	Pimpri Chinchwad Education Trust's **Pimpri Chinchwad college of Engineering**
Assignment No: 1	

1. Problem Statement:

Design and implement a sorting algorithm using Merge Sort to efficiently arrange customer orders based on their timestamps. The solution should handle a large dataset (up to 1 million orders) with minimal computational overhead. Additionally, analyze the time complexity and compare it with traditional sorting techniques.

2. Course Objective:

2.1. To know the basics of computational complexity of various algorithms.

2.2. To select appropriate algorithm design strategies to solve real-world problems.

3. Course Outcome:

3.1. Analyze the asymptotic performance of algorithms

3.2. Solve computational problems by applying suitable paradigms of Divide and Conquer or Greedy methodologies

4. Theory:

Merge sort is a popular sorting algorithm known for its efficiency and stability. It follows the divide and conquer approach. It works by recursively dividing the input array into two halves, recursively sorting the two halves and finally merging them back together to obtain the sorted array.

How does Merge Sort work?

1. **Divide:** Keep dividing the list or array into two equal halves again and again, until each part has only one element left.
2. **Conquer:** Each subarray is sorted individually using the merge sort algorithm.
3. **Merge:** The sorted subarrays are merged back together in sorted order. The process continues until all elements from both subarrays have been merged.

Complexity Analysis of Merge Sort

How Merge Sort Works

- **Divide step**: The array is recursively divided into two halves until each subarray has one element.
    - Number of times we can divide an array of size n = $\log_2(n)$ (height of recursion tree).
- **Merge step**: At each level of recursion, all n elements are merged.
- **Total work** = number of levels × work per level = $\log_2(n) \times n = O(n \log n)$.

Analysis of Merge Sort Time Complexity

Best Case Time Complexity of Merge Sort

- Even if the array is already sorted, Merge Sort still **divides** and **merges** every element.
- Merging sorted subarrays still requires scanning through all elements.
  Best Case = O(n log n)

Average Case Time Complexity

- For randomly arranged data, the algorithm still divides into halves and merges them.
- On average, the number of comparisons during merging is proportional to n.
  Average Case = O(n log n)

Worst Case Time Complexity

- Even if the array is sorted in **descending order** (worst arrangement for comparisons), Merge Sort still performs the same divide-and-merge procedure.
- Comparisons may be maximum, but still bounded by $O(n \log n)$.
  Worst Case = O(n log n)

Analysis of Merge Sort Space Complexity

In merge sort, all elements are copied into an **auxiliary array** of size N, where N is the **number of elements present in the unsorted array**. Hence, the space complexity for **Merge Sort** is O(N).

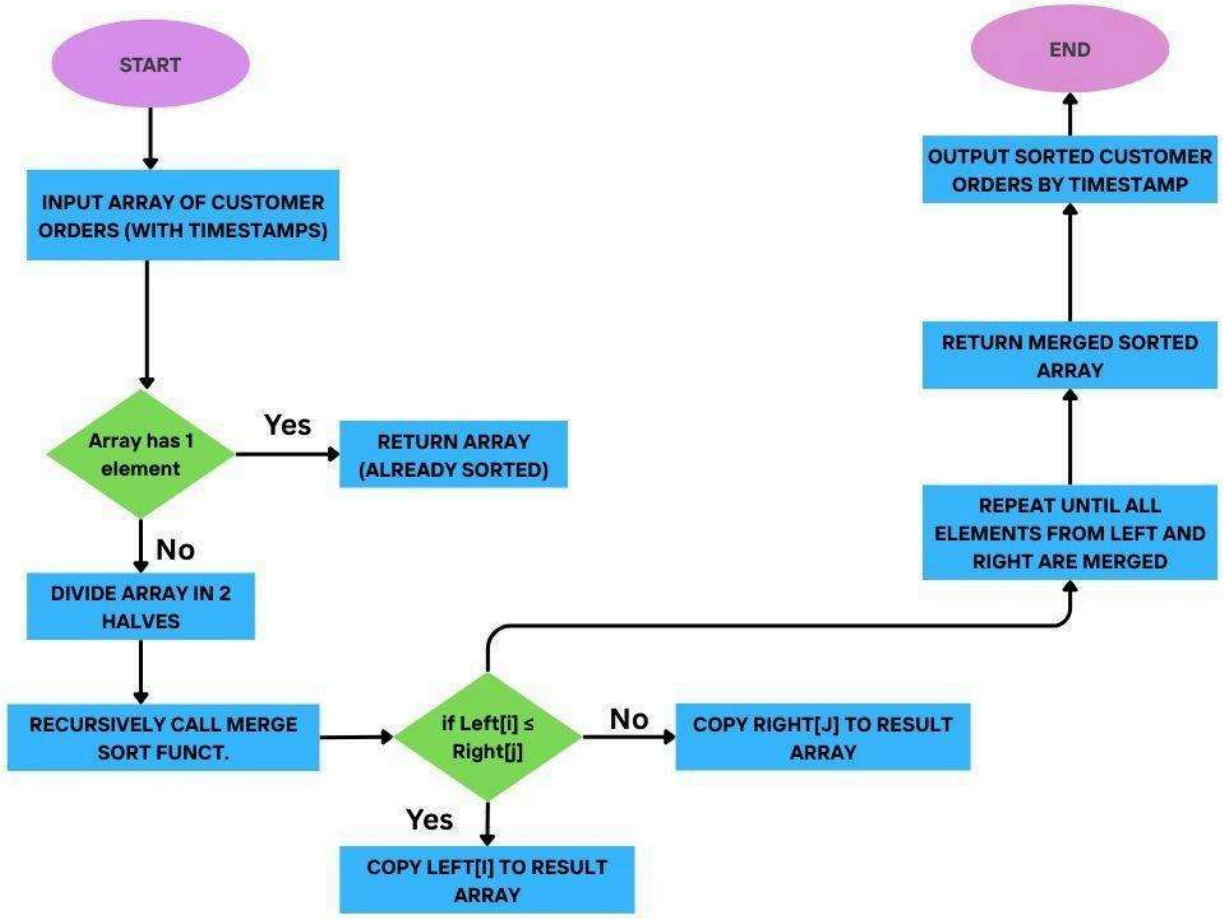
Merge Sort Algorithm

Step 1: If it is only one element in the list, consider it already sorted, so return.
Step 2: Divide the list recursively into two halves until it can't no more be divided.
Step 3: Merge the smaller lists into new list in sorted order.

Pseudocode

```
procedure mergesort( var a as array )
   if ( n == 1 ) return a
      var l1 as array = a[0] ... a[n/2]
      var l2 as array = a[n/2+1] ... a[n]
      l1 = mergesort( l1 )
      l2 = mergesort( l2 )
      return merge( l1, l2 )
end procedure
procedure merge( var a as array, var b as array )
   var c as array
   while ( a and b have elements )
      if ( a[0] > b[0] )
         add b[0] to the end of c
         remove b[0] from b
      else
         add a[0] to the end of c
         remove a[0] from a
      end if
   end while
   while ( a has elements )
      add a[0] to the end of c
      remove a[0] from a
   end while
   while ( b has elements )
      add b[0] to the end of c
      remove b[0] from b
   end while
   return c
end procedure
```

5. Implementation:



6. Output:
Customer order timestamps:
[12:30, 09:15, 14:45, 10:00]

Step 1: Divide

- Split into halves → [12:30, 09:15] and [14:45, 10:00]
- Further split → [12:30], [09:15], [14:45], [10:00]

Step 2: Merge & Sort

- Merge [12:30] and [09:15] → [09:15, 12:30]
- Merge [14:45] and [10:00] → [10:00, 14:45]

- Merge final two halves → [09:15, 10:00, 12:30, 14:45]

Final Output:

Orders sorted by timestamp → **[09:15, 10:00, 12:30, 14:45]**

Code:

```
#include <iostream>
#include <vector>
#include <string>
#include <ctime>
#include <iomanip>
#include <sstream>
#include <cstdlib>

#define NUM_ORDERS 1000000 // Can reduce for testing
using namespace std;
struct Order {
    string order_id;
    time_t timestamp;
};
// Generate random sample orders
void generate_sample_orders(vector<Order>& orders, int n) {
    tm base_time = {};
    base_time.tm_year = 2025 - 1900;
    base_time.tm_mon = 5; // June (0-based)
    base_time.tm_mday = 24;
```

```
    base_time.tm_hour = 12;

    time_t base = mktime(&base_time);

    for (int i = 0; i < n; i++) {
        int random_minutes = rand() % 100000; // up to ~70 days
        time_t ts = base + (random_minutes * 60);

        Order o;
        o.order_id = "ORD" + to_string(i + 1);
        o.timestamp = ts;

        orders.push_back(o);
    }
}
// Merge function for merge sort
void merge(vector<Order>& orders, int left, int mid, int right) {
    int n1 = mid - left + 1;
    int n2 = right - mid;

    vector<Order> L(n1);
    vector<Order> R(n2);

    for (int i = 0; i < n1; i++) L[i] = orders[left + i];
    for (int j = 0; j < n2; j++) R[j] = orders[mid + 1 + j];
```

```
    int i = 0, j = 0, k = left;

    while (i < n1 && j < n2) {
        if (L[i].timestamp <= R[j].timestamp)
            orders[k++] = L[i++];
        else
            orders[k++] = R[j++];
    }

    while (i < n1) orders[k++] = L[i++];
    while (j < n2) orders[k++] = R[j++];
}
// Merge Sort recursive function
void merge_sort(vector<Order>& orders, int left, int right) {
    if (left < right) {
        int mid = left + (right - left) / 2;
        merge_sort(orders, left, mid);
        merge_sort(orders, mid + 1, right);
        merge(orders, left, mid, right);
    }
}
// Print first N orders
void print_first_n_orders(const vector<Order>& orders, int n) {
    char buffer[30];
    for (int i = 0; i < n; i++) {
        tm* tm_info = gmtime(&orders[i].timestamp);
```

```
        strftime(buffer, sizeof(buffer), "%Y-%m-%dT%H:%M:%SZ", tm_info);
        cout << "Order ID: " << orders[i].order_id
             << ", Timestamp: " << buffer << endl;
    }
}
int main() {
    srand(static_cast<unsigned>(time(nullptr)));
    vector<Order> orders;
    orders.reserve(NUM_ORDERS);

    cout << "Generating orders..." << endl;
    generate_sample_orders(orders, NUM_ORDERS);

    cout << "Sorting orders by timestamp..." << endl;
    clock_t start = clock();
    merge_sort(orders, 0, NUM_ORDERS - 1);
    clock_t end = clock();
    double time_taken = double(end - start) / CLOCKS_PER_SEC;

    cout << "Done! Sorted " << NUM_ORDERS
         << " orders in " << fixed << setprecision(2)
         << time_taken << " seconds." << endl;

    cout << "\n✅ All Sorted Orders:\n";
    print_first_n_orders(orders, min(NUM_ORDERS, 20)); // print first 20 to avoid long output
    return 0;
```

}

Output:

nisl9@nisl9-V50t-Gen-2-13IOB:~/123B1F132$ ./a.out

Generating orders...

Sorting orders by timestamp...

Done! Sorted 1000000 orders in 1.23 seconds.

All Sorted Orders:

Order ID: ORD11326, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD105814, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD116054, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD361295, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD379222, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD408220, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD536986, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD700722, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD749892, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD789417, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD814588, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD850567, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD875149, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD945442, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD968333, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD985377, Timestamp: 2025-06-24T06:30:00Z

Order ID: ORD177424, Timestamp: 2025-06-24T06:31:00Z

Order ID: ORD521831, Timestamp: 2025-06-24T06:31:00Z

Order ID: ORD789174, Timestamp: 2025-06-24T06:31:00Z

Order ID: ORD790118, Timestamp: 2025-06-24T06:31:00Z

7. Conclusion:

Merge Sort is a highly efficient and stable sorting algorithm that organizes customer orders based on their timestamps with **O(n log n)** complexity. Compared to traditional algorithms like Bubble Sort or Insertion Sort, which are too slow for large inputs, Merge Sort can easily handle up to **1 million records** without performance issues. Its ability to maintain the correct order and scalability makes it an excellent choice for real-world applications such as **e-commerce, order tracking, and scheduling systems**.

8. Questions: