Functional Testing
(Testování funkčnosti)

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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 (end-to-end)**
  - Whole system in a target environment
  - Requirements specified by customers
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, TestNG, PyUnit, CPPUnit, Google Test, MSTest, NUnit, xUnit, and many others
JUnit

- Unit testing framework for Java
  - [https://github.com/junit-team/junit/wiki](https://github.com/junit-team/junit/wiki)
  - [http://junit.org/junit5/](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.x: annotations
import java.util.*;
import org.junit.jupiter.api.Test;
import static org.junit.jupiter.api.Assertions.*;

public class TestArrayList {
    @Test
    public void add() {
        List al = new ArrayList();
        int origSz = al.size();
        al.add("abc");
        int newSz = al.size();
        assertEquals(origSz + 1, newSz, "new != orig+1");
        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)
- assertNotNull(Object obj)
- assertNotNull(Object obj)
- fail([String message])
Running tests

- Many options
  - Command line (`java -cp ... <test runner>`)  
  - Build tools (Ant, Maven, Gradle, ...)
  - Popular IDEs (Eclipse, NetBeans, IntelliJ IDEA)
    - Warning: make sure you have a proper setup (various caches, libraries, classpath, ...)

- Information
  - [https://junit.org/junit5/docs/current/user-guide/#running-tests](https://junit.org/junit5/docs/current/user-guide/#running-tests)
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
  - [https://junit.org/junit5/](https://junit.org/junit5/)

- C#/.NET variant
  - `ArrayList` from the namespace `System.Collections`
  - `List<T>` from `System.Collections.Generic`
Fixture

- Goal: prepare objects in a known state
  - Set up a fixed environment for each test case

- Reset before each test case ➔ isolated tests

- Initialization
  - @BeforeEach
  - @BeforeAll

- Clean-up
  - @AfterEach
  - @AfterAll
import org.junit.jupiter.api.*;

public class TestArrayList {
    private List al;

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

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

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

public void testSomething() {
    assertThrows(MyEx.class, () ->
                 doSomeUnsafeOperation());
}
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/` directory
      - `cz/cuni/mff/myapp/MyClass.java`
    - `src/test/` directory
      - `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
  - Drawback: you need to write/produce lot more code
public class TestSquareRoot {

    public static Stream<Arguments> testData() {
        return Stream.of(
            arguments(1,1),
            arguments(4,2)
        );
    }

    @ParameterizedTest
    @MethodSource("testData")
    public void test(int expOutput, int valInput) {
        assertEquals(expOutput, Math.sqrt(valInput));
    }
}
Task 3

- Use some parameterized tests

- Try different ways how to specify test data
  - [https://junit.org/junit5/docs/current/user-guide/#writing-tests-parameterized-tests](https://junit.org/junit5/docs/current/user-guide/#writing-tests-parameterized-tests)
Advanced features of JUnit (4)

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

Further information
- [https://github.com/junit-team/junit/wiki](https://github.com/junit-team/junit/wiki)
JUnit 5 – new features

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

- User guide
  - [https://junit.org/junit5/docs/current/user-guide/](https://junit.org/junit5/docs/current/user-guide/)

- New syntax of annotations
  - `@BeforeEach` vs `@Before`, `@AfterEach` vs `@After`
  - `@BeforeAll` vs `@BeforeClass`, `@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
    ```java
    @BeforeEach
    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
Testing with mock objects

- Mock object
  - Stub that also checks whether it is used correctly by the object under test ➔ “behavior verification”

- Frameworks
  - EasyMock (https://easymock.org/)
  - Mockito (https://site.mockito.org/)
  - Moq (https://github.com/devlooped/moq)
  - Rhino Mocks (https://hibernatingrhinos.com/oss/rhino-mocks)
  - Microsoft Fakes in Visual Studio
    - Only stubs, not full mocks
Concurrency

- Testing does not work for concurrency
  - Programs with multiple threads

- Huge number of thread schedules
- Non-deterministic behavior
- Errors are hard to reproduce
Other artifacts and processes

- Configuration
- User interfaces
- Complete user scenarios (end-to-end)
Unit testing for C#/.NET/Windows

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

- Other frameworks
  - xUnit.net: [https://xunit.net/](https://xunit.net/)
Automation

- Generating tests with dynamic symbolic analysis
  - Manual writing of tests is very tedious

- Fuzzing techniques and tools
  - Search for inputs that may trigger some errors
  - SAGE & DART
    - Information and links: [https://patricegodefroid.github.io/](https://patricegodefroid.github.io/)
    - JDart: [https://github.com/psycopaths/jdart](https://github.com/psycopaths/jdart)
  - Useful for security bugs (critically important, hard-to-find)
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)
Links

- **JUnit**
  - [https://github.com/junit-team/junit/wiki](https://github.com/junit-team/junit/wiki)
  - [http://junit.org/junit5/](http://junit.org/junit5/)

- **TestNG**
  - [https://testng.org/doc/](https://testng.org/doc/)

- **MSTest**

- **NUnit**
  - [http://www.nunit.org](http://www.nunit.org)
  - [https://github.com/nunit/docs/wiki/NUnit-Documentation](https://github.com/nunit/docs/wiki/NUnit-Documentation)

- **CPPUnit**
  - [http://sourceforge.net/projects/cppunit](http://sourceforge.net/projects/cppunit)

- **Catch2**
  - [https://github.com/catchorg/Catch2](https://github.com/catchorg/Catch2)

- **Google Test**
  - [https://github.com/google/googletest](https://github.com/google/googletest)
Homework

• Assignment

• Deadline
  ▪ 14.4.2024

• You are free to use any programming language and testing framework
  ▪ Java with JUnit, C# with MSTest or xUnit, C++, Python