Program Structures & Algorithms
Spring 2022
Assignment No. 2

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Task

- (Part 1) Implementation of three methods in *Timer.java,* & check this implementation by running the unit tests in *BenchmarkTest.java* and *TimerTest.java*
- (Part 2) implementation of *InsertionSort* (in the *InsertionSort* class) & check this implementation by running the unit tests in *InsertionSortTest*
- (Part 3) Implementation of a main program to 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.
- Using doubling method for choosing *n* and test for at least five values of *n*
- Drawing conclusions from the observations regarding the order of growth

Relationship Conclusion

- Order of growth of the running time of Insertion Sort (Randomly ordered array of size *N*) is $\approx N^{2.04}$
- Order of growth of the running time of Insertion Sort (Ordered array of size *N*) is $\approx N^{0.92}$
- Order of growth of the running time of Insertion Sort (Partially ordered array of size *N*) is $\approx N^{1.97}$
- Order of growth of the running time of Insertion Sort (Reverse ordered array of size *N*) is $\approx N^{2.07}$
- In terms of order of growth, for the running time of Insertion sort:

$$Ordered < Partially\ Ordered < Randomly\ Ordered < Reverse\ Ordered$$

Evidence to the Conclusion

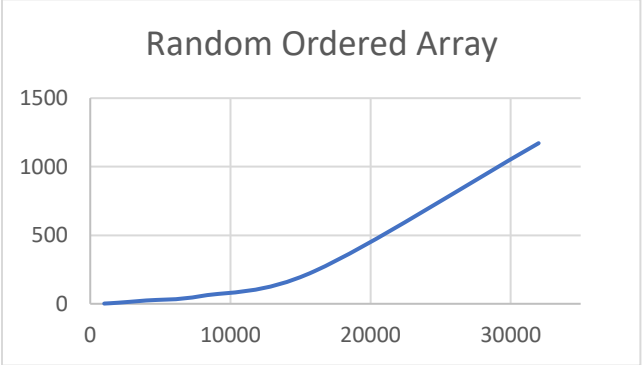
- Running time of the insertion sort for an array of 'n' numbers has been captured
- Each time the size of the array would be doubled and running time would be captured again (5 different sizes of array)
- Every time, we run the insertion sort algorithm, we make sure to test on four different states of the array (Ordered, Partially Ordered, Randomly Ordered, Reverse Ordered)

Random Ordered Array

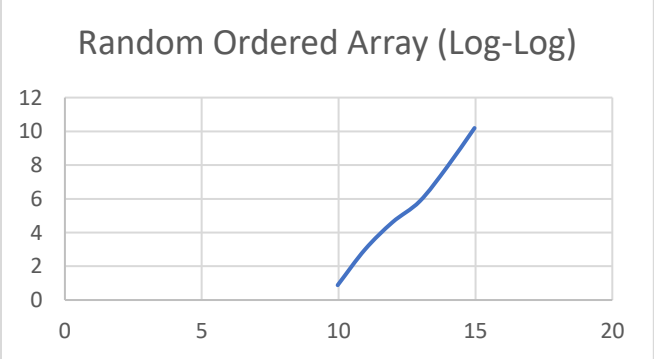
Various sizes of the Array and the running time of the Insertion sort

Randomly Ordered Array						
Array Size	**Time**	**Ratio (Time/Previous Time)**	**lg(Array Size)**	**lg(Time)**	**Log Ratio**	**Slope**
1000	1.84	-	9.97	0.88	11.33	
2000	7.99	4.34	10.97	3.00	3.66	2.12
4000	24.35	3.05	11.97	4.61	2.60	1.61
8000	57.85	2.38	12.97	5.85	2.21	1.25
16000	237.68	4.11	13.97	7.89	1.77	2.04
32000	1171.63	4.93	14.97	10.19	1.47	2.30
					Avg slope	2.04

Analysis of experimental data (the running time of insertion sort with random ordered input)



Standard Plot: Running time T(n) Vs Array size N



Log-Log Plot: lg(T(n)) Vs lg(N)

The equation of the log-log plot is

$$lg(T(N)) = 2.04\, lg\, N + lg\, a$$

Which is equivalent to,

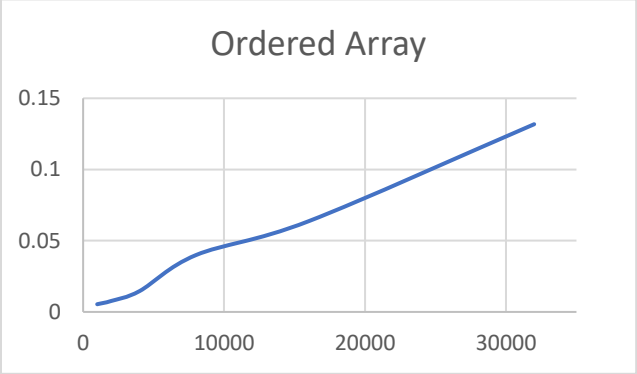
$$T(N) = aN^{2.04}$$

Ordered Array

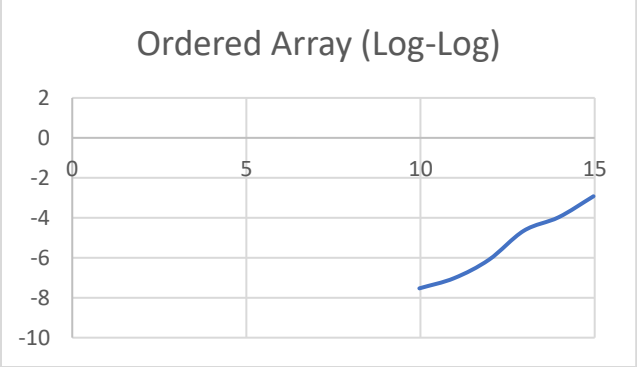
Various sizes of the Array and the running time of the Insertion sort

Ordered Array						
Array Size	**Time**	**Ratio (Time/Previous Time)**	**lg(Array Size)**	**lg(Time)**	**Log Ratio**	**Slope**
1000	0.0054		9.97	-7.53	-1.32	
2000	0.0077	1.43	10.97	-7.02	-1.56	0.51
4000	0.0146	1.90	11.97	-6.10	-1.96	0.92
8000	0.0399	2.73	12.97	-4.65	-2.79	1.45
16000	0.0637	1.60	13.97	-3.97	-3.52	0.67
32000	0.1318	2.07	14.97	-2.92	-5.12	1.05
					Avg slope	0.92

Analysis of experimental data (the running time of insertion sort with random ordered input)



Standard Plot: Running time T(n) Vs Array size N



Log-Log Plot: lg(T(n)) Vs lg(N)

The equation of the log-log plot is

$$lg(T(N)) = 0.92\, lg\, N + lg\, a$$

Which is equivalent to,

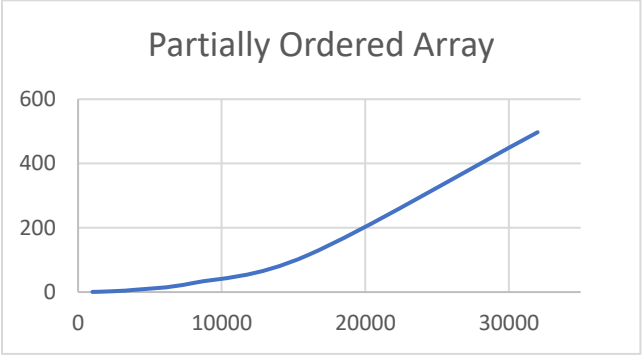
$$T(N) = aN^{0.92}$$

Partially Ordered Array

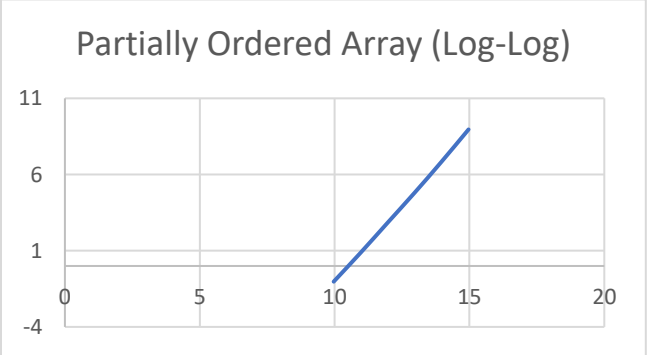
Various sizes of the Array and the running time of the Insertion sort

Partially Ordered Array						
Array Size	**Time**	**Ratio (Time/Previous Time)**	**lg(Array Size)**	**lg(Time)**	**Log Ratio**	**Slope**
1000	0.49		9.97	-1.03	-9.68	
2000	1.83	3.73	10.97	0.87	12.58	1.90
4000	7.16	3.91	11.97	2.84	4.21	1.97
8000	27.97	3.91	12.97	4.81	2.70	1.97
16000	114.85	4.11	13.97	6.84	2.04	2.04
32000	497.21	4.33	14.97	8.96	1.67	2.11
					Avg slope	1.97

Analysis of experimental data (the running time of insertion sort with random ordered input)



Standard Plot: Running time T(n) Vs Array size N



Log-Log Plot: lg(T(n)) Vs lg(N)

The equation of the log-log plot is

$$lg(T(N)) = 1.97\, lg\, N + lg\, a$$

Which is equivalent to,

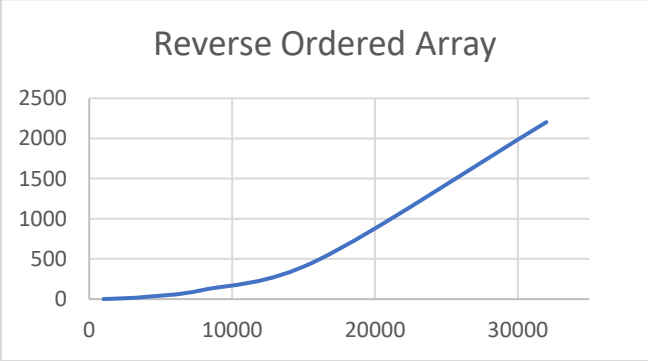
$$T(N) = aN^{1.97}$$

Reverse Ordered Array

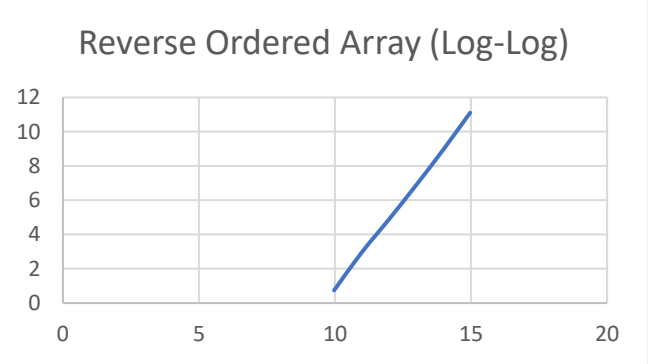
Various sizes of the Array and the running time of the Insertion sort

Reverse Ordered Array						
Array Size	Time	Ratio (Time/Previous Time)	lg(Array Size)	lg(Time)	Log Ratio	Slope
1000	1.67		9.97	0.74	13.47	
2000	7.58	4.54	10.97	2.92	3.75	2.18
4000	28.86	3.81	11.97	4.85	2.47	1.93
8000	115.39	4.00	12.97	6.85	1.89	2.00
16000	485.59	4.21	13.97	8.92	1.57	2.07
32000	2202.95	4.54	14.97	11.11	1.35	2.18
					Avg slope	2.07

Analysis of experimental data (the running time of insertion sort with random ordered input)



Standard Plot: Running time T(n) Vs Array size N



Log-Log Plot: lg(T(n)) Vs lg(N)

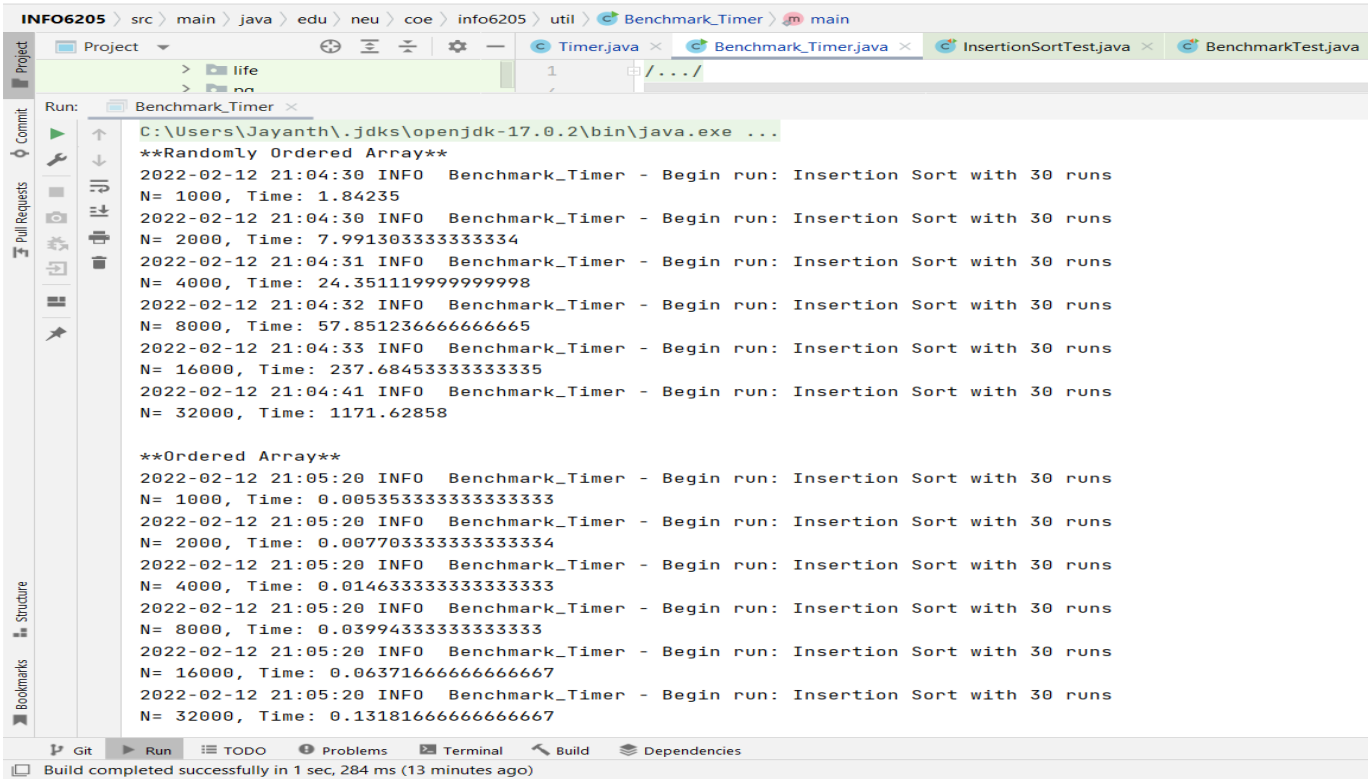
The equation of the log-log plot is

$$lg(T(N)) = 2.07\, lg\, N + lg\, a$$

Which is equivalent to,

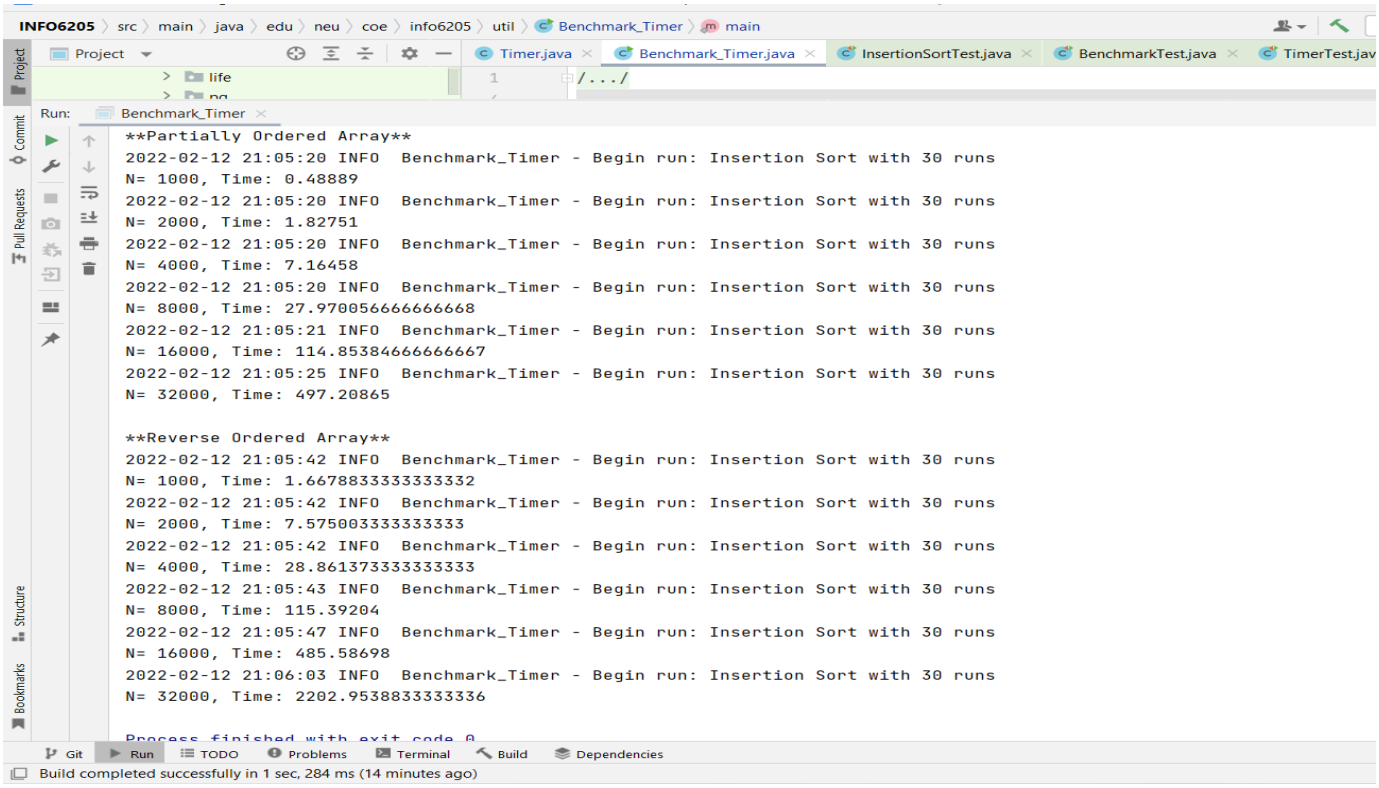
$$T(N) = aN^{2.07}$$

Output Screenshot



```
C:\Users\Jayanth\.jdks\openjdk-17.0.2\bin\java.exe ...
**Randomly Ordered Array**
2022-02-12 21:04:30 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 1000, Time: 1.84235
2022-02-12 21:04:30 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 2000, Time: 7.991303333333334
2022-02-12 21:04:31 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 4000, Time: 24.351119999999998
2022-02-12 21:04:32 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 8000, Time: 57.851236666666665
2022-02-12 21:04:33 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 237.68453333333335
2022-02-12 21:04:41 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 1171.62858

**Ordered Array**
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 1000, Time: 0.005353333333333333
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 2000, Time: 0.007703333333333334
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 4000, Time: 0.014633333333333333
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 8000, Time: 0.03994333333333333
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 0.06371666666666667
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 0.13181666666666667
```



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**Partially Ordered Array**
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 1000, Time: 0.48889
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 2000, Time: 1.82751
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 4000, Time: 7.16458
2022-02-12 21:05:20 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 8000, Time: 27.970056666666668
2022-02-12 21:05:21 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 114.85384666666667
2022-02-12 21:05:25 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 497.20865

**Reverse Ordered Array**
2022-02-12 21:05:42 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 1000, Time: 1.6678833333333332
2022-02-12 21:05:42 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 2000, Time: 7.575003333333333
2022-02-12 21:05:42 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 4000, Time: 28.861373333333333
2022-02-12 21:05:43 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 8000, Time: 115.39204
2022-02-12 21:05:47 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 485.58698
2022-02-12 21:06:03 INFO  Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 2202.9538833333336

Process finished with exit code 0
```

Output

Randomly Ordered Array
2022-02-12 21:04:30 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 1000, Time: 1.84235
2022-02-12 21:04:30 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
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N= 16000, Time: 237.68453333333335
2022-02-12 21:04:41 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 1171.62858

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N= 4000, Time: 0.014633333333333333
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N= 8000, Time: 0.03994333333333333
2022-02-12 21:05:20 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 0.06371666666666667
2022-02-12 21:05:20 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 0.13181666666666667

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N= 2000, Time: 1.82751
2022-02-12 21:05:20 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 4000, Time: 7.16458
2022-02-12 21:05:20 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 8000, Time: 27.970056666666668
2022-02-12 21:05:21 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 114.85384666666667
2022-02-12 21:05:25 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 497.20865

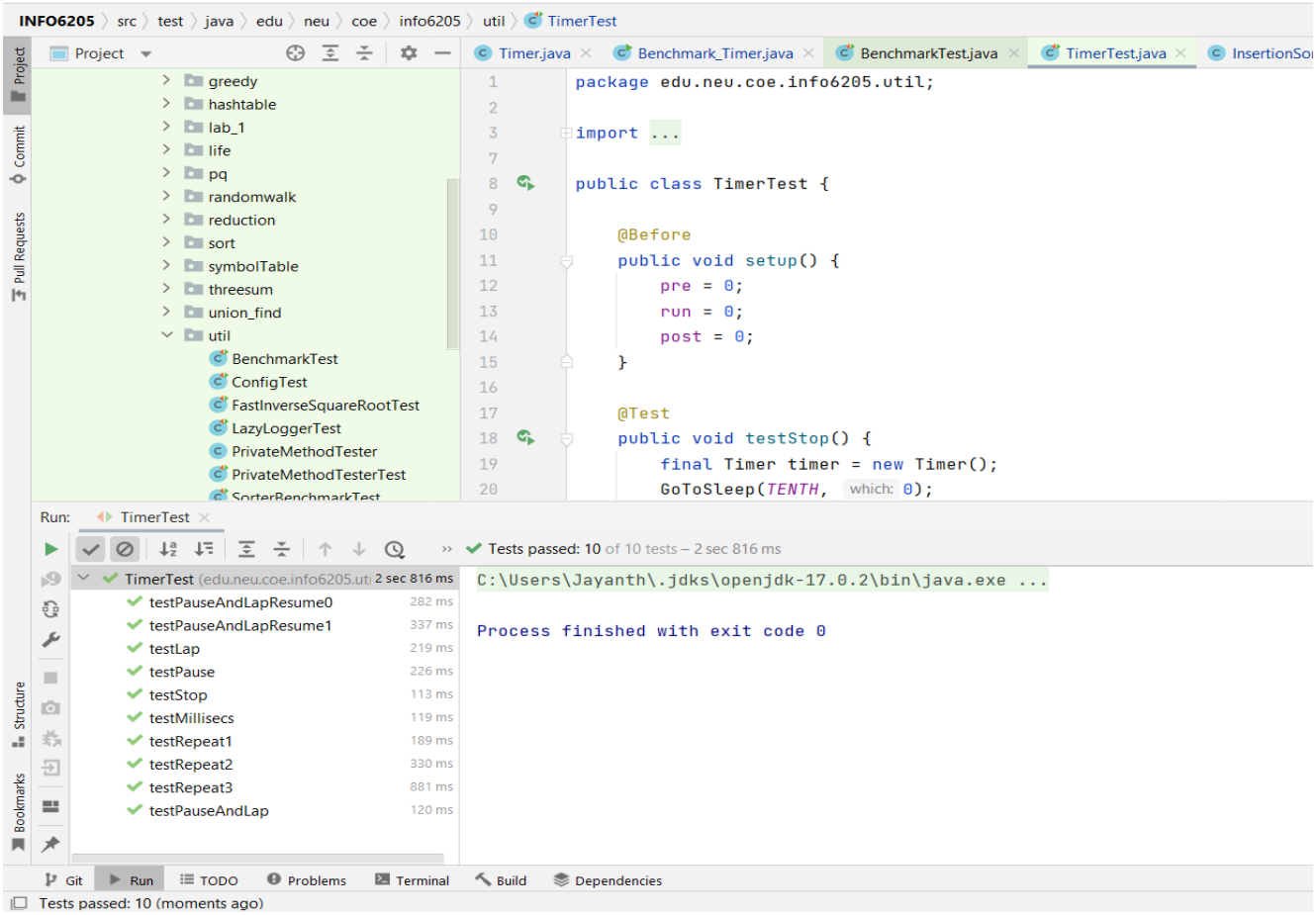
Reverse Ordered Array

2022-02-12 21:05:42 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 1000, Time: 1.6678833333333332
2022-02-12 21:05:42 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 2000, Time: 7.575003333333333
2022-02-12 21:05:42 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 4000, Time: 28.861373333333333
2022-02-12 21:05:43 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 8000, Time: 115.39204
2022-02-12 21:05:47 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 16000, Time: 485.58698
2022-02-12 21:06:03 INFO Benchmark_Timer - Begin run: Insertion Sort with 30 runs
N= 32000, Time: 2202.9538833333336

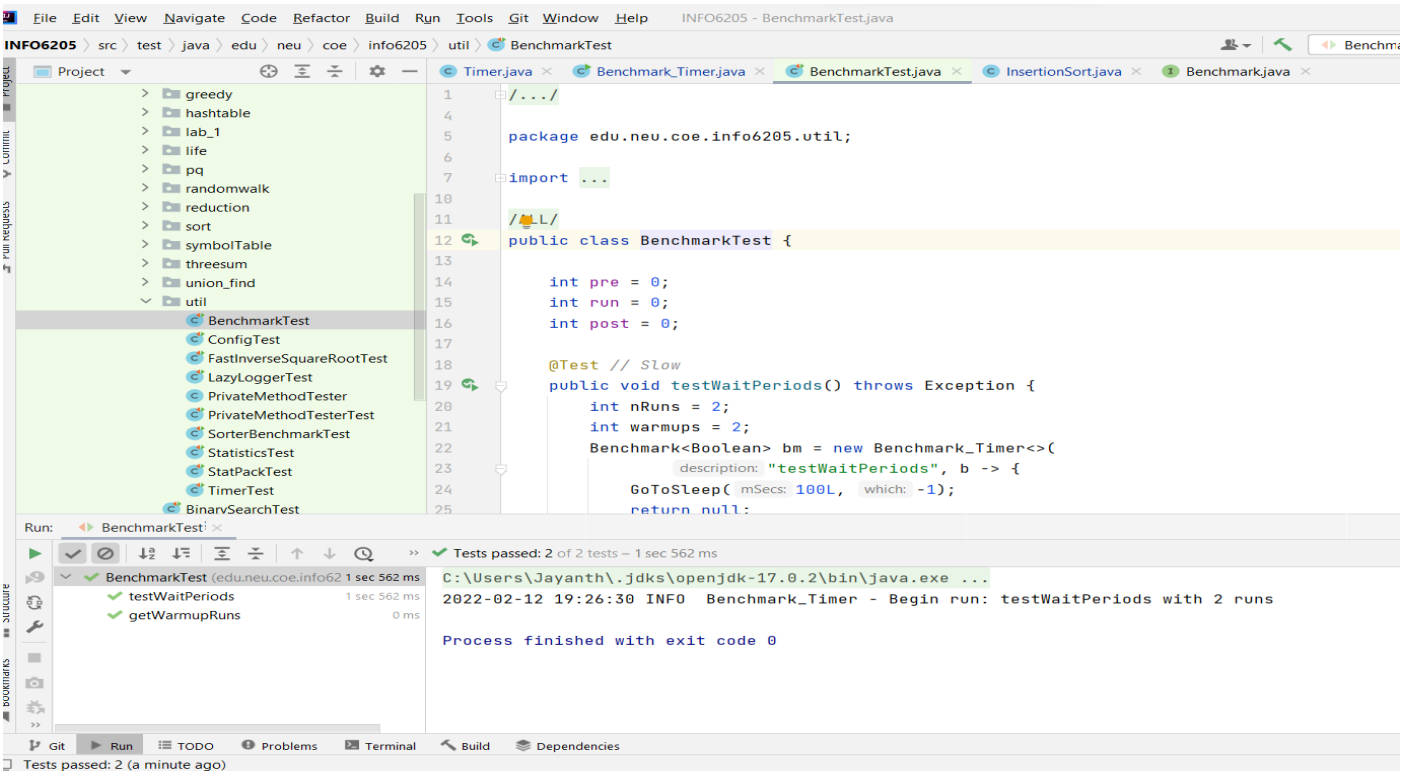
Process finished with exit code 0

Unit Tests

- ***TimerTest***



- ***BenchmarkTest***



- ***InsertionSortTest***