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JCWIT: A Correctness-Witness Validator for Java Programs based on Bounded Model Checking

Zaiyu Cheng, Tong Wu, Peter Schrammel, Norbert Tihanyi,
Eddie B. de Lima Filho, Lucas C. Cordeiro

University of Manchester
Department of Computer Science

Introduction

- **Witness validation** is a formal verification method to independently validate software verification tool result.

- The formal software verification work is usually performed by **untrusted verification engines** or **static analysis tools** with the risk of **false positives**.
  - — Witness validation is therefore particularly important.

➢ Correctness witness validation
➢ Violation witness validation

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Motivation

- There are several violation validation tools for the programming language **Java**.

  - GWIT
  - Wit4Java

There is no dedicated correctness witness validators exist!

- There were **seven** Java **verifiers** in SV-COMP 2023.

- Before **JCWIT** was born, there were only **two** Java **validators** in SV-COMP 2023.


```
JavaOverall:
  properties:
    - assert_java
  categories:
    - assert_java.ReachSafety-Java
  verifiers:
    - coastal
    - gdart
    - java-ranger
    - jayhorn
    - jbmc
    - jdart
    - mlb
    - spf
    - swat
  validators:
    - wit4java-violation-1.0
    - gwit-violation-1.0
```

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Princinples

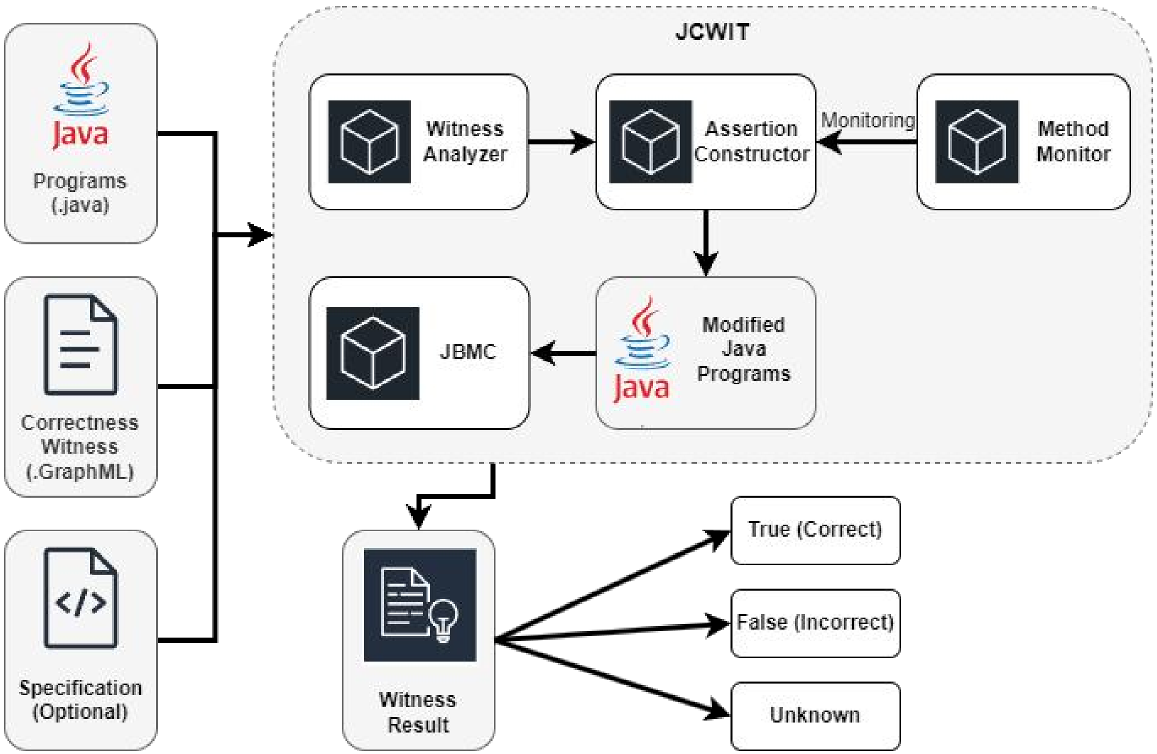
Drawing inspiration from the existing methodology
validation via verification

- Transform the program such that the invariants are **asserted**.
- A standard **verification engine** is then asked to verify that the **transformed program** satisfies the original **specification** and all **assertions** added to the program hold.

The core idea of this approach is to use **existing verification tools** to confirm the **accuracy** and **reliability** of the **evidence** generated by the verification process

Architecture

We implemented an open source[1] tool for Java Correctness Witness



1. https://github.com/Chriszai/JCWIT

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Witness Analyzer

- There are three data elements types in the witness.
  - ➢ Graph Data for Witness Automaton
  - ➢ Node Data for Automaton States
  - ➢ Edge Data for Automaton Transitions
- The data elements are accompanied by different annotations (or sub-elements) based on their respective categorizations.
- The analyser will check whether these annotations comply with three criteria:
  — whether an annotation comply with specific format requirements.
  — whether an annotation comply with optional value ranges.
  — whether an annotation is mandatory.

Assertion Constructor

1. Match and extract the values of value-type variables or class identifiers of reference-type variables from the invariants in the witness.

2. Assert the extracted invariants at the appropriate positions based on the meta-information.

```
<node id="n0">
    <data key="invariant">
        java.lang.Object.@class_identifier="java::Example";
    </data>
</node>
<edge source="n0" target="n1">...</edge>
<node id="n1"><data key="invariant">anonlocal::1i = 5;</data></node>
```

The value and class identifier are stored in the witness in the above form

Method Monitor

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When a particular method is executed multiple times, inserted assertions that are not pertinent to the current method invocation will be inadvertently executed

Solution:

1. Introduce method counters to record the frequency of method calls during program execution.

2. Upon each invocation, the corresponding method's counter is incremented accordingly.

3. The method monitor maintains a static method internally so that the different invariants corresponding to the same execution statement will be asserted separately rather than simultaneously.

The principle is to allow programs to be able to selectively execute assertions based on the current number of times a method is being invoked

Example

```
publics tatic void main(String[] args) {
    Example.isRightTriangle(3,4,5);
    Example.isRightTriangle(6,8,10);}
static void isRightTriangle(int a, int b, int c){
    int x =max(max(a,b),c);
    int y= a * a + b * b + c * c;
    if(y == 2* x * x) assert true;
    else assert false;}
```

```
//The counter of the example program is:
static int Example_isRightTriangle_III_V=0;
publicstatic void assertionSelection (
int index, boolean ... conditions){assert conditions[index];}
```

The static method that selectively executes assertions

The static method are inserted

```
publics tatic void main(String[] args) {
    Example.isRightTriangle(3,4,5);
    //Counter incremented.
    Example_isRightTriangle_III_V++;
    Example.isRightTriangle(6,8,10);}
static void isRightTriangle(int a, int b, int c){
    int x =max(max(a,b),c);
    assertionSelection(Example_isRightTriangle_III_V, x==5, x==10);
    int y= a * a + b * b + c * c;
    assertionSelection(Example_isRightTriangle_III_V, y==50, y==200);
    if(y == 2* x * x) assert true;
    else assert false;}
```

- On the first invocation, the invariants x = 5 and y = 50 are asserted. The method's counter is then incremented, and the invariants x = 10 and y = 200 are asserted on the second invocation.

Verification

- When everything is ready, JCWIT compiles the transformed program again as a .class file, and is then used as input for verification by the Java Bounded Model Checker (JBMC).

- The results of the verification will be divided into three types.

  - ➢ True
    - A successful verification report indicates that all invariants within a correctness witness automaton are valid.

  - ➢ False
    - A report informing verification failure means that a witness automaton contains erroneous program execution trajectories or that the invariants within the execution states are incorrect.

  - ➢ Unknown
    - A report informing an unknown verification result indicates that JCWIT has encountered impediments during the verification process of a .class file.

Evaluation

- Each verification run was initiated on machines equipped with the GNU/Linux operating system (x86_64-linux Ubuntu 22.04) and featuring an Intel Xeon E3-1230 v5 Computer Processing Unit (CPU) (3.40 GHz) with eight processing units.

JCWIT participated in JavaOverall category adhered to a single specification called ReachSafety in SV-COMP 2024.

Result Type	Quantities	Comment
Correct True	67	Witness Confirmed
Unknown (38 Witnesses)	13	Invariant Extraction/Insertion Failed
	19	Program Compilation Error
	3	Validation timeout
	3	IO Exception

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Reference

1. Howar, F., Mues, M. (2022). **GWIT: A Witness Validator for Java based on GraalVM (Competition Contribution)**. In: Fisman, D., Rosu, G. (eds) Tools and Algorithms for the Construction and Analysis of Systems. TACAS 2022. Lecture Notes in Computer Science, vol 13244. Springer, Cham. https://doi.org/10.1007/978-3-030-99527-0_29

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Thank you !