A Self-Aware Contract For Decentralized Peer-To-Peer (P2P) Commerce

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***Abstract*—Distributed Ledgers, such as blockchains implement business collaboration processes in the form of smart contracts (SCs). Blockchain technology and smart contracts have received significant attention as they exhibit autonomy, decentralization, trust, and transparency over peer-to-peer networks while moving the assets digitally among peers without a third-party such as lawyers in conventional contracts (CCs). Smart contracts are computerized scripts or protocols that execute contractual clauses when certain pre-defined conditions meet and thereby digitally enforce the negotiation and performance of a contract. Smart contracts, although, being self-executable and self-enforceable, are irreversible once written and lack contractual flexibility in the face of a contingency. A high degree of automation is sought to manifest blockchain enabled smart contracts into the so-called self-aware contracts (SAC) that can be aware of its internal contextual environment and the external environment or real-world events. This Ph.D. work aims to develop the belief-desire-intention (BDI) model based multi-agent system (MAS) on the top of the smart contracts to yield the so-called self-aware human-readable contracts for legal viability. This research follows the guidelines of the Design Science Research (DSR) methodology.**

***Index Terms*—Blockchain, Smart contracts, Multi-agent, Belief-Desire-Intention, Self-Aware Contracts, Human-Readable, Design-Science, Coloured Petri Nets, Practical Reasoning**

I. Motivation

A blockchain is a distributed database or a public ledger of all digital transactions or events that have been executed and shared among participants on a peer-to-peer network. Smart contracts [1] are the key use cases of blockchain technology. Smart contracts are self-executing and self-enforceable in the way they are coded and execute the terms of a contract respectively when certain pre-conditions meet. However, the open problem exists as smart contracts do neither offer the contractual flexibility in line with traditional contract laws nor do they understand the dynamics of contractual relationships among the parties. This situation often results in frequent contractual conflicts and the current smart contracts technical unsolvability to such conflicts lead to undesired contracts terminations. The existing blockchain platforms for smart contracts include Ethereum, Bitcoin, Counterparty, Codius, Dogeparty, Lisk, Rootstock, Monax, Stellar, Symbiont, and Tezos [1]. Ethereum [4] with a consensus algorithm similar to that of Bitcoin [7], is a market-leader for development of smart contracts. Norta et al. [8] explore suitability and expressiveness to include in smart contract languages through a cross-organizational collaboration ontology. Norta et al. [9] investigate the life-cycle of cross-organizational business process aware collaborating governance. Raskin et al. [11] analyze smart contracts from the legal perspective and contract law. Sabatucci et al. [12] discuss JASON platform based on the AgentSpeak language [10] and the belief-desire-intention (BDI) model [3] for self-aware MAS implementation. Bordini et al. [2] survey programming languages for MAS implementation. Celaya et al. [5] discuss the abstract model of the MAS architecture and the evaluation of the coordination protocols in MAS with Petri nets. Mahunnah et al. [6] discuss an agent-oriented model (AOM) and behavior-interface model for capturing socio-technical system behavior and capture the advantages of Coloured Petri nets (CPN) model over AOM for tool supported simulation, model checking, and performance testing based verification.

The state-of-the-art shows that the current smart contract approaches lack a required degree of intelligent automation to provide self-awareness and human-readability in smart contracts for their legal enforceability.

II. Objectives

The objective of this Ph.D. project is to solve the open problem of contractual inflexibility for legal viability in smart contracts. This paper fills the gap in the current state-of-the art by posing the main research question:

How to develop self-aware human-readable contracts for legal viability?

Smart contracts life-cycle do not explore the concept and properties from contract law and unaware of their environments to facilitate the contract life-cycle with practical reasoning [3] that could make them legally enforceable. We answer the main research question by developing a multi-agent system layer on the top of the smart contract code to cope with the limitations of the current blockchain-enabled smart contracts.

To reduce complexity and establish a separation of concerns, we deduce three further sub-questions as follows:

How to enable Smart contracts to become self-aware?

The knowledge to be gathered from the internal as well as external stimuli for the smart contract vary concerning goals in the internal context and the laws, policies, and constraints

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in the external context. Our model defines Ontologies to understand real-world abstraction in the form of a set of beliefs and rules for smart contracts. From the set of beliefs we filter out abstractions such as goals and intentions by developing the deliberation process [3] for self-aware contracts. We develop a set of plans in a plan library that execute when certain invocation conditions in the form of goals meet. Finally, the BDI model based MAS reasons and selects a course of action by executing the appropriate plan to achieve goals, i.e., the agent can deduce missed deadlines from obligations, or breached obligation as invocation conditions.

How to enable self-aware contracts to become human-manageable?

We build a BDI enabled AI engine that is capable of translating the customizable Graphical User Interface (GUI) or templates based human-readable contract created by the parties into complex smart contract code structures that execute the terms of a contract. Additionally, a natural language based legal document that corresponds to the smart contract code is created by the AI agent to ensure legal enforceability.

How to ensure contract immutability for legal viability?

It is necessary to store the events related to the contract obligations, e.g., payments that affect contract-execution immutably. By consuming the relevant events from the event storing repository, a separate agent processes the obligations of the contract to the present. Moreover, to reason about delays and deadlines, events consumed by the contract agent need to be time-stamped for ensuring legal viability.

III. Methodology

Our work deals with the open problem of contractual inflexibility that has a social relevance, and our work produces solution oriented and innovative artifact in the form of MAS. Design Science Research (DSR) methodology [13] provides a conceptual framework to create new and innovative artifacts for understanding, executing, and evaluating socio-technical information systems (IS) research. Therefore, DSR methodology is suitable for our work and we adhere to following DSR guidelines proposed by Hevner et al. [13] in our research.

- **Design as an Artifact:** DSR must produce a viable artifact in the form of a construct, a model, a method, or an instantiation. Our work produces a MAS model on BDI theory of practical reasoning [3].
- **Problem Relevance:** DSR must produce technology-based solutions to the relevant and important business problems. Our work solves the open problem of contractual inflexibility for legal viability in smart contracts.
- **Design Evaluation:** The utility, quality, and efficacy of a design artifact is to be rigorously demonstrated via evaluation methods. We use CPN as a modeling tool to assess the structural, communication, coordination, and deadlock avoidance properties of MAS. We use GUI structural metrics for human-manageability and Autonomy, Socialness, Reactiveness, Proactiveness, Design, and Performance metrics to evaluate MAS [14].
- **Research Contributions:** DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies. Our contribution is to develop multi-agent assisted Self-Aware human-readable contracts for peer-to-peer (P2P) network.
- **Research Rigor:** We rely upon rigorous model of practical reasoning, i.e., BDI model of rational agency to construct the artifact and CPN tool to test the design of artifacts with simulations and verification.
- **Design as a Search Process:** The search for an effective artifact requires utilizing available means to reach the desired ends. Our work incorporates self-awareness, human-manageability, and stores events immutably for legal viability in smart contracts aided by MAS during the contract lifecycle.
- **Communication of Research:** DSR must in effect presented to technology-oriented and management-oriented audiences. Our research outcomes have to get presented and discussed in the Workshops, Conferences, and Talks.

IV. Research Plan

At present, we have identified the problem relevance, research questions, and methodology. In Table 1, we discuss the time-line of our research with DSR guidelines.

Table 1: Time line for Ph.D. Research

Activity	2018 Jan-Dec	2019 Jan-Dec	2020 Jan-Dec	2021 Jan-Dec
Problem Relevance: Identification and analysis of challenges in blockchains, smart contracts, and MAS	✓			
Research Contribution: Design the contextual meta-knowledge processing model, plan library, deliberation model, search and execution algorithms	✓	✓		
Research Contribution: Design the AI engine, GUI, and natural language legal document generation		✓	✓	
Research Contribution: Design the repository for storing and timestamping the obligations events			✓	
Design as an Artifact /Design Evaluation / Design as a Search process: MAS construction and evaluation, Ph.D. thesis composition			✓	✓
Research Communication: The preliminary and final Ph.D. defense				✓

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