Ways of Interaction of Autonomous Economic Agents in Decentralized Autonomous Organizations

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Abstract

Decentralized Autonomous Organizations (DAO), which have already become independent participants in the relationship in the Web 3.0 economy, are currently neither decentralized nor autonomous because most of the functions and tools used are still centralized, the management of DAOs still largely depends on collective decision-making by all participants. Greater autonomy can be provided by the use of Autonomous Economic Agents (AEA) in DAOs to organize governance, improve communication between participants, create an autonomous reward system, and speed up the search for information and solutions. AEA can be used as a tool to conclude transactions or implement a part of their functions. The article provides an overview of the main technological developments in the field of AEA and DAO and also describes the main ways they could interact in economic peer-to-peer digital systems, taking into account their role, characteristics, and functions. Attention is also drawn to the economic benefits that a DAO acquires from the use of autonomous agents.

Keywords

DAO, Decentralized Autonomous Organizations, Autonomous Economic Agent, AEA, Multi-agent systems, Web 3.0, P2P system, smart contracts.

1. Introduction

Modern forms of DAO can offer various services for community members, including services that help collect information and make decisions. DAO smart contracts allow you to create and execute potentially complex business logic. There is an external trigger outside of the contract logic. This factor significantly limits the functionality of reactive systems. Thus, DAO and smart contract systems cannot be used to create applications with proactive behavior. The use of AEAs in DAO could significantly increase the efficiency of treasury management and decisions making [1, 2].

AEAs are intelligent agents acting on behalf of the owner, with little or no intervention from the owner, and whose goal is to create economic value. In a DAO, such agents can perform actions either on behalf of a participant in the system of such a DAO, or on behalf of the entire DAO, or its separate part. This opens up new opportunities for delegating authority to collect information and make decisions on behalf of the community.

AEA is a new type of non-personalized independent subject of economic relations described in the works of M. Porter. In the new decentralized (peer-to-peer) systems it will be difficult to determine the final personalized participant (stakeholder or beneficiary) due to its digital anonymity, taking into account the possibility of its complete replacement by a digital algorithm (Digital Twin). Thus, EAE can be represented as a participant in DAO that autonomously manages assets and makes decisions contributing to faster, safer, and cheaper operations. The first autonomous digital agent was a device called the Turing machine, developed in 1948 by Alan Turing, an English mathematician, logician, and cryptographer. Early autonomous agents were also presented in the "Mathematical Theory of Communication" published in 1948 by the American electrical

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engineer and mathematician Claude Elwood Shannon [3], where the author develops the topic of electronic communication with the participation of independent (autonomous) algorithms. Currently, several works devoted to the use of AEAs in combination with distributed ledger technologies are being carried out by a group of scientists led by David Minarsch and Marco Favorito. They described not only the concept of using smart contracts in cooperation with AEAs, but also created a framework for their subsequent use in decentralized applications [4].

This paper is structured as follows: In Section 2 we provide the P2P AEA technology overview. In Section 3 we follow with a description of AEAs and DAO Interactions.

2. P2P AEA Technology Overview

The application of blockchain technology, machine learning, artificial intelligence, digital identity, smart contracts, and robotics opens up new opportunities for peer-to-peer cooperation and partnership. A decentralized agent will be able to make direct peer-to-peer transactions together with a person, or another similar digital agent, which in turn makes it possible to develop the idea of their ability to conclude agreements cooperating with other persons and robots and could act as a part without the necessary economic legal personality in the traditional sense. The coexistence of robots and humans suggests the need to study interaction with DAO including within the framework of behavioral economics, game theory, and crypto economics.

It is believed that autonomous agents are endowed with the following properties: rationality is an individual property of intelligent agents, as well as cooperative multi-agent systems or teamwork, which is important for collective effort in the DAO community. Following the economic approach, the agent should maximize the utility function. To study the properties of autonomous agents in 1944, von Neumann and Morgenster created Decision Theory, combining utility theory with probability theory. In decision theory, a rational agent is an agent that chooses an action to maximize expected utility, where expected utility is defined as the actions available to the agent, the probabilities of certain outcomes, and the agent's preferences for those outcomes. In multi-agent scenarios where an agent must interact with other agents, game theory is also a powerful predictive and analysis tool. To solve problems with a sequence of multi-agent scenarios, in the late 1950s, Bellman developed Dynamic Programming based on the use of decision theory methods. Particular attention was paid to the interoperability of agents as the ability to interact, communicate and share knowledge using communication tools.

It is known that to receive information and communications, autonomous economic agents must have the appropriate tools. In 1990, Yoav Shoham, a computer scientist and professor at Stanford University, introduced an agent-oriented language known as Agent0, which was the first programming language specifically designed for mentally structured agents. The language consists of 4 following components: a set of abilities (what an agent can do); a set of initial beliefs; a set of initial commitments (what the agent will do); a set of rules of conduct (software part) with a precise indication of the scope of possible actions. To combine the Multi-agent system on smart contracts and a peer-to-peer environment a related protocol for communication between them is necessary. Such a system is usually called a Distributed Hash Table (DHT), which consists of the following components: Agent registration, Agent search, Agent deregistration, and Connection protocols. The use of DHT is associated with the need for certain costs, including payment for the use of the network, memory, database, etc., supporting the operation of peer nodes side [5]. The P2P technology selected for such activity could be the Solidity programing language to design and deploy contracts on the Ethereum network while the standard to be enhanced to operate on blockchain will be the Agent Communication Language released by Foundation for Intelligent Physical Agents [6]. Interaction with smart contracts allows to design of the modules for DAO, necessary for cooperation.

The use of autonomous agents is currently already available in the multi-agent peer-to-peer system for trading baskets of tokens [7].

For DAO we understand an AEA as an Intelligent agent acting on the owner's behalf with limited to no interference whose goal is to generate economic value and allow more complexity in smart contract logic and execution layer of decentralized communications [8]. AEA independently acquires new skills, either through the direct use of software modules or through independent or collective learning. Examples of the use of AEA can be the acquisition of digital assets at a bargain price, and having the

appropriate negotiation skills [9], while allowing the possibility of interacting with another agent autonomously representing the other party to the transaction. Skills of the AEA consist of three core abstractions as a Handler, a Behavior, and a Model, with a Decision Maker with access to the wallet [4].

The ability to use AEA at the second layer provides the ability to use tools modeled using artificial intelligence and machine learning. The high cost of developing autonomous agents makes their development difficult for one participant. A group of developers united in an organization could pool their efforts and funds to develop such agents. Currently, two-level models for AEAs are being developed that can reduce the cost of interacting with smart contracts [10]. Thus, as a result of the partnership and financial organization for product development interaction, the AEA becomes part of the DAO and operates for the entire community through the digital organization. In other situations, the DAO may acquire AEA or gain access to it for its purposes. In this case, access can be through smart contract standards specifically modeled for managing autonomous agents. At the same time, it is possible to develop various strategies for agents. The Richer and Competing strategies are considered as potential, that use a variety of techniques, including more advanced Reinforcement Learning (RL) algorithms and multiple skills implementation [4].

The problem of interaction between AEAs and smart contracts is considered in many scientific papers, where their interaction is confirmed by the example of experiments and, thus, the possibility of using them within a single product. Based on observations and scientific work, the following hypotheses can be made about the economic benefits of using AEA in working with DAO.

The development of peer-to-peer technologies and the increase in the number of transactions in networks will lead shortly to the construction of business networks where agents will negotiate, trade, cooperate and build partnerships with people, take part in DAO, and compete in a virtual social environment. Security and regulatory issues that apply to agents will become more and more relevant to create a secure environment that is comfortable for business. Autonomous agents will be able to not only share information in DAO but also perform joint tasks, such as partnering with financial institutions to detect fraud or studying customer information profiles without compromising their privacy. Peer-to-peer data mining agents can generate certain knowledge based on data flow, but without collecting the data in a single repository [11]. Whether AEAs are part of the DAO architecture or act on behalf of an individual DAO participant, they interact on their own in a Peer-to-Peer (P2P) or multi-peer environment designed for agent interaction. Each AEA can represent a participant in DAO, a group of participants, or act on behalf of DAO and perform certain actions in their interests, maximizing economic utility [12]. The goal of each agent may be to maximize the outcome by engaging in profitable trades based on their preferences [13].

To interact with elements of a peer-to-peer environment, an AEA must possess the appropriate characteristics that can interact with one or a set of functions of a P2P environment. For effective interaction of AEAs in a P2P environment, the following components are required: means of interaction with AEAs, messages delivery mechanism, access to a financial settlement system, and access to a search and discovery system [4]. Such functions are performed by system modules that enable operations between nodes. Fig. 1 shows some of the specific functions of a peer.

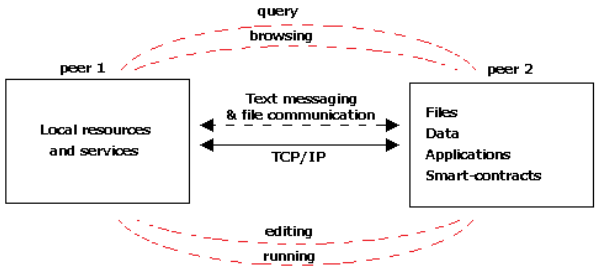

Figure 1: Structure of P2P interaction

AEAs, as well as DAOs, use the public internet for message transport. The agent communication network allows AEAs to communicate knowing their cryptographic addresses alone. The Agent Communication Network (ACN) allows AEAs to communicate with other peers and agents through a multi-tier messaging system with a P2P overlay network at its core. The peers maintain a distributed hash table that maps addresses to network addresses. The AEA framework that provides the tools for creating AEAs allows developers to use existing protocols, create new protocols and share them with other developers via the AEA registry. There is no limit to the type of interactions AEAs can engage in. A common example is two AEAs engaging in negotiation which results in a transaction on a ledger [14].

The concepts of agent and P2P are closely related to each other. Agents can improve the functionality of a P2P system, and a P2P architecture can become an environment in which the capabilities of agents are fully exploited. It can be argued that agent technology is the intersection point of AI and distributed systems. A possible solution to the current shortcomings of the P2P approach is the use of agent technology. Autonomous agents can perform extended (dynamic) functions in a P2P network where nodes (agents) behave intelligently (negotiate, learn, predict, cooperate, etc.) in one way or another, and where P2P functions can be optimized.

3. AEAs and DAO Interactions

The use of autonomous agent technology in P2P systems along with artificial intelligence technology is considered fairly new. It is assumed that agents can be both autonomous and intelligent objects in the network, having a digital form in the form of a code, and reside at the nodes, or move between them. They are endowed with the ability to independently identify problems or receive tasks from users or other agents, as well as discover the necessary resources, communicate with other agents (negotiate), and offer suitable solutions. They are also good at learning from the past, updating their knowledge, and predicting future events. The main difference between agents and conventional software is the ability to independently coordinate, interact and self-learn. By working together, agents optimally allocate resources, which can be like teamwork to solve a problem. With the ability to quickly adapt to new conditions, the use of agent technology is suitable for P2P dynamic systems. Such characteristics make them attractive for use in digital organizations that need to optimize the use of digital resources and perform some operations with such resources.

A necessary ecosystem for AEAs-DAO interactions can be built using principles from a branch of AI known as Multi-Agent Systems. Implementing agents as smart contracts of a blockchain may give birth to a completely new environment where agents' behavioral and communication rules will benefit from distributed ledger properties. Allowing secure communication among agents, along with certification of transactions and immutability of data, will therefore open widespread adoption to a wide range of problems that are not fulfilled by classic architectures. This may include a variety of applications in the Internet-of-Things and Big Data fields, such as security monitoring of sensitive sites or management of critical environmental parameters for early warning [15].

Multi-Agent Systems, built from their constituents, and agents, are suited for multi-stakeholder environments. Unlike traditional systems whose constituents are all typically built by the same developer and designed to work in harmony, each agent may be built and owned by a different stakeholder whose interests may not necessarily be aligned with the others. Despite their heterogeneity and self-interest, agents find ways to cooperate and work with other agents, much like humans. The application of a Multi-Party Computation (MPC) protocol with incentives for good behavior and penalties should ensure that the participants behave in good faith [16].

Some descriptions of AEAs talk about their social behavior as the ability of an agent to interact with external sources and the ability to share knowledge with other agents to jointly solve a specific problem [17]. Although agents have some level of dependency, they are endowed with communicative properties to jointly search for resources necessary to solve problems. Thus, it seems appropriate to use AEAs in the DAO structure to identify risks and abuse attempts. In addition to control functions, agents could perform part of the management functions delegated to them by participants of DAO, for example, managing the treasury, negotiating the terms of transactions, or analyzing and finding a solution to a problem. Thus, the existence of an environment where agents could interact creates the prerequisites for the design of any form of digital interaction with AEAs, including in the interests of the community represented by the digital DAO. Participants in interaction with EAEs can be not only the agents that jointly create multi-agent systems, but also participants of crypto-economy and their digital organizations.

Table 1
Forms of AEAs interactions with external entities

Interactions participants	Functions and characteristics	Examples of application
AEA <-> AEA	AEA framework for agents interaction, no limit to the type of interactions	AEAs engaging in negotiation which results in a transaction on a ledger
AEA <-> Server	AEAs connect to servers as clients, requesting whatever services the server provides	AEAs querying public APIs for information, e.g. public transport information
AEA <-> Client	Maintains servers to serve requests to other clients	AEA might run a server to allow its owner to connect to it via a web client
AEA <-> Blockchain node	AEAs act as off-chain elements: query ledger state, submit transactions, and make smart contract calls	AEAs might utilize the properties of blockchains, like public code execution and censorship-resistant exchange
AEA <-> Smart-contracts	AEAs activate smart contracts and receive information about the results. Can work as an oracle	Shared machine learning models, Stablecoin liquidity manager, micro mobility ecosystem incentive model, services, incentive model, exchange of information throughout the automotive value, chain automated market maker in DEX
AEA <-> DAO	AEAs interact with DAO smart contracts, DAO tools, and clients	Governs AUM of DAO Helps participants with interactions Provides data Manage interactions in DAO

AEAs in DAO can perform the following roles and functions: automation of processes involving smart contracts; automation of management (decision making and situation analysis); automation of collecting information for the work of the DAO, including about the activity of participants. AEA's ability to collect information and improve its skills, as well as the ability to customize the agent at the discretion of its owner, will greatly simplify the joint work of the agent with other participants of the DAO.

For example, an autonomous agent, being a participant of the DAO, could coordinate its work with other participants, including other agents, to interact more effectively to achieve joint results. Fig. 2 summarizes the process of finding a solution to a specific problem using the interaction of autonomous agents. Agent A, having received the problem, and understanding its possible solutions forms 4 subtasks. Subtask 1 is processed by agent A on its own, and each other subtask is sent to the responsible agent for further processing. The results are sent back to the original agent A, which forms a complex (integral) solution.

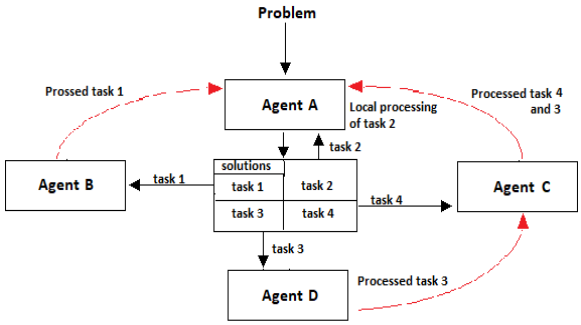

Figure 2: Problem-solving with the cooperation of the AEAs

With a range of tools, agents can efficiently search P2P systems to find the information they need. It is believed that the huge potential of agents can be applied in the discovery of medical records and data mining. A P2P technology for classifying and indexing medical data and a complete ontology in the field of healthcare using artificial intelligence is one example of the implementation of an autonomous economic agent. Data mining often requires the implementation of a series of searches, therefore, agents, have the tools to search for the necessary data, save resources and time, constantly improve their skills by refining the search for the necessary

data, and also improve methods in the process. Agents make decisions based on experience, and can also provide information about the data they collect and their actions to database administrators, who in turn can, through interaction, configure and improve the work of agents (improve and customize their search engines) [18]. Having a constant flow of information at their disposal, agents can determine the deviations from the norm of those objects of observation that are in their "field of view", analyze such data, or send them to analytical applications according to the appropriate subscription, acting as a data provider.

In such a partnership, it is possible to create alliances of agents or agent communities that will not necessarily interact for the benefit of the entire DAO. Agents will likely learn to create their own DAO to combine skills and make common decisions, as well as carry out verifiable computations [19]. In this case, it makes sense to talk about fully autonomous DAOs, in which agents will be crucial for the DAO. Accordingly, DAOs with human control will be considered limitedly autonomous. Characteristics of the autonomy of DAO depend on the absence of a single control center and the use of autonomous agents in its activity. As an extreme version of an autonomous organization, we can imagine a completely autonomous DAO created only by autonomous agents, fully controlling its activities and not depending on the provision of resources by other participants, including disconnecting them from individual nodes. It seems possible to call them ultra-autonomous DAO. There are practical difficulties in creating such completely independent agents, but with the development of technology, it is quite possible.

Table 2
DAO Autonomy Levels

Levels of Autonomy of DAO	Characteristics
Non-autonomous	Significant control by one participant
Possible autonomy	Difficulties with determining the level of control
Partially autonomous	Some tools and nodes work autonomously
Fully autonomous	Decisions are made using AEAs
Ultra-autonomous DAO	Organization and resources are fully managed by autonomous and independent P2P agents

Thus, we can judge the appearance of data-driven and fully automated organizations, known as Artificial Intelligence DAOs, and becoming a major threat to most traditional organizations in the years to come. As the goal of a DAO is the absence of human hierarchical management, any interaction between humans and organizations can be automated with a delegation of all management and administrative functions to AEAs that autonomously take decisions. Such a type of DAO could create its products and services using AEAs and sell them. The concept of DAO headed by Artificial Intelligence, as a completely human-less without any external support and no hierarchy organization, can be implemented in Generative Adversarial Network to generate art [20].

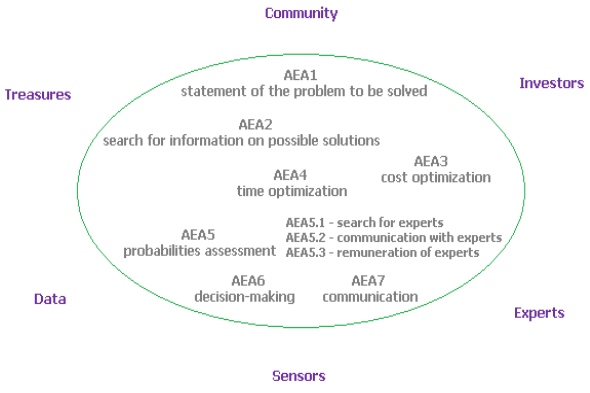

Figure 3: Possible AEAs structure for DAO

Depending on the goals in DAO, we distinguish the following types of interactions of AEAs (see Table 3).

When it comes to concrete use cases with AEAs in DAO, we can identify the following ones (see Table 4).

Table 3
Types of the interaction of AEA with DAO

Types of interaction	Description	Possible practical application
Informational	Search, receipt, and processing of information adapted for smart contracts	Receiving information from sensors Receiving information on the Internet Receiving information from databases Data marketplace for training machine learning models
Communicative	Communication with DAO participants and communities, Negotiation with partners and contractors	AI communication bot, analyzing the activity of participants Hiring employees to perform functions in/for DAO Production coordination and orders distribution
Analytical	Processing of collected information for a DAO or community	Setting up systems for decision-making or product manufacturing AEA-based solutions
Technical	Audit of the reliability of the systems	Checking vulnerability of smart contracts, including of other DAOs
Financial	Management of the treasury and transactions on behalf of the DAO	Participant reward Conducting airdrops and bounties Treasury management Transactions on CEX, DEX
Creative	Artworks creation Writing texts	Creation of the NFT Creating objects in Metaverses

Table 4
AEAs classification for DAO use

AEAs classification	Characteristics
Marketing agent	Selects the best companies or users to place advertising. AEA evaluates the ROI after each marketing cycle and adjusts its marketing actions according
Art commerce agent	Trades the creations made using generative models and distribute profits as cryptocurrency tokens to their shareholders. They can identify new trends (NLP on social media), create their object, and sell it online
Vending agent	Takes money, delivers the goods or services, automatically re-orders the goods, and manages accompanying services.
AI Agents	The autonomous entity acts, directing its activity towards achieving goals, upon an environment using observation through sensors and consequent actuators. Intelligent agents may also learn or use knowledge to achieve their goals. They may be very simple or very complex. Is capable of understanding the world as well as any human, and with the same capacity to learn how to carry out a huge range of tasks.
Marketing agent	Selects the best companies or users to place advertising. AEA evaluates the ROI after each marketing cycle and adjusts its marketing actions according.

Thus, to understand the role and place of an autonomous agent in the economic system, we can give it the following definition: An Autonomous Economic Agent (AEA) is an intelligent agent acting on its behalf or on behalf of the owner with limited intervention from the owner or other agents, or without such interference, and whose purpose is to create economic value for its owner or search for its resource. As a rule, AEAs have a narrow goal with a purposeful focus, assuming some economic benefit. It is believed that the autonomous operation of an agent is achieved through the use of peer-to-peer systems and certain algorithms (smart contracts) that underlie the architecture of agents and allow secure transactions without the participation of third parties. At the same time, they will be autonomous

if such a model does not require input from an individual user.

AEAs are also special in that they are created to generate some economic value through specialized software modules or digital skills. Using a method that translates smart contracts into probabilistic logic can be used AEA could analyze the expected values of several smart contracts' utility parameters [21]. AEA independently acquires new skills, either through the direct use of software modules or through independent or collective learning. Examples of the use of AEA can be the acquisition of digital assets at a bargain price, and having the appropriate negotiation skills, while allowing the possibility of interacting with another agent autonomously representing the other party to the transaction.

4. Conclusions

Agents and DAOs that can interact in P2P systems use specially designed frameworks when interacting. At the same time, mutually beneficial interaction between the community and autonomous agents is ensured. Communities can use agents to optimize decision-making and resource use, and agents are interested in acquiring new skills and participating in collective knowledge. Probable further studies will be directed to the design of agents for use in DAO as tools or as a decision-making center. Agents used in DAO will be able to hire experts, conduct negotiations with them and conclude deals, create teams based on the skills of participants, fairly distribute rewards based on the assessment of the effectiveness and contribution of each participant, manage the community, create requests and tasks, monitor the execution of work, and perform other functions in a digital organization.

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