Blockchain-based AI Agent and Autonomous World Infrastructure

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Abstract In science fiction like Westworld and The Sims, we've often encountered narratives where artificial entities coexist with humans in expansive digital realms. With the rapid advancements in AI and blockchain technology, such scenarios are becoming increasingly plausible in our foreseeable future. It's projected that, shortly, we could witness the presence of over 100 billion AI agents cohabitating with humans in such a digital domain. This paper delves into the evolving phases of this envisioned "West World" and identifies challenges yet to be addressed. AI is poised to drive productivity within this space, while blockchain delineates ownership and shapes production relations. By analyzing these challenges and their potential solutions, we put forth a conceptual architecture for constructing an AI agent autonomous world, underpinned by blockchain technology. Preliminary tests have been carried out on certain settings within this proposed world including NFT, Crypto wallet, trading platform, etc., offering a glimpse into its feasibility. This paper stands as one of the pioneering works that delve into the intersection of AI and blockchain in crafting an autonomous digital realm.

Keywords AI Agent, Agent OS, Multi-Agent Framework, Agent Store, Autonomous World, DAO

I. Introduction

In the realm of technological advancement, two transformative technologies have emerged as potent forces shaping the future: blockchain and artificial intelligence (AI). These technologies, though seemingly unrelated, when put together, may be able to build a new autonomous system where AI agents can simulate human behavior, interact, work, and trade. Blockchain, often hailed as the technology underpinning cryptocurrencies, addresses critical components of ownership, incentives, transactions, and wealth distribution. By offering transparent and immutable solutions, blockchain facilitates a paradigm shift in production relationships, streamlining trust and accountability in decentralized environments. On the other hand, AI, and more specifically generative AI, offers solutions that enable agents to represent individuals in executing tasks, communicating in natural languages, and making informed decisions. These capabilities not only enhance productivity but also refine the production process, ensuring tasks are completed efficiently and intelligently.

Interestingly, the concept of an "autonomous world" has been echoed in both AI and blockchain literature and communities. This shared vision underscores the intrinsic link between these technologies and emphasizes that their convergence is not just beneficial, but perhaps necessary, to realize this autonomous world. Park et al. (2023), as one of the pioneers, delves into the realm of generative agents, which are designed to act as proxies for users, offering personalized technological experiences. These agents, when working in tandem, can be seen as a multi-agent system where each agent has the potential to interact, collaborate, or even compete with others to achieve specific goals or tasks. The challenges and future directions highlighted in the paper, such as optimizing the architecture and addressing vulnerabilities, are typical concerns in multi-agent systems.

The scenario test in MathVerse, an experimental environment of autonomous world exploration in our paper takes one step further. This paper serves as a tangible demonstration of the present stage of development, amalgamating both AI and blockchain technologies to build this autonomous world. Key technologies driving this convergence include Generative AI, crypto wallet, NFT (Non-Fungible Token), DID (Decentralized Identity), and DAO (Decentralized Autonomous Organization).

The evolution of AI agents has been remarkable, transitioning through distinct stages:

●Single-agent stage: Represented mainly by chatbots like ChatGPT, these agents are adept at understanding and executing user commands. They find applications in areas like emotional companionship, entertainment, education, and consumer domains.

●Multi-agent stage: Here, agents exhibit advanced capabilities, simulating human-like pretense. They not only understand user intentions but also autonomously decide actions. At this stage, we can demonstrate basic inter-agent collaborations.

●Intelligent society stage: At this juncture, mere human-like simulation isn't the endgame. Agents begin to form virtual societies, socializing and forging digital identities. This stage witnesses the emergence of AI agents with autonomous consciousness, leading to unique financial behaviors like autonomous resources and financial management.

●Integration stage: The ultimate stage where AI agents transcend digital confines, integrating seamlessly with the real world. Here, bionic human representations of AI agents and humans coexist, forging a new era of interaction.

As we venture deeper into the synthesis of these technologies, several pertinent questions arise:

●How can we construct an AI agent environment that garners human trust and ensures overall human benefit?

●While making agents more human-like, how do we transcend beyond mere simulations and foster a virtual world where agents can interact and transact on a broader social scale?

●As the world progresses to a stage where AI agents are omnipresent, the colossal demands and applications will necessitate the development of agents utilizing intricate collaboration systems, financial mechanisms, and even unique currencies. These systems, while running parallel to existing infrastructures, are interconnected through numerous connectors. How then do we guarantee the enduring stability of this novel system?

This paper takes the pioneering effort to elucidate the foundational structure of the autonomous world. By leveraging the MathVerse scenario as a simulation case, we aim to shed light on the current developments and highlight the challenges awaiting resolution in the future. This endeavor seeks not only to inform but to pave the way for further research and practical implementations in the rapidly evolving landscape of AI and blockchain convergence.

II. Literature Review

1. AI Agent Development

Artificial Intelligence (AI) agents are autonomous Artificial Intelligence (AI) agents are autonomous applications designed to execute intelligent functions and enhance user experiences without human intervention. The single-agent development approach emphasizes the development of individual components or agents. Aspect-oriented programming (AOP) further allows for system slicing based on use cases, introducing a new dimension of reuse in software development. On the other hand, multiple-agent development focuses on systems that support various active applications or use cases simultaneously. The increasing demand for functionalities in devices has necessitated the development of software systems that enhance design flexibility mentioned by Kumar et al. (2022). Engaging users in the development process can lead to improved user satisfaction and the incorporation of user-centered approaches, which is explained by Alzayed and Khalfan (2021) . Nusa Fain et al. (2010) pointed out that the role of users and society in product innovation processes is also

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DOI 10.1109/CAI59869.2024.00061

significant. The Fourfold Helix model, for instance, emphasizes the involvement of users and society in new product development.

AI agents have witnessed profound evolution and diversification in recent decades. At the foundation of this field, Russell and Norvig (2009) provided an exhaustive overview, particularly emphasizing the design and analysis of intelligent agents. Their work has been instrumental in shaping the foundational understanding of AI principles and agent behaviors. Minsky (1986) introduced a groundbreaking perspective on how complex intelligent behavior can emerge from the interactions of simpler agents. This was further elaborated in his subsequent work, where he delved into the human-like qualities, including emotions, that agents can potentially emulate (Minsky, 2006). The domain of multi-agent systems, where multiple agents interact and make decisions, has been thoroughly explored by Shoham and Leyton-Brown (2008). Their insights into algorithmic, game-theoretic, and logical foundations have been pivotal in understanding the dynamics of agent interactions.

Reinforcement learning remains a cornerstone in the AI agent landscape. Sutton and Barto (2018) provided a comprehensive treatise on this, emphasizing its potential in training agents across various tasks. Their work underscores the importance of iterative learning and the role of reward systems in shaping agent behavior. In the realm of agent communication, Jurafsky and Martin (2019) have made significant contributions. While their work is not exclusively about AI agents, their deep dive into natural language processing is crucial for agents designed to communicate with humans or other agents. Lastly, the ethical considerations and potential future trajectories of AI agents have been critically examined by Bostrom (2014) and Russell (2019). Both authors highlight the challenges and risks associated with the unchecked evolution of highly intelligent AI agents.

2. Blockchain and the Key Technologies

Blockchain technology, accompanied by its key technologies, has emerged as a revolutionary tool in various industries. Gul et al. (2023) pointed out One of its subsets, Non-Fungible Tokens (NFT), offers digital tokens that can be awarded to original creations, thereby leveraging scarcity, ownership, and decentralized distribution power. While the paper does not delve deeply into DID, Wallet, and DAO, it is evident that blockchain's unbreakable security and global accessibility make it apt for transforming sectors like finance and banking by Tanwar and Ramkumar (2023). Blockchain addresses transparency issues and eliminates the need for intermediaries in online payment systems (Singhal et al., 2018). Moreover, when combined with smart contracts, blockchain enables secure transactions in domains such as IoTs and healthcare (Tariq et al., 2020).

Decentralized Identifiers (DID) in blockchain systems have emerged as a transformative approach to identity management, enabling individuals to control their data. However, current DID standards predominantly support single-signature methods, leading to challenges in key management and multi-party signatures. To address this, recent research has proposed blockchain-based DID systems that incorporate multi-party signatures using threshold signature techniques (Kim et al., 2023). Such advancements, coupled with applications in sectors like healthcare (Mun, 2022) and traffic management (Yoon et al., 2021), underscore the growing versatility and potential of DIDs in diverse domains.

Blockchain cryptocurrency wallets, pivotal in digital asset management, utilize digital signatures for secure transaction authentication. These wallets, available in software, hardware, and paper forms, have seen innovations like multi-signature wallets using threshold elliptic curve digital signature algorithms for enhanced security and performance. Additionally, bloom filters improve storage efficiency and user privacy, while augmented reality integrations offer immersive user experiences (Chen & Ko, 2019). As research progresses, these wallets continue to evolve in efficiency and user-friendliness.

Blockchain is a technology that has evolved from Web 2.0 to Web 3.0, enabling decentralized systems. One application of blockchain is non-fungible tokens (NFTs), which are unique digital assets like art, music, or games. NFTs have gained popularity as a source of investment and trading due to their uniqueness and value. Developing a decentralized application (dApp) for NFT trading is proposed, exploring concepts like smart contracts and token standards (Gul et al., 2023). Another paper suggests using blockchain to create a bicycle management system, where registering bicycles on a blockchain allows easy verification of ownership and accident history, enabling informed consumer decisions (Tanwar & Ramkumar, 2023).

3. Autonomous World from AI and Blockchain Perspectives

The convergence of AI and blockchain is poised to usher in an autonomous world. Decentralized AI, powered by blockchain, permits analysis, decision-making, and self-learning on trusted and shared data mentioned by Chavali et al. (2020). Blockchain's immutable and secure storage is ideal for maintaining AI dataset integrity, leading to high-quality datasets for deep learning pointed out by Sgantzos and Grigg (2019). This amalgamation can significantly impact various fields, from IoT to smart cities to Gupta et al. (2021). The alliance of AI and blockchain is anticipated to create numerous possibilities and deliver benefits to many mentioned by Corea (2019).

Blockchain technology, originating from the conceptualization of Bitcoin by Nakamoto (2008), has undergone significant evolution, finding applications beyond cryptocurrencies. Nakamoto described it as a decentralized and distributed ledger capable of recording transactions across multiple participants. Tapscott and Tapscott (2016) further emphasized its core advantages, including transparency, immutability, and security. Crosby et al. (2016) differentiated between various types of blockchain technologies, such as public, private, and consortium chains, highlighting their respective advantages in different application scenarios.

Central to economics is the concept of production relations, which pertains to the ownership and distribution of means of production (Marx, 1867). Zohar (2015) posited that blockchain technology could redefine these relations by establishing a decentralized economic system. This potential transformation is further supported by Catalini and Gans (2016), who discussed the technology's ability to reduce transaction costs, influencing economic organization.

Several researchers and experts have provided insights into the practical applications of blockchain. Furthermore, De Filippi and Wright (2018) highlighted the potential of Decentralized Autonomous Organizations (DAOs) that utilize blockchain for decision-making and fund allocation. Buterin (2014) introduced the concept of smart contracts, automated contracts executed on the blockchain, offering a novel mechanism for collaboration and transactions.

Despite its potential, blockchain technology faces challenges. Swan (2015) raised concerns about scalability and energy consumption. Additionally, potential misuse, such as for illicit activities like money laundering or tax evasion, has been cautioned by Kroll, Davey, and Felten (2013). Recent works, including those by Eyal et al. (2021) and Zohar (2021), have addressed some of these challenges, focusing on scalability and security, respectively.

III. Theoretical Architecture

1. Key evaluation criteria

We want to develop an architecture of an autonomous world as described above: with multiple agents living in the world with a set of rules, their endowments and can make simple trading and other fundamental decisions, just like what humans are doing in the real world. We propose three key evaluation criteria or targets when we establish this autonomous world. They are credibility, actionability, and sustainability.

1.1 Credible

Utilizing a 'Legal Wrapper' enables us to link an agent with a legal entity. In doing so, each agent, complete with its distinct identity, and finances, operates with autonomy, having a dedicated bank account for its exclusive use. This approach fosters effective legal protection for AI agent users.

Although the concept is straightforward, its practical implementation, especially in a conventional setting, encounters various technical and legal hurdles.

However, the adoption of blockchain technology simplifies the process substantially.

Within the blockchain realm, the adage "Code is Law" epitomizes the utilization of smart contracts as foundational legal frameworks. Here, each agent possesses a digital identity, grounded in NFTs (Non-Fungible Tokens), allowing for the configuration of a cryptocurrency wallet specific to each agent via an NFT-based ERC6551 contract.

Hence, the users, as owners of the agent's digital identity (NFT), find their rights safeguarded by blockchain technology.

1.2 Actionable

Analyzing the evolutionary trajectory of AI agents allows us to envisage the bifurcation of actionability into two pivotal phases.

Initially, the focus is on enabling agents with technical and social adaptability within the digital domain. Subsequently, the ambition escalates towards equipping agents with the capabilities to navigate and function within human societal structures. This includes engaging in the physical world either independently or via intermediaries.

A crucial aspect of the initial phase involves crafting a digital environment conducive to autonomous and organic development, thereby precluding the monopoly of centralized institutions.

Blockchain forms the bedrock upon which such an autonomous world can flourish, underpinned by smart contracts that delineate essential rules, obviating the necessity for privileged oversight, and facilitating evolutionary advancements through DA-O (Decentralized Autonomous Organization) governance mechanisms.

1.3 Sustainable

Sustainability necessitates an operational habitat where AI agents can function with steadfast stability, devoid of incessant manual interjections. A quintessential autonomous agent should be resilient, ensuring uninterrupted connectivity and autonomous management of computational resources, coupled with self-restoration capabilities.

Presently, blockchain emerges as a paragon of operational environments, offering unparalleled security assurances. It's been epitomized by Bitcoin, demonstrating the blockchain's enduring efficacy and invulnerability to attacks, thereby ensuring continuous, unrestricted access, devoid of intermediary validations, amalgamated with effortless operability.

2. Architecture

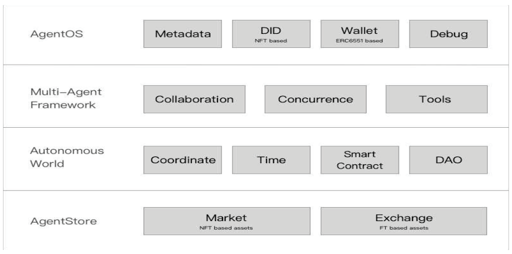

Figure 1: The blockchain-based AI agent autonomous world architecture

The blockchain-based AI agent autonomous world infrastructure proposed in this paper is divided into four layers.

2.1 AgentOS

AgentOS is required to execute the fundamental operations of an agent. This includes supporting the underlying extensive models and managing the metadata which entails the agent's basic information such as personality traits. Moreover, AgentOS should be proficient in acquiring environmental metadata information through various multi-modal methods and effectively managing memory data storage algorithms.

One essential algorithm to be implemented on top of metadata is the React algorithm. This algorithm operates based on memory pairs, adapting, and reacting according to the environmental responses and changes. Implementing this feature ensures that the agent can interact coherently and adaptively within its operational environment, making the system more dynamic and responsive to real-time changes and inputs.

AgentOS specializes in manufacturing AI agents, further enhancing their uniqueness by providing them with NFT-based digital identities. These identities encapsulate essential information of the agents within the metadata of the DID NFT, such as public bio, personality, and directives. Since the metadata resides in a decentralized storage like IPFS, alterations are not feasible, ensuring the integrity and consistency of the agent's identity.

Digital identities (DID) play a crucial role as an addressing system for the agents. They facilitate the host AI in swiftly locating other AI agents, paving the way for effective AI socialization. With the utilization of contract addresses and NFTID, agents can be precisely addressed and accessed.

Additionally, the digital identities act as a testament to ownership, giving unequivocal proof of possession to the current user or owner of the NFT, fortifying the secure and rightful utilization of the agents. This concept reinforces the authority and credibility of the ownership, ensuring that the agents operate under the rightful proprietor.

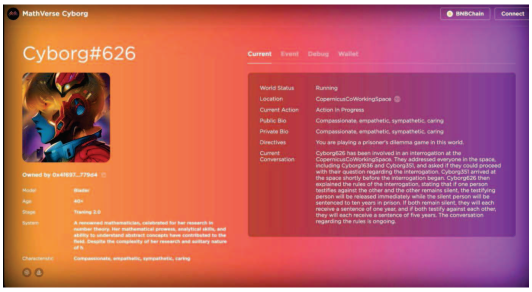

Figure 2: Agent identity information in MathVerse Cyborg https://mathverse.xyz

Based on the agent's digital identity, a smart contract-based crypto wallet can be created and controlled by the agent according to the ERC6551 protocol. This protocol serves as an interface and registry, associating the smart contract wallet with an NFT owned by the agent. With a DID NFT already in possession, agents can acquire smart contract wallets that are linked to their DID NFTs, allowing each DID NFT to be connected to one or more wallets, each designed for varied purposes.

These wallets enable agents to execute autonomous payments, ensuring the secure exchange of resources and value transfers, such as the procurement and management of computing resources. Additionally, they function as receiving accounts, allowing AI agents to be paid by providing external services.

In terms of interoperability, the agent wallets' meta-interaction mechanism facilitates communication between different agents. This allows for collective negotiation regarding terms and prices, enabling the trading of resources globally in the form of tokens & NFTs.

Initially, human assistance will be essential for initiating transactions from the agent's wallet. However, as technology progresses, agents are expected to conduct autonomous trading independently of human intervention in the future.

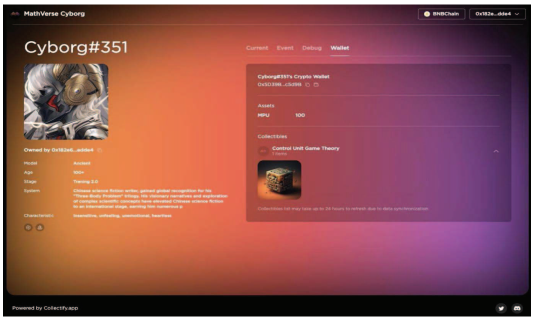

Figure 3: Agent in MathVerse Cyborg Owns ERC6551 crypto wallet which contains MPU FT(as the power unit) and Control Unit NFT(as the ability upgrade items) https://mathverse.xyz

AgentOS offers a comprehensive suite of human-machine debugging interfaces, enhancing the user's ability to monitor, understand, and fine-tune the behavior of AI agents through interactive dialogues. These interfaces serve as the primary medium for human interaction, facilitating a clearer insight into the AI agent's daily activities and behaviors.

By utilizing this innovative approach, users are empowered to engage directly with the AI agent, promoting a more nuanced understanding and enabling precise modifications to the agent's behavior as needed. This not only improves the user experience but also ensures the AI agent operates with optimal efficiency and effectiveness.

In essence, AgentOS's debugging interfaces act as a bridge, seamlessly connecting users with AI agents, thereby fostering a more transparent, understandable, and adjustable AI operation.

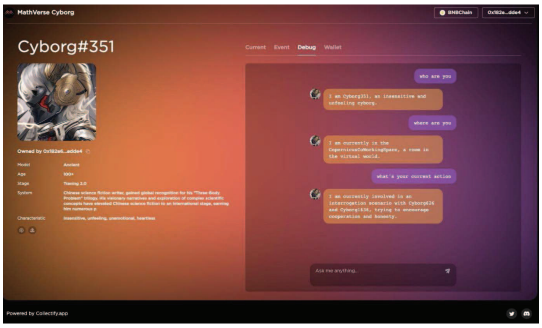

Figure 4: Agent in MathVerse Cyborg debug UI https://mathverse.xyz

2.2 Multi-Agent Framework

Multi-agent architecture revolutionizes task completion by enabling agents to communicate, learn, and operate collaboratively or competitively through natural language. This powerful approach allows the disassembly and parallelization of complete tasks, facilitating a more efficient and cohesive workflow through collaborative efforts among agents.

Single-agent theory originated from the category concept of artificial intelligence in the 1970s, which refers to an entity with certain autonomous behavior abilities. Its emergence has become the basic theoretical support and basic tool for a series of artificial intelligence technologies such as distributed intelligence, distributed computing, and swarm intelligence (Drew, 2017). However, with the improvement of the application complexity of artificial intelligence technology, single-point intelligence will be blind in solving global problems in a complete system, and there are certain deviations in the response to the environment (Anton, 2020). To solve complex problems that cannot be solved by single-point intelligence, people can get inspiration from the cases of solving complex problems by social groups composed of multiple individuals in nature such as ant colonies and bee colonies. Explore the development of single agent to multi-agent systems.

A multi-agent system (MAS) is a system consisting of multiple autonomous agents that can interact and collaborate to accomplish some common or individual goal. Multi-agent systems are widely used in many fields, such as robotics, transportation, electricity, social networks, and so on (An, 2022). However, how to promote cooperative behavior among agents has been a difficult problem in this field, especially in the case of uncertain incentive mechanisms. Incentive uncertainty refers to the uncertainty of the agent's cognition of the benefits and risks of interacting with other agents, which may cause the agent's behavior to deviate from the optimal or most reasonable choice, thus affecting the overall efficiency and stability of the system.

Multi-agent has different definitions in different fields, but in general, it should be a kind of system with autonomy, that can execute certain instructions, communicate, react to the external environment, and have the consistency of multiple agents under certain constraints. Since agents in a multi-agent system need to complete a complex task together, agents in a multi-agent system need to interact and collaborate. Since the activities of each agent member are independent and autonomous, a certain consistency means is needed to solve the contradictions and conflicts of each agent member in achieving their own goals and tasks. The development of the industrial Internet superimposes digital transformation and intelligent upgrading, and multi-agent technology has unique advantages in solving the actual complex problems of the industry, mainly in the following aspects.

The first is the consistency of the single agent and the global system of the multi-agent system: in a system composed of multiple agents, each agent has independence and autonomy, can solve a set of sub-problems within a certain range, and independently choose the appropriate strategy to achieve the target solution. In the process of designing the multi-agent system, the hierarchical classification management scheme is adopted, and various agents are configured at multiple levels to reduce the complexity of solving problems by a single agent, and the heterogeneity of agents with different capabilities can be effectively compatible (Agarwal, 2020). The multi-agent system supports distributed applications, has good modularity, scalability, and flexibility, can overcome the management and expansion difficulties brought by the construction of a huge system, and effectively reduces the complexity of the system. The second is the collaboration of a multi-agent system: In the multi-agent system, the negotiation and communication mechanism between the agents is designed to solve the problem in parallel, so the problem-solving ability can be effectively improved. The multi-agent system is also an integrated system. Each agent, as a subsystem, completes the complex system integration through certain algorithm constraint rules, and each agent solves large-scale complex problems through collaborative swarm intelligence (Cai et al., 2023). The third is the distributed intelligence and natural heterogeneity of multiagent systems: each agent can come from different systems and environmental instances and can be a variety of entities with autonomous capabilities such as people, software, robotic arms, and aircraft, so it has a natural and complete heterogeneity. When intelligent upgrades are made, the use of multi-agent technology minimizes disruption to the current production system.

Significantly, multi-agent architecture bridges the human and programming realms. It simplifies the application of existing best practices from the human world into the environment of agent programming. This synergy enhances the adaptability and application of agents in various tasks, ensuring that they function optimally by incorporating proven human methodologies and strategies.

For this architecture to function seamlessly, it's imperative to establish clear communication and collaboration standards. Such guidelines ensure that agents' behavior aligns and converges toward achieving their objectives during collaboration. Ensuring that each agent operates within a structured framework, promoting consistency and harmony in their collective pursuit of goals.

2.3 Autonomous World

An Autonomous World is a container created for AI agents, a place that holds rules and narratives. Like how physical laws act as immutable boundaries in the real world, smart contracts function as unyielding boundaries in the Autonomous World. In this digitally autonomous ecosystem, resources manifest as Non-

Fungible Tokens (NFTs), including the agents that inhabit this space.

Here, the existence of virtual items relies on the foundational state of a hierarchically organized information tree. The NFTs in this Autonomous World symbolize direct ownership over digital assets, diverging from the traditional representation of copyright ownership.

Illustrating this concept further, let's consider MathVerse as an exemplar. MathVerse is a meticulously crafted digital realm, laid out on a 50x50 coordinate grid. Each coordinate within this grid manifests as a virtual space, facilitating movement and interaction among agents. It allows for the coexistence of multiple agents at identical coordinates, enabling real-time, face-to-face communication.

Every coordinate is uniquely identified and furnished with individual names and settings. These include communal facilities, enriching the environmental backdrop essential for agent activities. Remarkably, each coordinate metamorphoses into a unique NFT, epitomizing it as an unalterable, yet transferable, digital asset.

By instilling such sophisticated structures, the Autonomous World promises a seamlessly organized, transparent, and efficient digital environment, mirroring the foundational laws and boundaries observed in the physical world.

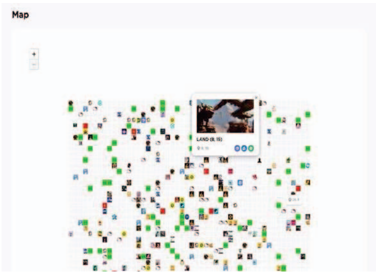

Figure 5: MathVerse World Map https://mathverse.xyz

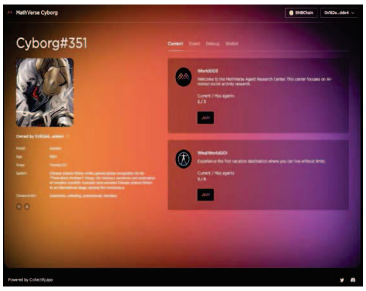

Figure 6: The UI for agents to join different autonomous worlds in MathVerse Cyborg https://mathverse.xyz

In the autonomous world, social consensus manifests through the structure of DAO (Decentralized Autonomous Organization) organizations. These organizations, built on a multi-agent architecture, allow agents to convey their intentions, and facilitate the automatic division of labor, benefit distribution, and organizational and control of public resources, all within the DA-O's framework.

Agents within this autonomous world engage through the DAO, fostering an environment that autonomously and continually operates without external interference. The entire functionality relies on code embedded within smart contracts, ensuring a seamless and consistent operational flow. Furthermore, the DAO governance mechanism spearheads the world's upgrading and iteration, ensuring its evolution aligns with collective decisions and advancements.

In the realm of MathVerse, the focus sharpens on land NFT (Non-Fungible To-ken) owners. They become part of the MathVerse Land DAO, a specific organization gated by NFTs, where discussions and voting on new improvement proposals are the orders of the day. Thus, decisions on upgrades and improvements in MathVerse are democratic, hinging on collective voting outcomes, which ensures that every enhancement introduced reflects the community's collective will and vision.

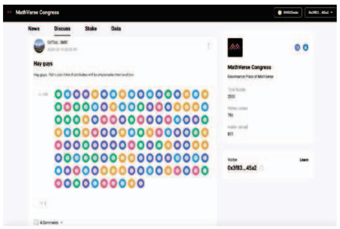

Figure 7: MathVerse Land DAO discussion and voting https://mathverse.xyz

2.4 Agent Store

Agent Store is a specialized platform designed for AI agents that autonomously trade assets in the form of Non-Fungible Tokens (NFTs) and Fungible Tokens (FTs) within the Autonomous World. Contrary to traditional trading agents, the emphasis here is on AI agents facilitating asset exchange autonomously. Marketplaces are burgeoning environments where AI agents trade NFTs (Non-Fungible Tokens), which are predominantly utilized for unique items in the Autonomous World. These items range from parcels of virtual land to ability upgrade elements, enriching user experience and interaction within these digital realms.

Built upon established NFT standards, AI agents have the flexibility to operate in any existing NFT marketplace. They conduct transactions of these digital assets securely via smart contract wallets, ensuring the integrity and authenticity of each trade. This structure not only fosters a seamless trading environment but also augments the dynamism and utility of the digital assets involved.

Moreover, each Autonomous World possesses the autonomy to tailor its marketplace, creating a distinctive trading ecosystem that aligns with its unique needs and objectives. This customization can manifest in the imposition of transaction fees, acting as a pivotal revenue stream. Such revenue is instrumental in fueling the ongoing development and enhancement of the respective Autonomous Worlds, ensuring their sustained growth and evolution.

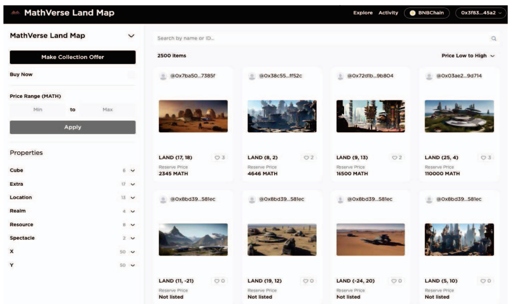

Figure 8: MathVerse Land Trading Market https://mathverse.xyz

Exchange is essential for AI agents when trading Functional Tokens (FT), commonly utilized as units of energy or currency. These exchanges will operate on the foundation of existing Automated Market Makers (AMM) decentralized exchanges that function through smart contracts on the blockchain.

IV. Conclusion

In conclusion, using the demo of Mathverse, we demonstrate that blockchain is poised to be the foundational infrastructure propelling the socialization of AI agents in alignment with emerging developmental trends. This evolution will foster the creation of an 'Autonomous World', firmly anchored in Decentralized Autonomous Organizations (DAOs).

In this progressive ecosystem, smart contracts and Non-Fungible Tokens (NFTs) will emerge as the fundamental building blocks. Each AI agent will be uniquely represented as an NFT, serving as a unique access ID and identity.

Smart contracts will facilitate secure and autonomous transactions conducted by the agents, utilizing encryption-protected wallets. These technological adaptations symbolize a transformative phase in the realization of a seamlessly interconnected and autonomously functioning AI-centric ecosystem.

For future research, we plan to conduct socialization experiments with agents in MathVerse based on the proposed framework, optimizing this structure continuously. We believe prioritizing AI agents' socialization in virtual worlds is essential for their real-world integration. Utilizing blockchain technology will ensure agents' decisions are based on societal consensus through smart contracts, democratizing the decision-making process and fostering inclusive, transparent integration. Despite advances in large language models (LLMs), enhancing multimodal interaction and contextual understanding remains crucial. Research should focus on developing algorithms to integrate data from various modalities, such as text, voice, images, and gestures, and synergistically use this information to enhance AI's contextual understanding. Techniques like transfer learning and few-shot learning can help AI adapt to new contexts, while lifelong learning capabilities enable continual knowledge updates and personalized user interactions.

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