CITS5507 – Project 2

Chenxin Hu (22961779)
21/10/2021

Part1 Experiment design

Overview

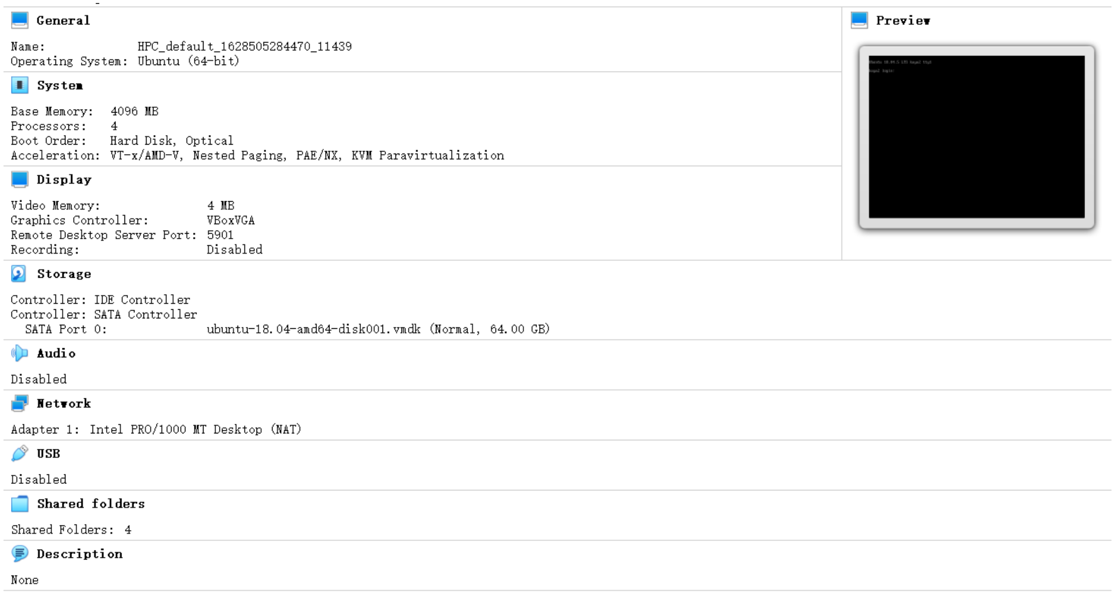
In this experiment, we develop the serial and parallel solutions for 3 sorting algorithms: quick sort, enumeration sort and merge sort using mpi.

Before sorting, another program used to write and read array from file is implemented using both serial and parallel methods.

The solutions for each algorithm are tested on virtual machine, using VirutalBox and Vagrant, the result of time consumption for each solution are recorded and analyzed.

Experiment Environment

The experiment is carried out on a virtual machine, environment is shown below (Generated from VirtualBox):



```
General
Name:             HPC_default_1628505284470_11439
Operating System: Ubuntu (64-bit)

System
Base Memory:   4096 MB
Processors:    4
Boot Order:    Hard Disk, Optical
Acceleration:  VT-x/AMD-V, Nested Paging, PAE/NX, KVM Paravirtualization

Display
Video Memory:               4 MB
Graphics Controller:        VBoxVGA
Remote Desktop Server Port: 5901
Recording:                  Disabled

Storage
Controller: IDE Controller
Controller: SATA Controller
  SATA Port 0:              ubuntu-18.04-amd64-disk001.vmdk (Normal, 64.00 GB)

Audio
Disabled

Network
Adapter 1: Intel PRO/1000 MT Desktop (NAT)

USB
Disabled

Shared folders
Shared Folders: 4

Description
None
```

Compile Codes

In this experiment, we use the

```
mpic++ -fopenmp fileName.cpp
```

instruction to compile the source code.
Using the instruction to run the executable file (a.out):

```
mpirun -n 2 a.out or mpirun -n 4 a.out
```

Pseudocodes

Write & Read Array Serial Solution

```
Generate a random array
Use ofstream to write it to file
Use ofstream to read it from file to a new array
Comparing 2 arrays to check the correctness
```

Write & Read Array Parallel Solution

```
Generate a random array
Use MPI_File_write to write it to file
Use serial solution to read it from file to a new array
Comparing 2 arrays to check the correctness
Use MPI_File_read to read it from file to a new array
Comparing 2 arrays to check the correctness
```

Enumeration Sort Serial Solution

```
Read array from file
Create a new empty array as temp array
For each item in the array
    while array not ending
        comparing the item with every item in the array.
        record how many items is smaller or equal to this item
    Add the item to the temp array in position number corresponding to record-1.
    #Cause the item Itself takes is one of these items that "smaller or equal to the item"#
For each item in the temp array
    If the item is empty #or, not fulfilled in the previous procedure
        Fulfill it with the nearest filled value which locates after the item.
        #Cause for one value shows many times in the array, the previous procedure only records it once in the temp array, so between the two fulfilled value, there is an empty zone. Fortunately, the empty value stands for the items have the same value but covered by the latest shown one, so the empty value should equal to the nearest fulfilled right value. #
```

```
Copy the temp array to the original array.
Delete temp array
```

Enumeration Sort Parallel Solution

```
Read array from file
Create a new empty array as temp array
Using MPI_BCAST To broadcast the array to all processors
Each do the following procedure:
For each item in the array
    determine the part of array it should process according to its processor id
    count the rank for every item in its part
Using MPI_SEND send back the rank message to processor 0
Processor 0 create a sorted array called data_out using the rank message
```

Quick Sort Serial Solution

```
Read array from file
Create two pointer points to edge of the array
If two pointers meet or go through each other, stop the function and return
Take the value of the item that left pointer points as sample value
Create two new pointers to record the current pointer
While two new pointers do not meet each other
    While new right pointer hasn't met the value larger or equal than the sample value
        Cursing left
    While new left pointer hasn't met the value smaller or equal than the sample value
        Cursing right
    Swap the items' value that two new pointers point.
Create new procedure, using the original left pointer as left pointer and new right pointer as right pointer
Create new procedure, using the original right pointer as right pointer and new right pointer as right pointer
```

Quick Sort Parallel Solution

```
Read array from file
Using MPI_BCAST To broadcast the array to all processors
Each do the following procedure:
If there exists processor which id=current id+2^(log2(ProcessorNum-1))
    Choose a pivot value
    Perform the first level iteration of serial quick sort, obtaining two unsorted arrays.
    Using MPI_SEND to send the second array to the processor which id=current id +
2^(log2(ProcessorNum-1))
Else
    perform parallel quick sorting procedure on array obtained
    Using MPI_SEND to send the sorted array to the processor which send this array
```

Merge Sort Serial Solution

```
Read array from file
Create two pointer points to edge of the array
If two pointers meet or go through each other, stop the function and return
Break the array from the middle into two parts, apply the same procedure, using two threads
to do the two parts individually
Merge two parts
```

Merge Procedure

```
Create a temp array
While array1 not end and array2 not end
    If the item value in array1 smaller than array2
        Put the value into the temp array
        Right cursing array1
    Else
        Put the value into the temp array
        Right cursing array2
Put the remaining value in array1 or array2 to temp array
Delete temp array.
```

Merge Sort Parallel Solution

```
Read array from file
Using MPI_Scatter to automatically divide array to every processor
For each processor
    Perform mergesort
Using MPI_Gather to gather results from all processors to processor 0
For processor 0
    Perform merge for the gathered arrays
```

Merge Procedure

```
Create a temp array
```

```
While array1 not end and array2 not end
    If the item value in array1 smaller than array2
        Put the value into the temp array
        Right cursing array1
    Else
        Put the value into the temp array
        Right cursing array2
Put the remaining value in array1 or array2 to temp array
Delete temp array.
```

Part2 Experiment Result and Analysis

Overview

In this experiment, we tested the sorting speed for each algorithm's parallel solution and serial solution, using array size 10^3, 10^4, 10^5 and 5*10^5. Larger array size should work, but the virtual machine execution time when the array size gets greater than 5*10^5 become unacceptable, hence we'll not using the array size larger than 5*10^5.

Also, the correctness of each algorithm's parallel solution is tested using a random array with size 10. Serial correctness is tested too.

The array used in this experiment is firstly generated and saved into file named text.txt using binary form. It is read to the storage when sorting program begins. A correctness test is done to make sure that the array read from the file is the same to the array write into the file.

The original execution screenshots, both the correctness test and speed test are in the attachment file named "screenshot.docx"

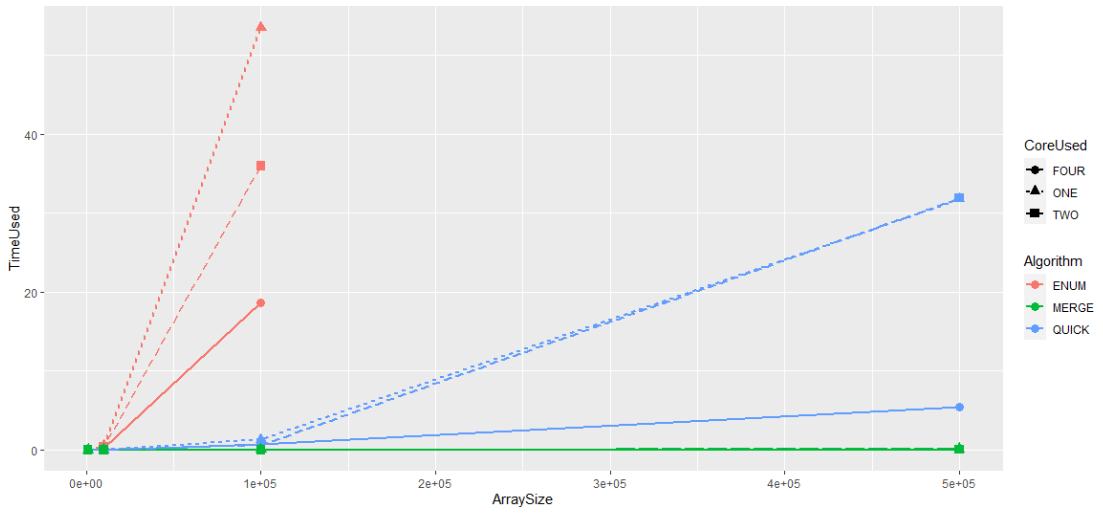
A result table is generated from the experiment:

Result Table (grouped by array size)

AS=10^3	1 Core	2 Cores	4 Cores	SpeedUp1	SpeedUp2
ENUM	0.005216	0.004002	0.002159	1.3033	2.2686
QUICK	0.000255	0.000184	0.000172	1.385	1.6195
MERGE	0.000156	0.000118	0.000211	1.1372	0.8257
AS=10^4	1 Core	2 Cores	4 Cores	SpeedUp1	SpeedUp2
ENUM	0.5281	0.3536	0.1924	1.4933	2.7345
QUICK	0.01405	0.01786	0.0023	0.7864	6.207
MERGE	0.0031	0.0016	0.0011	1.8788	2.8182
AS=10^5	1 Core	2 Cores	4 Cores	SpeedUp1	SpeedUp2

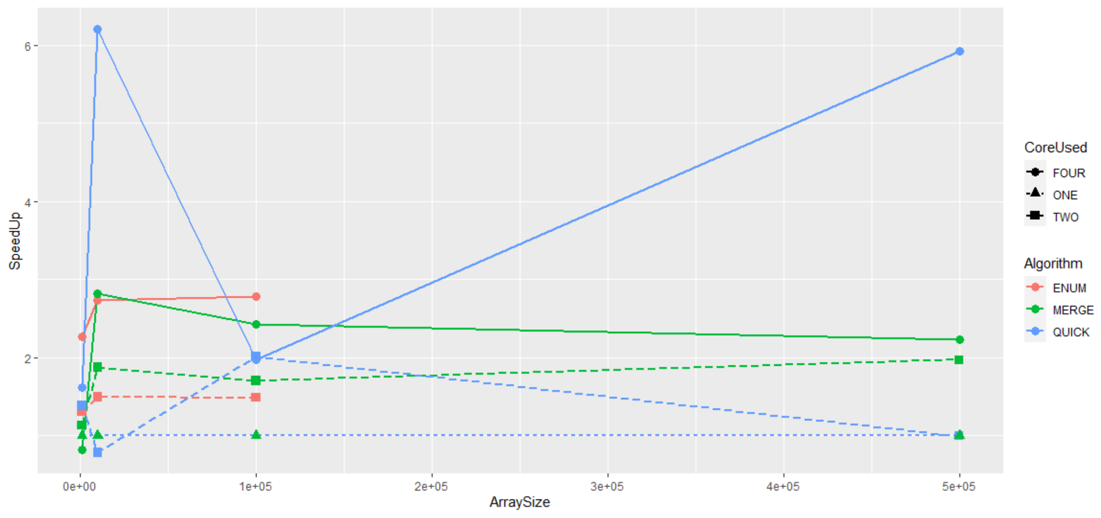
ENUM	53.5788	35.9891	18.6969	1.488	2.778
QUICK	1.27707	0.6342	0.6794	2.0134	1.9691
MERGE	0.0213	0.0125	0.00968	1.705	2.424
AS=5*10^5	1 Core	2 Cores	4 Cores	SpeedUp1	SpeedUp2
ENUM	NA	NA	NA	NA	NA
QUICK	31.8047	31.9071	5.454	0.9967	5.9239
MERGE	0.1217	0.0618	0.0545	1.9686	2.2357

(AS stands for array size, NA means the execution time is unacceptable, it only shows in the enumeration sort when array size is larger than 10^5)
To be more obvious, we can draw an overview graph using RStudio, with x-axis stands for the array size and y-axis stands for the time consumption.



From this graph we can see that for enumeration sort, as core number grows, the sorting speed grows too. While for quick sort, when core number is small, for example, 2, the sorting speed has no significant grow then using serial solutions, the tendency of merge sort remained unknown because of scaling, we'll look into it later.

Then we can draw another graph use speedup ratio as y-axis.

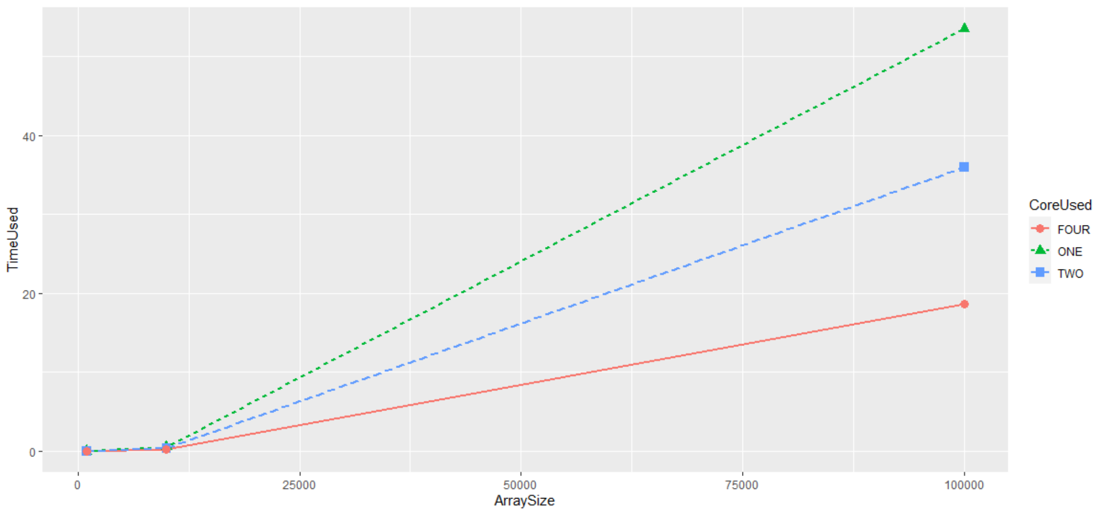


From this graph we can see that the speedup ratio for quick sort is unstable at all core numbers, the speedup ratio for merge sort and enumeration sort is stable, while merge sort's speedup ratio on 4 cores performs less better than 2 cores comparing to enumeration sort.

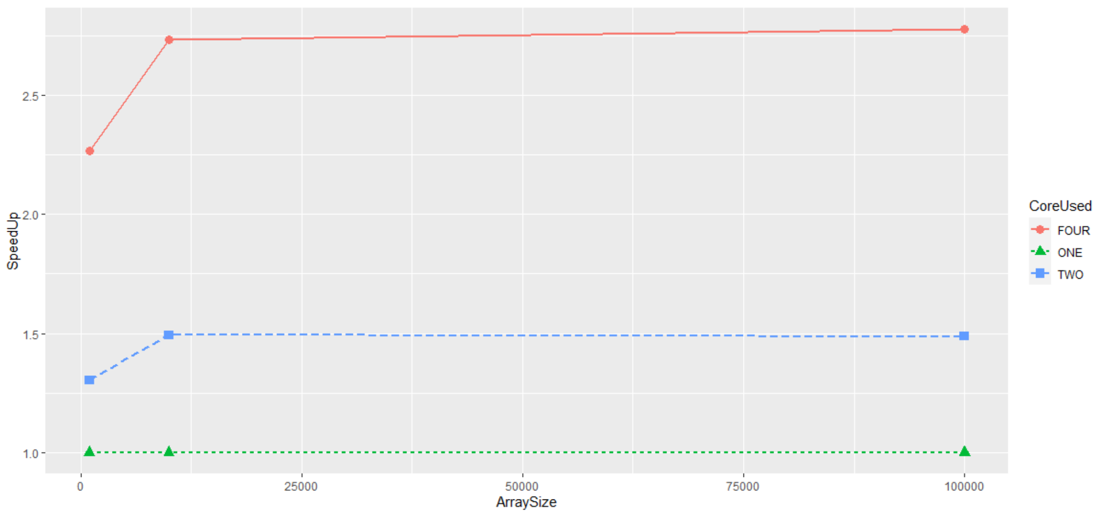
We'll investigate how parallel or serial programming influence the sorting speed detailed for each algorithm.

Enumeration Sort Analysis

For enumeration sort, the time consumption varies by array size and core used is shown below.



From this graph we can conclude that as core grows, the sorting speed has a significant rise. The 4 core solution reaches roughly 3 times quicker when array size is 10^6, the 2 core solution reaches roughly 1.5 times quicker. For more information, we can draw a plot use speedup ratio as y-axis

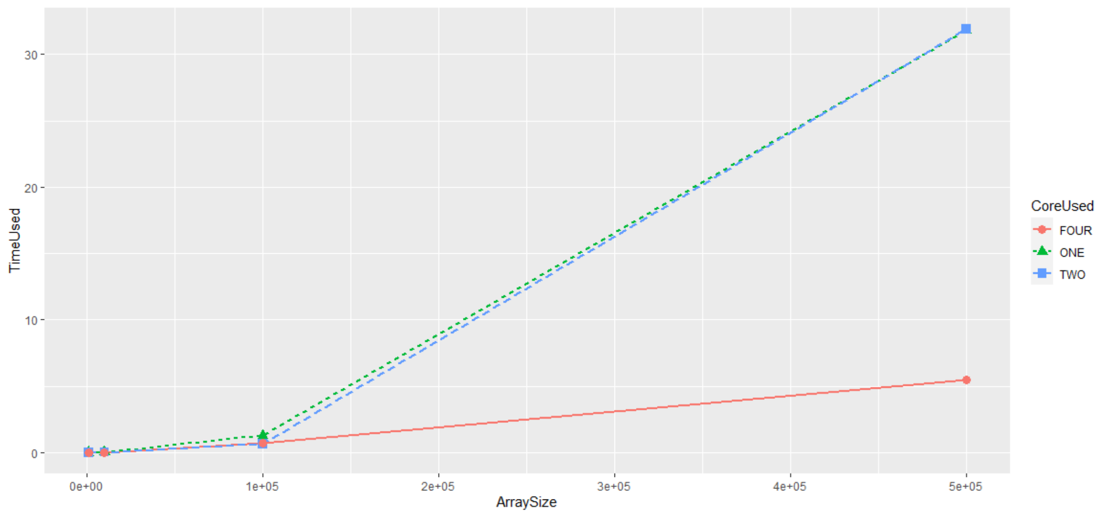


From this graph we can see that the speedup ratio for mulit-cores solution reaches its maxium when array size is still small, that is, about 10000. Idealy the speedup ratio for multi-cores solution in enmuration sort should be n （the core number）. But due to the communication between cores and the start of cores will consume time, the maxium speedup ratio for 4-cores solution only reaches 2.7 and 2-cores solution only reaches 1.5, the speedup ratio for 2-cores solution even droped a little as array size grows, that may becaues the communication between cores became larger when array size is big, and it consumes more time.

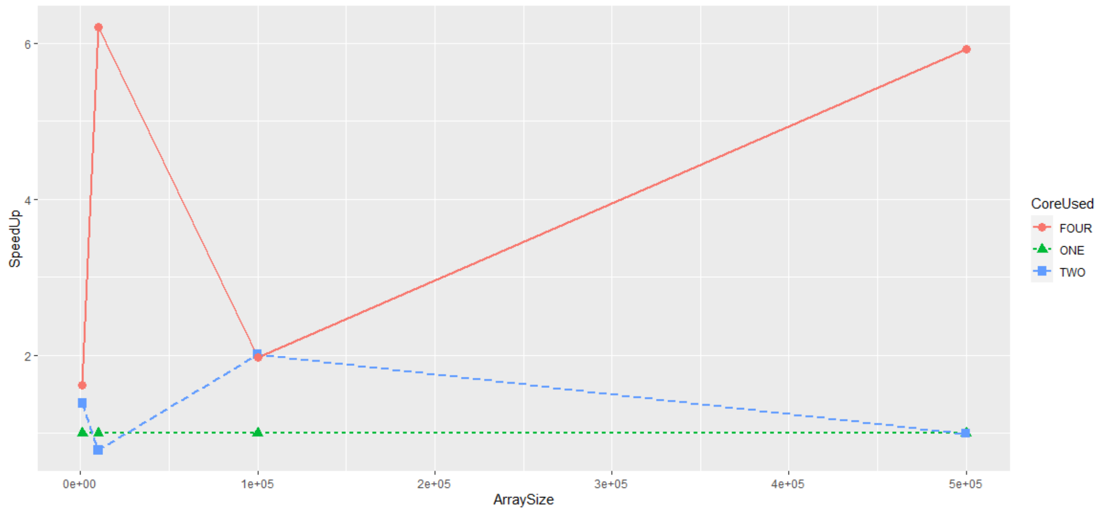
Algorithm	ArraySize	TimeUsed	CoreUsed	SpeedUp
ENUM	1000	0.005216	ONE	1
ENUM	1000	0.004002	TWO	1.3033
ENUM	1000	0.002159	FOUR	2.2686
ENUM	10000	0.5281	ONE	1
ENUM	10000	0.3536	TWO	1.4933
ENUM	10000	0.1924	FOUR	2.7345
ENUM	100000	53.5788	ONE	1
ENUM	100000	35.9891	TWO	1.488
ENUM	100000	18.6969	FOUR	2.778

Quick Sort Analysis

For quicksort, the time consumption varies by array size and core used is shown below.



The time consumption is small when core number reaches 4, but when core number is 2, the multi-core solution performs almost the same to the serial solution, to have a further view on it, we can draw a speedup ratio plot.



The tendency is more clear on speedup ratio plot, we can see the speedup ratio for multi-cores solution of quick sort is unstable, the 4-cores implementation can guarantee at least 2 times speedup while 2-cores implementation only performs better when the array size is middle.

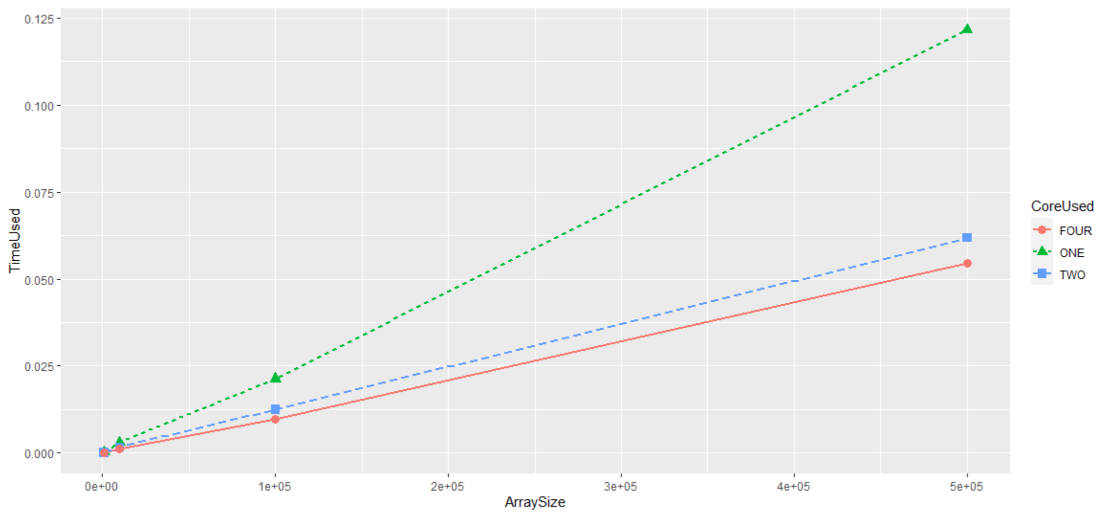
There're two possible reasons for this behavior, one is that the quick sort algorithm itself is an unstable sort algorithm, but it can hardly describe this behavior because both the serial and multi-core solutions use the same data set. Another possible reason is that the communication between cores consumes too much time, every iteration requires a data send and receive, so only when the array size is middle, that is less enough communication and large enough data size for serial solution to process, the multi-core solutions can perform better than serial solutions.

Observing the line shape and tendency of 4-core solutions, is similar to the 2-core solutions, we can assume that the speedup ratio will suffer a decline when the array size grows higher than 5*10^6.

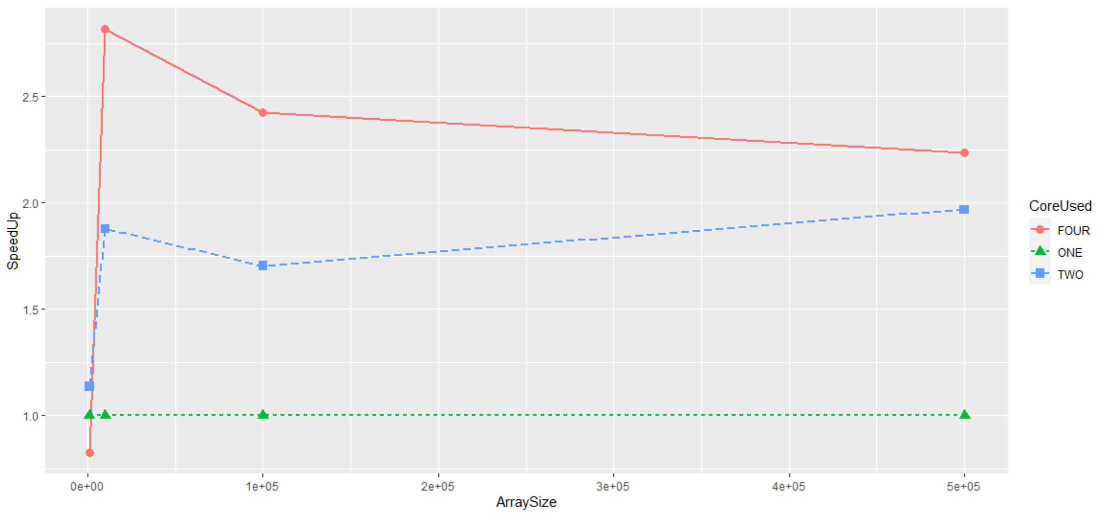
Algorithm	ArraySize	TimeUsed	CoreUsed	SpeedUp
QUICK	1000	0.000255	ONE	1
QUICK	1000	0.000184	TWO	1.385
QUICK	1000	0.000172	FOUR	1.6195
QUICK	10000	0.01405	ONE	1
QUICK	10000	0.01786	TWO	0.7864
QUICK	10000	0.0023	FOUR	6.207
QUICK	100000	1.27707	ONE	1
QUICK	100000	0.6342	TWO	2.0134
QUICK	100000	0.6794	FOUR	1.9691
QUICK	500000	31.8047	ONE	1
QUICK	500000	31.9071	TWO	0.9967
QUICK	500000	5.454	FOUR	5.9239

Merge Sort Analysis

For merge sort, the time consumption varies by array size and core used is shown below.



From this plot we can see that the multi-cores solution acts better than the serial solutions, as core number grow, its performance also improved. Then we can draw a speedup ratio plot for a deeper sight.



From this graph we can see the speedup ratio for multi-core solutions is stable as array size grows, the ideal speedup ratio should be n (n the core number), the 2-cores solution almost reaches the maximum while 4-cores solution only performs little better than the 2-cores solution, about half its maximum. That may because the communication between cores slows the 4-cores solution down, we can predict the speedup ratio for 4-cores solution will reach its maximum as array size grows.

Algorithm	ArraySize	TimeUsed	CoreUsed	SpeedUp
MERGE	1000	0.000156	ONE	1
MERGE	1000	0.000118	TWO	1.1372
MERGE	1000	0.000211	FOUR	0.8257
MERGE	10000	0.0031	ONE	1
MERGE	10000	0.0016	TWO	1.8788
MERGE	10000	0.0011	FOUR	2.8182
MERGE	100000	0.0213	ONE	1
MERGE	100000	0.0125	TWO	1.705
MERGE	100000	0.00968	FOUR	2.424
MERGE	500000	0.1217	ONE	1
MERGE	500000	0.0618	TWO	1.9686
MERGE	500000	0.0545	FOUR	2.2357

Part3 Conclusion

For enumeration sort, the speedup ratio is almost a constant as array size grows and core number grows, while for quick sort algorithm, its maximum speedup ratio is high, but it can only reach its maximum when the data set is of to a proper size, in other cases, its speedup ratio drops rapidly to a very low value.

The merge sort algorithm is like the enumeration sort, but with a higher speedup ratio maximum and reaches it linearly as the array size grown. It can also handle the large data sets while enumeration sort cannot.

In conclusion, when the data size is specified, we can pick one suitable core number to apply the quick sort algorithm for the best performance. When data set is small, the enumeration sort can be considered because it will immediately reach its best performance when data set is small. For general cases, the merge sort algorithm is the best option because it has a high and stable performance.