The Obstacles to Teaching Fuzzy Set Theory and Its Applications

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Abstract

One goal of an engineering curriculum is to produce graduates who are knowledgeable in current technology and practices. One of the better ways to do this is to provide a variety of senior-level technical electives in new and popular technology areas. The danger inherent in this is that many undergraduates are unprepared for exposure to these topics due either to a lack of prerequisite material or technical maturity. Further, inappropriately scoped technical electives can leave an undergraduate too specialized for their potential career path. This paper will address the issues of prerequisite material and specialization in the area of fuzzy set theory and its applications. It will be shown that there is little or no significant prerequisite material problems for most engineering majors and that an appropriate breadth-based approach to application areas can address the specialization issue. The results of teaching a quarter-long course in fuzzy sets for three years at the Milwaukee School of Engineering(MSOE) to electrical and computer engineers will also be presented.

Introduction

Fuzzy sets or fuzzy logic, as they are most often referred to, suffer from a number of problems in today's engineering marketplace. The first problem is the name itself, since their invention in 1965, the term "fuzzy" has been a significant source of confusion. To the uninitiated, saying that an engineering solution used "fuzzy logic" would normally cause immediate suspicion. Why would anyone want to use logic that was inexact? This is further compounded by the simplicity with which fuzzy sets and fuzzy logic can be implemented. In most cases the use of the functions MIN and MAX and simple first moment computation are all that is necessary to implement many fuzzy systems. Hence, a large number of engineers were using fuzzy logic without understanding why or how it worked and could not rigorously defend their use of the approach.

Having been exposed to fuzzy sets as a graduate student at Rensselaer Polytechnic Institute I had always considered the possibility of teaching a course in that area. In the 1991 technology issue of *IEEE Spectrum* I noted that fuzzy logic was mentioned in almost all the technology areas presented [1]. I made a proposal to my department chair to develop a senior technical elective in fuzzy logic which was accepted. I rapidly realized that I was facing two major obstacles. 1) Could students in a mathematical theory limited electrical engineering curriculum be able to grasp the fundamentals of fuzzy sets and still leave time for some practical uses. And 2) could sufficient breadth of material be presented so that the students would not be too specialized at such an early stage of their careers.

In the following sections this paper will address the stumbling blocks to teaching fuzzy sets. The first issue addressed will be the mathematical background in students that is necessary to teach fuzzy set theory. Suggestions on how to avoid limiting the topical scope of such a course (in a 10 week term) to just the theory and applications of fuzzy sets to control will then be presented. Finally the results from teaching EE481 - Fuzzy Sets and Applications over three academic years will be presented.

Prerequisites for Teaching Fuzzy Sets

The prerequisite requirements for fuzzy sets are relatively straightforward. Essentially fuzzy sets are an extension to traditional set theory where membership in a set is not restricted to completely a member and completely a non-member. Hence, the use of the term "fuzzy" since the set boundaries are no longer crisply defined. Unfortunately the Milwaukee School of Engineering does not require discrete mathematics for most engineering disciplines with the exception of computer engineering. Since the initial target for this material was electrical engineers, this presented a potential problem.

Fortunately it is not necessary to spend an inordinate amount of time in covering classical set theory to most engineers. The typical engineering curriculum (and especially electrical and computer engineering) has a requirement for a course in digital logic. A necessary component of this course is the study of Boolean algebra. Boolean algebra has a special relationship with set theory called duality. This means that both mathematical systems describe the same features using different notation. The AND, OR, and NOT of Boolean algebra are functionally identical to the INTERSECTION, UNION, and COMPLEMENT of set theory. This relationship can be established and demonstrated to most students in less than two class periods. Thus, the primary prerequisite for fuzzy sets is virtually any course in digital logic.

This, though, is not usually quite enough. In order to properly demonstrate the usefulness of fuzzy sets, most students need a variety of non-fuzzy approaches with which to compare. Generally senior standing is sufficient to address this issue, but previous course material in classical controls and artificial intelligence is also useful. The former because the primary application of fuzzy sets is to engineering control and the latter usually covers most of the remaining areas to which fuzzy sets have been applied. At MSOE the only formal prerequisite is digital logic and most students have previously taken or are currently taking a course in controls. Artificial intelligence is generally not taught until later in the school year.

Providing Breadth to a Course in Fuzzy Sets

Due to limitations in the number of technical electives that the typical engineering student has the time to take, most students are better served by electives which provide exposure to a number of topics. If the technical electives only provide intense specialization then many students will be ill-served and poorly prepared to adapt to new technical areas or to apply their specialized knowledge to new areas. The limitation of the quarter system (10 week terms) makes it all too tempting to develop a fuzzy sets course which would cover the basics and then concentrate on using fuzzy sets for control. This would not provide adequate breadth of material.

In reality, fuzzy set theory, provides an excellent forum for presenting material on a wide variety of engineering fields and applications. This is because fuzzy logic can be applied almost anywhere that non-linear systems must be modeled or where decision making and classification are an issue. It is possible to provide one or two lecture sequences in applying fuzzy logic to the areas of reasoning, control, databases and information retrieval, diagnosis, image recognition and segmentation, expert systems, and adaptive systems and neural networks

In many cases this is the first introduction most students have to these topical areas so they see a variety of applications. The scope of the course can be broadened further by having the students teach themselves. (Which is useful in its own right.) By requiring a research project into an application of fuzzy sets the students find any number of interesting uses for the theory they've just been taught. This need be nothing more than a literature search with a written summary.

The real benefit comes from requiring the students to present their findings to the rest of the class in short (10 minute) presentations. (Another useful thing for students to learn how to do.)

Results of Teaching Fuzzy Sets to Undergraduates

The course EE481 - Fuzzy Sets and Applications has been taught four times over the past four years at MSOE. The primary target for the course has been electrical engineering students, but some computer engineering and electrical engineering technology students have taken the course as well. The enrollment has been 20 students in Spring 1993, 6 students in Fall 1994, 23 students in Fall 1995, and is scheduled to run in Winter 1997. This makes this a fairly popular course since MSOE graduates about 50-60 electrical engineers each year.

In general the students have done well with the theoretical aspects of the course. Most have been adequately prepared and the only trouble area seems to be in understanding the full impact of associativity and commutativity to a mathematical operator. Some complaints have been made that there is too much math, but that is more a side-effect of the generally application orientation of the electrical engineering curriculum at MSOE.

The Table 1 below summarizes the topic choice for student presentations. Overall there are 15 different topical areas represented from many aspects of engineering (not just electrical engineering). Automotive applications seemed to be very popular this year which reflects a trend of more fuzzy theory being used to improve automotive performance.

Topical Area	Spring 1993	Fall 1994	Fall 1995
Power Systems	2	1	
Management and Business	1	1	
Application Tools	1		
Consumer Products[1]	3	1	2
Adaptive Control	2	1	
Neural Networks	3		1
Genetic Algorithms	1		
Robotics	2		3
Decision Systems and Classification	2		
Automotive Applications[2]	1	1	6
Control	1		4
Image Processing	1		
Hardware Implementations		1	1
Biomedical			1
Recognition Systems			5

1. Washing machines, camcorders, microwave ovens, etc.
2. Transmissions, braking, suspension, idle control, etc.

Table 1 – Topical distribution of student presentations in EE481

The success of teaching fuzzy sets to engineers with an undergraduate education has not been limited to electrical and computer engineers. In 1994 a tutorial on the mathematical foundations of fuzzy sets and fuzzy logic was presented at the industry conference Fuzzy Logic '94 [2]. Engineers representing a wide number of disciplines were present with the majority of the feed back being positive.

Conclusions

Fuzzy sets and their applications can be successfully taught to undergraduate engineers. The prerequisite obstacles are not extensive with a primary requirement of digital logic and the experience level of engineers. In addition, fuzzy sets and their applications also provide excellent material for a senior technical elective. By appropriately structuring the course any number of applications can be presented from many facets of engineering. This serves to broaden the appeal of the course as well as to prepare the engineering student to be at least aware of many technical areas.

References

[1] *IEEE Spectrum*, January, 1991.

[2] Welch, Henry L., "Fuzzy Logic and How it Works: A Mathematical Introduction," Proceedings of Fuzzy Logic '94, San Diego, CA, September, 1994.

Biography

Dr. Henry L. Welch is an Associate Professor of Electrical Engineering and Computer Science at the Milwaukee School of Engineering. He earned his Ph.D. in Computer and Systems Engineering from Rensselaer Polytechnic University in 1990. His primary teaching areas are in digital circuits, microprocessor systems, and advanced computer engineering topics such as computer graphics and fuzzy logic.