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Program Structures & Algorithms

Spring 2021

Assignment No. 4

- ## Task

We mentioned two alternatives for implementing Union-Find:

1. For weighted quick union, store the depth rather than the size;
2. For weighted quick union with path compression, do two loops, so that all intermediate nodes point to the root, not just the alternates.

For both of these, code the alternative and benchmark it against the implementation in the repository. You have all of that available from a previous assignment.

- ## Solution

The class UF_DWQU stores the weighted quick union by depth without path compression, UF_HWQU stores the weighted quick union by size without path compression, WQUPC OneLoop has weighted quick union, one pass variant of path compression, WQUPC has weighted quick union, two pass implementation of path compression and UF_HWQUPC stores the weighted quick union with one pass variant path compression. The test cases are written for all the classes and all of them benchmarked using the class Benchmark_Alternatives.

```
C:\Users\anjal\.jdks\openjdk-15.0.1\bin\java.exe ...
2021-03-02 10:26:52 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
2021-03-02 10:26:52 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


-------------------------------------------------500-------------------------------------------------------------
Weighted Quick Union by Depth - average time: 0.108 for 500 runs.
Weighted Quick Union by Size- average time: 0.104 for 500 runs.
Weighted Quick Union by Size - One pass - path compression - average time:: 0.102 for 500 runs.
Weighted Quick Union - One pass - path compression - average time: 0.084 for 500 runs.
Weighted Quick Union - Two pass - path compression - average time: 0.088 for 500 runs.


2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


-------------------------------------------------1000------------------------------------------------------------
Weighted Quick Union by Depth - average time: 0.152 for 500 runs.
Weighted Quick Union by Size- average time: 0.16 for 500 runs.
Weighted Quick Union by Size - One pass - path compression - average time:: 0.13 for 500 runs.
Weighted Quick Union - One pass - path compression - average time: 0.124 for 500 runs.
Weighted Quick Union - Two pass - path compression - average time: 0.138 for 500 runs.
```

```
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
2021-03-02 10:26:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
2021-03-02 10:26:54 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


----------------------------------------------------2000----------------------------------------------------------
Weighted Quick Union by Depth - average time: 0.282 for 500 runs.
Weighted Quick Union by Size- average time: 0.302 for 500 runs.
Weighted Quick Union by Size - One pass - path compression - average time:: 0.252 for 500 runs.
Weighted Quick Union - One pass - path compression - average time: 0.212 for 500 runs.
Weighted Quick Union - Two pass - path compression - average time: 0.244 for 500 runs.


2021-03-02 10:26:54 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
2021-03-02 10:26:54 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
2021-03-02 10:26:54 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
2021-03-02 10:26:55 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
2021-03-02 10:26:55 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


----------------------------------------------------4000----------------------------------------------------------
Weighted Quick Union by Depth - average time: 0.688 for 500 runs.
Weighted Quick Union by Size- average time: 0.624 for 500 runs.
Weighted Quick Union by Size - One pass - path compression - average time:: 0.488 for 500 runs.
Weighted Quick Union - One pass - path compression - average time: 0.474 for 500 runs.
Weighted Quick Union - Two pass - path compression - average time: 0.482 for 500 runs.


2021-03-02 10:26:55 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
2021-03-02 10:26:56 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
2021-03-02 10:26:57 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
2021-03-02 10:26:57 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
2021-03-02 10:26:58 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


----------------------------------------------------8000----------------------------------------------------------
Weighted Quick Union by Depth - average time: 1.402 for 500 runs.
Weighted Quick Union by Size- average time: 1.452 for 500 runs.
Weighted Quick Union by Size - One pass - path compression - average time:: 1.06 for 500 runs.
Weighted Quick Union - One pass - path compression - average time: 0.986 for 500 runs.
Weighted Quick Union - Two pass - path compression - average time: 1.012 for 500 runs.


2021-03-02 10:26:58 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
2021-03-02 10:27:00 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
2021-03-02 10:27:01 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
2021-03-02 10:27:03 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
2021-03-02 10:27:04 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


----------------------------------------------------16000----------------------------------------------------------
Weighted Quick Union by Depth - average time: 3.112 for 500 runs.
Weighted Quick Union by Size- average time: 3.206 for 500 runs.
Weighted Quick Union by Size - One pass - path compression - average time:: 2.324 for 500 runs.
Weighted Quick Union - One pass - path compression - average time: 2.238 for 500 runs.
Weighted Quick Union - Two pass - path compression - average time: 2.232 for 500 runs.
```

```
Run:    Benchmark_Alternatives ×
 ▶   ↑   2021-03-02 10:27:05 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
 ⚒   ↓   2021-03-02 10:27:08 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
 ■   ⤵   2021-03-02 10:27:12 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
 ⌷   ⬇   2021-03-02 10:27:15 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
 ⤦   🖶   2021-03-02 10:27:17 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs
 ⇥   🗑
         ---------------------------------------------------32000----------------------------------------------------
 ▦       Weighted Quick Union by Depth - average time: 6.97 for 500 runs.
 ⚲       Weighted Quick Union by Size- average time: 7.202 for 500 runs.
         Weighted Quick Union by Size - One pass - path compression - average time:: 5.04 for 500 runs.
         Weighted Quick Union - One pass - path compression - average time: 4.93 for 500 runs.
         Weighted Quick Union - Two pass - path compression - average time: 4.764 for 500 runs.


         2021-03-02 10:27:20 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
         2021-03-02 10:27:28 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
         2021-03-02 10:27:36 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
         2021-03-02 10:27:42 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
         2021-03-02 10:27:48 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


         ---------------------------------------------------64000----------------------------------------------------
         Weighted Quick Union by Depth - average time: 16.062 for 500 runs.
         Weighted Quick Union by Size- average time: 16.186 for 500 runs.
         Weighted Quick Union by Size - One pass - path compression - average time:: 11.546 for 500 runs.
         Weighted Quick Union - One pass - path compression - average time: 11.044 for 500 runs.
         Weighted Quick Union - Two pass - path compression - average time: 11.046 for 500 runs.


             2021-03-02 10:27:53 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Depth with 500 runs
             2021-03-02 10:28:15 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Size with 500 runs
             2021-03-02 10:28:37 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass - path compression with 500 runs
             2021-03-02 10:28:50 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - One pass -path compression with size with 500 runs
             2021-03-02 10:29:05 INFO  Benchmark_Timer - Begin run: Weighted Quick Union - Two pass - path compression with 500 runs


             ---------------------------------------------------128000----------------------------------------------------
             Weighted Quick Union by Depth - average time: 42.486 for 500 runs.
             Weighted Quick Union by Size- average time: 42.81 for 500 runs.
             Weighted Quick Union by Size - One pass - path compression - average time:: 28.294 for 500 runs.
             Weighted Quick Union - One pass - path compression - average time: 26.968 for 500 runs.
             Weighted Quick Union - Two pass - path compression - average time: 27.034 for 500 runs.


             Process finished with exit code 0
```

• Relationship Conclusion:

Part 1:

It can be observed from the result that when benchmarked the average time for weighted quick union by storing depth and size **are almost identical** i.e., very similar to each other. The only difference in both the methods as the find and union methods are same is in the way the tree stores the nodes.
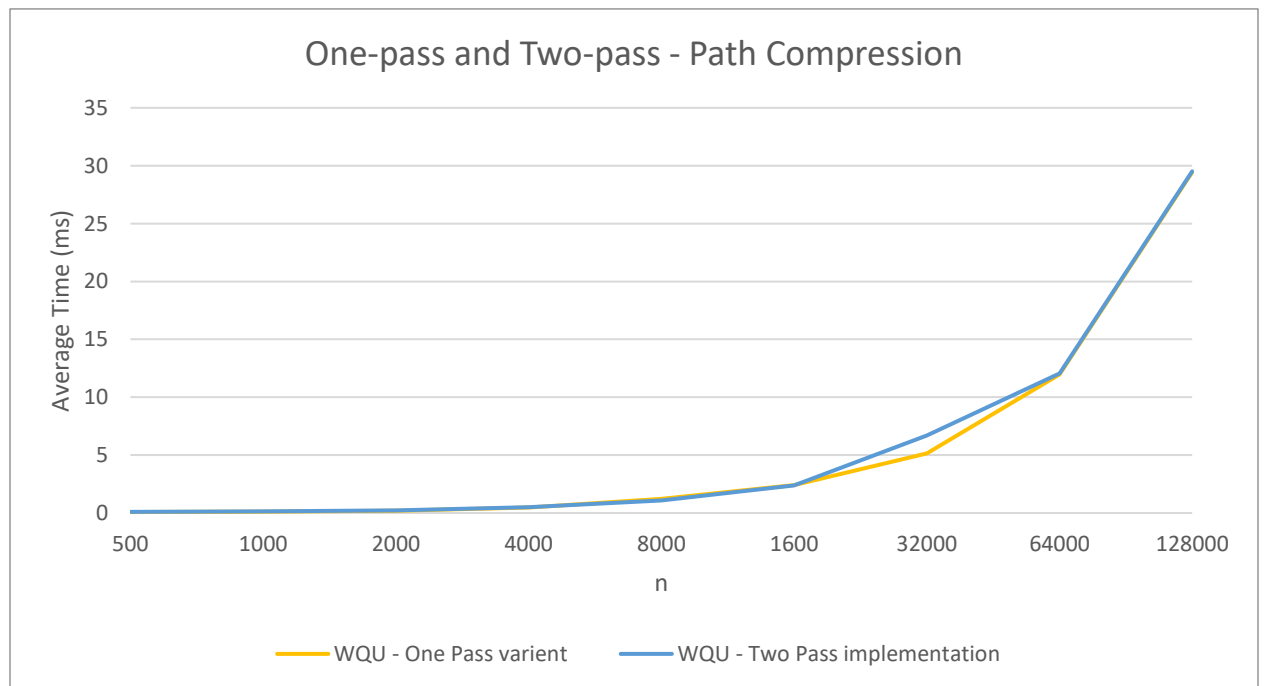
It can be observed that the weighted quick union with path compression has better average time than without path compression.
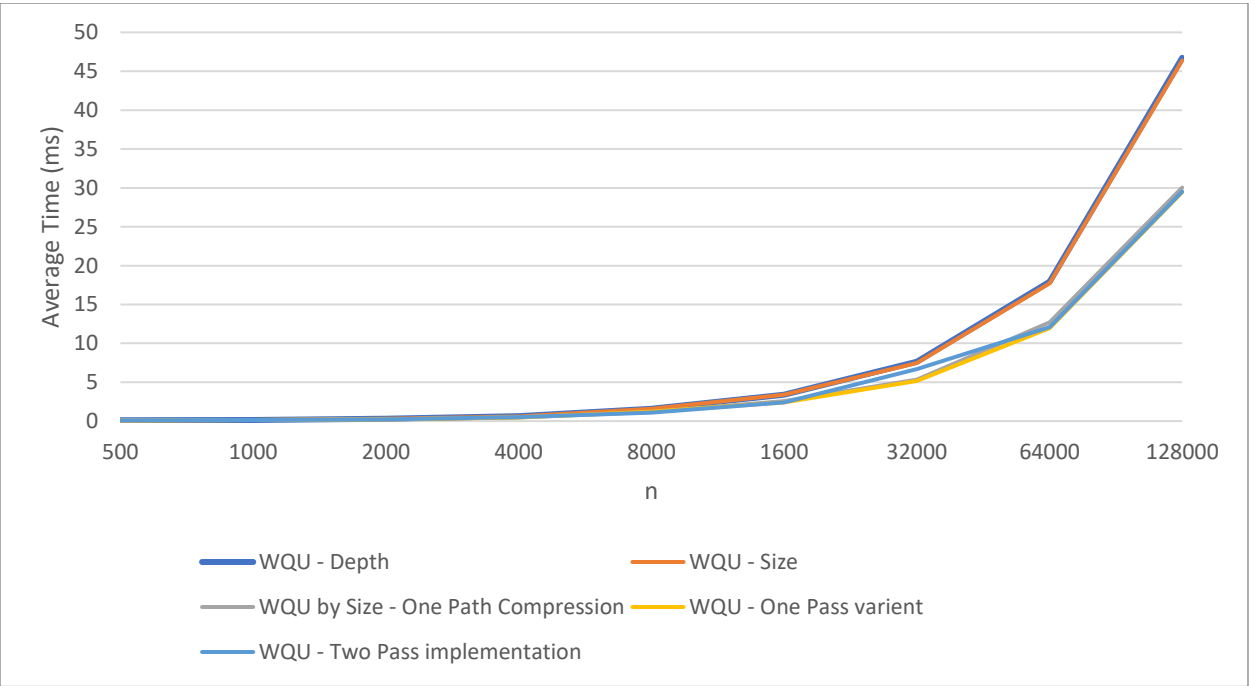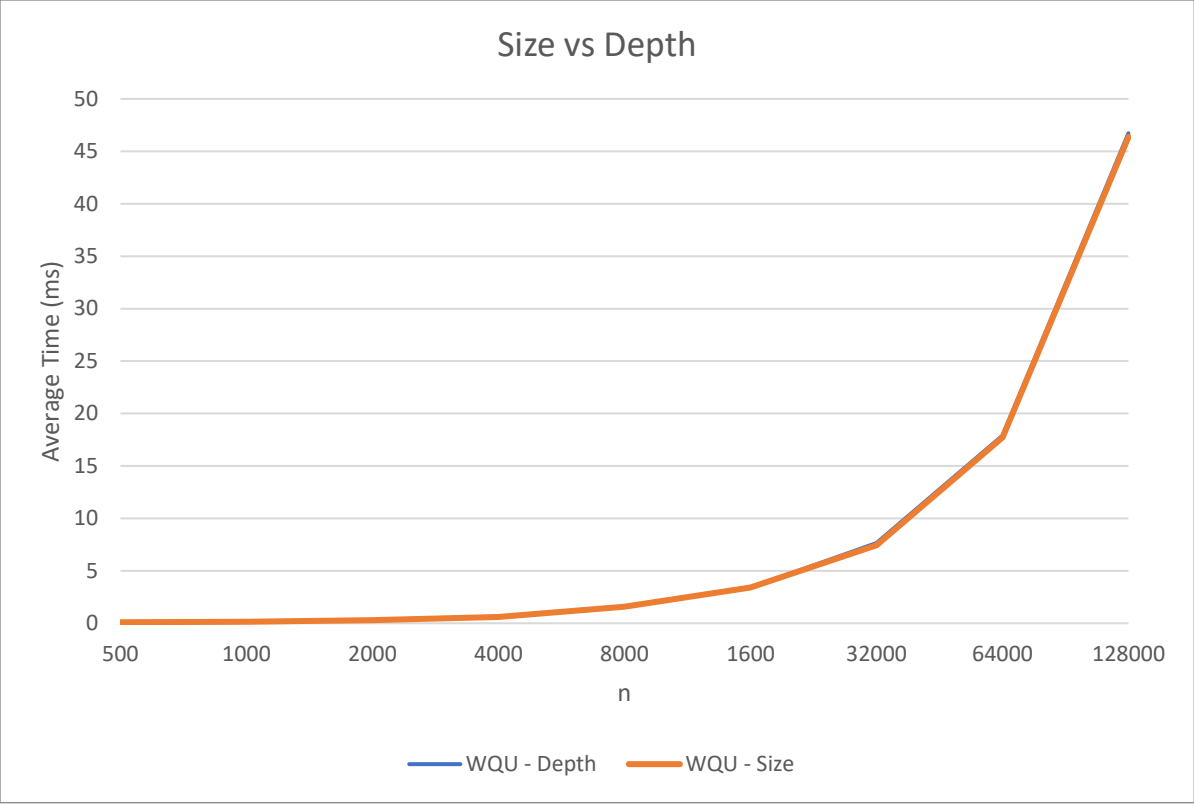
Part 2:

For the path compression with one – pass variant and two pass implementations, they both are very similar with one pass implementation being slightly (very small difference) better than the two-pass implementation.
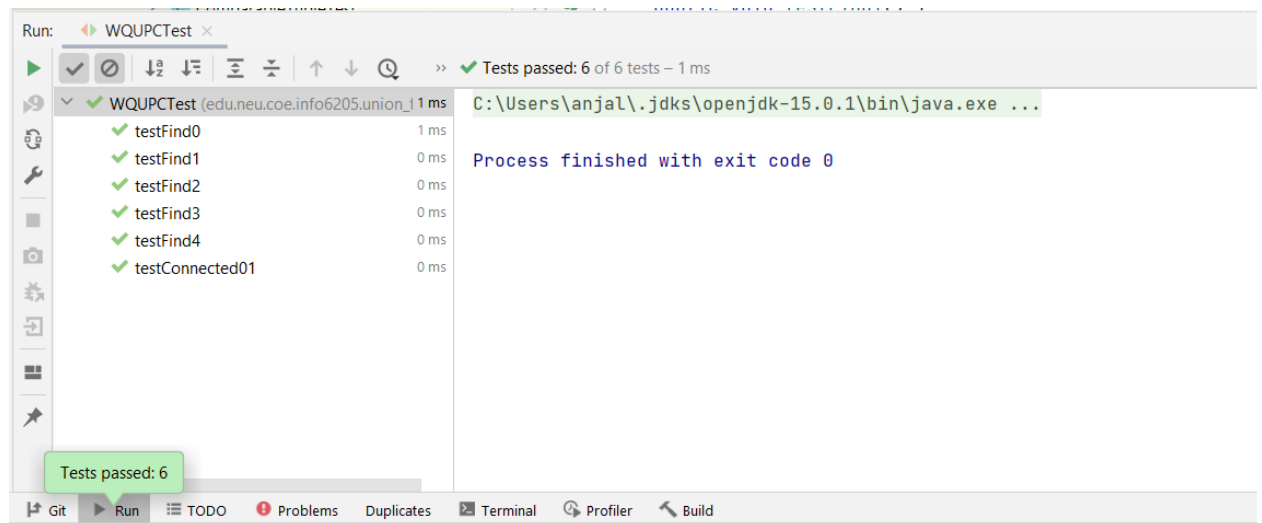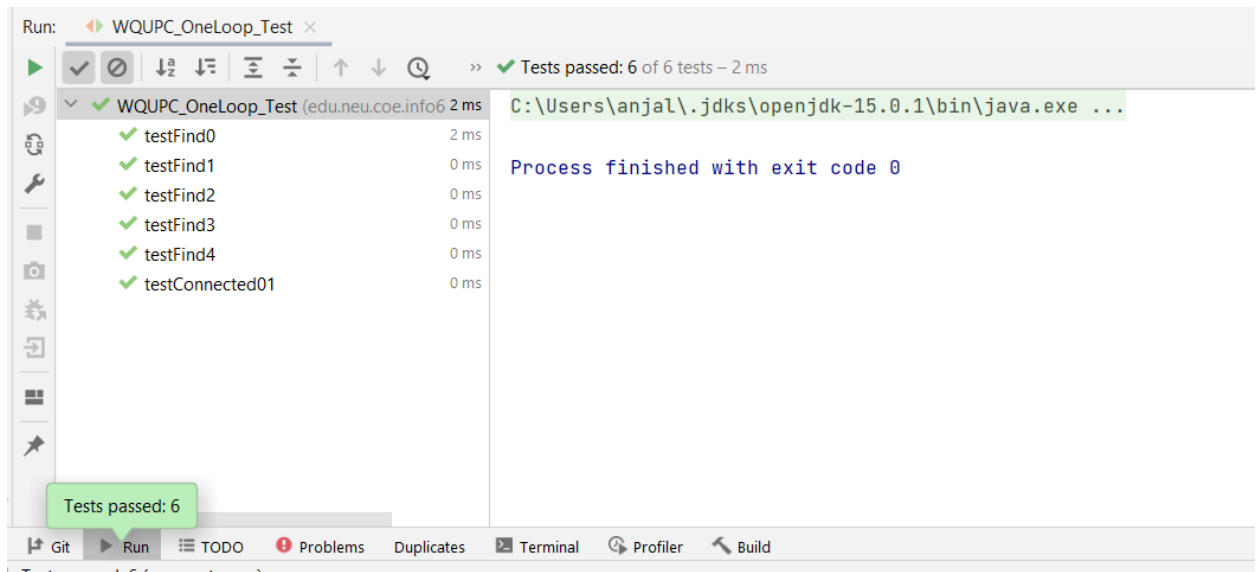
- **Evidence to support the conclusion and graphical representation:**

n	WQU - Depth	WQU - Size	WQU by Size - with path compression (one pass)	WQU - One Pass -Path Compression	WQU - Two Pass Implementation
500	0.11	0.098	0.096	0.08	0.096
1000	0.152	0.154	0.132	0.122	0.134
2000	0.294	0.288	0.22	0.204	0.212
4000	0.63	0.612	0.47	0.464	0.498
8000	1.57	1.57	1.178	1.23	1.088
1600	3.39	3.398	2.558	2.402	2.386
32000	7.634	7.448	5.314	5.144	6.692
64000	17.912	17.73	12.684	11.964	12.066
128000	46.726	46.37	30.034	29.442	29.516

Size vs Depth

Average Time (ms) vs n

WQU - Depth
WQU - Size

Average Time (ms) vs n

WQU - Depth
WQU - Size
WQU by Size - One Path Compression
WQU - One Pass varient
WQU - Two Pass implementation

- **Unit tests result:**