Software Engineering

Software Testing & Unit Tests

- Resources
  - Ian Sommerville
    Software Engineering 8th Edition
    Addison Wesley 2007
  - Robert v. Binder
    Testing Object-Oriented Systems - Models, Patterns, and Tools
    Addison Wesley 2000
Software Testing
Validation

“Are we building the right product?”

Verification

“Are we building the product right?”

Ian Sommerville

Software Engineering 8th Edition; Addison Wesley 2007
Two **complementary** approaches for verification and validation (V&V) can be distinguished.

- **Software Inspections or Peer Reviews**
  (Static Technique)
  “Software inspections” can be done at all stages of the process.

- **Software Testing**
  (Dynamic Technique)
Software inspections check the correspondence between a program and its specification.

• Some techniques

• **Program inspections**
  The goal is to find program defects, standards violations, poor code rather than to consider broader design issues; it is usually carried out by a team and the members systematically analyze the code. An inspection is usually driven by checklists.
  (Studies have shown that an inspection of roughly 100LoC takes about one person-day of effort.)

• ...
Software inspections check the correspondence between a program and its specification.

- Some techniques
  - ...

- **Automated source code analysis**
  Includes - among others - control flow analysis, data use / flow analysis, information flow analysis and path analysis.
  *Static analyses draw attention to anomalies.*

- ...

- ...
Software inspections check the correspondence between a program and its specification.

• Some techniques
  • ...

• **Formal verification**
  Formal verification can guarantee the absence of specific bugs. E.g., to guarantee that a program does not contain deadlocks, race conditions or buffer overflows.
Software inspections check the correspondence between a program and its specification.

Software inspections do not demonstrate that the software is useful.
Software testing refers to running an implementation of the software with test data to discover program defects.

- **Validation testing**
  Intended to show that the software is what the customer wants (Basically, there should be a test case for every requirement.)

- **Defect testing**
  Intended to reveal defects

- (Defect) Testing is...
  - fault directed when the intent is to reveal faults
  - conformance directed when the intent is to demonstrate conformance to required capabilities

No Strict Separation
Test plans set out the testing schedule and procedures; they establish standards for the testing process. They evolve during the development process.

- V&V is expensive; sometimes half of the development budget is spent on V&V
The scope of a test is the collection of software components to be verified.

- **Unit tests**
  (dt. Modultest)
  Comprises a relatively small executable; e.g., a single object

- **Integration test**
  Complete (sub)system. Interfaces among units are exercised to show that the units are collectively operable

- **System test**
  A complete integrated application. Categorized by the kind of conformance they seek to establish: functional, performance, stress or load
Testing can only show the presence of errors, not their absence.

E. Dijkstra
The design of tests is a multi-step process.

1. Identify, model and analyze the responsibilities of the system under test (SUT)  
   (E.g., use pre- and postconditions identified in use cases as input.)

2. Design test cases based on this external perspective

3. Add test cases based on code analysis, suspicions, and heuristics

4. Develop expected results for each test case or choose an approach to evaluate the pass / no pass status of each test case
After the test design a test automation system (TAS) needs to be developed.

A test automation system will...

• start the implementation under test (IUT)
• set up its environment
• bring it to the required pretest state
• apply the test inputs
• evaluate the resulting output and state
The goal of the test execution is to establish that the implementation under test (IUT) is minimally operational by exercising the interfaces between its parts.

To establish the goal...

1. execute the test suite; the result of each test is evaluated as pass or no pass
2. use a coverage tool to instrument the implementation under test; rerun the test suite and evaluate the reported coverage
3. if necessary, develop additional tests to exercise uncovered code
4. stop testing when the test goal is met; all tests pass

("Exhaustive" testing is generally not possible!)
Test Point
(dt. Testdatum (Prüfpunkt))

- A test point is a specific value for...
  - test case input
  - a state variable

- The test point is selected from a domain; the domain is the set of values that input or state variables may take

- Heuristics for test point selection:
  - Equivalence Classes
  - Boundary Value Analysis
  - Special Values Testing
Test Case
(dt. Testfall)

- Test cases specify:
  - pretest state of the implementation under test (IUT)
  - test inputs / conditions
  - expected results
Test Suite

- A test suite is a collection of test cases
Test Run
(dt. Testlauf)

- A test run is the execution (with results) of a test suite
- The IUT produces actual results when a test case is applied to it; a test whose actual results are the same as the expected results is said to pass
Test Driver & Test Harness/Automated Test Framework

- Test driver is a class or utility program that applies test cases to an IUT
- Test harness is a system of test drivers and other tools to support test execution
Failures, Errors & Bugs

Failure = dt. Defekt, Fehlschlag
Fault = dt. Mangel
Error = dt. Fehler

- A **failure** is the (manifested) inability of a system or component to perform a required function within specified limits
- A **software fault** is missing or incorrect code
- An **error** is a human action that produces a software fault
- **Bug**: error or fault.
Test Plan

• A document prepared for human use that explains a testing approach:
  • the work plan,
  • general procedures,
  • explanation of the test design,
  • ...

Software Testing - Terminology | 22
Testing must be based on a fault model.

Because the number of tests is infinite, we have to make (for practical purposes) an assumption about where faults are likely to be found!
Testing must be based on a fault model.

Two general fault models and corresponding testing strategies exist:
- Conformance-directed testing
- Fault-directed testing

Testing has to be efficient.
Let’s assume that we are going to write a tool for verifying Java code. In particular, we would like to assert that specific int based calculations always satisfies the stated assertions.

```java
public int doCalc(int i, int j) {
    if (i < 0 || i > 10 || j < 0 || j > 100)
        throw new IllegalArgumentException();

    return i * j; //ASSERT(i * j in [0,1000])
}
```
Developing a Test Plan

To represent Java int values, we are using the following classes and map the calculations to the respective methods.

```java
/** Representation of a primitive Java int value. */
abstract class IntValue {

    /**
     * Calculates the result of multiplying a and b. The result is as precise as possible given
     * the available information. If the result is either a or b, the respective object is
     * returned.
     */
    public abstract IntValue mul(IntValue other);
}

/** Represents a specific but unknown Java int value. */
class AnInt extends IntValue {

    public IntValue mul(IntValue other) {...}
}

/** Represents a value that is in the range [lb,ub]; however, the specific value is unknown. */
class Range extends IntValue {

    public final int lb;
    public final int ub;

    public Range(int lb, int ub) {
        this.lb = lb;
        this.ub = ub;
    }

    public IntValue mul(IntValue other) {...}
}
```

How does the test plan look like?
Developing a Test Plan

• Devise a test plan for a program that:
  • reads three integer values,
  • which are interpreted as the length of the sides of a triangle
• The program states whether the triangle is
  • scalene (dt. schief),
  • isosceles (dt. gleichschenklig), or
  • equilateral (dt. gleichseitig)

• A valid triangle must meet two conditions:
  • No side may have a length of zero
  • Each side must be shorter than the sum of all sides divided by 2
An Implementation of a Triangle

class Polygon extends Figure {
    abstract void draw(...);
    abstract float area();
}
class Triangle extends Polygon {
    public Triangle(...);
    public void setA(LineSegment a);
    public void setB(LineSegment b);
    public void setC(LineSegment c);
    public boolean isIsosceles();
    public boolean isScalene();
    public boolean isEquilateral();
}
## Test Descriptions

<table>
<thead>
<tr>
<th>Description</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Expected Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid scalene triangle</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>Scalene</td>
</tr>
<tr>
<td>Valid isosceles triangle</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>Isosceles</td>
</tr>
<tr>
<td>Valid equilateral triangle</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>Equilateral</td>
</tr>
<tr>
<td>First perm. of two equal sides</td>
<td>50</td>
<td>50</td>
<td>25</td>
<td>Isosceles</td>
</tr>
<tr>
<td>(Permutations of previous test case)</td>
<td></td>
<td></td>
<td></td>
<td>Isosceles</td>
</tr>
<tr>
<td>One side zero</td>
<td>1000</td>
<td>1000</td>
<td>0</td>
<td>Invalid</td>
</tr>
<tr>
<td>First perm. of two equal sides</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>Invalid</td>
</tr>
<tr>
<td>Sec. perm. of two equal sides</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>Invalid</td>
</tr>
<tr>
<td>Third perm. of two equal sides</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>Invalid</td>
</tr>
<tr>
<td>Three sides greater than zero, sum of two smallest less than the largest</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>Invalid</td>
</tr>
</tbody>
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## Test Descriptions

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<td>...</td>
<td>...</td>
<td>...</td>
<td>Invalid</td>
</tr>
<tr>
<td>All sides zero</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Invalid</td>
</tr>
<tr>
<td>One side equals the sum of the other</td>
<td>12</td>
<td>5</td>
<td>7</td>
<td>Invalid</td>
</tr>
<tr>
<td><em>(Permutations of previous test case)</em></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>Invalid</td>
</tr>
<tr>
<td>Three sides at maximum possible value</td>
<td>MAX</td>
<td>MAX</td>
<td>MAX</td>
<td>Equilateral</td>
</tr>
<tr>
<td>Two sides at maximum possible value</td>
<td>MAX</td>
<td>MAX</td>
<td>1</td>
<td>Isosceles</td>
</tr>
<tr>
<td>One side at maximum value</td>
<td>1</td>
<td>1</td>
<td>MAX</td>
<td>Invalid</td>
</tr>
</tbody>
</table>

*Further OO related tests w.r.t. the type hierarchy etc.*
* (e.g. are the line segments connected.)
Coverage

Coverage = dt. Abdeckung

- The completeness of a test suite w.r.t. a particular test case design method is measured by coverage.
- Coverage is the percentage of elements required by a test strategy.
The Control-flow Graph of a Method

static void doThat(int v, boolean b) {
    if (v > 100 && b) {
        print("if");
    }
    else {
        print("else");
    }
    return;
}

A Node consists of a sequence of statements without any branches in or out (except of the last statement).

A branch describes a possible control-flow.
• **Statement Coverage** is achieved when all statements in a method have been executed at least once

• **Branch Coverage** is achieved when every path from a node is executed at least once by a test suite; compound predicates are treated as a single statement

• **Simple Condition Coverage** requires that each simple condition be evaluated as true and false at least once (Hence, it does not require testing all possible branches.)

• **Condition Coverage** =
  
  Simple Condition Coverage + Branch Coverage

• **Multiple-condition Coverage** requires that all true-false combinations of simple conditions be exercised at least once
Conditions - Exemplified

```java
static void doThat(int v, boolean b) {
    simple/atomic condition(s)
    if (v > 100 && b) {
        print("if");
    }
    else {
        print("else");
    }
}
```

Here, “v > 100” is the first condition and “b” is the second condition.

In Java, simple/atomic conditions are separated by “&&” / “&” or “||”/“|” operators.
Compound Predicates - Exemplified

```java
static void doThat(int v, boolean b) {
    (compound) predicate (expression)
    if (v > 100 && b) {
        print("if");
    }
    else {
        print("else");
    }
}
```

Here, “v > 100 && b” is called a predicate resp. a compound predicate. This compound predicate consists of two “simple” conditions.
static void doThat(int v, boolean b) {
    if (v > 100 && b) {
        print("if");
    } else {
        print("else");
    }
}

100% Branch Coverage

v = 90, b = true
v = 101, b = true
Simple Condition Coverage Exemplified

Recall: The condition is an expression that evaluates to true or false. I.e., an expression such as !b (not b) is the condition.

```java
static void doThat(
    boolean a,
    boolean b,
    boolean c) {
    if ((a & c) | (c & b) | (b & a)) {
        print("if");
    } else {
        print("else");
    }
}
```

100% Simple Condition Coverage
- \( a = true, b = false, c = false \)
- \( a = false, b = true, c = false \)
- \( a = false, b = false, c = true \)

Recall: The condition is an expression that evaluates to true or false. I.e., an expression such as !b (not b) is the condition.
(Simple) Condition Coverage Exemplified

```
static void doThat(
    boolean a,
    boolean b,
    boolean c) {
    if (((a && c) || (c && b) || (b && a)) {
        print("if");
    } else {
        print("else");
    }
}
```

100% (Simple) Condition Coverage
- a = true, c = true (b is not relevant)
- a = false, c = true, b = true
- a = false, c = false, b = false

Recall, if we have shortcut evaluation, simple condition coverage implies branch coverage!
Basic Block Coverage

• A basic block is a sequence of consecutive instructions in which flow of control enters at the beginning and leaves at the end without halt or possibility of branching except at the end.

• Basic block coverage is achieved if all basic blocks of a method are executed.

(⚡ Sometimes “statement coverage” is used as a synonym for “basic block coverage” - however, we do not use these terms synonymously.)
(Basic blocks are sometimes called segments.)
Basic Block Coverage Exemplified

100% Basic Block Coverage

v = 90, b = “not relevant”
v = 101, b = true

static void doThat(int v, boolean b) {
    if (v > 100 && b) {
        print("if");
    } else {
        print("else");
    }
}
**Control-flow Graph**

```java
static void doThis(boolean a, boolean b) {
    if (a) {
        print("A");
    }
    if (b) {
        print("B");
    }
}
```

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statement</strong></td>
<td>TRUE</td>
<td>TRUE</td>
</tr>
<tr>
<td><strong>Basic Block</strong></td>
<td>TRUE</td>
<td>TRUE</td>
</tr>
<tr>
<td><strong>(Simple) Condition Coverage</strong></td>
<td>TRUE</td>
<td>TRUE</td>
</tr>
<tr>
<td><strong>Branch Coverage</strong></td>
<td>TRUE</td>
<td>TRUE</td>
</tr>
</tbody>
</table>

Here, condition coverage can also be achieved using other test cases. (E.g. a=false; b=true and a=true; b=false.)

No case covers all possible paths!

---

Software Testing - Code Coverage | 41

Basic Block
static void doThis(boolean a, boolean b) {
    if (a && b) {
        print("A && B");
    }
}

<table>
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<td></td>
</tr>
<tr>
<td><strong>Multiple Condition Coverage</strong></td>
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</tbody>
</table>

**Minimal Number of Tests to Achieve... Coverage**

**Fragen**

*Würde im Falle von Condition Coverage nicht auch "true, true" und "false, false" ausreichen?*

*Antwort*

Da im Ausdruck "a && b", "b" nur evaluiert wird wenn a wahr ist (Short-cut Evaluation von "&&" - siehe Graph) - ist "false / false" keine hilfreiche Belegung der Parameter.

**Fragen / Antwort:**

*Wäre der Code:

```java
if (a) {
    if (b) 
        print("A && B")
    else 
        print("Hello!")
} return;
```

dann wäre für "Statement Coverage" folgende Testfälle notwendig: a=true; b=false und a=true; b=true. (Ebenso für Basic Block Coverage)*
### Control-flow Graph

```java
static void doThis(boolean a, boolean b) {
    if (a || b) {
        print("A or B");
    }
}
```

We have achieved 100% statement coverage, though we have never evaluated the condition b.

<table>
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<th>a</th>
<th>b</th>
</tr>
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<tbody>
<tr>
<td>Statement</td>
<td>TRUE</td>
<td>/</td>
</tr>
<tr>
<td>Basic Block</td>
<td>FALSE</td>
<td>TRUE</td>
</tr>
<tr>
<td>(Simple) Condition Coverage</td>
<td>FALSE</td>
<td>TRUE</td>
</tr>
<tr>
<td></td>
<td>FALSE</td>
<td>FALSE</td>
</tr>
<tr>
<td></td>
<td>TRUE</td>
<td>/</td>
</tr>
</tbody>
</table>

### Basic Block

### Minimal Number of Tests to Achieve Coverage

```
static void doThis(boolean a, boolean b)
```

```java
if(a)
    t
f
if(b)
t
4
5
```

1. `print("A or B")`
2. `return`
3. Exit

We have achieved 100% statement coverage, though we have never evaluated the condition b.
static long process(String[] args) throws IllegalArgumentException {

    Stack values = new Stack();
    for (int i = 0; i < args.length; i++) {
        String arg = args[i];
        try {
            long value = Long.parseLong(arg);
            values.push(value);
        } catch (NumberFormatException nfe) {
            // there is no method to test if a string is a number ...

            if (values.size() > 1) {
                long r = values.pop();
                long l = values.pop();
                if (arg.equals("+")) {
                    values.push(l + r);
                    continue;
                }
                if (arg.equals("*")) {
                    values.push(l * r);
                    continue;
                }
            }
            throw new IllegalArgumentException("Too few operands or operator unknown.");
        }
    }
    if (values.size() == 1) return values.pop();
    else throw new IllegalArgumentException("Too few (0) or too many (>1) operands.");
}
static long process(java.lang.String[] args)

Basic Blocks of long process(String[] args)

0  stack = new demo.SimpleCalculator.Stack
    stack.<init>()

1  p14 = Φ(0, p65 + 11)
p17 = args.length
    if(p17 > p14)

2  p20 = args[p14]

3  long p23 = java.lang.Long.parseLong(p20)
    stack.push(p23)

5  java.lang.NumberFormatException
    int p30 = stack.size()
    if(1 >= p30)

8  long p40 = stack.pop()
    long p43 = stack.pop()
    p47 = p20.equals("+"")
        if(p47)

9  p50 = p20.equals("-")
        if(p50)

10 long p54 = p43 * p40
    stack.push(p54)

12 long p58 = p43 + p40
    stack.push(p58)

16 p72 = new IllegalArgumentException
    p72.<init>("...")
    throw p72

17 p76 = stack.pop()
    return p76

frage
Wie kommt dieser Graph zustande?
Antwort
Dieser Graph ist das Ergebnis der Repräsentation des kompilierten Programms. Wenn Sie Details dazu interessieren, dann suchen sie am Besten nach "Static Single Assignment". Ein Einstieg wäre:
http://en.wikipedia.org/wiki/Static_single_assignment_form
```
static long process(java.lang.String[] args)

0
stack = new demo.SimpleCalculator.Stack
stack.<init>()

1
p14 = Φ(0 ← 0, p65 ← 11)
p17 = args.length
if(p17 > p14)

2
p20 = args[p14]

3
long p23 = java.lang.Long.parseLong(p20)
stack.push(p23)

5
java.lang.NumberFormatException
int p30 = stack.size()
if(1 >= p30)

Handling Exceptions
```

```
Do not use a code coverage model as a test model.

Do not rely on code coverage models to devise test suites. Test from responsibility models and use coverage reports to analyze test suite adequacy.

Covering some aspect of a method [...] is never a guarantee of bug-free software.

Robert V. Bender

*Testing Object-Oriented Systems*

*Addison Wesley 2000*
• Recommended Reading
Limits of Testing
Limits of Testing
The number of input and output combinations for trivial programs is already (very) large.

Assume that we limit points to integers between 1 and 10; there are $10^4$ possible ways to draw (a single) line.

Since a triangle has three lines we have $10^4 \times 10^4 \times 10^4$ possible inputs of three lines (including invalid combinations).

We can never test all inputs, states, or outputs.
Limits of Testing
Branching and (dynamic binding) result in a very large number of unique execution sequences. Simple iteration increases the number of possible sequences to astronomical proportions.

```java
for (int i = 0; i < n; ++i)
{
    if (a.get(i) == b.get(i))
        x[i] = x[i]+100;
    else
        x[i] = x[i] / 2;
}
```
Limits of Testing
Branching and dynamic binding result in a very large number of unique execution sequences.

- If we count entry-exit paths without regarding iteration there are only three paths:
  - loop header, exit
  - loop header, cond., +100
  - loop header, cond., /2
Limits of Testing

Branching and dynamic binding result in a very large number of unique execution sequences. Simple iteration increases the number of possible sequences to astronomical proportions.

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<tr>
<td>1</td>
<td>$2^1 + 1 = 3$</td>
</tr>
<tr>
<td>2</td>
<td>$2^2 + 1 = 5$</td>
</tr>
<tr>
<td>3</td>
<td>$2^3 + 1 = 9$</td>
</tr>
<tr>
<td>10</td>
<td>1.025</td>
</tr>
<tr>
<td>20</td>
<td>1.048.577</td>
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1. Path
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3. Path
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Branching and dynamic binding result in a very large number of unique execution sequences. Simple iteration increases the number of possible sequences to astronomical proportions.

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</tr>
</thead>
<tbody>
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<td>$2^1 + 1 = 3$</td>
</tr>
<tr>
<td>2</td>
<td>$2^2 + 1 = 5$</td>
</tr>
<tr>
<td>3</td>
<td>$2^3 + 1 = 9$</td>
</tr>
<tr>
<td>10</td>
<td>1.025</td>
</tr>
<tr>
<td>20</td>
<td>1.048577</td>
</tr>
</tbody>
</table>

4. Path
Limits of Testing

Branching and dynamic binding result in a very large number of unique execution sequences. Simple iteration increases the number of possible sequences to astronomical proportions.

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5. Path
The ability of code to hide faults from a test suite is called its fault sensitivity.

Coincidental correctness is obtained when buggy code can produce correct results for some inputs. E.g. assuming that the correct code would be:

\[ x = x + x \]

but you wrote

\[ x = x^2 \]

If \( x = 2 \) is tested the code hides the bug: it produces a correct result from buggy code. However, this bug is easily identified.
Implementing Tests

• A Very First Glimpse
static long process(String[] args) throws IllegalArgumentException {

    Stack values = new Stack();
    for (int i = 0; i < args.length; i++) {
        String arg = args[i];
        try {
            long value = Long.parseLong(arg);
            values.push(value);
        } catch (NumberFormatException nfe) {
            // there is no method to test if a string is a number ...

            if (values.size() > 1) {
                long r = values.pop();
                long l = values.pop();
                if (arg.equals("+")) {
                    values.push(l + r);
                    continue;
                }
                if (arg.equals("*")) {
                    values.push(l * r);
                    continue;
                }
            }
            throw new IllegalArgumentException("Too few operands or operator unknown.");
        }
    }
    if (values.size() == 1) return values.pop();
    else throw new IllegalArgumentException("Too few (0) or too many (>1) operands.");
}
## A Test Plan That Achieves Basic Block Coverage

```java
static long process(java.lang.String[] args)
```

### Description

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<th>Expected Output</th>
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<td>&quot;4&quot;, &quot;5&quot;, &quot;+&quot;, &quot;7&quot;, &quot;*&quot;</td>
<td>63</td>
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<td>Test that too few operands leads to the corresponding exception</td>
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</tr>
<tr>
<td>Test that an illegal operator / operand throws the corresponding exception</td>
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static long process(String[] args)

0. stack = new demo.SimpleCalculator.Stack
   stack.init()

1. p14 = Φ(0→0, p65→11)
p17 = args.length
   if(p17 > p14)

2. p20 = args[p14]

3. long p23 = java.lang.Long.parseLong(p20)
   stack.push(p23)

4. int p65 = p14 + 1

5. java.lang.NumberFormatException
   int p30 = stack.size()
   if(1 >= p30)

6. p36 = new IllegalArgumentException
   p36.init("...")
   throw p36

7. p76 = stack.pop()
   return p76

8. long p40 = stack.pop()
   long p43 = stack.pop()
   p47 = p20.equals("+")
   if(p47)

9. p50 = p20.equals("*")
   if(p50)

10. long p54 = p43 * p40
    stack.push(p54)

11. int p65 = p14 + 1

12. long p58 = p43 + p40
    stack.push(p58)

13. p70 = stack.size()
    if(p70 != 1)

14. p36 = new IllegalArgumentException
    p36.init("...")
    throw p36

15. p70 = stack.size()
    if(p70 != 1)

16. p72 = new IllegalArgumentException
    p72.init("...")
    throw p72

17. p76 = stack.pop()
   return p76
static long process(java.lang.String[] args)

```java
for (int i = 0; i < args.length; i++) {
    String arg = args[i];
    try {
        long value = Long.parseLong(arg);
        values.push(value);
    } catch (NumberFormatException nfe) {
        // there is no method to test if a string is a number
    }
    if (values.size() > 1) {
        long r = values.pop();
        long l = values.pop();
        if (arg.equals("+")) {
            values.push(l + r);
            continue;
        }
        if (arg.equals("*")) {
            values.push(l * r);
            continue;
        }
    }
    throw new IllegalArgumentException("Too few operands or operators.");
}
```
import static org.junit.Assert.assertEquals;
import static org.junit.Assert.fail;
import java.util.Arrays;
import org.junit.Test;

public class SimpleCalculatorTest {

    @Test
    public void testProcess() {
        String[] term = new String[] {
            "4", "5", "+", "7", "*"
        };
        long result = SimpleCalculator.process(term);
        assertEquals(Arrays.toString(term), 63, result);
    }
}

Writing a Test Case using JUnit (4)
Writing a Test Case using JUnit (3)

- Testing Exception Handling

```java
import static org.junit.Assert.assertEquals;
import static org.junit.Assert.fail;
import java.util.Arrays;
import org.junit.Test;

public class SimpleCalculatorTest extends ...
{

    public void testProcess() {
        try {
            SimpleCalculator.process(new String[0]);
            fail();
        } catch (IllegalArgumentException iae) {
            assertEquals("Too few (0) or too many (>1) operands.", iae.getMessage());
        }
    }

```
import static org.junit.Assert.assertEquals;
import static org.junit.Assert.fail;
import java.util.Arrays;
import org.junit.Test;

public class SimpleCalculatorTest {

    @Test(expected=IllegalArgumentException.class)
    public void testProcess() {
        SimpleCalculator.process(new String[0]);
    }
}

Writing a Test Case using JUnit (4) - Testing Exception Handling
// This method will provide data to any test method
// that declares that its Data Provider is named "provider1".
@DataProvider(name = "provider1")
public Object[][] createData1() {
    return new Object[][] {
        { "Cedric", new Integer(36) },
        { "Anne", new Integer(37) }
    };
}

// This test method declares that its data should be
// supplied by the Data Provider named "provider1".
@Test(dataProvider = "provider1")
public void verifyData1(String n1, Integer n2) {
    System.out.println(n1 + " " + n2);
import static org.hamcrest.MatcherAssert.assertThat;
import static org.hamcrest.Matchers.*;
import junit.framework.TestCase;

public class BiscuitTest extends TestCase {
    public void testEquals() {
        Biscuit theBiscuit = new Biscuit("Ginger");
        Biscuit myBiscuit = new Biscuit("Ginger");
        assertThat(theBiscuit, equalTo(myBiscuit));
    }
}
ScalaTest
(Can also be used for testing Java.)

class DefaultIntegerRangesTest extends FunSpec with Matchers with ParallelTestExecution {
  
  describe("IntegerRange values") {
    
    describe("the behavior of irem") {
      
      it("AnIntegerValue % AnIntegerValue => AnIntegerValue + Exception") {
        val v1 = AnIntegerValue()
        val v2 = AnIntegerValue()
        
        val result = irem(-1, v1, v2)
        result.result shouldBe an[AnIntegerValue]
        result.exceptions match {
          case SObjectValue(ObjectType.ArithmeticException) ⇒ /*OK*/
          case v ⇒ fail(s"expected ArithmeticException; found $v")
        }
      }
    }
  }
}
Behavior-Driven Development

The goal is that developers define the behavioral intent of the system that they are developing.

http://behaviour-driven.org/

```scala
import org.specs.runner_
import org.specs_

object SimpleCalculatorSpec extends Specification {

  "The Simple Calculator" should {
    "return the value 36 for the input {"6","6","*"}" in {
      SimpleCalculator.process(Array("6","6","*")) must_== 36
    }
  }
}
```

Using ScalaSpec 1.5: http://code.google.com/p/specs/
(Method-) Stub

• A stub is a partial, temporary implementation of a component (e.g., a placeholder for an incomplete component)

• Stubs are often required to simulate complex systems; to make parts of complex systems testable in isolation

An alternative is to use a Mock object that mimics the original object in its behavior and facilitates testing.
Testing comprises the efforts to find defects.

Debugging is the process of locating and correcting defects.

(Hence, debugging is not testing, and testing is not debugging.)
Summary
The goal of this lecture is to enable you to systematically carry out small(er) software projects that produce quality software.

- Testing has to be done systematically; exhaustive testing is not possible.
- Test coverage models help you to assess the quality of your test suite; however, “just” satisfying a test coverage goal is usually by no means sufficient.
- Do take an “external” perspective when you develop your test suite.
The goal of this lecture is to enable you to systematically carry out small(er) commercial or open-source projects.
A Tester’s Courage

The Director of a software company proudly announced that a flight software developed by the company was installed in an airplane and the airline was offering free first flights to the members of the company. “Who are interested?” the Director asked. Nobody came forward. Finally, one person volunteered. The brave Software Tester stated, ‘I will do it. I know that the airplane will not be able to take off.’

Unknown Author

http://www.softwaretestingfundamentals.com