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HW4

1. Compilation and execution
    - The zip file contains a qsort_hypercube.cpp, qsort_hypercube_descending.cpp and Sorting_JOB.JOB files.
    - Compilation is done using command `mpiicpc -o qsort_hypercube.exe qsort_hypercube.cpp`
    - The output screenshots are as below.

```
[priyanka1331@ada8 Quick_sort]$ mpirun -np 2 ./qsort_hypercube.exe 4 -1
[Proc: 0]        8        7        6        5
[Proc: 1]        4        3        2        1
[Proc: 0] number of processes = 2, initial local list size = 4, hypercube quicksort time = 0.000245
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]        1        2        3        4        5
[Proc: 1]        6        7        8
[priyanka1331@ada8 Quick_sort]$ mpirun -np 4 ./qsort_hypercube.exe 4 -2
[Proc: 0]        1        2        3        4
[Proc: 1]        5        6        7        8
[Proc: 2]        9       10       11       12
[Proc: 3]       13       14       15       16
[Proc: 0] number of processes = 4, initial local list size = 4, hypercube quicksort time = 0.000388
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]        1        2        3        4        5
[Proc: 1]        6        7        8        9
[Proc: 2]       10       11       12       13
[Proc: 3]       14       15       16
[priyanka1331@ada8 Quick_sort]$ mpirun -np 8 ./qsort_hypercube.exe 4 -1
[Proc: 0]       32       31       30       29
[Proc: 1]       28       27       26       25
[Proc: 2]       24       23       22       21
[Proc: 3]       20       19       18       17
[Proc: 4]       16       15       14       13
[Proc: 5]       12       11       10        9
[Proc: 6]        8        7        6        5
[Proc: 7]        4        3        2        1
[Proc: 0] number of processes = 8, initial local list size = 4, hypercube quicksort time = 0.000702
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 4] check_list: local_error = 0
[Proc: 5] check_list: local_error = 0
[Proc: 6] check_list: local_error = 0
[Proc: 7] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]        1        2        3        4        5
[Proc: 1]        6        7        8        9
[Proc: 2]       10       11       12       13
[Proc: 3]       14       15       16       17
[Proc: 4]       18       19       20       21
[Proc: 5]       22       23       24       25
[Proc: 6]       26       27       28       29
[Proc: 7]       30       31       32
```

```
[priyanka1331@ada8 Quick_sort]$ mpirun -np 16 ./qsort_hypercube.exe 4 0
[Proc: 0]        14        40        54        41
[Proc: 1]        84        93        25         5
[Proc: 2]         3        45        47        18
[Proc: 3]        73        46        70        82
[Proc: 4]        44        98        92        95
[Proc: 5]        14        51        63        59
[Proc: 6]        85        51        85        72
[Proc: 7]        55         4         8        36
[Proc: 8]        26        56        30        49
[Proc: 9]        96         9         1        13
[Proc: 10]        15         9        23        26
[Proc: 11]        85        62        46        38
[Proc: 12]        56        14        16         3
[Proc: 13]        26        15        39        15
[Proc: 14]        97        67        61        80
[Proc: 15]        67        20        84        92
[Proc: 0] number of processes = 16, initial local list size = 4, hypercube quicksort time = 0.002327
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 4] check_list: local_error = 0
[Proc: 5] check_list: local_error = 0
[Proc: 6] check_list: local_error = 0
[Proc: 7] check_list: local_error = 0
[Proc: 8] check_list: local_error = 0
[Proc: 9] check_list: local_error = 0
[Proc: 10] check_list: local_error = 0
[Proc: 11] check_list: local_error = 0
[Proc: 12] check_list: local_error = 0
[Proc: 13] check_list: local_error = 0
[Proc: 14] check_list: local_error = 0
[Proc: 15] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]         1         3         3         4         5
[Proc: 1]         8         9         9        13
[Proc: 2]        14        14        14        15        15        15        16        18

[Proc: 3]        20        23        25        26        26        26
[Proc: 4]        30        36        38        39        40        41
[Proc: 5]        44        45        46        46        47
[Proc: 6]        49        51        51
[Proc: 7]        54
[Proc: 8]        55        56        56
[Proc: 9]        59        61        62
[Proc: 10]        63        67        67

[Proc: 12]        70        72        73        80        82        84        84
[Proc: 13]        85        85        85
[Proc: 14]        92        92        93        95
[Proc: 15]        96        97        98
```

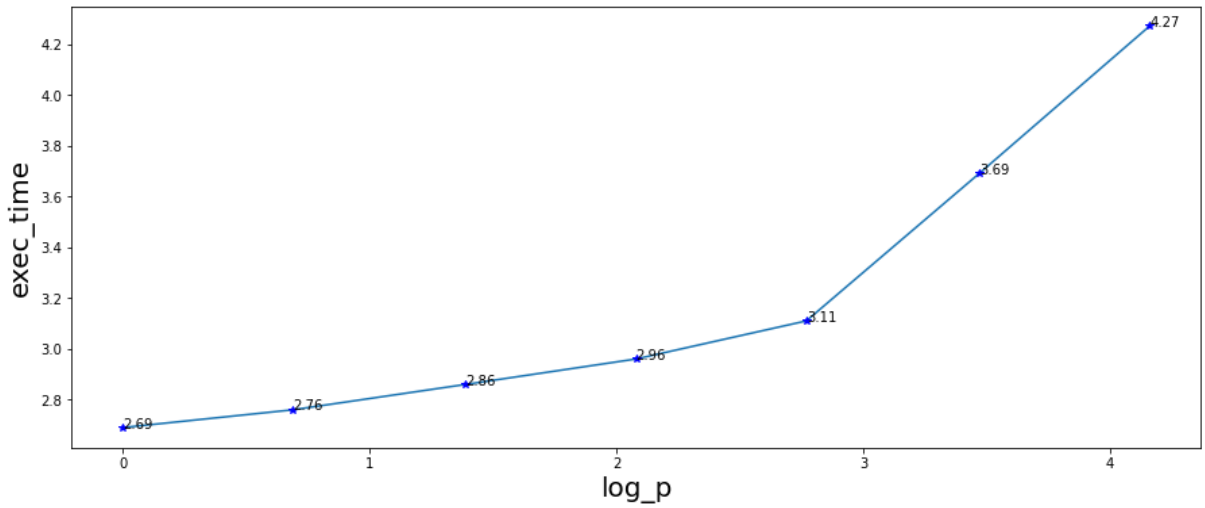
```
[priyanka1331@ada8 Quick_sort]$ mpirun -np 16 ./qsort_hypercube.exe 20480000 0
[Proc: 0] number of processes = 16, initial local list size = 20480000, hypercube quicksort time = 3.564706
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 4] check_list: local_error = 0
[Proc: 5] check_list: local_error = 0
[Proc: 6] check_list: local_error = 0
[Proc: 7] check_list: local_error = 0
[Proc: 8] check_list: local_error = 0
[Proc: 9] check_list: local_error = 0
[Proc: 10] check_list: local_error = 0
[Proc: 11] check_list: local_error = 0
[Proc: 12] check_list: local_error = 0
[Proc: 13] check_list: local_error = 0
[Proc: 14] check_list: local_error = 0
[Proc: 15] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[priyanka1331@ada8 Quick_sort]$
```

2. Weak Scalability Study:

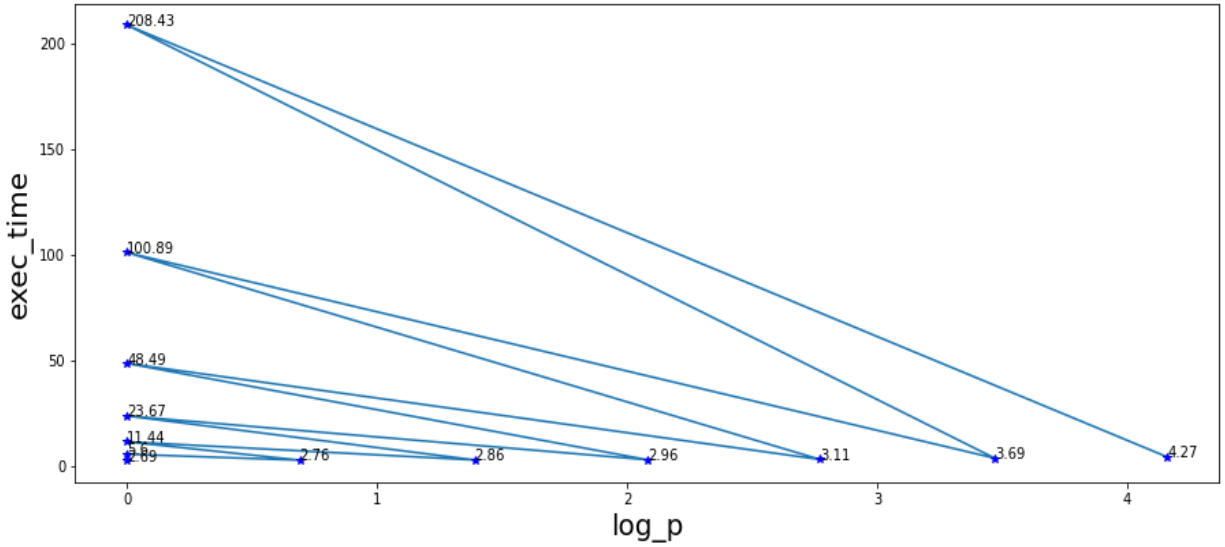
```
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 20480000, hypercube quicksort time = 2.692787
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 40960000, hypercube quicksort time = 5.605006
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
processors = 2^M
[Proc: 0] number of processes = 2, initial local list size = 20480000, hypercube quicksort time = 2.766110
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 81920000, hypercube quicksort time = 11.438250
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 4^M
[Proc: 0] number of processes = 4, initial local list size = 20480000, hypercube quicksort time = 2.865169
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 163840000, hypercube quicksort time = 23.679627
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 8^M
[Proc: 0] number of processes = 8, initial local list size = 20480000, hypercube quicksort time = 2.966783
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 327680000, hypercube quicksort time = 48.493035
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 16^M
[Proc: 0] number of processes = 16, initial local list size = 20480000, hypercube quicksort time = 3.105702
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 655360000, hypercube quicksort time = 100.892993
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 32^M
[Proc: 0] number of processes = 32, initial local list size = 20480000, hypercube quicksort time = 3.694343
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
```

```
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 1310720000, hypercube quicksort time = 208.430451
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 64^M
[Proc: 0] number of processes = 64, initial local list size = 20480000, hypercube quicksort time = 4.267347
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
```

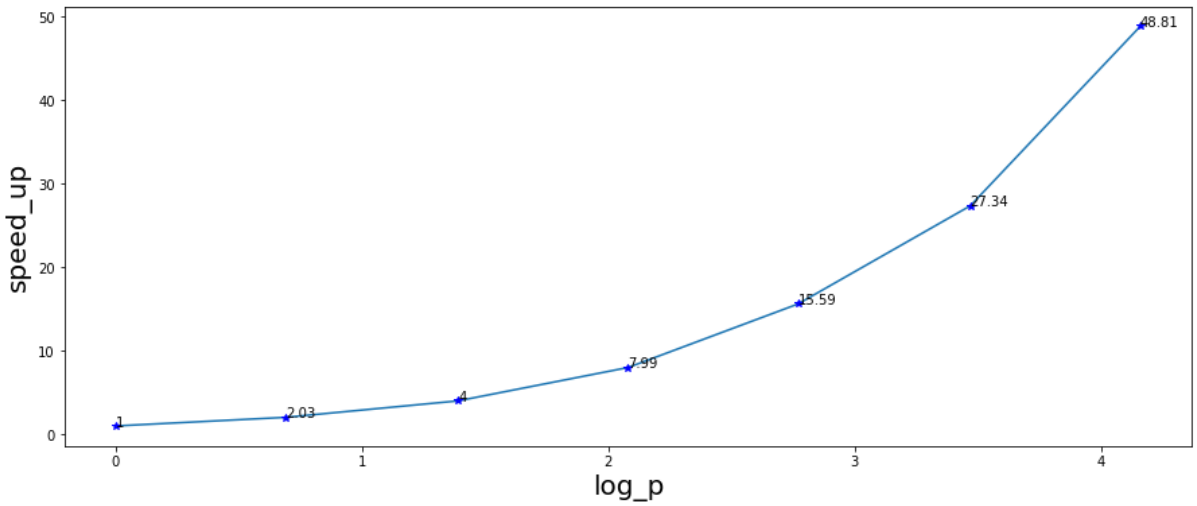
```
p =  [1, 1, 2, 1, 4, 1, 8, 1, 16, 1, 32, 1, 64]
time = [2.69, 5.6, 2.76, 11.44, 2.86, 23.67, 2.96, 48.49, 3.11, 100.89, 3.69, 208.43, 4.27]
```



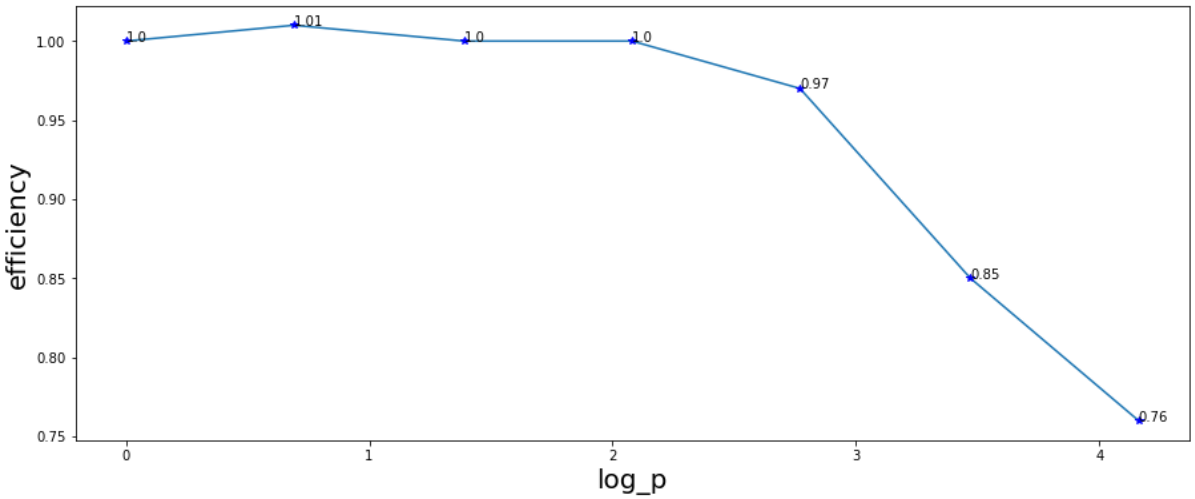
Execution time is increasing because n is doubling everytime. For plot, I have considered only p processors. If considering varying n and processors, then the plot is as below:




```
p =  [1, 2, 4, 8, 16, 32, 64]
log_p = [0.0, 0.69, 1.39, 2.08, 2.77, 3.47, 4.16]
speed_up =  [1, 2.03, 4, 7.99, 15.59, 27.34, 48.81]
```



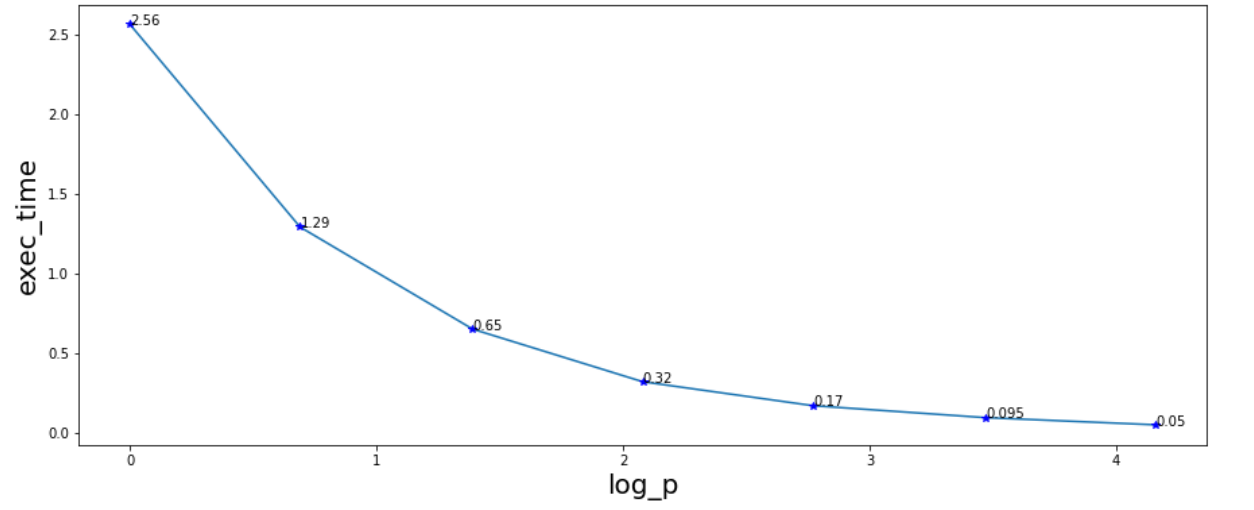

```
efficiency =  [1.0, 1.01, 1.0, 1.0, 0.97, 0.85, 0.76]
```

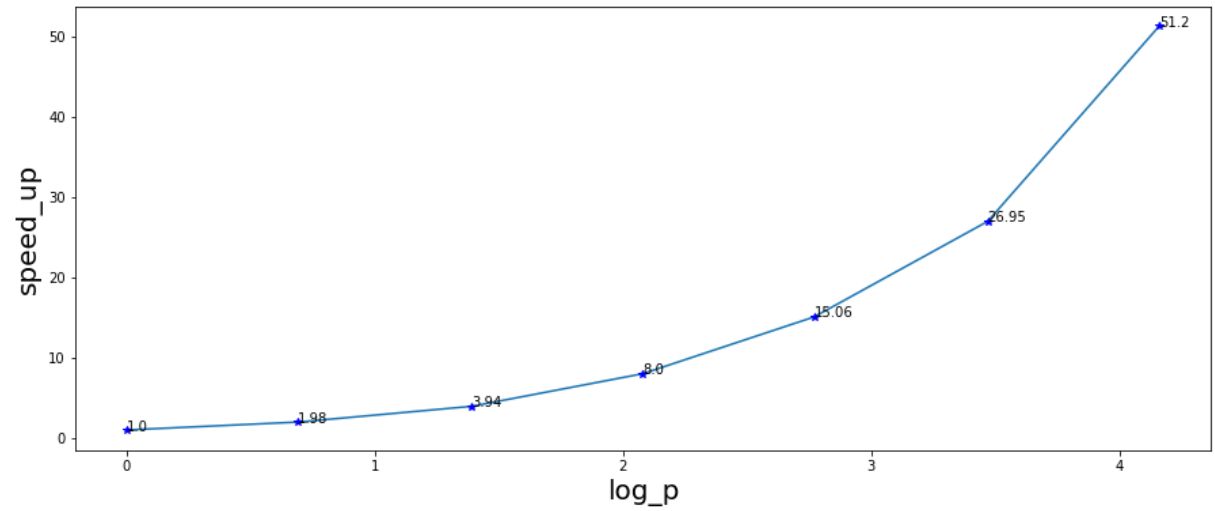


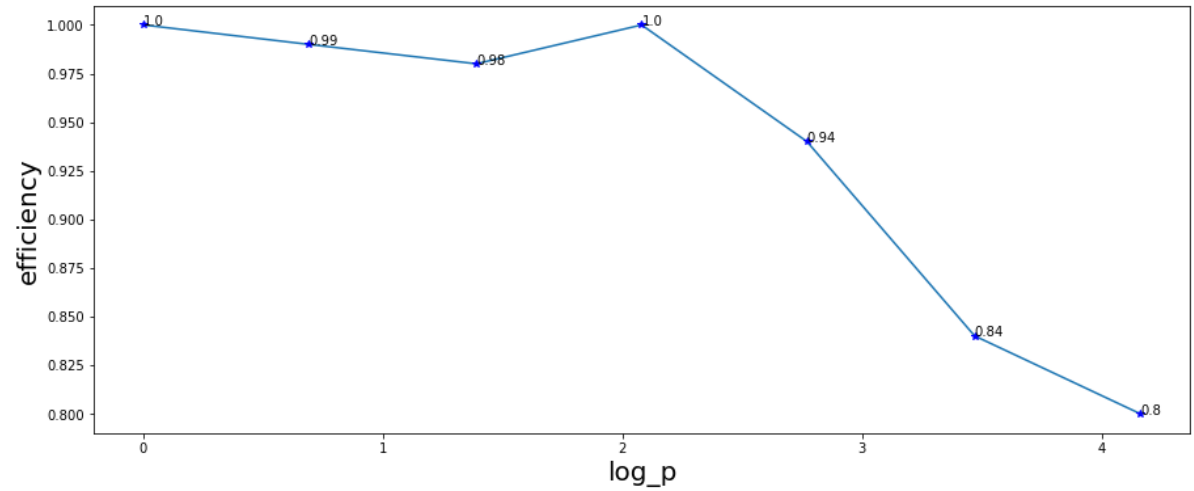
3. Strong scalability study:

```
processors = 1^M
[Proc: 0] number of processes = 1, initial local list size = 20480000, hypercube quicksort time = 2.563567
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 2^M
[Proc: 0] number of processes = 2, initial local list size = 10240000, hypercube quicksort time = 1.288124
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 4^M
[Proc: 0] number of processes = 4, initial local list size = 5120000, hypercube quicksort time = 0.653450
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 8^M
[Proc: 0] number of processes = 8, initial local list size = 2560000, hypercube quicksort time = 0.325760
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 16^M
[Proc: 0] number of processes = 16, initial local list size = 1280000, hypercube quicksort time = 0.169901
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 32^M
[Proc: 0] number of processes = 32, initial local list size = 640000, hypercube quicksort time = 0.095258
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
processors = 64^M
[Proc: 0] number of processes = 64, initial local list size = 320000, hypercube quicksort time = 0.050353
[Proc: 0] Congratulations. The list has been sorted correctly.
============================^M
============================^M
```

```
p =  [1, 2, 4, 8, 16, 32, 64]
time = [2.56, 1.29, 0.65, 0.32, 0.17, 0.095, 0.05]
log_p = [0.0, 0.69, 1.39, 2.08, 2.77, 3.47, 4.16]
speed_up =  [1.0, 1.98, 3.94, 8.0, 15.06, 26.95, 51.2]
efficiency =  [1.0, 0.99, 0.98, 1.0, 0.94, 0.84, 0.8]
```







4. The modified code runs as per expectations. The outputs are attached below:

```
[priyanka1331@ada8 Quick_sort]$ mpirun -np 2 ./qsort_hypercube_descending.exe 4 -1
[Proc: 0]        8        7        6        5
[Proc: 1]        4        3        2        1
[Proc: 0] number of processes = 2, initial local list size = 4, hypercube quicksort time = 0.000567
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]        8        7        6        5
[Proc: 1]        4        3        2        1
[priyanka1331@ada8 Quick_sort]$ mpirun -np 4 ./qsort_hypercube_descending.exe 4 -2
[Proc: 0]        1        2        3        4
[Proc: 1]        5        6        7        8
[Proc: 2]        9       10       11       12
[Proc: 3]       13       14       15       16
[Proc: 0] number of processes = 4, initial local list size = 4, hypercube quicksort time = 0.000398
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]       16       15       14       13
[Proc: 1]       12       11       10        9
[Proc: 2]        8        7        6        5
[Proc: 3]        4        3        2        1
[priyanka1331@ada8 Quick_sort]$ mpirun -np 8 ./qsort_hypercube_descending.exe 4 -1
[Proc: 0]       32       31       30       29
[Proc: 1]       28       27       26       25
[Proc: 2]       24       23       22       21
[Proc: 3]       20       19       18       17
[Proc: 4]       16       15       14       13
[Proc: 5]       12       11       10        9
[Proc: 6]        8        7        6        5
[Proc: 7]        4        3        2        1
[Proc: 0] number of processes = 8, initial local list size = 4, hypercube quicksort time = 0.001015
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 4] check_list: local_error = 0
[Proc: 5] check_list: local_error = 0
[Proc: 6] check_list: local_error = 0
[Proc: 7] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]       32       31       30       29
[Proc: 1]       28       27       26       25
[Proc: 2]       24       23       22       21
[Proc: 3]       20       19       18       17
[Proc: 4]       16       15       14       13
[Proc: 5]       12       11       10        9
[Proc: 6]        8        7        6        5
[Proc: 7]        4        3        2        1
```

```
[priyanka1331@ada8 Quick_sort]$ mpirun -np 16 ./qsort_hypercube_descending.exe 4 0
[Proc: 0]       14       40       54       41
[Proc: 1]       84       93       25        5
[Proc: 2]        3       45       47       18
[Proc: 3]       73       46       70       82
[Proc: 4]       44       98       92       95
[Proc: 5]       14       51       63       59
[Proc: 6]       85       51       85       72
[Proc: 7]       55        4        8       36
[Proc: 8]       26       56       30       49
[Proc: 9]       96        9        1       13
[Proc: 10]       15        9       23       26
[Proc: 11]       85       62       46       38
[Proc: 12]       56       14       16        3
[Proc: 13]       26       15       39       15
[Proc: 14]       97       67       61       80
[Proc: 15]       67       20       84       92
[Proc: 0] number of processes = 16, initial local list size = 4, hypercube quicksort time = 0.001398
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 4] check_list: local_error = 0
[Proc: 5] check_list: local_error = 0
[Proc: 6] check_list: local_error = 0
[Proc: 7] check_list: local_error = 0
[Proc: 8] check_list: local_error = 0
[Proc: 9] check_list: local_error = 0
[Proc: 10] check_list: local_error = 0
[Proc: 11] check_list: local_error = 0
[Proc: 12] check_list: local_error = 0
[Proc: 13] check_list: local_error = 0
[Proc: 14] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
[Proc: 0]       98       97       96       95
[Proc: 1]       93       92       92
[Proc: 15] check_list: local_error = 0
[Proc: 2]       85       85       85       84       84       82
[Proc: 3]       80       73       72       70       67       67
[Proc: 4]       63       62       61       59       56       56
[Proc: 5]       55       54       51       51       49
[Proc: 6]       47       46       46       45
[Proc: 7]       44       41       40       39
[Proc: 8]       38       36       30       26       26       26
[Proc: 9]       25       23
[Proc: 10]       20       18       16       15       15       15

[Proc: 12]       14       14       14       13
[Proc: 13]        9        9        8
[Proc: 14]        5        4        3        3
[Proc: 15]        1
```

```
[priyanka1331@ada8 Quick_sort]$ mpirun -np 16 ./qsort_hypercube_descending.exe 20480000 0
[Proc: 0] number of processes = 16, initial local list size = 20480000, hypercube quicksort time = 3.125650
[Proc: 0] check_list: local_error = 0
[Proc: 1] check_list: local_error = 0
[Proc: 2] check_list: local_error = 0
[Proc: 3] check_list: local_error = 0
[Proc: 4] check_list: local_error = 0
[Proc: 5] check_list: local_error = 0
[Proc: 6] check_list: local_error = 0
[Proc: 7] check_list: local_error = 0
[Proc: 8] check_list: local_error = 0
[Proc: 9] check_list: local_error = 0
[Proc: 10] check_list: local_error = 0
[Proc: 11] check_list: local_error = 0
[Proc: 12] check_list: local_error = 0
[Proc: 13] check_list: local_error = 0
[Proc: 14] check_list: local_error = 0
[Proc: 15] check_list: local_error = 0
[Proc: 0] Congratulations. The list has been sorted correctly.
```