Testing, Debugging, and Verification

Testing, Part II

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[1] Slides based on material from Wolfgang Aherndt

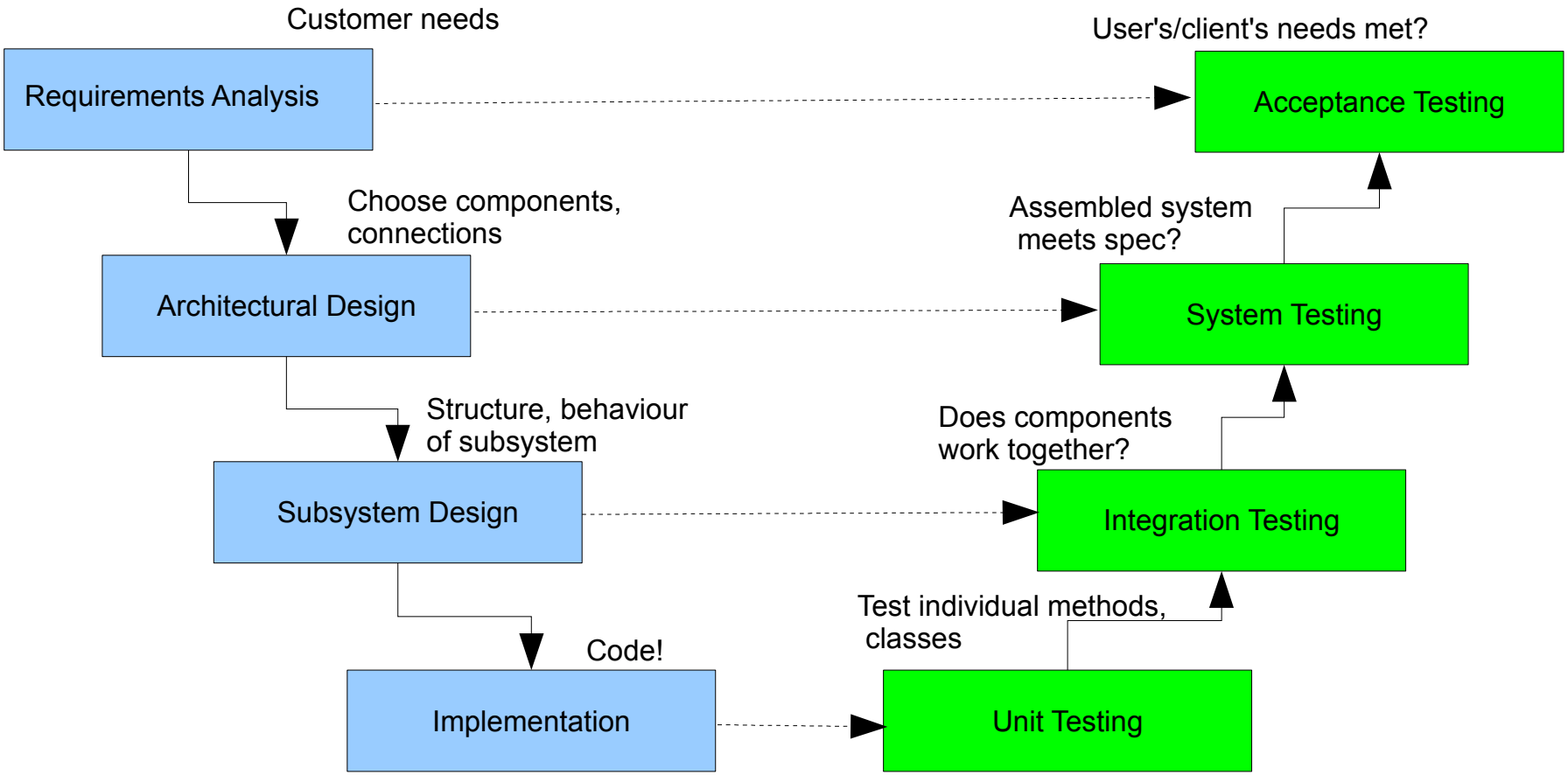
Lab and exercise sessions

- First lab session next week Monday
- First exercise session next week Friday
- please bring laptops
- install relevant tools before
  - topic: testing
  - install JUnit beforehand
    (version JUnit4 upwards)

Overview of this Lecture

- Testing levels and the V-model
- Focus on Unit Testing
- Terminology: Test case, test set, test suit, oracle
- Introduction to JUnit: a framework for rapid unit testing
- Extreme Testing using JUnit

Recall: The V-Model



(many variants!)

Examples: System, Unit and Integration Testing

Pentium Bug (-94)

- Wrong result on floating point divisions.
- Missing entries in the lookup table.
- Rarely happened (on system level).
- Easy catch in unit test.

Arianne 5 Rocket (-96)

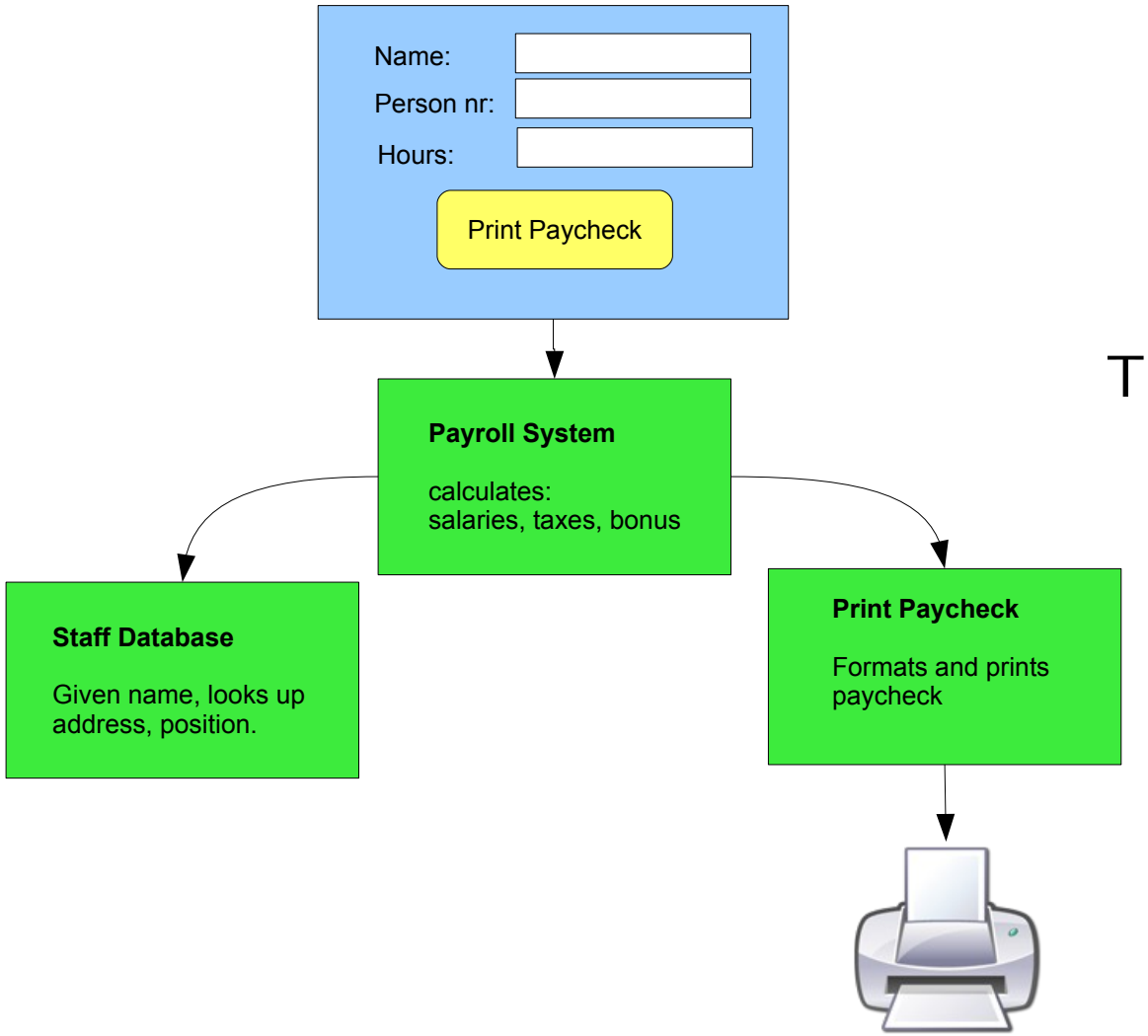
- Exploded 5 secs. after takeoff.
- Used guidance system from Arianne 4.
- Flight trajectory was different. Lacked system testing.

Examples: System, Unit and Integration Testing

Mars Lander (-99)

- Crashed on landing.
- Mismatch in units: imperial vs. metric.
- Lacking in integration 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 Tests
  - Enter data in GUI, does it print the correct paycheck, formatted as expected?
- Integration Tests
  - 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
  - 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

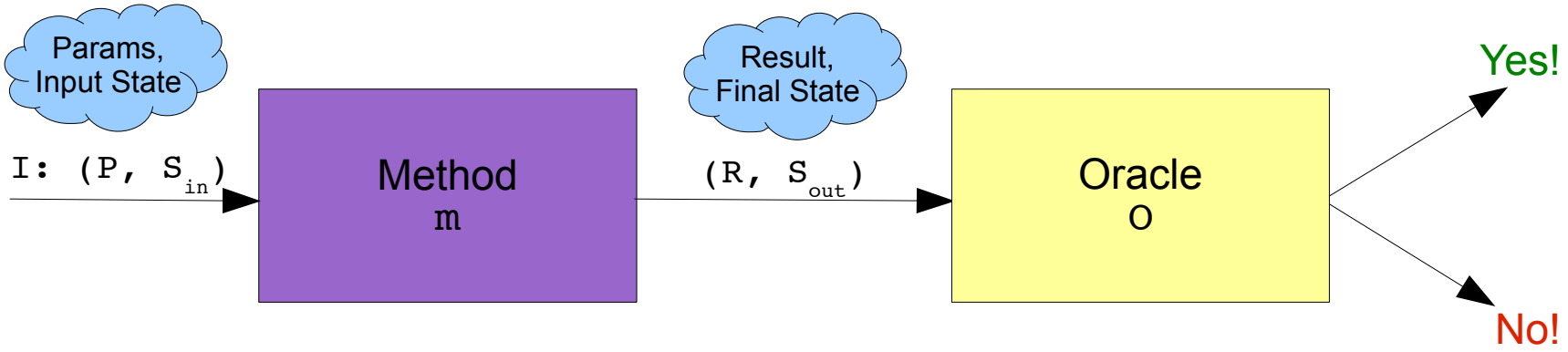
- two first parts seem enough for a test case,
- but test oracle is vital for *automated* evaluation of test

‘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:

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

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
    }
}
class Currency {
    private String name;
    public Currency(String name) {
        this.name = name;
    }
}
```

Demo in Eclipse.

Write a Test Case for add()

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

public class MoneyTest {

    @Test public void simpleAdd() {
        Currency sek = new Currency("SEK");
        Money m1 = new Money(120, sek);
        Money m2 = new Money(160, sek);
        Money result = m1.add(m2);
        Money expected = new Money(280, sek);
        assertTrue(expected.equals(result));
    }
}
```

@Test is an annotation, turning simpleAdd into a test case

Example: Class Money

Now, implement the method under test, and make sure it fails

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

    ....

    public Money add(Money m) {
        return null;
    }
}
```

Compile and Run JUnit test class

- JUnit reports failure
- Produce first 'real' implementation

Example: Class Money

First real attempt to implement the method under test

```
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) {
        return new Money(amount+m.amount,
         currency);
    }
}
```

Compile and Run JUnit test class

- JUnit will still report failure
- Fix possible defects, until test passes.
  - Can you spot it?
- What if we have different currencies?

Extend Functionality

Extend Money with Euro-exchange-rate first in test cases

```
public class MoneyTest {
    @Test public void simpleAdd() {
        Currency sek = new Currency("SEK",9.01);
        Money m1 = new Money(120, sek);
        ....
    }
    @Test public void addDifferentCurr() {
        Currency sek = new Currency("SEK",9.01);
        Money m1 = new Money(120, sek);
        Currency nok = new Currency("NOK",7.70);
        Money m2 = new Money(160, nok);
        Money result = m1.add(m2);
        Money expected = new Money(307, sek);
        assertTrue(expected.equals(result));
    }
}
```

Change, and test implementation

Common Parts into Test Fixture

```
public class MoneyTest {
    private Currency sek;
    private Money m1;

    @Before public void setUp() {
        sek = new Currency("SEK",9.01);
        m1 = new Money(120, sek);
    }

    @Test public void simpleAdd() {
        Money m2= new Money(140, sek);
        ....
    }
    @Test public void addDifferentCurr() {
        Currency nok = new Currency("NOK",7.70);
        Money m2 = new Money(160, nok);
        ...
    }
}
```

Integrating Test Units

Testing a unit may require:

Stubs to replace called procedures

- Simulate behaviour of component not yet developed.
- E.g. test code that calls a method not yet implemented.

Drivers to replace calling procedures

- Simulate environment from where procedure is called.
- E.g. test harness.

Incremental Testing: Top-Down and Bottom-Up

Explore *incremental* test strategies, following call hierarchy:

Top-Down Testing

Test main procedure, then go down the call hierarchy

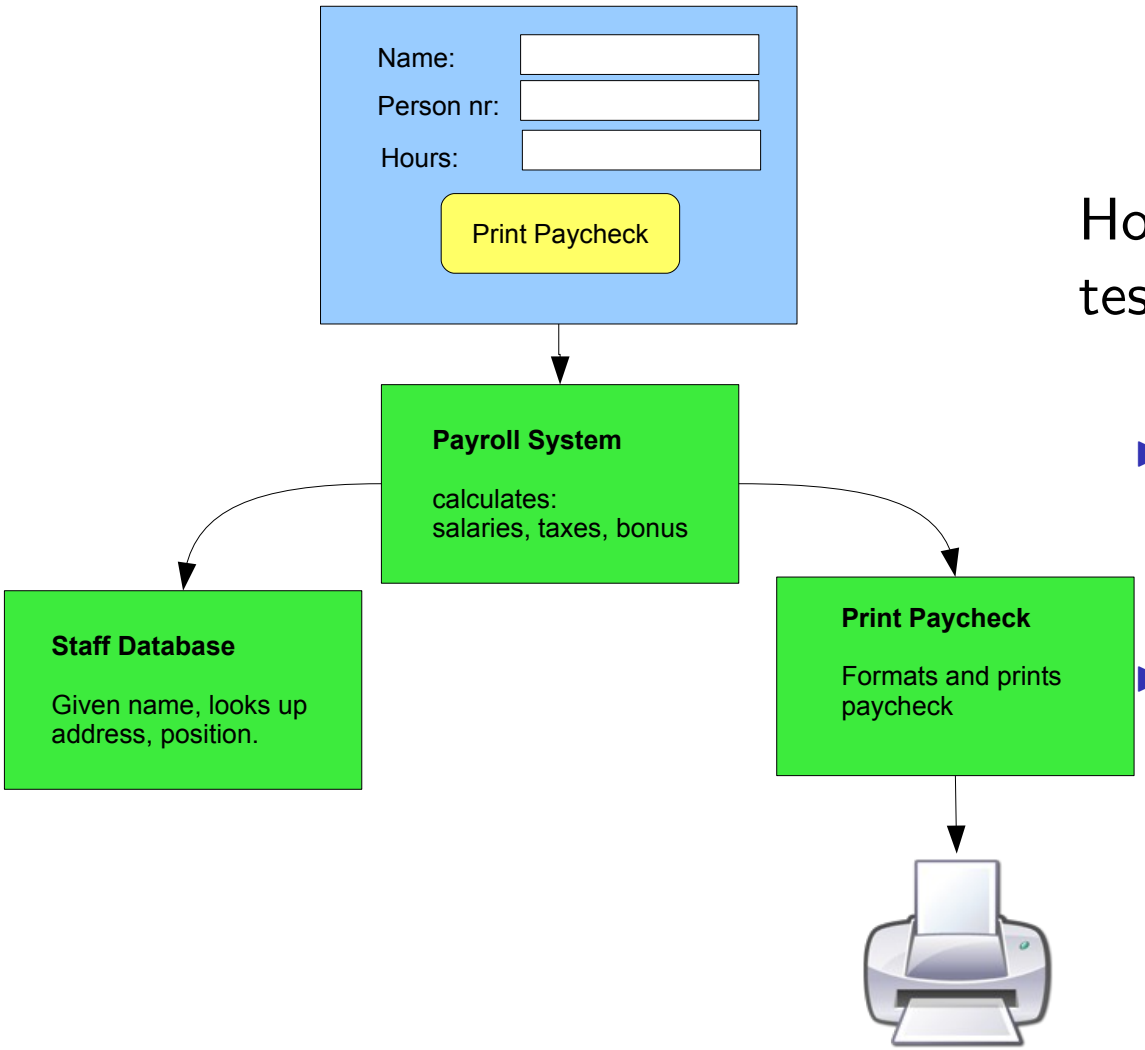
- requires stubs, but no drivers

Bottom-Up Testing

Test leaves in call hierarchy, and move up to the root.
Procedure is not tested until all 'children' have been tested.

- requires drivers, but no stubs

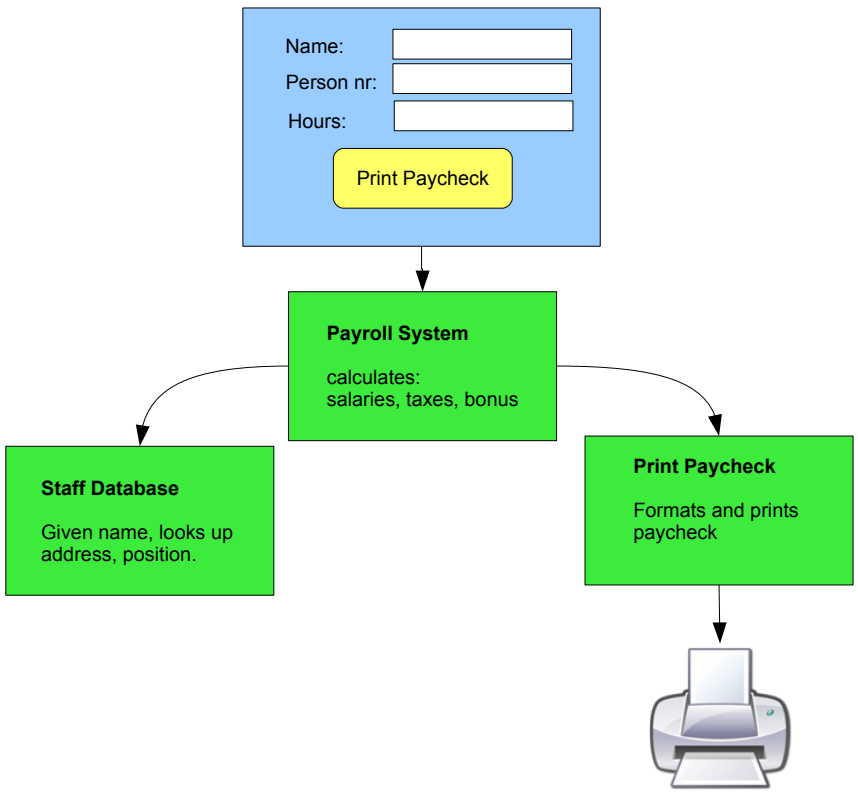
Discussion: Top-down vs Bottom-up Testing



How would you go about testing the Paycheck system

- Bottom-up?
  - Which drivers do you need?
- Top-down?
  - Which stubs do you need?

Discussion: Top-down vs Bottom-up Testing



- Bottom-up?
  start from e.g. Print Paycheck, Staff Database
  - Which drivers do you need?
  - Driver replacing the caller, here Payroll System, Interface.
- Top-down?
  start from e.g. Interface, then Payroll System
  - Which stubs do you need?
  - Stubs replacing called procedures, i.e. Payroll System, Staff Database, Print Paycheck.

Top-Down Testing: Pros and Cons

Advantages of Top-Down Testing

- Advantageous if major flaws occur toward top level.
- Early skeletal program allows demonstrations and boosts morale.

Disadvantages of Top-Down Testing

- Stubs must be produced (often more complicated than anticipated).
- Judgement of test results more difficult.
- Tempting to defer completion of testing of certain modules.

Bottom-Up Testing: Pros and Cons

Advantages of Bottom-Up Testing

- Advantageous if major flaws occur toward bottom level.
- Judgement of test results is easier.

Disadvantages of Bottom-Up Testing

- Driver units must be produced.
- The program as an entity does not exist until the last unit is added.