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50 Years of Fuzzy Sets in Germany

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1 Preface

Reviewing the development of fuzzy set theory in Germany poses some problems with respect to the focus of the review: Shall I focus on German authors, or on what happened in Germany during this time, or what contributions have originated in Germany? I shall focus on what happened in Germany in the fuzzy area within the last 50 years. A distinction between German and Not-German contributors to the fuzzy area becomes even more difficult because starting in the early 80s several colleagues and PhD candidates from other countries, such as China, Great Britain, India, Israel, Japan, USA spent some time in Aachen. Since there exist thousands of publications in this area, I will have to limit the references to a manageable number. That means I will only cite a number of characteristic German references and include also a few Non-Germans for purposes of calibration. This problem becomes even worse, because with the time Germans and Non-Germans team up as authors. Also events have happened in Germany and other events have been initiated in Germany, but happen elsewhere in the world. I shall include these two, but exclude even important events, that happen outside Germany or are not organized by Germans.

This paper presents a personal view. Hence, it will be from the point of view of somebody working in Operations Research (and not that of a mathematician or an economist). Finally, often the term "application" will be used. The reader should realize, that this a pretty fuzzy term. Many scientists imagine a problem, they model it formally and then apply a theory or method to it and they call it an application. By contrast to this, real problems have to be accepted as they are and then they can be modelled more or less appropriately. When I talk about applications I will mean "real" applications of the latter kind. For instance, the application of fuzzy set theory to linear programming is certainly an important application of a theory to a method but not a "real" application.

2 The Academic Press

As an Operations Researcher one aims to optimize processes and solve real applications, from the beginning of OR in interdisciplinary teams, because problems normally have features in several different disciplines, such as mathematics, engineering, psychology, law, business administration etc.. Working in OR I had always been frustrated about the fact, that in companies only problems on a very low level were considered to be solvable by OR, because problems on the level of top management were considered to be too ill structured to be accessible for OR. I was, therefore, very excited when I read Bellman & Zadeh's article [6] about decisions in ill-structured

environments in Management Science of 1970. I went to Berkeley right away and had fascinating discussions with Lotfi Zadeh. This started our research in Aachen in an interdisciplinary team (psychologists, mathematicians, statisticians, engineers, and business administrators). We had mathematical teams and empirical teams working in parallel primarily on two topics: 1. To fuzzify crisp OR methods (like linear programming etc.) and 2. How do real membership functions look like and do "min" or "product" model adequately the "and" humans are using. This research was particularly relevant for the so called "Expert Systems" which were very popular this time and very often not performing well. The research was mainly supported by the university in Aachen and by the German Science Foundation (DFG). This was the time when Kaufman published in France his first book on Fuzzy Sets [28] and Mamdani published the first results in the area of fuzzy control [36] and Yager published his first article decision making with several objective functions.

The results of our research were –concerning the first topic – fuzzy linear programming with one or more objective functions [70][72][21] and first applications of FLP [65][74]. Concerning topic 1 it turned out, that the min/max operators were not good models for the human "and" and "or" in general. Rather the "Hamacher Operator" and the family of Gamma-Operators modelled the human "and" and "or" acceptably well. [20][55][70][81][83].

At the end of our empirical research the DFG insisted that we show the applicability of our research and we started a project in which creditworthiness of bank customers – as estimated by bank employees- were modelled and empirically tested. It turned out, that the results of a fuzzy hierarchical aggregation of the determinants of creditworthiness were extremely good- and surprising to the bank managers [82][84]. However, it also turned out, that empirical research of the type we had been doing is very expensive. So, the DFG finished financing empirical research in the area of fuzzy sets.

In general research to fuzzify methods developed at this time in 4 directions: Optimization (FLP), knowledge-based-systems (expert systems and fuzzy control), classification, and pattern recognition.

Fuzzy Set research was not very popular in Germany at this time. In fact colleagues smiled at our research and considered it as "not enough scientific". Nevertheless, there were a few colleagues in other areas that were convinced of this approach and continued their research: Bock [10] worked and published in the area of fuzzy cluster analysis, Gottwald [18]did research in fuzzy sets on higher levels, Skala [49] worked on fuzzy logic and

Wechler [63] on fuzzy automata. With the exception of Aachen no courses on fuzzy topics were, however, offered at German universities.

Since researchers in the fuzzy area were distributed over the world and no common means of publication existed it seemed advisable to start one. So 1978 the Journal for Fuzzy Sets and Systems (FSS) was started and for the 21 years to come edited in Aachen. The first volume had approximately 600 pages. It is some indication of the importance of fuzzy set theory, that in the meantime the volume of this journal has grown to more than 3000 pages.

3 The Transition Phase

At the beginning of the 80s the interest in fuzzy sets started to rise slowly in Germany. The majority of publications concerned theory and methods. Fuzzy LP was further investigated [46], the first fuzzy programming language was offered [1][64], Fuzzy Petri nets were developed [35], and the first books in the fuzzy area were published by Germans [11][47][75][76]. Also the first publications on applications of fuzzy sets by German authors appeared: Inventory control [54]medical applications [2] and topics in social sciences were touched [73]. A real big application was the development of optimal routings for containerships by fuzzy LP [15]. FLP was used successfully in blending problems (paints, Champaign, rubber, etc.) Bezdek published his extremely important book on fuzzy clustering [7]. Also courses on fuzzy sets and expert systems were offered at the Technical University of Aachen.

At this time, it seemed to me that publications alone were not sufficient to advance the fuzzy area. Communications at that time were much slower than to day and researchers in the fuzzy area were located in different countries all over the world. I thought that talking to each other would be much more efficient. The result was, that IFSA (the International Fuzzy Systems Association) was founded in two steps in 1984: At first the European leading researchers met in Brussels and one month later I could ensemble interested academics in Hawaii in the framework of a NAFIPS conference and complete the founding of IFSA, which has proven very active since then. Already in 1985 there was the first IFSA conference in Mallorca (July 1 to 6, 1985) with 3 volumes of abstracts in conference proceedings.

During this time fuzzy control was already extensively used in Japan for consumer goods (video cameras, washing machines etc.) and even to direct a subway train in Sendai! In the German Economy one became aware of this, when a journalist, that had visited Japan, published an article in a German trade journal, warning the German enterprises, that they would lose

another market after the consumer electronics, if they would not do everything to catch up with Japan very fast. That article started in Germany the Fuzzy Boom.

4 The Fuzzy Boom in Germany

German scientists became interested in fuzzy sets and published books in this area [23][33] and also professionals published articles and books [57][61].

Hardly any trade journal related to computer science or computing dared not to publish articles on "Fuzzy Logik". For instance: HighTech published an article with the headline "unleashed open-minded thinkers" (Entfesselte Querdenker) [17] and an interview with Lotfi Zadeh under the topic" Fundamentaler Wandel". The front page of this issue presented a big picture of Zadeh with the slogan "How a new technique changes the world: Fuzzy Logic-the the magic formula for innovation". Axon [29] reported under the topic "Queuing for Fuzzy Logic" on masses of visitors queuing in front of exhibitors of fuzzy products at the Interkama and the Hannover Industrial Fair 1972. Elektronik [34] included an interview of Lennemann who reported that "Germany is 12 month ahead of Japan", see also [44] and [62]. Presented were mainly fuzzy control tools together with simple but impressive application examples, such as control of a travelling crane (7 fuzzy rules!), the checking of signatures, etc. These examples were mainly presented by big companies, such as Siemens, Omron, Klöckner-Moeller. By contrast to Japan, German companies hardly ever used "fuzzy" as an attractive label for consumer goods (such as cameras, washing machines, etc.). Probably because the German consumer attitude differs considerably from the Japanese.

A market research report in 1993 [3] lists 10 tools to develop fuzzy controllers of which 5 are German products. The same study one year later [4] lists already 10 fuzzy control tools, 3 control development systems and 4 Hybrid Neuro Fuzzy tools that can be used for fuzzy control, data analysis and pattern recognition. Of the last mentioned 2 were from Germany (DataEngine and FuzzyTech) and these were the only ones, that contained other operators than min/max. From the before mentioned 8 ware offered by German companies and institutions. More complete descriptions can be found in [12],[22],[51],[31] and [59]. Also Kiendl [30} published their first German book on Fuzzy Control.

Not only the number of "fuzzy shells", i.e. tools to build fuzzy systems, was growing pretty fast at this time. Probably inspired by the large publicity of Fuzzy Sets, numerous areas not directly connected to control

engineering started applying fuzzy methods to their problems. I shall mention a few of them: De-icing of air planes. During winter days planes have to be de-iced in order to avoid icing problems during the flight. At airports their wings are sprayed with a liquid, the composition depends on temperatures. The blending is optimized by employees and they use a fuzzy tool to determine the optimal blending depending on the weather and other factors [32]. Other applications in the chemical industry can be found in [16][37] and [41]. About the use of fuzzy tools in robotics reports Palm in [43]. An example that has similarities with very modern developments is the "fuzzy car", that was already presented at the Hannover Fair in 1992 and raised then a lot of attention: A model racing car was equipped with sensors and a fuzzy controller which enabled the car to go fast and without any human interaction from point A to point B without touching any of the obstacles [60] placed between these two points. An interesting example in finance can be found in [5]. Biethahn [8][9] published two books on applications in business administration. In 1999 interesting contributions comparing Fuzzy Set Theory with Stochastics were published [53].

The development of fuzzy applications was also supported by an event that happened in 1992: During the decades preceding the fuzzy boom in Germany three areas that all imitated natural living had been developing apart from each other: Genetic algorithms and Evolutionary Programming, Artificial Neural Nets, and Fuzzy Set Theory. Theories in these areas complement each other [79]. In 1992 three congresses took place, in Japan, USA, and Germany (Aachen) at which these areas joined forces. The combination of these three areas was henceforth called "Computational Intelligence". The meaning of CI was even rigorously defined at the conference in the USA. The result was, that many tools and applications used methods of CI, i.e. combinations of methods from the above mentioned areas.

Applications and application directed research in the area of CI in Germany was not only undertaken by big companies but also supported by the state and by other institutions: The state of North Rhein Westfalia (NRW) spent many millions of Deutschmarks in the "Fuzzy Initiative NRW" [45] and enabled the start of new companies and institutions that concentrated on CI. As the best known one should probably mention the "Fuzzy Demonstrationszentrum Dortmund" (Dortmund), ELITE (European Laboratory of Intelligent Techniques)(Aachen) which is a private non-profit foundation, MIT GmbH (Management of Intelligent Techniques)(Aachen), and already existent but with a new division "Fuzzy Technology": Inform GmbH(Aachen).

To strengthen the cooperation between theory and practice ERUDIT (European Network in Uncertainty Techniques Developments for Use in Information Technology) was started in the mid-nintees by the European Commission DG III Industry-Esprit Program as a Network of Excellence which was run by ELITE in Aachen. It had established efficient communication in the area of CI between more than 250 European nodes. It aimed at stimulating innovations and advanced research and was encouraging trans-European training activities. ERUDIT was structured in six technical committees : Primary Industries; Process Industries; Components, Capital, and Consumer Goods; Traffic and Communication; Human-,Medical and Healthcare; Finance, Trade and Services. It would obviously exceed the scope of this article to describe even a large part of the projects of this network. In addition to the projects ERUDIT also organized the "European Symposium on Intelligent Techniques" once a year in different European locations.

Training in the area of CI had also increased very much in the meantime. More than 20 German universities offered courses in fuzzy sets. Several university chairs had begun with research in the area of CI. Conferences and information centers had started. The most important in Germany seem to me the "Dortmund Fuzzy Tage" (started 1991 and was once every year) ,the "Aachener Fuzzy Symposium" organized by Inform , which started in 1991 and occurred once a year, and the "Symposia for Applications of Fuzzy Technologies" organized by MIT in Aachen twice a year, which started 1992 and were organized twice a year. The largest event was probably EUFIT (European Congress on Fuzzy and Intelligent Technologies) which was organized by ELITE once a year and started in 1993. This congress, which had generally about 650 participants, had one special feature: Besides the normal presentation in various areas of applications of CI it provided space for about 25 to 30 exhibitors of real fuzzy applications, which, of course, always attracted a pretty large crowd of interested conference participants. This conference was organized until 1999.

5 After the Millennium

After 2000 the "Fuzzy Situation" in Germany changed pretty fast: Reports on fuzzy applications disappeared from the media. In particular trade journals and other application oriented media stopped publishing anything on either fuzzy techniques or fuzzy real applications. Obviously they had found other topics of which they assumed public interest. Since German producers of consumer goods (washing machines etc.) hardly ever

used “fuzzy” as an attractive label, one good also nowhere detect advertisements with the label “fuzzy”.

Public financial support ended for several reasons. That meant no more start-ups in this area. No more CI-conferences were organized in Germany. As far as I know no more university lectures were offered at German universities. I left the Technical University in Aachen in 1999 and there were no more fuzzy courses after this time.

The producers of fuzzy tools disappeared largely from visible market and those who were further active concentrated on narrow sectors of application. Inform and MIT in Aachen, for instance, which had used their tools (DataEngine and fuzzyTech) in very many areas of application, focused either on customer segmentation in banks or on fraud detection and prevention in financial services. That, of course, might be due to the fact, that the possession of a fuzzy tool alone does not mean successful operations. It needs marketing activities to become known by potential customers.

1973 a survey [45] came to the conclusion, that 17% of the companies used already fuzzy technology and that 43% of the participants of the survey knew about fuzzy technology. This is certainly no longer the case in Germany. Nowadays some still remember the word “fuzzy” but know of very few companies that still use this technology.

More scientifically oriented journals, such as the Journal for Fuzzy Sets and Systems, still published articles by German authors [27][39][40][42][48][56], but they were all pretty mathematically oriented and the relative portion of German authors declined compared to authors from other countries. An exception is the year 2015 when more German scientists contributed to the two special issues of FSS and Informatik Spektrum dedicated to 50 years of fuzzy set theory [13][14][19][24][26][52][66].

With the exception of the two issues of FSS[24][52][66] and Informatik Spektrum [13][14][19][66] dedicated to 50 years of Fuzzy Set Theory only few German contributions can be found during the years after 2000.

It should also be realized, that soft-and hardware has become considerably faster since the 90s of last century. Hence, the need for systems that provide solutions in very short times has reduced in many areas. That is probably also one of the reasons that expert systems have lost very much of their attractiveness. Also the influence of computer science or digital computing in general has risen considerably since the 90s of last century. That has strengthened in general the digital thinking and, hence, made it more difficult for a theory like fuzzy set theory to be understood and

accepted, particularly if it is taught nowhere. A little personal story at this point: When my son was 11 (in the 90s) and had set theory at school, he was very interested in what I was doing, i.e. in fuzzy sets. One day he asked his math teachers what he knew about fuzzy sets. The answer was: "That is nonsense, an element can only belong to a set or not." When my son answered, that he somewhat disappointed because there were already hundreds of publications on the theory of fuzzy sets, the relationship between him and his teacher had been spoiled for a very long time.

There may also be another reason for the present situation of fuzzy sets in Germany: Fuzzy set theory has been sold for a very long time as a theory for uncertainty modelling and as a competitor to probability theory and statistics. In the meantime, there exist more than twenty uncertainty theories [78] and the contexts in which they should be used have not been defined clearly enough to allow the practitioner to decide which one to use when. So in practice very often the "Hammer Principle" is being applied: If I have a hammer in my hand everything starts looking like a nail. In this case the "hammer" is certainly probability theory.

6 Conclusions

Research in the fuzzy area in Germany seems to be limited to mathematical developments by those researchers who have already been working in fuzzy sets in the last century. German authors still publish in scientific journals, but relative to foreign researchers their number seem to decrease. Obviously there is still ample space for mathematical research, but Germany will in the future not one of the leading countries. The problems seems to me, that in this type of research it is generally assumed that numerical expressions are on an absolute scale level, which cannot be reached for numbers estimated by humans. As is known in psychology and probably also in linguistics human estimates generally only reach an ordinal scale. This can also not be cured by using membership functions of degree 2, because then the numerical effort becomes excessive.

Empirical research (on real shapes of membership functions or on context dependent operators) at the present time in Germany is not known to me. This, however, would be the bridge between formal theory and models of human behavior and reasoning. Also education or training in the area of fuzzy sets in Germany is not known to me. On the contrary for reasons already mentioned above, digital thinking seems to become more and more common.

Fuzzy tools and techniques do still exist. fuzzyTech, Riskshield and DataEngine, for instance, are still being used but in rather narrow areas.

Many tools, however, provided only the min/max theory and triangular membership functions. It had been attractive to use such simple models for simple problems, but more complex problems needed more powerful approaches. Fuzzy Linear programming is even available as 0/1 version [80], but it is very difficult to convince somebody to make use of it. The same is true for many modern heuristics.

These developments have reduced real applications of fuzzy sets in Germany drastically. Even though I am convinced, that the potential for using these methods is still very large. In all applications in which thoughts, texts, or communications have to be semantically correct translated into formal models to be processed on computers or to maintain the real meaning (for instance in laws !) fuzzy sets will also in the future be a very valuable tool.

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