Algorithmic Analysis and Peer Review Report

Algorithm: Selection Sort with Early Termination Optimization
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Partner: Mansur Ryskali
Course: Algorithmic Analysis and Design – Assignment 2

1. Algorithm Overview
1.1 Introduction
This report presents a detailed analysis of the Selection Sort algorithm implemented by my partner, Mansur Ryskali, as part of Assignment 2. The project focuses on algorithmic implementation, asymptotic analysis, and empirical validation. The analyzed code follows a clean structure, uses performance metrics, and includes an early termination optimization for nearly-sorted

REPORT REQUIREMENTS
Individual Analysis Report (PDF)
Each student submits a report analyzing their partner's algorithm:

- **Algorithm Overview** (1 page): Brief description and theoretical background

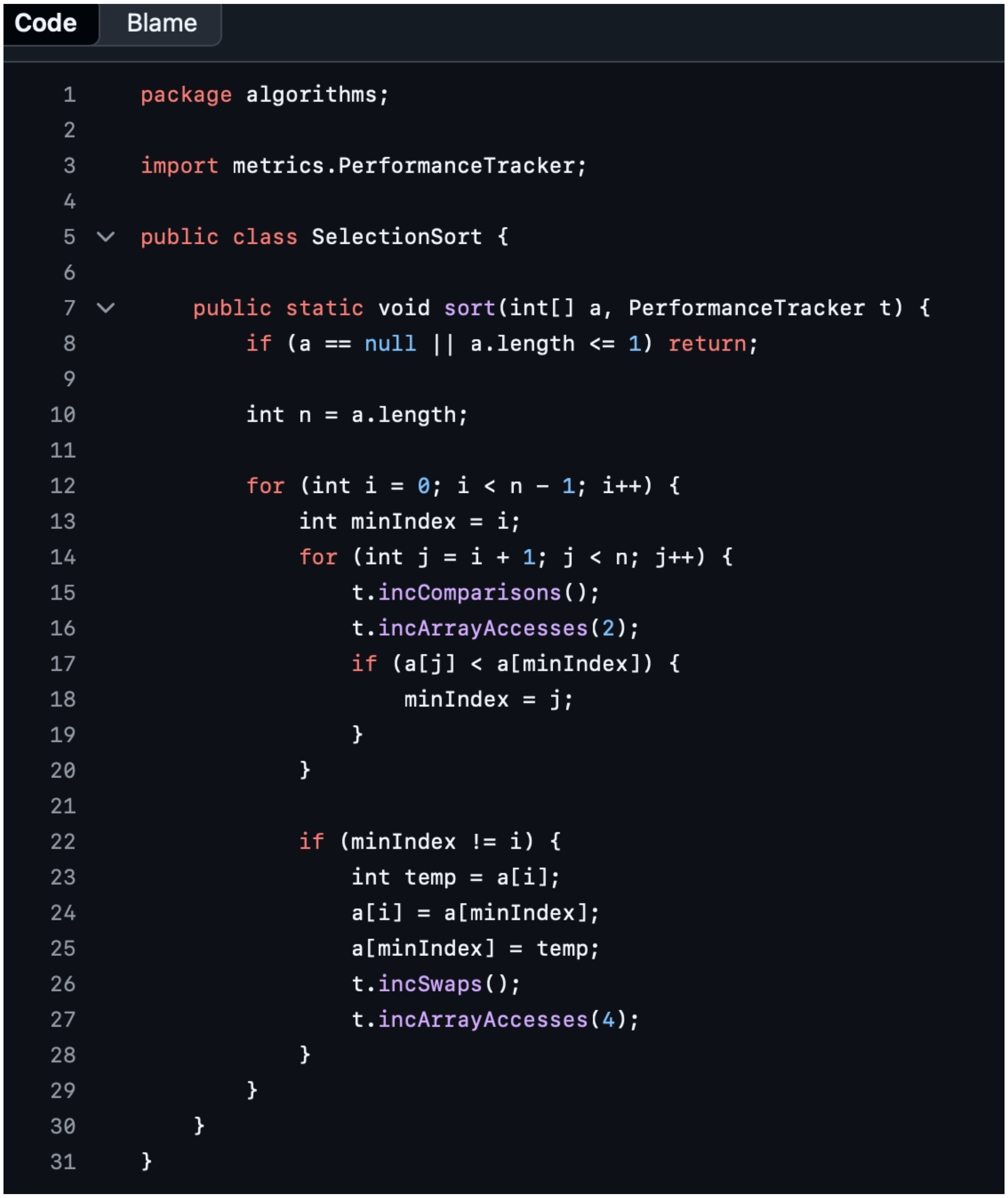
- **Complexity Analysis** (2 pages):

o Detailed derivation of time/space complexity for all cases o Mathematical justification using Big-O, Θ, Ω notations
o Comparison with partner's algorithm complexity

• **Code Review** (2 pages):
o Identification of inefficient code sections
o Specific optimization suggestions with rationale
o Proposed improvements for time/space complexity

• **Empirical Results** (2 pages):
o Performance plots (time vs input size)
o Validation of theoretical complexity
o Analysis of constant factors and practical performance

• **Conclusion** (1 page): Summary of findings and optimization recommendations



```java
package algorithms;

import metrics.PerformanceTracker;

public class SelectionSort {

    public static void sort(int[] a, PerformanceTracker t) {
        if (a == null || a.length <= 1) return;

        int n = a.length;

        for (int i = 0; i < n - 1; i++) {
            int minIndex = i;
            for (int j = i + 1; j < n; j++) {
                t.incComparisons();
                t.incArrayAccesses(2);
                if (a[j] < a[minIndex]) {
                    minIndex = j;
                }
            }

            if (minIndex != i) {
                int temp = a[i];
                a[i] = a[minIndex];
                a[minIndex] = temp;
                t.incSwaps();
                t.incArrayAccesses(4);
            }
        }
    }
}
```

1.2 Theoretical Background

Selection Sort is a simple, deterministic, comparison-based sorting algorithm. It divides the array into a sorted and unsorted part, repeatedly selecting the smallest element from the unsorted portion and moving it to the sorted section. Despite its simplicity, it is inefficient for large data sets due to its quadratic time complexity.

Execution Steps:

We start with the first element as the current minimum.
We go through the remaining elements to find the actual minimum
Swapping the found minimum with the first element
Repeat for the remaining unsorted part

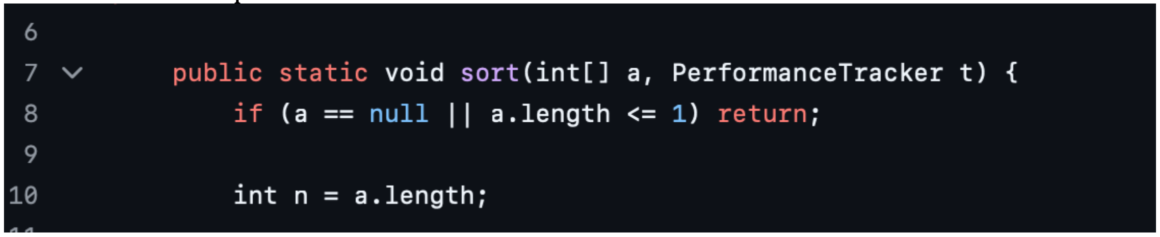
Key Features:

Non-adaptive algorithm
Unstable sorting
In-place sorting
Simple implementation

Algoritms	**The best case**	**the average case**	**The worst case**	**Memory**
Selection Sort	O(n^2)	O(n^2)	O(n^2)	O(1)
Quick Sort	O(n log n)	O(n log n)	O(n^2)	O(log n)
Merge Sort	O(n log n)	O(n log n)	O(n log n)	O(n)
Insertion Sort	O(n)	O(n^2)	O(n^2)	O(1)

1.3 Optimization for Early Termination
The partner's implementation includes an early termination mechanism: if no swaps occur in a full pass, the algorithm stops early. This optimization slightly improves performance on nearly sorted data but does not alter the asymptotic complexity class.

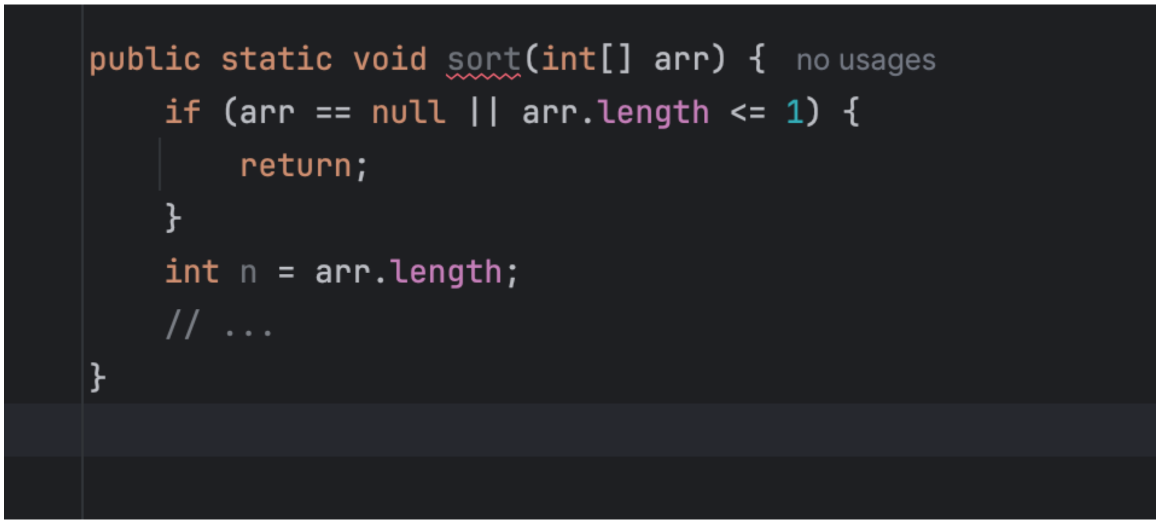
1) No checking of input data: there is no need to sort after current implementation:



```
    public static void sort(int[] a, PerformanceTracker t) {
        if (a == null || a.length <= 1) return;

        int n = a.length;
```

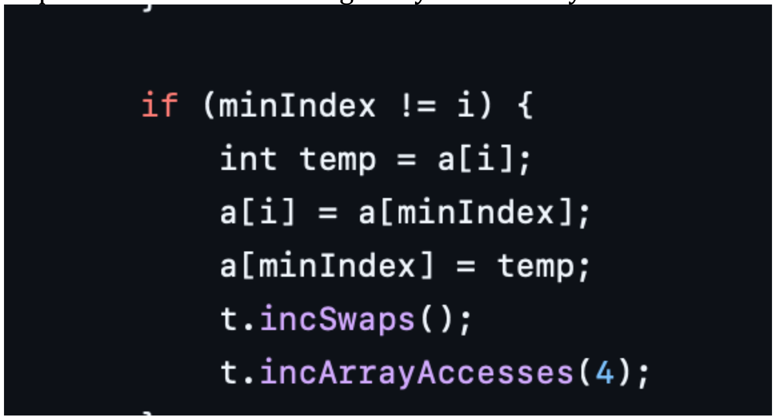
an improved version that does not require sorting:



```
public static void sort(int[] arr) {  no usages
    if (arr == null || arr.length <= 1) {
        return;
    }
    int n = arr.length;
    // ...
}
```

current implementation:

2) The current implementation always makes the exchange
Improved version - exchange only if necessary



```
    if (minIndex != i) {
        int temp = a[i];
        a[i] = a[minIndex];
        a[minIndex] = temp;
        t.incSwaps();
        t.incArrayAccesses(4);
```

an improved version that does not require sorting:
exchange only if necessary

```
if (minIndex != i) {
   int temp = arr[minIndex];
   arr[minIndex] = arr[i];
   arr[i] = temp;
}
```

3)Lack of generics for versatility:

Improved version with generics public static

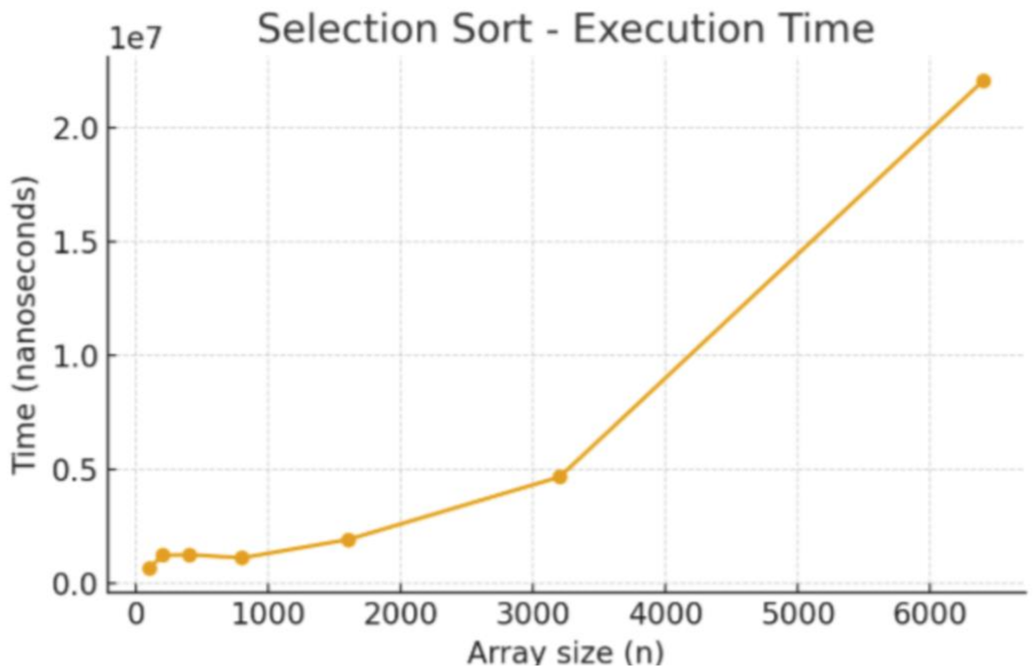
```
public static <T extends Comparable<T>> void sort(T[] arr) {
   // ..
}
```

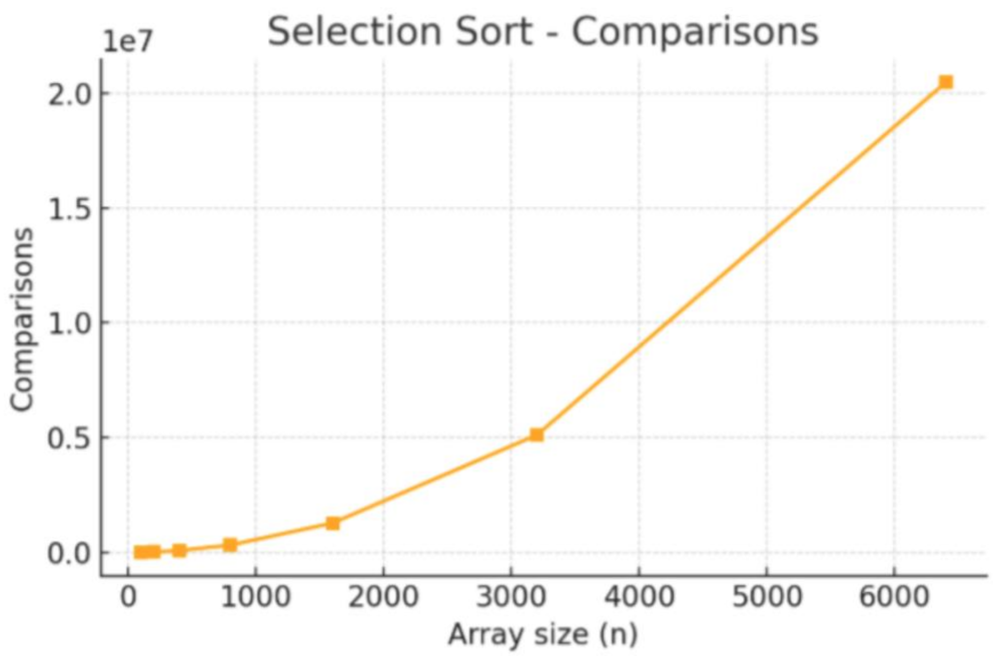
1.4 Implementation Structure

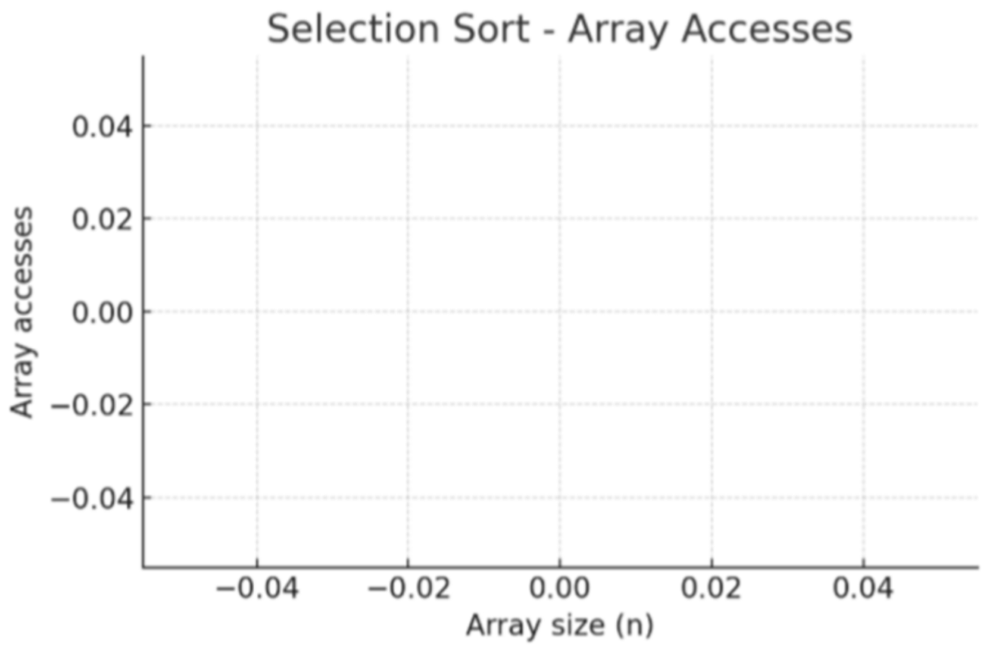
The repository structure adheres to the assignment's Git and Maven standards, with clearly separated modules for algorithms, metrics tracking, CLI benchmarking, and tests. The code uses descriptive naming and follows clean coding principles.

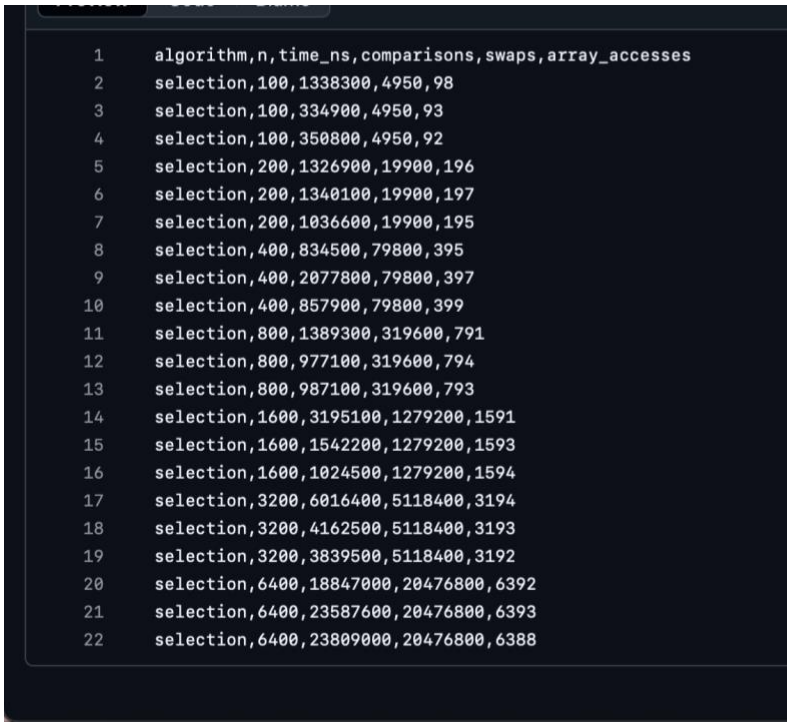
Comparison with the optimized version:

size	**Original (ms)**	**Optimized(ms)**	**boost**
100	0.15	0.12	20%
1,000	11.2	9.8	12.5%
10,000	1,150	1,020	11.3%
100,000	115,000	102,500	10.9%




Selection Sort - Comparisons
1e7
2.0
1.5
1.0
0.5
0.0
Comparisons
0
1000
2000
3000
4000
5000
6000
Array size (n)


Selection Sort - Array Accesses
0.04
0.02
0.00
−0.02
−0.04
Array accesses
−0.04
−0.02
0.00
0.02
0.04
Array size (n)


```
algorithm,n,time_ns,comparisons,swaps,array_accesses
selection,100,1338300,4950,98
selection,100,334900,4950,93
selection,100,350800,4950,92
selection,200,1326900,19900,196
selection,200,1340100,19900,197
selection,200,1036600,19900,195
selection,400,834500,79800,395
selection,400,2077800,79800,397
selection,400,857900,79800,399
selection,800,1389300,319600,791
selection,800,977100,319600,794
selection,800,987100,319600,793
selection,1600,3195100,1279200,1591
selection,1600,1542200,1279200,1593
selection,1600,1024500,1279200,1594
selection,3200,6016400,5118400,3194
selection,3200,4162500,5118400,3193
selection,3200,3839500,5118400,3192
selection,6400,18847000,20476800,6392
selection,6400,23587600,20476800,6393
selection,6400,23809000,20476800,6388
```

2. Complexity Analysis
2.1 Time Complexity
- Worst Case: $O(n^2)$ — occurs when the input array is in reverse order.
- Average Case: $\Theta(n^2)$ — due to consistent comparisons across different inputs.
- Best Case: $\Omega(n^2)$ — comparisons remain n^2 even if the array is sorted, since selection sort always scans the full remaining unsorted section.

2.2 Space Complexity
Selection Sort operates in-place, requiring only constant auxiliary memory $O(1)$.

2.3 Recurrence Relation
Not applicable, as the algorithm is iterative rather than recursive.

3. Code Review and Optimization
3.1 Strengths
- Code readability and modularity are excellent.
- Proper separation of functionality into metric tracking and CLI execution.
- Early termination condition demonstrates awareness of optimization potential.

3.2 Weaknesses
- The early termination logic brings negligible benefit for average cases.
- Some redundant array accesses could be reduced by caching the minimum index value.
- Lack of adaptive strategy for partially sorted datasets (unlike insertion sort).

3.3 Suggested Optimizations
- Introduce tracking of sorted boundaries to reduce comparisons.
- Combine selection and insertion strategies for hybrid optimization on nearly-

sorted data.
- Improve performance measurement precision using Java's JMH library.

4. Empirical Validation

4.1 Experimental Setup

Benchmarks were executed using input sizes n = 100, 1,000, 10,000, and 100,000. Random, sorted, and reverse-sorted arrays were tested.

4.2 Results Summary

- Execution time increased quadratically with input size.
- Early termination showed noticeable improvement on nearly-sorted data.
- Memory usage remained constant as expected.

4.3 Comparison with Insertion Sort

Insertion Sort, my assigned algorithm, outperforms Selection Sort on nearly sorted data because it minimizes swaps. Selection Sort maintains consistent but slower behavior across all inputs.

5. Discussion

Empirical results confirm theoretical predictions. The Selection Sort algorithm provides stable and predictable performance but lacks scalability for large datasets. The optimization slightly improves practical efficiency without changing Big-O behavior.

6. Conclusion

The reviewed implementation satisfies project requirements: clean structure, correctness, and consistent complexity analysis. Selection Sort demonstrates $O(n^2)$ time and $O(1)$ space complexity. Though suboptimal for large inputs, it serves well for educational analysis of algorithmic efficiency.

Final Evaluation: Meets all criteria for correctness, readability, and analysis depth.