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Editorial

Special Issue "Advances in Multi-Agent Systems": Editorial

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Abstract: Multi-agent systems (MAS) are collections of autonomous computational entities (the agents) capable of pro-actively pursuing goals and re-actively adapting to environment change. Agents in MAS exploit their social abilities, interacting with peers, and their situated capabilities as well, by perceiving and acting on the world around them. From distributed computing to intelligent systems, the relevance of agents and MAS as software abstractions is steadily growing as they are extensively and increasingly used to model, simulate, and build heterogeneous systems across a huge variety of diverse application scenarios and business domains, ranging from industrial manufacturing to robotics, from social simulation to applications, and more. The recent, renewed popularity of AI techniques has further spread the adoption of MAS, focusing in particular on the cognitive capabilities of agents, so that intelligent systems can be modelled and built as MAS. Along those lines, this Special Issue gathers five contributions that well represent the many diverse advancements that are currently ongoing in the MAS field.

Keywords: multi-agent systems; intelligent system engineering; agent-based simulation; machine learning

1. Introduction

As intelligent systems become more and more pervasive in our daily lives, the need for a unified set of concepts and tools to help in their design, development, and maintenance is rapidly morphing into one of the most relevant factors in the AI field. *Multi-agent systems* (MAS) still represent the most comprehensive and dependable source for these abstractions, offering *agents* as their main components, which embody key features, such as autonomy and cognition, along with all the the features required for building and operating intelligent systems in the real world. Years of research in both academia and industry, along with integration with recent AI advancements and IoT technologies, have led to the growth of new agent-based techniques, methods, and tools. This has increasingly solidified MAS as the forthcoming standard for the engineering of complex and trustworthy intelligent systems.

Yet, the complexity of this perspective MAS scenario is so extensive that a huge effort is required by researchers and practitioners in the MAS area to help the scientific and industrial community to fully grasp and address all the aspects and challenges of MAS techniques and methods across the many different application scenarios. Sharing new and innovative findings and results among MAS researchers through some platform is then crucial to support and drive the advancement of MAS models and technologies, and also to further empower widespread diffusion of AI models and techniques: overall, this is the main driving force behind this Special Issue.

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2. Overview

Before delving into the individual contributions gathered, a few general statistics and observations are useful to have an overview of the content and outreach of this Special Issue:

- In total, 17 papers have been submitted for peer review, out of which 5 were finally published, resulting in an acceptance rate of ≈29%;
- The average time to publish, intended as the time passed from submission to online availability, is ≈44 days, with a standard deviation of ≈23 days—dates are publicly available on each paper web page, accessible from the special issue home page (https://www.mdpi.com/journal/applsci/special_issues/Advances_in_Multi-Agent_Systems, last accessed on 30 December 2022);
- Papers have already generated an average of ≈1794 views (≈671 standard deviation)—we deem citations not worth considering yet;
- Published papers have been co-authored by authors coming from four different countries, Japan being the most represented.

Figure 1 shows the wordcloud generated from the full text of the published papers.

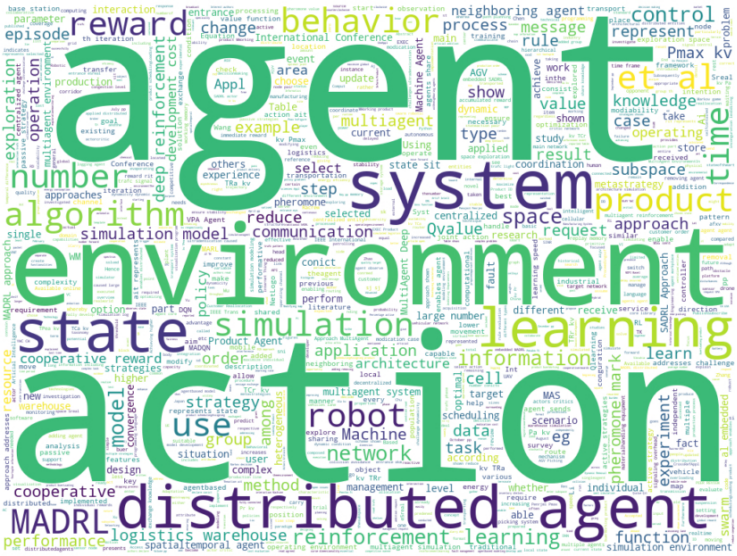

Figure 1. Wordcloud generated from the full text of each publication of the Special Issue.

Amongst the words that one could expect to find, since they are pervasive to MAS—such as "agent", "environment", "system"—there are others that well represent a recent trend in MAS research landscape, that the contributions gathered in this Special Issue witness accurately. As obvious as it could seem, the word "action" hints at the increasing interest of MAS community towards Reinforcement Learning (RL), when paired with words such as "reward", "learning", and even common MAS related terms such as "state" and "environment". Indeed, two out of the five contributions to this edition of the Special Issue are concerned with RL—see the next section, Commentary. Other contributions, instead, are more in line with the previous editions, dealing with long-standing and well-known applications of MAS: simulation, robotics, and decentralised control.

3. Commentary

This edition of the Special Issue turns out to be an interesting merge of consolidated, well-known strengths of MAS research, and novel, yet expanding applications.

3.1. The Good ol' MAS

A multi-agent based simulation environment is proposed in [1] to model and analyse logistics warehouses, with a focus on ease of development and customisation. To that purpose, authors propose a fully distributed architecture of self-contained agents: on

the one hand, communication through standard message passing protocols and format such as KQML ensures loose coupling and high interoperability of agents developed independently and running on different platforms; on the other hand, the separation of agents' implementation into a head (*when* to do *what*) and a body (*how* to do the *what*) favours modularity and eases system evolution—e.g., maintenance and extension.

A similar endeavour—that is, building a simulation environment—is undertaken in [2], yet in a different domain and with a different technique: the authors are concerned with the modelling and simulation of industrial manufacturing processes, so they adopt the actor model as the agent execution engine, and the publish–subscribe model (instead of direct message passing) as the communication paradigm.

A multi-agent approach is used in [3] to program the collective and individual behaviour of a swarm of mobile robots. Pheromone-based communication inspired to social insect colonies is adopted to achieve large scale coordination without centralised supervision, with the goal of covering an area. The authors demonstrate through experiments that their proposed approach is capable of achieving good coverage despite dealing with agents with heterogeneous capabilities and across different environments.

3.2. The New Kids on the Block

Reinforcement learning is applied to multi-agent collision avoidance in [4] in order to investigate learning of a meta coordination strategy where agents alternate passive behaviour—reactive to other agents behaviour—and active behaviour—proactively bringing the agent closer to its goal. An agent with no cooperative rewards (only caring about own right of way), one with cooperative rewards (giving way to others), and one with both rewards (aimed at learning the meta-strategy) are compared.

Deep reinforcement learning approaches applied to MAS are surveyed in [5], where the authors define a taxonomy based on the goal pursued—whether there are centralisation bottlenecks, the kind and extent of collaboration amongst learning agents (competitive vs. collaborative, limited to neighbourhoods or not), which performance measures has been adopted to evaluate the approach, and what application domain has been taken as reference scenario.

4. Conclusions

Both the quality and the range of the papers submitted, selected, and published in this Special Issue demonstrate the constant growth of the interest by the scientific community towards new models, techniques, and methods for multi-agent systems. Although MAS-related research is still developing along its most "classical" lines, at the same time it is also expanding towards new areas, mostly pushed by the new wave of AI, where learning capabilities over huge amounts of data often represent the main focus. On the MAS horizon, one may observe the convergence of those two branches towards the full development of a general software engineering discipline—where agents and MAS work as the sources of abstractions, models, and methods for the engineering of intelligent systems.

While this Special Issue can obviously only hint at that fundamental research goal, still mostly in the making, we are confident that the readers of *Applied Intelligence* will anyway get some critical understanding of the extent of the research and application scenarios that MAS are likely to cover in the next decades, as they keep on developing to become the conceptual and technical foundation for the modelling and engineering of the complex intelligent systems of the future.

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