

CS 412 Algorithm Analysis and Design (Term 1, 2019-2020)

Course Project (10% of course grade)

Due Date: Sunday Dec. 8, 2019 @ 9:00 AM

Part1: Comparison of Sorting Algorithms (8 points)

The objective of the first part of the project is to study how the theoretical analysis of a variety of sorting algorithms compares with their actual performance. The sorting algorithms you will study are:

- Insertion Sort
- Merge Sort
- Quick Sort
- Heap Sort

The major emphasis of this assignment is on analyzing the performance of the algorithms, **NOT** on coding the algorithms. Therefore, you will be given a template program which implements the above algorithms. You will need to make only a few modifications to test out different strategies. Most of your time should be spent on designing careful test cases and analyzing your results in order to draw useful conclusions regarding the performance of the various algorithms.

Template Program

The code is documented well enough for you to take it and modify it. The template program can read the input from a file, or to create three types of input lists: **(i)** random generated elements, **(ii)** elements sorted in increasing order, **(iii)** elements sorted in decreasing order. If needed, you can add additional functionality to it. The format of the input files is as follows:

```
[n] /*number of positive integers to sort*/ [element 1]
[element 2]
:
[element n]
```

The times returned are microseconds and seconds. However, the value returned is system dependent. The time reported as microseconds is 10^6 times the time reported as seconds. If you are unsure of the units you will have to check out the man page for your machine. However, primarily what it would be of interest to you is the **relative** times – i.e., the units should not matter except for determining the constants.

I don't think you will find a random number generator that generates a number in a range you specify. You will need to do a man on "rand," "drand", and "random" and its counterparts to see how they work, but most of them return a number in a specified range, say (0,1). To get a number in the range you want, say [F,L], you would need to find a way to translate the random number r in (0,1) to something in [F,L]. There are a number of ways to do this. Here is just one:

```
r1 = rand()           /* random number between 0 and 1 */
t1 = r1*(L-F)          /* random number between 0 and L-F */
r2 = F + t1            /* random number between F and L */
```

To compile the program, copy **sort.c** and **Makefile** into your directory and type make (it is written in C and uses the **gcc** compiler).

Coding

The version of *QuickSort* in the template program uses the first element in the array as the pivot element. You will study different strategies for selecting the pivot:

- **Pivot Choice 1:** The first element in the list (used in the template program)
- **Pivot Choice 2:** A random element in the array.
- **Pivot Choice 3:** The median of the first, middle, and last elements in the array.

You should implement the Pivot Choices 2 and 3 listed above. You will then have three different versions of QuickSort (you would need to add them to the template program as additional menu options).

Analysis

1. Theoretical question

Assume the n input elements are integers in the range $[0, n-1]$. For each algorithm, determine what are best, average, and worst-case inputs. Your write-up should list these for each algorithm. Include a sentence or two of justification for each one. You should answer what you expect to be true based on a theoretical analysis (and you should not refer to experimental results). In the subsequent questions we will compare the experimental results to these theoretical predictions.

2. Data generation and experimental setup.

The choice of test data is up to you (i.e., for each sorting algorithm, which input sizes should be tested, how many different inputs of the same size, which particular inputs of a given size.) Be smart about which experiments to run, i.e., don't run larger or more tests than you need to answer the above questions reasonably well. Also, note that you will need to run your experiments several times in order to get stable measurements (i.e., times will vary depending upon system load, input, etc.). Your experimental setup must be described in terms of the following:

- What kind of machine did you use?
- What timing mechanism?
- How many times did you repeat each experiment?
- What times are reported?
- How did you select the inputs?
- Did you use the same inputs for all sorting algorithms?

3. Which of the three versions of Quick sort seems to perform the best?

- Graph the best-case running time as a function of input size n for all three versions (use the best case input you determined in each case in part 1).
- Graph the worst-case running time as a function of input size n for all three versions (use the worst case input you determined in each case in part 1).
- Graph the average case running time as a function of input size n for all three versions.

4. Which of the four sorts seems to perform the best (consider the best version of Quicksort)?

- Graph the best-case running time as a function of input size n for the four sorts (use the best case input you determined in each case in part 1).
- Graph the worst-case running time as a function of input size n for the four sorts (use the best case input you determined in each case in part 1).
- Graph the average case running time as a function of input size n for the four sorts.

5. To what extent does the best, average and worst-case analyses (from class/textbook) of each sort agree with the experimental results?

To answer this question, you would need to find a way to compare the experimental results for a sort with its predicted theoretical times. One way to compare a time obtained experimentally to a predicted time of $O(f(n))$ (e.g., $f(n) = n^2$) would be to divide the time for a number of runs with different input sizes by $f(n)$ and see if you get a horizontal line (after some input size n_0). That n_0 would represent the n_0 value for the asymptotic analysis. The value on the y-axis (assuming you put input size on the x-axis) will give you the constant value of the big-O.

For each sort, and for each case (best, average, and worst), determine whether the observed experimental running time is of the same order as predicted by the asymptotic analysis. Your determination should be backed up by your experiments and analysis and you must explain your reasoning. If you found the sort didn't conform to the asymptotic analysis, you should try to understand why and provide an explanation.

6. For the comparison sorts, is the number of comparisons really a good predictor of the execution time? In other words, is a comparison a good choice of basic operation for analyzing these algorithms?

To answer this question, you would need to analyze your data to see if the number of comparisons is correlated with execution time. Plot (**time / #comp**) vs. n and refer to these plots in your answer.

Part2: Problem Solving and Analysis (2 points)

Design and implement an efficient algorithm that, given a set S of n integers and another integer x , **determines whether or not there exist** two elements in S whose sum is exactly x .

- (a) First, solve this problem in a brute-force manner by checking all possible pairs of elements. Show the pseudo-code and provide an analysis for the running time of this approach.
- (b) Second, find a more efficient algorithm that does not require checking all possible pairs of elements. Show the pseudo-code and provide an analysis for the running time of this approach.

Deliverables

○ **A HARDCOPY REPORT.**

- **Part#1:** It should address the points mentioned above. Your write-up must include a coherent discussion of which experiments you ran, how many times you ran them, etc. Grading on this assignment will put the greatest weight on the choice of test data and the quality and insightfulness of your discussion of your results. Don't be put off too much if there are some discrepancies between the theoretical results and the experiments. If that happens, try to explain why it occurred.
- **Part#2:** It should address the points mentioned above. Your write-up must include a coherent discussion of the running time analysis of each approach.

Reports must be typed and carry a high percentage of your grade. Write your report carefully; explain things as clearly as possible, check for spelling errors. Answer the questions in the order presented. Use meaningful titles for each subsection and figure captions to explain the graphs. Also, graphs should be numbered and must be in the same section where they are discussed.

- **AN ELECTRONIC COPY OF YOUR CODE + REPORT.** A soft copy of the report has to be submitted via the Blackboard's submission link with your code. If you have several files to turn in, then please submit them in a .rar file. Provide instructions of how to run your codes.
- **Presentation.** A presentation should be done in Week 15 by all group members and should discuss the 6 points covered by the report, highlighting the contribution of each group member.

Contribution Statement

This project is supposed to be completed by a group of **four to five** students. You should provide a detailed statement about the contribution of each group member in completing this project. Individual solutions will not be accepted. The report submitted should be your own work since you will be writing your own experiment results. If you need to refer to any other references, then please **USE YOUR OWN WORDS** and clearly cite the references.

Acknowledgment

We would like to thank Professor George Bebis (Department of Computer Science & Engineering, University of Nevada) who gave us the permission to use this project.
(Minor modifications were applied to the original project).