

Fuzzy Logic and AI

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Abstract

This panel will provide a forum for a timely discussion on important issues regarding fuzzy logic and AI, which include (1) successful AI applications that have been developed using fuzzy logic, (2) AI techniques that can be synergistically integrated with fuzzy logic, and (3) major roles that fuzzy logic can play in the development of next generation intelligent systems.

1 Introduction

Many industrial applications of fuzzy logic-based intelligent systems have been successfully developed in the past decade. Recently, Japanese consumer manufacturers such as Sony, Panasonic, Canon, Minolta, Hitachi, and Nissan has introduced a wide variety of "intelligent consumer products" employing fuzzy logic into the market. As a result, there has been an increasing interest in fuzzy logic in general and its relationship with artificial intelligence, in particular.

This panel on *Fuzzy Logic and AI* has three major objectives. First, it will provide an overview about the state of the art of fuzzy logic technology and its application in AI. Second, it will offer insights on promising directions of interdisciplinary research that may play a key role in the development of next generation intelligent systems. Third, and most importantly, such a panel will encourage fruitful technical exchanges between the general AI community and the fuzzy logic community.

To achieve these objectives, the panelists are asked to respond to the following questions:

1. In what areas in AI has fuzzy logic offered important contributions?
2. What techniques in AI have been successfully integrated with fuzzy logic?
3. What techniques in AI can be synergistically integrated with fuzzy logic?
4. What ideas/techniques in AI can contribute to the further advancement of fuzzy logic technology?
5. What role will fuzzy logic play in the next genera-

tion intelligent systems?

In the following sections, we will summarize the position statement of each panelist regarding the issues listed above.

2 Soft Computing

Lotfi A. Zadeh

The past few years have witnessed a rapid growth of interests in a cluster of modes of modeling and computation which collectively may be described as *soft computing*.

The distinguishing characteristic of soft computing is that its primary aim is to achieve tractability, robustness, low cost, and high MIQ (machine intelligence quotient) through an exploitation of the tolerance for imprecision and uncertainty. Thus, in soft computing what is usually sought is an approximate solution to a precisely formulated problem or, more typically, an approximate solution to an imprecisely formulated problem.

In general, high precision carries a high cost. The challenge, then, is to exploit the tolerance for imprecision by devising methods of computation which lead to an acceptable solution at low cost. This, in essence, is the guiding principle of soft computing. By its nature, soft computing is much closer to human reasoning than the traditional modes of computation.

At this juncture, the major components of soft computing are fuzzy logic, neural network theory, and probabilistic reasoning techniques, including genetic algorithms, chaos theory, and parts of learning theory. Increasingly, these techniques are used in combination to achieve significant improvement in performance adaptability. Among the important application areas for soft computing are control systems, expert systems, data compression techniques, image processing, and decision support systems.

It may be argued that it is soft computing - rather than the traditional hard computing - that should be viewed as the foundation for artificial intelligence. In the years ahead, this may well become a widely held position.

3 Fuzzy Logic Controllers: An AI Perspective

Piero P. Bonissone

A Fuzzy Logic Controller is a knowledge based system in which the knowledge of process operators or product engineers has been used to synthesize a closed loop controller for the process. We view fuzzy logic control technology as a high level language in which we can efficiently define and synthesize non-linear controllers for a given process. We contrast fuzzy Proportional Integral (PI) controllers with conventional PI and two dimensional sliding mode controllers. Then we compare the development of Fuzzy Logic Controllers (FLC) with that of Knowledge Based System (KBS) applications.

Traditional controllers are derived from a mathematical model of the open-loop process to be controlled, following classical control theory techniques. FLCs are typically derived from a knowledge acquisition process

(or are automatically synthesized from a self-organizing control architecture). In either case, the result of the synthesis is a Knowledge Base (KB), rather than an algorithm. The KB consists of a set of fuzzy-rules (rules and termsets), which is evaluated by an interpreter. The interpreter is composed of a quantification (or fuzzification) stage, an inference engine (or fuzzy matcher), and a defuzzification stage.

We analyze FLCs according to three organizing layers typically used in describing Knowledge Based Systems: knowledge representation, inference, and control. In the knowledge representation layer we will describe fuzzy state vectors, term-set of linguistic values, and fuzzy production rules. In the inference layer we will provide a geometric interpretation for the disjunctive case of the generalized modus ponens, and describe the inference process based on fuzzy predicate evaluation, rule Left Hand Side (LHS) evaluation, rule detachment, and rules aggregation. In the control layer we will show three different defuzzification methods and we illustrate meta-reasoning capabilities (supervisory mode).

FLC interpreters are used during the development phase of a FLC application to provide inference traceability (transparency), which facilitates the KB design, implementation, and refinement. However, the use of an interpreter requires the evaluation of all the rules in the KB at every iteration.

Therefore, after a functional validation (stability or robustness analysis), the KB is compiled like a programming language or a traditional knowledge base application, and a simpler run-time engine is used for deployment. The result of this compilation process is a look-up table that allows for a faster, more efficient execution that can be performed by simpler processors. This feature enables us to build inexpensive FLCs for cost-sensitive applications.

In summary, we consider a Fuzzy Logic Controller to be a high level language with its local semantics, interpreter, and compiler, which enables us to quickly synthesize non-linear controllers for dynamic systems.

Finally we will illustrate an application of Fuzzy Logic Controllers. We will describe the development of a fuzzy logic hierarchical controller for a recuperative Turbo-shaft engine. The problem consists in developing a hierarchical supervisory controller that governs the use of ten low level controller. Each low-level controller is designed to optimize the control function for a specific region of the engine state space or "engine mode". We will contrast the behavior of a classical supervisory controller performing mode selection with that a fuzzy supervisory controller performing mode melding.

4 Interpolative, Qualitative, and Plausible Reasoning Modes with Fuzzy Sets

Didier Dubois and Henri Prade

On the one hand, fuzzy sets are a simple but powerful tool for modeling flexibility and graduality in knowledge representation, when specifying soft constraints, criteria, queries, or expert rules. Then satisfaction, compatibil-

ity become a matter of degree. On the other hand, the concept of a possibility distribution for modeling imprecise or uncertain information, introduced by Zadeh in the seventies and the basic principles of approximate reasoning based on the combination and projection of possibility distributions, offer a unified view of soft constraint propagation and automated reasoning under uncertainty. Uncertainty is then captured in terms of two modalities graded by possibility and necessity measures. The underlying model of uncertainty is more qualitative than the probabilistic model since based on ordering rather than additivity. Especially the grades in the scale $[0,1]$ are mainly used in a purely ordinal manner. An advantage is that it is less demanding in terms of input data than probability theory and that it better gets along with usual symbolic deduction techniques.

Introducing flexibility in the satisfaction of constraints or queries enables the system to avoid situations where there is no solution, or too-many solutions, because the specifications are too demanding, or too permissive. Solutions can then be ordered according to the level of satisfaction of the specifications. Graduality in the satisfaction of the condition parts of rules enables the system to modulate its conclusion according to the extent to which the rules apply to a given situation. Moreover possibility theory, a companion framework based on fuzzy sets, offers an original and effective approach for dealing with uncertain and imprecise facts or conclusion parts of rules.

Inference methods based on fuzzy sets can be applied with success to a great variety of reasoning modes. Interpolative reasoning enables a control system to determine the value of the command to apply in situations which are intermediary between prototypical ones (where the actions to perform are known). This is encoded by rules of the form "the more the condition is satisfied, the closer we should be to what is prescribed in the conclusion". By attaching levels of certainty to logical formulas, possibilistic logic offers a simple tool for propagating uncertainty in deductive reasoning and for dealing with inconsistency in agreement with non-monotonic reasoning. This corresponds more generally to rules of the form "the more the condition is satisfied, the more certain the conclusion". Possibilistic ATMS based on possibilistic logic offer a tool for implementing hypothetical reasoning in presence of uncertainty. Analogical reasoning is captured using rules of the form "the more similar two situations according to some features, the more possible the similarity of the situations with respect to other features". In abductive reasoning, fuzzy causal relations have been used for a long time. A fuzzy causal relation can be interpreted in different ways. It may express the intensity of presence of non-binary effects for a given cause, or qualify the possibility or certainty of presence of binary effects. Besides the handling of qualitative or imprecise orders of magnitude in possibility theory is of interest for qualitative reasoning, and for numericalsymbolic interface.

Thus, applications concerned by fuzzy set-based reasoning methods are of various types : control systems, decision support systems, advanced information systems

and knowledge-based systems.

5 Beyond Fuzzy Sets

Christian Freksa

Although Fuzzy Set Theory was motivated largely by properties of *natural* human concepts*, *the theory has been most successful in artificial* engineering domains*, so far. We will look at 'fuzzy knowledge' from a cognitive point of view and identify several kinds of representation relations in each of which fuzziness plays a different role. We discuss differences between abstract domains, artificial real domains, and natural real domains and we argue that dealing with *cognitively* available knowledge suggests a different approach for dealing with fuzziness than dealing with *formal* knowledge.

We propose a fuzzy set - based approach to overcome certain problems of dealing with natural concepts. Like natural cognitive systems, this approach does not require numbers for representing fuzzy relations, however; instead, the notion of "conceptual neighborhood" that we have used in qualitative temporal and spatial reasoning is used for representing the mutual arrangement and ordering of concepts. Concept ordering is shown to be important along two distinct dimensions: 1) the ordering of competing concepts (horizontal dimension) and 2) the ordering of concepts according to different granularity levels (vertical dimension).

In our view, concepts cognitively typically refer to clear cut cases rather than to marginal cases. It is good practice to select concepts which fully apply to a given situation (if possible) rather than marginal concepts which apply to a low degree. Fuzziness mainly becomes an issue when we simultaneously deal with *two distinct* domains, for example with the physical domain and the conceptual domain or with the conceptual domains of two individuals; it is much less an issue *within* the conceptual domain of a single individuum. This is true particularly when this individuum deals with concepts abstractly. In other words, not the concepts are fuzzy but their compatibility with other entities.

We like to suggest that a significant fraction of a reasoning process can and should be carried out qualitatively *within* the conceptual domain without the need of going through fuzzy relations. Fuzzy relations, on the other hand, should be represented without numerical functions when we want to have a cognitively more adequate model. This requires the development of more elaborate models of the different domains involved in reasoning and their interaction. Specifically, we must represent situation contexts and concept contexts and their interaction in order to go beyond the comparatively well defined domain of engineering applications.

6 Fuzzy Logic: What and Why

Enrique H. Ruspini

We will discuss the basic concepts that underly fuzzy logic and explain the reasons for the success of this basic technology. In particular, we will focus on important conceptual connections between the notion of possibility and the concepts of similarity and utility.

We will also compare fuzzy logic with other approaches to approximate reasoning focusing on the important conceptual differences between probability and possibility theory.

Our discussion of fundamental concepts and their motivation will be illustrated by examples drawn from the application of fuzzy logic to the control of SRI's Autonomous Mobile Vehicle, which recently participated in the Robot Competition of the 1993 AAAI National Conference. We will also describe results from our research on intelligent control and analogical reasoning to clarify our conceptual points.

7 Local Fuzzy Logics in Large Modular Expert Systems

Ramon Lopez de Mantaras

Two of the main characteristics of human problem solving when faced to complex tasks are : the adequation of general knowledge to particular problems and the dependence of the kind of uncertainty management to different subtasks of the problem. Specific subtasks generally make use of only a subset of the KB. Modularization techniques are generally used to build such structured KBS's. From the management of uncertainty point of view, modularization allows to associate different local uncertainty calculi to the different modules if necessary. This rises a communication problem between the modules because facts deduced in a module (with their associated certainty value according to the local uncertainty calculus within this module) will be used by another module using a different uncertainty calculus and in general a different set of certainty values. One way to address this problem is using the capabilities of fuzzy logic as local logics and defining inference preserving mappings between these local logics. We have defined and implemented a modular language that, among other characteristics, allows to use fuzzy local logic with a finite number of linguistic certainty values in the different modules used to represent the deductive and control knowledge associated to the different subtasks of a given problem. This approach has been (and is being) used in the development of several large medical expert systems where the possibility to define fuzzy local logics greatly facilitated the solution to the problems encountered. Two large expert systems (one over 1000 rules and 400 facts and another with over 1500 rules and almost 500 facts as well as close to 100 meta-rules) have been developed and fully validated by means of a multi-centre validation involving six hospitals whose physicians had not been involved with the development of the systems.

For one of the applications we could compare the performance of the expert system with the physicians while it was being used in a field test in the urgency service of one hospital. The validation results show a superior performance since only two of the specialists were clearly better than the system.

8 Summary

We briefly summarize the statements of the panelists below:

1. In what applications areas in AI has fuzzy logic offered important contributions?
 - Intelligent control systems (Bonissone, Zadeh, Dubois and Prade)
 - Expert systems (Mantaras, Zadeh, Dubois and Prade)
 - Data compression techniques (Zadeh)
 - Image processing (Zadeh)
 - Decision support systems (Zadeh, Dubois and Prade)
 - Advanced information systems (Dubois and Prade)
 - Autonomous mobile robot (Ruspini)
2. What techniques in AI have been successfully integrated with fuzzy logic?
 - Possibility theory (Dubois and Prade)
 - Automated reasoning under uncertainty (Ruspini, Dubois and Prade)
 - Case-based reasoning (Bonissone)
3. What techniques in AI can be synergistically integrated with fuzzy logic?
 - Soft constraint satisfaction (Dubois and Prade)
 - Qualitative reasoning (Freksa)
4. What ideas/techniques in AI can contribute to the further advancement of fuzzy logic technology?
 - Nonmonotonic reasoning and ATMS (Dubois and Prade)
 - Multimodal matching and multicriteria decision making (Freksa)
5. What role will fuzzy logic play in the next generation intelligent systems?
 - Integrating symbolic reasoning with learning capabilities of neural networks and genetic algorithms (Zadeh, Dubois and Prade)
 - Soft computing (Zadeh)