Introduction

Summary

- Specifications (motivation, contracts, pre- and postconditions, what to think about)
- Testing (motivation, different kinds of testing, role in software development, junit)
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- Testing (motivation, different kinds of testing, role in software development, JUnit)

What’s next?

- More examples of test cases, presenting aspects of writing test cases and features of JUnit
- How to write a good test case?
- How to construct a good collection of test cases (test suite)?
A basic example of using junit.

```java
public class Ex1 {
    public static int find_min(int[] a) {
        int x, i;
        x = a[0];
        for (i = 1; i < a.length; i++) {
            if (a[i] < x) x = a[i];
        }
        return x;
    }

    // ...
public static int[] insert(int[] x, int n)
{
    int[] y = new int[x.length + 1];
    int i;
    for (i = 0; i < x.length; i++) {
        if (n < x[i]) break;
        y[i] = x[i];
    }
    y[i] = n;
    for (; i < x.length; i++) {
        y[i+1] = x[i];
    }
    return y;
}
```java
import org.junit.*;
import static org.junit.Assert.*;

public class Ex1Test {
    @Test
    public void testFind_min() {
        int[] a = {5, 1, 7};
        int res = Ex1.find_min(a);
        assertEquals(1, res);
    }

    @Test
    public void testInsert() {
        int[] a = {2, 7};
        int n = 6;
        int[] res = Ex1.insert(a, n);
        int[] expected = {2, 6, 7};
        assertArrayEquals(expected, res);
    }
}
```
Using the IUT to Setup or Check the Test

- May need to call methods in the class under test
  - to set up a test case,
  - to decide the outcome (testing oracle)
- How do we know that those methods do what they are supposed to, so that the method which is actually under test isn’t incorrectly blamed for a failure?
Using the IUT to Setup or Check the Test

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- How do we know that those methods do what they are supposed to, so that the method which is actually under test isn’t incorrectly blamed for a failure?
- Method design proceeds top-down, testing proceeds bottom-up.
- There is usually some ordering such that at most one new method is tested for each new test case.
- In the rare case of a circular dependency, the tester has to decide on the cause of the failure.
Example

Using IUT to set up and decide test case, and use fixture and common tests.

```java
import java.util.*;

public class Ex2_Set<X> {
    private ArrayList<X> arr;

    public Ex2_Set() {
        arr = new ArrayList<X>();
    }

    public void add(X x) {
        for (int i = 0; i < arr.size(); i++) {
            if (x.equals(arr.get(i))) return;
        }
        arr.add(x);
    }

    ...
```
public boolean member(X x) {
    for (int i = 0; i < arr.size(); i++) {
        if (x.equals(arr.get(i))) return true;
    }
    return false;
}

public int size() {
    return arr.size();
}

public void union(Ex2_Set<X> s) {
    for (int i = 0; i < s.arr.size(); i++) {
        add(s.arr.get(i));
    }
}
import org.junit.*;
import static org.junit.Assert.*;
import java.util.*;

public class Ex2_SetTest {

    private Ex2_Set<String> s, s2;

    @Before public void setup() {
        s = new Ex2_Set<String>();
        s.add("one"); s.add("two");
        s2 = new Ex2_Set<String>();
        s2.add("two"); s2.add("three");
    }

    ...
}
private void testset(String[] exp, Ex2_Set<String> s) {
    assertTrue(s.size() == exp.length);
    for (int i = 0; i < s.size(); i++) {
        assertTrue(s.member(exp[i]));
    }
}

@Test public void test_union_1() {
    s.union(s2);
    String[] exp = {"one", "two", "three"}
    testset(exp, s);
}
Performing More Than one Test in the Same Method

- Best practise: only one test per test case method.
- In principle, it is possible to perform more than one test in a test case method, because failures are reported as exceptions (which includes line numbers where they occurred).
- Use only if unavoidable.
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A slightly more convenient (but less flexible) way is to use the JUnit `@Before` and `@After` annotations. Thus annotated methods run before and after each test case.
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Testcases are Programs

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- Often similar kinds of tests are used in many test cases to decide if the succeeded or failed.
- Write methods which are called by many test cases.
- As JUnit tests are implemented in Java, all Java features may be used to make writing test cases more convenient.
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Abnormal Termination

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- Catch and analyse exceptions thrown by IUT in the test case method, or
JUnit propagates the result of an assertion by throwing an exception.

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To override this behaviour, there are two options:
- Catch and analyse exceptions thrown by IUT in the test case method, or
- Give an expected optional element of the @Test annotation.
Exception means failure:

```java
@Test public void test_find_min_1 () {
    int [] a = {};
    int res = Ex1.find_min(a);
}
```
Exceptions – Example

Exception means failure:

```java
@Test public void test_find_min_1() {
    int[] a = { };
    int res = Ex1.find_min(a);
}
```

Exception means success:

```java
@Test(expected=Exception.class) public void test_find_min_1() {
    int[] a = { };
    int res = Ex1.find_min(a);
}
```
Another general property that the IUT should have is that when calling a method with fulfilled precondition, then execution of the method should terminate.
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Non-termination

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- Better way: use the `timeout` option of `@Test`
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Better way: use the timeout option of @Test

If termination (or running time) is an issue for a certain part of the IUT, specify a timeout for the relevant test cases.
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Better way: use the timeout option of @Test

If termination (or running time) is an issue for a certain part of the IUT, specify a timeout for the relevant test cases.

If the execution of the tests does not terminate after this time, JUnit reports a failure, and the test runner proceeds with the remaining tests.
What is a Meaningful Test Case?
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Meaningful Test Case

▶ Obvious: the outcome check at the end of the test should signal success if the IUT did what it should, and failure if it didn’t.

▶ Easier to forget: the setup before the call and the parameters sent along should correspond to the intended usage of the IUT.
What is a Meaningful Test Case?

Meaningful Test Case

- Obvious: the outcome check at the end of the test should signal success if the IUT did what it should, and failure if it didn’t.
- Easier to forget: the setup before the call and the parameters sent along should correspond to the intended usage of the IUT.

In both cases we use the **specification**.

- The setup of the test should fulfill the specified precondition of the tested method,
- the outcome check should adhere to the postcondition.
public static void f(Integer a, Integer b, Integer c) {
    ...
}

Specification

Requires: a \leq b \text{ and } b \leq c
Ensures: ...

Testing f():
▶ f(2, 5, 6) = valid
▶ f(1, 4, 4) = valid
▶ f(3, 7, 5) = not valid
public static void f(Integer a, Integer b, Integer c) { ... }

Specification

Requires:  a ≤ b and b ≤ c
Ensures: ...

Testing f():
- f(2, 5, 6) = ... valid ✓
public static void f(Integer a, Integer b, Integer c) {

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- \( f(1, 4, 4) = \ldots \) valid ✔
public static void f(Integer a, Integer b, Integer c) {

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Testing f():

- \( f(2, 5, 6) = \ldots \) valid ✓
- \( f(1, 4, 4) = \ldots \) valid ✓
- \( f(3, 7, 5) = \ldots \) not valid ✗
Apart from having meaningful test cases and successfully executing each test case, we also want the tests in a test suite to test an IUT in as many different ways as possible. Maximize the chance that a bug is found by running the test suite. Common approach: find a set of tests which has a good coverage. We’ll consider different notions of coverage shortly.
Black-box and White-box Testing

The activity of deriving test cases can be divided into two categories wrt the sources of information used.
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**Black-box testing**

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Black-box testing
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White-box testing
The tester has also access to the source code of the IUT. The code can be used in addition to the specification to derive test cases.
The basic idea is to analyse the specification and try to cover all cases that it discriminates.

In addition, the tests should include corner cases of the involved types.
Either . . . Or

The two alternatives represent two different situations.

```java
public static Y f(X[] x) { ... }
```

**Specification**

*Requires:* x is either null or is non-null and contains at least one element.

*Ensures:* ...
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public static Y f(X[] x) { ... }
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**Specification**

*Requires:* \( x \) is either null or is non-null and contains at least one element.

*Ensures:* ...

**Testing** \( \text{f()} \):

- \( \text{f(null)} = \ldots \)
The two alternatives represent two different situations.

```java
public static Y f(X[] x) { ... }
```

**Specification**

*Requires:* $x$ is either null or is non-null and contains at least one element.

*Ensures:* ...

**Testing $f()$**:

- $f(null) = ...$
- $f(x, y) = ...$
The two alternatives represent two different situations.

```java
public static int half(int n) {
    ...}
```

**Specification**

*Requires:*

*Ensures:* Returns int, m, such that: If n is even \( n = 2 \times m \), otherwise \( n = 2 \times m + 1 \)
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```java
public static int half(int n) { ... }
```

**Specification**

*Requires:*

*Ensures: Returns int, m, such that: If n is even n = 2 * m, otherwise n = 2 * m + 1*

**Testing half():**

- `half(4) = 2`
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1 public static int half(int n) { ... }
```

**Specification**

**Requires:**

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**Testing half():**

- half(4) = 2
- half(7) = 3
Inequalities

The cases $<$, $=$ and $>$ represent different situations.

```java
public static int min(int a, int b) { ... }
```

**Specification**

- **Requires:**
- **Ensures:** If $a < b$ then returns $a$, otherwise returns $b$
The cases \(<\), \(\leq\) and \(\geq\) represent different situations.

```java
public static int min(int a, int b) {
    // ... }
```

**Specification**

**Requires:**

**Ensures:** If \(a < b\) then returns \(a\), otherwise returns \(b\)

**Testing min():**

- \(\text{min}(2, 5) = 2\)
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public static int min(int a, int b) {
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**Specification**

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**Testing min():**

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- $\text{min}(3, 3) = 3$
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public static int min(int a, int b) { ... }
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### Specification

*Requires:*

*Ensures: If \(a < b\) then returns \(a\), otherwise returns \(b\)*

### Testing min():

- `min(2, 5) = 2`
- `min(3, 3) = 3`
- `min(7, 1) = 1`
Other sources of distinctions

- Objects – non-null or null
- Arrays – empty or non-empty
- Integers – zero, positive or negative
- Booleans – true or false
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- Advantage: Code coverage is a quantitative measure of how thoroughly an implementation has been tested.
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The idea is that, by exercising all parts of a program, a bug should not be able to escape detection.

Advantage: Code coverage is a quantitative measure of how thoroughly an implementation has been tested.

However, there are no field studies that support it...
Coverage is a measure of the completeness of a test suite. It can be defined in several ways. Frequently discussed types of code coverage are

- **Method coverage**: Which methods have been called by the test suite?
- **Statement / Line coverage**: Every statement in the code should be executed at least once by the test suite.
- **Decision / Branch coverage**: For each branching point in the program, all alternatives should be executed.
- **Condition coverage**: All boolean subexpressions of a decision point should evaluate both to true and to false.
- **Path coverage**: All possible execution paths should be represented among the test cases. (Full path coverage is not possible in general.)

Coverage tool: EclEmma, an Eclipse plugin
public static int[] merge(int[] x, int[] y) {
    int[] z = new int[x.length + y.length];
    int i, j;
    for (i = 0, j = 0; i < x.length && j < y.length;) {
        if (x[i] < y[j]) {
            z[i + j] = x[i]; i++;
        } else {
            z[i + j] = y[j]; j++;
        }
    }
    for (; i < x.length; i++) {
        z[i + j] = x[i];
    }
    for (; j < y.length; j++) {
        z[i + j] = y[j];
    }
    return z;
}
Path Coverage

Not possible to test all paths

Infinitely many in general – instead of all, test up to a given maximum number of iterations of loops
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Not all paths are possible
Due to the logical relationship between branching points not all paths may be possible – keep in mind when deriving test cases
Summary (Testing)

- Informal software specifications
- Introduction to software testing (motivation, terminology)
- Writing test cases, in general and using JUnit
- Deriving test cases
- Black-box and white-box testing
- Code coverage