**Program Structures and Algorithms**
**Spring 2023(SEC –01)**
**Assignment-6**

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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.

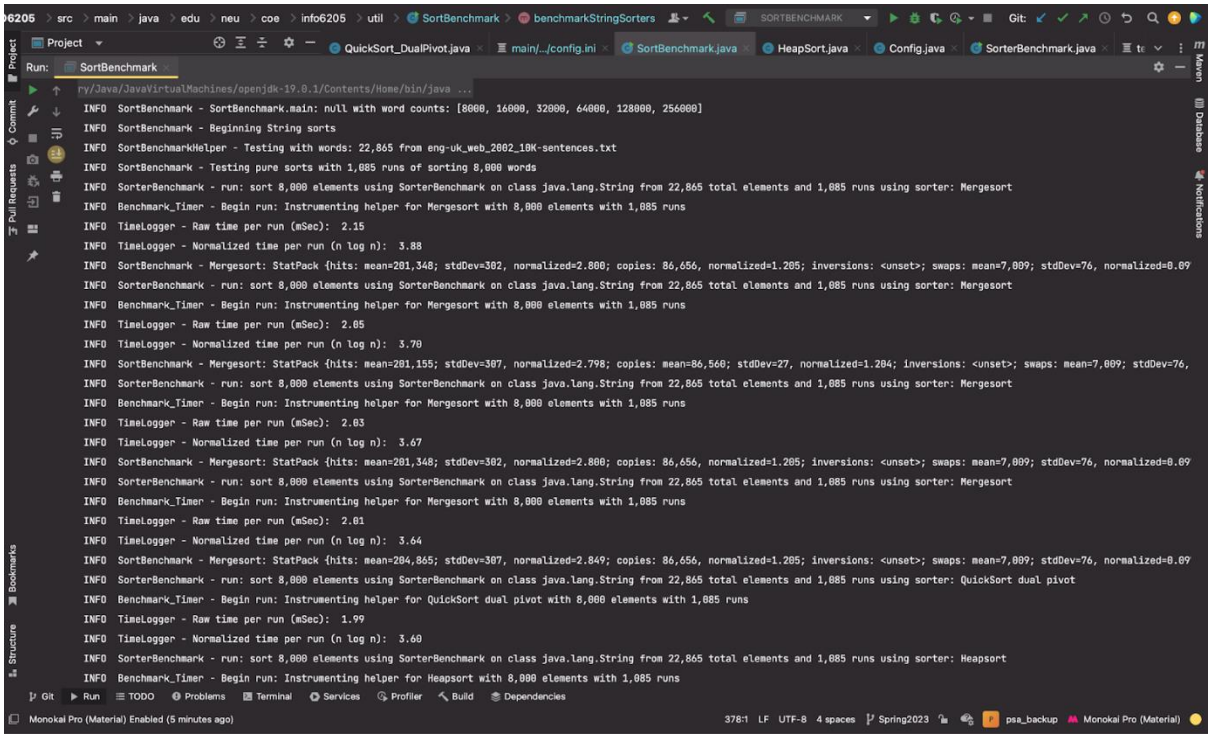
Of course, you will be using the *Benchmark* and/or *Timer* classes, as you did in a previous assignment.

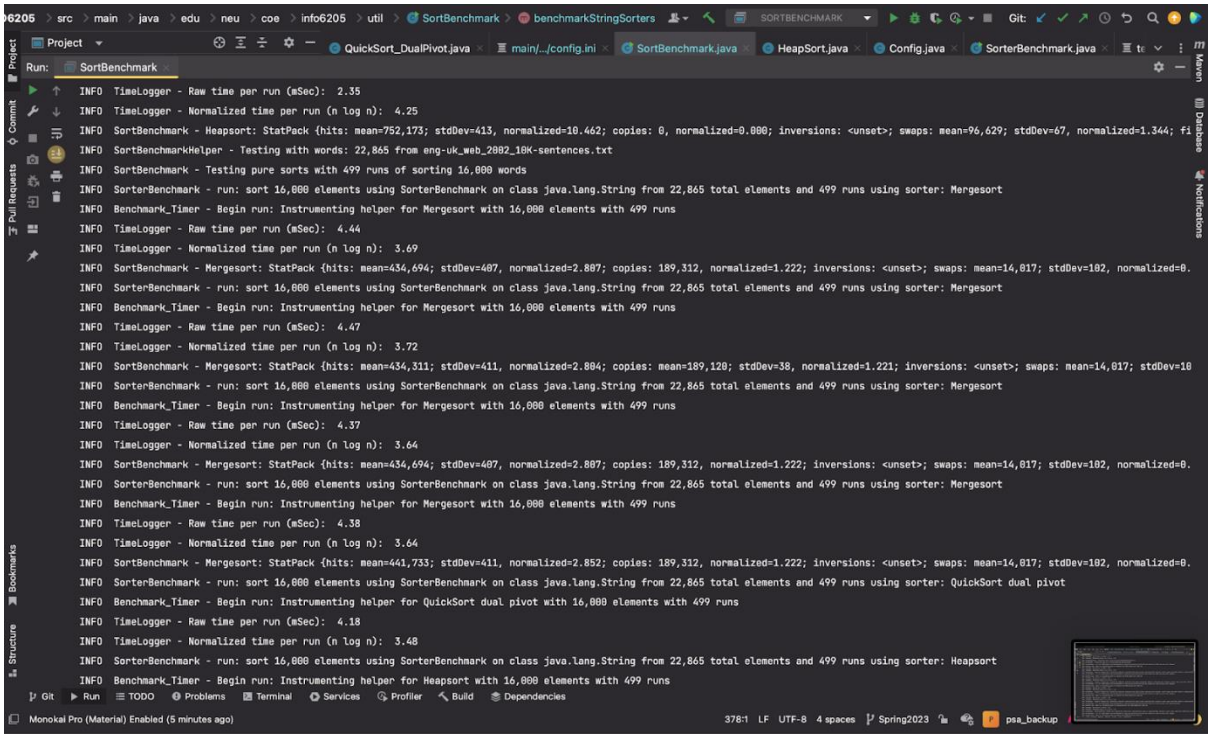
You must support your (clearly stated) conclusions with evidence from the benchmarks (you should provide log/log charts and spreadsheets typically).

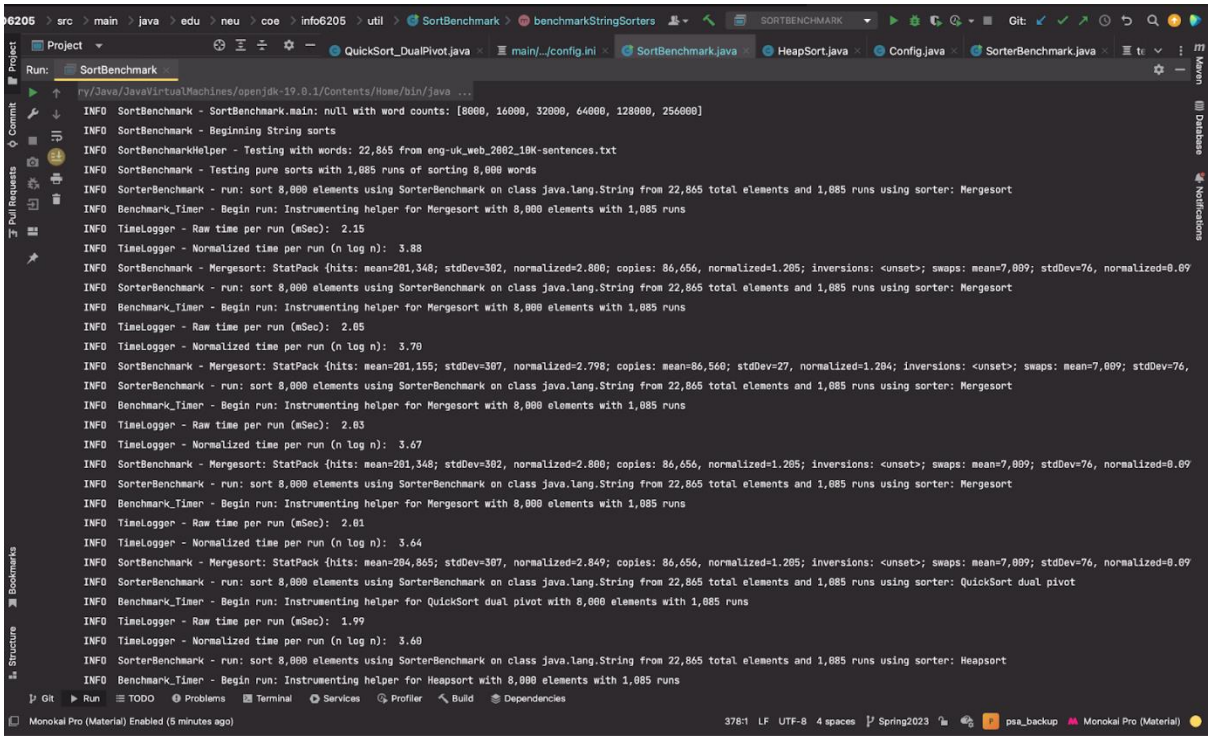
All of the code to count comparisons, swaps/copies, and hits, is already implemented in the *InstrumentedHelper* class. You can see examples of the usage of this kind of analysis in:

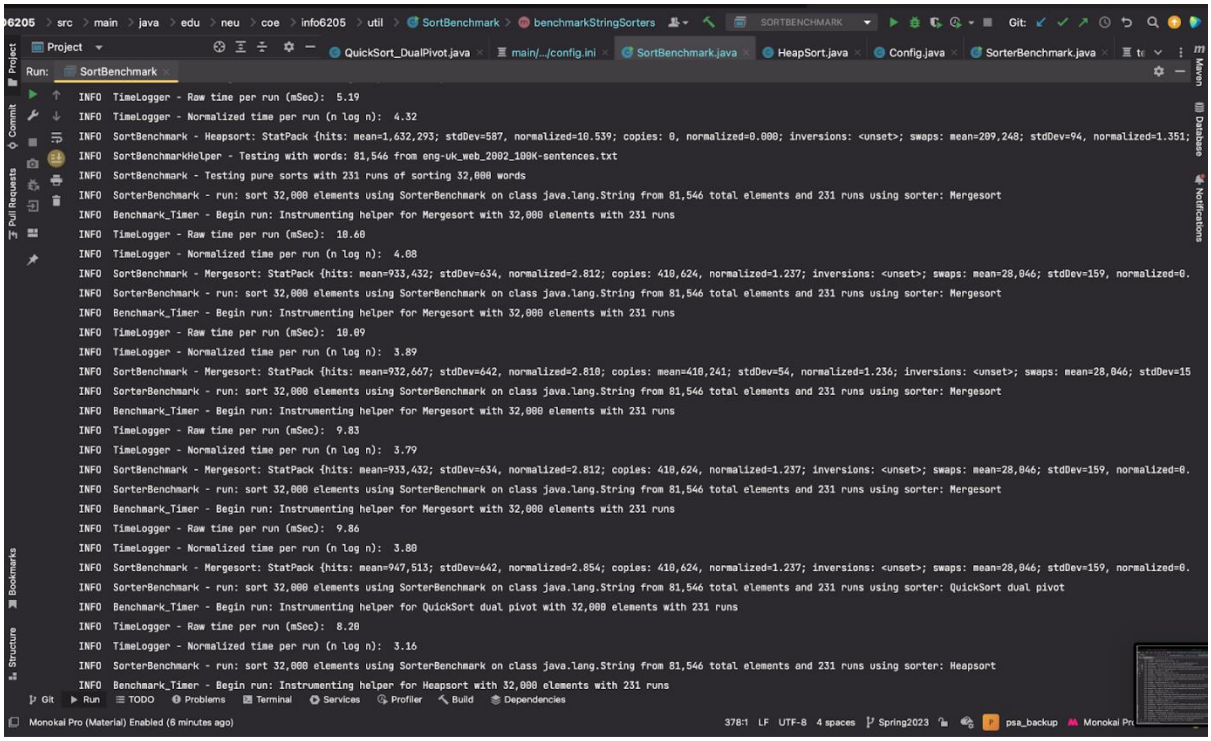
- src/main/java/edu/neu/coe/info6205/util/SorterBenchmark.java
- src/test/java/edu/neu/coe/info6205/sort/linearithmic/MergeSortTest.java
- src/test/java/edu/neu/coe/info6205/sort/linearithmic/QuickSortDualPivotTest.java
- src/test/java/edu/neu/coe/info6205/sort/elementary/HeapSortTest.java (you will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

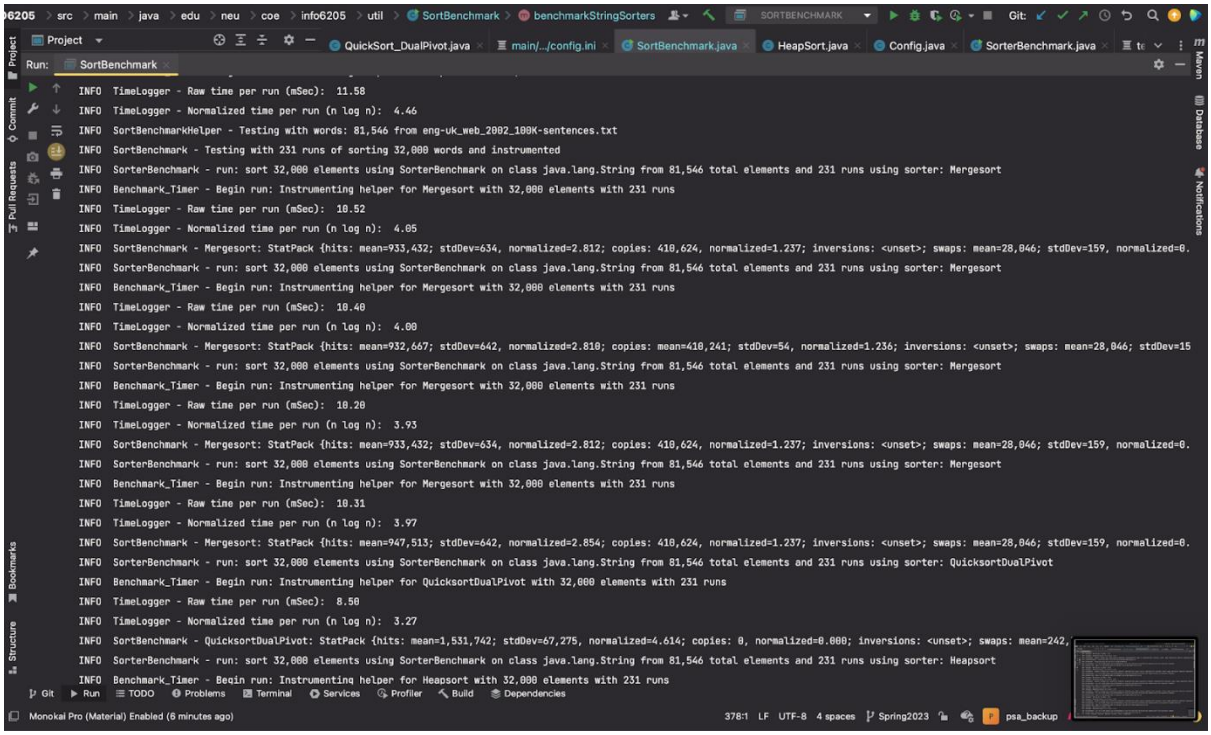
## Outputs and Test cases:

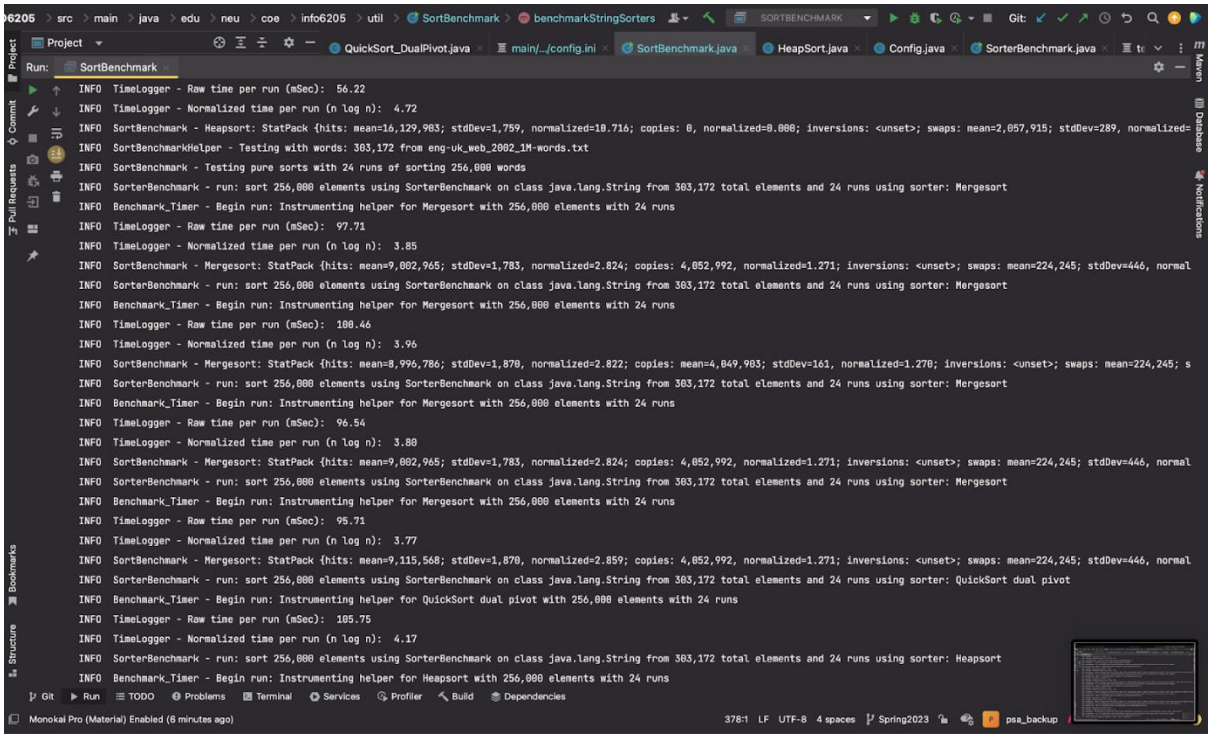


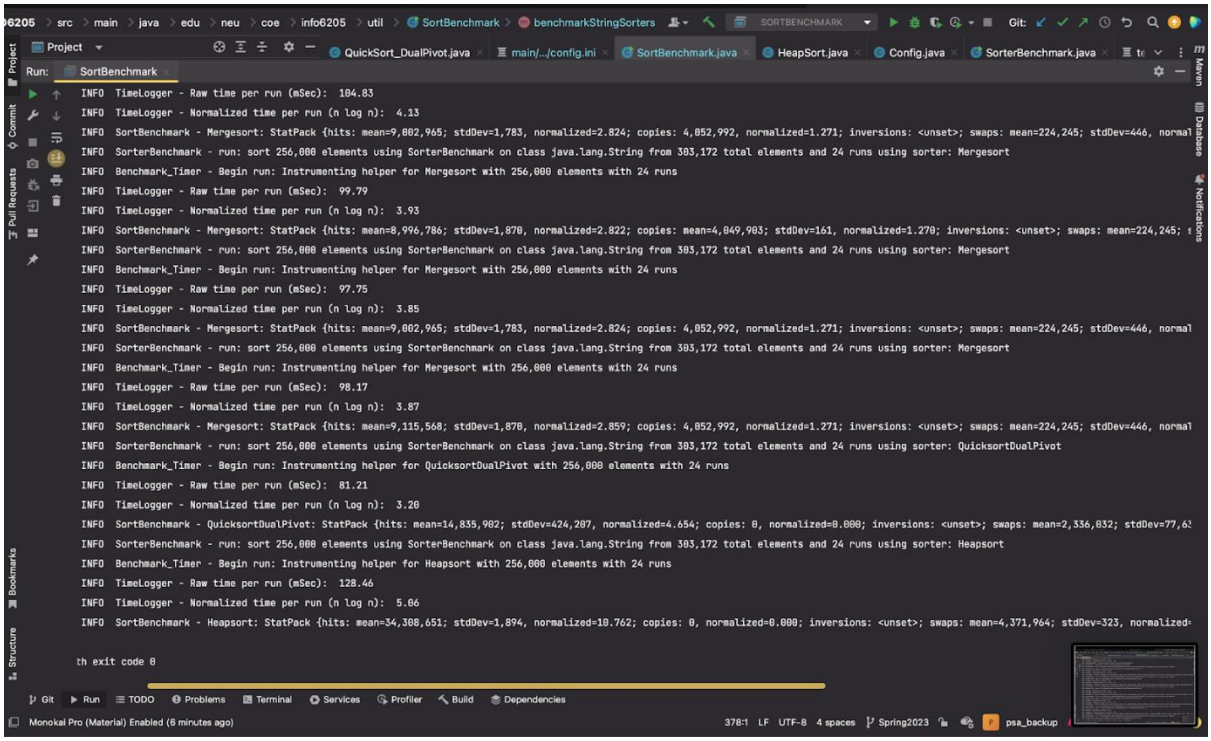



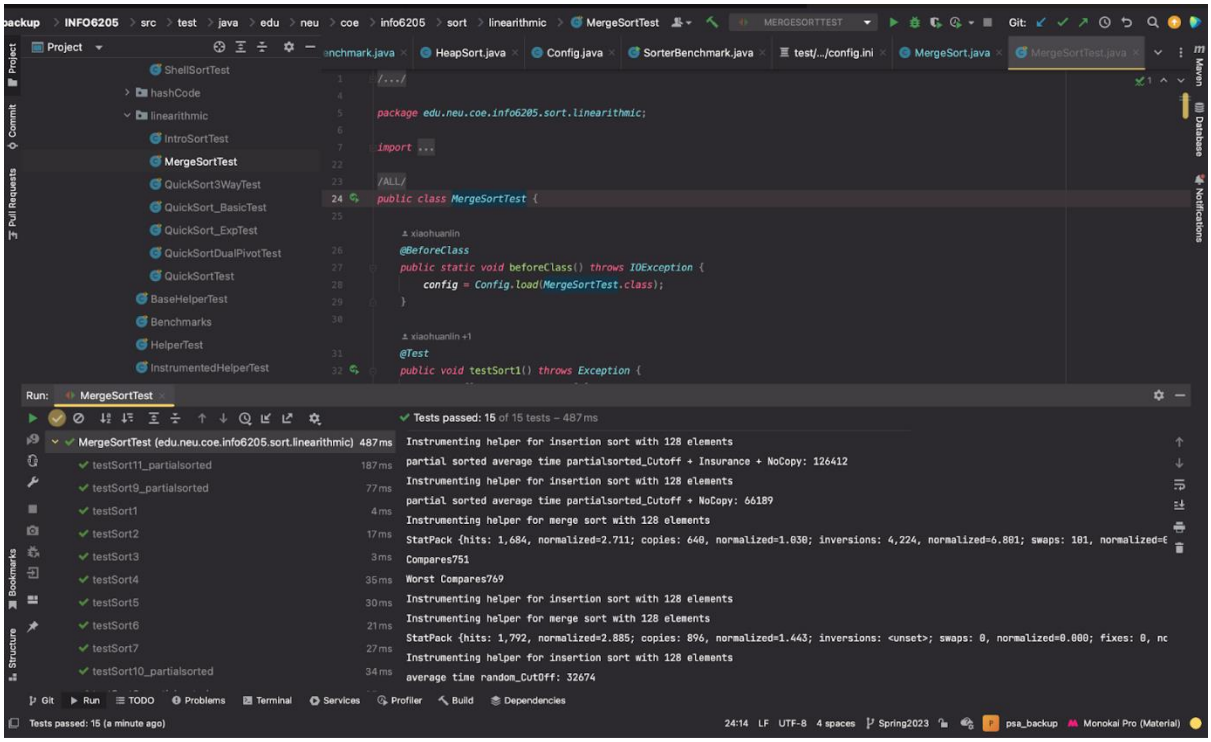

Run: SortBenchmark
INFO SortBenchmark - SortBenchmark.main: null with word counts: [8000, 16000, 32000, 64000, 128000, 256000]
INFO SortBenchmark - Beginning String sorts
INFO SortBenchmarkHelper - Testing with words: 22,865 from eng-uk_web_2002_10K-sentences.txt
INFO SortBenchmark - Testing pure sorts with 1,085 runs of sorting 8,000 words
INFO SorterBenchmark - run: sort 8,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 1,085 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 8,000 elements with 1,085 runs
INFO TimeLogger - Raw time per run (mSec): 2.15
INFO TimeLogger - Normalized time per run (n log n): 3.88
INFO SortBenchmark - Mergesort: StatPack {hits: mean=201,348; stdDev=302, normalized=2.800; copies: 86,656, normalized=1.205; inversions: <unset>; swaps: mean=7,009; stdDev=76, normalized=0.09
INFO SorterBenchmark - run: sort 8,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 1,085 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 8,000 elements with 1,085 runs
INFO TimeLogger - Raw time per run (mSec): 2.05
INFO TimeLogger - Normalized time per run (n log n): 3.70
INFO SortBenchmark - Mergesort: StatPack {hits: mean=201,155; stdDev=307, normalized=2.798; copies: mean=86,560; stdDev=27, normalized=1.204; inversions: <unset>; swaps: mean=7,009; stdDev=76,
INFO SorterBenchmark - run: sort 8,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 1,085 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 8,000 elements with 1,085 runs
INFO TimeLogger - Raw time per run (mSec): 2.03
INFO TimeLogger - Normalized time per run (n log n): 3.67
INFO SortBenchmark - Mergesort: StatPack {hits: mean=201,348; stdDev=302, normalized=2.800; copies: 86,656, normalized=1.205; inversions: <unset>; swaps: mean=7,009; stdDev=76, normalized=0.09
INFO SorterBenchmark - run: sort 8,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 1,085 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 8,000 elements with 1,085 runs
INFO TimeLogger - Raw time per run (mSec): 2.01
INFO TimeLogger - Normalized time per run (n log n): 3.64
INFO SortBenchmark - Mergesort: StatPack {hits: mean=204,865; stdDev=307, normalized=2.849; copies: 86,656, normalized=1.205; inversions: <unset>; swaps: mean=7,009; stdDev=76, normalized=0.09
INFO SorterBenchmark - run: sort 8,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 1,085 runs using sorter: QuickSort dual pivot
INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 8,000 elements with 1,085 runs
INFO TimeLogger - Raw time per run (mSec): 1.99
INFO TimeLogger - Normalized time per run (n log n): 3.60
INFO SorterBenchmark - run: sort 8,000 elements using SorterBenchmark on class java.lang.String from 22,865 total elements and 1,085 runs using sorter: Heapsort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 8,000 elements with 1,085 runs

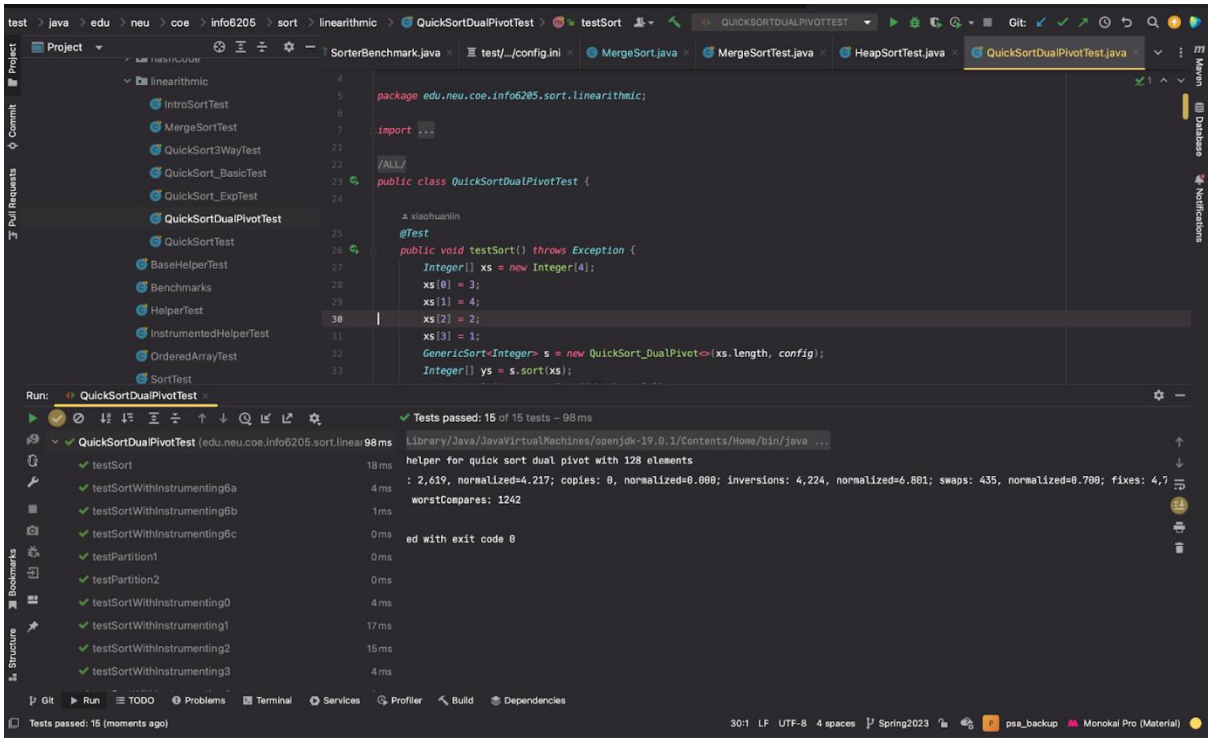

Run: SortBenchmark
INFO TimeLogger - Raw time per run (mSec): 5.19
INFO TimeLogger - Normalized time per run (n log n): 4.32
INFO SortBenchmark - Heapsort: StatPack {hits: mean=1,632,293; stdDev=587, normalized=10.539; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=209,248; stdDev=94, normalized=1.351;
INFO SortBenchmarkHelper - Testing with words: 81,546 from eng-uk_web_2002_100K-sentences.txt
INFO SortBenchmark - Testing pure sorts with 231 runs of sorting 32,000 words
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 10.60
INFO TimeLogger - Normalized time per run (n log n): 4.08
INFO SortBenchmark - Mergesort: StatPack {hits: mean=933,432; stdDev=634, normalized=2.812; copies: 410,624, normalized=1.237; inversions: <unset>; swaps: mean=28,046; stdDev=159, normalized=0.
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 10.09
INFO TimeLogger - Normalized time per run (n log n): 3.89
INFO SortBenchmark - Mergesort: StatPack {hits: mean=932,667; stdDev=642, normalized=2.810; copies: mean=410,241; stdDev=54, normalized=1.236; inversions: <unset>; swaps: mean=28,046; stdDev=15
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 9.83
INFO TimeLogger - Normalized time per run (n log n): 3.79
INFO SortBenchmark - Mergesort: StatPack {hits: mean=933,432; stdDev=634, normalized=2.812; copies: 410,624, normalized=1.237; inversions: <unset>; swaps: mean=28,046; stdDev=159, normalized=0.
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 9.86
INFO TimeLogger - Normalized time per run (n log n): 3.80
INFO SortBenchmark - Mergesort: StatPack {hits: mean=947,513; stdDev=642, normalized=2.854; copies: 410,624, normalized=1.237; inversions: <unset>; swaps: mean=28,046; stdDev=159, normalized=0.
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: QuickSort dual pivot
INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 8.20
INFO TimeLogger - Normalized time per run (n log n): 3.16
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Heapsort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 32,000 elements with 231 runs


INFO TimeLogger - Raw time per run (mSec): 11.58
INFO TimeLogger - Normalized time per run (n log n): 4.46
INFO SortBenchmarkHelper - Testing with words: 81,546 from eng-uk_web_2002_100K-sentences.txt
INFO SortBenchmark - Testing with 231 runs of sorting 32,000 words and instrumented
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 10.52
INFO TimeLogger - Normalized time per run (n log n): 4.05
INFO SortBenchmark - Mergesort: StatPack {hits: mean=933,432; stdDev=634, normalized=2.812; copies: 410,624, normalized=1.237; inversions: <unset>; swaps: mean=28,046; stdDev=159, normalized=0.
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 10.40
INFO TimeLogger - Normalized time per run (n log n): 4.00
INFO SortBenchmark - Mergesort: StatPack {hits: mean=932,667; stdDev=642, normalized=2.810; copies: mean=410,241; stdDev=54, normalized=1.236; inversions: <unset>; swaps: mean=28,046; stdDev=15
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 10.20
INFO TimeLogger - Normalized time per run (n log n): 3.93
INFO SortBenchmark - Mergesort: StatPack {hits: mean=933,432; stdDev=634, normalized=2.812; copies: 410,624, normalized=1.237; inversions: <unset>; swaps: mean=28,046; stdDev=159, normalized=0.
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 10.31
INFO TimeLogger - Normalized time per run (n log n): 3.97
INFO SortBenchmark - Mergesort: StatPack {hits: mean=947,513; stdDev=642, normalized=2.854; copies: 410,624, normalized=1.237; inversions: <unset>; swaps: mean=28,046; stdDev=159, normalized=0.
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: QuicksortDualPivot
INFO Benchmark_Timer - Begin run: Instrumenting helper for QuicksortDualPivot with 32,000 elements with 231 runs
INFO TimeLogger - Raw time per run (mSec): 8.50
INFO TimeLogger - Normalized time per run (n log n): 3.27
INFO SortBenchmark - QuicksortDualPivot: StatPack {hits: mean=1,531,742; stdDev=67,275, normalized=4.614; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=242,
INFO SorterBenchmark - run: sort 32,000 elements using SorterBenchmark on class java.lang.String from 81,546 total elements and 231 runs using sorter: Heapsort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 32,000 elements with 231 runs

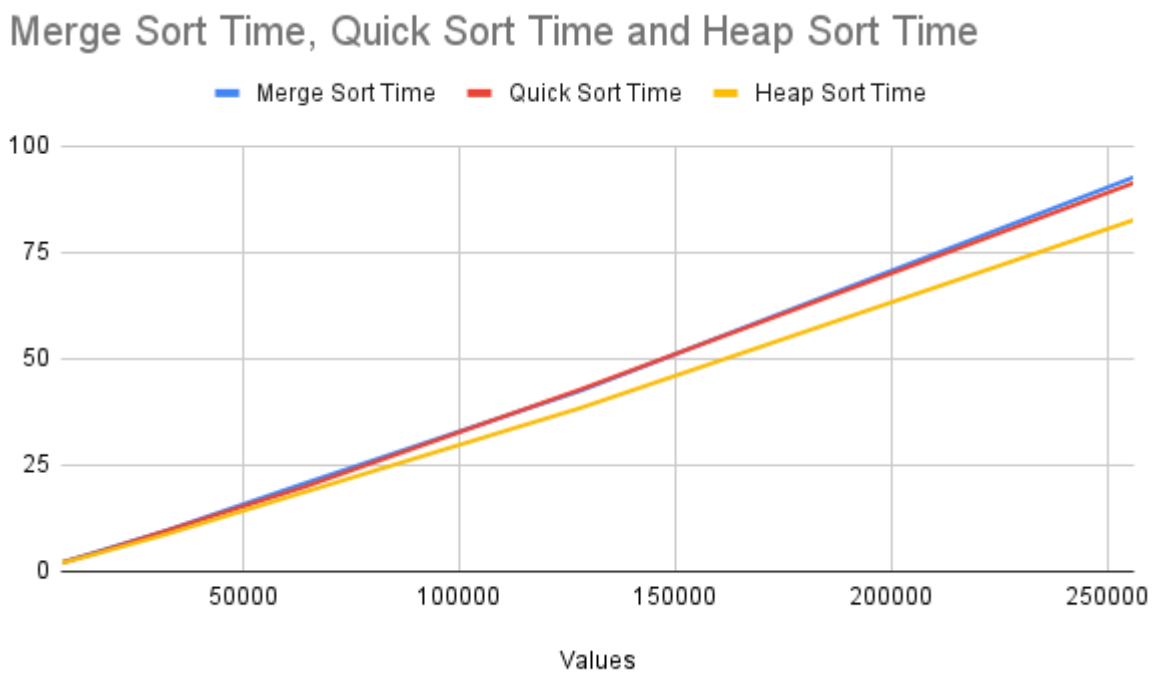

INFO TimeLogger - Raw time per run (mSec): 56.22
INFO TimeLogger - Normalized time per run (n log n): 4.72
INFO SortBenchmark - Heapsort: StatPack {hits: mean=16,129,903; stdDev=1,759, normalized=10.716; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=2,057,915; stdDev=289, normalized=
INFO SortBenchmarkHelper - Testing with words: 303,172 from eng-uk_web_2002_1M-words.txt
INFO SortBenchmark - Testing pure sorts with 24 runs of sorting 256,000 words
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 97.71
INFO TimeLogger - Normalized time per run (n log n): 3.85
INFO SortBenchmark - Mergesort: StatPack {hits: mean=9,002,965; stdDev=1,783, normalized=2.824; copies: 4,052,992, normalized=1.271; inversions: <unset>; swaps: mean=224,245; stdDev=446, normal
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 100.46
INFO TimeLogger - Normalized time per run (n log n): 3.96
INFO SortBenchmark - Mergesort: StatPack {hits: mean=8,996,786; stdDev=1,870, normalized=2.822; copies: mean=4,049,903; stdDev=161, normalized=1.270; inversions: <unset>; swaps: mean=224,245; s
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 96.54
INFO TimeLogger - Normalized time per run (n log n): 3.80
INFO SortBenchmark - Mergesort: StatPack {hits: mean=9,002,965; stdDev=1,783, normalized=2.824; copies: 4,052,992, normalized=1.271; inversions: <unset>; swaps: mean=224,245; stdDev=446, normal
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 95.71
INFO TimeLogger - Normalized time per run (n log n): 3.77
INFO SortBenchmark - Mergesort: StatPack {hits: mean=9,115,568; stdDev=1,870, normalized=2.859; copies: 4,052,992, normalized=1.271; inversions: <unset>; swaps: mean=224,245; stdDev=446, normal
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: QuickSort dual pivot
INFO Benchmark_Timer - Begin run: Instrumenting helper for QuickSort dual pivot with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 105.75
INFO TimeLogger - Normalized time per run (n log n): 4.17
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Heapsort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 256,000 elements with 24 runs


Run: SortBenchmark
INFO TimeLogger - Raw time per run (mSec): 104.83
INFO TimeLogger - Normalized time per run (n log n): 4.13
INFO SortBenchmark - Mergesort: StatPack {hits: mean=9,002,965; stdDev=1,783, normalized=2.824; copies: 4,052,992, normalized=1.271; inversions: <unset>; swaps: mean=224,245; stdDev=446,
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 99.79
INFO TimeLogger - Normalized time per run (n log n): 3.93
INFO SortBenchmark - Mergesort: StatPack {hits: mean=8,996,786; stdDev=1,870, normalized=2.822; copies: mean=4,049,903; stdDev=161, normalized=1.270; inversions: <unset>; swaps: mean=224,245;
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 97.75
INFO TimeLogger - Normalized time per run (n log n): 3.85
INFO SortBenchmark - Mergesort: StatPack {hits: mean=9,002,965; stdDev=1,783, normalized=2.824; copies: 4,052,992, normalized=1.271; inversions: <unset>; swaps: mean=224,245; stdDev=446,
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Mergesort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Mergesort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 98.17
INFO TimeLogger - Normalized time per run (n log n): 3.87
INFO SortBenchmark - Mergesort: StatPack {hits: mean=9,115,568; stdDev=1,870, normalized=2.859; copies: 4,052,992, normalized=1.271; inversions: <unset>; swaps: mean=224,245; stdDev=446,
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: QuicksortDualPivot
INFO Benchmark_Timer - Begin run: Instrumenting helper for QuicksortDualPivot with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 81.21
INFO TimeLogger - Normalized time per run (n log n): 3.20
INFO SortBenchmark - QuicksortDualPivot: StatPack {hits: mean=14,835,902; stdDev=424,207, normalized=4.654; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=2,336,032; stdDev=77,6
INFO SorterBenchmark - run: sort 256,000 elements using SorterBenchmark on class java.lang.String from 303,172 total elements and 24 runs using sorter: Heapsort
INFO Benchmark_Timer - Begin run: Instrumenting helper for Heapsort with 256,000 elements with 24 runs
INFO TimeLogger - Raw time per run (mSec): 128.46
INFO TimeLogger - Normalized time per run (n log n): 5.06
INFO SortBenchmark - Heapsort: StatPack {hits: mean=34,308,651; stdDev=1,894, normalized=10.762; copies: 0, normalized=0.000; inversions: <unset>; swaps: mean=4,371,964; stdDev=323, normalized=
th exit code 0


Run: MergeSortTest
Tests passed: 15 of 15 tests – 487 ms
MergeSortTest (edu.neu.coe.info6205.sort.linearithmic) 487 ms
testSort11_partialsorted 187 ms
testSort9_partialsorted 77 ms
testSort1 4 ms
testSort2 17 ms
testSort3 3 ms
testSort4 35 ms
testSort5 30 ms
testSort6 21 ms
testSort7 27 ms
testSort10_partialsorted 34 ms
Instrumenting helper for insertion sort with 128 elements
partial sorted average time partialsorted_Cutoff + Insurance + NoCopy: 126412
Instrumenting helper for insertion sort with 128 elements
partial sorted average time partialsorted_Cutoff + NoCopy: 66189
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=
Compares751
Worst Compares769
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, nc
Instrumenting helper for insertion sort with 128 elements
average time random_Cut0ff: 32674




## Relationship Conclusion/ Evidence Graph:



| Merge Sort | | | | | |
|---|---|---|---|---|---|
| Values | Raw Time | Normalized Time | Compares | Swaps | Hits |
| 8000 | 2.12 | 3.83 | 1.314 | 0.097 | 1.205 |
| 16000 | 4.52 | 3.76 | 1.323 | 0.091 | 2.807 |
| 32000 | 9.52 | 3.67 | 1.331 | 0.084 | 2.812 |
| 64000 | 20.62 | 3.7 | 1.338 | 0.079 | 1.25 |
| 128000 | 42.46 | 3.56 | 1.364 | 0.074 | 1.261 |
| 256000 | 92.67 | 3.65 | 1.368 | 0.07 | 1.27 |

| Quick sort | | | | | |
|---|---|---|---|---|---|
| Values | Raw Time | Normalized Time | Compares | Swaps | Hits |
| 8000 | 2 | 3.62 | 1.314 | 0.097 | 1.205 |
| 16000 | 4.32 | 3.59 | 1.347 | 0.091 | 1.222 |
| 32000 | 9.45 | 3.64 | 1.353 | 0.084 | 1.237 |
| 64000 | 19.79 | 3.55 | 1.359 | 0.079 | 1.25 |
| 128000 | 42.76 | 3.59 | 1.364 | 0.074 | 1.261 |
| 256000 | 91.33 | 3.6 | 1.367 | 0.07 | 1.271 |

| Heap sort | | | | | |
|---|---|---|---|---|---|
| Values | Raw Time | Normalized Time | Compares | Swaps | Hits |
| 8000 | 1.97 | 3.56 | 1.687 | 0.718 | 4.506 |
| 16000 | 4.12 | 3.43 | 1.712 | 0.718 | 4.537 |
| 32000 | 8.66 | 3.34 | 1.74 | 0.73 | 4.614 |
| 64000 | 18.59 | 3.33 | 1.749 | 0.729 | 4.626 |
| 128000 | 38.42 | 3.22 | 1.741 | 0.73 | 4.61 |
| 256000 | 82.62 | 3.26 | 1.758 | 0.733 | 4.654 |

From the graph and table values above, we can conclude that:

For dual-pivot-quick-sort the most obvious parameter for the best predictor would be the no of comparisons for this sorting algorithm it can be seen that as the number of comparisons for

the array increases the time taken also increases by a proportional factor. No. of swaps and hits could also be used here for the same.

For Merge sort the best predictor parameter is the no. of swaps and no. of hits which have an inverse relation with the time taken to run the sorting algorithm which increases when swaps decrease. This can also be explained by the extra space the merge algorithm takes to run the program.

For heap sort the best predictor is also the no. of comparisons as they are a direct indication of the time taken by the algorithm to complete its run. The no. of comparisons here is thus in a proportional relationship with the raw time of the program.