Measuring and Mitigating Gaps in Structural Testing

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Code Coverage

Apache Commons CSV

README.md

Apache Commons CSV

Java CI passing | codecov 98% | maven central 1.10.0 | javadoc 1.10.0 | CodeQL passing | openssf scorecard 8.6

The Apache Commons CSV library provides a simple interface for reading and writing CSV files of various types.

Documentation

More information can be found on the Apache Commons CSV homepage. The Javadoc can be browsed. Questions related to the usage of Apache Commons CSV should be posted to the [user mailing list][ml].

Where can I get the latest release?

Used by 29.4k

+ 29,404

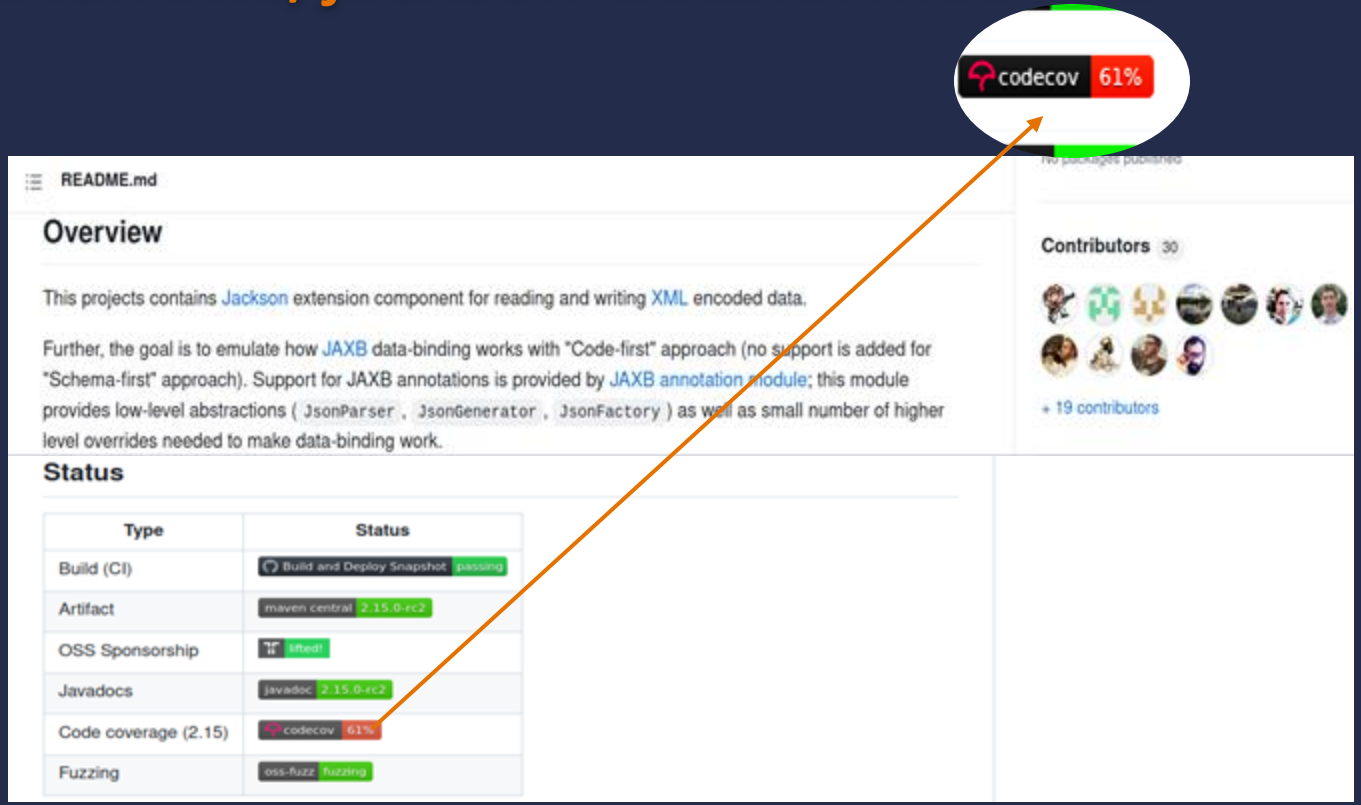
Contributors 38

+ 27 contributors

Languages

Java 99.8% Shell 0.2%

FasterXML/jackson-dataformat-xml



Based on statement coverage CSV seems to be better tested than jackson-dataformat.

Would we say the same thing if we considered the quality of the test oracles in addition to coverage?

Code Coverage, Test Oracle and Fault-detection

- Code coverage is *essential* but *insufficient*

Code Coverage, Test Oracle and Fault-detection

- Code coverage is *essential* but *insufficient*
- Test oracles and fault-detection are *strongly correlated*

Assertions Are Strongly Correlated with Test Suite Effectiveness

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ABSTRACT

Code coverage is a popular test adequacy criterion in practice. Code coverage, however, remains controversial as there is a lack of coherent empirical evidence for its relation with test suite effectiveness. More recently, test suite size has been shown to be highly correlated with effectiveness. However, previous studies treat test methods as the smallest unit of interest, and ignore potential factors influencing this relationship. We propose to go beyond test suite size, by investigating test assertions inside test methods. We empirically evaluate the relationship between a test suite's effectiveness and the (1) number of assertions, (2) assertion coverage, and (3) different types of assertions. We compose 6,700 test suites in total, using 24,000 assertions of five real-world Java projects. We find that the number of assertions in a test suite strongly correlates with its effectiveness, and this factor directly influences the relationship between test suite size and effectiveness. Our results also indicate that assertion coverage is strongly correlated with effectiveness and different types of assertions can influence the effectiveness of their containing test suites.

Categories and Subject Descriptors

D.2.5 [**Software Engineering**]: Testing and Debugging; D.2.8 [**Software Engineering**]: Metrics

General Terms

Experimentation, Measurement

Keywords

Test suite effectiveness, assertions, coverage

1. INTRODUCTION

Software testing has become an integral part of software development. A software product cannot be confidently released unless it is adequately tested. Code coverage is the most popular test adequacy criterion in practice. However, coverage alone is not the goal of software testing, since coverage without checking for correctness is meaningless. A more meaningful adequacy metric is the fault detection ability of a test suite, also known as test suite effectiveness.

There have been numerous studies analyzing the relationship between test suite size, code coverage, and test suite effectiveness [13, 14, 16, 17, 18, 19, 22]. More recently, Inozemtseva and Holmes [6] found that there is a moderate to very strong correlation between the effectiveness of a test suite and the number of test methods, but only a low to moderate correlation between the effectiveness and code coverage when the test suite size is controlled for. These findings imply that (1) the more test cases there are, the more effective a test suite becomes, (2) the more test cases there are, the higher the coverage, and thus (3) test suite size plays a prominent role in the observed correlation between coverage and effectiveness.

All these studies treat test methods as the smallest unit of interest. However, we believe such coarse-grained studies are not sufficient to show the main factors influencing a test suite's effectiveness. In this paper, we propose to dissect test methods and investigate why test suite size correlates strongly with effectiveness. To that end, we focus on test assertions inside test methods. Test assertions are statements in test methods through which desired specifications are checked against actual program behaviour. As such, assertions are at the core of test methods.

We hypothesize that assertions[1] have a strong influence on test suite effectiveness, and this influence, in turn, is the underlying reason behind the strong correlation between test suite size, code coverage, and test suite effectiveness. To the best of our knowledge, we are the first to conduct a large-scale empirical study on the direct relationship between assertions and test suite effectiveness.

In this paper, we conduct a series of experiments to quantitatively study the relationship between test suite effectiveness and the (1) number of assertions, (2) assertion coverage, and (3) different types of assertions.

This paper makes the following main contributions:

- The first large-scale study analyzing the relation between test assertions and test suite effectiveness. Our study composes 6,700 test suites in total, from 5,882 test cases and 24,701 assertions of five real-world Java projects in different sizes and domains.

[1]We use the terms 'assertion' and 'test assertion' interchangeably in this paper.

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Coverage Based on Test Oracles

- Considers program execution and test oracles
  - Support statement criterion
  - Only *assess* test suite
- We build on Checked Coverage by Schuler and Zeller
  - We support stronger criterion
  - We introduce and study the concept of *Coverage Gap*

Focus of Our Paper

- Measuring the gap between code that is executed and code that is checked by test oracles – we call this the *coverage gap*
- Evaluating the impact of the coverage gap on fault-detection
- Mitigating coverage gaps by enhancing test suites to achieve better fault detection

Measuring Gaps

	E	E∩C	G
1:	✓		✓
2:	✓		✓
3:	✓		✓
4:	✓	✓	
5:	✓		✓
6:	✓		✓
7:	✓		✓
8:	✓	✓	

```
public class Triangle {

    int s1, s2, s3, p, color;
    Triangle(int a1, int a2, int a3, int c) {
1:      s1 = a1;
2:      s2 = a2;
3:      s3 = a2;
4:      color = c;
5:      setPerimeter();
    }

    private void setPerimeter() {
6:      p = s1 + s2 + s3;
    }

    public int getPerimeter() {
7:      return p;
    }

    public int getColor() {
8:      return color;
    }
}
```

```
@Test
public void testColor() {
  Triangle t = new Triangle(2,3,2,1);
  t.getPerimeter();
  assertEquals(1, t.getColor());
}
```

Covered: 100%
Checked: 25%
In Gap: 75%

Mitigating Gaps

```
public class Triangle {

    int s1, s2, s3, p, color;
    Triangle(int a1, int a2, int a3, int c) {
1:      s1 = a1;
2:      s2 = a2;
3:      s3 = a2;
4:      color = c;
5:      setPerimeter();
    }

    private void setPerimeter() {
6:      p = s1 + s2 + s3;
    }

    public int getPerimeter() {
7:      return p;
    }

    public int getColor() {
8:      return color;
    }
}
```

field write: s1, s2, s3

field read: s1, s2, s3
write: p

field read: p

Recommendation
---
getPerimeter()

```
@Test
public void testColor() {
  Triangle t = new Triangle(2,3,2,1);
  assertEquals(1, t.getColor());
  assertEquals(7,t.getPerimeter());
}
```

Evaluation: Artifacts

- 13 Java Applications
- 16K tests
- 51.6K test assertions

TABLE I
DESCRIPTION OF ARTIFACTS

Artifact (version)	Description	Program Size(SLOC)[1]	Test Size(SLOC)[1]	Tests(#)[2]	Assertions(#)[2]
Commons-Cli (1.4) [14]	Command line option parsing	2,699	3,932	372	573
Commons-Codec (1.2) [15]	Common encodings	8,352	12,182	887	1,793
Commons-Csv (1.5) [16]	CSV utilities	1,615	4,467	296	934
Commons-Lang (3.6) [17]	Java helper utilities	27,265	48,172	2,908	15,424
Commons-Validator (1.6) [18]	Data validation	7,409	8,352	536	2,486
Gson (2.8.0) [22]	JSON support	7,815	13,762	1,014	1,780
Jackson-Dataformat-Xml (2.9.10) [27]	XML processing	4,945	5,728	185	556
Jaxen (1.2.0) [30]	XPath engine	10,760	8,042	716	587
JFreeChart (1.5.0) [31]	2D Charts	97,350	39,348	2,174	5,506
Joda-Time (2.10.11) [32]	Date and time library	28,811	55,849	4,238	17,973
Jsoup (1.10.1) [33]	HTML parsing	10,785	5,499	510	1,645
Plexus-Utils (3.1.0) [10]	Utility classes	18,496	6,337	304	799
XStream (1.14.15) [11]	XML serialization	21,741	25,518	1,830	1,554
	Total:	248K	237K	16K	51.6K

[1] Source lines of code (SLOC) are non-comment, non-blank lines reported by the IntelliJ statistic plugin.
[2] Tests are JUnit test cases annotated with @Test, and assertions are JUnit assertions.

Research Questions

- RQ1: Gaps in studied artifacts

  Finding: Gaps range from 19-51 percentage points (pp), with an average of 35pp

- RQ2: Impact of gaps on fault detection
- RQ3: Recommender performance
- RQ4: Recommended assertions and fault detection effectiveness

  Finding: Fault detection improved as much as 57*pp* and on avg. 13*pp*

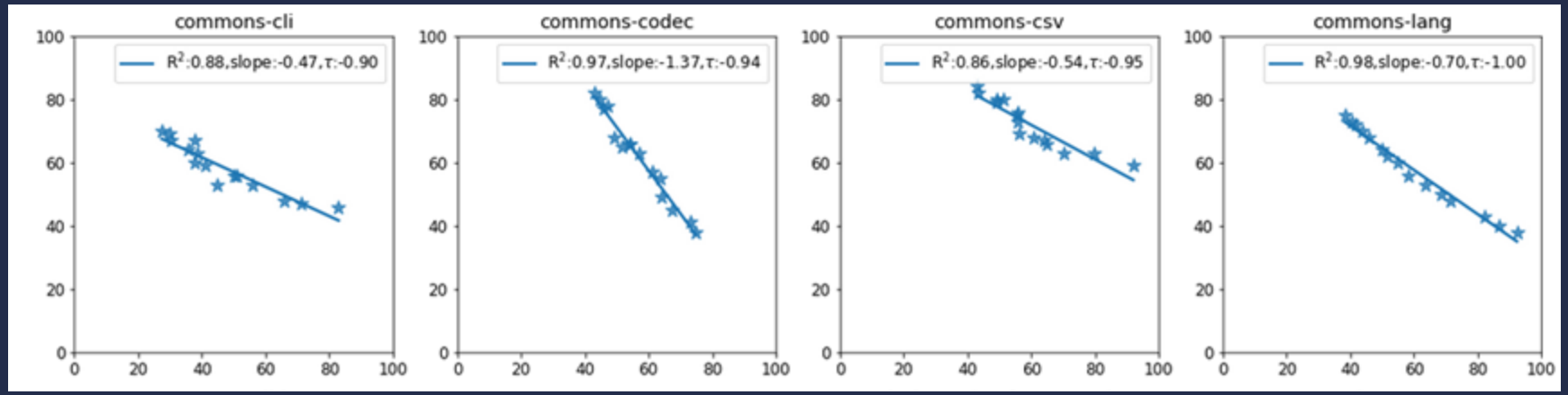
RQ2: Impact of Gaps on Fault Detection

Study Design:

- Generate 180 test suites by manipulating the gap size
- Generated 96K mutants to evaluate fault detection effectiveness
- Measure the correlation between gaps and kill scores

RQ2: Impact of Gaps on Fault Detection

Granularity: Application, Package
Criteria: Statement, Object branch



RQ2: Impact of Gaps on Fault Detection

Findings: Faults can hide in the coverage gap and there is a *strong negative* and *statistically-significant* correlation between gap size and fault-detection effectiveness.

RQ3: Recommender Performance

Study design:

- Remove developer written assertions from test suites
- Compute the resulting gap
- Analyze the SUT and the gap to recommend focus methods
- Compare recommended focus methods to focus methods in removed assertions

RQ3: Recommender Performance

TABLE III

PERCENTAGE OF ASSERTION FOCUS METHODS RECOMMENDED WITHIN THE TOP-K RECOMMENDATIONS ACROSS ALL 13 ARTIFACTS

Artifacts	Assert(#)	Top 1(%)	Top 5(%)	Top 10(%)
Commons-Cli	332	16	51	70
Commons-Codec	532	84	96	97
Commons-Csv	602	69	84	90
Commons-Lang	9843	80	96	98
Commons-Validator	1441	50	77	89
Jackson-Dataformat-Xml	83	33	43	63
Jaxen	134	11	30	37
JFreeChart	3240	82	93	97
Joda-Time	15775	17	43	53
Jsoup	1098	21	31	38
Gson	871	53	82	87
Plexus-Utils	365	55	75	78
XStream	578	38	56	59
Summary	**Total 34894**	**Average 46**	**Average 67**	**Average 73**

RQ3: Recommender Performance

Finding: On average, 67% of the focus methods in the original test suites are suggested within the top-5 recommendations. Restricting to the top-1 recommendation, nearly half of the developer-written focus methods are present.

In summary:

- Traditional coverage can mislead.
- Gaps better reflect the under-tested codes.

Moving forward:

- Scale forms of assertion-based coverage.
- Leverage gaps for test suite improvement.

Artifact: https://github.com/soneyahossain/hcc-gap-recommender

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