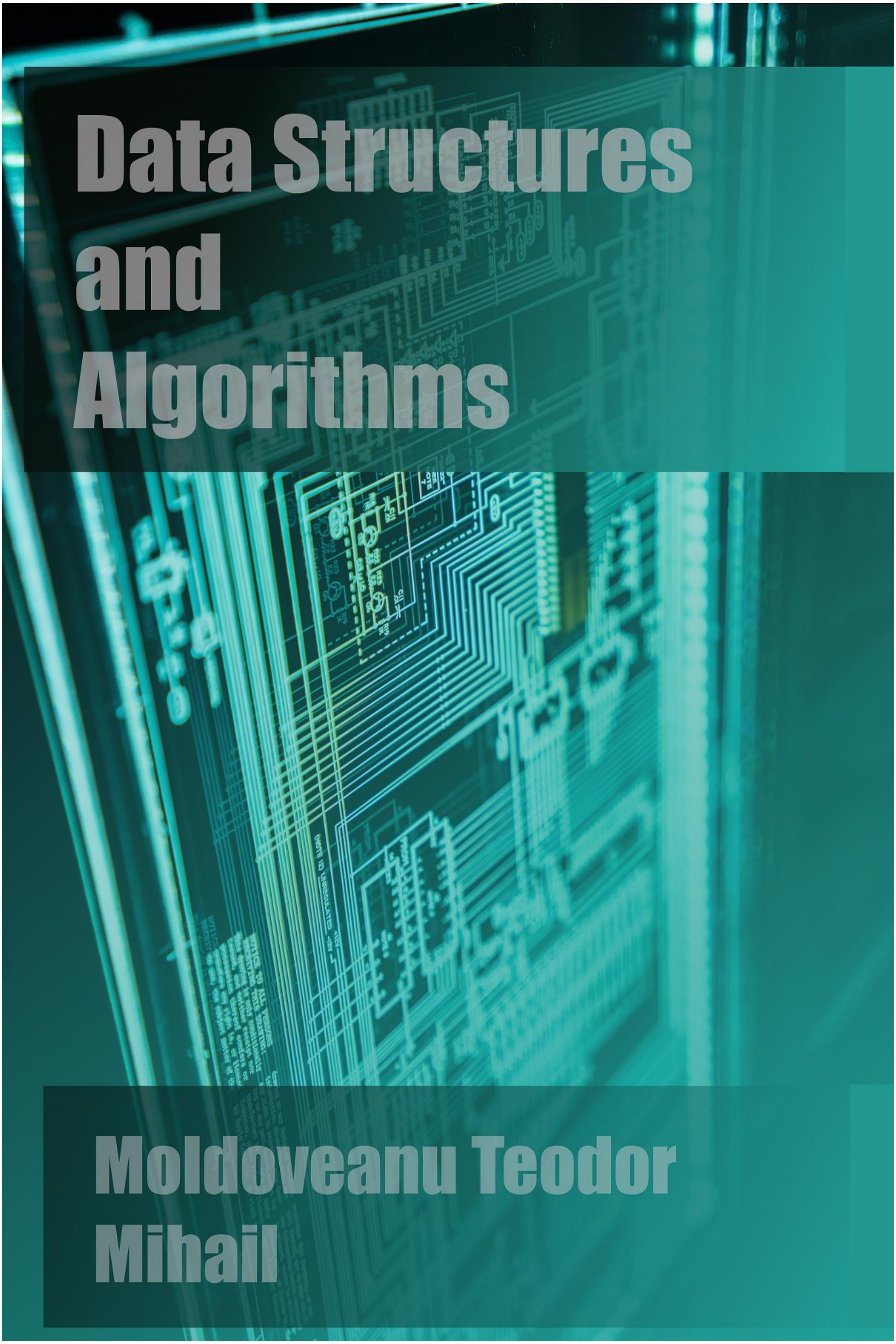


Data Structures and Algorithms

Moldoveanu Teodor Mihail

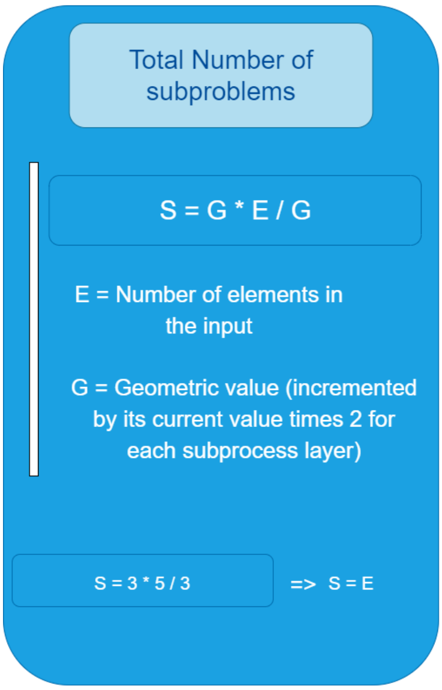
Table of contents:

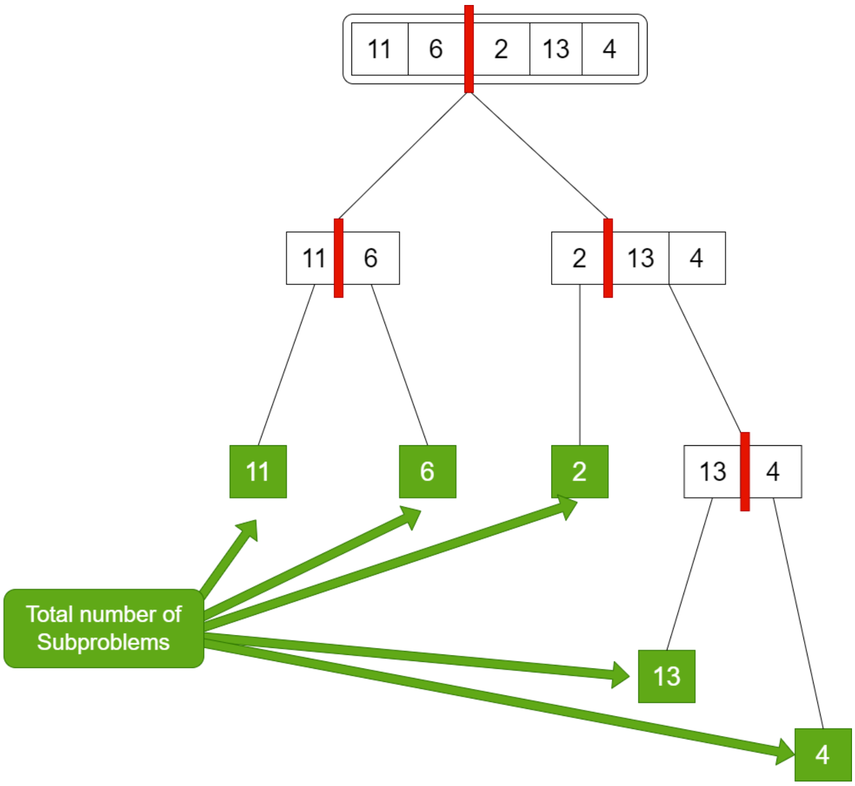
Task 1

Algorithms and specifications

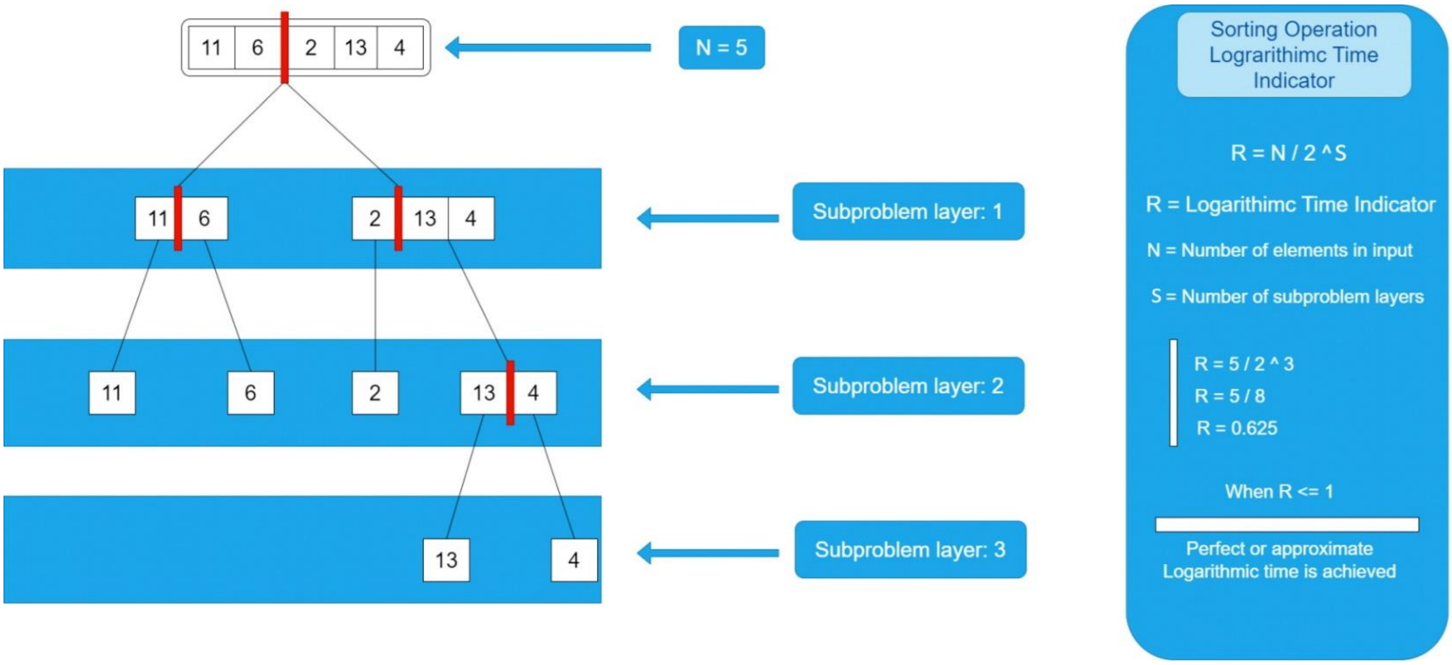
Merge Sort

Merge sort is a sorting algorithm that has a low time complexity needed to complete its operation, and to be more specific, the average and worst time complexities are both ***0(N * log(N))*** ***(GeeksforGeeks (2018). Merge Sort)***.





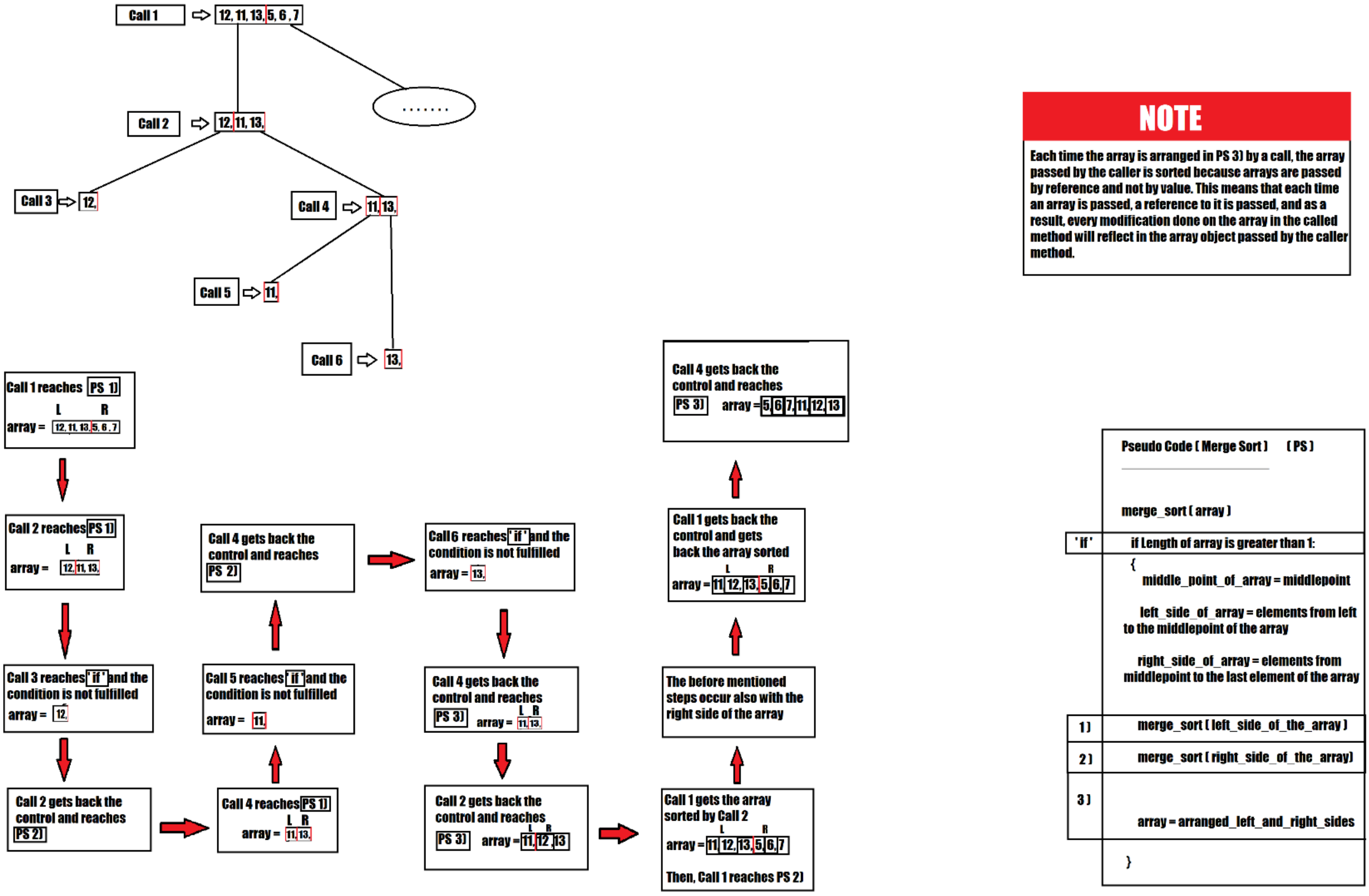
From the ***0(N * log(N))*** time complexity notation, the ***log(N)*** is representing the time complexity of the sorting procedure, which is resulted by dividing ***N*** by 2, where ***N*** is the linear time took to sort all the elements in the input, creating a total number of subproblems equal with ***S = G * E / G***, where ***S*** is the total number of subproblems, ***E*** is the total number of elements in the input, and ***G*** is the geometric sequence value with an initial value of 1 and that is incremented with the current ***G*** value times 2 for each subproblem layer.



The reason behind the halving of ***N*** until it reaches one can be extracted from ***R = N / 2^S***, where ***R*** is the logarithmic time indicator and where ***S*** is the number of subproblem layers which equals with the number of times ***N*** was divided by 2 and, as a result, when ***S*** in ***R = N / 2^S*** reaches a value that makes ***R*** be in range ***R <= 1***, ***S*** is equal or approximates ***log2(N)*** because if ***S*** is a product of raising 2 to any power ***R = 1***, otherwise it will be in range ***R < 1***, thus giving us the complete operational range ***R <= 1*** , which indicates that if ***R*** is within that range, the sorting operation achieved an approximate or perfect logarithmic time and as a result the division of ***N*** by 2 stops, thus indicating that the time complexity of ***O(log(N))*** for the sorting operation, regarding its recursion and input division mechanism, is achieved. The overall merge operation time complexity is the result of taking the time took to merge the elements in the input one by one, noted as ***N***, divided by the final number of subproblems, noted as ***S***, and multiplying the result by the number of times the merge operation occurs in all the subproblems noted as ***T***, giving us the expression ***(N / S) * T***, which is always equal to ***N***, resulting in the overall merge operation time complexity to be ***O(N)*** ***(Khan Academy. (n.d.). Analysis of merge sort)***. The merge sort's overall time complexity is the result of multiplying the time complexity of the merge operation by the time took by the sorting operation to create the final number of subproblems, because the merge operation is having an ***O(N)*** time complexity and is present in all subproblems and all subproblems are generated in an ***O(log(N))*** time and thus, resulting in the merge sort's time complexity to be ***O (N * log(N))***.

Merge sort way of operation

Merge sort, as the name implies, is sorting the input given by performing two operations, merging and sorting. The before mentioned operations are performed by using conditional recursion. The merge sort operation begins by splitting the array given as input into two arrays, the left half and right half. Then the merge sort algorithm is passing the left half of its current instance to a new instance of the merge sort method and so on, until the input reaches the length of one. Then, the method instances that terminated their execution pass the control to the caller methods, that will then pass the right half of the input of its current instance to a new instance, the new instances split their input in half, pass their left halves to new method instances until the input reaches the length of one, then those instances pass the control back, and so on, until the array is sorted. When any instance of the merge sort method sorted its left and right halves, then the left and right halves are arranged in increasing or decreasing order in the merge section, and then the method's instance passes the control to the caller instance. This is possible because lists and arrays are passed by reference, not by value. Passing by reference means passing a shallow copy to a method's instance, and by doing that, any change that is happening in the called method instance to the input passed to it, will reflect in the input passed by the caller in the caller method's instance. Below is a diagram explaining the merge sort mechanism step by step, reflecting the changes, and showing where the operation is taking place in the pseudo-code.



Merge Sort Advantages

Merge sort is one of the fastest sorting algorithms because merge sort has a best, average, and worst time complexity of ***O (N log(N))***. Merge sort is suitable for all data set sizes that need to be sorted fast because it has a low time complexity.

Merge Sort Disadvantages

Merge sort has a high spatial complexity, ***O(N)*** to be exact. This high spatial complexity makes the algorithm to consume a lot of ***RAM*** memory at runtime. This large ram consumption is caused by the fact that the algorithm is copying the input given at each iteration of the method into two temporary arrays, the left and right half. The left and right half have the number of elements equal with the number of elements passed as input, and thus for each element, with the memory used by it noted as ***m***, results that memory consumption per number of elements, noted as ***n***, results in ***N = m * n***. This fact makes merge sort unsuitable to be used with memory consuming data structures such as arrays, and suitable for use with low memory consumption data structures such as linked lists. Link list has an initial higher memory consumption greater than arrays because each node contains one or two pointers in comparison to arrays, which have assigned a memory address for each element within it. On the other hand, linked lists have a runtime memory consumption smaller than arrays because when an element within a linked list is changed, one or two pointers must be changed, in comparison with an array which when an element is changed, all the elements preceding it must be changed, making the insertion and/or deletion and/or substitution time complexity of an array of ***O(N – I - 1)***, where ***N*** is the number of elements, and ***I*** is the index of the current element where the operation is taking place. Because linked lists have a lower runtime memory consumption than arrays, this makes them suitable to be used with merge sort (***Stack Overflow. (n.d.). data structures - Why is insertion and deletion faster in a linked list compared to an array?***).

Merge sort implementation within the program

```
public static void Merge_Sort(Linked_List list)
{
    if(list.count > 1)
    {
        Linked_List<Integer> left_half = new Linked_List<>();
        Linked_List<Integer> right_half = new Linked_List<>();

        int sub_list_index = 0;
        int main_list_index = 0;

        while (sub_list_index < list.count / 2)
        {
            left_half.Add((Integer)list.Get_Element(main_list_index));
            sub_list_index++;
            main_list_index++;
        }

        sub_list_index = 0;


        while (sub_list_index < list.count - (list.count / 2))
        {
            right_half.Add((Integer)list.Get_Element(main_list_index));
            sub_list_index++;
            main_list_index++;
        }


        Merge_Sort(left_half);
        Merge_Sort(right_half);


        int left_list_index = 0;
        int right_list_index = 0;
        main_list_index = 0;
```

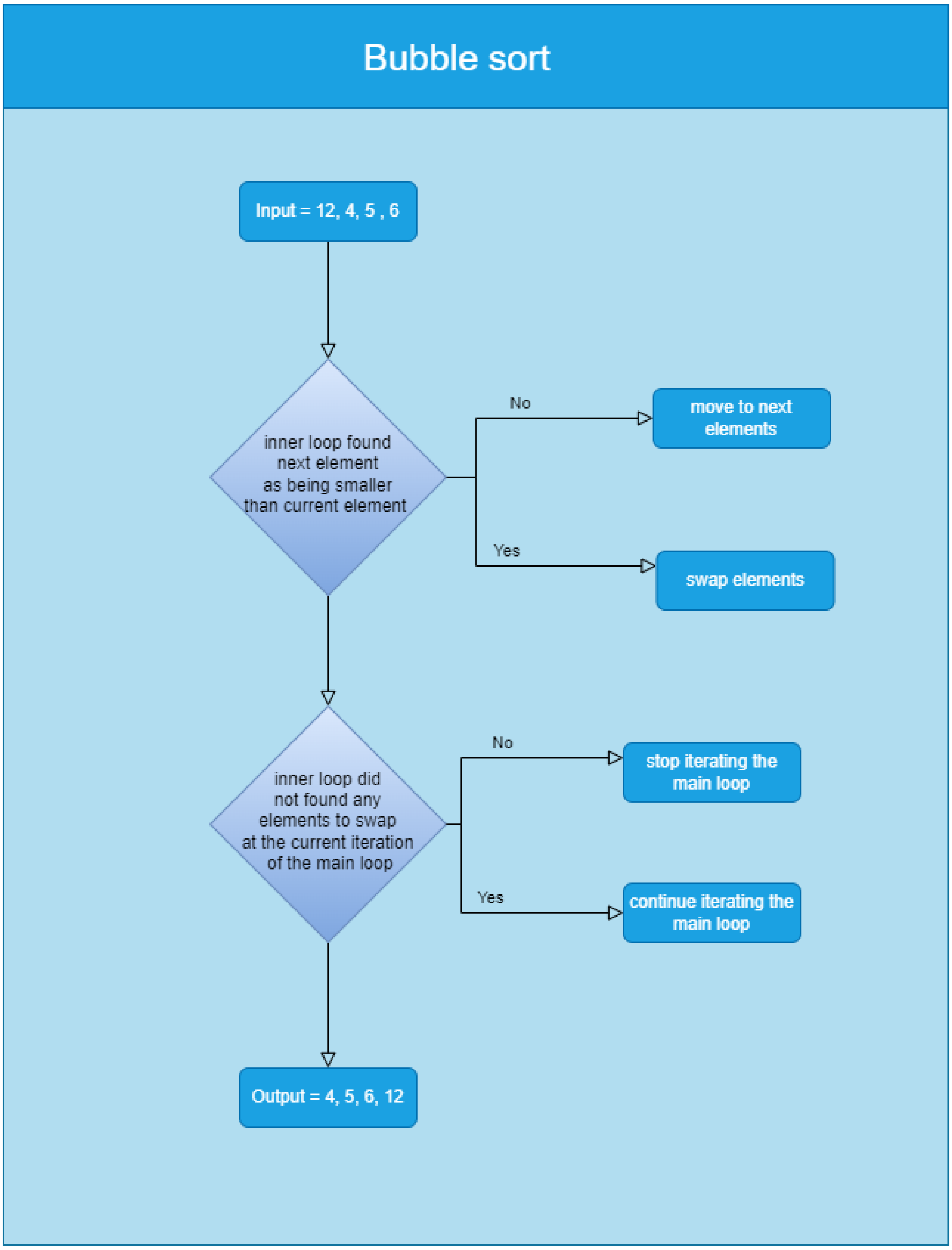
```
        while (left_list_index < left_half.count && right_list_index < right_half.count)
        {
            if(left_half.Get_Element(left_list_index) <= right_half.Get_Element(right_list_index))
            {
                list.Add(left_half.Get_Element(left_list_index), main_list_index);
                left_list_index++;
            }
            else
            {
                list.Add(right_half.Get_Element(right_list_index), main_list_index);
                right_list_index++;
            }

            main_list_index++;
        }

        while (left_list_index < left_half.count)
        {
            list.Add(left_half.Get_Element(left_list_index), main_list_index);
            left_list_index++;
            main_list_index++;
        }

        while (right_list_index < right_half.count)
        {
            list.Add(right_half.Get_Element(right_list_index), main_list_index);
            right_list_index++;
            main_list_index++;
        }

    }

}
```

Bubble Sort

Bubble sort is a sorting algorithm that has a high time complexity and a low spatial complexity. Bubble sort is suitable for small data sets because the negative impact brought up by the high time complexity does not have a significant impact on operations involving small data sets. Bubble sort's worst and average time complexities are ***O(N^2)*** and the best time complexity of ***O(N)***. The spatial complexity of the bubble sort is ***O (1)***, because bubble sort uses an integer as a buffer to store the key value, which is the where the value of the current index used to perform the swap is stored as a placeholder ***(GeeksforGeeks. (2014). Bubble Sort Algorithm)***.

Bubble Sort way of operation

Bubble sort modulus of operation is fulfilled by iterating a loop within a loop, ***N*** times, and swapping elements adjacent in memory that are greater than the current index. Swapping elements adjacent in memory means that the swap occurs between elements that are next to each other from an index perspective. The inner loop verifies if the element with a greater index has a value that is bigger than the current value at the current index and then saves the value of the element at the current index in the buffer, assigns the value of the next index as the value of the current index, and then it assigns the value of the of the element saved in the buffer to the element at the next index. Afterward, the inner loop compares the elements adjacent in memory and performs swaps until it finishes its iteration, if necessary, the main loop increments the index of the current element by one and the inner loop decreases the number of iterations by the number of recursions the main loop performed. If no swaps were performed by the inner loop, this means that no elements need to be sorted and the algorithm stops. Because a variable that stores the value of the element at the current index is used to perform the swap at each iteration the algorithm decides is necessary, the ***RAM*** memory consumed by the algorithm is ***O (1)***, which denotes that the memory consumed by one element within the input given, is required to perform the swap. Because the algorithm must perform iterations ***N*** times for ***N*** times, the algorithm's time complexity is ***T = O(N^2)***, where ***O(N^2) = N*N***. The before mentioned result is extracted from the fact that the algorithm is comprised from two nested for loops, that are set to loop ***N*** times. As a result of the fact that they are nested, the inner loop must loop ***N*** times for each iteration of the main loop, until the main loop iterates ***N*** times, as a result the number of iterations is ***N*N***, which can be further broken down as ***N^2***, and this concludes that the time complexity of bubble sort is ***T = O(N^2)***.


Bubble sort
Input = 12, 4, 5 , 6
inner loop found next element as being smaller than current element
No
move to next elements
Yes
swap elements
inner loop did not found any elements to swap at the current iteration of the main loop
No
stop iterating the main loop
Yes
continue iterating the main loop
Output = 4, 5, 6, 12

```
Bubble_Sort(input)

main_loop(main_number = 0; add 1 to main_number if main_number < number of elements in input)
{

        swap_detected  = false

        inner_loop(inner_number = 0; add 1 to inner_number if inner_number < number of elements in input - the value of main_number)
        {
                if element in input at index of inner_number > element in input at index of inner_number + 1
                {

                        swap_detected  = true

                        container_to_store_value_of_current_element = input at index of inner_number

                        replace the element at index inner_number WITH element at index inner_number + 1

                        replace the element at index inner_number + 1 WITH container_to_store_value_of_current_element
                }
        }

        if swap_detected  = false
        {
                stop_bubble_sort
        }

}
```

Bubble Sort Advantages

Bubble sort is a low memory consumption algorithm because, as is mentioned before, a variable is used to store the value of the element that needs to be swapped within the input. The spatial complexity is given by the fact that, for each iteration, the amount of memory consumed is ***O (1)*** because, as I mentioned before, a buffer that stores one element is used to perform the swap. This concludes that, bubble sort is suitable for use with small data sets and/or where memory consumption presents an issue.

Bubble Sort Disadvantages

Bubble sort is an extremely slow algorithm because it has a high time complexity. But even compared with algorithms with ***O(N^2)*** time complexity, it is slower than most of them. This is because bubble sort performs a few swaps equal with the number of comparisons made, resulting in many swaps, thus making the algorithm slow.

Bubble sort implementation within the program

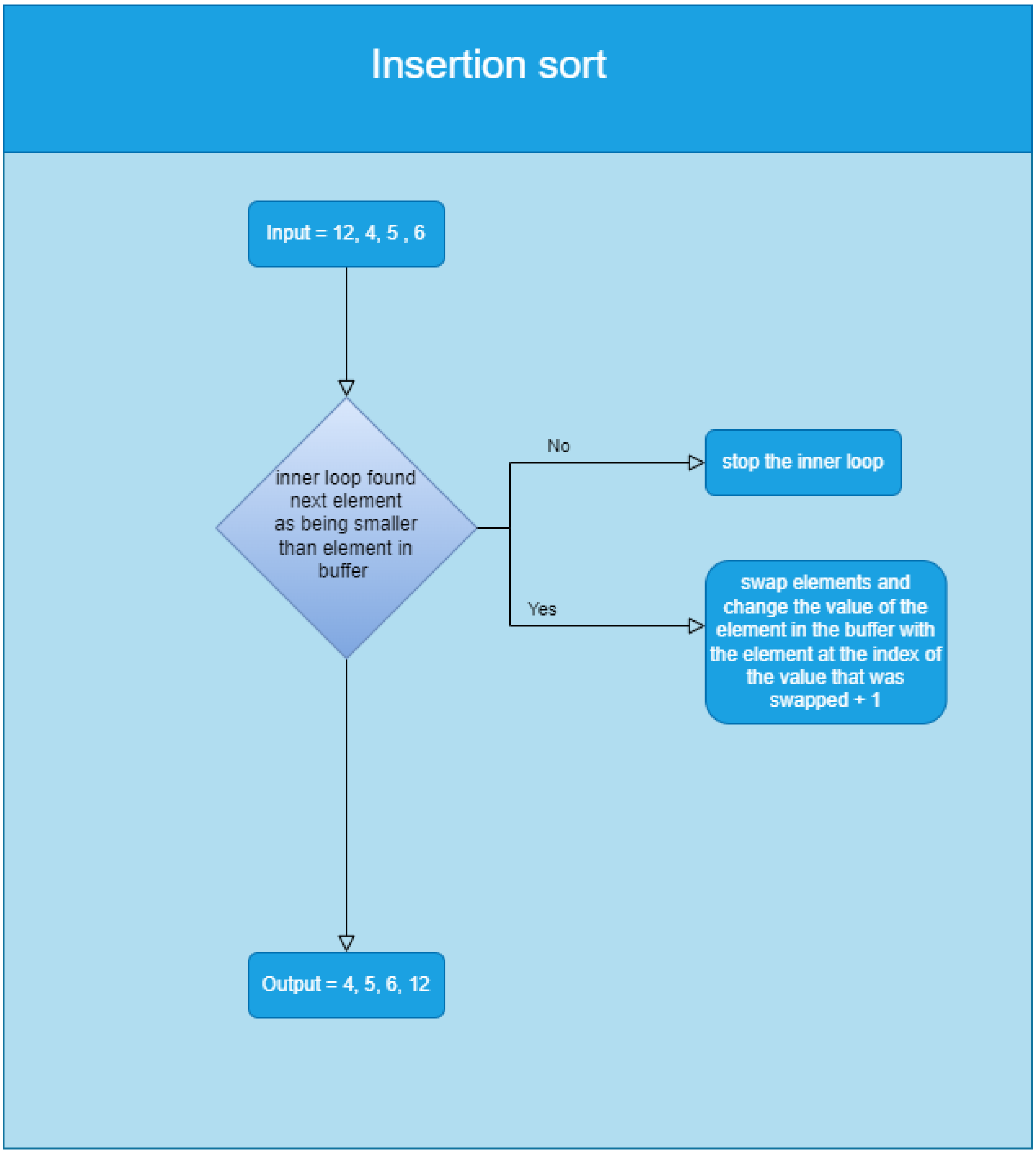
```
public static void Bubble_Sort(Linked_List list)
{
    int list_length = list.count;

    for (int index = 0; index < list_length; index++)
    {
        boolean swap_occurred = false;

        for (int inner_index = 0; inner_index < list_length - index - 1; inner_index++)
        {

            if((int)list.Get_Element(inner_index) > (int)list.Get_Element(inner_index + 1))
            {
                swap_occurred = true;
                int buffer = (int)list.Get_Element(inner_index + 1);

                list.Add(list.Get_Element(inner_index), inner_index + 1);
                list.Add(buffer, inner_index);
            }

        }

        if(swap_occurred = false)
        {
            break;
        }
    }
}
```

Insertion Sort

Insertion sort is a sorting algorithm that has a high time complexity and a low spatial complexity. Insertion sort is suitable for small data sets because the negative impact brought up by the high time complexity does not have a significant impact on operations involving small data sets. Insertion sort's worst and average time complexities are ***$O(N^2)$*** and the best time complexity of ***$O(N)$***. The spatial complexity of the insertion sort is ***$O(1)$***, because insertion sort uses an integer as a buffer to store the key value, which is where the value of the current index used to perform the swap is stored as a placeholder.

Insertion sort way of operation

Insertion sort is operating by using a main loop in which an inner loop is sorting the elements given as input. Within the main loop, insertion sort uses a variable to store the element at the current index, and a variable is used to store the value of the previous index. The inner loop iterates if the value of the previous index is greater or equal to zero and if the value of the element stored in the variable is smaller or equal than the value of the element at the previous index. If the condition is fulfilled, all the elements preceding the element at the current index are verified and swapped if their values are greater or equal than the value of the element stored in the variable, otherwise the loop will stop. After the inner loop finishes its execution, the value of the element stored in the variable will be used to replace the value of the element at the index where the swap index pointer stopped plus 1. Because a variable is used to store the value of the element at the current index within the main loop at each iteration, the spatial complexity of insertion sort is ***O (1)***. The time complexity of insertion sort is ***O(N^2)*** because the inner loop loops ***N*** times for each iteration of the main loop that is iterating ***N*** times, thus giving the time complexity ***T = N * N*** which is equal with ***T = N^2*** and as a result the time complexity is ***O(N^2)*** ***(GeeksforGeeks. (2013). Insertion Sort).***



```
Insertion_Sort(input)
{
	main_loop(main_loop_number = 0; increment main_loop_number by one if main_loop_number < number of elements within the input)
	{
		current_element_buffer = element in input WHERE index = main_loop_number
		previous_index = main_loop_number - 1

		inner_loop(if previous_index >= 0 AND element within input WHERE index = previous_index >= current_element_buffer)
		{
			replace element in input WHERE index = main_loop_number WITH element in input WHERE index = previous_index
			decrease value of previous_index by 1
		}

		replace element AT previous_index + 1 WITH current_element_buffer in input
	}
}
```

Insertion sort advantages

Insertion sort has the advantage of having a low spatial complexity of ***O (1)***. Insertion sort is better than bubble sort because it has the same spatial complexity and because it performs the swaps only if the elements that are targeted are greater than the element stored in the buffer and if this condition is not fulfilled, the iteration finishes.

Insertion sort disadvantages

Insertion sort has the disadvantage of having a high time complexity of ***O(N^2)*** and due to this fact, it must be implemented when small data sets are used so, that the high time complexity to not have a significant impact.

Insertion sort implementation within the program

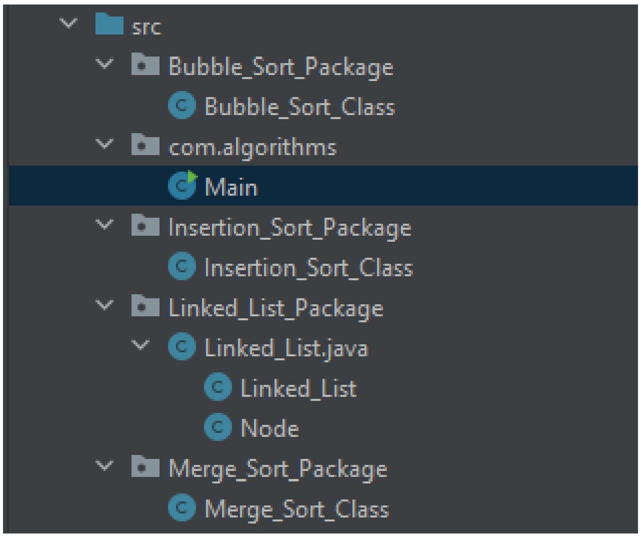
```
public static void Insertion_Sort(Linked_List list)
{
    for (int i = 1; i < list.count; i++)
    {
        int current_index_element = (int)list.Get_Element(i);
        int previous_index = i - 1;

        while(previous_index >= 0 && (int)list.Get_Element(previous_index) >= current_index_element)
        {
            list.Add(list.Get_Element(previous_index), i);
            previous_index--;
        }

        list.Add(current_index_element, index: previous_index + 1);
    }
}
```

Implementation of the algorithms within the program

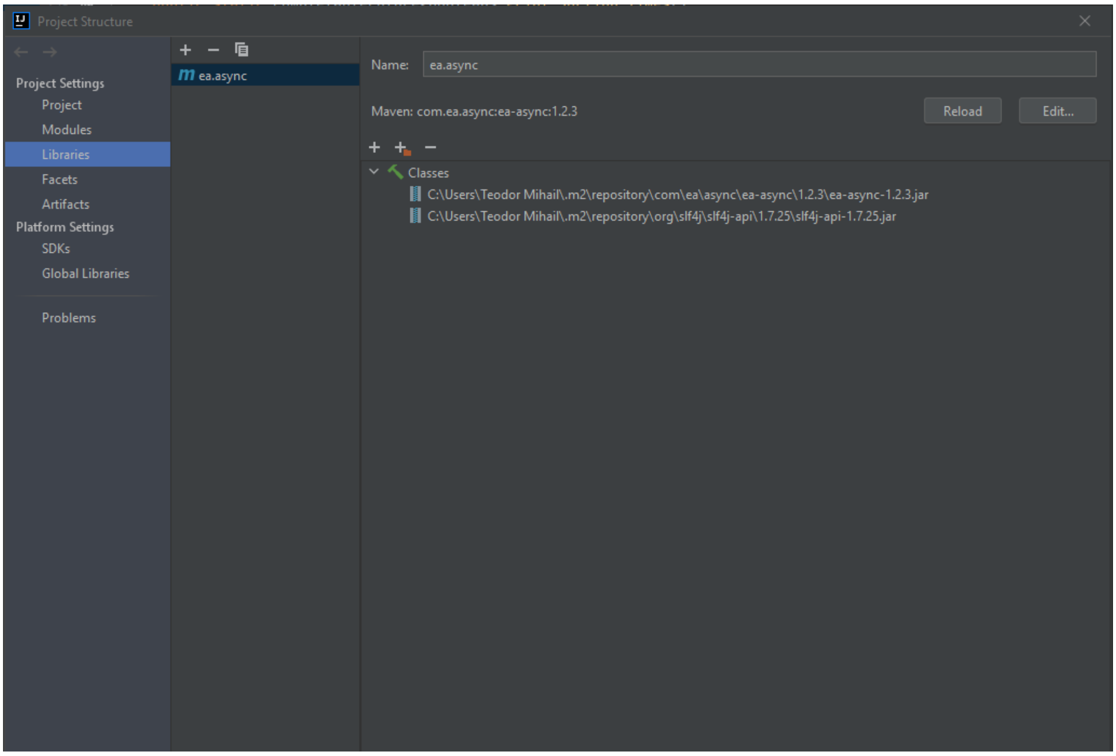
The Java program in which the algorithms were implemented, uses asynchronous programming, recursion, and multiple packages. All the before mentioned features and the implementation of the algorithms within the program are enumerated and explained below.

Program structure

The program is implementing the algorithms and the asynchronous program functionalities by having multiple packages and an imported package that is allowing the application to implement asynchronous method calls.



The Bubble_Sort_Package is the package responsible for storing and facilitating the implementation of the Bubble_Sort_Class, which is the class that has the function of sorting numbers using the bubble sort algorithm. The Insertion_Sort_Package is the package responsible for storing and facilitating the implementation of the Insertion_Sort_Class, which is the class that has the function of sorting numbers using the insertion sort algorithm. The Merge_Sort_Package is the package responsible for storing and facilitating the implementation of the Merge_Sort_Class, which is the class that has the function of sorting numbers using the merge sort algorithm. The Linked_List_Package is the package responsible for storing and facilitating the implementation of the Linked_List_Class and Node class, which together are facilitating the implementation of the linked list data structure. All these before mentioned packages are created manually without importing any additional library.



The last package within the file is the com.algorithms package, which is storing the Main class which is facilitating the main entry point for the program. For asynchronous method calls to be implemented, the ea.async library from the **Maven** repository was installed, which is facilitating asynchronous method calls.

Program's way of operation

Program's operational specifications and implementation

The program requirements specify that the program must sort lists of 10, 100, 1000, and 10000 integers respectively using bubble sort, insertion sort, and one algorithm of choice, which in this case, is merge sort. The program starts from the **main** method within the **Main** class.

```java
public static void main(String[] args) {

    int elements_configuration = 10;
    int recursion_counter = 0;
    int set_limit = 1000;

    String merge_sort_operation = "Merge Sort";
    String insertion_sort_operation = "Insertion Sort";
    String bubble_sort_operation = "Bubble Sort";

    await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit, merge_sort_operation)));
    await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit, insertion_sort_operation)));
    await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit,bubble_sort_operation)));

    CompletableFuture.completedFuture(Print_Sorting_Times());
}
```

The **main** method is initiated by creating some variables and assigning some values to them. Then these variables are passed to the `Sort_Async_Task` method, which is responsible for the entire sorting operation. The `elements_configuration` variable contains the value related to initial number of elements that the input should contain, `recursion_counter` variable contains the initial value of the counter responsible for counting recursions, the `set_limit` variable contains the maximum number of elements that the sorting method should generate and store within the input to be sorted, and the `merge_sort_operation`, `insertion_sort_operation`, and `bubble_sort_operation` are the variables that indicate what type of sorting algorithm the `Sort_Async_Task` method should implement during the method call's execution. After these variables are initiated, the `Sort_Async_Task` method is called multiple times to implement all the sorting algorithms required.

```java
public class Main {



    private static Linked_List<String> merge_sort_print_elements = new Linked_List<>();
    private static Linked_List<String> insert_sort_print_elements = new Linked_List<>();
    private static Linked_List<String> bubble_sort_print_elements = new Linked_List<>();




    static long slowest_time;
    static long average_time;
    static long fastest_time = Long.MAX_VALUE;
```

Within the **Main** class's body, 3 objects made from the Linked_List_Class class within the Linked_List_Package, are declared and initiated because their purpose is to store the fastest time, slowest time, and average time took by each algorithm to sort the number of elements given at that instance, and these variables are *merge_sort_print_elements*, *insert_sort_print_elements*, and *bubble_sort_print_elements*. The *slowest_time*, *average_time*, and *fastest_time* are used to calculate the time took by the algorithms to sort the number of elements given at that instance. Within the **Main** class, a **CompletableFeature** task method named Sort_Async_Task is implemented, and it has the use of sorting numbers using any given algorithm. A **CompletableFeature** in **Java** represents a task that can be run in parallel within the program's default thread pool, within a custom set thread pool, or within a raw thread ***(CalliCoder. (n.d.). Java CompletableFuture Tutorial with Examples)***. If a **CompletableFeature** is ran without invoking it asynchronously, the **CompletableFeature** will be ran on the program's default thread pool. If a **CompletableFeature** is ran by invoking it asynchronously, the **CompletableFeature** will be ran on a new thread pool. A thread is representing a virtual space within the CPU's physical environment that has the purpose of executing methods, functions, and other related tasks that programs will require to be processed by the CPU at any time. Threads have a limited amount of memory with they can use to process at any given time and as a result, the tasks that the program should execute must be marshalled on different threads in accordance with the resource consumption that the tasks have. A thread pool within java, represents a collection of threads that the program, by default, can run tasks on and these threads are standardised threads with no option in which the priority of the threads or other features can be set. The use of **CompletableFeature** in combination with **await** in the program is to prevent the congestion of the main thread, to await the execution of the tasks created on new thread pools, to prevent the overlap between the execution of the tasks and the possible interference of the tasks' operations between themselves when accessing static variables which can result in inaccurate results, and also to prevent stack overflow and heap overflow exceptions that can result from the execution of too many tasks at once which can create objects on the heap for the garbage collector to handle and generate too many variables and method calls on the stack.

```java
private static CompletableFuture<Boolean> Sort_Async_Task(int elements_configuration, int recursion_counter, int set_limit, String operation)
{

    if(elements_configuration <= set_limit)
    {
        Linked_List<Integer> list = new Linked_List<~>();

        await(Add_Random_Numbers(list, elements_configuration));


        long start_time = System.currentTimeMillis();

        switch (operation)
        {
            case "Merge Sort":
                Merge_Sort_Class.Merge_Sort(list);
                break;
            case "Insertion Sort":
                Insertion_Sort_Class.Insertion_Sort(list);
                break;
            case "Bubble Sort":
                Bubble_Sort_Class.Bubble_Sort(list);
                break;
        }
        long end_time = System.currentTimeMillis();


        long resulted_time = end_time - start_time;


        switch (operation)
        {
            case "Merge Sort":
                System.out.println("( Merge Sort (" + elements_configuration + " elements) ) Time elapsed:"  + resulted_time);
                break;
            case "Insertion Sort":
                System.out.println("( Insertion Sort (" + elements_configuration + " elements) ) Time elapsed:"  + resulted_time);
                break;
            case "Bubble Sort":
                System.out.println("( Bubble Sort (" + elements_configuration + " elements) ) Time elapsed:"  + resulted_time);
                break;
        }
```

```
        if(resulted_time > slowest_time)
        {
            slowest_time = resulted_time;
        }
        else if(resulted_time < fastest_time)
        {
            fastest_time = resulted_time;
        }

        average_time += resulted_time;


        if(recursion_counter < 100)
        {
            if(recursion_counter == 99)
            {

                switch (operation)
                {
                    case "Merge Sort":
                        merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Slowest Time:" + slowest_time);
                        merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Average Time:" + (average_time / 100));
                        merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Fastest Time:" + fastest_time);
                        break;
                    case "Insertion Sort":
                        insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Slowest Time:" + slowest_time);
                        insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Average Time:" + (average_time / 100));
                        insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Fastest Time:" + fastest_time);
                        break;
                    case "Bubble Sort":
                        bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Slowest Time:"  + slowest_time);
                        bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Average Time:"  + (average_time / 100));
                        bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Fastest Time:"  + fastest_time);
                        break;
                }

                slowest_time = 0;
                average_time = 0;
                fastest_time = Long.MAX_VALUE;
            }

            await(Sort_Async_Task(elements_configuration, recursion_counter: recursion_counter + 1, set_limit, operation));
        }
        else
        {
            slowest_time = 0;
            average_time = 0;
            fastest_time = Long.MAX_VALUE;

            await(Sort_Async_Task( elements_configuration: elements_configuration * 10, recursion_counter: 0, set_limit, operation));
        }
    }
```

The **main** method is calling the *Sort_Async_Task* completable future method 3 times to sort a number of elements using 3 sorting algorithms, and these are merge sort, insertion sort, and bubble sort.

```
await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit, merge_sort_operation)));
await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit, insertion_sort_operation)));
await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit,bubble_sort_operation)));
```

The main method is calling the method asynchronously and awaits the main thread, to initiate the sorting operation on a new thread pool by using the *runAsync* method of the **CompletableFeature** class. This is done to ensure that the main thread is not solicited, and that the thread operations within the thread pool of each instance the method *Sort_Async_Task* is called to perform a different sorting algorithm do not overlap and interact with the variables that this method is using, and that the heap overflow and stack overflow exceptions do not occur because the method *Sort_Async_Task* is performing conditional tail recursion. Within each awaited method call `await(CompletableFuture.runAsync(()->Sort_Async_Task(elements_configuration, recursion_counter,set_limit, merge_sort_operation)));` , within the *runAsync* method of the **CompletableFeature** class, the method *Sort_Async_Task* is called using a lambda expression. This is because the *runAsync* method is requiring each time is called to be passed a **Runnable** object, which is an interface. To avoid the creation of overridden **Runnable** interface instances, an anonymous lambda expression is used to pass the *Sort_Async_Task* method as a parameter to the *runAsync* method. The `()->` means that an undeclared method of the required type, which in this case is **Runnable** and noted as `()`, is the input and where the input is equal with a given value, noted as `->` and followed by the content which is `Sort_Async_Task(elements_configuration, recursion_counter,set_limit, merge_sort_operation)));` . Within the *Sort_Async_Task* method, a set of random numbers with a size determined by the `elements_configuration` variable, is generated by calling the method `Add_Random_Numbers` by awaiting the current thread within the current thread pool of the *Sort_Async_Task* method.

```java
private static CompletableFuture<Boolean> Sort_Async_Task(int elements_configuration, int recursion_counter, int set_limit, String operation)
{

    if(elements_configuration <= set_limit)
    {
        Linked_List<Integer> list = new Linked_List<~>();

        await(Add_Random_Numbers(list, elements_configuration));
```

```java
private static CompletableFuture<Boolean> Add_Random_Numbers(Linked_List list, int elements_configuration)
{
    Random rand = new Random();


    for (int i = 0; i < elements_configuration; i ++)
    {
        list.Add(rand.nextInt( bound: 1000000));
    }

    return CompletableFuture.completedFuture(true);
}
```

Within the `Add_Random_Numbers` method, a `Random` object is created and a for loop is used to add a number of random elements, that is determined by the `elements_configuration` variable, using the created `Random` object in the `Linked_List` object passed as a parameter to this method. After the random numbers were added to the list created in the `Sort_Async_Task` method, the number of milliseconds passed from the beginning of the day are stored in a variable called `start_time`, using the `currentTimeMillis` method of the `System` class.

```java
private static CompletableFuture<Boolean> Sort_Async_Task(int elements_configuration, int recursion_counter, int set_limit, String operation)
{

    if(elements_configuration <= set_limit)
    {
        Linked_List<Integer> list = new Linked_List<~>();

        await(Add_Random_Numbers(list, elements_configuration));


        long start_time = System.currentTimeMillis();
```

Afterwards, the method is sorting the elements using the value associated with its specific algorithm stored within the variable `operation` that is passed as a parameter to the method to detect what sorting algorithm to use.

```java
private static CompletableFuture<Boolean> Sort_Async_Task(int elements_configuration, int recursion_counter, int set_limit, String operation)
{

    if(elements_configuration <= set_limit)
    {
        Linked_List<Integer> list = new Linked_List<~>();

        await(Add_Random_Numbers(list, elements_configuration));


        long start_time = System.currentTimeMillis();

        switch (operation)
        {
            case "Merge Sort":
                Merge_Sort_Class.Merge_Sort(list);
                break;
            case "Insertion Sort":
                Insertion_Sort_Class.Insertion_Sort(list);
                break;
            case "Bubble Sort":
                Bubble_Sort_Class.Bubble_Sort(list);
                break;
        }
```

After the numbers were sorted, the number milliseconds passed from the beginning of the day are stored in a variable called `end_time`, using the `currentTimeMillis` method of the `System` class.

```java
private static CompletableFuture<Boolean> Sort_Async_Task(int elements_configuration, int recursion_counter, int set_limit, String operation)
{

    if(elements_configuration <= set_limit)
    {
        Linked_List<Integer> list = new Linked_List<~>();

        await(Add_Random_Numbers(list, elements_configuration));


        long start_time = System.currentTimeMillis();

        switch (operation)
        {
            case "Merge Sort":
                Merge_Sort_Class.Merge_Sort(list);
                break;
            case "Insertion Sort":
                Insertion_Sort_Class.Insertion_Sort(list);
                break;
            case "Bubble Sort":
                Bubble_Sort_Class.Bubble_Sort(list);
                break;
        }
        long end_time = System.currentTimeMillis();
```

Then, in a variable called `resulted_time`, the value of the `start_time` variable is subtracted from the `end_time` variable and stored to obtain the time spent by the algorithm to sort the list of generated random numbers.

```java
private static CompletableFuture<Boolean> Sort_Async_Task(int elements_configuration, int recursion_counter, int set_limit, String operation)
{

    if(elements_configuration <= set_limit)
    {
        Linked_List<Integer> list = new Linked_List<~>();

        await(Add_Random_Numbers(list, elements_configuration));


        long start_time = System.currentTimeMillis();

        switch (operation)
        {
            case "Merge Sort":
                Merge_Sort_Class.Merge_Sort(list);
                break;
            case "Insertion Sort":
                Insertion_Sort_Class.Insertion_Sort(list);
                break;
            case "Bubble Sort":
                Bubble_Sort_Class.Bubble_Sort(list);
                break;
        }
        long end_time = System.currentTimeMillis();


        long resulted_time = end_time - start_time;
```

Then a conditional block is checking whether the value of the variable `resulted_time` is greater than the value of the variable *`slowest_time`* and if the condition is true this means the time spent by the algorithm to sort numbers is the slowest occurrence for the given number of elements and algorithm type, otherwise the conditional block checks the second condition to see if `resulted_time` is less than the value of the variable *`fastest_time`* and if the condition is true this means that the time spent by the algorithm to sort numbers is the fastest occurrence for the given number of elements and algorithm type.

```
if(resulted_time > slowest_time)
{
    slowest_time = resulted_time;
}
else if(resulted_time < fastest_time)
{
    fastest_time = resulted_time;
}

average_time += resulted_time;
```

After this, the variable called `resulted_time` is used to increment the value of the variable `average_time`.

```
average_time += resulted_time;
```

Then a condition is checking the `recursion_counter` variable to see if the method performed a number of recursions less than 100 since the variable had the value of 0, else in the else statement an awaited recursion call is performed, passing all the parameters with the same value excepting the `elements_configuration` variable which its value is multiplied by 10.

```
if(recursion_counter < 100)
{
    if(recursion_counter == 99)
    {

        switch (operation)
        {
            case "Merge Sort":
                merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Slowest Time:" + slowest_time);
                merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Average Time:" + (average_time / 100));
                merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Fastest Time:" + fastest_time);
                break;
            case "Insertion Sort":
                insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Slowest Time:" + slowest_time);
                insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Average Time:" + (average_time / 100));
                insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Fastest Time:" + fastest_time);
                break;
            case "Bubble Sort":
                bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Slowest Time:"  + slowest_time);
                bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Average Time:"  + (average_time / 100));
                bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Fastest Time:"  + fastest_time);
                break;
        }

        slowest_time = 0;
        average_time = 0;
        fastest_time = Long.MAX_VALUE;
    }

    await(Sort_Async_Task(elements_configuration, recursion_counter: recursion_counter + 1, set_limit, operation));
}
else
{
    slowest_time = 0;
    average_time = 0;
    fastest_time = Long.MAX_VALUE;

    await(Sort_Async_Task( elements_configuration: elements_configuration * 10, recursion_counter: 0, set_limit, operation));
}
```

Within the if statement, a nested conditional block is checking if the current value of the `recursion_counter` variable is 99.

```
if(recursion_counter == 99)
{

    switch (operation)
    {
        case "Merge Sort":
            merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Slowest Time:" + slowest_time);
            merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Average Time:" + (average_time / 100));
            merge_sort_print_elements.Add( data: "( Merge Sort (" + elements_configuration + " elements) ) Fastest Time:" + fastest_time);
            break;
        case "Insertion Sort":
            insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Slowest Time:" + slowest_time);
            insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Average Time:" + (average_time / 100));
            insert_sort_print_elements.Add( data: "( Insertion Sort (" + elements_configuration + " elements) ) Fastest Time:" + fastest_time);
            break;
        case "Bubble Sort":
            bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Slowest Time:"  + slowest_time);
            bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Average Time:"  + (average_time / 100));
            bubble_sort_print_elements.Add( data: "( Bubble Sort (" + elements_configuration + " elements) ) Fastest Time:"  + fastest_time);
            break;
    }

    slowest_time = 0;
    average_time = 0;
    fastest_time = Long.MAX_VALUE;
}

await(Sort_Async_Task(elements_configuration, recursion_counter: recursion_counter + 1, set_limit, operation));
```

If the condition is true the slowest and fastest times are stored in the linked list object that is responsible for storing performance metrics for the algorithm the method is currently implementing, the average time is calculated by dividing the value of the *`average_time`* variable by 100 and stored within the same linked list object, and then the variables *`slowest_time`*, *`average_time`*, and *`fastest_time`* are reset to their initial values. Then, an awaited recursion call in performed by passing all the parameters with the same value, excepting the `recursion_counter` parameter which is incremented by one.

```
await(Sort_Async_Task(elements_configuration, recursion_counter: recursion_counter + 1, set_limit, operation));
```

The recursions will stop performing if the `elements_configuration` variable is greater than the `set_limit` variable because of a condition at the beginning of the *`Sort_Async_Task`* method and thus all the callee instances of the *`Sort_Async_Task`* method are finishing the execution and passing the control to the caller instances of the *`Sort_Async_Task`* method, until the control is passed to the initial caller, which is the **main** method. After this, the `Print_Sorting_Times` method is called synchronously to print the times took by the sorting algorithms to sort the generated sets of numbers.

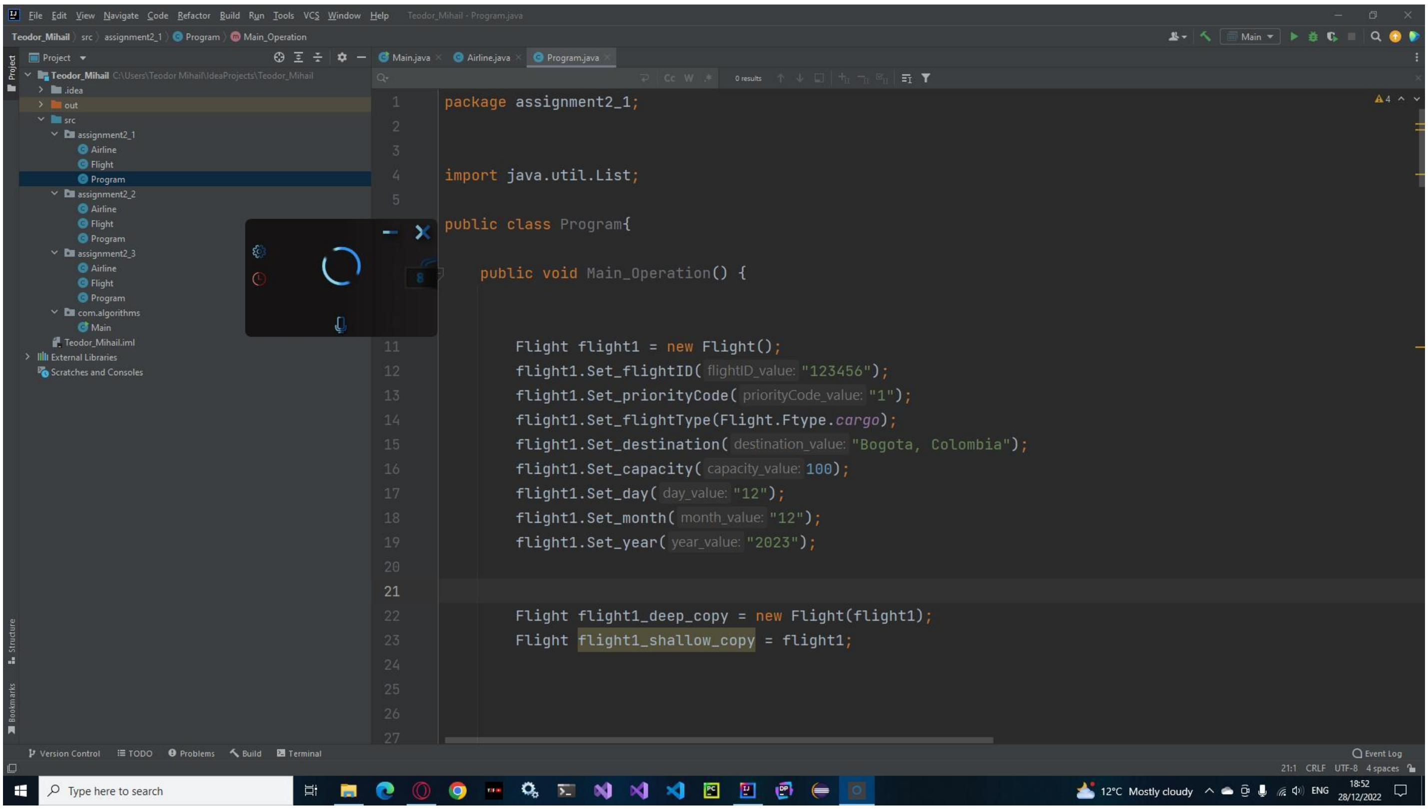
```java
public static CompletableFuture<Boolean> Print_Sorting_Times()
{
    int sorting_type = 0;

    while (sorting_type < 3)
    {
        Linked_List<String> sorting_times = null;

        System.out.print("\n\n\n\n");

        switch (sorting_type)
        {
            case 0:
                sorting_times = merge_sort_print_elements;
                break;
            case 1:
                sorting_times = insert_sort_print_elements;
                break;
            case 2:
                sorting_times = bubble_sort_print_elements;
                break;
        }

        for (int index = 0; index < sorting_times.count; index++)
        {
            if (index % 3 == 0)
            {
                System.out.print("\n");
            }

            System.out.println(sorting_times.Get_Element(index));
        }

        sorting_type++;
    }

    return CompletableFuture.completedFuture(true);
}
```

Execution times of the algorithms

```
( Merge Sort (10 elements) ) Slowest Time:1
( Merge Sort (10 elements) ) Average Time:0
( Merge Sort (10 elements) ) Fastest Time:0

( Merge Sort (100 elements) ) Slowest Time:1
( Merge Sort (100 elements) ) Average Time:0
( Merge Sort (100 elements) ) Fastest Time:0

( Merge Sort (1000 elements) ) Slowest Time:11
( Merge Sort (1000 elements) ) Average Time:4
( Merge Sort (1000 elements) ) Fastest Time:4




( Insertion Sort (10 elements) ) Slowest Time:1
( Insertion Sort (10 elements) ) Average Time:0
( Insertion Sort (10 elements) ) Fastest Time:0

( Insertion Sort (100 elements) ) Slowest Time:1
( Insertion Sort (100 elements) ) Average Time:0
( Insertion Sort (100 elements) ) Fastest Time:0

( Insertion Sort (1000 elements) ) Slowest Time:21
( Insertion Sort (1000 elements) ) Average Time:16
( Insertion Sort (1000 elements) ) Fastest Time:13




( Bubble Sort (10 elements) ) Slowest Time:1
( Bubble Sort (10 elements) ) Average Time:0
( Bubble Sort (10 elements) ) Fastest Time:0

( Bubble Sort (100 elements) ) Slowest Time:2
( Bubble Sort (100 elements) ) Average Time:0
( Bubble Sort (100 elements) ) Fastest Time:0

( Bubble Sort (1000 elements) ) Slowest Time:887
( Bubble Sort (1000 elements) ) Average Time:869
( Bubble Sort (1000 elements) ) Fastest Time:845
```

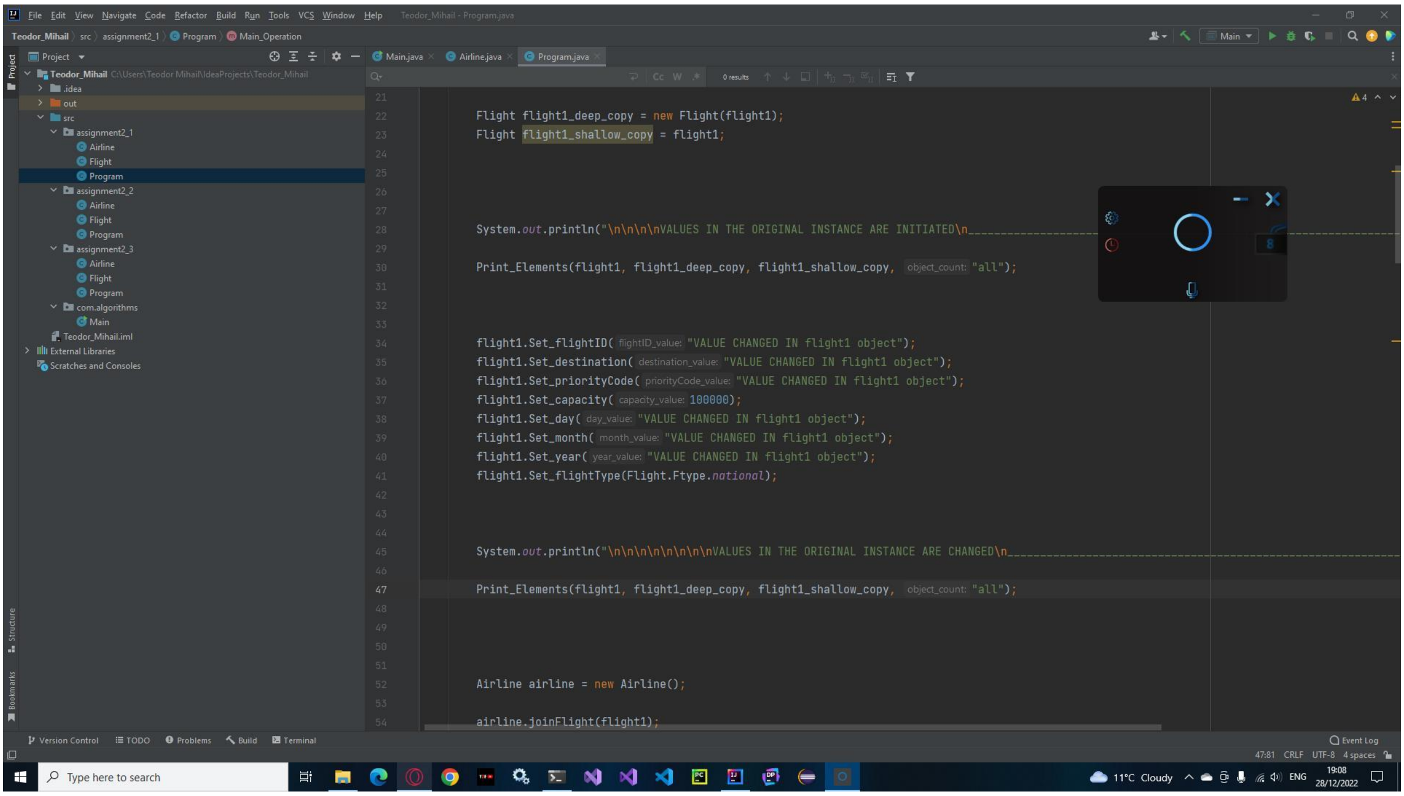
Task 2

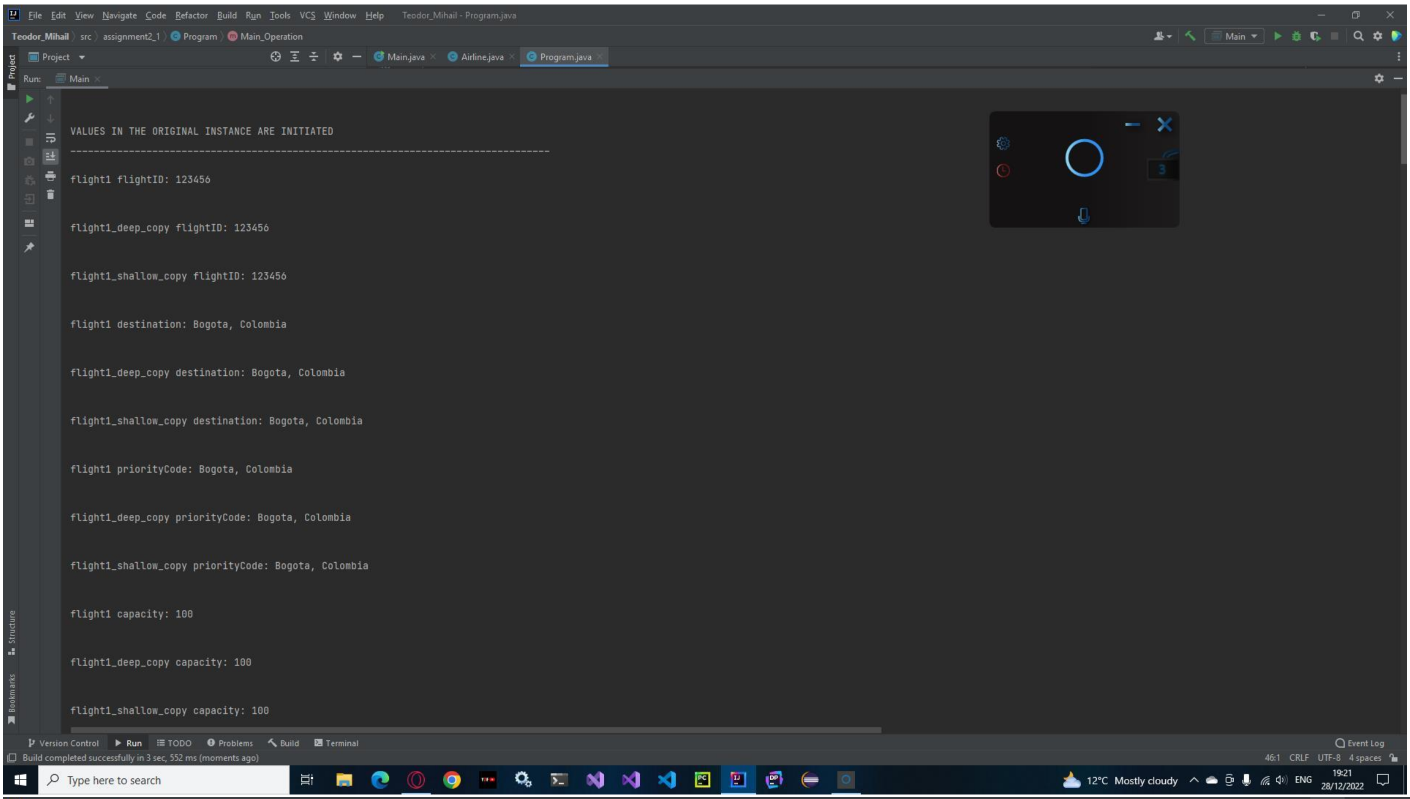
Within the Program class of this task's program, there are 3 objects made from the **Flight** class. The first object is the original instance of the class, the second object is the deep copy instance of the **Flight** class object, and the third object is the shallow copy instance of the **Flight** class object. A deep copy is a copy of an object that retains all the proprieties of the original object without acting as a reference in memory of the object that is copied from. A shallow copy is a copy of an object that retains all the proprieties of the original object, and this object is a reference in memory of the object that is copied from, meaning that any changes made in the copy reflect in the original object.

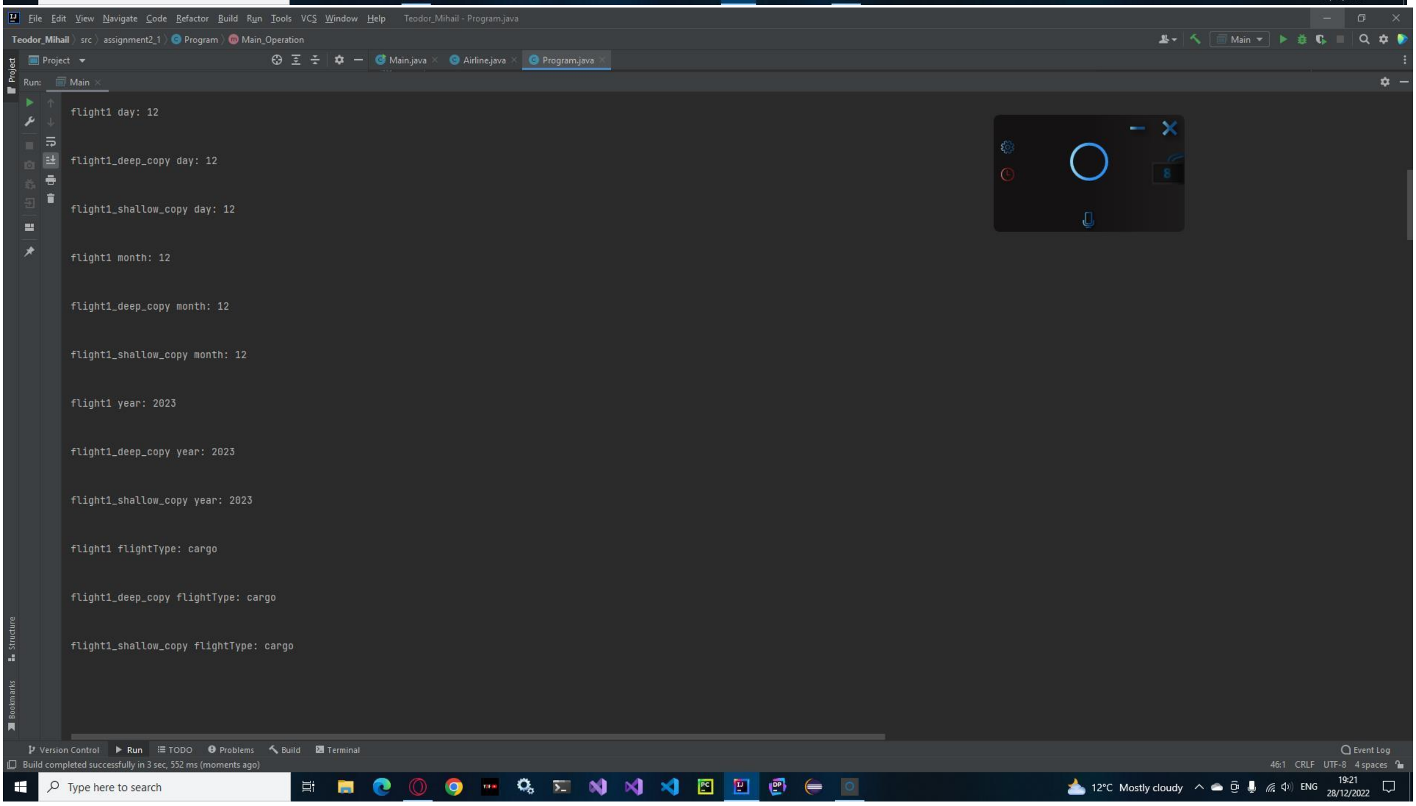


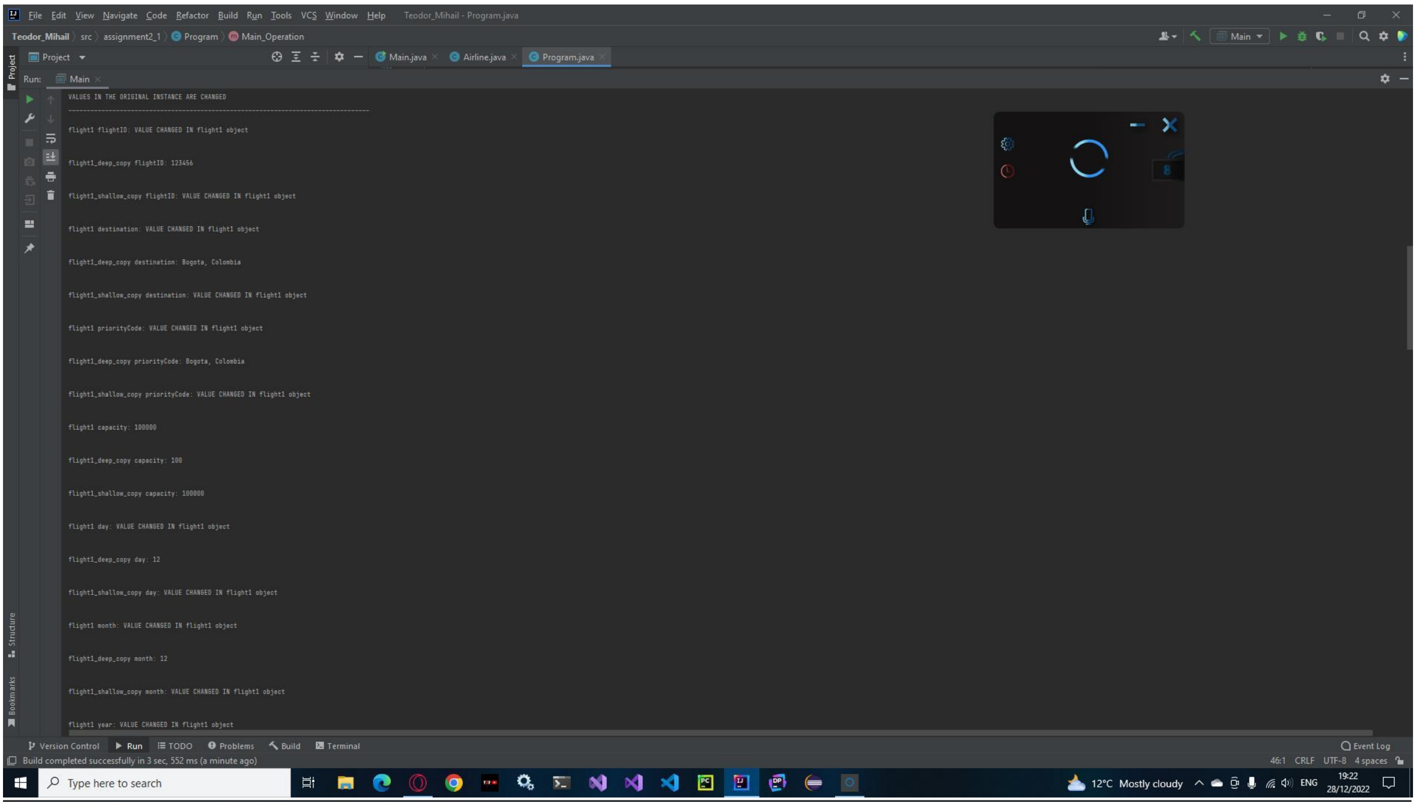
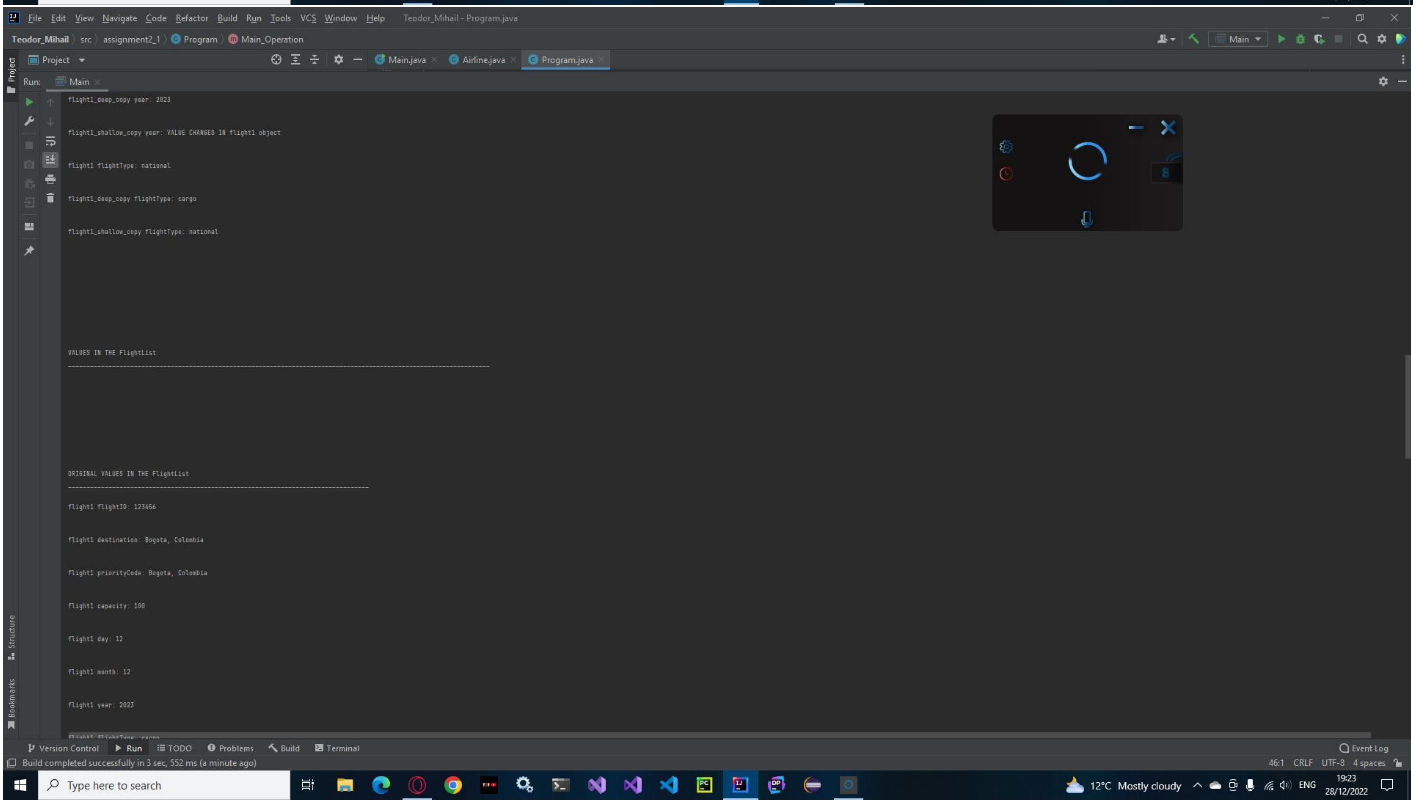
Test case

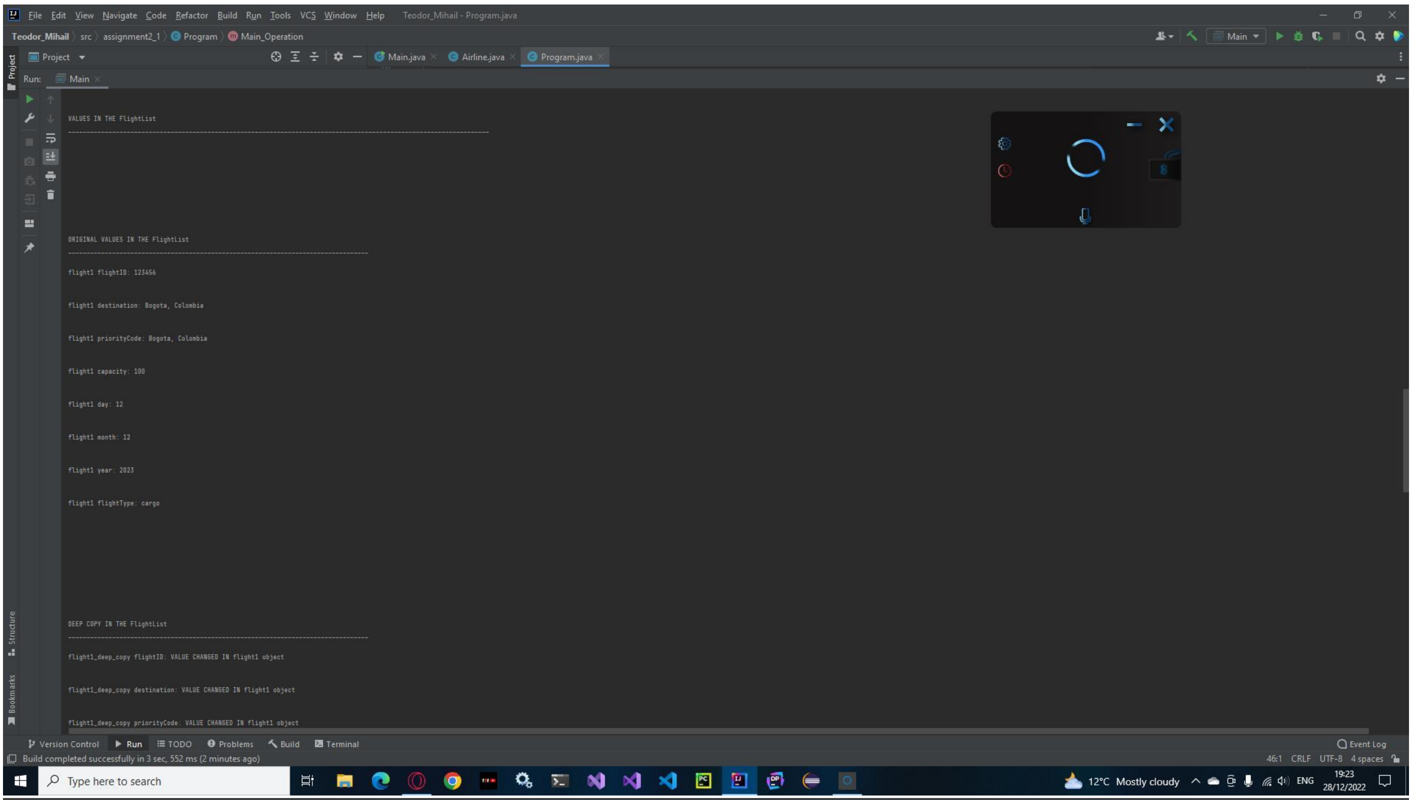
To see how these copies behave when data inserted the original object is changed, the information within the original object and the copies is printed, the data in the original object is then changed, and then the information within the original object and the copies is printed again. To test the Airline class FlightList **ArrayList** implementation, the original **Flight** class object and its copies are inserted inside the FlightList **ArrayList**, and then the last object that is inserted is removed.

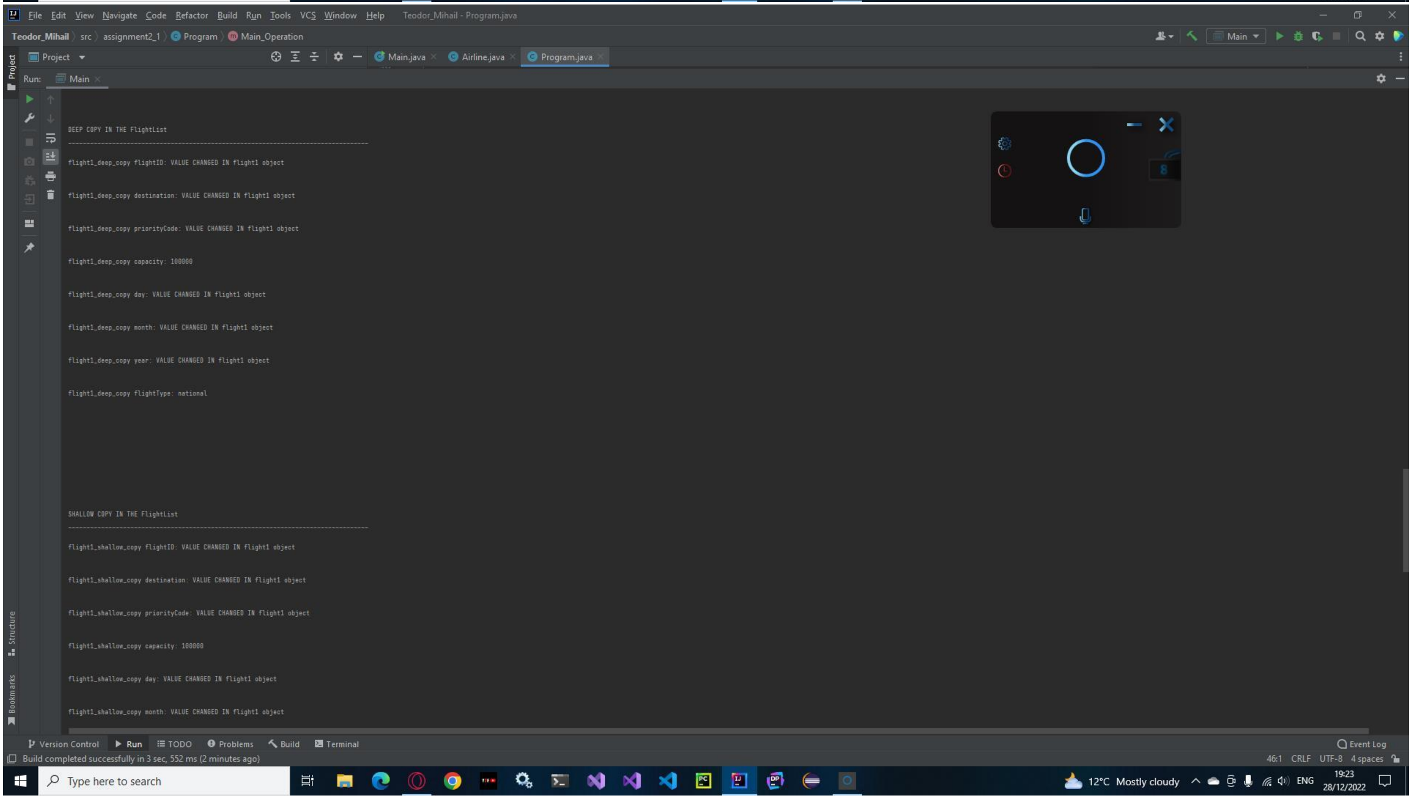


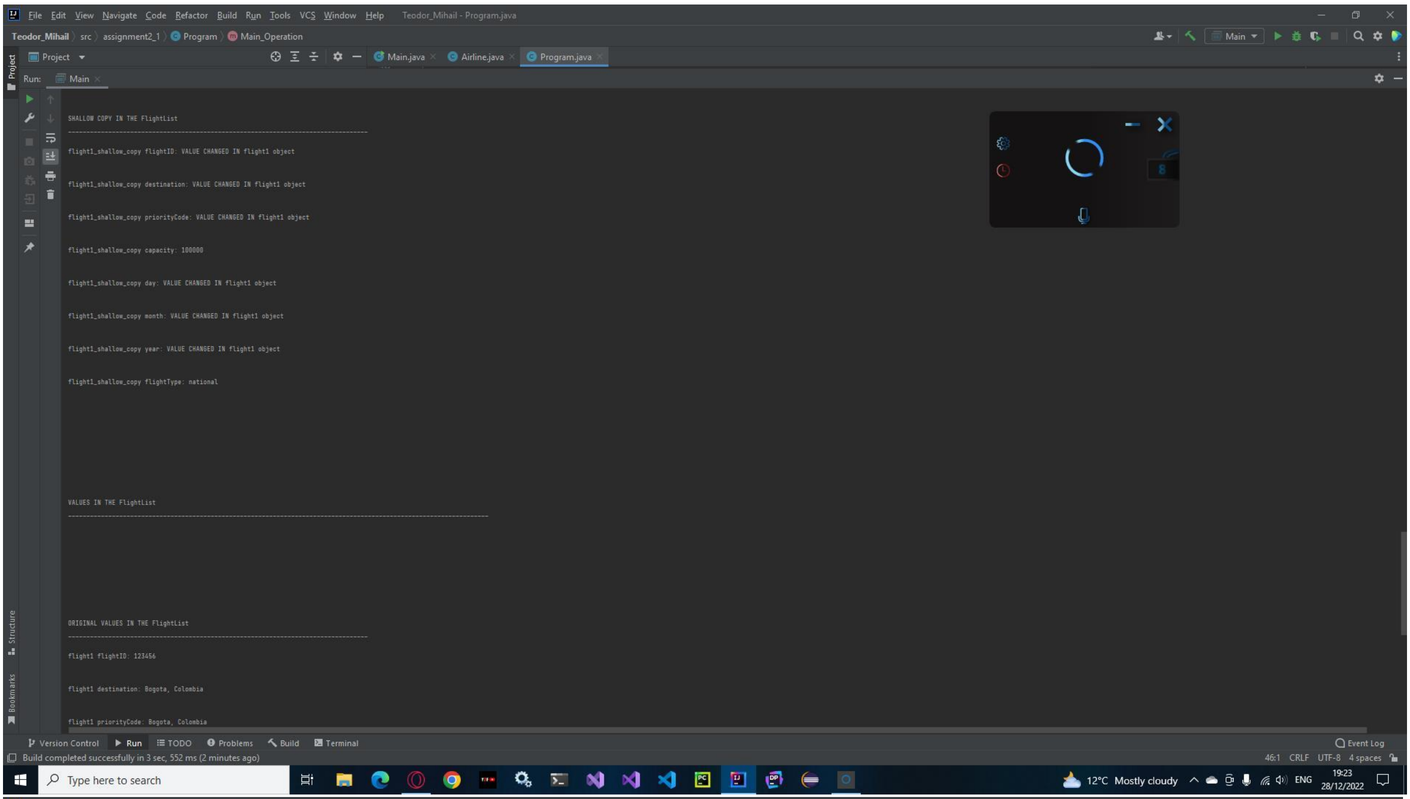
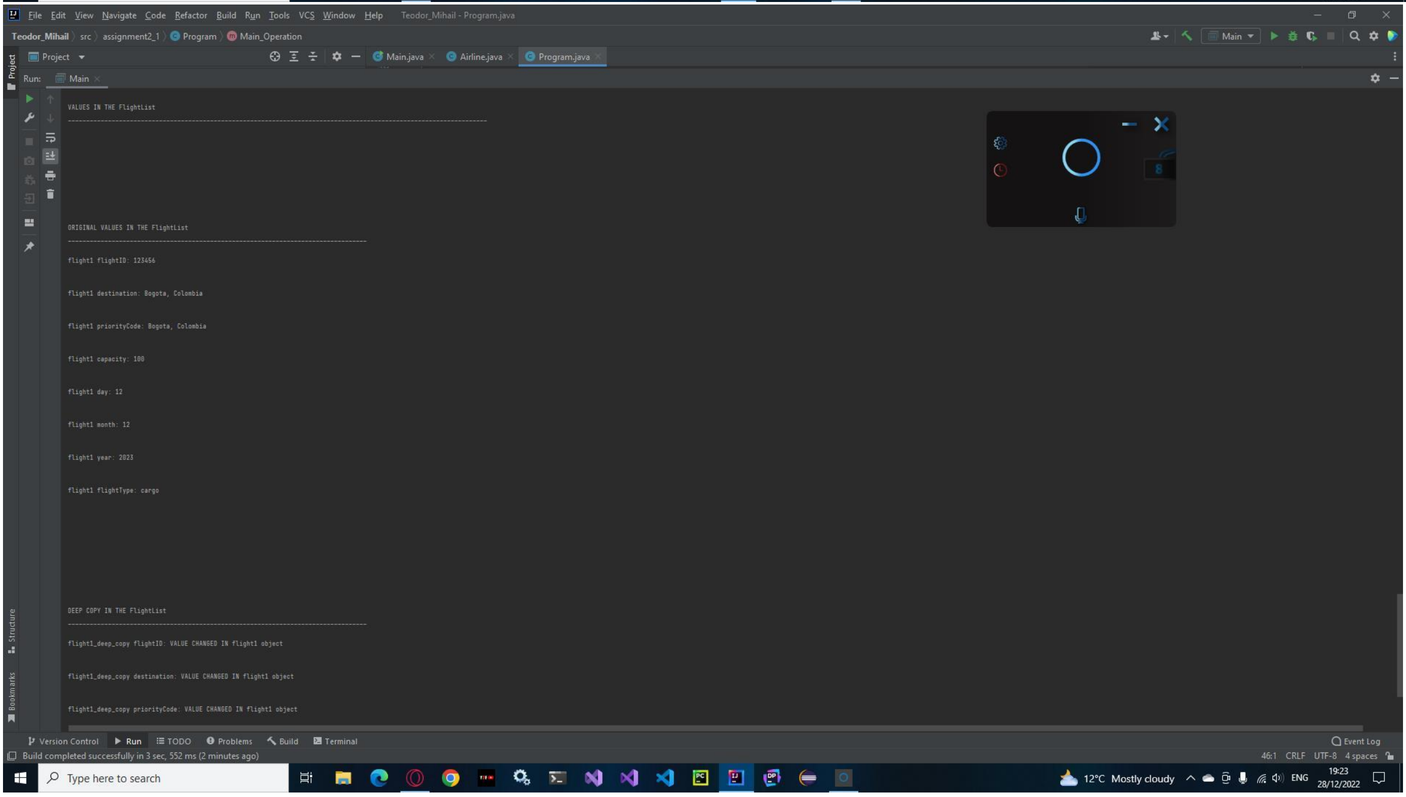

VALUES IN THE ORIGINAL INSTANCE ARE INITIATED
flight1 flightID: 123456
flight1_deep_copy flightID: 123456
flight1_shallow_copy flightID: 123456
flight1 destination: Bogota, Colombia
flight1_deep_copy destination: Bogota, Colombia
flight1_shallow_copy destination: Bogota, Colombia
flight1 priorityCode: Bogota, Colombia
flight1_deep_copy priorityCode: Bogota, Colombia
flight1_shallow_copy priorityCode: Bogota, Colombia
flight1 capacity: 100
flight1_deep_copy capacity: 100
flight1_shallow_copy capacity: 100
Build completed successfully in 3 sec, 552 ms (moments ago)

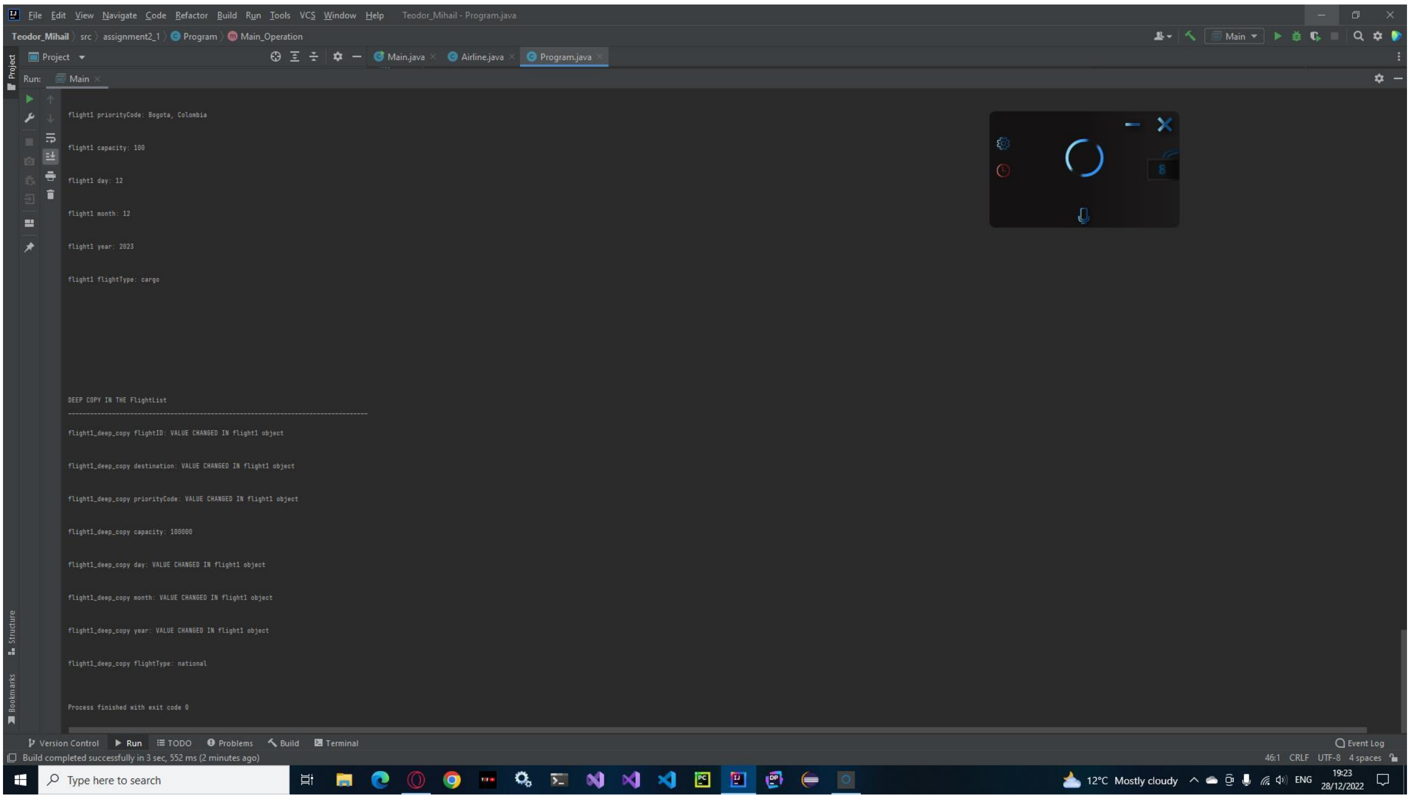

flight1 day: 12
flight1_deep_copy day: 12
flight1_shallow_copy day: 12
flight1 month: 12
flight1_deep_copy month: 12
flight1_shallow_copy month: 12
flight1 year: 2023
flight1_deep_copy year: 2023
flight1_shallow_copy year: 2023
flight1 flightType: cargo
flight1_deep_copy flightType: cargo
flight1_shallow_copy flightType: cargo
Build completed successfully in 3 sec, 552 ms (moments ago)


Teodor_Mihail - Program.java
Teodor_Mihail src assignment2_1 Program Main_Operation
Main.java Airline.java Program.java
VALUES IN THE ORIGINAL INSTANCE ARE CHANGED
flight1 flightID: VALUE CHANGED IN flight1 object
flight1_deep_copy flightID: 123456
flight1_shallow_copy flightID: VALUE CHANGED IN flight1 object
flight1 destination: VALUE CHANGED IN flight1 object
flight1_deep_copy destination: Bogota, Colombia
flight1_shallow_copy destination: VALUE CHANGED IN flight1 object
flight1 priorityCode: VALUE CHANGED IN flight1 object
flight1_deep_copy priorityCode: Bogota, Colombia
flight1_shallow_copy priorityCode: VALUE CHANGED IN flight1 object
flight1 capacity: 100000
flight1_deep_copy capacity: 100
flight1_shallow_copy capacity: 100000
flight1 day: VALUE CHANGED IN flight1 object
flight1_deep_copy day: 12
flight1_shallow_copy day: VALUE CHANGED IN flight1 object
flight1 month: VALUE CHANGED IN flight1 object
flight1_deep_copy month: 12
flight1_shallow_copy month: VALUE CHANGED IN flight1 object
flight1 year: VALUE CHANGED IN flight1 object
Build completed successfully in 3 sec, 552 ms (a minute ago)
Type here to search
12°C Mostly cloudy
19:22
28/12/2022

Teodor_Mihail - Program.java
Teodor_Mihail src assignment2_1 Program Main_Operation
Main.java Airline.java Program.java
flight1_deep_copy year: 2023
flight1_shallow_copy year: VALUE CHANGED IN flight1 object
flight1 flightType: national
flight1_deep_copy flightType: cargo
flight1_shallow_copy flightType: national
VALUES IN THE FlightList
ORIGINAL VALUES IN THE FlightList
flight1 flightID: 123456
flight1 destination: Bogota, Colombia
flight1 priorityCode: Bogota, Colombia
flight1 capacity: 100
flight1 day: 12
flight1 month: 12
flight1 year: 2023
Build completed successfully in 3 sec, 552 ms (a minute ago)
Type here to search
12°C Mostly cloudy
19:23
28/12/2022


Teodor_Mihail - Program.java
Teodor_Mihail › src › assignment2_1 › Program › Main_Operation
Main.java
Airline.java
Program.java
Run: Main
VALUES IN THE FlightList
ORIGINAL VALUES IN THE FlightList
flight1 flightID: 123456
flight1 destination: Bogota, Colombia
flight1 priorityCode: Bogota, Colombia
flight1 capacity: 100
flight1 day: 12
flight1 month: 12
flight1 year: 2023
flight1 flightType: cargo
DEEP COPY IN THE FlightList
flight1_deep_copy flightID: VALUE CHANGED IN flight1 object
flight1_deep_copy destination: VALUE CHANGED IN flight1 object
flight1_deep_copy priorityCode: VALUE CHANGED IN flight1 object
Version Control
Run
TODO
Problems
Build
Terminal
Build completed successfully in 3 sec, 552 ms (2 minutes ago)
Type here to search
12°C Mostly cloudy
19:23
28/12/2022


Teodor_Mihail - Program.java
Teodor_Mihail › src › assignment2_1 › Program › Main_Operation
Main.java
Airline.java
Program.java
Run: Main
DEEP COPY IN THE FlightList
flight1_deep_copy flightID: VALUE CHANGED IN flight1 object
flight1_deep_copy destination: VALUE CHANGED IN flight1 object
flight1_deep_copy priorityCode: VALUE CHANGED IN flight1 object
flight1_deep_copy capacity: 100000
flight1_deep_copy day: VALUE CHANGED IN flight1 object
flight1_deep_copy month: VALUE CHANGED IN flight1 object
flight1_deep_copy year: VALUE CHANGED IN flight1 object
flight1_deep_copy flightType: national
SHALLOW COPY IN THE FlightList
flight1_shallow_copy flightID: VALUE CHANGED IN flight1 object
flight1_shallow_copy destination: VALUE CHANGED IN flight1 object
flight1_shallow_copy priorityCode: VALUE CHANGED IN flight1 object
flight1_shallow_copy capacity: 100000
flight1_shallow_copy day: VALUE CHANGED IN flight1 object
flight1_shallow_copy month: VALUE CHANGED IN flight1 object
Version Control
Run
TODO
Problems
Build
Terminal
Build completed successfully in 3 sec, 552 ms (2 minutes ago)
Type here to search
12°C Mostly cloudy
19:23
28/12/2022


File Edit View Navigate Code Refactor Build Run Tools VCS Window Help Teodor_Mihail - Program.java
Teodor_Mihail src assignment2_1 Program Main_Operation
Project Main.java Airline.java Program.java
Run: Main
SHALLOW COPY IN THE FlightList
flight1_shallow_copy flightID: VALUE CHANGED IN flight1 object
flight1_shallow_copy destination: VALUE CHANGED IN flight1 object
flight1_shallow_copy priorityCode: VALUE CHANGED IN flight1 object
flight1_shallow_copy capacity: 100000
flight1_shallow_copy day: VALUE CHANGED IN flight1 object
flight1_shallow_copy month: VALUE CHANGED IN flight1 object
flight1_shallow_copy year: VALUE CHANGED IN flight1 object
flight1_shallow_copy flightType: national
VALUES IN THE FlightList
ORIGINAL VALUES IN THE FlightList
flight1 flightID: 123456
flight1 destination: Bogota, Colombia
flight1 priorityCode: Bogota, Colombia
Version Control Run TODO Problems Build Terminal
Build completed successfully in 3 sec, 552 ms (2 minutes ago)
Type here to search
12°C Mostly cloudy
19:23
28/12/2022

File Edit View Navigate Code Refactor Build Run Tools VCS Window Help Teodor_Mihail - Program.java
Teodor_Mihail src assignment2_1 Program Main_Operation
Project Main.java Airline.java Program.java
Run: Main
VALUES IN THE FlightList
ORIGINAL VALUES IN THE FlightList
flight1 flightID: 123456
flight1 destination: Bogota, Colombia
flight1 priorityCode: Bogota, Colombia
flight1 capacity: 100
flight1 day: 12
flight1 month: 12
flight1 year: 2023
flight1 flightType: cargo
DEEP COPY IN THE FlightList
flight1_deep_copy flightID: VALUE CHANGED IN flight1 object
flight1_deep_copy destination: VALUE CHANGED IN flight1 object
flight1_deep_copy priorityCode: VALUE CHANGED IN flight1 object
Version Control Run TODO Problems Build Terminal
Build completed successfully in 3 sec, 552 ms (2 minutes ago)
Type here to search
12°C Mostly cloudy
19:23
28/12/2022



FlightList ArrayList implementation advantages

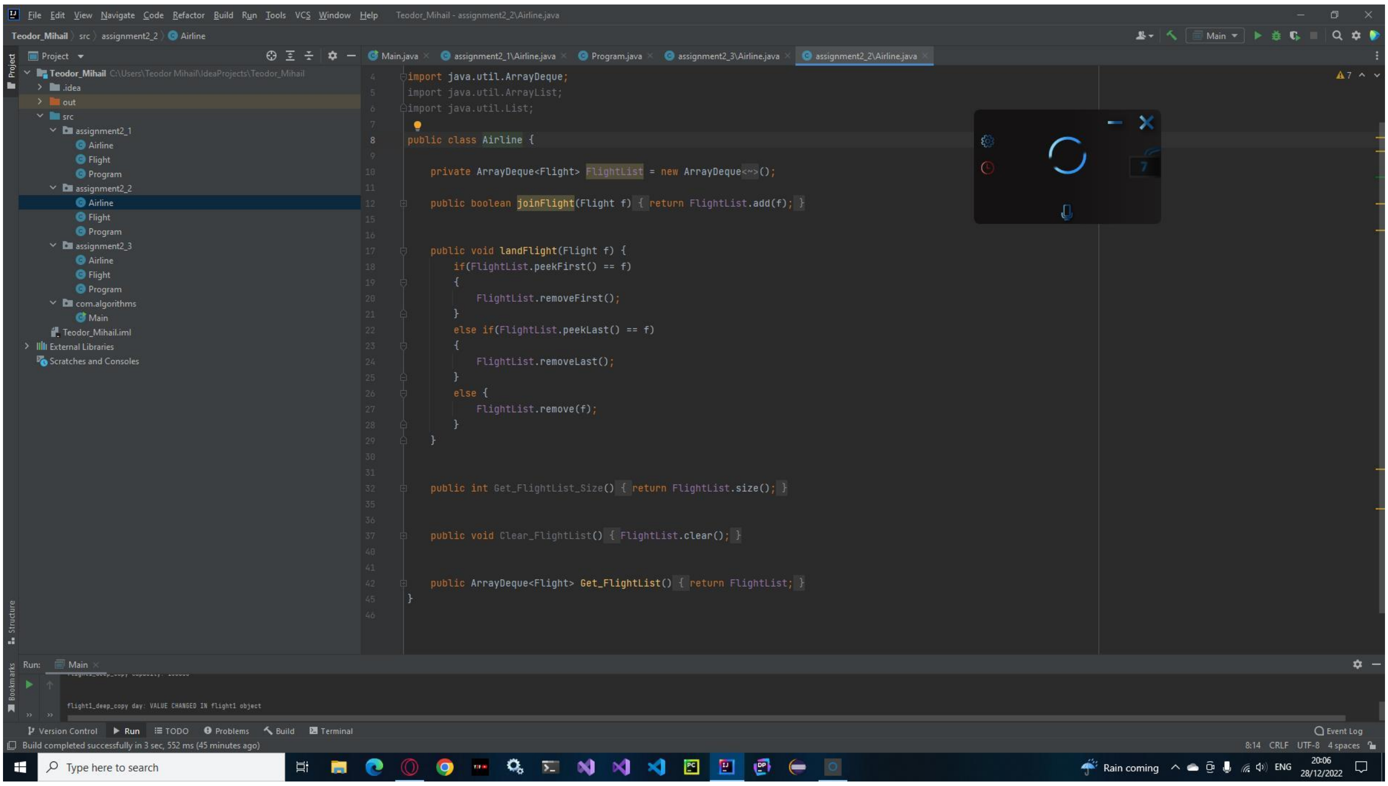
The **ArrayList** implementation has the advantages of having a lower runtime memory consumption than other data structures, and the ability to add elements at the end of the list, remove elements at the beginning and end of the list, search elements at the beginning and end of the list, and replace elements at the end and beginning of the list in **O (1)** time. This time complexity is given by the fact that an **ArrayList** is a doubly linked list, and these time complexity characteristics are given for the before mentioned data structure.

FlightList ArrayList implementation disadvantages

The **ArrayList** implementation has the disadvantages of having a larger initial memory consumption than other data structures and having an **O(N)** time complexity for element replacement, element search, and element removal operations within the middle of the list because the data structure must iterate each element one by one to reach the desired elements.

Task 3

As the task requires, the FlightList implementation within the Airline class had been changed with an **ArrayDeque** implementation.



FlightList ArrayDeque implementation advantages

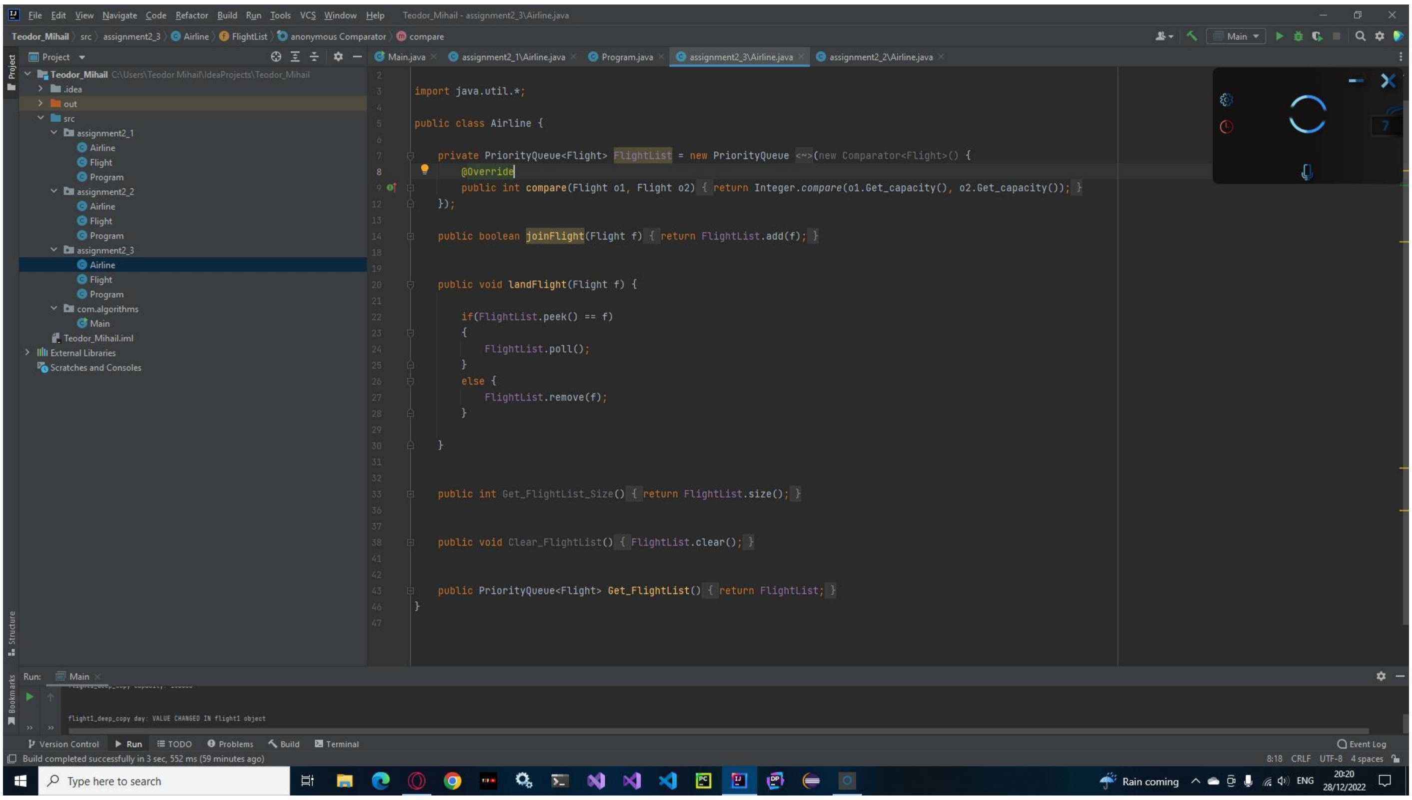
The **ArrayDeque** implementation has the advantages of having a low runtime memory consumption and having the ability to add elements at the beginning and the end, remove elements at the beginning and the end, search elements at the beginning and end, and replace elements at the beginning and the end in **O (1)** time ***(baeldung (2017). Introduction to the Java ArrayDeque)***.

FlightList ArrayDeque implementation disadvantages

The **ArrayDeque** implementation has the disadvantage of having a higher runtime memory consumption than other data structures and having an **O(N)** time complexity for element replacement, element search, and element removal operations within the middle of the list because the data structure must iterate each element one by one to reach the desired elements (***GeeksforGeeks. (2018). ArrayDeque offer() Method in Java***).

Task 4

As the task requires, the FlightList implementation had been changed within the Airline class with a **PriorityQueue** implementation.



This implementation of the **PriorityQueue** is using the capacity variable within the first inserted **Flight** object to order at runtime the objects added within the **PriorityQueue** (***GeeksforGeeks. (2016). PriorityQueue in Java***) (***Stack Overflow. (n.d.). java - How do I use a PriorityQueue?***) (***PrepBytes Blog. (2022). Implement Priority Queue Comparator Java***).

FlightList PriorityQueue implementation advantages

The **PriorityQueue** implementation has the advantages of having a low runtime memory and having the ability to add elements at the end, remove elements, search elements, and replace elements in **O (log N)** time. It also has the advantage of decreasing the time complexity for all these before mentioned functions by ordering at runtime the elements that are added in increasing order (***digitalocean. (n.d.). Priority Queue Java | DigitalOcean***).

FlightList PriorityQueue implementation disadvantages

The **PriorityQueue** implementation has the disadvantage of having a higher runtime memory consumption than other data structures and having an **O (log N)** time complexity for element replacement and element removal operations within the list because the data structure, even if the element is at the beginning or end.

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Appendix

Task 1 program:
https://drive.google.com/drive/folders/1lzpr16MkEccaJ_xWygsOJiWNaITb4mA3?usp=sharing

Task 2, Task 3, Task 4 program:
https://drive.google.com/drive/folders/1vevVEQRl1Pa4CyaK8_W2w30ijjtQg6xQ?usp=sharing