Why blockchain and smart contracts need semantic descriptions

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Abstract

We argue that there is a hierarchy of levels describing to that particular level relevant features of reality behind the content and behavior of blockchain and smart contracts in their realistic deployment. Choice, design, audit and legal control of these systems could be more informed, easier and raised to a higher level, if research on foundations of these descriptions develops and sets the formalisms, tools and standards for such descriptions.

1 Introduction

Blockchains and smart contracting platforms are usually presented either in rather algorithmic (or architectural) manner, emphasizing technical implementation or as highly idealized and simplified devices for highly controllable application scenarios. Surely, there is some common awareness of fallability or misuse of some of intended mechanisms which is typically attributed to a rather vague dependence on surrounding “ecosystem”. While these pictures are suitable for some engineering tasks, or as a first introduction to users, they are typically insufficient for critical analysis needed by those initiating or systematically controlling their deployment, say policy makers, platform choosers, smart contracting platform architects. If this technology becomes prominent in real life clarity of recommendation will become a daily need. To give a metaphor, if we need to use a vehicle it is not sufficient to take some vehicle and to know how to drive one vehicle, but the vehicle and driving have to be appropriate, should it be a bike, boat, jeep, tank, motorcycle, an airplane or dirigible. The features of blockchains and smart contracts are
even more diverse while much more opaque to observe than in the vehicle
metaphor.

It will take us a while to describe what we mean by *semantic description*
and the account below is somewhat personal. In different areas, like philos-
ophy, linguistics, computer science and logic, semantics refers to a slightly
different concept or a subdiscipline. Our search is maybe closest to the us-
age in programming languages context. In early times of programming, code
was written mainly ad hoc using whatever tricks and tools, which gradually
included sophisticated compilers, debuggers, task scheduling in engineering
teams and so on. Regardless sophistication, a question arose if two different
implementations really operate the same, is the code verifiably correct and
so on. Therefore the meaning and/or operational content should in partic-
ular be in some sense the same, whatever correct implementation is. Hence
one had to answer the question what is the operational content, what is the
effect of the code. Different approaches like denotational and operational
semantics, agent model etc. are devised to define properly and model this
content.

Blockchains and more general distributed ledgers are distributed systems
physically realized by a network of computers as nodes, whose making in-
volves concurrency, consensus and possibly adversaries in the system. Hence
its behaviour is not fully predictable. However, the genius of the invention
is that incentives to parties operating in the system make certain aspects of
handling the data which enter the ledger, which includes smart contracts,
well behaved, reliable, replicable and so on to large extent. For some con-
sensus mechanisms, very recent data on the ledger may be only tentative as
choice of recognized fork takes some latency time and leads to abandoning
some very recent blocks. The data on the ledger are processed and checked
multiple times by varios nodes, leading to inefficiencies in addition to the
inefficiencies which come from the computational price of consensus mecha-
nism, say proof of work. For reasons of scalability and price, some data which
logically have direct meaning to the algorithms in smart contracts on chain
(= written in the ledger) are stored off chain, and only the handles (hashes
or other identifiers) are stored on the chain. The hashes on the chain make
verifying that the off chain data are correct cryptographic provable, how-
ever additional incentives are needed to mitagate the risk of unavailability of
these data to complete the information needed in the algorithms of smart
contracts on chain. Thus, the availability of off chain data is one semantic
characteristic of these data, which makes reality of smart programs very dif-
ferent then when the data are completely on chain. This is still engineer-
level, recognized in blockchain community.

Much deeper problems happen when we include in the considera-
tion meaning of the data processed by smart contracts in real world, like tokenized
representations of assets, witness statements on achieved milestones in real
world, timing information and so on. Clear picture is of ultimate importance
for security of smart contracts: can contracts be explored by third parties,
how to resolve conflicts, what is the risk analysis for assets and finally how
should courts analyze and judge about the intended content and resolve the
abuse, conflicts or technical glitches in procedures involving smart contracts.
Some of the assets, like cryptocurrencies have their reality on chain and anal-
ysis of risks is limited to on chain plus possibly some off chain related second
layer platform data. Many such analyses exist already. Next level is consid-
ering witness mechanisms. There are several cryptographic mechanisms how
information about real world is verified on blockchain. First of all, smart con-
tract can name holders of cryptographic keys of some blockchain addresses as
verified witnesses who can enter information into a smart contract and this
information is considered relevant, that is nontrivially influences the com-
putation. These are usually called oracles. In a variant, oracle addresses
are not predetermined but anybody who puts certain stake can be an oracle,
and information is weighted over a pool of oracles who are rewarded for
information but whose part of a stake is taken if the oracle’s prediction is
incorrect in the sense that it is far from the information given by majority
of other oracles. This system is more in the spirit of decentralization than in
advance certified oracles, but it requires handling the oracle market, which
needs volume, good balance of incentives and may suffer from usual ideas of
gaming the system which happen in rating and popularity systems. Oracle
mechanisms may be combined with more involved cryptographic proofs from
off chain world. That means that on chain, there is a preset verification test
which can verify the cryptographic proof.

Let us also mention the timing. Unlike usual programs which may run
continuously and interact with surrounding signals during that execution,
smart contracts run only when they are called, and the execution finishes
within one block. There can be complementary off chain device which may
be able to initiate a call to a program and take care to do it at right time.
The blockchain itself has very rough timing information in the blocks, precise
consensus on time is usually not present and it is difficult to incorporate
beyond very rough precision. Of course, a smart contract can itself call
another smart contract and we can have a chain of executions. There are now variants, depending on blockchain in place. Either calls have to be executed also within the same block in which the original smart contract has been under execution or only a message has been written on chain by one smart contract to another and then this message will be interpreted as a call in the next block. The latter is useful if the platform is such that sharding has been extensively used, that is one divides the job between groups of miners, and then if a call has been made for a contract in a different shard it may be not feasible to execute within the same computing cycle but rather a request is made via a message which is on chain.

2 Basics on what is semantics

To setup our problem it is good to rethink of what a semantics can be. In different disciplines like philosophy, linguistics, computer science, and logic, by semantics we mean somewhat different things. Maybe we could say that a common ground is that the situation considered in most settings is that we have some sort of reality and a presentation of this reality in somewhat symbolic terms, say a thought, language construct, formal language construct, computer program. There have been volumes of philosophical discussion on the character of the correspondence between the presentation and the reality. In the case of human language a convention sets up what is the standard interpretation of some utterance. According to Hirsch [8], however the only consistent interpretation of human texts is the one which tries to find which meaning has been intended by the creator of the text; other interpretations are possible to produce but do not truly pertain to the task of text interpretation. Thus, the linguistic conventions are not exhaustive factors in human communication. Our experience brings awareness that while our thoughts can be arbitrary, interaction with other beings and our existence make that our arbitrary will is useless in comparison to following patterns in appearance of new reality from known reality. This brings distinguishing some facts as more real, truthful to others, and some sequences of thoughts as regularly bring new things again as real, hence conclusions of truthful statements. The reasonings in that endeavor boil down to logical reasoning, not only classical, but if reality is understood in various senses of useful experience, including conditional, hypothetical, contractual and so on leading to various kinds of logic. These reasoning chains are as a rule finite. Our experience can sim-
ply not confirm others, except indirectly as artifacts of finite ones, though reality also may have non-finite ones which we do not comprehend as part of our experience. Formalization of such logical systems, and axiomatic bases of knowledge can again be presented in terms of finite presentations by states in a computer or sequences (or nonlinear utterances) of symbols. Formalization then has two aspects, one is the system of utterances itself (basic symbols and the syntax use to organize more complicated systems from basic symbols), another is the intended representation. One can however have another system for which, using the same rules of logical reasonings, one can have valid reasoning for a different intended reality. In mathematical logic these are called models.

In the study of computing, programs are producing reality rather than proofs, at least at first inspection. This reality can be abstracted to operations which happen with data (operational semantics), or we can go toward assigning denotations to programming language constructs which will correspond again to the reality of program execution. This is very vague, but enough for rough comparison that we are talking about the same subject. Again the program is just a symbolic presentation which has no meaning outside of the system. Knowing how to present semantics of a computer language is extremely important. For example, if we change a platform and redo programming some critical system for this platform in the language suitable for this platform do we get the same? Do the outputs of compiling the same code by two different compilers give the same output? Usually, computer languages do not have fully determined semantics by their design. Namely there are situations where an undefined behavior is possible (say choices). Some languages are designed so that their semantics is very predictable, especially functional languages what makes them more relevant in recent years. These languages are designed having in mind semantics of type theory [7], a flavor of a logical system which came out of philosophy and logic but has wide applications nowadays. Programs in this world can be viewed as producing proofs of truth for some logical deductions. Useful theoretical connections to category theory are widely explored.

Regarding that the early languages for smart contracts (say, Solidity) are rather ad hoc written without advanced programming language theory properly adapted to blockchain, some systems nowadays produce smart contracts from functional languages, then there is an intermediate presentation which formalizes some level of semantics, which is prone to better analysis, for verification, security and other reasons. Then, from the intermediate repre-
sentation one produces automatically, in a way similar to code generation in compilers, an actual program in old fashioned smart contract language. Optimization reasons suggest nowdays that the operational content should be done in low level bytecode virtual machines and Webassemby VM seem to be a tendency, complemented by system interface (set of standardized system calls from VM). This way modularity of interaction between the execution in VM and other aspects of blockchain and of off chain reality is recognized, but not sufficiently modeled at abstract level.

3 Assets on blockchain

Handling off chain assets on blockchain requires a representation of the assets on blockchain, most usually, but not exclusively, in tokenized form. This is in a complete analogy to an auction. In an auction, parties sign up before an auction and they are preverified for ability to pay. During the auction no real money is involved, certified party enters purchase by a promise statement. After the auction, off auction mechanisms are involved to collect the money promised. Similarly, an off chain asset is represented on the blockchain showing the representation of the asset and a blockchain address of the owner (the owner may be even some other smart contract). Now a number of issues come into play. First of all, with cryptocurrencies a double spending problem is solved on chain but the existence and possible multiple representations in different systems of a real asset can be regulated only off chain, in real world and with help of a legal system. Say, if some jurisdiction decides that all real estate in this jurisdiction is represented on some blockchain as a primary place of verification, then the issuer of real world certificate to this property, and that is the jurisdiction itself is the default place of a resolution of a conflict. Namely if some property is sold elsewhere and not on the authorized blockchain it should be considered legally not binding, and in most cases cheating or criminal misappropriation.

Most proponents of smart contracts in past put the emphasis on variants of smart contracts which contain also the legal statements written on blockchain, describing the smart contract in legal terms. These so called Ricardian contracts are hence a pair of a real contract and a smart contract. This is typically considered as safe if the legal contract described the smart contract sufficiently precisely. One can always have a less verbose real contract which just says, accept whatever this code gives, making the promise
to respect the outcome of the contract, but this opens the possibility that if one side of a contract is technically superior there can be hidden advantages in a contract designed and offered by such a side. This is very similar to the notion of business intelligence, but it is far ore opaque. In the case of business intelligence, say, a bank user opens an account or more complicated financial device and signs some document with the bank. The account is handled by a program set up by the bank, and has many defaults which are typically not specified in the account and it is often not fully in agreement with all exceptions which exist elsewhere in the law or are tacit assumptions of the user when signing the contract about the financial device. If a user sees that something worked out different from the intution, the bank representative will usually say this is the way our computer handles this situation, I am sorry for this, but this is the business rule. It appears as the business logic within the bank is above the external contract between the bank and the user and brings additional rules which are not in the contract. This is an abuse of power by the bank per excellence. Now if the business logic is replaced by procedures on the blockchain then in principle, the user can check the correctness and so on and does not rely on hidden third party software and unchecked computation within the bank (we are neglecting the problem of account privacy here, as we consider a different aspect). But still the user can not have a way to audit the system without third party services. And even then, if we come to the court, is there a decscription of the reality behind the smart contract which makes the implications of the contract clear enough for a court resolution. The fact that the code is visible, at least, and the execution deterministic (up to factors like the content of oracle messages, execution timing etc.), makes it less attractive to cheating. The collection of processing data is simpler and achieving to a conclusion is simpler as long as parties do not dispute the content of the smart contract but only following or not in real world the consequences of the actions of smart contracts on symbolic representations of real world assets.

In traditional systems there are some mechanisms of handling the inequality in comprehension of contracts. This rules are hard to enforce in practice as it is hard to prove both the intention to cheat, and miscomprehension of a side in a contract. In situations like selling a material item over the internet, there is a tendency in law that a customer (the weak party) should read more details of the contract if it is expected that (s)he is less familiar. For example, if you already used the service or if you are profiled as highly educated the system may simplify the procedure in which you are forced to check for
more details. This is one of the prime cases belonging to the subject of the personalized law [2, 3].

4 Hierarchies

Which parts of the blockchain reality or smart contract reality we should model? It is important for a problem (say a security analysis, risk analysis, legal analysis, porting to another platform, refactoring code) to be able to limit the content to a closed system using only idalizations abstracting from phenomena which are either irrelevant or could be separately modelled.

The very basic one is off chain and on chain in the strict sense. Hence we do not imply the data or programs which are represented by hashes on the blockchain or which are initiated by change of flags on the blockchain. Even this basic reality of transactions in blocks may have variants. One is to include or not the temporary forks which may be dispenses later. Another is how deeply we go into the semantic of data within the on chain transactions. For example, do we take into account the data as programs (smart contracts) or not.

Now say, we consider smart contracts as programs. These programs do not execute when we want. Namely, in each block miners include some transactions, these transactions may be calls to smart contracts from the account or from other smart contracts together with a trace these smart contracts make on chain, that is the part of the results of execution which concern the global variables, those whose value is written on chain. There are incentives that the miners include certain transactions but it may be that a transaction is delayed several blocks just because it happens that the miners selected other transactions as more interesting for inclusion into blocks.

Typically most variables of a smart contract are off chain. Do we work in idealization in which these data are available or we take into account conditional semantics in which these data are not secured?

There are two very different problems we want to describe and this is in a complete analogy with programming languages. In the latter case, one is the semantics of a programming language in the sense of a model how to model all programs in that programming language. In a research people study aspect by aspect of a programming language when doing this. Another is the semantic representation of an instance, a particular program. This assumes producing tools, used say for verification or so. The two realities are not much
different in that case. In the case of smart contracts, however, studying the expressive content of say a smart contracting language is usually at a higher level of abstraction than when we study the content of a particular system of smart contract. In the latter case, the semantics of data used, may be considered in a more specific way, if we know the context. So, without a context, say a variable of type asset is sort of class which has some features, for example it is desirable that the language does not allow making copies but only transfer of the asset values. Such things were already used in the design of a more advanced languages for smart contracts, say Libra’s Move language. In a context, we may have an information which is not part of the semantics of the smart contracting language. For example, we may know that some oracle’s addresses are trusted and others are semireliable or behave as selfish agents collecting rewards in a way regulated by given smart contracts. Thus the semantics of the programming language for smart contract, which is already specific is less expressive than the semantics needed to model some smart contract in the context. From the point of view of research, although the real life contexts are limitless, we indeed have some typical colorings of the data which mainly center around the notions of availability, trust and timeliness.

The whole situation is also prone to cryptographic factors. Users can loose cryptographic keys, keys can be compromised and the information in various channels of execution can or can not see information in other channels due encryption, off chain execution mechanisms and so on. This is the usual situation in distributive systems. Concurrency and cryptography has been studied extensively using agent systems, process algebra, modal logic and its modal theory, some aspects of which like Kripke models, bisimulation etc. appear also in categorical treatments.

Another aspect is when moving part of the computation to a state channel of chain. Namely, for scalability purposes allowing wider applications, or for privacy or other reasons, one can sometimes move some computation off chain and expect some guarantees that the computation has been correct. It can be a cryptographic proof, or else, all interested parties for a subset of smart contracts instances, may be present in side channel with the same computational rules as on the main chain and if a computation in some step of the channel does not follow the rules a party can challenge the execution on the main chain. The steps in between are digitally signed so the complaining party has the proof that the block before the challenged block happened. Then a verification game can resolve the dispute at the level of the main chain. Now,
the execution in state channel uses some data from the main chain which were withdrawn to the channel, for example, some assets can be frozen on the main chain and used for the computation in the channel and then at the moment of closing the channel, many blocks later, the redistributed assets are returned to the main chain. This phenomenon of temporary passing of a part of the state to a channel is usually regulated by the rules of another system of smart contracts which establishes the mechanism of setting up the channel. Thus this is not a characteristic of a blockchain itself, but of a smart contracting platform which includes the system of contracts regulating the issue. Of course, such mechanisms can be included potentially in the basic protocol of some blockchain and the instances will just require signing up to an instantiation of such a channel. However this is not obvious as it is not clear which kind of variables other than most simple asset types can figure out in such channeling procedures.

It is an open question how to make these potential models compatible with the reality of the contract legislation, which should adapt to smart contracts as a variant with classical issues like incompleteness of contracts, conflict resolution etc. [10]

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