Knowledge-Based Artificial Intelligence: Methods and Applications

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INTRODUCTION

Artificial Intelligence (AI) and Data Science are among the most (if not the most) transformative scientific and engineering disciplines of our era, impacting many aspects of everyday lives and science itself. Availability of data and computing power makes data-based machine learning approaches particularly efficient but also raises questions about the trustworthiness of deployed systems especially in critical applications (Wing, 2021). This important issue causes the re-examination of pure machine learning based approaches and the employment of formal knowledge-based approaches that have been used extensively in AI. Knowledge-Based approaches are often contrasting Data-Based approaches such as Neural Networks, although this distinction is actually not as sharp as past debates imply and they are both needed in order to achieve deployment of efficient AI systems (Goel, A., 2022).

Based on the above observations and the misconception that AI and Data Science are only about Machine Learning, often ignoring alternative and complementary approaches the current chapter is focused on Knowledge Based methods in order to provide to the reader an overview of this vast and fruitful area of research. Being able to deploy and combine both Machine Learning Based and Knowledge Based approaches in practice will be crucial in overcoming limitations of pure Machine Learning systems and building explainable and trustworthy systems, thus an overview of Knowledge Based methods will be useful to an AI practitioner and will help avoiding a narrow focus on a specific set of methods often ignoring useful existing methods following a different approach. The chapter contains a background section followed by presentation of various logic-based approaches in AI including classic logic, logic programming and non-monotonic logics, modal and temporal logics and the more recent Semantic Web and Answer Set Programming methods. This is followed be presenting recent work on large scale semantic reasoning which brings symbolic knowledge-based methods to the Big Data era and finally concussions and discussion about future work.

BACKGROUND

Since the emergence of Artificial Intelligence in 50s, approaches based on logic based reasoning combined with formal encoding of human knowledge have been of the forefront of artificial intelligence research, due to their similarly to the human way of thinking and their suitability for automation (Van Harmelen et al., 2008). Having lost their preeminence since the so called "AI winter" of late 80s and early 90s and

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currently overshadowed by data intensive Machine Learning (ML) approaches, especially deep learning approaches, the Knowledge Based (KB) approaches are currently not in the focus of attention of the majority of AI community and the public in general to the same degree as in the early days of AI. On the other hand they still remain a crucial building block of AI applications and an important approach for overcoming current problems caused when deploying AI systems.

As machine learning approaches are applied in an ever-increasing number of application domains several issues are raised related to biases of Machine learning generated models, resulting from biases in training datasets, and the explainability of produced models which contradicts the requirement of accountability of deployed Artificial Intelligence Applications. Since AI is getting more important and ML is applied to critical tasks, such as medical diagnosis and self-driving cars, accountability becomes a major issue as exemplified by EU's regulations (Goodman & Flaxman, 2017) and DARPA's explainable AI initiative (Gunning & Aha, 2019).

Neural Networks in particular, although achieving human level, or higher, performance on various applications such as image recognition and automatic translation and being the leading paradigm in current AI research, suffer from their lack of explainability. Specifically the structure of Neural Networks is complex and the interpretation of internal nodes and weights of edges is typically missing making them a "black box" approach, non-compatible with accountability requirements. Deploying such non interpretable systems for a critical task contradicts with the accountability requirements typical for critical applications such as autonomous vehicles and medical diagnosis (Tjoa & Guan, 2020).

Knowledge Based approaches, whose development is based on constant involvement of domain experts, on the other hand, are based on formal encoding of human knowledge and logic rules, thus offering transparent models and leading to an explainable decision making process. In addition, recent research activity on knowledge based systems has led to novel formalisms having increased expressivity and performance. Various approaches have been developed, optimized for specific types of applications and theoretical work has led to a clear understanding to the tradeoff between expressivity and performance of employed approaches allowing of optimal decisions with respect to the selected formalism for each application type. Table 1 summarizes the main characteristics of symbolic and ML based approaches.

Large scale semantic reasoning is an active area of research, bringing knowledge based approaches to the big data era and making such approaches suitable to data intensive applications. The abovementioned advances in Knowledge Based AI offer alternative or complementary solutions to machine learning based approaches, especially deep learning, bringing with them the deep understanding which is needed for efficient and accountable deployment of Artificial Intelligence. An overview of the current landscape and the state of the art of Knowledge Based AI approaches is presented in the following, containing related work and methods.

CLASSIC LOGIC

Logic has been studied extensively since ancient times beginning with Aristotle and continuing throughout the Middle Ages. Modern Logic has been introduced by Boole and Frege and advanced rapidly in the 20th century combined with the advent of computers (Robinson, 2000). Propositional Logic used to reason about sentences and propositions is the basic widely studied logic and several approaches for reasoning have been proposed, leading to decidable (i.e., there is an effective method for determining whether an arbitrary propositional formula is logically valid) and efficient methods for automatic reasoning, especially in knowledge bases in restricted forms. In particular Satisfiability Solvers (SAT Solvers)