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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 by size with path compression. The test cases are written for all the classes and all of them benchmarked using the class Benchmark_Alternatives.

```
Run:    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:**

<u>Part 1:</u>

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. Hence it can be concluded that even if depth or size is used for weighted quick union it does not change the average run time. As both the find and union methods are same, the only difference in them is in the way the tree stores the nodes.

It can also be observed that the weighted quick union by size with path compression has better average time than without path compression.

For the path compression with one pass variant and two pass implementations, they both are very similar with one pass implementation having a slightly better average runtime (very small margin) than the two-pass implementation.

When comparing the WQU by size with path compression and two pass implementation method. The two-pass implementation method is slightly better for larger values of n i.e., has less run time average. It can be observed from the table given in evidence section.

- **Evidence to support the conclusion and graphical representation:**

| n | WQU - Depth | WQU - Size | WQU by Size - with path compression | 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 |

## One-pass and Two-pass - Path Compression



## Size vs Depth
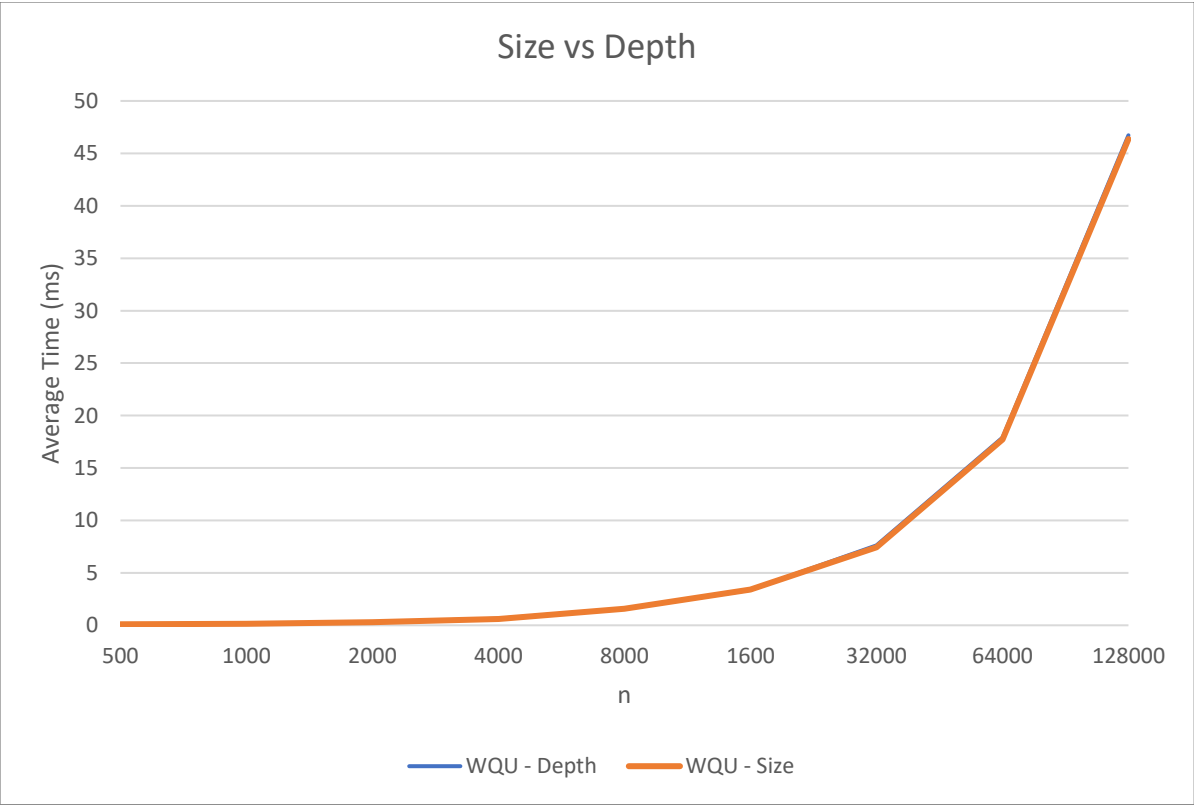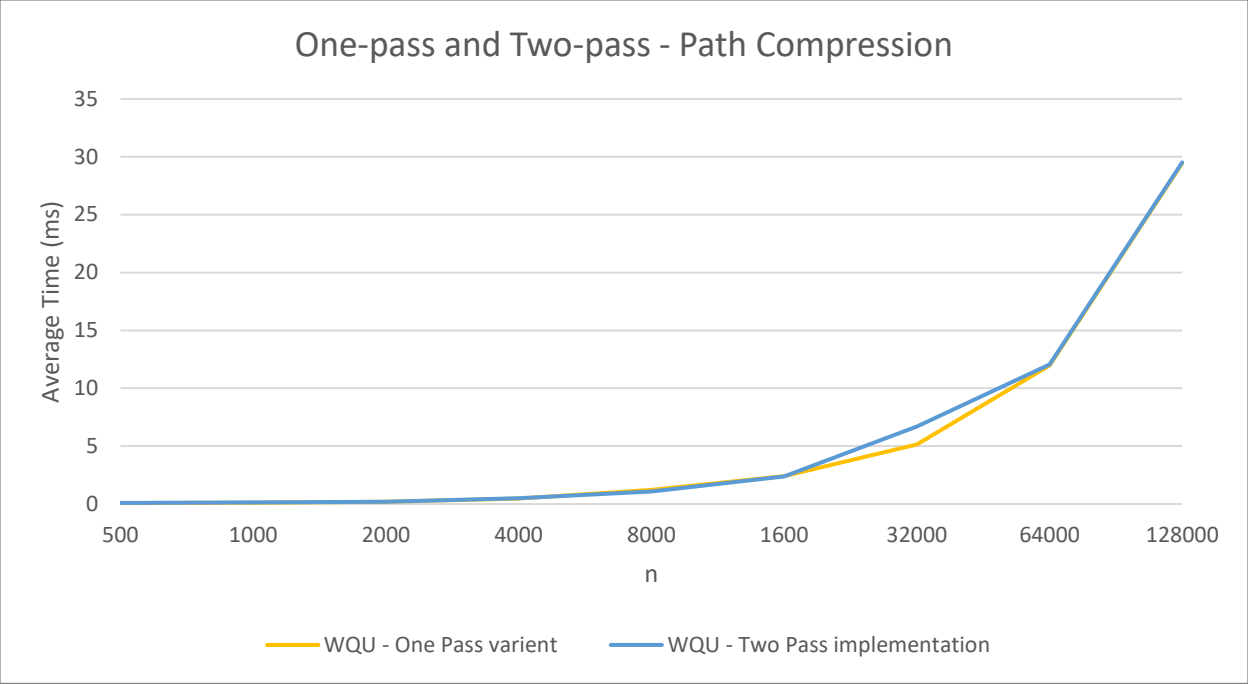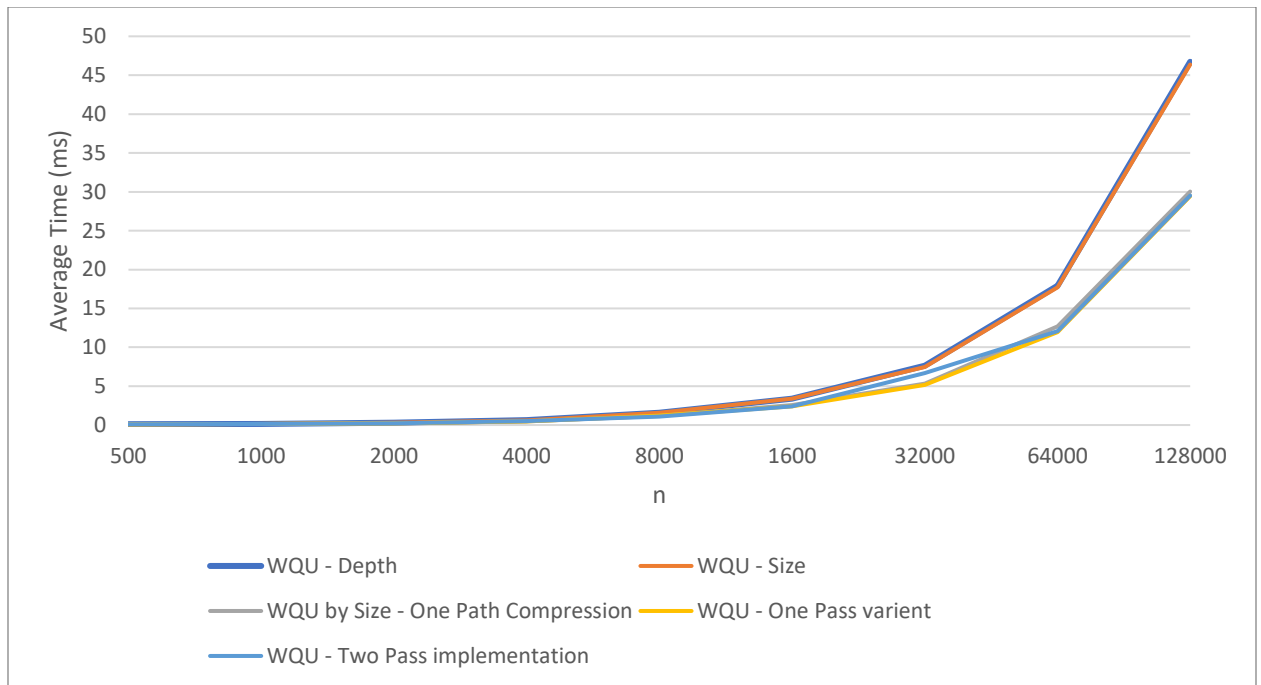
- **Unit tests result:**

Run: ◆▶ WQUPCTest ✕

✓ ⊘ | ↓ₐᶻ ↓⁼ | ⤒ ⤓ | ↑ ↓ | ⏱ | ›› | ✓ Tests passed: 6 of 6 tests – 1 ms

✓ ✓ WQUPCTest (edu.neu.coe.info6205.union_1 1 ms     C:\Users\anjal\.jdks\openjdk-15.0.1\bin\java.exe ...
    ✓ testFind0                              1 ms
    ✓ testFind1                              0 ms     Process finished with exit code 0
    ✓ testFind2                              0 ms
    ✓ testFind3                              0 ms
    ✓ testFind4                              0 ms
    ✓ testConnected01                        0 ms

                    Tests passed: 6

�ᵖ Git    ▶ Run    ☰ TODO    ❗ Problems    Duplicates    ⌦ Terminal    ⏲ Profiler    ⚒ Build

Run: ◆▶ UF_DWQU_Test ✕

✓ ⊘ | ↓ₐᶻ ↓⁼ | ⤒ ⤓ | ↑ ↓ | ⏱ | ›› | ✓ Tests passed: 11 of 11 tests – 3 ms

✓ ✓ UF_DWQU_Test (edu.neu.coe.info6205.uni 3 ms     C:\Users\anjal\.jdks\openjdk-15.0.1\bin\java.exe ...
    ✓ testIsConnected01                      1 ms
    ✓ testIsConnected02                      1 ms     Process finished with exit code 0
    ✓ testFind0                              0 ms
    ✓ testFind1                              0 ms
    ✓ testFind2                              0 ms
    ✓ testFind3                              1 ms
    ✓ testFind5                              0 ms
    ✓ testToString                           0 ms
    ✓ testConnect01                          0 ms
    ✓ testConnect02                          0 ms
    ✓ testConnected01                        0 ms

                    Tests passed: 11

�ᵖ Git    ▶ Run    ☰ TODO    ❗ Problems    Duplicates    ⌦ Terminal    ⏲ Profiler    ⚒ Build

Run: ◆▶ UF_HWQU_Test ✕

✓ ⊘ | ↓ₐᶻ ↓⁼ | ⤒ ⤓ | ↑ ↓ | ⏱ | ›› | ✓ Tests passed: 12 of 12 tests – 4 ms

✓ ✓ UF_HWQU_Test (edu.neu.coe.info6205.uni 4 ms     C:\Users\anjal\.jdks\openjdk-15.0.1\bin\java.exe ...
    ✓ testIsConnected01                      1 ms
    ✓ testIsConnected02                      0 ms     Process finished with exit code 0
    ✓ testIsConnected03                      2 ms
    ✓ testFind0                              0 ms
    ✓ testFind1                              0 ms
    ✓ testFind2                              1 ms
    ✓ testFind3                              0 ms
    ✓ testFind5                              0 ms
    ✓ testToString                           0 ms
    ✓ testConnect01                          0 ms
    ✓ testConnect02                          0 ms
    ✓ testConnected01                        0 ms