

## A Tribute to Father of Fuzzy Set Theory and Fuzzy Logic (Dr. Lotfi A. Zadeh)

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### Who he Was?

The legend and great Artificial Intelligence expert and father of Fuzzy Mathematical Logic Dr. Lotfi A. Zadeh passed away on September 6<sup>th</sup>, 2017 at the age of 96 years [1].

Every person related to Artificial Intelligence field must know about Dr. Lotfi A. Zadeh, the father of Fuzzy mathematics and Fuzzy Logic, a legend, a great and well-known professor, computer scientist, electrical engineer and artificial intelligence researcher. His full name was Lotfi Aliaskar Zadeh and was born on 4<sup>th</sup> February 1921 in Baku, Azerbaijan to a Muslim journalist father Rahim Aleskerzade from Ardabil (Iran) who shifted to Azerbaijan for his job, and Russian Jewish mother Fanya Korenman, a medical doctor, also from Odessa (Iran) [2].



Figure 1: Dr. Lotfi Zadeh.

### Education and Working

His elementary schooling for three years was from Azerbaijan and according to Dr. Zadeh "that schooling time had a significant and long-lasting influence on my thinking and on my way of looking at things" [3]. After that he shifted to Tehran (Iran) in 1931 with his parents, when his age was 10 years. In Tehran he was admitted to Alborz College, an American missionary school where he met with Fay who became his wife in future.

He got his Electrical Engineering degree from University of Tehran in 1942. This was the time when more than half of world countries were suffering from World War II, and about 30,000 American soldiers were in Iran due Iranian support for Germany in World War. Dr. Zadeh and his father started working for American soldiers; they provide them hardware and buildings related materials.

After that, in 1943 he with his family moved to the United States of America via Cairo and reached to Philadelphia in mid-1944, where he

changed his name from Lotfi Aliaskar Zadeh to Lotfi Askar Zadeh. In USA, he got admission in Massachusetts Institute of Technology (MIT) for Master's in Electrical Engineering and graduated in 1946. Later, in 1949 he got his PhD in Electrical Engineering from Columbia University, USA.

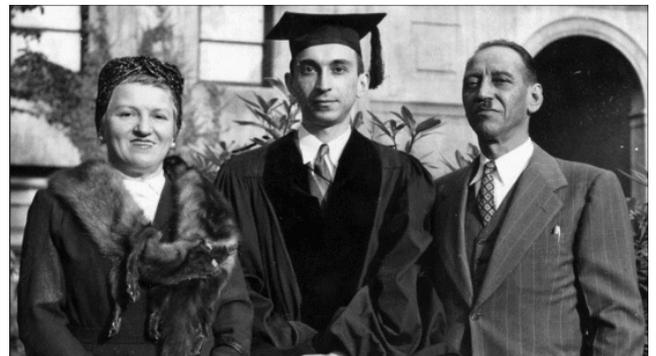


Figure 2: Dr. Zadeh at PhD Graduation, Columbia University, New York 1949.

For 13 years Dr. Zadeh worked at Columbia University from 1946 to 1959 as a faculty member; there he contributed by working on frequency analysis of time-varying networks and conducted fruitful and significant research in this field. He worked on z-transformations with collaboration of Dr. John R. Ragazzini, and z-transformation is used very much in signal processing applications. The work done by Dr. Zadeh was mainly focused on applications of mathematics to real life problems [4].

Dr. Zadeh was moved to Electrical Engineering Department University of California, Berkeley (UCB) in 1959 and started working on optimal control, time varying systems, system theory and system identification etc. Due to his dedication, hardworking and research work he was appointed as department chairman in 1963; there he founded and analyzed the importance of emerging computer science and electrical engineering fields, so he emerged computer science department with electrical engineering and new department was named as Electrical Engineering and Computer Science (EECS) department that is world's one of the top ranked computer science department. This emerging sample of departments was adopted in later coming days by many other well-known universities and institutes. Dr. Zadeh had visiting positions also at different universities and organization like IBM research lab San Jose (California), MIT, Princeton and Stanford Universities. He was serving as Professor Emeritus and Director of Berkeley Institute of Soft Computing (BISC) at University of California, Berkeley since 1991 till last days of his life,

and had won many prizes and awards for his teaching and research work [5].

## Fuzzy Mathematics

When Dr. Zadeh was working on his book “*Linear System Theory – The State Space Approach*” in 1963, he thought and realized that there should be such a set which have curved boundaries and can be used for approximations same as real measurements. He found solution of this problem in 1964 which is named as “*fuzzy sets*” and was published in 1965 [6]. The objects belong to normal sets and the objects don't belong to normal sets are separated by sharp boundaries of those sets, whereas in fuzzy sets there is a membership function which is used to keep the given object to a real number within interval (0-1). This case can be understood by this example, let suppose there is a fuzzy set A and object x belongs to this fuzzy set with membership value, let suppose 0.5, and this is obtained from fuzzy set's membership function [7].

After that, Dr. Zadeh became more concentrate on this newly proposed fuzzy set theory and extended it to fuzzy relations, fuzzy propositions and fuzzy logic, and this combination is known as fuzzy mathematics. In 1973, Dr. Zadeh proposed linguistic variables which are used for If...Then rule in fuzzy and approximate reasoning [8]. For example, the age of a person can determine linguistic variable more prominently as the person can be young, middle-aged or old, but the range for these specifications can be different for different group of people, so here the linguistic variable will give a hyperbolic curve to specify a range. The linguistic variables are also known as granular variables where the given values are information granules. For computing with words, linguistic variable was a great and significant contribution, which played a vital role in intelligent soft computing.

The membership functions, fuzzy set theory and fuzzy logic is much more natural, feasible to use and understandable as compared to probability and density functions, this theory was given by Dr. Lotfi A. Zadeh. He thought that simulation and duplication of human being capacity in reasoning and decision making is totally based on perceptions and nature of this behaviour is totally fuzzy and generalized logical system, such as fuzzy logic, is basic need of this behaviour. Thinking, reasoning, decision making, talking and conversation etc are abilities associated with human being, and fuzzy logic provides such a platform to perform all these real-world tasks by machines, like computers etc [8].

## Fuzzy logic for knowledge representation and natural language processing

The fuzzy logic contains different facets such as fuzzy set theoretic facet, fuzzy logic facet, fuzzy relational facet and fuzzy epistemic facet etc; this was mentioned and proposed by Dr. Zadeh. The multi-valued logic is deal by logical facet, classes with unsharp boundaries are provided by fuzzy set theoretic facet, epistemic facet of fuzzy logic deals with natural language processing and knowledge representation, while relational facet explains linguistic variable and their dependencies like if...then and if...then...else etc.

Famous mathematician of that time Dr. Garrett Birkhoff first criticized and disbelief this theory of Dr. Zadeh but later he appreciated it, and the main reason of disbelief on this proposal was because it was challenging other basic mathematical frameworks which are backbones of artificial intelligence, like probability. This criticism was accepted by Dr. Zadeh with open heart and fearlessly

proved that his proposed theory is much more beneficial and able to deal with real world problems and approximate reasoning. And this proposal was liked by many young researchers and they started research on it, and as a result this theory got more growth.



Figure 3: Dr. Lotfi Zadeh in his office.

## Fuzzy logic real life applications

The fuzzy logic and fuzzy mathematics had got a strong establishment and a well-known position due to its very powerful theoretical bases and unlimited successful applications and in research till end of 1970s and start of 1980s. The first meaningful application of fuzzy logic was in Sendai city of Japan on underground high-speed train to maximize the comforts and economy [9]. Other uses of fuzzy logic in early stages were as helicopter's flight aid, halting accuracy, hand writing identification in Sony pocket computers, automobiles fuel consumption improvements, washing machine's single button controlling system, to make driving comfortable and easy on subways, vacuum cleaners' automatic control according to surface and soil and was mainly used at Institute of Seismology Bureau of Meteorology, Japan to earthquake predictions [10].

Fuzzy logic and fuzzy mathematics have been used for many scientific, engineering and industrial purposes like NASA, consumer applications, infinite navigation of vehicles, medical diagnosis, intelligent systems, intelligent data and information processing, data analysis, decision making, robotics and advancements of piloting systems etc.

## Further working on fuzzy logic

The very first journal on fuzzy theory for advancement of theory and applications was “*fuzzy sets and systems*” launched in 1978, many other well-known and dedicated journals, societies and conferences followed this journal. After that, fuzzy logic was spread to many other branches like fuzzy probability, fuzzy stability, fuzzy topology, fuzzy linear programming, fuzzy control, fuzzy group theory and fuzzy arithmetic etc, and many hybridized techniques such as fuzzy chaos, fuzzy genetics, neuro-fuzzy and fuzzy-SVM etc were also introduced [6].

In early 1990s a new branch of computing was introduced by Dr. Zadeh to extend fuzzy logic to other notable techniques like Neural Networks, Multiagent System and Genetic Algorithms etc, and was

known as Soft Computing. Berkeley University launched Berkeley Initiative on Soft Computing (BISC) in 1991 which was under Dr. Zadeh. He portrayed the main and basic ideas of soft computing in his paper “*Soft Computing and Fuzzy Logic*” published in 1994, due to this theory many other commercial, scientific and consumer products related applications were introduced and came in market. The hybridized fuzzy techniques proved much better and result oriented in real life as those have more blunder patience and fault tolerance, so there is a lot of working done and doing on these fields for further applications to make human life easier and to benefit public and societies.

### Fuzzy sets as a basis for a theory of possibility

Dr. Zadeh was the first person who introduced possibility theory in 1978. A mathematical theory that is substitute of probability theory and is used for managing certain types of uncertainty us Possibility Theory. The possibility theory is an enhancement of fuzzy mathematics. Further contributions in this theory were made by Dubois et al. [11].

Probability and possibility theories have legal, formal and academic correspondence with each other and addition operator has the maximum correspondence. According to Dempster-Shafer theory a modern development of the theory of evidence says that possibility measure can be a consonant plausibility measure and possibility theory operators can be hyper-cautious version of transferable belief model operators. By using tools of imprecise probabilities this matter allows to study possibility theory [12]. According to Dr. Zadeh “*much of the information on which human decisions are based is possibilistic rather than probabilistic in nature, and the intrinsic fuzziness of natural languages-which is a logical consequence of the necessity to express information in a summarized form-is, in the main, possibilistic in origin*” [12].

### Publications and Citations

A Google Scholar search for query “*fuzzy set*” shows about 2,190,000 documents and for query “*fuzzy logic*” there are 1,470,000 documents. Dr. Zadeh’s work total citations are about more than 186,587 till December 2017 and his work named as “*fuzzy sets*” have about

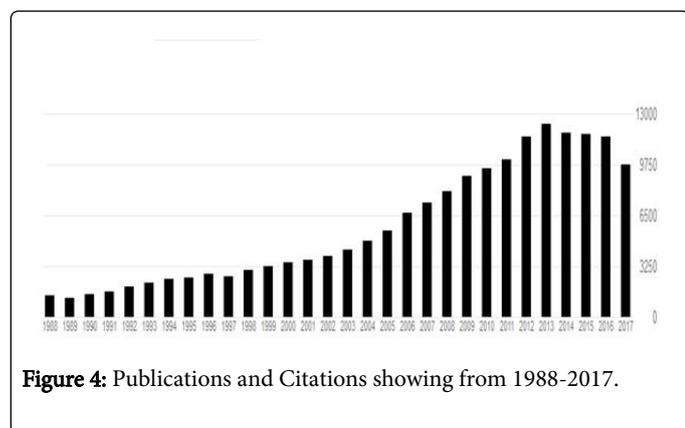


Figure 4: Publications and Citations showing from 1988-2017.

more than 950,000 citations, his H-index is 106 and i10-index is 317 till December 2017. Dr. Zadeh published more than 200 papers as single author, and the most important and notable thing is that he was

even active in his fundamental works and innovations at the age of 96 years.

The Google Scholars shows about 2,880,000 results when do search with keyword “*Fuzzy*”, and about 1,560,000 results with keyword “*Fuzzy Logic*”, and 1,630,000 results for “*Fuzzy Sets*” keyword and about 2,050,000 results for keyword “*Fuzzy System*”. (This statistic counted on 24<sup>th</sup> December 2017). In following table, the bibliometrics about publication history of Dr. Zadeh is shown: [13].

Publication Years	1971-2017
Publication count	125
Citation Count	2,896
Available for download	7
Downloads (6 Weeks)	20
Downloads (12 Months)	232
Downloads (cumulative)	9,414
Average downloads per article	1,344.86
Average citations per article	23.17

Table 1: Bibliometrics about publication history of Dr. Zadeh.

### Views about Dr. Zadeh and Fuzzy Mathematics

Dr. Zadeh’s proposal could be severely, wildly and even brutally condemned from a technical point of view, but this would be out of place here. The question here arises that is Dr. Zadeh presenting important ideas or is he entertaining in desirous thought? No doubt keen interest for fuzziness of Dr. Zadeh has been built-up by the dominant climate in the USA, is an exceptional indulgence. Fuzzification is a kind of scientific indulgence and it contributes in socially attractive expressions unattended by the practice of hard scientific work and tolerant consideration [14].

Fuzzy logic is a superset of Boolean logic which has been lengthened to deal with the idea of partial truth which may have true or false value and it is basic component of AI. Lotfi Zadeh has great and uncountable contributions as a creator of new field of mathematics “*fuzzy set theory and fuzzy logic*”. System theory, AI, expert systems, information processing, natural language understanding, and theory of evidence are also some other great works of Dr. Zadeh. Fuzzy logic, soft computing and computing with words are his current research areas, which have association with fuzzy logic, evolutionary computing, probabilistic computing, neurocomputing and parts of machine learning [15].

There are two logical formalisms which give priority to target natural language and each of these focused on any of two specified and desired features of logic for handling natural languages and those formalisms are Conceptual Graphs (CGs) by Sowa and Fuzzy Logic by Dr. Zadeh [16].

### Honours and Awards

Dr. Lotfi A. Zadeh had many honours and awards and some of those are as fellow of different institutes, societies and associations like IEEE, IFSA, AAAS, ACM and AAAI etc, and was member of NAE (National Academy of Engineering), foreign member of institutes like IASS (The

International Academy of Systems Studies), KAST (Korean Academy of Sciences and Technology), BAS (Bulgarian Academy of Sciences), FAS (Finnish Academy of Sciences) and PAS (Polish Academy of Sciences), Moscow National Academy of Sciences and Azerbaijan National Academy of Sciences etc [5].

Dr. Zadeh received many awards as well, and some of those are like 1973 IEEE Education medal, IEEE Richard W. Hamming medal in 1992, IEEE medal of honor in 1995, IEEE Centennial Medal, the IEEE Millennium medal, the Norbert Wiener award of the IEEE Systems, the AI Hall of Fame, the ACM 2001 Allen Newell award, the Kampe de Fariet medal, the B. Bolzano medal of the Czech Academy of Sciences, the Honda Prize, the Okawa Prize, the AIM information science award, the AACC Richard E. Bellman control heritage award, the SOFT scientific contribution memorial award of Japan Society for Fuzzy Theory, the Grigore Moisil Prize, the IEEE-SMC J.P Wohl career achievement award, Man and Cybernetics Society, International Association for Fuzzy-Set Management and Economy (SIGEF), the V. Kaufmann award, the medal of the Foundation by the Trust of the Foundation for the Advancement of Soft Computing, the High State award "friendship Order" from the President of Republic of Azerbaijan and many other awards and about 24 honorary doctorates from different universities of different countries [4-5]. He was founding member of Eurasian Academy [17].



Figure 6: Dr. Lotfi A. Zadeh with his family.

### Some Prominent Publications

- J. R. Ragazzini and L. A. Zadeh, "The analysis of sampled-data systems," *Trans. American Institute of Electrical Engineers, Part II (Applications and Industry)*, vol. 1, no. 3, pp. 225-234, Nov. 1952.
- L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338-353, June 1965
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Figure 5: Dr. Zadeh at the Benjamin Franklin Award Ceremony in Philadelphia, 2009.

### Personal Life

Dr. Zadeh described himself as "an American, mathematically oriented, electrical engineer of Iranian descent, born in Russia" [18]. On other occasion he said about himself "The question really is not whether I am American, Russian, Iranian, Azerbaijani, or anything else. I have been shaped by all these people and cultures and I feel quite comfortable among all of them". [19] He was married to his Alborz College fellow Fay Zadeh in 1946 and from her Stella Zadeh was his daughter and Norman Zada was son. His daughter Stella was died in 2006 and his wife Fay passed away earlier 2017, and he was survived by his son Norman till his death [4].

On September 6<sup>th</sup>, 2017, Dr. Lotfi A. Zadeh died at his home in Berkeley, California; his age was 96 years and was buried in the first Alley of Honor in Baku, Azerbaijan, his birth place where highly respected people like the President of Azerbaijan attended his funeral [20].

- A complete list of publications is on the website: <http://www.cs.berkeley.edu/~zadeh/>

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