1$, and Player $N-1$ is the left neighbor of player 0.

2.1 Communication Mechanism Resources:

- Refer to our lecture notes and example code on TCP sockets for establishing communication between the ringmaster and players. You can find [06-L4-tcp_example.zip](#) under Sakai resources to study the general process of establishing TCP communication.
- [Beej's Guide to Network Programming](#) is an excellent reference resource for this assignment.

Note that you can directly use the code provided in [06-L4-tcp_example.zip](#) and Beej's book mentioned above.

- You will also find that you will need to use the “select” call over a set of file descriptors from both the ringmaster and player processes in order to know when some information has been written to one of a set of the socket connections. You will likely also find the functions “gethostname” and “gethostbyname” helpful in establishing the

connections between neighboring players in the ring and between players and the ringmaster. “getsockname” would help find the port on which your client program has bound to listen.

- You will also need to create random numbers (e.g. between 0 to N). To do so, you may use the `rand()` call. Your code should first seed the random number generator:

```
srand((unsigned int)time(NULL)+player_id);
```

Then you may generate a random number between 0 and N-1 using:

```
int random = rand() % N;
```

- Make sure that the third parameter (representing the length of data to send/receive) of the `send()` and `recv()` functions is consistent between the server and client when using them.

2.2 Output:

The programs you create must follow the description below precisely. If you deviate from what is expected, it will impact your grade.

The following describes **all** the output of the `ringmaster` program. Do not have any other output.

Initially:

Potato Ringmaster

Players = <number>

Hops = <number>

Upon connection with a player (i.e. each player should send some initial message to the ringmaster to indicate that it is ready and possibly provide other information about that player):

Player <number> is ready to play

When launching the potato to the first randomly chosen player:

Ready to start the game, sending potato to player <number>

When it gets the potato back (at the end of the game). The trace is a comma separated list of player numbers. No spaces or newlines in the list.

Trace of potato:

<n>,<n>, ...

2.2.1 Sample Ringmaster Output:

Potato Ringmaster

Players = 3

Hops = 200

Player 1 is ready to play

```
Player 0 is ready to play
Player 2 is ready to play
Ready to start the game, sending potato to player 2
Trace of potato:
2,1,2,0,2,1,0,2,...
```

The following describes **all** the output of the `player` program. Do not have any other output. Note: The reason why "Player 1" is printed before "Player 0" in the sample output is because the master process needs to ensure that both players are able to communicate with each other before starting the game. In this case, the Player server needs to know who its neighbor is and establish a connection with them. As a result, although Player 0 reaches the master process first, it spends more time establishing its neighbor connections, which causes it to be ready later than the other player.

After receiving an initial message from the ringmaster to tell the player the total number of players in the game, and possibly other information (e.g. info about that player's neighbors):

```
Connected as player <number> out of <number> total players
```

When forwarding the potato to another player:

```
Sending potato to <number>
```

When number of hops is reached:

```
I'm it
```

2.2.2 Sample Player Output:

Player 0 (in this example not the last player):

```
Connected as player 0 out of 3 total players
Sending potato to 2
Sending potato to 1
Sending potato to 1
Sending potato to 2
Sending potato to 2
Sending potato to 2
...
Sending potato to 1
```

Similar for Player 2

Player 1 (in this example the last player, i.e. receives potato on last hop):

```
Connected as player 0 out of 3 total players
Sending potato to 0
Sending potato to 2
Sending potato to 0
Sending potato to 0
```

```
Sending potato to 2  
Sending potato to 2  
Sending potato to 2  
...  
Sending potato to 0  
I'm it
```

3 Testing

As this is a project with multiple processes, in order to test your program, you will need to run a ringmaster and several players (depending on your specific testing configuration) in separate terminals. Instructions for invoking the ringmaster and player can be found in the Communication Mechanism section mentioned earlier.

4 Detailed Submission Instructions

Your submission will include source code files and a Makefile that you create. Your files should contain at least the following:

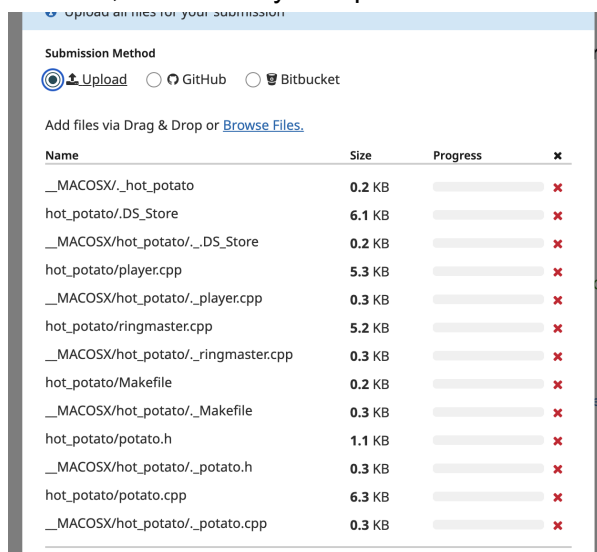
1. **ringmaster.c** – The source code for your ringmaster program as described above.
2. **player.c** – The source code for your player program as described above.
3. **Makefile** – A makefile that will compile ringmaster.c and player.c into executable programs named ringmaster and player, respectively
4. **potato.h** – A source code file containing a potato structure that can be sent across TCP sockets between players and between players and the ringmaster.

You will submit a single zip file to Gradescope.

You should create a **directory named hot_potato** first, include below files and compress.
ringmaster.c player.c potato.h Makefile

You could submit your program to pre-test on Gradescope.

For Mac, make sure your uploaded file structure to Project 3 is as:



Name	Size	Progress	
__MACOSX/.hot_potato	0.2 KB		✗
hot_potato/.DS_Store	6.1 KB		✗
__MACOSX/hot_potato/.DS_Store	0.2 KB		✗
hot_potato/player.cpp	5.3 KB		✗
__MACOSX/hot_potato/.player.cpp	0.3 KB		✗
hot_potato/ringmaster.cpp	5.2 KB		✗
__MACOSX/hot_potato/.ringmaster.cpp	0.3 KB		✗
hot_potato/Makefile	0.2 KB		✗
__MACOSX/hot_potato/.Makefile	0.3 KB		✗
hot_potato/potato.h	1.1 KB		✗
__MACOSX/hot_potato/.potato.h	0.3 KB		✗
hot_potato/potato.cpp	6.3 KB		✗
__MACOSX/hot_potato/.potato.cpp	0.3 KB		✗

For Windows, your submission may not include documents like "__MACOSX/.XXX". You only need to ensure that your submission format is "hot_potato/XXX".

5 Grading

5.1 Rubrics

- Establishing connection between server and players: 20%
- Test cases for programming part: 50%
- Writing part: 30%

5.2 Auto-grader Policy

When you submit your code, you won't be able to see the autograder grade immediately. However, we will release a pre-grade of the autograder two days before the due date (on Feb 25 at 11:59 pm). If you'd like to view your autograder result, please make sure to submit your code before this pre-release date.

6 FAQ

1. Q: Can we use C++?

A: Yes, but you need to provide a compilable Makefile.

2. Q: Should the game work across the network on different machines?

A: Yes. **Network sockets must work on the network**, therefore, running the ringmaster and player on different machines should still allow a functional game.

3. Q: Will our code be checked against Valgrind for memory errors?

A: Not directly. However, these issues may show up in other testing as practical problems. Also, it is always recommended to write leak free code.

Some common issues and how to fix them:

- Sending uninitialized bytes on the socket: Use `memset()` to initialize the data buffer.
- Forgetting to free objects allocated on the heap: e.g. forgetting `freeaddrinfo()` after `getaddrinfo()`, `free()` after `malloc()`, etc.

How to use valgrind to catch above issues:

```
valgrind -v --leak-check=full --track-origins=yes
```

4. Q: How to use `getaddrinfo()`?

A: Look at the man page. Make sure to loop through the results of `getaddrinfo()` for the bind etc. as seen in the man page. This is to help overcome practical constraints of invalid hostnames, etc.

5. Q: Which address and port should I bind to for accepting incoming connections?
A: The address you bind to will be the address that clients will connect to. For example, **if you bind to 127.0.0.1, others can only connect by connecting to 127.0.0.1, which limits the clients to be on the same machine.**
However, if you bind to 0.0.0.0 (aka `INADDR_ANY`), clients can connect to you using any address, including 127.0.0.1 and the public IP of the machine (if any). Therefore the most general solution is to bind to address 0.0.0.0.
If you have a specific port number to bind to, use that. Otherwise, if you specify 0 in `sin_port` when calling `bind`, the OS will assign a port for you. After that, you can use `getsockname()` to see which port the socket is bound to.
6. Q: How do I know my own IP address?
A: The command `ip addr` can show you the IP address of each of your network interface.
For the purpose of Project 3, neither the ringmaster nor the player has to do that. The player can know the ringmaster's address by resolving its hostname, which is given in the arguments. The ringmaster can know the player's address as well; see the next question.
7. Q: If a client connects to me, how do I know its IP address?
A: The `accept` syscall will fill in the `addr` argument, which is a `sockaddr` struct containing the client's IP address.
8. Q: My laptop cannot accept incoming connections.
A: Your laptop may not have a public IP address and/or a hostname that is recognized by others. Solving these problems is beyond the scope of Assignment 3. You might be interested in the following readings, though: [Network address translation](#), [Port forwarding](#), [DMZ](#).
For the purpose of this assignment, it is a good idea to test your programs on machines that have public IPs and/or hostnames. VCM is a good choice, and I believe you should be able to get at least 2 VMs.
9. Q: My system has a max limit on number of incoming socket connections I can accept. Is this okay?
A: Yes. On the `accept` call of the ringmaster, you may only be able to support 1020 incoming connections. This can also be checked using `ulimit -n`. You do not have to modify or worry about this.
10. Q: Do I care about what `send()` and `recv()` return?
A: Yes. See the man pages for both. Also, make sure to handle the error conditions and socket closure cases, e.g. -1 for error, 0 for closed socket on `recv`, etc. See the man pages for more details.

11. Q: What is `select()`? Do I care about it?

A: See `man select`. `select()` is a function that allows you to see which of your file descriptors is ready to send you content. Since this game involves each player being connected to two other players and you may get a potato from any side, you need to use this function to check where to `recv` data from.

Also, make sure to reset the `readfds` structure used by this function every time since after calling `select`, it only contains the fds of sockets that are currently sending you data.

12. Q: `send()` fails to send my complete message.

A: This is not a bug. This is how `send()` is designed. In C/C++ without using additional libraries, the basic `send()` does not guarantee that all of the bytes specified in message buffer size will be sent. On success, these calls return the number of bytes sent. See [man page for send](#).

You may need to use some loops to make sure your entire message buffer is sent.

13. Q: `recv()` fails to receive a complete message.

A: Same as above. However, you can use `MSG_WAITALL` if you're certain about the number of bytes you need to receive.

14. Q: What data structure should I send in the **socket buffer**?

A: The socket buffer takes a byte stream. It may be good enough to have a protocol that sends the size of a string followed by a string, i.e. char stream in your buffer. The size will let you know how much data to receive, since these communications may be of varied length. Feel free to play around and invent your own protocol. **Sending structs on a socket buffer will need more work as opposed to a string.**

15. Q: Can the number of hops be 0?

A: Yes. *"Zero is a valid number of hops. In this case, the game must create the ring of processes. After the ring is created, the ringmaster immediately shuts down the game."* - as Described in Communication Mechanism

Note: No trace of hops is printed in this case.

16. Q: What is the first hop?

A: The first hop is from the ringmaster to the first player, selected at random.

17. Q: What happens on the last hop? / When should the game end?

A: When the potato is passed to a player on the last hop, the game ends. The full trace of the potato should then be sent to the ringmaster -- this does not count as a hop. **The game ends and all processes must close/complete. The order in which processes exit does not matter.**

18. Q: When I try to run the ringmaster consecutively using the same port it gives me an error that the port is in use although I ended the program. What should I do?

A: It takes a while for the port to be set as free again. You can let the OS know to set it to free immediately by using the `setsockopt()` with `SO_REUSEADDR` option. See [ref](#).

19. Q: Can I add some time delay in my code for synchronization?

A: No, you may not. Synchronization must be achieved using a good logical series of steps and any loops as required to ensure success of connections. **Timing based connections are arbitrary and not acceptable solutions.** This will also cause the grading time for your code to get out of hand and may result in a penalty.

20. Q: Do I have to deal with a malicious/arbitrary process connecting to my players/ringmaster and sending random messages?

A: No. You can design your own communication protocol and adhere to it. We will not test how you handle arbitrary connections in your game instead of your own players, etc.

21. Q: Is there a specification on how to handle issues such as player disconnecting in the middle of the game, loss of network, etc.?

A: No, you may choose how you deal with these situations. However, **silent failure is a bad software engineering practice.**

22. Q: Can I make C++17/20 files on Gradescope for assignment 3, and are we allowed to use existing wrappers on Github for TCP (e.g. Boost)?

A: You can make C++17/20 files. But we don't recommend it. You don't have to use C++17 or C++20, we just want you to learn how socket work and how to use it. I believe that none of this requires using any C++ features newer than 98 versions, but if you want to use some New Features to make it easier for you to implement functions other than socket, you can use them.