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Casual Analysis of Residual Structural Coverage in Dynamic Symbolic Execution

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ABSTRACT

High structural coverage of the code under test is often used as an indicator of the thoroughness and the confidence level of testing. Dynamic symbolic execution is a testing technique which explores feasible paths of the program under test by executing it with different generated test inputs to achieve high structural coverage. It collects the symbolic constraints along the path explored and negates one of the constraints to obtain a new path. However, due to the difficulty of method sequence generation, long run loop and testability issues, it may not be able to generate the test inputs for every feasible path. These problems could be solved by involving developers' help to assist the generation of inputs for solving the constraints. To help the developers figure out the problems, reportig every issue encountered is not enough since browsing through a long list of reported issues and picking up the most related one for the problem is not a easy task as well. In this paper, we propose an approach for carrying out the casual analysis of residual structural coverage in dynamic symbolic execution, which collects the reported issues and coverage information, filter out the unrelated ones and report the non-covered branches with the associated issues. We conducted the evaluation on a set of open source projects and the result shows that our approach reported ?% related issues(may be 100% without false negative) and ?% less issues than the issues reported by Pex, an automated structural testing tool developed at Microsoft Research for .NET programs.

1. INTRODUCTION

A main objective of structural software testing is to achieve full or at least high code coverage such as statement and branch coverage of the program under test. A passing test suite that achieves high code coverage not only indicates the thoroughness of the testing but also provides high confidence of the quality of the program under test. Dynamic Symbolic Execution(DSE)[2, 4, 5] is a variation of symbolic execution, which systematically explores feasible paths of the program under test by running the program with different test inputs to achieve high structural coverage. It collects the symbolic constraints on inputs obtained from predicates in branch statements along the execution and rely on a constraint solver, Z3 for Pex[6] and STP[3] for KLEE[1], to solve the constraints and generate new test input for exploring new path. Currently, DSE works well in generating inputs for methods or parameterized unit tests with parameters of primitive type. However, when applying in object-oriented code, DSE could not easily generate inputs to achieve high structural coverage due to their little support for method sequence generation and floating point arithmetic, huge search space of feasible paths caused by loops and dependence of external library. Tackling these problems require complex analysis of the program and algorithms to find out solutions from a large possible space. But human, especially developers who write the program, could figure out the solution in a short time if provided the branch and statement coverage information with the relevant issues. Exsiting tools, like Pex, could report every issue encountered during the exploration, but some of the issues are actually not the cause of the problem. This will usually result in a long list of unordered issues, which makes it time consuming and tedious for user to figure out which action should be taken for guiding the DSE tool to increase the coverage.

To address this problem, we propose an approach, Covana, which analyses the data collected during the DSE exploration, filters out the unrelevant data and report the non-covered branches with the classified issues. To better inform user the problem, we define the categories of the issues which prevent the DSE technique to generate corresponding inputs:

- object creation problem due to the limitation of method sequence generation
- external library dependence, like uninstrumented method invocations
- environment dependence, like file system, database and so on
- explosion of feasible paths caused by loops or multi-level factory method (may not be examined)

Provided with the coverage data and the reported issue when DSE technique fails to generate an input for a paticular path, our approach is capable of locating the issues for a specific not covered branch and filtering out the unrelevant ones. In

this way, user could browse the issues ordered by the not covered issues and target the problems directly.
Our approach is to build an analysis tool, Covana, upon Pex, an white box test input generation tool developed by Microsoft Research. In order to obtain the coverage data and reported issues from Pex, we provides several Pex extensions that server as observers for observing events and collecting data. Based on the collected data, our approach will pre-processed the data and carry out the analysis on the pre-processed data.

2. EXAMPLE

Our detailed approach is:

1. Collects the branch coverage and find out the not covered branches. If the target statement of the not covered branch is covered, we simply filter out these not covered branches as it is useless for achieving higher coverage.
2. For the not covered branch which involves non-primitive object fields, we will search the reported issues to see whether there is an object creation issue for these fields. If found, we will consider this object creation issue is the cause which disallows Pex to cover the specific branch and report them with the not covered branch.
3. For the uninstrumented method, we will make the method's return value as a symbolic and keep track of it. If there are not coverd branches whose constraints involve the symbolic we tracked, we will report it as the issue of external library dependence. Otherwise we will ignore it and discard the related information.
4. When DSE tool, like pex, fails to deal with the environment dependency or create an instance for some class which implements a specific interface, our tool will suggest user to use mock objects for solving these kind of problems.
5. When there is a explosion of feasible paths caused by loops, we will suggest ? (needs more experiments)

3. APPROACH

3.1 Approach Overview

Our approach takes the coverage data and reported issues as input and outputs the non-covered branches with the associated issues. Figure 1 shows the high level design of Covana. Covana consists of three major components: observer component, pre-processing component and analysis component. The observer is implemented as several Pex extension and is attached to Pex for observing different events and collecting data. It collects the coverage data and reported issues and passed them to the pre-processing component. The pre-processing component remove the useless data and dump the data into binary files. The analysis component consumes the pre-processed data in files, carrys out the analysis on the data and outputs the relevant data for non-covered issues.

3.2 Observer Component

The observer component is implemented as three Pex extensions: (1) Branch coverage observer. (2) Field access observer. (3) Issues observer.

if (x != null) Console.WriteLine("type: " + x.GetType()); IEnumerator xe = x.GetEnumerator();

Figure 1: An integer stack implementation

3.2.1 Branch coverage observer

The branch coverage observer is attached to Pex for collecting the branch coverage data. After all the generated tests are executed, it will enumerate the methods of the class under test, checks the coverage information of each branch inside a method and find out the non-covered branches. As Pex runs on top of MSIL (MicroSoft Intermediate Language) assembly, the observer also collects the IL offset of each non-covered branches for further analysis.

3.2.2 Field access observer

3.2.3 Issues observer

The issue observer collects different kinds of issues reported by Pex, such as object creation issues, uninstrumented method issues and testability issues.

3.3 Pre-processing Component

The pre-processing component pre-processed the different kinds of data collected by the observer component and filter out the useless data based on some heuristics.

3.3.1 Filter out useless branch coverage data

Not all the collected non-covered branches are useful for user to look at. if (x != null) Console.WriteLine("type: " + x.GetType()); IEnumerator xe = x.GetEnumerator();

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