

# **Program Structures and Algorithms**

**Spring 2023(SEC –01)**

## **Assignment-6**

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### **Problem**

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, and 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).

The configuration for these benchmarks is determined by the *config.ini* file. It should be reasonably easy to figure out how it all works.

### **Observation:-**

For the Dual Pivot Quick Sort algorithm, the most crucial factor affecting its runtime is the number of comparisons made during the sorting process. Although other predictors such as swaps, hits, and copies are essential, they do not have as significant an impact on the overall execution time as the number of comparisons.

As for the Merge Sort algorithm, as the size of the input data increases, more temporary arrays are required, resulting in a rise in the number of copies and hits. Therefore, the number of copies and hits can be considered reliable predictors of the Merge Sort algorithm's runtime.

For the Heap Sort algorithm, the number of comparisons made during the sorting process is the most crucial factor affecting its runtime. Although the other metrics such as swaps, hits, and copies increase slightly with the input size, they do not have as significant an impact on the overall execution time as the number of comparisons. Consequently, the number of comparisons can be relied upon as the most dependable metric for forecasting the Heap Sort algorithm's overall execution time. Additionally, the normalized time, which quantifies the total execution time

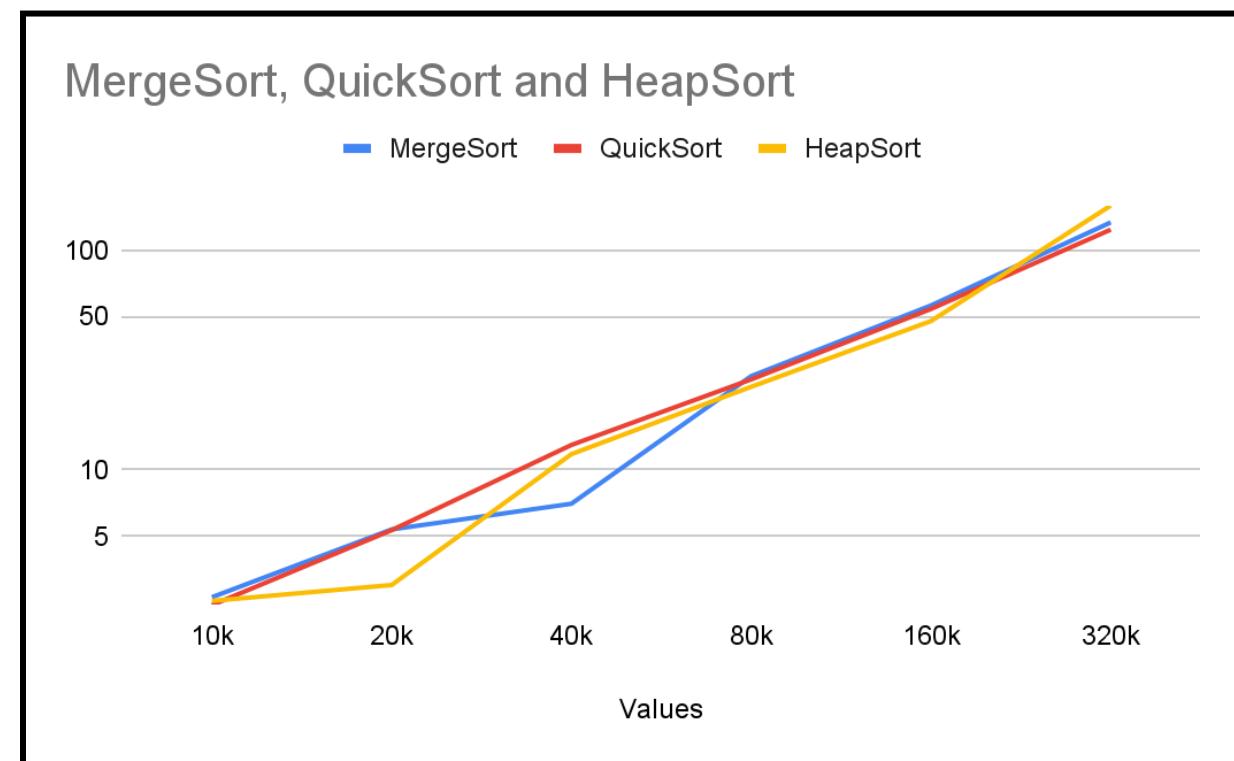
### **Output Result:-**

MergeSort						
Values	RawTime	NormalizedTime	Compares	Swaps	Hits	
10k	2.64	3.72	1.319	0.106	2.813	
20k	5.37	3.48	1.348	0.099	2.817	
40k	7.03	4.56	2.579	1.355	10.577	
80k	26.76	3.76	1.342	0.086	2.826	
160k	56.1	3.69	1.348	0.081	2.28	
320k	133.95	4.14	1.369	0.077	2.832	

QuickSort						
Values	RawTime	NormalizedTime	Compares	Swaps	Hits	
10k	2.43	3.41	1.693	0.722	4.532	
20k	5.33	3.46	1.348	0.099	1.212	
40k	13.01	3.91	1.354	0.092	1.227	
80k	25.86	3.63	1.36	0.086	2.861	
160k	54.08	3.56	1.365	0.081	2.863	
320k	124.16	3.84	1.369	0.077	2.864	

HeapSort						
Values	RawTime	NormalizedTime	Compares	Swaps	Hits	
10k	2.54	3.58	1.341	0.106	2.856	
20k	3	4.22	2.556	1.349	10.505	
40k	11.82	3.56	1.73	0.729	4.6	
80k	23.93	3.36	1.741	0.725	4.602	
160k	47.64	3.13	1.763	0.735	4.663	
320k	158.74	3.36	1.782	0.735	4.687	

Values	MergeSort	QuickSort	HeapSort
10k	2.64	2.43	2.54
20k	5.37	5.33	3
40k	7.03	13.01	11.82
80k	26.76	25.86	23.93
160k	56.1	54.08	47.64
320k	133.95	124.16	159.74



The screenshot shows a Java IDE interface with a terminal window displaying log output. The log output details the execution of a sorting benchmark, specifically comparing different sorting algorithms (Mergesort, SorterBenchmark, and Heapsort) on a dataset of 10,000 elements. The log includes timestamps, algorithm names, and performance metrics like time per run and swap counts.

```
/Users/swarag/Library/Java/JavaVirtualMachines/openjdk-19.0.1/Contents/Home/bin/java ...
2023-03-12 23:40:35 INFO SortBenchmark - SortBenchmark.main: null with word counts: [10000, 20000, 40000, 80000, 160000, 320000]
2023-03-12 23:40:35 INFO SortBenchmark - Beginning String sorts
2023-03-12 23:40:35 INFO SortBenchmarkHelper - Testing with words: 22,865 from eng-uk_web_2002_10K-sentences.txt
2023-03-12 23:40:35 INFO SortBenchmark - Testing pure sorts with 844 runs of sorting 10,000 words
2023-03-12 23:40:35 INFO SorterBenchmark - run: sort 10,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 844 runs using sorter: Mergesort
2023-03-12 23:40:35 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 10,000 elements with 844 runs
2023-03-12 23:40:38 INFO TimeLogger - Raw time per run (mSec): 2.64
2023-03-12 23:40:38 INFO TimeLogger - Normalized time per run (n log n): 3.72
2023-03-12 23:40:38 INFO SortBenchmark - Mergesort: StatPack {hits: mean=259,042; stdDev=340, normalized=2.813; copies: 110,000, normalized=1.194; inversions: <unset>; swaps: mean=9,761; stdDev
2023-03-12 23:40:40 INFO SorterBenchmark - run: sort 10,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 844 runs using sorter: Mergesort
2023-03-12 23:40:40 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 10,000 elements with 844 runs
2023-03-12 23:40:40 INFO TimeLogger - Raw time per run (mSec): 2.51
2023-03-12 23:40:40 INFO TimeLogger - Normalized time per run (n log n): 3.53
2023-03-12 23:40:42 INFO SortBenchmark - Mergesort: StatPack {hits: mean=258,945; stdDev=343, normalized=2.811; copies: mean=109,952; stdDev=21, normalized=1.194; inversions: <unset>; swaps: me
2023-03-12 23:40:42 INFO SorterBenchmark - run: sort 10,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 844 runs using sorter: Mergesort
2023-03-12 23:40:42 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 10,000 elements with 844 runs
2023-03-12 23:40:42 INFO TimeLogger - Raw time per run (mSec): 2.49
2023-03-12 23:40:42 INFO TimeLogger - Normalized time per run (n log n): 3.50
2023-03-12 23:40:45 INFO SortBenchmark - Mergesort: StatPack {hits: mean=259,042; stdDev=340, normalized=2.813; copies: 110,000, normalized=1.194; inversions: <unset>; swaps: mean=9,761; stdDev
2023-03-12 23:40:42 INFO SorterBenchmark - run: sort 10,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 844 runs using sorter: Mergesort
2023-03-12 23:40:42 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 10,000 elements with 844 runs
2023-03-12 23:40:45 INFO TimeLogger - Raw time per run (mSec): 2.49
2023-03-12 23:40:45 INFO TimeLogger - Normalized time per run (n log n): 3.50
2023-03-12 23:40:45 INFO SortBenchmark - Mergesort: StatPack {hits: mean=263,039; stdDev=343, normalized=2.856; copies: 110,000, normalized=1.194; inversions: <unset>; swaps: mean=9,761; stdDev
2023-03-12 23:40:45 INFO SorterBenchmark - run: sort 10,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 844 runs using sorter: QuickSort dual pivot
2023-03-12 23:40:45 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 10,000 elements with 844 runs
2023-03-12 23:40:47 INFO TimeLogger - Raw time per run (mSec): 2.54
2023-03-12 23:40:47 INFO TimeLogger - Normalized time per run (n log n): 3.58
2023-03-12 23:40:47 INFO SorterBenchmark - run: sort 10,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 844 runs using sorter: Heapsort
2023-03-12 23:40:47 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 10,000 elements with 844 runs
```



```
psa_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > HeapSort.java > SortBenchmark.java > Config.java > SorterBenchmark.java > test.../config.ini > MergeSort.java > Ins > Run: SortBenchmark >
```

Run: SortBenchmark

```
2023-03-12 23:41:19 INFO TimeLogger - Raw time per run (mSec): 6.61
2023-03-12 23:41:19 INFO TimeLogger - Normalized time per run (n log n): 4.29
2023-03-12 23:41:19 INFO SortBenchmarkHelper - Testing with words: 22,865 from eng-uk_web_2082_10K-sentences.txt
2023-03-12 23:41:19 INFO SortBenchmark - Testing with 389 runs of sorting 20,000 words and instrumented
2023-03-12 23:41:19 INFO SorterBenchmark - run: sort 20,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 389 runs using sorter: Mergesort
2023-03-12 23:41:19 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 20,000 elements with 389 runs
2023-03-12 23:41:21 INFO TimeLogger - Raw time per run (mSec): 5.38
2023-03-12 23:41:21 INFO TimeLogger - Normalized time per run (n log n): 3.49
2023-03-12 23:41:21 INFO SortBenchmark - Mergesort: StatPack {hits: mean=558,079; stdDev=482, normalized=2.818; copies: 240,000, normalized=1.212; inversions: <unset>; swaps: mean=19,529; stdDev=1,076}
2023-03-12 23:41:21 INFO SorterBenchmark - run: sort 20,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 389 runs using sorter: Mergesort
2023-03-12 23:41:21 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 20,000 elements with 389 runs
2023-03-12 23:41:23 INFO TimeLogger - Raw time per run (mSec): 5.45
2023-03-12 23:41:23 INFO SortBenchmark - Mergesort: StatPack {hits: mean=557,886; stdDev=485, normalized=2.817; copies: mean=239,903; stdDev=31, normalized=1.211; inversions: <unset>; swaps: mean=19,528; stdDev=1,076}
2023-03-12 23:41:23 INFO SorterBenchmark - run: sort 20,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 389 runs using sorter: Mergesort
2023-03-12 23:41:23 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 20,000 elements with 389 runs
2023-03-12 23:41:26 INFO TimeLogger - Raw time per run (mSec): 5.32
2023-03-12 23:41:26 INFO TimeLogger - Normalized time per run (n log n): 3.45
2023-03-12 23:41:26 INFO SortBenchmark - Mergesort: StatPack {hits: mean=558,079; stdDev=482, normalized=2.818; copies: 240,000, normalized=1.212; inversions: <unset>; swaps: mean=19,528; stdDev=1,076}
2023-03-12 23:41:26 INFO SorterBenchmark - run: sort 20,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 389 runs using sorter: Mergesort
2023-03-12 23:41:26 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 20,000 elements with 389 runs
2023-03-12 23:41:28 INFO TimeLogger - Raw time per run (mSec): 5.41
2023-03-12 23:41:28 INFO TimeLogger - Normalized time per run (n log n): 3.51
2023-03-12 23:41:28 INFO SortBenchmark - Mergesort: StatPack {hits: mean=566,076; stdDev=485, normalized=2.858; copies: 240,000, normalized=1.212; inversions: <unset>; swaps: mean=19,528; stdDev=1,076}
2023-03-12 23:41:28 INFO SorterBenchmark - run: sort 20,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 389 runs using sorter: Mergesort
2023-03-12 23:41:28 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuicksortDualPivot with 20,000 elements with 389 runs
2023-03-12 23:41:30 INFO TimeLogger - Raw time per run (mSec): 5.31
2023-03-12 23:41:30 INFO TimeLogger - Normalized time per run (n log n): 3.44
2023-03-12 23:41:30 INFO SortBenchmark - QuicksortDualPivot: StatPack {hits: mean=901,631; stdDev=37,033, normalized=4.552; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=142,489}
2023-03-12 23:41:30 INFO SorterBenchmark - run: sort 20,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 389 runs using sorter: Heapsort
2023-03-12 23:41:30 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 20,000 elements with 389 runs
Build completed successfully in 3 sec, 701 ms (29 minutes ago)
```

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psa_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > HeapSort.java > SortBenchmark.java > Config.java > SorterBenchmark.java > test.../config.ini > MergeSort.java > Ins > Run: SortBenchmark >
```

Run: SortBenchmark

```
2023-03-12 23:41:33 INFO TimeLogger - Raw time per run (mSec): 7.03
2023-03-12 23:41:33 INFO TimeLogger - Normalized time per run (n log n): 4.56
2023-03-12 23:41:33 INFO SortBenchmark - Heapsort: StatPack {hits: mean=2,695,056; stdDev=628, normalized=10.577; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=268,396; stdDev=1,076}
2023-03-12 23:41:34 INFO SortBenchmarkHelper - Testing with words: 81,546 from eng-uk_web_2082_10K-sentences.txt
2023-03-12 23:41:34 INFO SortBenchmark - Testing pure sorts with 181 runs of sorting 40,000 words
2023-03-12 23:41:34 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:34 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:37 INFO TimeLogger - Raw time per run (mSec): 13.19
2023-03-12 23:41:37 INFO TimeLogger - Normalized time per run (n log n): 3.97
2023-03-12 23:41:37 INFO SortBenchmark - Mergesort: StatPack {hits: mean=1,196,150; stdDev=710, normalized=2.822; copies: 520,000, normalized=1.227; inversions: <unset>; swaps: mean=39,037; stdDev=1,076}
2023-03-12 23:41:37 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:37 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:39 INFO TimeLogger - Raw time per run (mSec): 13.03
2023-03-12 23:41:39 INFO TimeLogger - Normalized time per run (n log n): 3.92
2023-03-12 23:41:39 INFO SortBenchmark - Mergesort: StatPack {hits: mean=1,195,778; stdDev=724, normalized=2.821; copies: mean=519,810; stdDev=46, normalized=1.226; inversions: <unset>; swaps: mean=39,037; stdDev=1,076}
2023-03-12 23:41:39 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:39 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:42 INFO TimeLogger - Raw time per run (mSec): 12.22
2023-03-12 23:41:42 INFO TimeLogger - Normalized time per run (n log n): 3.68
2023-03-12 23:41:42 INFO SortBenchmark - Mergesort: StatPack {hits: mean=1,196,150; stdDev=710, normalized=2.822; copies: 520,000, normalized=1.227; inversions: <unset>; swaps: mean=39,037; stdDev=1,076}
2023-03-12 23:41:42 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:42 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:45 INFO TimeLogger - Raw time per run (mSec): 13.01
2023-03-12 23:41:45 INFO TimeLogger - Normalized time per run (n log n): 3.91
2023-03-12 23:41:45 INFO SortBenchmark - Mergesort: StatPack {hits: mean=1,212,152; stdDev=724, normalized=2.868; copies: 520,000, normalized=1.227; inversions: <unset>; swaps: mean=39,037; stdDev=1,076}
2023-03-12 23:41:45 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: QuickSort dual pivot
2023-03-12 23:41:45 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 40,000 elements with 181 runs
2023-03-12 23:41:47 INFO TimeLogger - Raw time per run (mSec): 10.49
2023-03-12 23:41:47 INFO TimeLogger - Normalized time per run (n log n): 3.16
2023-03-12 23:41:47 INFO SortBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Heapsort
2023-03-12 23:41:47 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 40,000 elements with 181 runs
Build completed successfully in 3 sec, 701 ms (29 minutes ago)
```

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psa_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > SortBenchmark.java > HeapSort.java > Config.java > SorterBenchmark.java > test.../config.ini > MergeSort.java > Ins > m
```

Run: SortBenchmark

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2023-03-12 23:41:50 INFO TimeLogger - Raw time per run (mSec): 15.18
2023-03-12 23:41:50 INFO TimeLogger - Normalized time per run (n log n): 4.57
2023-03-12 23:41:50 INFO SortBenchmarkHelper - Testing with words: 81,546 from eng-uk_web_2002_100K-sentences.txt
2023-03-12 23:41:50 INFO SorterBenchmark - Testing with 181 runs of sorting 40,000 words and instrumented
2023-03-12 23:41:50 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:53 INFO TimeLogger - Raw time per run (mSec): 12.69
2023-03-12 23:41:53 INFO SorterBenchmark - Normalized time per run (n log n): 3.82
2023-03-12 23:41:53 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=1,196,150; stdDev=710, normalized=2.822; copies: 520,000, normalized=1.227; inversions: <unset>; swaps: mean=39,037; stdDev=1,196,150}
2023-03-12 23:41:53 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:53 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:55 INFO TimeLogger - Raw time per run (mSec): 12.46
2023-03-12 23:41:55 INFO TimeLogger - Normalized time per run (n log n): 3.75
2023-03-12 23:41:55 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=1,195,770; stdDev=724, normalized=2.821; copies: mean=519,810; stdDev=46, normalized=1.226; inversions: <unset>; swaps: i}
2023-03-12 23:41:55 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:55 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:41:58 INFO TimeLogger - Raw time per run (mSec): 12.78
2023-03-12 23:41:58 INFO SorterBenchmark - Normalized time per run (n log n): 3.85
2023-03-12 23:41:58 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=1,196,150; stdDev=710, normalized=2.822; copies: 520,000, normalized=1.227; inversions: <unset>; swaps: mean=39,037; stdDev=1,196,150}
2023-03-12 23:41:58 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Mergesort
2023-03-12 23:41:58 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 40,000 elements with 181 runs
2023-03-12 23:42:01 INFO TimeLogger - Raw time per run (mSec): 14.06
2023-03-12 23:42:01 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=1,212,152; stdDev=724, normalized=2.868; copies: 520,000, normalized=1.227; inversions: <unset>; swaps: mean=39,037; stdDev=1,212,152}
2023-03-12 23:42:01 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: QuicksortDualPivot
2023-03-12 23:42:01 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuicksortDualPivot with 40,000 elements with 181 runs
2023-03-12 23:42:04 INFO TimeLogger - Raw time per run (mSec): 11.82
2023-03-12 23:42:04 INFO SorterBenchmark - Normalized time per run (n log n): 3.56
2023-03-12 23:42:04 INFO SorterBenchmark - QuicksortDualPivot: StatPack {hits: mean=1,949,902; stdDev=72,586, normalized=4.600; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=308,7}
2023-03-12 23:42:04 INFO SorterBenchmark - run: sort 40,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 181 runs using sorter: Heapsort
2023-03-12 23:42:06 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 40,000 elements with 181 runs
```

Build completed successfully in 3 sec, 701 ms (29 minutes ago)

```
psa_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > SortBenchmark.java > HeapSort.java > Config.java > SorterBenchmark.java > test.../config.ini > MergeSort.java > Ins > m
```

Run: SortBenchmark

```
2023-03-12 23:42:04 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 40,000 elements with 181 runs
2023-03-12 23:42:07 INFO TimeLogger - Raw time per run (mSec): 15.99
2023-03-12 23:42:07 INFO TimeLogger - Normalized time per run (n log n): 4.81
2023-03-12 23:42:07 INFO SortBenchmark - Heapsort: StatPack {hits: mean=4,510,166; stdDev=946, normalized=10.641; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=576,797; stdDev=1,196,150}
2023-03-12 23:42:07 INFO SortBenchmarkHelper - Testing with words: 81,546 from eng-uk_web_2002_100K-sentences.txt
2023-03-12 23:42:07 INFO SorterBenchmark - Testing pure sorts with 84 runs of sorting 80,000 words
2023-03-12 23:42:07 INFO SorterBenchmark - run: sort 80,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 84 runs using sorter: Mergesort
2023-03-12 23:42:07 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 80,000 elements with 84 runs
2023-03-12 23:42:10 INFO TimeLogger - Raw time per run (mSec): 26.76
2023-03-12 23:42:10 INFO TimeLogger - Normalized time per run (n log n): 3.76
2023-03-12 23:42:10 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=2,552,243; stdDev=1,009, normalized=2.826; copies: 1,120,000, normalized=1.240; inversions: <unset>; swaps: mean=78,061; stdDev=2,552,243}
2023-03-12 23:42:10 INFO SorterBenchmark - run: sort 80,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 84 runs using sorter: Mergesort
2023-03-12 23:42:10 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 80,000 elements with 84 runs
2023-03-12 23:42:15 INFO TimeLogger - Raw time per run (mSec): 27.93
2023-03-12 23:42:15 INFO TimeLogger - Normalized time per run (n log n): 3.92
2023-03-12 23:42:15 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=2,551,481; stdDev=1,019, normalized=2.825; copies: mean=1,119,619; stdDev=64, normalized=1.240; inversions: <unset>; swaps: mean=78,061; stdDev=2,551,481}
2023-03-12 23:42:15 INFO SorterBenchmark - run: sort 80,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 84 runs using sorter: Mergesort
2023-03-12 23:42:15 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 80,000 elements with 84 runs
2023-03-12 23:42:18 INFO TimeLogger - Raw time per run (mSec): 25.86
2023-03-12 23:42:18 INFO TimeLogger - Normalized time per run (n log n): 3.63
2023-03-12 23:42:18 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=2,584,247; stdDev=1,019, normalized=2.861; copies: 1,120,000, normalized=1.240; inversions: <unset>; swaps: mean=78,061; stdDev=2,584,247}
2023-03-12 23:42:18 INFO SorterBenchmark - run: sort 80,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 84 runs using sorter: QuickSort dual pivot
2023-03-12 23:42:18 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 80,000 elements with 84 runs
2023-03-12 23:42:20 INFO TimeLogger - Raw time per run (mSec): 22.68
2023-03-12 23:42:20 INFO TimeLogger - Normalized time per run (n log n): 3.18
2023-03-12 23:42:20 INFO SorterBenchmark - run: sort 80,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 84 runs using sorter: Heapsort
```

Build completed successfully in 3 sec, 701 ms (29 minutes ago)



psa\_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > SortBenchmark.java

```

2023-03-12 23:42:53 INFO TimeLogger - Normalized time per run (n log n): 3.12
2023-03-12 23:42:53 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Heapsort
2023-03-12 23:42:53 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 160,000 elements with 39 runs
2023-03-12 23:42:56 INFO TimeLogger - Raw time per run (mSec): 72.15
2023-03-12 23:42:56 INFO TimeLogger - Normalized time per run (n log n): 4.74
2023-03-12 23:42:56 INFO SorterBenchmarkHelper - Testing with words: 303,172 from eng-uk_web_2002_1M-words.txt
2023-03-12 23:42:56 INFO SorterBenchmark - Testing with 39 runs of sorting 160,000 words and instrumented
2023-03-12 23:42:56 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Mergesort
2023-03-12 23:42:56 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 160,000 elements with 39 runs
2023-03-12 23:42:59 INFO TimeLogger - Raw time per run (mSec): 57.97
2023-03-12 23:42:59 INFO TimeLogger - Normalized time per run (n log n): 3.81
2023-03-12 23:42:59 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=5,424,406; stdDev=1,630, normalized=2.829; copies: 2,400,000, normalized=1.252; inversions: <unset>; swaps: mean=156,101
2023-03-12 23:42:59 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Mergesort
2023-03-12 23:42:59 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 160,000 elements with 39 runs
2023-03-12 23:43:01 INFO TimeLogger - Raw time per run (mSec): 57.62
2023-03-12 23:43:01 INFO TimeLogger - Normalized time per run (n log n): 3.79
2023-03-12 23:43:01 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=5,422,842; stdDev=1,648, normalized=2.828; copies: mean=2,399,218; stdDev=77, normalized=1.251; inversions: <unset>; swaps: mean=156,101
2023-03-12 23:43:01 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Mergesort
2023-03-12 23:43:01 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 160,000 elements with 39 runs
2023-03-12 23:43:04 INFO TimeLogger - Raw time per run (mSec): 55.36
2023-03-12 23:43:04 INFO TimeLogger - Normalized time per run (n log n): 3.64
2023-03-12 23:43:04 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=5,424,406; stdDev=1,630, normalized=2.829; copies: 2,400,000, normalized=1.252; inversions: <unset>; swaps: mean=156,101
2023-03-12 23:43:04 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Mergesort
2023-03-12 23:43:04 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 160,000 elements with 39 runs
2023-03-12 23:43:06 INFO TimeLogger - Raw time per run (mSec): 54.90
2023-03-12 23:43:06 INFO TimeLogger - Normalized time per run (n log n): 3.61
2023-03-12 23:43:06 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=5,488,376; stdDev=1,648, normalized=2.863; copies: 2,400,000, normalized=1.252; inversions: <unset>; swaps: mean=156,101
2023-03-12 23:43:06 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Mergesort
2023-03-12 23:43:06 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuicksortDualPivot with 160,000 elements with 39 runs
2023-03-12 23:43:08 INFO TimeLogger - Raw time per run (mSec): 47.64

```

Build completed successfully in 3 sec, 701 ms (29 minutes ago)

psa\_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > SortBenchmark.java

```

2023-03-12 23:43:08 INFO TimeLogger - Raw time per run (mSec): 47.64
2023-03-12 23:43:08 INFO TimeLogger - Normalized time per run (n log n): 3.13
2023-03-12 23:43:08 INFO SorterBenchmark - QuicksortDualPivot: StatPack {hits: mean=8,940,447; stdDev=296,239, normalized=4.663; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=1,480
2023-03-12 23:43:08 INFO SorterBenchmark - run: sort 160,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 39 runs using sorter: Heapsort
2023-03-12 23:43:12 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 160,000 elements with 39 runs
2023-03-12 23:43:12 INFO TimeLogger - Raw time per run (mSec): 71.95
2023-03-12 23:43:12 INFO TimeLogger - Normalized time per run (n log n): 4.73
2023-03-12 23:43:12 INFO SorterBenchmark - Heapsort: StatPack {hits: mean=20,600,863; stdDev=2,289, normalized=10.745; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=2,627,215; stdDev=1,480
2023-03-12 23:43:12 INFO SorterBenchmarkHelper - Testing with words: 303,172 from eng-uk_web_2002_1M-words.txt
2023-03-12 23:43:12 INFO SorterBenchmark - Testing pure sorts with 19 runs of sorting 320,000 words
2023-03-12 23:43:12 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:12 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:15 INFO TimeLogger - Raw time per run (mSec): 124.16
2023-03-12 23:43:15 INFO TimeLogger - Normalized time per run (n log n): 3.84
2023-03-12 23:43:15 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=11,488,999; stdDev=2,051, normalized=2.832; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:15 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:15 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:18 INFO TimeLogger - Raw time per run (mSec): 133.95
2023-03-12 23:43:18 INFO TimeLogger - Normalized time per run (n log n): 4.14
2023-03-12 23:43:18 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=11,485,885; stdDev=2,045, normalized=2.832; copies: mean=5,118,443; stdDev=100, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:18 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:18 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:21 INFO TimeLogger - Raw time per run (mSec): 122.95
2023-03-12 23:43:21 INFO TimeLogger - Normalized time per run (n log n): 3.88
2023-03-12 23:43:21 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=11,488,999; stdDev=2,051, normalized=2.832; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:21 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:21 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:23 INFO TimeLogger - Raw time per run (mSec): 122.74
2023-03-12 23:43:23 INFO TimeLogger - Normalized time per run (n log n): 3.79
2023-03-12 23:43:23 INFO SorterBenchmark - Mergesort: StatPack {hits: mean=11,616,955; stdDev=2,045, normalized=2.864; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251

```

Build completed successfully in 3 sec, 701 ms (30 minutes ago)

psa\_backup > INFO6205 > src > main > java > edu > neu > coe > info6205 > sort > elementary > SortBenchmark.java

```

2023-03-12 23:43:23 INFO SortBenchmark - Mergesort: StatPack {hits: mean=11,616,955; stdDev=2,045, normalized=2.864; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:23 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: QuickSort dual pivot
2023-03-12 23:43:23 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 320,000 elements with 19 runs
2023-03-12 23:43:26 INFO TimeLogger - Raw time per run (mSec): 111.21
2023-03-12 23:43:26 INFO TimeLogger - Normalized time per run (n log n): 3.44
2023-03-12 23:43:26 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Heapsort
2023-03-12 23:43:26 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 320,000 elements with 19 runs
2023-03-12 23:43:30 INFO TimeLogger - Raw time per run (mSec): 162.00
2023-03-12 23:43:30 INFO TimeLogger - Normalized time per run (n log n): 5.01
2023-03-12 23:43:30 INFO SortBenchmarkHelper - Testing with words: 303,172 from eng-uk_web_2002_1M-words.txt
2023-03-12 23:43:30 INFO SortBenchmark - Testing with 19 runs of sorting 320,000 words and instrumented
2023-03-12 23:43:30 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:30 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:33 INFO TimeLogger - Raw time per run (mSec): 129.16
2023-03-12 23:43:33 INFO TimeLogger - Normalized time per run (n log n): 3.99
2023-03-12 23:43:33 INFO SortBenchmark - Mergesort: StatPack {hits: mean=11,488,999; stdDev=2,051, normalized=2.832; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:33 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:33 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:36 INFO TimeLogger - Raw time per run (mSec): 128.32
2023-03-12 23:43:36 INFO TimeLogger - Normalized time per run (n log n): 3.97
2023-03-12 23:43:36 INFO SortBenchmark - Mergesort: StatPack {hits: mean=11,485,885; stdDev=2,051, normalized=2.832; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:36 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:36 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:39 INFO TimeLogger - Raw time per run (mSec): 127.11
2023-03-12 23:43:39 INFO TimeLogger - Normalized time per run (n log n): 3.93
2023-03-12 23:43:39 INFO SortBenchmark - Mergesort: StatPack {hits: mean=11,488,999; stdDev=2,051, normalized=2.832; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:39 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Mergesort
2023-03-12 23:43:39 INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 320,000 elements with 19 runs
2023-03-12 23:43:42 INFO TimeLogger - Raw time per run (mSec): 124.16
2023-03-12 23:43:42 INFO TimeLogger - Normalized time per run (n log n): 3.84
2023-03-12 23:43:42 INFO SortBenchmark - Mergesort: StatPack {hits: mean=11,616,955; stdDev=2,045, normalized=2.864; copies: 5,120,000, normalized=1.262; inversions: <unset>; swaps: mean=312,251
2023-03-12 23:43:42 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: QuicksortDualPivot
2023-03-12 23:43:42 INFO Benchmark_Timer - Begin run: Instrumenting helper for QuicksortDualPivot with 320,000 elements with 19 runs
2023-03-12 23:43:44 INFO TimeLogger - Raw time per run (mSec): 108.74
2023-03-12 23:43:44 INFO TimeLogger - Normalized time per run (n log n): 3.36
2023-03-12 23:43:44 INFO SortBenchmark - QuicksortDualPivot: StatPack {hits: mean=19,010,228; stdDev=710,290, normalized=4.687; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=2,9
2023-03-12 23:43:44 INFO SorterBenchmark - run: sort 320,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 19 runs using sorter: Heapsort
2023-03-12 23:43:44 INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 320,000 elements with 19 runs
2023-03-12 23:43:48 INFO TimeLogger - Raw time per run (mSec): 161.84
2023-03-12 23:43:48 INFO SortBenchmark - Heapsort: StatPack {hits: mean=43,761,478; stdDev=3,844, normalized=10.788; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=5,574,414; std

```

Process finished with exit code 0

Build completed successfully in 3 sec, 701 ms (30 minutes ago)

## Test Execution

The screenshot shows an IDE interface with the following details:

- Project Structure:** The project is named "test" and contains a package "linearithmic" which includes various test classes like IntroSortTest, MergeSortTest, QuickSort3WayTest, QuickSort\_BasicTest, QuickSort\_ExpTest, QuickSortDualPivotTest, QuickSortTest, BaseHelperTest, Benchmarks, HelperTest, InstrumentedHelperTest, OrderedArrayTest, and SortTest.
- Code Editor:** The "QuickSortDualPivotTest.java" file is open, showing two test methods: `testSortWithInstrumenting1()` and `testSortWithInstrumenting2()`. Both methods use annotations `@Test` and `@Test` respectively, and both call `sorter.sort(xs)`.
- Run Tab:** The "Run" tab is active, showing the output of the test run. It indicates 15 tests passed in 98ms. The output shows the execution of `testSort` and its sub-tests, including `testSortWithinstrumenting6a`, `testSortWithinstrumenting6b`, `testSortWithinstrumenting6c`, `testPartition1`, `testPartition2`, `testSortWithinstrumenting0`, `testSortWithinstrumenting1`, `testSortWithinstrumenting2`, and `testSortWithinstrumenting3`. The total time for these tests is 18ms, with a detailed breakdown of 4.217ms for StatPack metrics and 1.7ms for compares.
- Bottom Status Bar:** The status bar at the bottom shows "Material Oceanic Enabled (7 minutes ago)" and other system information like date and time.

Project: backup > INFO6205 > src > test > java > edu > neu > coe > info6205 > sort > linearithmic > MergeSortTest

MergeSortTest.java

```
1  ...
4
5 package edu.neu.coe.info6205.sort.linearithmic;
6
7 import ...
8
9 /ALL/
10 public class MergeSortTest {
11
12     @xiaohuanlin
13     @beforeClass
14     public static void beforeClass() throws IOException {
15         config = Config.load(MergeSortTest.class);
16     }
17
18     @xiaohuanlin +1
19     @test
20     public void testSort1() throws Exception {
21
22         ...
23     }
24 }
```

Run: MergeSortTest

Tests passed: 15 of 15 tests – 443ms

MergeSortTest (edu.neu.coe.info6205.sort.linearithmic) 443ms

- ✓ testSort11\_partialsorted 159ms
- ✓ testSort9\_partialsorted 67ms
- ✓ testSort1 3ms
- ✓ testSort2 14ms
- ✓ testSort3 4ms
- ✓ testSort4 32ms
- ✓ testSort5 27ms
- ✓ testSort6 20ms
- ✓ testSort7 30ms
- ✓ testSort10\_partialsorted 34ms

Instrumenting helper for insertion sort with 128 elements  
partial sorted average time partialsorted\_Cutoff + Insurance + NoCopy: 117576

Instrumenting helper for insertion sort with 128 elements  
partial sorted average time partialsorted\_Cutoff + NoCopy: 58073

Instrumenting helper for merge sort with 128 elements  
StatPack {hits: 1,684, normalized=2.711; copies: 640, normalized=1.030; inversions: 4,224, normalized=6.801; swaps: 101, normalized=751}

Worst Comparisons769

Instrumenting helper for insertion sort with 128 elements

Instrumenting helper for merge sort with 128 elements  
StatPack {hits: 1,792, normalized=2.885; copies: 896, normalized=1.443; inversions: <unset>; swaps: 0, normalized=0.000; fixes: 0, normalized=0}

Instrumenting helper for insertion sort with 128 elements

24:14 LF UTF-8 4 spaces Spring2023 psa\_backup Material Oceanic

Project: backup > INFO6205 > src > test > java > edu > neu > coe > info6205 > sort > elementary > HeapSortTest

HeapSortTest.java

```
1  ...
4
5 package edu.neu.coe.info6205.sort.elementary;
6
7 import ...
8
9 /ALL/
10 public class HeapSortTest {
11
12     @akshaymatad
13     @test
14     public void sort0() throws Exception {
15         final List<Integer> list = new ArrayList<>();
16         list.add(1);
17         list.add(2);
18         list.add(3);
19         list.add(4);
20         Integer[] xs = list.toArray(new Integer[0]);
21         final Config config = Config.setupConfig(instrumenting: "true", seed: "0", inversions: "1", cutoff: "", interimInversions: "");
22     }
23 }
```

Run: HeapSortTest

Tests passed: 5 of 5 tests – 252ms

HeapSortTest (edu.neu.coe.info6205.sort.elementary) 252ms

- ✓ testMutatingHeapSort 208ms
- ✓ sort0 17ms
- ✓ sort1 13ms
- ✓ sort2 11ms
- ✓ sort3 3ms

Helper for HeapSort with 4 elements

Process finished with exit code 0

22:20 LF UTF-8 4 spaces Spring2023 psa\_backup Material Oceanic