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On Fuzzy Data Analysis

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Fuzzy systems can be found in nearly all industrial branches, e.g. automobile, control engineering, finance, medicine, logistics, telecommunications. Their advantage is their inherent simplicity. Fuzzy rule-based models often turn out to be useful and easily understandable in many real-world applications. In order to learn such models from data – may they be fuzzy or not – intelligent data analysis methods for learning and reasoning are necessary. Thus there is a need for fuzzy data analysis.

The aim of this paper is twofold: In the first part Rudolf Kruse presents some memoirs on early research in fuzzy data analysis and some anecdotes about Lotfi Zadeh in this context. The second part is donated to real-world applications of fuzzy methods and some thoughts about perspectives of fuzzy data analysis.

49.1 Memoirs on Early Research in Fuzzy Data Analysis

Until 1980 the *pioneers* in fuzzy research had no problems with mathematicians and statisticians because there were only a few researchers in this field. On the contrary, lots of people were just curious what type of research was hidden behind the funny name *fuzzy sets*. At that time I was a student of mathematics at the University of Braunschweig in Germany. I asked my supervisor Ernst Henze, an open minded, application-oriented statistician, whether he could recommend a challenging and new topic for my diploma thesis. Henze proposed to study the new field of fuzzy systems because he had found an interesting paper by Lotfi Zadeh [1]. I got interested in the application of fuzzy measures and fuzzy integrals and studied the papers of Michio Sugeno. My doctoral thesis was on fuzzy measures. I draw my attention onto the fuzzy random variables and finished my habilitation in 1984. These days the situation in the fuzzy systems field changed drastically since (1) the number of researchers in this field increased rapidly, (2) it became apparent that dealing with fuzzy data is a complicated research topic with no simple solutions, (3) some fuzzy researchers published papers where it turned out that they were not familiar with the respective standard methods, and (4) there were newspapers articles about potentials and industrial successes of fuzzy logic methods, especially in control engineering. In this situation some mathematicians and statisticians realized that there were interesting real-world applications and capacities for new scientific fields. Other researchers tended to fight against fuzzy sets because they considered its community as an

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academic rival that is weaker from a scientific point of view, but having successes in newspapers and by industrial applications, too.

I attended the first IFSA Congress in Palma de Mallorca [2], a large congress in incredibly hot rooms where I met some well-known fuzzy researchers for the first time. Lotfi introduced himself walking on the street from the hotel to the conference rooms by saying "My name is Lotfi. I just reviewed your paper [3]". I was deeply impressed because the famous Lotfi Zadeh seemed to be a *normal* person. What a surprise! At this conference in Palma during the breakfast and after a long night at the beach in El'Arenal I was invited to write a book about the topic of fuzzy data analysis for Reidel Publishing Company. The editor of this series, Heinz Skala, was aware of the fact that my doctorate student Klaus-Dieter Meier and myself had developed useful fuzzy methods and a software tool for statistical applications for the Siemens AG. Nevertheless did he recommend avoiding the name *fuzzy* in the title. Thus the title of the book was *Statistics with vague data* [4].

These days some mathematicians were already fighting against fuzzy methods. During a panel discussion at the 8th International Congress of Cybernetics and Systems in June 1990 the famous mathematician Saunders MacLane had heavily criticized fuzzy set theory: "The fuzzy world is often full of fog. The ingenious notion of a fuzzy set was a notable novelty. Unfortunately it has now become a considerably inflated fashion [...]. This may account for the present sorry state of fuzzy statistics [...]. One text which I examined [4] had little to say about data. In spite of several serious attempts, I have yet to find a decisive application."

As you can imagine I got somewhat unhappy by listening to his contribution after Ron Yager's party on top of an apartment house in New York City. Lotfi commented the situation by saying "Take it as a compliment. Now the people know your name". I am still grateful for his encouraging comments. Of course MacLane was right in some of his remarks concerning fuzzy theories. But he should be blamed for not seeing the potentials of these new ideas. Before the conference he was not even aware that there were already lots of successful fuzzy applications at that time, e.g. in washing machines, photo cameras.

49.2 Real World Applications with Fuzzy Methods

In 1986 the fuzzy research group in Braunschweig has been established. The group had several industrial projects, mainly in the field of uncertainty handling. The group for example implemented the first Bayesian Network in Germany for Dornier in 1988.

The group was asked by a Volkswagen (VW) research leader to evaluate the usefulness of fuzzy logic control theory. There were no fuzzy researchers at VW and they knew that the group had background in academics as well as in industry. The reason for the VW activity was as follows: On the one hand there were lots of newspaper articles about spectacular new fuzzy applications in Japan. On the other hand there were lots of warnings by several control engineers in Germany about using fuzzy methods in control engineering. So, as a good research manager, he had to

check both the potentials of fuzzy logic as a new technology and the use of the marketing potential of the innovative label *fuzzy logic*. The group and VW agreed on a similar project named "Idle speed control with fuzzy logic". This project was of great interest for the group because here they were asked to study real applications in which mathematical background in fuzzy theory could help. For the group it was an interesting challenge to cooperate with control engineers. This project was a big success from the scientific and the technology transfer point of view. It was realized that there are several semantics of fuzzy sets, e.g. uncertainty, similarity, preference, and that control engineers use a completely different interpretation than people working in the field of fuzzy logic – in the narrow sense of a multivalued logic [5]. It turned out that fuzzy control can be seen as a new kind of interpolation – the control engineers liked this view, because it explains fuzzy control in "their" scientific language. A paper on these results received the best paper award of the *IEEE Transaction on Fuzzy Systems* in 1995 [6]. The idle speed controller that students developed within that project turned out to be better than the series line controller. The classical control engineers were puzzled. As a result of this project fuzzy control methods were tolerated at Volkswagen and another student of the group was allowed to develop an automatic gearbox that uses *fuzzy logic* to adapt to the driver's style. This controller was used in the New Beetle series [7]. From a methodological point of view, this problem was considered as a fuzzy data analysis problem. The task was to analyze data from the car to classify the sportiness of the driver. So this was a classification, data analysis, and model learning problem. Lotfi sent a fax with a New York Times article about the New Beetle in which the fuzzy automatic gearbox was mentioned.

Lotfi accepted the invitation by the Technical University in Braunschweig on the occasion of its 250th anniversary to give a talk about fuzzy logic. The conference was a big event because of the plenary talks from the Secretary of State Henry Kissinger, the later German chancellor Gerhard Schröder, the physics hero Carl Friedrich von Weizsäcker, Volkswagen boss Ferdinand Piëch and other prominent speakers. Lotfi and the first author of this paper gave a tandem plenary talk – the former presented some ideas about fuzzy logic and soft computing whereas the latter the fuzzy automatic gearbox. Lotfi was treated in Braunschweig as a VIP (see Fig. 49.1). A female employee was responsible for him during his stay in Braunschweig. Later on she wrote the following lines in a short essay [8] about Lotfi's stay in Braunschweig: "I had to be really careful not to loose him. Scarcely I left him alone for a moment when countless scientists immediately bustled around him. [...] I became aware why Prof. Zadeh attracted so much attention on him. My admiration for him grew every day that I could take care of him. No, not only because he is a authority on his métier but also because I got to know him as an always accommodating, grounded, pleasant human being despite his international celebrity."

49.3 Perspectives of Fuzzy Data Analysis

One can find successful fuzzy systems in almost all industrial areas where optimization, learning and handling imprecise knowledge play a role, i.e. classification,

prediction, planning, control, decision making – just to mention a few fruitful areas. We guess that in the near future these *classical* ones will remain the main areas for successful industrial applications of fuzzy systems. These fuzzy systems have always impressed by their simplicity. Fuzzy rule-based models (e.g. á la Mamdani or Sugeno) often turn out to be useful, understandable, not complex and easy to handle.

In a long term run we think that there will be more *intelligent* systems in the role of a *companion of humans*. We already see the trend in the automobile industry where lots of assistant systems are used or in health care for elderly people, which will be another huge market in the future. In order to develop such systems, fuzzy methods could be helpful. Definitely, improved methods for human computer interaction are necessary. So we are sure that, in cooperation with neuroscience, new brain-machine interaction methods will have to be developed. For our research areas we can say that to reach the aim of having more *intelligent* methods, we need much better learning and reasoning systems.

Fig. 49.1. Lotfi in Braunschweig

We think, that in order to reach this goal there is a need for fuzzy data analysis. We must differentiate between *fuzzy* data analysis and *fuzzy data* analysis. The former deals with the analysis of classical data using methods based on fuzzy set theory.

These methods, e.g. fuzzy clustering or fuzzy regression analysis, have been used successfully in lots of industrial applications. The second approach tries to analyze *fuzzy data* by using statistical methods. It seems that there are lots of fuzzy data in the *real* world, and that these data should be used in intelligent systems. This second approach is conceptionally much more difficult than the first approach, because it is often not clear, what a *fuzzy datum* actually means. There are lots of different semantics of a fuzzy datum: Often a fuzzy datum is considered as a "solid object", in other cases it is considered as a kind of "summary" of a more complex underlying phenomenon. The chosen semantics of the fuzzy data have to be taken into account in a serious statistical analysis. So we need models that are able to handle different type of phenomena, e.g. second-order uncertainty models. Such models are much more complicated than "classical" fuzzy methods, and industrial users often hesitate to use such complicated models that need further theoretical insides. Another problem with the second approach is that there are neither software tools available, nor databases for benchmarks. Nevertheless are there lots of challenging open real-world problems in which *fuzzy data* occur, and there is a need to evaluate such data, e.g. for decision making. So, we think that in the future, by using improved mathematical models that combine different qualitative and quantitative modeling approaches, and by increased computational power, fuzzy data analysis and related uncertainty handling technique can be successfully applied in lots of applications.

References

1. Zadeh, L.A.: Probability measures of fuzzy events. Journal of Mathematical Analysis and Applications 23(2), 421–427 (1968)
2. Kruse, R.: On a language and an interpreter for calculation and statistics on linguistic data. In: Proc. First IFSA Congress, Palma de Mallorca, Spain (1986)
3. Kruse, R.: On the variance of random sets. Journal of Mathematical Analysis and Applications 122(2), 469–473 (1987)
4. Kruse, R., Meyer, K.D.: Statistics with Vague Data. In: Mathematical and Statistical Methods. D. Reidel Publishing Company, Dordrecht (1987)
5. Kruse, R., Gebhardt, J., Klawonn, F.: Foundations of Fuzzy Systems. John Wiley & Sons Ltd., Chichester (1994)
6. Klawonn, F., Gebhardt, J., Kruse, R.: Fuzzy control on the basis of equality relations with an example from idle speed control. IEEE Transactions on Fuzzy Systems 3(3), 336–350 (1995)
7. Schröder, M., Petersen, R., Klawonn, F., Kruse, R.: Two paradigms of automotive fuzzy logic applications. In: Jamshidi, M., Titli, A., Zadeh, L., Boverie, S. (eds.) Applications of Fuzzy Logic: Towards High Machine Intelligence Quotient Systems. Environmental and Intelligent Manufacturing Systems Series, vol. 9, pp. 153–174. Prentice-Hall, Inc., Upper Saddle River (1997)
8. Syring, F.: Lotfi Zadeh in Braunschweig. In: Rebe, B., Schnieder, E., Grumbach-Raasch, E. (eds.) Moment eines Jubiläums: 250 Jahre Technische Universität Braunschweig, Technische Universität Braunschweig, pp. 331–332 (1996)