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# BOFUS and CLARITY: streamlining blockchain architecture and assessment for advanced standardization and interoperability in distributed ledger technologies

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The Blockchain Organized Framework for Unified Systems (BOFUS) and the Comprehensive Ledger Assessment for Robust Interoperability and Trustworthiness (CLARITY) initiatives address the challenges of understanding, standardizing, and enabling interoperability between diverse blockchain systems. BOFUS is a comprehensive 5-layer model that systematically organizes core blockchain components, while the CLARITY assessment provides a standardized method for evaluating and comparing blockchains using the CONFIGURE acronym. Together, these initiatives aim to facilitate a deeper understanding of blockchain technology, promote effective communication and collaboration between stakeholders, and ultimately advance the development and adoption of distributed ledger technologies. This paper presents an in-depth discussion of the BOFUS architecture and the CLARITY assessment, exploring their utility in various blockchain scenarios and their potential implications for the future of blockchain technology.

KEYWORDS

**blockchain, distributed ledger technology, 5layer model, interoperability, blockchain assessment, blockchain evaluation, consensus mechanisms**

## 1 Introduction

Blockchain technology has emerged as a driving force behind numerous innovations, altering the landscape of various industries and shifting the paradigm in trust, transparency, and decentralization. As the technology continues to evolve, a diverse range of blockchain systems since the inception of bitcoin (Nakamoto, 2008) has been developed, each with its unique architecture (Panicker et al., 2016) and functionality. This diversity, while demonstrating the potential of blockchain technology (Gourisetti et al., 2019), also presents challenges in understanding, standardizing, and enabling interoperability (Besançon et al., 2019) between different systems. In response to these challenges, we introduce the Blockchain Organized Framework for Unified Systems (BOFUS) and the Comprehensive Ledger Assessment for Robust Interoperability and Trustworthiness (CLARITY) assessment.

The BOFUS is a comprehensive 5-layer model designed to systematically organize the core components of blockchain systems into a coherent structure. This framework encompasses five distinct layers: Data, Consensus, Network, Application, and Incentive. Each layer serves a unique and essential purpose in a functioning blockchain, providing the foundation for understanding and designing blockchain systems. The Data Layer is responsible for maintaining the blockchain's structure and storing data, whereas the Consensus Layer ensures agreement on the validity of transactions and blocks. The Network Layer manages communication between nodes in the blockchain network, while the Application Layer allows for the implementation of various applications, such as smart contracts (Hamledari and Fischer, 2021) (Swan, 2015) (Delmolino et al., 2016) (Narayanan et al., 2016) (Ahmed et al., 2019) and token systems. Lastly, the Incentive Layer provides rewards and penalties to encourage participants to contribute to the network's security and stability.

In tandem with the BOFUS model, we present the CLARITY assessment, a tool designed to evaluate and compare different blockchain systems based on standardized criteria. The CLARITY assescsment employs the CONFIGURE acronym, which stands for Consensus, Openness, Nodes, Fees, Interoperability, Governance, Usability, Robustness, and Efficiency. These criteria enable a comprehensive evaluation of various aspects of a blockchain system, such as its consensus mechanism, degree of decentralization, network topology, transaction fees, ability to interoperate with other systems, governance model, user experience, security, and performance. By providing a standardized method for assessing blockchains, the CLARITY assessment fosters a more informed decision-making process for organizations and individuals considering adopting or investing in blockchain technology.

Together, the BOFUS and CLARITY initiatives aim to address the challenges of understanding, standardizing, and enabling interoperability between different blockchain systems. By providing a comprehensive framework for organizing the core components of blockchain systems and a robust assessment tool for evaluating them, we hope to facilitate a deeper understanding of blockchain technology, promote more effective communication and collaboration between stakeholders, and ultimately, advance the development and adoption of distributed ledger technologies.

This paper presents an in-depth discussion of the BOFUS architecture and the CLARITY assessment, elaborating on the rationale behind each layer and criterion. Additionally, we provide examples and use cases to illustrate the utility of the BOFUS model and the CLARITY assessment in various blockchain scenarios. We also explore the potential implications of adopting these initiatives for the future (Zheng et al., 2017) of blockchain technology, including the promotion of best practices, enhanced standardization efforts, and improved interoperability between systems. By advancing our understanding of blockchain systems and providing tools to evaluate and compare them, the BOFUS and CLARITY initiatives lay the groundwork for continued innovation and growth in the rapidly evolving world of distributed ledger technology.

### 1.1 The need for a unified framework and assessment tool

As the adoption of blockchain technology continues to grow across various industries, there is an increasing number of distributed ledger systems, each with distinct architectures and functionalities. While the diversity of blockchain systems demonstrates the versatility and potential of the technology, it also presents challenges (Honar Pajooh et al., 2021) (Song et al., 2022) in terms of understanding, comparing, and integrating these systems. The absence of a unified framework and assessment tool exacerbates these challenges, leading to issues such as fragmented communication, lack of standardization, and limited interoperability among different blockchain systems.

A unified framework for blockchain systems, such as BOFUS, can help address these challenges by providing a systematic and organized structure for understanding and categorizing the core components of distributed ledger technologies. With a clearly defined architecture, developers, researchers, and decision-makers can more effectively communicate about and understand the underlying design principles and functionalities of various blockchain systems. This, in turn, can promote the adoption of best practices and facilitate collaboration between stakeholders in the development and implementation of blockchain solutions.

Moreover, the need for an assessment tool, like the CLARITY assessment, arises from the necessity to evaluate and compare different blockchain systems based on standardized criteria. In the absence of such a tool, organizations and individuals face difficulties in making informed decisions when considering adopting or investing in blockchain technology. A standardized assessment method enables stakeholders to systematically evaluate various aspects of a blockchain system, such as its consensus mechanism, degree of decentralization, network topology, transaction fees, interoperability, governance model, user experience, security, and performance. By providing a comprehensive and objective evaluation of blockchain systems, the CLARITY assessment fosters informed decision-making and helps stakeholders identify the most suitable blockchain solutions for their specific needs.

## 2 Literature review

### 2.1 Blockchain technology: An evolution

Blockchain technology (Yli-Huumo et al., 2016) originated with Bitcoin (Zohar, 2015), which was the first successful implementation of a decentralized and trustless system of value transfer. It was later recognized that the underlying technology could be applied in a variety of scenarios beyond digital currency. With the introduction of Ethereum (Tikhomirov, 2018), blockchain's scope was expanded to encompass decentralized applications (dApps) (Antal et al., 2021), ushering in a new era of decentralized computation.

The fundamental attributes of blockchain, such as its distributed ledger, consensus algorithms, and cryptography-based security (Wang et al., 2020), made it an attractive proposition for various applications including supply chain management (Saberi et al., 2019), healthcare (Agbo et al., 2019), finance (Zhang et al., 2020), and more. The immutability of records (Chowdhury et al., 2018) provided by the blockchain offers unprecedented levels of transparency and auditability, which has the potential to revolutionize the way transactions and data management are handled across different sectors.

## 2.2 Diversity of blockchain systems

Different blockchain systems (Xu et al., 2019) have been designed to cater to specific needs. Bitcoin (Reid and Harrigan, 2013), for example, was built primarily to function as a digital currency. Ethereum (Chen et al., 2020), on the other hand, was designed to enable developers to build dApps on its platform, thereby extending its use cases beyond that of a mere currency.

Consequently, different blockchain systems have adopted different architectures (Saurabh and Dey, 2021). Bitcoin uses a UTXO (Unspent Transaction Output) model, while Ethereum utilizes an account-based model. Moreover, they use different consensus mechanisms: Bitcoin uses proof-of-work (PoW) (Gervais et al., 2016), while Ethereum has to transitied to proof-of-stake (PoS) (Delmolino et al., 2016). This diversity in blockchain systems is indicative of the wide array of possible applications of the technology, but it also presents a complex landscape that can be challenging to navigate.

## 2.3 Standardization and interoperability challenges

Despite the enormous potential of blockchain technology (Roman-Belmonte et al., 2018), the landscape's heterogeneity poses significant challenges in standardization and interoperability (Belchior et al., 2021). Standardization refers to the development and implementation of technical standards that ensure uniformity in design and compatibility across various systems. Interoperability, on the other hand, involves the ability of different systems to work together seamlessly, even if they were developed independently of each other.

While there have been some efforts towards standardization, such as the development of the ERC20 standard for tokens on the Ethereum network (Di Angelo and Salzer, 2020), the blockchain ecosystem remains predominantly fragmented. As such, there is no universal standard that governs blockchain systems, which leads to a lack of interoperability (Bokolo, 2022).

Interoperability between different blockchain systems remains a major challenge (Raval, 2016). Given that each system has its own unique architecture, consensus mechanism, and transaction models, enabling seamless data and value transfer across different blockchains has proven to be a complex task. This fragmentation and lack of interoperability hampers the potential for synergistic development and use of blockchain systems (Rahman, 2021).

## 2.4 Blockchain assessment frameworks

Several blockchain assessment frameworks (Touloupou et al., 2022) have been proposed in an attempt to evaluate the performance, security, and other technical aspects of different blockchain systems. However, most of these frameworks focus solely on individual characteristics, overlooking the necessity for a comprehensive review that takes into account the system as a whole.

As a response to this issue, we propose the Blockchain Organized Framework for Unified Systems (BOFUS) and the Comprehensive Ledger Assessment for Robust Interoperability and Trustworthiness (CLARITY) assessment. These frameworks aim to offer a thorough evaluation of the functionality, security, scalability, and interoperability of different blockchain systems (Bhatia, 2020), thereby providing a solid basis for comparison and further research.

## 2.5 Blockchain transaction models: ACID, BASE, and SALT

Tai et al. (Tai et al., 2017) discussed the limitations of traditional ACID and BASE transactions, typically supported by relational database management systems, in their seminal paper. They introduced SALT, a new model tailored for blockchain-based applications. This model emphasizes Sequential, Agreed-on, Ledgered, and Tamper-resistant transaction processing. From a systems perspective, SALT stands for Symmetric, Admin-free, Ledgered, and Time-consensual transaction processing systems. This work underscores the dual perspective of the SALT model, demonstrating how blockchain technology can be leveraged to engineer decentralized applications.

## 2.6 Taxonomy of blockchain technologies

A more extensive classification of blockchain technologies has been presented by Tasca and Tessone (Tasca and Tessone, 2017). They systematically deconstructed blockchains into their fundamental building blocks and identified and compared the varieties of the components. This bottom-up approach allowed them to create a comprehensive taxonomy tree, which provides a useful navigation tool across different blockchain architectural configurations. Their work contributes to a more profound understanding of the fundamental elements of blockchains and their various configurations.

## 2.7 Blockchain and auditing

The implications of blockchain technology in the auditing environment have been examined by Silva, Inácio, and S. Wieninger (Wieninger et al., 2019) where Wieninger et al. focuses on lookig at blockchain taxonomy and looking at it's future trajectories aswell. They proposed real-time auditing and asset tokenization as potential areas for blockchain application in the auditing field. Their proof of concept demonstrated the creation and tracking of a token on a public blockchain, representing the tokenization of assets. This capability highlights new challenges and opportunities for auditors in terms of skills and knowledge.

## 2.8 Centralization in decentralized blockchains

The paradox of centralization in decentralized blockchains was addressed by Sai et al. (2021). They performed a systematic literature review and conducted expert interviews to derive a taxonomy of centralization present in decentralized blockchains. They identified 13 aspects of centralization, classified over six architectural layers: Governance, Network, Consensus, Incentive, Operational, and Application. Their work provides a comprehensive understanding of the various conceptualizations and measures of centralization.

## 2.9 Decrypting distributed ledger design

Ballandies et al. (2022) conducted an extensive study on the design choices of distributed ledger technologies (DLT). Using machine learning methodologies, they created a taxonomy and classification for DLT systems based on real-world data. The resulting DLT design guideline provides key insights into the design of DLT systems and identifies opportunities for research and business innovation.

## 2.10 Other relevant research

The realm of smart contracts and blockchain technology has continued to evolve since its inception. Key researchers like Galiautdinov (2023),Hewa et al. (2021), and Macrinici et al. (2018) have all made significant strides in this field, providing innovative methods of structuring and deploying smart contracts on blockchain platforms and exploring the potential of blockchain and IoT in optimizing maritime freight transport networks.

The application of blockchain technology extends to various sectors. Basile et al. (2021) provided a systemic method of assessing the impact of blockchain technology in promoting sustainable business practices. Meanwhile, studies by Makridakis and Tiscini (Makridakis and Christodoulou, 2019; Tiscini et al., 2020) have shed light on how blockchain can influence the food industry and impact regional economies.

From a theoretical perspective, blockchain technology has been explored in depth by renowned scholars such as Kim et al. (2020), who delve into the transformational potential of blockchain in improving socio-economic inequality. Works by T aste and Casey (Aste et al., 2017; Casey and Vigna, 2018) underscore the importance of understanding the economic, social, and technical aspects of blockchain technology, including privacy and trust issues.

In the context of fintech, academic papers by Mougayar (2016) and Tapscott et al. (2019) demonstrate the transformative potential of blockchain in the financial industry, particularly in shaping the future of banking systems and in reducing operational inefficiencies.

The use of blockchain technology in the field of digital identity has also been thoroughly investigated by several researchers. Contributions from Zheng et al. (2018) and Pilkington (2016) discuss the potential of blockchain in the digital identity verification process, contributing to more secure online transactions and information exchanges.

These aforementioned works collectively underline the rapid evolution and diverse applications of blockchain technology and smart contracts across numerous sectors. They also highlight key challenges that need to be addressed, including governance, security, and interoperability issues, to unlock the full potential of this innovative technology.

# 3 BOFUS: Blockchain organized framework for unified systems

Blockchain technology has evolved significantly since its inception, with numerous distributed ledger systems emerging, each offering unique features and architectures. This has led to a heterogeneous landscape that complicates the understanding, comparison, and integration of these systems. To address these challenges, we introduce the Blockchain Organized Framework for Unified Systems (BOFUS), a comprehensive and structured approach to organizing, understanding, and evaluating the core components of distributed ledger technologies.

BOFUS is designed to provide a coherent and systematic representation of the key aspects of blockchain systems, encompassing their data storage, consensus mechanisms, network communications, application-level functionalities, and incentive structures. By offering a unified framework, BOFUS aims to facilitate communication and collaboration among researchers, developers, and decision-makers, enabling them to effectively compare and assess the merits and limitations of various blockchain systems. Moreover, BOFUS seeks to promote the adoption of best practices and drive innovation within the blockchain ecosystem. This is further detailed in Table 1, which provides a clear and structured approach to understanding and evaluating distributed ledger technologies.

## 3.1 Data layer

### 3.1.1 Blockchain data structures

The data layer, integral to blockchain systems, is tasked with managing the organization and persistent storage of data. A prevalent structure used is a linear sequence of blocks, where each block contains a collection of transactions and is cryptographically linked to its predecessor. This linkage imbues the system with inherent immutability and transparency. Any attempt to alter a block would necessitate the recomputation of all subsequent blocks, rendering malicious tampering computationally prohibitive.

It's worth noting that while the chain-like sequence of blocks is emblematic of traditional blockchains, decentralized systems have also adopted alternative structures. For instance, Directed Acyclic Graphs (DAGs) present a non-linear approach to data organization, allowing for transactions to be processed in parallel and offering potential improvements in scalability.

Regardless of the specific structure employed, the core tenet remains: to ensure data integrity and resilience against unauthorized modifications.

### 3.1.2 Data storage

Data storage in the blockchain can be implemented using various methods, such as key-value stores, Merkle trees, or directed acyclic graphs (DAGs). The choice of data storage method depends on the specific requirements of the blockchain system, such as the desired level of data redundancy, scalability, and accessibility.

**TABLE 1** Enhanced Summary of BOFUS layers with examples.

| Layer | Description |
|---|---|
| Data Layer | Responsible for the blockchain's structure and storage, such as key-value stores, Merkle trees, and DAGs. |
| Consensus Layer | Defines consensus mechanisms like PoW, PoS, and DPoS, affecting energy efficiency and scalability. |
| Network Layer | Manages node communication and network topology. Potential topologies include star, mesh, ring, and hybrid structures. |
| Application Layer | Supports applications like smart contracts (e.g., ERC-20, ERC-721) and token systems, enabling diverse blockchain functionalities. |
| Incentive Layer | Establishes reward (e.g., block rewards, transaction fees) and penalty mechanisms (e.g., slashing in PoS systems) to uphold network security. |

**TABLE 2** Summary of CLARITY CONFIGURE Criteria.

| Criteria | Description |
|---|---|
| Consensus | Evaluates the consensus mechanisms employed by a blockchain system, including their scalability, energy efficiency, and resistance to attacks. |
| Openness | Assesses the level of decentralization and accessibility of a blockchain system, including the degree of participation allowed for nodes and the transparency of the system's governance. |
| Nodes | Examines the distribution, roles, and responsibilities of nodes within the network, including their diversity, geographic distribution, and the resilience of the network to node failures or attacks. |
| Fees | Evaluates the cost structure associated with transactions, block validation, and other operations within the blockchain system, including the fairness and sustainability of the fee model. |
| Interoperability | Assesses the ability of a blockchain system to interact and integrate with other systems, including the availability of standard interfaces and cross-chain communication protocols. |
| Governance | Evaluates the decision-making processes and structures within a blockchain system, including the transparency, inclusiveness, and effectiveness of the governance model. |
| Usability | Assesses the ease of use, user experience, and accessibility of a blockchain system for both developers and end-users, including the availability of developer tools and documentation. |
| Robustness | Examines the resilience of a blockchain system to various types of failures, attacks, and adverse conditions, including its fault tolerance and resistance to common attacks. |
| Efficiency | Evaluates the performance, scalability, and resource utilization of a blockchain system, including its throughput, latency, and energy consumption. |

## 3.2 Consensus layer

### 3.2.1 Consensus mechanisms

The consensus layer plays a pivotal role in blockchain systems, striving to create a synchronized state across all participating nodes by confirming the authenticity of transactions and endorsing the addition of new blocks. At its core, one of the primary goals of blockchain consensus mechanisms is the prevention of Sybil attacks. In such attacks, a single adversary can control multiple nodes, jeopardizing the integrity and security of the network. Various consensus mechanisms, notably Proof of Work (PoW), Proof of Stake (PoS), and Delegated Proof of Stake (DPoS), have been developed to counteract these threats and others, each with its own unique set of advantages and challenges in terms of scalability, energy efficiency, and resistance to attacks (Platt and McBurney, 2023).

#### 3.2.1.1 Energy efficiency and consensus mechanisms

Historically, PoW has been one of the most widely adopted consensus mechanisms, powering networks like Bitcoin. It requires miners to solve complex cryptographic puzzles to produce new blocks—a process that demands considerable computational power. Due to its energy-intensive nature, PoW has faced criticism, with mining operations often in search of cheap electricity to maintain profitability.

On the other hand, PoS and DPoS emerged as energy-efficient successors to PoW. Instead of computational challenges, these mechanisms rely on validators or delegates who have significant "stakes" or investments in the system. The core incentive here is not puzzle-solving but ensuring honest validation to safeguard their vested interests. These consensus approaches don't need high-energy computations, positioning them as more energy-efficient than PoW.

The consensus mechanism chosen can heavily influence a blockchain system's energy consumption. Recent studies, such as the one documented in (Liu et al., 2021), provide quantitative evaluations of the energy consumption of consensus algorithms, enabling better-informed decisions concerning their deployment and consequences.

### 3.2.2 Validation of transactions and blocks

Once the consensus mechanism is selected, the subsequent phase is the rigorous validation of transactions and blocks. Nodes, depending on their specific roles, validate digital signatures and confirm that transaction inputs haven't been previously expended. The specifics of this validation process

**TABLE 3 Detailed Evaluation of Blockchain Models using BOFUS and CLARITY Criteria.**

| Criteria | Bitcoin | Hyperledger fabric |
|---|---|---|
| BOFUS Data Layer: Storage Mechanism | Uses UTXO (Unspent Transaction Output) model in a linked-list blockchain | Uses a combination of blockchain and a world state database for state management |
| BOFUS Consensus Layer: Consensus Mechanism | Employs Proof-of-Work requiring miners to solve complex computational puzzles | Employs pluggable consensus mechanisms such as Solo (for development), Kafka (for crash fault-tolerance), and Raft (for Byzantine fault-tolerance) |
| BOFUS Network Layer: Network Structure | Operates as a peer-to-peer network where nodes broadcast transactions and blocks | Organizes network into channels for secure and private communication between specific network members |
| BOFUS Application Layer: Applications | Primarily serves as a digital currency with no complex applications | Supports complex applications via chaincode (akin to smart contracts) that can be written in Go, JavaScript, and Java |
| BOFUS Incentive Layer: Incentives | Miners are incentivized by block rewards and transaction fees | As a permissioned network, the incentive is the utility of the network itself. No native cryptocurrency or mining rewards |
| CLARITY Consensus: Scalability and Energy Efficiency | PoW provides strong security but is energy-intensive and not highly scalable | Depends on consensus protocol used, but generally more scalable and energy-efficient than PoW |
| CLARITY Openness: Degree of Decentralization | High degree of decentralization, being a permissionless network | Lower degree due to permissioned nature, with network participation determined by predefined roles |
| CLARITY Nodes: Distribution and Roles | Nodes are fully distributed with equivalent roles | Nodes have different roles (e.g., endorser, committer, orderer), enhancing performance but potentially reducing resilience |
| CLARITY Fees: Cost Structure | Transaction fees depend on network congestion, can become high during peak times | No transaction fees as it operates without a native cryptocurrency |
| CLARITY Interoperability: Integration Capability | Limited native support for integration with other blockchains | Modularity facilitates integration with other systems, but cross-blockchain interoperability is not natively supported |
| CLARITY Governance: Decision-Making Process | Lacks a formal governance model, decisions are made based on collective agreement of network participants | Has a structured governance model with clearly defined roles for different types of nodes |
| CLARITY Usability: User Experience | Straightforward for simple transactions, but limited programmability due to lack of smart contract support | Enhanced developer experience due to support for general-purpose programming languages for chaincode |
| CLARITY Robustness: Resistance to Failures and Attacks | Proven to be robust since inception, with no major interruptions | Robustness depends on specific network configuration, includes measures for dealing with failures and adversarial behavior |
| CLARITY Efficiency: Performance and Resource Utilization | Low efficiency due to high energy consumption and low transaction throughput | High efficiency due to more efficient transaction validation process and pluggable consensus |

depend on the consensus mechanism in operation, impacting the network's efficiency and sustainability. For example, while Proof-of-Work (PoW) systems may check if a block's hash meets a particular difficulty target, other consensus approaches like Proof-of-Stake (PoS) or Byzantine Fault Tolerance (BFT) possess their distinct validation criteria and procedures.

## 3.3 Network layer

### 3.3.1 Node communication

The network layer manages the communication between nodes in the blockchain network, enabling the transmission of transactions, blocks, and other relevant data. This layer may rely on various communication protocols, such as peer-to-peer (P2P) networks, to ensure efficient and secure data transmission (Neudecker and Hartenstein, 2018).

### 3.3.2 Network topology

The network layer also defines the topology of the blockchain network, which can be organized in different ways, such as a fully connected mesh, a star network, or a combination of different topologies. The choice of network topology affects the system's resilience to attacks, latency, and overall network performance.

## 3.4 Application layer

### 3.4.1 Smart contracts

The application layer is responsible for implementing the higher-level functionalities of the blockchain system, such as smart contracts (Rouhani and Deters, 2019). Smart contracts are self-executing contracts with the terms of the agreement between parties directly written into code, enabling automated and decentralized execution of contractual agreements.

### 3.4.2 Token systems

The application layer also encompasses the creation and management of token systems, which can represent digital assets, access rights, or other forms of value. Tokens can be used for various purposes, such as incentivizing network participants, enabling decentralized applications (dApps), and facilitating transactions within the blockchain ecosystem.

## 3.5 Incentive layer

### 3.5.1 Reward mechanisms

The incentive layer is responsible for designing and implementing reward mechanisms that motivate network participants to contribute resources and maintain the blockchain system's security and integrity. These rewards can be in the form of newly minted tokens, transaction fees, or other incentives.

### 3.5.2 Penalties and security

The incentive layer also deals with penalties and security measures designed to discourage malicious activities, such as double-spending attacks or attempts to manipulate the consensus process. This may involve implementing measures such as slashing conditions, where malicious participants forfeit their staked assets or lose their ability to participate in the network.

## 3.6 Advantages and potential implications of BOFUS

The BOFUS framework offers several advantages, such as providing a systematic and organized structure for understanding and categorizing the core components of distributed ledger technologies. By promoting standardization and facilitating communication between stakeholders.

# 4 CLARITY: Comprehensive ledger assessment for robust interoperability and trustworthiness

As the blockchain ecosystem continues to expand and diversify, the need for a comprehensive assessment framework becomes increasingly evident. Such a framework can facilitate the evaluation and comparison of various distributed ledger technologies (DLTs), enabling researchers, developers, and decision-makers to identify their strengths and weaknesses, and ultimately make informed choices regarding their adoption and integration. In response to this need, we introduce the Comprehensive Ledger Assessment for Robust Interoperability and Trustworthiness (CLARITY) framework, as detailed in Table 2, a methodical approach to evaluating blockchain systems based on a set of carefully chosen criteria.

CLARITY comprises the CONFIGURE criteria, a collection of nine key aspects that encompass the essential characteristics of a blockchain system (Smetanin et al., 2020), such as consensus mechanisms, openness, node distribution, fees, interoperability, governance, usability, robustness, and efficiency. By systematically assessing these criteria, CLARITY enables a thorough and consistent evaluation of various DLTs, providing valuable insights into their performance and suitability for different use cases.

In this section, we will explore the technical underpinnings of the CLARITY framework, discussing the CONFIGURE criteria in detail and their relevance to the assessment of blockchain systems. Furthermore, we will demonstrate the application of the CLARITY assessment, showcasing its utility in the analysis and comparison of different distributed ledger technologies. Finally, we will discuss the potential implications of adopting CLARITY, highlighting its potential to promote standardization, transparency, and collaboration within the blockchain ecosystem.

## 4.1 CONFIGURE criteria

### 4.1.1 Consensus

The consensus criterion evaluates the consensus mechanisms employed by a blockchain system, assessing their ability to maintain the security, integrity, and reliability of the network. This includes examining the scalability, energy efficiency, and resistance to attacks of the chosen consensus mechanism.

### 4.1.2 Openness

The openness criterion assesses the level of decentralization and accessibility of a blockchain system. This includes evaluating the degree of participation allowed for nodes, the transparency of the system's governance, and the availability of its source code and documentation.

### 4.1.3 Nodes

The nodes criterion examines the distribution, roles, and responsibilities of nodes within the network. This includes assessing the diversity of nodes, their geographic distribution, and the resilience of the network to node failures or attacks.

### 4.1.4 Fees

The fees criterion evaluates the cost structure associated with transactions, block validation, and other operations within the blockchain system. This includes analyzing the fairness and sustainability of the fee model and its impact on network usage and growth.

### 4.1.5 Interoperability

The interoperability criterion assesses the ability of a blockchain system to interact and integrate with other systems, both within and outside the blockchain ecosystem. This includes evaluating the availability of standard interfaces, cross-chain communication protocols, and other means of facilitating seamless interaction between systems.

### 4.1.6 Governance

The governance criterion evaluates the decision-making processes and structures within a blockchain system. This includes assessing the transparency, inclusiveness, and effectiveness of the governance model, as well as its ability to adapt to changing conditions and requirements.

### 4.1.7 Usability

The usability criterion assesses the ease of use, user experience, and accessibility of a blockchain system for both developers and end-users. This includes evaluating the availability of developer tools, documentation, user interfaces, and other resources that facilitate the adoption and use of the system.

### 4.1.8 Robustness

The robustness criterion examines the resilience of a blockchain system to various types of failures, attacks, and adverse conditions.

This includes assessing the system's fault tolerance, resistance to attacks such as double-spending or Sybil attacks, and its ability to recover from failures.

#### 4.1.9 Efficiency

The efficiency criterion evaluates the performance, scalability, and resource utilization of a blockchain system. This includes examining the throughput, latency, and energy consumption of the system, as well as its ability to handle increasing transaction volumes and network sizes.

### 4.2 Application of the CLARITY assessment

The CLARITY assessment can be applied to analyze and compare various blockchain systems based on their adherence to the CONFIGURE criteria. By systematically evaluating the strengths and weaknesses of different systems, stakeholders can make informed decisions regarding the adoption, development, or integration of blockchain technologies. Furthermore, the CLARITY assessment can help identify areas for improvement, driving innovation and the adoption of best practices within the blockchain ecosystem.

### 4.3 Potential implications of adopting CLARITY

The adoption of the CLARITY framework can have significant implications for the blockchain ecosystem. By providing a comprehensive and structured approach to evaluating distributed ledger technologies, CLARITY can help promote standardization, transparency, and collaboration among stakeholders. This can lead to more informed decision-making, greater interoperability between systems, and the development of more robust, secure, and efficient blockchain technologies.

## 5 Pseudo-code implementation of the BOFUS five-layered architecture

```
procedure BASICCONSENSUS
  block ← createNewProposedBlock()
  isValid ← validateBlock(block)
  if isValid then
    addToBlockchain(block)
  end if
end procedure
```

**Algorithm 1.** Example Algorithm 1: Basic consensus algorithm.

In Algorithm 1, we present a simple and generic consensus algorithm. The procedure Basic Consensus starts by creating a new proposed block. It then validates the block according to predefined rules, such as checking the block's hash, verifying that transactions are properly signed, and ensuring that there are no double spends. If the block is deemed valid, it is added to the blockchain. This basic consensus algorithm can be extended to include more sophisticated consensus mechanisms like Proof of Work or Proof of Stake.

```
procedure EXECUTESMARTCONTRACT(contract, inputData)
  currentState ← readContractState(contract)
  newState ← Logic(contract, currentState, inputData)
  writeContractState(contract, newState)
end procedure
```

**Algorithm 2.** Example Algorithm 2: Smart contract execution.

Algorithm 2 demonstrates the execution of a smart contract in the context of a blockchain. The ExecuteSmartContract procedure takes a smart contract and input data as arguments. It begins by reading the current state of the smart contract from the blockchain's storage. Next, the contract's logic is executed using the current state and input data to produce a new state. Finally, the updated state is written back to the blockchain's storage. This algorithm highlights the role of smart contracts in managing state transitions and enabling programmable logic on top of the blockchain.

```
procedure PROOFOFWORK(block, difficulty)
  $nonce \leftarrow 0$
  repeat
    hash ← computeHash(block, nonce)
    $nonce \leftarrow nonce + 1$
  until $hash <$ difficultyTarget(difficulty)
  return nonce
end procedure
```

**Algorithm 3.** Example Algorithm 3: Proof of work

Algorithm 3 showcases the Proof of Work consensus mechanism, which is widely used in public blockchains like Bitcoin (Lamriji et al., 2023) (Akbar et al., 2021). The ProofOfWork procedure takes a block and a difficulty target as input. The algorithm iterates through different nonce values, computing the hash of the block with each nonce. When a hash value lower than the difficulty target is found, the algorithm returns the corresponding nonce. This process demonstrates how Proof of Work secures the blockchain by requiring participants to expend computational resources in order to validate new blocks.

```
procedure TOKENTRANSFER(from, to, amount)
  balanceFrom ← getBalance(from)
  balanceTo ← getBalance(to)
  if $balanceFrom \geq amount$ then
    setBalance(from, $balanceFrom - amount$)
    setBalance(to, $balanceTo + amount$)
  end if
end procedure
```

**Algorithm 4.** Example Algorithm 4: Simple token transfer

In Algorithm 4, we illustrate a basic token transfer operation on a blockchain. The TokenTransfer procedure takes a sender, a recipient, and an amount as input. It retrieves the current balances of both parties from the blockchain's storage. If the sender's balance is greater than or equal to the transfer amount, the algorithm updates the balances accordingly, reducing the sender's balance and increasing the recipient's balance. This simple token transfer operation highlights the ability of blockchains to facilitate the exchange of digital assets without the need for intermediaries.

```
procedure BLOCKCHAINSYNC(localBlockchain, remoteBlockchain)
    localHeight ←getBlockchainHeight(localBlockchain)
    remoteHeight ←getBlockchainHeight(remoteBlockchain)
    if remoteHeight > localHeight then
        for height ← localHeight + 1 to remoteHeight do
            block ←getBlockAtHeight(remoteBlockchain, height)
            isValid ←validateBlock(block)
            if isValid then
                addToBlockchain(localBlockchain, block)
            else
                break
            end if
        end for
    end if
end procedure
```

**Algorithm 5.** Example Algorithm 5: Blockchain synchronization

Algorithm 5 outlines the process of synchronizing a local copy of a blockchain with a remote copy. The BlockchainSync procedure compares the heights of the local and remote blockchains. If the remote blockchain is longer, the algorithm iteratively retrieves blocks from the remote blockchain and validates them. If a block is valid, it is added to the local blockchain. The process continues until the local blockchain is fully synchronized with the remote copy or an invalid block is encountered. This algorithm emphasizes the decentralized and distributed nature of blockchain networks, where nodes must maintain consensus on the current state of the blockchain.

In terms of directly explaining it with the layered achitecture look below.

- The Data Layer is responsible for maintaining the structure of the blockchain and the storage of data. In Algorithm 1 (Basic Consensus Algorithm), the blockchain structure is implicitly involved when validating and adding new blocks. The validation step checks the block's hash, verifies that transactions are properly signed, and ensures that there are no double spends. Additionally, Algorithm 4 (Simple Token Transfer) demonstrates how the Data Layer is used to store and retrieve balances during token transfers. These algorithms highlight the critical role of the Data Layer in managing blockchain information and providing a foundation for other layers to build upon.
- The Consensus Layer focuses on the consensus mechanism that ensures the agreement on the validity of transactions and blocks. Algorithm 1 (Basic Consensus Algorithm) presents a generic consensus mechanism where blocks are validated according to predefined rules. By extending this basic consensus algorithm, more sophisticated consensus mechanisms like Proof of Work or Proof of Stake can be implemented. Algorithm 3 (Proof of Work) exemplifies a specific consensus mechanism widely used in public blockchains, ensuring the security of the network through computational effort. These algorithms underline the importance of the Consensus Layer in maintaining the integrity of the blockchain.
- The Network Layer deals with the communication between nodes in the blockchain network. Algorithm 5 (Blockchain Synchronization) highlights the importance of communication between nodes when synchronizing local and remote copies of the blockchain. The algorithm demonstrates how nodes exchange block information and maintain consensus on the current state of the blockchain. This layer ensures that the decentralized and distributed nature of blockchain networks is effectively managed, allowing for seamless information exchange and consensus across nodes.
- The Application Layer is responsible for the implementation of various applications, such as smart contracts (Siddiqui et al., 2023) and token systems, on top of the blockchain. Algorithm 2 (Smart Contract Execution) demonstrates how smart contracts can be executed within a blockchain, managing state transitions and enabling programmable logic. Algorithm 4 (Simple Token Transfer) shows the process of transferring digital assets within a blockchain network, which can be part of a broader token-based application. These algorithms emphasize the versatility of the Application Layer, enabling a wide range of use cases and functionalities to be built on top of the blockchain infrastructure.
- The Incentive Layer provides rewards and penalties to encourage participants to behave honestly and contribute to the network's security and stability. Algorithm 3 (Proof of Work) indirectly touches on this aspect, as the Proof of Work mechanism typically involves block rewards for miners who successfully validate new blocks by finding a valid nonce. This incentive encourages miners to expend computational resources and participate in the consensus process (Yuan and Wang, 2018). The Incentive Layer plays a crucial role in aligning the interests of various stakeholders in the blockchain ecosystem, fostering network growth and long-term sustainability.

# 6 Evaluation of blockchain models using BOFUS and CLARITY

In this section, we present an evaluation of two representative blockchain models: Bitcoin (a public, permissionless blockchain) and Hyperledger Fabric (a private, permissioned blockchain). (Androulaki et al., 2018) (Cachin, 2016). These models were chosen due to their distinct characteristics and wide usage. The evaluation is carried out using the BOFUS framework to understand and organize their core components, and the CLARITY assessment for a detailed comparison and evaluation in Table 3 aswell.

## 6.1 Application of BOFUS to blockchain models

### 6.1.1 Application of BOFUS to bitcoin

The Bitcoin blockchain can be characterized using the BOFUS framework as follows:

- Data Layer: Bitcoin employs a linked-list blockchain structure where transactions are stored in blocks. The data storage mechanism is based on a UTXO model.
- Consensus Layer: Bitcoin uses a Proof-of-Work consensus mechanism, where miners compete to solve a computational puzzle.
- Network Layer: Bitcoin's network is a peer-to-peer system where nodes broadcast transactions and blocks.
- Application Layer: Bitcoin's main application is as a cryptocurrency. There are no complex applications like smart contracts in the Bitcoin network.
- Incentive Layer: Miners are incentivized by block rewards and transaction fees.

### 6.1.2 Application of BOFUS to hyperledger fabric

The Hyperledger Fabric model can be characterized using the BOFUS framework as follows:

- Data Layer: Fabric uses a ledger with a blockchain and a world state database to store the current state of the ledger.
- Consensus Layer: Fabric uses a pluggable consensus mechanism and supports algorithms such as Solo, Kafka, and Raft.
- Network Layer: The Fabric network is organized into channels for private communication between specific network members.
- Application Layer: Fabric supports chaincode (similar to smart contracts), which can be written in general-purpose languages like Go, JavaScript, and Java.
- Incentive Layer: Being a permissioned network, Fabric doesn't require incentivization through cryptocurrency. The incentive is the utility of the network itself.

## 6.2 Application of CLARITY to blockchain models

### 6.2.1 Application of CLARITY to bitcoin

The CLARITY assessment can be applied to Bitcoin as follows:

- Consensus: Bitcoin uses a Proof-of-Work consensus mechanism which is robust but lacks in terms of scalability and energy efficiency.
- Openness: Bitcoin scores high on openness, being a permissionless, transparent, and fully decentralized network.
- Nodes: Bitcoin's network consists of fully distributed nodes, enhancing the system's resiliency.
- Fees: Transaction fees depend on network congestion. In periods of high demand, fees can become relatively high.
- Interoperability: Bitcoin does not natively support interoperability with other blockchains.
- Governance: Bitcoin lacks a formal governance model. Decisions are made based on the collective agreement of network participants.
- Usability: While Bitcoin's usage is straightforward for simple transactions, it has limitations in terms of programmability and smart contract capabilities.
- Robustness: Bitcoin's network has proven to be robust, having operated without major interruptions since its inception.
- Efficiency: The Bitcoin network is not particularly efficient due to its high energy consumption and relatively low transaction throughput.

### 6.2.2 Application of CLARITY to hyperledger fabric

The CLARITY assessment can be applied to Hyperledger Fabric as follows:

- Consensus: Fabric uses a pluggable consensus, which allows for flexibility and scalability, though the resistance to attacks depends on the specific algorithm used.
- Openness: As a permissioned network, Fabric does not offer the same level of openness as Bitcoin.
- Nodes: Nodes in Fabric have different roles and permissions, which can enhance performance but may reduce resilience compared to a fully distributed model.
- Fees: Fabric does not have transaction fees as it operates without a native cryptocurrency.
- Interoperability: Fabric is designed with modularity in mind, facilitating integration with other systems, though cross-blockchain interoperability is not natively supported.
- Governance: Fabric has a structured governance model with clearly defined roles for different types of nodes.
- Usability: Fabric's support for chaincode in general-purpose programming languages enhances its usability for developers.
- Robustness: Fabric's design includes measures for dealing with failures and adversarial behavior, although its robustness depends on the specific network configuration.
- Efficiency: Fabric's performance and scalability are enhanced by its use of a pluggable consensus and a more efficient transaction validation process.

## 6.3 Comparison of blockchain models

After applying the BOFUS and CLARITY frameworks to both Bitcoin and Hyperledger Fabric, we can form a comparative analysis, illustrating the different strengths and weaknesses of each blockchain model. This comparison is useful for understanding which model may be more appropriate for a specific use case or scenario.

This comparison illustrates how Bitcoin, a public blockchain, prioritizes decentralization, security, and transparency, with trade-offs in scalability and efficiency. On the other hand, Hyperledger Fabric, as a private blockchain, provides greater scalability and efficiency, with trade-offs in decentralization and openness.

The choice between these models (or a hybrid model that tries to combine the best of both) depends largely on the specific needs of a project or application. Public blockchains like Bitcoin are suited for applications that require strong guarantees of censorship resistance, while private blockchains like Hyperledger Fabric are more suited for business applications where privacy, permissioning, and high throughput are more important also we need to realise While our evaluation offers a detailed comparison, it is important to acknowledge its limitations. The blockchain technology landscape is rapidly evolving, and newer models and frameworks may offer different advantages or pose new challenges. Therefore, our findings represent a snapshot of the current state of blockchain technology.

**TABLE 4 CLARITY evaluation of civic.**

| Criteria | Evaluation |
|---|---|
| Consensus | Civic uses the Ethereum consensus mechanism, currently Proof of Stake with Ethereum 2.0. This enhance scalability and efficiency. |
| Openness | Civic, built on Ethereum, shares its level of openness, transparency, and accessibility. However, given Civic's identity verification nature, only verified identities can participate in specific actions within its ecosystem. |
| Nodes | The distribution of nodes in Civic follows the same pattern as Ethereum, leading to a robust and resilient network. |
| Fees | Civic's transaction fees are tied to Ethereum's gas fees and can vary based on network congestion. |
| Interoperability | As a protocol on Ethereum, Civic has potential compatibility with any Ethereum-compliant application. |
| Governance | Civic governance involves token holders, who can propose and vote on governance matters, offering a level of decentralization in decision-making. |
| Usability | Civic provides a user-friendly interface for managing identity data and an easy-to-use Identity Wallet for individuals to control their personal information. |
| Robustness | The robustness of Civic is tied to Ethereum's infrastructure. Given Ethereum's proven resilience, Civic can be deemed robust as well. |
| Efficiency | Civic's efficiency depends on Ethereum's performance. The expected Ethereum 2.0 upgrade should significantly enhance transaction speed and reduce energy consumption. |

Future work could involve expanding this evaluation to include emerging blockchain models, or refining the BOFUS and CLARITY frameworks based on the advancements in the field.

We have compared CIVIC blockchain system and UniSwap for a better understanding below.

# 7 Civic identity verification ecosystem evaluation

In this section, we apply the BOFUS and CLARITY frameworks to Civic, a leading blockchain-based identity management system, to obtain a comprehensive understanding of its technical and operational characteristics.

## 7.1 BOFUS evaluation of civic

The Civic platform, built on Ethereum, can be evaluated using the BOFUS framework as follows:

- **Data Layer:** Civic utilizes Ethereum's blockchain structure to store identity verification transactions. It creates attestations of identity that are securely and immutably stored on the blockchain.
- **Consensus Layer:** Civic relies on Ethereum's consensus protocol. Currently, Ethereum uses Proof of Work, but it is transitioning to Proof of Stake under Ethereum 2.0.
- **Network Layer:** The network structure of Civic is determined by Ethereum, which operates as a peer-to-peer network where transactions are propagated across the network.
- **Application Layer:** Civic provides identity verification solutions including a Secure Identity Platform (SIP), an Identity Wallet, and an Identity Verification (IDV) system, leveraging the blockchain technology to offer decentralized and secure identity management.
- **Incentive Layer:** Civic provides a native utility token (CVC) used for transactions within the Civic ecosystem. The utility of the platform and the use of the CVC token incentivize activity within the network.

## 7.2 CLARITY evaluation of civic

For a deeper analysis of Civic, we can apply the CLARITY framework.

This evaluation provides in Table 4 a high-level overview of Civic's characteristics. However, actual performance and utility may vary based on specific use cases, regulatory considerations, and developments in the blockchain space.

# 8 Uniswap DeFi platform evaluation

In this section, we delve into the technical and operational characteristics of Uniswap, a prominent decentralized finance (DeFi) platform, by employing the BOFUS and CLARITY frameworks.

## 8.1 BOFUS evaluation of uniswap

The Uniswap platform, built on Ethereum, can be characterized using the BOFUS framework as follows:

- **Data Layer:** Uniswap utilizes Ethereum's blockchain to record transactions of token swaps and liquidity provisions. It consists of a series of smart contracts that define how these operations occur.
- **Consensus Layer:** Like Civic, Uniswap relies on Ethereum's consensus protocol. Ethereum currently operates under Proof of Stake.
- **Network Layer:** Uniswap follows Ethereum's peer-to-peer network structure, facilitating the propagation of transactions across the network.
- **Application Layer:** Uniswap offers decentralized token exchange services. It uses an automated market maker

**TABLE 5** CLARITY evaluation of uniswap.

| Criteria | Evaluation |
|---|---|
| Consensus | Uniswap uses the Ethereum consensus mechanism, which will enhance scalability and efficiency after the transition to Proof of Stake. |
| Openness | Uniswap shares Ethereum's open, transparent, and permissionless nature. Anyone can create a new liquidity pool or trade tokens. |
| Nodes | The distribution of nodes in Uniswap follows the same pattern as Ethereum, providing the network with resilience and robustness. |
| Fees | Transaction fees in Uniswap are tied to Ethereum's gas fees and are shared among liquidity providers. |
| Interoperability | Uniswap can interact with any Ethereum-based protocol, offering significant interoperability within the Ethereum ecosystem. |
| Governance | Uniswap has introduced a decentralized governance process involving a native token (UNI). Token holders can vote on various proposals. |
| Usability | Uniswap's interface is user-friendly, and its operations are relatively straightforward, enhancing its usability. |
| Robustness | Uniswap's robustness is linked to Ethereum's infrastructure. The platform's design, combined with Ethereum's proven resilience, contributes to its overall robustness. |
| Efficiency | The efficiency of Uniswap depends on Ethereum's performance. The planned Ethereum 2.0 upgrade should improve transaction speed and reduce energy consumption. |

system where users can trade tokens directly from a liquidity pool.

- **Incentive Layer:** Uniswap offers incentives for liquidity providers who earn fees from the trading activity that takes place in their liquidity pool.

## 8.2 CLARITY evaluation of uniswap

We can apply the CLARITY framework for a more in-depth analysis of Uniswap.

This detailed analysis in Table 5 a comprehensive understanding of Uniswap's technical and operational characteristics, providing valuable insights into its workings as a DeFi platform.

# 9 Case study

This case study delves into the intricate details of blockchain application, bringing theory to life. We navigate through the application of the theoretical frameworks of CLARITY and BOFUS to two real-world, cutting-edge scenarios: a Decentralized Finance (DeFi) platform and a Decentralized Identity Management System. Additionally, we show how Bitcoin and Hyperledger, two leading blockchain technologies, can be employed to construct these innovative solutions.

## 9.1 Scenario 1: Harnessing the power of bitcoin for a decentralized finance (DeFi) platform

The world of finance has been evolving, embracing decentralized models. We commence this exploration by harnessing the power of Bitcoin's blockchain, integrating it into the 5-layer blockchain model, creating a conceptual DeFi platform.

- **Infrastructure Layer (BOFUS' Data Layer):** Bitcoin's blockchain, known for its decentralization and security, offers a sturdy foundation for our DeFi platform. Its immutable ledger is the ideal choice for tracking all transactions, ensuring full transparency and irrefutable trust.
- **Middleware & Services Layer (BOFUS' Network Layer):** Bitcoin's peer-to-peer network facilitates a seamless exchange of information, aiding in the smooth execution of DeFi services. Additionally, smart contracts for lending, borrowing, and other financial services could be developed, fueling the DeFi platform.
- **Application Layer:** Bitcoin's blockchain can be leveraged to craft unique financial applications, building a user-friendly interface for various operations like lending, borrowing, and trading.
- **Regulatory & Compliance Layer:** Applying the CLARITY framework, Bitcoin offers exceptional Auditability, facilitating public verification of all transactions. Its robust blockchain also brings in Tamper-Proof capabilities, ensuring the integrity of transactions.
- **Ecosystem Layer (BOFUS' Incentive Layer):** Bitcoin's unique incentive structure, where miners are rewarded with new bitcoins, encourages active participation and contribution within the DeFi ecosystem.

## 9.2 Scenario 2: Constructing a decentralized identity management system with hyperledger

Next, we traverse into the world of identity management, transforming how we perceive identities. Using Hyperledger Fabric, a flexible, modular, and extensible blockchain framework, we can realize a secure and user-centric identity management system.

- **Infrastructure Layer (BOFUS' Data Layer):** Hyperledger Fabric's robust and secure blockchain ledger is ideal for storing and managing digital identities. Its permissioned structure ensures privacy and trust.
- **Middleware & Services Layer (BOFUS' Network Layer):** Hyperledger's network empowers the system to maintain

privacy, ensuring that only verified and authorized parties have access to identity data.

- **Application Layer:** Leveraging Hyperledger, applications can be designed for creating, updating, and revoking digital identities. Users and organizations can effortlessly interact with the identity management system, ensuring smooth operations.
- **Regulatory & Compliance Layer:** Applying the CLARITY framework to Hyperledger, we achieve remarkable Auditability, with all changes to identities being easily tracked and verified. Additionally, Tamper-Proof capabilities assure the stored identities' integrity.
- **Ecosystem Layer (BOFUS' Incentive Layer):** Within the Hyperledger network, incentives are drawn from the shared benefits of a secure and transparent ecosystem, fostering active cooperation and contribution.

The confluence of Bitcoin and Hyperledger with the models of BOFUS and CLARITY brings into focus how blockchain architectures can be leveraged to design innovative solutions. These scenarios not only elucidate the practical application of these models but also offer a roadmap for envisioning and realizing advancements in fields like DeFi and decentralized identity management.

## 10 Advantages and challenges

### 10.1 Advantages

- **Interoperability:** The five-layer model facilitates standardization of blockchain architecture, fostering improved cross-chain solutions and blockchain network interoperability (Choo et al., 2020) (Morkunas et al., 2019) (de Rossi et al., 2019).
- **Enhanced Communication:** By systematically organizing blockchain components, the model facilitates improved understanding and communication among various stakeholders.
- **Modular Development:** The layered model encourages a modular approach to blockchain design and development, allowing for targeted optimizations to enhance system performance.
- **Framework for Innovation:** The model offers a structured basis for identifying research gaps and promoting innovation within specific blockchain layers or components.
- **Integration of New Technologies:** The layered approach facilitates easy incorporation of emerging technologies within appropriate layers, ensuring blockchain systems remain updated.
- **Compliance Management:** The explicit inclusion of a regulatory and compliance layer provides a structured approach to managing legal, auditing, and risk-related aspects in blockchain systems.
- **Performance Improvement:** The model's layered approach allows for identification and resolution of performance bottlenecks, thereby improving system scalability and performance.
- **Educational Tool:** The five-layer model serves as an effective pedagogical tool, aiding comprehensive understanding of blockchain technology.

### 10.2 Challenges

- **Adoption and Standardization:** Achieving widespread acceptance of the model within the blockchain community is a significant challenge, necessitating consensus and standardization across diverse platforms.
- **Simplicity and Flexibility Balance:** The model must maintain a balance between simplifying blockchain understanding and ensuring flexibility to accommodate different platforms, mechanisms, and use cases.
- **Keeping Pace with Advancements:** Given the rapid evolution of blockchain technology, the model must remain adaptable and contemporary, which presents a significant challenge.
- **Security and Privacy:** Ensuring comprehensive security and privacy is paramount; the model must consider potential threats and vulnerabilities across each layer and incorporate appropriate security measures.
- **Regulatory Compliance:** The model must successfully navigate the complex and disjointed regulatory landscape of blockchain technology.
- **Education and Awareness:** Effective model implementation requires extensive awareness and education efforts among developers, researchers, businesses, and regulators.
- **Resistance to Change:** Overcoming resistance from stakeholders, particularly those invested in existing frameworks, and demonstrating the model's benefits is a notable challenge.

## 11 Discussion and future directions

In this paper, we have proposed BOFUS, a Blockchain Organized Framework for Unified Systems, and CLARITY, a Comprehensive Ledger Assessment for Robust Interoperability and Trustworthiness. BOFUS provides a comprehensive framework for organizing the different layers of a blockchain system, including data, consensus, network, application, and incentive layers. CLARITY offers a set of criteria for assessing the robustness, interoperability, and trustworthiness of different blockchain systems.

In this section, we discuss the role of BOFUS and CLARITY in promoting standardization and best practices, the challenges and limitations of the proposed framework and assessment tool, and future research directions and potential improvements.

### 11.1 Standardization and best practices

BOFUS and CLARITY can play a critical role in promoting standardization and best practices in the blockchain industry. By providing a standardized framework and assessment tool, developers and organizations can ensure that their blockchain systems are designed and implemented in a consistent and efficient manner. This can lead to greater interoperability and communication between different blockchain systems, as well as greater trust and transparency among users.

Moreover, the adoption of BOFUS and CLARITY can facilitate the development of regulatory frameworks for the blockchain industry. Regulators can use these tools to evaluate the compliance and effectiveness of different blockchain systems, and to ensure that they meet the necessary legal and ethical requirements. This can ultimately lead to greater adoption of blockchain technology in different industries and sectors.

### 11.2 Challenges and limitations

One of the main challenges of the proposed framework and assessment tool is the need for ongoing updates and revisions. As the blockchain industry continues to evolve and new technologies and standards emerge, BOFUS and CLARITY will need to be updated to reflect these changes. This will require ongoing research and collaboration among developers, organizations, and regulatory bodies.

Another challenge is the potential for subjective bias in the assessment of different blockchain systems. While CLARITY provides a set of objective criteria for assessing the trustworthiness and interoperability of blockchain systems, there may still be subjective interpretations of these criteria. To mitigate this challenge, it is important to have a diverse and multidisciplinary team involved in the assessment process.

### 11.3 Future research directions

Future research directions for BOFUS and CLARITY include the development of additional criteria and standards for assessing blockchain systems, the integration of artificial intelligence and machine learning techniques into the assessment process, and the exploration of the ethical and social implications of blockchain technology.

Moreover, the adoption and implementation of BOFUS and CLARITY can lead to a greater understanding of the technical and practical challenges of blockchain systems. This can inform the development of new applications and use cases for blockchain technology, and ultimately lead to greater innovation and impact in different industries and sectors.

## 12 Conclusion

In this paper, we have presented the Blockchain Organized Framework for Unified Systems (BOFUS) and the Comprehensive Ledger Assessment for Robust Interoperability and Trustworthiness (CLARITY) as tools to address the challenges of blockchain system design and evaluation. BOFUS provides a five-layer model for blockchain system architecture that emphasizes modularity, scalability, and interoperability. CLARITY, on the other hand, offers a set of criteria for assessing the trustworthiness and interoperability of blockchain systems, with the goal of facilitating their integration and interoperation. By combining the use of BOFUS and CLARITY, blockchain system designers and evaluators can achieve a more systematic, comprehensive, and objective approach to blockchain system development and assessment.

Through our analysis and discussion of BOFUS and CLARITY, we have shown that a unified framework for blockchain system design and evaluation is necessary to address the current fragmentation and lack of interoperability in the blockchain ecosystem. By adopting a standardized and modular approach to blockchain system development and assessment, stakeholders can facilitate the creation of blockchain systems that are both efficient and secure, and that can effectively interoperate with other systems.

Future research can build on the ideas presented in this paper by further developing and refining the BOFUS and CLARITY frameworks, as well as by applying them to real-world case studies and examples. We believe that the use of these frameworks can ultimately contribute to the wider adoption and integration of blockchain technology across various domains, and pave the way for a more interoperable and efficient decentralized ecosystem.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

## Author contributions

AS conducted the primary research, literature review, and analysis of both the BOFUS architecture and the CLARITY assessment. BC supervised the research, providing critical feedback, strategic guidance, and manuscript approval. All authors contributed to the article and approved the submitted version.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

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