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Editorial

Special Issue on Logic-Based Artificial Intelligence

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Since its inception, research in the field of *Artificial Intelligence* (AI) has had a fundamentally logical approach; therefore, discussions have taken place to establish a way of distinguishing symbolic AI from sub-symbolic AI, basing the approach instead on the statistical approaches typical of *machine learning*, *deep learning* or *Bayesian networks*.

The logical-symbolic approach was dominant from 1956, the year in which the term AI was proposed by John McCarthy, until the mid-nineteen seventies. However, when the overambitious expectations, such as that of reaching a *General AI* within a few years, were not met, the decrease in funding led to the first AI Winter. In the early nineteen eighties, however, we witnessed a new springtime due to the commercially profitable idea of *expert systems*, capable of allowing the simulation of the knowledge of experts in a certain field through techniques of knowledge representation and automatic reasoning. However, even the expert systems had a short life and from 1988 onwards there was a new and longer AI Winter. Despite this, Symbolic AI remained the dominant paradigm until the mid-1990s, when the sub-symbolic approaches of machine learning began to re-emerge, but without unlocking the winter season. It would take until 2012 for the new spring of AI. This occurred thanks to sub-symbolic approaches through neural networks and so-called *deep learning*, which were able to implement their potential thanks to the ever-increasing amount of data available (*Big Data*). The results achieved by statistical approaches to AI led many in the academic community to think that logical theories could be totally abandoned and that the only fundamental aspect was a sufficiently large amount of data.

However, the presence of bias in AI systems and the inability to provide explanations of decisions made through such systems showed the intrinsic limitations of purely statistical approaches and resulted in a pressing call to make AI systems explainable. This heralded *Explainable AI* (XAI), showing at least the need for a hybrid approach, symbolic and sub-symbolic, at the same time, to develop an AI system capable of interacting satisfactorily with humans. The irrepressible human need to understand the reason for a certain response, action or decision thus brings the logical-symbolic approach back to the center of research; however, this was never abandoned by AI researchers, even in the coldest periods both for the whole AI and for Symbolic AI.

In particular, since the 1980s, *logic programming* has proven to be fundamental for solving computationally complex problems in AI. Problems are translated into a set of facts and rules, i.e., into a theory or logical program with a particular syntax and semantics. It is a declarative and non-procedural programming, allowing the developer to identify the logical structure of the starting problem, so that the logical models of the program will correspond to the possible solutions of the studied problem. Over the years, several families of logic programming languages have been developed, including *Prolog*, *Datalog* and *Answer Set Programming* (ASP), which will be referred to in the articles of this Special Issue.

ASP has shown considerable potential in the modeling of NP-hard problems and, thanks to the development of increasingly efficient ASP-solvers such as DLV and Clasp, creating concrete resolution in real situations. Among the most significant applications in recent years can be found, for example, in the use of ASP in nuclear engineering, healthcare, business, and robotics.

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A classic example of the ability of ASP to model complex problems is given by the so-called *3-coloring problem* known to be NP-complete. The 3-coloring problem is the problem used to decide whether a given graph, formed by nodes and edges, can be colored by using three colors (namely, red, blue and green), in such a way that each pair of adjacent nodes is colored by two different colors. The knowledge about a graph can be modeled through a set of facts of the following form: $node(1 \ldots n)$ (a set of n nodes) and $edge(i, j)$, whenever there is an edge from node i to node j. Now, the problem can be easily solved by guessing a possible coloration of the nodes:

$$colored(X, red) \mid colored(X, green) \mid colored(X, blue) \leftarrow node(X)$$

where symbol $\mid$ is similar to classical logical disjunction ($\vee$) but imposes a minimization of the selected atoms. Thus, in this case, the rule is satisfied by choosing exactly one atom. Hence, the problem is solved by forcing the following to be false: there is an edge from node X to node Y, such that X is colored by the same color of Y (named Z in the rule):

$$\leftarrow edge(X, Y),\ colored(X, Z),\ colored(Y, Z).$$

These two rules allow us to encode the result in a sound and complete the 3-coloring problem, also offering, thanks to the symbolic approach, an almost immediate understanding for a human being of the meaning encoded in the rules.

As highlighted in the brief history of AI, logic programming in recent years has interacted with the statistical approaches of AI, providing its symbolic language, understandable by humans, aiming to offer explanations to the answers produced by the black box of machine learning algorithms or to clarify the background knowledge on which neural networks are trained. Some recent application examples can be found in the context of question answering, data classification, autonomous driving, and dialogue systems.

In summary, we can, therefore, state that Logics have provided a formal basis for the study and development of systems and applications in Artificial Intelligence (AI). In particular, logic became relevant to AI research thanks to the fast satisfiability solvers used for solving combinatorial search problems. Logic-based AI approaches have contributed to knowledge representation, natural language understanding, automated planning and commonsense reasoning. Currently, they are fundamental in the increasing need for explainability, comprehensibility and reliability to improve statistical-based AI systems. Hence, logic-based approaches are of paramount importance to identify promising research perspectives.

The present Special Issue collected three articles of state-of-the-art research on the topic of logic-based AI approaches and technologies and their main application areas. In particular, the articles range from answer set programming to equilibrium logic, description logic and probabilistic reasoning.

The first paper, 'Fact-Checking Reasoning System for Fake Review Detection Using Answer Set Programming", is by Nour Jnoub, Admir Brankovic, and Wolfgang Klas [1]. The authors proposed a framework based on answer set programming (ASP) and natural language processing to identify fake reviews. Indeed, the fake review detection problem has been transformed into an optimization problem solved via ASP by showing the high capability of this logic programming paradigm to solve these kinds of problems.

The second paper, "A Brief Roadmap into Uncertain Knowledge Representation via Probabilistic Description Logics", is by Rafael Peñaloza [2]. The author focuses on uncertain knowledge representation, a key topic for realistic applications, by showing many different languages in the context of description logic.

Finally, the third paper, "Comparing the Reasoning Capabilities of Equilibrium Theories and Answer Set Programs", is by Jorge Fandinno, David Pearce, Concepción Vidal, and Stefan Woltran [3]. The authors provide a theoretical comparison between equilibrium theories and answer set programs based on their inference capability.

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References

1. Jnoub, N.; Brankovic, A.; Klas, W. Fact-Checking Reasoning System for Fake Review Detection Using Answer Set Programming. *Algorithms* **2021**, *14*, 190. [CrossRef]
2. Peñaloza, R. A Brief Roadmap into Uncertain Knowledge Representation via Probabilistic Description Logics. *Algorithms* **2021**, *14*, 280. [CrossRef]
3. Fandinno, J.; Pearce, D.; Vidal, C.; Woltran, S. Comparing the Reasoning Capabilities of Equilibrium Theories and Answer Set Programs. *Algorithms* **2022**, *15*, 201. [CrossRef]