MY FIRST TWO DECADES WITH THE SCHOOL OF FUZZY-ISM*

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To the scientists and engineers who have contributed so much to the notion of graded membership inherent to the human cognitive faculty.

1. THE FIRST DECADE (1968-77)

A beautiful blanket wraps our scientific environment and thoughts, but it is woven with fragile threads of two kinds of uncertainty. The first one arises from the physical, chemical and biological systems and the second one from the human cognitive faculty; that is, thinking, reasoning and perception. A disdainful act towards this wrapper may break the fragile threads and then our thoughts will be just naked, emotionless and impotent. Let us create more respect for this fragile uncertainty and generate intelligible rules for its morphology.

1.1 Entrance to the School of Fuzzy-ism

The theory of deterministic systems and stochastic processes has been an integral part of my graduate studies, teaching and research. In fact, I was, and I am still, a member of the school of determinism and stochasticism. Professor Lotfi A. Zadeh created a new mathematics [1] to give a formulation to the uncertainty which arises from human thinking, reasoning, cognition, mentation and perception. It was in the month of August, 1968, two decades ago, that I had the first opportunity to listen to Professor Zadeh, the founder and exponent of the '*School of Fuzzy-ism*' at the Symposium on System Sensitivity and Adaptivity held under the auspices of the International Federation of Automatic Control (IFAC) at Dubrovnik, Yugoslavia [2]. His lucid exposition on Fuzzy Set Theory aroused my interest in this new class of uncertainty and mathematics, and since then I have been a student of the '*School of Fuzzy-ism*' as well.

On the first day of the IFAC Symposium, while I was having my breakfast, and at the same time glancing through the symposium preprints, my attention was drawn to the kind words '*May I join you for breakfast*?' I looked up and saw a smiling gentleman with a beautiful young lady. They introduced themselves as Lotfi and Fay Zadeh from the University of California, Berkeley. Though I had extensively studied some of Zadeh's previous work on the state variable approach, frequency analysis of time-varying systems and other famous works in the systems theory, this was the first time that I met this admirable person and his kind wife. Indeed, it was a great honour to meet such an academic personality and a privilege to have the couple join me at breakfast. After some usual greetings, Professor Zadeh started talking about some of his recent work on the theory of fuzzy sets. He explained to me the notion of the theory and graded-membership functions. He elucidated that this notion captures the uncertainty that is associated with our cognition and perception in examples, such as, 'Mary is *young*', 'she is *very old*', 'John is *very kind* but *highly temperamental*', and 'Lydia is *more or less* a happy person',

etc. Since I was brought up in the school of stochasticism, it was beyond my cognition to capture the significance of the uncertainty in these examples.

I did attend the plenary session at which Professor Zadeh introduced the notion of fuzzy sets. The theory was founded in 1965 [1], but most of the participants, like me, were not aware of it. In fact, I heard someone say 'Is Lotfi drunk?' During this symposium, I had the honour of spending much time with Lotfi at the technical sessions, social gatherings and sightseeing trips. During these trips, which were joined by many scientists from the USSR, I remember Lotfi ordering special vegetarian meals for me.

1.2 After Dubrovnik

Since I had a great deal of respect for Professor Zadeh's earlier work, this meeting at Dubrovnik increased my interest in studying his work on fuzzy sets. On my return to the University of Saskatchewan, I continued my casual interest in the field by occasionally reading the literature, but without much excitement. It was in 1972 that I came across some very interesting and convincing papers [3-9] which reawakened my interest in the theory of fuzzy sets.

During these studies I soon realized that the 'lack of uncertainty', and the excess of precision and certainty in our engineering design, decision and control problems, were providing us with unrealizable solutions. The certainty (precision) has become an absolute standard and far too often it is introduced into our scientific work without much thought or feeling. Precision is the attribute which does not exist in the cognitive faculty of humans. A baby of one week starts recognizing his mother by smiling at her, but the recognition of his mother and his environment is not 'precise'. This same imprecision and uncertainty plays an important role in thinking and reasoning throughout his life.

Control systems scientists realized the importance of this kind of uncertainty and I was invited to organize a special Round Table Discussion on 'Estimation and Control in a Fuzzy Environment' at the Third IFAC Symposium on Identification and Parameter Estimation held at the Hague, The Netherlands, in June 1973 [10]. Panel members of international repute from North America, USSR and Europe were invited to present their views on the subject, followed by a long but lively discussion. This discussion provided a basis for understanding the notion of the theory and opened challenges for further theoretical studies and applied research in the field [10]. The discussion (which lasted over six hours with a participation of over 125 people) inspired many new and young researchers in the field of control systems and decision analysis.

Following this, a very successful U.S. - Japan Seminar on 'Fuzzy Sets and Their Applications to Cognitive and Decision Processes' was held at the University of California, Berkeley, in July, 1974 [11]. This was the first seminar of its kind and many interesting theoretical developments, as well as some applications, were presented. Some important papers then appeared in a volume edited by Zadeh, Fu, Tanaka and Shimura [11].

Following the success of the session at the Hague, I was invited to organize and chair the Second IFAC Round Table Discussion on 'Fuzzy Automata and Decision Processes' at MIT during the Sixth Triennial World IFAC Congress at Boston/Cambridge, August 24-30, 1975 [12]. A panel of researchers from various institutions around the world were invited to present their research results. Professor Zadeh, as usual, emphasized the importance of this theory in decision making processes. In fact, the presentations at this discussion session were an integrated and balanced mixture of both theory and applications [13].

Also, during these years, two very well written texts appeared in the field by Kaufmann [14], and Negoita and Ralescu [15]. These two texts provided students and researchers with a unified treatment of the theory.

In 1977 I was invited by Professor King-Sun Fu to organize a special symposium on Fuzzy Set Theory and Applications as part of the IEEE-CDC held at New Orleans. Though some sessions were organized during the past as a part of the IEEE-CDC, JACC, and IFAC symposia, this special symposium was overwhelmingly successful as it brought many control system scientists, particularly from North America, closer to the theme of fuzzy sets and possibility theory. Again, perhaps it was the influence of the IEEE-CDC Symposium Chairman, Professor Fu, and the zest of Professor Zadeh, that the notions of fuzzy set theory with its possible applications were introduced to systems scientists.

Towards the end of my 'first decade' with the school of fuzzy-ism, a new edited volume entitled 'Fuzzy Automata and Decision Processes' appeared [16, 17].

The first decade of the theory, and my first decade with the school, exhibited an exponential growth [17], from a mere two publications in 1965, the year it was founded, to about 100 by 1973, the year of the first IFAC Round Table Discussion Session at the Hague, 450 by the time of the IFAC Congress at Boston/Cambridge in 1975 and over 600 by the end of May 1976. (See the annotated bibliography in [16].)

In my view, the reasons for this impressive growth in the field may be attributed to: (i) the importance of the notion of fuzziness in our decision making processes and

scientific work, and (ii) the boldness, scientific talent, missionary zest, and great energy of Professor Lotfi A. Zadeh.

In my own studies, this theory provided me with many intellectual and scientific relevations. I applied the theory to both feedback control and medical diagnostic problems. This, then is the story of my first decade of happy association with the *School of Fuzzy-ism*.

2 THE SECOND DECADE [1978-88]

2.1 Publication of Some Important Books and Journals

My second decade with the school of fuzzy-ism started with the introduction of a new journal, 'International Journal of Fuzzy Sets and Systems', under the editorship of Professor H.J. Zimmerman (Principal Editor), Professor C.V. Negoita and Professor L.A. Zadeh [20]. Naturally, our fuzzy community was delighted to have its own journal. I was asked to organize a round table discussion session at the Seventh Triennial IFAC World Congress held at Helsinki in June, 1978. This session was attended by numerous researchers from the USSR, Eastern and Western Europe, Japan and North America [21].

I was delighted to see my second volume published on the subject, including new theoretical works and applications, and an extended set of bibliographical material [22]. A book authored by Dubois and Prade [23], which contained many seminal works by the authors also appeared in 1980.

There were many important achievements during this second decade, but since I would like to be brief I will only mention the most important events with which I was associated.

2.2 Under the Mango Tree and the Founding of the NAFIP*

It was in 1980 that I was asked to organize some special sessions at the International Congress of Applied Systems Research and Cybernetics held at Acapulco, Mexico, December

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* In May 1987 I was invited to deliver the K.S. Fu Memorial Lecture at the Founders Session of the NAFIP Society held at Purdue University. In this lecture I briefly gave some historical accounts on the evolution of fuzzy set theory including a brief account of the incident under the mango tree. Professor M.N. McAllister, the Bulletin Editor of the International Journal of Approximate Reasoning, invited me to write these accounts in detail, and I am glad that I am able to do so now after a period of over one year or so.

12-15, which was attended by many international researchers from our fuzzy community [24].

After dinner, Lotfi invited some members of the fuzzy community for an 'usual' informal discussion. It was a very pleasant evening, and we were sitting around a big table within a grove of trees in the hotel yard. The full moon was throwing rays on to the nearby beach, and our group was engaged in informal discussions on various issues in the field. I presented a proposal to organize our own formal group or society in North America, similar to what Japan and Europe had. My proposal was turned down with much skepticism. Suddenly, an object dropped on the table almost hitting me. The first thought evolving from my cognitive faculty was that it was the effect of some skepticism. However, when I picked up the object and used my natural sensors, the vision and the touch, I perceived it to be a ripe mango, and we soon realized that we were sitting under a mango tree. It was a very sweet mango. Indeed, according to my grandmother back in India, an incidental acquisition of a 'fruit' or a 'flower' is an indication of a good omen.

On our return air trip from Acapulco, several of us flew together to Los Angeles. I raised the issue of forming a fuzzy group in North America with Enrique Ruspini. His very positive attitude delighted me and I immediately arranged a brief meeting in the plane with Enrique Ruspini, Jim Bezdek and myself. The response was very positive and I was asked to discuss the proposal further with Lotfi. I proposed the tentative name 'North American Fuzzy Information Processing (NAFIP) Group'. On my arrival at Saskatoon, I phoned Lotfi Zadeh who encouraged me to proceed with the NAFIP proposal and suggested that I request Professor King-Sun Fu to formalize such an organization. Professor Fu supported the idea of NAFIP, but he felt that he was too busy to accept an additional responsibility. However, after some persuasion I assured him that an incremental change in his work load would be only by an ϵ - amount, and he luckily agreed to formalize and chair the organization. Professor Fu called for a meeting at the 1981 IEEE-CDC to be held at San Diego in December. Thus, the North American Information Processing (NAFIP) Group, which was conceived at Acapulco in December 1980, was born in December 1981 with Professor King-Sun Fu as its first President, and Professor Lotfi A. Zadeh as a life member.

The NAFIP Group has since then had annual meetings, and after some time the status of the group was elevated to the NAFIP Society. This year the society met at San Francisco, near Berkeley, the birth place of Fuzzy Sets, celebrating its twenty-third birthday. Subsequently, the NAFIP Society joined the International Fuzzy Systems Association. Recently, a new journal, 'International Journal of

Approximate Reasoning', published under the auspices of NAFIP [25] came into being under the editorship of Dr. Jim Bezdek. Dr. Didier Dubois and Dr. Henri Prade introduced a bulletin, 'BUSEFAL', for the rapid publication of the results in the field [26]. Indeed, BUSEFAL is now doing a great service to our growing fuzzy community.

With the co-operation of Elie Sanchez, I edited two more volumes on the theory and applications of fuzzy sets [29, 30]. And under the auspices of the IFAC, and jointly with Elie Sanchez, we were able to have our own truly first international conference on 'Fuzzy Information, Knowledge Representation and Decision Analysis' at Marseille, France [31]. During this period, I had the opportunity to travel to the People's Republic of China where we also held a successful workshop on fuzzy set theory and participated in the conference in the field [27].

Through the efforts of Professor D.K. Dutta Majumder of the Indian Statistical Institute, Calcutta, and Professor Mihir K. Chakraborty of Calcutta University, we were able to form a group in India, the Indian Society of Fuzzy Mathematics and Information Processing (ISFUMIP), thus, bringing many Indian scientists and mathematicians together in the field.

Between 1965 and now, many more interesting events have occurred. With the co-operation of Professor Arnold Kaufmann, we authored the book 'Introduction to Fuzzy Arithmetic', 1985 [32]. This widely cited book has gained a profound acceptance from students as well as researchers. The co-operative efforts with Kandel, Bandler, and Kiszka resulted in another edited volume [33].

In 1981, Pergamon Press, Oxford, under the editorship of Dr. M.G. Singh and with 27 subject editors, launched the Systems and Control Encyclopedia. I was the subject editor of Fuzzy Systems and Pattern Recognition. The contribution from the fuzzy community to this encyclopedia is greater than 12% with over 150 major titles dealing with the theory and many interesting applications. This encyclopedia appeared in eight volumes in 1987 [35, 39].

More recently, Professor A. Kaufmann and I authored another book on 'Fuzzy Mathematical Models in Engineering and Management Science', the first book of its kind. With the co-operation of Dr. T. Yamakawa, two more volumes [37, 38], have been edited.

During this decade, I have had the opportunity and honour of visiting many scientific laboratories around the world, and attending many international conferences, especially in the area of fuzzy sets and systems.

I would like to recall an incident during my visit to the People's Republic of China in July, 1987. The Vice-Governor of Guangzhou Province had arranged a banquet at Guiyang during the International Symposium on Fuzzy Sets and Knowledge Engineering. At this banquet, to my surprise, I was served special vegetarian meals. I was quite impressed by the Chinese hospitality, and when I asked the Vice-Governor how he knew that I was a vegetarian, his response was 'We know everything about you!'.

I also was quite impressed by the work that is being carried out in the eastern part of the world (India, Japan, China). As some one pointed out, the intellectual traditions of the '*east*' are more amenable to the graded membership than those of the '*west*'. For example, a North American politician may be using '*yes*', '*no*' (*crisp sets*) during a discussion, while a good Japanese politician will always use '*maybe*' (*a fuzzy set*).

During the present decade, my own laboratory was honoured by many visits from Professor Zadeh. In fact, Professor Zadeh gave a new name to my laboratory, Intelligent Systems Research Laboratory (old name: Cybernetics Research Laboratory). Also, I have had the honour of working with many international colleagues and students. Recently, the Natural Sciences and Engineering Research Council of Canada (NSERC) recognized the work of my laboratory by citing our project on 'Fuzzy Logics and its Applications' and giving it a special merit award.

3. EPILOGUE

From the purely mathematical viewpoint, the evolution of the theory is very exciting, but complex. Many scientific theories start by borrowing notions from the already developed areas of mathematics but, in this case, Professor Zadeh introduced the basic notion of 'vagueness' which has no sharp morphology and which is so common in human cognitive processes.

Indeed, Professor Zadeh laid the foundation of fuzzy mathematics on a very robust rock. It now serves the needs of many existing scientific disciplines, but equally important is the fact that many new disciplines, such as the study of neural networks, have started arising around this mathematics. Thus, this mathematics has united several noble (both old and new) narrow streams of scientific disciplines into one, while at the same time instilling life into several other streams that have been dormant.

The study of such a formless uncertainty provides us with a scientific challenge. Scientists have now started to think of giving a morphology to this amorphous uncertainty.

In the past, mathematicians have disdained this challenge and have increasingly chosen to flee from natural mentation by devising theories unrelated to human perception, feelings and emotions.

Indeed, the applications of these fuzzy sets, which were once thought to be dull and dry, can be found in many scientific and scholarly works. It is true that Boole introduced the beautiful notion of binary sets which are so pervasive in our digital world, however, this beauty is naked without any adornment. Boolean logic is unable to model the human cognition and thinking process. This is the very reason why no one is indifferent today to the logic of fuzzy sets. In fact, many view their first encounter with fuzzy logic as a totally new and exciting experience in their scientific life.

Since 1968, when the notion of fuzzy mathematics was first introduced to me, I have done many studies on this topic. These studies have brought many intellectual and scientific revelations to me. Presently, I am engaged in several scientific studies using fuzzy logic. For example, the research in my laboratory is heavily committed to cognitive uncertainty through such studies as neural networks and neural computing, signal and image processing, cognitive information processing, cognitive vision fields, perception, etc., with applications to intelligent robotic systems, medical imaging and computer vision. I found recently the application of the calculus of fuzzy logic and the framework of neural networks the most exciting and challenging one in my work on the biological basis for the machine vision: emulation of vision at the retinal and cortex levels.

I started this story of '*two-decades*' with an incident at the breakfast table at Dubrovnik in 1968. Now I will finish it with a recent breakfast meeting with Dr. Jerzy Kiszka and Dr. Witold Pedrycz in Saskatoon. It was on July 15 1988, almost two decades after the first incident, that we were discussing several issues including historical incidents of the fuzzy sets. It was realized that somehow the word 'fuzzy' bears a negative connotation. It was suggested during the discussion to use a synonym '*nebulous sets*'. Nebula (n) means an interstellar mass of cloudlike appearance and gaseous matter in various degrees of density. While nebulous (adj) means vague, unclear, fuzzy, cloudlike, misty. The word '*nebulous*', which is related to a natural phenomenon, may not have a negative connotative effect on many of our researchers working in the field. However, the word '*fuzzy*' is now very widely accepted, and I do not suggest any changes in spite of some negative connotation in the minds of a few who still can not capture the beauty of the fuzzy sets inherent in the human cognitive uncertainty.

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