JUnit Testing

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Slides and Java examples are available in Moodle

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Software Testing

Testing: the process of executing a program with the intent of finding errors.

Myers, 1979

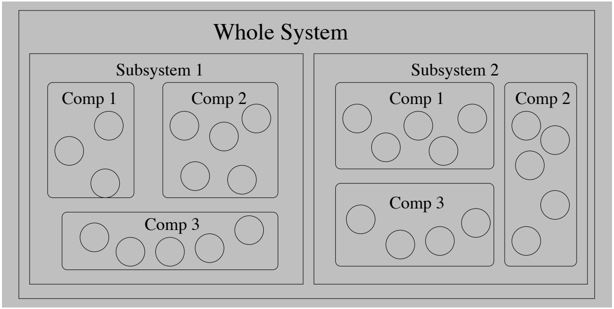
Testing in General

- Software Development
- Motivation
- Different types of testing
- Limitations

Unit Testing

- Unit testing
- JUnit
  - Tool Presentation
  - Test Cases
  - JUnit Design

A Hierarchical View of an OO System



- A **system** consists of many **subsystems** ...
- ... which consists of many **components** ...
- ... which consists of many **classes**.
- A class is the smallest unit in an object-oriented system.

Different Types of Testing

- **Component** or **Unit**
  Test of isolated components in order to find errors.
- **Integration**
  Test the interaction of components and subsystems in order to find errors.
- **Regression**
  Test that takes place after a code change/update.
- **Performance**
  Test to verify acceptable time and memory costs.
- **Release** (α-testing)
  Test the whole system in order to verify that all requirments are satisfied.
- **Acceptance** (β-testing)
  Actual client/customer test the system in their own enviroment using realistic data.

Independent, Black- and White-box Testing

- **Independent Testing**: Developers have a tendency to write tests that "fits" their implementation. Not becuase they are lazy or evil, but because they are trapped in a way of thinking.
  - Advantage: Better chans to find logical errors.
  - Disadvantage: More costly in terms of hours (or money).
- **Black-Box Testing**: The test designer has no access/knowledge of implementations details. An interface test checking if a system/component fulfills its requirement spec.
  - Advantage: Independent testing possible
  - Disadvantage: Impossible to make sure that every part of the code is tested.
- **White-Box Testing:** The test designer has access to the source code and can make sure that every part of the code is tested.
  - Advantage: Every part of the code can be tested.
  - Disadvantage: Practically impossible for larger system.

Test Interpretation

Testing can only show the presence of errors, not their absence.
Dijkstra, 1972

In general

- Infinite set of possible input data
- Infinite set of possible user scenarios

$\Rightarrow$ We can not test all possible executions
$\Rightarrow$ We can not prove absence of errors.

Verification: Theoretical proofs that a program (or method) always behaves correctly. Extremely time-consuming $\Rightarrow$ rarely used in practice.

Why Testing Then?

Testing is a process intended to build confidence in the software.
Sommerville, 2004

Thus, tests do not verify the absence of errors,
they only make them less likely.

Reasons for testing

1. Detect Defects:
   - System crashes
   - Incorrect computations
   - Data corruption

2. Verify (indicate) that system meets its requirements

When Should Testing Take Place?

Possible times for testing

- After system development but before release
  - The old fashion approach
  - Proven to be very costly for larger systems
  - Still popular among students
- As an integrated part of the development process
  - The recommended approach today
  - Errors are discovered as early as possible
- Before implementation
  - Not as stupid as it sounds
  - Enforces a goal directed development strategy
  - A part of the E**X**treme **P**rogramming approach

In general, we want to find problems/errors as early as possible.

Components and Unit Testing

- Components are rather small and self-consisting parts of a system
- Typical components:
  - Data structures (e.g. lists, trees, graphs, sets)
  - Algorithms (e.g. Merge sort, Strongly Connected Components)
  - Well-defined entities in general
- In this context: Every part of the program that can be tested in isolation is a component.

Unit Testing

- Goal: Convince ourselves that a component is working properly in isolation (and detect errors indicating that it doesn't).
- When: During (preferred) or directly after implementation
- Who: The component developers
- Type: White-box

Suitable fixtures will be discussed later

Test Case Design $\Rightarrow$ Test Plans

Algorithm for test case design

1. Identify a set of features $F = \{f_1, \ldots, f_p\}$ which if succesfully tested can verify (indicate) that the requirements are fulfilled.
2. For each feature $f \in F$
   - 2.1 find input data $\{i_i, \ldots, i_n\}$ that tests different aspects of feature f,
   - 2.2 find corresponding output data $\{o_i, \ldots, o_n\}$ that verifies a correct behaviour.

- A tripple $(f, \{i_i, \ldots, i_n\}), \{o_i, \ldots, o_n\})$ is called a **test plan** for feature f
- The input data $\{i_i, \ldots, i_n\}$ to a test is called its **fixture**.
- Notice:
  - Test plans created before the implementation $\Longrightarrow$ black-box testing.
  - Formulating requirements as testable statements is a part of the design process.

Example: A Sorting Routine

- Assume a method `sort(int[] array)` that sorts integers
- Exhaustive testing ⇒ test all possible cases ⇒ impossible!
- My suggestion:
  - `array = new int[0];` (empty list)
  - `array = {7};` (singleton list)
  - `array = {1,34,56,2,-8,9,61,-55};` (even size)
  - `array = {-10,34,8,-6,56,12,78};` (odd size)
  - `array = {3,34,-8,76,-13, ... };` (very large array)
- Reasons:
  - Most problems show up at extreme values
  - Many algorithms (e.g. merge and quick sort) works a bit different for odd and even sized lists.
  - Test reasonable speed and memory requirement using a very large array.

Unit Testing: Choosing Fixture

- General:
  - Test all extreme cases
  - Test a few (not many) standard cases
  - Test scalability by testing a *large* case
    (Only makes sense for certain methods. Pointless for get/set methods.)
- White-box testing:
  - Make sure that every method is tested (Minimum!)
  - Make sure that every statement is tested (Realistic Goal)
- Experience: constructing a suitable fixture is often more time consuming than writing the actual tests.
- Notice: To figure out what input data that is required to execute a certain statement is in general non-trivial.
- The developers are most suited to handle this type of tests.

Unit Testing: Suggested Approach

The literature suggests

- implement method m_1, test m_1
- implement method m_2, test m_2
- ...

The Extreme Programming (XP) Approach

- write test for m, implement m, test m
- ...

The XP believers claim that:

- Writing tests first is a good preparation.
  (It forces you to identify problematic cases)
- The implementation is more goal directed.
  (Your task is completed when you pass the test.)
- You will save time once you get used to it.

Non-believers say that it doesn't scale to larger projects.

10 minute break?

zzzzzzzzzzzzzzzzzzzzzzzzzz

JUnit: Introduction

- JUnit is a tool designed to simplify the testing of Java components
- It is for free. Information and download at

  `http://junit.org/`

- Available in other languages (C++, Visual Basic, Python)
- Supported by Eclipse
- Uses annotations and reflection $\Rightarrow$ difficult to understand what is going on
- My view of JUnit:
  - A very useful tool (especially if you use Eclipse)
  - Easy to start using
  - Difficult to understand in detail how it works
- We will use the latest version (**JUnit 5**) that makes use of Java 8 features
- **JUnit in Eclipse**
  - Eclipse provides plenty of support for JUnit test cases.
  - Execution: Right-click and chose "Run as JUnit Test"

First Example: MyMath.mult(int a, int b)

Method to be tested:

```
// A static method computing a*b using recursion.
// Requires 2nd argument b to be non-negative.
public static int mult(int a,int b) {
   if (b < 0)
      throw new IllegalArgumentException("2nd parameter must be non-negative
   else if (b == 0)
      return 0;
   else
      return a + mult(a,b-1);
}
```

Test Idea

- Test extreme cases: `0*5, 5*0, 1*5, 5*1`
- Test standard cases: `7*5, 12*16`
- Test with large values: `27638*7492`
- Test exception: `10*-1`

First JUnit Test

```
// Support for JUnit annotations (e.g. @Test)
import org.junit.jupiter.api.Test;
 // Make static Assert methods available
import static org.junit.jupiter.api.Assertions.*;

public class MyMathTest {
   @Test public void testMultiply() {
      // Test extreme cases
      assertEquals(0, MyMath.mult(10, 0));  // check 10*0 = 0
      assertEquals(10, MyMath.mult(10, 1));  // check 10*1 = 10
      assertEquals(0, MyMath.mult(0, 10));  // check 0*10 = 0

      // Test a few standard cases, provide
      assertEquals(50, MyMath.mult(10, 5), "10 x 5 = 50");
      assertEquals(-35, MyMath.mult(-7, 5), "-7 x 5 = -35");

      // Test with large numbers, check 23246*7958 = 184991668
      assertEquals(184991668, MyMath.mult(23246, 7958));

   ...
   }
```

Details in First Example

- Required imports:

```
// Support for JUnit annotations (e.g. @Test)
import org.junit.jupiter.api.Test;
 // Make static Assert methods available
import static org.junit.jupiter.api.Assertions.*;
```

- Each method annotated with `@Test` is a *Test Case*
  $\Rightarrow$ A *run* in JUnit that either fails or passes
- Methods starting with `assert...` are the actuals tests

```
assertEquals(0, MyMath.mult(0, 10));
assertEquals(50, MyMath.mult(10, 5), "10 x 5 must be 50");
```

  In the second case we provide a suitable error message
- There are many available assert methods
- There are many available annotations
- Test 1-2 methods in each Test method

Exception Testing

MyMath.mult() should raise an exception when the 2nd argument is negative.

```
public class MyMathTest {
   @Test public void testMultiply() {
      // Test extreme cases
      assertEquals(0, MyMath.mult(10, 0));  // check 10*0 = 0
     ...   other tests

      // Check for IllegalArgumentException
      assertThrows(IllegalArgumentException.class,
                   () -> MyMath.mult(10, -1));   // Trigger exception
```

JUnit 5 use lambda expressions (a Runnable) to trigger exceptions.

assertThrows takes a Runnable and an (expected) exception type as input.

Second Example: MyMath.sort(int[] in)

```
// A static method sorting an integer array using Selection Sort.
public static void sort(int[] in) {
    int sz = in.length;
    for (int i=0; i<sz-1; i++) {
        int first = i;          // position to update
        int min = first;        // initialize min
        for (int j=first+1; j<sz; j++) {  // remaining elements
            if ( in[j] < in[min] )
                min = j;
        }
        /* Swap first and min */
        int tmp = in[first];
        in[first] = in[min];
        in[min] = tmp;
    }
}
```

Test Idea: empty array, singleton array, a few standard cases, one large array

Second JUnit Test Method

```
@Test public void testSorting() {
    // Dropping small tests (empty, singleton, few elements, ... )

    int[] arr5 = random(100,100);   // Random array of size 100
    MyMath.sort(arr5);
    for (int i=0; i<arr5.length-1;i++)
        assertTrue( arr5[i] <= arr5[i+1] );        // Check if sorted

    int[] arr6 = random(100000,1000000);  // About 15s to sort 100000 elements
    MyMath.sort(arr6);
    for (int i=0; i<arr6.length-1;i++)
        assertTrue( arr6[i] <= arr6[i+1] );        // Check if sorted
}
private int[] random(int size,int max) {   // Private help method
    Random rand = new Random();
    int[] arr = new int[size];
    for (int i=0;i<size;i++) {           // "size" elements
        arr[i] =1+rand.nextInt(max);     // in range [1,max]
    }
    return arr;
}
```

The `Assert` Class

```
// JUnit annotations (e.g. @Test, @AfterEach, @BeforeEach)
import org.junit.jupiter.api.Test;
 // Make static Assert methods available
import static org.junit.jupiter.api.Assertions.*;
```

The class `Assert` contains static methods like

- `assertEquals` (uses `equals()` on objects)
- `assertSame`, `assertNotSame` (uses `==`, `!=` on objects)
- `assertTrue`, `assertFalse`
- `assertNull`, `assertNotNull`

The static import has the same effect as

```
import org.junit.jupiter.api.Assertions;  // Make Assertions
                                          // class available
@Test public void testMultiplying() {
     ...
    Assertions. assertEquals(35, MyMath.mult(5,7));
```

A Larger Example: IntList

We have a class IntListImpl implementing the following interface:

```
public interface IntList {
   /** Add integer n to list */
   public void add(int n);

   /** Remove integer at position index */
   public void remove(int index) throws IndexOutOfBoundsException;

   /** Get integer at position index */
   public int get(int index) throws IndexOutOfBoundsException;

   /** Number of integers currently stored */
   public int size();

   /** Find position of integer n, otherwise return -1 */
   public int indexOf(int n);

   /** Sort list in ascending order */
   public void sort();
}
```

Example: IntListTest - Overview

```
public class IntListTest {
   private static int count = 0;

   /* Executed before every test method. */
   @BeforeEach public void setUp() {
      System.out.println("Run test method: "+(++count));
   }
   /* Executed after every test method. */
   @AfterEach public void tearDown() {
      System.out.println(" --- done with test "+count);
   }

   /* My list of test methods */
   @Test public void testInitSize() { ... }
   @Test public void testAddGet() { ...}
   @Test public void testIndexOf() { ... }
   @Test public void testRemove() { ... }
   @Test public void testSort() { ...}
}
```

JUnit Execution Using Eclipse

What Happens?

1. JUnit identifies method tagged with `@BeforeAll` and executes it.
   (No such method in the `IntListTest` example.)
2. JUnit identifies methods tagged with `@BeforeEach` and `@AfterEach` ⇒ `setUp()` and `tearDown()` in the `IntListTest` example
3. JUnit identifies all methods annotated with `@Test`
   ⇒ methods named like `testXXXX()` in the `IntListTest` example
4. For each found method `testXXXX()` annotated with `@Test` it executes
   4.1 `@BeforeEach setUp()`
   4.2 `@Test testXXXX()`
   4.3 `@AfterEach tearDown()`
5. JUnit identifies method tagged with `@AfterAll` and executes it.
   (No such method in the `IntListTest` example.)

Methods annotated with `@Before...` and `@After...` are used to prepare (and restore) data used in the various tests.

JUnit5Demo.java

A simple example showing the order in which methods are executed.

```
@BeforeAll
public static void oneTimeSetUp() { ... }

@AfterAll
public static void oneTimeTearDown() { ... }

@BeforeEach
public void setUp() { ... }

@AfterEach
public void tearDown() { ... }

@Test
public void testMethod1() { ... }

@Test
public void testMethod2() { ... }

@Test
public void testMethod3() { ... }
```

Annotations and Reflection

JUnit uses two advanced Java features:

1. **Annotations** ⇒ tags in source code so that tools can process them
   - Annotations can be attached to classes, methods, fields, ...
   - Annotations have no effect on the execution
   - Inserted to be used by other tools
   - Example: `@Override` is used by compiler to check inheritance
   - Example: `@SuppressWarnings` is used to avoid warning messages
   - Example: `@Test` is used by JUnit to identify test methods

2. **Reflection** ⇒ Java's capability to analyze classes at runtime.
   - Find all methods, fields and constructors in a given class.
   - Create new objects and invoke calls upon them.

```
public static void invokeToString(String class_name) {
   Class cl = Class.forName(class_name);  // Find class
   Method m = cl.getMethod("toString");   // Find toString()
   Object obj = cl.newInstance();     // Create new instance
   // Call obj.toString()
   System.out.println(cl.getName()+"\t"+m.invoke(obj));
}
```

   - Usage: `invokeToString("java.util.Date");`
     ⇒ current date will be printed

Example: IntListTest.testAddGet()

```
@Test
public void testAddGet() {
    /* Test add(int n) used in build() */
    IntList list1 = build(5); // list1 = [0,1,2,3,4]
    assertEquals(5,list1.size());

    IntList list2 = build(10);  // [0,1,2,3,4,5,6,7,8,9]
    assertEquals(10,list2.size());

    /* Test get(int n) */
    for (int i=0;i<list2.size();i++)
        assertEquals(i,list2.get(i));

    /* Test if get(int index) throws exception */
    assertThrows(IndexOutOfBoundsException.class, () -> list2.get(-8));
    assertThrows(IndexOutOfBoundsException.class, () -> list2.get(123));
}
```

Example: Generating Test Data

Constructing help methods to generate test data saves time in the long run.

```
private IntList build(int size) {
    IntList list = new IntListImpl();
    for (int i=0;i<size;i++)
        list.add(i);           // [0,1,2,3,4, ... ]
    return list;
}

private IntList random(int size,int max) {
    Random rand = new Random();

    IntList list = new IntListImpl();
    for (int i=0;i<size;i++) {      // Add ‘‘size’’ random numbers to list
        int n = 1 + rand.nextInt(max)    // int in range [1,max]
        list.add(n);
    }
    return list;
}
```

JUnit Suggestions (Isolated Components)

- Implement a method, write a test
- Each test method tests 1-2 methods
- No exhaustive tests:
  - Test a few standard cases
  - Focus on extreme cases
  - Add more tests on demands (when bugs appear)
- Create a few help methods to generate fixtures.
  (e.g. like `build()` and `random()` in our example.)

JUnit - Getting Started

Suggested Approach

- JUnit 5 is installed in newer version of Eclipse (Oxygen or later)
- Create a new JUnit 5 test case:
  `File --> New --> JUnit Test Case`
  Then select `New JUnit Jupiter test`
- Download my JUnit Examples and test them in Eclipse
- Study and understand how they work
- Start working on the JUnit exercises

JUnit 5 Reading

- Plenty of information at `junit.org/junit5`
- User Guide at `junit.org/junit5/docs/current/user-guide/`
- API Documentation at `http://junit.org/junit5/docs/current/api/`
- Google on *JUnit 5 + Tutorial*

Make sure to serach for JUnit 5 (which is quite different from JUnit 4).

JUnit - Exercises in Assignment 2

Suggested Approach

- JUnit 1: A JUnit test for the queue in Exercise 1
- JUnit 2 (VG): A JUnit test for the circular queue in Exercise 2