Testing, Debugging, and Verification

Testing, Part II

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30 November 2012

Testing Levels Based on Software Activity

Acceptance Testing

assess software with respect to user requirements

System Testing

assess software with respect to system-level specification

Integration Testing

assess software with respect to high-level design

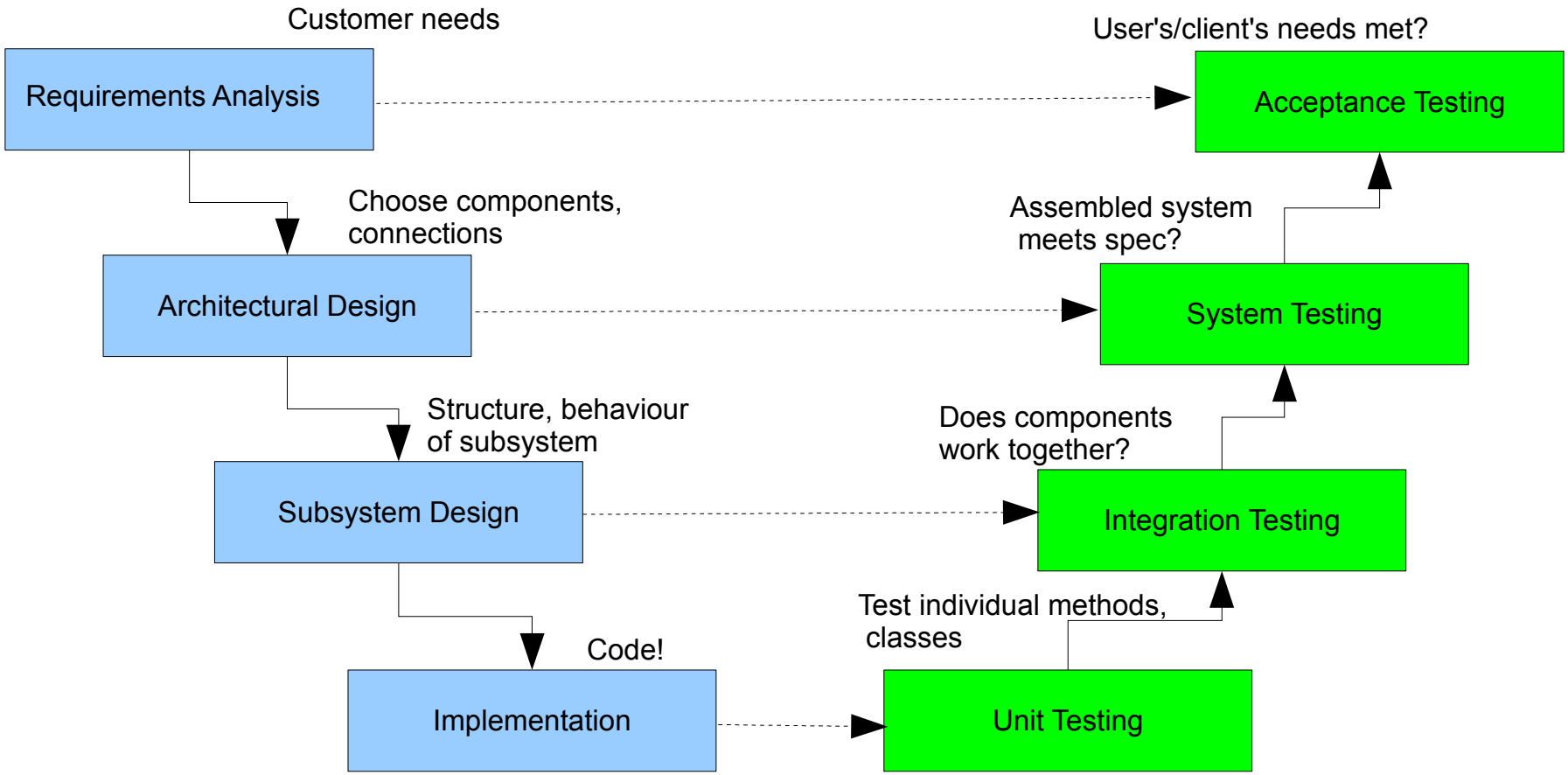
Unit Testing

assess software with respect to low-level unit design

remarks:

– terminology, and depth of this hierarchy, varies in literature

V-Model



(many variants!)

Testing Levels Based on Software Activity (cont'd)

System Testing – testing system against specification of externally observable behaviour

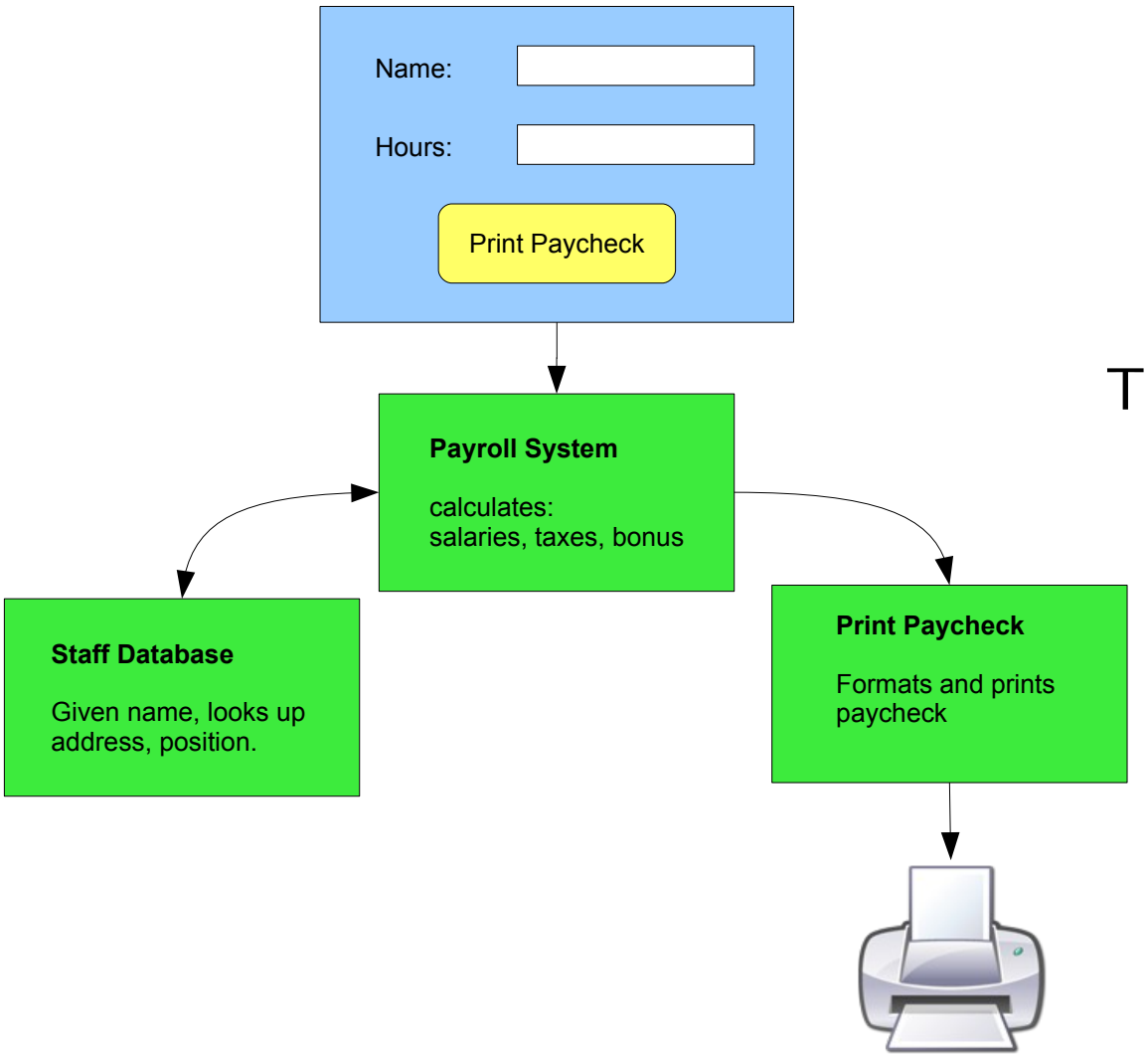
Integration Testing – testing interaction between modules

Unit Testing – testing individual units of a system
traditionally: unit = procedure
in object-orientation (JAVA): unit = method

Failures on higher levels less useful for debugging, as propagation from defect to failure is difficult to trace.

This course focuses on lower level: unit testing

Discussion: Testing Levels of a System for Printing Paychecks



Think of examples of:

- System Tests
- Integration Tests
- Unit Tests

Some examples of Tests

- System Test
  - Enter data in GUI, does it print the correct paycheck, formatted as expected?
- Integration Tests, e.g.
  - Payroll asks database for staff data, are values what's expected? Maybe there are special characters (unexpected!).
  - Are paychecks formatted correctly for different kinds of printers?
- Unit Tests, e.g.
  - Does payroll system compute correct tax-rate, bonus etc?
  - Does the Print Paycheck button react when clicked?
  - ...

Regression Testing

Orthogonal to the above testing levels:

Regression Testing

- Testing that is done after changes in the software.
- Purpose:
  gain confidence that the change(s) did not cause (new) failures.
- Standard part of the maintenance phase of software development.

E.g. Suppose Payroll subsystem is updated. Need to re-run tests (which ones?).

Unit Testing

Rest of testing part of the course: focusing largely on unit testing

recall: unit testing = procedure testing = (in oo) method testing

major issues in unit testing:

1. unit test cases ('test cases' in short)
2. order in which to test and integrate units

start with 1.

Test Cases

The science of testing is largely the science of test cases.

What does a test case consists of?

(to be refined later)

Test case

- Initialisation (of class instance and input arguments)
- Call to the method under test.
- Decision (oracle) whether the test succeeds or fails

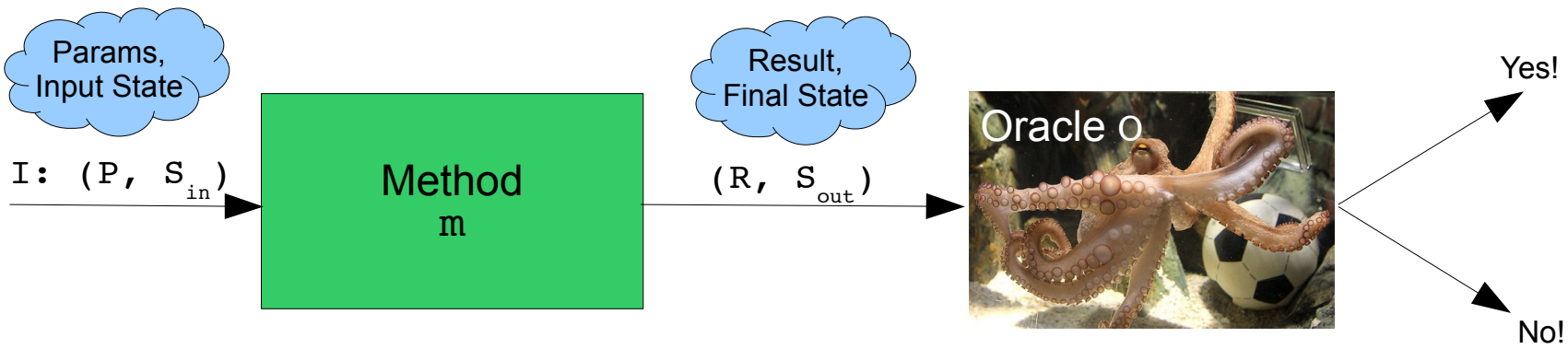
- two first parts seem enough for a test case,
- but test oracle is vital for *automated* evaluation of test

‘Success’ vs. ‘Failure’ of Tests

What does it mean for a test to succed?

... or fail?

Test Cases, more precise



More formally...

A test case is a tuple $\langle \mathtt{m}, \mathtt{I}, \mathtt{O} \rangle$ of method $\mathtt{m}$, input $\mathtt{I}$, and oracle $\mathtt{O}$, where

- $\mathtt{m}$ is the method under test
- $\mathtt{I}$ is a tuple $\langle \mathtt{P}, \mathtt{S_{in}} \rangle$
  of call parameters $\mathtt{P}$ and initial state $\mathtt{S_{in}}$
- $\mathtt{O}(\mathtt{R}, \mathtt{S_{out}}) \mapsto \{\mathit{pass}, \mathit{fail}\}$
  is a function on return value R and final state $\mathtt{S_{out}}$, telling whether they comply with correct behaviour

Test Set

A test set $TS^{\mathtt{m}}$ for a (Java) method $\mathtt{m}$ consists of n test cases:

$$TS^{m} = \{\langle \mathtt{m}, \mathtt{I_1}, \mathtt{O_1} \rangle, \ldots, \langle \mathtt{m}, \mathtt{I_n}, \mathtt{O_n} \rangle\}$$

In general, $\mathtt{O_i}$ is specific for each test case!

Test Suite

A test suite for methods $\mathtt{m}_1, \ldots, \mathtt{m}_k$ is a union of corresponding test sets:

$$TS^{m_1} \cup \ldots \cup TS^{\mathtt{m}_k}$$

Test Oracle, Remarks

While $\mathtt{O}$ is in general specific for each and every test case, it is desirable to go beyond.

- Desirable to have, for each method $\mathtt{m}$, one uniform oracle $\mathtt{O}^{\mathtt{m}}$.
- Then, a test suit is:
  $TS^{\mathtt{m}} = \{\langle \mathtt{m}, \mathtt{I}_1, \mathtt{O}^{\mathtt{m}} \rangle, \ldots, \langle \mathtt{m}, \mathtt{I}_{\mathtt{n}}, \mathtt{O}^{\mathtt{m}} \rangle\}$
- Moreover, desirable to have such uniform oracles generated automatically.

These issues not addressed in the following,
but in 'Test Case Generation' part of the course.

Automated and Repeatable Testing

Basic idea: write code that performs the tests.

- By using a tool you can automatically run a large collection of tests
- The testing code can be integrated into the actual code, thus stored in an organised way
- side-effect: documentation
- After debugging, the tests are rerun to check if failure is gone
- Whenever code is extended, all old test cases can be rerun to check that nothing is broken (regression testing)

Automated and Repeatable Testing (cont'd)

We will use JUnit for writing and running the test cases.

JUnit: small tool offering

- some functionality repeatedly needed when writing test cases
- a way to annotate methods as being test cases
- a way to run and evaluate test cases automatically in a batch

JUnit

- JAVA testing framework to write and run automated tests
- JUnit features include:
  - Assertions for testing expected results
  - Annotations to designate test cases
  - Sharing of common test data
  - Graphical and textual test runners
- JUnit is widely used in industry
- JUnit used from command line or within an IDE (e.g., Eclipse)

(Demo)

Basic JUnit usage

```
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;
  }
...
```

Basic JUnit usage

continued from prev page

```
...
  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;
  }

}
```

Basic JUnit usage

JUnit can test for expected return values.

```
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(Arrays.equals(expected, res));
  }
}
```

Testing for Exceptions

JUnit can test for expected exceptions

```
@Test(expected=IndexOutOfBoundsException.class)
  public void outOfBounds() {
    new ArrayList<Object>().get(1);
  }
```

`expected` declares that `outOfBounds()` should throw an `IndexOutOfBoundsException`.
If it does

- not throw any exception, or
- throw a different exception

the test fails.

Compile and Run JUnit test class

- JUnit plugin in Eclipse IDE:
  Right click on your project (or choose when creating project):
  Build Path → Add Libraries... → Choose JUnit 4.
- Run the tester class as usual in Eclipse.

Alt.

- Compile test class:
  `javac -cp .:`*`pathToJunitJarFile`* `Ex1Test.java`
- To run all methods annotated with `@Test` in a class:
  `java -cp .:`*`pathToJunitJarFile`*
  `org.junit.runner.JUnitCore Ex1Test`

(under Windows: ';' instead of ':')

Reflection: Extreme Testing

- JUnit designed for Extreme Testing paradigm
- Extreme Testing part of Extreme Programming (but not depending on that)

Reflection: Extreme Testing (cont'd)

A few words Extreme Programming
(no introduction here, but see [Myers], Chapter 8)

- Extreme Programming (XP) invented by Beck (co-author of JUnit)
- Most popular agile development process
- Must create tests first, then create code basis
- Must run unit tests for every incremental code change
- Motivation:
  - oo programming allows rapid development
  - still, quality is not guaranteed
  - aim of XP: create quality programs in short time frames
- XP relies heavily on unit and acceptance testing

Extreme Unit Testing

modules (classes) must have unit tests before coding begins

benefits:

- You gain confidence that code will meet specification.
- You better understand specification and requirements.
- You express end result before you start coding.
- You may implement simple designs and optimise later while reducing the risk of breaking the specification.

Extreme Testing Example: Class Money

```
class Money {
    private int amount;
    private Currency currency;

    public Money(int amount, Currency currency) {
        this.amount = amount;
        this.currency = currency;
    }
    public Money add(Money m) {
        // NO IMPLEMENTATION YET, WRITE TEST FIRST
    }
}
```

Demo in Eclipse.

Literature related to this Lecture

Myers see course literature.

AmmannOffutt see course literature.

Beizer Boris Beizer: Software Testing Techniques.
Van Nostrand Reinhold, 2nd edition, 1990.