MUTATION TESTING

START HUNTING THE BUGS

@SVENRUPPERT

vaadin}>

Do you have bugs in your code ?

no

since years you are working hard on this….

The Environment

Codebase is > 13 years old

no test coverage

no dedicated refactoring budget

decrease complexity

but… lets start with the basics

are you using jUnit?

assume that the following would make sense.. ;-)

```
public class Service {
  public int add(int a, int b){
    if(a<2){
      return (a+b) * -1;
    } else {
      return a+b;
    }
  }
}
```

How many tests you will need ?

it depends ;-)

TDD with jUnit

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```
public class Service {
  public int add(int a, int b){
    if(a<2){
      return (a+b) * -1;
    } else {
      return a+b;
    }
  }
}
```

How many tests you will need ?

it depends ;-)

for line 100% coverage 2

but will this be enough? **maybe ;-)**

TDD with jUnit

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```
public class Service {
  public int add(int a, int b){
    if(a<2){
      return (a+b) * -1;
    } else {
      return a+b;
    }
  }
}
```

How many tests you will need ?

it depends ;-)

for line 100% coverage 2

but will this be enough? **maybe ;-)**

how to find out, what will be enough?

how to find the right tests?

TDD with jUnit


```
public class Service {
  public int add(int a, int b){
    if(a<2){
      return (a+b) * -1;
    } else {
      return a+b;
    }
  }
}
```

```
@Test
public void testAdd001() throws Exception {
  final int add = new Service().add(0, 0);
  Assertions.assertThat(add).isEqualTo(0);
}

@Test
public void testAdd002() throws Exception {
  final int add = new Service().add(3, 0);
  Assertions.assertThat(add).isEqualTo(3);
}
```

How many tests you will need ?

Mutation Testing

Mutation Testing is a structural testing method

we want to find a way to write "good" tests

how to find "good" tests?

let the machine find the targets

let´s mutate it... but how?

Mutation Testing - the Idea

a mutation is a small change in the code

.. small enough to be a small defect

P will be the program

T will be the collection of all tests / Test Suite

Mutation Testing - the Idea

P will be the program

T will be the collection of all tests / Test Suite

we will create a sequence of mutations / **P1**,**P2**,**P3**...

.. **Px** will have only one mutation compared to **P**

running all tests from **T** against **Px**

green: **T** will kill the mutation

.. at leased one test from **T** will fail

red: if all tests are green

Mutation Testing - the Idea

if we kill **k** out of **n** mutants

-> we are not good enough ;-)

we are **perfect** enough if we are reaching : **k == n**

how to create all versions of Px ?

.. the good thing..

we could almost generate/ automate everything

Mutation Testing

practical TDD with Mutation Testing

generating the mutants and

running all junit tests

check the reports

write more / better tests

loop until quality target reached

Mutation Testing - Kinds of Mutation

but.. what is a mutation?

Value Mutation

changing constants,
loop bounds (adding/subtracting values)

Mutation Testing - Kinds of Mutation

but.. what is a mutation?

Value Mutation

Decision Mutation

for example **<** will be changed to **<=**

Mutation Testing - Kinds of Mutation

but.. what is a mutation?

Value Mutation Decision Mutation

Statement Mutation

for example swapping/deleting/duplicating
lines of code

Mutation Testing - Kinds of Mutation

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but.. what is a mutation?

Value Mutation Decision Mutation
Statement Mutation

for **Java** you could think about more language spec. mutations

.. changing modifiers

.. changing between static / non static

.. delete member initialization

.. delete this.

.. argument order change

Mutation Testing - in short words

mutation testing is an add on to normal jUnit TDD

tools are supporting it well

generating and running all tests are time consuming

but most important

will effect your project structure

Mutation Testing - Frameworks

muJava

inactive

2003. First released as JMutation (Java Mutation System).
2004. The name was changed to MuJava (Mutation S
2005. Software Copyright Registration, ALL RI
2005. Version 2 released with several fault fix utation operators.
2008. Version 3 released with minimal support 1.5 and 1.6.
2013. Version 4 released to support JUnit tests and Java 1.6 language features, including generics, annotations, enumerations, varargs, enhanced for-each loops, and static imports.
2015. Additional and improved error messages. Bug fixes for OpenJava. Licensing changed to the Apache license.

https://cs.gmu.edu/~offutt/mujava/

https://github.com/jeffoffutt/muJava/graphs/contributors

Mutation Testing - Frameworks

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http://pitest.org/

2012. started around 2012 with a small codebase.
2014. very active since 2014

likes Kotlin ;-)

active ;-)

http://pitest.org/

assume the following would make sense ;-)

```
public class Service {
  public int add(int a, int b){
    if (a<2) {
      return (a+b) * -1;
    } else {
      return a+b;
    }
  }
}
```

Mutation Testing - Hello World


```
public class Service {
  public int add(int a, int b){
    if (a<2) { return (a+b) * -1; }
    else     { return a+b;        }
  }
}
```

100% Line Coverage… and…

```
@Test
public void testAdd001() throws Exception {
  final int add = new Service().add(0, 0);
  Assertions.assertThat(add).isEqualTo(0);
}
      @Test
      public void testAdd002() throws Exception {
        final int add = new Service().add(3, 0);
        Assertions.assertThat(add).isEqualTo(3);
      }
```

Mutation Testing - Hello World


```
final int add = new Service().add(0, 0);
Assertions.assertThat(add).isEqualTo(0);
```

```
 6. public class Service {
 7.   public int add(int a, int b) {
 8.     if (a < 2) {
 9.       return (a + b) * -1;
10.     } else {
11.       return a + b;
12.     }
13.   }
```

```
final int add = new Service().add(3, 0);
Assertions.assertThat(add).isEqualTo(3);
```

```
 6. public class Service {
 7.   public int add(int a, int b) {
 8.     if (a < 2) {
 9.       return (a + b) * -1;
10.     } else {
11.       return a + b;
12.     }
13.   }
```

Mutation Testing - Hello World


```
final int add = new Service().add(0, 0);
Assertions.assertThat(add).isEqualTo(0);
final int add = new Service().add(3, 0);
Assertions.assertThat(add).isEqualTo(3);
```

we got 100% Line Coverage

How good these tests are?

How to measure if these test are good?

How to find the good tests?

Mutation Testing - Hello World


```
final int add = new Service().add(0, 0);
```

```
final int add = new Service().add(3, 0);
```

How to find the good tests?

let´s generate a the mutation report

with maven : **pitest: mutationCoverage**

>> Generated 54 mutations Killed 3

org.pitest……mutators.**ConditionalsBoundaryMutator**
org.pitest……mutators.**IncrementsMutator**
org.pitest……mutators.**ReturnValsMutator**
org.pitest……mutators.**MathMutator**
org.pitest……mutators.**NegateConditionalsMutator**

Mutation Testing - Hello World

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```
final int add = new Service().add(0, 0);
final int add = new Service().add(3, 0);
```

>> Generated 54 mutations Killed 3

Breakd

Name	Coverage
Service.j	3/7

```
6    public class Service {
7      public int add(int a, int b) {
8  2     if (a < 2) {
9  3       return (a + b) * -1;
10       } else {
11 2       return a + b;
12       }
13     }
```

Mutation Testing - Hello World

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```
final int add = new Service().add(0, 0);
final int add = new Service().add(3, 0);
```

>> Generated 54 mutations Killed 3

8	2	if (a < 2) {
9	3	return (a + b) * -1;
10		} else {
11	2	return a + b;

8	1. changed conditional boundary → SURVIVED
	2. negated conditional → KILLED
9	1. Replaced integer addition with subtraction → SURVIVED
	2. Replaced integer multiplication with division → SURVIVED
	3. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED
11	1. Replaced integer addition with subtraction → SURVIVED
	2. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

Mutation Testing - Hello World

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```
final int add = new Service().add(0, 0);
final int add = new Service().add(3, 0);
final int add = new Service().add(2, 0);
```

>> Generated 54 mutations Killed 4

```
8   2     if (a < 2) {
9   3        return (a + b) * -1;
10       } else {
11  2        return a + b;
12       }
```

8
1. changed conditional boundary → KILLED
2. negated conditional → KILLED

9
1. Replaced integer addition with subtraction → SURVIVED
2. Replaced integer multiplication with division → SURVIVED
3. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

11
1. Replaced integer addition with subtraction → SURVIVED
2. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

Mutation Testing - Hello World

@SvenRuppert

```
final int add = new Service().add(2, 0);
final int add = new Service().add(1, 1);
```

>> Generated 54 mutations Killed 5

killed 9:1

```
8   2    if (a < 2) {
9   3        return (a + b) * -1;
10       } else {
11  2        return a + b;
12       }
```

8
1. changed conditional boundary → KILLED
2. negated conditional → KILLED

9
1. Replaced integer addition with subtraction → KILLED
2. Replaced integer multiplication with division → SURVIVED
3. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

11
1. Replaced integer addition with subtraction → SURVIVED
2. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

Mutation Testing - Hello World

@SvenRuppert

```
final int add = new Service().add(2, 0);
final int add = new Service().add(1, 1);
final int add = new Service().add(2, 2);
```

>> Generated 54 mutations Killed 6

killed 9:11:1

```
8  2      if (a < 2) {
9  3        return (a + b) * -1;
10       } else {
11 2        return a + b;
12       }
```

8
1. changed conditional boundary → KILLED
2. negated conditional → KILLED

9
1. Replaced integer addition with subtraction → KILLED
2. Replaced integer multiplication with division → SURVIVED
3. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

11
1. Replaced integer addition with subtraction → KILLED
2. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

Mutation Testing - Hello World

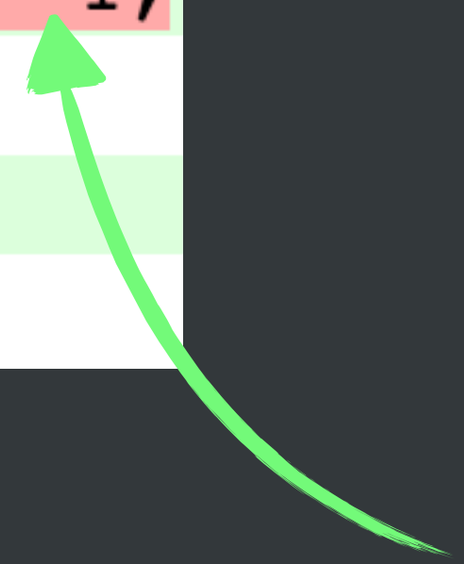
@SvenRuppert

```
final int add = new Service().add(1, 1);
final int add = new Service().add(2, 2);
```

>> Generated 54 mutations Killed 6

8	1. changed conditional boundary → KILLED 2. negated conditional → KILLED
9	1. Replaced integer addition with subtraction → KILLED 2. Replaced integer multiplication with division → SURVIVED 3. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED
11	1. Replaced integer addition with subtraction → KILLED 2. replaced return of integer sized value with (x == 0 ? 1 : 0) → KILLED

```
8  2      if (a < 2) {
9  3          return (a + b) * -1;
10         } else {
11 2          return a + b;
12         }
```



Mutation Testing - Lesson Learned

mutation tests are often leading to

…cleaner code compared to jUnit only

Mutation Testing - Lesson Learned

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```
public static final String[] discardCommonPrefix(String a, String b) {
  String[] ret = { a, b };
  int l = a.length() < b.length() ? a.length() : b.length();
  for (int i = 0; i < l; i++) {
    if (a.charAt(i) == b.charAt(i)) {
      if (i + 1 < l) { ret[0] = a.substring(i + 1); ret[1] = b.substring(i + 1); }
      else {
        if (a.length() < b.length())  { ret[0] = ""; ret[1] = b.substring(i + 1); }
        if (a.length() == b.length()) { ret[0] = ""; ret[1] = „"; }
        if (a.length() > b.length())  { ret[0] = a.substring(i + 1); ret[1] = „"; }
      }
    } else break;
  }
  return ret;
}
```

Mutation Testing - Lesson Learned

@SvenRuppert

```
public String[] discardCommonPrefix(String a, String b) {
  final String[] ret = new String[2];
  int l;
  if (a.length() < b.length()) { l = a.length(); }
  else                         { l = b.length(); }

  int position = 0;
  for (; position < l; position++) {
    final char charA = a.charAt(position);
    final char charB = b.charAt(position);
    if (charA != charB) { break; }
  }

  if (position >= a.length()) { ret[0] = ""; }
  else                        { ret[0] = a.substring(position); }

  if (position >= b.length()) { ret[1] = ""; }
  else                        { ret[1] = b.substring(position); }
  return ret;
}
```

Mutation Testing - Lesson Learned

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Version 1

```
for {
   if {
     if
     else {
       if
       if
       if
     }
  } else
}
```

Version 2

```
if else

for {
   if
}

if  else

if  else
```

Mutation Testing - Lesson Learned

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mutation tests are often leading to

…cleaner code compared to jUnit only

… smaller modules (shorter mutation runtime)

and something nice…
helps to find useless code

Example of useless Code

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```
12  public class ReflectionUtils extends org.reflections.ReflectionUtils {
13
14    public boolean checkInterface(final Type aClass, Class targetInterface) {
15 2    if (aClass.equals(targetInterface)) return true;
16
17    final Type[] genericInterfaces = ((Class) aClass).getGenericInterfaces();
18 2    if (genericInterfaces.length > 0) {
19 3      for (Type genericInterface : genericInterfaces) {
21
22          final Type[] nextLevBackArray = ((Class) genericInterface).getGenericInterfaces();
23 2        if (nextLevBackArray.length > 0)
24 3          for (Type type : nextLevBackArray) {
25 2            if (checkInterface(type, targetInterface)) return true;
26            }
27        }
28      }
29    final Type genericSuperclass = ((Class) aClass).getGenericSuperclass();
30 1  if (genericSuperclass != null) {
31 2    if (checkInterface(genericSuperclass, targetInterface)) return true;
32    }
33
34
35 1  return false;
36  }
```

Mutation Testing - How to start

you need jUnit - to generate the reference

add the pitest-plugin to the build section

configure the plugin

generate the reference -> clean , install

run **pitest: mutationCoverage**

report will be under **target/pit-reports**

Mutation Testing - How to start

pom.xml - example - build

```
<plugin>
  <groupId>org.pitest</groupId>
  <artifactId>pitest-maven</artifactId>
  <configuration>
    <outputFormats>
      <outputFormat>XML</outputFormat>
      <outputFormat>HTML</outputFormat>
    </outputFormats>
    <targetClasses>
      <param>org.rapidpm.*</param>
    </targetClasses>
    <targetTests>
      <param>org.rapidpm.*</param>
      <param>junit.org.rapidpm.*</param>
    </targetTests>
  </configuration>
</plugin>
```

pom.xml - example - reporting

```
<reporting>
  <plugins>
    <plugin>
      <groupId>org.pitest</groupId>
      <artifactId>pitest-maven</artifactId>
      <reportSets>
        <reportSet>
          <reports>
            <report>report</report>
          </reports>
        </reportSet>
      </reportSets>
    </plugin>
  </plugins>
</reporting>
```

Mutation Testing - practical usage

Start with some tests

generate the pitest report

write more tests to kill mutations

if you have time, eliminate useless tests

do it one by one

Mutation 001 **Survived** ⇢ **Killed**

Mutation 002 **Survived** ⇢ **Killed**

Mutation 003 **Survived** ⇢ **Killed**

Mutation 004 **Survived** ⇢ **Killed**

Mutation Testing - Real Code Examples

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```
Tests run: 86, Failures: 0, Errors: 0, Skipped: 0

[INFO] ------------------------------------------------------------------------
[INFO] Reactor Summary:
[INFO]
[INFO] RapidPM Dynamic Dependency Injection ..... SUCCESS [  3.117 s]
[INFO] rapidpm-dynamic-cdi-bom ................... SUCCESS [  0.623 s]
[INFO] rapidpm-dynamic-cdi-modules ............... SUCCESS [  0.557 s]
[INFO] rapidpm-dynamic-cdi-modules-core .......... SUCCESS [ 39.017 s]
[INFO] ------------------------------------------------------------------------
[INFO] BUILD SUCCESS
[INFO] ------------------------------------------------------------------------
[INFO] Total time: 43.526 s
[INFO] Finished at: 2018-03-01T12:09:33+01:00
[INFO] Final Memory: 29M/656M
[INFO] ------------------------------------------------------------------------
```

```
[INFO] ------------------------------------------------------------------------
[INFO] Reactor Summary:
[INFO]
[INFO] RapidPM Dynamic Dependency Injection ..... SUCCESS [  1.034 s]
[INFO] rapidpm-dynamic-cdi-bom ................... SUCCESS [  0.021 s]
[INFO] rapidpm-dynamic-cdi-modules ............... SUCCESS [  0.019 s]
[INFO] rapidpm-dynamic-cdi-modules-core .......... SUCCESS [03:36 min]
[INFO] ------------------------------------------------------------------------
[INFO] BUILD SUCCESS
[INFO] ------------------------------------------------------------------------
[INFO] Total time: 03:37 min
[INFO] Finished at: 2018-03-01T11:56:30+01:00
[INFO] Final Memory: 15M/326M
[INFO] ------------------------------------------------------------------------
```

Mutation Testing - Real Code Examples

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rapidpm-dynamic-cdi-modules-core — Sessions

rapidpm-dynamic-cdi-modules-core

Element	Missed Instructions	Cov.	Missed Branches	Cov.	Missed	Cxty	Missed	Lines	Missed	Methods	Missed	Classes
org.rapidpm.ddi		86%		81%	7	53	13	137	3	42	0	3
org.rapidpm.ddi.producer		94%		92%	4	37	3	104	0	11	0	2
org.rapidpm.ddi.implresolver		93%		92%	2	28	5	61	0	14	0	1
org.rapidpm.ddi.reflections		97%		89%	6	52	5	128	2	33	0	3
org.rapidpm.ddi.scopes		97%		75%	4	33	2	79	0	25	0	2
org.rapidpm.ddi.bootstrap		97%		75%	1	4	1	7	0	2	0	1
org.rapidpm.ddi.scopes.provided		100%		100%	0	8	0	13	0	6	0	1
org.rapidpm.ddi.producerresolver		100%		n/a	0	4	0	10	0	4	0	1
Total	126 of 2.191	94%	19 of 164	88%	24	219	29	539	5	137	0	14

Created with JaCoCo 0.8.0.201801022044

Pit Test Coverage Report

Project Summary

Number of Classes	Line Coverage		Mutation Coverage	
11	94%	505/536	84%	217/259

Breakdown by Package

Name	Number of Classes	Line Coverage		Mutation Coverage	
org.rapidpm.ddi	1	92%	120/131	84%	59/70
org.rapidpm.ddi.bootstrap	1	86%	6/7	100%	1/1
org.rapidpm.ddi.implresolver	1	92%	56/61	81%	30/37
org.rapidpm.ddi.producer	2	95%	101/106	80%	39/49
org.rapidpm.ddi.producerresolver	1	100%	10/10	100%	3/3
org.rapidpm.ddi.reflections	3	96%	123/128	89%	51/57
org.rapidpm.ddi.scopes	1	95%	76/80	78%	28/36
org.rapidpm.ddi.scopes.provided	1	100%	13/13	100%	6/6

Report generated by PIT 1.3.2