Editorial

Multi-Agent Systems

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Abstract: With the current advance of technology, agent-based applications are becoming a standard in a great variety of domains such as e-commerce, logistics, supply chain management, telecommunications, healthcare, and manufacturing. Another reason for the widespread interest in multi-agent systems is that these systems are seen as a technology and a tool that helps in the analysis and development of new models and theories in large-scale distributed systems or in human-centered systems. This last aspect is currently of great interest due to the need for democratization in the use of technology that allows people without technical preparation to interact with the devices in a simple and coherent way. In this Special Issue, different interesting approaches that advance this research discipline have been selected and presented.

Keywords: multi-agent systems; agent methodologies; agent-based simulation; ambient intelligence; smart cities

1. Introduction

The concept of n intelligent agent is a concept that is born from the area of artificial intelligence; in fact, a commonly-accepted definition relates the discipline of artificial intelligence with the analysis and design of autonomous entities capable of exhibiting intelligent behavior. From that perspective, it is assumed that an intelligent agent must be able to perceive its environment, reason about how to achieve its objectives, act towards achieving them through the application of some principle of rationality, and interact with other intelligent agents, being artificial or human [1].

Multi-agent systems are a particular case of a distributed system, and its particularity lies in the fact that the components of the system are autonomous and selfish, seeking to satisfy their own objectives. In addition, these systems also stand out for being open systems without a centralized design [2]. One main reason for the great interest and attention that multi-agent systems have received is that they are seen as an enabling technology for complex applications that require distributed and parallel processing of data and operate autonomously in complex and dynamic domains.

Research in the discipline of multi-agent systems (MAS) is based on the results of distributed computing asking new questions about how agents must interact with each other in order to coordinate their activities and solve complex problems. Most current research focuses on designing appropriate coordination mechanisms for managing coalitions or teams of agents. The programming of intelligent agents poses complex challenges to engineers because in addition to the complexity of designing concurrent and distributed systems, there is the added complexity that the components must have an architecture that includes aspects such as *reactivity*, *proactivity*, and *sociability*. These properties are not easy to program when the environment is dynamic and complex. In order to achieve real agent programming, a multitude of proposals have been made, by many researchers, for agent architectures, communication languages, and decision-making and coordination mechanisms. In the latter case,

the need arises that agents have to be able to reach *agreements* in order to be able to operate in a multi-agent system. Here lies an important aspect of the programming complexity of intelligent agents.

This Special Issue attempts to advance the paradigm of multi-agent systems by proposing new works in different areas of interest. In this way, works are proposed in the areas of agent-oriented software engineering, multi-agent learning, agent based simulation, and agent applications in highly topical domains such as smart cities and ambient intelligence. The following sections detail the selected contributions in each of these areas.

2. MAS and Methodologies

Within the framework of artificial intelligence, multi-agent systems have been characterized by offering a possible solution to the development of complex problems with distributed characteristics. When approaching the development of multi-agent systems, there is undoubtedly a significant increase in complexity, as well as the need for adapting existing techniques, or in some situations, developing new techniques and tools. In recent years, different works have appeared trying to propose new processes and techniques for the development of multi-agent systems [3].

The construction of MAS integrates technologies from different areas of knowledge: software engineering techniques to structure the development process; AI techniques to provide systems with the capacity to deal with unexpected situations and to make decisions, and concurrent programming to address task coordination executed on different machines under different scheduling policies. Due to this mix of technologies, the development of MASis complicated. In this sense, during the last few years, there have been different development platforms and tools that provide partial solutions for the modeling and design of agent-based systems [4].

There is still much work to be done in this area. Thus, in this Special Issue, three works related to agent-oriented software engineering have been included. The first work [5] shows how accountability plays a central role in MAS engineering. Accountability is a well-known key resource inside human organizations, and the idea of this proposal is to propose the design of agent systems where accountability is a property that is guaranteed by design. The authors proposed an interaction protocol, called ADOPT, that allows the realization of accountable MAS organizations. The proposed protocol has been implements using JaCaMo [6], allowing one to demonstrate how to develop agents and the organization to which they belong, being mutually accountable.

The second work [7] proposed a new development methodology for the development of MAS working in semantic web environments. The proposed methodology is based on a domain-specific modeling language, called Semantic Web-Enabled Agent Modeling Language (SEA_ML) [8]. The study was demonstrated using a case study implemented using the well-known JACKplatform (http://aosgrp.com/products/jack/). The proposed example consists of a set of agents that exchange services or goods of owners according to their preferences without using any currency. Finally, the third work [9] introduced an agent development framework for mobile devices. The proposed framework allows users to build intelligent agents with the typical agent-oriented attributes of social ability, reactivity, proactivity, and autonomy. Actually, the main contribution is the linked data support of the framework. Linked data support corresponds to the ability to supply the agent's beliefs from the linked data environment and to use those beliefs during the planning process. According to the authors, these kinds of agent development frameworks, specifically addressed for mobile devices, will be of great importance in domains such as cyber physical systems and the Internet of Things in the near future.

3. MAS and Learning

Learning in MAS is a paradigm of great importance because a system capable of learning and changing its way of acting dynamically provides great potential to face many problems for which we do not know the behavior of other agents in the environment. This adds more levels of difficulty in

tasks of consensus and coordination between agents, as they may be learning at all times and changing their behavior.

Multi-Agent Learning (MAL) [10] allows us to design certain guidelines from which an agent will be able to exploit the dynamics of its environment and use them to adapt to it. In a multi-agent environment, learning is both more important and more difficult, since the selection of actions has to be done in the presence of other agents, who do not necessarily have to follow the rules of the environment and can make non-deterministic decisions. These agents in turn will adapt their actions to those previously carried out by the other agents. The problems seen in the MAL have a strong relationship with the theory of games, in which an agent selects actions to maximize his/her advantage over the rest.

In the area of MAS learning, this Special Issue contributes with two papers. The first one [11] dealt with the problem of coordinated control of multiple hovercrafts. To address this problem, the authors proposed the design of coordinated control algorithms for multiple agents. For a single vehicle, they proposed to use Radial Basis Function Neural Networks (RBFNNs) to improve the robustness of the controller. For multiple vehicles, they considered the use of a directed topology, but considering that communication among vehicles is continuous.

The second work [12] proposed an approach to learn behavior models as behavior trees for autonomous agents. The main goal of the proposal is to facilitate behavior modeling for autonomous agents in simulation and computer games. The experiments, carried out on the Pac-Man game environment, showed the effectiveness of the proposal, although it is necessary to broaden the applications of the proposed approach in more complex scenarios and configurations.

4. MAS in Ambient Intelligence

Ambient Intelligence (AmI) was built to respond to the technological call to monitor and act in the homes of people with disabilities. Its aim was to create a nest of sensor systems that together could provide more information than alone, thus transforming data into knowledge [13–15]. This is achieved by incorporating digital environments that are sensitive to people's needs, can respond to their requirements, anticipate behaviors, and adjust the response accordingly. In the last few years, several projects have been developed to attend to the needs of the AmI, being very recently under the focus of the industry, a result of the advances of the sensor systems and their decrease of cost, as well as the introduction into mobile devices. Furthermore, the advances of the Internet of Things (IoT) have introduced a new hypothesis of communicating with the home appliances and, above all, introducing them in the home network where they can be remotely controlled [16–18].

Over the last few years, MAS have been employed as a tool for the development of many AmI frameworks. As examples, we can highlight the iGendaframework [19,20], which has as its main goal providing intelligent event management, consisting of a platform that receives events from other users and tries to schedule them according to its importance, having the ability to create, move, and delete events. Moreover, aiming for the implementation of the active aging concept, it schedules ludic activities in the users' free time, adjusted to their medical conditions, user shared events being the last implemented feature. Another example is ALZ-MAS [21], which consists of an Ambient Intelligence framework based on multi-agent technology aimed at enhancing the assistance and health care for Alzheimer patients.

In this Special Issue, three new contributions in this area have been presented. The first one [22] presented a tool, the goal of which is to assist in creating a work environment that is adapted to the needs of people with disabilities. The tool measures the degree of accessibility in the place of work and identifies the architectural barriers of the environment by considering the activities carried out by workers. A case study was conducted to assess the performance of the system, analyzing the accessibility of the different jobs in a real company. Although the tool was initially conceived of for the detection of accessibility problems in office environments, it can be considered a valid

tool for the simulation of any agent production process representing human beings in the field of office environments.

The second contribution [23] explored the representation of user interaction levels using an intelligent hybrid system approach with agents. The authors considered the use of an intelligent hybrid approach to provide a decision-making system to an agent that self-evaluates interactions in interactive modules in a museum exhibition. The main goal of this work was to provide a solution to the problem of overcrowding in museums, making museums smart spaces with multi-user adaptive interaction exhibitions. As a case study, the authors built software agents that represented a high-level abstraction of a gallery, specifically an interactive exhibition module in a real museum in Mexico.

Finally, the third work [24] presented CogHelper, which is an orientation system for people with cognitive disabilities. The main idea is that using this system, people with cognitive disabilities may have a more active life, reducing the worry of getting lost both indoors and outdoors. CogHelper will guide users taking into consideration his preferences. To achieve this behavior, the proposed system applies a speculative computation module [25], which needs to be loaded by the traveling path before its execution. For the moment, the system is just a prototype, and authors will test the entire system in real case scenarios in the near future.

5. MAS and Simulation

Agent-based simulation is an approach to modeling systems, which focuses on the simulation of complex technical systems that are distributed and involve complex interaction between humans and machines [26]. It can be seen as a type of computational model that allows the simulation of actions and interactions of autonomous individuals within an environment and allows determining what effects they produce in the system as a whole. It combines elements of game theory, complex systems, emergency, computational sociology, multi-agent systems, and evolutionary programming. The models simulate the simultaneous operations of multiple entities (agents) in an attempt to recreate and predict the actions of complex phenomena. It is an emergency process from the most elementary level (micro) to the highest level (macro).

In this way, agent-based simulation can be seen as a powerful research method that allows dealing in a simple way with the complexity, the emergency, and the non-linearity typical of many social, political, and economic phenomena [27] through mechanisms that allude to the actions of agents and the structure of the interaction between them.

In this Special Issue, the work proposed in [28] took into account the problem of the simulation of Double Action (DA) markets [29]: both buyers and sellers submit their bids, and an auctioneer determines resource allocation and prices on the basis of their bids. Recent works have not considered the fluctuating nature of perishable goods markets, where supply and demand change dynamically and unpredictably. To solve the problem, the authors have developed an online DA market, in which multiple buyers and sellers dynamically tender their bids for trading commodities before their due dates. The experimental results using multi-agent simulation showed that the proposed DA mechanism was effective at promoting the truthful behavior of traders for realizing the fair distribution of large utilities between sellers and buyers. With this work, the authors hope to contribute to promoting successful deployment of electronic markets for fisheries and improve the welfare of people in the area by attracting more traders online.

Moreover, the work presented in [22], mentioned in the previous section, can also be seen as a simulation platform for a 3D environment, which is capable of modeling and enabling simulations in office environments.

6. MAS in Smart Cities

The concept of the smart city [30] arises from the need to find a solution to rapid population growth and the risks this entails for a city, economic risks such as unemployment or physical risks such as over-pollution. To solve these problems, different technologies, among many others, have been

applied in order to find solutions in this area. Multi-agent systems together with the Internet of Things [18] are traditionally the most employed.

Typically, these concepts come together, designing intercommunicated networks that responds to the needs of citizens both individually and as a whole and also monitoring through sensors the levels of pollution, traffic, noise, etc. A smart city is a great intercommunicated organism that, together with an intelligent government, seeks to improve the quality of life of its citizens [31].

Therefore, a smart city would be full of sensors constantly collecting information about actions that happen in the city, humidity sensors, temperature sensors, noise, pollution, etc. All these sensors are part of a data collection system that will be responsible for processing information quickly and intelligently. It is for this point where the use of multi-agent systems make sense. The decentralized control of an MAS offers the possibility of managing all available information in a distributed way and also coordinating possible actions effectively over the city. Moreover, decision making processes, apart from being coordinated, can execute in parallel actions at different points of the city, without a strong centralized control, which gives greater flexibility and adaptation to the whole system.

This Special Issue contributes with three works in the area of smart cities. The first work [32] proposed a multi-agent system that provides visualization and prediction tools for bike sharing systems. The proposed MAS includes an agent that performs data collection and cleaning processes, and it is also capable of creating demand forecasting models for each bicycle station. The authors included a case study, which validated the proposed system, by implementing it in a public bicycle sharing system in Salamanca, called SalenBici. In the proposed solution, the information collected was employed by the agents who performed demand forecasting. Moreover, different regression algorithms have also been employed in the process of bike demand prediction. Additionally, a statistical analysis has been performed in order to show the differences in their performance and to determine the relevance of results. The second approach presented in this Special Issue regarding smart cities is the work done in [33], where a multi-agent system was proposed, in order to facilitate the analysis of different possible placement configurations for electric vehicles charging stations in a city. The MAS proposed in this paper integrates the information extracted from heterogeneous data sources as a starting point to specify the areas where future charging stations could potentially be placed. To do this, the proposed MAS integrates an optimization algorithm, which is in charge of the locating process. Finally, the third contribution, presented in [34], analyzed the use of agreement technologies [35], which envisions the next-generation of open distributed systems, where interactions between software components are based on the concept of agreement. In this sense, the authors increased the coordination among entities using agreement technologies in the domain of smart cities as a way to enable the development of novel applications. Concretely, they proposed the use of these techniques in a specific domain such as the coordination in emergency medical services, which includes many tasks that require flexible, on-demand negotiation, initiation, coordination, information exchange, and supervision among different involved entities. All these aspects can be solved through the use of, as previously mentioned, agreement technologies.

7. Conclusions

As it has been possible to observe throughout the analysis carried out on the accepted articles, research on MAS continues to provide technological solutions in a wide variety of domains. MAS researchers develop new advances that allow the development of more powerful, flexible, and adapted systems that allow predicting a fruitful future. This Special Issue of Applied Sciences gives us a precise view of the area covering different hot topics.

The high number of submissions and the quality of the selected works gives us an idea of the potential of the multi-agent systems area and their excellent health after more than two decades of research. In this way, the main goal of this Special Issue is considered to be more than reached, which has allowed us to extend it to new editions to continue disseminating high-quality works in this area.

References

1. Russell, S.; Norvig, P. *Artificial Intelligence: A Modern Approach*, 3rd ed.; Prentice Hall Press: Upper Saddle River, NJ, USA, 2009.

2. Wooldridge, M. *An Introduction to MultiAgent Systems*, 2nd ed.; Wiley Publishing: Hoboken, NJ, USA, 2009.

3. Shehory, O.; Sturm, A. *Agent-Oriented Software Engineering: Reflections on Architectures, Methodologies, Languages, and Frameworks*; Springer: Berlin/Heidelberg, Germany, 2014.

4. Kravari, K.; Bassiliades, N. A Survey of Agent Platforms. *J. Artif. Soc. Soc. Simul.* **2015**, *18*, 11. [CrossRef]

5. Baldoni, M.; Baroglio, C.; May, K.; Micalizio, R.; Tedeschi, S. Computational accountability in MAS organizations with ADOPT. *Appl. Sci.* **2018**, *8*, 489. [CrossRef]

6. Boissier, O.; Bordini, R.H.; Hübner, J.F.; Ricci, A.; Santi, A. Multi-agent Oriented Programming with JaCaMo. *Sci. Comput. Program.* **2013**, *78*, 747–761. [CrossRef]

7. Challenger, M.; Tezel, B.; Alaca, O.; Tekinerdogan, B.; Kardas, G. Development of semantic web-enabled BDI multi-agent systems using SEA_ML: an electronic bartering case study. *Appl. Sci.* **2018**, *8*, 688. [CrossRef]

8. Challenger, M.; Demirkol, S.; Getir, S.; Mernik, M.; Kardas, G.; Kosar, T. On the Use of a Domain-specific Modeling Language in the Development of Multiagent Systems. *Eng. Appl. Artif. Intell.* **2014**, *28*, 111–141. [CrossRef]

9. Boztepe, I.; Erdur, R. Linked Data Aware Agent Development Framework for Mobile Devices. *Appl. Sci.* **2018**, *8*, 1831. [CrossRef]

10. Shoham, Y.; Powers, R.; Grenager, T. If Multi-agent Learning is the Answer, What is the Question? *Artif. Intell.* **2007**, *171*, 365–377. [CrossRef]

11. Duan, K.; Fong, S.; Zhuang, Y.; Song, W. Artificial Neural Networks in Coordinated Control of Multiple Hovercrafts with Unmodeled Terms. *Appl. Sci.* **2018**, *8*, 862. [CrossRef]

12. Zhang, Q.; Yao, J.; Yin, Q.; Zha, Y. Learning Behavior Trees for Autonomous Agents with Hybrid Constraints Evolution. *Appl. Sci.* **2018**, *8*, 1077. [CrossRef]

13. Aarts, E.H.; Encarnação, J.L. *True Visions: The Emergence of Ambient Intelligence*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2006.

14. Aarts, E.; Harwig, E.; Schuurmans, M. Ambient Intelligence. In *The Invisible Future*; Denning, J.; Ed.; McGraw-Hill, Inc.: New York, NY, USA, 2001.

15. Cook, D.J.; Augusto, J.C.; Jakkula, V.R. Ambient intelligence: Technologies, applications, and opportunities. *Pervasive Mob. Comput.* **2009**, *5*, 277–298. [CrossRef]

16. Kranz, M.; Holleis, P.; Schmidt, A. Embedded interaction: Interacting with the internet of things. *IEEE Internet Comput.* **2010**, *14*, 46–53. [CrossRef]

17. Gershenfeld, N.; Krikorian, R.; Cohen, D. The internet of things. *Sci. Am.* **2004**, *291*, 76–81. [CrossRef] [PubMed]

18. Atzori, L.; Iera, A.; Morabito, G. The Internet of Things: A Survey. *Comput. Netw.* **2010**, *54*, 2787–2805. [CrossRef]

19. Costa, Â.; Novais, P.; Corchado, J.M.; Neves, J. Increased performance and better patient attendance in an hospital with the use of smart agendas. *Log. J. IGPL* **2011**, *20*, 689–698. [CrossRef]

20. Costa, Â.; Novais, P. An intelligent multi-agent memory assistant. In *Handbook of Digital Homecare*; Springer: Berlin/Heidelberg, Germany, 2011; pp. 192–221.

21. Tapia, D.I.; Corchado, J.M. An Ambient Intelligence Based Multi-Agent System for Alzheimer Health Care. *IJACI* **2009**, *1*, 15–26. [CrossRef]

22. Barriuso, A.; De la Prieta, F.; Villarrubia González, G.; De La Iglesia, D.; Lozano, Á. MOVICLOUD: Agent-Based 3D Platform for the Labor Integration of Disabled People. *Appl. Sci.* **2018**, *8*, 337. [CrossRef]

23. Rosales, R.; Castañón-Puga, M.; Lara-Rosano, F.; Flores-Parra, J.; Evans, R.; Osuna-Millan, N.; Gaxiola-Pacheco, C. Modelling the Interaction Levels in HCI Using an Intelligent Hybrid System with Interactive Agents: A Case Study of an Interactive Museum Exhibition Module in Mexico. *Appl. Sci.* **2018**, *8*, 446. [CrossRef]

24. Ramos, J.; Oliveira, T.; Satoh, K.; Neves, J.; Novais, P. Cognitive Assistants—An Analysis and Future Trends Based on Speculative Default Reasoning. *Appl. Sci.* **2018**, *8*, 742. [CrossRef]

25. Satoh, K. Speculative Computation and Abduction for an Autonomous Agent. *IEICE Trans. Inf. Syst.* **2005**, *E88-D*, 2031–2038. [CrossRef]

26. Davidsson, P. Multi Agent Based Simulation: Beyond Social Simulation. In *Proceedings of the Second International Workshop on Multi-Agent-Based Simulation-Revised and Additional Papers*; Springer: London, UK, 2001; pp. 97–107.

27. Uhrmacher, A.M.; Weyns, D. *Multi-Agent Systems: Simulation and Applications*, 1st ed.; CRC Press, Inc.: Boca Raton, FL, USA, 2009.

28. Miyashita, K. Incremental Design of Perishable Goods Markets through Multi-Agent Simulations. *Appl. Sci.* **2017**, *7*, 1300. [CrossRef]

29. Friedman, D. *The Double Auction Market: Institutions, Theories, and Evidence*; Routledge: Abingdon-on-Thames, UK, 2018.

30. Albino, V.; Berardi, U.; Dangelico, R.M. Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *J. Urban Technol.* **2015**, *22*, 3–21. [CrossRef]

31. Roscia, M.; Longo, M.; Lazaroiu, G.C. Smart City by multi-agent systems. In Proceedings of the 2013 International Conference on Renewable Energy Research and Applications (ICRERA), Madrid, Spain, 20–23 October 2013; pp. 371–376. [CrossRef]

32. Lozano, Á.; De Paz, J.; Villarrubia González, G.; Iglesia, D.; Bajo, J. Multi-agent system for demand prediction and trip visualization in bike sharing systems. *Appl. Sci.* **2018**, *8*, 67. [CrossRef]

33. Jordán, J.; Palanca, J.; del Val, E.; Julian, V.; Botti, V. A Multi-Agent System for the Dynamic Emplacement of Electric Vehicle Charging Stations. *Appl. Sci.* **2018**, *8*, 313. [CrossRef]

34. Billhardt, H.; Fernández, A.; Lujak, M.; Ossowski, S. Agreement Technologies for Coordination in Smart Cities. *Appl. Sci.* **2018**, *8*, 816. [CrossRef]

35. Ossowski, S. *Agreement Technologies*; Springer: Dordrecht, The Netherlands, 2012.