INFO6205 PROGRAM STRUCTURES AND ALGORITHMS

Assignment-2

Task:

Part1: To implement three methods of a class called Timer and check implementation by running the unit tests in BenchmarkTest and TimerTest.

```
public class Timer {
... // see below for methods to be implemented...
}

public <T, U> double repeat(int n, Supplier<T> supplier, Function<T, U> function, UnaryOperator<T> preFunction, Consumer<U> post
Function) {
// TO BE IMPLEMENTED
}

private static long getClock() {
   // TO BE IMPLEMENTED
}

private static double toMillisecs(long ticks) {
   // TO BE IMPLEMENTED
}
```

Part2: To Implement InsertionSort (in the InsertionSort class) by simply looking up the insertion code used by Arrays.sort and run the unit tests in InsertionSortTest.

Part3: To Implement a main program (or you could do it via your own unit tests) to actually run the following benchmarks: measure the running times of this sort, using four different initial array ordering situations: random, ordered, partially-ordered and reverse-ordered, arrays to be sorted are of type Integer and Draw any conclusions from observations regarding the order of growth.

Unit tests and Output:

Conducted the timer test and the benchmark test for insertion sort by randomly generating an input array of type integers and size n and running the experiment 100 times for each n values doubling. The size of n was: 100,200,400,800, 1600, 3200. I have run the experiment for an ordered array, randomly ordered array, reverse ordered array and partially ordered array. Below are the test results for the experiments:

```
2021-02-03 23:26:57 INFO  Benchmark_Timer - Begin run: Benchmark test for InsertionSort  with 10 runs
For Ordered Array of input size: 100 insertion sort takes meantime of :  0.02452
-------------------------------------------------------------------------------------------------
2021-02-03 23:26:57 INFO  Benchmark_Timer - Begin run: Benchmark test for InsertionSort  with 10 runs
For Ordered Array of input size: 200 insertion sort takes meantime of :  0.01601
-------------------------------------------------------------------------------------------------
2021-02-03 23:26:57 INFO  Benchmark_Timer - Begin run: Benchmark test for InsertionSort  with 10 runs
For Ordered Array of input size: 400 insertion sort takes meantime of :  0.032690000000000004
-------------------------------------------------------------------------------------------------
2021-02-03 23:26:57 INFO  Benchmark_Timer - Begin run: Benchmark test for InsertionSort  with 10 runs
For Ordered Array of input size: 800 insertion sort takes meantime of :  0.058530000000000006
-------------------------------------------------------------------------------------------------
2021-02-03 23:26:57 INFO  Benchmark_Timer - Begin run: Benchmark test for InsertionSort  with 10 runs
```

For Ordered Array of input size: 1600 insertion sort takes meantime of : 0.10612999999999999

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Ordered Array of input size: 3200 insertion sort takes meantime of : 0.1679

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Ordered Array of input size: 6400 insertion sort takes meantime of : 0.09666

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Ordered Array of input size: 12800 insertion sort takes meantime of : 0.30384

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Ordered Array of input size: 25600 insertion sort takes meantime of : 0.20813

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 100 insertion sort takes meantime of : 0.11334

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 200 insertion sort takes meantime of : 0.33304

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 400 insertion sort takes meantime of : 0.63213

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 800 insertion sort takes meantime of : 0.36543000000000003

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 1600 insertion sort takes meantime of : 1.08005

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 3200 insertion sort takes meantime of : 3.9644799999999996

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 6400 insertion sort takes meantime of : 18.21021

2021-02-03 23:26:57 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 12800 insertion sort takes meantime of : 64.99396

2021-02-03 23:26:58 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For PartiallyOrdered Array of input size: 25600 insertion sort takes meantime of : 265.03508

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 100 insertion sort takes meantime of : 0.01462

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 200 insertion sort takes meantime of : 0.04858

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs

For Random Array of input size: 400 insertion sort takes meantime of : 0.1784

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 800 insertion sort takes meantime of : 0.67229

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 1600 insertion sort takes meantime of : 2.58039

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 3200 insertion sort takes meantime of : 10.24742

2021-02-03 23:27:01 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 6400 insertion sort takes meantime of : 41.7941

2021-02-03 23:27:02 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 12800 insertion sort takes meantime of : 187.67301

2021-02-03 23:27:04 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Random Array of input size: 25600 insertion sort takes meantime of : 837.8533299999999

2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 100 insertion sort takes meantime of : 0.025879999999999997

2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 200 insertion sort takes meantime of : 0.09218

2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 400 insertion sort takes meantime of : 0.34345

2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 800 insertion sort takes meantime of : 1.31698

2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 1600 insertion sort takes meantime of : 5.16375

2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 3200 insertion sort takes meantime of : 20.53088

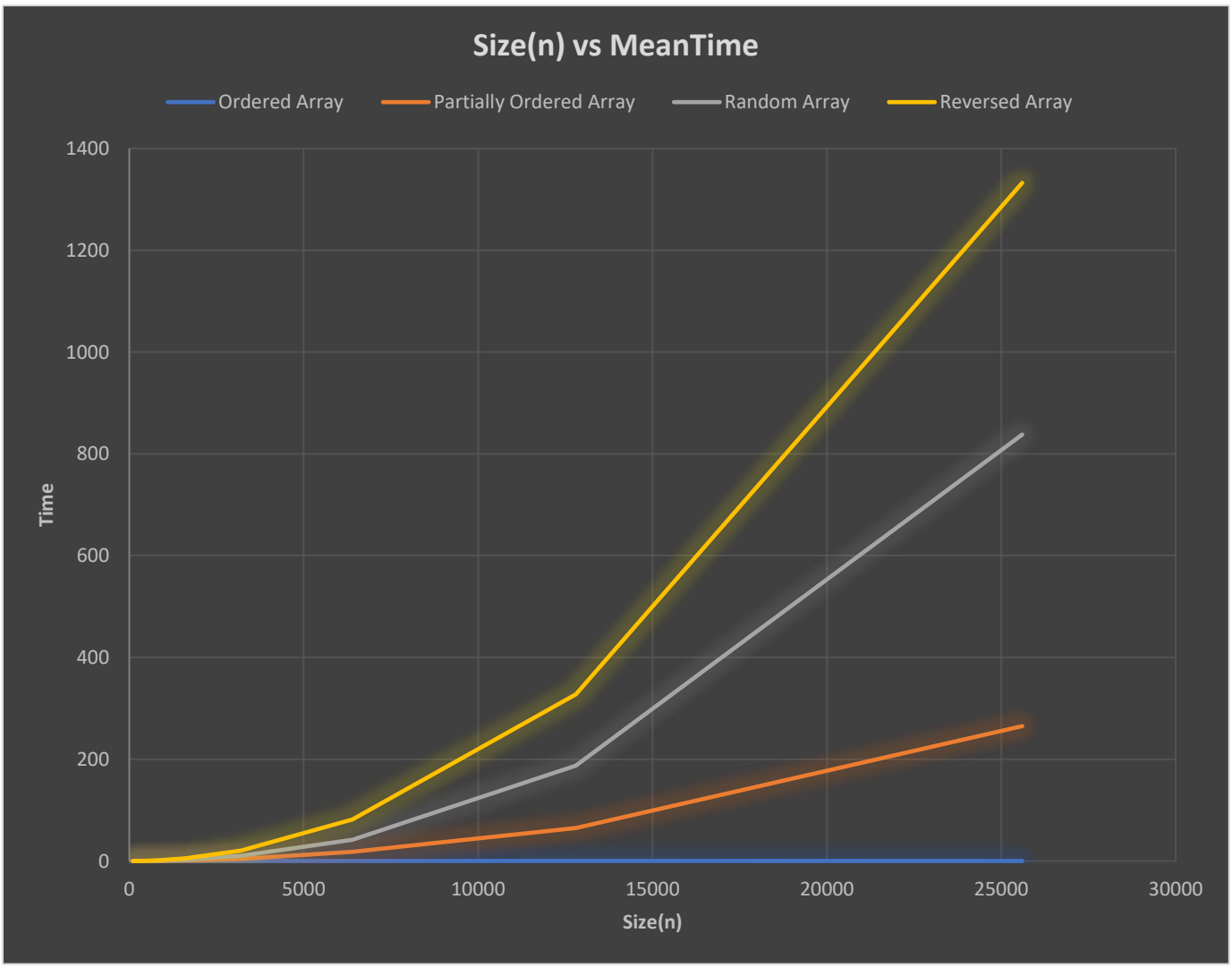
2021-02-03 23:27:14 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 6400 insertion sort takes meantime of : 81.89444999999999

2021-02-03 23:27:15 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 12800 insertion sort takes meantime of : 327.55728

2021-02-03 23:27:19 INFO Benchmark_Timer - Begin run: Benchmark test for InsertionSort with 10 runs
For Reversed Array of input size: 25600 insertion sort takes meantime of : 1332.59077

Summary of time taken by insertion sort (in milliseconds) to run on array orderings of four types: ordered array, partially ordered array, randomly ordered array and reverse ordered array are given below in the table with its corresponding graphical representation:

Size (n)	Ordered Array	Partially Ordered Array	Random Array	Reversed Array
100	0.02452	0.11334	0.01462	0.025879
200	0.01601	0.33304	0.04858	0.09218
400	0.03269	0.63213	0.1784	0.34345
800	0.05853	0.36543	0.67229	1.31698
1600	0.10612	1.08005	2.58039	5.16375
3200	0.1679	3.964479	10.24742	20.53088
6400	0.09666	18.21021	41.7941	81.89444
12800	0.30384	64.99396	187.67301	327.55728
25600	0.20813	265.03508	837.85332	1332.59077



Conclusion:

As we can know that Insertion sort scans the array, compares each pair of elements and swaps elements if they are not in order. Since each operation contributes to the runtime of the algorithm, insertion sort can run in O(n) or O(n2) time depending on how the array to be sorted is ordered.

We make the following observations and conclusions from our timer and benchmark tests:

1. In the best-case scenario, insertion sort will simply compare elements in O(n) time and perform 0 swaps. Hence, the best-case scenario happens when the array is sorted, and insertion sort runs in O(n) time.

2. In the worst-case scenario, to insert the last element alone we will need n-1 comparisons and perform n-1 swaps. Similarly, for second last element, we will need n-2 comparisons and n-2 swaps, and so on.

The number of operations for the worst case in insertion sort is 2x (1 + 2 + ⋯ + n − 2 + n − 1)

Using the summation, we get: 2(n − 1) (n − 1 + 1) 2 = n (n − 1)

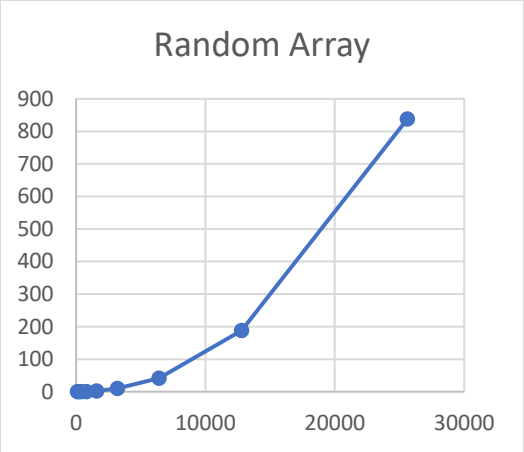
So, in the worst case, insertion sort takes O (n^2), that is, when the array is sorted in reverse order.

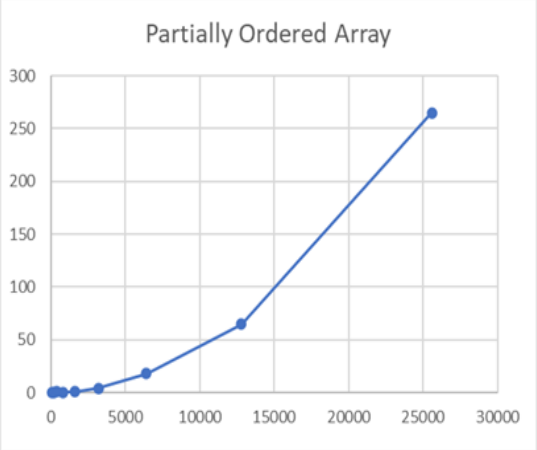
From the values of experiments, we observe that on an average (randomly ordered array, partially ordered array) insertion sort takes O (n^2) time approximately.

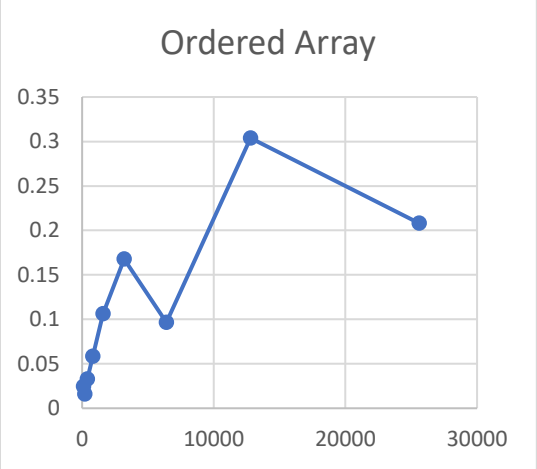
Analyzing the table values of the run time for each algorithm and its graph, we can conclude that the run time for insertion sort for different ordered arrays follows as

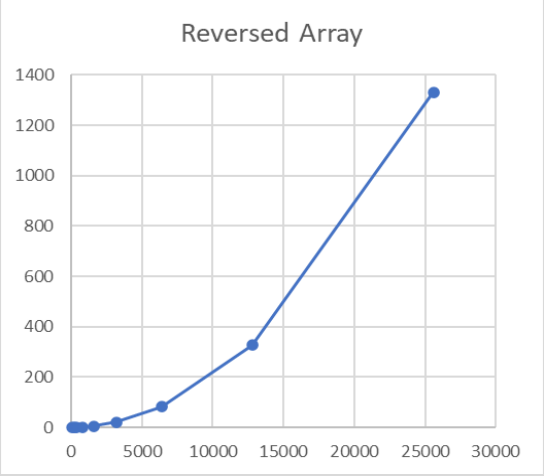
Reverse Sorted Array > Randomly Ordered Array > Partially Ordered Array > Ordered Array

3. Also from Observing the graphs if we find the slope of the line it would approx. be ≈ 2, giving the power of the relationship.









4. For each array types in the graphs above we can observe that the mean time increases with the increase of n. In addition, the relationship between them is approximate Meantime = k n where k is a constant.

Ordered array $MeanTime \propto n$

Reverse-Order array $MeanTime \propto n^2$

Random-Order array $MeanTime \propto n^2$

Partially-Order array $MeanTime \propto n^2$

Screenshots of Tests: