On the Optimized Utilization of Smart Contracts in DLTs from the Perspective of Legal Representation and Legal Reasoning

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Abstract. Smart contracts are computer programs stored in blockchain which open a wide range of applications but also raise some important issues. When we convert traditional legal contracts written in natural language into smart contracts written in lines of code, problems will arise. Translation errors will exist in the process of conversion since the law in natural language is ambiguous and imprecise, full of conflicts, and the emergence of new evidence may influence the processing of reasoning. This research project has three purposes: the first aims at the resolution of these problems from logic and technical perspective, exploring a more novel and advanced logic-based language to represent legal contracts, and analyzing an extended argumentation framework with rich expressiveness to develop the accuracy and human-readability of smart contracts; the second purpose is to investigate various existing technologies like Akoma Ntoso and LegalRuleML, making the legal knowledge and reasoning machine-readable and be linked with the real world; third, to investigate the implementation a mature multi-agent system incorporating the software agents with sensing, inferring, learning, decision-making and social abilities that can be fitted onto DLTs.

Keywords: Smart Contract, Decentralized ledger technologies, Legal representation, Legal reasoning, Logic-based language, Argumentation, Akoma Ntoso, LegalRuleML, BDI

1 Introduction

In the last decade, the emergence of Decentralized ledger technologies(DLTs) has opened a wide range of useful applications. The most representative implementation of DLTs is the popularity of Bitcoin transactions over the blockchain. In Distributed Ledger Technologies (DLTs), described by the EU central bank in [1], customers are allowed to store and access information that is related to a given property and holders in the shared databases or ledgers, instead of depending on the trustable central verification system[1]. In other words, contrary to traditional trading ledger records, DLTs are featured with decentralization, anonymity, transparency and tamper resistance[2].

A standard way to enforce trusted transactions and agreements across a DLTs network is to use smart contracts, i.e., self-executing contracts codifying the terms of the agreement between the parties[2]. In practical applications, smart contracts keep away risks of performance to enable the fulfillment of contracts to realize autonomy, dispensing with courts and other intermediaries to supervise their execution.

Although smart contracts are widely used, challenges and drawbacks will exist especially when they are used for modeling legal agreements or elements of legal agreements. Legal language may contain vague terms to be applicable to a large variety of (specific) real contexts and situations; these terms need to be legally interpreted on a case-by-case basis. However, by far the smart contracts are developed by programmers who may lack the knowledge of law so that the smart contracts are incomplete compared with the traditional written legal agreements[3], also the translation problems will arise when converting traditional contract, written in natural language, into smart contracts, written in lines of code. Besides, the code is not explained in a human-readable language so that few people involving in the transactions can understand them[4].

Smart contracts employ strict and formal imperative languages to describe well-defined categories, predefined conditions, and accurately-specified methods fit to reduce system security risk. Obviously, translation errors unavoidably exist in the conversion process, thus subsequently influencing the legal effect of smart contracts. These errors will inevitably cause an unreasonable and unfair result on the parties involved in the contracts. Due to the complexity, contradictoriness, and constantly changing conditions of the law, the analysis, representation, and inference of legal knowledge within smart contracts need more advanced and flexible methods.

On the other hand, smart contracts refer to enforce transactions by using autonomous code executing in a distributed manner over DLTs with the agreement of all the parties on the network without trusting any intermediaries, this property makes it harder to terminate the execution or perform modification of a smart contract once it has been triggered[4]. Thus, to realize the life-cycle will be rather difficult because of the most remarkable properties of smart contracts.

2 State of the Art

The nature of legal contracts in the law scenario is that the legal consequences must adapt to the new information and the conflicts between the rules have to be resolved. Thus non-monotonic logic is suitable to be applied in legal representation and legal reasoning. Defeasible Logic (DL)[5] is a rule-based approach to non-monotonic reasoning due to its flexibility which is skeptical. The DL is aimed at resolution of conflicts that may arise from the contract by using the priorities defined over rules. Since DL does not explicitly reason on deontic logic, [6]adds deontic operators, e.g. permissions, obligations, and violations to enhance the expressiveness. Another important extension of DL is related to the contrary-to-duty obligations (CTD)[7], which is a conditional obligation that arises when another obligation has been violated. Afterward, various novel and advanced systems have been developed to develop DL.

We can approach the legal reasoning as the process of argumentation, since we can calculate the justified conclusion based on the relationship between the arguments, i.e., formal argumentation can be used to reason about legal rules and norms, to deal with conflicts[8]. Many AI and law researches have been done with models based on Dung's influential work, such as $ASPIC^{+}$[9], in terms of the structure of arguments, the nature of attacks and the use of preference. Although the Dung's abstract argumentation framework (AF)[10] is quite powerful, it shows the limited ability of expression when it comes to some applications and is easy to be inconsistent with reality or to model all aspects of an argumentation problem. There is considerable enrichment of Dung' work has been done which introduces a more general formal system by introducing support relation between arguments. In [11], AF has been extended to cope with the combination of interaction(attack and support), into a so-called bipolar abstract argumentation framework(BAF), leading to the development of several other more specialized frameworks with support, such as deductive[12], necessary[13], and evidential[14] support. To calculate the semantics of BAF, disparate approaches have been proposed. According to the different interpretations of support, in [15], the authors introduce several kinds of indirect attacks based on which to model various reductions from BAF to AF, then to use Dung's theory to retrieve extensions. In [16], the researchers turn BAF into a meta-argumentation framework where only attacks occur between sets of arguments, characterized as coalitions of supporting arguments. In argumentation theory, one of the key problems is how to deal with dynamics. Since when we integrate a legal context into an argumentation system, the system must efficiently adapt to the new evidence and conflicts between the rules. In this respect, Beishui proposed a division-based method to cope with the dynamics of the argumentation system in[17]. In[18], Baumann proposed a similar approach that is based on Lifschitz and Turner's splitting results for logic programs[19]. These researches focus on abstract argumentation frameworks, but they pay no attention to an important relation between structured arguments which is called sub-argument relation.

In order to make the logic-based language contracts to be machine-readable and then be used on DLTs, we need other technologies like LegalRuleML[20], which is an interchange language for modeling defeasibility of legal rules, defeasible logic and deontic operators (e.g., obligations, permissions, prohibitions, rights)[21], and then to execute automatic legal reasoning. From this perspective, the Ricardian contracts[22]were proposed to represent all the contracts to fill the gap between traditional contracts and lines of code which is readable by both machines and humans, but it is still not ideal to represent complex legal proses. [23] is the refinement of ricardian contracts to address to serialization of legal prose and to achieve the purpose of managing the whole lifecycle of the contracts. To make the smart contracts more related to real-life, the Akoma Ntoso [24] is a legal XML vocabulary can be used to modeling laws, legal changes over time and so on.

3 Research question

Although considerable work has been done about legal representation and legal reasoning, it is still necessary to explore more advanced and flexible methods. After investigating suitable languages, realizing the machine-readability is also in need.

Future research must be advocated around following main research questions:

(1) is it possible to find a suitable logic-based language of smart contracts that is more human-readable and more precise?

a. to what extent it is possible to establish and formalize correspondences between traditional legal contracts and smart contracts, able to incorporate different legal interpretations of the terms included in the former?

(2) how to conduct more effective inference when using logic-based language to present smart contracts?

a. how to define sub-argument and argumentation framework with sub-argument(AFwS), if there are additional constraints?

b. What are the constraints on this structure that distinguish sub-argument from the more general class of support relations?

c. how to calculate the semantics of AFwS efficiently?

d. What are the principles governing the semantics of AFwS?

(3) how to make the more advanced representation of smart contract machine-readable?

(4) the smart contracts in DLTs system are not allowed to be modified and terminated, how it is possible to include in the smart contracts self-adjustment mechanisms for fast adapting them to new legal interpretations like in the real-world scenario?

4 Research methodology

During my Ph.D. activities, I will address the above research questions by investigating proper and novel representations of legal expressions in smart contracts. Starting points for this investigation will be[25], which analyses (logic-based) languages for handling the connection between legal contracts and smart contracts, and[26], which presents a novel deontic logic to represent sentences from natural language (legal) text via the LegalRuleML legal standard[21].

As for the argumentation research area, I will investigate the definition of various support relations and AFwS from both structured and abstract perspectives. A possible starting point is the work in[27], in which the author defined how a premise and a conclusion can be combined into an argument to generate different types of structural arguments. Besides, this project will include a more systematic study and comparison of semantic. Starting points for this investigation will be[28]and [29], the former gives a complete classification of the main alternatives for the semantics of argumentation using main principles discussed in the literature on abstract argumentation and lays a foundation for a principle-based approach, the latter one uses the principle-based and axiomatic approach to choose an argumentation semantics for preference argumentation framework and to guide the search for new semantics, there is a remarkable resemblance with the principles for BAF.

After finding the new way to represent and reason smart contracts to make it more human-readable, this project also needs to focus on making this new contracts machine-readable. For this objective, the start point is [30], in which the authors introduce a novel model of automatically executable digital contracts on blockchain in order to bridge the gap between nature language written contracts and digital contracts, they also describe the implementation of the new kind of contracts. This work is an ideal source to date and will point to more useful sources.

Another part of this project is to combine the logic-based language and argumentation theory to contribute to a multi-agent system incorporating the software agents with sensing, inferring, learning, decision-making and social abilities. A standard way to express these intelligent agents is to use the BDI model. The BDI model can be extended with deontic components to corporate obligations and norms and needs to perform reasoning with dynamics and inconsistent knowledge, e.g., there may be new evidence, new legal interpretation during the lifecycle of smart contracts. We can investigate a BDI model based on the defeasible logic language and argumentation, because the knowledge base of the model is changeable which can be represented in logic-based language and the reasoning and decision making can be based on argumentation. Smart contract agents can form a complex social system through coordination and evolution, and such a multi-agent system has great social and engineering complexity. Its implementation requires advanced forms of legal reasoning that I will also investigate during the Ph.D.; a possible starting point is the work in[31].

5 Lead time and Objectives

As for this research project, the objectives are as follows:

(1) the more efficient, accurate and human-readable representation model and more effective reasoning method of smart contracts will be further explored;

(2) to make the logic-based language machine-readable, to reach this goal, it is necessary to investigate LegalRuleML and Akoma Ntoso;

(3) a mature multi-agent system to be used for relating the smart contracts with the real world is supposed to be investigated.

Table 1. Lead time and Objectives.

Objective:	The 1st Month … The 36th Month
Develop a new smart contract which is readable for both humans and machines, and to legally model their life-cycle: like modification and termination.	
1. Learn more about the logic-based language, especially the extended defeasible logic, analyzing how to combine it with the corresponding argumentation framework;	
2. Learn about the DLT systems and the properties of smart contracts in DLT, find a way to fit logic-based smart contract in DLTs, I need to make the logic-based language be machine-readable, to reach this goal, I need to investigate LegalRuleML and Akoma Ntoso;	
3. Investigate the multi-agents model based on logic language and study how to use the model to make the smart contracts self-adapt in DLTs.	

Acronyms

AF	Argumentation Framework
AFwS	Argumentation Framework with sub-arguments
BAF	Bipolar Argumentation Framework
BDI	Belief-desire-intension
CTD	Contrary to Duty
DLTs	Decentralized ledger technologies
DL	Defeasible Logic
XML	Extensible Markup Language

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