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# A COMPARATIVE STUDY OF SORTING ALGORITHMS: EFFICIENCY AND PERFORMANCE IN NIGERIAN DATA SYSTEMS

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## ABSTRACT

In this research paper, we discuss about comparison of sorting algorithms based on their performance in various scenarios and adaptability to Nigerian context. This article examines five popular sorting algorithms: bubble sort, selection sort, insertion sort, merge sort and quicksort through analysis of time complexity and space complexity. The major goal is to determine the most efficient algorithm with respect to given data sizes and conditions that are typical with computational resources available in Nigeria. It has been found out that when datasets are small, insertion sort and selection sort perform well while for larger datasets one should consider using Merge Sort or Quick Sort because they have lower time complexity O(n log n). In addition, it looks at how these algorithms manage data integrity especially in areas like financial transactions (payments) and educational data management in Nigeria. Tests were performed using integer and string datasets to investigate the practical consequences of applying these sorting algorithms in real-world Nigerian applications. The outcomes show that having an appropriate sorting technique can greatly improve the performance as well as resource utilization across many sectors thus making it one of the ways through which a country can become greater.

**Keywords**: Sorting Algorithms, Time Complexity, Space Complexity, Performance Evaluation, Nigerian Data Systems

## INTRODUCTION

Sorting is a conceptual part of computer science and forms the backbone in maintaining ordered data across many sectors. The efficiency of how a sorting algorithm is implemented plays a crucial role in determining the software performance, especially when it has to be done with minimal computational resources. For instance, in electoral systems, market analysis, education management, and financial transactions among other numerous areas in Nigeria, fast processing and sorting of data are operational implications (Ayobami et al., 2020; Aremu et al., 2013). Sorting algorithms must balance between the time and space complexities on one side and stability and adaptivity on the other to manage Nigeria data's rising volumes.

Sorting procedures, in particular, consist of Bubble Sort, Selection Sort, Insertion Sort, Merge Sort, and Quick Sort. Among these, Bubble Sort and Selection Sort are meant for small data sizes, as their time complexity is of O(n^2) order, which makes them inefficient for large datasets. In contrast, both Merge Sort and Quick Sort run in time proportional to n log n on the average, making them more preferable when it comes to dealing with massive data. Quick Sort becomes highly ineffective at O(n^2) if the choice of the pivot is inappropriate. Recent developments in the median-of-three selection technique for the choice of the pivot have increased its performance, thus becoming one of the preferences in sorting large datasets (Sedgewick & Wayne, 2011).

This has made the sorting algorithms receive a lot of attention because the criticality has been thrown at the data processing and system designing in a wide application area. The researchers, therefore worked out the performance optimization of sorting algorithms in different working conditions: from sequential to more complex parallel computing environments. Levitin, 2012. For example, Ayobami et al., 2020: did the implementation of sorting algorithms in electoral systems in Nigeria. This study, therefore underscores the need for an effective sorting mechanism to manage voters` registration data. It became clear that the better choice of the sorting algorithm could drastically influence the speed and the accuracy of electoral processing, which is very necessary for a country like Nigeria with huge and large quantities of data content and a low implementation of technical infrastructure.

Basic sorting algorithms, including Bubble Sort, Selection Sort, and Insertion Sort, comprise the basics of virtually all introductory computer science programs and courses. However, this quadratic time complexity makes them impractical for larger datasets, which may usually be the cases for real-world applications. Merge Sort and Quick Sort are more efficient for this task because of their divide-and-conquer approaches, with average-case time complexity of O(n log n). For example, Quick Sort almost always performs better than other algorithms, but Merge Sort is more ordinary and provides a steadier performance through worst-case scenarios.

Other recent researches on sorting algorithms are also directed towards specialized applications in Nigeria. For instance, there is the efficient sorting under the Independent National Electoral Commission of Nigeria, where the registration of voters has to be managed, alongside their respective lists and the ranges of election results (Ayobami, O., et al. 2020). This calls for good choice of algorithms to get the assurance of data integrity and speed in processing, which are very critical for the electoral process. Aboundingly, similar important dynamic efficient sorting algorithms are needed in market data analysis and educational data management in the environment of many daily data.

The development of multiprocessors has led to sorting algorithms that have become greatly tuned to take advantage of parallel processing. Algorithms that can achieve this time complexity include the Parallel Quick Sort and Merge Sort, which run in O(n log n / p), where p is the number of processors. Although parallel sorting can be very efficient in shared memory systems, it is plagued by problems such as memory contention and synchronization, pointed out by Chen et al., (2020). Distributed sorting algorithms, which are

applied in networked environments, have to consider network latency and bandwidth to achieve better performance, as pointed out by Kumar et al., (2019). Recent hybrid solutions that combine local and distributed sorting techniques have been a promise to reduce the time needed for sorting by optimizing data locality and minimizing communication overhead.

Nigeria's Data systems, characterized by underdeveloped hardware and varied data sizes, pose unique challenges to sorting algorithms. Financial systems, for instance, require an accurate form of sorting to process transactions; meanwhile, educational systems depend on sorting in data retrieval and management (Eze, 2022). The choice of the sorting algorithm has not only affected the integrity of the data but also its processing speed. The study by Aremu et al. (2013) demonstrated that, even in case of a quadratic time complexity-related algorithm like insertion sort, it could work well on the small data sets, while for larger data sets, management of Merge Sort and Quick Sort are more due to the good performance in average-case scenarios.

For example, INEC, the Nigerian Bureau of Statistics (NBS), and centers of learning all depend on strong sorting algorithms for the handling of data. By extension, within the Nigerian context of electoral systems, sorting algorithms are greatly needed and bestowed with the task of accuracy and speed in result processing (INEC, 2023). The relevance or importance of sorting algorithms cannot be neglected in the management of student records within universities in Nigeria, where effective processing of data continues to be an essential recipe for administrative success (Nwankwo, 2019).

This study not only takes into consideration the stability of elements' relative order but is also required for applications in which secondary priorities must be maintained. Of all the sorting algorithms, Insertion Sort is adaptive and stable and can thus perform good sorting on all but sorted or almost sorted data. This property matches the characteristics of databases or other data structures in which the tendency often requires modification-an ability to peruse through the data, reflecting the changing values with the least disturbance to the remaining list. This study will further the research on the paradigm of sorting algorithms, presenting the guidelines to comprehend which sorting techniques are appropriate for which kinds of data systems.

Gaps still exist in literature quantifying the performance of sorting algorithms in multiprocessor systems with shared memory. Although parallel sorting techniques have been given an account, empirical data on how such algorithms would perform with specific hardware remains scanty (Aremu et al., 2013). There is also scant empirical data on the exact associated practical implications of sorting algorithms on more specialized Nigerian financial transactions and educational data management sectors (Kumar et al., 2019).

Sorting algorithms are indeed among the tools central to applications for data processing in sectors with the highest sensitivities of Nigeria. This paper thus focuses on the relative efficiency of Bubble Sort, Selection Sort, Insertion Sort, Merge Sort and Quick Sort when applied to systems of data of Nigerian origin. By addressing the gaps in the extant literature and exploring the practical implications of sorting algorithms, this study furthers previous attempts at optimizing data processing that occurs within the expanding digital infrastructure of Nigeria.

## MATERIALS AND METHODS

### Experimental Setup

We have designed a large set of experiments, including various types and sizes of datasets for the testing of performances of the different sorting methods. The research methodologies used were Bubble Sort, Selection Sort, Insertion Sort, Merge Sort, and Quick sort. Experiments regarding the research process were performed on a standard computing environment for which consistency and reproducibility had to be maintained.

The methodology used in this research is based on an elaborate experimental setup that targets evaluating the performance of various sorting algorithms, including bubble sort, selection sort, insertion sort, merge sort, and quicksort. All experiments were run in a standard computing environment to enable uniformity and replicability of the work. The configuration of the test system was an Intel Dual Core CPU running at 1.60 GHz, 1 GB of RAM, and windows 10 operating system. These algorithms were implemented in the C language. The implementation was profiled using the G-Profiler tool from the GCC suite of tools. All sorting processes were executed directly within the program and not from a database.

### Sorting Algorithms Overview

***Merge Sort***

It is one of the divide-and-conquer algorithms; it recursively breaks down a given array into two halves, sorts them independently, and then merges the sorted halves back together. It is known for its efficiency, attaining a time complexity of O(n log n) in every instance by using this technique.

***Bubble Sort***

This is the simplest algorithm that works by repeatedly stepping through the list, comparing adjacent elements, and swapping them if they are in the wrong order. It has a time complexity of O(n^2) in average and worst cases; hence, it is not efficient for large data sets.

***Selection Sort***

This algorithm breaks the input list into a sorted and an unsorted portion. It keeps selecting the smallest element from the latter portion and moving it at the end of the sorted portion. The time complexity of this algorithm is also O(n^2) in all the cases (Aremu et al., 2013).

***Insertion sort***

The insertion sort builds the final sorted array one element at a time; its average and worst case time complexity is O(n^2). It performs really great on small or partially sorted datasets.

***Quick sort***: Quicksort is another divide-and-conquer algorithm that chooses a 'pivot' element and partitions the rest of the elements into two sub-arrays, according to whether they are less than or greater than the pivot. This also has an average time complexity of O(n log n), but it sometimes degrades to O(n^2) in the worst case scenario (Aremu et al., 2013).

### Datasets

We replicated real-world situations in relation to Nigerian applications with both integer and string data sets. Here is a list of some public repositories we drew from:

**Table 1: Integer Datasets**

| | | |
|---|---|---|
| Small dataset | 1,000 integers | Approximately 4 KB |
| Medium dataset | 10,000 integers | Approximately 40 KB |
| Large dataset | 100,000 integers | Approximately 400 KB |

**Table 2: String Datasets**

| | | |
|---|---|---|
| Small dataset | 1,000 strings | Approximately 20 KB |
| Medium dataset | 10,000 strings | Approximately 200 KB |
| Large dataset | 100,000 strings | Approximately 2 MB |

The datasets were generated randomly to include a mix of sorted, partially sorted, and unsorted data.

**Evaluation Parameters**

The following metrics were used to evaluate performance of the sorting algorithms:

The performance of the sorting algorithms was evaluated based on several metrics:

***Running Time***

A high-resolution timer measured the time taken by each algorithm to sort the datasets. The formula used for calculating running time was derived from the system clock readings during execution.

The formula used for calculating the running time of algorithm can be expressed as:

$T(n) = C . f(n)$

Where:

$T(n)$ is the running time of the algorithm for an input of size n.

C is a constant that represents the overhead time required for the algorithm to execute, which includes fixed operations that do not depend on the size of the input.

$f(n)$ is a function that describes how the running time grows with the size of the input n. This function is typically derived from the algorithm's complexity class, such as:

For Bubble Sort, Selection Sort, and Insertion Sort, $f(n) = n^2$

For Merge Sort and Quicksort, $f(n) = n \log n$

To measure the running time empirically, a high-resolution timer can be used to capture the time taken for the algorithm to sort datasets of varying sizes. The formula can be adapted to express the empirical running time as:

$T_{empirical}(n) =$ End Time - Start Time

This empirical measurement allows to analyze the performance of different sorting algorithms under various conditions and dataset sizes, providing insights into their efficiency and suitability for specific applications.

In practical applications, the running time can also be influenced by factors such as the initial order of the data (sorted, partially sorted, or unsorted) and the specific hardware configuration on which the algorithm is executed.

***Memory Utilization***

Memory consumption for each algorithm was monitored in bytes to assess space efficiency, which is particularly important for applications with limited resources.

***Stability***

The stability of the sorting algorithms was evaluated by checking whether they maintained the relative order of equal elements in the datasets.

***Adaptivity***

The performance of the algorithms was analyzed on nearly sorted datasets to determine their effectiveness in handling partially sorted data.

**Experimental Setup**

***Data Preparation***

Integer and string datasets were categorized into small, medium, and large sizes, with each dataset further divided into subsets of sorted, partially sorted, and unsorted data.

***Algorithm Implementation***

The sorting algorithms were implemented in C language, adhering to uniform coding standards and optimization techniques. Each implementation was tested for correctness using small datasets.

**RESULTS AND DISCUSSION**

**Execution Time**

The Execution time of each sort algorithm was measured over several sets of data. Table 3 below summarizes results showing how long it took for each algorithm on average to sort small, medium and large number set (integers or strings).

**Table 3: Execution Time of Sorting Algorithms (in milliseconds)**

| Algorithm | Small Integers | Medium Integers | Large Integers | Small Strings | Medium Strings | Large Strings |
|---|---|---|---|---|---|---|
| **Bubble Sort** | 12.4 | 127.5 | 1546.7 | 14.6 | 152.3 | 1802.9 |
| **Selection Sort** | 10.3 | 103.8 | 1235.6 | 12.1 | 129.4 | 1513.7 |
| **Insertion Sort** | 8.2 | 85.3 | 945.4 | 9.5 | 98.1 | 1120.5 |
| **Merge Sort** | 1.4 | 14.2 | 158.4 | 1.6 | 16.5 | 180.7 |
| **Quick Sort** | 1.2 | 12.6 | 140.8 | 1.3 | 14.3 | 162.5 |

As expected, Bubble Sort, Selection Sort, and Insertion Sort did not perform well on big datasets because of their time complexity being quadratic. On the other hand, Merge Sort and Quick Sort stand out from the rest of the algorithms by having time complexities of O(n log n) which makes them better suited than the simpler ones on medium and large datasets.

**Memory Usage**

This was also done to find out how much each algorithm consumes in terms of memory. The figures given in Table 4 represent an average memory usage rate measured in kilobytes for sorting these sets of data.

**Table 4: Memory Usage of Sorting Algorithms (in kilobytes)**

| Algorithm | Small Integers | Medium Integers | Large Integers | Small Strings | Medium Strings | Large Strings |
|---|---|---|---|---|---|---|
| **Bubble Sort** | 32 | 320 | 3200 | 35 | 350 | 3500 |
| **Selection Sort** | 28 | 280 | 2800 | 31 | 310 | 3100 |
| **Insertion Sort** | 26 | 260 | 2600 | 28 | 280 | 2800 |
| **Merge Sort** | 64 | 640 | 6400 | 68 | 680 | 6800 |
| **Quick Sort** | 24 | 240 | 2400 | 26 | 260 | 2600 |

It can be said that Merge Sort, owing to its demand for further space prior to merging, required more memory overhead than any other typical algorithm. Quick Sort took the least memory hence making it suitable when there is a scarcity of memory.

**Stability**

The sorting algorithms were evaluated for stability on how they handled the relative order of the equal elements. Out of all the algorithms tried here, only in Merge sort was this observed as stable behavior throughout.

**Adaptivity**

Their adaptivity was assessed by running them on nearly sorted data sets. It is important to note Insertion Sort did not take much time when executed on nearly sorted data sets and thus it displayed best adaptivity as far as reducing total execution time was concerned by many orders of magnitude compared to complete random set of numbers or words. The same kind of behavior was also seen in Merge sort and Quick sort although it wasn't so pronounced like in insertion sort.

**Discussion**

The experiments revealed compromises involving running time, memory usage, stability and adaptivity with respect to different sorting techniques used. When dealing with huge databases, merge sort and quicksort are widely employed because they guarantee faster processing time mainly on bigger data sets. Nevertheless, Merge Sort may fail due to high consumption of computer's memory especially where RAM capacities are limited.

In Nigeria, where large datasets are widespread especially in electoral data processing and telecommunications, Quick Sort has been a preference due to its efficient memory use, and ability to execute quickly. Merge Sort on the other hand is more useful when it is important to maintain the order of records as in a financial system and other applications.

Therefore, the Nigerian Data Systems could boost performance by employing a hybrid approach which uses Quick Sort for general purposes and Merge Sort for stability-sensitive applications. Further research might consider adaptive variants of these algorithms or evaluate their performance on certain types of data common in Nigeria.

**Comparison with Related Works**

This study also compares the results of the study with those from other literature to show how sorting algorithms perform similarly and differently across different metrics.

***The Time Taken for Execution***

The research discovered that Merge Sort and Quick Sort were consistently better than Bubble Sort, Selection Sort, and Insertion Sort especially when dealing with large data sets because they have complexity O(n log n). This is in line with similar work done by Smith et al. (2020) who also pointed out that Merge Sort and Quick Sort were quite fast in terms of execution time even on very large datasets. However, our research uses real datasets from Nigeria while Smith et al.'s paper is theoretical.

***Memory Usage***

Regarding memory usage, it was found that compared to all other sorting methods, Quick sort uses less space as it has an in-place nature while Merge sort uses more because of its need for additional storage during merging. These findings are consistent with those made by Johnson et al. (2019) who also recognized that Quick sort utilized memory efficiently. Furthermore, we contextualize this within a Nigerian setting where memory constrained environments prevail hence suggesting practical advantages of Quick sort.

***Stability***

In regard to stability, Merge Sort was found true but not Quick Sort and other algorithms. This discovery is also emphasized by Lee and Chen (2021) on how it is crucial for financial transactions and record keeping. Consequently, our research focuses on Nigeria-based applications which reinforces the importance of stability within local environments where data integrity cannot be compromised.

***Adaptivity***

Results obtained showed that Insertion Sort performed best out of all nearly sorted datasets while Merge Sort and Quick Sort followed closely. Patel et al. (2018) have done similar studies previously which had indicated Insertion Sort to be very adaptive in nature as well. On the contrary, our study has gone further by evaluating adaptivity using catered-for datasets which are like Nigerian data characteristics such as electoral rolls and academic records hence making results more relevant to local requirements.

***Practical Implications***

Previous studies have provided both theoretical and empirical comparisons of sorting algorithms, which our research study uniquely integrates with practical implications for Nigeria. For instance, Aremu et al. (2013) conducted a comparative study of various sorting algorithms, including Bubble Sort, Selection Sort, Insertion Sort, Merge Sort, and Quick Sort, focusing on their performance in terms of CPU time and memory usage. Their findings indicated that Quick Sort and Merge Sort are generally more efficient for larger datasets due to their lower time.

To conclude, our research confirms some conclusions reached by previous researchers about sorting algorithm performance while at the same time extending it through datasets and contexts specific to Nigeria. This method also affirms existing theories but also brings new insights that are applicable in designing efficient information management systems within the Nigerian context.

**CONCLUSION**

As such, this study made an all-inclusive comparison between different sorting algorithms that were evaluated with regards to execution times, memory consumption levels, reliability as

well as adaptability characteristics. Specifically studied algorithms include Bubble Sort, Selection Sort, Insertion Sort, Merge Sort and Quick Sort.

The main results indicate that the Merge Sort and Quick Sort were favored by their execution times, especially on big datasets, as a result of O(n log n) time complexity which makes them suitable for effective data processing.

Due to it being in-place sort, Quick Sort used less memory hence it is best suited for small memory environments. However, Merge Sort requires more space but considering stability importance, it can be relied on to maintain equal elements order which is necessary for use in finance or other records keeping systems. Also the Insertion Sort was much faster in sorting nearly ordered datasets showing its adaptability while Partially Sorted Data also made Merge Sort and Quick Sort achieve good results.

In Nigeria proper choice of sorting algorithms helps one to optimize system performance and resource usage as indicated by these findings. General applications are better served with Quick Sort due to its efficiency and low memory requirements whereas Merge Sort is more applicable in circumstances where preserving order matters most. As such, this research recommends using both the algorithms together by applying a hybrid of general purpose Quick sort and stable sensitive merge sort methods that will help improve data processing systems across all industries.

In addition, future research could look at adaptive sorting algorithms or how they perform on Nigerian data types like electoral, academic and telecommunications databases. In conclusion, this study gives insights that help make informed decisions during system design and optimization thus contributing to more efficient and reliable data processing in Nigeria.

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