# CITS5507 – Project 1

Chenxin Hu (22961779)

17/9/2021

## 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. The solutions for each algorithms 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, the environment is shown below (Generated from VirtualBox):

图形用户界面, 文本, 应用程序, 电子邮件

描述已自动生成

### **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 1 a.out

Because we use multiple threads instead of multiple process, we set the parameter to 1.

Also, using instruction:

G++ -fopenmp filename.cpp -o executableFileName

./executableFileName.out

Could work too.

Sample:

文本

描述已自动生成

文本

描述已自动生成

### **Pseudocodes**

**Enumeration Sort Serial Solution**

Generate a random array

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**

Generate a random array

Create a new empty array as temp array

Using omp parallel to automatically divide the array to equal parts,

Each do the following procedure：

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.

Done parallel

#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

**Quick Sort Serial Solution**

Generate a random array

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**

Generate a random array

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.

If flag>0

Set flag=flag-1

Use two threads to do the following procedure separately：

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

Done Parallel：

Else

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

**Merge Sort Serial Solution**

Generate a random array

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**

Generate a random array

Create two pointer points to edge of the array

If two pointers meet or go through each other, stop the function and return

If flag>0

Set flag=flag-1

Use two threads to do the following procedure separately：

Break the array from the middle into two parts, apply the same procedure.

Done Parallel：

Else

Break the array from the middle into two parts, apply the same procedure.

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.

## 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, but not screenshotted, because the parallel solution is a more complex solution based on the serial solution. If the parallel one worked correctly, serial should work correctly too.

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 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:

图表, 折线图

描述已自动生成

From the graph we can obtain that the enumeration sort and quick sort’s time consumption grow exponentially while merge sort’s time consumption grows linear. The merge sort consumes littlest time and enumeration sort consumes the most time.

This is a simple introduction not considering the parallel or serial programming’s influence. 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 vary by array size and type of solution（serial or parallel）, is shown below

图表, 折线图

描述已自动生成

From the graph we can conclude that enumeration sort’s time consumption grows exponentially as the array size grow, despite of what solution is use.

The algorithm contains 3 main parts: 1. Search every item in array and count how many items are smaller than the item. 2. Create a new array then find suitable place in the new array for items using the information obtained before. 3. copying the new array to the original array.

The parallelism can be applied in step 1 and 3, while step 2 is hard to apply parallelism because the loop needs the information from previous round in the same loop (Due to the design of algorithm, it may not be necessary).

The omp parallel function is used to achieve parallelism, because we don’t need to carefully decide how loop is divided. Due to the environment, only four processors are available, the omp will divide the for loop to 4 parts. Step 1 and step 3 can reduce 3/4 time it originally costs. Step 2 cannot be speed up, but step 2’s time consumption is small and grow slowly too, it could be ignored.

In conclusion, the time consumed in parallel solution should be 1/4 of the serial solution time consumption theoretically. (i.e., the speedup ratio is 4)

In realistic execution, the speed up ratio is calculated below:



The speedup ratio is smaller until array size gets 10^4, it is because the start for each threads consumes time which is too large to ignore when the total time consumption is slow.

When the array size reaches 10^5, the speedup ratio reaches 4.3555, more the theoretical predict. It should be caused by the little instability generated in the if sentence, every if with a true judgement will cause more steps for the program to do.

Using the same array in two solutions can avoid this problem. But using only one array and renew it every time before using can save more space for the program.

### Quick Sort Analysis

For quicksort, the time consumption vary by array size and type of solution（serial or parallel）,is shown below

图表, 折线图

描述已自动生成

In the graph, we can obtain that the time consumption for quick sort also grows exponentially, despite of what solution is use.

We first expected the parallelism applied in quick sort can reduce the sorting time to 1 of n (n the number of processor), but unfortunately, each iteration divides the array into two parts with different length, because sorting stops when both parts are done, the time cost is mainly dependent on the time used to sort larger part of two parts.

For example, if in first iteration, the array is divided to parts that length are 3/4 and 1/4, in serial solution, the program first finish the 3/4 part’s sort, then finish the 1/4 part’s sort, total time consumption is 1, but in parallel solution, the program start sorting the two parts from the same time, 1/4 part is first sorted but it wait until the 3/4 part is sorted, so the combine time consumption is 3/4, speedup ration should be 1/(3/4), smaller than 2.

In conclude, the speedup ratio for quick sort should be in range 1 to n when using n threads.

In realistic execution, the speedup ratio is calculated below (using 2 threads):



When array length is 10^3, the speedup ratio is 0.1153 because the start time for threads is significant.

As array size grow, the speedup ratio is close to 1.45 and float above or under it. The cause for this behavior is explained before.

### Merge Sort Analysis

For merge sort, the time consumption vary by array size and type of solution（serial or parallel）, is shown below

图表, 折线图

描述已自动生成

In merge sort, because the array is uniformly separated in every round of iterations, the time consumption should be reduced to 1/n (n the number of processor) original time consumption.

That is, the speedup ratio should be 1/2 when using two threads

In realistic execution, the speedup ratio is calculated below (using 2 threads):



Like the quick sort, the speedup ratio is low when array size is small, because the start time for threads is significantly large.

The speedup ratio keeps on rising as the array size grows, but only reached 1.7213 when array size is 5\*10^5. Is that because the array is not enough so the speedup ratio cannot reach 2?

The answer is yes. Due to the merge sort’s time consumption grows linear, the time consumption is still low even the array size is 5\*10^5, that means the start time for threads still influences the result significantly. It can be predicted that the speedup ratio will reach 2 if the array size keeps growing

## Part3 Conclusion

The parallel solution can significantly speed up the sorting algorithms.

For enumeration sort, the speedup ratio close to n (n the number of threads).

For quicksort, the speedup ratio changes as the data in array changes, but it should be in range 1 to n.

For merge sort, the speedup ratio can reach n.

Both algorithms’ parallel solutions reach the theoretical speedup ratio when the array size is large enough, or they may be slower than the serial solutions when array size is small.