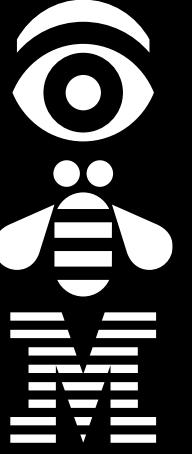


Mutation Testing



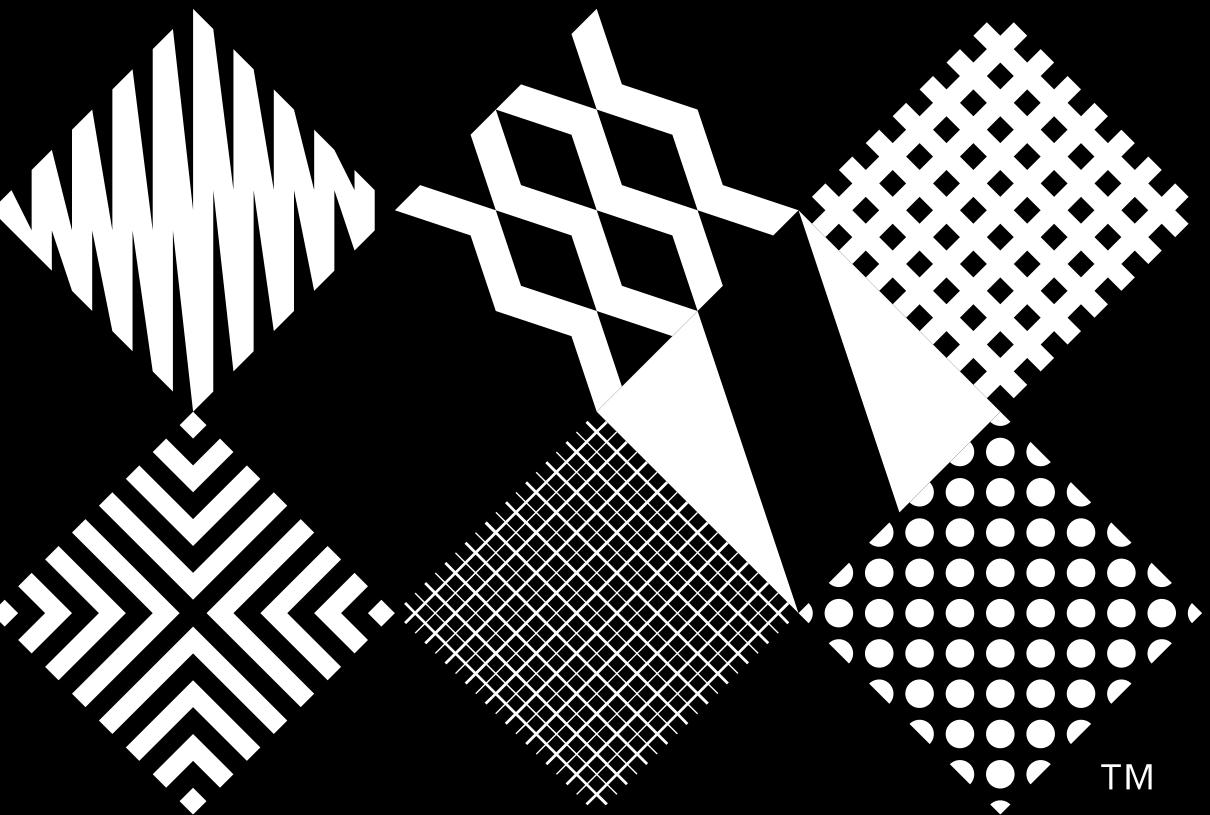
JavaCRO 2022, Autumn
10.10.2022

Your presenter

Stjepan Benčić

Java Web Developer – Adobe experience manager

stjepan.bencic@ibmix.hr



Our agenda

- 1) Introduction
- 2) Basic Idea
- 3) Papers
- 4) Java libs



Introduction

My Feature #1

[Edit](#)[Open with ▾](#)**Merged**merciremi merged 313 commits into [main](#) from [my-feature-branch](#)  on 28 Apr Conversation 0 Commits 6 Checks 1 Files changed 20

merciremi commented on 28 Apr

Owner



...

No description provided.

merciremi added 313 commits on 20 Apr

 313rd commit

706261d Labels

 312th commit

81293b9 None yet

 311th commit

70762d6 Projects



+12 875 -338



Reviewers



No reviews

Assignees



No one—assign yourself



I Am Devloper

@iamdevloper

Follow



10 lines of code = 10 issues.

500 lines of code = "looks fine."

Code reviews.

1:58 AM - 5 Nov 2013

8,035 Retweets 4,401 Likes



106

8.0K

4.4K

```
@Test  
protected void getSystemUser( ) {  
  
    final MyServiceImpl myService = spy(this.myServiceImpl);  
    myService.getUser();  
    lenient().when(this.config.getUser( )).thenReturn("testUser");  
  
    assertEquals("testUser", this.config.getUser( ));  
}
```

```
public static String foo(int i) {  
    if(i >= 0){  
        return "foo";  
    } else {  
        return "bar";  
    }  
}
```

```
public static String foo(int i) {  
    if(i >= 0){  
        return "foo";  
    } else {  
        return "bar";  
    }  
  
    @Test  
    public void shouldReturnFooWhenGiven1() {  
        assertEquals("foo", foo(1));  
    }  
  
    @Test  
    public void shouldReturnBarWhenGivenMinus1() {  
        assertEquals("bar", foo(-1));  
    }  
}
```

Basic Idea

```
class Foo{
    int min;

    public void bar(int i) {
        if(i < min) {
            min = i;
        }
    }
}
```

```
class Foo{
    int min;

    public void bar(int i) {
        if(i > min) {
            min = i;
        }
    }
}

class Foo{
    int min;

    public void bar(int i) {
        if(i < min) {
            min = i;
        }
    }
}
```

```
class Foo{
    int min;

    public void bar(int i) {
        if(i > min) {
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```
class Foo{
    int min;

    public void bar(int i) {
        if(i < min) {
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```
class Foo{
    int min;

    public void bar(int i) {
        if(i > min) {
            min = i;
        }
    }
}

class Foo{
    int min;

    public void bar(int i) {
    }
}
```

Mutant

Mutant

Survived mutant

Mutant

Survived mutant

Killed mutant

Mutant

Survived mutant

Killed mutant

Mutation operator

Mutant

Survived mutant

Killed mutant

Mutation operator

Equivalent mutants

Equivalent Mutants

```
class Foo{  
    int min;  
  
    public void bar(int i) {  
        if (i < min) {  
            min = i;  
        }  
    }  
}
```

Equivalent Mutants

```
class Foo{  
    int min;  
  
    public void bar(int i) {  
        if (i < min) {  
            min = i;  
        }  
    }  
}
```

```
class Foo{  
    int min;  
  
    public void bar(int i) {  
        if (i <= min) {  
            min = i;  
        }  
    }  
}
```

Equivalent Mutants

```
class Foo{  
    int min;  
  
    public void bar(int i) {  
        if (i < min) {  
            min = i;  
        }  
    }  
}
```

```
class Foo{  
    int min;  
  
    public void bar(int i) {  
        if (i <= min) {  
            min = i;  
        }  
    }  
}
```

Test Strength

$$\text{Mutation score} = \frac{killed}{(survived + killed)} * 100\%$$

Time cost

TRUTH LIBRARY

- 3k lines
- 3s compile
- 7s run tests
- 700 mutants
- 2h mutation testing
- With Pitest 37s

Time cost

TRUTH LIBRARY

- 3k lines
- 3s compile
- 7s run tests
- 700 mutants
- 2h mutation testing
- With Pitest 37s

JODA TIME

- 68k lines
- ~10s compile
- ~ 16s run tests
- 10k mutants
- 72h mutation testing

Time cost

TRUTH LIBRARY

- 3k lines
- 3s compile
- 7s run tests
- 700 mutants
- 2h mutation testing
- With Pitest 37s

INTERNAL PROJECT

- 2 years
- Java: ~66k lines
- Pitest ~20min

JODA TIME

- 68k lines
- ~10s compile
- ~ 16s run tests
- 10k mutants
- 72h mutation testing

Papers

Alphabet (Google)

G. Petrovic, M. Ivankovic,

“State of Mutation Testing in Google”
ACM, 2018.

G. Petrovic, M. Ivankovic, G. Fraser, R. Just

“Does mutation testing improve testing practices?”
2021 IEEE/ACM 43rd International Conference on Software
Engineering (ICSE)



Overview

– Since 2014

Overview

- Since 2014
- 14,730,562 mutants

Overview

- Since 2014
- 14,730,562 mutants
- Survival rate ~15%

Overview

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- 662,484 code changes

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Overview

- Since 2014
- 14,730,562 mutants
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- Diff-based

Overview

- Since 2014
- 14,730,562 mutants
- Survival rate ~15%
- 662,484 code changes
- 446,604 files changed
- Diff-based
- Probabilistic mutation

1
2
3
4
5
6
7
8

```
namespace testing {
namespace mutation {
namespace example {

int RunMe(int a, int b) {
    if (a == b || b == 1) {
```

▼ Mutants Changing this 1 line to

14:25, 28 Mar

```
        if (a != b || b == 1) {
```

does not cause any test exercising them to fail.

Consider adding test cases that fail when the code is mutated to ensure those bugs would be caught.

Mutants ran because goranpetrovic is whitelisted

[Please fix](#)

[Not useful](#)

9
10
11
12
13
14
15
16

```
        return 1;
    }
    return 2;
}

} // namespace example
} // namespace mutation
} // namespace testing
```

1
2
3
4
5
6
7
8

```
namespace testing {  
namespace mutation {  
namespace example {  
  
int RunMe(int a, int b) {  
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```

▼ Mutants Changing this 1 line to

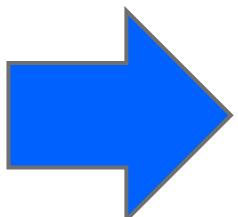
14:25, 28 Mar

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[Please fix](#)

[Not useful](#)

```
        return 1;  
    }  
    return 2;  
}  
} // namespace example  
} // namespace mutation  
} // namespace testing
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9
10
11
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```

▼ Mutants Changing this 1 line to

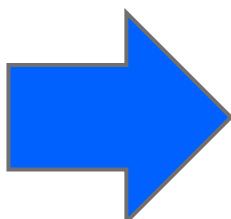
14:25, 28 Mar

```
        if (a != b || b == 1) {
```

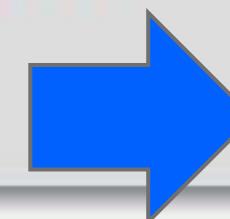
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[Please fix](#)

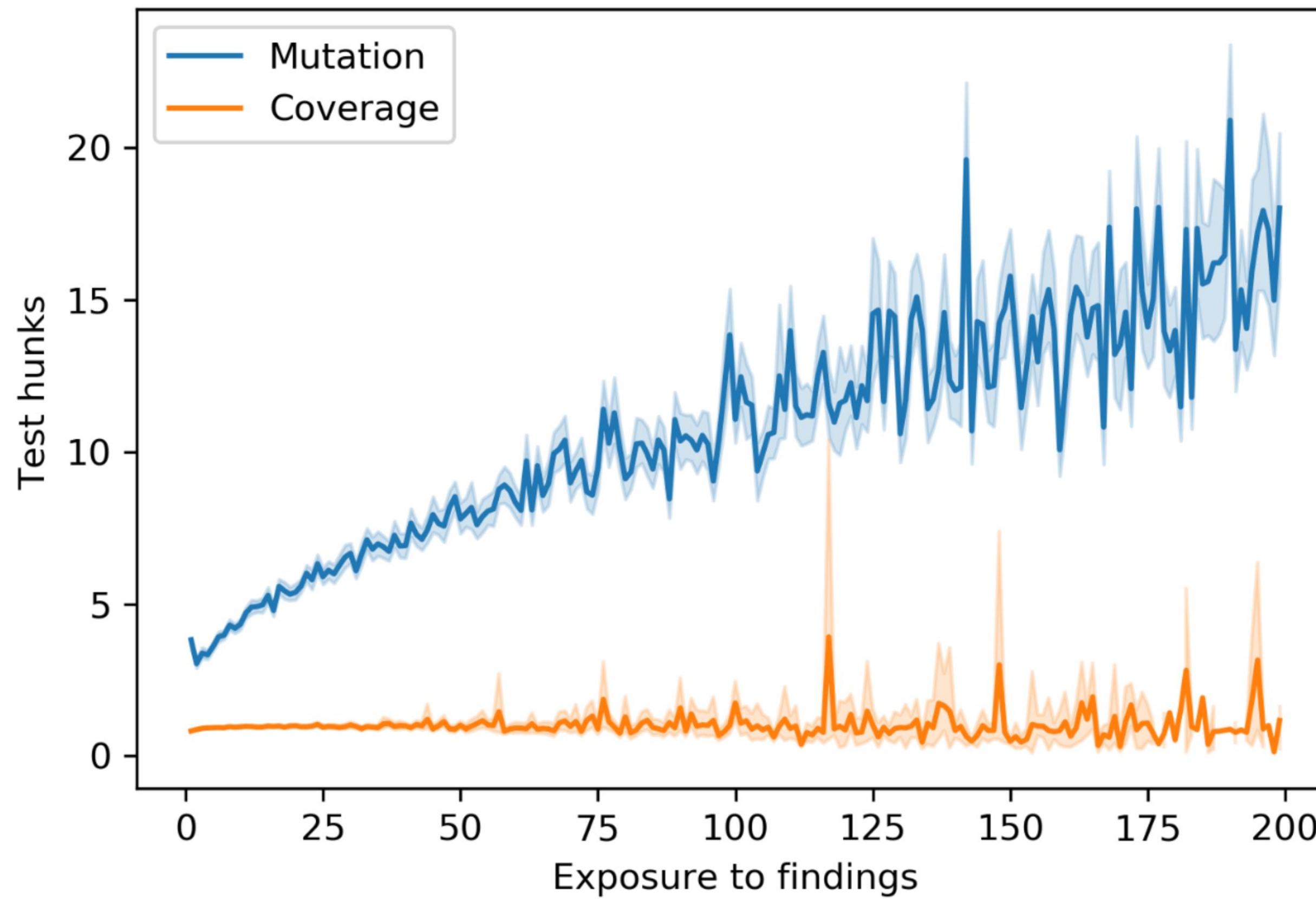


[Not useful](#)

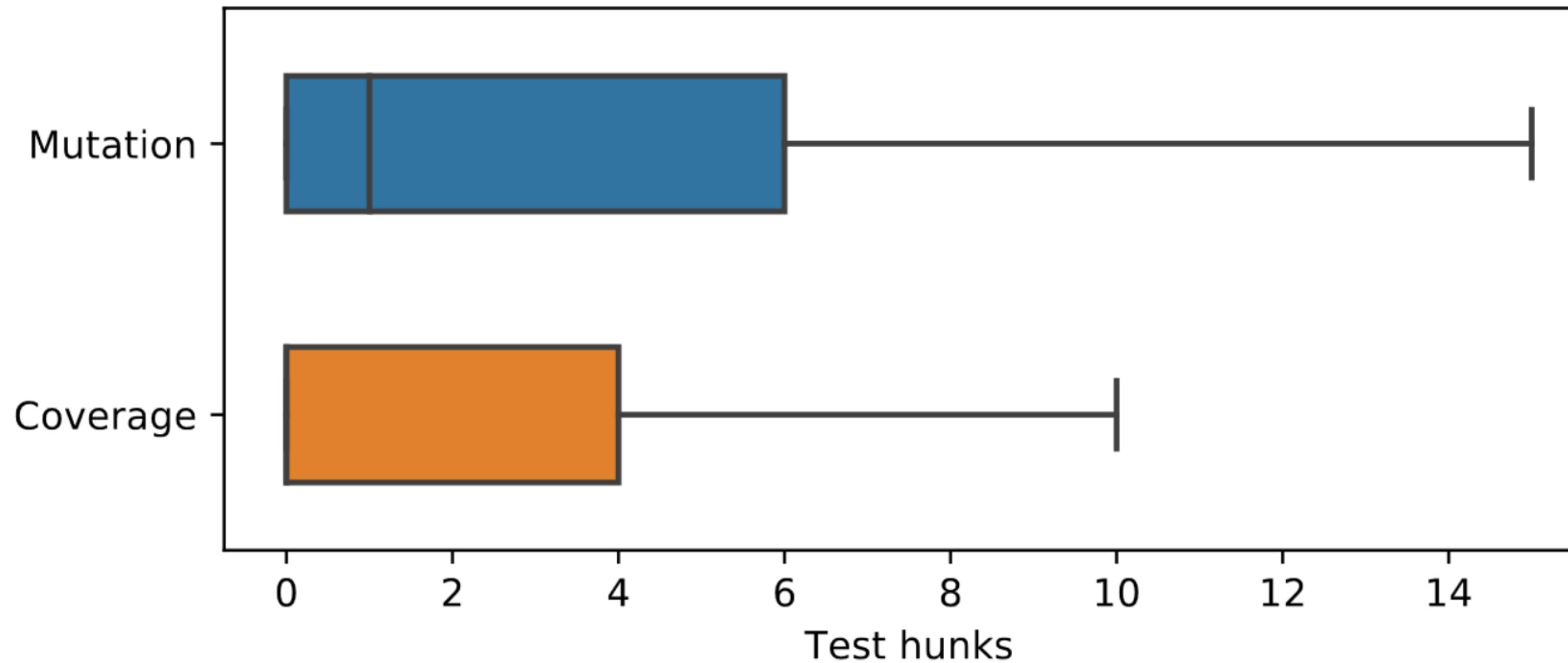
```
            return 1;  
    }  
    return 2;  
}  
} // namespace example  
} // namespace mutation  
} // namespace testing
```

9
10
11
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13
14
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16

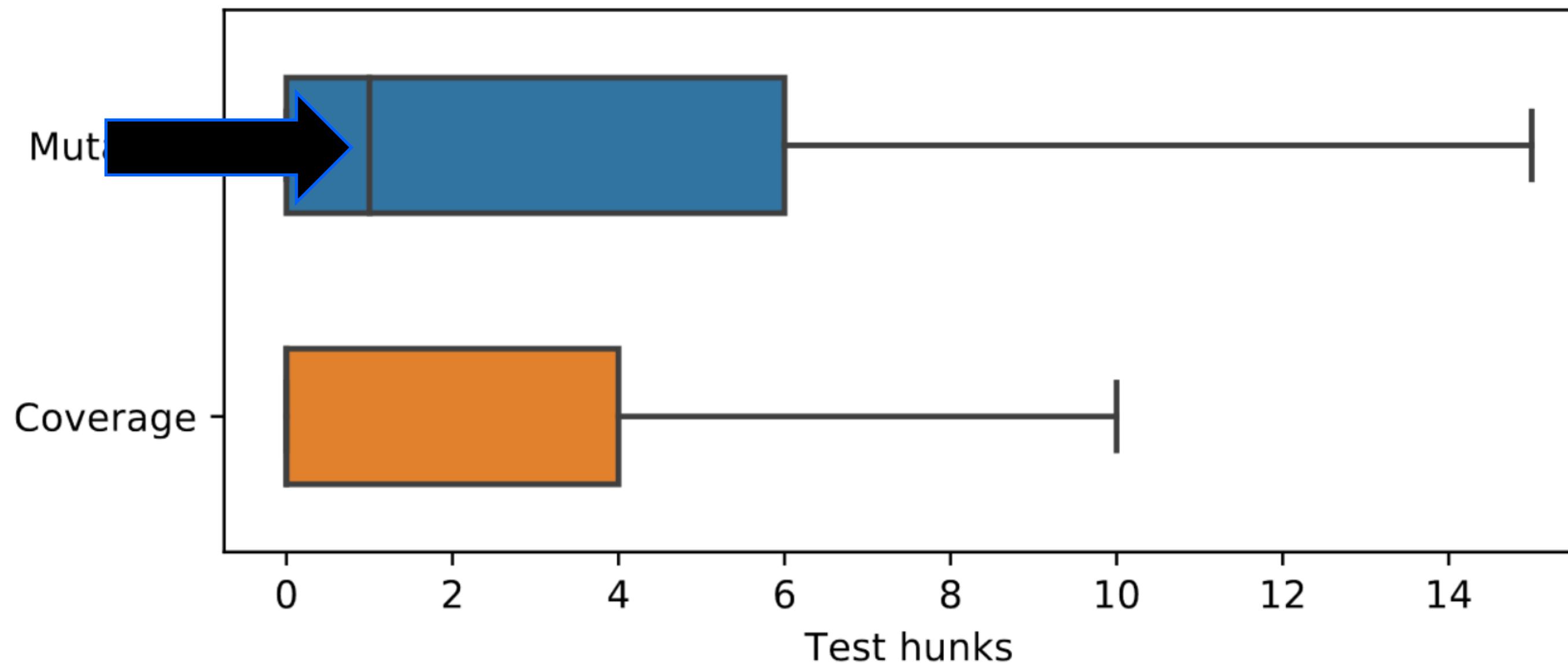
EFFECTS ON QUANTITY



EFFECTS ON QUANTITY



EFFECTS ON QUANTITY

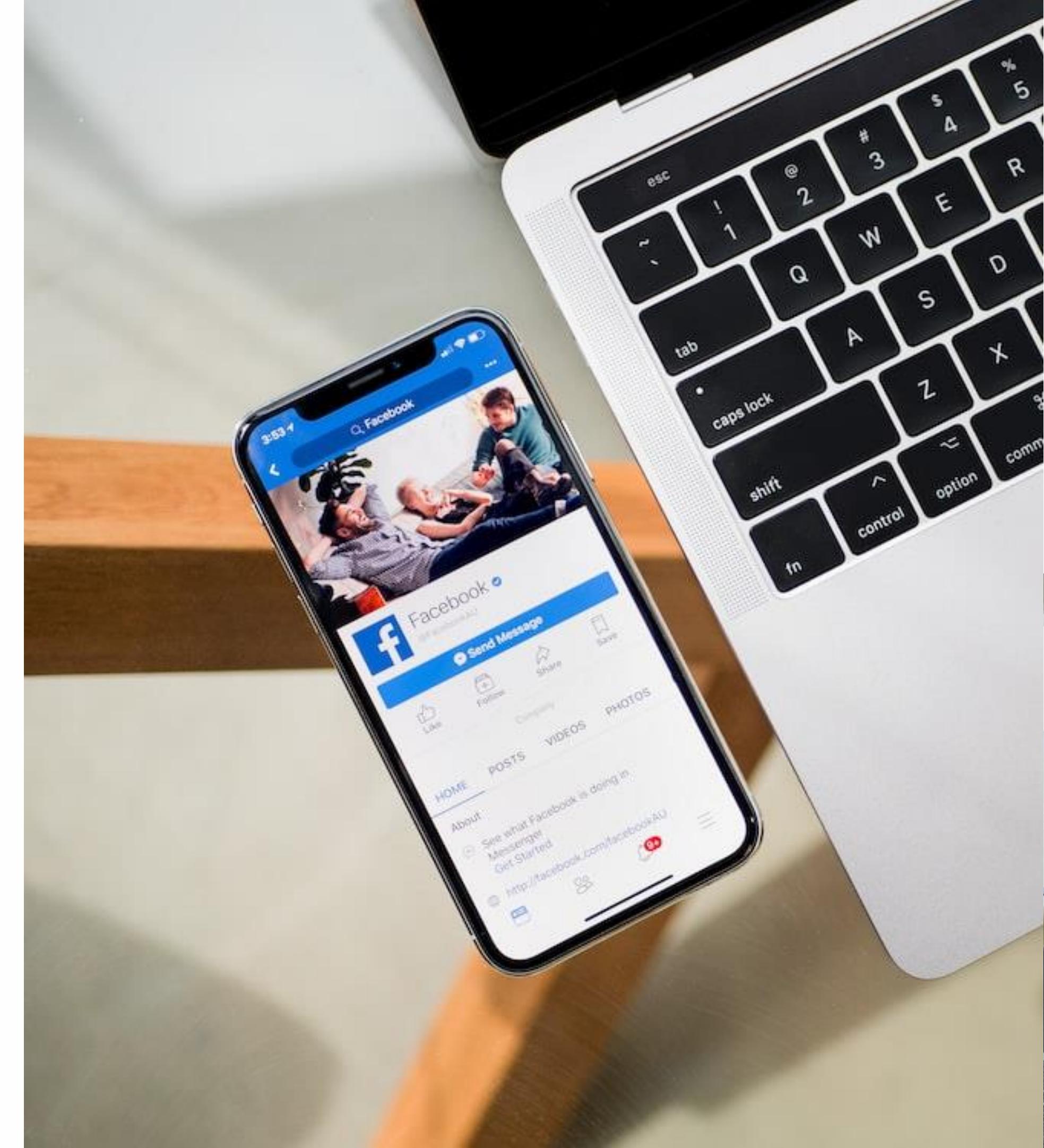


META (Facebook)

M. Beller, C. Wong, J. Bader, A. Scott, M. Machalica,
S. Chandra, E. Meijer,

[“What It Would Take to Use Mutation Testing In Industry – A Study at Facebook”](#)

ACM, 2021.



Overview

- 15000 mutants

Overview

- 15000 mutants
- Defects4J, intern bugs

Overview

- 15000 mutants
- Defects4J, intern bugs
- New mutation operators

Overview

- 15000 mutants
- Defects4J, intern bugs
- New mutation operators
- 26 developers

Overview

- 15000 mutants
- Defects4J, intern bugs
- New mutation operators
- 26 developers
- 1 monthdd test

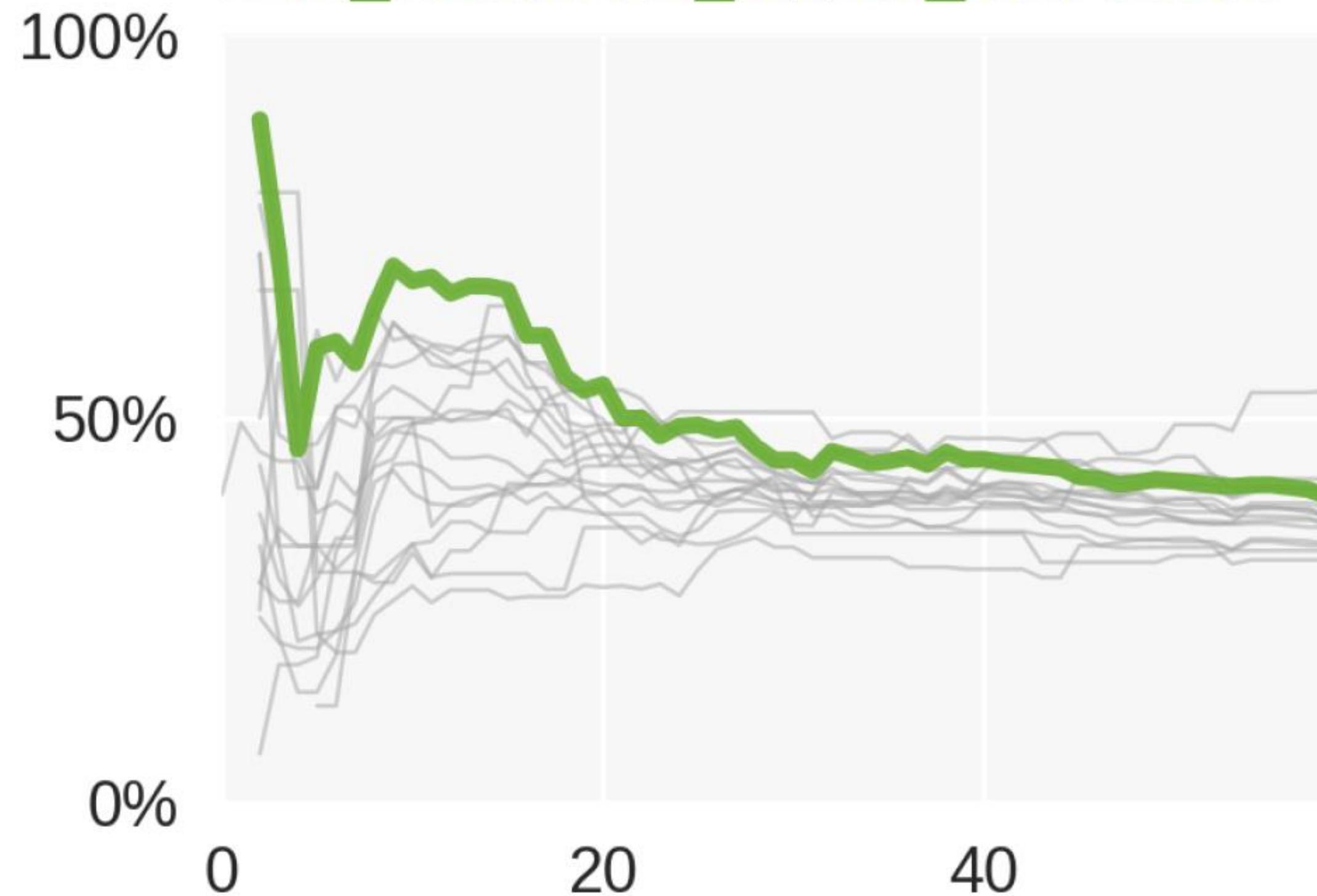
Overview

- 15000 mutants
- Defects4J, intern bugs
- New mutation operators
- 26 developers
- 1 month
- 22/26 lack of testing

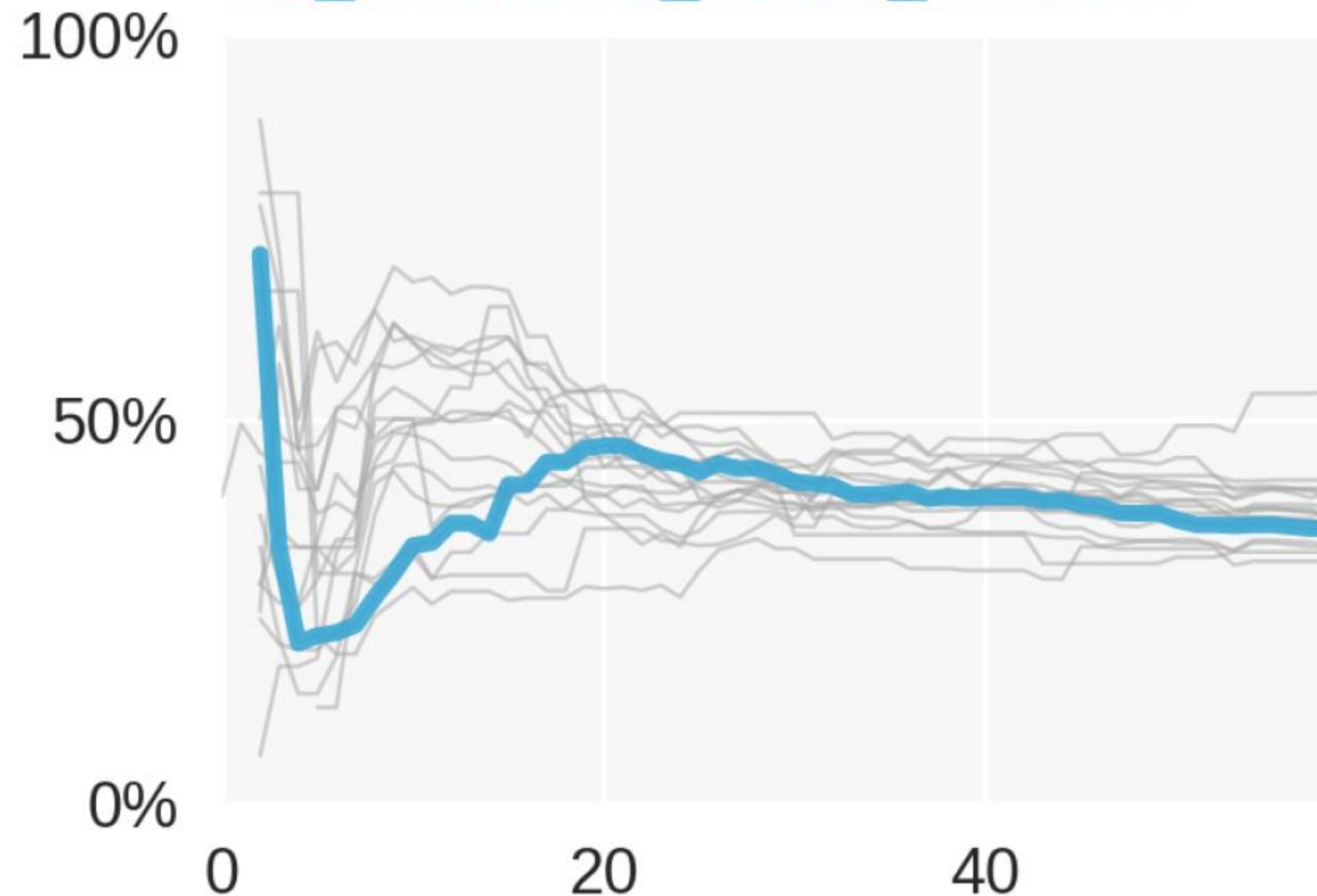
Overview

- 15000 mutants
- Defects4J, intern bugs
- New mutation operators
- 26 developers
- 1 month
- 22/26 lack of testing
- 12/26 would add test

D4J_REMOVE_THEN_BRANCH



FB_REMOVE_NULL_CHECK



Java libs

PiTest

- Fast, scalable



PiTest

- Fast, scalable
- Maintained largely by Henry Coles



PiTest

- Fast, scalable
- Maintained largely by Henry Coles
- Configurable



PiTest

- Fast, scalable
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- Configurable
- Different mutation engines



PiTest

- Fast, scalable
- Maintained largely by Henry Coles
- Configurable
- Different mutation engines
- Different groups of mutators



PiTest

- Fast, scalable
- Maintained largely by Henry Coles
- Configurable
- Different mutation engines
- Different groups of mutators
 - OLD_DEFAULTS
 - DEFAULTS
 - STRONGER_ALL



Google vs. PiTest

- Arithmetic operator replacement
- Logical connector replacement
- Relational operator replacement
- Unary operator insertion
- Statement block removal

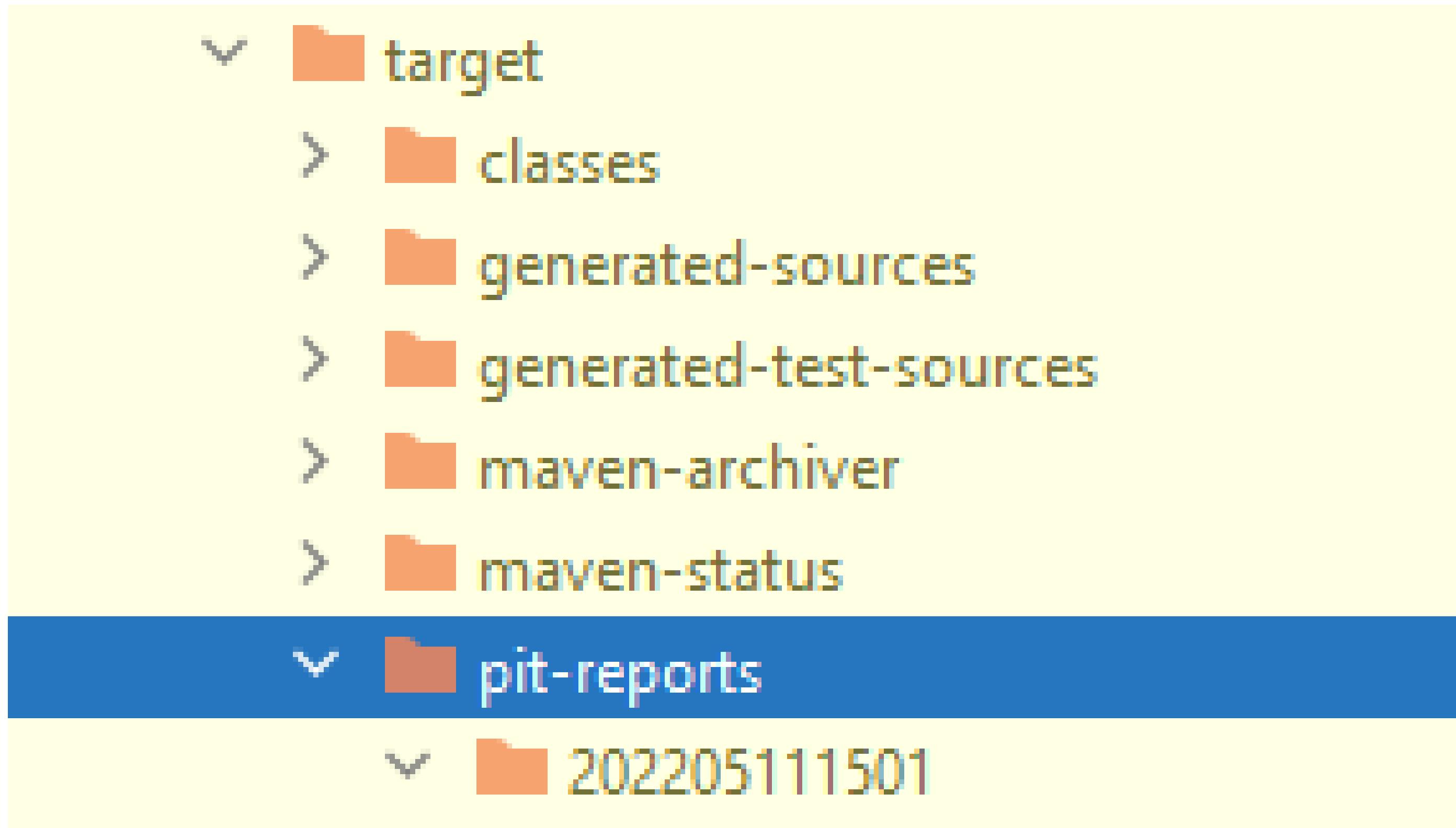
Google vs. PiTest

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- Math mutator
- Conditionals boundary mutator
- Increments mutator
- Empty returns mutator

Google vs. PiTest

- Arithmetic operator replacement
- Logical connector replacement
- Relational operator replacement
- Unary operator insertion
- Statement block removal
- Math mutator
- Conditionals boundary mutator
- Increments mutator
- Empty returns mutator
- Invert negatives
- Negate Conditionals
- Void method calls removal
- False/true returns
- Null returns
- Primitive returns

```
<plugin>
    <groupId>org.pitest</groupId>
    <artifactId>pitest-maven</artifactId>
    <version>LATEST</version>
    <configuration>
        <targetClasses>
            <param>com.your.package.root.want.to.mutate*</param>
        </targetClasses>
        <targetTests>
            <param>com.your.package.root*</param>
        </targetTests>
    </configuration>
</plugin>
```



Number of Classes	Line Coverage		Mutation Coverage		Test Strength	
	Value	Count	Value	Count	Value	Count
2	100%	2/2	0%	0/2	0%	0/2
8	100%	8/8	60%	3/5	60%	3/5
55	84%	46/55	38%	5/13	45%	5/11
9	100%	9/9	0%	0/2	0%	0/2
58	19%	11/58	0%	0/30	0%	0/3
12	75%	9/12	100%	7/7	100%	7/7
8	100%	8/8	0%	0/6	0%	0/6
12	100%	12/12	50%	1/2	50%	1/2
130	92%	119/130	69%	51/74	72%	51/71
10	100%	10/10	100%	3/3	100%	3/3
322	99%	319/322	96%	201/209	96%	201/209
137	98%	134/137	86%	68/79	87%	68/78
25	44%	11/25	50%	2/4	50%	2/4
11	64%	7/11	100%	2/2	100%	2/2
3	54%	3/3	26%	10/39	100%	10/10
136	81%	136/136	81%	86/139	86%	86/96
137	80%	136/137	77%	85/136	88%	86/101
138	80%	136/138	88%	98/138	88%	86/101
139	80%	136/139	80%	81/139	80%	81/101
140	80%	136/140	80%	81/140	80%	81/101
141	80%	136/141	80%	81/141	80%	81/101
142	80%	136/142	80%	81/142	80%	81/101
143	80%	136/143	80%	81/143	80%	81/101
144	80%	136/144	80%	81/144	80%	81/101
145	80%	136/145	80%	81/145	80%	81/101
146	80%	136/146	80%	81/146	80%	81/101
147	80%	136/147	80%	81/147	80%	81/101
148	80%	136/148	80%	81/148	80%	81/101
149	80%	136/149	80%	81/149	80%	81/101
150	80%	136/150	80%	81/150	80%	81/101
151	80%	136/151	80%	81/151	80%	81/101
152	80%	136/152	80%	81/152	80%	81/101
153	80%	136/153	80%	81/153	80%	81/101
154	80%	136/154	80%	81/154	80%	81/101
155	80%	136/155	80%	81/155	80%	81/101
156	80%	136/156	80%	81/156	80%	81/101
157	80%	136/157	80%	81/157	80%	81/101
158	80%	136/158	80%	81/158	80%	81/101
159	80%	136/159	80%	81/159	80%	81/101
160	80%	136/160	80%	81/160	80%	81/101
161	80%	136/161	80%	81/161	80%	81/101
162	80%	136/162	80%	81/162	80%	81/101
163	80%	136/163	80%	81/163	80%	81/101
164	80%	136/164	80%	81/164	80%	81/101
165	80%	136/165	80%	81/165	80%	81/101
166	80%	136/166	80%	81/166	80%	81/101
167	80%	136/167	80%	81/167	80%	81/101
168	80%	136/168	80%	81/168	80%	81/101
169	80%	136/169	80%	81/169	80%	81/101
170	80%	136/170	80%	81/170	80%	81/101
171	80%	136/171	80%	81/171	80%	81/101
172	80%	136/172	80%	81/172	80%	81/101
173	80%	136/173	80%	81/173	80%	81/101
174	80%	136/174	80%	81/174	80%	81/101
175	80%	136/175	80%	81/175	80%	81/101
176	80%	136/176	80%	81/176	80%	81/101
177	80%	136/177	80%	81/177	80%	81/101
178	80%	136/178	80%	81/178	80%	81/101
179	80%	136/179	80%	81/179	80%	81/101
180	80%	136/180	80%	81/180	80%	81/101
181	80%	136/181	80%	81/181	80%	81/101
182	80%	136/182	80%	81/182	80%	81/101
183	80%	136/183	80%	81/183	80%	81/101
184	80%	136/184	80%	81/184	80%	81/101
185	80%	136/185	80%	81/185	80%	81/101
186	80%	136/186	80%	81/186	80%	81/101
187	80%	136/187	80%	81/187	80%	81/101
188	80%	136/188	80%	81/188	80%	81/101
189	80%	136/189	80%	81/189	80%	81/101
190	80%	136/190	80%	81/190	80%	81/101
191	80%	136/191	80%	81/191	80%	81/101
192	80%	136/192	80%	81/192	80%	81/101
193	80%	136/193	80%	81/193	80%	81/101
194	80%	136/194	80%	81/194	80%	81/101
195	80%	136/195	80%	81/195	80%	81/101
196	80%	136/196	80%	81/196	80%	81/101
197	80%	136/197	80%	81/197	80%	81/101
198	80%	136/198	80%	81/198	80%	81/101
199	80%	136/199	80%	81/199	80%	81/101
200	80%	136/200	80%	81/200	80%	81/101
201	80%	136/201	80%	81/201	80%	81/101
202	80%	136/202	80%	81/202	80%	81/101
203	80%	136/203	80%	81/203	80%	81/101
204	80%	136/204	80%	81/204	80%	81/101
205	80%	136/205	80%	81/205	80%	81/101
206	80%	136/206	80%	81/206	80%	81/101
207	80%	136/207	80%	81/207	80%	81/101
208	80%	136/208	80%	81/208	80%	81/101
209	80%	136/209	80%	81/209	80%	81/101
210	80%	136/210	80%	81/210	80%	81/101
211	80%	136/211	80%	81/211	80%	81/101
212	80%	136/212	80%	81/212	80%	81/101
213	80%	136/213	80%	81/213	80%	81/101
214	80%	136/214	80%	81/214	80%	81/101
215	80%	136/215	80%	81/215	80%	81/101
216	80%	136/216	80%	81/216	80%	81/101
217	80%	136/217	80%	81/217	80%	81/101
218	80%	136/218	80%	81/218	80%	81/101
219	80%	136/219	80%	81/219	80%	81/101
220	80%	136/220	80%	81/220	80%	81/101
221	80%	136/221	80%	81/221	80%	81/101
222	80%	136/222	80%	81/222	80%	81/101
223	80%	136/223	80%	81/223	80%	81/101
224	80%	136/224	80%	81/224	80%	81/101
225	80%	136/225	80%	81/225	80%	81/101
226	80%	136/226	80%	81/226	80%	81/101
227	80%	136/227	80%	81/227	80%	81/101
228	80%	136/228	80%	81/228	80%	81/101
229	80%	136/229	80%	81/229	80%	81/101
230	80%	136/230	80%	81/230	80%	81/101
231	80%	136/231	80%	81/231	80%	81/101

Pit Test Coverage Report

Project Summary

Number of Classes	Line Coverage	Mutation Coverage	Test Strength
1	100% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">105/105</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>

Breakdown by Package

Name	Number of Classes	Line Coverage	Mutation Coverage	Test Strength
com.example.module1	1	100% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">105/105</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>

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Breakdown by Package

Name	Num	Line Coverage	Mutation Coverage	Test Strength
com.trendyol.mediatools.appliance	1	100% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">105/105</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>

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Breakdown by Package

Name	Number of Classes	Line Coverage	Mutation Coverage	Test Strength
com.trendyol.mediatools.apimarketplace	1	100% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">105/105</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>

Pit Test Coverage Report

Project Summary

Number of Classes	Line Coverage	Mutation Coverage	Test Strength
1	100% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">105/105</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>

Breakdown by Package

Name	Number of Classes	Line Coverage	Mutation Coverage	Test Strength
com.trendyol.mediatools.appliance	1	100% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">105/105</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>	99% <div style="background-color: #e0f2e0; border: 1px solid black; padding: 2px;">71/72</div>

```
122 // Verify for a ".." component at next iter
123 3 if ((newcomponents.get(i)).length() > 0 {
124 {
125     newcomponents.remove(i);
126     newcomponents.remove(i);
127 1 i = i - 2;
128 1 if (i < -1)
129 {
130     i = -1;
131 }
132 }
133 }
```

ARCMUTATE

- Integration with
 - Git, GitHub, BitBucket, Azure Devops, Gitlab



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- Adds new mutator's group
 - EXTENDED



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- Junit 5 acceleration
- Kotlin support





Henry Coles @henry.coles · 6 days ago

- Surviving mutants in this change: 10
- Killed mutants in this change: 0

class	surviving	killed
com.example.moduleb.CatConverter	8	0
com.example.moduleb.AClass	2	0

```
    .map(this::toAnnotationsFile)
46 +     .filter(Files::exists)
47 +
```



Henry Coles @henry.coles · 10 minutes ago

Maintainer



2 different changes can be made to a lambda on line 47 without causing a test to fail

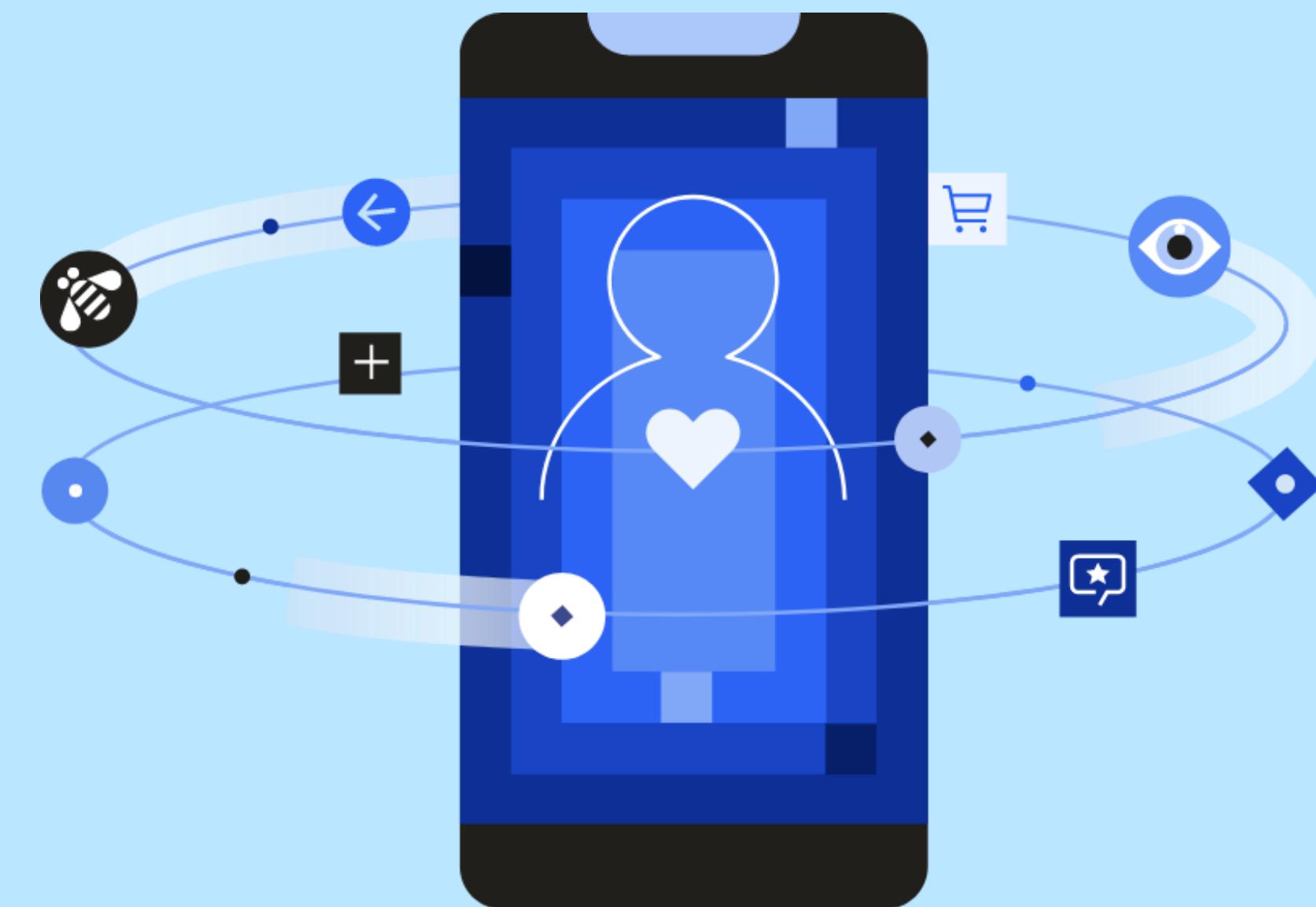
- replaced boolean return with false for 1st lambda in findAnnotationsFiles (0 tests run BooleanFalseReturnValsMutator)
- replaced boolean return with true for 1st lambda in findAnnotationsFiles (0 tests run BooleanTrueReturnValsMutator)

Reply...

Resolve thread



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