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Fuzzy Logic, Control Engineering and Artificial Intelligence

A Personal Point of View

Didier DUBOIS and Henri PRADE

Institut de Recherche en Informatique de Toulouse – C.N.R.S.
Université Paul Sabatier, 118 route de Narbonne
31062 TOULOUSE Cedex, France

The term "fuzzy logic" is rather ambiguous because it refers to problems and methods that belong to different fields of investigation. When scanning the literature, it is possible to find three meanings for the expression "fuzzy logic". In its most popular acception, it refers to numerical computations based on fuzzy rules, for the purpose of modeling a control law in systems engineering. However, in the mathematical literature fuzzy logic means multiple-valued logics, with the purpose of modeling partial truth values and vagueness. Lastly, in Zadeh's papers fuzzy logic is better understood as fuzzy set-based methods for approximate reasoning at large, and approximate reasoning is a subtopic of Artificial Intelligence. This state of facts creates communication problems between researchers in the fuzzy set area, and consequently, outside the fuzzy world as well. Indeed the fields concerned by "fuzzy logic", and that use this terminology, are control engineering, formal logic and Artificial Intelligence, and some of those fields almost never communicate with one another. Fuzzy logic, as understood by control engineers, is no logic at all, from the points of view of logicians. Moreover the research programs of Artificial Intelligence and Control Engineering are quite divergent : the latter is based on numerical methods and is black-box oriented. The former insists on symbolic processing and knowledge representation. Fuzzy logic is devoted to knowledge representation and symbolic/ numeric interface, and its status is rather ambiguous in that respect. Fuzzy set theory has brought together researchers that had little background in common and the temptation exists for each community (Artificial Intelligence, Logic and Control), to emphasize a narrow view of fuzzy logic that fits its own tradition.

Interestingly, the original motivation of fuzzy logic control was to represent expert knowledge in a rule-based style and to build a standard control law that faithfully reflects this knowledge. Fuzzy logic control was thus put from the start in the perspective of Artificial Intelligence, because it did not use the classical control engineering paradigm of modeling a physical system and deriving the control law from the model. As such fuzzy logic control is viewed as an application of the approximate reasoning methodology proposed by Zadeh, that exploits formal models of commonsense reasoning. Following this path may sound promising, even for control engineers, since they do employ heuristic knowledge in practice, be it to specify objectives to attain. Supervision also involves a lot of know-how, despite the existing sophisticated control theory.

However in the last five years, a significant deviation from original motivations and practice of fuzzy logic has been observed in the control engineering community. Namely, fuzzy rule-based systems are more and more considered as standard, non-fuzzy universal approximators of functions, and less and less as a means of extracting control laws from heuristic knowledge. This trend raises several questions for fuzzy logic. First, if fuzzy logic is to compete alternative methods in approximation theory, it faces a big challenge because approximation theory is a well-established field in which many results exist. Approximate representation of functions should be general enough to capture a large class of functions, should be simple enough (especially the primitive objects, here the fuzzy rules) to achieve efficient computation and economical storage, and should be amenable to capabilities of learning from data. Are fuzzy rules capable of competing with standard approximation methods on such grounds? the answer is far from clear. On the one hand the universal approximation results for fuzzy rule-based systems presuppose a large number of rules. This is good neither for the economy of representation nor for linguistic relevance. On the other hand the identification between fuzzy rule-based systems with neural nets or variants thereof (radial basis functions and the like) has created a lot of confusion as to the actual contribution of fuzzy logic. To some extent it is not clear that fuzzy logic-based approximations methods for modeling and control needs fuzzy set theory any longer. Moreover the connection to knowledge representation, part of which relies on the "readability" of fuzzy rules as knowledge chunks, is lost. Actually, from the point of view of approximation capabilities, the good performance of a fuzzy rule-based system seems to be incompatible with the linguistic relevance of the rules. This incompatibility leads systems engineers into cutting off the links between fuzzy logic and Artificial Intelligence, hence with fuzzy set theory itself. This is very surprizing a posteriori since the incompatibility between high precision and linguistic meaningfulness in the description of complex systems behavior is exactly what prompted Zadeh to introduce fuzzy sets as a tool for exploiting human knowledge.

It is questionable whether the present tendency of fuzzy engineering to immerse fuzzy logic inside the jungle of function approximation methods will produce path breaking results that puts fuzzy rule-based systems well over already existing tools. It is not clear either that it will accelerate the recognition of fuzzy set theory, since there is a clear trend to keep the name "fuzzy" and drop the contents of the theory.

Yet, it seems that control engineering practice can benefit from the readability of fuzzy rule-based systems. The latter are easier to modify, they can serve as tools for integrating heuristic, symbolic knowledge about systems, and numerical control laws issued from mathematical modeling. Some interesting works have also been done in fuzzy rule-based tuning of PID controllers. More generally the ranges of applicability of fuzzy controllers and classical control theory are complementary. Whenever modeling is possible, control theory offers a safer approach, although a lot of work is sometimes necessary to bridge the gap with practical problems. Fuzzy logic sounds reasonable when modeling is difficult or costly, but knowledge is available in order to derive fuzzy rules. This philosophy, which has led to successful applications in Europe before fuzzy logic become worldwide popular (for instance the cement kilns controllers of Østergaard), tends to disappear from the literature of fuzzy control, when one looks at the recent literature.

It must be noticed that while in the beginning of fuzzy control, fuzzy rule-based systems were construed as relevant to Artificial Intelligence, Artificial Intelligence had rejected fuzzy control as a non-orthodox approach that was not purely symbolic processing. To-date, fuzzy logic advocates tend to reject symbolic Artificial Intelligence as not capable of dealing with real complex systems analysis tasks. Proposing the recently emerged buzz-word "soft computing", a mixture of fuzzy rules, neural nets and genetic algorithms as a new scientific paradigm that make traditional Artificial Intelligence research obsolete sounds hasty and somewhat dangerous. Doing so there is a danger of cutting fuzzy logic from its roots and making fuzzy set theory obsolete as well. Zadeh himself recently advocated the idea of computing with words as being the ultimate purpose of fuzzy logic. In order to achieve this program, it seems that part of fuzzy logic research should go back to Artificial Intelligence problems, and that fuzzy logic should again serve as a bridge between Systems Engineering and Artificial Intelligence research. Needless to say that in that perspective, control engineers should receive some education in logic, and Artificial Intelligence researchers interested in systems engineering should be aware of control theory. Such a shift in education and concerns would open the road to addressing, in a less ad hoc way, issues in the supervision of complex systems, a problem whose solution requires a blending between knowledge and control engineering, and not only tools for approximating real functions, be they non-linear.