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Editorial

Advancements in the Practical Applications of Agents, Multi-Agent Systems and Simulating Complex Systems

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Introduction

This Editorial summarizes the content of the Special Issue entitled *Advancements in The Practical Applications of* Agents, Multi-Agent Systems *and Simulating Complex Systems*, published in the "Complex Systems" section of *Systems* (ISSN 2079-8954).

Complex systems have played a fundamental role in the simulation, modeling, and analysis of information in dynamic environments and under unexpected constraints [1–3]. These agent-based systems have evolved significantly throughout history, providing increasingly sophisticated solutions to address the complex challenges encountered across multiple fields. The history of complex systems dates back to early research in systems theory and cybernetics in the 1940s [4]. These disciplines laid the foundation for understanding and addressing problems involving complex and emergent interactions between multiple components. As computer technology advanced, the first agent-based modeling and simulation approaches emerged, allowing complex systems to be represented through the interaction of multiple autonomous entities [5,6].

At the heart of complex systems are agents, which can be individuals, organizations, robots, or any entity with the ability to make decisions and respond to its environment. These agents interact with each other and with their environment, generating emergent patterns and collective behaviors that cannot be attributed solely to the individual characteristics of the agents. Agent-based systems technology has been advancing rapidly, enabling greater sophistication in the representation and simulation of complex systems [7]. The importance of complex systems lies in their ability to address real-world problems in a wide range of disciplines, including economics, biology, ecology, logistics, and supply chain management, among others. These systems can model and simulate complex phenomena such as crowd behavior, traffic flow, the spread of disease, climate change, and the evolution of ecosystems [8–10].

The simulation and modeling of complex systems offer several significant advantages. First, they enable the evaluation of different scenarios and strategies without incurring the costs and risks associated with real-world implementation. This is especially valuable when dealing with unpredictable or highly complex environments wherein it is difficult to obtain empirical data or conduct controlled experiments [11]. Complex systems provide a deeper understanding of the underlying mechanisms and interactions that shape the system being studied. This helps to identify emerging patterns, hotspots, and non-intuitive behaviors, which in turn can guide decision-making and strategic planning. By better understanding complex systems, it is possible to reduce the risks and costs associated with the design and development of real-world validation tests [12–14].

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An Overview of Published Articles

This Special Issue consists of fifteen practical papers covering key topics in the field of multi-agent systems and complex systems. These articles, presented during the 20th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS'22) (https://www.paams.net, 6 September 2023), are noteworthy for their highly innovative results and trends [15]. The conference was held in L'Aquila, Italy, and it was organized by the University of L'Aquila (Italy), Umeå University (Sweden), the University of Lille (France), and the University of Salamanca (Spain)

The first three articles address the relevance of using multi-agent systems for the analysis of information. Such an analysis is carried out through the application of natural language processing techniques. These articles aimed to understand public opinion, detect false information, or identify accounts that provide misleading information. Guzmán Rincon et al. (Contribution 1) present a mathematical model to simulate scenarios of disinformation propagation in social networks caused by bots, trolls, and others. The authors carried out simulations related to the increase in the rate of the activation and deactivation of disinformation agents and the disinformation caused by this mechanism. Ye et al. (Contribution 2) explored the specific attributes of individuals and opinion network nodes by incorporating parameters such as individual conformity and the strength of individual online relationships for the purpose of identifying an online opinion polarization of a group. Through simulations, the authors found that individual conformity and the difference in environmental attitude greatly influence the trajectory of opinion polarization events. Similarly, the analysis of shared beliefs, opinions, and views in groups is a topic of great interest that has been debated in sociology, political science, communication, and organizational science. Koponen (Contribution 3) performed an analysis of consensus group formation through an agent-based model. Agents' views were described as complex, and they have extensive structures, similar to semantic networks, i.e., belief networks. In the agent-based model presented by the author, the agents' interactions and their participation in the sharing of their views depend on the similarity of the agents' belief webs; the higher the similarity, the more likely the interaction and the sharing of webs of belief elements.

In the areas of economics, finance, and e-commerce, complex systems have also had a major impact. Zhao et al. (Contribution 4) present an agent-based model created using empirical data from a number of cities as sample data to simulate the evolutionary trajectory of eco-protection and high-quality development under different policy scenarios, such as green innovation, ecological constraints on the environment, ecological compensation, etc. The model shows how, depending on the existing development model, the economic development of cities will be subject to different degrees of ecological and resource constraints and that different policy scenarios significantly affect the evolutionary trends of economic development. Other authors, such as Bae et al. (Contribution 5), introduce a formalism or multi-resolution translational discrete event system specification (MRT-DEVS) intended to facilitate the implementation of simulations and reduce simulation execution costs. MRT-DEVS embeds state and event translation functions into the model's specifications so that it enables multi-resolution modeling with less complex mechanisms in terms of operations. Wang et al. (Contribution 6) studied the product encroachment behavior of composite e-commerce platforms with double-differentiated multi-product competition and constructed a game model of product innovation by an independent seller and product encroachment by the platform owner. Using multi-agent simulation, the authors simulated the bounded rational decision-making and interaction process of multiple agents in multiple periods and analyzed the influence of the main parameters. Moreover, Castañón-Puga et al. (Contribution 7) illustrate how earned value management (EVM) is an efficient method for measuring a project's performance by comparing actual progress against planned activities, thus facilitating the formulation of more accurate predicted estimations using an agent-based simulation model.

Researchers have also focused on applying complex system algorithms to facilitate problem solving in the field of transport. Karalakou et al. (Contribution 8) propose the

design of autonomous vehicles using deep reinforcement learning and the combination between various reward components that are able to gradually learn effective policies in environments with different levels of difficulty, especially when all the proposed reward components are appropriately combined. Spanoudakis et al. (Contribution 9) have designed an open system for the V2G/G2V power transfer problem domain using an agent-based architecture involving flexible microservices that are interconnected via an IoT platform. Gómez Vilchez et al. (Contribution 10) describe a simulation model that facilitates the analysis of potential emission penalties in the broader context of the financial position of original equipment manufacturers. Through their simulation, the authors aim to understand the channels through which money flows (e.g., to promote R&D in cleaner vehicles and to finance zero-emission powertrain sales) between market players.

On the other hand, agent systems have demonstrated successful performance in the application of Cartesian genetic programming to solve a series of use cases, such as complete enumeration in local agent decisions. In this context, Bremer et al. (Contribution 11) present the adaptation of a distributed optimization heuristic protocol for Cartesian genetic programming and an extension using CMA-ES (Covariant Matrix Adaption Evolution Strategy) to improve local agent decisions. By decomposing the evolution on an algorithmic level, it becomes possible to distribute the nodes and regard the evolution process as a parallel, asynchronous execution of an individual coordinate's descent.

Atrazhev et al. (Contribution 12) address the issue of choosing an appropriate reward function in multi-agent reinforcement learning. Among the traditional approaches to employing joint rewards for team performance, this one is questioned because of its lack of theoretical support. Thus, the authors explore the impact of changing the reward function from joint to individual on learning centralized–decentralized execution algorithms in a level-based foraging environment. The results show that different algorithms are affected differently, with value factorization and proximal policy optimization (PPO)-based methods taking advantage of the increased variance to achieve better performance. This study sheds light on the importance of considering the choice of a reward function and its impact on multi-agent reinforcement learning systems.

Within the area of optimization, Pincheira et al. (Contribution 13) present a framework for evaluating the infrastructure costs and benefits of blockchain applications. The framework includes a taxonomy that classifies relevant transactions, a model to evaluate the infrastructure costs and application benefits using public or private blockchains, and guidance on how to use the model. Another research work focusing on optimization comes in the form of the paper by Esmaelii et al. (Contribution 14). The authors of this paper introduce an agent-based collaborative technique for finding near-optimal values for any arbitrary set of hyperparameters (or decision variables) in a machine learning model (or a blackbox function optimization problem). The developed method forms a hierarchical agent-based architecture for the distribution of the searching operations at different dimensions and employs a cooperative searching procedure based on an adaptive width-based random sampling technique to locate the optima.

Finally, within this Special Issue, Roussel et al. (Contribution 15) address the issue of conflicting bundle allocation and weighted directed acyclic graphs. The authors propose several models for novel resource allocation problems where agents express their preferences over conflicting bundles of items as edge-weighted on a directed acyclic graph (directed path allocation problem, or DPAP), particularizing conflicts on vertices (V-DPAP) and conflicts on resources (R-DPAP). The multi-agent system proposed by the authors allows for the search of path allocation. Conflicting bundle allocation and weighted directed acyclic graphs are also commonly simulated using complex systems.

Conclusions

This Special Issue showcases a variety of research papers on practical approaches to the use of complex systems and complementary agent-based AI models, facilitating the parallel use of data treatment and knowledge processing algorithms.

List of Contributions

1. Guzmán Rincón, A.; Carrillo Barbosa, R.L.; Segovia-García, N.; Africano Franco, D.R. Disinformation in Social Networks and Bots: Simulated Scenarios of Its Spread from System Dynamics. *Systems* **2022**, *10*, 34.
2. Ye, Y.; Zhang, R.; Zhao, Y.; Yu, Y.; Du, W.; Chen, T. A Novel Public Opinion Polarization Model Based on BA Network. *Systems* **2022**, *10*, 46.
3. Koponen, I.T. Agent-Based Modeling of Consensus Group Formation with Complex Webs of Beliefs. *Systems* **2022**, *10*, 212.
4. Zhao, A.; Wang, J.; Sun, Z.; Guan, H. Research on the Evolutionary Path of Eco-Conservation and High-Quality Development in the Yellow River Basin Based on an Agent-Based Model. *Systems* **2022**, *10*, 105.
5. Bae, J.W.; Moon, I.-C. Practical Formalism-Based Approaches for Multi-Resolution Modeling and Simulation. *Systems* **2022**, *10*, 174.
6. Wang, Z.; Yang, T. Multi-Category Innovation and Encroachment Strategy Evolution of Composite E-Commerce Platform Based on Multi-Agent Simulation. *Systems* **2022**, *10*, 215.
7. Castañón-Puga, M.; Rosales-Cisneros, R.F.; Acosta-Prado, J.C.; Tirado-Ramos, A.; Khatchikian, C.; Aburto-Camacllanqui, E. Earned Value Management Agent-Based Simulation Model. *Systems* **2023**, *11*, 86.
8. Karalakou, A.; Troullinos, D.; Chalkiadakis, G.; Papageorgiou, M. Deep Reinforcement Learning Reward Function Design for Autonomous Driving in Lane-Free Traffic. *Systems* **2023**, *11*, 134.
9. Spanoudakis, N.I.; Akasiadis, C.; Iatrakis, G.; Chalkiadakis, G. Engineering IoT-Based Open MAS for Large-Scale V2G/G2V. *Systems* **2023**, *11*, 157.
10. Gómez Vilchez, J.J.; Pasqualino, R. The Hidden Side of Electro-Mobility: Modelling Agents’ Financial Statements and Their Interactions with a European Focus. *Systems* **2023**, *11*, 132.
11. Bremer, J.; Lehnhoff, S. Enhancing Local Decisions in Agent-Based Cartesian Genetic Programming by CMA-ES. *Systems* **2023**, *11*, 177.
12. Atrazhev, P.; Musilek, P. It's All about Reward: Contrasting Joint Rewards and Individual Reward in Centralized Learning Decentralized Execution Algorithms. *Systems* **2023**, *11*, 180.
13. Pincheira, M.; Donini, E.; Vecchio, M.; Giaffreda, R. An Infrastructure Cost and Benefits Evaluation Framework for Blockchain-Based Applications. *Systems* **2023**, *11*, 184.
14. Esmaeili, A.; Ghorrati, Z.; Matson, E.T. Agent-Based Collaborative Random Search for Hyperparameter Tuning and Global Function Optimization. *Systems* **2023**, *11*, 228.
15. Roussel, S.; Picard, G.; Pralet, C.; Maqrot, S. Conflicting Bundle Allocation with Preferences in Weighted Directed Acyclic Graphs: Application to Orbit Slot Allocation Problems. *Systems* **2023**, *11*, 297.

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