Program Structures and Algorithms
Spring 2023(SEC 01)

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Task:

In this assignment, your task is to determine--for sorting algorithms--what is the best predictor of total execution time: comparisons, swaps/copies, hits (array accesses), or something else.

You will run the benchmarks for merge sort, (dual-pivot) quick sort, and heap sort. You will sort randomly generated arrays of between 10,000 and 256,000 elements (doubling the size each time). If you use the *SortBenchmark*, as I expect, the number of runs is chosen for you. So, you can ignore the instructions about setting the number of runs.

For each experiment (a sort method of a given size), you will run it twice: once for the instrumentation, once (without instrumentation) for the timing.

Of course, you will be using the *Benchmark* and/or *Timer* classes, as you did in a previous assignment.

You must support your (clearly stated) conclusions with evidence from the benchmarks (you should provide log/log charts and spreadsheets typically).

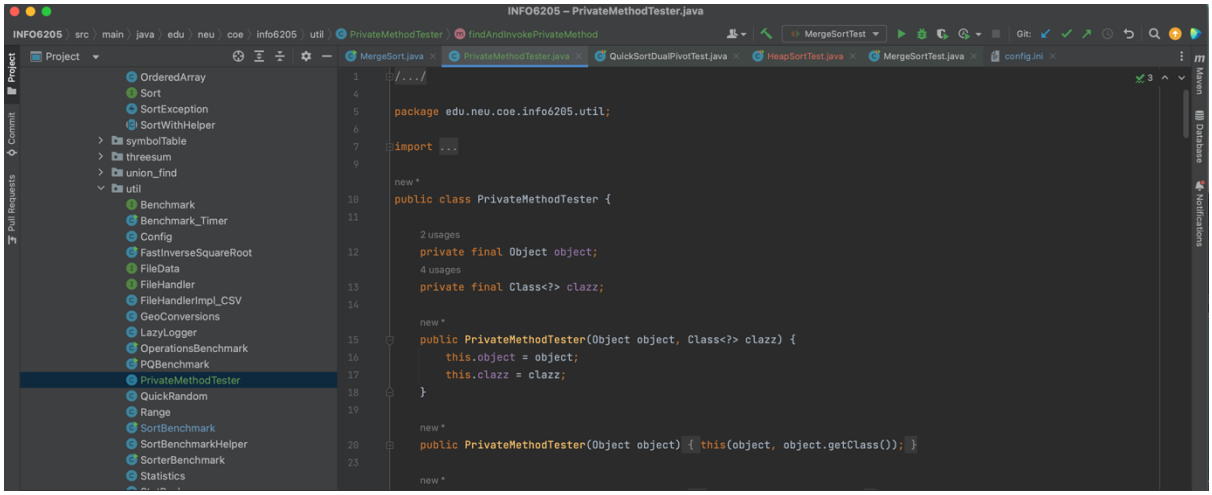
All of the code to count comparisons, swaps/copies, and hits, is already implemented in the *InstrumentedHelper* class. You can see examples of the usage of this kind of analysis in:

- src/main/java/edu/neu/coe/info6205/util/SorterBenchmark.java
- src/test/java/edu/neu/coe/info6205/sort/linearithmic/MergeSortTest.java
- src/test/java/edu/neu/coe/info6205/sort/linearithmic/QuickSortDualPivotTest.java
- src/test/java/edu/neu/coe/info6205/sort/elementary/HeapSortTest.java (you will have to refresh your repository for HeapSort).

Output Screenshots:-

Code Changes:-

1. Added a class named PrivateMethodTester in the util of main, similar to the util of the Test folder.



This helps for the instrumentation execution required for the sorts.

2. Added following code in the mergeSort for noCopy and Insurance.

```
5 usages   Shivani Datar *
private void sort(X[] a, X[] aux, int from, int to) {
    final Helper<X> helper = getHelper();
    Config config = helper.getConfig();
    boolean insurance = config.getBoolean(MERGESORT, INSURANCE);
    boolean noCopy = config.getBoolean(MERGESORT, NOCOPY);
    if (to <= from + helper.cutoff()) {
        insertionSort.sort(a, from, to);
        return;
    }
    // FIXME : implement merge sort with insurance and no-copy optimizations
    int middle = from + (to - from) / 2;
    if (noCopy) {
        sort(aux, a, from, middle);
        sort(aux, a, middle, to);
        if (insurance && helper.less(aux,  i: middle - 1, middle)) {
            System.arraycopy(aux, from, a, from,  length: to - from);
            helper.incrementCopies( n: to - from);
        } else
            merge(aux, a, from, middle, to);
    } else {
        sort(a, aux, from, middle);
        sort(a, aux, middle, to);
        System.arraycopy(a, from, aux, from,  length: to - from);
        if (insurance && helper.less(a[middle - 1], a[middle])) return;
        merge(aux, a, from, middle, to);
    }


    // END
```

3. Added a main method in the MergeSort.java file, it has a Config c set which is later on used for all objects of the sorts. The elements in the random array generation has a bound 10000. The size of array starts from 10,000 until 160,000. This is generated using a for-loop. The sorting method is called out twice, once for the timing purposes, where I am using the Benchmark class object and passing either mergesort/quicksort/heapsort object's sort method in the fRun which is executed for 20 number of runs. The second call is done for the sorting method, the helper is generated while creation of the sort object, that helper is preprocess is done before the Benchmarking and after the second call postprocess is done on the helper, which enables us to get the statPack associated while sorting the xs array into the final sorted ys array. Then from this statPack we are getting our metrics involved which are number of compares, swaps and array hits, number of copies(in case of the merge Sort). Following is the code for the main method,

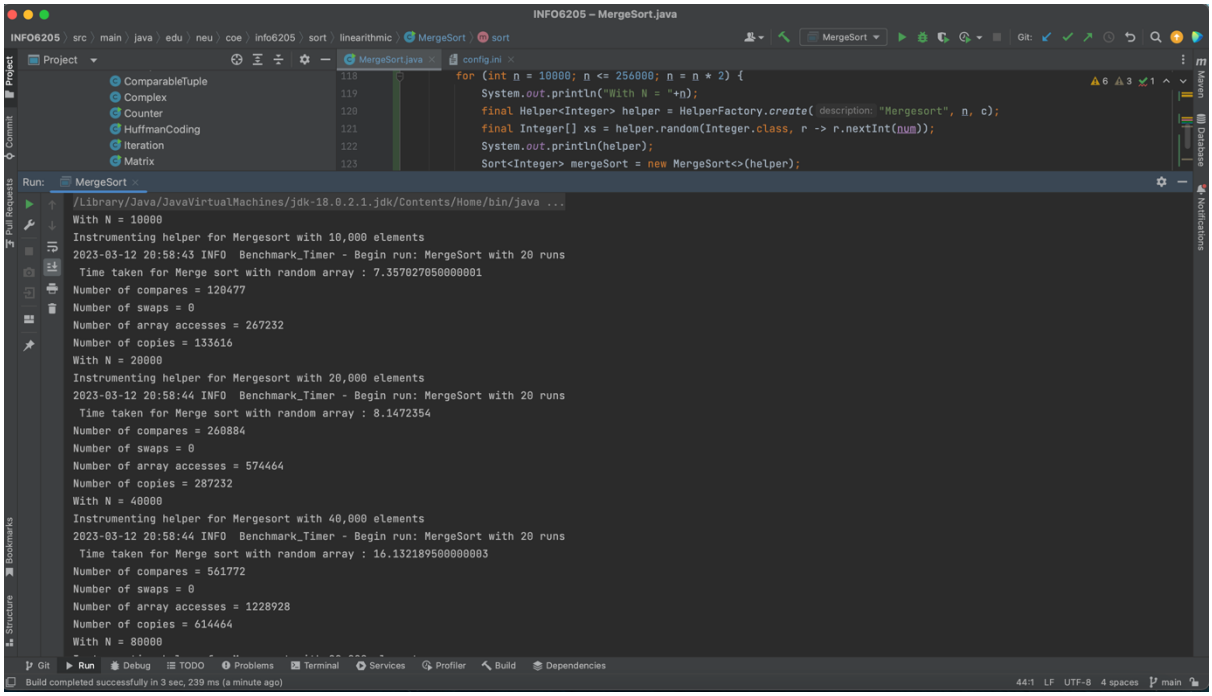
```java
public static void main(String[] args){
    //Random rand = new Random();
    Config c = Config.setupConfig( instrumenting: "true",  seed: "",  inversions: "0",  cutoff: "1",  interimInversions: "");
    final int num = 10000;
    // Merge Sort
    for (int n = 10000; n <= 256000; n = n * 2) {
        System.out.println("With N = "+n);
        final Helper<Integer> helper = HelperFactory.create( description: "Mergesort", n, c);
        final Integer[] xs = helper.random(Integer.class, r -> r.nextInt(num));
        System.out.println(helper);
        Sort<Integer> mergeSort = new MergeSort<>(helper);
        mergeSort.init(n);
        helper.preProcess(xs);
        Benchmark<Boolean> benchmarkRandom = new Benchmark_Timer<>(
                description: "MergeSort", b -> {
            mergeSort.sort(xs.clone(),  from: 0, xs.length);
        });
        double resultRandom = benchmarkRandom.run( t: true,  m: 20);
        Integer[] ys = mergeSort.sort(xs);
        helper.postProcess(ys);
        PrivateMethodTester privateMethodTester = new PrivateMethodTester(helper);
        StatPack statPack = (StatPack) privateMethodTester.invokePrivate( name: "getStatPack");
       //InstrumentedHelper stat = new InstrumentedHelper("MergeSort",n,c);
       int compares = (int) statPack.getStatistics(InstrumentedHelper.COMPARES).mean();
       int swaps = (int) statPack.getStatistics(InstrumentedHelper.SWAPS).mean();
       int hits = (int) statPack.getStatistics(InstrumentedHelper.HITS).mean();
       int copies = (int) statPack.getStatistics(InstrumentedHelper.COPIES).mean();
       System.out.println(" Time taken for Merge sort with random array : " + resultRandom);
       System.out.println("Number of compares = "+compares);
```

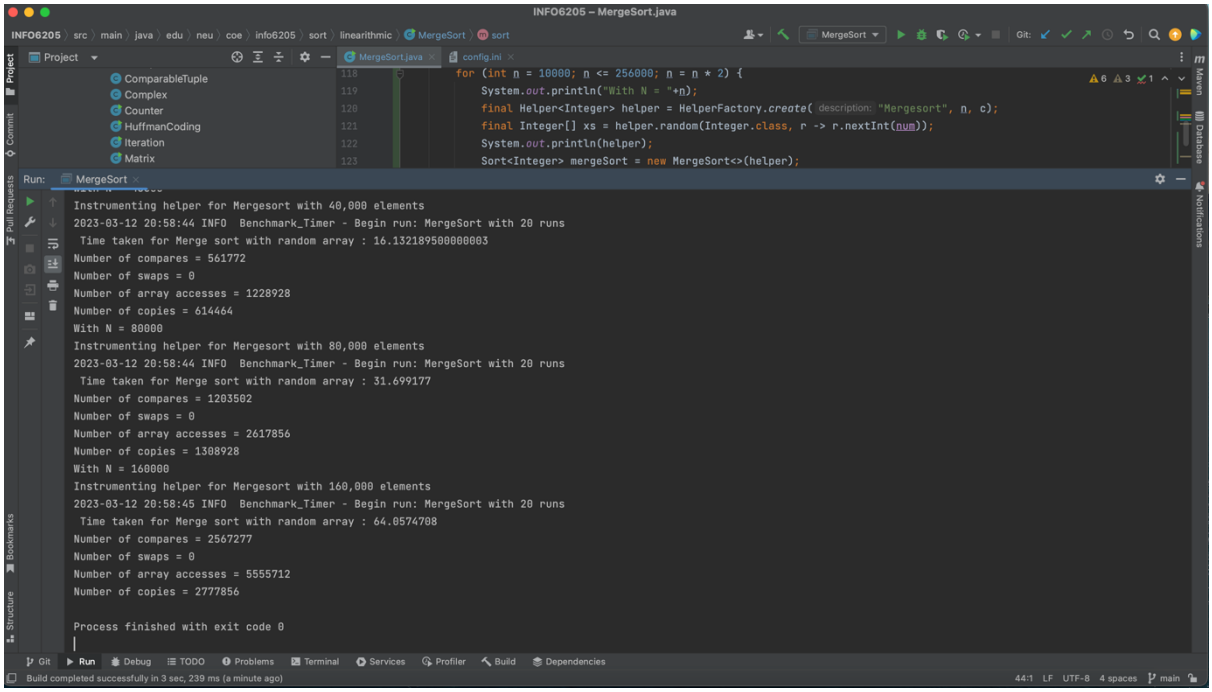
```java
//Quick sort dual pivot

final BaseHelper<Integer> helper1 = (BaseHelper<Integer>) HelperFactory.create( description: "quick sort dual pivot", n, c);
//System.out.println(helper1);
Sort<Integer> quicksort = new QuickSort_DualPivot<>(helper1);
quicksort.init(n);
//final int f = 500000;
final Integer[] xs1 = helper1.random(Integer.class, r -> r.nextInt(num));
System.out.println(helper1);
helper1.preProcess(xs1);
Benchmark<Boolean> benchmarkRandom1 = new Benchmark_Timer<>(
        description: "QuickDualPivotSort", b -> {
    quicksort.sort(xs1);
});
double resultRandom1 = benchmarkRandom1.run( t: true,  m: 20);
Integer[] ys1 = quicksort.sort(xs1);
helper1.postProcess(ys1);
final PrivateMethodTester privateMethodTester1 = new PrivateMethodTester(helper1);
final StatPack statPack1 = (StatPack) privateMethodTester1.invokePrivate( name: "getStatPack");
int compares1 = (int) statPack1.getStatistics(InstrumentedHelper.COMPARES).mean();
int swaps1 = (int) statPack1.getStatistics(InstrumentedHelper.SWAPS).mean();
int hits1 = (int) statPack1.getStatistics(InstrumentedHelper.HITS).mean();
System.out.println(" Time taken for Quick sort with random array : " + resultRandom1);
System.out.println("Number of compares = "+compares1);
```

```
        System.out.println("Number of swaps = "+swaps1);
        System.out.println("Number of array accesses = "+hits1);

         //Heap Sort

        Helper<Integer> helper2 = HelperFactory.create( description: "HeapSort", n, c);
        final Integer[] randomArray = helper2.random(Integer.class, r -> r.nextInt(num));
        helper2.init(n);
        SortWithHelper<Integer> heapsort = new HeapSort<Integer>(helper2);
        heapsort.preProcess(randomArray);
        Benchmark<Boolean> benchmarkRandom2 = new Benchmark_Timer<>(
                description: "HeapSort", b -> {
            heapsort.sort(randomArray);
        });
        double resultRandom2 = benchmarkRandom2.run( t: true,  m: 20);
        PrivateMethodTester privateMethodTester2 = new PrivateMethodTester(helper2);
        StatPack statPack2 = (StatPack) privateMethodTester2.invokePrivate( name: "getStatPack");
        Integer[] ys2 = heapsort.sort(randomArray);
        helper2.postProcess(ys2);
        int compares2 = (int) statPack2.getStatistics(InstrumentedHelper.COMPARES).mean();
        int swaps2 = (int) statPack2.getStatistics(InstrumentedHelper.SWAPS).mean();
        int hits2 = (int) statPack2.getStatistics(InstrumentedHelper.HITS).mean();
        System.out.println(" Time taken for Heap sort with random array : " + resultRandom2);
        System.out.println("Number of compares = "+compares2);
        System.out.println("Number of swaps = "+swaps2);
        System.out.println("Number of array accesses = "+hits2);
```

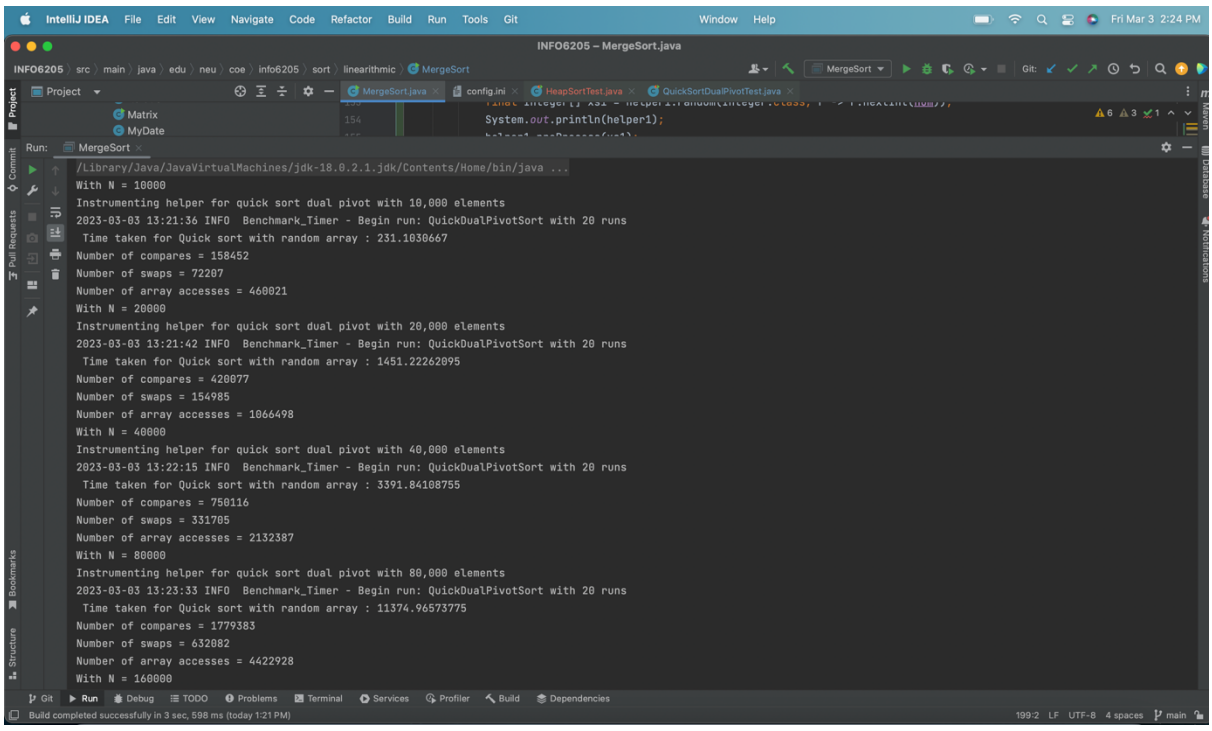
While the time of execution 2 sorts where commented and only 1 sort was executed for the code efficiency. Following are the outputs generated for Merge, Quick and Heap Sort.

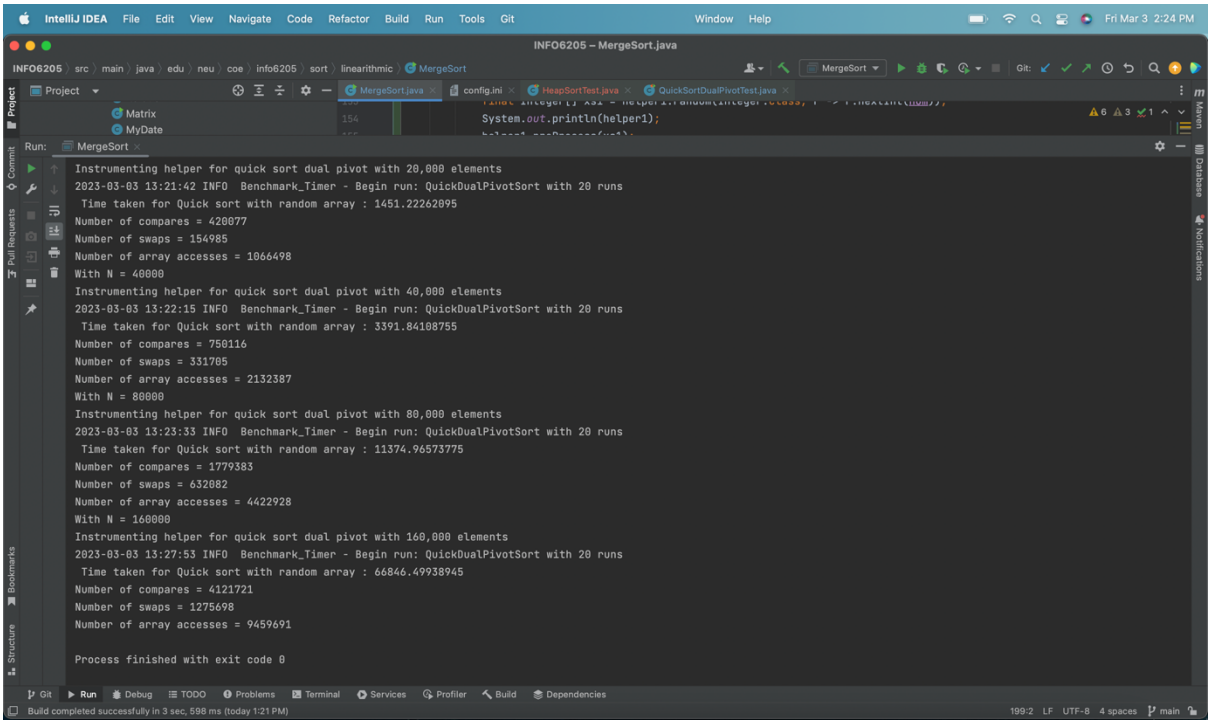
1. Merge Sort Output :-



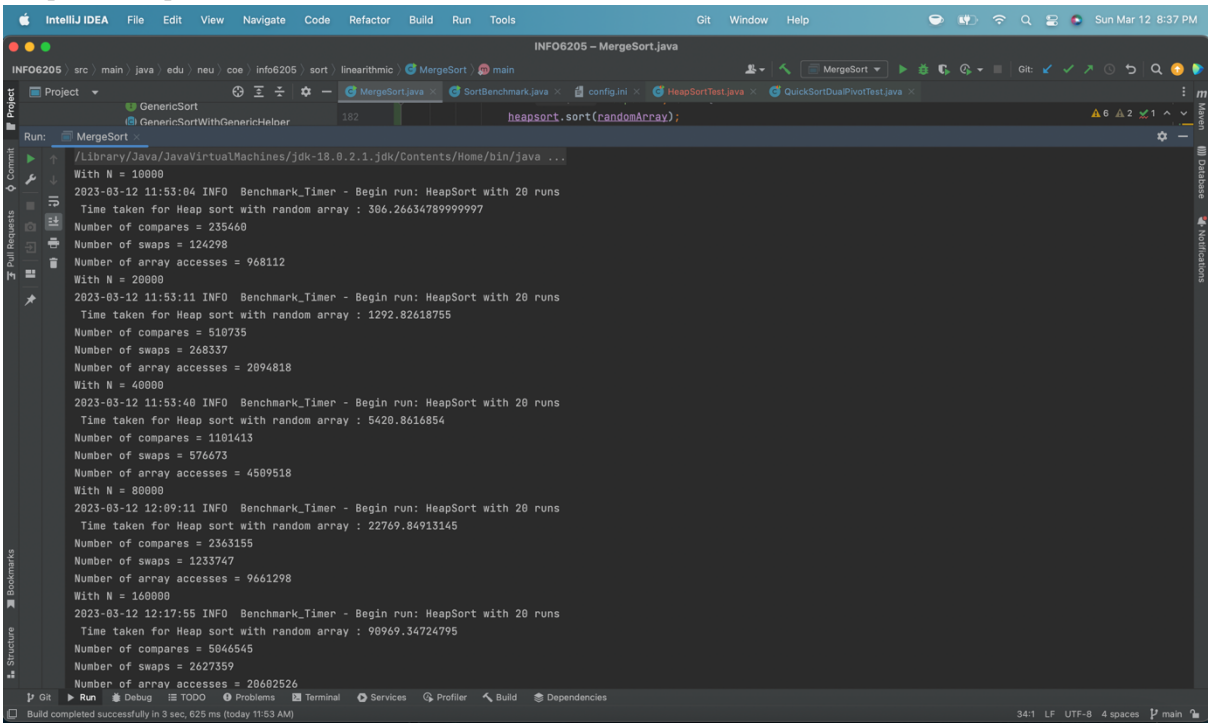


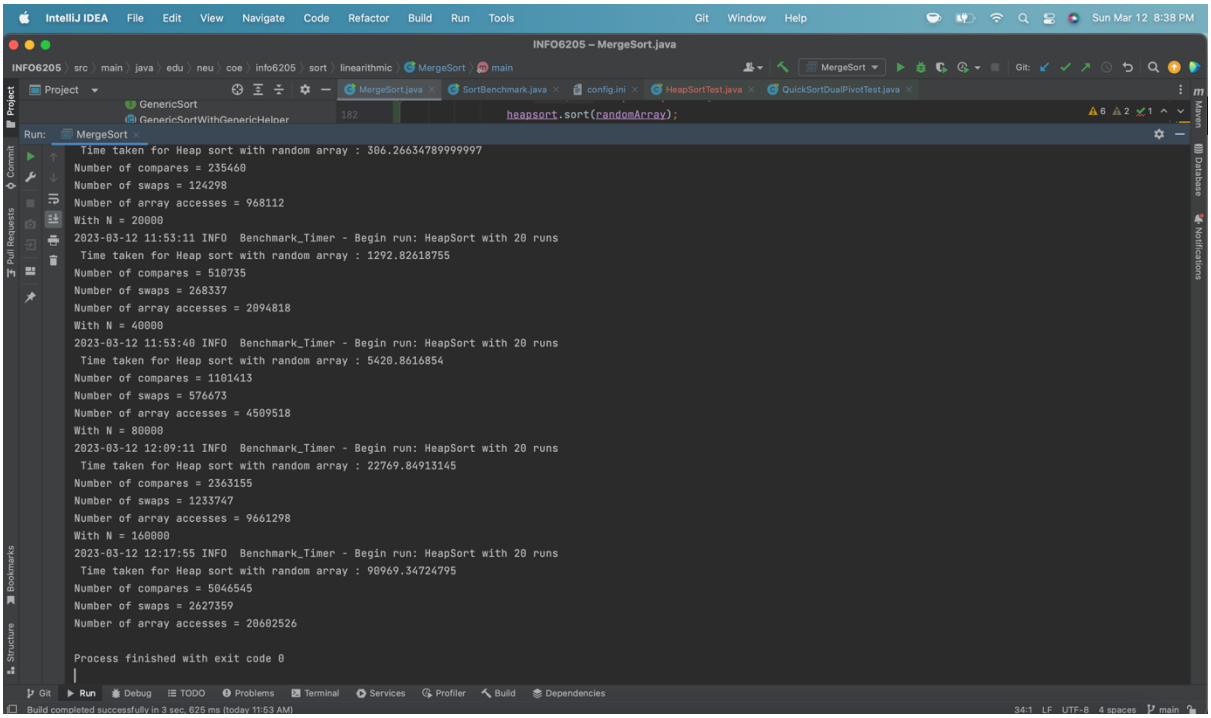
Quick Dual Pivot Sort Output :-





Heap Sort Output :-





Relationship Conclusion :-

From the graphs we can say that the best predictor for the time is number of hits, as number of hits is the best fit for the graph against the time.

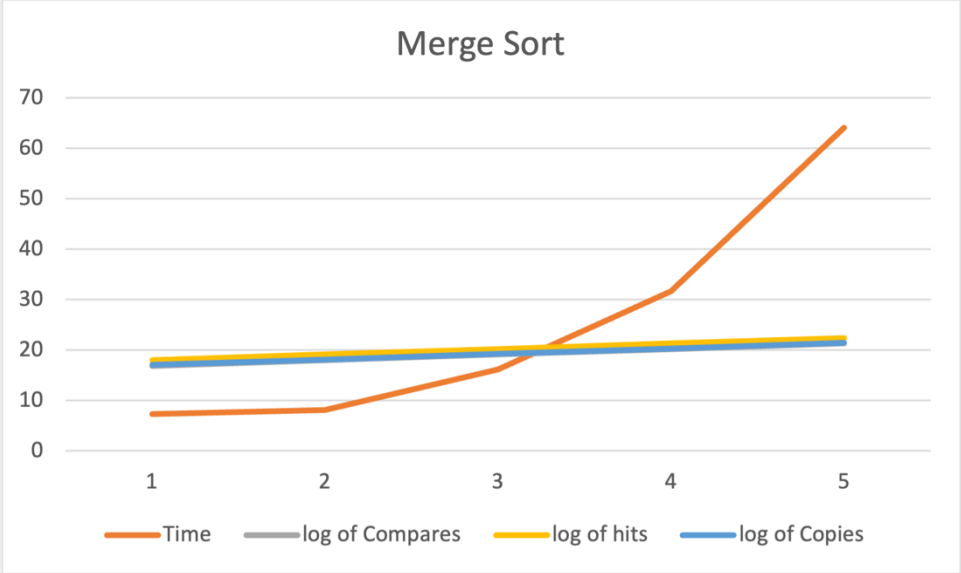
Evidence to support that conclusion and Graphical Representation:

For merge Sort following is the table for N, time taken for 20 runs and number of compares, swaps, hits and copies, followed by the table with log values of compares, hits and copies to the base 2.

N	Time	Compares	Swaps	Hits	Copies
10000	7.35702705	120477	0	267232	133616
20000	8.1472354	260884	0	574464	287232
40000	16.1321895	561772	0	1228928	614464
80000	31.699177	1203502	0	2617856	1308928
160000	64.0574708	2567277	0	5555712	2777856

N	Time	log of Compares	log of hits	log of Copies
10000	7.35702705	16.87839823	18.0277333	17.0277333
20000	8.1472354	17.99304894	19.131857	18.131857
40000	16.1321895	19.09962519	20.228969	19.228969
80000	31.699177	20.19880711	21.3199543	20.3199543
160000	64.0574708	21.29180754	22.4055404	21.4055404

Graph for the Merge Sort:- taking time with the log values of the metrics involved.



For Quick Sort with Dual Pivot :-

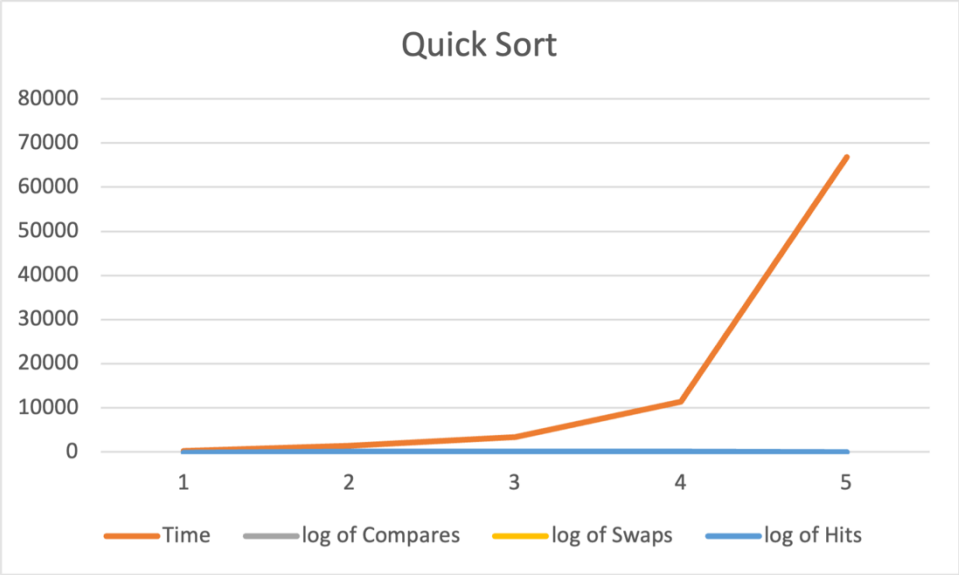
For quick Sort following is the table for N, time taken for 20 runs and number of compares, swaps, hits and followed by the table with log values of compares, swaps and hits to the base 2.

N	Time	Compares	Swaps	Hits
10000	231.103067	158452	72207	460021
20000	1451.22262	420077	154985	1066498
40000	3391.84109	750116	331705	2132387
80000	11374.9657	1779383	632082	4422928
160000	66846.4994	4121721	1275698	9459691

N	Time	log of Compares	log of Swaps	log of Hits
10000	231.103067	17.27368634	16.1398511	18.8113402
20000	1451.22262	18.68029427	17.2417691	20.0244498
40000	3391.84109	19.51675419	18.3395412	21.0240379
80000	11374.9657	20.76294564	19.2697522	22.0765703
160000	66846.4994	21.97481542	20.2828554	23.1733616

Graph for Quick Sort Dual Pivot :- taking time with the log values of the metrics involved.

Here we can see log of compares, swaps and hits are close by and coincide with each other, but the log of Hits has highest value, making it best fit with the time graph.



For Heap Sort:-

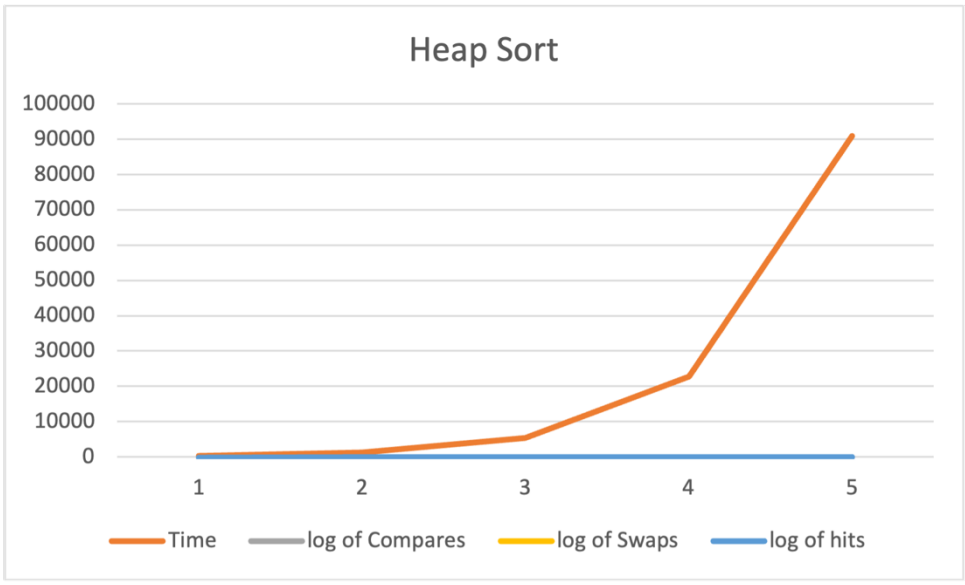
For Heap Sort following is the table for N, time taken for 20 runs and number of compares, swaps, hits and followed by the table with log values of compares, swaps and hits to the base 2.

N	Time	Comapres	Swaps	Hits
10000	306.266348	235460	124298	968112
20000	1292.82619	510735	268337	2094818
40000	5420.86169	1101413	576673	4509518
80000	22769.8491	2363155	1233747	9661298
160000	90969.3473	5046545	2627359	20602526

N	Time	log of Compares	log of Swaps	log of hits
10000	306.266348	17.84512247	16.9234436	19.8848144
20000	1292.82619	18.9622154	18.0336865	20.9983935
40000	5420.86169	20.07092411	19.137394	22.1045418
80000	22769.8491	21.17228283	20.2346152	23.2037856
160000	90969.3473	22.26686459	21.3251819	24.2963179

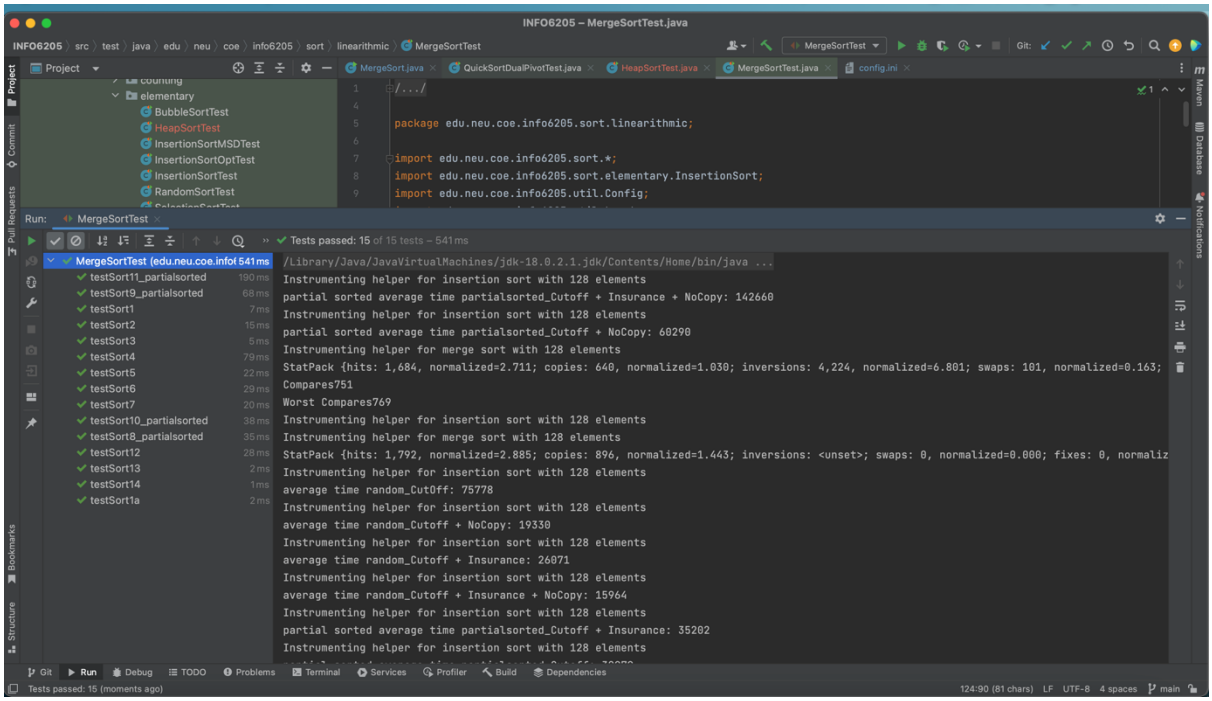
Graph for Heap Sort:- taking time with the log values of the metrics involved.

Here we can see log of compares, swaps and hits are close by and coincide with each other, but the log of Hits has highest value, making it best fit with the time graph.

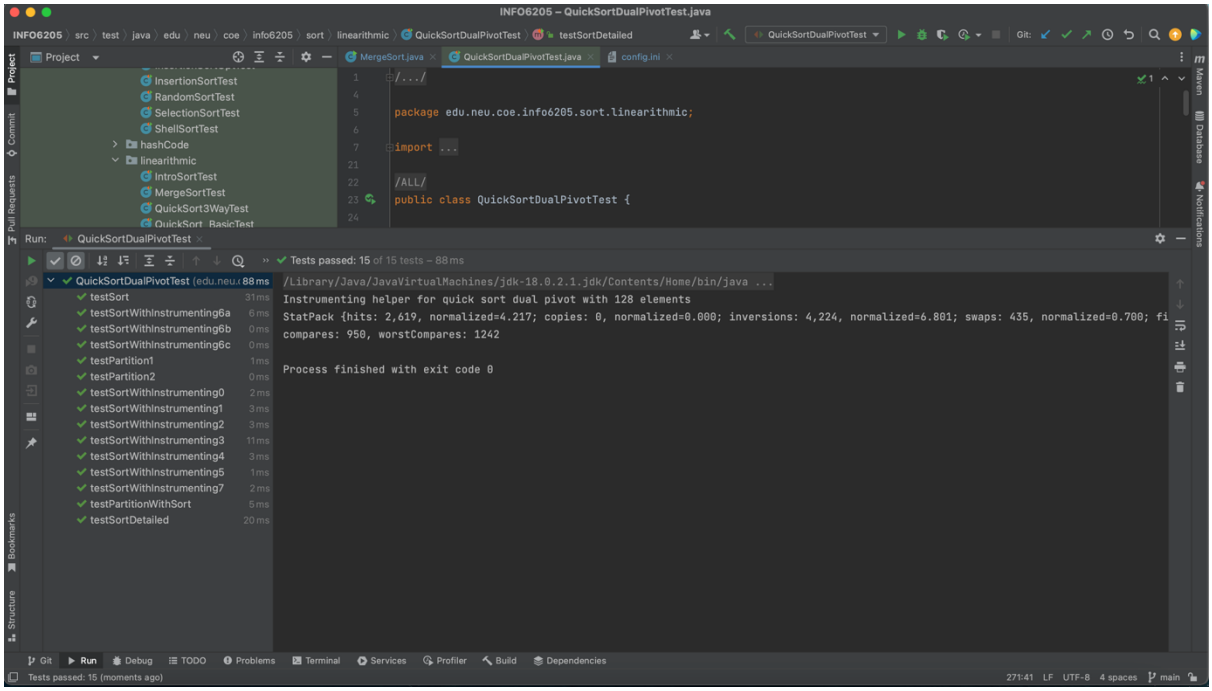


Unit Test Cases:

Screenshot for MergeSort Test Cases:-



Screenshot for Quick Sort Dual Pivot Test Cases:-



Screenshot for HeapSort Test cases:-