Atlantic Technological University

Higher Diploma in Science in Software Development

Computational Thinking with Algorithms

Sorting Algorithms - Report

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# Introduction

*A sorting algorithm* is a set of instructions used to arrange a collection of items, such as numbers or strings, in a particular order. The algorithm takes an unordered list or array of elements as an input, rearranges it using step by step approach, and outputs an ordered sequence of items.

Sorting algorithms are valuable tools in computing as they make it easier to organize, analyse and search for information.

Even though they are used to accomplish the same task of ordering data, sorting algorithms may differ significantly from one another in their approach and efficiency at sorting. When measuring an algorithm’s performance we typically look at its time and space complexity.

### Time and Space Complexity

**Time complexity,** often considered the most important aspect for determining an algorithm’s performance, describes the time required to execute an algorithm as a function of its input size. In other words, time complexity helps us to understand how the algorithm’s efficiency scales as the input size increases.

**Space complexity**, on the other hand, is a measure of memory usage of a sorting algorithm based on the size of the input.

The complexity of an algorithm is typically expressed by the *Big O notation* - a mathematical notation that represents an upper bound on the growth rate of the given algorithm, that is, its worst case performance in terms of the time complexity (running time), and the space complexity (memory usage).

Despite Big O being the most commonly used notation to determine the time and space complexity of a sorting algorithm, since it provides information about algorithm efficiency in the worst case scenario, for a comprehensive analysis of a particular sorting algorithm, *Big Theta (Ω)* and Big Omega (Θ) notations are used to measure average and best case performances.

Common Big O running times, from fastest to slowest:

* O (1) - running time does not depend on the size of the input (constant time)
* O (log n) - runtime increases logarithmically with the input size (log time)
* O (n) - runtime increases linearly with the size of the input
* O (n log n) - linear increase of runtime with the logarithm of input size
* O (n2) - quadratic time complexity (running time increases quadratically)
* O (2n) - exponential time complexity
* O (n!) - factorial time complexity

#### A graphical representation of growth in time complexity of algorithms (Aguilera, 2018, para.2):

A diagram of a complexity

Description automatically generated

### In-place and Stable Sorting Algorithms

The type of algorithm that arranges items within the original data structure is called the *in-place sorting algorithm*. It is often used when space efficiency is the main concern since it doesn’t require significantly more extra memory beyond the amount needed for the original input array or list. Some algorithms that fit into this category are Bubble Sort, Insertion Sort, Selection Sort and Quick Sort.

Another category of algorithms is *Stable sorting* *algorithms* implemented in a way that preserves the relative order of equal elements. In other words, if two or more elements have the same value (key) within the input data structure, once sorting is completed, their relative order will stay the same.

As an example of this, we can take a list of students, sorted alphabetically, by their names and then by their grades. If a stable sorting algorithm is used, then the students with the same name will stay in the same order after the list is sorted, even if their grades change (Thakrani, 2023, para.2).

Looking at the example above, we can say that stable sorting algorithms are useful when data holds more than one property, and we want to sort that data by only a specific property while maintaining the order of another.

Common stable sorting algorithms are Bubble Sort, Insertion Sort, Merge Sort, Tim Sort and Counting Sort.

### Comparison and Non-comparison Based Sorting Algorithms

The most common approach to sorting elements of a given data set is by comparing them with one another and placing them at the appropriate position. *Comparison-based sorting algorithms* use what is called a *comparator function* to achieve this result. The comparator function is used to determine which of two elements should occur first in the final sorted list (Wikipedia, n.d., para.1) by returning a value indicating their relative order.

Algorithms that use comparison-based sorting are Bubble Sort, Selection Sort, Insertion Sort, Merge Sort, Quick Sort and others.

Although versatile and widely used, comparison-based sorting algorithms have some limitations. For example, they may perform poorly on partially or nearly sorted data sets, resulting in unnecessary comparisons and swaps. Also, some of them are unstable, not preserving the relative order of the equal elements. Another disadvantage is that, in the average and worst case scenarios, comparison-based sorting algorithms cannot perform faster than O(n log n).

*Non-comparison based algorithms,* on the other hand, can perform sorting without comparing the elements of a data set, but rather by making assumptions about the data to be sorted. Common assumptions include the data types of input set or assumptions about the range of possible values.

By having near linear time and space complexity, non-comparison based sorting algorithms can offer better performance for specific data type, but are not as versatile as comparison based ones.

Common non-comparison based sorting algorithms are Counting Sort, Radix Sort and Bucket Sort.

# Sorting Algorithms

Introduce each algorithm, discuss its space and time complexity, and explain how each algorithm works using bespoke diagrams. As example input for the algorithms you MUST use the digits of your student number i.e. if your student number is G00398809 then use 3,9,8,8,0,9 as the input for your diagrams. If your diagrams are not original creations you will get zero, if you don’t use your student number you will also get zero.

## Bubble Sort

## Selection Sort

## Insertion Sort

## Merge Sort

## Counting Sort

# Implementation and Benchmarking

This section will describe the process followed when implementing the application, and present the results of benchmarking. Discuss how the measured performance of the algorithms differed – were the results similar to what you would expect, given the time complexity of each chosen algorithm? In this section you should use both a table and a graph to summarise the results obtained (see samples below).

#### Benchmarks results table

All values are in milliseconds, and represent the average of 10 repeated runs

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SIZE | 100 | 250 | 500 | 750 | 1000 | 2500 | 5000 | 7500 | 10000 |
| Bubble Sort | 0.107 | 0.180 | 0.282 | 0.445 | 0.733 | 4.150 | 18.764 | 49.203 | 90.896 |
| Selection Sort | 0.067 | 0.117 | 0.204 | 0.217 | 0.294 | 1.765 | 6.179 | 13.132 | 22.951 |
| Insertion Sort | 0.035 | 0.111 | 0.138 | 0.236 | 0.141 | 0.706 | 2.110 | 5.030 | 7.119 |
| Merge Sort | 0.086 | 0.031 | 0.074 | 0.125 | 0.182 | 0.363 | 0.913 | 0.537 | 1.240 |
| Counting Sort | 0.010 | 0.019 | 0.038 | 0.054 | 0.047 | 0.036 | 0.075 | 0.096 | 0.211 |

#### Graphical representation of time performance of sorting algorithms

# References

Aguilera, R. (Sep 7, 2018). *Big O Notation and Sorting Algorithms.* Medium*.* <https://medium.com/@raul.aguilera/big-o-notation-and-sorting-algorithms-2b21115a1c96>

Thakrani, S. (Jul 21, 2023). *What are stable sorting algorithms and in-place sorting algorithms.* Medium.<https://medium.com/@suhailthakrani12/what-are-stable-sorting-algorithms-and-in-place-sorting-algorithms-672820a8e36c>

Wikipedia (Jan 4, 2024). *Comparison Sort.* <https://en.wikipedia.org/wiki/Comparison_sort>