Question 1

Given the following two functions find1() and find2() which are both passed an integer array, arrA[] , and its associated size, size, and return an integer. In addition, the function find1() is passed the value size - 1 for curr initially. (Line numbers are included):

```
1. // curr should be size - 1 for the first call
2. int find1(int arrA[], int size, int curr)
3. {
4.     if (size == 1)
5.     {
6.         return (curr);
7.     }
8.     else if (arrA[curr] < arrA[size - 2])
9.     {
10.        return (find1(arrA, size - 1, size - 2));
11.    }
12.    else
13.    {
14.        return (find1(arrA, size - 1, curr));
15.    }
16. }
17. int find2(int arrA[], int size)
18. {
19.    int curr = 0;
20.    for (int i = 1; i < size; i++)
21.    {
22.        if (arrA[i] > arrA[curr])
23.        {
24.            curr = i;
25.        }
26.    }
27.    return (curr);
28. }
```

With respect to time complexity analysis, and assuming a worst-case scenario, calculate the number of timesteps of each function as a function of the array size N. Explain your approach and any assumptions, clearly showing how the timesteps are calculated.

For find1

Line	Cost	numTimes	cost*numTimes	Total
4	1	N	N	
6	1	1	1	
8	1	N-1	N-1	
10	1	0	0	
14	1	N-1	N-1	
				f(N) = 3N-1

L4 will be executed N times, because in worst case scenario is when size will be equal to 0

L6 will be executed once when the condition will be true

L8 will execute N-1,because first if statement will not come true N-1 times

L10 will not be executed, because in worst case scenario size will be equal 1 and the condition in else if wont be true

L14 else statement will be executed N-1 times

In the worst case scenario the maximum element will be at index curr(N-1).

For find2

Line	Cost	numTimes	cost*numTimes	Total
19	1	1	1	
20	1	N-1	N-1	
22	1	N-1	N-1	
24	1	0	0	
27	1	1	1	
				f(N) = 2N

I the worst case scenario L24 will not be executed, because maximum element will be at index curr = 0;

Question 2

The following function merge(), merges two sorted portions (from lb to mid and from mid+1 to ub) of an array arrA[]. (Line numbers are included).

```
 L1. void merge(int arrA[], int lb, int mid, int ub)
 L2. {
 L3.     int i, j, k;
 L4.     int size = ub - lb + 1;
 L5.     int *arrC = (int *)calloc(size, sizeof(int));
 L6.     for (i = lb, j = mid + 1, k = 0; i <= mid && j <= ub; k++)
 L7.     {
 L8.         if (arrA[i] <= arrA[j])
 L9.         {
L10.             arrC[k] = arrA[i++];
L11.         }
L12.         else
L13.         {
L14.             arrC[k] = arrA[j++];
L15.         }
L16.     } // end for loop
L17.     while (i <= mid)
L18.     {
L19.         arrC[k++] = arrA[i++];
L20.     }
L21.     while (j <= ub)
L22.     {
L23.         arrC[k++] = arrA[j++];
L24.     }
L25.     for (i = lb, k = 0; i <= ub; i++, k++)
L26.     {
L27.         arrA[i] = arrC[k];
L28.     }
L29. }
```

Using some sample data, and with reference to the code line numbers, explain, in your own words, how the function merge() works.

In L3 variables **i**, **j** and **k** are being declared.

In **L4** size of the array is being calculated by subtracting lower band from upper band and adding one . It will be later used in **L4** to dynamically allocate memory to **arrC** of size that is calculated in L3.

In **L6** a loop is initialized starting from **i** set to **lb**, **j** set to **mid + 1**, and **k** set to **0**. This loop runs until either **i** reaches **mid** or **j** reaches **ub**, whichever comes first.

Inside the loop**(L8-L15)**, elements are being compared at indices **i** and **j** of **arrA[].** If the element at **arrA[i]** is less than or equal to the element at **arrA[j], arrA[i]** is being assigned to **arrC[k]** and **i** is incremented. Otherwise, **arrA[j]** is assigned to **arrC[k]** and increment **j**.

(L17-L24) After exiting the loop there is possibility that there are some remaining elements in either of the two portions. Two separate while loops are used to copy any remaining elements from either portion into arrC[].

(L25-L28) Then elements from **arrC** are being merged back into the original array staring from index **lb** up to **ub**

```
Initialization:
   lb = 0
   mid = 3
   ub = 7
Declaration and Memory Allocation:
   size = 7 - 0 + 1 = 8
   Allocate memory for arrC[] of size 8.
Merging Process:
   Initialize i, j, and k:
      i = 0, j = mid + 1 = 4, k = 0
   Iteration 1:
      Compare arrA[0] (2) and arrA[4] (1) - false.
      So, arrC[0] = arrA[4] = 1 and increment j.
      Result: arrC[] = {1, _, _, _, _, _, _, _}
   Iteration 2:
      Compare arrA[0] (2) and arrA[5] (3) - true.
      So, arrC[1] = arrA[0] = 2 and increment i.
      Result: arrC[] = {1, 2, _, _, _, _, _, _}
   Iteration 3:
      Compare arrA[1] (4) and arrA[5] (3) - false.
      So, arrC[2] = arrA[5] = 3 and increment j.
      Result: arrC[] = {1, 2, 3, _, _, _, _, _}
   Iteration 4:
      Compare arrA[1] (4) and arrA[6] (5) - true.
      So, arrC[3] = arrA[1] = 4 and increment i.
      Result: arrC[] = {1, 2, 3, 4, _, _, _, _}
   Iteration 5:
      Compare arrA[2] (6) and arrA[6] (5) - false.
      So, arrC[4] = arrA[6] = 5 and increment j.
      Result: arrC[] = {1, 2, 3, 4, 5, _, _, _}
   Iteration 6:
      Compare arrA[2] (6) and arrA[7] (7) - true.
      So, arrC[5] = arrA[2] = 6 and increment i.
      Result: arrC[] = {1, 2, 3, 4, 5, 6, _, _}
   Iteration 7:
      Compare arrA[3] (8) and arrA[7] (7) - false.
      So, arrC[6] = arrA[7] = 7 and increment j.
      Result: arrC[] = {1, 2, 3, 4, 5, 6, 7, _}

Copying Remaining Elements:
   No remaining elements in the first portion (i > mid), but there are elements remaining in the second portion.
Copy these remaining elements into arrC[].

Copying Back to Original Array:
    Copy elements from arrC[] back to arrA[] starting from index lb to ub.

After completing the merge() function, arrA[] will be {1, 2, 3, 4, 5, 6, 7, 8}.
```

Question 3

Given the test file, file1.txt (with 10,000 integers), perform a comparison of the two sorting techniques Merge Sort and Quick Sort considering different values of N (array size) in terms of:

a) time taken
b) number of swaps/data moves
c) number of comparisons
d) number of function calls (recursive if using, and non-recursive)

Present your results in a meaningful and clear way so that it is easy to see differences between the algorithms for the same value of N. You may re-use your code from assignment 1.

In my testing approach I was evaluating 4 sorting algorithms. Testing is performed on array of different size ranging from 1000 to 10000 in increments of 1000, for each size. Numbers are read from given file.

Counting swaps, comparisons and function calls is executed in each soring algorithm. The time taken to sort the array is measured by recording the time before and after the sorting algorithm is executed, and then calculating the difference.

After sorting an array and gathering all data, the sorted array is checked to ensure that it is sorted correctly.

Results are being saved to .csv file.

Below I've included analysis of gathered data and parts of code. Full code and csv files are available in the GitHub repository on branch **Assignment-2-Submission**

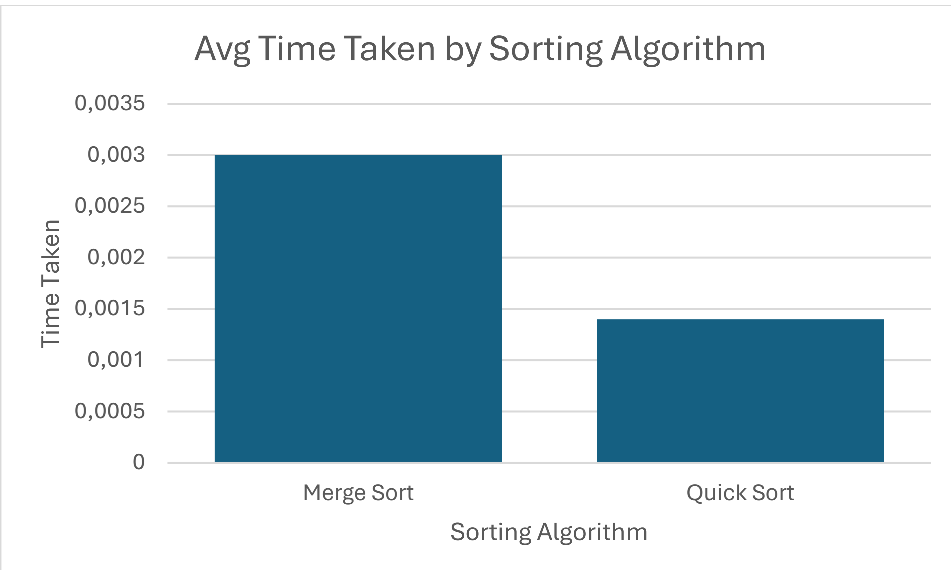
https://github.com/Olszewski-Jakub/Sorting-Algorithms-Performance-Analysis/tree/Assignment-2-Submission

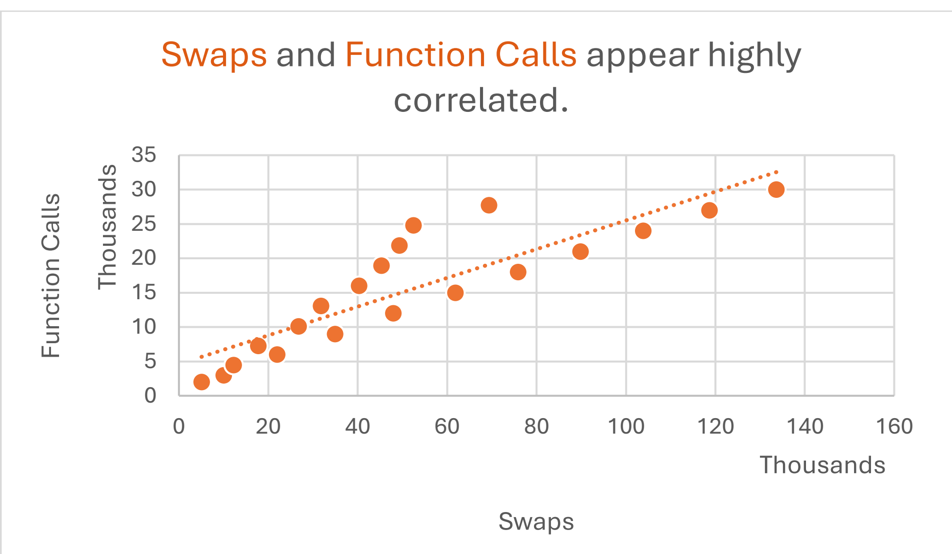
Csv file with gathered data

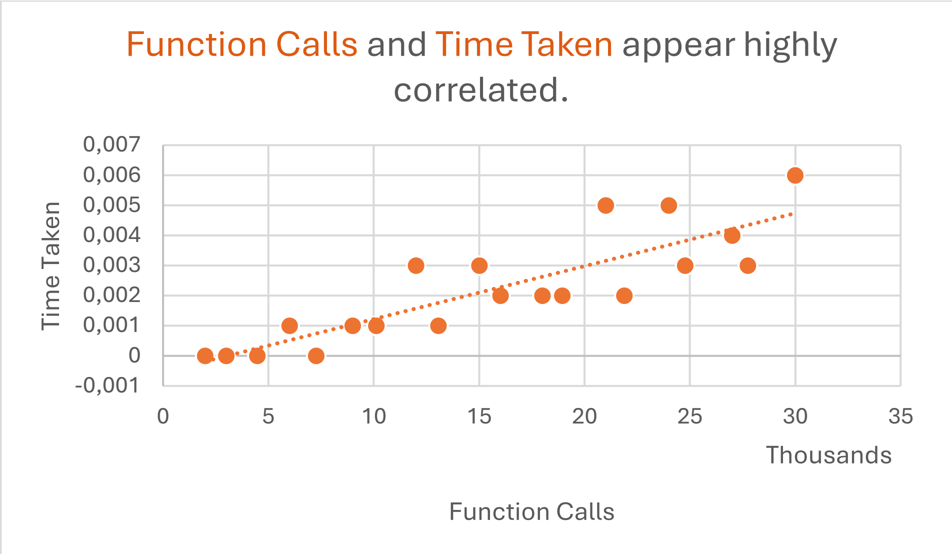
Sorting algorithms

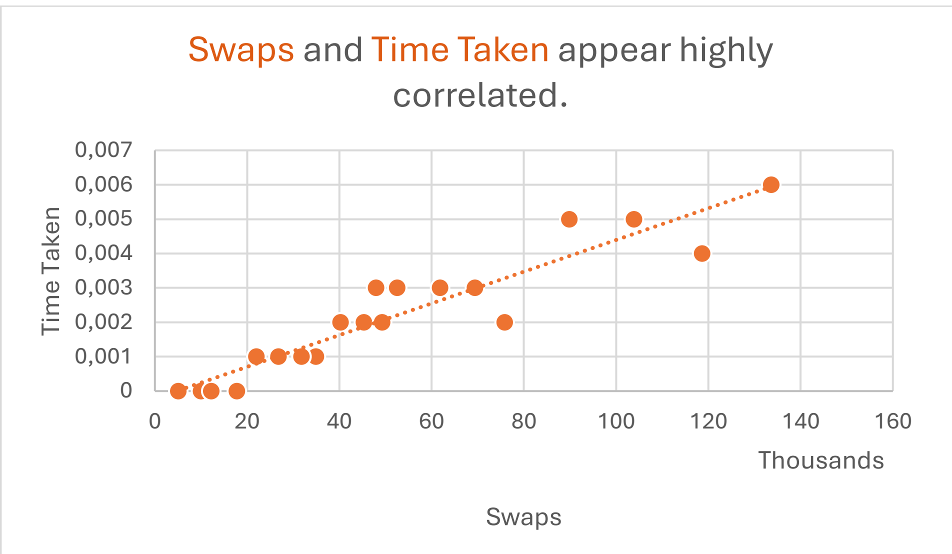
Algorithm execution and data gathering

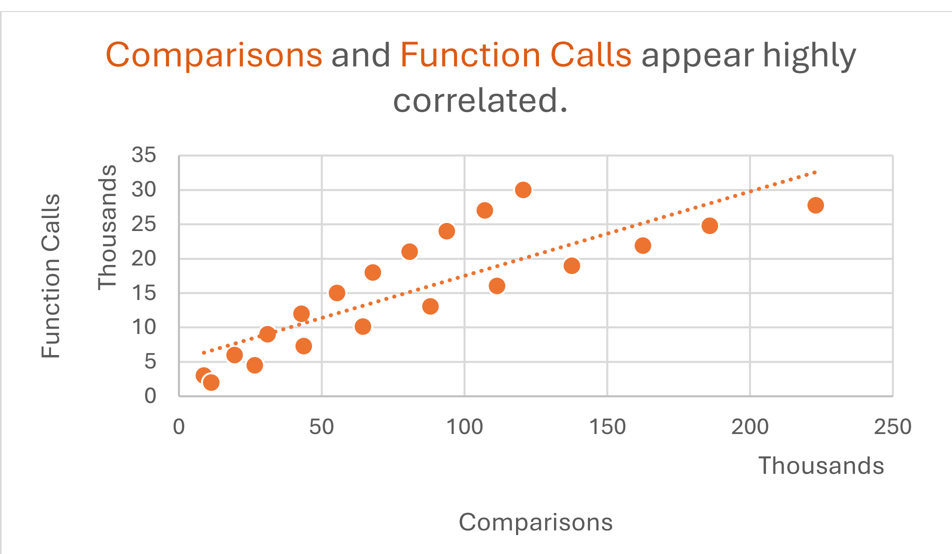
Row Labels	Merge Sort	Quick Sort
1000	0	0
2000	0,001	0
3000	0,001	0
4000	0,003	0,001
5000	0,003	0,001
6000	0,002	0,002
7000	0,005	0,002
8000	0,005	0,002
9000	0,004	0,003
10000	0,006	0,003

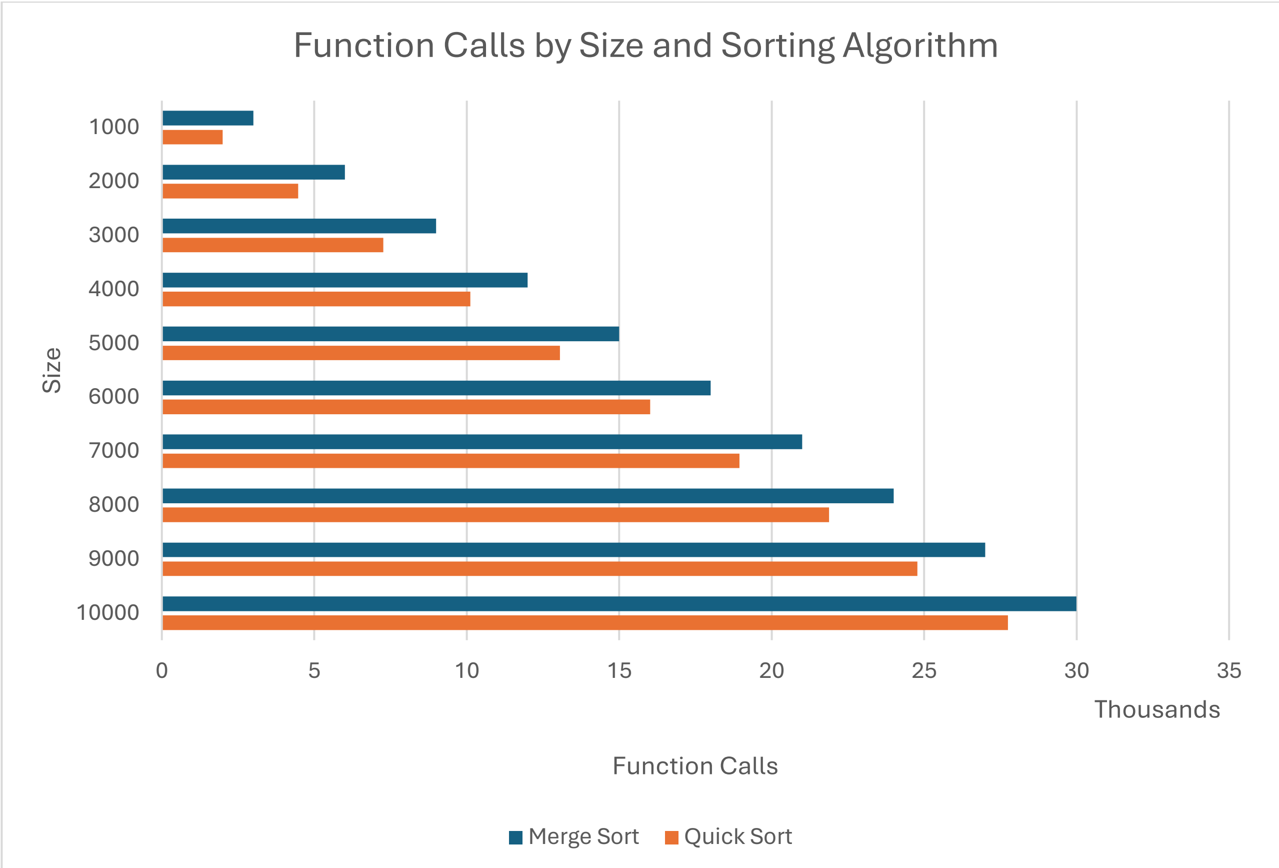





Function Calls and Time Taken appear highly correlated.
Time Taken
0,007
0,006
0,005
0,004
0,003
0,002
0,001
0
-0,001
0
5
10
15
20
25
30
35
Thousands
Function Calls


Swaps and Time Taken appear highly correlated.
Time Taken
0,007
0,006
0,005
0,004
0,003
0,002
0,001
0
0
20
40
60
80
100
120
140
160
Thousands
Swaps


Comparisons and Function Calls appear highly correlated.
Function Calls
Thousands
35
30
25
20
15
10
5
0
0
50
100
150
200
250
Thousands
Comparisons


Function Calls by Size and Sorting Algorithm
Size
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
5
10
15
20
25
30
35
Thousands
Function Calls
Merge Sort
Quick Sort

Data

Sorting Algorithm	Size	Swaps	Comparisons	Function Calls	Time Taken
Merge Sort	1000	9976	8727	2998	0
Merge Sort	2000	21952	19445	5998	0,001
Merge Sort	3000	34904	30972	8998	0,001
Merge Sort	4000	47904	42886	11998	0,003
Merge Sort	5000	61808	55269	14998	0,003
Merge Sort	6000	75808	67903	17998	0,002
Merge Sort	7000	89808	80710	20998	0,005
Merge Sort	8000	103808	93732	23998	0,005
Merge Sort	9000	118616	107032	26998	0,004
Merge Sort	10000	133616	120530	29998	0,006
Quick Sort	1000	5060	11226	1990	0
Quick Sort	2000	12170	26550	4471	0
Quick Sort	3000	17744	43682	7258	0
Quick Sort	4000	26741	64342	10117	0,001
Quick Sort	5000	31774	88044	13054	0,001
Quick Sort	6000	40238	111284	16009	0,002
Quick Sort	7000	45251	137563	18937	0,002
Quick Sort	8000	49257	162389	21880	0,002
Quick Sort	9000	52462	185817	24775	0,003
Quick Sort	10000	69361	222955	27742	0,003

Sorting Algorithms

```c
void quickSortRecursive(int arrA[], int startval, int endval, int *swaps, int *comparisons, int *functionCalls) {
    // Increment function call count
    (*functionCalls)++;
    // If there are more than one elements to sort
    if ((endval - startval) >= 1) {
        // Partition the array and get the pivot position
        int k = partition(arrA, startval, endval, swaps, comparisons, functionCalls);
        // Recursively sort elements before pivot
        quickSortRecursive(arrA, startval, k - 1, swaps, comparisons, functionCalls);
        // Recursively sort elements after pivot
        quickSortRecursive(arrA, k + 1, endval, swaps, comparisons, functionCalls);
    }
}

// Partition function for Quick Sort
int partition(int arrA[], int startval, int endval, int *swaps, int *comparisons, int *functionCalls) {
    // Increment function call count
    (*functionCalls)++;
    // Calculate mid point
    int mid = startval + (endval - startval) / 2;
    // Sort start, mid and end elements to find the median
    if (arrA[startval] > arrA[mid]) {
        swap(&arrA[startval], &arrA[mid]);
        (*swaps)++;
    }
    if (arrA[startval] > arrA[endval]) {
        swap(&arrA[startval], &arrA[endval]);
        (*swaps)++;
    }
    if (arrA[mid] > arrA[endval]) {
        swap(&arrA[mid], &arrA[endval]);
        (*swaps)++;
    }
    // Swap mid element with start element
    swap(&arrA[mid], &arrA[startval]);
    (*comparisons) += 3;
    // Choose pivot as start element
    int pivot = arrA[startval];
    int k = startval;
    // Partition the array around pivot
    for (int j = startval + 1; j <= endval; j++) {
        (*comparisons)++;
        if (arrA[j] <= pivot) {
            k++;
            if (k != j) {
                swap(&arrA[k], &arrA[j]);
                (*swaps)++;
            }
        }
    }
    // Swap pivot with element at k
    swap(&arrA[k], &arrA[startval]);
    (*swaps)++;
    // Return pivot position
    return k;
}
```

```c
// Recursive function for Merge Sort
void mergeSortRecursive(int arrA[], int lb, int ub, int *swaps, int *comparisons, int *functionCalls) {
    // Increment function call count
    (*functionCalls)++;
    int mid;
    // If lower bound is less than upper bound
    if (lb < ub) {
        // Calculate mid point
        mid = (lb + ub) / 2;
        // Recursively sort first half
        mergeSortRecursive(arrA, lb, ub: mid, swaps, comparisons, functionCalls);
        // Recursively sort second half
        mergeSortRecursive(arrA, lb: mid + 1, ub, swaps, comparisons, functionCalls);
        // Merge the two halves
        merge(arrA, lb, mid, ub, swaps, comparisons, functionCalls);
    }
}

// Merge function for Merge Sort
void merge(int arrA[], int lb, int mid, int ub, int *swaps, int *comparisons, int *functionCalls) {
    // Increment the function call count
    (*functionCalls)++;
    int i, j, k;
    // Calculate size of the array to be merged
    int size = ub - lb + 1;
    // Allocate memory for temporary array
    int *arrC = (int *) calloc( NumOfElements: size, SizeOfElements: sizeof(int));
    // Initialize indices
    i = lb;
    j = mid + 1;
    k = 0;
    // Merge the two halves into temporary array
    while (i <= mid && j <= ub) {
        (*comparisons)++;
        if (arrA[i] <= arrA[j]) {
            arrC[k] = arrA[i];
            i++;
        } else {
            arrC[k] = arrA[j];
            j++;
        }
        k++;
        (*swaps)++;
    }
    // Copy remaining elements from first half, if any
    while (i <= mid) {
        arrC[k] = arrA[i];
        i++;
        k++;
        (*swaps)++;
    }
    // Copy remaining elements from second half, if any
    while (j <= ub) {
        arrC[k] = arrA[j];
        j++;
        k++;
        (*swaps)++;
    }
    // Copy sorted array back to original array
    i = lb;
    k = 0;
    while (i <= ub) {
        arrA[i] = arrC[k];
        i++;
        k++;
    }
    // Free dynamically allocated memory
    free( Memory: arrC);
}
```

I am aware of what plagiarism is and include this here to confirm that this work is my own