Report: Emprical Analysis

In this report, we analyze and compare the performance of various sorting algorithms, including both basic and improved versions. The goal is to understand their efficiency based on input size, sorted and unsorted datasets, and different data distributions. The analysis focuses on time complexity, space complexity, and the impact of negative values, large ranges, and sorted inputs on algorithm performance.

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1. Bubble Sort

- **Description**: Bubble Sort is a simple, comparison-based sorting algorithm that repeatedly steps through the list, compares adjacent elements, and swaps them if they are in the wrong order. This process is repeated until no more swaps are needed.
- **Performance Analysis**:
  - Performs well on sorted arrays since no swaps are required, allowing early termination with the improved version using a swapped flag.
  - Struggles with large datasets and random inputs due to its (O(n^2)) complexity.
  - Handling negative values decreases performance significantly due to the nature of swap operations.

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2. Improved Bubble Sort

- **Description**: An optimized version of Bubble Sort that introduces a flag (`swapped`) to check if any swaps were made during an iteration. If no swaps are made, the algorithm terminates early.
- **Performance Analysis**:
  - Improves on sorted datasets by reducing unnecessary swaps.
  - Shows overhead on random datasets as it still iteratively checks each element.
  - Particularly efficient when handling sorted data or smaller input sizes.

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3. Merge Sort

- **Description**: Merge Sort is a divide-and-conquer algorithm that splits the array into halves, recursively sorts each half, and then merges them.
- **Performance Analysis**:
  - Efficient for larger datasets as it consistently divides and merges arrays, maintaining O(n log n) complexity.
  - Struggles when handling uneven distributions or negative values as split operations increase.
  - Exhibits improved performance as input sizes grow since fewer splits and merges are required.

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4. Quick Sort

- **Description**: Quick Sort selects a pivot, partitions the array around the pivot, and recursively sorts the partitions.
- **Performance Analysis**:
  - Efficient for larger datasets with balanced partitions, offering O(n log n) time complexity.

    - Poor pivot choices can degrade performance, especially for sorted datasets, resulting in unbalanced partitions.
    - Performance drops when handling negative values or large input ranges.

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5. Improved Quick Sort

- **Description**: An optimized version of Quick Sort that uses tail recursion and improves pivot selection strategies.
- **Performance Analysis**:
    - Shows better performance on sorted datasets and manages balanced partitions effectively.
    - Slightly slower on random datasets due to additional checks, but optimizations save time on sorted inputs.

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6. Radix Sort

- **Description**: Radix Sort sorts integers by processing individual digits, from the least significant to the most significant.
- **Performance Analysis**:
    - Performs consistently well regardless of input size and type, making it efficient for both sorted and unsorted datasets.
    - Struggles slightly with larger value ranges as more passes over data are required, but remains efficient for lower ranges.

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7. Selection Sort

- **Description**: Selection Sort divides the array into a sorted and unsorted portion and repeatedly selects the smallest element from the unsorted portion.
- **Performance Analysis**:
    - Performs well on sorted arrays with consistent time complexity of O(n^2).
    - Suffers when dealing with large input sizes and uneven distributions, especially with negative values.

In conclusion, each sorting algorithm presents unique trade-offs depending on the dataset characteristics, including size, distribution, and the presence of negative values. Improved versions of Bubble Sort and Quick Sort show substantial efficiency gains, especially on sorted and smaller datasets. Radix Sort consistently outperforms due to its non-comparison-based nature, making it effective across various scenarios. On the other hand, Selection Sort and basic Bubble Sort struggle with larger datasets and random distributions. Overall, algorithm selection should be guided by the nature of the data to achieve optimal performance.