A Tribute to Prof. Lotfi A. Zadeh

Ch. Aswani Kumar

*School of Information Technology & Engineering
VIT University, Vellore, India
cherukuri@acm.org*

Published 20 November 2017

Prof. Lotfi Aliasker Zadeh, father of fuzzy set theory and fuzzy logic and a world-renowned scientist has passed away on 6th September 2017. Prof. Zadeh was born on 4th February 1921 in Baku, Azerbaijan to Rahim Aleskerzade and Fanya Korenman. He attended elementary school in Azerbaijan and moved to Iran in 1931. He graduated in electrical engineering in 1942 from the University of Tehran. During World War II, Dr. Zadeh worked along with his father for American soldiers

supplying them the building and hardware materials. Later, his family moved to the USA in 1943 and changed his name to Lotfi Asker Zadeh. He received his master's in electrical engineering from Massachusetts Institute of Technology in 1946 and Ph.D. from Columbia University in 1949. He worked as a faculty at Columbia University from 1946 to 1959. During this period, Dr. Zadeh has made significant contributions on frequency analysis of time-varying networks. He worked along with Dr. John R. Ragazzini on z -transformations, which is mainly used in signal processing applications. Dr. Zadeh's work was focussed on applications of mathematics to real world problems.

In 1959, Dr. Zadeh moved to Electrical Engineering Department of University of California, Berkeley (UCB) in 1959. His initial contributions in UCB were focussed on system theory, optimal control, time-varying systems and system identification. He was appointed as department chair in 1963. Understanding the significance of computer technology, emerging those days, Dr. Zadeh has transformed the Electrical Engineering Department to Electrical Engineering and Computer Science (EECS) department, which is now one of the top-ranked department for Computer Science in the world. Later, several universities have followed this transformation. He had visiting positions at MIT; Princeton; Stanford; IBM Research Laboratory San Jose, CA. Since 1991, he is serving as Professor Emeritus and Director of Berkeley Initiative in Soft Computing (BISC), University of California, Berkeley.

Dr. Zadeh realised the need for a set with unsharp boundaries while drafting his book *Linear System Theory — The State Space Approach* in 1963. To meet that requirement, he formulated fuzzy set in 1964 and published the same in 1965. The classical set theory provides a sharp boundary that separates the objects belonging to a set and the objects that do not belong to the set. Fuzzy set uses a membership function that maps the given object to a real number in the interval $[0,1]$. Hence an object x will belong to a fuzzy set A with a membership value, say 0.3, which is derived from the membership function of the fuzzy set.

Later, investigations of Dr. Zadeh were focussed on extending this fuzzy set principles to fuzzy relations, fuzzy propositions and to fuzzy logic. He introduced linguistic variable in 1973 which is used in approximate reasoning and fuzzy if then rules. Age is the best example of a linguistic variable having the values such as young, middle-age, old. Linguistic variable is also known as granular variable and the values are information granules. Introducing linguistic variables is a significant contribution in the direction of computing with words. Through this theory, Dr. Zadeh proposed that use of membership functions, fuzzy logic, and fuzzy set theory is more natural and understandable than with probability and density functions. His viewpoint was that in order to replicate the remarkable capability of humans in reasoning and decision making based on perceptions, which are essentially fuzzy in nature, requires generalised logical systems such as fuzzy logic. Humans are having certain remarkable abilities such as conversing, thinking, reasoning and derive logical decisions even with imprecise, uncertain and partial information. Fuzzy logic provided a means with which one performs precisiation of the imprecision in the real world.

As mentioned by Dr. Zadeh, fuzzy logic has different facets including: fuzzy logical facet, fuzzy set theoretic facet, fuzzy epistemic facet and fuzzy relational facet. Logical facet of fuzzy logic generalises the multivalued logic. Fuzzy set theoretic facet provides classes with unsharp boundaries which are the backbone of fuzzy logic. Knowledge representation and natural language processing are handled in the epistemic facet of fuzzy theory. Linguistic variables and their dependencies in the form of fuzzy if-then rules are described in the relational facet.

While this theory was well appreciated by famous mathematicians such as Dr. Garrett Birkhoff, the kind of criticism, skepticism, and derision for his proposal during the early days was so profuse. One of the reasons for this criticism was that it has challenged other mathematical frameworks such as probability which are the backbone for modern artificial intelligence. Dr. Zadeh received this criticism with open hands. Undeterred by the criticism, he proved that fuzzy logic is a precise framework to handle imprecision in real world problems and to derive approximate reasoning. In spite of emotional criticism in the early days, his proposal attracted several young researchers which has resulted in a significant and focussed growth of the theory.

By the late 1970s and early 1980s, fuzzy logic and fuzzy mathematics were established with both strong theoretical foundations and a myriad of successful real world industrial applications. The theory was perceived first by the Japan Scientists who applied it in the Japan's Sendai underground train system for automatic control of the speed of the trains. Since then, the theory was widely applied in several

industrial applications including, medical diagnosis, NASA advanced piloting systems, consumer applications and currently in autonomous vehicles navigation.

During the last 50 years, fuzzy logic and fuzzy mathematics have penetrated into several scientific and engineering domains. In 1978, the first journal on fuzzy theory, *Fuzzy Sets and Systems*, was launched to advance the theory and applications. This was followed by several other dedicated societies, journals and conferences. Fuzzy logic was extended to fuzzy arithmetic, fuzzy linear programming, fuzzy control, fuzzy group theory, fuzzy topology, fuzzy stability, fuzzy probability, etc. Also several hybrid techniques such as neuro-fuzzy, fuzzy-genetic, fuzzy chaos, fuzzy-SVM, etc. were proposed. Dr. Zadeh introduced Soft Computing in early 1990s, extending fuzzy logic to other techniques such as neural networks, genetic algorithms, etc. In 1991, Berkeley Initiative on Soft Computing (BISC) was launched. In one of his papers published in 1994 entitled *Soft Computing and Fuzzy Logic*, Dr. Zadeh narrated the basic underlying ideas of soft computing. This theory has propelled several applications including scientific, commercial and consumer products. The models and techniques hybridised with fuzzy were proven to be better models of reality with tolerance to imprecision. Scholarly publications evidence the magnitude of fuzzy logic and fuzzy sets in different applications and theoretical investigations. A search on Google scholar shows 2,190,000 documents for the query *fuzzy set* and 1,470,000 documents for the query *fuzzy logic*. Dr. Zadeh's total citations are 180,555. His h-index is 104 and i10 index is 305. His first paper on fuzzy sets published in 1964 has 93,213 citations. These statistics are as on 12th October 2017. He has published more than 200 single-authored papers. Even at the age of 96 he continued his innovations and fundamental works.

For his outstanding and exemplary contributions, Prof. Zadeh received several honours and awards which include: Fellow of IEEE, ACM, AAI, IFSA; Member of

NAE, Academics of Sciences of Azerbaijan, Bulgaria, Finland, Poland, Korea. He received 24 honorary doctorates. He was the recipient of ACM Allen Newell Award, IEEE Medal of honour, IEEE Education Medal, IEEE Centennial Medal, Benjamin Franklin Medal, etc. He received 24 honorary doctorates from different universities in different countries.

Dr. Zadeh was a personality with care and concern for human values and a man of great humanity. While he pioneered the progress of computer science as discipline, Dr. Zadeh had reservations about the work culture and cut-throat competition of silicon valley. In several interviews and lectures, he emphasised that dignity and collegiality are the two parameters that are to be considered along with the pay package during the selection of a work place. In one of the interviews, Dr. Zadeh quoted his philosophy of life as “*Try not to make enemies. Friends come and go, but enemies accumulate*”.

Dr. Zadeh married Fay Zadeh in 1946 and had two children, Stella Zadeh and Norman Zadeh. His wife Fay passed away this year and his daughter Stella passed away in 2006. Dr. Zadeh is a transnational personality with no boundaries as like his theory fuzzy logic. His demise is a big loss for the entire researchers’ families of soft computing and fuzzy logic, and the computer science academic fraternity. Dr. Zadeh left a great scientific legacy which would continue to inspire the curious minds.

Selected Publications of Dr. Zadeh

- Zadeh, LA (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353.
- Zadeh, LA (1968). Probability measures of fuzzy events. *Journal of Mathematical Analysis and Applications*, 23(2), 421–427.
- Zadeh, LA (1975). Fuzzy logic and approximate reasoning. *Synthese*, 30(3), 407–428.
- Zadeh, LA (1975). The concept of a linguistic variable and its application to approximate reasoning — I. *Information Sciences*, 8(3), 199–249.
- Zadeh, LA (1975). The concept of a linguistic variable and its application to approximate reasoning-III. *Information Sciences*, 9(1), 43–80.
- Zadeh, LA (1994). Soft computing and fuzzy logic. *IEEE Software*, 11(6), 48–56.
- Zadeh, LA (1994). Fuzzy logic, neural networks, and soft computing. *Communications of the ACM*, 37(3), 77–85.
- Zadeh, LA (1996). Fuzzy logic = computing with words. *IEEE Transactions on Fuzzy Systems*, 4(2), 103–111.
- Zadeh, LA (1997). Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. *Fuzzy Sets and Systems*, 90(2), 111–127.
- Zadeh, LA (2001). A new direction in AI: Toward a computational theory of perceptions. *AI Magazine*, 22(1), 73.
- Zadeh, LA (2008). Is there a need for fuzzy logic? *Information Sciences*, 178(13), 2751–2779.
- Zadeh, LA (2012). *Computing with Words: Principal Concepts and Ideas*, Vol. 277. Berlin: Springer.
- Zadeh, LA (2014). A note on similarity-based definitions of possibility and probability. *Information Sciences*, 267, 334–336.
- Zadeh, LA (2015). Fuzzy logic — a personal perspective. *Fuzzy Sets and Systems*, 281, 4–20.