A Formal Approach To Validate Block-Chains

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Abstract—Our goal is to propose a suitable approach for validating blockchains. For this purpose, we intend to adopt formal methods which are based on strong mathematical foundations. More precisely, we follow a model-based testing approach. The latter consists in describing the behavior of the system using a specific formalism, deriving test cases from the obtained model and then executing the obtained tests on the implementation to check whether it is correct or not. The adopted formalism corresponds to the timed automaton Model. The generated tests may be either digital or analog. Moreover, we propose several techniques which allow to solve the state explosion which may be encountered during the verification and test generation phases.

Index Terms—BlockChains, Formal Methods, Model Based Testing, Generation, Execution.

I. INTRODUCTION

Blockchains correspond to a new technology which is becoming more and more famous nowadays. It is mainly used for the establishment of new crypto-currencies (like bitcoins) and for electronic money transactions. [1] define it as "a distributed ledger shared between nodes in a peer-to-peer network. Basically, a ledger is simply a database that is maintained and updated by every node in the network". The Blockchain is not a new technology and it combines four types of technology to enable it and build a ledger. These technologies are peer to peer network, Merkle trees, hashes and public/private key cryptosystem. There are a lot of applications for Blockchain, such as , Cryptocurrencies, Healthcare, Supply Chain Management and Cybersecurity [2]. Also, it can be used in Internet of Things (IoT) such as Smart Homes and cites [3]. Furthermore, it can be integrated with another technology to store and control the transaction such as fog computing and cloud computing [4], [5].

Our goal in this work is to validate blockchains by adopting formal methods based on sophisticated mathematical techniques. For that purpose, we opt for a model-based testing approach which consists in deriving test cases automatically from a formal description of the blockchain behavior. In Section II, a brief overview about blockchains will be given. In Section III, the notion of formal methods will be introduced. In Section IV, some challenges related to blockchains testing will be we listed. In Section V, the main steps for validating blockchains following a model-based approach will be presented. Finally, Section VI concludes the paper.

II. ABOUT BLOCKCHAINS

The Blockchain idea was first introduced in 1991. It is a chain of sequential information that is constantly updated. The information is grouped into blocks, which are generated gradually from the resulting data. From each block, a hash function calculates a hash value, which in turn is inserted at the beginning of the next block. To prove the integrity of the chain, all that is needed is to recalculate the hash values for each block and compare the final score to the published value. Manipulations of the chain are therefore immediately apparent during the test [6].

The way blockchain looks in practice differs depending on the implementation - and the combination of techniques and methodologies in conjunction with the blockchain. Therefore, cryptocurrencies and smart contracts and system architecture security are discussed below [7].

The Blockchain idea can be used to create and manage a decentralized and anonymous currency such as Bitcoin. In the Bitcoin system, computers around the world maintain identical copies of the same block chain, which records all financial transactions based on that currency. Once a Bitcoin transfer is made, it is distributed via peer-to-peer to store it in the world famous blockchain [8].

From the published bank transfer credentials, anyone can create and republish a new block, so the blockchain is continually being extended. If you want to update the blockchain you have to solve a cryptographic puzzle: The puzzle states that the hash value must start at the beginning of a block with a defined number of zeros. Such a hash value can only be found by adding a matching code to the transfer information in the new block of the chain. The search for a corresponding code is called scouring or mines. This is intentionally very elaborate, requires the use of enormous amounts of energy and is therefore as the model of mining very resource hungry. In 2014 alone, mining required so much electricity worldwide that Ireland could have been completely supplied with it. As an automatic reward built into the system, the successful prospector of a block receives new bitcoins. Who creates a block, thus also coins new coins [9].

Bitcoin is not the only cryptocurrency based on blockchain. A handful of Altcoins (alternative coins) have managed to pick up on the Bitcoin idea and expand it significantly. Of particular note is Ethereum, a currency more likely to be more interesting to developers than Bitcoin, which offers the ability to create smart contracts and do more than just write simple scripts [10].

Ethereum significantly reduces the write delay of the

information compared to Bitcoin. If the miners in the Bitcoin system create a new block only about every ten minutes, the Ethereum miners add a new block to the chain every twelve seconds. In addition, Ethereum adds an account concept. Accounts can be charged with the Bitcoin equivalent of ether. A specific account - called the zero account - is called to create a smart contract. This Smart Contract then has the amount of Ether that should be transferred with the transaction and can be automatically triggered by external events. If, for example, a specific situation occurs and the smart contract is deemed to have been fulfilled, the credit is typically transferred to a predefined account. However, there are also no-money smart contracts that send messages to other smart contracts and trigger a response [11].

The crypto-currencies need protection against such attacks, where a participant claims to be a large number of different participants, jeopardizing the consensus-based integrity of the decentralized network. At Bitcoin, miners have to use power to participate in the infrastructure - and an individual can never have that much power and computing resources to mimic more than half of the world's miners. This approach is called Proof of Work. In the case of Ethereum, the inventors are planning a new model that appeals to the self-interest of the participants. Accordingly, the right to coinage would be paid by paying existing Ethereum coins (ethers). This model is based on the assumption that no investor wants to endanger the integrity of a system in which he has invested himself - this would jeopardize the value of the entire currency and thus its capital [12], [11].

III. CHALLENGES FOR TESTING

This development has major consequences for testers. The test professional will have to do his work differently than now. There are a number of reasons for this:

- A programming error in a Self Executing Contract leads faster than now to a test blocking finding. We can no longer intervene manually within the process.
- Stricter than now, attention must be paid in the test preparation to the creation, reading, updating and deletion (CRUD) of test data during test execution. Test data cannot be changed as quickly anymore. A test network is usually used for testing.
- Transaction can initially be approved, but can be rejected retroactively in a subsequent block. Bitcoin uses the rule to wait at least two blocks before you can assume that the transaction has been approved.
- Authorization who is allowed to view and change which data is now done by the blockchain whereby it is checked whether the correct encryption key is supplied. This depends on the implementation, the foreign or the private key. The authorization layer in the front application must take this into account. Certainly if data is supplied through the OTAP street when software is delivered.
- It becomes even more complex when data from other block chains is consulted. At the moment, however, it

is unclear whether the dynamics of periodically making a block definitive allow this kind of direction at all.

On the other hand, the work of testers also becomes easier on a number of points. A number of test types are no longer necessary for the blockchain itself, unless it is a private blockchain. In the latter case, checking whether the architecture has been put in place is important. If we assume that a public blockchain is being used, then it seems to be agreed that:

- Performance testing is given a completely different meaning. The performance is partly determined by the speed of the network. In part, the performance is determined by the method of approval of the transactions.
- Failover test from one database to another is not necessary, because the blockchain is distributed. When a node in the network fails, there is simply less capacity available, the database as such remains in operation.
- Fallback test is not necessary if the different nodes are geographically dispersed.
- Security testing on the database becomes more limited because all data is stored encrypted and can only be read with a foreign or private key, depending on the implementation. The strength of the encryption is enforced in the code of the blockchain.

Functional testing of the Self Executing Contract is of course always necessary, whether it is a public or private blockchain, just like the applications with which the data in the blockchain can be consulted and changed. Some changes will always remain manual, such as contract termination because the customer goes to another supplier. There are also applications that will continue to be intentionally done with human intervention to prevent someone from selling a valuable object such as his house under pressure [13], [14].

The challenges of functional testing of a system using blockchains are fully valid for other test types such as the User Acceptance Test, the Usability Test, the Security Test, and the Production Acceptance Test of the chain as a whole.

IV. FORMAL METHODS

Formal methods can be used to calculate whether a system description (specification) is inherently consistent, whether certain properties can be guaranteed, and whether the requirements have been properly designed and implemented (currently only theoretical). Furthermore, the specification can be used for simulation / animation, for code generation, for test generation and test evaluation [15]. The extra effort to describe something formally must have a justification. Just formalizing to get a formal specification is no justification. A formal specification is not meaningful at all costs and for all parts of a system. Non-safety-critical parts do not necessarily have to be formally described. For each formal component, it must be clear in which analyzes and constructions the formalization is used, or if it is intended as a documentation, it should be clear who should read it (can he read it?). If this is not clearly defined, the effort for a formal specification is not worthwhile.

A development with formal methods differs from a traditional development in several points. To explain these points, one must first distinguish two varieties of formal specification: operational and axiomatic.

In an operational specification, only what is explicitly specified happens (as in an imperative programming language). In an axiomatic specification, anything can happen that has not been explicitly excluded. An operational specification describes the function of the system, while an axiomatic specification describes the properties.

A. Timed Automata

Timed Automata (TA) [16], [17] correspond to a simple graphical formalism for describing the behaviour of wide classes of systems which combine continuous and discrete aspects.

Fig. 1. A timed automaton with 5 states, 4 transitions, 4 actions and 2 clocks.

In Figure 1 we give an example of a timed automaton which has 5 nodes, 4 transitions, 4 actions and 2 clocks.

B. Different Types of Testers

One may distinguish between different types of tests:

- TA Testers: presented as a TA.
- On-the-Fly Analog Testers: measure time with precision and are generated during the test execution phase.
- Digital Testers: represented as trees and use numerical clocks to estimate time.

C. Conformance Relations

For untimed systems we consider the *conformance relation* *ioco* [18] and for timed systems we could adopt the relation *tioco* [19], [20], [21] which allows to compare timed specifications and implementations.

V. PROPOSED APPROACH

Our goal is to follow a Model-Based Testing methodology to validate block-chains. Next we give a brief overview about the main steps of this approach.

A. Model Specification

The First challenge corresponds to the fact of providing a suitable Model for the specification of the blockchain to test. The proposed model should be written within an adequate formalism. For instance, we may adopt the model of Timed Automata as in [21], [22].

B. Test Generation

We get inspired by the generation algorithm of [23]. The later constructs a test case in the form of a tree. The proposed test generation methodology is based on model checking. The basic principle is to encode test generation as a reachability analysis that can be tackled using the tool UPPAAL [24].

C. Test Selection and Execution

Selection techniques help to reduce the number of generated test scenarios. For that purpose, we need to consider specific coverage criteria like states coverage, actions coverage, locations coverage etc. Concerning test execution we need to adopt a standard-based platforms like TTCN3 [25], [26], [27]. In addition, we may need to consider appropriate test isolation policies which allow to avoid interference between business functionalities and test cases as proposed in the work of [28].

D. Test Component Placement

The task here consists in optimizing the placement of the different test components. For this goal, we are inspired by the work of [29] from which we identify the following ingredients.

- Different Constraints:

Constraint Type	References
Network Constraints	[30] [31]
Energy Constraints	[32] [33]
Application Constraints	[34]
Node Constraints	[35]

- Objective Functions:

Objective Function	References
QoS-assurance	[30] [36]
Cost	[35] [37]
Energy	[32] [38]
Migrations	[39] [40]
Network Delay and Execution Time	[31]

- Algorithms:

Algorithm	References
Search-based Algorithms	[41] [34]
Dynamic Programming	[33] [42]
Genetic Algorithms	[43] [44]
Game Theory	[45]
Deep Learning	[46]
Complex networks	[40]
Mathematical Programming	[31]

E. Solving State Explosion Problem

Formal methods usually suffer from state explosion problem which means obtaining a state graph which is huge and difficult to manipulate. Next, we list some solutions to deal with this problem.

- For formal verification:

Technique	References
Abstraction	[47] [48]
Modularization and Compositionality	[49] [50]
Symmetry Detection	[51] [52] [53]
Data Independence Detection	[54] [55]
Removing Functional Dependencies	[56] [57]
Using Reversible Rules	[58] [59]

- For Model-Based Testing:

Technique	References
Refinement Methods	[60]
Diminishing the Size of Digital Tests	[61]
Generating TA Testers	[62][63][61]
Updating Test Cases after System Evolution	[64]
Resource Aware Test Component Placement	[65][66]
State Identification	[67][68][69]

VI. CONCLUSION

Our work is at its beginning and many tasks have to be achieved in the near future. We need to choose adequate formalism with adequate tools. Then we need to identify the specific aspects to model in order to keep the size of the obtained formal specification and to avoid the space explosion problem from which formal methods suffer in general. Moreover, we will need to implement the proposed approach and to validate it experimentally. We may also work on combining functional and load aspects as proposed in [70], [71], [72], [73], [74], [75].

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