Kaya: A Testing Framework for Blockchain-based Decentralized Applications

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Abstract—In recent years, many decentralized applications based on blockchain (DApp) have been developed. However, due to inadequate testing, DApps are easily exposed to serious vulnerabilities. We find three main challenges for DApp testing, i.e., the inherent complexity of DApp, inconvenient pre-state setting, and not-so-readable logs. In this paper, we propose a testing framework named Kaya to bridge these gaps. Kaya has three main functions. Firstly, Kaya proposes DApp behavior description language (DBDL) to make writing test cases easier. Test cases written in DBDL can also be automatically executed by Kaya. Secondly, Kaya supports a flexible and convenient way for test engineers to set the blockchain pre-states easily. Thirdly, Kaya transforms incomprehensible addresses into readable variables for easy comprehension. With these functions, Kaya can help test engineers test DApps more easily. Besides, to fit the various application environments, we provide two ways for test engineers to use Kaya, i.e., UI and command-line. Our experimental case demonstrates the potential of Kaya in helping test engineers to test DApps more easily.

Index Terms—Decentralized Application Testing, DApp Behavior Description Language, Testing Framework

I. INTRODUCTION

Since the decentralized cryptocurrency BitCoin was proposed by Satoshi Nakamoto [1], blockchain, smart contracts, and DApps have developed rapidly. DApp is an application which usually uses a browser as its front-end and uses smart contracts as its back-end. DApp enables end users to interact directly with blockchain, e.g., exchanging tokens and playing a blockchain-based game. With this property, DApps have become really popular in market. According to the report published by dapp.com, the annual transaction volume of DApps based on blockchain has reached up to 10 billion dollars in 2019.

Before publishing a powerful DApp, comprehensive testing is essential. However, due to the difficulty of executing test cases on DApps, many DApps are lack of comprehensive testing and some of them are exposed to serious vulnerabilities, e.g., the Parity wallet was attacked in July 2017 which causes the loss of 31M dollars and MyEtherWallet was attacked in April 2018 and lost 17M dollars.

DApp testing involves not only users’ behaviors but also the logic of smart contracts [3]. Hence, recent popular smart contract testing tools e.g. Remix[4] and Truffle[5] are not suitable for DApp testing. These tools focus on the development, testing, and deployment of smart contracts, i.e., these tools are trying to help smart contract developers rather than DApp test engineers. Through the investigation of DApp ecology, we find three main challenges and list them as follows.

Challenge 1: Inherent complexity of DApp. In practice, it is necessary for test engineers to test all relevant aspects of DApp at the same time, including front-end events, back-end logic, and some deeper restrictions. This means testing DApps is more complex than testing other applications. However, there is a lack of effective tools to reduce the complexity.

Challenge 2: Inconvenient pre-state setting. Blockchain is stateful. Different pre-states may lead to different execution result. During testing, there are some test cases should be executed in certain pre-states, i.e., integer overflow. Existing method to simulate a certain pre-state is redeploying the smart contract and setting state variables’ value separately using their incomprehensible addresses. It is costly and inconvenient. How to conveniently and flexibly change these pre-states is still an unsolved problem.

Challenge 3: Requirements for comprehensive logs. In traditional programs, logs are readable and easy to understand. However, In DApps, logs produced by smart contract virtual machine (SCVM)[6] are not as readable as traditional logs. The variables in SCVM logs are displayed as addresses rather than readable names, and the operations taken by SCVM are shown in a format similar to assembly code. Both of them make SCVM logs difficult to understand.

In this paper, we propose a testing framework called Kaya[7] to help test engineers test DApps more easily. Kaya implements three core functions to solve above three challenges.

1) Provide an easy way for testing by writing test cases with DBDL and executing test cases automatically. Using DBDL, test engineers can easily pack those complex front-end events and back-end smart contracts into simple test cases. Kaya will execute these test cases automatically.

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cally, i.e. simulating front-end events, setting blockchain pre-states and running smart contracts.

2) Provide a flexible and convenient way for test engineers to set the blockchain pre-state as they need. Before executing test cases, Kaya will construct the blockchain pre-state according to the settings of test engineer.

3) Generate readable analysis report for easy comprehension. Kaya can calculate the correspondence between addresses and variables and transform not-so-readable logs produced by SCVM into a form which is much easier to understand for test engineers.

The first function simplifies the work of writing and executing test cases, which solves the Challenge 1. The second function makes test cases can be executed in a certain state to solve the Challenge 2. The third function overcomes Challenge 3 by helping test engineers to analyze the results of DApp testing like normal software testing. In this paper, we conduct experimental cases to evaluate the effect of Kaya. These cases show that Kaya is indeed effective in DApp testing.

II. OVERVIEW

In this section, we will introduce the framework and workflow of Kaya. Kaya is composed of three modules, i.e. Kaya Graphical User Interface (KGUI), Core Function Module (CFM), and Log Analyzer (LA). Each of these three modules plays a unique role in Kaya. KGUI helps test engineers to write test cases with DBDL easily and quickly. CFM executes test cases and transforms variables into addresses. LA generates readable analysis reports for test engineers. The relationship between these three modules in Kaya is illustrated as Fig. 1.

A. Kaya Graphical User Interface

KGUI accepts inputs from test engineers and outputs test cases written in DBDL to CFM. DBDL is a domain specific language created for describing test cases in Kaya, the details of DBDL are introduced in Section III. The inputs in KGUI should be the smart contracts used by the target DApp, front-end events description, and blockchain pre-state parameters. KGUI follows the following steps to work.

1) Accept Smart Contracts. At the beginning of this module, test engineers need to input the source codes of smart contracts used in the target DApp.

2) Extract Variables. Then, all useful variables contained in the source codes of smart contracts are extracted. These variables will become the parameters when setting pre-state.

3) Add Front-end Events. Next, test engineers can add front-end events to describe the usage of the target DApp. These events should be written in DBDL.

4) Set Pre-states. Test engineers can also set some parameters to construct the blockchain pre-states. The constructed pre-states will be the runtime environment of those test cases. Settable parameters include the variables extracted from smart contracts and the attributes of used blockchain accounts, e.g. the balance.

5) Get Test Cases. Finally, front-end events and blockchain pre-state parameters are packed into test cases written in DBDL. These test cases are transmitted to CFM for further execution.

B. Core Function Module

CFM is the key module in Kaya. It takes the responsibilities of executing test cases automatically, including collecting useful information, transforming blockchain pre-state parameters into (address, value) pairs, executing test cases, converting the output of SCVM to a readable format. The workflow of this module is shown as follows.

1) Interpret DBDL. This step accepts test cases written in DBDL and translates them into the data structure which is convenient for the next step to handle. During interpretation, front-end events are executed by Kaya to obtain necessary information.

2) Transform Variables. In this step, all blockchain pre-state parameters are transformed into (address, value) pairs in SCVM according the address calculation rules. Without this step, SCVM cannot recognize these parameters.

3) Deploy Blockchain Pre-State. Blockchain pre-state are the runtime environment of test cases. Before running a test case, CFM will deploy the blockchain pre-state according to the setted parameters.

4) Execute Smart Contracts. Run smart contracts in SCVM with the pre-state.

5) Collect Variable Traces. Collect all variable traces produced by SCVM for further analysis.

6) Decode Addresses. This step transforms addresses into the origin names of variables. After this step, logs are readable for test engineers.
C. Log Analyzer

LA analyzes the outputs generated by CFM. After analysis, a report is produced to show changes of each variable. With this report, test engineers can easily check the program logics implemented by the target DApp.

III. DApp Behavior Description Language

DBDL is created for writing test cases conveniently in Kaya. With DBDL, test engineers can easily add front-end events and pre-state parameters to simulate various scenarios of DApp usage. An example of a test case written in DBDL is shown in Fig. 2.

![Fig. 2: A test case written in DBDL](image)

In DBDL, a test case can be divided into three main fields, i.e., Transactions with front-end events, sender_info with account attributes, and setted_params with variables of smart contracts. sender_info and setted_params form the blockchain pre-state parameters.

The content in field Transactions is consist of two layers. The outer layer is Event Layer, which represents front-end events. Each front-end event has a self-defined event name (name), an access address (url), and an Action Layer. An event may be composed of several actions, so there may be multiple actions in Action Layer. Each action consists of the target area (area), target tag name (tag_name), filter (filter_key and filter_value), and the taken action (action_key and action_value) to find the target element and perform the defined action. If there are multiple events and actions, Kaya will perform them in order, i.e., from beginning to end.

Field sender_info records the pre-state of the blockchain account. Attributes of this account can directly be used as the tag in this field.

Field setted_params records the variables of smart contracts. These variables are grouped by the name of the smart contract they belong to. Each tag item means a variable, including a self-defined name, access path, and the value user want to set (the default value is zero).

DBDL allows to define the values of variables in smart contracts. We require that all tags except root should declare their attributes by type to ensure the normal execution of test cases.

IV. Case Study

In this section, we will provide two cases to show the features of Kaya. The tested DApp is SnailThrone which is a King of the Hill game on Ethereum. Related source codes that integrate EVM into Kaya have been released.

It is worth noting that Kaya is a testing framework. It is not limited to a specific blockchain platform. To apply it to other blockchain platforms, developers need to implement the key modules of Kaya according to the SCVM used in the target blockchain platform.

A. Case with User Interface

KGUI of Kaya guides test engineers to test a DApp step by step. At first, test engineers should input the name and source code of a smart contract. Then Kaya analyzes the smart contract to provide a list of useful variables. Test engineers can add front-end events to simulate user behaviors or set blockchain pre-state parameters to obtain expected blockchain pre-state. This step is shown in Fig. 3.

![Fig. 3: The key step to generate test cases](image)

Next, Kaya extracts useful information from front-end events and constructs pre-states to execute test cases. Finally, Kaya outputs the analysis report like Fig. 4.

When the whole process finishes, test engineers can identify the features of DApp from all output variables. For example, from Fig. 4, we can know the earning of a player (playerEarnings[0]) may have a positive correlation with the number of snails (hatcherySnail[3...38]) he has.

B. Case with Command-line Tool

Except for the user interface, experienced test engineers can also use the command-line tool to perform test cases with Kaya. This command-line tool called kaya_cmd, which can analyze the variables contained in a smart contract and perform test cases. To improve the efficiency, kaya_cmd supplies a more

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6https://snailking.github.io/snailthrone/game
7https://github.com/Ghands/Kaya
practical function: test engineers can directly input the source code of smart contracts, front-end events, and Blockchain pre-state parameters together to skip the steps in KGUI. Fig. 5 shows a case with this command-line tool, the output is as simple and clear as it showed in the user interface.

Fig. 4: The analysis report generated by Kaya

V. RELATED WORK

Program Testing. Our work is related to DApp testing, web application testing and smart contract analysis. In DApp Testing, Gao et al. [3] proposed an automated testing technique called Sungari for DApps. It achieves significant optimization compared to the random testing approach. For Web Applications, Artzi et al. [4] proposed a framework for feedback-directed automated test generation for JavaScript and implemented a tool called Artemis. Billes et al. [5] presents the first fully automated technique called Simian for multi-client web applications. Smart contract analysis mainly focuses on discovering vulnerabilities. Luu et al. [6] develop Oyente to detect some types of smart contract bugs with a symbolic execution based technique. Zeus [7] is a tool to analyze smart contract with format verification. In addition, fuzzing [8] is also introduced into smart contract analysis.

Interface Description Language. Jensen et al. [9] proposed an IDL for the automated testing of JavaScript web applications and incorporated it into the testing tool Artemis. Mahmud et al. [10] proposed an easy-to-understand scripting language for test engineers to create test scripts that lower the barriers to the website testing. Rajan et al. [11] created an extensive user interface in their tool to specify requirements for web applications easily.

VI. CONCLUSION

In this paper, we propose a DApp testing framework called Kaya, which aims to help test engineers test DApps more easily. Kaya provides an easy way for testing by writing test cases with DBDL and executing test cases automatically, provide a flexible and convenient way for test engineers to set the blockchain pre-state as they need, generate readable analysis report for easy comprehension. To the best of our knowledge, Kaya is the first framework which helps test engineers to test DApps in an easier way. We hope the correctness, reliability, and security of DApps can be enhanced by using Kaya. In the future, we will continue to improve the ecology of DApp by improving the efficiency and coverage of DApp testing.

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