The State of The Art and Future Trends of Decentralized Autonomous Organizations Enabled by Blockchain and Smart Contracts

XiaolongLiang,WenwenDing, JiachenHou,YounesRouabeh, XiaoWang, YongYuan, NaiqiWu,andFei-YueWang

Abstract—Decentralized Autonomous Organization (DAO) is widely considered as a major form of organizations in crypto worlds. In recent years, the DAO market practice has been witnessed to evolve fast towards maturing with the continuous improvement of blockchain ecosystems, underlying DAO platforms and decentralized tools for governance. As a small-scale social experiment, however, DAO is still in its early stage with a series of open problems and challenges awaiting further research efforts, e.g., predicting the centralized risks of DAO, evaluating the degree of public participation, as well as transferring the DAO governance from judicial authorities to algorithmic authorities, etc. In this paper, we aim at presenting a comprehensive and up to date analysis of the concept and trends of DAO. We provide a comparative analysis of DAOs based on the five-layers model, summarize the development trend of DAOs and discuss the potential research directions. Specially, we propose the parallel DAO to solve the controllable governance issue of DAO, aiming at providing useful guidance and reference for future research efforts.

***Index Termsi*—Decentralized Autonomous Organizations, Blockchain, Smart Contracts, Computational Governance, Parallel DAO.**

This work was supported in part by the National Key R&D Program of China (2018AAA0101401), the Science and Technology Development Fund, Macau SAR (File no. 0050/2020/A1), and the National Natural Science Foundation of China (61533019, 71702182). (Corresponding author: Yong Yuan.)

XiaoLong Liang and WenWen Ding are co-first authors of this paper, and contribute equally 1o Il]is work. They are with the Institute of Systems Engineering, Macau University of Science and Technology, Macao 999078, China. (e-mail: 2009853DMI30003@student. must. edu. mo, 2009853EMI30001@student.must.edu.mo).

JiaChen Hou and Younes Rouabeh are with the Institute of Systems Engineering, Macau University of Science and Technology, Macao 999078, C1]ina. (e-mail: 2009853DMI20002@student. must. edu. mo, unesrouabeh@gmail.com).

Xiao Wang is with the State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing 100190, China (e-mail: x.wang@ia.ac.cn).

Yong Yuan is with the School of Mathematics, Renmin University of China, and the Engineering Research Center of Finance Computation and Digital Engineering, Ministry of Education, Beijing, 100872, China. (e-mail:yong.yuan@ruc.edu.cn).

NaiQi Wu is with the Institute of Systems Engineering and Collaborative Laboratory for Intelligent Science and Systems, Macau University of Science and Technology, Macao 999078, China, and also with the Stale Key Laboratory of Precision Electronic Manufacturing Technology and Equipment, Guangdong University of Technology, Guangzhou 510006, China (e-mail: nqwu Co) lnust.edu.lno).

Fei-Yue Wang is with the Stale Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing 100190, China, and also with the Qingdao Academy of Intelligent Industries, Qingdao 266109, China, and also with the the Institute of Systems Engineering, Macau University of Science and Technology, Macau 999078, China (e-mail: feiyue.wang@ia.ac.cn).

1. INTRODUCTION

Traditionally, complex and volatile transactions need to be performed within a firm's boundaries [1], [2]. However, in complex environments featuring uncertainty, diversity and continously evolving technologies, the organizations might suffer from increasingly evident issues including contract risks and intermediating costs [3], [4], [5] [9]. Therefore, there is an urgent need for novel governance technologies to solve these problems with a higher level of transparency and also reduce the bureaucracy via applying self-executing codes. Blockchain and smart contracts are among these governance technologies that can minimize the existing principal-agent dilemmas of organizations and the subsequent moral hazards [10], and thus created a new form of organization, i.e., the Decentralized Autonomous Organization (DAO) [11].

DAOs run entirely through underlying protocols that are encoded and enforced via blockchain-enabled smart contracts [12]. With the emergence of the Ethereum network, the concept of DAOs moved up the technology stack from the blockchain protocol to the smart contract, and became widely known to the public because of "The DAO" project [10]. In terms of organizational form and vitality, DAO is not a new concept. The self-organization phenomenon in natural ecosystems [13], [14], the online Cyber-enabled Movement Organizations (CMOs) [15] [17], and the Distributed Artificial Intelligence (DAI) or so-called Swarm Intelligence [18] can all be considered as the embryonic forms of DAOs and lay the foundation for its emergence. However, there is a significant difference between DAOs and other forms of organizations in that DAOs run on top of the blockchain and smart contracts, which feature technical advantages including distributed and decentralized architectures, au-

tonomous and automated operations, as well as organized and ordered data [19]. In this respect, DAOs can be considered as an emerging novel and to some extent revolutionary organizational paradigm [20].

With the emergence of the Ethereum smart contracts platform, DAOs and the associated ecosystems have rapidly evolved and developed into two different branches. The one is built from scratch, and the other is created from a template provided by the DAO platforms [21]. The DAOs created from scratch, such as MarkerDao, MolochDao, and Stratis, usually are based on blockchain technology and require highly specialized programming knowledge. The other branch of DAOs, such as Aragon, DAOstack and Colony, are typically enabled by online platforms that assist users wifia minimum knowledge to build a DAO using a customizable template.

DAOs have already been intensively studied in literature. Most of the previous research efforts are focused on fiae following issues, including but not limited to defining fiae concept and framework of DAOs [22], [23], analyzing fiae current progresses and costs of DAO governance [24], [25], exploring fiae legal issues faced by DAOs and the corresponding counter-measures [26], [27], evaluating the potential impacts of blockchain and smart contracts on DAOs [28], [29], designing smart contracts in DAOs and its applications [30], [31], as well as analyzing the events of the DAO projects [32] [34]. However, little research has been done so far for providing an in depth analysis of DAOs, especially for comparing such key components of DAOs as fiae underlying technologies, governance mechanisms, incentive mechanisms, and legal organization structures in different application scenarios. This motivates our work. In this paper, we aim at conducting a comprehensive survey of the state-of-the-art developments in DAOs.

This paper is structured as follows. Section II discussed fiae concept and characteristics of DAOs, and Section III presented the state-of-the-art research progresses of DAOs. In Section IV, we gave a comparative analysis of DAOs. The development trends and future research directions are discussed in Section V. Section VI concludes.

2. The Concept and Characteristics of DAOs

DAO has been a widely-discussed topic in the recent years. However, no consensus is reached so far on the concept of DAOs. As such, in fiais section, we will discuss the existing definitions and fiae key characteristics of DAOs.

2.1. DAOs: Perspectives from Technicians

Technicians are mainly concerned with the relationship between blockchain, smart contracts and fiae DAOs. In one of these definitions, DAOs are described as novel technical systems where a new way of coordination and decision making is settled. These systems provide an essential host for different blockchain projects or blockchain-based businesses. For instance, blockchain-enabled DAOs emerged as a new form of collective governance, in which communities may be organized relying on the decentralized infrastructure [21].

On the other hand, DAOs can be described as work that requires smart contracts usage running on a blockchain [35]. The blockchain is a shared, immutable ledger that facilitates fiae process of recording transactions and tracking assets in a business network [36]. Smart contracts allow specific, irrevocable, and automatical executions of code-based contracts. Consequently, smart contracts can be encoded into a blockchain and automatically execute once specific and preprogrammed conditions are met [37]. From another perspective, blockchain and smart contracts themselves can also be viewed as a decentralized autonomous organization (DAO) [38], [39].

2.2. DAOs: Perspectives from Legists

When it comes to the point of view of legists, DAOs regulations will typically be taken into consideration. DAOs can be defined as a new decentralized form of social and cooperative organization because of the incorporated statutes in the smart contracts and their execution on the blockchain [40]. Hence, DAOs can be depicted using fi~ree main characteristics, i. e., an entity organized as a corporation form, autonomy powered by blockchain, and regulation enabled by fixed smart contracts rules.

A broader view also exists, where a DAO is described as "a computer program, running on a peer-to-peer network, incorporating governance and decision-making rules" [41]. Furthermore, DAO is an effective community, with its resources organized according to predefined rules and chain codes. DAOs are open-source software, which can only be modified through consensus among participants. Compared with other definitions, this point-of-view highlights the rela tionship between technology and rules in a neutral way.

However, there also exists an entirely different perspective, where a DAO is defined as a pseudo-legal organization running with an aggregation of human and "robotic" participants [42]. The robotic participants are algorithmic rules that run on the distributed Ethereum blockchain and automatically respond to inputs according to a set of programmed rules. Based on these inputs and the pre-programmed logic stored in a distributed blockchain, a DAO can automatically and irreversibly initiate an action.

According to the above description, we believe that the pseudo legal organization contains two connotations. On one hand, the automated-executing bylaws can be considered as the executive department of the organizations in the virtual world, which is different from the real-world law-enforcing authorities. On the other hand, due to its characteristics conflicting with the organizational model under the real-world legal structure, DAO is also considered as a law-breaking legal organization.

2.3. DAOs: Perspectives from Economists

In contrast to the traditional corporate operations, the economists define DAOs primarily based on the perspective of crypto-assets and incentive mechanisms. As a result,

crypto currency can be seen as a Decentralized Autonomous Corporation (DAC) where the bylaws are represented using source codes and token-holders are shareholders. Activities can be performed on the free market to maximize the values of token holders [43]. For example, BitShares is widely considered as a DAO in which "money was raised, tokens were allocated, and token-holders were given the ability to vote on how to spend community money and set blockchain parameters" [44]. Therefore, the authors in [45] developed a more elaborated definition of a DAC that can be seen as an entity running by an "incorruptible set of business rules" executed independently without human involvement.

However, another point of view differentiates DACs from DAOs, stating that DACs were "basically a subclass of DAOs" and DACs introduced the concept of shares. Therefore, DACs were for-profit entities, while DAOs were typically defined as non-profit entities, even though participants can make money in their ecosystems [46]. In this respect, the term "DAO" was adopted instead of "DAC", to avoid potential legal issues caused by the word "company" in DACs [44].

According to Riva, DAOs are entities constructed from crypto assets controlled through pre-made governance rules, which are inscribed on a series of smart contracts deployed on a blockchain. These smart contracts can provide the participants with a framework to help define how they can spend the entity's assets [47].

2.4. DAOs: Perspectives from Governments

The most interesting concept from governments is that DAOs can be defined as a new organizational paradigm, where governors pay more attention to the democracy degree and governance measures of the organizations. In [12], authors define ideal DAOs as organizations running entirely through protocols that are encoded and enforced via smart contracts.

According to Jentzsch, the term "DAO" refers to a distxibuted organization whose governance is largely automated by computer codes. A DAO operates by allowing pseudonymous token-holders to submit proposals on which other token holders can vote in proportion to their total number of tokens. These submitted proposals are typically investment ideas but could also theoretically be malicious actions, such as trans ferring all the DAOs assets to a single attacker's address [24].

DAOs also can be considered as non-hierarchical organizations with routine tasks recorded and executed on a peer-to peer, cryptographically secure, and public network. Voluntary contributions from internal stakeholders are required for these non-hierarchical organizations to operate, manage and evolve themselves [48]. The granularity of management is determined by the DAO contracts encoded on the blockchain, and participants can also vote for details of group decisions in DAOs.

2.5. DAOs: Comprehensive Definitions

In addition to the aforementioned viewpoints, some researchers define DAO from a hroader perspective. In [49], a DAO is viewed as an organization whose essential operations are automated-executed roles, and principles are assigned in chain-codes without human involvement. On the other hand, the authors in [50] consider a DAO as an Intemet-native entity without central management that obeys a set of automatically enforceable roles regulated via a public blockchain, while others [51] define DAOs as an organizational form that coordinates the efforts and resources of members via a prior binding, formalized and transparent set of rules that are agreed upon in a multi-lateral fashion.

Considering the diversified DAO definitions mentioned above, we here define a DAO as a human-machine hybrid governed self-organization with no centralized hierarchy, controlled by smart contracts running on the blockchain. These smart contracts contain crypto assets and programmable by laws that reached consensus through collective governance to ensure the execution pattern of the organization. All transactions, roles, and decisions are stored entirely in the blockchain to guarantee the trustworthiness and reliability of the organization. A DAO can be summarized using three pairs of key features: Distributed and Decentralized, Autonomous and Automated, Organized and Ordered [19], [22].

3. The State of The Art of DAOs

DAO attracted intensive interests from both academia and industry between 2017 and 2018, and has been studied from different aspects [52] [55]. The bubble peak in cryptocurrency markets sparked the enthusiasm for DAOs at that time [56], [57]. However, the rapid market crash thereafter forced the public to reconsider the essence and true value of DAOs [58], [59].

Large numbers of underlying DAO platforms have been developed and new decentralized governance tools were created since 2019, necessitating research efforts on blockchain based collaboration schemes and new business models of DAOs [60]. In 2020, decentralized finance (a.k.a., DeFi) firmly announced itself and made its presence with DAO as its backbone. In the first ten months of that year, the ETH value locked in DeFi protocols has increased 194%, which motivates researchers to make a clear definition of the DeFi and explore its developments [61] [63].

Despite the rapid development, DAO is still in its infancy stage with a long way ahead. As such, there is a critical need for a panoramic analysis to offer a comprehensive understanding of the state of the art of DAOs, and our work is targeted at filling in this important gap. Table 1 shows the Websites where our data was collected using a crawler and completed by an artificial method. It is worth noting that it will be counted as different data if two or more items have the same name but different available contract addresses. Finally, we obtained a high-quality dataset with 1885 DAOs.

3.1. Macro-scopic Analysis of DAOs' Development

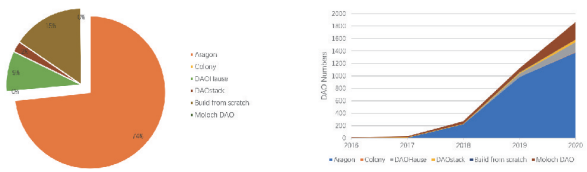
Our macro-scopic analysis is conducted from three per-

TABLE I: Data Collection Websites

Website	Country	Subject	Link
Etherscan	Malaysia	Analytics Platform for Ethereum	https://etherscan.io/
CoinGecko	Singapore	Digital currency price and information data platform	https://www.coingecko.com/
Deepdao	Israel	Insights and analysis on DAO	https://deepdao.io/
Scout	United State of America	Business intelligence and data analytics software	https://scout.cool/

spectives, i. e., public acceptance, market evaluation, and self development status. Considering that the volume and growth speed of DAOs are affected by researchers' experiments and exploring on them, they can be treated as measurements of DAOs public acceptance. The balance of DAOs, which is the amount of deposit assets on them, can be treated as an evaluation indicator by the market [64]. The scale distribution of DAOs which closely co-related to their healthy development reflects the self-development status. Based on these discussions, we can implement the following analysis from three perspectives, i.e., volume, balance, and scale distribution.

On 18 December 2020, the number of DAOs has reached 1885. More than 80% of these DAOs are built on four major platforms, that is, Aragon, DAOstack, DAOHause, and Colony.Aragon, one of the earliest and relatively mature operating system, supports more than three-quarters of the DAOs. However, Aragon was created as a general-purpose platform and cannot be fully customized for a variety of unique needs. At the same time, a variety of platforms were developed, and Aragon was no longer the only choice for building DAOs. As shown in Figure 1, in 2020, the growth of Aragon-based DAOs is witnessed to gradually slow down, while the number of DAOs hosted on other platforms keeps increasing. Currently, the four most prevalent platforms have their own focuses, respectively, thus attracting users with different needs. For instance, Aragon aims at providing a universal platform, DAOstack is targeted at solving large-scale decentralized decision-making issues, Colony offers a solution to the resource allocation problem [65], while MolochDAO solves the incentive compatibility problem via aligning incentives from individuals and the organizations [66].



(a) Platform Distribution of 1885 DAOs

(b) Growth of DAOs' number over time

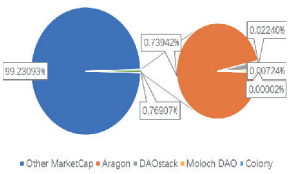
Fig. 1: Volume Distribution of DAOs

After excluding the data without balance information, a total of 1557 data records are available. As shown in Figure 2, the total balance of DAOs has exceeded 560 millions, which is close to 1% of the total value of ETH market. Among these DAOs, 16 out of the 20 DAOs with the largest balances are built on the Aragon platform, and more than half of them are used in DeFi and funding application scenarios. It also can be observed that the top 2 DAOs possess nearly half of the total balance. Typically, more profitable DAOs are inclined to attract larger numbers of participants to lock their assets in protocols, so we can expect an even increasing trend on the centralization of assets on DAOs.

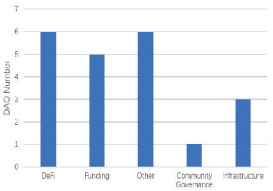
A total of 886 data items with available membership information were selected from the dataset and used in our scale distribution analysis. The result is shown in Figure 3. Since DAO is still in its early stage, many DAOs are created as experimental projects. As shown in Figure 3, only 4% of DAOs have more than 1000 members, while over 75% of filem have less than 10 members. For those DAOs with over 1000 members, more than half of them are currently used in DeFi projects, since those DAO-based DeFi organizations with clear business models and well-defined goals can grow quickly when driven by profitable business models.

3.2. Micro-scopic Analysis of DAOs Development

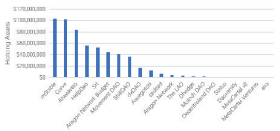
According to the five-layer model of the DAO structure, our micro-scopic analysis can be conducted in four aspects, that is, infrastructure, governance and incentive mechanism, legal organization structure, and application scenario.



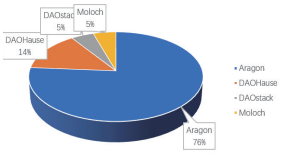
(a) DAO Hold Nearly 1% of ETH Total Market Cap



(b) Application Scenarios Distribution of Top 20 DADs

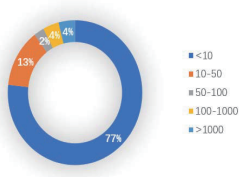


(c) Balance Distribution of Top 20 DADs

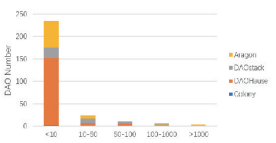


(d) Platform Distribution of Top 20 DAOs

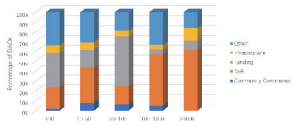
Fig. 2: Balance Distribution of DAOs



(a) Scale Distribution of DADs



(b) Scale Distribution of DAOs on Different Platforms



(c) Scale Distribution of DADs on Different Application Scenarios
Fig. 3: Scale Distribution of DAOs

Among the various DAO infrastructures, blockchain is the most essential one since DAOs rely heavily on it for guaranteeing their autonomy and decentralization. Therefore, we mainly focus on blockchain in the analysis of DAO infrastructures. As shown in Figure 4, over 98% of DAOs are built based on the Ethereum platform, 0.11% are based on xDai, and only a few DAOs choose other blockchain platforms such as Polkadot and Wanxiang blockchain.

To analyze the governance mechanism, we manually tagged the data according to the white papers, official Websites and other materials of the DAOs, resulting in 1620 available items. As shown in Figure 5, the most commonly-used governance mechanisms are "Vote by Token;' "Update Governance by Voting;' "Liquid Democracy;' and "Decentralized Court."

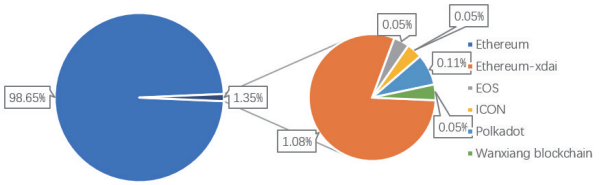
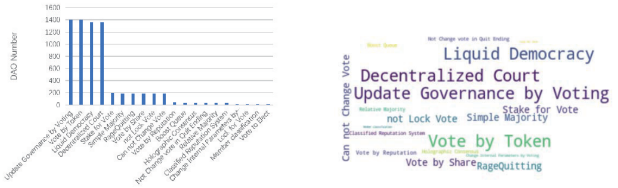
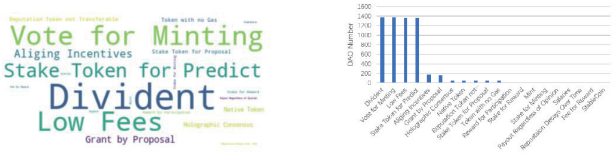


Fig. 4: Distribution of DAOs on Infrastructures



(a) Top Frequent Governance Labels (b) Governance Labels World Cloud
Fig. 5: Distribution of DAOs on Governance Labels

Considering the similarity between incentive mechanism and governance mechanism, we process the incentive mechanisms using a similar method and obtain a total of 1620 available items. Figure 6 shows the result, where the most frequently-used incentive mechanisms are "Dividend," "Increate Token Decided by Voting," "Stake Token for Predict, " and "Low Fees."



(a) Top Frequent Incentive Labels (b) Incentive Labels Word Cloud
Fig. 6: Distribution of DAOs on Incentive Labels

Since DAOs need to be integrated with real-world laws to guarantee their legal functionalities [47], a proper legal organization structure is essential. We analyzed the dataset and obtained 92 available DAO items fi~at contain information about the legal organizational structure. As shown in Figure 7, filere are four kinds of legal organization structures for DAOs, which are community, foundation and community, company and community, and a mix of the three. More than half of these structures are in form of the company and community, and only 3% are formed in a pure community.

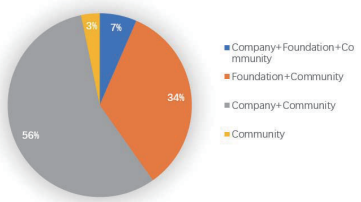


Fig. 7: Distribution of DAOs on Legal Organization Structures

Via combining different dataset elements, a total of 337 items were obtained to analyze the DAO distribution among different application scenarios. For the sake of analysis, we classified the DAOs into five categories, which are community governance, DeFi, funding, infrastructure, and ofilers. As shown in Figure 8, three categories with the largest proportions are DeFi, funding, and others, and their proportions are all close to 30%.

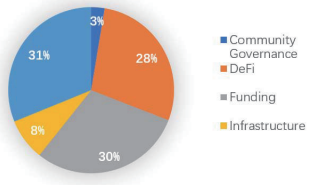


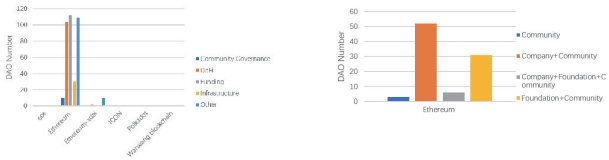
Fig. 8: Distribution of DAOs on Application Scenarios

4. Comparative Analysis of DAOs

In this part, a comparative analysis will be conducted in four layers of infrastructure, governance and incentive mechanism, legal organization structure, and application scenario.

4.1. Analysis of The Infrastructures

As mentioned in section III. B, in the analysis of infrastructures, we focus on blockchain. In this section, the infrastructure is used as the mainline to compare the mechanisms of each layer, and the results are shown in Figure 9 and Figure 10.

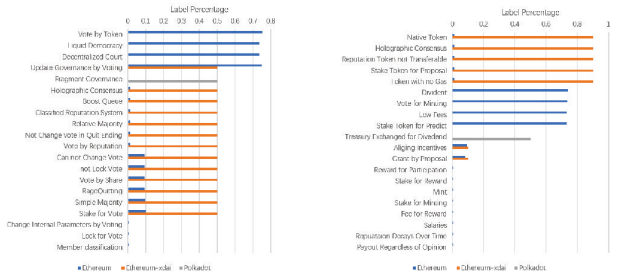


(a) Distribution of Application Scenarios on Infrastructure (b) Distribution of Legal Organization Structures on Infrastructure
Fig. 9: Distribution of Application Scenarios and Legal Organization Structures on Infrastructure

Six types of blockchains were observed in the data samples, namely Ethereum, xDai, EOS, ICON, Polkadot, and WangXiang. Being the first blockchains to implement smart contracts, EtJaereum has a great advantage in this domain [67]. As Figure 9 shows, there is an overwhelming number of DAOs built on Ethereum whether in distribution of application scenarios or legal organization structures. However, Ethereum uses transaction fees as the core of its incentive mechanisms. Fees are measured in gas and paid for operations on the network, such as transactions, smart contracts, and decentralized applications. With the development of Ethereum, fees continue to grow, which has caused many practitioners to quit the Ethereum platform. Besides, since Ethereum adopts the Proof of Work (POW) consensus mechanism, it will limit the transaction speed. For example, the rapid development of DeFi applications on Ethereum has caused severe congestion on the entire network.

Due to the shortcomings of Ethereum, some DAOs began to explore other platforms, as shown in Figure 9. As a fast, cheap, and stable trading platform, xDai adopts a new consensus mechanism, namely Proof of Stake Decentralized Autonomous Organization (PSDAO), to solve Ethereum's high transaction fees and network congestion problems [68]. The gas fees in xDai are lower so that the cost of running a DAO is cheaper on it. Besides, the EOS platform uses WebAssembly virtual machine to improve the execution efficiency of smart contracts [69].

Ideally, the underlying blockchain architecuture for a DAO should be decentralized, secured, and scalable. Due to the blockchain trilemma issue, however, no blockchain so far is able to optimize these three performances simultaneously. Which one is the most important to a DAO? Our data shows that only a small number of DAOs are moving from more decentralized infrastructures, such as Ethereum, to more scalable ones, such as xDai, and thus Ethereum remains to be the optimal choice for building DAOs today.



(a) Distribution of Governance labels on Infrastructure

(b) Distribution of Incentive labels on Infrastructure

Fig. 10: Distribution of Governance Labels and Incentive Labels on Infrastructure

4.2. Analysis of Governance and Incentive Mechanism

Unlike traditional organizations, where executive powersrelied heavily on one or few specific persons, decision-making in DAOs have to be based on the consensus from a majority of stakeholders. Bitcoin has proved the effectiveness of this kind of governance model in a virtual economy, but more evidence is still needed for verifying whether the model works in the real world. In this part, we focus on the governance and incentives.

4.2.1. The Governance Mechanism: As aforementioned, the governance mechanisms' dataset was obtained by manual tagging according to the white papers, official websites, and other materials of DAOs. The comparative analysis of DAOs governance mechanism with other layers is shown in Figure 11.

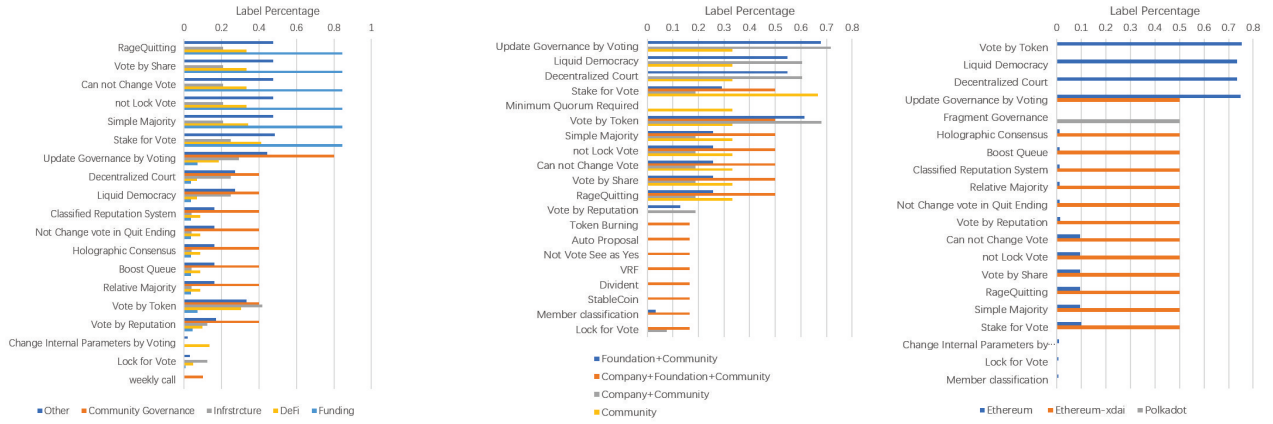
In Figure 11, we calculated the percentage and the variance of each governance mechanism under different categories. The figure shows the top 20 mechanisms with the highest variances.

Usually, the governance mechanism of DAOs is related to the decision-making process, where decisions can only be executed after a vote is taken. The choice of governance mechanisms depends not only on the structure of the relationships between the organization members, but also on the organization's business. However, there are two non-negligible issues, i. e., the low-level participation of the organization's members, and the disputes among them. Figure 11 has shown the attempts made by some DAOs to address these issues.

In Figure 11, "Simple Majority;' "Relative Majority;' and "Holographic Consensus" can be observed in the top 20 governance mechanisms, and these mechanisms are closely related to the issue of member's low-level participation. Since a proposal can only be passed when more than half of all members in DAOs vote yes, the mechanism "Simple majority" is highly affected by this issue. Besides, the mechanism may waste member's attention on unimportant things. To solve this problem, DAOstack adopted the mechanism "Holographic Consensus". By introducing a market where members can play stake-based predictions games, the mechanism attracts members to make important decisions fl'trough token rewards. In this mechanism, the proposals that secure enough stakes will be promoted and given high priority, and in this situation a "Relative Majority" can make the proposal pass.

"Decentralized Court" and "RageQuitting" mechanisms can be used to address the dispute among members. The "Decentralized court" provides a way to solve disputes without a centralized, slow, and expensive legal procedure, where the judges are selected randomly among stake-holder participants, and decisions are made fi'trough online voting. Two famous decentralized court projects are Aragon Court and Kelors, where Aragon Court mainly serves for DAOs running on Aragon while Kelors is open for everyone. "RageQuitting" is another mechanism for resolving disputes, and it is adopted by the famous funding project called MolochDAO. It allows members to exit with funds after voting if they disagree with the voting result, and such design also gives the MolochDAO the ability to resist the 51% attack.

4.2.2. The Incentive Mechanism: Incentive mechanisms based on game theory is usually adopted in DAOs, which can be divided into intrinsic and extrinsic factors [70]. The intrinsic factor emphasizes that individuals are typically



(a) Distribution of Governance labels on Application Scenarios

(b) Distribution of Governance labels on Legal Organization Structures

(c) Distribution of Governance labels on Infrastructure

Fig. 11: Distribution of Governance Labels on Application Scenarios, Legal Organization Structures, and Infrastructures

driven by his/her interests, not by external rewards or challenges. The intrinsic factors are often related to a reputation system with a well-designed reputation mechanism. For example, "Reputation not Transferable" and "Reputation Decays over Time" in Figure 12 are reflections of these kinds of mechanisms. External incentives are usually derived from external rewards, such as monetary rewards. Figure 12 shows that "Low Fees, " "Dividends, " and "Stake for Reward" are among the top 20, which are more likely to be external incentives.

Besides that, there are some incentive mechanisms dedicated for particular cases, such as "Aligning Incentive" and "Buyback", where the "Aligning Incentive" is adopted to solve the individual incentives misalignment with global optimal outcomes, while the "Buyback" mechanism for maintaining the stability of tokens.

From the above analysis, we can see a fast evolution of governance and incentive mechanisms, where they are designed and practiced for both general and particular cases.

4.3. Analysis of Legal Organization Structure

There are two ways to define the legal form of a DAO: the one is a legal entity with legal personhood, which integrates a DAO into the existing legislative environment, the other is a legal entity without legal personhood, which views DAOs as an organizational form independent from the existing legislative environment. In this paper, the legal organization structure of DAOs was divided into the following forms: community, company and community, foundation and community, a mix of the three. We used the legal organization structure of DAOs as the mainline to study the impacts of such structures on other layers. The results are shown in Figure 13 and Figure 14.

Based on the results, almost all legal organization structures of DAOs contain the form of community, which is inseparable from the characteristics of DAOs. First, DAO is a decentralized shared-ownership organization. Second, while DAO needs a way to ensure a good operation, smart contracts are not suitable for encoding a complex logic. Also, DAOs focus on consensus building that needs to be carried out through collective governance or democratic governance.

A set of default rules is required to standardize the obligations and responsibilities of the organizers and protect the rights and interests of the investors. This set of rules can be achieved if the DAO has a legal identity. However, a DAO does not fit well within the current landscape of recognized organizational structures. Hence, In Figure 13, we find that few DAOs are in form of community, while the most common form is a mix of community with foundation and company.

As shown in Figure 14, apart from the mixed form of community, company, and foundation, others are not significantly different in governance and incentives mechanisms. The mixed form takes a higher percentage in mechanisms such as "Reward for Participation, " "Stabilization, " and "Debt;' "Token Buring".

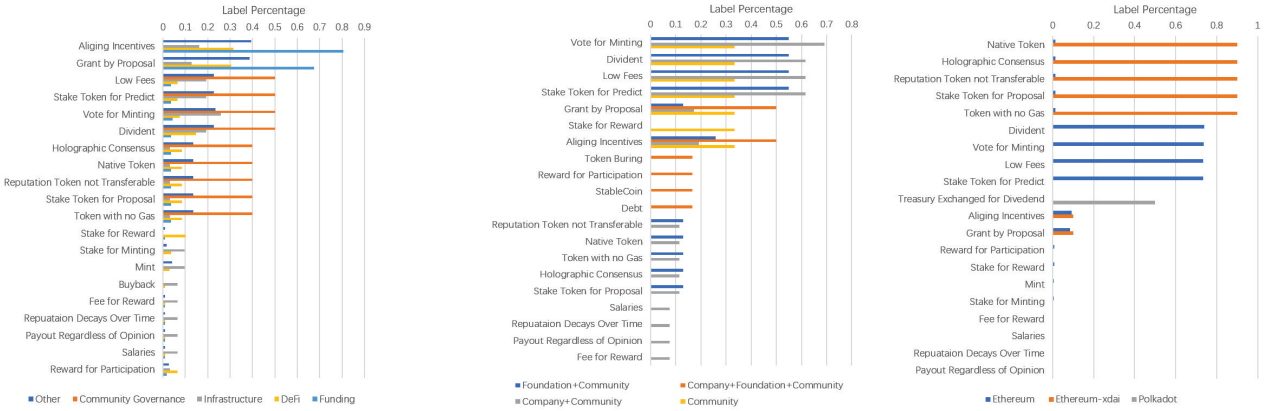
Based on the above discussion, we can conclude that DAOs are exploring different legal organizational structures to ensure the integration with the real world.

4.4. Analysis of Application Scenarios

In order to compare the similarities and differences of DAOs in different application scenarios, we will conduct a comparative analysis with application scenarios as the mainline. Figure 15 and Figure 16 show the results.

As mentioned, for simplicity of analysis, we grouped the application scenarios into five categories, that is, infrastructure, DeFi, funding, community governance, and ofilers.

We classified the infrastructure DAOs as those who provide software and hardware services for building DAOs, e. g., Aragon, DAOstack, Newtonium. In the infrastructure category, blockchains and platforms need a well-designed incentive mechanism to attract new users. Also, a well governed community is essential to keep the organization operating regularly. It is noticed from Figure 15 that only two kinds of legal organization structures exist in the category of infrastructure DAOs: foundation and community, company



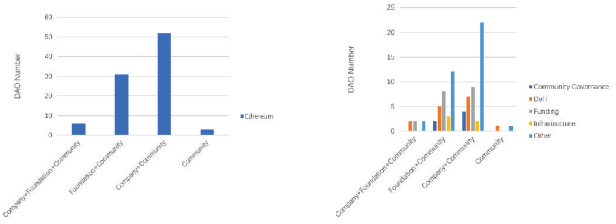
(a) Distribution of Incentive labels on Application Scenarios

(b) Distribution of Incentive labels on Legal Organization Structures

(c) Distribution of Incentive labels on Infrastructures

Fig. 12: Distribution of Incentive Labels on Application Scenarios, Legal Organization Structures and Infrastructures

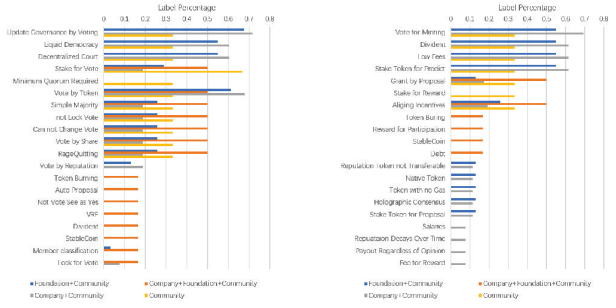
and community. In terms of incentives, a clear difference between the Application scenarios of infrastructure and ofilers is also observed in Figure 16, where incentive mechanisms such as "Fee for Reward;' "Mint," and "Stake for Minting" takes a larger percentage.



(a) Distribution of Infrastructure on Legal Organization Structures

(b) Distribution of Application Scenarios on Legal Organization Structures

Fig. 13: Distribution of Infrastructures and Application Scenarios on Legal Organization Structures

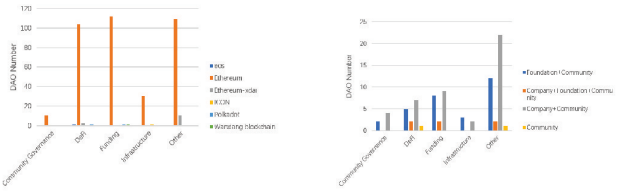


(a) Distribution of Governance labels on Legal Organization Structures

(b) Distribution of Incentive labels on Legal Organization Structures

Fig. 14: Distribution of Governance and Incentive Labels on Legal Organization Structures

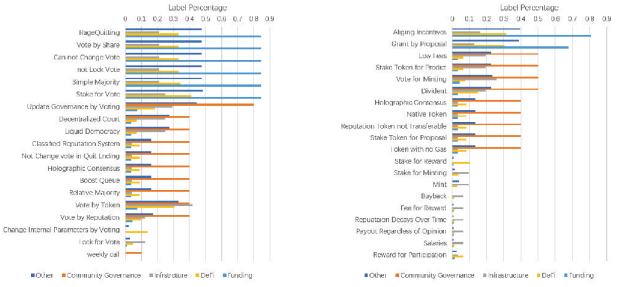
DAOs used for raising finance to support various projects are classified in funding category. Funding for software development is one of the essential applications of DAOs, and the well-known MolochDAO is a classic funding project used to enhance the development of Ethereum 2.0. As



(a) Distribution of Infrastructures on Application Scenarios

(b) Distribution of Legal Organization Structure on Application Scenarios

Fig. 15: Distribution of Infrastructures and Legal Organization Structures on Application Scenarios



(a) Distribution of Governance Labels on Application Scenarios

(b) Distribution of Incentive Labels on Application Scenarios

Fig. 16: Distribution of Governance and Incentive Labels on Application Scenarios

shown in Figure 16, governance mechanisms such as "RageQuitting," "Stake for Vote," "Voting by Shares" have a larger percentage in the funding category.

DeFi represents the financial DAOs that does not rely on central financial intermediaries such as brokerages, exchanges, or banks, and instead utilize smart contracts. For example, pieDAO is aimed to provide a tokenized portfolio allocation on the EtJaereum network.

Community governance DAOs are used for online community governance. One of the famous community governance DAOs is 1Hive, whose mission is to experiment and explore DAO's governance. In Figure 16, we can see that community governance DAOs differ significantly from oth-

er categories in governance mechanism, where it take a larger percentage in mechanisms such as "Update Governance by Voting," "Boost Queue," and "Decentralized Court."

The experimentation of DAOs has not been fully validated m practice. It worked in some application scenarios while not m ofilers. However, the development priority for DAOs has already shifted to the management of the constructed systems, protocols and platforms.

5. DEVELOPMENT TRENDS AND OUTLOOK

5.1. Development Trends

5.1.1. The Participant of DAOs: Since the fall of "The DAO" project, the exploration and development of DAOs are continuing actively. However, it is at a relatively small-scale, more cautious stage of social experimentations.

Since the emergence of "The DAO", the possibilities of DAOs in various fields are actively explored. Nowadays, the exploration of DAOs is no longer limited to the crypto world, and begins to integrate with the real world on a small scale. For example, Melon began as a company and was broke down into a DAO at the time when their protocol reached the consensus stage. On the other hand, DeveriFi started as a spin-off of an exchanging center that makes great strides into a fully governed DEX ruled by a DAO. In 2020, the venture backed startup Compound revealed its governance token, after obtaining several hundred million USD under management for its protocol.

However, DAOs are still a weird name for an obscure concept, only known by a small group of people, even compared to the number of people interested m cryptocurrencies and blockcham technologies m general. As aforementioned, only 4% of DAOs have more than 1000 members and about 77% of them have less than 10 members, and thus a majority of the DAO platforms are simple experimentations. DAOs that are capable of scaling and coordinating a large number of members have yet to arise.

5.1.2. The Governance of DAOs: The governance practice of DAOs has become more and more multi-dimensional and mature. However, there are still some difficulties m designing and governing algorithm systems, constructing governance participation measurement indicators, and predicting gover nance risks.

First, the emergence and governance of DAOs are facilitated by the improvement of blockchain ecosystems, DAO's underlying platforms, and decentralized governance tools. For instance, Steemit, Ox, and DigixDAO launched new DAOs. The distributed court system of Aragon went live, reputation based voting has been proposed by DAOstack, and Gitcoin Grants raised a round of Quadratic Funding. Second, DAO's governance model is evolving from a donation-based model to a development funding model focused on projects and DApps. The key is to solve the first-generation on-chain governance issues and improve the community-managed funding through on-chain processes and issuance models. Then, many well known projects will opt for a transition over time from a centralized strategy to a decentralized one, resulting in the emergence of novel infrastructures, mechanisms and even governance methods, e.g., Melonport's counsel.

Alfilough many on-chain governed projects began conducting meaningful votes, the participation rate varies by protocol, and it is still not clear how to measure and improve the participation rate. In most cases, participation referred to the percent of total eligible tokens for voting. If the voting is not organized and carried out on a "one person, one vote" ratio, "a higher participation" does not mean that the decisions are made based on the viewpoints of the majority. A few "whales" could have a higher amount of token participation than those from a larger number of smaller token holders. Besides, it remains a challenge to design and govern the algorithmic systems to avoid the risks associated with logical centralization. DAOs can be structurally decentralized, geographically distributed, but logically centralized protocols. Upgrading the codes typically requires specific knowledge from domain experts to deal with the technical and legal complexity, leading to potential risks of centralization.

5.1.3. The Incentives of DAOs: The tokenization and incentive design of DAOs are evolving towards a valuable direction, but the incentive design still lacks research and industrial efforts.

Token is both an effective investment tool and an essential component of the decentralized DAO network. The understanding of tokens in this field is consistently deepening, and Ponzi cases of maliciously constructed token structures are gradually decreasing. Evidence akeady emerged of evolving new networks blending with tokens that can capture more value than traditional equity. However, the token economies or incentives contain many uncertain, complex variables that needs game-theoretic analysis. Therefore, more m-depth game theory research should be conducted to successfully avoid problems such as the commons tragedy, malicious behavior and principal-agent issues.

5.1.4. The Legal Organization Structure of DAOs: Currently, legal wrappers have emerged and quasi-judicial systems have been introduced m DAOs. However, integrating DAOs with the existing legal environment and shifting from judicial aufilority to algorithmic authority remains a challenge.

To facilitate the integration of DAOs with the real-world, some DAOs and their respective communities have attempted to merge DAOs with the traditional legal structures such as LLCs. Whether this trend will succeed in the long term or not remains to be proved. If it succeeds, it will provide the mdustxy with the opportunity of not only interacting with traditional organizations but also integrating traditional organizations into a more decentralized, borderless, and code-oriented structure.

Also, there are attempts to replicate judicial and court systems through smart contracts, such as the Aragon court, and kleros. It is worth noting that this approach is focused on most rules and financial penalties and may undermine objective judgment. Meanwhile, only selecting jurors from a

group of token holders, coupled with financial rewards for participation, will inevitably lead to fundamentally different groups of jurors from traditional court systems.

5.2. Outlook

The key to design good DAOs is to structure an efficient set of consensus rules that resolve complex participant coordination problems. The real challenge in implementing DAOs might not be purely technological, but raffler social. In cyber-physical-social systems witJa complex human behavior and group decisions, an effective way for the explanation, prediction and prescription of online DAO markets require the parallel DAO approach. Parallel DAO is a combination of Artificial systems, Computational experiments, and Parallel execution (ACP) approach [71] [73] and the DAO. In aparallel DAO, the artificial systems (A) part is used to model one or more artificial DAO systems corresponding to the real-world DAO systems. Based on the coevolving real-world and artificial blockchain systems, diversified computational experiments could be designed and conducted in the computational experiments (C) part to evaluate and verify specific behavior, mechanisms, and strategies involved in the DAO systems. The optimal solution will emerge through these experiments and feedback to the real-world DAO systems in the parallel execution (P) part to realize the decision optimization and parallel tuning the DAO systems.

In the parallel DAO, different governance mechanisms, economic models can be validated using three different approaches, i.e., Learning and Training, Experiment and Evalu ation, Management and Control [74] [76], so as to solve the following three problems faced by DAOs: voting issues in governance including how to construct indicators to measure participants and how to increase the voting participation, predicting the risks of centralization caused by designing and governing algorithmic systems to avoid logical failures of smart contracts, as well as alleviating such issues as the commons tragedies, malicious behaviors, principal-agent and prisoner's dilemma.

6. Conclusion

In recent years, DAO has attracted intensive research and industrial interests with the development of its governance mechanisms and incentive mechanisms. The industry has been exploring the way to design crypto-economic systems to motivate and organize economic activities using the novel organization form of DAO. Therefore, in this work, we reviewed the concept of DAOs and conducted a systematic analysis using a crawled dataset with 1885 DAOs. Based on the five-layer model, we conducted a comparative analysis of DAO from such aspects as infrastructure, governance and incentive mechanisms, legal organization structure, and application scenarios. Our work aimed at providing helpful guidance and reference for DAO's future research and industrial applications.

References

[1] R. H. CoAse, "Tile nature of the firm," Economica, vol. 4, no. 16, pp. 386-405, 1937.

[2] Williamson and E. Oliver, "Tile economics of organization: Tile transaction cost approach," American journal of sociology, vol. 87, no. 3, pp. 548-577, 1981.

[3] M. Josefy, S. Kuban and R. Duane, et al., "All things great and small: Organizational size, boundaries of the firm, and a changing environment," Academy of Management Annals, vol. 9, no. 1, pp. 715-802, 2015.

[4] T. R. Zenger, T. Felin and L. Bigelow, "Theories of file firm -market boundary;' Academy of Management Annals, vol. 5, no. 1, pp 89-133, 2011.

[5] M. C. Jensen and W. H. Meckling, "Theory of tile firm: Managerial behavior, agency costs and ownership structure;' Journal of financial economics, vol. 3, no. 4, pp. 305-360, 1976.

[6] J. S. Ang, R. A. Cole and J. W. Lin, "Agency costs and ownership structure;' tile Journal of Finance, vol. 55, no. 1, pp. 81-106, 2000.

[7] C.M. Daily, M. Catherine and D. R. Dalton, "CEO and director turnover in failing firms: An illusion of change?;' Strategic management journal, vol. 16, no. 5, pp. 393-400, 1995.

[8] D. R. Dalton, M. A. Hin and S. T Certo, et al., "1 Tile fundalnental agency problem and its lnitigation: independence, equity, and tile market for corporate control," Academy of Management annals, vol. 1, no. 1, pp.1-64, 2007.

[9] A. J. Nyberg, I. S. Fuhner and B. Gerhart, et al., "Agency theory revisited: CEO return and shareholder interest alignment," Academy of Management Journal, vol. 53, no. 5, pp. 1029-1049, 2010.

[10] S. Voshlngir, Token Economy-How theWeb3 reinvents file Intemet. Haftungsbeschr?nkt, DE: Token Kitchen, 2020.

[11] S. Wang, L. Ouyang and Y. Yuan, et al., "Blockchain-enabled smart contracts: architecture, applications, and future trends; ' IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 49, no. 11, pp. 2266-2277, 2019.

[12] A. Murray, S. Kuban and M. Josefy, et al., "Contracting in tile smart era: Tile implications of blockchain and Decentralized Autonomous Organizations for contracting and corporate governance, " Academy of Management Perspectives, jR, 2019. Available: ProQuest, [Online]. https: //joumals. aom. org/doi/abs/10.5465/AMFt 2018.0066. [Accessed Jan. 20, 2021].

[13] R. Braakman, M. J. Follows and S. W. Chisholm, "Metabolic evolution and tile self-organization of ecosystems," Proceedings of tile National Academy of Sciences, vol. 114, no. 15, pp. 3091-3100, 2017.

[14] Y. Luo, G. Iyengar andV. Venkatasubramanian, "Socialinfluence makes self-interested crowds smarter: An optimal control perspective," IEEE Transactions on Computational Social Systems, vol. 5, no. 1, pp. 200-209, 2018.

[15] F. Y. Wang, "Study on cyber-enabled social movement organizations based on social computing and parallel systems," Journal of University of Shanghai for Science and Technology, vol. 33, no. 1, pp. 8-17, 2011.

[16] F. Y. Wang, X. Wang, J. Li, Ft Ye and Q Li, "Social computing: From crowdsourcing to crowd intelligence by cyber movement organizations;'IEEE Transactions on Computational Social Systems, vol. 6, no. 4, pp. 619-626, 2019.

[17] W. Xiao, S. S. Han, L. Y. Yang, K. Zeng and F. W. Wang, "The research on ACP-based modeling and computational experiment for cyber movement organizations;' Acta Automatica Sinica, vol. 46, no. 4, pp. 653-669, 2020.

[18] J. Ferber and G. Weiss, Multi-agent systems: an introduction to dis tributed ariificial intelligence. Vol. 1, Boston, US: Adclison-Wesley, 1999.

[19] R. Qin, Y. Yuan and F. Y. Wang, "Blockchain-Based Knowledge

Automation for CPSS-Oriented Parallel Management, " IEEE Transactions on Computational Social Systems, vol. 7, no. 5, pp. 1180-1188, 2020.

[20] Cointelegraph. What is DAD. New york, US. [Online]. Available: https: //cointelegraph'com/ethereum-f~r-beginners/what-is-da[Ac - cessed Jan. 20, 2021].

[21] Y. E. Faqir, J. Youssef and S Hassan, "An overview of decentralized autonomous organizations on tile blockchain, " In Proceedings of tile 16th International Symposium on Open Collaboration, Madrid, Spain, August 26-27, 2020, pp. 1-8. 2020.

[22] S. Wang, W. W. Ding, J. J. Li, Y. Yuan, L. W. Ouyang and F. Y Wang, "Decentralized autonomous organizations: concept, model, and applications; ' IEEE Transactions on Computational Social Systems, vol. 6, no. 5, pp. 870-878, 2019.

[23] Y. Guseva, "A Conceptual Framework for Daos, Dapps, Coins and Tokens: New Trends and Conflicts in Securities Law." Maryland Law Review, to be published. [Online]. Available: hnps://papers. ssm. com/sol3/papers. cfin? abstract_id=3619643 [Accessed Jan. 20, 2021].

[24] C. Jentzsch, "Decentralized autonomous organization to automate governance,' Minweida, Sachsen, Germany, White paper, November, 2016. [Online]. Available: hnps://law~fthelevel'lexblogplatformlthree'com/wPcontent/uploads/sites/187/2017/O7/WhitePaerl. pdf. [Accessed Jan. 20, 2021].

[25] U. W. Chohan, "Tile decentralized autonomous organization and governance issues;' to be published, [Online]. Available: hnps://papers. ssrn. com/so13/papers. cfm? abstract_id=3082055. [Accessed Jan. 20, 2021].

[26] U. R. Rodrigues, "Law and tile Blockcbain, " Iowa Law Review, vol. 104, pp. 679, 2018.

[27] L. Metjahic, "Deconstructing tbe DAO: The Need for Legal Recognition and file Application of Securities Laws to Decentralized Organizations," Cardozo Law Review, vol. 39, pp. 1533, 2017.

[28] J. Umeb, "Blockcbain double bubble or double trouble?," It now, vol. 58, no. 1, pp. 58-61, 2016.

[29] Y. Yuan and E Y. Wang, "Blockcbain and cryptocurrencies: Model, techniques, and applications, " IEEE Transactions on Systems, Mall, and Cybernetics: Systems, vol. 48, no. 9, pp. 1421-1428, 2018.

[30] A. Norta, "Designing a smart-contract application layer for transacting decentralized autonomous organizations; ' In International Conference oil Advances in Computing and Data Sciences, Gbaziabad, India, November 11-12, 2016, pp. 595-604.

[31] B. Nissen, K. Symons and E. %llyn, el al., "New value transactions: Understanding and designing for distributed autonomous organisations," In Proceedings of tbe 2017 ACM Conference Companion Publication oil Designing Interactive Systems, Association for Computing Machinery, New York, US, 2017, pp. 352-355.

[32] M. I. Mebar, C. L. Shier and A. Cda2nbanista, et al., "Understanding a revolutionary and flawed grand experiment in blockcbain: the DAO attack," Journal of Cases on Information Technology, vol. 21, no. 1, pp.19- 32, 2019.

[33] S. Tikholnirov, E. Voskresenskaya and I. Ivanitskiy, el al., "Smartcheck: Static analysis of ethereum smart contracts," In proceedings of the 1st International Workshop oil Emerging Trends in Software Engineering for Blockcbain, Gotbenburg, Sweden, May 27-June 3 2018, pp. 9-16.

[34] G. Destefanis, M. Marcbesi and M. Ortu, et al., "Smart contracts vulnerabilities: a call for blockcbain software engineering?; ' In 2018 International Workshop on Blockcbain Oriented Software Engineering, Campobasso, Italypp March 20, 2018, pp. 19-25.

[35] C. Blaise and V. Botteron, "How smart can a contract be?," in Blockcbains, Smart Contracts, Decentralised Autonomous Organisations and tbe Law, D. Kraus, Ed., Cheltenham, UK: Edward Elgar Publishing,2019, pp. 101-143.

[36] T. Laurence, Blockchain for dulnmies. Hoboken, NJ, US: John Wiley & Soils, 2019.

[37] J.M. Sklaroff, "Smart contracts and tbe cost of inflexibility," University of Pennsylvania Law Review, vol. 166, no.1, pp. 263, 2017.

[38] S. %kagi, "Organizational impact of blockcbain through decentralized autonomous organizations," International Journal of Economic Policy Studies, vol. 12, no. 1, pp. 22-41, 2017.

[39] K. T. Minn, "Towards Enhanced Oversight of 'Self-Governing' De centralized Autonomous Organizations: Case Study of the DAO and Its Shortcomings," Intellectual property and entertainment law ledger, vol. 9, pp. 139, 2019.

[40] D. Kraus and C. Boulay, "Blockcbains: aspects of intellectual property law," in Blockcbains, Smart Contracts, Decentralised Autonomous Organisations and tbe Law, D. Kraus, Ed., Cheltenham, UK: Edward Elgar Publishing, 2019, pp. 240-271.

[41] L. Caisley, L. David and Z. Michael, "Decentralized Autonomous Organizations, " Allen & Overy LLP, 2016, [Online], Available: hnp://www'allen~very'c~m/Sit eC~llecti~nD~cument s/Article Decentralized Autonomous. [Accessed Jail. 20, 2021].

[42] Q. DuPont, "Experiments in algorilbmic governance: A history and ethnography of ?~The DAO,?_+ a failed decentralized autonomous organization; ' in Bitcoin and beyond, M. Verduyn, Ed., Abingdon, UK: Routledge, 2017, pp.157-177.

[43] D. Latimer, "Overpaying for security: tbe hidden costs of Bitcoin," Lets %lk Bitcoin, 2013. [Online], Available: hnps://letstalkbitcoin. com/is-bitcoin-overpaying-for-false-security. [Accessed Jail. 20, 2021].

[44] D. Latimer, "Is Tile DAO going to be DOA?,"[Online], Available: hnps: //steemit'C~ll]/crypt~ -news/~~dan/is-tbe-da~ -g~ing-t~ -bed~a' [Accessed Jail. 20, 2021].

[45] S. Latimer, "Bitcoin and the Three Laws of Robotics, The Let's % lk Bitcoin! Network," 2013, [Online], Available: hnps://letstalkbitcoin. com/bitcoin-and-tbe-tbree-laws-of-robotics. [Accessed Jail. 20, 2021].

[46] V. Buterin, "DAOs, DACs, DAs and More: All Incomplete Temtinology Guide, " Etbereum Blog, 2014, [Online], Available: hnps://blog. etbereum. org/2014/05/06/daos- dacs- das- andmore- an-incomplete-terminologyguide/. [Accessed Jail. 20, 2021].

[47] S. Riva, "Decentralized Autonomous Organizations (DAOs) as Subjects of Law 4be Recognition of DAOs in tbe Swiss Legal Order," Master's Thesis, 2019. [Online], Available: hnps://sci-hub.do/ hnps://papers. ssm. com/so13/papers. cfin? abstract~_id=3515229. [Accessed Jail. 20, 2021].

[48] D. Bollier, Ih De Filippi and J. Dietz, el al. "Distributed collaborative organisations: distributed networks & regu latory frameworks,"Coin Center Working Paper, 2015. [Online], Available: hnp://bollier, org/sites/de fault/files/misc fileupload/ files/DistributedNet worksandtbeLaw report, SwamlCoin Center-Berkinan. perf. [Accessed Jail. 20, 2021]

[49] M. Singh and Shiho Kim. "Blockcbain technology for decentralized autonomous organizations," In Advances in Computers, vol. 115, pp. 115- 140, 2019.

[50] L. Cuende, "Definition Aragon DAO platform, " 2020. [Online], Available: hnps://twiner, com/licuende/status/1263511552709267 4567. [Ac-cessed Jail. 20, 2021]

[51] Binance Research, Hong Kong, China, "Theory and praxis of DAOs: How can DAOs be conceptualized and classified?;' 2020. [Online], Avail-able: https://research.binance.com/en/analysis/daotbeory. [Accessed Jan. 20, 2021]

[52] D. Mark, V. Zamfir and E.G. Sirer, A Call for a Temporary Moratorium on The DAO. [Online], Available: https://docs. google. coln/ doculnent/d/10kTyCmGPbvZy94 F7VWyS- dQ41sB acR2dUgGTtV98 C40/e~lit. [Ac- cessed Jail. 20, 2021].

[53] X. F. Zbao, Z. Y. Cheil, X. Cheil, Y. X. Wang and C. B. Tang. "The DAO attack paradoxes in propositional logic," In 2017 4tb Interna-

tional Conference on Systelm and Informatics (ICSAI), Hangzhou, China, November 11-13, 2017, pp. 1743-1746.
[54] lq Santos and V. Kostakis, "Tile DAO: a million dollar lesson in blockcbain governance;' M. S. dissertation, Dept. Bus. Gov-., Ragnar Nurkse Univ., Tallinn, ES, 2018.
[55] V. Dhillon, D. Metcalf, and M. Hooper, "Tile DAO Hacked," in Blockcbain Enabled Applications, Berkeley, CA: Apress, 2017, pp. 67 -78
[56] W. Fruebwirt, L. Hocbfilzer and L. Weydemann, et al., "Cumulation, crash, coherency: A cryptocurrency bubble wavelet analysis," Finance Research Letters, to be published, [Online], Available: hnps://www. sciencedirect. com/science/alticle/abs/pii/S 1544612 320303421. [Accessed Jan. 20, 2021].
[57] T. Hanori, and R. Isbida, "Did tile introduction of Bitcoin futures crash tile Bitcoin market at tile end of 20177," Tile Noltb American Journal of Economics and Finance, to be published, doi: 10.1016/j.najef.2020.101322
[58] Y. Y. Hsieb, J. Ih Vergne and Ih A, el al., "Bitcoin and tile rise of decentralized autonomous organizations," Journal of Organization Design, vol. 7, no. 1, pp. 1-16, 2018.
[59] M. C. Valiente, S. Hassan and J. Pav"?n. "Results and Experiences from Developing DAOs witb Aragon: A case study;' [Online], Available: hnps: //core. ac. uk/download/pdf/334606407. pdf. [Accessed Jail. 20, 2021].
[60] Y. Chen and C. Bellavitis. "Blockcbain disruption and decentralized finance: Tile rise of decentralized business models;' Journal of Business Venturing Insights, vol. 13, pp. 151, 2020.
[61] D. W. Amer, R. Auer and J. Frost, "Stablecoins: risks, potential and regulation," Online , Available: hnps://www. bis. org/publ/work905.htln. [Accessed Jan. 20, 2021].
[62] D.A. Zetzscbe, D. W. Arner and R. Ih Buckley. "Decentralized finance;' Journal of Financial Regulation, vol. 6, no. 2, pp. 172-203, 2020.
[63] L. X. Lin, J. H. Bergquist and M. S. Panesir, el al., "Deconstructing Decentralized Exchanges," Stanford Journal of Blockcbain Law & Policy., vol. 2, no. 1, pp. 58-77, 2019.
[64] D. Ramos and G. Zal]ko. "A Review of tile Current State of Decentralized Finance as a Subsector of tile Cryptocurrency Market," MobileyourLife. 2020 [Online], Available: hnps://www. mobileyourlife.com/ research. [Accessed Jan. 20, 2021].
[65] A. Rea, D. Kronovet and J. Rose, el al., "Technical White Paper," 2020. [Online], Available: hnps://static. coinpaprika. com/storage/cdl]/whitepapers/10619139.pcff. [Accessed Jan. 20, 2021].
[66] A. Soleimani, A. Bhuptalri and R. Setburam, "The Moloch DAO Beating tile Tragedy of tile Commons using Decentralized;' 2017. [Online], Available: hnps://gitbub'com/MolochVentures/Whitepaper/blob/ master/Whitepaper.pdf. [Accessed Jail. 20, 2021].
[67] Ethereum Foundation. Ethereum, s white paper. [Online], Available hnps: //gitbub'com/etbereumwiki/wiki/White-Paper' 2016. [Accessed Jail. 20,2021].
[68] L. Barinov, V. Arasev and A. Fackler, el al., "Proof of Stake Decentralized Autonomous Organization," 2019. [Online], Available: hnps: //coinpare. io/whitepaper/xdai. p~ff. [Accessed Jail. 20, 2021].
[69] B. Xu, D. Lutbra, Z. Cole and N. Blakely, "EOS: An Architectural Performance and Economic Analysis," 2019, [online] Available: hnps://www. whiteblock. io/library/eos-test-report. pdf. [Accessed Jail. 20, 2021].
[70] Smart H20. "Incentive models and algorithms," 2016. [Online], Available: hTTps://cordis. europa. eu/docs/pr oj ecTs/cnect/2/619172/080/deliverables/001- sh2oD43 POLIM IWP4incentive-modelsandalgorithmsv 12.pdf. [Accessed Jan. 20, 2021].
[71] F. Y. Wang, "Toward a paradigm shift in social computing: Tile ACP approach," IEEE Intelligent SysTems, vol. 22, no. 5, pp. 65-67, 2007.
[72] J. Zhang, Ih D. Xu, and F. Y. Wang. "Parallel systems and digital twins: A daTa-driven maThenlatical representation and computational framework," Autonlatica Sinica, vol. 46, no. 7, pp. 1346-1356, 2020.
[73] F. Y. Wang, Y. Yuan and C. Rong, el al. "Parallel blockchain: All architecture for CPSS-based smart societies," IEEE Transactions on Computational Social SysTems, vol. 5, no.2, pp. 303-310, 2018
[74] F. Y. Wang, "Parallel economics: A new supply Cdemand philosophy via parallel organizations and parallel management," IEEE Transactions on Computational Social Systems, vol. 7, no. 4, pp. 840-848, 2020.
[75] S. Wang~ J Wang, X Wang, el al., "Blockchain-powered parallel healthcare systems based oil The ACP approach" IEEE Transactions oil Computational Social SysTems, vol.5, no.4, pp. 942-950, 2019.
[76] R. Qin, Y. Yuan, S. Wang and F. Y. Wang, "Economic issues in bitcoin mining and blockchain research" In 2018 IEEE Intelligent Vehicles Symposium, Changshu, Suzhou, China, June 26-July 1, 2018, pp.268-273.

XiaoLong Liang received the B.S., and M.S. degrees in computer science and technology from the ShanDong university, JiNan, Shandong, China, in 2011 and 2016, repectively. He is currently pursuing the Ph. D. degree with the Institute of Systems Engineering, Macau University of Science and Technology, Macao 999078, China.

His current research interests include Decentralized Autonomous Organization, Computational Governance and Knowledge Graph .

WenWen Ding received the waster's degree in public administration from Zhengzhou University, Zhengzhou, China, in 2018. She is currently pursuing the Ph. D. degree with the Institute of Systems Engineering, Macau University of Science and Technology, Macau 999078, China.

Her current research interests include Decentralized Autonomous Organization, and Computational Governance.

JiaChen Hou is currently pursuing die MS degree in system engineering al Macau University of Science and Technology, Macau 999078, China. From 2008 to 2016, he was a engineer with die Institute of Automatio, Chinese Academy of Sciences, Beijing, China. From 2017 to 2020, he was a engineer with die Qingdao Academy of Intelligent Industries, Qingdao, China.

His research interest includes die development of blockchain and management techniques.

Younes Rouabeh received BS, and MS degrees in computer science and technology from Mohamed Kheidher University, Biskra, Algeria, in 2016 and 2018, respectively. He is currently pursuing die PhD degree with die institute of System Engineering, Macau University of Science and Technology, Macao 999078, China.

His current research interests includes Peri net theory and application, supervisory control of discrete event systems.

Xiao Wang (Member, IEEE) received the bachelor's degree in network engineering from the Dalian University of Technology, Dalian, Liaon-ing, China, in 2011, and the Ph.D. degree in social computing from 1lie University of Chinese Academy of Sciences, Beijing, China, in 2016.

She is currently all Associate Professor with The State Key Laboratory for Management and Control of Complex Systems, Institute of Autonlation, Chinese Academy of Sciences. Her research interests include social transportation, cyber movement organizations, artificial intelligence, and social network analysis. She has authored or coauthored more than a dozen of SCI/El articles and translated three technical books (English to Chinese).

Dr. Wang served the IEEE TRANSACTIONS OF INTELLIGENT TRANSPORTATION SYSTEMS, IEEE/CAA JOURNAL OF AUTOMATION SINICA, and ACM Transactions of InteUigent Systems and Technology as peer reviewers with a good reputation.

Yong Yuan received the B.S., M.S., and Ph.D. degrees in computer software and theory from the Shandong University of Science and Technology, Shandong, China, in 2001, 2004, and 2008, respectively.

He is currently a Professor with the School of Mathe-nlatics, Remnin University of China. He is also with the Engineering Research Center of Finance Computation and Digital Engineering, Ministry of Education, and the State Key Laboratory for Management and Control of Complex Systems, Institute of Autonlation, Chinese Academy of Sciences, Beijing, China. He has authored over 120 papers published in academic journals and conferences. His current research interests include blockchain, cryptocurrency, and smart contract.

Dr. Yuan is currently all Associate Eclitor of the IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS and Acta Autonlatica Sinica. He is the Chair of the IEEE Council oil RFID Technical Committee on Blockchain, the Co-Chair of the IEEE SMC Technical Committee on Blockchain, and the Director of the Chinese Association of Autonlation Technical Committee of Blockchain. He is the Secretary General of the IEEE SMC Technical Committee oil Social Computing and Social Intelligence, the Vice Chair of the IFAC Technical Committee oil Economic, Business and Financial Systems (TC 9.1), and the Chair of the ACM Beijing Chapter on Social and Economic Computing. He is also the Secretary General of the Chinese Association of Artificial Intelligence Technical Committee oil Social Computing and Social Intelligence, and the Vice Director and the Secretary General of the Chinese Academy of Management Technical Committee on Parallel Management.

NaiQi Wu (Fellow~ IEEE) received the B.S. degree in electrical engineering from tile Anhui University of Technology, Huainan, China, in 1982, and tile M.S. and Ph.D. degrees in systems engineering from Xl' all Jiaotong University, Xl' an, China, in 1985 and 1988, respectively.

From 1988 to 1995, he was with the Chinese Academy of Sciences, Shenyang Institute of Automation, Shenyang, China. From 1995 to 1998, he was with Shantou University, Shantou, China. He moved to Guangdong University of Technology, Guangzhou, China, in 1998. He joined the Macau University of Science and Technology, Macao, China, in 2013, where he is currently a Professor with the Institute of Systems Engineering. He is the author or a coauthor of one book, five book chapters, and more than 170 peer-reviewed journal articles. His research interests include production planning and scheduling, manufacturing system modeling and control, discrete-event systems, Peiri net theory and applications, intelligent transportation systems, and energy systems.

Dr. Wu is an Associate Editor of Information Sciences and the IEEE/CAA JOURNAL OF AUTOMATICA SINICA.

Fei-Yue Wang (S'87-M'89-SM'94-F'03) received his Ph.D. degree in computer and systems engineering from the Rensselaer Polytechnic Institute, Troy, NY, USA, in 1990. He joined The University of Arizona in 1990 and became a Professor and the Director of the Robotics and Automation Laboratory and the Program in Advanced Research for Complex Systems. In 1999, he founded the Intelligent Control and Systems Engineering Center at the Institute of Automation, Chinese Academy of Sciences (CAS), Beijing, China, under the support of the Outstanding Chinese Talents Program from the State Planning Council, and in 2002, was appointed as the Director of 1he Key Laboratory of Complex Systems and Intelligence Science, CAS. In 2011, he became the State Specially Appointed Expert and the Director of the State Key Laboratory for Management and Control of Complex Systems.

His current research focuses on methods and applications for parallelintelligence, social computing, and knowledge automation. He is a fellow of INCOSE, IFAC, ASME, and AAAS. In 2007, he received the National Prize in Natural Sciences of China and became an Outstanding Scientist of ACM for iris work in intelligent control and social computing. He received the IEEE ITS Outstanding Application and Research Awards in 2009 and 2011, respectively. In 2014, he received the IEEE SMC Society Norbert Wiener Award. Since 1997, he has been serving as the General or Program Chair of over 30 IEEE, INFORMS, IFAC, ACM, and ASME conferences. He was the President of the IEEE ITS Society from 2005 to 2007, the Chinese Association for Science and Technology, USA, in 2005, the American Zhu Kezhen Education Foundation from 2007 to 2008, the Vice President of file ACM China Council from 2010 to 2011, file Vice President and the Secretary

General of the Chinese Association of Automation from 2008-2018. He was the Founding Editor-in-Chief (EiC) of the International Journal of Intelligent Control and Systems from 1995 to 2000, the IEEE ITS Magazine from 2006 to 2007, the IEEE/CAA JOURNAL OF AUTOMATICA SINICA from 2014-2017, and the China's Journal of Command and Control from 2015-2020. He was the EiC of the IEEE Intelligent Systems from 2009 to 2012, the IEEE TRANSACTIONS ON Intelligent Transportation Systems from 2009 to 2016, and is the EiC of the IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS since 2017, and the Founding EiC of China's Journal of Intelligent Science and Technology since 2019. Culrently, he is the President of CAA's Supervision Council, IEEE Council on RHD, and Vice President of IEEE Systems, Man, and Cybernetics Society.