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Program Structures &Algorithms

Fall2021

Assignment No.3

Task(WQUPC)

Your task is

Step 1:

(a) Implement height-weighted Quick Union with Path Compression. For this, you will flesh out the class UF_HWQUPC. All you have to do is to fill in the sections marked with // TO BE IMPLEMENTED ... // ...END IMPLEMENTATION.

(b) Check that the unit tests for this class all work. You must show "green" test results in your submission (screenshot is OK).

Step 2:

Using your implementation of UF_HWQUPC, develop a UF ("union-find") client that takes an integer value n from the command line to determine the number of "sites." Then generates random pairs of integers between 0 and n-1, calling connected() to determine if they are connected and union() if not. Loop until all sites are connected then print the number of connections generated. Package your program as a static method count() that takes n as the argument and returns the number of connections; and a main() that takes n from the command line, calls count() and prints the returned value. If you prefer, you can create a main program that doesn't require any input and runs the experiment for a fixed set of n values. Show evidence of your run(s).

Step 3:

Determine the relationship between the number of objects (*n*) and the number of pairs (*m*) generated to accomplish this (i.e. to reduce the number of components from *n* to 1). Justify your conclusion in terms of your observations and what you think might be going on.

NOTE: although I'm not going to tell you in advance what the relationship is, I can assure you that it is a *simple* relationship.

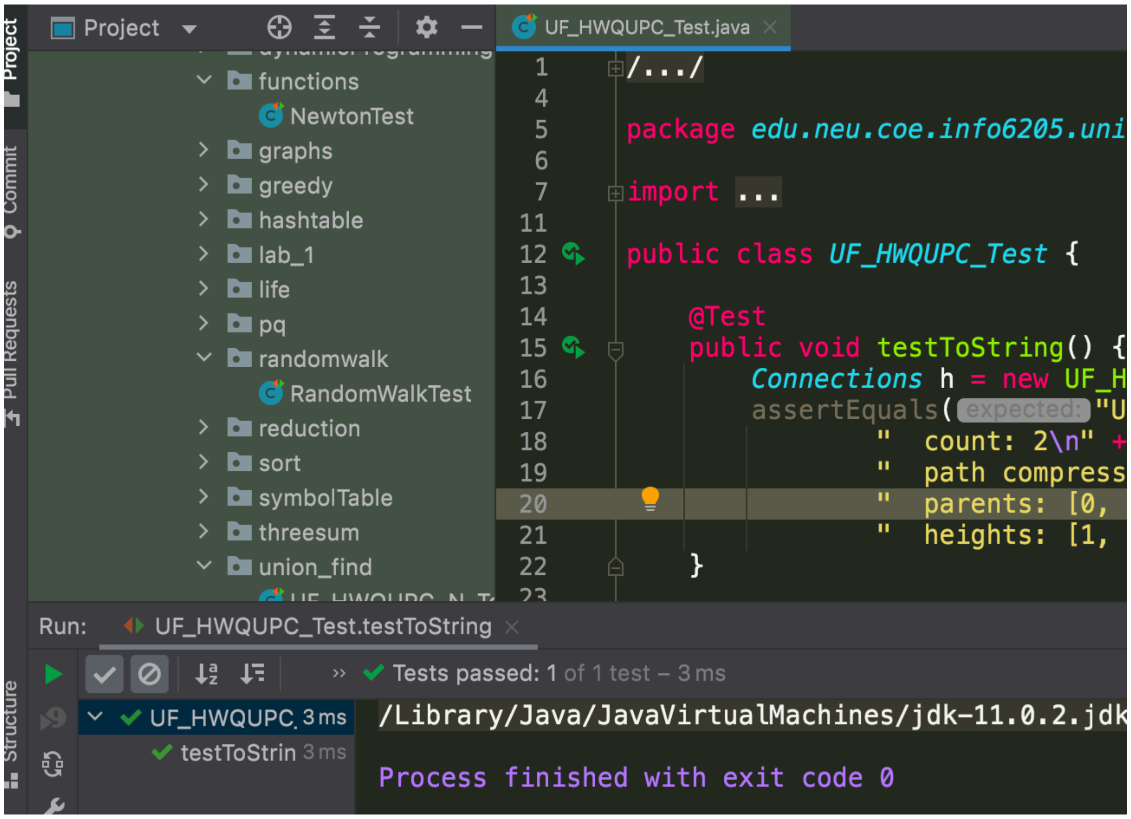
Don't forget to follow the submission guidelines. And to use sufficient (and sufficiently large) different values of n.

Step1

UF_HWQUPC

a. Code
https://github.com/slowpeace2020/INFO6205/blob/Fall2021/src/main/java/edu/neu/coe/info6205/union_find/UF_HWQUPC.java

b. Unit test



Project

functions
NewtonTest
graphs
greedy
hashtable
lab_1
life
pq
randomwalk
RandomWalkTest
reduction
sort
symbolTable
threesum
union_find

UF_HWQUPC_Test.java

```
/.../

package edu.neu.coe.info6205.uni

import ...

public class UF_HWQUPC_Test {

    @Test
    public void testToString() {
        Connections h = new UF_H
        assertEquals( expected: "U
                "  count: 2\n" +
                "  path compress
                "  parents: [0,
                "  heights: [1,
    }
```

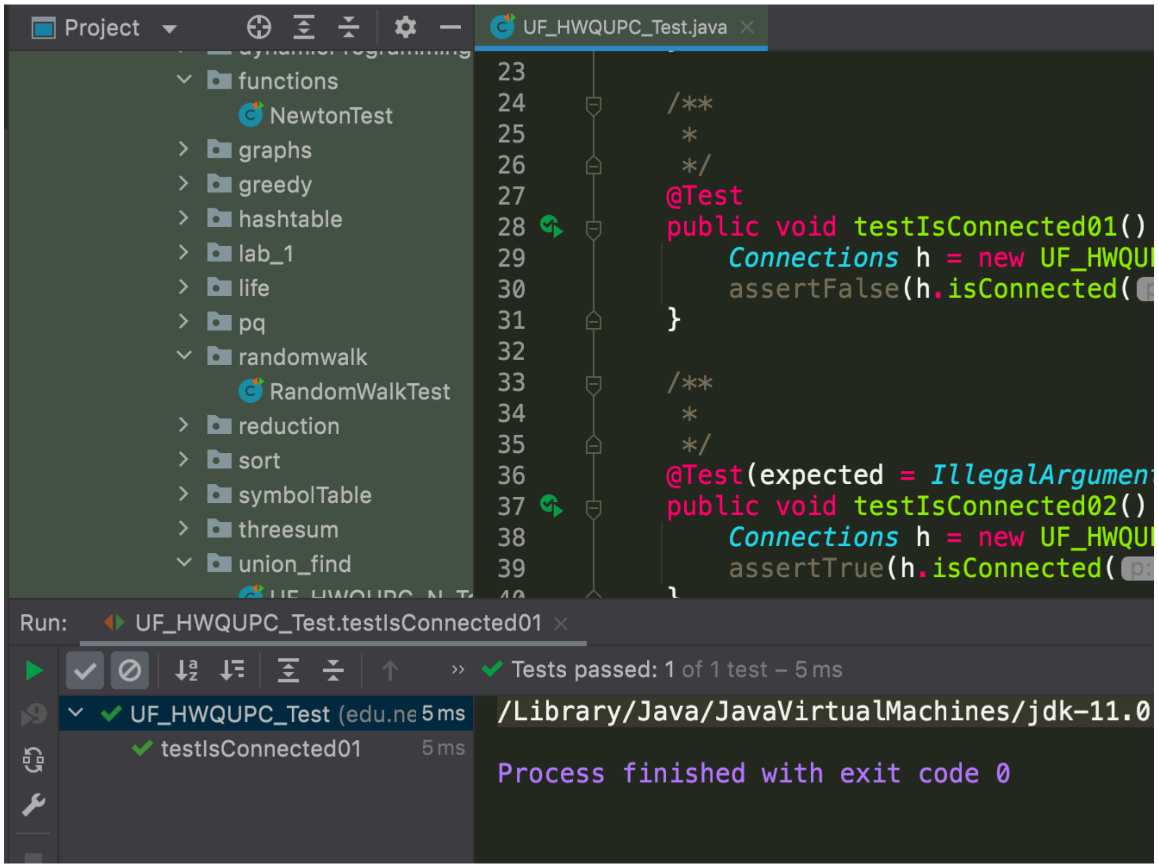
Run: UF_HWQUPC_Test.testToString

Tests passed: 1 of 1 test – 3 ms

UF_HWQUPC 3 ms
testToStrin 3 ms

```
/Library/Java/JavaVirtualMachines/jdk-11.0.2.jdk

Process finished with exit code 0
```

(grap1. UF_HWQUPC_Test method testToString)



Project

functions
NewtonTest
graphs
greedy
hashtable
lab_1
life
pq
randomwalk
RandomWalkTest
reduction
sort
symbolTable
threesum
union_find

UF_HWQUPC_Test.java

```
    /**
     *
     */
    @Test
    public void testIsConnected01()
        Connections h = new UF_HWQU
        assertFalse(h.isConnected(
    }

    /**
     *
     */
    @Test(expected = IllegalArgumen
    public void testIsConnected02()
        Connections h = new UF_HWQU
        assertTrue(h.isConnected(
```

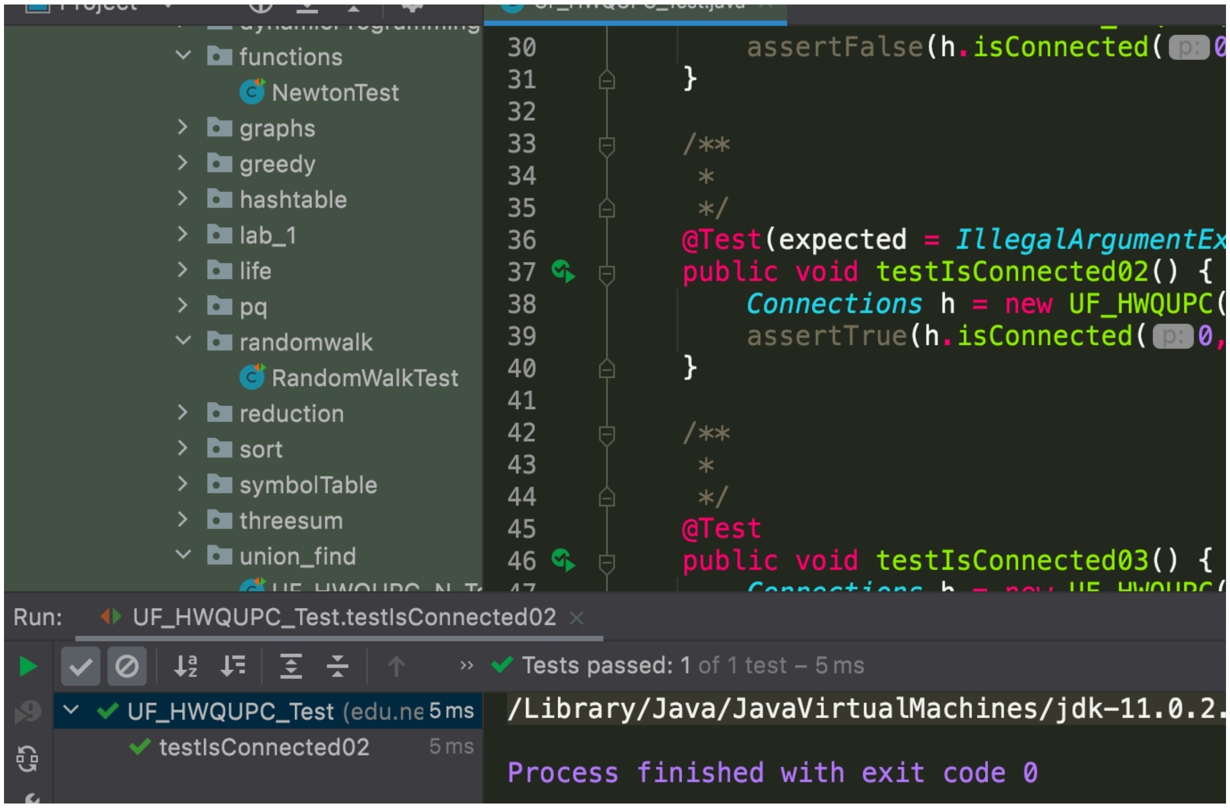
Run: UF_HWQUPC_Test.testIsConnected01

Tests passed: 1 of 1 test – 5 ms

UF_HWQUPC_Test (edu.ne 5 ms
testIsConnected01 5 ms

```
/Library/Java/JavaVirtualMachines/jdk-11.0

Process finished with exit code 0
```

(graph 2. UF_HWQUPC_Test method testIsConnected01)



```
        assertFalse(h.isConnected( p: 0
    }

    /**
     *
     */
    @Test(expected = IllegalArgumentEx
    public void testIsConnected02() {
        Connections h = new UF_HWQUPC(
        assertTrue(h.isConnected( p: 0,
    }

    /**
     *
     */
    @Test
    public void testIsConnected03() {
```

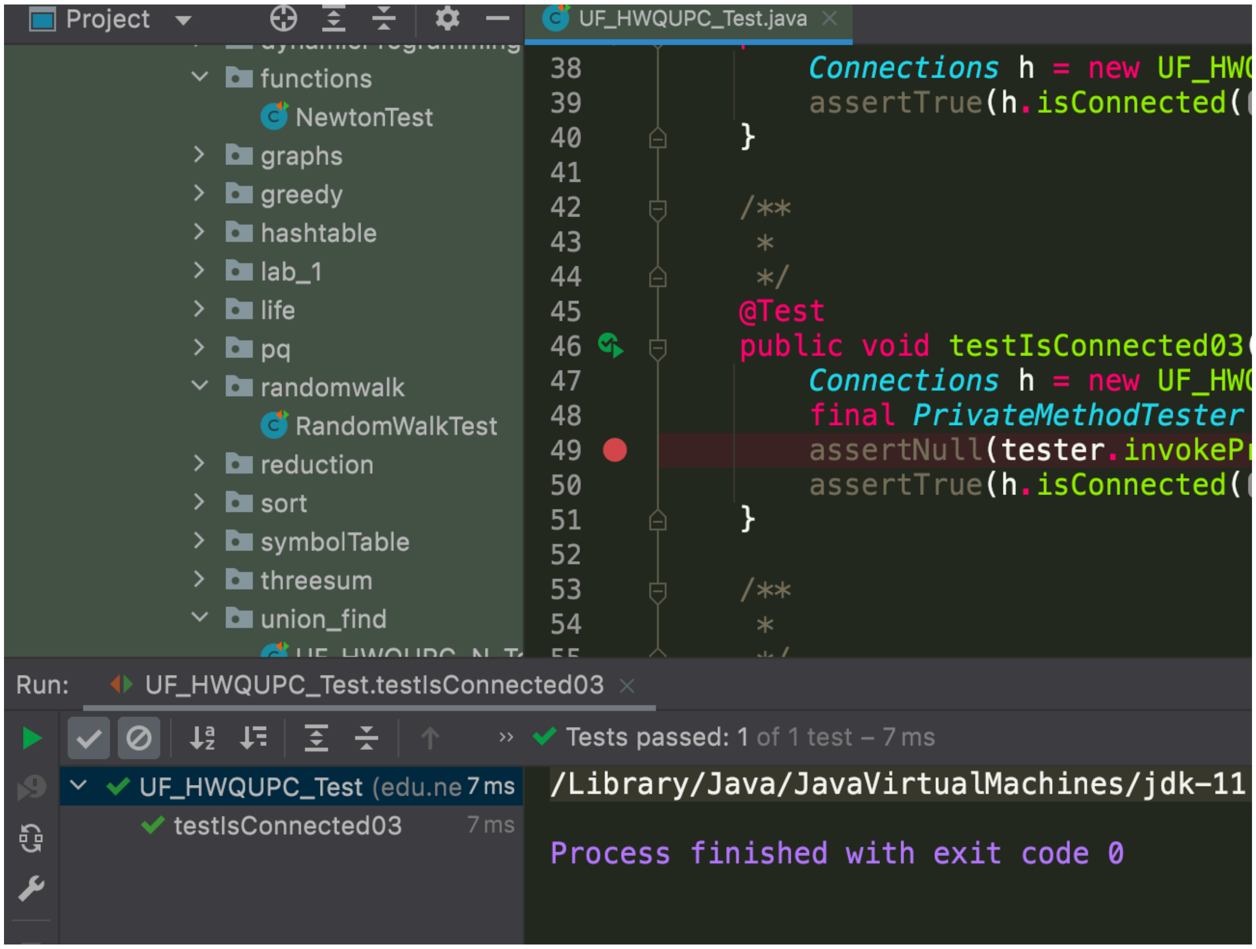
Run: UF_HWQUPC_Test.testIsConnected02

Tests passed: 1 of 1 test – 5 ms

UF_HWQUPC_Test (edu.ne 5 ms
testIsConnected02 5 ms

```
/Library/Java/JavaVirtualMachines/jdk-11.0.2.

Process finished with exit code 0
```

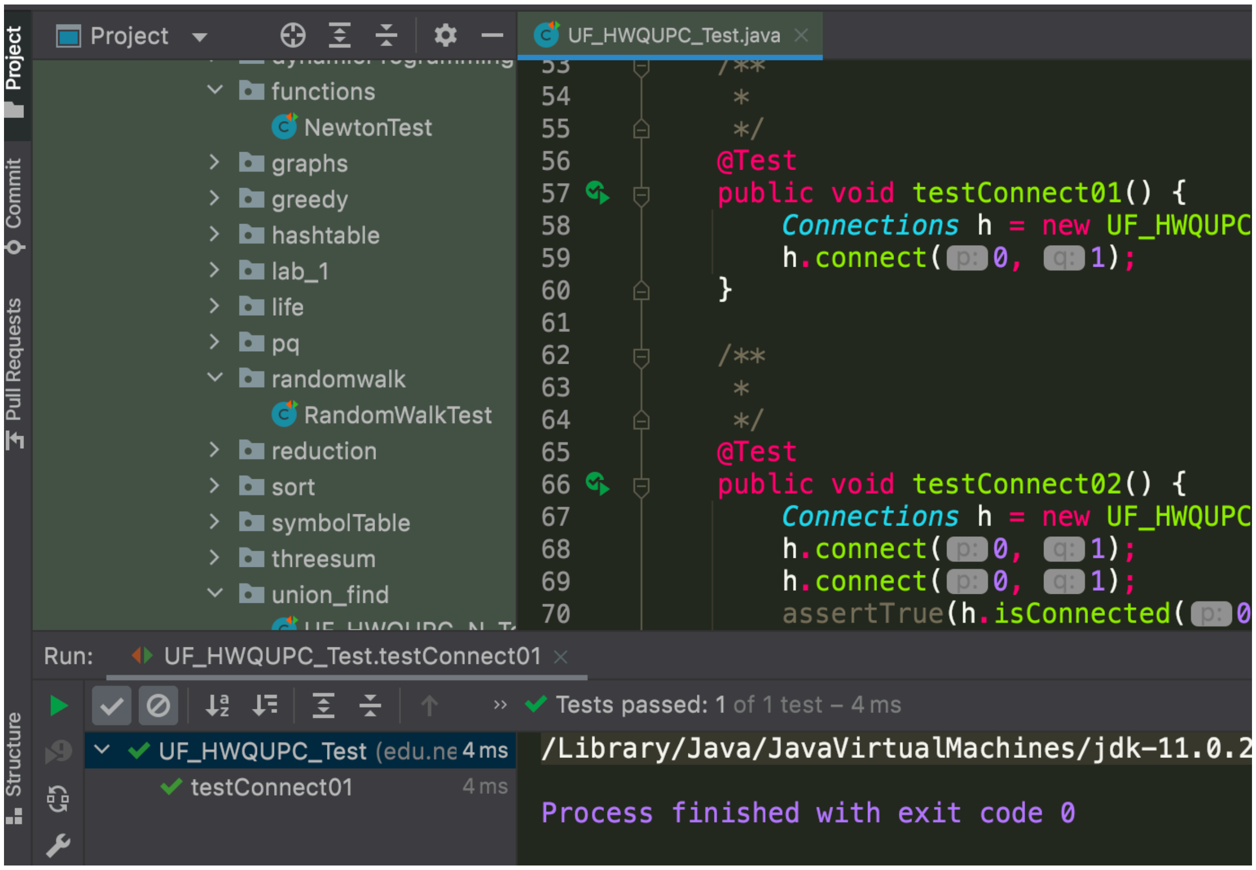
(graph 3. UF_HWQUPC_Test method testIsConnected02)



```
            Connections h = new UF_HW
            assertTrue(h.isConnected(
        }

        /**
         *
         */
        @Test
        public void testIsConnected03(
            Connections h = new UF_HW
            final PrivateMethodTester
            assertNull(tester.invokeP
            assertTrue(h.isConnected(
        }

        /**
         *
```

```
✓ Tests passed: 1 of 1 test – 7 ms
✓ UF_HWQUPC_Test (edu.ne 7 ms
  ✓ testIsConnected03    7 ms

/Library/Java/JavaVirtualMachines/jdk-11

Process finished with exit code 0
```

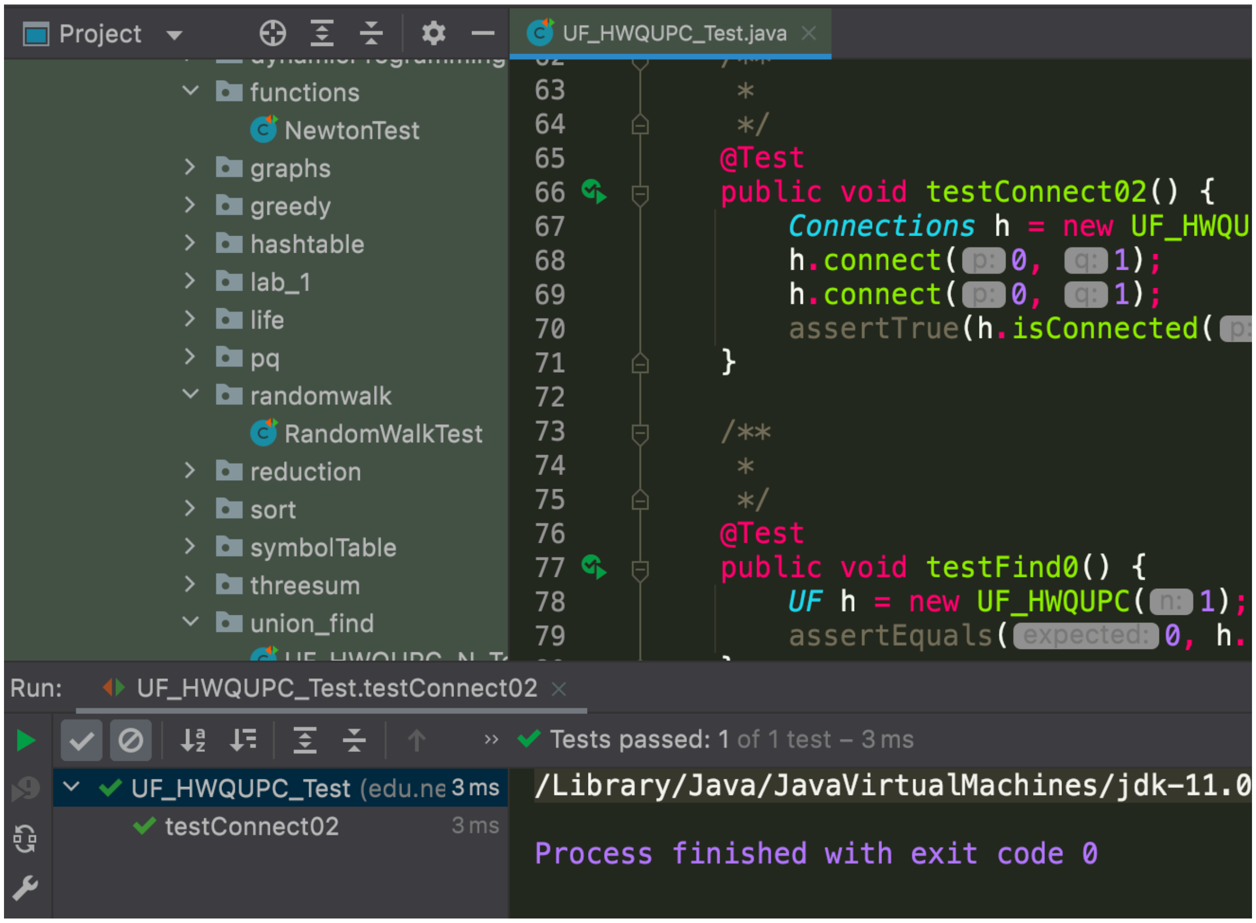
(graph 4. UF_HWQUPC_Test method testIsConnected03)



```
         *
         */
        @Test
        public void testConnect01() {
            Connections h = new UF_HWQUPC
            h.connect( p: 0,  q: 1);
        }

        /**
         *
         */
        @Test
        public void testConnect02() {
            Connections h = new UF_HWQUPC
            h.connect( p: 0,  q: 1);
            h.connect( p: 0,  q: 1);
            assertTrue(h.isConnected( p: 0
```

```
✓ Tests passed: 1 of 1 test – 4 ms
✓ UF_HWQUPC_Test (edu.ne 4 ms
  ✓ testConnect01    4 ms

/Library/Java/JavaVirtualMachines/jdk-11.0.2

Process finished with exit code 0
```

(graph 5. UF_HWQUPC_Test method testConnect01)

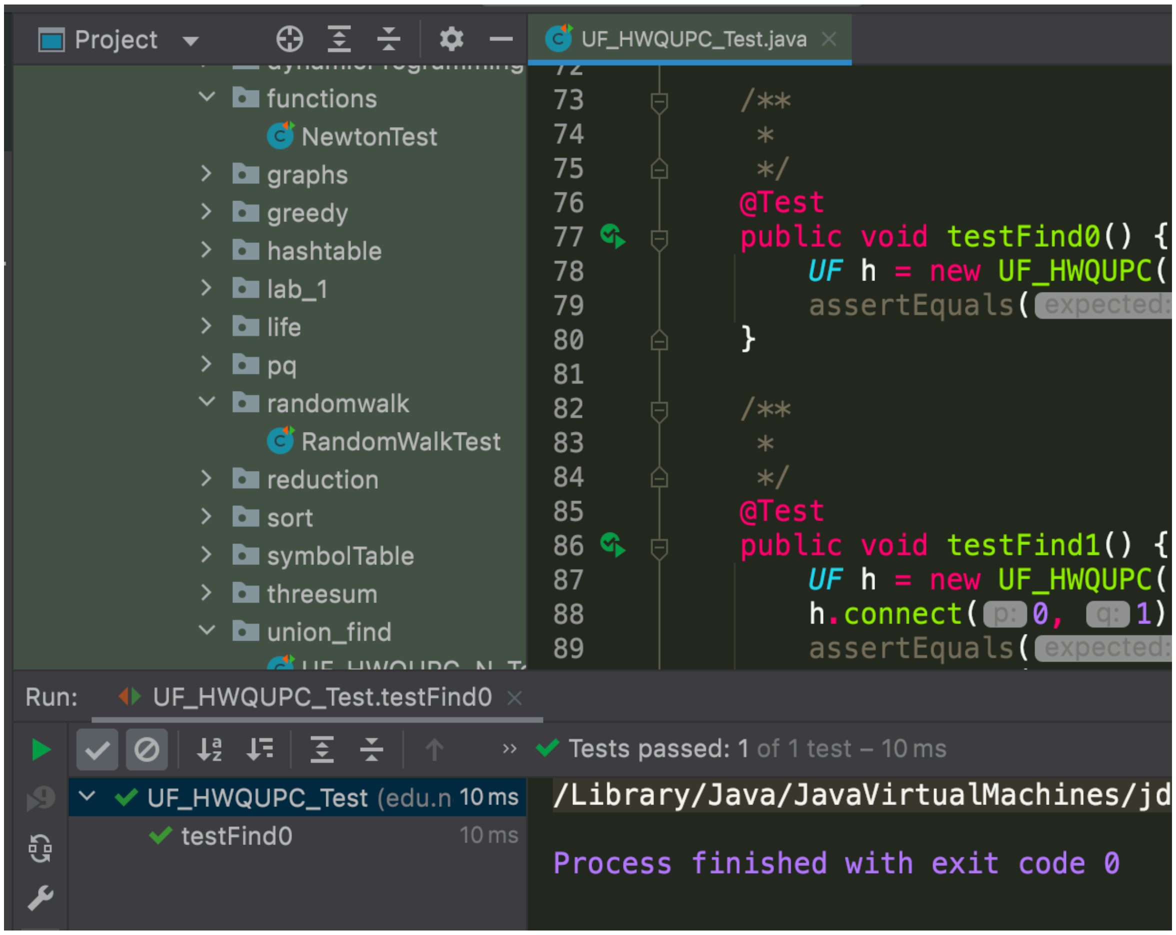


```
     *
     */
    @Test
    public void testConnect02() {
        Connections h = new UF_HWQU
        h.connect( p: 0,  q: 1);
        h.connect( p: 0,  q: 1);
        assertTrue(h.isConnected( p:
    }

    /**
     *
     */
    @Test
    public void testFind0() {
        UF h = new UF_HWQUPC( n: 1);
        assertEquals( expected: 0, h.
```

Tests passed: 1 of 1 test – 3 ms

```
/Library/Java/JavaVirtualMachines/jdk-11.0

Process finished with exit code 0
```

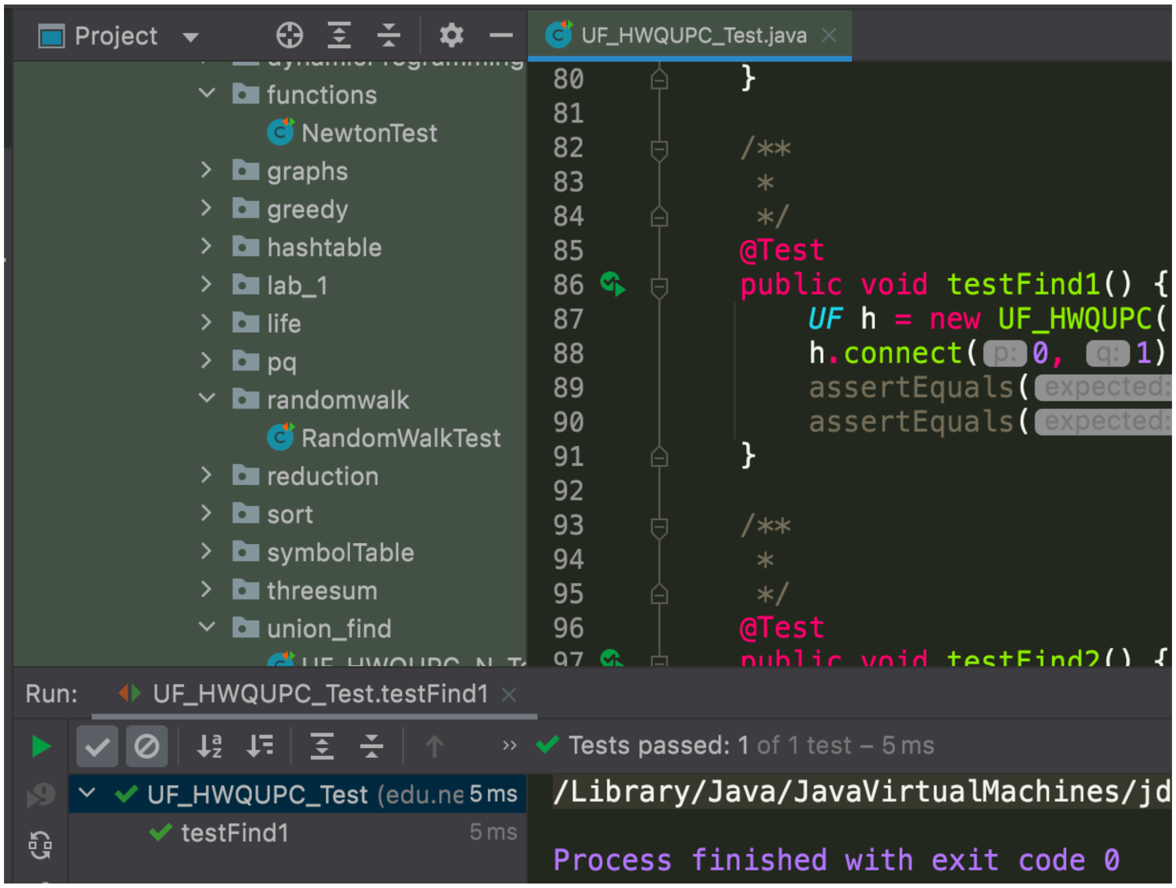
(graph 6. UF_HWQUPC_Test method testConnect02)



```
    /**
     *
     */
    @Test
    public void testFind0() {
        UF h = new UF_HWQUPC(
        assertEquals( expected:
    }

    /**
     *
     */
    @Test
    public void testFind1() {
        UF h = new UF_HWQUPC(
        h.connect( p: 0,  q: 1)
        assertEquals( expected:
```

```
✓ Tests passed: 1 of 1 test – 10 ms
✓ UF_HWQUPC_Test (edu.n 10 ms
    ✓ testFind0          10 ms

/Library/Java/JavaVirtualMachines/jd

Process finished with exit code 0
```

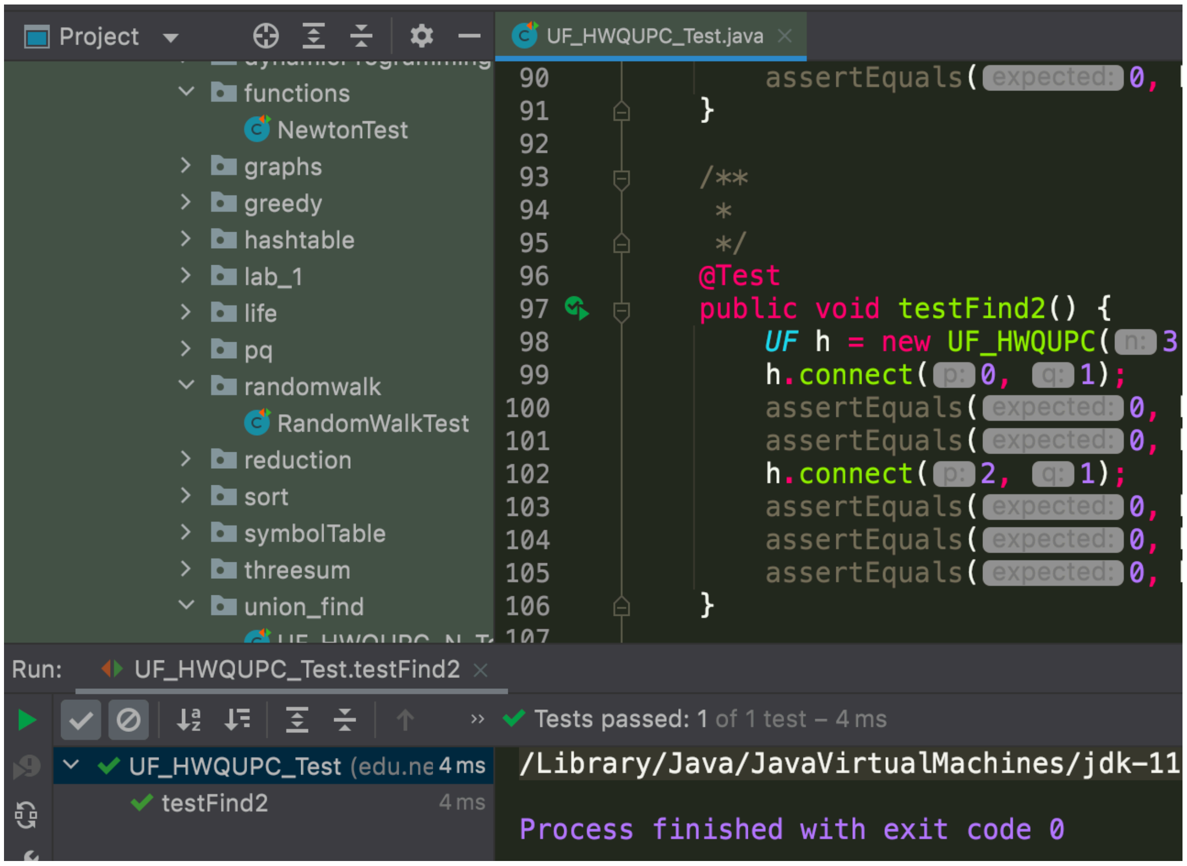
(graph 7. UF_HWQUPC_Test method testFind0)



```
    }

    /**
     *
     */
    @Test
    public void testFind1() {
        UF h = new UF_HWQUPC(
        h.connect( p: 0,  q: 1)
        assertEquals( expected:
        assertEquals( expected:
    }

    /**
     *
     */
    @Test
    public void testFind2() {
```

```
✓ Tests passed: 1 of 1 test – 5 ms
✓ UF_HWQUPC_Test (edu.ne 5 ms
    ✓ testFind1          5 ms

/Library/Java/JavaVirtualMachines/jd

Process finished with exit code 0
```

(graph 8. UF_HWQUPC_Test method testFind1)

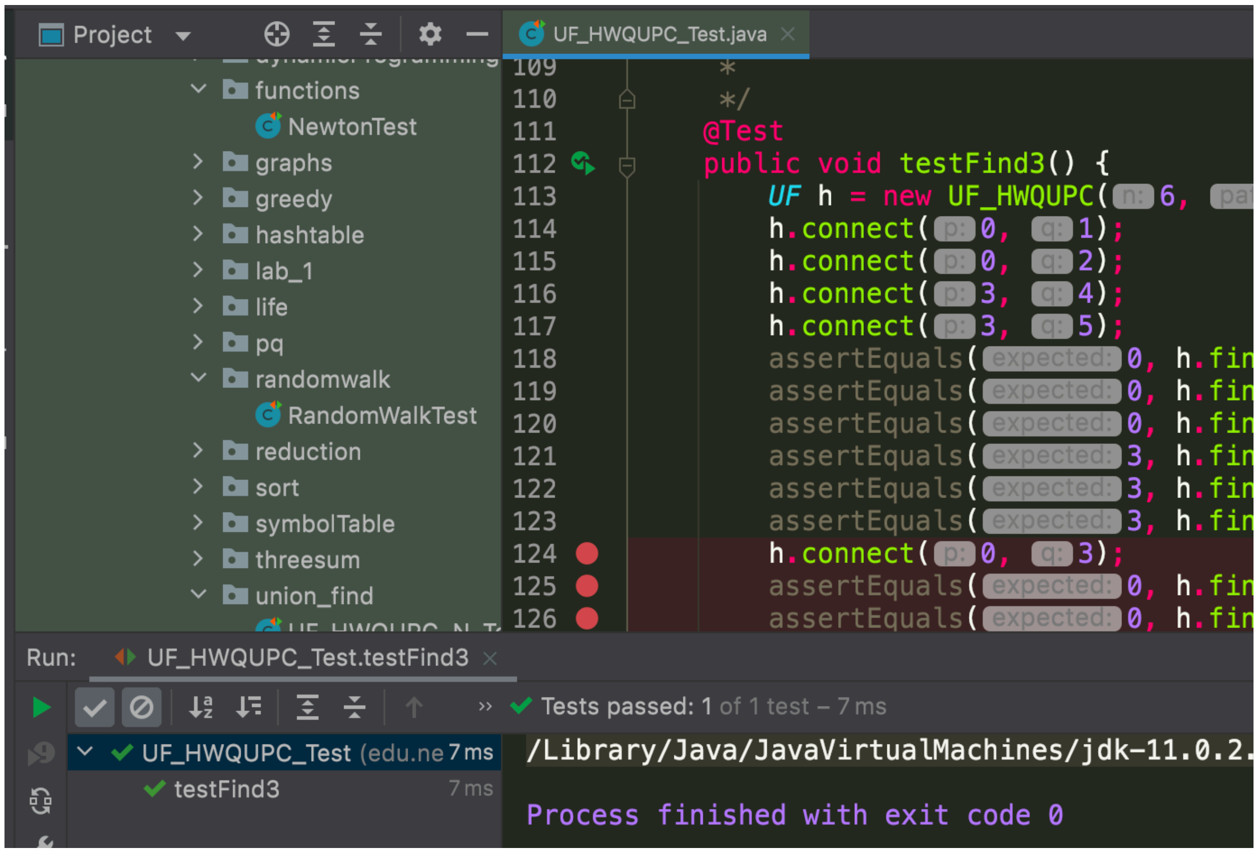


```
            assertEquals( expected: 0,
        }

        /**
         *
         */
        @Test
        public void testFind2() {
            UF h = new UF_HWQUPC( n: 3
            h.connect( p: 0,  q: 1);
            assertEquals( expected: 0,
            assertEquals( expected: 0,
            h.connect( p: 2,  q: 1);
            assertEquals( expected: 0,
            assertEquals( expected: 0,
            assertEquals( expected: 0,
        }
```

```
Tests passed: 1 of 1 test – 4 ms
UF_HWQUPC_Test (edu.ne 4 ms
  testFind2            4 ms
```

```
/Library/Java/JavaVirtualMachines/jdk-11

Process finished with exit code 0
```

(graph 9. UF_HWQUPC_Test method testFind2)

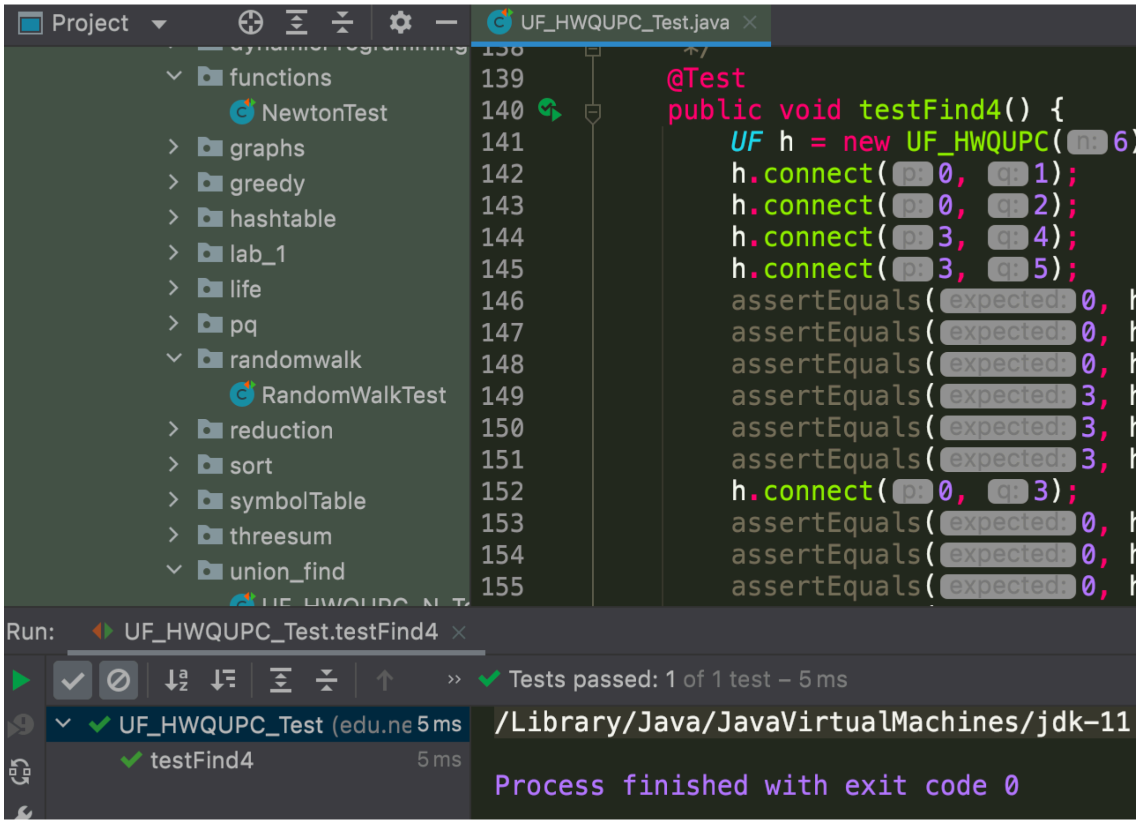


```
         *
         */
        @Test
        public void testFind3() {
            UF h = new UF_HWQUPC( n: 6,  pa
            h.connect( p: 0,  q: 1);
            h.connect( p: 0,  q: 2);
            h.connect( p: 3,  q: 4);
            h.connect( p: 3,  q: 5);
            assertEquals( expected: 0,  h.fin
            assertEquals( expected: 0,  h.fin
            assertEquals( expected: 0,  h.fin
            assertEquals( expected: 3,  h.fin
            assertEquals( expected: 3,  h.fin
            assertEquals( expected: 3,  h.fin
            h.connect( p: 0,  q: 3);
            assertEquals( expected: 0,  h.fin
            assertEquals( expected: 0,  h.fin
```

```
Tests passed: 1 of 1 test – 7 ms
UF_HWQUPC_Test (edu.ne 7 ms
  testFind3            7 ms
```

```
/Library/Java/JavaVirtualMachines/jdk-11.0.2.

Process finished with exit code 0
```

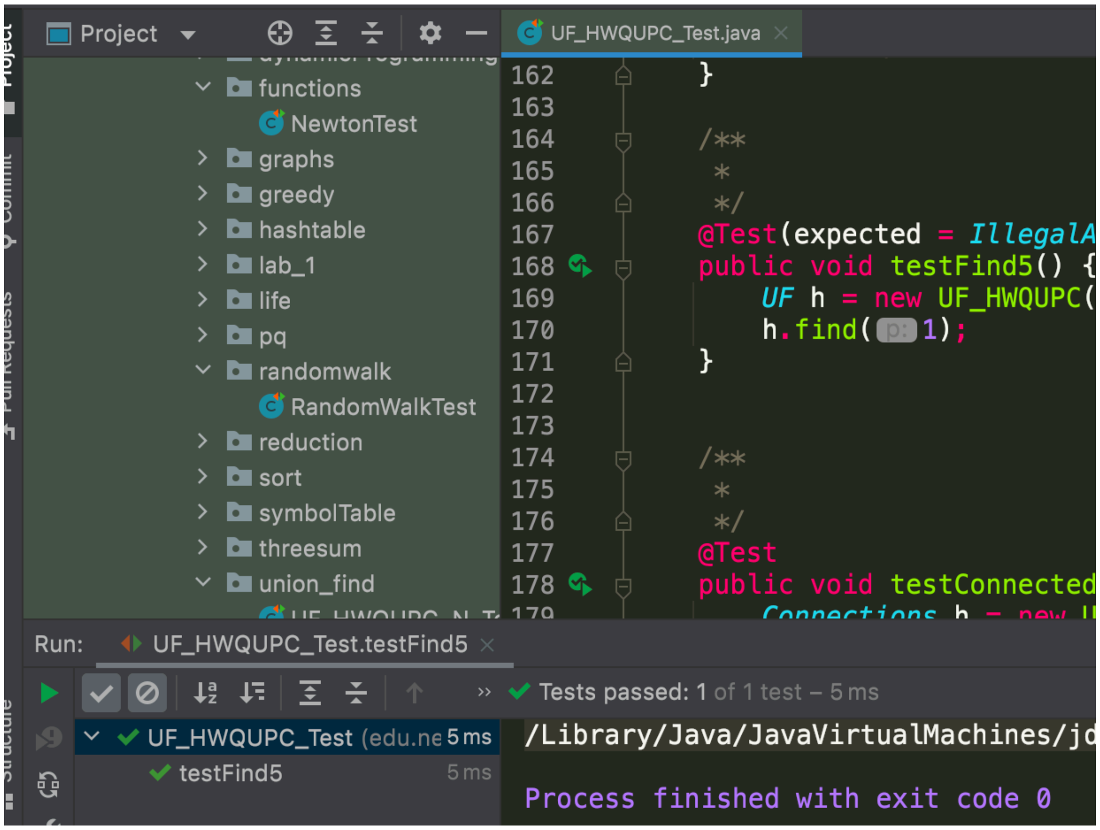
(graph 10. UF_HWQUPC_Test method testFind3)



```
    @Test
    public void testFind4() {
        UF h = new UF_HWQUPC( n: 6)
        h.connect( p: 0,  q: 1);
        h.connect( p: 0,  q: 2);
        h.connect( p: 3,  q: 4);
        h.connect( p: 3,  q: 5);
        assertEquals( expected: 0, h
        assertEquals( expected: 0, h
        assertEquals( expected: 0, h
        assertEquals( expected: 3, h
        assertEquals( expected: 3, h
        assertEquals( expected: 3, h
        h.connect( p: 0,  q: 3);
        assertEquals( expected: 0, h
        assertEquals( expected: 0, h
        assertEquals( expected: 0, h
```

```
Tests passed: 1 of 1 test – 5 ms
UF_HWQUPC_Test (edu.ne 5 ms
  testFind4            5 ms

/Library/Java/JavaVirtualMachines/jdk-11

Process finished with exit code 0
```

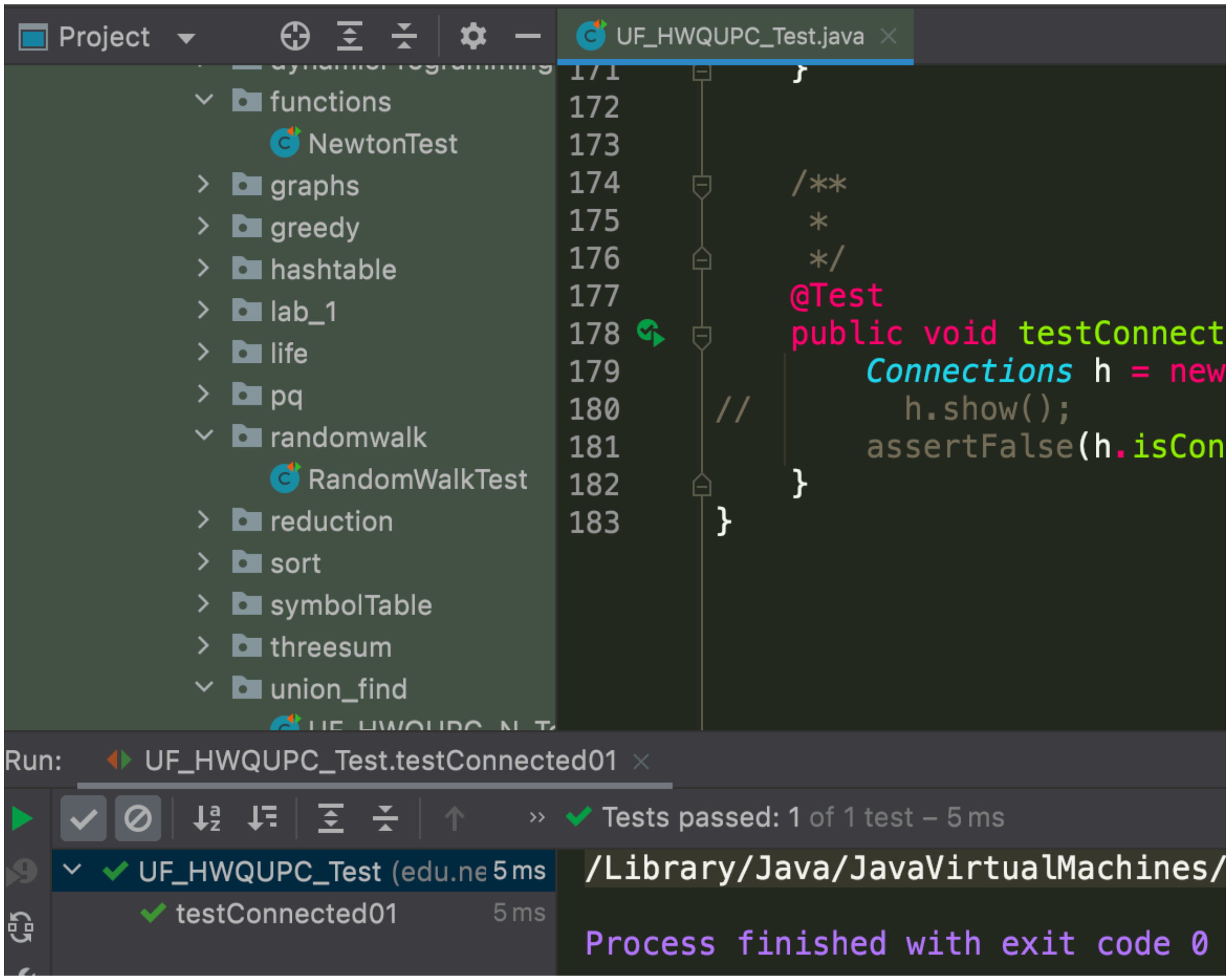
(graph 11. UF_HWQUPC_Test method testFind4)



```
    }

    /**
     *
     */
    @Test(expected = IllegalA
    public void testFind5() {
        UF h = new UF_HWQUPC(
        h.find( p: 1);
    }


    /**
     *
     */
    @Test
    public void testConnected
```

```
Tests passed: 1 of 1 test – 5 ms
UF_HWQUPC_Test (edu.ne 5 ms
  testFind5            5 ms

/Library/Java/JavaVirtualMachines/jd

Process finished with exit code 0
```

(graph 12. UF_HWQUPC_Test method testFind5)



```
        }


        /**
         *
         */
        @Test
        public void testConnect
            Connections h = new
//            h.show();
            assertFalse(h.isCon
        }
}
```

Tests passed: 1 of 1 test – 5 ms

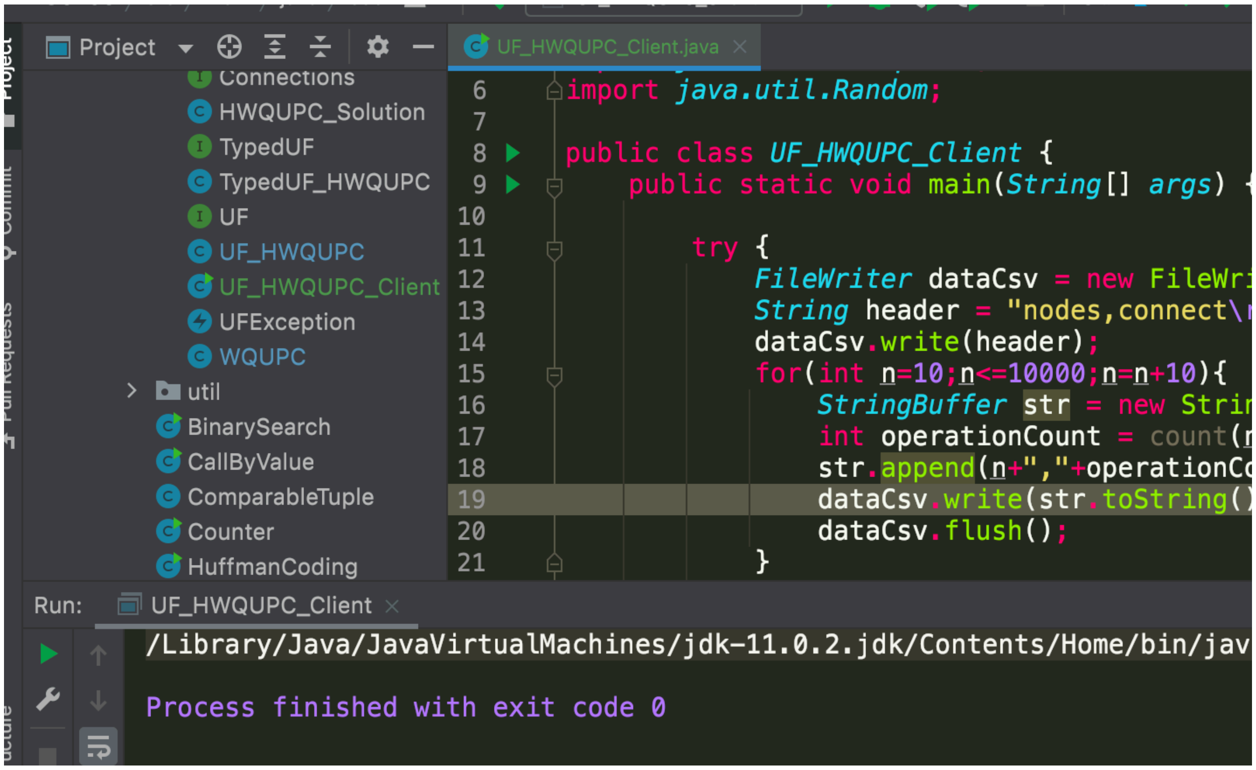
```
/Library/Java/JavaVirtualMachines/

Process finished with exit code 0
```

(graph 13. UF_HWQUPC_Test method testConnected01)

Step2

Implementation of UF_HWQUPC, I created a main program that doesn't require any input and runs the experiment for a fixed set of n values(10-10000, steps=10), for every n value. Experiment for 100 times, get the average value.

Code:
https://github.com/slowpeace2020/INFO6205/blob/Fall2021/src/main/java/edu/neu/coe/info6205/union_find/UF_HWQUPC_Client.java



```
import java.util.Random;

public class UF_HWQUPC_Client {
    public static void main(String[] args) {

        try {
            FileWriter dataCsv = new FileWri
            String header = "nodes,connect\
            dataCsv.write(header);
            for(int n=10;n<=10000;n=n+10){
                StringBuffer str = new Strin
                int operationCount = count(
                str.append(n+","+operationC
                dataCsv.write(str.toString()
                dataCsv.flush();
            }
```

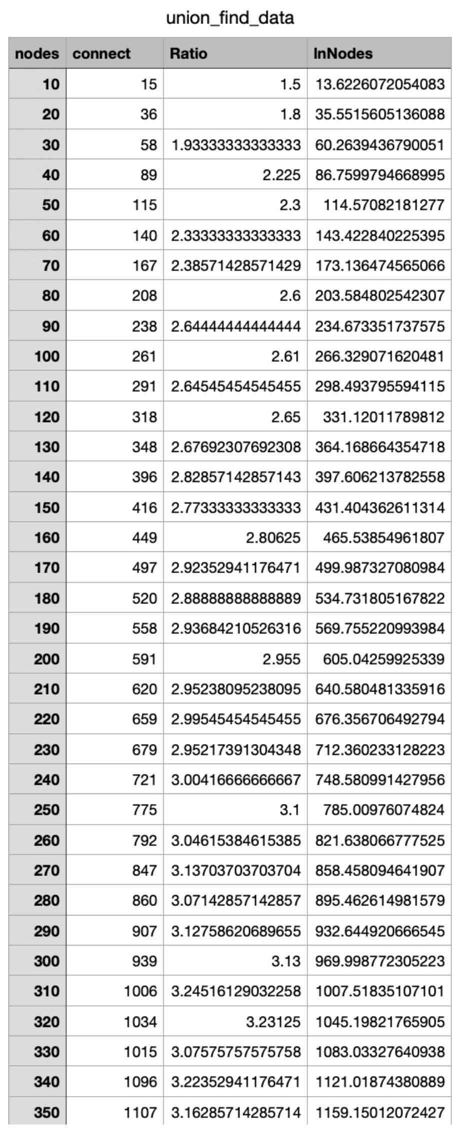
```
/Library/Java/JavaVirtualMachines/jdk-11.0.2.jdk/Contents/Home/bin/jav

Process finished with exit code 0
```

(graph 13. UF_HWQUPC_Client experient)

Step3

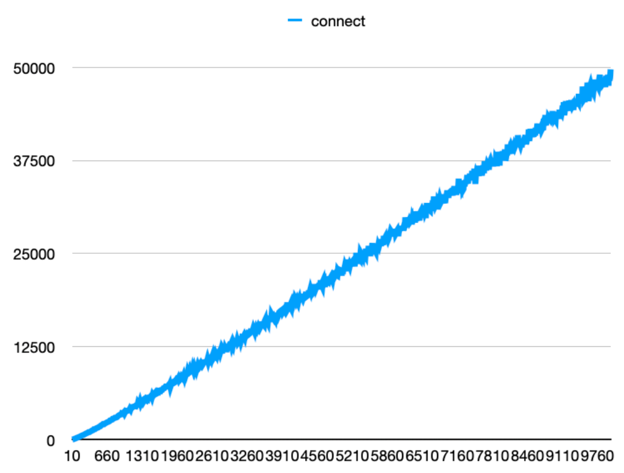
Evidence

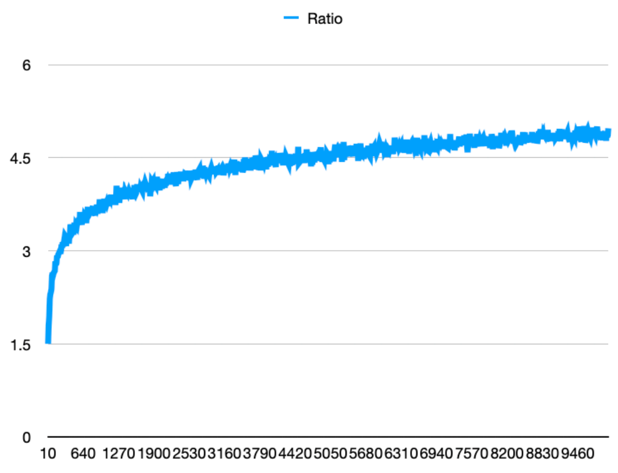
Csv data
Write the experimental results into csv, and draw graphs to show the relationship the number of objects (*n*) and the number of pairs (*m*) .



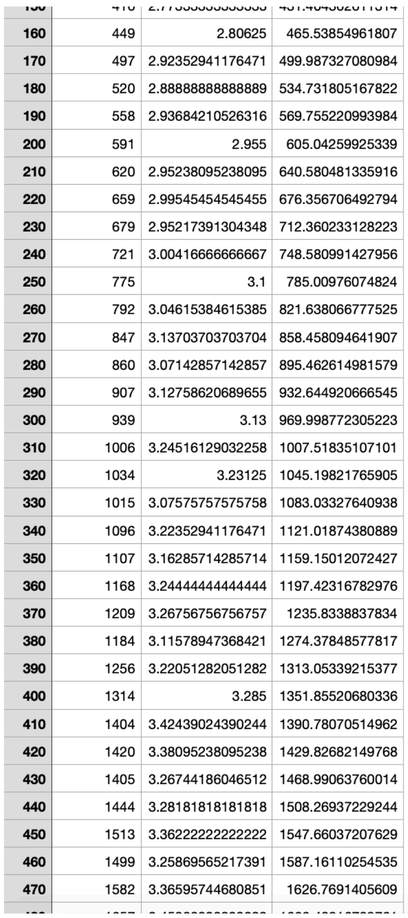
union_find_data

nodes	connect	Ratio	lnNodes
10	15	1.5	13.6226072054083
20	36	1.8	35.5515605136088
30	58	1.93333333333333	60.2639436790051
40	89	2.225	86.7599794668995
50	115	2.3	114.57082181277
60	140	2.33333333333333	143.422840225395
70	167	2.38571428571429	173.136474565066
80	208	2.6	203.584802542307
90	238	2.64444444444444	234.673351737575
100	261	2.61	266.329071620481
110	291	2.64545454545455	298.493795594115
120	318	2.65	331.12011789812
130	348	2.67692307692308	364.168664354718
140	396	2.82857142857143	397.606213782558
150	416	2.77333333333333	431.404362611314
160	449	2.80625	465.53854961807
170	497	2.92352941176471	499.987327080984
180	520	2.88888888888889	534.731805167822
190	558	2.93684210526316	569.755220993984
200	591	2.955	605.04259925339
210	620	2.95238095238095	640.580481335916
220	659	2.99545454545455	676.356706492794
230	679	2.95217391304348	712.360233128223
240	721	3.00416666666667	748.580991427956
250	775	3.1	785.00976074824
260	792	3.04615384615385	821.638066777525
270	847	3.13703703703704	858.458094641907
280	860	3.07142857142857	895.462614981579
290	907	3.12758620689655	932.644920666545
300	939	3.13	969.998772305223
310	1006	3.24516129032258	1007.51835107101
320	1034	3.23125	1045.19821765905
330	1015	3.07575757575758	1083.03327640938
340	1096	3.22352941176471	1121.01874380889
350	1107	3.16285714285714	1159.15012072427

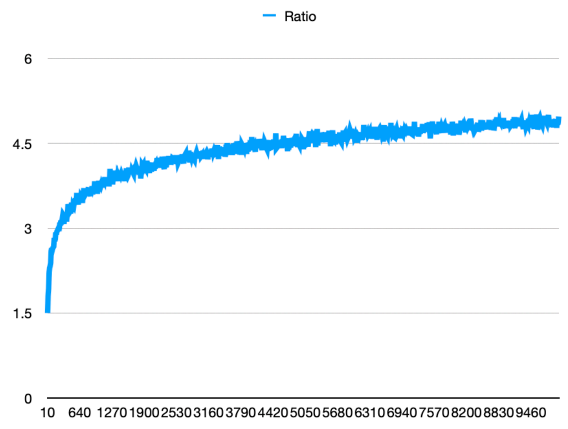


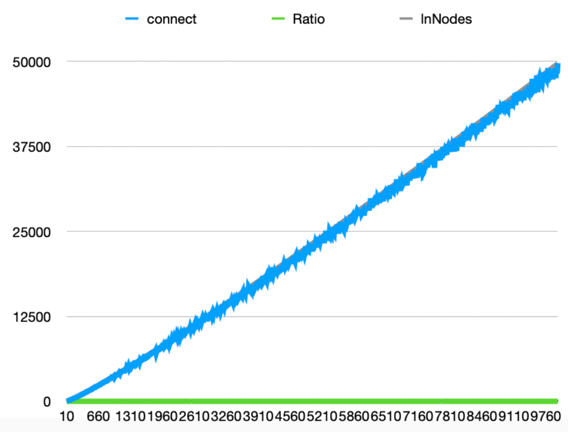


(graph 14. UF_HWQUPC_Client experiments data the figure between n and m and their ratio)



160	449	2.80625	465.53854961807
170	497	2.92352941176471	499.987327080984
180	520	2.88888888888889	534.731805167822
190	558	2.93684210526316	569.755220993984
200	591	2.955	605.04259925339
210	620	2.95238095238095	640.580481335916
220	659	2.99545454545455	676.356706492794
230	679	2.95217391304348	712.360233128223
240	721	3.00416666666667	748.580991427956
250	775	3.1	785.00976074824
260	792	3.04615384615385	821.638066777525
270	847	3.13703703703704	858.458094641907
280	860	3.07142857142857	895.462614981579
290	907	3.12758620689655	932.644920666545
300	939	3.13	969.998772305223
310	1006	3.24516129032258	1007.51835107101
320	1034	3.23125	1045.19821765905
330	1015	3.07575757575758	1083.03327640938
340	1096	3.22352941176471	1121.01874380889
350	1107	3.16285714285714	1159.15012072427
360	1168	3.24444444444444	1197.42316782976
370	1209	3.26756756756757	1235.8338837834
380	1184	3.11578947368421	1274.37848577817
390	1256	3.22051282051282	1313.05339215377
400	1314	3.285	1351.85520680336
410	1404	3.42439024390244	1390.78070514962
420	1420	3.38095238095238	1429.82682149768
430	1405	3.26744186046512	1468.99063760014
440	1444	3.28181818181818	1508.26937229244
450	1513	3.36222222222222	1547.66037207629
460	1499	3.25869565217391	1587.16110254535
470	1582	3.36595744680851	1626.7691405609





At first I thought the relationship between them was linear, because from the first graph it looked like a straight line, but I calculated the ratio between them and found that this ratio becomes more and more as the number of nodes increases. The larger the coming, the ratio itself grows in a log function.

Conclusion

So it is guessed that this coefficient should be related to the log function. After trying, they almost overlap. It was found that the relationship the number of objects (*N*) and the number of pairs (*M*):

$$M = N*\log(N*\ln N)$$