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Fuzzy Logic: An Interface Between Logic and Human Reasoning

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Charles Elkan addresses two distinct areas of fuzzy logic: formal expressiveness and practical usefulness.[0] He describes as a paradox that although the theory of fuzzy logic is not generally accepted, it is successfully used in many real-world applications. He also calls paradoxical the fact that these applications are predominantly found in the control domain.

I will not discuss here the alleged equivalence between fuzzy and two-valued logic; by choosing criteria established for the more restricted two-valued formalism, Elkan does not have a suitable framework for a meaningful comparison. To point out prerequisites for the practical usefulness of knowledge representation formalisms, I will focus on the role of fuzzy logic in linking two formally incommensurable worlds: the natural world of human perception and experience that leads to subjective cognitive concepts, and the formal world of classical logic that yields universal truth conditions.

Given the premise that there is no one-to-one mapping between human conceptual structures and the framework of classical logic, it is not important for the analysis of a formal representation structure if two logically equivalent expressions are evaluated identically; what we have to ensure is that derivations accepted in human reasoning can also be derived in our formalism.

Classical logic and human knowledge. In AI, propositions and various kinds of logic formalisms serve to represent and derive knowledge about formal or real domains. Traditionally, most effort has been put into the development of logically correct and consistent operations *within the formal representation;* however, little attention has been paid to the correspondence problem between the structure of these propositions and operations, on one hand, and the knowledge structure they are supposed to represent, on the other. When we represent formal domains (for example, card games or mathematical theorems), establishing this correspondence may not cause major problems. However, when we represent knowledge about a real domain, the correspondence between our formalism and the represented structure becomes a major issue.

A representation system consists of:

- a represented world, and the relations and operations in it;
- a representing world, and the relations and operations in it; and
- the correspondence between the two worlds.[1]

When representing knowledge about the real world, it is inherently impossible to prove something about the represented real-world knowledge; this part of the representation system is outside the formalism. We only can prove something within the representing formalism. Thus, the represented real world and its representation are *formally* incommensurable.

In expert systems, the knowledge engineer establishes the correspondence between the real and formal worlds, but he cannot prove its correctness; he depends on his perception and intuition to determine the equivalence between the two. Usually, a knowledge engineer relies upon assumptions to determine the validity of operations on a representation. These assumptions stem from his knowledge about formal logic, rather than from knowledge about specific properties of human reasoning. Nevertheless – as Elkan's article shows – this approach appears to be widely accepted for the treatment of human knowledge.

One of Lotfi Zadeh's main motivations for introducing the notions of fuzzy sets and fuzzy logic was his observation that real-world knowledge generally has a different structure and requires different formalization than existing formal systems. Contrary to established practice, a one-to-one correspondence between natural-language propositions and predicate calculus propositions can be shown to be inadequate. In particular, the instantaneous switch from truth to falsity can easily distinguish propositions in classical logic from those in natural language. In addition, numerous assumptions of the formally correct treatment of the propositions cannot be established in the corresponding source knowledge.

The fuzzy logic interface. Zadeh recognized the power of a formal approach to knowledge processing as well as the advantages of using soft knowledge in human reasoning. He thus took a first step in incrementally relaxing constraints imposed on existing formalisms to accommodate important properties of natural inference. This step was to generalize the classical notion of a set to the notion of a fuzzy set that allowed gradual membership. The choice of numerical degrees of membership was largely made for formal reasons: it provided a transparent way of formally treating the new notion. Using the familiar language of mathematics, the theory can easily be implemented in computer systems, while at the same time offering a better approximation to the associated human concepts. Because human notions and concepts form the basis for reasoning in expert systems, the success of these systems depends upon the correspondence relation between human concepts and their formalization. Studying the formal properties of the representation is insufficient.

Zadeh realized that it was much more important to have a good model of the semantics of human concepts and perform reasonable operations than to have a bad model and perform verifiably correct operations. He never insisted that his initial proposal for a fuzzy logic should be viewed as the final solution for representing human knowledge about the world; rather, he offered a model based on established notions that could easily be grasped by engineers and researchers alike as a step toward formalizing human reasoning. Because of this, Zadeh's basic notion of a fuzzy set stimulated enormous research activity in soft knowledge processing.

Zadeh's work also helped establish a radically different view of the status of expert knowledge. No longer is it viewed as a collection of absolute truths piped into an inference engine to derive all sorts of unexpected results; rather, it is now considered as a system of more or less soft constraints that are applied to specific situations to make reasonable decisions.

Soft knowledge is processed differently than logic clauses – the reasoning power is typically due to processing breadth rather than depth. The ability to use shallow processing to merge knowledge from different sources produced useful decisions. (Elkan uses the terms "deep" and "shallow" in two different senses: to distinguish general knowledge from specific knowledge, and to distinguish extensive and restricted knowledge propagation. I use the terms here in the second sense, which is the usual sense.) Elkan appears to attribute the fact that fuzzy systems employ only a few rules to the domain's simplicity. However, this fact can also be attributed to the important capability of summarizing complex knowledge into a dense and transparent description.

Success and limitations. The fuzzy set paradigm introduced a new concept of soft knowledge that helped characterize an important aspect of knowledge about complex environments. It also provides a language to bridge the gap between soft and shallow knowledge, on the one hand, and systematic and formal methods for dealing with it, on the other. This contribution might have a much more significant impact on human thought and the role of classical logic in systems analysis than the fuzzy set notion will have on the success of expert systems. As the transition from crisp sets to fuzzy sets is a rather moderate step toward accounting for the nature of human concepts, we should not expect it to solve all our problems. In particular, fuzzy sets and fuzzy logic do not answer the fact that human concepts develop and are modified in an open world, while formal concepts are fixed in closed worlds, for the most part. Therefore, it is not surprising that successful applications of fuzzy logic are so far found mainly in well-defined closed domains like control problems which, to a large extent, share the properties of synthetic, formal problems. The way gradual membership is represented in fuzzy sets quite naturally suits such application domains.

The further we move from representing human knowledge about clearly delineated problems to representing concepts relating to open domains, the more we will have to overcome certain rigidities of the classical formal approaches.

*C*lassical logic has proved extremely useful for solving formal problems specified in two-valued terms. Fuzzy logic is proving particularly useful for quasi-formal problems involving gradual transitions between various system states. For adequately formalizing less rigid domains, like the open world of human fuzzy concepts, we must relax the constraints on the formalisms even more. Specifically, numerical graduation of membership used in classical fuzzy logic is hardly justified for the representation of cognitive concepts;

instead, less constraining ordering relations like partial orderings may be appropriate.

Considering the fact that it took 25 years to put fuzzy logic into wide use in the well-understood engineering domain of control, we should not be surprised if some barriers must be removed before fuzzy logic will be widely applied to more delicate areas of fuzzy reasoning.

For judging the quality of a representation formalism, I have proposed taking a representation-theoretical viewpoint: The correspondence between the represented domain and the formalism is at least as important as the representation's formal properties taken by themselves. This viewpoint permits a high-level characterization of the overall representation problem. I have also argued that real-world knowledge and formal knowledge are formally incommensurable. As long as the laws of human reasoning are not well understood, a good model of human reasoning should be expected to preserve some paradoxes; experimentation with the model may deepen the understanding and help resolve them.

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References

0. C. Elkan, "The Paradoxical Success of Fuzzy Logic," IEEE Expert, to appear.

1. S.E. Palmer, "Fundamental Aspects of Cognitive Representation," Cognition and Categorization, Lawrence Erlbaum, Hillsdale, N.J., 1978. pp. 259-303.

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