

Test-Driven Development (TDD) with JUnit



EECS2030 B & E: Advanced
Object Oriented Programming
Fall 2021

CHEN-WEI WANG

Learning Outcomes

This module is designed to help you learn about:

- **Testing** the Solution to a Bounded Counter Problem
- How Manual, Console Testers are Limited
- Deriving **Test Cases** for a Bounded Variable
- How Automated, JUnit Test Cases are Effective
- Test Driven Development (TDD) via **Regression Testing**

Motivating Example: Two Types of Errors (1)

Consider two kinds of exceptions for a counter:

```
public class ValueTooLargeException extends Exception {  
    ValueTooLargeException(String s) { super(s); }  
}  
public class ValueTooSmallException extends Exception {  
    ValueTooSmallException(String s) { super(s); }  
}
```

Any thrown object instantiated from these two classes must be handled (*catch-specify requirement*):

- Either *specify* throws ... in the method signature (i.e., propagating it to other caller)
- Or *handle* it in a try-catch block

Motivating Example: Two Types of Errors (2)

Approach 1 – Specify: Indicate in the method signature that a specific exception might be thrown.

Example 1: Method that throws the exception

```
class C1 {  
    void m1(int x) throws ValueTooSmallException {  
        if(x < 0) {  
            throw new ValueTooSmallException("val " + x);  
        }  
    }  
}
```

Example 2: Method that calls another which throws the exception

```
class C2 {  
    C1 c1;  
    void m2(int x) throws ValueTooSmallException {  
        c1.m1(x);  
    }  
}
```

Motivating Example: Two Types of Errors (3)

Approach 2 – Catch: Handle the thrown exception(s) in a try-catch block.

```
class C3 {  
    public static void main(String[] args) {  
        Scanner input = new Scanner(System.in);  
        int x = input.nextInt();  
        C2 c2 = new C2();  
        try {  
            c2.m2(x);  
        }  
        catch (ValueTooSmallException e) { ... }  
    }  
}
```

A Simple Counter (1)

Consider a class for keeping track of an integer counter value:

```
public class Counter {  
    public final static int MAX_VALUE = 3;  
    public final static int MIN_VALUE = 0;  
    private int value;  
    public Counter() {  
        this.value = Counter.MIN_VALUE;  
    }  
    public int getValue() {  
        return value;  
    }  
    ... /* more later! */  
}
```

- Access **private** attribute value using **public** accessor `getValue`.
- Two class-wide (i.e., `static`) constants (i.e., `final`) for lower and upper bounds of the counter value.
- Initialize the counter value to its lower bound.
- **Requirement** :

The counter value must be between its lower and upper bounds.

Exceptional Scenarios

Consider the two possible exceptional scenarios:

- An attempt to increment *above* the counter's upper bound.
- An attempt to decrement *below* the counter's lower bound.

A Simple Counter (2)

```
/* class Counter */  
public void increment() throws ValueTooLargeException {  
    if(value == Counter.MAX_VALUE) {  
        throw new ValueTooLargeException("value is " + value);  
    }  
    else { value ++; }  
}  
  
public void decrement() throws ValueTooSmallException {  
    if(value == Counter.MIN_VALUE) {  
        throw new ValueTooSmallException("value is " + value);  
    }  
    else { value --; }  
}  
}
```

- Change the counter value via two mutator methods.
- Changes on the counter value may **trigger an exception**:
 - Attempt to **increment** when counter already reaches its **maximum**.
 - Attempt to **decrement** when counter already reaches its **minimum**.

Components of a Test

- Manipulate the relevant object(s).
 - e.g., *Initialize a counter object c, then call c.increment().*
 - e.g., *Initialize a counter object c, then call c.decrement().*
- What do you **expect to happen**?
 - e.g., *value of counter is such that Counter.MIN_VALUE + 1*
 - e.g., *ValueTooSmallException is thrown*
- What does your program **actually produce**?
 - e.g., *call c.getValue() to find out.*
 - e.g., *Use a try-catch block to find out* (to be discussed!).
- A test:
 - **Passes** if expected outcome occurs.
 - **Fails** if expected outcome does *not* occur.
- To start with, we develop tests via a **console tester** class (i.e., with the `main` method).

Testing Counter via Console V1 (1.1)

```
1 public class CounterTester1 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Init val: " + c.getValue());
5         try {
6             c.decrement();
7             println("Error: ValueTooSmallException NOT thrown.");
8         }
9         catch (ValueTooSmallException e) {
10            println("Success: ValueTooSmallException thrown.");
11        }
12    } /* end of main method */
13 } /* end of class CounterTester1 */
```

- o **L3** sets `c.value` to 0.
- o At **L6**, if method `decrement` is implemented:
 - **Correctly** ⇒ we expect a `ValueTooSmallException`.
⇒ Execution jumps to **L9, L10 – L12**, then the program terminates.
 - **Incorrectly** ⇒ expected `ValueTooSmallException` *wouldn't* occur.
⇒ Execution continues to **L7, L8, L12**, then the program terminates.

Testing Counter via Console V1 (1.2)

```
1 public class CounterTester1 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Init val: " + c.getValue());
5         try {
6             c.decrement();
7             println("Error: ValueTooSmallException NOT thrown.");
8         }
9         catch (ValueTooSmallException e) {
10            println("Success: ValueTooSmallException thrown.");
11        }
12    } /* end of main method */
13 } /* end of class CounterTester1 */
```

- Say method `decrement` is implemented **correctly**.
- **Lines 3 – 6, 9 – 11, 12** executed, giving the Console Output:

```
Init val: 0
Success: ValueTooSmallException thrown.
```

Testing Counter via Console V1 (1.3.1)

- The real value of a **test** is:
 - Not only to confirm when your implementation is **correct**,
 - But also to reveal errors when your implementation is **incorrect**.
- Say now method `decrement` was implemented **incorrectly**:

```
class Counter {  
    ...  
    public void decrement() throws ValueTooSmallException {  
        if (value < Counter.MIN_VALUE) {  
            throw new ValueTooSmallException("value is " + value);  
        }  
        else { value --; }  
    }  
}
```

- Is the same console tester able to **reveal** this **incorrect** implementation?

Testing Counter via Console V1 (1.3.2)

```
1 public class CounterTester1 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Init val: " + c.getValue());
5         try {
6             c.decrement();
7             println("Error: ValueTooSmallException NOT thrown.");
8         }
9         catch (ValueTooSmallException e) {
10            println("Success: ValueTooSmallException thrown.");
11        }
12    } /* end of main method */
13 } /* end of class CounterTester1 */
```

- Say method `decrement` is implemented **incorrectly**.
- **Lines 3 – 6, 7 – 8, 12** executed, giving the Console Output:

```
Init val: 0
Error: ValueTooSmallException NOT thrown.
```

Testing Counter via Console V2 (2.1)

```
1 public class CounterTester2 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Current val: " + c.getValue());
5         try {
6             c.increment(); c.increment(); c.increment();
7             println("Current val: " + c.getValue());
8             try {
9                 c.increment();
10                println("Error: ValueTooLargeException NOT thrown.");
11            } /* end of inner try */
12            catch (ValueTooLargeException e) {
13                println("Success: ValueTooLargeException thrown.");
14            } /* end of inner catch */
15        } /* end of outer try */
16        catch (ValueTooLargeException e) {
17            println("Error: ValueTooLargeException thrown unexpectedly.");
18        } /* end of outer catch */
19    } /* end of main method */
20 } /* end of CounterTester2 class */
```

See the equivalent, automated JUnit test `testIncFromMaxValue`.

Testing Counter via Console V2 (2.2)

```
1 public class CounterTester2 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Current val: " + c.getValue());
5         try {
6             c.increment(); c.increment(); c.increment();
7             println("Current val: " + c.getValue());
8             try {
9                 c.increment();
10                println("Error: ValueTooLargeException NOT thrown.");
11            } /* end of inner try */
12            catch (ValueTooLargeException e) {
13                println("Success: ValueTooLargeException thrown.");
14            } /* end of inner catch */
15        } /* end of outer try */
16        catch (ValueTooLargeException e) {
17            println("Error: ValueTooLargeException thrown unexpectedly.");
18        } /* end of outer catch */
19    } /* end of main method */
20 } /* end of CounterTester2 class */
```

- Say method increment is implemented **correctly**.
- **Lines 3 – 9, 12 – 15, 19** executed, with Console Output:

```
Current val: 0
Current val: 3
Success: ValueTooLargeException thrown.
```

Testing Counter via Console V2 (2.3.1)

```
1 public class CounterTester2 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Current val: " + c.getValue());
5         try {
6             c.increment(); c.increment(); c.increment();
7             println("Current val: " + c.getValue());
8             try {
9                 c.increment();
10                println("Error: ValueTooLargeException NOT thrown.");
11            } /* end of inner try */
12            catch (ValueTooLargeException e) {
13                println("Success: ValueTooLargeException thrown.");
14            } /* end of inner catch */
15        } /* end of outer try */
16        catch (ValueTooLargeException e) {
17            println("Error: ValueTooLargeException thrown unexpectedly.");
18        } /* end of outer catch */
19    } /* end of main method */
20 } /* end of CounterTester2 class */
```

- o **Exercise:** Give an *incorrect* method `increment`, so that
- o **Lines 3 – 6, 16 – 18, 19** executed, with Console Output:

```
Current val: 0
```

```
Error: ValueTooLargeException was thrown unexpectedly.
```


Testing Counter via Console V2 (2.3.2)

```
1 public class CounterTester2 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Current val: " + c.getValue());
5         try {
6             c.increment(); c.increment(); c.increment();
7             println("Current val: " + c.getValue());
8             try {
9                 c.increment();
10                println("Error: ValueTooLargeException NOT thrown.");
11            } /* end of inner try */
12            catch (ValueTooLargeException e) {
13                println("Success: ValueTooLargeException thrown.");
14            } /* end of inner catch */
15        } /* end of outer try */
16        catch (ValueTooLargeException e) {
17            println("Error: ValueTooLargeException thrown unexpectedly.");
18        } /* end of outer catch */
19    } /* end of main method */
20 } /* end of CounterTester2 class */
```

- o **Exercise:** Give an *incorrect* method increment, so that
- o **Lines 3 – 11, 15, 19** executed, with Console Output:

```
Current val: 0
Current val: 3
```

Error: ValueTooLargeException was NOT thrown.

Testing Counter via Console V2 (2.3.3)

Q. Can this alternative to ConsoleTester2 work (without nested try-catch)?

```
1 public class CounterTester2 {
2     public static void main(String[] args) {
3         Counter c = new Counter();
4         println("Current val: " + c.getValue());
5         try {
6             c.increment(); c.increment(); c.increment();
7             println("Current val: " + c.getValue());
8         }
9         catch (ValueTooLargeException e) {
10            println("Error: ValueTooLargeException thrown unexpectedly.");
11        }
12        try {
13            c.increment();
14            println("Error: ValueTooLargeException NOT thrown.");
15        } /* end of inner try */
16        catch (ValueTooLargeException e) {
17            println("Success: ValueTooLargeException thrown.");
18        } /* end of inner catch */
19    } /* end of main method */
20 } /* end of CounterTester2 class */
```

A. Say one of the first 3 `c.increment()` **mistakenly** throws VTLE.

- After L10 is executed, flow of execution **still continues** to L12.
- This allows the 4th `c.increment` to be executed!
- Contrast this with the structurally-similar JUnit test `testIncFromMaxValue`: here.

Testing Counter via Console (V3)

```
import java.util.Scanner;
public class CounterTester3 {
    public static void main(String[] args) {
        Scanner input = new Scanner(System.in);
        String cmd = null; Counter c = new Counter();
        boolean userWantsToContinue = true;
        while(userWantsToContinue) {
            println("Enter \"inc\", \"dec\", or \"val\":");
            cmd = input.nextLine();
            try {
                if(cmd.equals("inc")) { c.increment(); }
                else if(cmd.equals("dec")) { c.decrement(); }
                else if(cmd.equals("val")) { println(c.getValue()); }
                else { userWantsToContinue = false; println("Bye!"); }
            } /* end of try */
            catch(ValueTooLargeException e){ println("Value too big!"); }
            catch(ValueTooSmallException e){ println("Value too small!"); }
        } /* end of while */
    } /* end of main method */
} /* end of class CounterTester3 */
```

Testing Counter via Console (V3): Test 1

Test Case 1: Decrement when the counter value is too small.

```
Enter "inc", "dec", or "val":
```

```
val
```

```
0
```

```
Enter "inc", "dec", or "val":
```

```
dec
```

```
Value too small!
```

```
Enter "inc", "dec", or "val":
```

```
exit
```

```
Bye!
```

Testing Counter via Console (V3): Test 2

Test Case 2: Increment when the counter value is too big.

```
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
val  
3  
Enter "inc", "dec", or "val":  
inc  
Value too big!  
Enter "inc", "dec", or "val":  
exit  
Bye!
```

Limitations of Testing from the Console

- Do **Test Cases 1 & 2** suffice to test `Counter`'s **correctness**?
 - Is it plausible to claim that the implementation of `Counter` is **correct** because it passes the two test cases?

- What other test cases can you think of?

<code>c.getValue()</code>	<code>c.increment()</code>	<code>c.decrement()</code>
0	1	<code>ValueTooSmall</code>
1	2	0
2	3	1
3	<code>ValueTooLarge</code>	2

- So in total we need 8 test cases. \Rightarrow 6 more separate
 - `CounterTester` classes to create (like `CounterTester1`!)
 - Console interactions with `CounterTester3`!
- Problems? It is inconvenient and **error-prone** to:
 - Run each TC by executing `main` of a `CounterTester` and comparing console outputs **with your eyes**.
 - Re-run manually** all TCs whenever `Counter` is changed.

Regression Testing: Any **change** introduced to your software **must not compromise** its established **correctness**.

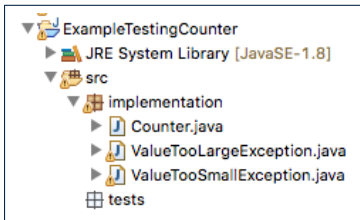
Why JUnit?

- **Automate** the *testing of correctness* of your Java classes.
- Once you derive the list of tests, translate it into a JUnit test case, which is just a Java class that you can execute upon.
- JUnit tests are **helpful callers/clients** of your classes, where each test may:
 - Either attempt to use a method in a **legal** way (i.e., **satisfying** its precondition), and report:
 - **Success** if the result is as expected
 - **Failure** if the result is **not** as expected
 - Or attempt to use a method in an **illegal** way (i.e., **not satisfying** its precondition), and report:
 - **Success** if the expected exception (e.g., `ValueTooSmallException`) occurs.
 - **Failure** if the expected exception does **not** occur.

How to Use JUnit: Packages

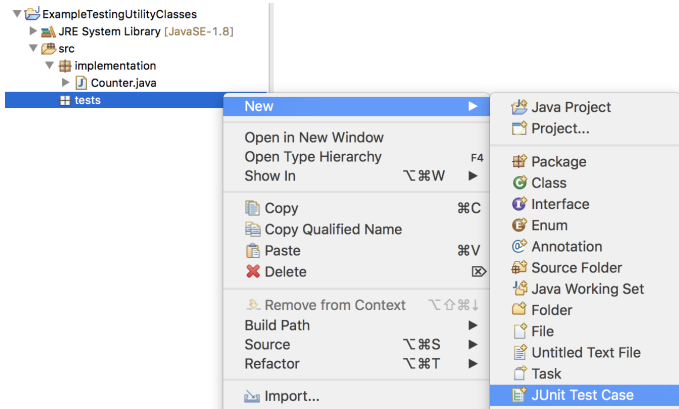
Step 1:

- In Eclipse, create a Java project `ExampleTestingCounter`
- **Separation of concerns** :
 - Group classes for **implementation** (i.e., `Counter`) into package `implementation`.
 - Group classes for **testing** (to be created) into package `tests`.



How to Use JUnit: New JUnit Test Case (1)

Step 2: Create a new *JUnit Test Case* in tests package.

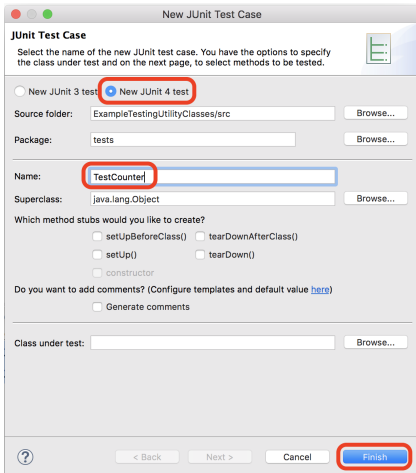


Create one JUnit Test Case to test one Java class only.

⇒ If you have *n Java classes to test*, create *n JUnit test cases*.

How to Use JUnit: New JUnit Test Case (2)

Step 3: Select the version of JUnit (JUnit 4); Enter the name of test case (`TestCounter`); Finish creating the new test case.



New JUnit Test Case

JUnit Test Case

Select the name of the new JUnit test case. You have the options to specify the class under test and on the next page, to select methods to be tested.

New JUnit 3 test **New JUnit 4 test**

Source folder: ExampleTestingUtilityClasses/src

Package: tests

Name: **TestCounter**

Superclass: java.lang.Object

Which method stubs would you like to create?

setUpBeforeClass() tearDownAfterClass()
 setUp() tearDown()
 constructor

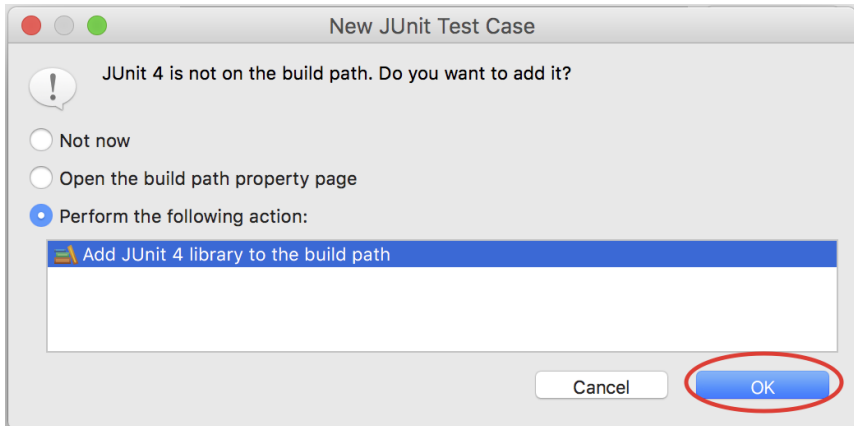
Do you want to add comments? (Configure templates and default value [here](#))

Generate comments

Class under test:

How to Use JUnit: Adding JUnit Library

Upon creating the very first test case, you will be prompted to add the JUnit library to your project's build path.



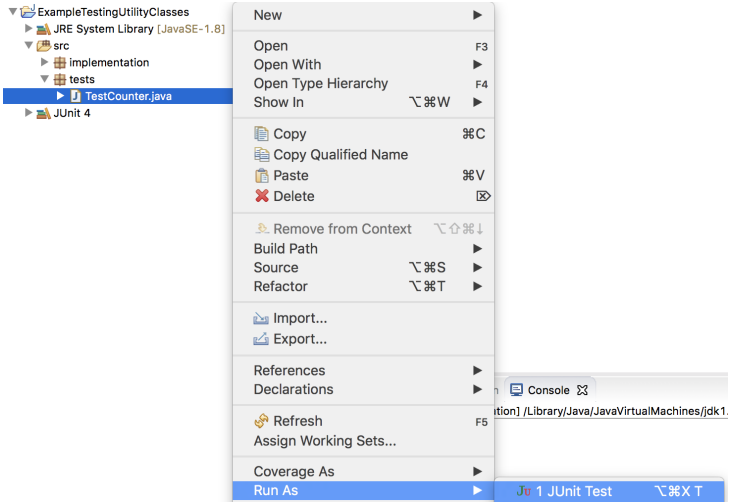
How to Use JUnit: Generated Test Case

```
TestCounter.java ✖
1 package tests;
2 import static org.junit.Assert.*;
3 import org.junit.Test;
4 public class TestCounter {
5     @Test
6     public void test() {
7         fail("Not yet implemented");
8     }
9 }
```

- **Lines 6 – 8:** `test` is just an *ordinary mutator method* that has a one-line implementation body.
- **Line 5** is critical: Prepend the tag `@Test` verbatim, requiring that *the method is to be treated as a JUnit test*.
⇒ When `TestCounter` is run as a JUnit Test Case, only *those methods prepended by the @Test tags* will be run and reported.
- **Line 7:** By default, we deliberately fail the test with a message “Not yet implemented”.

How to Use JUnit: Running Test Case

Step 4: Run the `TestCounter` class as a JUnit Test.



The screenshot shows an IDE interface with a project tree on the left and a context menu open over the `TestCounter.java` file. The project tree shows the following structure:

- ExampleTestingUtilityClasses
 - JRE System Library [JavaSE-1.8]
 - src
 - implementation
 - tests
 - TestCounter.java**
 - JUnit 4

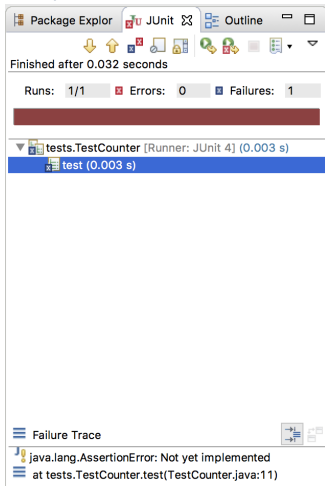
The context menu is open, showing the following options:

- New
- Open (F3)
- Open With
- Open Type Hierarchy (F4)
- Show In (⌘ %W)
- Copy (⌘ C)
- Copy Qualified Name
- Paste (⌘ V)
- Delete (⌘ X)
- Remove from Context (⌘ ⬆ ⬇)
- Build Path
- Source (⌘ %S)
- Refactor (⌘ %T)
- Import...
- Export...
- References
- Declarations
- Refresh (F5)
- Assign Working Sets...
- Coverage As
- Run As (⌘ %X T)**

The 'Run As' option is highlighted, and a sub-menu is visible showing 'JUnit 4 JUnit Test'.

How to Use JUnit: Generating Test Report

A **report** is generated after running all tests (i.e., methods prepended with **@Test**) in `TestCounter`.



The screenshot shows the JUnit test runner interface. At the top, it says "Finished after 0.032 seconds". Below that, it displays "Runs: 1/1", "Errors: 0", and "Failures: 1". A red progress bar indicates the test status. The test results list shows "tests.TestCounter [Runner: JUnit 4] (0.003 s)" expanded to show "test (0.003 s)". At the bottom, the "Failure Trace" section shows the error: "java.lang.AssertionError: Not yet implemented" at "tests.TestCounter.test(TestCounter.java:11)".

How to Use JUnit: Interpreting Test Report

- A **test** is a method prepended with the **@Test** tag.
- The result of running a test is considered:
 - **Failure** if either
 - an assertion failure (e.g., caused by `fail`, `assertTrue`, `assertEquals`) occurs; or
 - an **unexpected** exception (e.g., `NullPointerException`, `ArrayIndexOutOfBoundsException`) is thrown.
 - **Success** if neither assertion failures nor **unexpected** exceptions occur.
- After running all tests:
 - A **green** bar means that **all** tests succeed.
⇒ Keep challenging yourself if **more tests** may be added.
 - A **red** bar means that **at least one** test fails.
⇒ Keep fixing the class under test and re-running all tests, until you receive a **green** bar.
- **Question:** What is the easiest way to making test a **success**?
Answer: Delete the call `fail("Not yet implemented")`.

How to Use JUnit: Revising Test Case

```
TestCounter.java ✕
1 package tests;
2 import static org.junit.Assert.*;
3 import org.junit.Test;
4 public class TestCounter {
5     @Test
6     public void test() {
7         // fail("Not yet implemented");
8     }
9 }
```

Now, the body of `test` simply does nothing.

⇒ Neither assertion failures nor exceptions will occur.

⇒ The execution of `test` will be considered as a **success**.

∴ There is currently only one test in `TestCounter`.

∴ We will receive a **green** bar!

Caution: `test` which passes at the moment is **not useful** at all!

How to Use JUnit: Re-Running Test Case

A new report is generated after re-running all tests (i.e., methods prepended with `@Test`) in `TestCounter`.



The screenshot shows the JUnit runner interface in an IDE. At the top, it says "Finished after 0.017 seconds". Below that, the status is "Runs: 1/1", "Errors: 0", and "Failures: 0". A green progress bar is visible. The test results are listed as follows:

- tests.TestCounter [Runner: JUnit 4] (0.000 s)
 - test (0.000 s)

At the bottom, there is a "Failure Trace" section which is currently empty.

How to Use JUnit: Adding More Tests (1)

- Recall the complete list of cases for testing Counter:

c.getValue()	c.increment()	c.decrement()
0	1	ValueTooSmall
1	2	0
2	3	1
3	ValueTooLarge	2

- Let's turn the two cases in the 1st row into two JUnit tests:
 - Test for the *green* cell *succeeds* if:
 - No failures and exceptions occur; and
 - The new counter value is 1.
 - Tests for *red* cells *succeed* if the **expected exceptions** occur (ValueTooSmallException & ValueTooLargeException).
 - Common JUnit assertion methods:
 - `void assertNull(Object o)`
 - `void assertEquals(int expected, int actual)`
 - `void assertEquals(double exp, double act, double epsilon)`
 - `void assertEquals(expected, actuals)`
 - `void assertTrue(boolean condition)`
 - `void fail(String message)`

JUnit Assertions: Examples (1)

Consider the following class:

```
public class Point {  
    private int x; private int y;  
    public Point(int x, int y) { this.x = x; this.y = y; }  
    public int getX() { return this.x; }  
    public int getY() { return this.y; }  
}
```

Then consider these assertions. Do they **pass** or **fail**?

```
Point p;  
assertNull(p); ✓  
assertTrue(p == null); ✓  
assertFalse(p != null); ✓  
assertEquals(3, p.getX()); ✗ /* NullPointerException */  
p = new Point(3, 4);  
assertNull(p); ✗  
assertTrue(p == null); ✗  
assertFalse(p != null); ✗  
assertEquals(3, p.getX()); ✓  
assertTrue(p.getX() == 3 && p.getY() == 4); ✓
```

JUnit Assertions: Examples (2)

- Consider the following class:

```
public class Circle {  
    private double radius;  
    public Circle(double radius) { this.radius = radius; }  
    public int getArea() { return 3.14 * radius * radius; }  
}
```

- How do we test `c.getArea()`?
 - Mathematically: $3.4 \times 3.4 \times 3.14 = 36.2984$
 - However, base-10 numbers **cannot** be represented perfectly in the binary format.
 - When comparing fractional numbers, allow some **tolerance**:

$$36.2984 - 0.01 \leq c.getArea() \leq 36.2984 + 0.01$$

- Then consider these assertions. Do they **pass** or **fail**?

```
Circle c = new Circle(3.4);  
assertTrue(36.2984, c.getArea(), 0.01); ✓
```

How to Use JUnit: Assertion Methods

method name / parameters	description
<code>assertTrue(test)</code> <code>assertTrue("message", test)</code>	Causes this test method to fail if the given boolean test is not <code>true</code> .
<code>assertFalse(test)</code> <code>assertFalse("message", test)</code>	Causes this test method to fail if the given boolean test is not <code>false</code> .
<code>assertEquals(expectedValue, value)</code> <code>assertEquals("message", expectedValue, value)</code>	Causes this test method to fail if the given two values are not equal to each other. (For objects, it uses the <code>equals</code> method to compare them.) The first of the two values is considered to be the result that you expect; the second is the actual result produced by the class under test.
<code>assertNotEquals(value1, value2)</code> <code>assertNotEquals("message", value1, value2)</code>	Causes this test method to fail if the given two values <i>are</i> equal to each other. (For objects, it uses the <code>equals</code> method to compare them.)
<code>assertNull(value)</code> <code>assertNull("message", value)</code>	Causes this test method to fail if the given value is not <code>null</code> .
<code>assertNotNull(value)</code> <code>assertNotNull("message", value)</code>	Causes this test method to fail if the given value <i>is</i> <code>null</code> .
<code>assertSame(expectedValue, value)</code> <code>assertSame("message", expectedValue, value)</code> <code>assertNotSame(value1, value2)</code> <code>assertNotSame("message", value1, value2)</code>	Identical to <code>assertEquals</code> and <code>assertNotEquals</code> respectively, except that for objects, it uses the <code>==</code> operator rather than the <code>equals</code> method to compare them. (The difference is that two objects that have the same state might be <code>equals</code> to each other, but not <code>==</code> to each other. An object is only <code>==</code> to itself.)
<code>fail()</code> <code>fail("message")</code>	Causes this test method to fail.

How to Use JUnit: Adding More Tests (2.1)

```
1  @Test
2  public void testIncAfterCreation() {
3      Counter c = new Counter();
4      assertEquals(Counter.MIN_VALUE, c.getValue());
5      try {
6          c.increment();
7          assertEquals(1, c.getValue());
8      }
9      catch(ValueTooBigException e) {
10         /* Exception is not expected to be thrown. */
11         fail("ValueTooBigException is not expected.");
12     }
13 }
```

- **Line 6** requires a try-catch block \therefore potential *ValueTooBigException*
- **Lines 4, 7 11** are all assertions:
 - **Lines 4 & 7** assert that *c.getValue()* returns the expected values.
 - **Line 11**: an assertion failure \therefore unexpected *ValueTooBigException*
- **Line 7** can be rewritten as `assertTrue(1 == c.getValue())`.

How to Use JUnit: Adding More Tests (2.2)

- Don't lose the big picture!
- JUnit test in previous slide automates this console interaction:

```
Enter "inc", "dec", or "val":  
val  
0  
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
val  
1  
Enter "inc", "dec", or "val":  
exit  
Bye!
```

- **Automation** is exactly rationale behind using JUnit!

How to Use JUnit: Adding More Tests (3.1)

```
1  @Test
2  public void testDecFromMinValue() {
3      Counter c = new Counter();
4      assertEquals(Counter.MIN_VALUE, c.getValue());
5      try {
6          c.decrement();
7          fail("ValueTooSmallException is expected.");
8      }
9      catch(ValueTooSmallException e) {
10         /* Exception is expected to be thrown. */
11     }
12 }
```

- o **Line 6** requires a try-catch block \therefore potential *ValueTooBigException*
- o **Lines 4 & 7** are both assertions:
 - **Lines 4** asserts that *c.getValue()* returns the expected value (i.e., *Counter.MIN_VALUE*).
 - **Line 7**: an assertion failure \therefore expected *ValueTooSmallException* not thrown

See the equivalent, manual `ConsoleTester1`.

How to Use JUnit: Adding More Tests (3.2)

- Again, don't lose the big picture!
Automation is exactly rationale behind using JUnit!
- JUnit test in previous slide automates CounterTester1 and the following console interaction for CounterTester3:

```
Enter "inc", "dec", or "val":  
val  
0  
Enter "inc", "dec", or "val":  
dec  
Value too small!  
Enter "inc", "dec", or "val":  
exit  
Bye!
```

How to Use JUnit: Adding More Tests (4.1.1)

```
1  @Test
2  public void testIncFromMaxValue() {
3      Counter c = new Counter();
4      try {
5          c.increment(); c.increment(); c.increment();
6      }
7      catch (ValueTooLargeException e) {
8          fail("ValueTooLargeException was thrown unexpectedly.");
9      }
10     assertEquals(Counter.MAX_VALUE, c.getValue());
11     try {
12         c.increment();
13         fail("ValueTooLargeException was NOT thrown as expected.");
14     }
15     catch (ValueTooLargeException e) {
16         /* Do nothing: ValueTooLargeException thrown as expected. */
17     }
18 }
```

- o **L4 – L9:** a VTLE *is not* expected; **L11 – 17:** a VTLE *is* expected.

How to Use JUnit: Adding More Tests (4.1.2)

```
1  @Test
2  public void testIncFromMaxValue() {
3      Counter c = new Counter();
4      try {
5          c.increment(); c.increment(); c.increment();
6      }
7      catch (ValueTooLargeException e) {
8          fail("ValueTooLargeException was thrown unexpectedly.");
9      }
10     assertEquals(Counter.MAX_VALUE, c.getValue());
11     try {
12         c.increment();
13         fail("ValueTooLargeException was NOT thrown as expected.");
14     }
15     catch (ValueTooLargeException e) {
16         /* Do nothing: ValueTooLargeException thrown as expected. */
17     }
18 }
```

Contrast with the structurally-similar console tester.

How to Use JUnit: Adding More Tests (4.2)

- JUnit test in previous slide *automates* CounterTester2 and the following console interaction for CounterTester3:

```
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
inc  
Enter "inc", "dec", or "val":  
val  
3  
Enter "inc", "dec", or "val":  
inc  
Value too big!  
Enter "inc", "dec", or "val":  
exit  
Bye!
```

How to Use JUnit: Adding More Tests (4.3)

Q: Can we rewrite `testIncFromMaxValue` to:

```
1  @Test
2  public void testIncFromMaxValue() {
3      Counter c = new Counter();
4      try {
5          c.increment();
6          c.increment();
7          c.increment();
8          assertEquals(Counter.MAX_VALUE, c.getValue());
9          c.increment();
10         fail("ValueTooLargeException was NOT thrown as expected.");
11     }
12     catch (ValueTooLargeException e) { }
13 }
```

No!

At **Line 12**, we would not know which line throws the VTLE:

- If it was any of the calls in **L5 – L7**, then it's *not right*.
- If it was **L9**, then it's *right*.

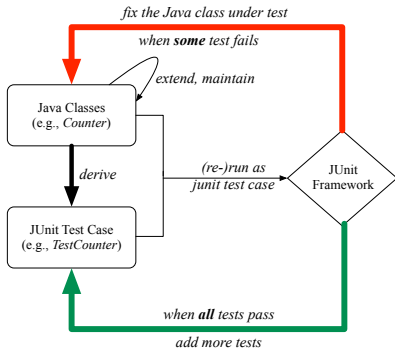
How to Use JUnit: Adding More Tests (5)

Loops can make it effective on generating test cases:

```
1  @Test
2  public void testIncDecFromMiddleValues() {
3      Counter c = new Counter();
4      try {
5          for(int i = Counter.MIN_VALUE; i < Counter.MAX_VALUE; i ++ ) {
6              int currentValue = c.getValue();
7              c.increment();
8              assertEquals(currentValue + 1, c.getValue());
9          }
10         for(int i = Counter.MAX_VALUE; i > Counter.MIN_VALUE; i -- ) {
11             int currentValue = c.getValue();
12             c.decrement();
13             assertEquals(currentValue - 1, c.getValue());
14         }
15     }
16     catch(ValueTooLargeException e) {
17         fail("ValueTooLargeException is thrown unexpectedly");
18     }
19     catch(ValueTooSmallException e) {
20         fail("ValueTooSmallException is thrown unexpectedly");
21     }
22 }
```

1. Run all 8 tests and make sure you receive a *green* bar.
2. Now, introduction an error to the implementation: Change the line `value ++` in `Counter.increment` to `--`.
 - Re-run all 8 tests and you should receive a *red* bar. [Why?]
 - Undo the *injection of error*, and re-run all 8 tests. [What happens?]

Test-Driven Development (TDD)



Maintain a collection of tests which define the **correctness** of your Java class under development (CUD):

- Derive and run tests as soon as your CUD is **testable**.
i.e., A Java class is testable when defined with method signatures.
- **Red** bar reported: Fix the class under test (CUT) until **green** bar.
- **Green** bar reported: Add more tests and Fix CUT when necessary.

- Official Site of JUnit 4:

<http://junit.org/junit4/>

- API of JUnit assertions:

<http://junit.sourceforge.net/javadoc/org/junit/Assert.html>

- Another JUnit Tutorial example:

<https://courses.cs.washington.edu/courses/cse143/11wi/eclipse-tutorial/junit.shtml>

Beyond this lecture...

Play with the source code `ExampleTestingCounter.zip`

Tip. Change input values so as to explore, in Eclipse *debugger*, possible (*normal* vs. *abnormal*) **execution paths**.

Index (1)

Learning Outcomes

Motivating Example: Two Types of Errors (1)

Motivating Example: Two Types of Errors (2)

Motivating Example: Two Types of Errors (3)

A Simple Counter (1)

Exceptional Scenarios

A Simple Counter (2)

Components of a Test

Testing Counter via Console V1 (1.1)

Testing Counter via Console V1 (1.2)

Testing Counter via Console V1 (1.3.1)

Index (2)

Testing Counter via Console V1 (1.3.2)

Testing Counter via Console V2 (2.1)

Testing Counter via Console V2 (2.2)

Testing Counter via Console V2 (2.3.1)

Testing Counter via Console V2 (2.3.2)

Testing Counter via Console V2 (2.3.3)

Testing Counter via Console (V3)

Testing Counter via Console (V3): Test 1

Testing Counter via Console (V3): Test 2

Limitations of Testing from the Console

Why JUnit?

Index (3)

How to Use JUnit: Packages

How to Use JUnit: New JUnit Test Case (1)

How to Use JUnit: New JUnit Test Case (2)

How to Use JUnit: Adding JUnit Library

How to Use JUnit: Generated Test Case

How to Use JUnit: Running Test Case

How to Use JUnit: Generating Test Report

How to Use JUnit: Interpreting Test Report

How to Use JUnit: Revising Test Case

How to Use JUnit: Re-Running Test Case

How to Use JUnit: Adding More Tests (1)

Index (4)

JUnit Assertions: Examples (1)

JUnit Assertions: Examples (2)

How to Use JUnit: Assertion Methods

How to Use JUnit: Adding More Tests (2.1)

How to Use JUnit: Adding More Tests (2.2)

How to Use JUnit: Adding More Tests (3.1)

How to Use JUnit: Adding More Tests (3.2)

How to Use JUnit: Adding More Tests (4.1.1)

How to Use JUnit: Adding More Tests (4.1.2)

How to Use JUnit: Adding More Tests (4.2)

How to Use JUnit: Adding More Tests (4.3)

Index (5)

How to Use JUnit: Adding More Tests (5)

Exercises

Test-Driven Development (TDD)

Resources

Beyond this lecture. . .