Summary

- Specifications (motivation, contracts, pre- and postconditions, what to think about)
- 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)?
Let's review the 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;
    }
    ...
}
```
... continued from prev page

```java
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;
}
```

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Basic JUnit Usage
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```java
import org.junit.*;
import static org.junit.Assert.*;
import java.util.*;

public class Ex1Test {
    @Test public void test_find_min_1() {
        int[] a = {5, 1, 7};
        int res = Ex1.find_min(a);
        assertTrue(res == 1);
    }

    @Test public void test_insert_1() {
        int[] x = {2, 7};
        int n = 6;
        int[] res = Ex1.insert(x, n);
        int[] expected = {2, 6, 7};
        assertTrue(Array.equals(expected, res));
    }
}
```

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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?

The “helper” methods of a test should be tested themselves in other test cases.

There should be some ordering such that at most one new method is tested for each new test case.

Sometimes there can be circular dependencies which do not permit this approach.

In that case it is up to the tester to decide in what method call the cause of the failure lies.
Using IUT to setup 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);
    }
}
```
continued from prev page

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

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

```java
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);
}
With JUnit it’s in principle 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).

We just talked about a situation where this may be necessary.

But in other situations it may also seem appealing to put several tests in one methods.

Best practise: keep them apart in individual methods and use fixtures and such to keep the code compact.
Often several tests need to set up in the same or a similar way.

This common setup of a set of tests is called preamble, or fixture.

Write submethods which perform the common setup, and which are called from each test case.

A slightly more convenient (but less flexible) way is to use the JUnit @Before and @After annotations.

See previous example
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.

See previous example
JUnit propagates the result of an assertion by throwing an exception.

Default treatment: report failure if the IUT throws an exception.

Most of the time: correct behavior (no unhandled exceptions in the IUT).

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);
}
```

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.

Non-termination becomes obvious when running a test suite, because it hangs on a particular test.

Better way: use the \texttt{timeout} option of \texttt{\@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 Correct Test Case?

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Correct 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.
1 public static void f(Integer a, Integer b, Integer c) { ... }

**Specification**

*Requires:* \(a \leq b\) and \(b \leq c\)

*Ensures:* ...

**Testing \(f()\):**

- \(f(2, 5, 6) = \ldots\) valid ✓
- \(f(1, 4, 4) = \ldots\) valid ✓
- \(f(3, 7, 5) = \ldots\) not valid ❌
Apart from getting each test case right, 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.
The activity of deriving test cases can be divided into two categories wrt what sources of information are used.

**Black-box testing**
The tester has access to a specification and the compiled code only. The specification is used to derive test cases and the code is executed to see if it behaves correctly.

**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.
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 \( n = 2 \times m + 1 \)

**Testing half():**

- half(4) = 2
- half(7) = 3
The cases <, = and > represent different situations.

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

**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
A white-box tester has more information at hand and may write a better test suite.

Not only the intended behavior but also the particular implementation can be reflected in the test cases.

The specification is still needed to check if each individual test case is correct. (Correct use of IUT and test oracle)

The normal way of making use of the source code is to write test cases which “cover” the code as good as possible – code coverage

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...
Code coverage can be defined in several ways. The most frequently seen types of code coverage are

- **Statement (or line) coverage**: Every statement in the code should be executed at least once by the test suite.
- **Branch coverage**: Every branching point in the program should be executed, and for each of them all alternatives should be executed.
- **Path coverage**: All possible execution paths should be represented among the test cases. (Full path coverage is not possible in general.)
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 < x.length; j++) {
        z[i + j] = y[j];
    }
    return z;
}
Not possible to test all paths

- Infinitely many in general – instead of all, test up to a given maximum number of iterations of loops

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