



Testing 101

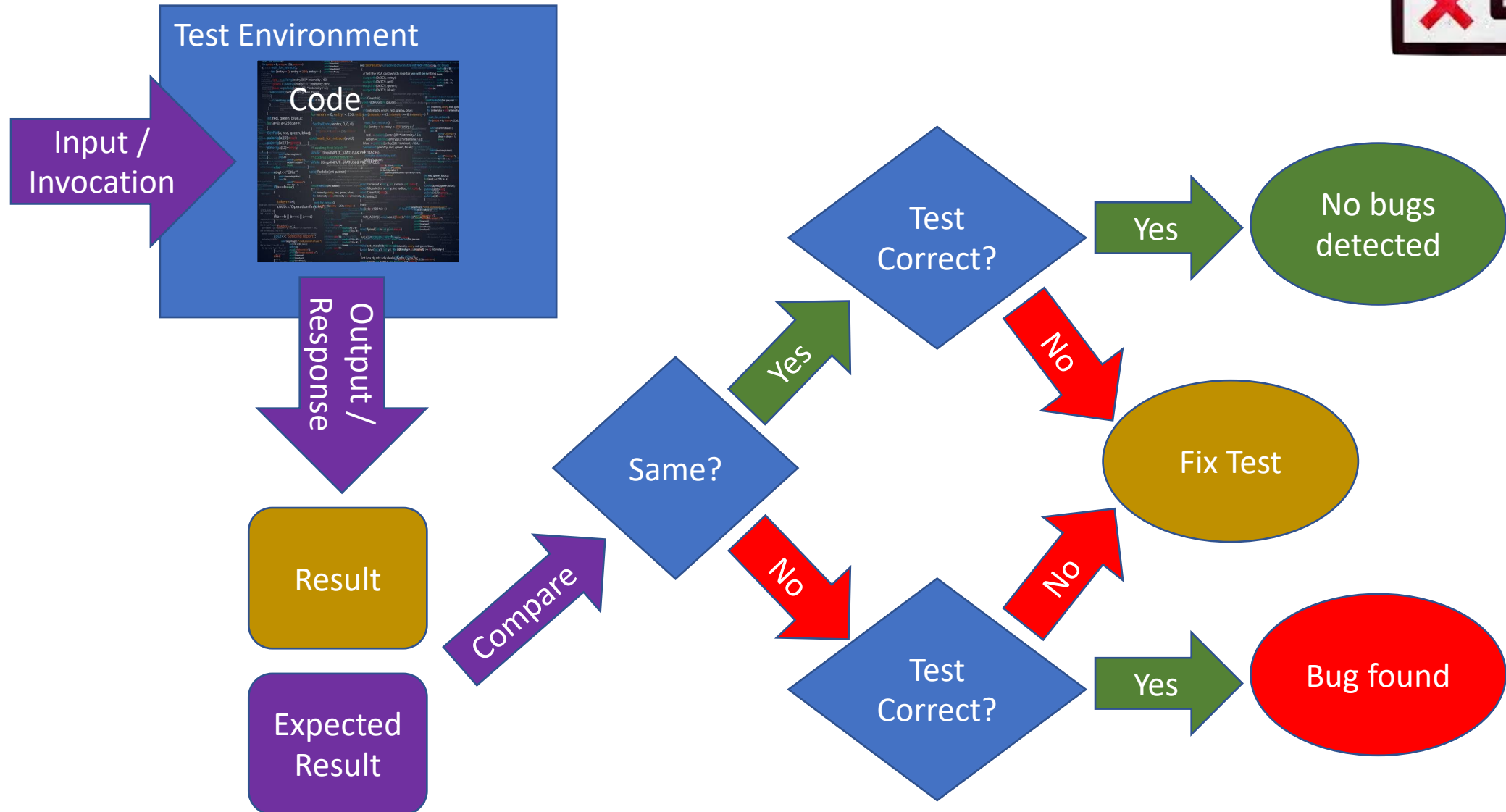
Introduction to Unit Testing and JUnit

CSCI 2134: Software Development

Agenda

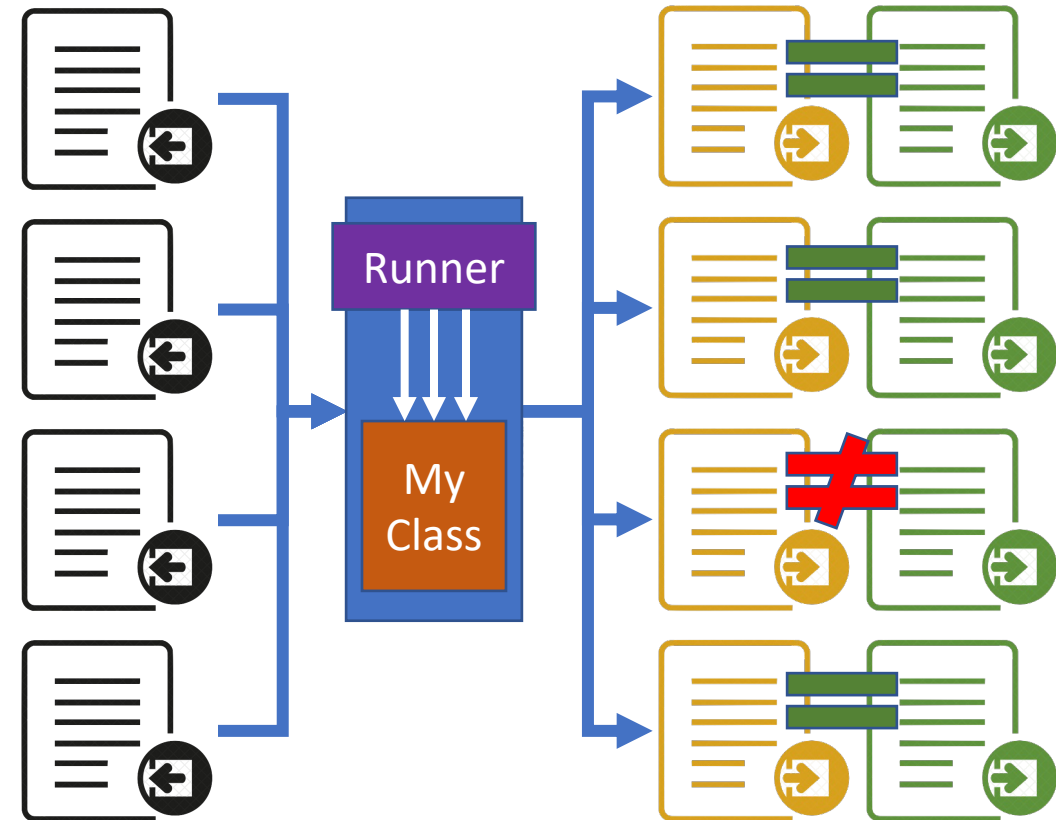
- Lecture Contents
 - What is a Test
 - What is Unit Testing
 - Introduction to JUnit
 - Whitebox and Blackbox Testing
- Brightspace Quiz
- Readings:
 - This Lecture: Chapter 22
 - Next Lecture: Chapter 22

What Is a Test?



Testing: A Blast from the Past

- CSCI 1105 and CSCI 1110
 - Input/Output Tests
 - Codio tests
 - Mimir tests
 - Runner / Class tests
- CSCI 2110 (Winter)
 - Input/Output Tests
 - Mimir tests



Example from a CSCI 2110 Assignment



Input

```
502788 32
503612 33
503775 34
```

```
public ArrayList computeTraffic(Scanner stream) {
    ArrayList list = new ArrayList();

    if( stream.hasNextLong() ) {
        curTime = stream.nextLong();
        curSpeed = stream.nextInt();

        while( stream.hasNextLong() ) {
            list.add( nextVehicle( stream ) );
        }
    }
    return list;
}
...
```

Actual Output

```
502: heavy truck, 1 2
```

Expected Output

```
502: Heavy truck, 1 2
```

Compare

Same?

No

Bug found

Unit Testing and JUnit

- Unit testing involves testing small parts of a program written by a single developer
 - Methods
 - Classes (small)
- Unit testing is made easier using the JUnit framework
- JUnit provides a way to
 - Test each method of a class
 - Run the tests at a click of a button
 - Debug failed tests
 - Write tests as you develop
- We will be using JUnit 5

JUnit in a Nutshell

```
public MyClassTest {  
    ...  
    public int method1Test1(...) { ... }  
    ✗ public int method1Test2(...) { ... }  
    public int method1Test3(...) { ... }  
    ✗ public int method2Test1(...) { ... }  
    public int method2Test2(...) { ... }  
    public int method3Test1(...) { ... }  
    public int method3Test2(...) { ... }  
    ✗ public int method4Test(...) { ... }  
    ✗ public int method5Test1(...) { ... }  
    public int method5Test2(...) { ... }  
    ...  
}
```

JUnit

```
public MyClass {  
    ...  
    public int method1(...) { ... }  
    public int method2(...) { ... }  
    public int method3(...) { ... }  
    public int method4(...) { ... }  
    public int method5(...) { ... }  
    public int method6(...) { ... }  
}
```


Example of Using JUnit in IntelliJ

MatrixTest.java

```
MatrixTest.java
1 import ...
2
3 class MatrixTest {
4     private final static String simpleMatrix = "2 2 1 2 3 4"; // [
5                                     // [
6
7     private final static String nonSqMatrix = "3 2 1 2 3 4 5 6"; //
8                                     // [ 3 4 ]
9
10
11     @Test
12     void getElem() {
13         Matrix m = new Matrix(new Scanner(simpleMatrix));
14         assertEquals( expected: 2, m.getElem( i: 1, j: 2), message: "getE
15     }
16
17     @Test
18     void setElem() {
19         Matrix m = new Matrix(new Scanner(simpleMatrix));
20         m.setElem( i: 2, j: 1, v: 5);
21         assertEquals( expected: 5, m.getElem( i: 2, j: 1), message: "se
22     }
23
24     @Test
25     void negate() {
26         Matrix m = new Matrix(new Scanner(simpleMatrix));
27         m.negate();
28         assertEquals( expected: -1, m.getElem( i: 1, j: 1), message: "negate() did not negate element (1,1
29         assertEquals( expected: -2, m.getElem( i: 1, j: 2), message: "negate() did not negate element (1,2
30
31 }
```

Run: MatrixTest

Test Results 140 ms

- MatrixTest 140 ms
 - equal2s() 43 ms
 - equals() 19 ms
 - negate() 22 ms
 - multiplyWithMatrix() 13 ms
 - getElem() 7 ms
 - add() 18 ms
 - multiplyWithScalar() 5 ms
 - getHeight() 5 ms
 - getWidth() 4 ms
 - setElem() 4 ms

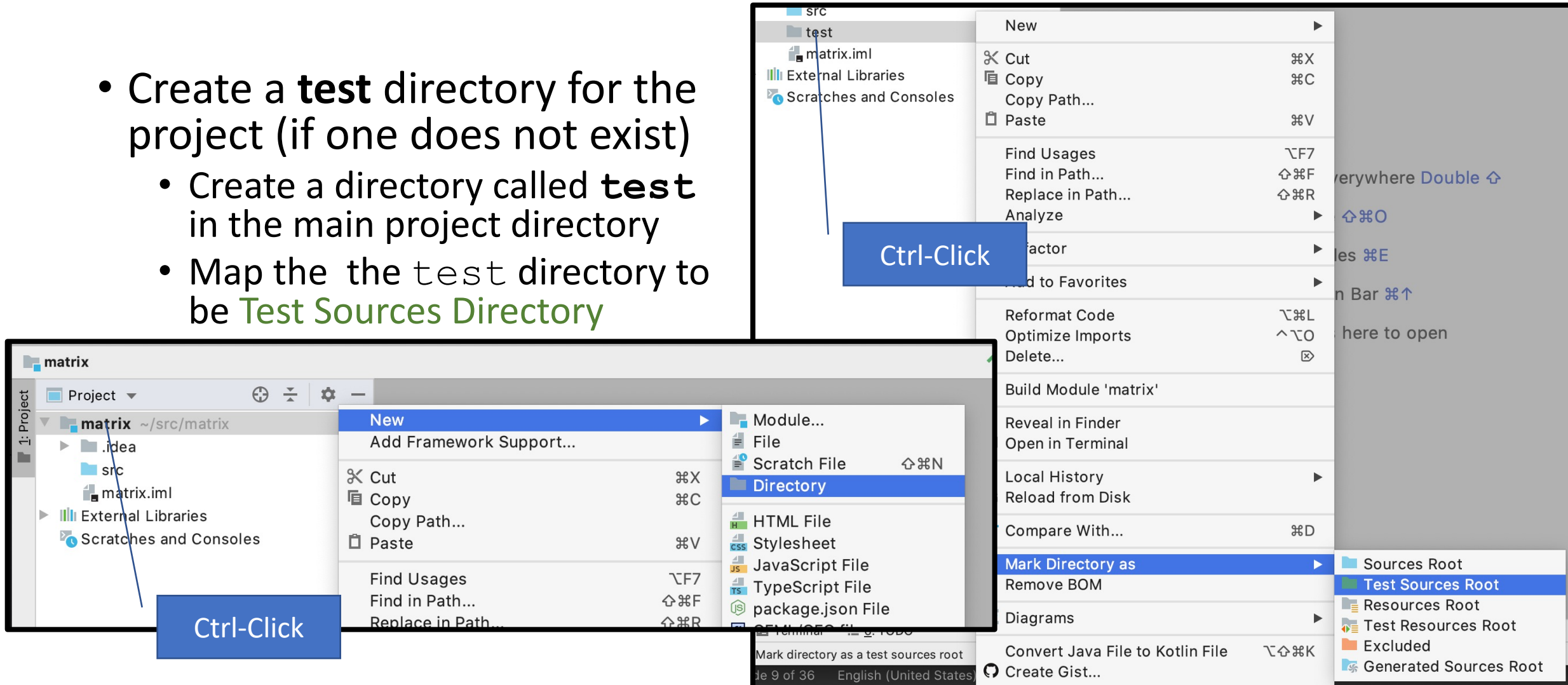
Terminal 0: Messages 4: Run 6: TODO

Matrix.java

```
Matrix.java
1 2D array stores matrix of size height x width
2 number of rows in the matrix
3 number of columns in the matrix
4
5 matrix of size m x n.
6 matrix
7 matrix
8
9 initialize height and width fields.
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How to Create JUnit Test Class in IntelliJ 1

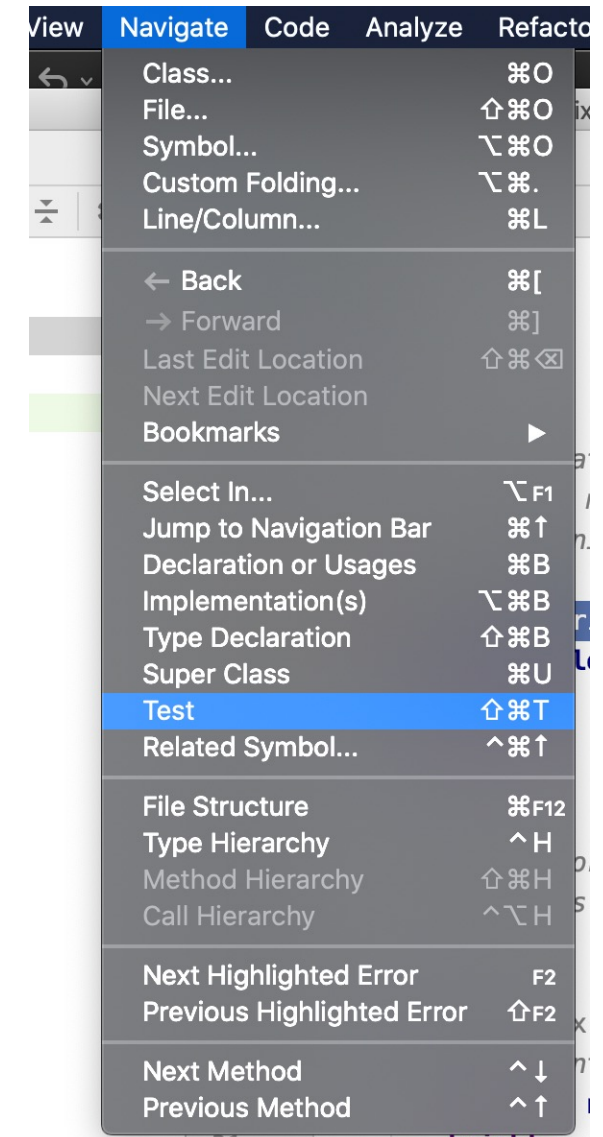
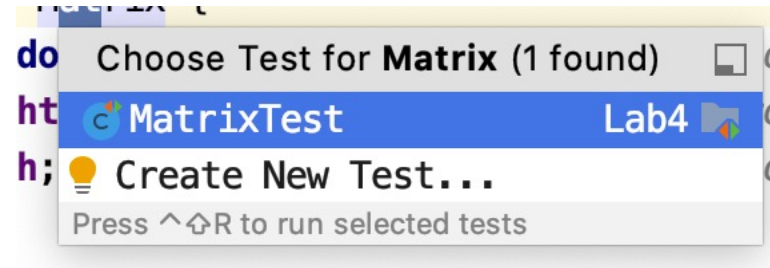
- Create a **test** directory for the project (if one does not exist)
 - Create a directory called **test** in the main project directory
 - Map the **test** directory to be **Test Sources Directory**



How to Create JUnit Test Class in IntelliJ 2

```
16 // is easy to manipulate.
17
18 public class Matrix {
19     private double [][] matrix; // 2D array stores matrix of size height x width
20     int height;                // number of rows in the matrix
21     int width;                 // number of columns in the matrix
22 }
```

- Select the class you wish to test
 - Open the desired .java file in the **src** directory
 - Highlight the public class in the file and click on **Navigate → Test**
 - Click on **Create New Test** in the pop-up menu



How to Create JUnit Test Class in IntelliJ 3

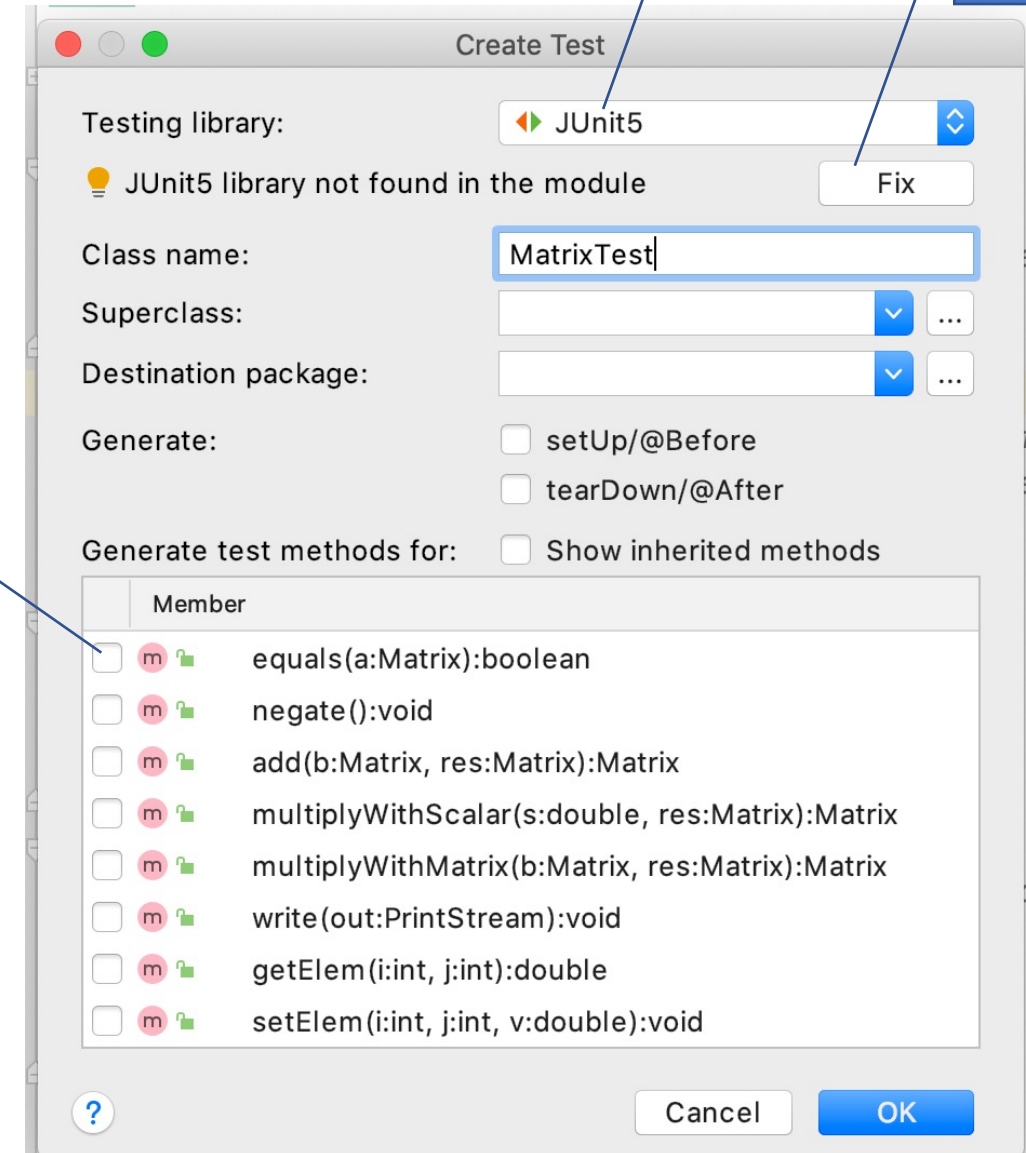
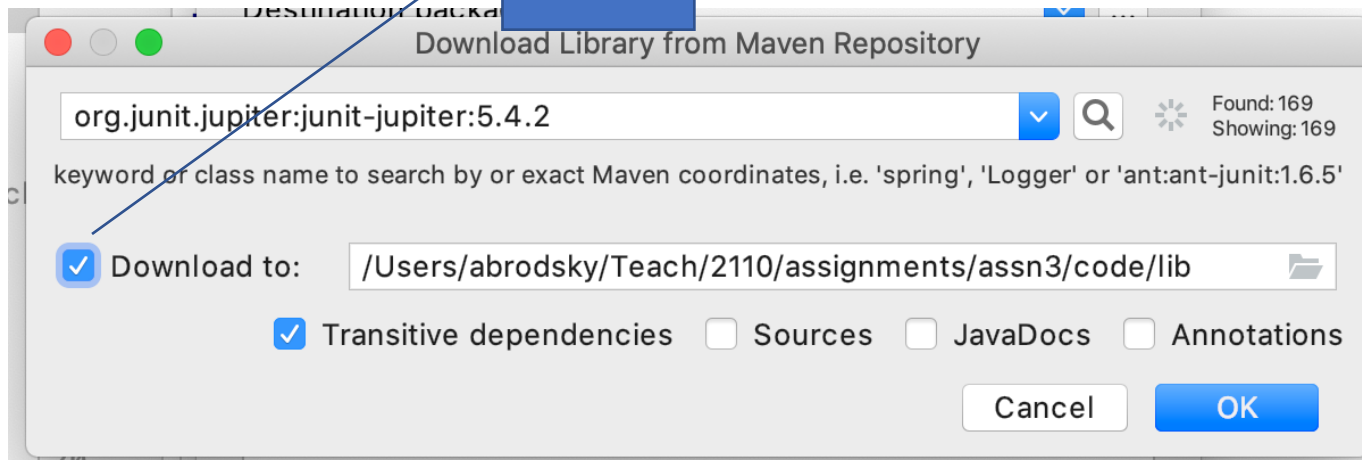
- Create the JUnit class
 - When the dialog box appears, ensure **JUnit5** is selected
 - If the JUnit library is not found, click on the **Fix** button right below the selector
 - Check the **Download to: ...** box in the **Download Library** dialog
 - Click on **OK**
 - The test class name is the class' name, suffixed with **Test**
 - Select all the methods that you wish to test
 - Typically all the public and some private
 - Click on **OK**

Select

Select all

Select

Fix



How to Create JUnit Test Class in IntelliJ

- Create a **test** directory for the project (if one does not exist)
 - Create a directory called **test** in the main project directory
 - Map the `test` directory to be **Test Sources Directory**
- Select the class you wish to test
 - Open the desired `.java` file in the **src** directory
 - Highlight the public class in the file and click on **Navigate → Test**
 - Click on **Create Test** in the pop-up menu
- Create the JUnit class
 - When the dialog box appears, ensure **JUnit5** is selected
 - If the JUnit library is not found, click on the **Fix** button right below the selector
 - Check the **Download to: ...** box in the **Download Library** dialog
 - Click on **OK**
 - The test class name is the class' name, suffixed with **Test**
 - Select all the methods that you wish to test
 - Typically all the public and some private
 - Click on **OK**
- The test class will be created and opened in IntelliJ

```
import ...

class MatrixTest {

    @Test
    void testEquals() {

    }

    @Test
    void negate() {

    }

    @Test
    void add() {

    }

    @Test
    void multiplyWithScalar() {

    }

    @Test
    void multiplyWithMatrix() {

    }

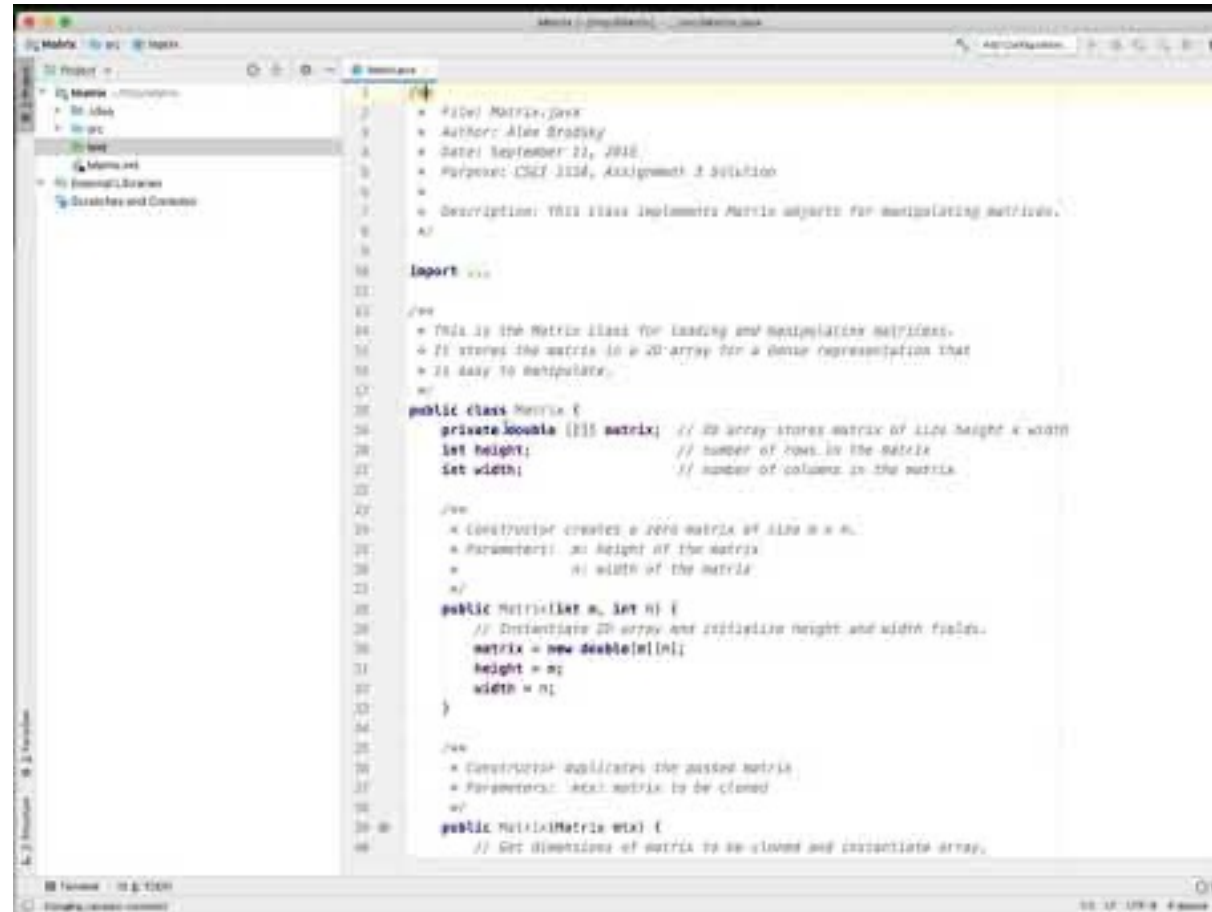
    @Test
    void write() {

    }

    @Test
    void getWidth() {

    }
}
```

Creating JUnit5 Tests in IntelliJ



Anatomy of a Test Method in JUnit 5

- A JUnit *test method* is intended to test a method in the target class
 - Typically with the same name
- A test method contains several parts:
 - **Setup**: instantiation of necessary objects and data structures
 - Typically, an object of the class being tested is instantiated
 - **Call**: call to the target method
 - **Evaluation**: the result of the call to the target method is evaluated.
 - This involves a call to one or more assertion functions
- JUnit provides other mechanisms for instantiating and setting up classes and objects once for an entire set of tests

Example of *MatrixTest* Class

```
1 import ...
7 class MatrixTest {
8     private final static String simpleMatrix = "2 2 1 2 3 4"; // [ 1 2 ]
9                                     // [ 3 4 ]
10    private final static String nonSqMatrix = "3 2 1 2 3 4 5 6"; // [ 1 2 3 ]
11                                     // [ 4 5 6 ]
12
13    @Test
14    void getElem() {
15        Matrix m = new Matrix(new Scanner(simpleMatrix));
16        assertEquals( expected: 2, m.getElem( i: 1, j: 2),
17            message: "getElem() did not return correct value");
18    }
19
20    @Test
21    void setElem() {
22        Matrix m = new Matrix(new Scanner(simpleMatrix));
23        m.setElem( i: 2, j: 1, v: 5);
24        assertEquals( expected: 5, m.getElem( i: 2, j: 1),
25            message: "setElem() may not have set correct value");
26    }
27 }
```

Data used by the tests
(a 2x2 and 2x3 matrices)

Setup: Instantiate a
Matrix object

Call: the `getElem()`
method on *Matrix*

Evaluation: compare
return value of call

Setup: Instantiate a
Matrix object

Call: the `setElem()`
method on *Matrix*

Evaluation: compare
return value of call

Aside on Assert

- Idea: JUnit provides assert functions to allow the test method to communicate the success of the test
- The *org.junit.jupiter.api.Assertions* class provides hundreds of assertions to use (static methods).
- See online documentation for list of all the possible assertion

| Assertion | Description |
|-------------------------|------------------------------------|
| assertTrue(boolean b) | Test fails if b is false |
| assertFalse(boolean b) | Test fails if b is true |
| assertNotNull(Object o) | Test fails if o is null |
| assertNull(Object o) | Test fails if o is not null |
| assertEquals(x,y) | Test fails if x is not equal to y |
| assertNotEquals(x,y) | Test fails if x equals y |
| assertArrayEquals(a, b) | Test fails if arrays are not equal |

How Do We Design a Test?

- Two General Approaches
 - White Box Testing
 - Black Box Testing
- White Box Testing
 - Test based on implementation of code
 - Typically try to test every code path through the method
- Black Box Testing
 - Test based on specification of what code should do
 - Use the description of class and method(s) to test if specification is being met.

Example: A White Box Test

```
/**
 * Return element  $E\{i,j\}$  of the matrix. If  $i$  or  $j$  is less than 1
 * or greater than height or width, respectively, the behaviour is
 * undefined.
 * Parameters:   $i$ : row of entry
 *               $j$ : column of entry
 */
public double getElem(int i, int j) {
    // return corresponding entry in matrix.
    return matrix[i][j];
}
```

- **Observation:** Single path through method
- Proposed test:
 - Initialize *Matrix* object with known values
 - Perform `getElem()`
 - Expectation: It should return the known value

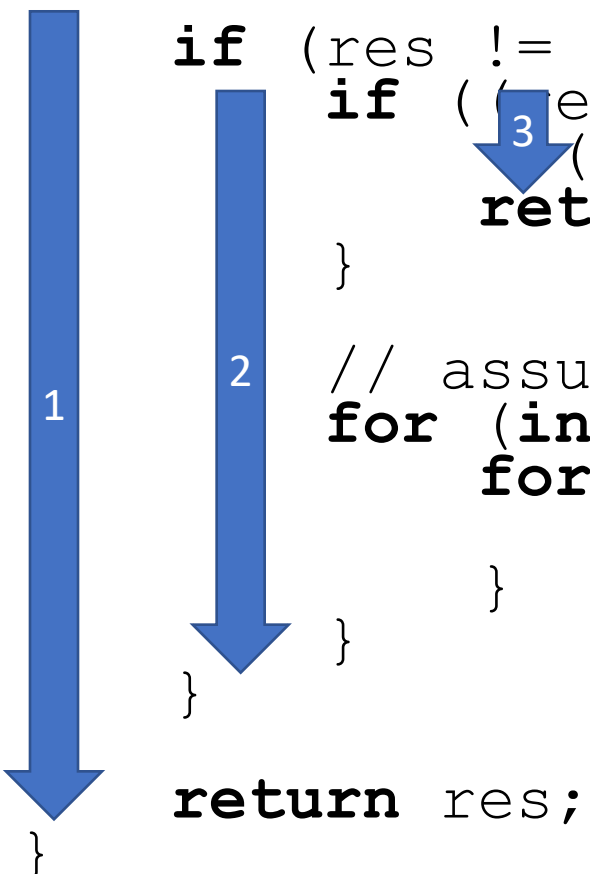
```
@Test
void getElem() {
    Matrix m = new Matrix(new Scanner(simpleMatrix));
    assertEquals( expected: 2, m.getElem( i: 1, j: 2),
        message: "getElem() did not return correct value");
}
```

An Intro to Structured Basis Testing

- Idea:
 - For each method create tests that test each part of the code in the method
 - Each part of the code needs to be tested once
 - A kind of white box testing
- Algorithm
 - Start with one test case at start of method
 - Add a test case for each
 - Loop
 - if statement
 - Part of a Boolean condition
 - Every code branch
- Observation: Smaller methods need fewer test cases

Example: How many tests do we need?

```
public Matrix multiplyWithScalar(double s, Matrix res) {  
    if (res != null) {  
        if (res.getHeight() != height) ||  
            (res.getWidth() != width) {  
            return null;  
        }  
        // assume height, width > 0  
        for (int i = 0; i < height; i++) {  
            for (int j = 0; j < width; j++) {  
                res.matrix[i][j] = s * matrix[i][j];  
            }  
        }  
    }  
    return res;  
}
```



Test Cases:

1. `res == null`; expected return: null
2. `res.height == height, res.width == width`, expected return `s*this`
3. `res != null, res.height != height`, expected return null
4. `res.height == height, res.width != width`, expected return null

Test Cases in JUnit

| Test Cases | Test code |
|---|---|
| <code>res == null</code> | <pre>Matrix m = new Matrix(1,1) assertNull(m.multiplyWithScalar(1, null))</pre> |
| <code>res != null</code> <code>res.height == height,</code> <code>res.width == width</code> | <pre>Matrix m = new Matrix(...) // 2 x 2 matrix Matrix n = new Matrix(2,2) n = m.multiplyWithScalar(2, n) assertNotNull(n) assertEquals(2 * m.getElem(1,1) == n.getElem(1,1)) assertEquals(2 * m.getElem(2,1) == n.getElem(2,1)) assertEquals(2 * m.getElem(1,2) == n.getElem(1,2)) assertEquals(2 * m.getElem(2,2) == n.getElem(2,2))</pre> |
| <code>res != null,</code> <code>res.height != height</code> | <pre>Matrix m = new Matrix(1,1) Matrix n = new Matrix(2,1) assertNull(m.multiplyWithScalar(1, n))</pre> |
| <code>res != null</code> <code>res.height == height</code> <code>res.width != width</code> | <pre>Matrix m = new Matrix(1,1) Matrix n = new Matrix(1,2) assertNull(m.multiplyWithScalar(1, n))</pre> |

Black Box Testing: Specification-based Testing

- Idea:
 - For each method create tests that are based on the description of the method
- Need to create tests for
 - Common cases
 - Boundary cases
 - Possibly, exceptional cases

Example: A Black Box Test

```
/**
 * Return element  $E\{i,j\}$  of the matrix. If  $i$  or  $j$  is less than 1
 * or greater than height or width, respectively, the behaviour is
 * undefined.
 * Parameters:   $i$ : row of entry
 *               $j$ : column of entry
 */
public double getElem(int i, int j) {
    [REDACTED]
}
```

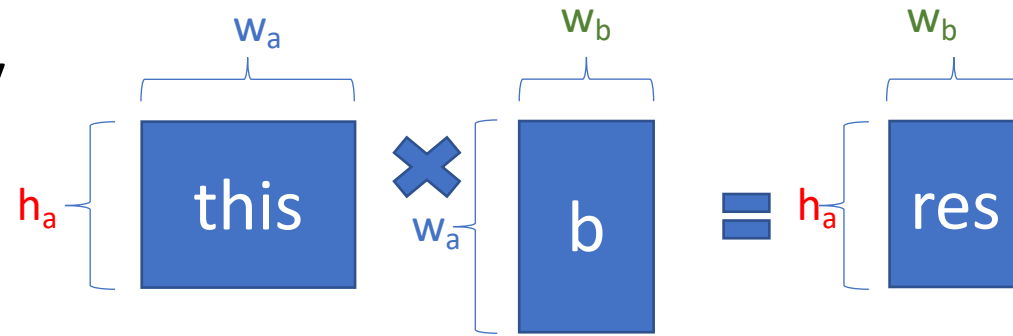
- **Cases to Consider:**
 - i and/or j on the edge of a matrix
 - Common case: i, j are not on the edge
- Nothing to test if i, j are < 1 or $> \text{sizeof}(E)$

```
@Test
void getElem() {
    Matrix m = new Matrix(new Scanner(simpleMatrix));
    assertEquals( expected: 2, m.getElem( i: 1, j: 2),
                 message: "getElem() did not return correct value");
}
```


Specification-based Testing

- Identify all common cases in the specification
 - Need one test-case per case
- Identify all boundary cases in the specification
 - Need one test case per boundary
- If a specification has exceptional cases include those as well

Example: How many tests do we need?



```
/**
 * Multiply the current matrix with matrix b and store the results in
 * res. If matrices are not allocated or correctly sized, return null.
 * Parameters: b: matrix to be multiplied with the current matrix
 *                res: destination matrix where the result is placed.
 * Return: returns res matrix for programming convenience.
 */
public Matrix multiplyWithMatrix(Matrix b, Matrix res) { ... }
```

Test Cases:

1. Null matrices: returns null

- `res == null, b != null`
- `res != null, b == null`
- `res == null, b == null`

2. Mismatched dimensions: returns null

- `this.width != b.height`
- `res.height != this.height`
- `res.width = b.width`

Test Cases:

3. Boundary conditions: return is `this * b`

- `this.height = 1`
- `this.width = 1`
- `b.width = 1`

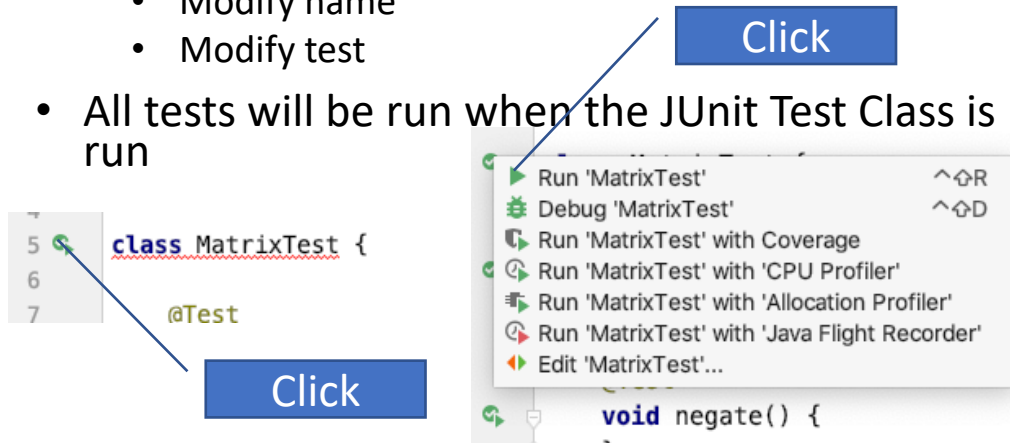
4. Normal cases: return is `this * b`

- `1 < this.height == this.width`
- `1 < this.height < this.width`
- `1 < this.width < this.height`
- `b.width >= 1` (with the above)

15+ Test Cases!

Adding Tests to a JUnit Test Class

- By default, IntelliJ creates one test method for each method in the target class
- If we have multiple tests for a method, we have two options
 - Put all tests in a single test method
 - Create multiple test methods for the same method
- Idea: Multiple small test methods are better:
 - Easier to understand
 - Easier to determine which tests failed
- To create another test method
 - Process make a copy of an existing test method
 - Modify name
 - Modify test
- All tests will be run when the JUnit Test Class is run



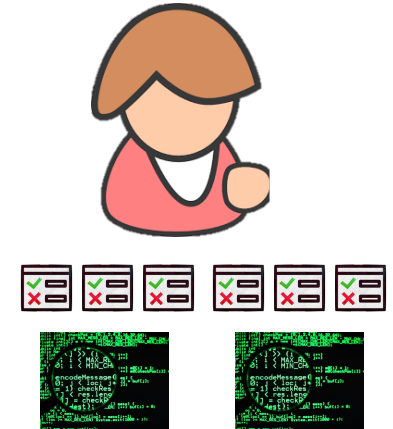
```
@Test
void multiplyWithMatrix_bIsNull() {
    ...
}

@Test
void multiplyWithMatrix_heightMismatch() {
    ...
}

@Test
void multiplyWithMatrix_bIsWidth1() {
    ...
}
```

Unit Testing

- **JUnit** got its name from unit testing
- Unit testing is the execution of a complete class, routine, or small program, which is tested in isolation from the more complete system
- **Scope:** Small units of code
 - Methods and functions
 - Simple classes
 - Typically written by a single developer
- **Goal:** Ensure the small simple building blocks work
 - Easiest to do because they focus on small chunks of code
- **Principle:** In most cases smaller pieces of code are easier to test
- Three types, depending on how much is known about the implementation
 - Tests are based on:
 - **Black Box:** Strictly on specification or interface
 - **White Box:** Specification or interface, and the implementation
 - **Grey Box:** Specification or interface, and partial knowledge of the implementation



Why Start with Unit Testing

- First kind of testing done by the developer
- Serves as a basis for higher level testing
 - Unit tests are incorporated into higher level tests
- Easier to learn how to test small pieces of code
- Typically done individually
- Does not require a dedicated server
- Next Lecture will be a top-down view of testing!

Key Points

- A test is a combination of an execution framework, input, and output that runs a target piece of code to detect defects
- JUnit is a unit-testing framework that allows us to easily create, run, and debug tests
- Whitebox testing uses tests that are guided by knowledge of the implementation
- Blackbox testing uses tests that are guided by the specification for the code
- Unit testing focuses on small pieces of code that we want to test in isolation

Image References

Retrieved January 8, 2020

- <http://pengetouristboard.co.uk/vote-best-takeaway-se20/>
- <https://i.pinimg.com/originals/b5/22/38/b52238fad11b0a3ecac36fa176041d98.jpg>
- https://www.nbs-system.com/wp-content/uploads/2016/05/160503_Tests_boites-788x433.jpg
- https://www.pclipart.com/picdir/middle/29-293393_challenges-peace-first-clip-art-work-teamwork-clip.png
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