Functional Testing
(Testování funkčnosti)

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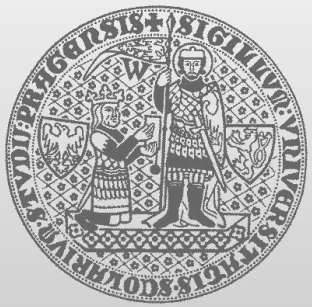

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faculty of mathematics and physics

Software testing

- Purpose
  - Checking whether a given program satisfies certain requirements and expectations about its behavior
- Basic idea
  - Pick specific inputs (a set of values)
  - Run the program for each input
  - Inspect the output and final state
- Shows only presence of errors
  - You can try just few selected input values

Terminology

- Test case
  - Checks single requirement on the program behavior
  - Defines test input and expected output (final state)
- Test suite
  - Collection of related test cases
- Fixture
  - Common environment for test cases in a given suite

When to run tests

- Development
  1) Write code and some tests
  2) Run all tests and find bugs
  3) Fix bugs detected by tests
  4) Go to step 1 until deadline

- Regressions
  - Execute all passed tests after every modification
    - bug fix, refactoring, new unrelated feature, optimization
  - Goal: check whether everything still works then

Testing on different levels

- Unit testing
  - Small components (method, class)
  - Automatic easily repeatable tests
  - Provides clear answer (pass or fail)
- Integration testing
  - Checking interaction between components
- System testing
  - Whole system in a target environment
  - Requirements specified by customers

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Unit testing

- Developers write code that
  - Specifies test inputs and required properties
  - Checks whether all tests successfully passed
    - Comparing expected outputs (and program state) with actual outputs
- Frameworks
  - JUnit, PyUnit, CPPUnit, NUnit, xUnit, MSTest, ...

JUnit

- Unit testing framework for Java
  - https://github.com/junit-team/junit/wiki
  - http://junit.org/junit5/
- Key features
  - Test cases are normal Java methods
  - Test suites are normal Java classes
  - Results analyzed in an automated way
- Versions
  - JUnit 3.8.x: fixed method names, reflection
  - JUnit 4.x/5: annotations

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Simple test case

```
import java.util.*;

import org.junit.Test;
import static org.junit.Assert.*;

public class TestArrayList {
  @Test
  public void add() {
    List al = new ArrayList();
    int origSz = al.size();
    al.add("abc");
    int newSz = al.size();
    assertEquals("new != orig+1", origSz+1, newSz);
    assertTrue(al.contains("abc"));
  }
}
```

Assert statements

- public static void assertXY ([message], ...)

- assertEquals(*T* expected, *T* actual)
- assertArrayEquals(*T*[] expected, *T*[] actual)
- assertSame(*Object* expected, *Object* actual)
- assertTrue(*boolean* condition)
- assertFalse(*boolean* condition)
- assertNull(*Object* obj)
- assertNotNull(*Object* obj)

- fail([String message])

Running tests

- Command line

```
java -cp lib/junit-4.11.jar:<dir with tests>
   org.junit.runner.JUnitCore  <test class name>
```

- Ant

```
<target name="run.tests" depends="build.tests">
  <junit haltonfailure="no">
    <formatter type="brief" usefile="false"/>
    <classpath refid="cp.run.tests"/>
    <batchtest>
      <fileset dir="${build.dir}">
        <include name="**/Test*.class"/>
      </fileset>
    </batchtest>
  </junit>
</target>
```

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What you should test

- Method contracts (API)
- All branches in the code
- All control-flow paths
- Special (corner) cases
  - “off by one”, bad inputs
- Regressions
  - Inputs triggering previously discovered bugs

Task 1

- Write unit tests for `java.util.ArrayList`
  - Selected methods: add(o), get(i), remove(i), remove(o), clear(), size(), contains(o)
- Try different assert statements
- Create also some failing tests
  - Inspect output of JUnit to see how it typically looks
- JUnit library
  - http://d3s.mff.cuni.cz/teaching/software_development_tools/files/junit-4.11.jar
  - http://d3s.mff.cuni.cz/teaching/software_development_tools/files/hamcrest-core-1.3.jar
- C#/.NET variant
  - `ArrayList` from the namespace `System.Collections`
  - `List<T>` from `System.Collections.Generic`

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Fixture

- Goal: prepare objects in a known state
  - Set up a fixed environment for each test cases
- Reset before each test case ➔ isolated tests
- Initialization
  - @Before
  - @BeforeClass
- Clean-up
  - @After
  - @AfterClass

Test case with a simple fixture

```
import org.junit.*;

public class TestArrayList {
  private List al;

  @Before
  public void setUp() {
    al = new ArrayList();
    al.add("abc");
  }

  @After
  public void tearDown() {
    al = null;
  }

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

Expected exceptions

```
@Test(expected=MyEx.class)
public void testSomething() {
  doSomeOperationThatThrowsException();
}
```

Task 2

- Extend your tests for `ArrayList`
- Define common fixtures
  - Extract duplicate initialization code
- Test against expected exceptions
  - get(i): `IndexOutOfBoundsException`

Recommended practice

- Place tests in the same package as target classes
  - Directory layout

```
src/main/cz/cuni/mff/myapp/MyClass.java
src/tests/cz/cuni/mff/myapp/TestMyClass.java
```

- Define single assertion in each test method
  - JUnit reports only the first failed assert in a test case
  - Multiple assertions ➔ some failures possibly missed

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Parameterized tests

```
@RunWith(Parameterized.class)
public class TestSquareRoot {

  @Parameters
  public static Collection<Object[]> data() {
    return Arrays.asList(new Object[][]{ {1,1}, {4,2} });
  }

  private int valInput;
  private int expOutput;

  public TestSquareRoot(int i, int e) {
    valInput = i; expOutput = e;
  }

  @Test
  public void test() {
    assertEquals(expOutput, Math.sqrt(valInput));
  }
}
```

HTML report

```
<target name="test">
  <junit fork="on">
    <formatter type="xml" />
    <classpath refid="...">
    <batchtest>
      ...
    </batchtest>
  </junit>
</target>

<target name="report">
  <mkdir dir="reports"/>
  <junitreport todir="./reports">
    <fileset dir=".">
      <include name="TEST-*.xml"/>
    </fileset>
    <report format="frames" todir="./reports/html"/>
  </junitreport>
</target>
```

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Task 3

- Use some parameterized tests
- Try reports in HTML (with Ant)

Advanced features of JUnit

- Matchers
  - `assertThat`
- Assumptions
- Rules
  - `TemporaryFolder`
  - `ErrorCollector`
- Categories

- Further information
  - https://github.com/junit-team/junit/wiki

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JUnit 5 – new features

- Framework decomposed into several modules
- Distributed through Maven central repository

- User guide
  - https://junit.org/junit5/docs/current/user-guide/

- New syntax of annotations
  - @Before vs @BeforeEach, @After vs @AfterEach
  - @BeforeClass vs @BeforeAll, @AfterAll

- New modern API
  - Classes and interfaces => different imports
  - Named assertions, grouping via assertAll
  - Syntax for parameterized tests (data source)

Testing methods

- Black-box testing
  - Zero knowledge about the implementation (no access)
  - Tests based only on specification and interfaces (API)
  - Checking outputs against expectations for input values
- White-box testing
  - Full knowledge of the implementation (access to code)
  - Tester can modify the system a little bit for easy testing
- Grey-box testing
  - Tester knows the system (code), but cannot modify it

Dependencies among objects

- Units typically have dependencies
  - Very hard to test such units in full isolation
  - Approach: complex fixtures and test cases
  - Example

```
@Before
public void setUp() {
  java.sql.Connection db = ... // complex init
  PersistenceMngr pm = new MyPersistenceMngr(db);
}
```

- Possible solutions
  - dummy objects, fake, stubs, mock objects

Dependencies among objects

- Dummy objects
  - Passed around but never used (e.g., parameter list)
- Fake
  - Working simpler implementation (e.g., in-memory DB)
- Stub
  - “empty” implementation with predefined responses to method calls
- Mock object
  - Stub that also checks whether it is used correctly by the object under test ➔ “behavior verification”
  - Frameworks: EasyMock, Mockito, Rhino Mocks, Moq

Concurrency

- Testing does not work for concurrency
  - Programs with multiple threads
- Huge number of thread schedules
- Non-deterministic behavior
- Errors are hard to reproduce

Unit testing for Windows/.NET

- MSTest (Visual Studio)
  - Annotations: `[TestClass]`, `[TestMethod]`
  - Basic assertion statements
    - `Assert.AreEqual(Object, Object, String)`
    - `IsTrue`, `IsNotNull`, `IsInstanceOfType`, `Fail`, …
  - More advanced: StringAssert, CollectionAssert

- Other frameworks
  - NUnit: http://nunit.org/, https://github.com/nunit
  - xUnit.net: http://xunit.github.io/

Automation

- Generating tests with dynamic symbolic analysis
  - Manual writing of tests is very tedious
  - KLEE: http://klee.github.io/
  - IntelliTest: https://docs.microsoft.com/cs-cz/visualstudio/test/generate-unit-tests-for-your-code-with-intellitest?view=vs-2017
- Fuzzing techniques and tools
  - Search for inputs that may trigger some errors
  - SAGE & DART
    - Information and links: https://patricegodefroid.github.io/
  - JDart: https://github.com/psycopaths/jdart
  - Useful for security bugs (critically important, hard-to-find)

Related courses

- More general information about testing
  - NTIN070: Testování software (ZS)
- But you can do better than simple unit testing ...
  - **NSWI126: Pokročilé nástroje pro vývoj a monitorování software (LS)**
- ... and you can even model, analyze, and verify program behavior
  - NSWI101: Modely a verifikace chování systémů (ZS)
  - **NSWI132: Analýza programů a verifikace kódu (LS)**

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Links

- JUnit
  - https://github.com/junit-team/junit/wiki
  - http://junit.org/junit5/
- MSTest
  - https://docs.microsoft.com/cs-cz/visualstudio/test/unit-test-your-code?view=vs-2017
- NUnit
  - http://www.nunit.org
  - https://github.com/nunit/docs/wiki/NUnit-Documentation
- CPPUnit
  - http://sourceforge.net/projects/cppunit
- Catch2
  - https://github.com/catchorg/Catch2
- Google Test
  - https://github.com/google/googletest

Homework

- Assignment
  - http://d3s.mff.cuni.cz/~parizek/teaching/sdt/
- Deadline
  - 26.11.2018 / 27.11.2018

- Homework targets Java and JUnit
  - Alternative 1: C# and suitable framework
    - They use same concepts but little bit different syntax
    - Write similar test cases for the corresponding classes from the .NET base class library (e.g., SortedDictionary)
  - Alternative 2: In fact, any other language with support for unit testing can be used
    - For example: C++, Python, Scala

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