The following materials have been collected from the numerous sources such as Stanford CS106 and Harvard CS50 including my own and my students over the years of teaching and experiences of programming. Please help me to keep this tutorial up-to-date by reporting any issues or questions. Please send any comments or criticisms to [idebtor@gmail.com](mailto:idebtor@gmail.com). Your assistances and comments will be appreciated.

PSet: Profiling – Performance Analysis

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# Purpose of Assignment

This project seeks to verify empirically the accuracy of those analysis’s by measuring performance of each algorithm under specific conditions. Performance measurement or program profiling provides detailed empirical data on algorithm performance at different levels of granularity and measures.

“Program Profiling” measures, for example, the space (memory) or time [complexity of a program](https://en.wikipedia.org/wiki/Computational_complexity_theory), the [usage of particular instructions](https://en.wikipedia.org/wiki/Instruction_set_simulator), or the frequency and duration of function calls. Let us use the elapsed times printed by program execution even though it may not be as accurate as special profiling tools. With small input data size, all times will likely be 0.0000 because the clock interval is too large to measure the execution times. In that case, you should try to get sufficiently accurate results with various data sets and/or extra lines of code repetitions. Our focus on this assignment is to compare the time complexity of two sorting algorithms.

# Files provided

* profiling.pdf – this file
* profling.cpp – a skeleton code Step 1 and 2
* **profilingx.exe** – for pc, a solution for Step 1and 2
* **profiling – for mac**
* **sortDriver3.cpp – a skeleton code for Step 4**
* sortx.exe – for pc, a solution for Step 4
* sortx - for mac

# Step 1. Handling user's input and complete getStep()

Read and run the program **profiling.cpp** provided in this pset.

## Task 1: User's input

Run **profilingx.exe** and be familiar with how it works.

There are two ways to start the program, profilingx.exe. Users may start it by the executable file. Then the program must prompt the user to enter "the number of the maximum sample numbers to sort". If the number entered is less than **STARTING\_SAMPLES** (a magic number stored in sort.h), quit the program but with a proper message.

// sort.h

const int STARTING\_SAMPLES = 500;

Users may give the number of samples in the command line argument. We must check whether or not it is larger than **STARTING\_SAMPLES**, exit the program if it is not with a proper message. Run sortx.exe to see the error message.

Once you get the max sample size N, you must allocate the memory accordingly and deallocate after use.

NOTICE: To make profiling.cpp simple, **don't use** nowic library functions such as GetInt(), and GetChar() and so on.

## Task 2: getStep()

Currently the step increases in linear scale such as 100, 200, … , 1000, 1100, 1200. In order to measure the performance, the step size should be incremented by 100 between 100 and 1000; the step size will be 1,000 between 1000 and 10,000; From 10,000 to 100,000, the step size will be 10,000 and so on. Rewrite getStep() function accordingly.

Implement **getStep(n)** function such that it returns **1** for n=**[0..9],** **10** for n=**[10..99],** **100** for n=**[100..999], 1000 for n=[1000..9999],** and so on. The variable step defined in the program would be many different values, depending on the number of samples. The sample sizes could reach up to **billions.**

You should **not** code something like below:

// this is not the way of coding.

int getStep(int n) {

if (n < 100) step = 10;

else if (n < 1000) step = 100;

else if (n < 10000) step = 1000;

……

……

return step;

}

// this is not the way of coding.

int getStep(int n) {

if (n == 100) step = 100;

else if (n == 1000) step = 1000;

else if (n == 10000) step = 10000;

……

……

return step;

}

# Step 2. Build and run executables

The skeleton code, profiling.cpp, are already invoking sorting functions as we need. Now we would like to compare the elapsed time of following cases:

1. **insertionSort()** 
   1. Best case – O(n), Input data is already sorted
   2. Average case - O(), Input data is randomly ordered
   3. Worst case - O(), Input data is reversely ordered
2. **quickSort()** 
   1. Average case - O(n log n), Input data is randomly ordered

Sample run:

$ ./profiling 10000

The minimum number of entries is set to 500

Enter the number of max entries to sort: 10000

The maximum sample data size is 10000

insertionSort(): already sorted - best case.

Data will NOT be randomized before use.

n repetitions sort(sec)

500 351798 0.000003

600 318514 0.000003

700 282230 0.000004

800 250027 0.000004

900 236931 0.000004

1000 219992 0.000005

2000 121951 0.000008

3000 90212 0.000011

4000 70272 0.000014

5000 56832 0.000018

6000 48603 0.000021

7000 40910 0.000024

8000 35896 0.000028

9000 32081 0.000031

10000 28353 0.000035

insertionSort(): randomized - average case.

Randomized Data will be used during sorting.

n repetitions sort(sec)

500 5543 0.000180

600 3908 0.000256

700 2674 0.000374

800 2097 0.000477

900 1604 0.000623

1000 1299 0.000770

2000 351 0.002855

3000 152 0.006579

4000 90 0.011144

5000 69 0.014565

6000 44 0.023295

7000 35 0.028571

8000 28 0.036643

9000 21 0.047810

10000 16 0.063062

insertionSort(): sorted reversed - worst case.

Data will NOT be randomized before use.

n repetitions sort(sec)

500 2934 0.000341

600 2241 0.000446

700 1500 0.000667

800 930 0.001075

900 1010 0.000990

1000 551 0.001815

2000 202 0.004960

3000 92 0.010967

4000 46 0.021761

5000 33 0.030485

6000 23 0.043783

7000 18 0.057889

8000 13 0.077769

9000 11 0.095909

10000 9 0.118778

quickSort(): randomized - average case.

Randomized Data will be used during sorting.

n repetitions sort(sec)

500 2631 0.000380

600 1522 0.000657

700 1533 0.000652

800 1396 0.000716

900 605 0.001653

1000 1054 0.000949

2000 586 0.001706

3000 361 0.002773

4000 242 0.004145

5000 210 0.004781

6000 172 0.005814

7000 146 0.006897

8000 120 0.008350

9000 107 0.009346

10000 101 0.009941

* You are going to use these files to draw a graph to show the **growth rate** of the algorithm as the sample size n increases and compare them in Step 2.
* Make sure that you have the appropriate function calls before you redirect the output. You may need to recompile after you switch the sort function.

## Tips and Hints

Read the skeleton code provided and follow the instruction properly.

The quicksort really runs worst if the input data is already sorted. To test the worst-case quicksort, you must pass a sorted data. For other cases, you just pass the randomized data.

* **How to compile:** Using your own **libsort.a** as you made it in **lab6** before.  
  $ g++ profiling.cpp printList.cpp -I../../include -L../../lib –lsort –o profiling,
* **How to run:**   
  $ ./profiling 100000 # PowerShell  
  $ profiling 100000 # cmd
* **How to save the output into a file:**   
  $ ./profiling 100000 > profiling.txt  
  $ profiling 100000 > profiing.txt
* **How to increase the stack size**The worst-case quicksort may not finish completely since it requires a lot of stack memory. In this case, you must increase stack since it is only 1megabyte by default. The following command increase the stack size to 16 megabytes. By the way, these compiler option does not work in the Windows PowerShell, you must change PowerShell to cmd windows before run the command.

$ cmd

$ g++ -Wl,--stack,16777216 profiling.cpp printList.cpp -I../../include -L../../lib –lsort –o profiling

$ profiling

# Step 3 – Compute the time complexity of best/average/worst cases

We would like to do the performance analysis with our programs and data. In this step, the question we want to answer **is "How long will my program take, as function of the input size?”**  To help answer this question, we plot data with the problem size N on the x-axis and the running time T(N) on the y-axis.

Let's suppose we have the running time, as a function of the input size,

,

where is a constant and is a growth rate.

Let's suppose that you can get the growth rate b in the following step. Then we want to estimate the elapsed time of one samples. We can use one of our data points to solve for – for example,

With this equation, you can estimate the elapsed time for one million samples or billion samples as well.

**Compute** the **growth rate b** of the running time as a function of n using the output (profiling.txt) you got from Step 2 and fill the following table for their comparison. Assume that the running time obeys a power law . Based on the elapsed time between n = 4,000 and n = 8,000 shown in the table below, **compute** the measured growth rate **.**

How to compute the measured growth rate b

We safely assume that most algorithms approximately have the order of growth of the running time:

**T(N) a Nb**

To predict running times, multiply the last observed running time by 2b and double N, continuing as long as desired. Let us compute b using the double ratio.

**Since T(N) a Nb , T(2N) = a (2N)b, then**

Log both sides

In our example,

For b in the table below, you must show how you get your answer. You may use a calculator and compute up to two digits after the decimal separator. It should be close to 2.0 for the insertionSort, 1.2 ~ 1.5 for the average case quickSort.

Now, we use this b to compute a in

,

as shown previously.

**Estimate** the elapsed time for one million samples based your computation of b in your machine. Fill the blank in the table below. Show your exact steps how you compute the estimated time using the **growth rate b** and write it in your report. Use a proper time unit. For example, don’t say 1,234.57 sec., but 20 min 35 sec.

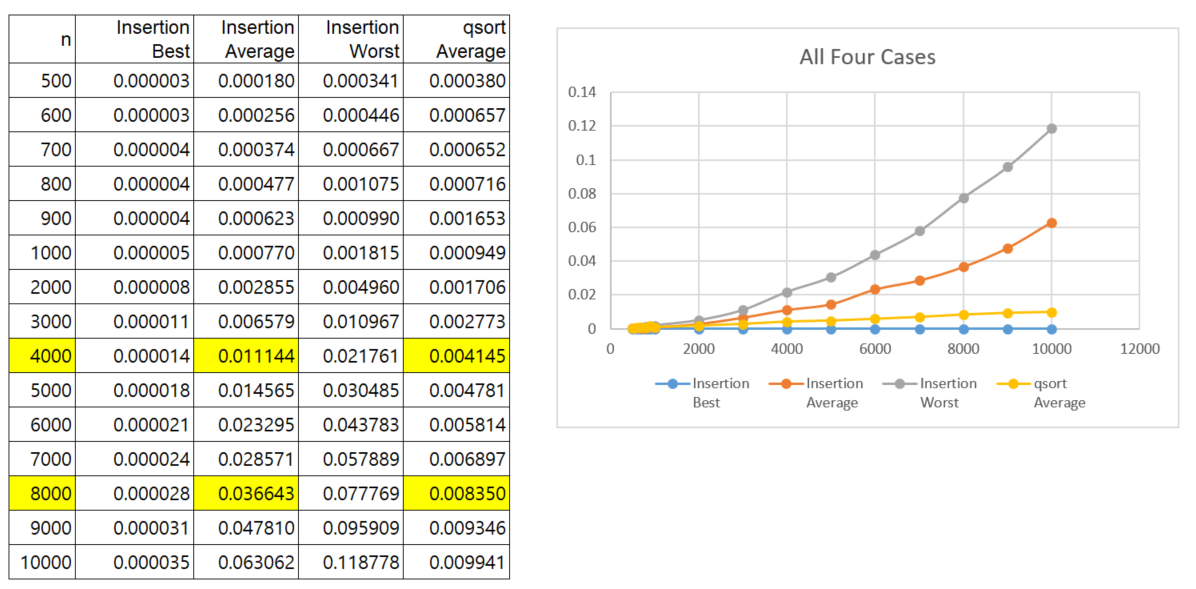
Fill blanks in the table below with the elapsed time actually measured in your computer while running them with 1 million samples.

**Hints and Tips:** Refer to **DiscreteMath.pdf** provided for this computation.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | ,  **a =  b=**  insertionSort – Best | | ,  **a =  b=**  insertionSort – Average | | ,  **a =  b=**  insertionSort – Worst | |
| N | 4,000 | Time for Million | 4,000 | Time for Million | 4,000 | Time for Million |
| Time |  | Estimated:  Measured: |  | Estimated:  Measured: |  | Estimated:  Measured: |
| N | 8,000 | 8,000 | 8,000 |
| Time |  |  |  |

|  |  |  |
| --- | --- | --- |
|  | ,  **a =  b=** Average qsort O**(N log N)** | |
| N | 4,000 | Time for Million |
| Time |  | Estimated:  Measured: |
| N | 8,000 |
| Time |  |

**Plot** the data sets that you got from Step 2 to compare them graphically as shown below. You may use Excel Chart(분산형) to plot them. An output example combined data from InsertionSort and quickSort for plotting and report.



# Step 4 – Be ready for all “sorts” of profiling

In this step, let the user have many choices of sort algorithm to run the profiling of sort with other options that you implemented in PSet2. For this purpose, add two options **p** and **v** in **sortDriver3.cpp** and call profiling() defined in **profiling.cpp.**

* + - * 1. Add “p” option which invokes profiling() in profiling.cpp with a sort algorithm chosen.

Add the function proto-type at the top of sortDriver3.cpp as needed.

When you invoke it, you have to pass the function pointer as an argument.

If the number of samples are less than STARTING\_SAMPLES , print the error message such that the user changes the number of samples much larger than STARTING\_SAMPLES.

* + - * 1. Add an option **“v”** which sets **the list as sorted list** in ascending or descending order. It toggles. If the current list is in ascending order, set it in descending order and vice versa. Using this option, the user can set the data in either ascending or descending order eventually. This option, therefore, enables us to test sorting algorithms with a reverse ordered form of data sets.
        2. Before compiling, you must comment out the main() part in **profiling.cpp** by setting #if 0 just above main() since we are using main() in sortDriver3.cpp. Use your own **libsort.a** as you made it lab6 before, use the following command to build sort.exe.

g++ sortDriver3.cpp, profiling.cpp printList.cpp -I../../include -L../../lib -lnowic -lsort -o sort

* + - * 1. You may check your implementation with **sortx.exe** provided.

# Step 5 – Selection Sort and QuickSort

Now, we would like to use this new menu-driven profiling program developed in Step 4 and apply for selectionSort() and quickSort().

**Task 1:** Run profiling for selectionSort using this sort.exe and make sure that it produces the same results by profiling.exe.

**Task 2:** Do profiling for the following three cases of selectionSort().

* Case 1. Input data is already sorted
* Case 2. Input data is randomly ordered
* Case 3. Input data is reversely ordered

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | ,  **a =  b=**  selectionSort – Case 1 | | ,  **a =  b=**  selectionSort – Case 2 | | ,  **a =  b=**  selectionSort – Case 3 | |
| N | 4,000 | Time for Million | 4,000 | Time for Million | 4,000 | Time for Million |
| Time |  | Estimated:  Measured: |  | Estimated:  Measured: |  | Estimated:  Measured: |
| N | 8,000 | 8,000 | 8,000 |
| Time |  |  |  |

**Task 3.** Compare the results with insertionSort() and write about your findings.

**Task 4.**  In the previous steps, we have run quickSort() with only randomized data set (so-called average case). This time, run quickSort() with different kind of data sets such as sorted and reversed. Observe the results and write what you found in the report.

# Submitting your solution

* **On my honour, I pledge that I have neither received nor provided improper assistance in the completion of this assignment.   
  Signed: \_\_\_\_\_\_\_\_\_\_\_\_\_ Section: \_\_\_\_\_\_\_ Student Number: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**
* Make sure your code **compiles** and **runs** right before you submit it. Don't make "a tiny last-minute change" and assume your code still compiles. You will not receive sympathy for code that "almost" works.
* If you only manage to work out the Project problem partially before the deadline, you still need to turn it in. However, don’t turn it in if it does not compile and run.
* Place your source files in the folder you and I are sharing.
* After submitting, if you realize one of your programs is flawed, you may fix it and submit again as long as it is **before the deadline**. You will have to resubmit any related files together, even if you only change one. You may submit as often as you like. **Only the last version** you submit before the deadline will be graded.

## Files to submit

* profiling.cpp, sortDriver3.cpp
* report.docx: at least 4 pages long report includes the followings:
  + Screen capture of profiling.exe output
  + Complete the performance analysis tables
  + The excel chart and graph for comparing best/average/worst cases
  + Comparison and analysis of algorithms: For example, Insertion vs quick sort, Timing, Stack problem, best/average/worst cases analysis
  + Draw a graph for the worst case of quickSort(). You first need to increase the stack size and test it.

## Due and Grade points

* Due: 11:55 pm, Sept. 30
* 5 points