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On Fuzzy Sets and the Precisiation of Meaning – An Interview with Prof. Dr. Lotfi A. Zadeh

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Abstract This interview was planned to appear in one of the next issues of the *Newsletter Philosophy and Soft Computing*. As all the other interviews in this *Newsletter* it was arranged as an e-mail-interview. When the edition of the *Newsletter* stopped in the beginning of the year 2013 to give way to the advent of this new journal it was the intention to publish this interview with Professor Zadeh in the first issue. Perhaps there would have been not enough time to finish this interview via e-mail before this issue appeared but I had the opportunity to travel to Berkeley, CA, in March and April 2013 and Professor Zadeh agreed to finish this interview at the morning of March 29 in his apartment in Berkeley. Therefore the first parts of this interview are texts that have been communicated via e-mail and the second part is a transcription of our recorded spoken word. This printed version of the interview is authorized to be published in this journal by Professor L. A. Zadeh.

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Figure 1: L. A. Zadeh in his office at Soda Hall, UC Berkeley, in August 2012 (Photo: R. Seising).

R. Seising: Professor Zadeh, thank you very much that you accepted to give this interview via e-mail. This is an interesting experiment. About ten years ago we had already a series of interviews when I started to write my book on the history of Fuzzy Sets and Systems.[1] Now, we are interested in links of the theory of fuzzy sets and systems on the one hand and the field of humanities and social sciences on the other hand. My first question is: In your view, what is the connection between fuzzy sets and systems on the one hand and the field of humanities and social sciences on the other hand?

L. A. Zadeh: To respond to your question, I have to go back to what motivated me to come up with the concept of a fuzzy set. Before publishing my first paper on fuzzy sets in 1965,[2] my interests and my research were focused on systems analysis. Although I am not a mathematician by training, I believed that the armamentarium of mathematics was sufficient for analyzing systems of any kind and in any field including fields which fell within the province of

[1] Seising, R.: *The Fuzzification of Systems. The Genesis of Fuzzy Set Theory and Its Initial Applications – Developments up to the 1970s* (Studies in Fuzziness and Soft Computing, vol. 216) Berlin, New York, [et al.]: Springer 2007.

[2] L. A. Z:"Fuzzy Sets", *Information and Control*, vol. 8, 1965, pp. 338-353.

humanities and biological sciences. My faith began to erode in the early sixties when I began to realize that techniques which were effective in dealing with physical systems were far less effective in dealing with human-centric systems such as linguistics, psychology, sociology, biology, economics and law. The question in my mind was: Why? Gradually, I came to the conclusion that the problem was rooted in unsharpness of class boundaries in systems in which human judgment, perceptions and emotions play an important role as they do in human-centric fields. In a paper published in 1962,"From Circuit Theory to System Theory," this is what I had to say.

> "In fact, there is a fairly wide gap between what might be regarded as "animate" system theorists and "inanimate' system theorists at the present time, and it is not at all certain that this gap will be narrowed, much less closed, in the near future. There are some who feel that this gap reflects the fundamental inadequacy of the conventional mathematics the mathematics of precisely-defined points, functions, sets, probability measures, etc. for coping with the analysis of biological systems, and that to deal effectively with such systems, which are generally orders of magnitude more complex than man-made systems, we need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not describable in terms of probability distributions. Indeed, the need for such mathematics is becoming increasingly apparent even in the realm of inanimate systems, for in most practical cases the a priori data as well as the criteria by which the performance of a man-made system is judged are far from being precisely specified or having accurately known probability distributions."[3]

Since I was not a mathematician by training, I tried to persuade my two best friends who were prominent mathematicians Herbert Robbins[4] and Richard Bellman[5] to develop a mathematical theory of classes with unsharp boundaries. I was not successful. I had to do something on my own. In Fall of 1964,

[3]L. A. Z: "From Circuit Theory to System Theory," *Proceedings of the IRE*, vol. 50, 1962, pp. 856-865.

[4]The US-American mathematician and statistician Herbert Ellis Robbins (1915- 2001) was born in New Castle, Pennsylvania. He attended *Harvard University* as undergraduate and there he received a doctorate in mathematics in 1938 under the supervision of Hassler Whitney (1907-1989). From 1939 to 1941 he was an instructor at *New York University*. After World War II, Robbins became one of the original members of the department of mathematical statistics at the *University of North Carolina* at Chapel Hill (1946- 1952). He spent a year at the *Institute for Advanced Study* (IAS) in Princeton and in 1953; he became a professor of mathematical statistics at *Columbia University* in New York. Robbins co-authored with Richard Courant (1888-1972) *What is Mathematics? An Elementary Approach to Ideas and Methods*, London: Oxford University Press, 1941.

[5]The US-American mathematician Richard Ernest Bellman (1920-1984) was born in 1920 in New York City: After his studies of mathematics at *Brooklyn College* where he received a BA in 1941 he earned an MA from the *University of Wisconsin-Madison*. During World War II he worked for a

while I was in New York, a simple idea occurred to me: Define a class with unsharp boundaries, *A*, in a space *U*, through what I called a membership function – a function which associates with each element of *U* its grade of membership in *A*. This was the genesis of the concept of a fuzzy set. Once the idea occurred to me, it was not difficult to develop a conceptual framework in which various basic concepts in set theory were generalized to fuzzy sets.[6] This was the substance of my 1965 paper, "Fuzzy Sets", which was published in Information and Control. What pleases me is that this paper, with over 26,000 citations, is by far the highest-cited paper in *Information and Control*.




Figure 2: Left: H. Robbins, right: R. E. Bellman; (Photos: L. A. Zadeh).

When I wrote my 1965 paper my expectation was that the concepts and ideas outlined in my paper would be welcomed by the human-centric community. This did not happen. The deep-seated tradition of relying on classical, Aristotelian logic and probability theory stood in the way. To some degree, this is still true today. However, what one can see is that fuzzy set theory and fuzzy logic are gaining growing acceptance in humanities and social sciences. It is

Theoretical Physics Division group in Los Alamos. In 1946 he received his Ph.D. at *Princeton* under the supervision of Solomon Lefschetz (1884-1972). At *Princeton* he was then an instructor and assistant professor before becoming an associate professor at *Stanford University* in 1948. Bellman took a position at the *RAND Corporation* in 1952, where he remained until 1965. Following that, he served as a professor of mathematics, electrical engineering and medicine at the *University of Southern California* in Los Angeles until 1984. See the obituary by L. A. Z: In Memoriam Richard Bellman (1920-1984), *IEEE Transactions on Automatic Control*, vol. AC-29, No. 11, Nov. 1984, p. 961.

[6]For more details on the history of Fuzzy sets see: R. S: *The Fuzzification of Systems* (see fn. 2).

a slow process because courses on fuzzy set theory and fuzzy logic are rarely included in humanities curricula.

A turning point in the evolution of fuzzy set theory came with the introduction of the key concept of a linguistic variable in my 1973, "Outline of a new approach to the analysis of complex systems and decision processes",[7] and further developed in my 1975 paper "The concept of a linguistic variable and its application to approximate reasoning part I, II and III.[8] Informally, a linguistic variable is a variable whose values are words rather than numbers. For example, Age is a linguistic variable when its values are young, middle-aged, old, not very young, quite old, etc. Such words play the role of labels of fuzzy sets in the interval [0, 120]. The concept of a linguistic variable had no precursors.

In science, there is a very deep-seated tradition of according much more respect to numbers than to words. The concept of a linguistic variable was counter-traditional. For this reason, the initial reaction was skeptical, and sometimes hostile. What the critics did not appreciate is that there are decisive rationales for the use of words in place of numbers in a wide variety of applications. Stated briefly, there are three principal rationales. Basic premises: Words are less precise than numbers; Precision carries a cost; and Numbers are respected, words are not. **Rationale *A*.** Use words when true numbers are not known or are too costly to obtain. Use of words is a necessity. **Rationale *B*.** Words are good enough. True numbers are known but there is a tolerance for imprecision which can be exploited by employing words in place of numbers, aiming at a reduction in cost and achieving simplicity. Use of words is advantageous. **Rationale *C*.** Linguistic summarization. Words are used to summarize numerical information.

Rationales *A*, *B* and *C* underlie a wide variety of applications of fuzzy set theory and fuzzy logic in science and engineering. But in human-centric fields the entrenchment of traditional, Aristotelian, bivalent logic and probability theory is too deep to give way to fuzzy set theory and fuzzy logic without resistance. One manifestation of this resistance is the way in which concepts are defined. As an illustration, the concept of recession is defined as a bivalent concept, meaning that economy is in a state of recession or is not in a state of recession, with no shades of truth allowed. The official definition is: An economy is in a state of recession if and only if the *Gross Domestic Product* (GDP) declines in two successive quarters. Clearly, this definition is not realistic. Recession is a matter of degree. A realistic definition would define recession as a fuzzy concept, with degrees expressed as functions of appropriate indicators. Such a definition would be in the spirit of the Richter scale for

[7] L. A. Z: "Outline of a new approach to the analysis of complex systems and decision processes," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. SMC-3 (1), January, 1973, pp. 28-44.

[8] L. A. Z: "The Concept of a Linguistic Variable and its Application to Approximate Reasoning – I, II, III," *Information Science*, vol. 8, 1975, pp. 199-249; pp. 301-357; vol. 9, pp. 43-80.

earthquakes.

In large measure, scientific progress is driven by a quest for better models of reality. Through formalization of classes with unsharp boundaries, fuzzy set theory and fuzzy logic open the door to construction of better models of reality and a wide-ranging enlargement of the role of natural languages in scientific theories.

S: One year ago we started the e-mail interview and maybe here and now we can continue! In that interview you said already that in the early 1960s you wanted to establish a new theory of vague concepts and you asked Robbins and Bellman to do so but they couldn't, so you did it by yourself. Then I was thinking on your paper in 1962 where you wrote something about this "deep gap" and that reminds me to the lecture "The Two Cultures and the Scientific Revolution" given by Sir Charles Percy Snow in 1959.[9] He said in this lecture that sciences and humanities established the "two cultures" of modern society, "literary intellectuals" on the one hand and scientists on the other hand, and that there is a deep gulf or rift in between! In this lecture he made the case of a breakdown of communication between these "two cultures" and he claimed that this breakdown is a major hindrance to solving the world's problems. Without looking beyond one's own nose, he claimed, that both cultures will become poorer. Did you remember this lecture when you wrote your paper "Fuzzy Sets"? Was it important for you?

Z: Well, I was following what he was doing but I was not greatly influenced by his writings. He had two Cultures, true - but you know, a sort of yes, I said yes, but I was not reading it. What I was concerned with was *precisiation* and *formalization* rather than discussion on a sort of a purely philosophical level or social level and so forth. So, I was interested in a mathematical approach and his approach was not mathematical approach and that's why I tried to interest Herbert Robbins and Richard Bellman, my close friends, both mathematicians, to do something because I felt that that was not really my job. It required people who were professional mathematicians, not like me who was an engineer by training and had some understanding of mathematics and so forth but was not really professionally trained as a mathematician.

S: What did they say why couldn't they do it?

Z: Well, they were just very busy with their own things. And also this whole issue, you used the word "vagueness", I use the word "fuzziness", was somewhere on the periphery of scientific activities. People said "Well, we have more immediate problems to worry about. It is somewhat remote" and there was no

[9] Sir Charles Percy Snow (1905-1980) gave his Rede's-Lecture "The Two Cultures and the Scientific Revolution" at May 7, 1959 at the Senate House in Cambridge, UK.

recognition really that this is an important issue.
S: Some years before, I think it was in 1962 or 1963, there was this conference organized by Mihajlo Mesarovic,[10] and there were some people from electrical engineering who did system theory and there were other people from the side of biology, sociology, and so on, also concerned with system theory, and I think the idea was to bring them together.

Z: Right!

S: In the preface to the proceedings Mesarovic wrote that it was a big disaster; it didn't work.[11] Do you remember this conference?

Z: Yes, yes.

S: How did it come that it didn't work?

Z: Well, you see, the problem is this: that some of the people who were doing work in systems analysis that was not mathematical oriented – Ludwig von Bertalanffy[12] is one of them – they knew no mathematics.

[10]The Serbian-American engineer and scientist Mihajlo D. Mesarovic (born 1928) has been the Cady-Staley Professor of Systems Engineering and Mathematics at Case Western since 1978. Mesarovic is a member of the Club of Rome. He organized the *Second Systems Symposium* that took place at the Case Institute of Technology in Cleveland (Ohio) in the spring of 1963. 17 presenters and over 200 participants included not only scientists representing General Systems Theory and Cybernetics but also engineering scientists and philosophers.

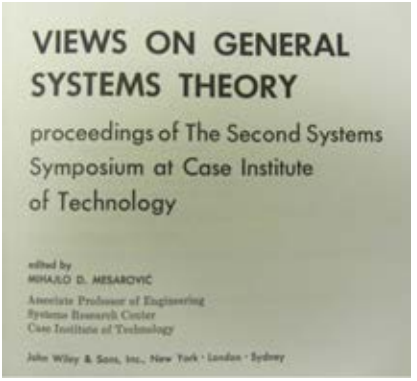
[11]Mesarovic published the conference proceedings under the title *Views on General Systems Theory* (Proceedings of The Second Systems Symposium at Case Institute of Technology, Huntington, New York: Robert E. Krieger Publ. Comp., 1964.) This book does indeed contain some very diverse approaches. In the foreword, however, Mesarovic pointed out that all of the contributors had been in agreement on one point: "necessity for the development of a general systems theory." There were many different opinions, however, when it came to the "how"! First of all, some of the participants took a definite stand, venturing to define a system and then discussing the consequences of such a definition. A second group of participants argued that the general systems theory should not be formalized since this very act will limit its generating power and make it more or less specific. A third group proposed to consider systems theory as a view point taken when one approaches the solution of a given (practical) problem. Finally, it was expressed that a broad-enough collection of powerful methods for the synthesis (design) of systems of diverse kinds should be considered as constituting the sought-for theory and any further integration was unnecessary. There were also participants that shared the viewpoints of more than one of the above groups." (M. Mesarovic: *Views on General Systems Theory*, p. xiv)

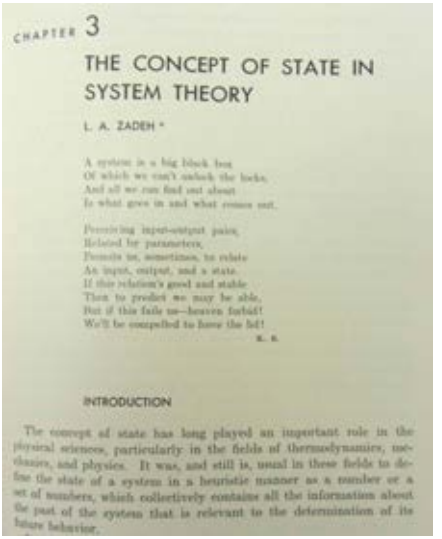
[12]The Austrian-Canadian biologist, philosopher and founder of *General System Theory* Carl Ludwig von Bertalanffy (1901-1972) turned his attention from philosophy and art history to the natural sciences, particularly biology. He earned his doctorate in 1926 with a thesis about the physicist and philosopher Gustav Theodor Fechner (1801-1887) and qualified as a professor in 1934. The content of this paper became the first of two volumes which appeared as *Theoretical Biology* (Volume 1: Berlin: Gebr˝der Borntrğer, 1928). Bertalanffy founded a "theoretical biology", which was a popular university subject in the US, and he developed "organismic biology" synthesized from mechanistic and vitalistic ideas into a "General System Studies", which was first published

So you take a person like that and you put next to him somebody who does more or less mathematical work, they don't have a common language. They don't speak the same language. The attitudes are very different. So it didn't work.

S: I think there were some people who were in both camps.

Z: Yes!




CHAPTER 3

THE CONCEPT OF STATE IN SYSTEM THEORY

L. A. ZADEH *

A system is a big black box
Of which we can't unlock the locks,
And all we can find out about
Is what goes in and what comes out.

Perceiving input-output pairs,
Related by parameters,
Permits us, sometimes, to relate
An input, output, and a state.
If this relation's good and stable
Then to predict we may be able,
But if this fails us—heaven forbid!
We'll be compelled to know the bid!

K. B.

INTRODUCTION

The concept of state has long played an important role in the physical sciences, particularly in the fields of thermodynamics, mechanics, and physics. It was, and still is, usual in these fields to define the state of a system in a heuristic manner as a number or a set of numbers, which collectively contains all the information about the past of the system that is relevant to the determination of its future behavior.

Figure 3: Left: the Proceedings of the Second Systems Symposium; right: first page (excerpt) of Zadeh's paper with the poem by K. Boulding.

S: For instance Kenneth Boulding,[13] you remember, he wrote poems to the talks at this Second Systems Symposium.[14]

in 1949. He then expanded this to the "General System Theory", the principles of which he then expanded from biology to also include psychology and sociology. Von Bertalanffy was a professor at the *University of Vienna* (1934-48), *University of London* (1948-49), *Universite de Montreal* (1949), *University of Ottawa* (1950-54), *University of Southern California* (1955-58), the *Menninger Foundation* (1958-60), *University of Alberta* (1961-68), and *State University of New York* at Buffalo (SUNY) (1969-72). He died in Buffalo, New York in 1972.

[13]The US-American economist, educator, peace activist, poet, religious mystic, systems scientist, and philosopher Kenneth Ewart Boulding (1910-1993) was cofounder of *General Systems Theory* and founder of numerous ongoing intellectual projects in economics and social science.

[14]Boulding found himself inspired during some of the presentations to compose little poems, which were printed in the proceedings as introductions to the papers. Boulding treated Zadeh's contribution "The Concept of State in System Theory" (M. Mesarovic, *Views on General Systems Theory*, 1964, pp. 39-50) as is shown in Fig. 3.

Z: But there were not many people like that, it required more than one or two persons, there were some people like that, Robert Rosen[15] was another one, but there was rather a sort of a schism between the two camps: one camp, mathematical oriented, was interested in some applications to information this, that, systems analysis; the other camp was interested in more biological sort of aspects, something that did not lend itself to mathematical analysis.

S: I learned some years ago that at the same time when you were chair of the department you also were very concerned with education in electrical engineering.



U.C.
ELECTRONICS
NEWSLETTER

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Vol. 5, No. 3 — Spring 1963

LOTFI A. ZADEH APPOINTED EE DEPARTMENT CHAIRMAN

Lotfi A. Zadeh, Professor of Electrical Engineering at the University of California in Berkeley since 1959, has been appointed chairman of the Department of Electrical Engineering. Professor Zadeh takes over the position from Professor Robert M. Saunders, who is returning to his full-time academic work, after having held the chairmanship for four years. The policy of appointing department chairmen for limited terms allows faculty members who are actively engaged in teaching and research to take the position.

Professor Zadeh is a graduate of an American missionary school in Teheran, Iran. He obtained the B.S. degree from the University of Teheran in 1942, the S.M. from M.I.T. in 1946, and the Ph.D. from Columbia in 1949. He joined the staff of the Department of Electrical

L. A. Zadeh

Figure 4: In 1963 Lotfi A. Zadeh became chair of the department (excerpt).

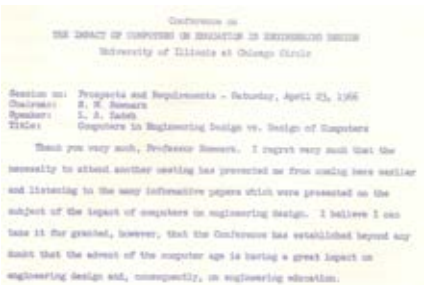
Z: Yes.

[15] The US-American theoretical biologist Robert Rosen (1934-1998) studied biology, mathematics, physics, philosophy, and history; particularly, the history of science. At the *University of Chicago* and under the guidance of Professor Nicolas Rashevsky (1899-1972) he obtained in 1959 a PhD in Mathematical Biology. He remained at the *University of Chicago* until 1964. He moved to the *University of Buffalo* with a full associate professorship, while holding a joint appointment at the *Center for Theoretical Biology*. Later he was Professor of Biophysics at *Dalhousie University*.

S: How did that come? Can you explain this? Why were you concerned with education?

Z: Let me tell you that I am very impressed by your understanding of some events that took place many, many years ago.

S: Thank you!



Conference on
THE IMPACT OF COMPUTERS ON EDUCATION IN ENGINEERING DESIGN
University of Illinois at Chicago Circle

Session on: Prospects and Requirements - Saturday, April 23, 1966
Chairman: S. M. Sawmark
Speaker: L. A. Zadeh
Title: Computers in Engineering Design vs. Design of Computers

Thank you very much, Professor Sawmark. I regret very much that the necessity to attend another meeting has prevented me from coming here earlier and listening to the many informative papers which were presented on the subject of the impact of computers on engineering design. I believe I can take it for granted, however, that the Conference has established beyond any doubt that the advent of the computer age is having a great impact on engineering design and, consequently, on engineering education.



Electrical Engineering at the Crossroads

L. A. ZADEH, FELLOW, IRE

Figure 5: Left: Announcement to a conference "The Impact of Computers on Education in Engineering Design" (April 1966) where Zadeh was the speaker; right: Zadeh's article "Electrical Engineering at the Crossroads" (see fn. 20).

Z: So, the situation is this: that at that time there was a war between computer science and electrical engineering. Call it competition, call it war, call it whatever you wish, but electrical engineering then had to do something to strengthen its position in that war. It could not spend a lot of time on things which were no longer relevant.

Let me tell you that when I became chair of electrical engineering in 1963 and we were in this state of war, that in electrical engineering there were some required subjects, and one of them was drafting,[16] another one was surveying,[17] you know. Now, it could not compete with computer science, if our students had to spend some time on drafting, etc. Computer science people would say, you see, electrical engineering should not be in the computer field because

[16] Also "technical drawing".
[17] Also "measuring".

this is what they do. So I persuaded the dean at that time George Maslach[18] to support the reform and to make these courses elective rather than required. If somebody wanted it - well, fine! But no student was required to do that.

This was local at Berkeley but I felt that the same situation prevailed outside of Berkeley. In electrical engineering there were too many courses that were not really, that were sort of old-fashioned courses. Something had to be done. And that is why I wrote that article so that it would have a certain influence beyond Berkeley. That was the idea.



Practical experience and engineering education

Myron Tribus
L. A. Zadeh
Ernst Weber

I. Herbert Hollomon
Thomas F. Jones
R. H. Lyon

Myron Tribus



L. A. Zadeh

Figure 6: Excerpts from the article "Practical Experience and Engineering Education" by Myron Tribus, L. A. Zadeh et al. in 1967 (see fn. 20).

S: It was not only one article; it was a lot of articles![19]

[18]The US-American aeronautical engineer George J. Maslach (1920-2004) was Professor of Mechanical Engineering. He joined the *UC Berkeley* faculty in 1952, he was named dean of the College of Engineering in 1963, and during his nine-year tenure, the college boosted enrollment and surged to No. 2 in the national rankings. In 1972, he was appointed provost for professional schools and colleges, and served as Berkeley's vice chancellor for research and academic affairs from 1981 to 1983.

[19]E.g. L. A. Z: "Electrical Engineering at the Crossroads", *IEEE Transactions on Education*, Vol. E-8, Nos 2-3, June-September 1965, pp. 30-33; "Education in Computer Science", *Proceedings of the National Conference on Data Processing*, Jerusalem, Information Processing Association of Israel, 1968, pp. E157-E167; Tribus et al.: Practical Engineering and Engineering Education, *IEEE spectrum,* May 1967, pp. 60ff; figures 5, 6.

Z: Yes!

S: … and I remember in one article you also wrote that computer science is a fuzzy set in electrical engineering and you said, ok, computer languages is with membership value 0.5, and e.g. logic is with membership value 0.3 a part of the fuzzy set of computer science.[20]

Z: That's right!



Computer Science as a Discipline

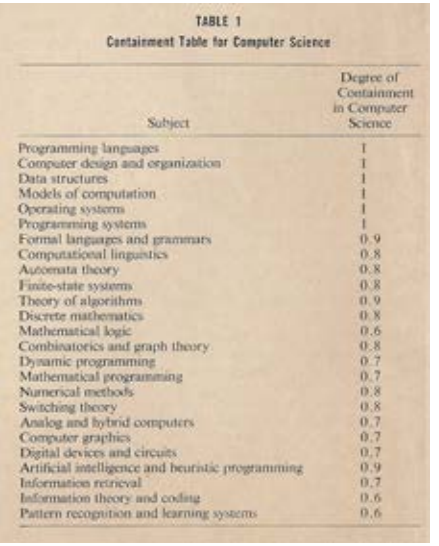


TABLE 1
Containment Table for Computer Science

Subject	Degree of Containment in Computer Science
Programming languages	1
Computer design and organization	1
Data structures	1
Models of computation	1
Operating systems	1
Programming systems	1
Formal languages and grammars	0.9
Computational linguistics	0.8
Automata theory	0.8
Finite-state systems	0.8
Theory of algorithms	0.9
Discrete mathematics	0.8
Mathematical logic	0.6
Combinatorics and graph theory	0.8
Dynamic programming	0.7
Mathematical programming	0.7
Numerical methods	0.8
Switching theory	0.8
Analog and hybrid computers	0.7
Computer graphics	0.7
Digital devices and circuits	0.7
Artificial intelligence and heuristic programming	0.9
Information retrieval	0.7
Information theory and coding	0.6
Pattern recognition and learning systems	0.6

Figure 7: Excerpts from "Computer Science as a Discipline" (see fn. 21).

S: But you didn't continue with this work in education after writing these articles!

Z: No, because, you know, I was busy with other things, and then, remember that I wrote my paper on Fuzzy Sets, I wrote in 64 and it was published in 65. So, I was, … my main thing … partly it was more with computer science, and so far as my research is concerned it was related to issues that in one way or in another related to – call it vagueness, call it fuzziness – you mentioned this 1962-paper[21] in which I said that we need something.
S: You know, now there are some people who think that may be fuzzy sets

[20] See figure 7. L.A. Z: "Computer Science as a Discipline", *Journal of Engineering Education*, vol. 58, No. 8, April 1968, pp. 913-916.
[21] Zadeh, L. A.: "From Circuit Theory to System Theory", see fn. 4.

should be more in the direction of social sciences and humanities, philosophy. For instance, Enric Trillas[22] says that maybe there is a connection between Fuzzy Sets and what Wittgenstein[23] did in his last years, this language game thinking. What do you think about that?

Z: Well, I tried to understand Wittgenstein. I could never understand Wittgenstein! The reason why I couldn't is because there are many, many statements which he cannot tell them, are they true, are they false, they are sort of I use the word "vague" – "vague" means "insufficiently specific". So if you say: "All men are equal." well, ok, what does it mean? "All men are different.", "All men are equal.", you know this sort of a general statement ...

I was interested in what Wittgenstein had to say. In 19... – I think it was 1981 – at Wittgenstein Symposium I gave an invited lecture[24] but as I said, I could not really develop a good understanding of Wittgenstein. – Yes, I do agree with Trillas and I say – as you know – when in my 65-paper I thought that's really when most applications not so much in engineering but in those areas, but I think the reason why that did not happen is, because people in some of these areas, psychology etc., have very poor mathematical background. The paper on Fuzzy Sets they cannot read it!

S: Also in this ... I think it was in the seventies, there were some people inter-

[22]The Spanish mathematician Enrique Trillas Ruiz (born 1940) got a Ph D on Sciences from the *University of Barcelona* and he became Professor at the *Technical University of Catalonia* in 1974. In 1989 moved to the *Technical University of Madrid*, where he was Professor at the Department of Artificial Intelligence until September 2006. Formerly, and among other positions, he was Vice-Rector of the *Technical University of Catalonia*, President of the *High Council for Scientific Research* (CSIC), Director General of the *National Institute for Aerospace Technology* (INTA), Secretary General of the *National Plan for Scientific and Technological Research*, and Chairman of the company *Aerospace Engineering and Services* (INSA).

[23]The Austrian-British philosopher Ludwig Josef Johann Wittgenstein (1889-1951) worked primarily in logic, the philosophy of mathematics, the philosophy of mind, and the philosophy of language. His books *Tractatus Logico-Philosophicus* (Routledge & Kegan Paul, London, 1922 (First in German: Ludwig Wittgenstein: *Logisch-Philosophische Abhandlung*, Ostwalds Annalen der Naturphilosophie, Band 14, Leipzig 1921) and *Philosophical Investigations* (Blackwell Publishing, Oxford (1953) are among the most important books of the 20th-century philosophy.

[24]L. A. Z: "Possibility theory as a basis for meaning representation", in: W. Leinfellner, E. Kraemer, J. Schank (eds.): *Sprache und Ontologie: Akten des sechsten internationalen Wittgenstein Symposiums*: 23 bis 30. August 1981, Kirchberg am Wechsel (Ø"'sterreich), (Schriftenreihe der Wittgenstein-Gesellschaft; 8), Wien 1982, pp. 253-272. English version: W. Leinfellner. et al (eds.): *Language and Ontology: Proceedings of the sixth international Wittgenstein symposium*: 23rd to 30th August 1981, Kirchberg am Wechsel (Austria), Vienna 1982, pp. 253-272.

ested, I remember Joseph Goguen,[25] George Lakoff,[26] Eleanor Rosch,[27] these people in the seventies kind of worked together with you isn't it? So, they tried to use fuzzy sets in linguistics and in psychology.



Figure 8: Joseph Goguen, Eleanor Rosch, George Lakoff, and Hans-Joachim Bremermann.

Z: Yes, well, yes – Eleanor Rosch – right. She was concerned with categories but she did not really know Fuzzy Set Theory, so she did not use Fuzzy Set Theory in her work. Her work is very, very non-mathematical. You won't find a single equation, not one equation in her paper not one equation! And Lakoff is also not mathematical but perhaps a little more mathematical than Rosch. So in 1972, Lakoff at that time was not at Berkeley, he was at the *Center for Advanced Study in Behavioral Sciences* ...

S: ... at Stanford ...

Z: ... but we talked frequently and so I wrote my paper on Hedges[28] and he wrote something on Hedges[29] which was not published but it was appearing in proceedings of some society.[30] But if you look at his paper and my paper you find that his is very non-mathematic, ok there is a little bit here and there ...

[25]The American mathematician Joseph Amadee Goguen (1941-2006) wrote his Ph D thesis "Categories of Fuzzy Sets" in 1968 at *UC Berkeley* under guidance of L. A. Zadeh and the German-US-American mathematician Hans-Joachim Bremermann (1926-1996). Goguen taught at *UC Berkeley*, the *University of Chicago* and *University of California* in Los Angeles, where he was professor in the Department of Computer Science and Engineering.

[26]The US-American cognitive linguist George P. Lakoff (born 1941) is professor of linguistics at the *UC Berkeley* where he has taught since 1972.

[27]The US-American psychologist, Eleanor Rosch (born 1938) is professor of psychology at the *UC Berkeley*.

[28]L. A. Z: "A Fuzzy-Set-Theoretic Interpretation of Linguistic Hedges", *Journal of Cybernetics*, vol 2, 1972, pp. 4-34.

[29]G. Lakoff: "Hedges: A Study in Meaning Criteria and the Logic of Fuzzy Concepts", *Journal of Philosophical Logic*, vol. 2, 1973, pp. 458-508.

[30]This was a former version of Lakoffs paper (see footnote 28), published in the "Proceedings of the Eight Regional Meeting of the Chicago Linguistics Society", 1972.

S: One last question: I noticed in the last days, that you are writing a paper on meaning and truth. Can you tell me some points of this?

Z: Yes, I have it here, the paper is finished!

S: You finished it – Congratulations!

Z: It is ready to be sent to Information Sciences.[31] Over the weekend I have to read it carefully to make sure that … I am very pleased with this paper!

S: Can you tell me something about it for the readers of the new *Archive on the Philosophy and History of Soft Computing*?

Z: Yes. In there I say it's a departure from traditional theories. It's not like traditional theories, but it is rooted in some of the things that I have done in the late seventies and eighties and my references go there, but in particular the concept of meaning …

One concept which I have been talking about for some time now is *precisiation*. So precisiation is a new word, it's not in the dictionary. So I differentiate between understanding and precisiation. So, I say keep on the refrigeration, you understand, but it's not precise. What does it mean: "Keep on the refrigeration"? Keep it one hour, two hours, three hours? – You have not precisiated really, you see! So what I being saying is that if you want to use natural language in science, in robotics, in here, there, you have to precisisate it. So, Wittgenstein said all kinds of things, but he did not really precisiate what he said. So this whole thing then is concerned with precisiation of meaning and in my *AI-Magazine*-paper on "Precisiated Natural language"[32] I talked about it: I said we need to precisiate natural language to use it here, there, and so forth. People in AI did not understand it. Now, I had two papers published about the same time in *AI-Magazine*, one called "Precisiated Natural Language" the other one "A New Direction in AI. Toward a Computational Theory of Perceptions".[33] Reviewers did reviews like this: Initially, the reviewers were very negative then, eventually, after a lot of correspondence and explanation they said "Ok". – They didn't understand. They didn't understand the concept of precisiation! So in traditional theories there is no precisiation. So here, meaning is defined in mathematical terms. It's not for somebody who doesn't know what meaning is, no it's not like that. So I said, well it's a possibility distribution over this and this and this and that … It's defined in terms which are like

[31] L. A. Zadeh: "Toward a restriction-centered theory of truth and meaning (RCT)", Information Sciences, vol. 248, 2013, pp. 1–14./

[32] L. A. Z: "Precisiated Natural Language (PNL)", *AI-Magazine*, vol. 25, no. 3, 2004, pp. 74-91.

[33] L. A. Z: "A New Direction in AI. Toward a Computational Theory of Perceptions", *AI-Magazine*, vol. 22, no. 1, 2001, pp. 73-84.

this. And I can do that because it's based on Fuzzy Logic. If it's based on two-valued logic, you cannot do anything about it. So, the reason why I am pleased with it is because … decades of arguments, books, papers on meaning this that, so forth, but they never really explained what they do talk about meaning of meaning, and when I started teaching courses in computer science, and that was in 1968, many years ago, I tried to understand some of these things, because previously I was not concerned with linguistic notions. I looked at the book on *Meaning of Meaning*[34] I don't understand. I couldn't understand! So, that's why I said at some point said, you know what: Let me do it my way! You see? So I took concepts in systems analysis, those concepts, and applied to meaning. So there were *restriction* and previously I used the word "generalized constraint". [Inaudible] the meaning is a constraint, it constraints something, you see! Restriction constraints something! So how does it constrain? – So, that's meaning.

And truth is related to meaning, because you cannot say whether something is true or not unless you understand the meaning. If I say "gabbeldigoggelt-dithrough" – is it true or not – you can't say. You have to understand the meaning. But, again, understanding meaning in a precise way, because I am interested in saying "Degree of truth is 0.8." or 0.9 or whatever. To be able of say that you have to precisiate meaning! If I say "Most Swedes are tall." and if I say that's 0.9 true then I have to precisiate what is meant by "most", by "tall", what's the "population"? And so forth! So, there we have a formula says, if "through" is this and "most" is this and population is this, then, the degree of truth is 0.8. So, there is no that such thing in the literature of linguistics and computational linguistics, nothing! So this is something that, once it is understood, people see it's a turn. It's a turn!

S: But this is possible only with Fuzzy Logic or Possibility theory!

Z: I did it right in the beginning. I said traditional theories, for the most part, are based on two-valued logic; you cannot do much with that. So, this is based on fuzzy logic. And once you base it on fuzzy logic then you can precisiate it, what I say "Most Swedes are tall." or, you know, things of this type.

S: So at the end you think that Fuzzy Logic will be important for linguistics, too?

Z: Well, I think that more and more, I think so, Fuzzy Logic will have an impact in those fields. You see, in the eighties Fuzzy Logic was in Japan used for

[34] Ivor Armstrong Richards and Charles Kay Ogden: *The Meaning of Meaning. A Study of the Influence of Language upon Thought and of the Science of Symbolism*, New York: McGraw-Hill Companies Inc., 1923, 1997. See also (but Zadeh did not have a look to this): Hilary Putnam: "The meaning of 'meaning", *Minnesota Studies in the Philosophy of Science*, vol. 7, 1975, pp. 131-193

manufactured things: Blood pressure meters, this, that and so forth. So the importance of fuzzy logic during that period was measured basically in Dollars! How much did you produce? You see? Did you produce 10 Million blood pressure meters then you brought 1 Billion Dollars for it at a certain impact. But mass production today, well, they do things so forth but it's not like the ways in the eighties and nineties, no longer that sort of a thing. So, it will not be mass production but it will be papers in linguistics, in mathematics. So, you saw perhaps those figures about topology, fuzzy topology; I was surprised that there are 67 books on Fuzzy Topology. – If you would have asked me before Ixel[35] found those numbers, "How many books?", I would have said "One, two!" So, presumably you know something about, you say "One, two", there were 67 books on Fuzzy Topology. And the number is growing! So it will be interesting, perhaps you could do that, – use Google! – that you see how many books are there in other fields of mathematics: Fuzzy Differential Equations, Fuzzy Algebra, Fuzzy Graph Theory, Fuzzy this, Fuzzy that. So, I think that even though fuzzy is not a good word in mathematics, nevertheless it will be doing it. So, notice that they don't call it "vague topology". It didn't make sense to call it "vague topology". They call it "Fuzzy Topology"! That's the way only word for unsharp classes, that's really what it means.

S: Congratulations to that. Many thanks for this interview!

Z: I'd like to congratulate you, too, for initiating the new journal, the Archives for the Philosophy and History of Soft Computing. – Some time ago I suggested to Elsevier to have a journal "Computing with Words" but at some point I became busy with other things, so I did not push it. But I am pretty sure that there will be journals like that.

S: Maybe we can do this with the journal we started now?

Z: That's right!

S: We will see! May be this would be successful.

Z: Yes, I am sure! Because there are many people who are beginning to understand, e.g. John Mordeson,[36] and there are other people … in Policy Analysis

[35] Ms. Ixel Chavez is Professor Zadeh's assistant.

[36] The mathematician John N. Mordeson is professor and director the *Center for Mathematics of Uncertainty* in the department of mathematics at *Creighton University*, Omaha, Nebraska. Mordeson, his colleagues Terry Clark and Joshua D. Potter (Political Science department), Mark J. Wierman (Computer Science department) and former student Jennifer M. Larson collaborate to examine problems in political science using fuzzy mathematics, see e.g.: T. D. Clark, J. M. Larson, J. N. Mordeson, J.D. Potter, M. J. Wierman: *Applying Fuzzy Mathematics to Formal Models in Comparative Politics*, (Studies in Fuzziness and Soft Computing, Volume 225), Berlin [et. al.]: Springer, 2008.

and so forth. There are many fields not in my capturing … I also want to mention something else: Why did Fuzzy Logic, why did it turn out to be successful in engineering and so forth? Because it exploits the tolerance for imprecisiation that is called "fuzzy logic gambit": you describe relationship between talk and speed in words, use Fuzzy If-then-rules: If something is high and something is … and so forth … but: you precisiate the words. So it's very important and you have to make note of it. You differentiate between two concepts of precision, precision in value and precision in meaning. So, in Fuzzy Logic, I have written about it, but it is not so obvious, if I say "Robert is tall." then it values imprecise but I precisiate "tall". I say "tall" is this … So I precisiated meaning, but I did not precisiate value. So this is a crucial point. You take something, you use Fuzzy if-then-rules, you do not precisiate value, but you precisiate meaning, so your computer can execute Fuzzy-if-then-rules. So that's one of the reasons why it turned out to be successful: because you don't need high precision. Rice cookers don't need high precision, use words! You don't need transmission; you don't need high precision in value. You don't need it!

S: Thank you very much for this interview!





Figure 9: At the BISC round table meeting, April 20, 2013 at UC Berkeley: Lotfi Zadeh discussing with Dana Scott (emeritus Hillman University Professor of Computer Science, Philosophy, and Mathematical Logic at Carnegie Mellon University).