Neural-Based Test Oracle Generation: A Large-Scale Evaluation and Lessons Learned

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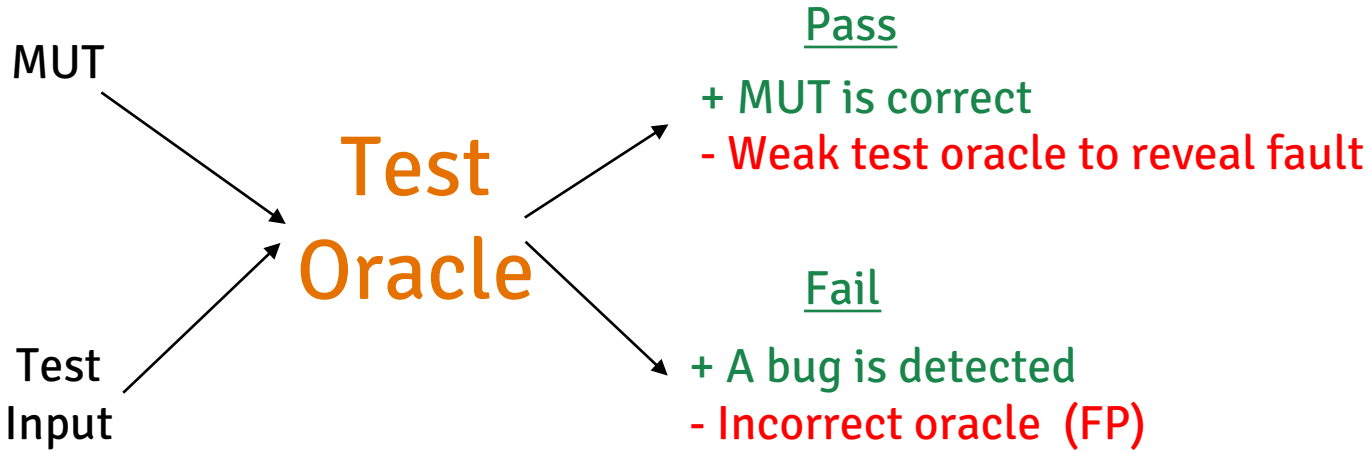


Automated test oracle generation, while advancing, still faces significant challenges

EvoSuite

- An automated unit test generation method for Java
- Produces test inputs to achieve high code coverage
- Suggests assertion or exception oracles based on observed behavior

Test Prefix + Assertion Oracle

Test Prefix

```
public void test00() throws Throwable  {
    Stack<Integer> s0 = new Stack<Integer>();
    Integer int0 = new Integer(0);
    s0.push(int0);
    assertEquals(1, s0.size());
}
```

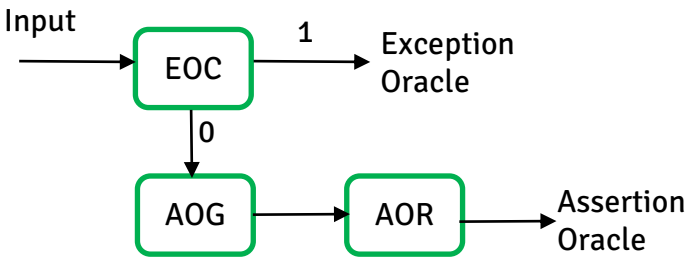
Test Prefix + Exception Oracle

```
public void test11() throws Throwable  {
   Stack<Integer> s0 = new Stack<Integer>();
    try {
      s0.pop();
      fail();
     } catch(EmptyStackException e) {
        verifyException("Stack", e);
    }
}
```

Learning-based Method

- Learns from large-scale training data
- Understands both code and natural language document
- Detects bugs in the current program version

TOGA [1], a state-of-the-art method for test oracle generation



1. *Elizabeth Dinella et al. (2022). TOGA: Neural Method for Test Oracle Generation. ICSE '22, ACM, pp. 2130–2141. https://doi.org/10.1145/3510003.3510141*

Example of Learning-based Oracles

Test Prefix

```
public void test03() throws Throwable {
  Stack<Object> s0 = new Stack<Object>();
  boolean b0 = s0.isEmpty();
}
```

Test Prefix With Assertion Oracle

```
public void test03() throws Throwable {
  Stack<Object> s0 = new Stack<Object>();
  boolean b0 = s0.isEmpty();
  assertTrue(b0)
}
```

Test Prefix

```
public void test05() throws Throwable {
  Stack<Object> s0 = new Stack<Object>();
  s0.peek();
}
```

Test Prefix With Exception Oracle

```
public void test05() throws Throwable {
  Stack<Object> s0 = new Stack<Object>();
    try {
      s0.peek();
      fail();
    } catch (Exception e){
      verifyException("Stack", e);
    }
}
```

Overview

- Validating prior results
  - revealed several issues with the original study setup
- Investigating precision
  - revealed a very high false positive rates
- Investigating bug detection effectiveness
  - revealed limited bug detection effectiveness

Validating Prior Results, Findings and Lesson

TOGA Defects4J Study

Original Study:

- Generated test cases on fixed programs
- Considered bug reaching tests (tests that fail on the buggy version)
- Generated oracles for the bug reaching prefixes
- A bug is detected if a test passed fixed version and failed on the buggy version
- Detected 57 bugs, outperforming other methods (Randoop, seq2seq, JDoctor, AthenaTest)

Our Findings:

Confirmed original results

Most bugs (67%) were detected by implicit oracles when executing EvoSuite test prefixes

TOGA Defects4J Study

Original Study:

- Generated test cases on fixed programs
- Considered bug-reaching tests (tests that fail on

- Detected 57 bugs, outperforming other methods (Randoop, seq2seq, JDoctor, AthenaTest)

Our Findings:

Implicit oracles should be used as a baseline to report fault-detection improvement

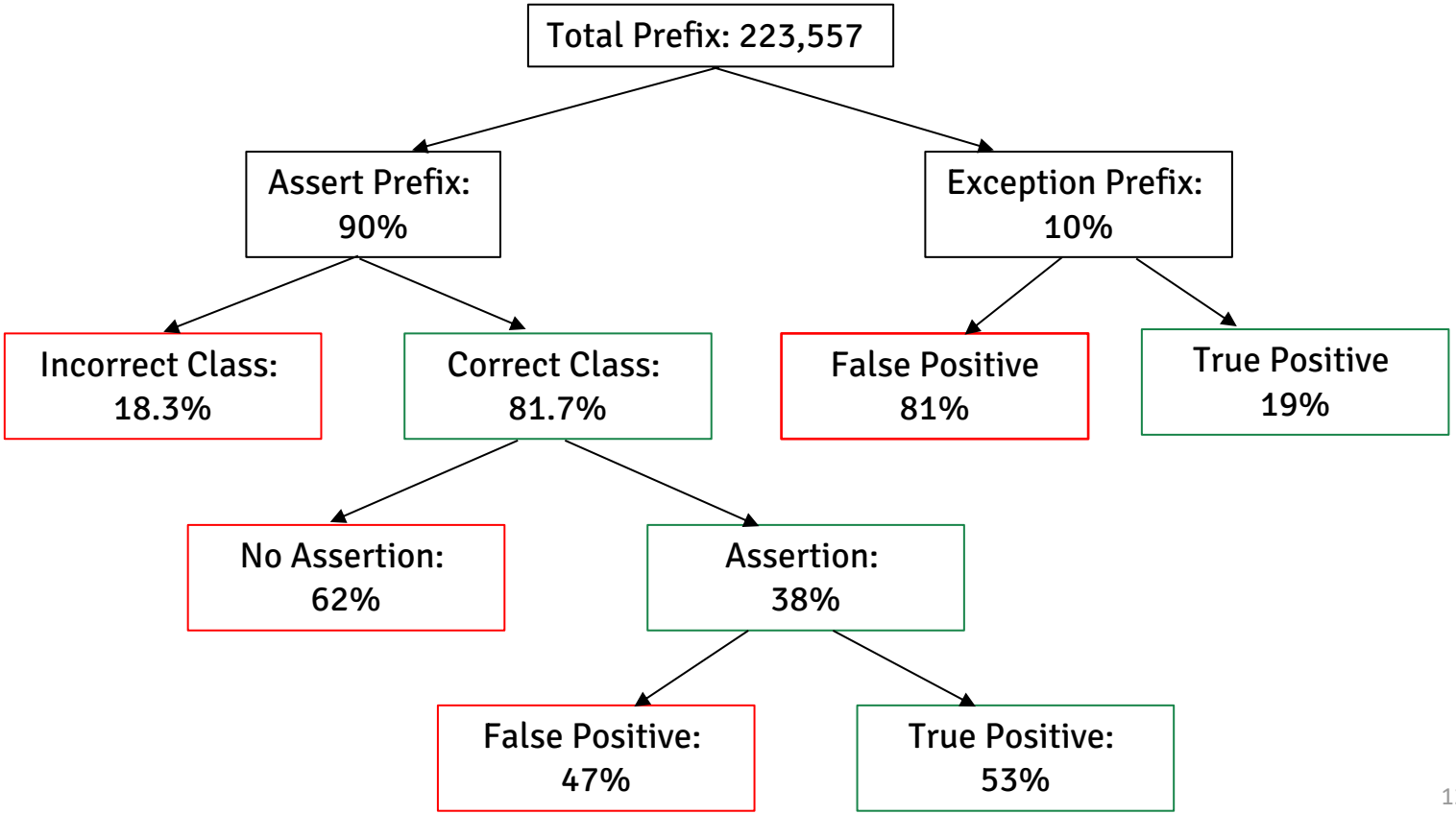
Precision Study, Findings and Lesson

Precision of Learning-based Method

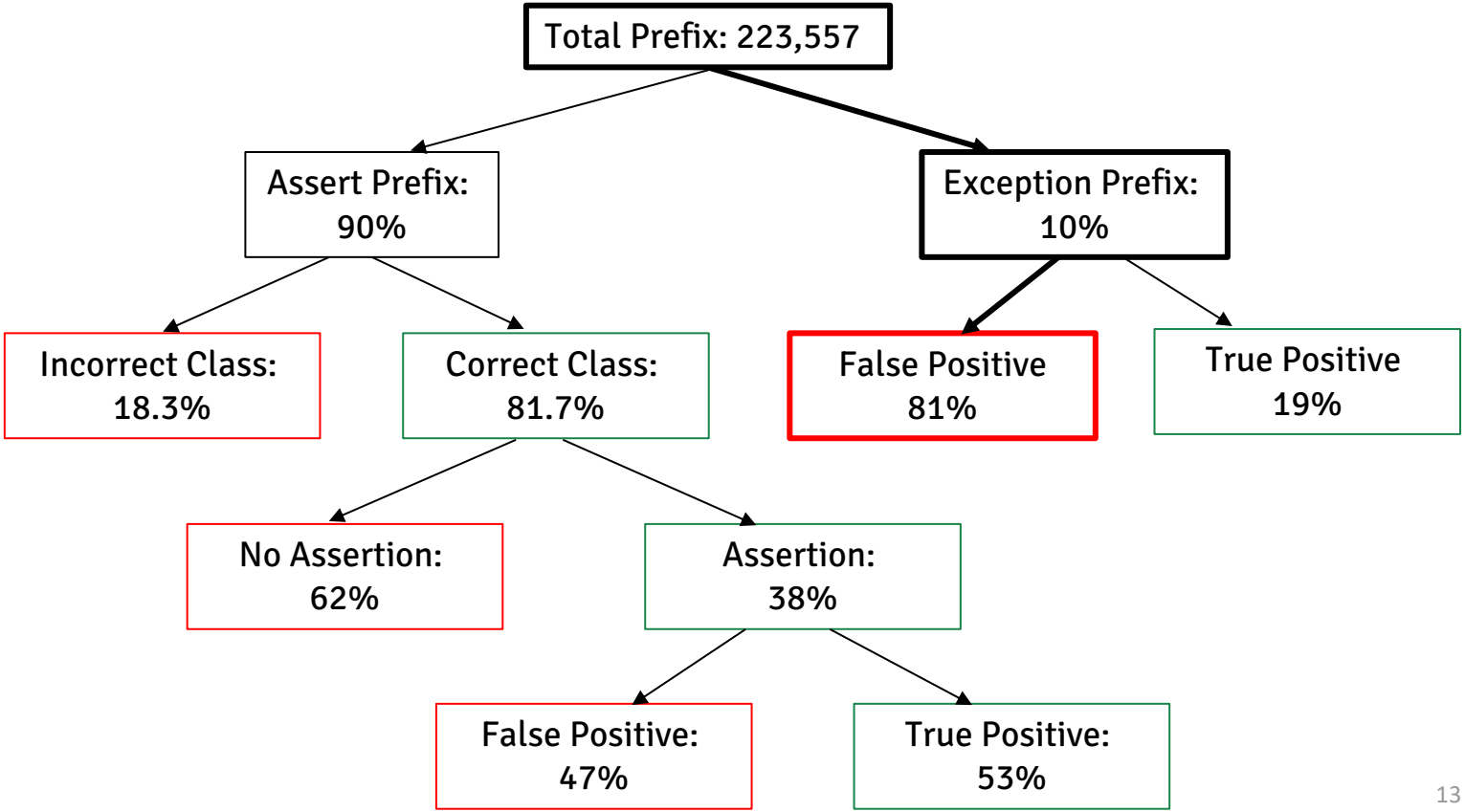
Study Setup:

- Prepared a large-scale dataset from 25 Java applications, consisting of 223.5K test cases
- Generated ground truth oracles using EvoSuite
- Prepared inputs for TOGA to generate oracle
- Ran the integrated tests for validation

Our Findings



Our Findings



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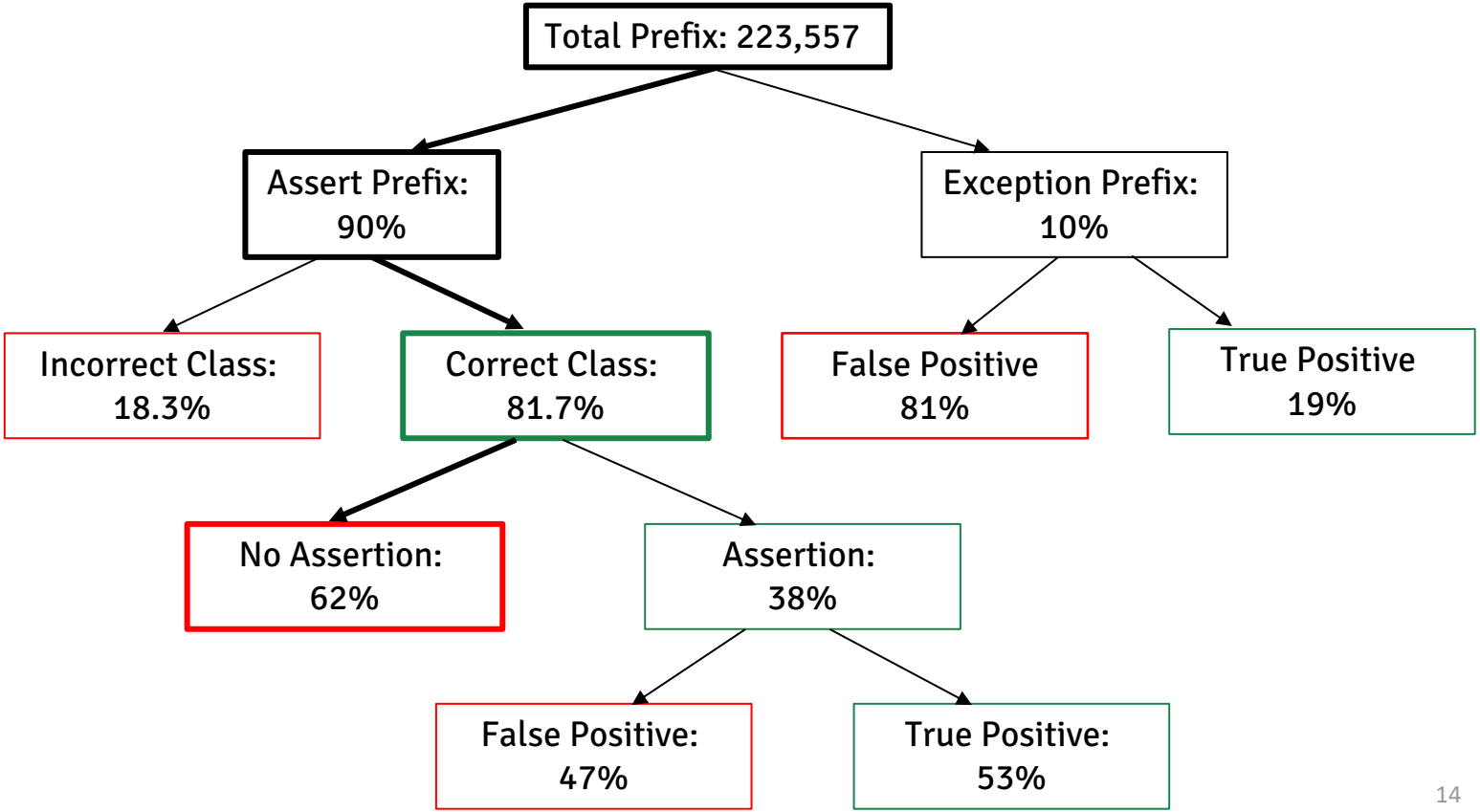
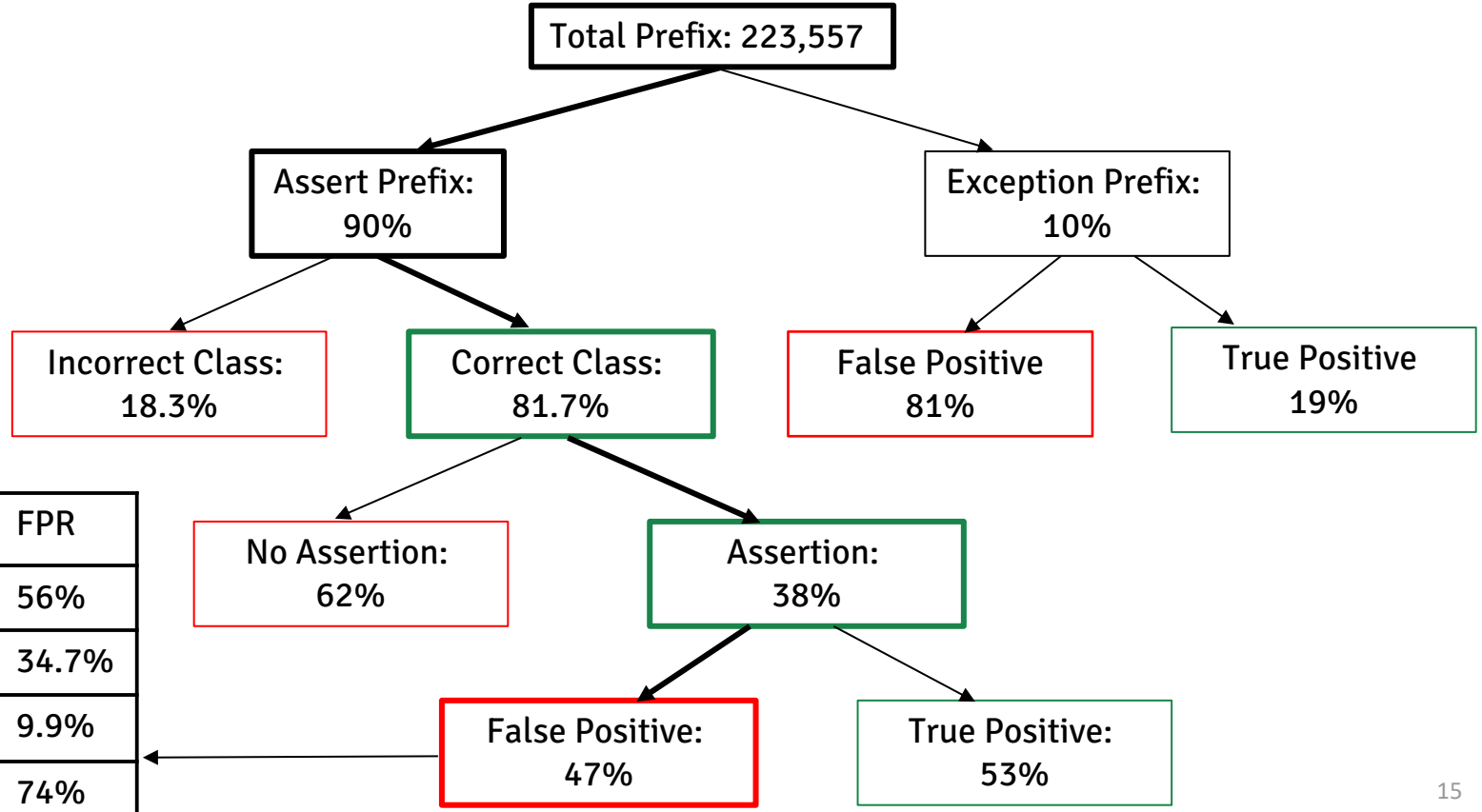
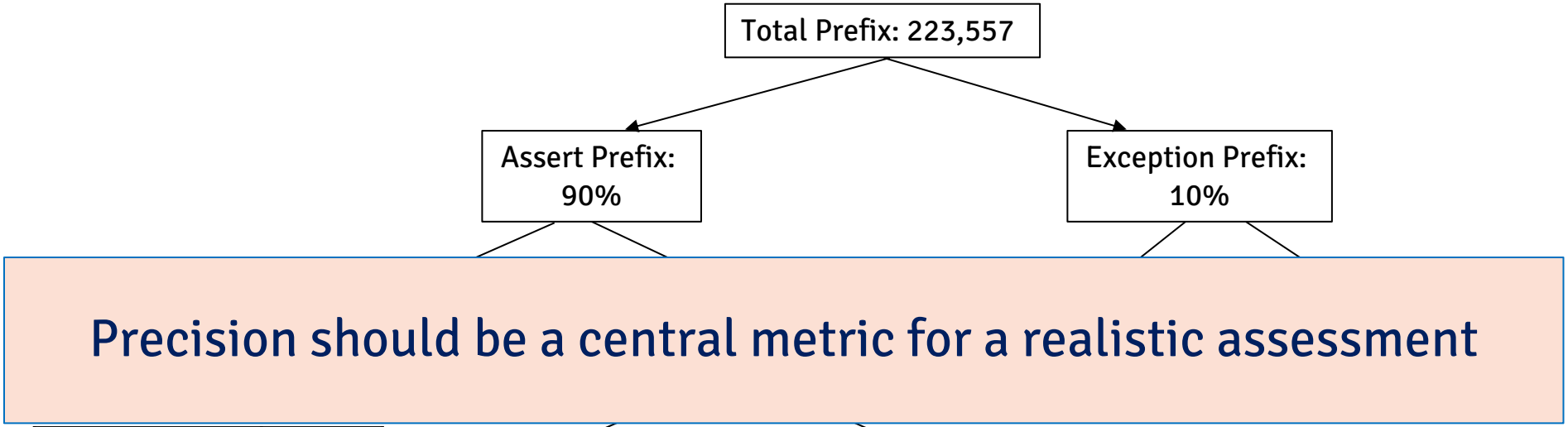


Our Findings



Assertion Type	FPR
assertTrue	56%
assertFalse	34.7%
assertNotNull	9.9%
assertEquals	74%

Our Findings



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Bug Detection Study, Findings and Lesson

Bug Detection Effectiveness of Learning-based Method

Study Setup:

- Considered only true positive assertions

- Prepared three test suites with identical prefixes but with different type of assertions: implicit assertions, EvoSuite assertions, learning-based assertions

- Generated 51K mutated programs and ran different test suites to detect them

- Compared and analyzed relative bug detection effectiveness

Findings

Total Tests	Total Mutants	Mutant Detected by				
		Implicit Oracle (#)	EvoSuite Assertion (#)	EvoSuite Unique (#)	TOGA Assertion (#)	TOGA Unique(#)
34,378	51,385	20,597 (40%)	9,814 (19%)	3,026 (5.9%)	6,893 (13.4%)	105 (0.2%)

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To avoid bias, a more realistic evaluation should use mutation testing

In Summary …

Finding - 1: 67% of the Defects4J bugs can be detected by implicit oracles
Lesson - 1: Implicit oracles should be used as the baseline

Finding – 2: SOTA learning-based method has a very high false positives rate
Lesson – 2: Precision should be a central evaluation metric for a realistic assessment

Finding - 3: SOTA learning-based method has limited unique bug detection capability
Lesson - 3: To avoid bias, a more realistic evaluation should use mutation testing

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Artifact: https://doi.org/10.6084/m9.figshare.21973091.v4

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