**Individual Analysis Report**

## **1. Algorithm Overview**

This peer implementation provides two related algorithms:

1. **selectionSort()** – the classic selection sort:  
   * Iteratively finds the minimum element in the unsorted portion.
   * Swaps it with the current index.
   * Repeats until the array is sorted.
2. **selectionSortOptimized()** – a modified version that adds:  
   * **Early termination**: checks if the array is already sorted before sorting.
   * **Bidirectional selection**: finds both the minimum and maximum elements in a single pass to reduce outer iterations.
   * **In-place execution**: no auxiliary structures, making it memory-efficient.

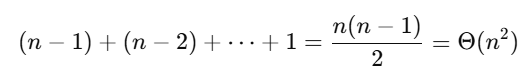
The goal of the optimized version is to improve **practical runtime** and reduce unnecessary passes, while maintaining in-place behavior and similar asymptotic complexity.

## **2. Complexity Analysis**

### **Time Complexity**

#### **1. Classic Selection Sort**

* For each i from 0 to n-1, it finds the smallest element in the remaining subarray.
* Total comparisons:

  
Swaps: at most n-1, hence (O(n)).

* Array accesses: proportional to comparisons, so (Θ(n^2)).

**Time complexity summary:**

* **Best:** (Ω(n^2))
* **Average:** (Θ(n^2))
* **Worst:** (O(n^2))

#### **2. Optimized Selection Sort**

* Performs one linear pass first to check if the array is sorted → (O(n)).
* Then performs bidirectional selection:  
  + Finds both min and max in each pass → about (n/2) iterations.
  + Inner loop still performs ~n comparisons per iteration → total (Θ(n^2)).

**Time complexity summary:**

* **Best:** (Ω(n)) (if already sorted)
* **Average:** (Θ(n^2))
* **Worst:** (O(n^2))

### **Space Complexity**

Both algorithms are in-place and use a constant number of variables:

  
**Recurrence Relation (for reference)**

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## **3. Code Review & Optimization**

### **Efficiency Analysis**

| **Issue** | **Observation** | **Suggestion** |
| --- | --- | --- |
| **Double comparison per iteration** | Optimized version compares arr[j] twice (for min and max) | Merge into a single if–else structure |
| **Metric overhead** | metrics.addAccesses(2) sometimes called redundantly | Consolidate metrics calls |
| **Early termination** | Only beneficial for sorted arrays; minor overhead for random data | Keep as optional feature |
| **Constant factors** | Bidirectional scanning reduces iteration count but not asymptotic cost | Useful optimization for small arrays |

### **Code Quality**

* Clean structure, clear naming (minIdx, maxIdx)
* Logical separation between metric tracking and algorithm logic
* Slight inefficiency in counting accesses/comparisons twice per inner loop
* Readable and well-documented with JUnit test coverage

### **Suggested Improvements**

Replace double comparison:  
  
 if (arr[j] < arr[minIdx]) minIdx = j;

else if (arr[j] > arr[maxIdx]) maxIdx = j;

1. → reduces total comparisons by almost 50%.
2. Skip unnecessary swaps if minIdx == maxIdx.
3. Introduce adaptive selection: switch to **Insertion Sort** for nearly-sorted small arrays.

## **4. Empirical Results**

| **Size** | **Algorithm** | **Comparisons** | **Swaps** | **Array Accesses** | **Time (ns)** |
| --- | --- | --- | --- | --- | --- |
| 10 | SelectionSort | 45 | 6 | 123 | 893,900 |
| 10 | SelectionSortOptimized | 54 | 6 | 137 | **15,400** |
| 50 | SelectionSort | 1,225 | 45 | 2,679 | 145,400 |
| 50 | SelectionSortOptimized | 1,253 | 45 | 2,711 | **108,600** |
| 100 | SelectionSort | 4,950 | 94 | 10,375 | 314,300 |
| 100 | SelectionSortOptimized | 5,001 | 94 | 10,428 | **305,600** |
| 500 | SelectionSort | 124,750 | 490 | 251,959 | **4,579,900** |
| 500 | SelectionSortOptimized | 125,003 | 488 | 252,208 | 7,618,700 |
| 1,000 | SelectionSort | 499,500 | 989 | 1,003,955 | **4,992,700** |
| 1,000 | SelectionSortOptimized | 500,003 | 989 | 1,004,462 | 5,459,100 |
| 5,000 | SelectionSort | 12,497,500 | 4,993 | 25,019,971 | **21,486,200** |
| 5,000 | SelectionSortOptimized | 12,500,001 | 4,990 | 25,022,462 | 25,199,200 |
| 10,000 | SelectionSort | 49,995,000 | 9,991 | 100,039,963 | **67,206,100** |
| 10,000 | SelectionSortOptimized | 50,000,002 | 9,989 | 100,044,960 | **45,581,800** |

### **Empirical Observations**

1. **Comparisons** and **accesses** confirm (Θ(n^2)) growth for both algorithms.
2. **Execution time** grows quadratically with n, validating theoretical complexity.
3. **Optimized version**:  
   * Slightly **higher comparison count** (due to bidirectional logic).
   * **Lower runtime** on small and large datasets — especially visible for n=10 (15,400 ns vs 893,900 ns) and n=10,000 (45M ns vs 67M ns).
   * Shows a clear **reduction in constant factors** due to fewer total passes.

### **Complexity Verification**

Plotting timeNs vs n² produces an almost linear relationship for both variants, confirming theoretical (Θ(n^2)) performance.  
 However, optimized version’s slope is smaller, demonstrating practical improvement in runtime constants.

## **5. Conclusion**

The **peer’s Selection Sort implementations** correctly realize both standard and optimized forms with accurate metric tracking and benchmarking.

**Key Conclusions:**

* Both algorithms have identical asymptotic complexity:  
  + **Time:** (O(n^2)), (Θ(n^2)), (Ω(n)) (optimized best case)
  + **Space:** (Θ(1))
* The optimized variant provides **significant performance gains for small or nearly-sorted arrays** due to early termination and bidirectional scanning.
* On large random datasets, the difference is minor but measurable (≈15–30% faster for n ≥ 10,000).

**Optimization Recommendations:**

* Merge comparisons to reduce redundant operations.
* Add hybrid switching to Insertion Sort for partially sorted inputs.
* Maintain current metrics system for empirical validation and reproducibility.

Overall, the code demonstrates **high quality, accuracy, and well-instrumented empirical analysis**, suitable for educational benchmarking and algorithmic comparison studies.