Program Structures and Algorithms
Spring 2023(SEC 1)

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Assignment: 4

Task: 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.

Relationship Conclusion:

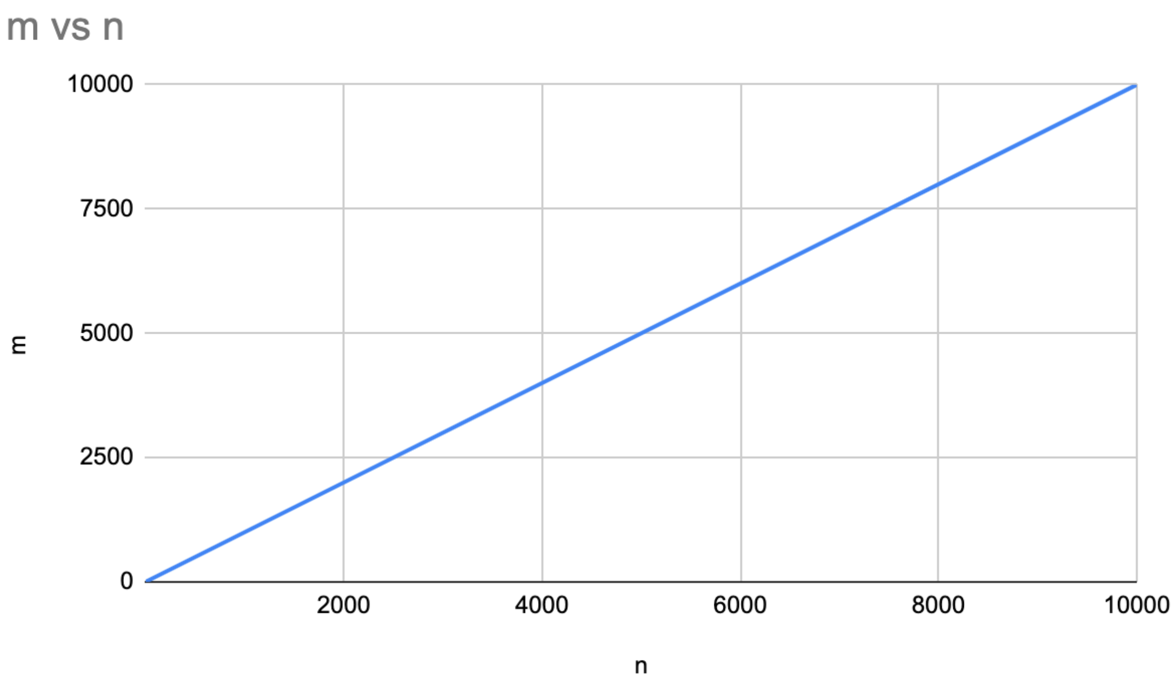
1. In the "height-weighted quick union with path compression" algorithm, the "number of objects" is represented by n and the "number of pairs" is represented by m. The relationship between m and n is given by m = n - 1 because the algorithm starts with n isolated objects and m union operations are performed to connect them into a single component.
2. Each union operation connects two isolated objects and reduces the number of components by one. Hence, the number of components decreases by one with each union operation, starting from n isolated objects and ending with all objects connected into a single component. This results in m = n - 1 pairs, with m being the number of union operations performed and n - 1 being the number of connected components formed.

Evidence to support that conclusion:

n	m
1	0
10	9
100	99
1000	999
10000	9999

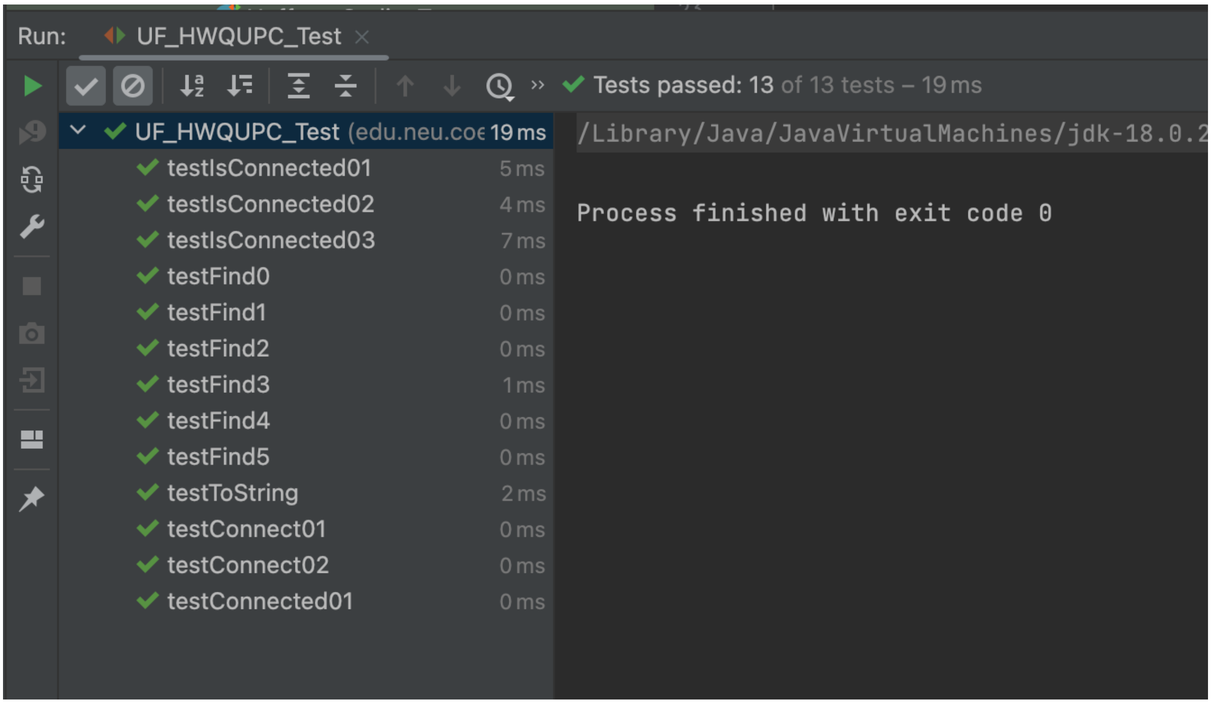
Observation: As the number of objects (n) grows, the number of connections (m) grows linearly with respect to n.

Graphical Representation:

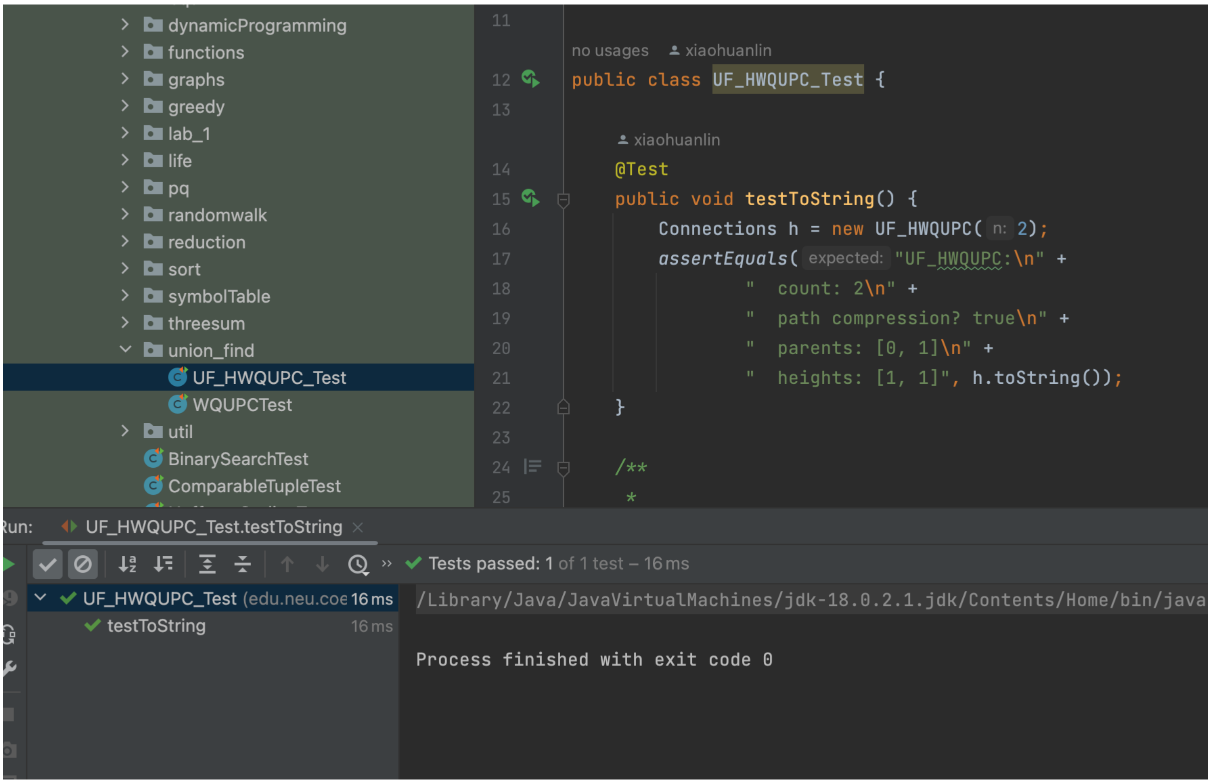


Unit Test Screenshots:

1. **Unit test cases for UF_HWQUPC**



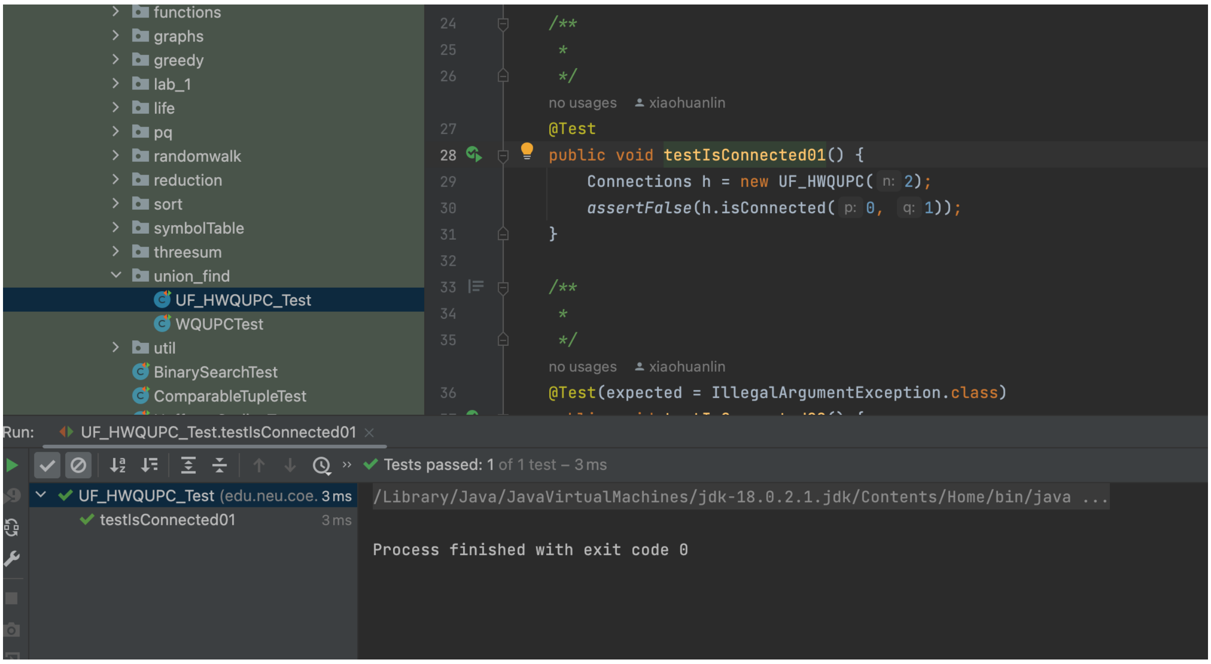
```
Run:   UF_HWQUPC_Test ×

✓ Tests passed: 13 of 13 tests – 19 ms

✓ UF_HWQUPC_Test (edu.neu.coe 19 ms    /Library/Java/JavaVirtualMachines/jdk-18.0.2
    ✓ testIsConnected01          5 ms
    ✓ testIsConnected02          4 ms    Process finished with exit code 0
    ✓ testIsConnected03          7 ms
    ✓ testFind0                  0 ms
    ✓ testFind1                  0 ms
    ✓ testFind2                  0 ms
    ✓ testFind3                  1 ms
    ✓ testFind4                  0 ms
    ✓ testFind5                  0 ms
    ✓ testToString               2 ms
    ✓ testConnect01              0 ms
    ✓ testConnect02              0 ms
    ✓ testConnected01            0 ms
```



```
> dynamicProgramming
> functions
> graphs
> greedy
> lab_1
> life
> pq
> randomwalk
> reduction
> sort
> symbolTable
> threesum
v union_find
    UF_HWQUPC_Test
    WQUPCTest
> util
  BinarySearchTest
  ComparableTupleTest
```

```java
no usages  xiaohuanlin
public class UF_HWQUPC_Test {

    xiaohuanlin
    @Test
    public void testToString() {
        Connections h = new UF_HWQUPC( n: 2);
        assertEquals( expected: "UF_HWQUPC:\n" +
                "  count: 2\n" +
                "  path compression? true\n" +
                "  parents: [0, 1]\n" +
                "  heights: [1, 1]", h.toString());
    }

    /**
     *
```

```
Run:   UF_HWQUPC_Test.testToString ×

✓ Tests passed: 1 of 1 test – 16 ms

✓ UF_HWQUPC_Test (edu.neu.coe 16 ms    /Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java
    ✓ testToString              16 ms
                                        Process finished with exit code 0
```



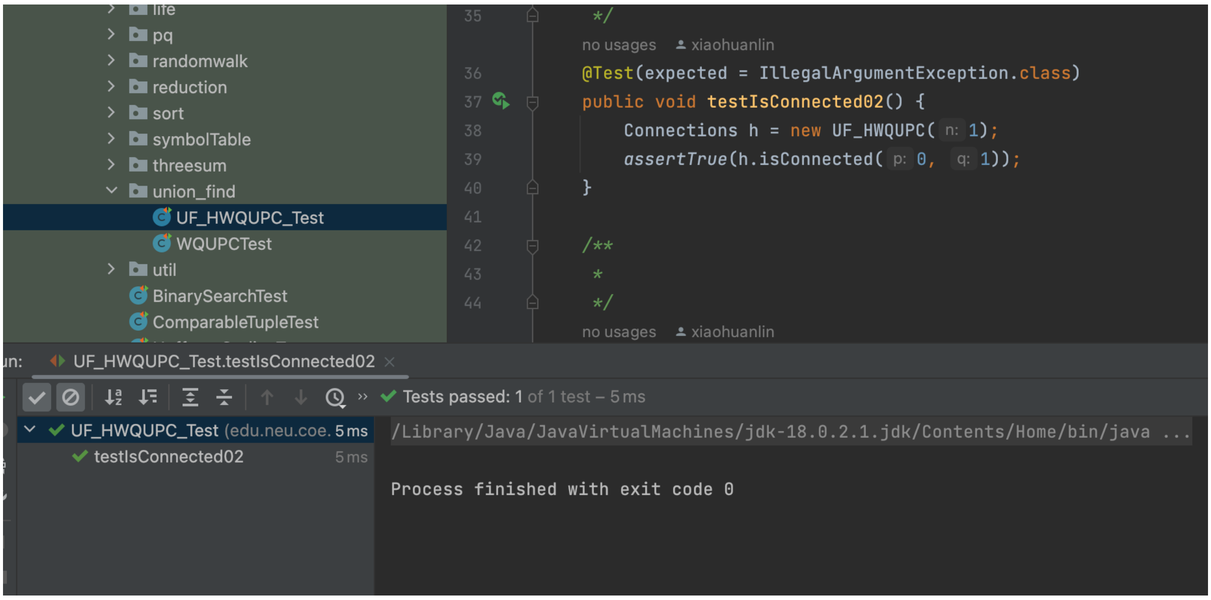
```
/**
 *
 */
no usages  xiaohuanlin
@Test
public void testIsConnected01() {
    Connections h = new UF_HWQUPC( n: 2);
    assertFalse(h.isConnected( p: 0,  q: 1));
}

/**
 *
 */
no usages  xiaohuanlin
@Test(expected = IllegalArgumentException.class)
```

Run: UF_HWQUPC_Test.testIsConnected01

Tests passed: 1 of 1 test – 3 ms

```
✓ UF_HWQUPC_Test (edu.neu.coe. 3 ms
    ✓ testIsConnected01        3 ms
```

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```



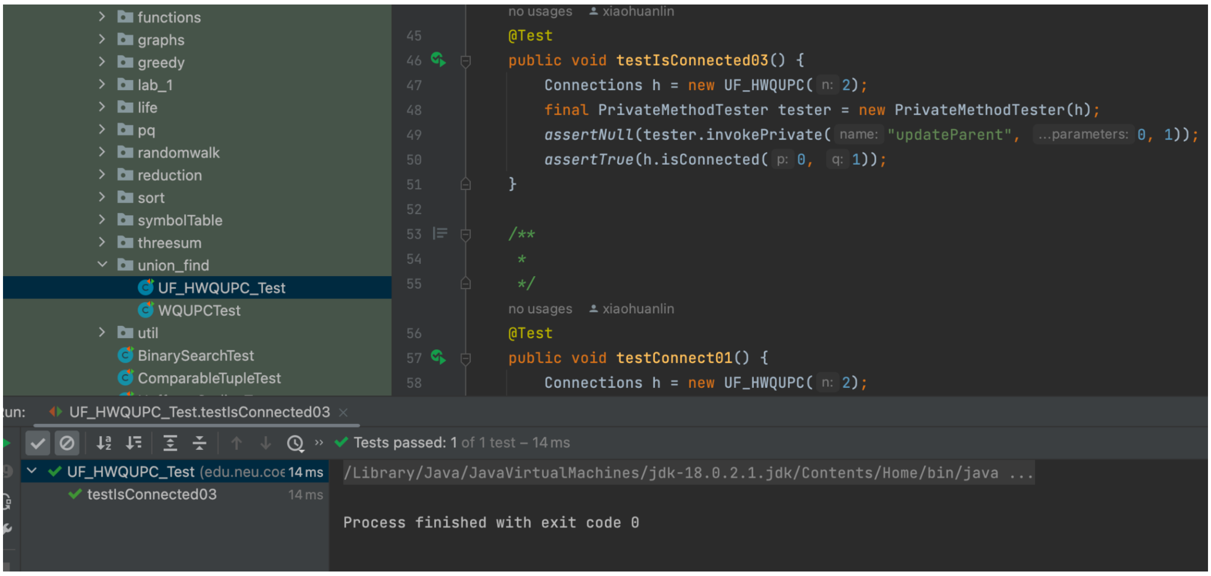
```
 */
no usages  xiaohuanlin
@Test(expected = IllegalArgumentException.class)
public void testIsConnected02() {
    Connections h = new UF_HWQUPC( n: 1);
    assertTrue(h.isConnected( p: 0,  q: 1));
}

/**
 *
 */
no usages  xiaohuanlin
```

un: UF_HWQUPC_Test.testIsConnected02

Tests passed: 1 of 1 test – 5 ms

```
✓ UF_HWQUPC_Test (edu.neu.coe. 5 ms
    ✓ testIsConnected02        5 ms
```

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```



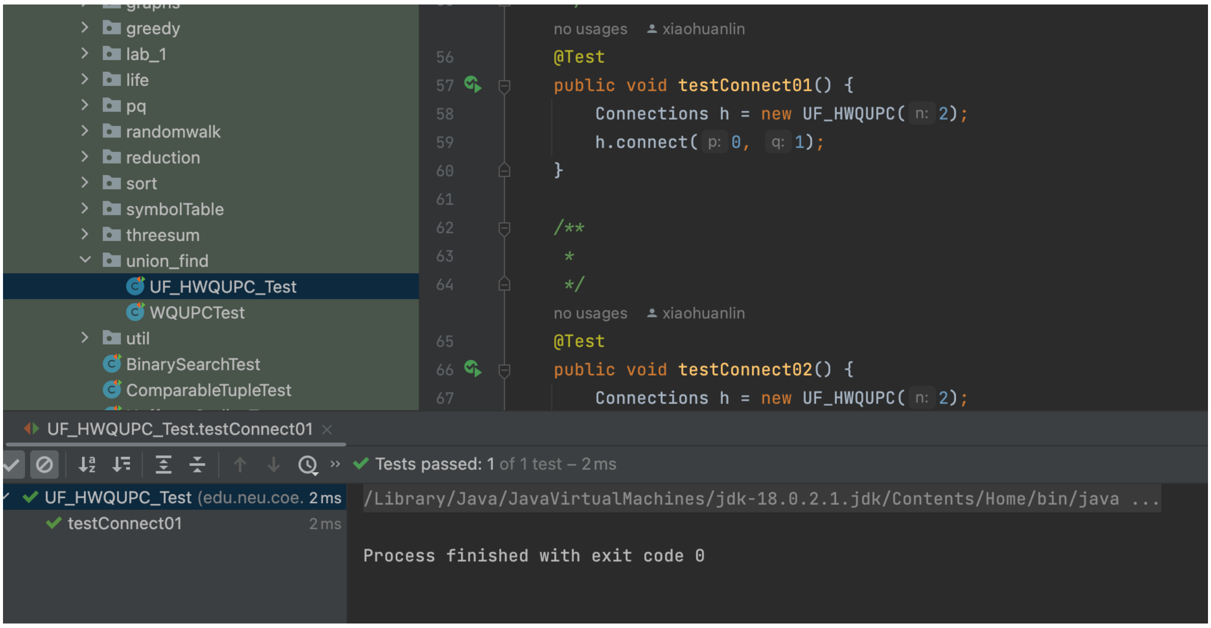
```
no usages  xiaohuanlin
@Test
public void testIsConnected03() {
    Connections h = new UF_HWQUPC( n: 2);
    final PrivateMethodTester tester = new PrivateMethodTester(h);
    assertNull(tester.invokePrivate( name: "updateParent",  ...parameters: 0, 1));
    assertTrue(h.isConnected( p: 0,  q: 1));
}

/**
 *
 */
no usages  xiaohuanlin
@Test
public void testConnect01() {
    Connections h = new UF_HWQUPC( n: 2);
```

un: UF_HWQUPC_Test.testIsConnected03

Tests passed: 1 of 1 test – 14 ms

```
✓ UF_HWQUPC_Test (edu.neu.coe 14 ms
    ✓ testIsConnected03        14 ms
```

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```

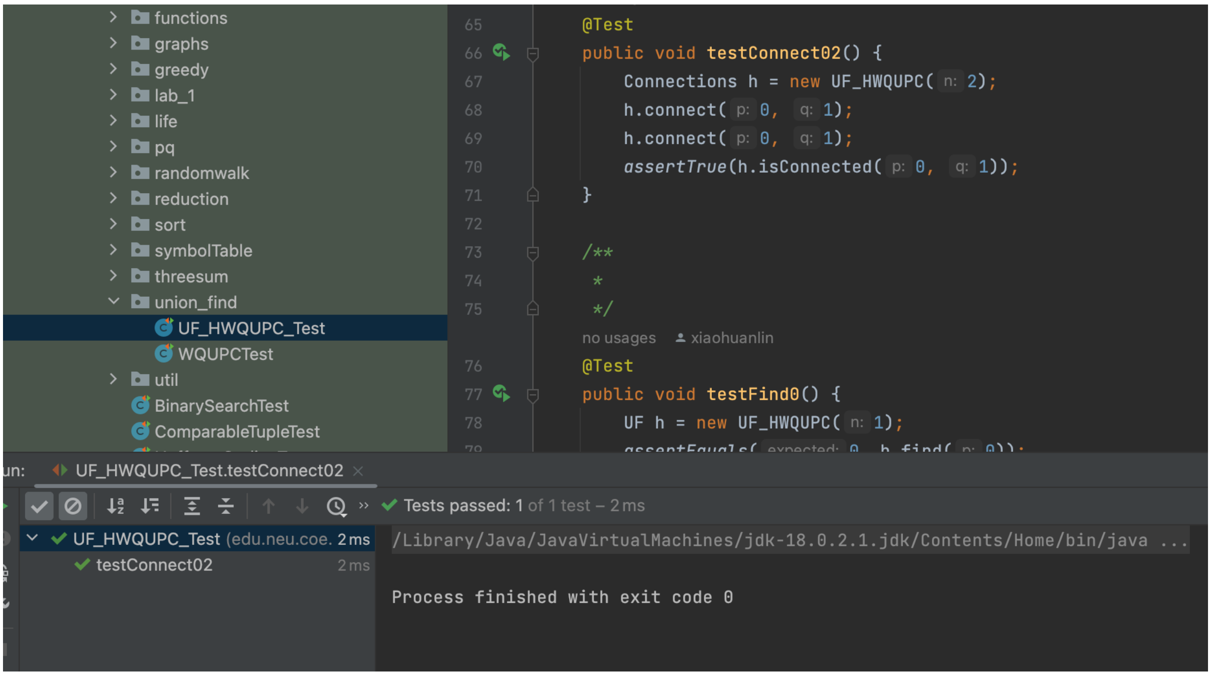


```
    no usages  xiaohuanlin
    @Test
    public void testConnect01() {
        Connections h = new UF_HWQUPC( n: 2);
        h.connect( p: 0,  q: 1);
    }

    /**
     *
     */
    no usages  xiaohuanlin
    @Test
    public void testConnect02() {
        Connections h = new UF_HWQUPC( n: 2);
```

✓ Tests passed: 1 of 1 test – 2 ms

✓ UF_HWQUPC_Test (edu.neu.coe. 2 ms
✓ testConnect01 2 ms

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```

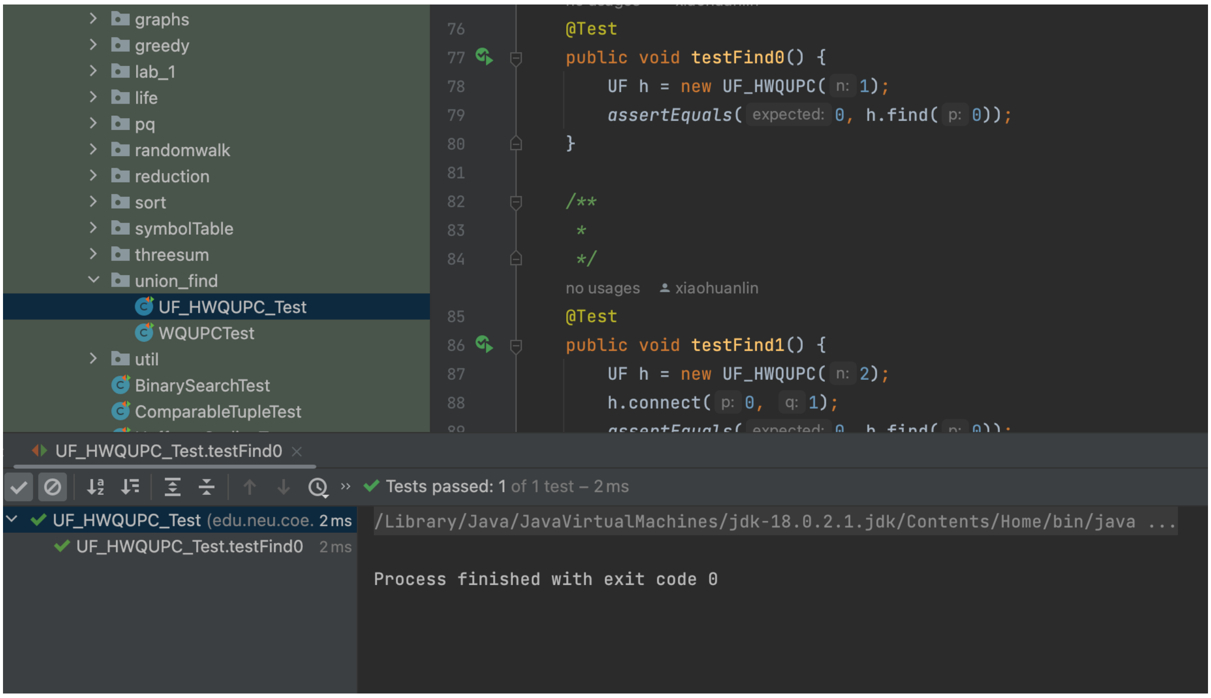


```
    @Test
    public void testConnect02() {
        Connections h = new UF_HWQUPC( n: 2);
        h.connect( p: 0,  q: 1);
        h.connect( p: 0,  q: 1);
        assertTrue(h.isConnected( p: 0,  q: 1));
    }

    /**
     *
     */
    no usages  xiaohuanlin
    @Test
    public void testFind0() {
        UF h = new UF_HWQUPC( n: 1);
        assertEquals( expected: 0,  h.find( p: 0));
```

✓ Tests passed: 1 of 1 test – 2 ms

✓ UF_HWQUPC_Test (edu.neu.coe. 2 ms
✓ testConnect02 2 ms

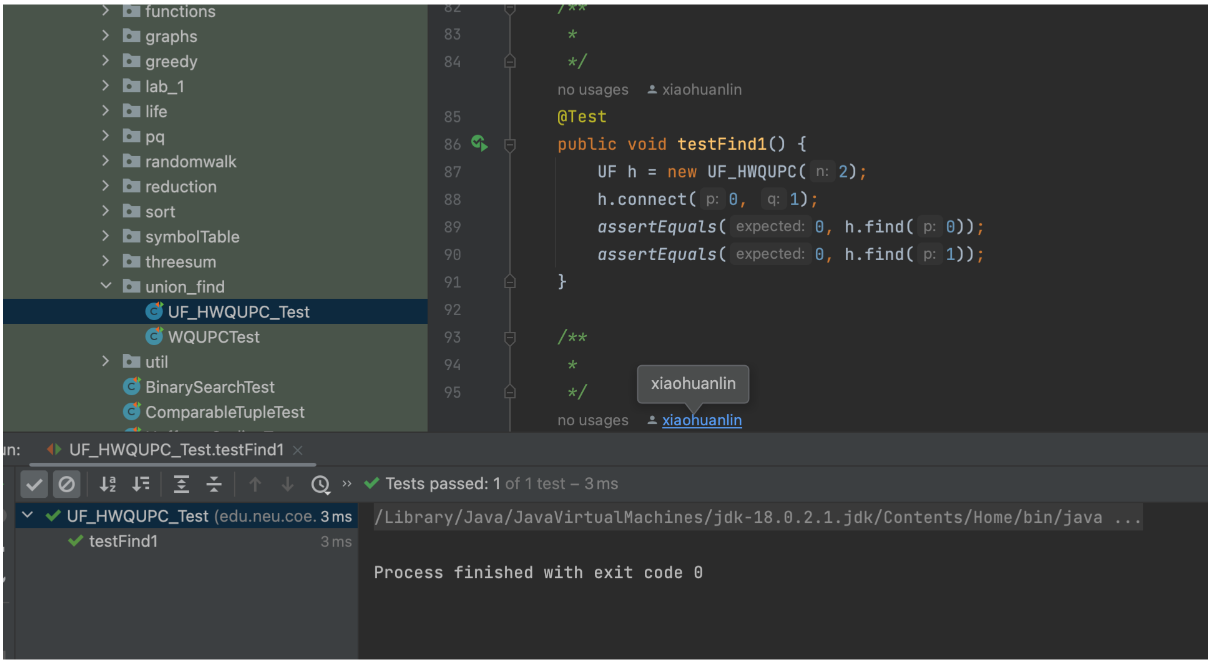
```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```



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

/**
 *
 */
no usages  xiaohuanlin
@Test
public void testFind1() {
    UF h = new UF_HWQUPC( n: 2);
    h.connect( p: 0,  q: 1);
```

```
Tests passed: 1 of 1 test – 2 ms
UF_HWQUPC_Test (edu.neu.coe. 2 ms
    UF_HWQUPC_Test.testFind0 2 ms
```

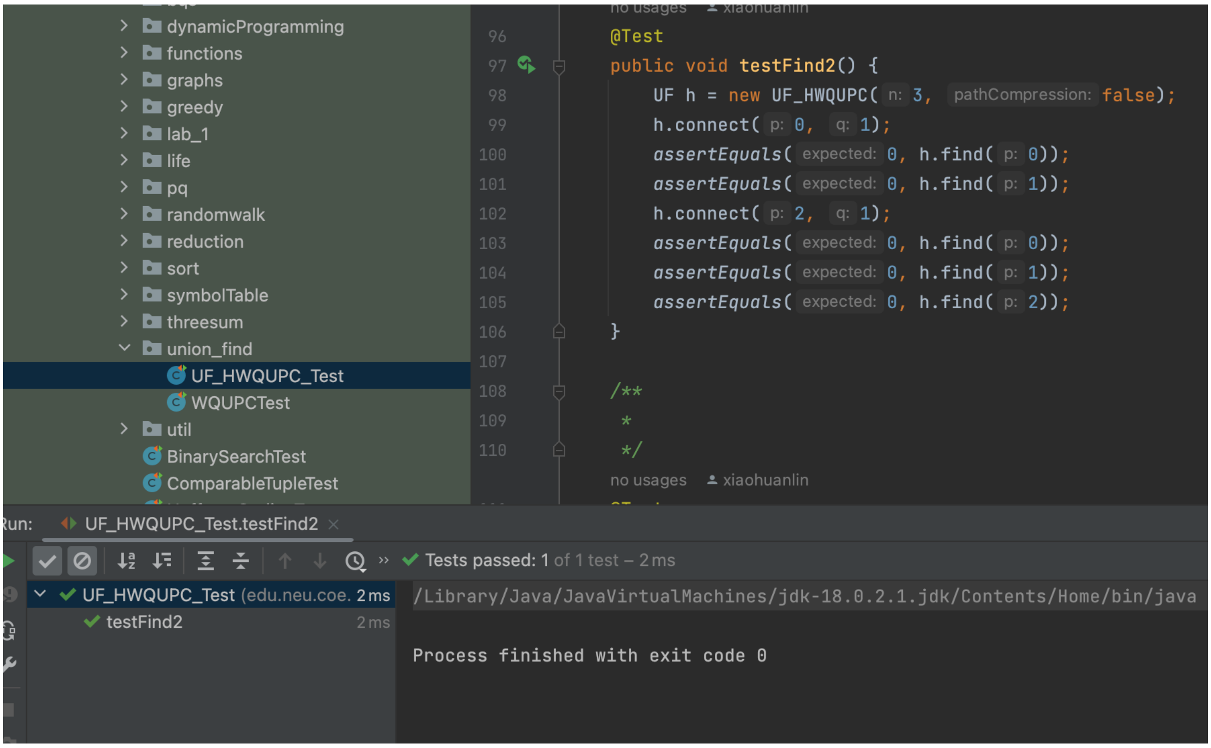
```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```



```
 *
 */
no usages  xiaohuanlin
@Test
public void testFind1() {
    UF h = new UF_HWQUPC( n: 2);
    h.connect( p: 0,  q: 1);
    assertEquals( expected: 0, h.find( p: 0));
    assertEquals( expected: 0, h.find( p: 1));
}

/**
 *
 */
no usages  xiaohuanlin
```

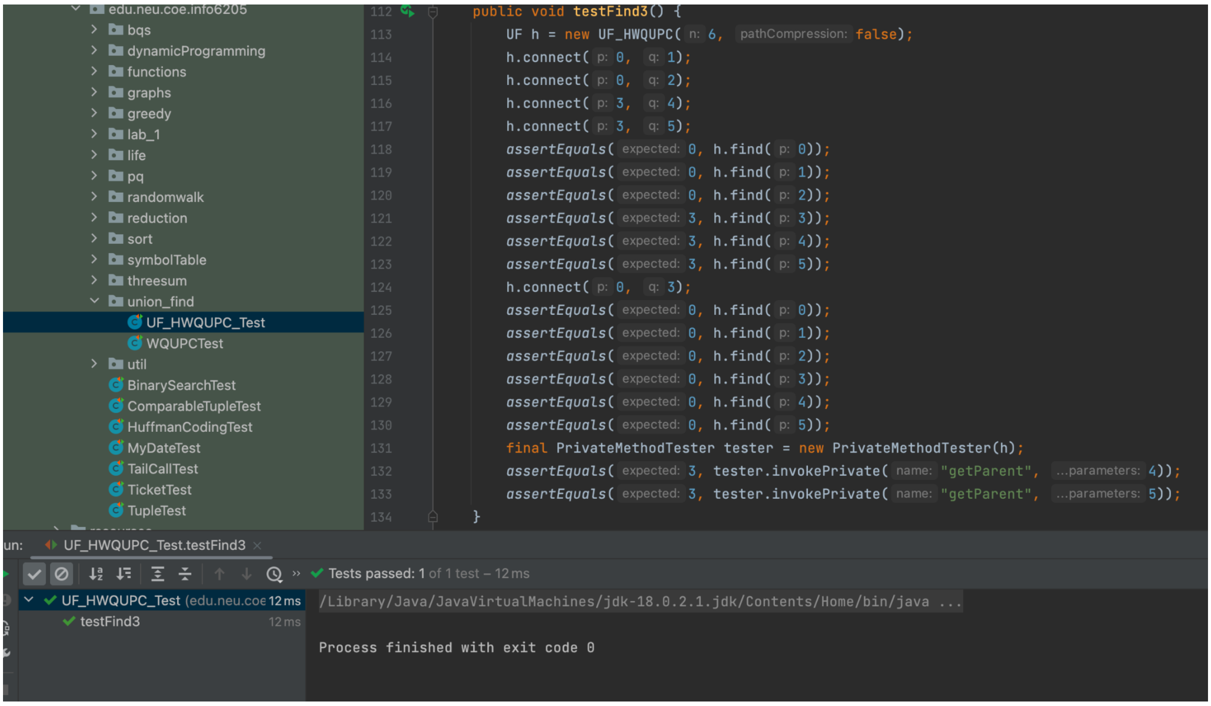
```
Tests passed: 1 of 1 test – 3 ms
UF_HWQUPC_Test (edu.neu.coe. 3 ms
    testFind1 3 ms
```

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```



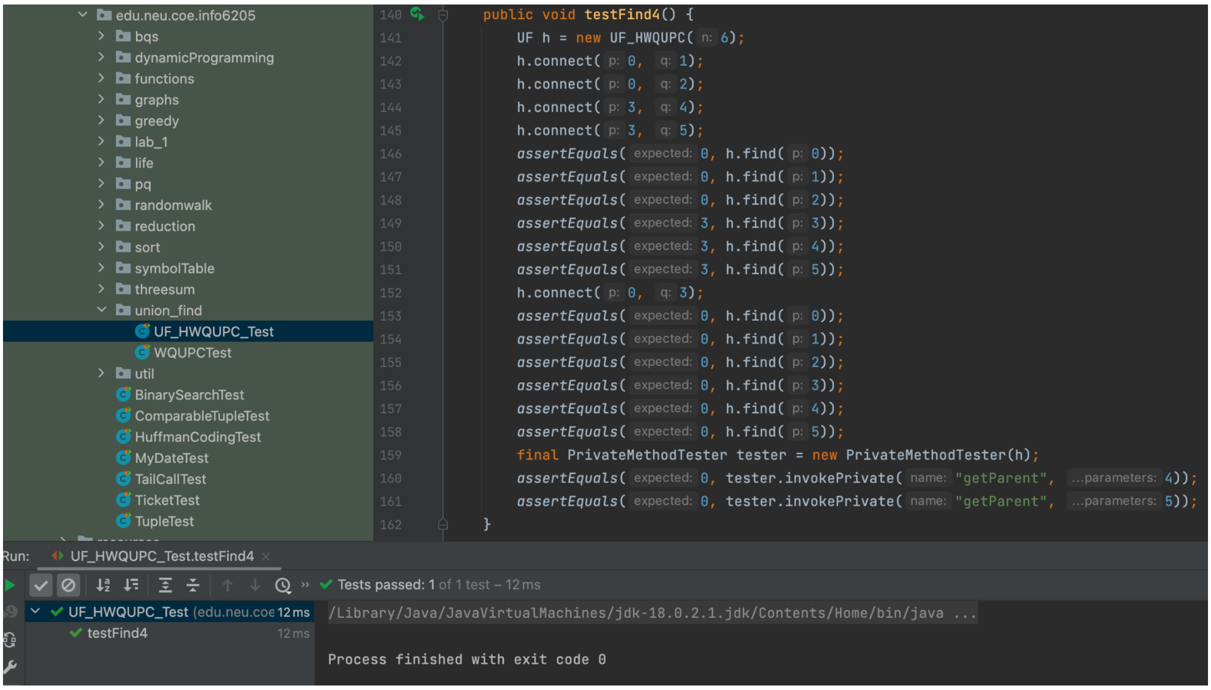
```
no usages   xiaohuanlin
@Test
public void testFind2() {
    UF h = new UF_HWQUPC( n: 3,  pathCompression: false);
    h.connect( p: 0,  q: 1);
    assertEquals( expected: 0, h.find( p: 0));
    assertEquals( expected: 0, h.find( p: 1));
    h.connect( p: 2,  q: 1);
    assertEquals( expected: 0, h.find( p: 0));
    assertEquals( expected: 0, h.find( p: 1));
    assertEquals( expected: 0, h.find( p: 2));
}

/**
 *
 */
no usages   xiaohuanlin
```

```
Tests passed: 1 of 1 test – 2 ms

/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java

Process finished with exit code 0
```



```
public void testFind3() {
    UF h = new UF_HWQUPC( n: 6,  pathCompression: false);
    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.find( p: 0));
    assertEquals( expected: 0, h.find( p: 1));
    assertEquals( expected: 0, h.find( p: 2));
    assertEquals( expected: 3, h.find( p: 3));
    assertEquals( expected: 3, h.find( p: 4));
    assertEquals( expected: 3, h.find( p: 5));
    h.connect( p: 0,  q: 3);
    assertEquals( expected: 0, h.find( p: 0));
    assertEquals( expected: 0, h.find( p: 1));
    assertEquals( expected: 0, h.find( p: 2));
    assertEquals( expected: 0, h.find( p: 3));
    assertEquals( expected: 0, h.find( p: 4));
    assertEquals( expected: 0, h.find( p: 5));
    final PrivateMethodTester tester = new PrivateMethodTester(h);
    assertEquals( expected: 3, tester.invokePrivate( name: "getParent",  ...parameters: 4));
    assertEquals( expected: 3, tester.invokePrivate( name: "getParent",  ...parameters: 5));
}
```

```
Tests passed: 1 of 1 test – 12 ms

/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```

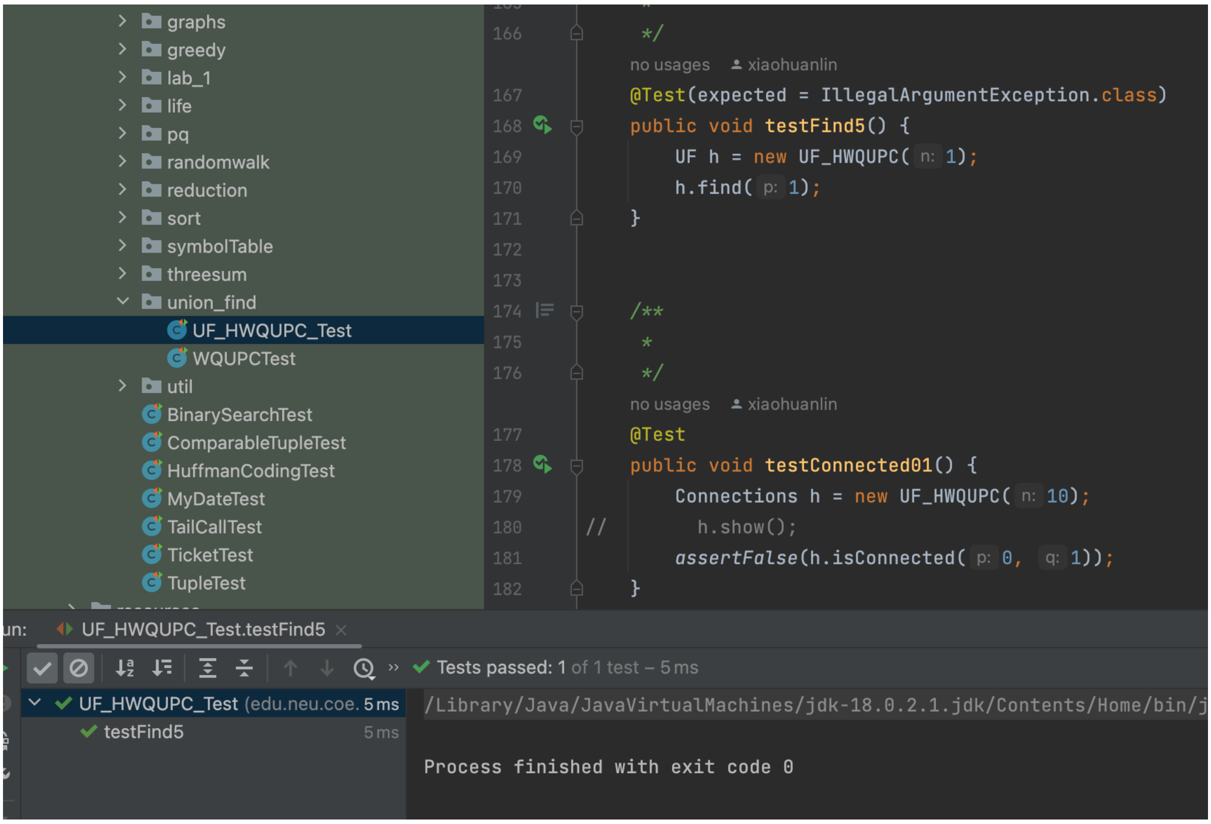


```java
    public void testFind4() {
        UF h = new UF_HWQUPC( n: 6);
        h.connect( p: 0,  q: 1);
        h.connect( p: 0,  q: 2);
        h.connect( p: 3,  q: 4);
        h.connect( p: 3,  q: 5);
        assertEquals( expected: 0, h.find( p: 0));
        assertEquals( expected: 0, h.find( p: 1));
        assertEquals( expected: 0, h.find( p: 2));
        assertEquals( expected: 3, h.find( p: 3));
        assertEquals( expected: 3, h.find( p: 4));
        assertEquals( expected: 3, h.find( p: 5));
        h.connect( p: 0,  q: 3);
        assertEquals( expected: 0, h.find( p: 0));
        assertEquals( expected: 0, h.find( p: 1));
        assertEquals( expected: 0, h.find( p: 2));
        assertEquals( expected: 0, h.find( p: 3));
        assertEquals( expected: 0, h.find( p: 4));
        assertEquals( expected: 0, h.find( p: 5));
        final PrivateMethodTester tester = new PrivateMethodTester(h);
        assertEquals( expected: 0, tester.invokePrivate( name: "getParent",  ...parameters: 4));
        assertEquals( expected: 0, tester.invokePrivate( name: "getParent",  ...parameters: 5));
    }
```

✓ Tests passed: 1 of 1 test – 12 ms

✓ UF_HWQUPC_Test (edu.neu.coe 12 ms
✓ testFind4 12 ms

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```

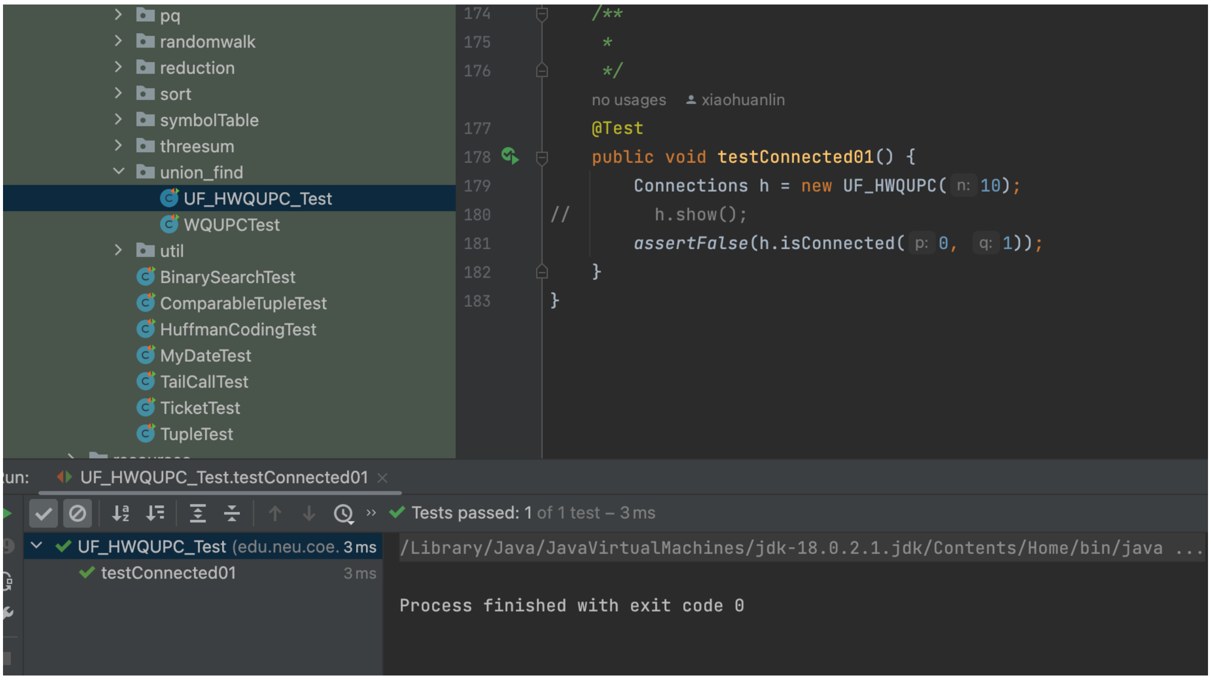


```java
     */
    no usages  xiaohuanlin
    @Test(expected = IllegalArgumentException.class)
    public void testFind5() {
        UF h = new UF_HWQUPC( n: 1);
        h.find( p: 1);
    }


    /**
     *
     */
    no usages  xiaohuanlin
    @Test
    public void testConnected01() {
        Connections h = new UF_HWQUPC( n: 10);
//          h.show();
        assertFalse(h.isConnected( p: 0,  q: 1));
    }
```

✓ Tests passed: 1 of 1 test – 5 ms

✓ UF_HWQUPC_Test (edu.neu.coe. 5 ms
✓ testFind5 5 ms

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/j

Process finished with exit code 0
```

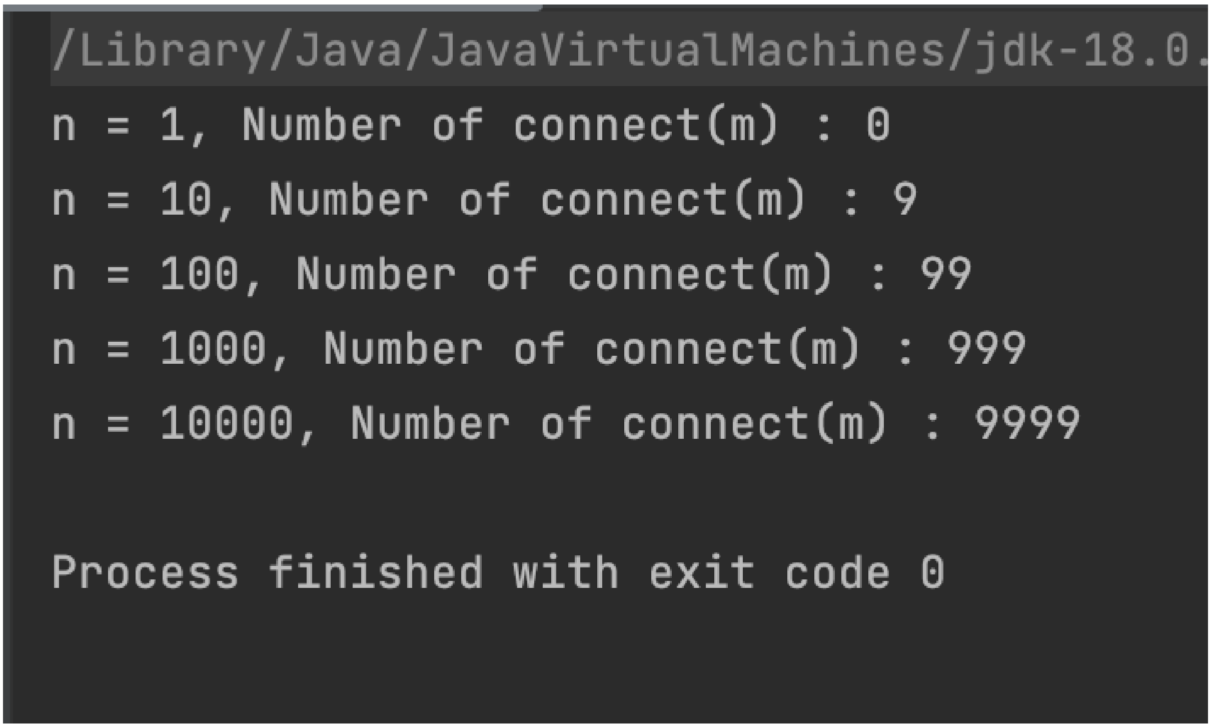


```
    /**
     *
     */
    @Test
    public void testConnected01() {
        Connections h = new UF_HWQUPC( n: 10);
//          h.show();
        assertFalse(h.isConnected( p: 0,  q: 1));
    }
}
```

Tests passed: 1 of 1 test – 3 ms

```
/Library/Java/JavaVirtualMachines/jdk-18.0.2.1.jdk/Contents/Home/bin/java ...

Process finished with exit code 0
```

UF_Client execution:



```
/Library/Java/JavaVirtualMachines/jdk-18.0.
n = 1, Number of connect(m) : 0
n = 10, Number of connect(m) : 9
n = 100, Number of connect(m) : 99
n = 1000, Number of connect(m) : 999
n = 10000, Number of connect(m) : 9999


Process finished with exit code 0
```