Looking at the Branches and Roots

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Abstract. When looking at the future of Fuzzy Logic (FL), it is immediate to think at applications where FL could be used to compute with perceptions, possibly expressed in natural language, thus enabling Explainable Artificial Intelligence (XAI). Scholars in FL have been working on Interpretability, an important part of XAI, for decades. Yet, the research community in FL seems isolated from other Artificial Intelligence (AI) communities. There is a gap between FL and AI that due to the relative youth of FL when compared with the foundational theories underlying AI. If we want FL growing its branches in XAI as well as in other fields, we need to develop, both in Research and Education, more robust roots supporting all the theories, the methodologies and the technologies that are going to be developed now and in future.

Keywords: Foundations of Fuzzy Logic · Explainable Artificial Intelligence

Extended Abstract

We are all happy with the infosphere.[1] We live, strive, fight, love and die for information. And we want more. Technology, our complacent servant, gives us more and more opportunities to replace our physical lives with an informational counterpart, so much that someone started to worry that, in a not so far future, we may well be Technology's servants. But this is the time of enthusiasm and we want information technology every-where, every-time. That is why we are witnessing a bloom of applied science, and applied research. This has a cultural impact too. Computer Science is more and more oriented towards finding new applications and teaching students how to create new artifacts that work well and eventually make profits. So, when looking at the future of FL, the first thing that comes into mind is: what are the applications where FL could be more successful? Zadeh was indefatigable in telling us that machine intelligence can be improved by enabling perception-based computing, and FL is *the* scientific way to compute with perceptions [14]; therefore outstanding applications are those

[1] Infosphere denotes denote the whole informational environment constituted by all informational entities, their properties, interactions, processes and mutual relations. See Floridi [5] but also https://en.wikipedia.org/wiki/Infosphere.

R. Fullér et al. (Eds.): WILF 2018, LNAI 11291, pp. 249–252, 2019.
https://doi.org/10.1007/978-3-030-12544-8_22

dealing with perception-based information and knowledge, possibly expressed in natural language.

Explainable Artificial Intelligence (XAI) is an evolution of AI methodologies focusing on the development of agents capable of both (i) generating decisions that a human could understand in a given context, and (ii) explicitly explaining decisions [9]. What is an explanation, what are its function and structure are questions posed in Philosophy, Psychology and Cognitive Science. Interestingly, these are the very same fields where the concept of perception has been formulated and studied. Many concepts in the human mind are formed through an act of perception, i.e. the organization, identification and interpretation of a sensation in order to form a mental representation [11, Ch. 4]. Since what is perceived belongs to a continuous Reality and concepts are formed through perceptions, it is straightforward to assume that such concepts reflect the continuity of perceptions. Therefore, as FL gives a computational account to perception representation and processing, it is arguable that XAI is a field where FL could flourish, especially in the days after the binge of deep learning, when we will eventually realize that black boxes might be fragile [10] or even dangerous [8]. I am pretty sure that XAI will be the right mean for *collaborative* intelligence [4], with machine helping and not replacing humans to tackle more and more complex problems. This would dramatically reduce the risks of fear and opposition to the advancement of AI technologies, which are more and more often seen as competing with humans and menacing well-being. But to achieve collaboration, humans and machines should be able to communicate at the same level: this might be accomplished if machines embody perception-based knowledge as FL promises to provide.

XAI is a relatively new field where a number of research efforts are converging. If we look back in the history of FL, we see that in the last twenty years a great deal of research was around the keyword "interpretability" and, with due distinctions, interpretability of fuzzy systems may be considered part of the XAI program. In fact, research on interpretability moved from the definition of a number of structural constraints aimed at keeping knowledge representation as simple as possible, towards the recognition of a more complex phenomenon embracing both structural and semantical aspects [2]. However, a recent research of ours showed that, within XAI at least, the research community in FL is isolated from other Artificial Intelligence (AI) communities [1]; as a consequence, wheels are often re-discovered and a common language is not matured.

There is a gap between FL and AI. Some scholars between the two worlds already recognized this problem and tried to find the reasons of this separation [7]. FL appears as a growing tree but its roots are still not as robust as in other AI branches. In fact, AI is based on theoretical foundations that have hundreds or thousands of years, while FL challenges some well-established dogmas on the basis of a visionary viewpoint that may not be easily accepted. This is not a problem in principle but in practice. If we want FL growing its branches in XAI as well as in other fields, we need robust roots supporting all the theories, the

methodologies and the technologies that are going to be developed now and in future.

We have infinite degrees of freedom in developing models based on FL. This makes modeling very difficult because it may be extremely hard to give a clear rationale behind all the design choices in a FL model: shape of membership functions, type of set operators, type of inference mechanism, defuzzification, etc. Sometimes, all such degrees of freedom are translated into parameterized models that are subject of numerical or evolutionary optimization; but the results are completely opaque and incomprehensible to the final users; as a consequence, with such an approach, the vision of FL to support XAI gets lost. Sometimes it is even hard to see a clear distinction between fuzzy set and membership function (and we find a fuzzy set *exactly* defined as its membership function, although denoted by two different symbols). In short, we see amazing applications without sound foundations. We should not content ourselves with such a partial result, because a beautiful tree with big branches but undersized roots is destined to fall.

This is why the future of fuzzy logic must look at its roots, other than at its branches. Sometimes, the need of a new Mathematics is invoked to develop the foundations of FL; but I do not subscribe to this point of view. Mathematics, as we know it, is a suitable language for a plethora of scientific theories, from Boolean algebra to Quantum Mechanics: there is no need to invent a new one for FL. Instead, within Mathematics, we need to formalize the irrefutable ideas behind FL[2] and, within Informatics, to undoubtedly show that they have the real world as a model. To this end, the recent works of some FL scholars (see, e.g. Trillas [12])—which separate the concept of fuzzy set as a collection of loosely ordered objects, and the concept of membership function as a (possibly approximate) measure of gradualness—are very promising and deserve to be further investigated in future. Also, the seminal works of Dubois and Prade on Possibility Theory and—more in general—on systematizing the semantics of fuzzy sets [3], the theoretical breakthroughs given by Mathematical Fuzzy Logic [6], etc. constitute the roots of FL in the soil of Science, which deserve both development in Research and settlement in Education.

Education in FL should give a strong emphasis on the theoretical foundations of FL, including some basics on Mathematical Fuzzy Logic, Possibility Theory, lattice theory, L-fuzzy sets and everything else that allows students to understand the roots of FL so as to develop applications with a stronger awareness of what they are doing. Current education programs may be too much oriented towards an engineering approach aimed at quickly enabling students to be productive; a step back so as to plunge deeper on theory is however important to preserve the scientific culture from oblivion. (An interesting endeavor is given by Trillas and Eciolaza [13].)

[2] Of course, FL in the wide sense is implicitly intended; Mathematical Fuzzy Logic is a well formalized discipline, but sometimes distant from the concepts and ideas of FL in the wide sense. Bridging the gap between narrow and wide FL is another interesting way to look at the future of FL.

Zadeh's genius moved thousands of people to question the rigid structure of theories onto which many classical AI methodologies are founded. Thanks to him, we found the key ingredient for human-centric information processing. Now time is come to make this wonderful vision a hard-rock science.

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