My heart to "fuzziness" with some memories

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Your Excellency The Rector Magnificus,
Academic Authorities,
Faculty Members,
Ladies and Gentlemen:

It is indeed a great honor for me to receive the degree of Doctor Honoris Causa from the Universidad Politecnica de Madrid. My feelings at this moment are to deep to express adequately my gratitude for this honor. On this occasion, I would like to address a few words to all of you kindly joining this ceremony. It is a great pleasure for me to talk about some of my research works. Please allow me to include partly my private affairs in this talk.

As a student of the University of Tokyo, I studied theoretical physics. After graduation from the University, in 1962, I worked at a nuclear power industry where I was engaged in the experiments of nuclear reactor physics which was related to the Japanese first nuclear ship. Then I moved to the Tokyo Institute of Technology in 1965 where I worked at the Department of Control Engineering as research associate. In the same year 1965, an epoch-making paper 'Fuzzy Sets' written by Professor Lotfi Zadeh was published. Professor Zadeh was a distinguished researcher in the field of control theory. In those days I was just looking for something new for my future research. In this way in the late sixties, I happened to find this paper "Fuzzy Sets" in my Institute Library.

In fuzzy sets theory, we deal with the fuzziness of a concept or a word in terms of membership grades. Let us choose a word 'middle-aged'. If someone is considered perfectly to be middle-aged, we attached a numerical grade 'one' to him or her. If someone is never considered to be middle-aged, we attach a numerical grade 'zero' to him or her. For instance, the grade of a person aged 35 is 0.5. The grade of a person aged 40 is 0.8 and the grade of a person aged 60 is 0.4. As we see the grade of a person belonging to a class of'middle-aged' is fuzzy. By the way, the concept of fuzziness is closely related to human subjectivity, because human subjectivity is fuzzy in its nature rather than crisp. At that time my philosophical feelings, I had liked philosophy since my students days, were shifting from objectivity to subjectivity. I was becoming more interested in human subjectivity. This was why I started my research work in the setting of fuzzy sets concept.

Now I would like to take up three issues in my talk.Those are fuzzy measures, fuzzy control and intelligent computing or computing with texts. I found that the concept of fuzzy sets is a kind of algebraic tool to deal with fuzziness and felt that we also need a kind of analytic tool to deal with fuzziness. I was interested in Artificial Intelligence and working on computer-game-playing like chess game. The problem was how to determine the next play estimating the opponent play. The opponent play is of course uncertain. We cannot know it beforehand. One of the conventional methods in artificial intelligence is to use probabilities to estimate the opponent play. However a human player does not obey probabilities. A human's player thinking is somewhat rather fuzzy that probabilistic. Based on this sort of thinking, I came to an idea of fuzzy measures as an extension of probabilities and presented a paper on this subject in 1972.

Then I received the degree of Doctor on Engineering by a study on fuzzy measures and integrals from Tokyo Institute of Technology in 1974. I would like to explain the concept of fuzzy measures and integrals. Mathematically a fuzzy measure is an extension of the Lebesgue measure. Here we can simply consider a measure as a scale to measure something, for instance, distance or length. Probability is also considered to be a measure in mathematics. The Lebesgue measure is characterised by the so-called additivity, and on the other hand a fuzzy measure is characterised by the non-additivity.

Let us take a simple example. We suppose a factory where some workers produce some products. We consider the productivity of workers: how much they produce in one hour. We divide the workers into two groups: group A and group B, and we consider the productivity of both groups. If group A and group B work separately, then the productivity of both groups is obtained by the addition of group A's productivity and group B's productivity. That is, the productivity is additive in this case. For instance '1 plus 1' makes 2. However, if two groups collaborate efficiently, the productivity of two groups can became bigger than the addition of the individual productivities. In this case the productivity is not additive but super-additive. For instance, '1 plus 1' can make 3, more than 2. And also if two groups cannot collaborate efficiently, the productivity of two groups is less than the addition. For instance, '1 plus 1' might make 1.5 smaller than 2. In that case the productivity is sub-additive.

Usually we find that additivity does not hold in a collaborative work by groups. But, summarising our consideration on group-productivity we find that the productivity has monotonicity. That is, the productivity of two groups is at least bigger than an individual productivity. A fuzzy measure is an extended measure with this monotonicity. Monotonicity includes additivity. As such a fuzzy measure includes Lebesgue measure in its special case.

Now as I told you, a measure in mathematics is a kind of a scale. For example, we measure length or height by using a scale. The French mathematician H. Lebesgue presented a general method to measure an area such as a square or a circle by using the Lebesgue measure, more than one hundred years ago. This concept is known as the 'Lebesgue integral'. A fuzzy integral, I presented together with fuzzy measures, is a kind of integral by using a fuzzy measure.

By the way, I would like to tell you a small story. I remember I first got to know Professor Enric Trillas through my Doctor Thesis. I stayed as visiting researcher at a French laboratory of automatic control in Toulouse in 1976. One day Professor Trillas came to the laboratory and he took away a copy of my Doctor Thesis to Barcelona. A Few months later he kindly invited me for a talk on fuzzy measures and integrals in Barcelona in January 1977. It was exactly 20 years ago. I took a train from Toulouse via Pyrenees covered with snow to Barcelona. Since then, he has been and he is one of my closest friends, and Spain is my favourite country. In Barcelona, I also met Professor Miguel Delgado and many other distinguished scholars.

Now I return to the main argument. As for fuzzy integrals, I had one problem. That is, a fuzzy integral is not an extended Lebesgue integral. A fuzzy measure includes a Lebesgue measure but a fuzzy integral does not include a Lebesgue integral. For a long time I had been wondering if we could derive an extended Lebesgue integral with respect to a fuzzy measure. Fortunately fifteen years later, Dr. Murofushi and me found a solution to this problem. We suggested a truly extended version. This is now called the Choquet integral. Choquet is also a French mathematician. The Choquet integral is derived from his capacity theory suggested in 1956. What we have concluded recently is that there exist two essential integrals with respect to a fuzzy measure: the Choquet integral including the Lebesgue integral and my fuzzy integral.

As for applications, we can use a fuzzy measure to subjectively evaluate some objects. For example, the niceness of a house, the quality of wine, the attractiveness of Madrid and so on. These objects have some attributes. In the case of a house, the attributes are the size of a house, its location, its looking, the view from windows and so on. A fuzzy measure is used as a scale for the importance of attributes and a fuzzy integral is used to aggregate the goodness of each attribute. For example in Japan, a fuzzy integral has been applied to evaluate the quality of rice and also the quality of coffee beans. As a matter of fact, we have many applications.

Now I would like to switch to the second issue. After having spent two years in Europe, I went back to Japan. Fuzzy theory was becoming gradually known in Japan. However we had a lot of criticisms to fuzzy theory. For example I heard very often a criticism that "fuzzy theory is not science, 'fuzzy researchers' play with subjectivity, but science has to always follow objectivity". In fact according to Cartesian philosophy, we have to make a continuous effort to eliminate any piece of subjectivity out of science. I believed, as other fuzzy researchers, that fuzziness is an essential feature of human being, and so for example, if we want to deal with man-machine systems, we must introduce fuzziness into systems so that a machine can understand a human. Then I came to thought how I could show the excellence of fuzzy theory to people. My answer was to demonstrate fuzzy control applications. Fuzzy control was first examined by Professor Mandani at University of London. I spent about one year with him in London before I went to Toulouse.

Usually in control we use mathematical formula to determine an appropriate input to a process. In the case of the temperature control of this room, the input would be the amount of heat to warm up the room. However in fuzzy control, we do not use a mathematical formula. Instead we use linguistic rules to determine an input. Let us consider a case of driving a car. We know how to make a turn at a corner. For example: 'reduce the speed gradually to a corner; in a corner turn slowly the steering handle to the right, and then turn back the steering handle, increasing the speed". These linguistic rules have a form of 'if something then something'. And we use fuzzy words 'reduce the speed gradually', 'turn slowly' and so on. Fuzzy control is a new method to apply this sort of human thinking based on fuzzy logic.

I began to work with some engineers of Fuji-Electric Company on control of a water-purification process. After three years of efforts, in 1983, Fuji-Electric introduced the first real application of fuzzy control in Japan. It was quite successful. We achieved much better performance than by a conventional control. Fuzzy control is nowadays used at many water purification processes in Japan.

On the other hand, I developed a fuzzy car at my Institute. It was a model car with fuzzy control which we can control using voice commands such as 'start', 'turn right', 'enter garage'. A point is that, if the car is ordered 'turn right', it has to continue to go straight until it finds a corner where it can turn right. Also it has a capability of automatically find a garage and enter it. I remember I had a talk on this subject here in Madrid in 1987. Some articles on my fuzzy car appeared on the newspapers such as EL PAIS and EL DIA. In 1989 Matsushita, Panasonic, first applied fuzzy logic to a consumer product. That was a warm water supply unit for home use. I worked with Matsushita for two years to develop this world first consumer product. After this year we had a fuzzy boom in Japan. We had so many applications to consumer products such as washing machines, vacuum cleaners, and electronic ovens and also vehicles such as automobiles, subways and elevators.

Next I wanted to apply fuzzy control to one of the most difficult systems. That was a helicopter. It is very difficult to control the helicopter because it is totally unstable and easily affected by its environment like wind, height, air temperature. A pilot has to work very hard always. If he does not control any in a second, the helicopter may drop down. Since 1988, I have been developing an unmanned helicopter at my Institute. This time, the helicopter I am using is not a model helicopter but a real unmanned helicopter which is widely used for agricultural spraying in Japan.

My fuzzy helicopter, right now, has the following functions. First of all we can control it just by giving voice commands such as 'take off', 'hover', 'fly straight', 'turn left' and so on. Even a beginner can easily control this helicopter because he has only to speak to the helicopter. Next we can navigate this helicopter using Global Positioning System which is simply called GPS. GPS is a system to measure three dimensional position using satellites. The helicopter flies to its destination using GPS signal. The accuracy is about one meter. Finally the fuzzy helicopter can search for a landing spot with a camera and automatically land on it. And it can also track, that is, follow a moving object using an active image sensor. I am now thinking to practically use this intelligent helicopter. We have two sorts of uses. One is for monotonous missions. As some examples we can consider detecting fish in the sea, oil pipeline inspection, monitoring traffic conditions on highways and so on. The other is for dangerous missions: for example, sea or mountain rescue, searching a crashed aircraft, accident monitoring of oil tankers, fire fighting at mountains or high buildings, and so on.

Now I am coming to the third subject. Recently I also began to work on fuzzy modelling. Professor Zadeh, the founder of the theory, often says 'computing with words'. This means the following. We can express the fuzziness of a word using a fuzzy set. Adjectives such as 'Small', Old' or 'Tall' are typical examples of fuzzy sets. As I have explained at the beginning, we can express the meanings of these words in term of membership grades and we can put these into a computer. As such, computing with fuzzy sets means 'computing with words'. Also after some computation, on the contrary by translating membership grades into words, we can obtain results in term of words. This is exactly what we, human beings, are doing everyday. We speak to someone with words and he or she replies us with words after some processing in his or her brain.

Fuzzy sets are very useful for fuzzy modelling. Fuzzy modelling is a qualitative modelling rather than quantitative modelling. For example, instead of saying 1, 2, 3 we can simply say 'small'. In fact this is a fuzzy model of numerical values 1, 2, 3. This is a translation of numerical values into a word. We can also consider this as understanding the meaning of numerical values. In a certain situation, we might say 'big' for 1, 2, 3.

We, human beings, have this ability. Some years ago, I suggested a systematic way to build a fuzzy model of a system. For example, given input-output of a plant, we can explain the behaviour of a plant linguistically by using a fuzzy model. As another example, let us consider the trend data of a stock. An expert dealer in the stock market can easily explain the trend of a stock price qualitatively with words. We can make a computer do the same thing using a fuzzy model.

If we extend this idea further, we come to an idea of 'computing with texts'. That is, we deal with texts rather than words. A text is, for example, my present speech, an article on a newspaper, a conversation at a hamburger shop, or something like that. A text is characterised by its meaning. However fuzzy theory cannot solve everything. In order to understand the meaning of a text, we need a certain linguistic theory. My suggestion is to use functional linguistic theory. So my idea is to combine fuzzy theory and functional linguistic theory. Our question would be now, why language?.

Here I would like to consider why language is important in intelligent systems. Human intelligence is characterised in several ways. Someone says that a human is intelligent because he or she can build or use a tool. A monkey, usually, cannot use a tool. A psychologist may say that it is because a human has self-consciousness. For instance a human can think on his or her own death, but a monkey can not. Also someone points out that the size of the human brain is bigger than that of a monkey. In philosophy and in linguistics they say that a human is intelligent because he or she can use language. I like to take this last point of view.

Now I would like to mention two issues: fuzziness of language and functions of language. I think there are three essential uncertainties in our world. The first one is uncertainty of phenomena which is treated by probability theory. The second one is uncertainty of concepts or words which is treated by fuzzy sets theory. Probability theory was initiated in the 17th century and fuzzy theory was introduced just 30 years ago. The last one is the uncertainty of the human subjective feelings which, I do not think, can be treated mathematically. If possible, we could create an artificial man.

To show that language is essentially fuzzy, I like to refer to a Wittgenstein's text. Wittgenstein is said to be one of the most distinguished philosophers in this century. He says

> *"How is the concept of a game bounded? - The concept 'game' is a concept with blurred edges"*

He uses a concept 'game', or better 'language game', often in his text as a typical example of words. He states that the concept of a word has no sharp boundary and it is essentially fuzzy. In fact we recognise that almost all words we use everyday are fuzzy. When we say to meet someone at one o'clock in the afternoon, it does not imply exactly at one o'clock, but imply some time around one o'clock.

Let us next consider functions of language. Among many functions of language, recognition, thinking, memory and communication are specially important. No doubt, language essentially exists for communications. Today let us just think about cognition with language. I would like to refer to a Professor Halliday's text. He is a founder of the functional linguistic theory which I am using in my research.

Language has to interpreted the whole of our experience, reducing the indefinitely varied phenomena of the world around us, and also of the world around us, to a manageable number of classes of phenomena.

He points out here two important things. Firstly we interpret, or we recognise the physical world by means of language. Secondly the procedure is to classify continuous phenomena into some finite number of discrete phenomena with language.

Let us look at a rainbow in the sky. A rainbow is a continuous optical spectrum. We, human beings, divide this continuous entity into some number of colours such us red, yellow, green, blue and so on. This is our way to recognise the world around us. We also use language for sensor fusion. We have five senses, the sense of sight, the sense of hearing, the sense of smell, the sense of taste and the sense of touch. For example, when we say 'sweet smell', we combine the sense of taste and the sense of smell. When we say 'soft voice', we also combine the sense of touch with the sense of hearing. Animals cannot recognise the outside world like this because those do not have language. Language enables us to make such a high level cognition. A classification with language, such as the colours of a rainbow is apparently a fuzzy classification. There is no sharp boundary between red and orange. There is no physical definition of the colours of a rainbow. Above all, the number of colours in a rainbow is arbitrary. Most American people see six colours, Japanese people see seven colours and some African people see three colours. The number of colours depend on a language or a culture and does not depend on the physical nature of a rainbow. What we have learned is that we understand the meaning of the outside world with language. In other words we translate the physical world into everyday language, and this is precisely our intelligent recognition. So, my suggestion is to use everyday language for information processing with a computer.

Recently I am proposing to make a research on intelligent computing. Intelligent computing is a paradigm to develop intelligent systems. The essence of intelligent computing is to use everyday language. The framework of intelligent computing consists of three parts. The first part is the summarization of information. In our age of multimedia, we need to deal with multi-modal information such us numerical information, acoustic information, visual information textual information and so on.

In the first part, we understand the meaning of each information with language. That is, we summarize the numerical figures 1, 2, 3 as 'small', we summarize the optical spectrum of a rainbow as 'red, orange, yellow and so on' and we summarize a long text as a 'short abstract'. In such a way we translate different information sources into common language.

In the second part we make information fusion together with knowledge base. This process is nothing but language processing with a computer. We have here all the pieces of information and knowledge in terms of everyday language and so we can deal with those meanings using a linguistic theory. We need a special type of dictionary to understand meanings in a computer. My suggestion is to develop a situational database because meanings depend on situations. We write down all the possible situations concerned with human activities and put those in a huge database.

Finally in the third part we output linguistic information for various applications. I would like to show you a simple example about weather forecasting. In weather forecasting, a weather forecaster uses, as we know, numerical data such as strength of wind, temperature, humidity and geographical data of air pressure distribution, and also qualitative data, that is, his or her knowledge derived from experience. As we see information used for weather forecasting is multi-modal. And finally he or she forecasts tomorrow's weather in term of the everyday language. So my idea is quite simple. I am just suggesting to imitate more and more a human way of seeing, thinking and doing, and to make a computer intelligent. A keytool to this aim is our everyday language.

Finally I express my sincere thanks to Your Excellency The Rector Magnificus of the Spanish Universidad Politécnica de Madrid, Professor Saturnino de la Plaza, and all the Faculty Members for giving me this great opportunity. Also I am very grateful to my old friends in this country, Professor Trillas, Professor Batle, Professor Delgado and Professor Lopez de Mantaras for their continuous friendship. Please accept my apology for not calling all the names because I have so many friends.

I thank you, distinguished guests, ladies and gentlemen for your kind attendance and for your very kind attention. Thank you very much.