

UNIVERSITY PARTNER



DISTRIBUTE AND CLOUD SYSTEMS PROGRAMMING (5CS022)

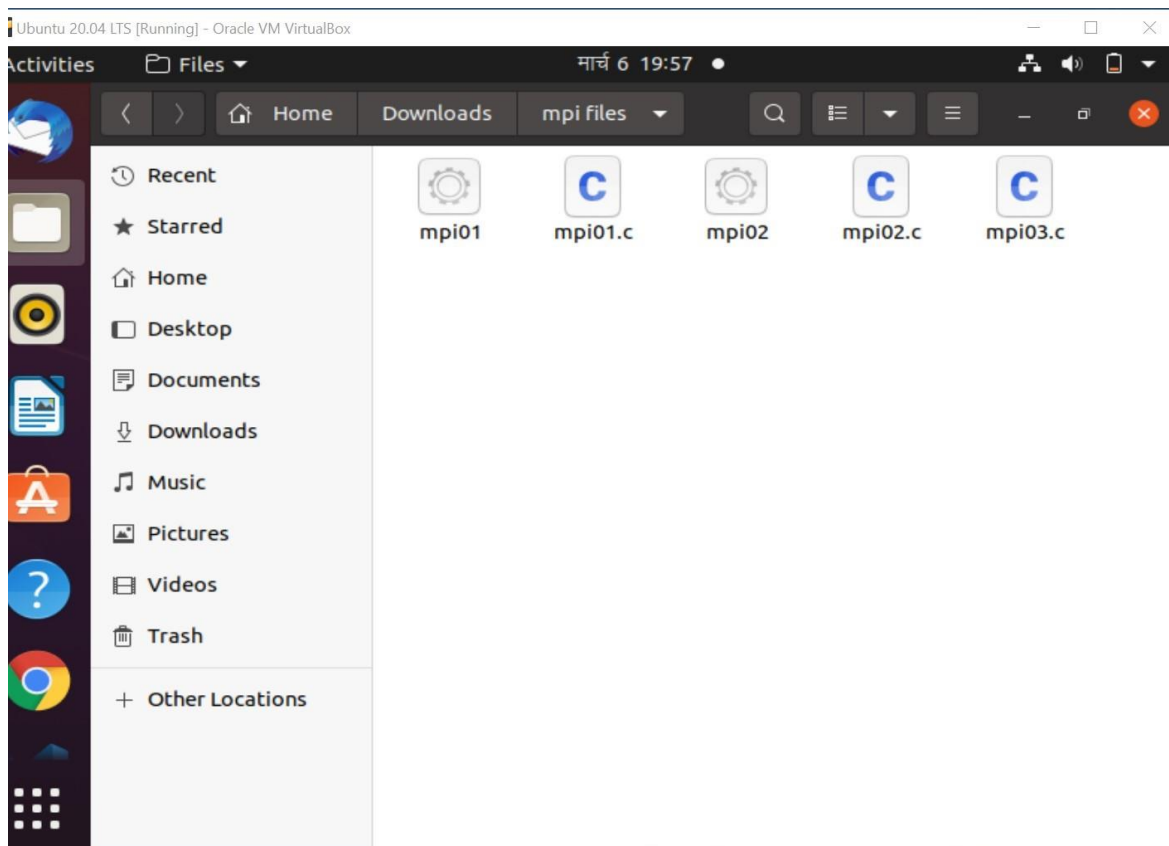
WEEK 1 WORKSHOP

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5CS022 Distribute and Cloud Systems Programming Week 1 Workshop

Tasks

1. Download the sample MPI programs from Canvas into your Linux system.



Compile and run the program `mpi01.c`. To compile it, run the following command in the terminal:

```
mpicc mpi01.c -o mpi01
```

Now run it with the following:

```
mpiexec ./mpi01
```

This will (probably) only run only one process, which is not very interesting. Run it again with the following command::

```
mpiexec -n 4 -oversubscribe ./mpi01
```

Note the output this time. It should indicate that 4 processes have run and they all have different process IDs.

```
Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox
Activities Terminal मार्च 6 18:56
dheerazsah@dhiraj-virtualbox: ~/Downloads/mpi files
dheerazsah@dhiraj-virtualbox:~$ ls
Desktop Downloads MyModules Public Templates Videos
Documents Music Pictures snap test
dheerazsah@dhiraj-virtualbox:~$ cd Downloads/
dheerazsah@dhiraj-virtualbox:~/Downloads$ ls
code_1.65.0-1646220682_amd64.deb 'mpi files' primenum.c
'google-chrome-stable_current_amd64(1).deb' 'mpi files test'
google-chrome-stable_current_amd64.deb 'mpi files.zip'
dheerazsah@dhiraj-virtualbox:~/Downloads$ cd mpi\ files/
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ ls
mpi01.c mpi02.c mpi03.c
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpicc mpi01.c -o mpi01
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ ls
mpi01 mpi01.c mpi02.c mpi03.c
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec ./mpi01
I am 0 of 1
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 4 -oversubscribe
./mpi01
I am 1 of 4
I am 3 of 4
I am 2 of 4
I am 0 of 4
```

In the above screenshot, details of the available directories are checked and then is redirected to Downloads and then mpi files to compile them. The mpi01.c file consisting source code is then compiled using mpicc mpi01.c -o mpi01. Then mpiexec ./mpi01 is executed which runs only one process. To run four processes mpiexec -n 4 -oversubscribe ./mpi01 is compiled with different IDs.

Experiment with higher and higher numbers of processes until it stops running. Then have a look at the error message and try and work out why it stop working.

```
>_ dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 6 -oversubscribe
./mpi01
I am 1 of 6
I am 0 of 6
I am 4 of 6
I am 2 of 6
I am 5 of 6
```

```
dheerazsah@dhiraj-virtualbox: ~/Downloads/mpi files
I am 6 of 10
I am 0 of 10
I am 4 of 10
I am 9 of 10
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 20 -oversubscrib
e ./mpi01
I am 1 of 20
I am 2 of 20
I am 4 of 20
I am 7 of 20
I am 3 of 20
I am 6 of 20
I am 8 of 20
I am 10 of 20
I am 0 of 20
I am 5 of 20
I am 9 of 20
I am 11 of 20
I am 12 of 20
I am 14 of 20
I am 16 of 20
I am 15 of 20
I am 13 of 20
I am 18 of 20
I am 17 of 20
I am 19 of 20
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 100 -oversubscri
be ./mpi01
```

```
Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox
Activities Terminal मार्च 6 19:01
dheerazsah@dhiraj-virtualbox: ~/Downloads/mpi files
I am 19 of 20
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 100 -oversubscri
be ./mpi01
I am 51 of 100
I am 55 of 100
I am 57 of 100
I am 58 of 100
I am 59 of 100
I am 60 of 100
I am 61 of 100
I am 64 of 100
I am 68 of 100
I am 69 of 100
I am 72 of 100
I am 75 of 100
I am 77 of 100
I am 84 of 100
I am 88 of 100
I am 92 of 100
I am 93 of 100
I am 97 of 100
I am 1 of 100
I am 3 of 100
I am 4 of 100
I am 5 of 100
I am 6 of 100
I am 7 of 100
I am 8 of 100
I am 10 of 100
```

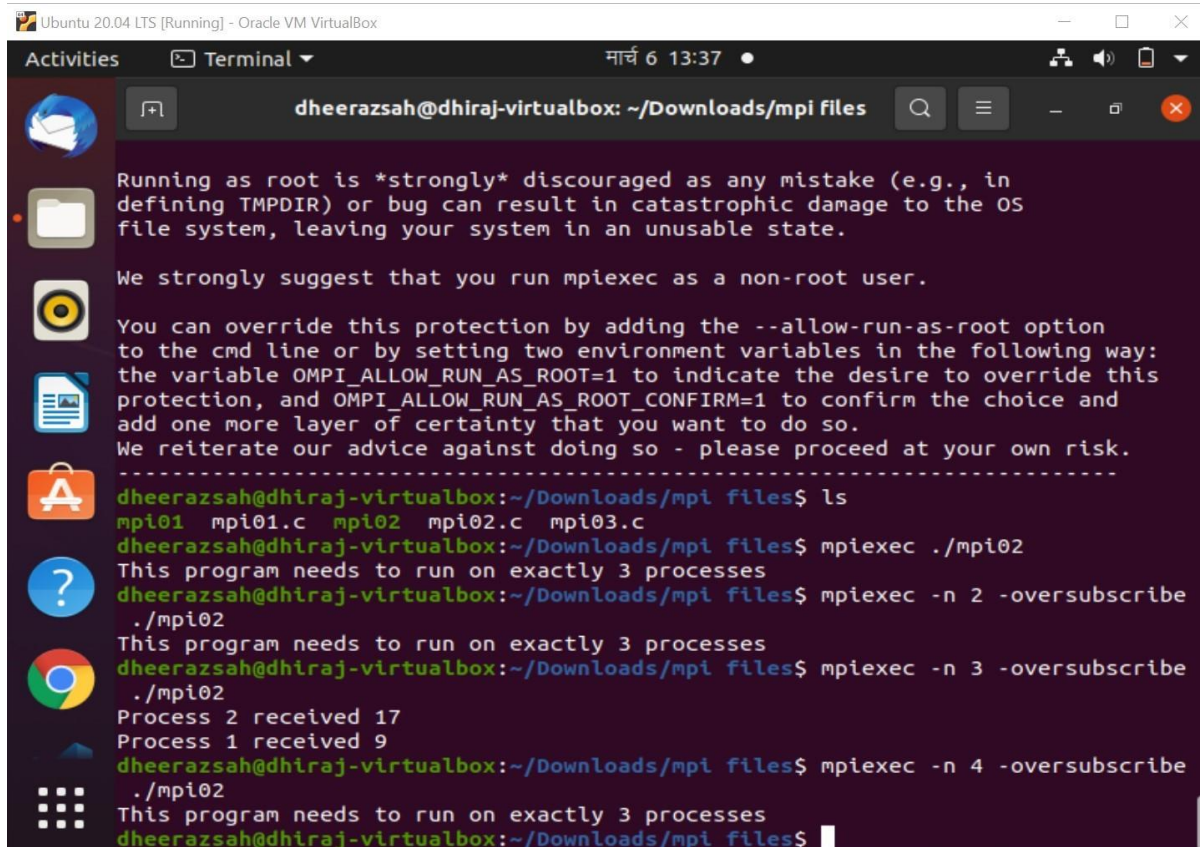
```
Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox
Activities Terminal मार्च 6 19:00
dheerazsah@dhiraj-virtualbox: ~/Downloads/mpi files
I am 56 of 100
I am 62 of 100
I am 63 of 100
I am 65 of 100
I am 66 of 100
I am 67 of 100
I am 70 of 100
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -1000 -oversubscri
e ./mpi01
mpiexec: Error: unknown option "-1000"
Type 'mpiexec --help' for usage.
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 1000 -oversubr
ibe ./mpi01
[dhiraj-virtualbox:03969] [[29777,0],0] ORTE_ERROR_LOG: The system limit on num
ber of pipes a process can open was reached in file base/iof_base_setup.c at li
ne 118
[dhiraj-virtualbox:03969] [[29777,0],0] ORTE_ERROR_LOG: The system limit on num
ber of pipes a process can open was reached in file base/odls_base_default_fns.
c at line 1438
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
mpiexec: Forwarding signal 18 to job
```

While experimenting with higher and higher number of processors, I found that after reaching a certain number it shows error when executed. To demonstrate, I used 6 processes, 10 processes, 20 processes, 100 processes then 1000 processes. Here, the program was not compiled when it reached 1000 processes. Here the number of processes were too much higher than the number of data.

2. Compile and run the program mpi02.c. Try running it with 2, 3 and 4 processes. Eg.:

```
mpixec -n 2 -oversubscribe ./mpi02
mpixec -n 3 -oversubscribe ./mpi02
mpixec -n 4 -oversubscribe ./mpi02
```

Note what happens. It doesn't let you run the program with anything other than 3 processes.



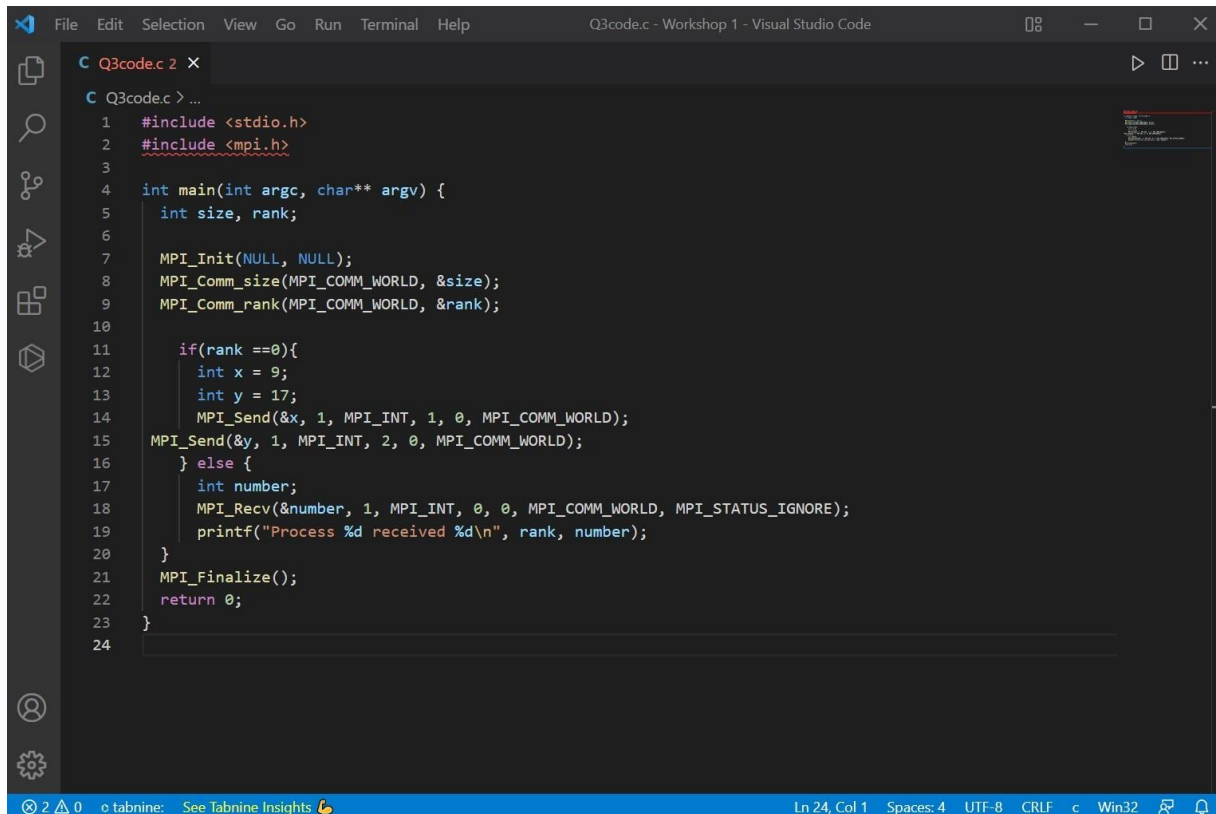
```
Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox
Activities Terminal  मार्च 6 13:37
dheerazsah@dhiraj-virtualbox: ~/Downloads/mpi files
Running as root is *strongly* discouraged as any mistake (e.g., in
defining TMPDIR) or bug can result in catastrophic damage to the OS
file system, leaving your system in an unusable state.

We strongly suggest that you run mpiexec as a non-root user.

You can override this protection by adding the --allow-run-as-root
option to the cmd line or by setting two environment variables in
the following way: the variable OMPI_ALLOW_RUN_AS_ROOT=1 to indicate
the desire to override this protection, and OMPI_ALLOW_RUN_AS_ROOT_CONFIRM=1 to confirm the choice and add one more layer of
certainty that you want to do so.
We reiterate our advice against doing so - please proceed at your
own risk.
-----
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ ls
mpi01 mpi01.c mpi02 mpi02.c mpi03.c
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec ./mpi02
This program needs to run on exactly 3 processes
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 2 -oversubscribe
./mpi02
This program needs to run on exactly 3 processes
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 3 -oversubscribe
./mpi02
Process 2 received 17
Process 1 received 9
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 4 -oversubscribe
./mpi02
This program needs to run on exactly 3 processes
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$
```

In the above screenshot, the program is executed using 2, 3, and 4 processes. At first, mpiexec ./mpi02 is compiled which runs on the processes used by the virtual box rather than using the processes of the actual device. To actually use different processes –oversubscribe is used, similarly to use a particular number of processes –n is used. The above program needs to run on exactly 3 processes. This is because the source code of this program will not accept size except 3.

- Now change the code so that you remove the check for only 3 processes. Now run it with 2, then 3, then 4 and then more processes.



```
Q3code.c 2 x
C Q3code.c > ...
1  #include <stdio.h>
2  #include <mpi.h>
3
4  int main(int argc, char** argv) {
5      int size, rank;
6
7      MPI_Init(NULL, NULL);
8      MPI_Comm_size(MPI_COMM_WORLD, &size);
9      MPI_Comm_rank(MPI_COMM_WORLD, &rank);
10
11     if(rank == 0){
12         int x = 9;
13         int y = 17;
14         MPI_Send(&x, 1, MPI_INT, 1, 0, MPI_COMM_WORLD);
15         MPI_Send(&y, 1, MPI_INT, 2, 0, MPI_COMM_WORLD);
16     } else {
17         int number;
18         MPI_Recv(&number, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
19         printf("Process %d received %d\n", rank, number);
20     }
21     MPI_Finalize();
22     return 0;
23 }
24
```

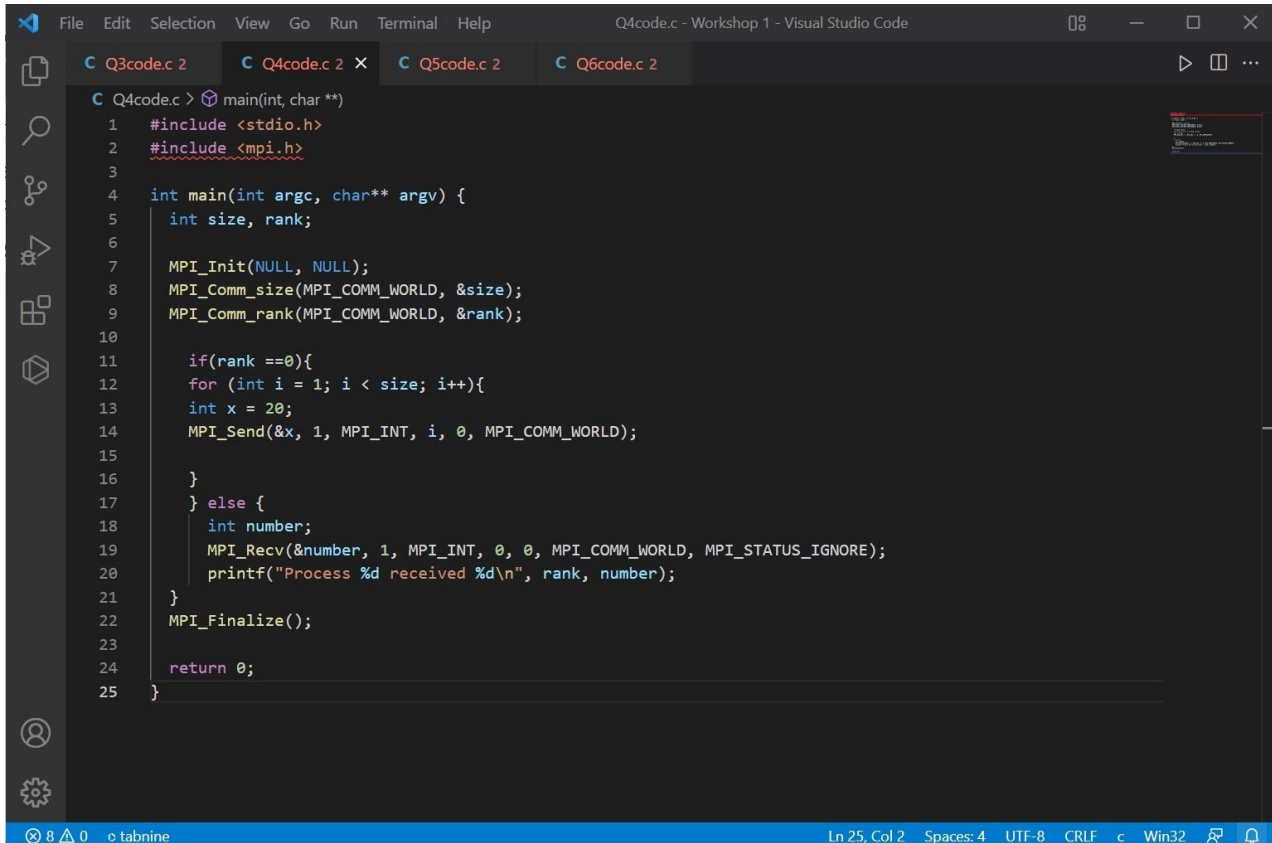
The above screenshot is the altered version of code of mpi02.c. Here, I have removed the if-else condition which was applied first and was not letting run any processes except 3. But now the condition `if(size != 3) { if(rank == 0) { print(" This program needs to run on exactly 3 processes\n") ;} } else` part was removed. The above code will let this program run in any processes.


```
Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox
Activities Terminal ॐ मार्च 6 19:53
dheerazsah@dhiraj-virtualbox: ~/Downloads/mpi files
Type 'mpiexec --help' for usage.
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 5 -oversubscribe ./mpi02
Process 2 received 17
Process 1 received 9
^Cdheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 6 -oversubscribe ./mpi02
mpiexec: Error: unknown option "-oversusubscribe"
Type 'mpiexec --help' for usage.
dheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 6 -oversubscribe ./mpi02
Process 1 received 9
Process 2 received 17
^Cdheerazsah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 10 -oversubscribe ./mpi02
Process 1 received 9
Process 2 received 17
```

Here, I tried to use more processes, every time the program was executed but was never ending due to lack of data and every time it required to stop the program forcefully.

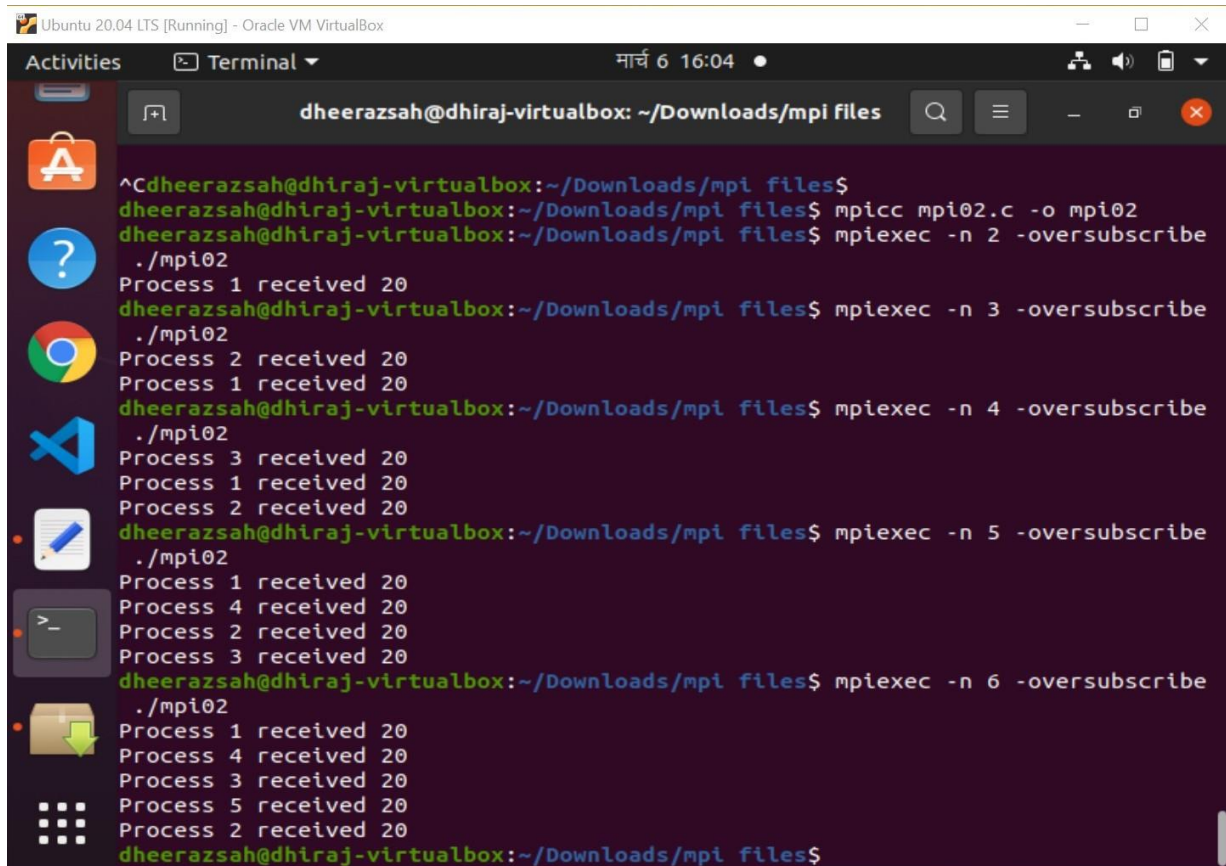
4. When you try to run it with 4 or more processes, it probably runs and appear to work, but never ends. You will have to end with "Ctrl-C". Why do you think it doesn't end when you run it with more than 3 processes? Change it so that it will work with any number of processes.

The if-else condition inside the source code was not letting run any processes except 3. When I tried to run the program using 4 and more processes, it didn't let the program end, this is because there were more number of processes than the data due to which the processes started looking for data and as there was no data to left to look for, the program ended up never-ending.



```
Q4code.c > main(int, char **)
1  #include <stdio.h>
2  #include <mpi.h>
3
4  int main(int argc, char** argv) {
5      int size, rank;
6
7      MPI_Init(NULL, NULL);
8      MPI_Comm_size(MPI_COMM_WORLD, &size);
9      MPI_Comm_rank(MPI_COMM_WORLD, &rank);
10
11     if(rank == 0){
12         for (int i = 1; i < size; i++){
13             int x = 20;
14             MPI_Send(&x, 1, MPI_INT, i, 0, MPI_COMM_WORLD);
15         }
16     } else {
17         int number;
18         MPI_Recv(&number, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
19         printf("Process %d received %d\\n", rank, number);
20     }
21     MPI_Finalize();
22     return 0;
23 }
24
25
```

In the above code, instead fixing the ranks, initializing $i=1$ and creating a loop was done which selects processes from rank 1 to any large number of processes.



The screenshot shows a terminal window titled 'dheerazzah@dhiraj-virtualbox: ~/Downloads/mpi files'. The user has compiled a program 'mpi02.c' using 'mpicc' and is running it with 'mpiexec -n' followed by the number of processes (2, 3, 4, 5, 6) and the '-oversubscribe' flag. Each time, the output shows the number of processes that received the value 20. For example, with 6 processes, it shows 'Process 1 received 20', 'Process 4 received 20', 'Process 3 received 20', 'Process 5 received 20', and 'Process 2 received 20'.

```
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpicc mpi02.c -o mpi02
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 2 -oversubscribe
./mpi02
Process 1 received 20
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 3 -oversubscribe
./mpi02
Process 2 received 20
Process 1 received 20
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 4 -oversubscribe
./mpi02
Process 3 received 20
Process 1 received 20
Process 2 received 20
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 5 -oversubscribe
./mpi02
Process 1 received 20
Process 4 received 20
Process 2 received 20
Process 3 received 20
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 6 -oversubscribe
./mpi02
Process 1 received 20
Process 4 received 20
Process 3 received 20
Process 5 received 20
Process 2 received 20
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$
```

Here, we can see that the code is now fixed and is working on different processes properly rather than working only in 3 processes. To demonstrate, I tried to run the program in 2, 3, 4, 5 and 6 processes. Neither the program showed any error nor it ended up never-ending.

5. Build and run the program mpi03.c. In this program Process 0 will wait for messages from Process 1 and Process 2. However, Process 1 ends up blocking Process 2 because it sleeps for 5 seconds. How would you change the code so that Process 1 does not block Process 2, even if it does sleep for 5 seconds?

```
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiccc mpi03.c -o mpi03
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ ls
mpi01  mpi01.c  mpi02  mpi02.c  mpi03  mpi03.c
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec ./mpi03
This program needs to run on exactly 3 processes
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 3 -oversubscribe
./mpi03
Received 11 from process 1
Received 12 from process 2
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiccc mpi03.c -o mpi03
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ ls
mpi01  mpi01.c  mpi02  mpi02.c  mpi03  mpi03.c
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$ mpiexec -n 3 -oversubscribe
./mpi03
Received 12 from process 1
Received 11 from process 2
dheerazzah@dhiraj-virtualbox:~/Downloads/mpi files$
```

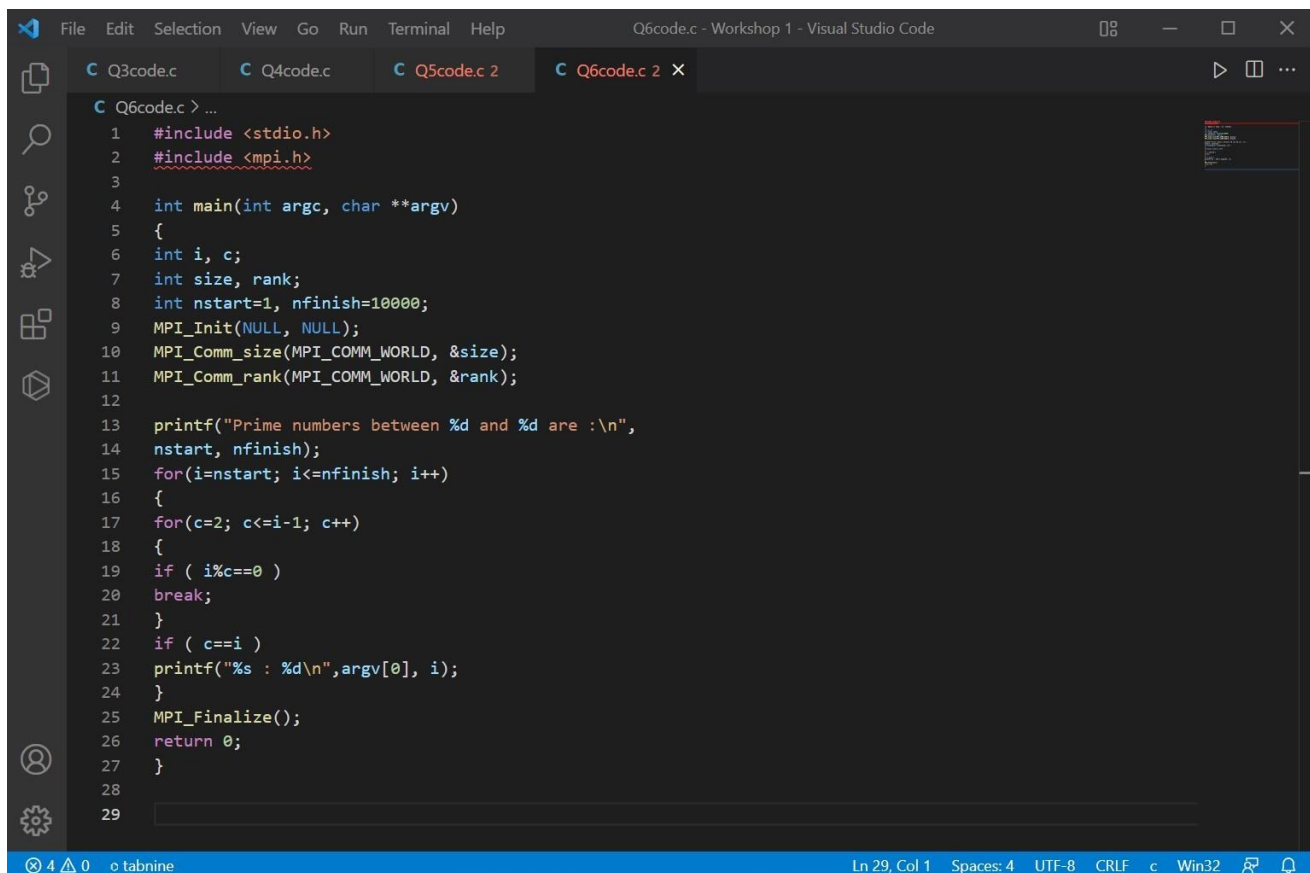
In the above screenshot, I tried to execute the mpi program without selecting a particular process, which then showed it requires exactly 3 processes to run. After executing the program with 3 processes, the program was executed but it took 5 seconds to show the result. At first while receiving we used the value of rank 1 where MPI_COMM_WORLD is helping to establish a communication area. Instead using the value of rank 1, value of rank 2 was used this is because rank 2 processes is not waiting for 5 seconds. Process 1 is blocking the executing process for few seconds so a slight change in line 16 and line 18 is done where the processes 1 and 2 are interchanged with each other. This after executing gives prompt result as 'Received 12 from process 1' and waits 5 seconds to give 'Received 11 from process 2' result.

6. The following is a simple program that looks for prime numbers between 1 to 10000:

```
#include <stdio.h>

int main(int argc, char **argv)
{
    int i, c;
    int nstart=1, nfinish=10000;
    printf("%s : Prime numbers between %d and %d are :\n",
           nstart, nfinish);
    for(i=nstart; i<=nfinish; i++)
    {
        for(c=2; c<=i-1; c++)
        {
            if ( i%c==0 )
                break;
        }
        if ( c==i )
            printf("%s : %d\n",argv[0], i);
    }
    return 0;
}
```

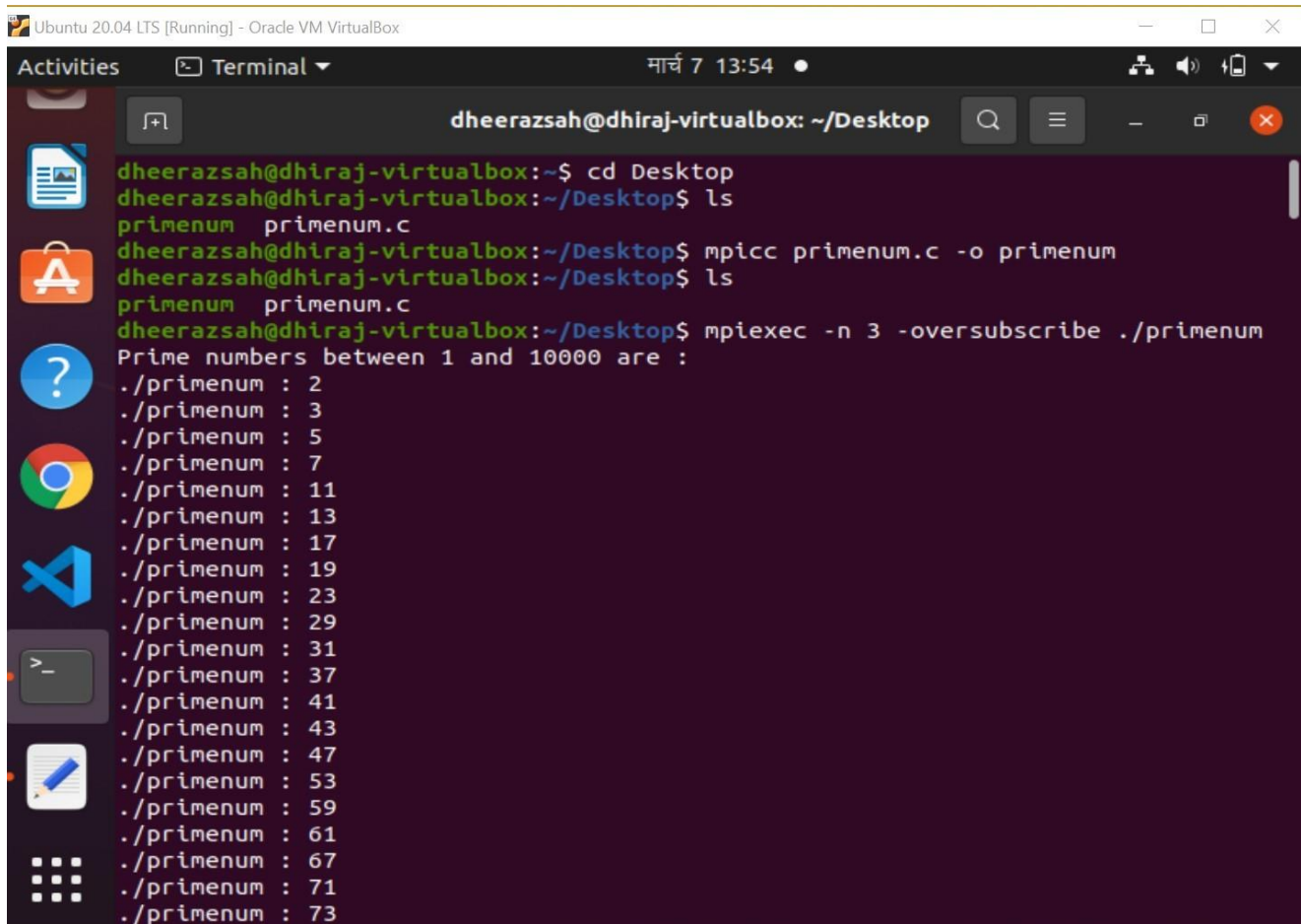
Convert it to MPI so that it can run with different numbers of processes including just one process.

A screenshot of the Visual Studio Code editor interface. The top menu bar includes File, Edit, Selection, View, Go, Run, Terminal, and Help. The title bar shows 'Q6code.c - Workshop 1 - Visual Studio Code'. The editor has four tabs: 'Q3code.c', 'Q4code.c', 'Q5code.c 2', and 'Q6code.c 2 X'. The active tab 'Q6code.c 2' contains the following C code:

```
1  #include <stdio.h>
2  #include <mpi.h>
3
4  int main(int argc, char **argv)
5  {
6      int i, c;
7      int size, rank;
8      int nstart=1, nfinish=10000;
9      MPI_Init(NULL, NULL);
10     MPI_Comm_size(MPI_COMM_WORLD, &size);
11     MPI_Comm_rank(MPI_COMM_WORLD, &rank);
12
13     printf("Prime numbers between %d and %d are :\n",
14           nstart, nfinish);
15     for(i=nstart; i<=nfinish; i++)
16     {
17         for(c=2; c<=i-1; c++)
18         {
19             if ( i%c==0 )
20                 break;
21         }
22         if ( c==i )
23             printf("%s : %d\n",argv[0], i);
24     }
25     MPI_Finalize();
26     return 0;
27 }
28
29
```

The status bar at the bottom shows 'Ln 29, Col 1', 'Spaces: 4', 'UTF-8', 'CRLF', 'c', 'Win32', and icons for a search, a bell, and a refresh.

In the above screenshot, I converted the simple program into MPI. First I implemented mpi library using `#include <mpi.h>`. Then, initializing and finalizing the MPI was implemented. Also `MPI_COMM_WORLD` was included to create a environment for communication. Starting value was entered as 1 and ending value as 1000 as mentioned in the question.



```
dheerazsah@dhiraj-virtualbox: ~/Desktop
dheerazsah@dhiraj-virtualbox:~$ cd Desktop
dheerazsah@dhiraj-virtualbox:~/Desktop$ ls
primenum  primenum.c
dheerazsah@dhiraj-virtualbox:~/Desktop$ mpicc primenum.c -o primenum
dheerazsah@dhiraj-virtualbox:~/Desktop$ ls
primenum  primenum.c
dheerazsah@dhiraj-virtualbox:~/Desktop$ mpiexec -n 3 -oversubscribe ./primenum
Prime numbers between 1 and 10000 are :
./primenum : 2
./primenum : 3
./primenum : 5
./primenum : 7
./primenum : 11
./primenum : 13
./primenum : 17
./primenum : 19
./primenum : 23
./primenum : 29
./primenum : 31
./primenum : 37
./primenum : 41
./primenum : 43
./primenum : 47
./primenum : 53
./primenum : 59
./primenum : 61
./primenum : 67
./primenum : 71
./primenum : 73
```

Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox

Activities Terminal मार्च 7 13:55

dheerazsah@dhiraj-virtualbox: ~/Desktop

```
./primenum : 929
./primenum : 937
./primenum : 941
./primenum : 947
./primenum : 953
./primenum : 967
Prime numbers between 1 and 10000 are :
./primenum : 2
./primenum : 3
./primenum : 5
./primenum : 7
./primenum : 11
./primenum : 13
./primenum : 17
./primenum : 19
./primenum : 23
./primenum : 29
./primenum : 31
./primenum : 37
./primenum : 41
./primenum : 43
./primenum : 47
./primenum : 53
./primenum : 59
./primenum : 61
./primenum : 67
./primenum : 71
./primenum : 73
./primenum : 79
```

Ubuntu 20.04 LTS [Running] - Oracle VM VirtualBox

Activities Terminal मार्च 7 13:55

dheerazsah@dhiraj-virtualbox: ~/Desktop

```
./primenum : 4159
./primenum : 4177
./primenum : 4201
./primenum : 4211
./primenum : 4217
./primenum : 4219
./primenum : 4229
./primenum : 4231
./primenum : 4241
./primenum : 4243
Prime numbers between 1 and 10000 are :
./primenum : 2
./primenum : 3
./primenum : 5
./primenum : 7
./primenum : 11
./primenum : 13
./primenum : 17
./primenum : 19
./primenum : 23
./primenum : 29
./primenum : 31
./primenum : 37
./primenum : 41
./primenum : 43
./primenum : 47
./primenum : 53
./primenum : 59
./primenum : 61
```