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Does machine learning need fuzzy logic?

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Abstract

This article is a short position paper in which the author outlines his (necessarily subjective) perception of current research in fuzzy machine learning, that is, the use of formal concepts and mathematical tools from fuzzy sets and fuzzy logic in the field of machine learning. The paper starts with a critical appraisal of previous contributions to fuzzy machine learning and ends with a suggestion of some directions for future work.

Keywords: Fuzzy sets; Fuzzy logic; Machine learning

1. Introduction

Since their inception 50 years ago, marked by Lotfi Zadeh's seminal paper [32], and rapid emergence in the following decades, fuzzy sets and fuzzy logic have found their way into numerous fields of application, such as engineering and control, operations research and optimization, databases and information retrieval, data analysis and statistics, just to name a few.

More recently, fuzzy concepts have also been used in machine learning, giving birth to the field of *fuzzy machine learning*. This development has largely been triggered by the increasing popularity of machine learning as a key methodology of artificial intelligence (AI), modern information technology and the data sciences. Moreover, it has come along with a shift from *knowedge-based* to *data-driven* fuzzy modeling, i.e., from the manual design of fuzzy systems by human experts to the automatic construction of such systems by fitting (fuzzy) models to data.

In more classical applications like information processing and expert systems, fuzzy logic is primarily used for the purpose of knowledge representation, and inference is mostly of a *deductive* nature. Machine learning, on the other hand, is mainly concerned with *inductive* inference, namely, the induction of general, idealized models from specific, empirical data. Thus, while the key importance of probability theory and statistics as mathematical foundations of machine learning is immediately understandable and indisputable, the role of fuzzy logic in this field is arguably much less obvious at first sight.

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The goal of this paper is to outline the author's perception of current research in fuzzy machine learning, which includes the discussion of the role of fuzzy sets in machine learning. This perception is based on significant experience with both research communities, fuzzy logic and machine learning, not only as an author of research papers but also as a reviewer, conference organizer and journal editor. In spite of this, it goes without saying that the presentation will necessarily remain subjective and potentially biased.

Prior to proceeding, it should be emphasized that this is not a survey paper. In fact, references are rather sparse and sometimes deliberately omitted (especially in connection with more critical comments or negative remarks), and the fraction of self-citations is higher than usual. Moreover, the focus of this paper is more on machine learning (model induction) and less on data mining (pattern mining, exploratory data analysis, data description). Although both fields are closely connected, there are nevertheless important differences between them, and these differences are not unimportant with regard to the possible role and potential contributions of fuzzy logic—see [16] for a more detailed discussion of this point.

2. The status quo

Inside the fuzzy (logic) community, fuzzy machine learning can nowadays be seen as an established subfield. The number of publications on this topic is still not as high as for some other subfields, such as fuzzy control, but notable and continuously increasing. There is a EUSFLAT working group on Machine Learning and Data Mining[1] and an IEEE CIS Task Force on Machine Learning.[2] Moreover, special sessions on this topic are organized quite regularly on the occasion of fuzzy conferences every year, just like special issues in journals.

That being said, the connection between the fuzzy and the core machine learning community is not well established at all. On the contrary, the two communities seem to be sharply separated, with very little (if any) interaction in the form of joint meetings, research initiatives or mutual conference attendance. For example, contributions on fuzzy machine learning are almost exclusively published in fuzzy journals and conferences, whereas it is extremely difficult to find a fuzzy paper in a core machine learning conference or journal.

Related to the lack of communication between the communities, the recognition of fuzzy logic inside machine learning is still rather moderate, to put it mildly. To some extent, this might be explained by the general reservation of AI scholars against fuzzy logic, which has diminished but not fully disappeared, as well as the fact that most ML researchers, while being well trained in probability and statistics, are still quite unfamiliar with the basics of fuzzy logic. Honestly, however, reasons can also be found on the side of the fuzzy community. For some reason, many fuzzy papers admittedly fall short of the scientific standards in machine learning, which have continuously increased over the past decades. Without attempting to give an explanation, this reflects the author's personal impression based on reviewing and editorial experience. Moreover, the fuzzy ML community seems to be somewhat lagging behind in terms of timeliness. Machine learning has developed quite rapidly in the recent past, and "hot topics" are changing quickly. While ML scholars are focusing on topics such as deep learning, manifold learning, structured output prediction, sparsity and compressed sensing, constructive induction, etc., the majority of fuzzy papers is still about rule induction, a topic that matured and essentially stopped in ML research in the 1990s.

In the following sections, existing work in fuzzy machine learning and contributions often emphasized by fuzzy scholars will be discussed in some more detail, albeit more in an exemplary rather than a comprehensive way. The next section comments on model fuzzification, because this is what most papers on fuzzy machine learning are about. Section 4 addresses the aspect of interpretability, which is typically highlighted as the main advantage of fuzzy approaches, while Section 5 is devoted to the representation of uncertainty in machine learning. Some interesting directions for future work are sketched in Section 6, prior to concluding the paper in Section 7.

3. Fuzzification of models

The bulk of contributions in fuzzy machine learning deals with the fuzzy extension of standard, non-fuzzy methods: from rule induction to fuzzy rule induction [19,14,5], from decision trees to fuzzy decisions trees [20,27,26],

[1] http://www.eusflat.org/research_wg_dami.php.
[2] http://cis.ieee.org/emergent-technologies-tc.html.