Exercise 0: Explain your system?

Processor	i7-5500U , 2.40GHz
Cores	4
Operating system	Windows 64 Bit
Ram	8GB
Programming Language	Python 3.7.7

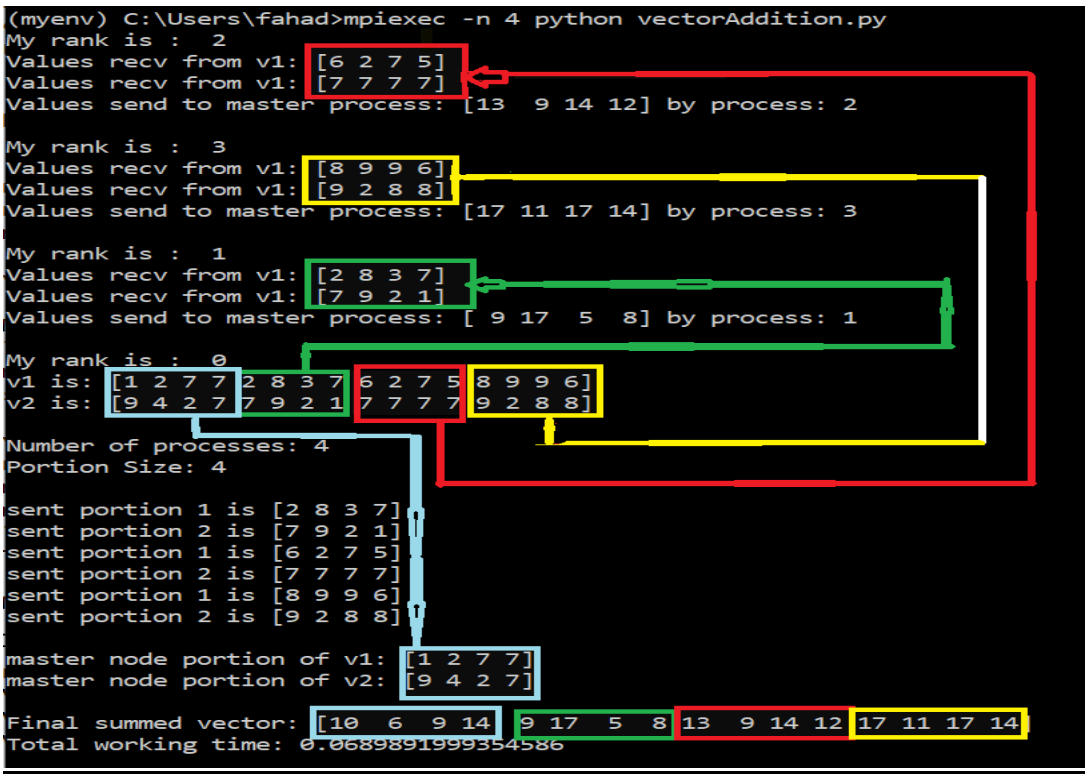
Exercise 1: Basic Parallel Vector Operations with MPI?

Part a)

Steps:

1. Consider 1st process as master node and other as worker node.
2. Master process will create two vectors v1, v2.
3. Then divide the vectors in equal portion and send that portion to other worker processes.
4. The worker receive chunk of vectors and perform addition on that vectors and return the result.
5. The master node performs addition on its chunk of vector.
6. The master node collects the result from other worker.
7. It appends and displays the results.

Processes: 4, Vectors size: 16



Time:

Size / P	10^7	10^12	10^15
1	0.24	Error	Error
2	0.29		
3	0.32		
4	0.34		
5	0.36		
6	0.38		
7	0.48		
8	0.50		
16	0.75		

Vector size: 10^7

```
(myenv) C:\Users\fahad>mpiexec -n 16 python vectorAddition.py

Final summed vector: [ 5  7  7 ... 13  9 14]
Total working time: 1.4472008999437094
```

Vector size: 10^12

```
myenv) C:\Users\fahad>mpiexec -n 2 python vectorAddition.py
raceback (most recent call last):
 File "vectorAddition.py", line 12, in <module>
   v1 = np.random.randint(1,10, vector_size, dtype=int)
 File "mtrand.pyx", line 741, in numpy.random.mtrand.RandomState.randint
 File "_bounded_integers.pyx", line 1362, in numpy.random._bounded_integers._rand_int32
lemoryError: Unable to allocate 3.64 TiB for an array with shape (1000000000000,) and data type int32
```

Vector size: 10^15

```
(myenv) C:\Users\fahad>mpiexec -n 2 python vectorAddition.py
Traceback (most recent call last):
  File "vectorAddition.py", line 12, in <module>
    v1 = np.random.randint(1,10, vector_size, dtype=int)
  File "mtrand.pyx", line 741, in numpy.random.mtrand.RandomState.randint
  File "_bounded_integers.pyx", line 1362, in numpy.random._bounded_integers._rand_int32
MemoryError: Unable to allocate 3.55 PiB for an array with shape (1000000000000000,) and data type int32
```

Code in file VectorAddition.py and output with results are shown in file VectorAddition.html

Part b)

Steps:

1. Consider 1st process as master node and other as worker node.
2. Master process will create vectors v1.
3. Then divide the vectors in equal portion and send that portion to other worker processes.
4. The worker receive chunk of vector and perform addition on that vector and return the result.
5. The master node performs addition on its chunk of vector.
6. The master node collects the result from other worker.
7. It adds the results and divides by size of vector and displays the average of values in vector.

Processes: 4, Vectors size: 16

```
(myenv) C:\Users\fahad>mpiexec -n 4 python vectorAvg.py
My rank is :  2
Values recv from v1: [6 8 8 7]
Values send to master process: 29 by process: 2

My rank is :  1
Values recv from v1: [9 5 5 3]
Values send to master process: 22 by process: 1

My rank is :  3
Values recv from v1: [2 6 2 9]
Values send to master process: 19 by process: 3

My rank is :  0
v1 is: [6 6 7 5 9 5 5 3 6 8 8 7 2 6 2 9]

Number of processes: 4
Portion Size: 4

sent portion 1 is [9 5 5 3]
sent portion 1 is [6 8 8 7]
sent portion 1 is [2 6 2 9]

master node portion of v1: [6 6 7 5]

Avg of vector: 5.875
Total working time: 0.027080000028945506
```

Time:

Size / P	10^7	10^12	10^15
1	0.22	Error	Error
2	0.25		
3	0.26		
4	0.29		
5	0.32		
6	0.37		
7	0.35		
8	0.37		
16	0.67		

Vector size: 10^7

```
Avg of vector: 5.0000146
Total working time: 0.7552609000122175
```

Vector size: 10^12

```
(myenv) C:\Users\fahad>mpiexec -n 16 python vectorAvg.py
My rank is :  0
Traceback (most recent call last):
  File "vectorAvg.py", line 13, in <module>
    v1 = np.random.randint(1, 10, vector_size, dtype=int)
  File "mtrand.pyx", line 741, in numpy.random.mtrand.RandomState.randint
  File "_bounded_integers.pyx", line 1362, in numpy.random._bounded_integers._rand_int32
MemoryError: Unable to allocate 3.55 PiB for an array with shape (1000000000000000,) and data type int32
```

Vector size: 10^15

```
(myenv) C:\Users\fahad>mpiexec -n 16 python vectorAvg.py
My rank is :  0
Traceback (most recent call last):
  File "vectorAvg.py", line 13, in <module>
    v1 = np.random.randint(1, 10, vector_size, dtype=int)
  File "mtrand.pyx", line 741, in numpy.random.mtrand.RandomState.randint
  File "_bounded_integers.pyx", line 1362, in numpy.random._bounded_integers._rand_int32
MemoryError: Unable to allocate 3.64 TiB for an array with shape (1000000000000,) and data type int32
```

Code in file VectorAvg.py and output with results are shown in file VectorAvg.html

Exercise 2: Parallel Matrix Vector multiplication using MPI?

Steps:

1. Consider 1st process as master node and other as worker node.
2. Master process will create matrix m and vector v.
3. Then divide the matrix by dividing matrix size with total number of available process and send that portion of matrix and vector to other worker processes.
4. The workers receive chunk of matrix and vector and perform multiplication and return the results.
5. The master node performs multiplication on its chunk of matrix and vector.

6. The master node collects the results from other workers , append and display results.

Processes: 4, Matrix size: (4,4), Vector size:(4,1)

Vector size 4 with 4 processes

```
In [1]: !mpiexec -n 4 python matVec.py
m is: [[6 4 3 7]
 [1 4 6 3]
 [5 3 6 2]
 [4 2 4 1]]
v is: [[9]
 [7]
 [5]
 [5]]

Number of processes: 4
Portion Size: 1


Final vector: [[132]
 [ 82]
 [106]
 [ 75]]
Total working time: 0.003249199944548309
```

Time:

Size / P	10^2	10^3	10^4
1	0.0003	0.02	2.3
2	0.001	0.03	2.8
3	0.005	0.03	3.13
4	0.002	0.04	3.2
5	0.123	0.07	3.23
6	0.055	0.139	3.56
7	0.22	0.095	3.39
8	0.066	0.121	3.18
16	0.206	0.34	3.64

Code in file MatVec.py and output with results are shown in file MatVecRes.html

Exercise 3: Parallel Matrix Operation using MPI?

Steps:

1. Consider 1st process as master node and other as worker node.
2. Through collective communication broadcast matrix m1_share, m2_share and their mat size.
3. All the processes divide the matrix by dividing matrix size with total number of available process and multiply that chunk of m1_share matrix to other m2_share matrix and send result back to master node.
4. The master node performs its multiplication on its chunk of matrix m1_share and m2_share.
5. The master node collects the results from other workers, append, reshape and display results.

Processes: 4, Matrix size: (4,4)

```
My rank is :  1
My rank is :  2
My rank is :  3
My rank is :  0
[[7 7 9 1]
 [0 4 2 8]
 [3 1 3 6]
 [5 9 3 0]]
[[2 7 0 8]
 [1 8 6 0]
 [2 0 0 8]
 [1 3 9 3]]
Matrix-matrix multiplication result: [[ 40 108  51 131]
 [ 16  56  96  40]
 [ 19  47  60  66]
 [ 25 107  54  64]]
time 0.016908499994315207
```

Time:

Size / P	10^2	10^3	10^4
1	0.002	1.57	Taking too much time
2	0.003	1.28	
3	0.002	1.15	
4	0.004	1.17	
5	0.010	1.25	
6	0.057	1.24	
7	0.102	1.26	
8	0.104	1.6	
16	0.24	2.4	

Code in file MatrixMultiplication.py and output with results are shown in file MatrixMultiplication.py

Conclusion for all questions:

- If the number of processes that we run through mpi4py is more than then available cores then OS has to run multiple processes on one core. In this case there is context switching between processes and it increases the time taken to do our operations. As you can see in question 3 time table when number of processes (5, 6, 7, 8, and 16) is more than the available cores (4), then mostly instead of decreasing time for matric multiplication, time take is increased. But in some case time is decreased due to efficient handling of processes by OS internally.

- Also, when we increase the # of process from 1 to 2 then time should be decreased because now we are doing multiprocessing. But results show that time taken when # of processes are 2 is more than when # of processes were 1. This may be because our OS is still running the 2 processes on single core due to which there is context switching involved which instead of increases the time, decreases it.