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Ph.D. THESIS SUMMARY

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TRANZACȚII ECONOMICE EFECTUATE CU AJUTORUL TEHNOLOGIE BLOCKCHAIN: ÎNREGISTRAREA DREPTURILOR ȘI OBLIGAȚIILOR ȘI EFECTUAREA PLAȚILOR FINANCIARE RECURENTE

BLOCKCHAIN-ENABLED ECONOMIC TRANSACTIONS: RECURRING FINANCIAL ACCRUAL AND PAYMENTS

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Chapter 1

Introduction

1.1 Presentation of the field of the doctoral thesis

Blockchain technology has emerged as a transformative force, with the potential to revolutionize various sectors since its introduction in 2008. Despite initial skepticism, blockchain has proven its ability to address fundamental challenges in finance, economics, and accounting. This doctoral thesis explores the potential of blockchain technology to improve the efficiency and reliability of economic transactions, focusing specifically on recurring transactions governed by implicit or explicit contracts. By leveraging a blockchain-based universal contract, this research investigates how economic transactions can be executed more effectively and how the resulting transactions can be transparently recorded and reconciled among participants.

The central premise of this study is that economic transactions rely on contractual agreements that define the rights and obligations of parties involved. Through the proposed blockchain-based prototype, the essence of recurring economic transactions is captured, showcasing the enhanced effectiveness, efficiency, and quasi-real-time tracking of these transactions. The Ethereum blockchain is utilized as the smart contract platform due to its maturity and widespread adoption. Notably, this research uncovers limitations in current blockchain technology related to automatic recurring payments, providing valuable insights into areas for improvement.

The primary objective of this interdisciplinary study is to investigate how blockchain technology can significantly enhance current practices in economics, accounting, and auditing. The research aims to automate and streamline general-purpose universal transactions while focusing on the specific application of recurring transactions. By developing a prototype that automates both the accrual and payment aspects of recurring transactions, this research seeks to improve the recording process, enhance auditing capabilities, and facilitate revenue forecasts.

To accomplish these objectives, this study emphasizes empirical research and the development of a realistic prototype that faithfully mirrors the behavior of economic transactions. Drawing upon methodologies from economics, finance, computer science, and cryptography, the research employs self-generated data to construct a robust simulation that captures the intricate dynamics of recurring economic transactions. This approach enables a deeper understanding and exploration of how these transactions are recorded, surpassing traditional data-driven approaches.

Ultimately, this research contributes to the growing body of knowledge on blockchain technology's potential in revolutionizing economic transactions. By highlighting its ability to streamline recurring transactions and improve various aspects of the transaction lifecycle, this study paves the way for further advancements in integrating blockchain technology into economic, accounting, and auditing practices.

Furthermore, this study aims to contribute to the standardization of handling recurring transactions. As a direct result of the findings and insights derived from this research, the newly formed standard body within IEEE has been set up in June 2023 - Recurring Transactions on the Distributed Ledger Technologies (DLTs) Working Group" (P3228 WG). The standard body will work towards defining best practices and guidelines for implementing blockchain-based solutions in the context of recurring transactions, fostering greater efficiency and interoperability in future implementations.

1.2 Scope of the doctoral thesis

The objective of this research is to investigate how the current practices in the economic, accounting and auditing space can be substantially improved and benefit from blockchain technology. The aim is to explore the challenges and opportunities associated with integrating blockchain technology to automate and streamline general purpose universal transactions and then drill down into the more specfic application of recurring transactions. The research aims to develop a prototype that automates recurring transactions, including both the accrual and payment part, improves the recording process, enhances auditing capabilities, and facilitates revenue forecasts.

1.2.1 Universal Contract Automation using blockchain technology

An significat objective of this research is to examine the automation of universal contracts. While the primary focus is on recurring transactions within accrual accounting systems, this objective aims to investigate the broader concept of automating general economic transactions through the application of blockchain technology. Universal contracts encompass a wide range of economic transactions across various industries and contexts.

By exploring the automation of these contracts, the research seeks to identify common patterns, challenges, and solutions that can be applied to streamline and enhance transaction management processes. This objective will provide a comprehensive understanding of the potential benefits and limitations of automating universal contracts using blockchain technology. By studying the broader scope before delving into the specific case of recurring transactions, the research aims to extract valuable insights and develop a methodology that can be universally applied in transaction management practices.

1.2.2 Prototype Development for Automated Recurring Transactions

The main objective of this research is to develop a prototype that automates recurring transactions on the blockchain. The prototype will incorporate a methodology that ensures the accurate recognition of rights and obligations throughout the entire transaction lifecycle. The core of the prototype will be a smart contract, serving as the engine for automating both the accrual and payment aspects of recurring transactions.

1.2.3 Limitations and Challenges of Recurring Transaction Automation

The objective is to address the limitations associated with recurring payments on the blockchain. The research aims to identify and propose solutions for challenges such as the requirement to consistently hold the private key for seamless recurring payments. By doing so, this research aims to contribute to the development of key management solutions, security protocols, or alternative approaches to securely automate recurring payments on the blockchain.

1.2.4 Standardization of Recurring Transactions and Payments

To promote interoperability and reliability, a goal of this research is to drive standardization in the field of recurring transactions and payments on distributed ledger technologies. By establishing guidelines, protocols, and best practices, this research aims to facilitate the effective management and automation of recurring transactions across various industries and contexts.

1.2.5 Exploration of ares for future development - Integrating Prototype with Machine Learning for Economic Soundness Prediction

The integration of the prototype with machine learning algorithms represents another objective of this future research. By leveraging historical blockchain data, the research aims to develop a framework that can predict the economic soundness of businesses. This integration seeks to enable proactive risk management, informed decision-making, and the prevention of unexpected financial distress or bankruptcies.

In conclusion, the objectives of this PhD thesis revolve around exploring the potential benefits of integrating blockchain technology with accrual accounting systems for recurring transactions. By developing a prototype, addressing limitations, driving standardization, this research aims to pave the way for the automation and efficiency of recurring transaction management. The findings will contribute to academic knowledge, industry practices, and the advancement of standardization efforts in this domain.

1.3 Content of the doctoral thesis

1.3.1 Chapter 2 - State of the Art

This chapter provides a comprehensive overview of the existing state of the art regarding handling economic transactions using blockchain technology. It looks into various existing solutions such as Hyperledger and explores use cases in finance, healthcare, energy, supply chain, voting, and digital identity management. The chapter highlights the interoperability, scalability, and regulation challenges in blockchain adoption. It also looks towards the future, envisioning blockchain integration with AI and IoT. This chapter sets the stage for understanding the issues faced by the current economic environment and how this can be addressed at the general and specific use case levels.

1.3.2 Chapter 3 - Universal Contract on Blockchain

This chapter explores the concept of a universal contract on the blockchain and its transformative potential. It discusses the limitations of Bitcoin and the emergence of smart contracts on other blockchains like Ethereum. Transactions are highlighted as fundamental building blocks of the blockchain ecosystem. It explains the difference between cash-based and accrual-based accounting and highlights the need to consider both in blockchain solutions. Design requirements, permission layers, and privacy of transactions are discussed. The chapter discussed different architecture solutions to handle universal contracts and economic transactions using blockchain. It outlines the benefits of blockchain for financial information access and audits and introduces hashing for contract authenticity.

1.3.3 Chapter 4 - Recurring Economic Transactions on Blockchain: Asset Rental Case Study

This chapter builds upon the theoretical concepts discussed in Chapter 3 delves into a more specific and practical case of recurring economic transactions within the blockchain ecosystem, explicitly focusing on asset rentals as a case study. The chapter delves into the theoretical aspects of recurring transactions and their practical implementation by developing a prototype. This prototype is a tangible representation, showcasing how recurring transactions can be effectively recorded and managed on the blockchain. It provides a comprehensive demonstration of the entire lifecycle of a recurring contract-type transaction, encompassing the rights and obligations of all parties involved in the trade. Moreover, the payment aspect of the transaction is also recorded and managed using blockchain technology.

The chapter delves into the intricacies of implementing recurring payments within the blockchain ecosystem. It highlights the challenges encountered in achieving automatic recurring payments on the Ethereum blockchain, revealing that existing blockchain protocols do not natively support this functionality in a non-custodial manner. However, through rigorous investigation and analysis, the chapter proposes a solution in the form of an entirely new blockchain standard explicitly designed for Ethereum. As of the writing of this thesis, such a standard has been generated under IEEE SA as a direct result of the work performed.

1.3.4 Chapter 5 - Conclusions

Finally, Chapter 5 completes the research on blockchain-enabled economic transactions, explicitly focusing on recurring financial accrual and payments. The chapter also highlights the original contributions made throughout the research and outlines perspectives for further developments in the field.

The empirical research conducted in this thesis led to the development of a prototype that automates recurring transactions, improves the recording process, enhances auditing capabilities, and facilitates revenue forecasts. This prototype demonstrates how blockchain technology can effectively manage and record recurring transactions. It showcases the potential of blockchain in ensuring accurate recognition of rights and obligations throughout the entire lifecycle of a transaction.

The research also reveals a significant limitation concerning recurring payments on the blockchain. Existing blockchain protocols do not natively support automatic recurring payments in a non-custodial manner. This limitation emphasizes the need for further development and innovation. To address this issue, a new working group, the "Recurring Transactions on the Distributed Ledger Technologies (DLTs) Working Group" (P3228 WG), has been established within the Institute of Electrical and Electronics Engineers (IEEE) as a direct result of this research. This working group aims to develop a standard focused on recurring transactions and payments using blockchain technology.

The research contributions are categorized and listed. The methodology for managing general economic transactions, stemming from a universal contract, is developed, providing a broad scope and applicability across industries.

In summary, the research on blockchain-enabled economic transactions has made significant contributions to the field. The developed prototype showcases the potential of blockchain technology in automating recurring transactions, and the establishment of the P3228 WG emphasizes the importance of standardization in this field. Future developments will continue to advance the integration of machine learning, enhance stability and fiat integration, improve contract activation and control, and address privacy concerns. These advancements will further transform and refine the management of recurring transactions using blockchain technology.

Chapter 2

State of the art

2.1 Related Work

A holistic approach on how to include both the accrual part as well as the payment part of economic transactions has been taken by R.Mihai in the article ”Universal Contract on Blockchain” [1]. The author argues that virtually any economic transaction can, with proper configuration, be put on the blockchain. The article offers the general framework of implementation, leaving the specifics for future work. In this paper, we are building on this general idea and implementing a particular case for recurring transactions for a rental contract. A number of research initiatives address the potential benefits that blockchain technology brings to the financial world. The MIT zkledger Privacy-preserving auditing on distributed ledger [2] explores auditing transactions using private blockchain and a zero-knowledge proof in the context of a bank. This work recognizes the benefits of blockchain in the context of transfer of funds (i.e., payments). The paper is thus making a case only for the one part of the transaction, i.e., cash settlement. Other initiatives have touched upon specifically how to address the recurring payments; however, these proposed solutions are custodial in nature which makes them reliant on a central party, and do not address the accrual part of the transactions [3], [4]. Section **??** discusses the limitation of the existing blockchain technology with respect to recurring payments.

2.2 An Introduction to Blockchain Technology

2.2.1 Blockchain as a General-Purpose Technology

Blockchain was made famous by Bitcoin - its first application [5]. The technology has attracted much attention in recent years, demonstrating its huge potential for a wide array of applications stretching far beyond cryptocurrencies. Blockchain combines components of many disciplines; concepts from economics, cryptography, computer science – both hardware and software; also, from mathematics (e.g., graph theory and probability theory); hence understanding how the blockchain technology works and its current and future implications is far from an easy task. As well as providing a state-of-the-art snapshot of Blockchain as it now is, this report creates a bridge between the economic and technical spaces to facilitate the better understanding of the Blockchain technology and its future applications.

Blockchain technology has been defined as a general-purpose technology [6]. General-purpose technologies generate the most economic growth over the long run. Examples are the steam engine, harnessing electricity, the internet. Whenever such an invention emerges, it is not unusual for many years to pass before the full benefits are realized. What makes them "general" is that they can be applied to more than one industry segment; hence it can take time to diffuse through the economy.

Traditional accounting practice is a double-entry approach where a financial transaction is recorded in the books of both transacting parties. Blockchain has increasingly been recognized as an opportunity to allow for triple-entry accounting, i.e., recording a financial transaction on a system separate from the individual participating parties' systems [7].

Proof of Work

Proof of Work("PoW"), the most notorious algorithm, is the consensus algorithm used by Bitcoin and Ethereum blockchain. Under the PoW consensus, miners (i.e. nodes) are required to solve a complex mathematical problem that will allow them to attach the block to the blockchain. It is essential to understand that solving this complex mathematical problem does not bring knowledge by itself, such as finding a solution to a complex known mathematical problem. It is simply similar to solving a puzzle which allows the miners to participate in the blockchain lottery. Solving the puzzle requires computing power, which in turns translates into energy consumption. This is they price of the "lottery ticket" to participate in the "blockchain game". The concept of proof of work was first introduced by Dwork et al. in 2005 when it was called also called "proof of computational effort" [8]. The concept had several applications, such as avoiding e-mail spamming, before being made notorious in the bitcoin context.

Proof of Stake

The proof of stake consensus protocol solves the ambiguity problem by choosing the next block winner using a lottery system. PoS works with a form of Byzantine consensus protocol where multiple nodes (i.e., validators) verify and agree on the block being proposed. PoS has been developed partly as a need to solve the energy consumption required to maintain and secure a blockchain.

Validators place some of their tokens into an escrow account as collateral — "Proof of Stake." If a validator were to add an invalid block to the blockchain, they would risk losing that collateral. PoS protocols differ in how validators are chosen for each round. In some instances, the group of validators is static, while in others, the validators rotate between lottery rounds.

Typically, the chance of winning a lottery round depends on the stake a validator has in the system. So, for example, a validator with a 10% stake will be able to confirm approximately 10% of blocks. This lottery-like system has other features such as, for example, how long the stakes have been in place. These specific features are meant to both solve the ambiguity problem and secure the blockchain at the same time.

Smart Contracts

Digital money has been in existence for a relatively long time now. Today, most of the interactions with the banks are digital. Where is then the innovation introduced by the cryptocurrency such as Bitcoin or Ether? The challenge is that money was not programmable. All digital assets created on top of the blockchain network are programmable from the very beginning. This is where smart contracts come into play.

A smart contract is essentially a contract that acts in certain ways defined by the terms of the contract. Smart contracts start with a cryptocurrency, and then layers can be added on top. For example, a simple leasing contract can be constructed where the tenant pays the rent automatically to the landlord at the end of the specified period, provided certain conditions are met. These conditions are essentially programmable instructions that react to situations in the environment or to new events that emerge.

2.3 Business Applications of Blockchain

2.3.1 Enterprise Blockchain Platforms

Blockchain technology has caught the attention of the enterprise world, and thus a number of blockchain platforms, typically private and permissioned have been developed. This section aims to cover the most well-known and promising enterprise-level blockchain to the date of writing. While private blockchain allows only certain participants to enter the network, permissioned blockchains stand somewhere in between public and private blockchain. In a permissioned blockchain, participants are allowed to join the network upon verification of their identity; the participants in a permission blockchain are allowed to perform only certain activities in the blockchain [9]. For example, a participant can be allowed to read but not to append the blockchain.

2.3.2 Use Cases and Industries

Financial sector

Ripple is an example which illustrates how a blockchain concept has evolved from a cryptocurrency application, originally called OpenCoin, into a blockchain protocol adopted by a significant number of financial institutions, especially banks. Heavily influenced by the specific needs of banks and financial institutions, Ripple's main selling point is the speed of executing transactions compared to the other existing blockchain solutions, thus making it an alternative to bank remittances using the traditional SWIFT protocol. Related to, but distinct from the its blockchain protocol. Ripple has its own cryptocurrency (i.e., XRP) which tends to fluctuate between the number three and four position after Bitcoin and Ethereum in terms of market capitalization (i.e., $8.7 bn, as of the date of this report).

Healthcare

Ensuring the integrity and accessibility of medical records is paramount of a well-functioning of a healthcare system. A critical challenge with medical records is data privacy. It is important to note that there is no opposition between privacy and blockchain. Data privacy is an option in blockchain; it is not a constraint. Medicalchain stores medical records on the blockchain but allows accessibility upon authorization from the user's mobile. Other prominent organizations that tap into the potential of the blockchain in the healthcare space include MIT's MedRec and Taipei Medical University Hospital.

Energy

The Energy sector offers considerable potential for blockchain-based applications. However, companies in this sector have proven to be a slow adopter of the blockchain technology compared to other industries. Significant areas that could benefit from blockchain solutions include energy trading, decentralized generation, grid management, and smart metering. One of the first implementations of a blockchain experimental solution took place in 2018 when Transactive Grid, in partnership with LO3 Energy, Consensus, Siemens and Centrica have created a blockchain-based peer-to-peer energy trading platform. In essence, consumers can sell their excess energy directly to their neighbors by using an Ethereum based smart contract [10].

Voting

Blockchain has the potential to significantly improve the voting process by adding the necessary level of security to online voting. The inherent characteristics of blockchain help eliminate fraud and can increase voter turnout in elections. Such an experiment had already been conducted in November 2018, in West Virginia, US, where citizens located outside the US have been given the option to vote online using a blockchain-based application called Voatz. The blockchain protocol arguably ensures transparency in the electoral process, reducing the personnel required to conduct an election. An MIT study [11] , published in February 2020, identified vulnerabilities in the application which caused the researchers to refer their findings to the Department of Homeland Security. The main vulnerabilities found revolved around the possibility of an adversary to infer the user's voting choice or corruption of audit trail. Blockchain complemented with Artificial Intelligence has the potential to dramatically change the way our society is governed starting with voting but extending to a number of complex and dynamic aspects facing the world today [12].

Digital Identity Management

Identity management is a concept that easily lends itself to blockchain applications. It provides an excellent example where data privacy becomes an option in a blockchain application as opposed to a constraint. There are numerous situations where an ID is required to be allowed access in a building, for example. In a situation like this, permission information would suffice to allow access as opposed to the full identity details such as name, address, or date of birth. Well known blockchain-based applications include uPort, which focuses on creating a digital identity that ultimately represents a person or an organization, allowing them to make statements about who they are. The application uploads the information on an independent data decentralized data storage while maintaining its address on the Ethereum blockchain. An important distinction is warranted here between where data is stored (i.e., decentralized data storage) and the blockchain address, which provides the validity of stored data. Sovrin is yet another blockchain-based application for digital identity management. Unlike uPort, the Sovrin project has built a custom blockchain specially designed for this purpose, which potentially scales more effectively at the global level that the Ethereum based applications.

2.4 Challenges in Blockchain Technology Adoption

There are a number of challenges facing the adoption and deployment of blockchain technology. Most of these roadblocks are inherent in any transition toward a new technological stage, such as while others are specific to the technology itself. The main obstacles are:

2.4.1 Interoperability

There is a lack of standards to ensure the interoperability between various blockchain platforms given the early stage of development. One of the most critical aspects warranting special attention are the protocols around key loss and theft [13]. This challenge is, however, on its way to being address with the establishing in 2016 of International Organization for Standardization for Blockchain and Distributed Ledger Technologies. Moreover, thereis an equally great challenge poised by the interoperability between blockchain platforms and legacy information systems.

2.4.2 Scalability

Scalability has been recognized from the very beginning as one of the biggest concerns of blockchain implementations. In the Ethereum Yellow Paper [14], Woods, makes a clear reference that given the generalized state transition function of the blockchain, it is difficult to partition and parallelize to apply the divide-and-conquer strategy. On the other hand, Croman et. al, proposed in 2016 an approach to dividing blockchains into various abstract layers called planes, with each plane being responsible for performing specific functions: network plane, consensus plane, storage plane, view plane, and side plane [15]. According to their position paper – On scaling decentralized blockchains – the authors propose that this abstraction allows tackling the inherent limitations of blockchains at each such plane individually in a structured manner.

2.4.3 Regulatory challenges

Today the regulatory environment is not as friendly to cryptocurrencies as it was to the Internet. We should keep in mind though that cryptocurrencies are just an application of the blockchain technology. It is essential to make this separation and not to generalize when we tackle the topic of regulation. Regulators are looking at cryptocurrencies with caution for two fundamental reasons. First, there have been a number of scams in the cryptocurrency field [16], of which Mt. Gox is the most notorious example in the Bitcoin space; thus, regulators are rightly concerned. Second, there is a perception that the decentralization aspect of the blockchain technology calls into question the very power of the state to create currency or the power of the regulators to regulate.

2.5 The Future of Blockchain Technology

One of the most interesting developments to look forward to is how blockchain technology will interact with other disruptive technologies such as artificial intelligence (AI) and the Internet of Things (IoT). Blockchain has been increasingly recognized as a general-purpose technology. As discussed earlier in this report, one of the key characteristics of GPT is that it catalyzes innovation in complementary technology. At the same time, artificial intelligence and machine learning have had an impressive resurgence in recent years since research in this field began in the 1950's. The combination of blockchain and artificial intelligence has the potential to radically change a series of important industry verticals, including the accounting and auditing profession [17].

Several solutions have surfaced which propose to solve, for example, the confirmation of financial transactions with the help of blockchain and to analyze those transactions and come up with a suitable diagnosis mechanism that will help make a more effective financial decision with the support of Artificial Intelligence [18].

The European Commission created the EU Blockchain Observatory and Forum to encourage the region's cross border engagement with the technology and its various stakeholders. The EU predicts that blockchain and AI could also help secure blockchain-based financial services platforms in the anti-money laundering (AML) process by tracing transactions and detecting fraud risks [19].

Amazon is pushing ahead on this front of combining the blockchain, artificial intelligence and IoT. In addition to their AWS Blockchain Services, the company has developed AWS IoT platform, a cloud-based platform that allows for the creation and deployment of models in the cloud which arguably runs twice as fast as their conventional alternatives [20].

Chapter 3

Universal Contract on Blockchain

Despite being called by its sceptics a solution looking for a problem, the technology has the potential to address fundamental financial, economic, and accounting challenges. At the core of every economic transaction, there is an implicit or explicit contract that stipulates the rights and obligations of the parties to the transaction. Beginning from this fundamental agreement, this chapter examines how economic transactions can be performed more efficiently and effectively, based on a blockchain-based universal contract; and examines how the resulting transactions can be more reliably and transparently recorded and reconciled among the economic participants.

3.1 Introduction

The recently proposed blockchains gave way to the development of a broader range of applications and brought about several consensus algorithms which are different from the initial Proof of Work known for being energy intensive. The best known blockchain which enables the deployment of smart contracts is Ethereum, which at the date of this paper is transitioning from a Proof of Work to a Proof of Stake consensus [21].

Despite the initial hype in the applications of smart contracts, "smart contracts" have proven to be not so smart in reality [22]. On the contrary, smart contracts allow simply automated execution if a given a set of conditions are met, and therefore can be considered "dumb contracts".

3.2 Basis of Accounting: Accrual vs. Cash

The principal difference between cash-based accounting and accrual-based accounting is when the booking of revenues and expenses in the accounting records takes place. In cash-based accounting, revenue and expenses are recorded when money is exchanged between the two parties of a transaction. In contrast, in an accrual-based accounting, revenues are recorded when earned, irrespective of whether they have been collected, i.e., cashed; and expenses are recorded when there is an assumed obligation to pay the respective expense but not necessarily when the expense is paid.

The MIT zkledger Privacy-preserving auditing on distributed ledger [2] investigates auditing transactions using private blockchain and zero-knowledge proof in a banking context. This work recognizes the importance of real-time audit but focuses strictly on a banking context where funds are transferred from the sender to the receiver. In essence, the paper proposes a solution only for the first part of the equation, i.e., cash transactions, and fails to tackle the accrual side of an economic transaction.

3.3 Design requirements

We foresee the creation of a universal contract that can encapsulate and parametrize all the details of a typical commercial contract beyond the scope of a simple lending contract. All the details of such a universal contract will be able to be stored in a format that can be read by humans but also read, interpreted, and executed by a machine. JSON (JavaScript Object Notation) format makes for a good candidate to represent and transmit generic data as it involves a limited number of data types: strings, numbers, Boolean, list, objects and null. These data types are represented in all major programming language and can be used by API and databases.

3.4 Commercial contract hashing

"Hashing" provides a reliable way to prove that a given commercial contract has been uniquely signed by parties taking part to that transaction. A commercial contract, whether in the form of a smart contract or a traditional contract in digital form, can be save in a distributed database or a cloud resource, whereas the hash of the contract is put the blockchain. In this way the authenticity of the contract is verified beyond doubt by any interested party.

3.5 Transactions

Transactions are the most fundamental building blocks of the blockchain. The fact that blockchain has found its "use case" in the financial space may create confusion for what a transaction is, in the context of blockchain. The term transaction in the context of blockchain includes the definition of a transaction from a financial standpoint. In a more holistic sense, however, it means transacting, i.e., transmitting a set of information from point A (sender) to point B (receiver). A transaction is assimilated to relaying and storing a record, which may include, but is not limited to, a money settlement.

Chapter 4

Recurring Economic Transactions on Blockchain: Asset Rental Case Study

Note: The content of this chapter is fundamentally based on the paper titled "Blockchain-Enabled Economic Transactions: Recurring Financial Accruals and Payments," which was published the 2022 IEEE 1st Global Emerging Technology Blockchain Forum: Blockchain & Beyond conference [23].

Economic transactions are based upon implicit or explicit contracts that set out the rights and obligations of the parties to the transactions. Blockchain technology can address fundamental financial, economic, and accounting challenges. We propose a blockchain-based prototype capable of capturing the essence of recurring economic transactions. For this purpose, we have devised a asset rental contract to show how economic transactions are recorded and tracked more effectively, efficiently, and in quasi-real-time. We use the Ethereum blockchain as the most evolved and widely used smart contract platform. We showcase a significant discovery related to current blockchain technology limitations to make automatic recurring payments. We show how the prototype can be extended to a range of recurring transactions.

4.1 Introduction

The potential of blockchain technology lies far beyond the cryptocurrency applications. Some argue that blockchain is an accounting technology [24], having the potential to streamline both the execution of economic transactions and how these transactions are recorded and verified.

Transactions are the building blocks of the blockchain. The term transaction in the context of blockchain includes its definition from a financial standpoint; however, in a more abstract sense, transacting means transmitting an information set from point A (sender) to point B (receiver). A transaction is thus similar to sending and receiving a record, which may include, but is not limited to, a money settlement [1].

Accrual vs. Payments. Accrual Accounting is the most widely used accounting method requiring the recording of revenues when earned, and of expenses when incurred, regardless of the timing of receipt or payment. In contrast, Cash Accounting records the revenues and expenses when settled in cash. The fundamental difference between these two methods often gives rise to confusion for those not familiar with accounting principles and practices.

The role of the independent verifier, i.e., auditor, is likely to significantly change from the manual work currently performed to check details in documents, to auditing the smart contracts underlying the economic transactions on the blockchain [18]. This article documents a specific prototype implementation of how this can be practically achieved. To this end, we use an asset rental example in which the customer (i.e. lessee) recognizes the obligation to pay, and makes monthly payments to the supplier (i.e. lessor).

4.2 Prototype Architecture

4.2.1 Specifications

A contract between two economic players contains several terms and conditions spread over sometimes an intimidating number of text pages. However, in most cases, the critical number of parameters is rather limited. The prototype blockchain architecture is presented in Fig. 4.1. Ongoing documentation, code, and test results can be found at: https://github.com/UniversalContractOnBlockchain/Recurring-Economic-Transactions. The fundamental parameters without which a contract cannot exist are as follows:

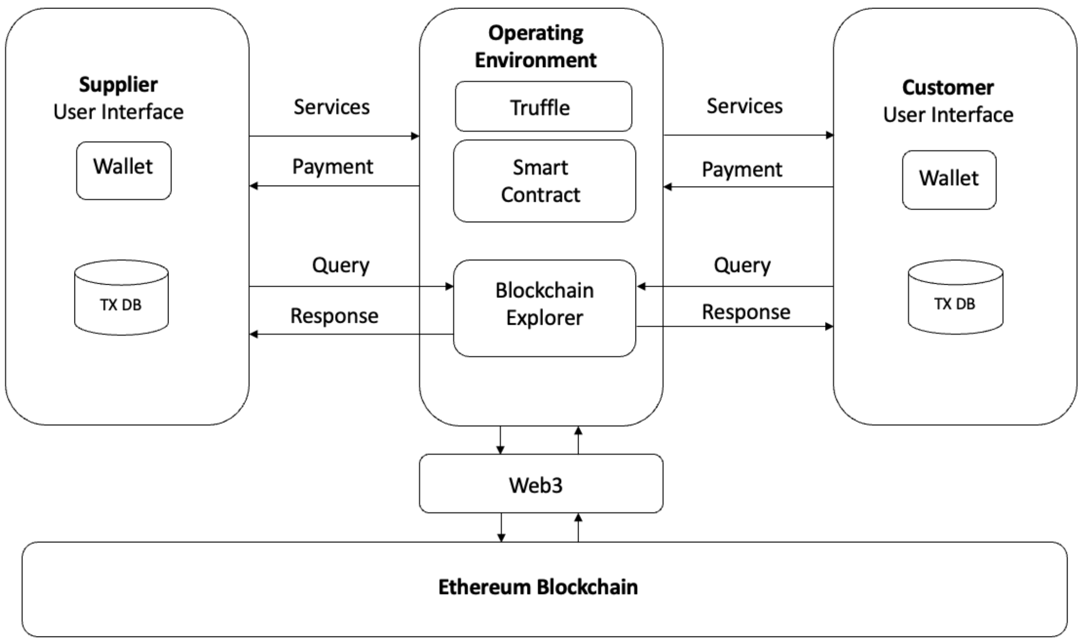

Fig. 4.1 Prototype Architecture Overview

Supplier. The unique id of a supplier is typically used here, e.g., company's *name*, commercial/fiscal registration *number*, and registered office *address*. However, the essential element in a blockchain setting is the *public address* - the unique number used to record and settle transactions.

Customer. The information will mirror the parameters described above in the case of the supplier. In both instances (supplier and the customer), if an individual instead of a company, the required information is: the full *name* of the individual, id *number*, and *address* as stated on the id documents, as well as the *public address*.

Duration. The duration for which the contract is valid from and until. We need to know how long the contract will hold its validity and make the payments accordingly. This means blocking some payments if they are not due or taking another course of action if they are overdue.

Amount. This parameter is crucial for the smart contract to calculate the total payment as well as knowing how much or rather how many tokens to charge each recurring month. Instead of making the supplier entering the entire amount during the duration of the contract (duration of the contract x monthly payment) we allow entering the monthly payment and calculating the rest when showing that information to the end user.

4.2.2 User Interface Design

The user interaction with the system is described in Fig. 4.2, which captures the fundamental functionalities of the proposed prototype. To reduce the system payload and streamline the contract initiation, the prototype is designed in such a way that only the supplier can initiate the contract. Users of the system can either be a supplier or a customer at any given time. The default prototype configuration is that users can see others' contract information to the extent that they are part of that particular contract, unless the public key of any given supplier or customer is already known. However, as described in Section **??**, privacy is an option rather than a constraint, and therefore these features can be subsequently adjusted to take account of the particular needs of parties to the transactions. Basic functionalities of the prototype are listed here:

- Make a new contract (Only as Supplier)
  - Customer public address
  - Contract duration
  - Amount to be paid each month
- View contracts (Supplier and Customer)
- Accept the terms of the contract (Only as Customer)

- Make payment on the contract (Only as the Customer)
- Inspect transactions history on Blockchain Explorer (Supplier and Customer)

It is important to note that when the user signs a transaction, the digital signature is applied to the hash of the transaction. Specifically, on Ethereum, the user signs the Keccak-256 hash of the RLP-serialized transaction data [25].

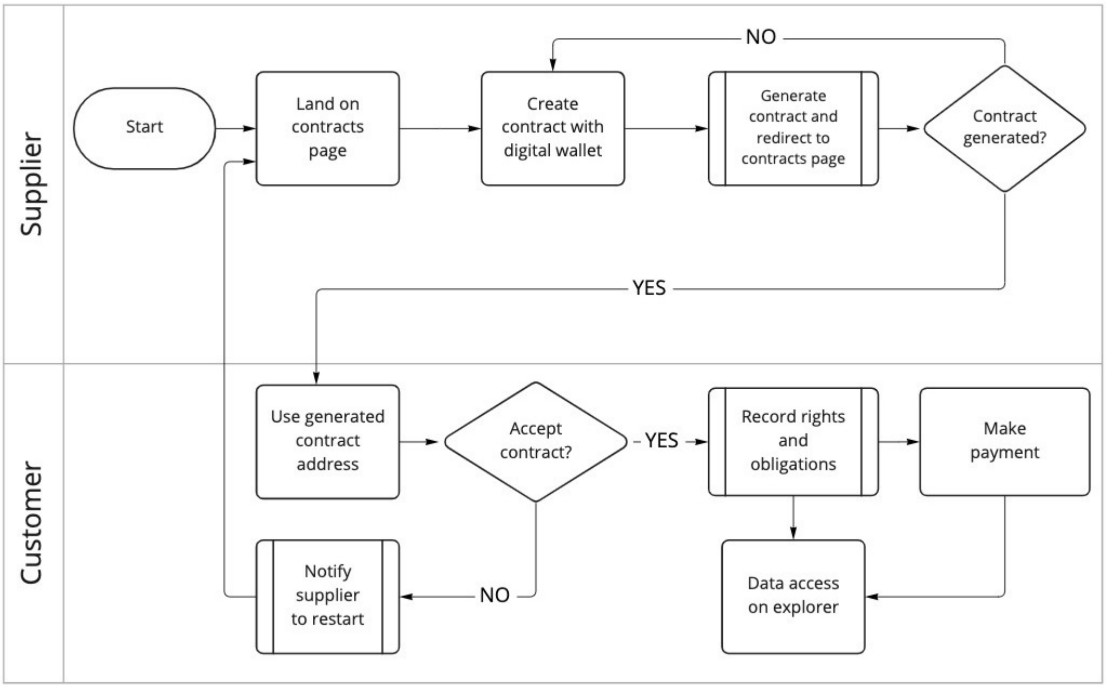

Fig. 4.2 User Interface Flow

4.2.3 Smart Contract Logic

The existing methods of creating a smart contract are not optimal for the specific requirement of the envisaged type of transactions. Additional information, such as the amount paid to the contract, is required. Even though it is possible to use the conventional way to access the instance of a specific transaction and retrieve the amount details, this is a cumbersome task. Therefore, we have constructed a custom data type structure ("struct History") which saves the required data efficiently.

4.2.4 Module Interactions

A visual representation of the system's software modules and their interrelationships is presented in Fig. 4.3, where modules are depicted as boxes and their interconnections as arrows. The diagram offers insights into the system's architecture from the perspective of the software modules involved, their behavior, and their interactions.

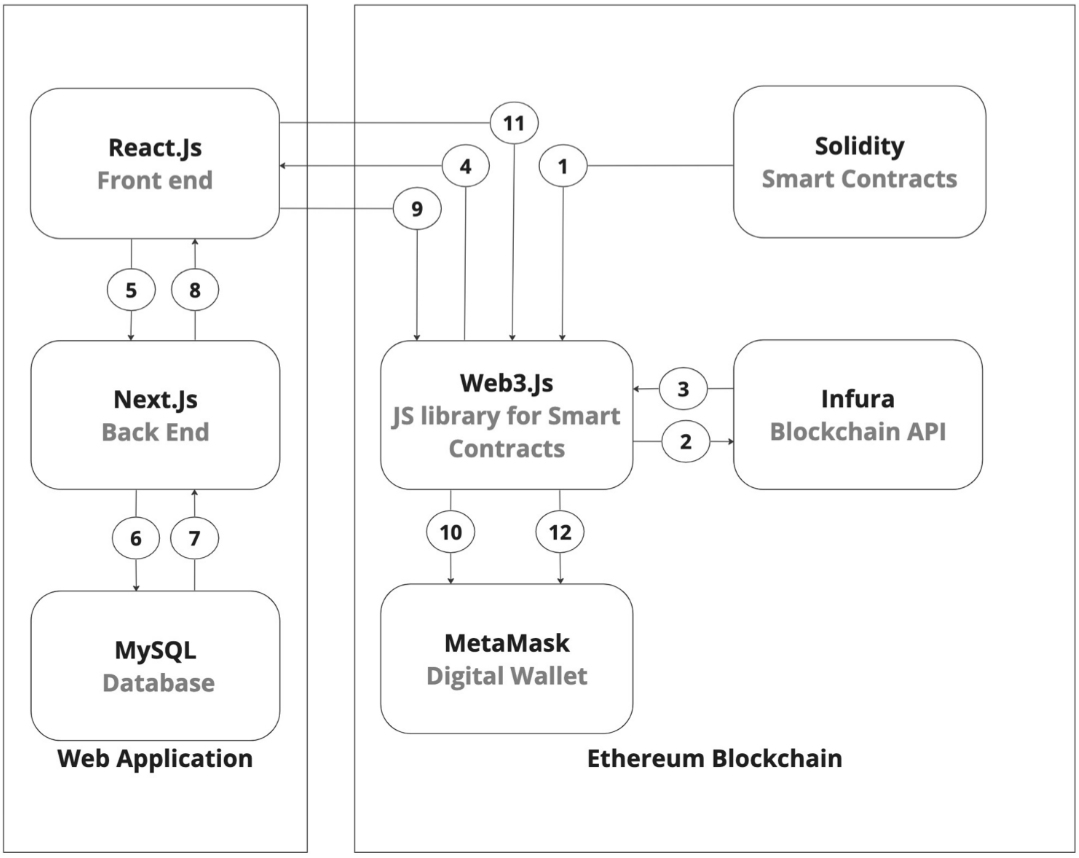

Fig. 4.3 Module Interactions

4.2.5 User Interactions

This subsection serves as a comprehensive user guide detailing the essential steps required to interact with a blockchain prototype designed to streamline recurring transactions and payments. The increasing popularity of blockchain technology has opened new avenues for improving efficiency, transparency, and security in financial systems. By leveraging the decentralized nature of blockchain, this prototype aims to simplify the process of recurring transactions, eliminating the need for intermediaries and minimizing transactional friction. An outline of the sequential steps involved is presented to illustrate accessing, setting up an account, managing recurring transactions, and ensuring secure and seamless transactions recording and payments through the blockchain prototype. For a visual demonstration of how the streamlined blockchain prototype for recurring transactions and payments works, a video demo is available at *www.recurringtransactions.xyz*.

4.3 Recurring Payments Automation

Significant Discovery. We have discovered that automatic recurring payments are not supported natively in a non-custodial manner by the Ethereum blockchain. In fact, each token transaction needs to be manually signed at the moment of the transfer. Crucially, the inability to be able to make recurring payments is not an Ethereum-specific issue. Most popular blockchain protocols [26] do not support automatic recurring payments at predefined dates, as transaction participants must have control over the private key at all times.

We have investigated the scenario where the customer supplies the private key into an encrypted database, similar to how passwords are stored. We have concluded that this is an inadequate option as it is vulnerable to hacking. There are various solutions in development; however, these are either custodial in nature (i.e., centralized) or not linked to the underlying accrual part of the transaction [3, 4].

New Blockchain Standard. We finally concluded that the best course of action to solve the identified problem by both ensuring a non-custodial environment and connecting the recurring payment to the related accrual part of the transaction is to develop an entirely new standard specific to the Ethereum blockchain.

Chapter 5

Conclusions

We have proposed a blockchain-based prototype design to capture the economic essence of recurring transactions between two parties. For implementation, we have chosen Ethereum blockchain as the most matured and widely used smart contract platform. The specific case of our prototype implementation revolves around a lease contract with fixed, regular payments.

However, the solution can be extended to virtually any recurring type of transaction as a recurring transactions extend far beyond the specific use case presented in this paper, i.e., a rental asset agreement. Other types of recurring transactions such as loan repayments with equal monthly installments or subscription-based services, e.g., medical subscriptions [27], are good candidates for being automated and traced using the proposed solution. Payroll and their related taxes and burdens are generally fixed and recurring, making them yet another suitable use case for the application of the proposed prototype.

5.1 Obtained results

We have demonstrated the blockchain technology's potential to complement and ultimately replace the traditional way of account keeping. In Section 4.3 , we present a ***significant discovery*** regarding the ***limitation*** of the current blockchain solutions with respect to making ***automated recurring payments***. This significant discovery asks for the drafting of a new blockchain standard to allow for making recurring payments in a non-custodial manner and to connect these payments to the underlying accrual part of the economic transaction.

As a direct result of this finding, the establishment of the "Recurring Transactions on the Distributed Ledger Technologies (DLTs) Working Group" (P3228 WG) within the Institute of Electrical and Electronics Engineers (IEEE) stands to show the importance of the research in improving and guiding the management of recurring transactions using blockchain technology.

In conclusion, the empirical research, focusing on the concepts of accrual accounting and blockchain technology, led to the creation of a prototype that effectively automates recurring transactions, improves the recording process, enhances auditing capabilities, and facilitates revenue forecasts. The prototype showcased the potential of blockchain in ensuring the accurate recognition of rights and obligations throughout the entire lifecycle. However, the limitation concerning recurring payments highlights the need for further development. The establishment of the "Recurring Transactions on the Distributed Ledger Technologies (DLTs) Working Group" (P3228 WG) (https://opensource.ieee.org/oscom/official-project-requests/-/issues/15) emphasizes the crucial importance of the research in advancing the management of recurring transactions using blockchain technology.

5.2 Original contributions

5.2.1 Advancing Economic Transaction Management: A Methodology for Universal Contracts

In this part of the research, the focus lies on the development of a methodology for managing general economic transactions, with an emphasis on how economic transactions stem from a universal contract. The work has been focused on development of the methodology, which can be applied across various industries and contexts. It implies a broader scope and applicability, encompassing economic transactions as a whole.

5.2.2 Exploring the Dynamics of Recurring Economic Transactions: Methodology, Challenges and Solutions

This work specifically highlights the contribution related to recurring economic transactions. It emphasizes the in-depth exploration of the complexities and challenges associated with managing recurring transactions within the accrual accounting system. This work narrows focus on recurring transactions and indicates the research's aim to identify solutions and insights tailored to this specific subset of transactions.

5.2.3 Prototype Development for Automated Recurring Transactions on the Ethereum Blockchain

In addition to the contributions mentioned above, a third significant contribution is the development of a prototype that automates recurring transactions on the Ethereum blockchain. This prototype incorporates the methodology developed earlier, providing a practical implementation of the research findings.

The development of the prototype involved the creation of detailed specifications. At the core of the specifications is the smart contract, which serves as the engine for automating both the accrual and payment aspects of recurring transactions. By leveraging the capabilities of the Ethereum blockchain, the prototype ensures the accuracy and reliability of transaction recording, encompassing the entire transaction lifecycle.

5.2.4 Unveiling Limitations and Enhancements in Automating Recurring Transactions on the Blockchain

As part of the prototype implementation and testing, a fourth significant contribution emerges, highlighting the discovery of a limitation within blockchain technology concerning the automation of recurring payments. The research and testing process shed light on a specific challenge associated with recurring transactions: the requirement to hold the private key at all times.

5.2.5 Driving Standardization for Recurring Transactions and Payments: A New IEEE Working Group for Standard Development

In addition to the contributions mentioned earlier, a fifth significant contribution emerges as a result of uncovering the limitation regarding the automation of recurring payments on the blockchain. This discovery has led to the establishment of a new working group within the Institute of Electrical and Electronics Engineers (IEEE) with the aim of developing a standard specifically addressing recurring transactions and payments.

Recognizing the importance of addressing this limitation and advancing the field, the working group, officially known as the "Recurring Transactions on the Distributed Ledger Technologies (DLTs) Working Group" (P3228 WG), has been founded and is currently operational as of June 2023. Founding and serving as a board member of this prestigious group is Razvan Mihai, the researcher responsible for the groundbreaking work in automating recurring transactions on the blockchain.

5.2.6 Integrating Prototype and Machine Learning for Economic Soundness Prediction

The development of a framework that integrates the prototype, designed for automating recurring transactions on the blockchain, with a machine learning solution represents a significant contribution [18]. This integration aims to leverage blockchain data to predict the economic soundness of businesses, facilitating risk identification and promoting financial stability.

In summary, the integration of the prototype and machine learning represents a significant contribution to the field. By leveraging blockchain data and predictive analytics, the framework enables the prediction of economic soundness, risk identification, and prevention of unexpected bankruptcies. This integration enhances risk management practices, supports informed decision-making, and fosters financial stability in the business landscape.

5.3 List of original publications

1. R. Mihai, O. F. Ozkul, G. Datta, N. Goga, S. Grybniak, and C. V. Marian, "Blockchain-enabled economic transactions: Recurring financial accruals and payments," in 2022 IEEE Is Global Emerging Technology Blockchain Forum: Blockchain & Beyond. Irvine, CA, USA: IEEE, 2022, pp. 1-5. https://ieeexplore.ieee.org/document/10087074 [23]
2. R. Mihai, T. E. Nyberg, E. Michaelsen, I. Rizea-Popp, M. Dascalu, and G. M. Stefan, "IT-based financial confirmation and diagnosis mechanisms," ROMANIAN JOURNAL OF INFORMATION SCIENCE AND TECHNOLOGY, vol. 22, pp. 284–299, 2019 [18].
3. R. Mihai, "Universal contract on blockchain," Economics of Financial Technology Conference, Edinburgh, 2022-05-13. https://www.eftconference.business-school.ed.ac.uk/past-papers?title=&page=4 [1].
4. R. Mihai, M. Malita, G.M. Stefan: "Nano-Structural Requirements for Artificial Intelligence and Blockchain Applications" Proceedings of the 42nd International Semiconductor Conference CAS 2019, 9—11 October 2019, Sinaia, Romania, pp 115-118. DOI: 10.1109/SMICND.2019.8923787 At: https://ieeexplore.ieee.org/document/8923787 [28].
5. M. Malița, G. M. Ștefan, and R. Mihai, "Architectural features for artificial inteligence and blockchain in the nano-era," Romanian Journal of Information Science and Technology, vol. 23, no. 2, pp. 115–126, 2020 [29].
6. G. M. Ștefan and R. Mihai, "IT driven distributed consensus for an integrated globalized world," Romanian Journal of Information Science and Technology, vol. 21, no. 2, pp. 114–128, 2018 [12].
7. S. Grybniak et al., "Recurring payments on EVM-based platforms," in 2022 IEEE 1st Global Emerging Technology Blockchain Forum: Blockchain & Beyond (iGETblockchain). Irvine, CA, USA: IEEE, 2022, pp. 1–6. [30].

5.4 Perspectives for further developments

5.4.1 Advancing the Prototype: Integrating a Machine Learning Solution with the Existing Blockchain-Based Framework

As part of the future development of our work, the focus now shifts to the implementation of the defined framework that integrates the prototype with a machine learning solution. While the framework has been conceptualized and designed to leverage blockchain data for predicting economic soundness and promoting financial stability [18], the next phase entails the actual implementation of the machine learning model.

5.4.2 Navigating Blockchain's Challenge: Pursuing Decentralized Automated Payments

Section 4.3 Recurring Payments Automation has revealed a key challenge in blockchain technology: automating recurring payments without manual intervention. Our focus shifts to addressing this limitation. A preliminary effort [30], co-authored by the thesis author, marks the inception of this pursuit. Future work entails designing a solution for decentralized automated payments. This scholarly endeavor blends theoretical insight with practical application, propelling us toward a promising future where blockchain's potential is harnessed to harmonize decentralized autonomy with seamless automation. This future work complements the effort of contributing to the elaboration of the IEEE standard on recurring payemnts as outlined in Section 5.2.5 Driving Standardization for Recurring Transactions and Payments: A New IEEE Working Group for Standard Development.

5.4.3 Enhancing Privacy in Blockchain-Based Economic Transactions: Integrating Zero-Knowledge Proofs for Improved Confidentiality

In order to enhance the prototype, particular attention will be given to addressing the concept of data privacy in blockchain technology. It is crucial to dispel any misconceptions surrounding the use of cryptographic hash algorithms in blockchain, which are primarily employed to ensure block validity and transaction security rather than conceal funds transfers.

To cater to the privacy requirements of participants in the economic context, improvements will be made by incorporating layer 2 emerging technologies such as zero-knowledge proofs into the prototype. Zero-knowledge proofs offer promising solutions to enhance privacy while maintaining the integrity and transparency of the blockchain.

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