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Fuzzy Logic: Issues, Contentions and Perspectives

by

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Professor Zadeh furnished us with this abstract of his informal, affable lecture; we have displayed with it a few of the many overhead projections he used to illustrate significant points.

Abstract

There is a long-standing tradition in science – the tradition of according much more respect to theories which are quantitative, formal and precise than to those which are qualitative, informal and approximate in nature. In recent years, however, the validity of this tradition has been called into question. More specifically, what has become increasingly obvious is that many of the basic problems relating to the conception and design of intelligent systems do not lend themselves to solution within the framework of classical logic and probability theory. To address such problems, we frequently have no choice but to accept solutions which are lacking in precision. Furthermore, even when precise solutions can be obtained, their cost is generally much higher than that of solutions which are approximate and yet yield results which fall within the range of acceptability.

Seen against this background, fuzzy logic may be viewed as an attempt at formalization of modes of reasoning which are approximate rather than exact. What is important to note is that approximate reasoning plays a key role in human reasoning and underlies the remarkable human ability to make rational decisions in an environment of uncertainty and imprecision.

THE REAL WORLD IS PERVASIVELY IMPRECISE, UNCERTAIN AND COMPLEX

contention : ***to enhance their effectiveness in dealing with real world problems, most methodologies need an infusion of fuzzy concepts and techniques***

examples :

- ***probability theory***
- ***decision analysis***
- ***systems analysis***
- ***forecasting***
- ***control theory***
- ...

EVOLUTION OF FUZZY LOGIC (FL)

- ***what is fuzzy logic?***

fuzzy logic — ***narrow (FLn)*** ***logic of approximate reasoning***

fuzzy logic — ***wide (FLw)*** ***fuzzy set theory (FST)*** ***(theory of classes with unsharp boundaries)***

fuzzy set theory:	***fuzzy sets***	***fuzzy probabilities***
	fuzzy relations	***fuzzy equations***
	fuzzy rules	***fuzzy algorithms***
	fuzzy graphs	***fuzzy topology***
	fuzzy logic (narrow)	***fuzzy X***
	...	...

- ***any field X can be fuzzified by replacing crisp sets in X by fuzzy sets***
- ***currently fuzzy logic (FL) is commonly used in its wide sense (FLw)***

EVOLUTION OF FUZZY LOGIC

- ***FLn is an extension of multivalued logic (Lukasiewicz, Post, Kleene)***
- ***in MVL there are more than two truth values (3-valued, 4-valued, n-valued, continuous-valued)***
- ***although multivalued logical systems have been in existence since the twenties, their impact has been very limited***
- ***most of the current applications of FL involve concepts which are not a part of MVL***
  - ***linguistic variable***
  - ***canonical form***
  - ***interpolative reasoning***
  - ***hedges (predicate modifiers)***
  - ***fuzzy quantification***
  - ***fuzzy probabilities***

In a sense, fuzzy logic may be regarded as a generalization of both multivalued logic and probability theory. However, the agenda of fuzzy logic is quite different from the agendas of classical logical systems. In essence, the distinct orientation of fuzzy logic reflects the fact that – unlike traditional systems – it is aimed at finding an accommodation with the pervasive uncertainty and imprecision of the real world. In particular, in contrast to classical logical systems, the inference processes in fuzzy logic are computational rather than symbolic. Thus, in general, inference in fuzzy logic reduces to the solution of a nonlinear program. This reflects the fact that in fuzzy logic a proposition is interpreted as a constraint on a variable, with constraint propagation playing the role of chaining and aggregation. A branch of fuzzy logic which plays a particularly important role in the representation and inference from common sense knowledge is that of dispositional logic. As its name implies, this logic deals with dispositions, that is, with propositions which are preponderantly but not necessarily always true, e.g., birds can fly, seat belts work, Swedes are blond, etc. A related concept is that of a subdisposition, which may be interpreted as an assertion concerning an increase in the conditional fuzzy probability which is implicit in the defining proposition.

WHAT IS GAINED BY FUZZIFICATION?

a. greater generality (carries a cost)

b. enhanced ability to model real-world systems

c. enhanced ability to exploit tolerance for imprecision

- ***fuzzy topology (a)***
- ***fuzzy arithmetic (a, b)***
- ***fuzzy logic (a, b, c)***
- ***fuzzy probability theory (a, b)***
- ***fuzzy group decision analysis (a, b)***
- ***fuzzy causality (a, b)***
- ***fuzzy control (a, b, c)***

▪ ***eventually most theories will be fuzzified***

Fuzzy logic is playing a key role in the conception and design of what might be called high MIQ (Machine Intelligence Quotient) systems. There are two concepts within FL which play a central role in its applications. The first is that of a linguistic variable, that is, a variable whose values are words or sentences in a natural or synthetic language. The other is that of a fuzzy if-then rule in which the antecedent and consequent are propositions containing linguistic variables. The essential function served by linguistic variables is that of granulation of variables and their dependencies. In effect, the use of linguistic variables and fuzzy if-then rules results – through granulation – in soft data compression which exploits the tolerance for imprecision and uncertainty. In this

HOW MUCH IS GAINED BY FUZZIFICATION?

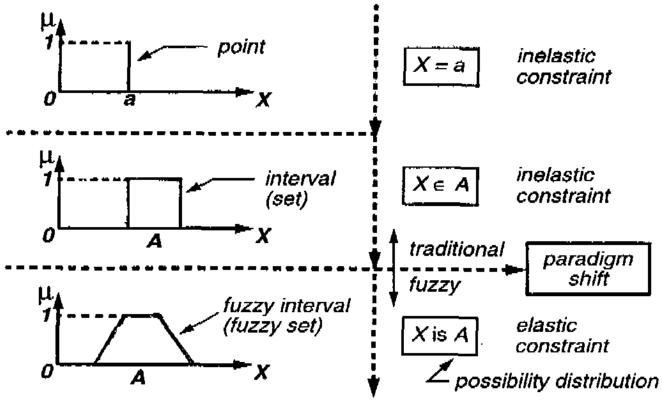
- ***control***
  - ***rule-based control***
  - ***task-oriented control***
- ***probability theory***
  - ***formulation of subjective probabilities***
- ***decision analysis***
  - ***group decision analysis***
- ***natural languages and knowledge representation***
- ***logic***
  - ***approximate reasoning***

respect, fuzzy logic mimics the crucial ability of the human mind to summarize data and focus on decision-relevant information.

Currently, many of the visible applications of fuzzy logic are in the realm of consumer products. But what is potentially more important is the impact of fuzzy logic on the basic sciences — especially in the domains of mathematical, physical and cognitive sciences.

In the realm of basic and applied sciences, the impact of fuzzy logic entails two paradigm shifts. In the first shift, a crisp theory X is fuzzified by replacing crisp sets in X by fuzzy sets. In application to basic fields such as arithmetic, topology, graph theory and probability theory, fuzzification leads to fuzzy arithmetic, fuzzy topology, fuzzy graph theory and fuzzy probability theory. Similarly, in application to applied fields such as neural network theory, stability theory and mathematical programming, fuzzification leads to fuzzy neural network theory, fuzzy stability theory and fuzzy mathematical programming. What is gained through fuzzification is greater generality, higher expressive power, an enhanced ability to model real-world problems and, most importantly, a methodology for exploiting the tolerance for imprecision — a methodology which serves to achieve tractability, robustness and lower solution cost.

PROGRESSION FROM CRISP TO FUZZY



UNIQUE FEATURES OF FL

- ***FUZZIFIABILITY* (any theory can be fuzzified)**
  - ***fuzzy control theory***
  - ***fuzzy neural network theory***
  - ***fuzzy genetic algorithms theory***
  - ***fuzzy probability theory***
  - ***fuzzy arithmetic***
- ***INFORMATION GRANULARITY***
  - ***fuzzy if-then rules***
  - ***fuzzy graphs***
  - ***rough sets***
- ***RULES OF INFERENCE***
  - ***generalized modus ponens***
  - ***syllogistic reasoning***

COMPUTATION WITH LINGUISTIC VARIABLES

- ***fuzzy numbers***

Dana is young

Tandy is a few years older than Dana

Dana is (young + few) years old

box A contains several large balls

box B contains a few large balls

contents of A and B are put in C

C contains ?X large balls

C contains (few + several) large balls ?

C = A U* B ***U* = multi-set union***

In the second shift, the concept of a theorem is broadened, leading to the concept of a fuzzy theorem. As its name suggests, the premises and conclusions in a fuzzy theorem are fuzzy rather than crisp. A fuzzy theorem may be categorical, e.g., *If X and Y are large numbers, then so is X + Y.* More generally, a fuzzy theorem may be dispositional, as in: *usually* (if most A's are B's and most B's are C's, then at least a few A's are C's). The importance of the concept of a dispositional fuzzy theorem derives from the fact that in many cases it may not be possible to formulate and prove a crisp theorem – or even a categorical fuzzy theorem – which captures the complexity of a real-world problem. In such cases, a dispositional fuzzy theorem may provide a way of achieving a compromise between precision and relevance.

In coming years, problems relating to the analytical aspects – and especially the semantic aspects – of natural languages are likely to play an increasingly important role in fuzzy logic and its applications. In this realm, what is emerging now is a methodology based on fuzzy logic that may be referred to as *computing with words* (CW). In CW, a word is viewed as a label of a granule, that is, a fuzzy constraint set whose elements are drawn together by similarity. In essence, computing with words involves an explicitation of fuzzy constraints and their propagation to conclusions which are expressed in a natural language. These and other issues relating to fuzzy logic and its applications are addressed and illustrated by examples.

Biographical Note

Adapted from the Profile in *IEEE Spectrum, June 1995, pp. 32-35*

Lotfi A. Zadeh was born in 1921 in Azerbaijan. When he was ten his family moved to Iran. From an early age his ambition had been to become a professor of Electrical Engineering; at the University of Teheran he earned a B.S. in that subject. But feeling he could not do real scientific work in Iran, he emigrated to the United States. In 1946, having earned a M.S. at M.I.T., he moved to New York City to join his family. He became an instructor at Columbia University, and completed his Ph.D. there in 1949. He soon became well-known in the field of analysis of time-varying systems.

An unexpected offer from the University of California at Berkeley presented him with the challenge he thought was missing in his comfortable post at Columbia. He has never regretted moving to Berkeley, where he became Department Chairman and is now Professor Emeritus. He soon recognized the importance of computers to electrical engineering, and his "polite persistence" overcame those colleagues who considered the computer trend a fad. In 1967 his unit became the Department of Electrical Engineering and Computer Sciences.

In 1961 he wrote that traditional techniques of system analysis were too precise for real-world problems; a new one was needed, a "fuzzy" kind of mathematics. Its formulation itself was fuzzy until 1964, when a canceled dinner engagement gave him some hours to imagine the theory of fuzzy sets. After leaving the department chairmanship in 1968, he had time to promulgate it. It was immediately controversial, mostly because of the name he gave it; he knew it would be, but finding no better one, proceeded without regrets. "I think it is better to be visible and provocative than to be bland."

Provocative Indeed! "Fuzzy theory is wrong, wrong, and pernicious. The danger ... is that it will encourage the sort of imprecise thinking that has brought us to so much trouble." (William Kahane, Professor of Computer Sciences and Mathematics at Berkeley, 1975). "No doubt Professor Zadeh's enthusiasm for fuzziness has been reinforced by the prevailing political climate in the United States – one of unprecedented permissiveness... Fuzzification ...tends to result in socially appealing slogans unaccompanied by the discipline of hard scientific work." (R. E. Kalman, now Professor at Florida State University in Tallahassee, said this in 1972.) Former Senator William Proxmire, who announced "Golden Fleece Awards" for what he considered waste of government money, suggested to the National Science Foundation, which funded much of Zadeh's work, that it qualified for such a nomination.

The Japanese, however, took fuzzy theory seriously, and applied it, to Zadeh's surprise, to ingenious consumer products: controlled temperature shower heads, washing machines, air conditioners, cameras, automobiles, etc., etc. Hundreds of books and thousands of technical papers have been published on fuzzification, and Zadeh has earned prestigious awards: the Japan Honda Prize (1989), and the Institute of Electrical and Electronics Engineers Medal of Honor (1995). Zadeh said: "The important criterion of your impact is: has what you have done generated a following? With fuzzy sets, I can definitely say 'Yes'."