Fuzzy systems research in Hungary – a subjective story

Laszlo T. Koczy[1]

[1] Budapest University of Technology and Economics

Email: koczy@tmit.bme.hu

1   Fuzzy systems research in Hungary – a subjective story

Although, When I try to write the brief history of fuzzy systems related research in Hungary it will inadvertently become a subjective story, reflecting the view of the author, i.e., myself, and focusing on events and activities where I took part in personally. There is also no chronological order in this article; it is like when memories come to one's mind in a random way, connected by associations...

I read the first fuzzy papers in 1973 when one of the lecturers at Budapest University of Technology (**Miklos Hajnal**) dumped a large amount of journal articles related to various aspects of intelligent systems in front of a group of selected students (in the present Bologna system we were MSc students at the time), with the remark, we should select whichever we found containing interesting topics, and should start research work in the selected field. I do not know why Lotfi Zadeh's famous *Fuzzy sets* article caught my eyes immediately, but it did! And then I took with me all the other papers which had the word "fuzzy" in the title. I still remember Goguen's L-fuzzy sets being among them, and a few others, on fuzzy automata and other motley topics.

I started to read the papers - and a fascinating new world opened in front of me. Since then 43 years passed and this fascination never faded away. What happened to me was like love at the first sight, a love that continued in a happy marriage.

Soon I wrote up my first technical report [1], motivated by an interesting remark I found in a footnote of Zadeh's crucial paper. Although the definitions for union and intersection suggested in the main body of paper were the max and min operators, an alternative pair of definitions what Zadeh called "interactive operators" was what in the modern literature are known as algebraic norms. I found them quite interesting, because I had the intuitive feeling that subjective truth is generally increased by repeated statement, i.e. the strictly monotonic increasing and decreasing property of this pair of operations would reflect more adequately the nature of every day logic than the properties of the standard pair of operations. I found a strong supporting argument in a book by the famous researcher of stress, H. Selye, a scientist of Hungarian descent. This was the book *From Dream To Discovery On Being A Scientist*. In this book Selye clearly states that repeated results of experiments confirming the same hypothesis lead to increasing conviction about the truth of the same. In my report I proposed the argument that interactive operators should be promoted and widely used, and that it was worth while studying their axiomatic properties. When I was

ready I sent a copy of this report to Lotfi Zadeh, to Berkeley.

I was surprised how supportive and positive Lotfi's reaction was! Even though that time I had not met him yet in person, I count his first letter to me as the beginning of a friendship, of course, a friendship between an experienced scientist, a mentor, and a young researcher just starting to open his eyes to the beauty of knowledge and the amazing phenomenon of permanent expansion of scientific knowledge. After his first response Lotfi also sent me a bunch of papers and technical reports from UCB, which I still keep as special treasures in my collection on fuzzy technical literature.

I was very much pleased when I found years later that Lotfi even kept my first technical report in his library and thus later it was included in several bibliographies published in the 1970's and 80's by various authors.

Soon I found out that I was not the only one in Hungary at that time who was somehow interested in the fuzzy world, although I still think today, probably I was the most determined at that time to devote my whole scientific carrier to fuzzy research, and I was the first one to publish international papers.

Although Zadeh published his seminal paper in 1965, in Hungary the first interest in this new area started only in the early 1970-s. **Tibor Vamos**, that time very active in IFAC, knew Lotfi in person and they even became friends. Although Vamos did not publish essentially new papers dealing with fuzzy approaches, in the 1970-s he became a great promoter of fuzzy research in Hungary, and being part of the political establishment and a very influential member of the Hungarian Academy of Science, his support was rather important in a small country governed by leftist doctrines, even in the field of scientific research. Vamos later became the first Hungarian editorial board member of *Fuzzy Sets and Systems*. He also played a crucial role in providing an opportunity for me to meet Lotfi in person in 1975.

In the early 1970-s in several scholarly communities in Hungary the fuzzy idea came up, at least as something worthwhile looking at it. One of these was the research seminar at the Research Institute for Telecommunication, where after some overview seminars by local researchers I was also invited to give several talks in 1974 and 75.

It was in 1975 that I got my MSc equivalent degree in Control Engineering. The topic of the thesis was purely fuzzy. I was also extremely lucky, as in 1974 the Ministry of Education gave permission to the Faculty (School) of Electrical Engineering to introduce an experimental type of doctoral school program, and I was one of the first to be admitted. In this experiment, while working on the MSc thesis the few privileged students were allowed to start a very intensive doctoral training and so it came that

in 1977 I got my PhD (that time called Dr. techn. in Hungary). The topic was, of course, fuzzy control. That way I was the first young researcher in the country who actually earned a doctoral degree by fuzzy research. The topic was so new and unknown that in my degree certificate the field was indicated as "Probability Theory"; meaning that this was the closest "legitimate" field of science. I will come back to the topic in more detail somewhat later.

At the Budapest University of Technology the first who became interested in the fuzzy field was my later friend **Peter Varlaki** who got in contact with fuzzy papers through another friend of his. He remembers those years as follows:

"I could get acquainted deeper with the concept of fuzzy sets (after the cursory knowledge of fuzzy automata) for the first time in 1972 by Gabor Bonyhai. This accomplished scholar of literature and hermeneutics, who died early in 1996, read the original introductory papers of Zadeh on fuzzy sets and thought they could be very important and might have a productive effect on the field of research in general linguistics and the science of literature, as well. In the early 60-s, as a special talented high school student, he started to deal with mathematical logic, the science of modern logic, and with the results of the schools of philosophical logic of the 20-s and 30-s in particular. Thus, he studied *inter alia* the works of Carnap and Lukasiewicz. He dealt with subjective probability approaches closely linked with the fuzzy concept, which played important role in his hermeneutical analyses. He intended to identify and show dynamic systems of value, to be explored at the background of the system of the plot in several major literary works, where during the analysis both the fuzzy and the subjective probabilistic approach played an important role according to his practical investigations. His paper *The Language of Value*, published in German, may be of particular interest, in which the description of value systems was examined using modern linguistic analysis and the theory of communication. In this case, the fuzzy approach could play an important role."

Note that Bonyhai writes in above cited works about "moegliche Welten", i.e. he already recognized the difference between possibility and probability or likelihood. Varlaki further writes:

"Perhaps it is worth to note that already in 1971 I had the opportunity to get acquainted with the idea of fuzzy automata, in particular with regard to the theory of the stochastic and non-deterministic abstract automata. I also talked a lot with my late friend Ferenc Szatmari on the conceptual and philosophical issues of fuzzy, deterministic, non-deterministic and

stochastic abstract automata. Szatmari gave a lecture on the abstract automata and algorithms in 1973 at the First Hungarian Conference on Theory of Systems in Sopron. Later, in the spring of 1977 during my Moscow PhD studies, where, together with my scientific leader Naum S. Raibman, we published subjective probability models using Kalman filters, and I again encountered the fuzzy idea, as Professor Raibmann's good friend and colleague Professor Aiserman was a member of the editorial board of *Fuzzy Sets and Systems*, a periodical just recently started. I remember my trip from Moscow back home, in June, for summer holiday. I traveled on the train together with **Margit Kovacs** and **Istvan Joo**, to whom both I showed the first issue of FSS. I suggested Margit, who specialized in the Tykhonov regularization method in connection with numerical analytic problems, that she should study fuzzy theory, since it could obviously mean a compensation of regularization type for solving tasks in connection with ill-posed problems. Much later Kovacs started to deal with fuzzy sets actively, and she became the author of several papers in this field. Also, I wrote several papers together with her, especially on the modeling of specific economic and econometric problems. This way I inadvertently contributed to starting the opportunity that Kovacs's excellent students, **Janos Fodor** [2, 3] and **Robert Fuller** [4, 5, 6], who became really successful in the fuzzy field.

From the 90's, together with my colleague and friend Laszlo T. Koczy, and with Istvan Joo, a more than twenty-fold co-author of Pal Erdos, we have elaborated important issues on fuzzy interpolation. In the late 1990s and early 2000s, I had the pleasure of carrying out research work with **Peter Baranyi**, a former student of Laszlo, addressing special fuzzy linguistic problems.

In around 2010, I joined my above mentioned friend Robert Fuller in his research work, which he had carried out for years in the field of possibility correlation theory. Together with my student **Istvan Harmati**, and Robert, we constructed and tested new possibility measures of dependence [7], primarily on the basis of Alfred Renyi's approximation method of stochastic dependence measures. Recently, together with Harmati and my other friend **Laszlo Szeidl**, we attempted developing the theory of fuzzy number stationary time series."

Peter Foldesi who is at present the Rector (President) of Szechenyi Istvan University was also among the PhD students of Varlaki. In the 2000-s he started to work with me and we published jointly some fuzzy papers related to basic problems of logistics. An example is the Traveling Salesman Problem with fuzzy constraints and weights [8].

After citing Varlaki remembering his own fuzzy story, we may come back to the mid 1970s. One of the most active and earliest Hungarian fuzzy pioneers was **Jozsef Dombi**. He started to work with Hans-Jurgen Zimmermann, and spent several years with him in Aachen. The most important contribution of Dombi to fuzzy science is undoubtedly the pair of fuzzy operations (intersection and union), which are known and cited in the literature as Dombi-operations (cf. [9]). Throughout the decades Dombi did a lot of work on fuzzy aggregations (e.g. [10]) and in 2011 he succeeded in obtaining the highest Hungarian earnable scientific degree: DSc from the Hungarian Academy of Science, which is a postdoctoral title rather hard to get, and what is considered to be much more prestigious than a full professor's title (which is also conferred centrally in Hungary, by the government, although a condition of initial conferment of the title is the recommendation of a respective university). I was one of Jozsef's reviewers in the procedure, as by then I already had had that title for a while – as first in Hungary in the fuzzy field.

Personaélély for me it was quite a surprise when we recognized some much unexpected properties of the Dombi operations when we worked on artificial neural network construction with my former PhD student **Rita Lovassy**, starting from fuzzy operations and fuzzy flip-flop units (which I will mention later) [11]. We compared all available fuzzy aggregation families (later, by the idea another PhD student of mine, **Laszlo Gal**, we even proposed a new aggregation pair [12]), and we found that the learning properties derived from all these fuzzy operations were best for Dombi's ones! Thus we presented the results in our publications and it is no surprise that Jozsef was quite happy to learn about our results. It is worth mentioning that the best networks we thus constructed with Rita had several advantageous properties compared to e.g. the widely used Mathlab NN Toolbox. Our fuzzy neural network lacks the disadvantageous overfitting property and provides a smoother and more realistic fit, even in the presence of outliers.

With Jozsef we often debated about which of us to was the first active fuzzy researcher in Hungary. Anyway, we kept our friendship since the 1970-s, and even nowadays we occasionally invite each other to the committees of our conferences, or PhD exams. It is worthwhile mentioning about Jozsef that – despite being a mathematician – he founded his private company for consultancy and IT solutions, among others offering practical help in large size logistic optimization tasks. Fuzzy can help in so many different fields!

Returning to the historical decades, in the 1980-s I prepared my CSc

thesis (a kind of elevated PhD type degree, abolished in 1992, introduced originally in the Soviet Union, but taken over by most Eastern European countries, that was issued centrally by the respective national Academies of Science), and submitted it to the Hungarian Academy of Science. The topic was disguised as the optimization of hierarchical structured telecommunication networks, because in those days fuzzy research was rather frowned upon by official Hungarian research gurus. The real topic was however the optimization of fuzzy trees and the application problem could have been the optimization of hierarchical networks of human agents, management structures or networks providing services or material flow with varying availability or throughput [13]. In 1989 I got the degree and thus became the first CSc in fuzzy in Hungary!

Rather in parallel with my efforts to obtain official recognition to fuzzy research by the omnipotent Academy, Margit Kovacs also worked on a fuzzy topic at Eotvos Lorand University: fuzzy mathematical programming [14]. She received her CSc degree in 1990, and even though her main topic was not fuzzy programming, she had mentioned fuzzy options in her thesis. It is a pity that later she turned her back to fuzzy research, even denounced fuzzy as a "useless field". In 1990 however, Margit was still very enthusiastic and proposed the foundation of a Hungarian Fuzzy Association. Some 30 researchers came together and elected me to President of the Association. (In fact, to Co-president as I proposed on site that we elect Tibor Vamos in his absence to another Co-president, due to his continuous strong support of the field.) Margit was appointed Secretary General of HFA.

At this point a very important event connected to Vamos must be mentioned. Yet in 1975 he organized a bilateral conference at his institute, the US-Hungarian Joint Seminar on Pattern Recognition. Among the invited speakers from the American site was Lotfi Zadeh, the famous Father of Fuzzy Sets! Each foreign guest speaker was assigned a Hungarian "lance-bearer" by Vamos, and in Lotfi's case I had the honor. This was an excellent opportunity to spend a short

One of my first discussions with Lotfi in 1975 in Hungary

week with Lotfi and his wife Fay. I remember that I was amazed how modest, almost puritanical this famous researcher was. During those days I learned a lot from him about how to proceed with my fuzzy studies. The Seminar itself offered me a lot of new knowledge, in many respects. I was surprised, because all invited Hungarian speakers discussed one or another aspect of statistical pattern recognition, while the guests covered a very wide scale of different approaches, including semantic and, of course, fuzzy pattern recognition techniques. I realized then and there that Hungarian science had a certain "benevolent dictatorship", where some influential scientists always unambiguously determine the "only feasible" approach to a given problem. In a way it is still like that in my country...

Another important moral of the conference for me was the reaction to the fact that I received an offer for a PhD scholarship at the University of Pennsylvania, with a joint MSc scholarship to my freshly married wife studying control engineering at the time, by an another American participant: King-Sun Fu. When I namely mentioned about this offer to my university superiors the answer was "There are many other more senior colleagues waiting for such an offer. You must be patient until your turn comes!" Of course these "senior colleagues" had been members of the Communist Party, and had had no research activity at all...

So, I had to do my (first) doctoral degree in Hungary, as I mentioned it

earlier. The topic I chose was the axiomatic system of a fuzzy algebra of which algebraic operations and more general Hamacher-operations were a possible representation. Based on this, a new fuzzy control technology was proposed (very different from Mamdani-control, an extension of the idea of bang-bang control), and it worked rather well for some simulated systems. In that thesis I proposed – as first in the literature – inverse set operations for strictly monotonic norms and co-norms; and based on those a successfully applied simple clustering algorithm was also presented. This research resulted in my first international journal papers, among others my first paper in Information Sciences.
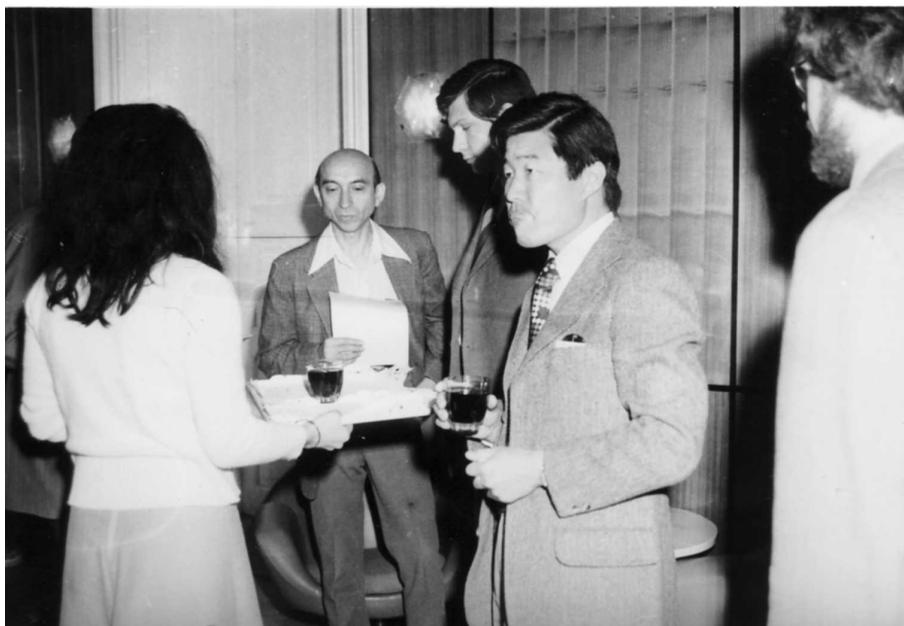
Coffee break of the conference, I am talking with Lotfi; in the foreground Kenji Hanakata

1975 also brought some other important events for me. In the summer I attended two international conferences, one in Edinburgh (presenting the fuzzy clustering method applied for karyometric classification), and one in Bucharest, the congress of the World Organization of General Systems and Cybernetics (where I presented my first results on strictly monotonic norms and algebraic systems) [15]. At this conference I met Hans-Jurgen Zimmermann and participated with him in the formation of the EURO Working Group on Fuzzy Sets.

After 1975 however, for a very long time I had no chance for participation at conferences in the Western World, because in 1976 I was

allegedly involved in "activities against the state". Nevertheless, I continued working and sent some manuscripts to international journals. I also tried to stay in connection with some of the researchers I met in 1975 at one of the two international conferences, but my letters and reprints I sent to them often returned with the remark "addressee unknown" (even though I sent those letters to the addresses on the business cards I had from them). Luckily this was not the case with Lotfi, who continued sending me papers and reports, and also not with leading Japanese fuzzy researcher Toshiro Terano whom I also exchanged letters and papers with during the next years. I only had a chance to meet Prof. Terano in person much later, in the late 1980-s, and after that I also had the privilege to call him another fatherly friend.

Nevertheless, in this period of relative isolation I still could attend several fuzzy events in the Eastern half of Europe, among others the famous fuzzy meeting in Eisenach, in the Wartburg castle – where I met the second time my later close friend Peter Klement. One year earlier he had sent me an invitation to give a couple of talks at Johannes Kepler University in Linz (Austria), where I could present my ideas about monotonic norms, inverse operators, etc. Although Peter sponsored my trip completely I was allowed by the Hungarian authorities to stay on site only three days, anyway, during those three days I could suck in an incredible amount of information from Peter's fuzzy library.

Using a bilateral exchange trip later I also could visit Hans in Aachen, where I presented a seminar talk on a new fuzzy similarity degree. Later I attended all fuzzy conferences of Hans in Aachen with talks – but that happened already in a completely different political situation…

In 1987 my personal position suddenly improved as the political system was somewhat relaxing and applying to an American foundation I got support for participation in the 3rd IFSA World Congress in Tokyo where I presented some results on describing the relative position of two components of an image by a fuzzy degree [16]. This research lead soon to a journal paper [17].

This was the first IFSA WC that I could attend, and ever since I never missed one… In Tokyo I met Kaoru Hirota with whom we published afterwards a large number of papers, first on Fuzzy Flip-Flops [18], later on Fuzzy Rule Interpolation [19, 20, 21], a topic that I still now consider as my most important contribution to the fuzzy field (and which topic also brought a large number of citations by other researchers). From that year I could annually participate in some major fuzzy conference and I started vivid personal interactions with many fuzzy scientists around the world. In

1988 I went to Iizuka, and attended later all subsequent Iizuka conferences. I attended in 1989 the IFSA WC in Seattle, and have attended all other IFSA WC-s since then. In addition in 1988 I also could go to Egypt, to a conference that later became notorious among the many Japanese participants, because of many organizational mistakes – nevertheless we met there with Kaoru and had a chance to discuss further collaboration.

At the IFSA WC in Tokyo, with Kaoru Hirota. On the left, Witold Pedrycz, on the right the late Ernest Czogala

At the IFSA WC in Seattle (1989) with Christer Carlsson, Janusz Kacprzyk and Kaoru

1990 brought at last democracy and freedom to Hungary and thus establishing societies and associations became possible – this is how the Hungarian Fuzzy Association was founded. Among the initial members there were also Margit Kovacs's two excellent PhD students: Janos Fodor and Robert Fuller.

Janos got his CSc degree soon after this founding event, in 1991, with a thesis on fuzzy preference modeling. Ever after he continued research in this field and got his Dr.habil degree (one more exotic postdoctoral title in the complicated labyrinth of the Hungarian system of scientific degrees and titles!) in 2000 and the DSc title in 2004 with the thesis "Preference structures and aggregation procedures". In all these degree defense procedures I was given a role as an examiner or committee member.

Janos collaborated with many famous fuzzy researchers, such as Marc Roubens, Bernard De Baets, Radko Mesiar, Didier Dubois and Henri Prade, Ulrich Bodenhofer, Ronald Yager and probably he became the most cited Hungarian fuzzy researcher. I helped him all along his career, supporting some of his first trips from my own grants, and by recommendation letters. We also had a joint paper with Janos when in 1991 Kaoru and I organized

the First Joint Hungarian-Japanese Symposium on Fuzzy Systems and Applications, with Tibor Vamos and Toshiro Terano as Honorary Chairs. Later we organized a series of international fuzzy conferences in Budapest jointly with Janos, having such prominent plenary speakers as Lotfi and Hans among many others. Janos passed away in 2016 as Rector of Obuda University – a grave loss to the Hungarian and the international fuzzy community!

At the Sphynx with Kaoru – the beginnings of fuzzy rule interpolation

One of the PhD students of Janos deserves special attention: this is **Sandor Jenei**, a very talented mathematician who achieved results in the construction and structural description of residuated monoids, the standard completeness, and monoidal t-norm logic, which results had a strong impact on fuzzy algebraic structures. The latter is a natural continuation of similar results on Lukasiewicz and Godel logics. Further he has results on the geometry of associativity, in connection with full Lambek algebra with exchange (FLe-algebra). Sandor has a large number of publications, some jointly with B. De Baets or F. Montagna [22, 23].

As General Chairs of the First Joint Hungarian-Japanese Symposium on Fuzzy Systems and Applications, with the two organizing secretaries

The other excellent member of the Eotvos Lorand University group was Robert Fuller who started fuzzy research even earlier, receiving the first doctorate in 1984 for his thesis on Fuzzy Spaces and their Fixed Point Theorems. In 1987 he obtained CSc from Moscow State University in Fuzzy Linear Problems. In 1999 he got Dr. habil. for fuzzy optimization, and eventually in 2015 the DSc title for Multicriteria Decision Models with Imprecise Information. In the last two procedures I participated again as committee member and examiner.

Robert also spent a period with Hans Zimmermann in Aachen, and then he moved to Turku in Finland to the Abo Akademi University, collaborating first with Patrik Eklund, later with Christer Carlsson, as a Finland Distinguished Professor. In the meantime he also visited the University of Trento in Italy collaborating with Mario Fedrizzi. Robert's wide spread research activities cover fuzzy probability, OWA operators, neuro-fuzzy systems and a large number of real life management and economics applications of fuzzy models and algorithms.

Continuing my personal story in the fuzzy context, in 1990 I received an invitation from James Keller to the University of Missouri in Columbia as

a visiting professor. It was a grimace of fate that I had not been granted the necessary working visa by the USA, because I was coming from a recently communist country. In all my active life until 1990 I was discriminated, even persecuted because of my conservative political views by the dictatorial state in Hungary, and in 1990 I was rejected by the West because of my Hungarian citizenship! And, of course, because of by then fuzzy was a very sensitive research field, which had been recognized as crucially important for the defense and space industries.

The USA being closed for me I was looking for another position abroad, and in 1992 I went to Korea, as visiting professor at the Pohang Institute of Science Technology, an excellent private university – later appearing in some university rankings as Nr.1 in the world among universities not older than 50 years. In Pohang I developed a Fuzzy Systems course using George Klir's excellent textbook and my own research.

From there I went soon to Japan and in 1993/94 I held the Fuzzy Theory Chair at the Tokyo Institute and Technology – a very honoring and prestigious position that I definitely thanked to my successful collaboration with Kaoru Hirota and to cordial relations with Toshiro Terano. In Tokyo I further developed the Fuzzy Systems course and taught it to a large class of graduate students, many of them being students of Michio Sugeno. During this time I wrote several papers on Fuzzy Rule Interpolation (FRI, see earlier) with Kaoru and one journal paper on the explicit mathematical expressions of fuzzy controllers with Michio [24], and a few more papers with many Japanese and other co-authors.

The Fuzzy Systems course was further developed later and it has been taught in Hungary (in Budapest, where it is an elective course now, and in Gyor where it was included in four new master programs, as an obligatory). I also delivered that course in several other European countries, such as in Austria, Italy and Poland; and at several Australian universities. My textbook on fuzzy systems in Hungarian language (with two editions as far) was also based on this course [30].

Besides this course, in some years when there was enough interest I have been teaching another elective on more advanced topics of fuzzy systems (FS 2). I also have had a series of MSc and PhD students doing fuzzy research. The first programs for Fuzzy Rule Interpolation simulation and some new technics of the FRI algorithm family were written by my MSc students **Akos Juhasz** and **Gyorgy Vass**, and others, in the late 1980-s and early 1990-s.

My first purely fuzzy PhD student, **Szilveszter Kovacs** did a thorough analysis of the non-linearity of membership degrees obtained by linear rule

interpolation, establishing conditions for acceptable approximations [25]. On the other hand, he proposed a new type of FRI algorithm based on Kruse's and Klawonn's vague environment. This latter was our first successful real application, the control of an automatic guided vehicle, where the size of the fuzzy control rule base could be drastically reduced by FRI, while keeping all advantages of the original fuzzy control. Szilveszter is now an Associate Professor of the University of Miskolc and Vice-President of the Hungarian Fuzzy Association.

From the mid 1990-s I started to be intensively interested in automatic rule based generation based on input-output data, motivated by the work of Michio (with his student T. Yasukawa). With Alex Chong, whose supervisor Tom D. Gedeon asked me to join him in the supervisory panel at Murdoch University in Perth; we achieved quite good results in solving a difficult modeling problem, the evaluation of geological data from the point of view of the likelihood of finding petroleum in an area (estimation of the building porosity). Identifying the hierarchical fuzzy interpolative rule based model by applying fuzzy clustering led to a better fitting model than any previous one [26].

Since 1994 we have worked closely together with Tom, among others, proposing new FRI approaches and later also in the area of Fuzzy Signatures (FSig), often co-supervising postdocs, PhD and master students, while I was partner or co-investigator of quite a few ARC grants. In the past two decades I spent about two and a half years at various Australian universities doing joint research with close friend Tom and other colleagues. I want to mention Kevin Wong, who joined Tom at Murdoch as a postdoc, and with whom we did quite a lot of joint work, mainly in applying Fuzzy Signatures, which collaboration continued when Kevin left for Nanyang Technical University in Singapore, and also when he returned to Murdoch while Tom was already at the Australian National University. At ANU our joint PhD student was Sumudu Mendis, with whom we achieved quite nice results similarly in the Fuzzy Signature field [27]. When I was teaching the fuzzy systems course at ANU in 2015, Sumudu led the tutorials for my lectures. Many of my Hungarian PhD students got involved in collaboration and joint publication with both Kevin and Sumudu, when I arranged visiting stays for them in Tom's research group.

Kaoru in Budapest, at one of his frequent visits to Hungary with my student Peter Baranyi, who became my son-in-law in the next year

Among a long series of Hungarian graduate students, I must mention several, who did remarkable work in the fuzzy field. **Domonkos Tikk** with a degree in mathematics went into the rather ambiguous field of fuzzy systems as universal approximators. While quite a few papers were published in this respect from the early 1990-s by various researchers, none of the authors went into the computational complexity aspect of the matter. When Peter Klement with his PhD student Bernhard Moser and other colleagues published an extreme result, proving that virtually any function can be generated by only two fuzzy Takagi-Sugeno rules, it became obvious that these results were rather relative, as the difficulty was pushed from the system to be modeled into the creation of the membership functions themselves, thus involving comparable difficulties and resource intensity. After we started to closely collaborate again (myself teaching Peter's fuzzy course in two academic years in Linz) I suggested Bernhard to go along with the complexity issue, and in his later thesis he presented a very important theorem on the nowhere denseness of the functions created by bounded size Takagi-Sugeno controllers [28]. My Hungarian student Domonkos continued this research and proved a similar theorem for the Takagi-Sugeno-Kang

controller class as well [29]. It was Domonkos who co-authored my fuzzy textbook I mentioned earlier that is still in use at several universities in Hungary [30].

Peter Baranyi joined me with bringing a brilliant new idea in the FRI area. He proposed a new algorithm extending the original FRI family to rule bases with subnormal and non-convex membership functions, thus virtually to any kind of rule base [31]. I think Peter was my most talented PhD student ever. He is very active these days as a professor and researcher in several fields from virtual reality to tensor product transformation, that latter including also Takagi-Sugeno controller related issues. It is an interesting fact that he also became my son-in-law and father of my two eldest grandchildren, these days two sweet teenager girls.

In the late 1990-s I continued the works started with Alex Chong, however applying evolutionary and memetic algorithms for rule base identification. An idea coming from the neural network field, the application of the Levenberg- Marquardt algorithm proposed by my good friend and collaborator Antonio B. Ruano, that I tried to combine with Takeshi Furuhashi's Bacterial Evolutionary Algorithm produced a very efficient model identification method. Several graduate students were involved in this research, the most advanced algorithms proposed by former PhD student Laszlo Gal, whom I mentioned earlier.

Another family of local search methods, applicable to discrete problems (n-opt, n=1,2,3; and bounded n-opt) led to very competitive results in optimizing NP-hard problems, especially the Travelling Salesman Problem, producing in some reference cases better results than the standard Concorde approach. The best results in this direction have been achieved with my current student **Boldizsar Tuu-Szabo**.

One more former student, **Krisztian Balazs** must be definitely mentioned as with Krisztian we did a rather thorough comparison of various evolutionary and memetic algorithms, based on a large set of reference data sets, and applying them for the construction of fuzzy rule based models. These extensive comparisons provided firm evidence that the Bacterial Memetic Algorithm I had proposed earlier is the best or at least one of the best available population based meta-heuristics. Applying this approach to the identification of hierarchical interpolative rule based models brought us a Best Paper Award from FUZZ-IEEE in 2011 [32, 33].

With my PhD students Krisztian Balazs, Rita Lovassy, Laszlo Gal at a workshop in Prague

Besides the methodological research we have done in this past decade in considerable amount of application oriented, or at least application triggered investigation was carried out, mostly with colleagues, PhD students and postdocs.

The application of Fuzzy Signatures and its extensions for mobile robot collaboration was started with Tom, and continued with PhD student **Aron Ballagi**, along with my friend **Claudiu R. Pozna** [34]. The extended idea of Fuzzy Signatures, leading to spatial Fuzzy Situational Maps (FSM) was used beside robot communication and collaboration, also for modeling 3D warehouses from a logistics optimization point of view.

As I have mentioned it earlier, we researched other logistics problems jointly with Peter Foldesi. These have included the TSP problem already mentioned, a fuzzy approach to bin packing optimization and various network and resource allocation optimization problems.

FSig could be also efficiently used for the evaluation and optimization of assessment of the condition and optimization of of residential buildings. Several results led to two PhD degrees (**Adam Bukovics** and **Gergely**

Molnarka), and investigations of the sensitivity of such evaluations for various aggregations used in the FSig trees (with Istvan Harmati) produced also interesting results.

Another interesting line of application, modeling environmental management systems (proposed by former PhD student, **Adrienn Buruzs**) triggered our research activities concerning Fuzzy Cognitive Maps [35]. Some quite new algorithms for refining and reducing FCM models have been intensively researched with **Miklos Hatwagner**, later in an international collaboration context (with Elpiniki Papageorgiou, Engin Yesil, Vesa Niskanen and others) [36].

I never gave up image processing and recognition type research, and **Alex Tormasi** is just now in the procedure of submitting his thesis on single and multiple stroke handwritten character recognition where fuzzy technics were successfully combined with evolutionary meta-heuristics.

Telecommunication network management and optimization type problems were investigated with several graduate students, one of them being my other PhD student who just submitted his thesis, **Ferenc Lilik**, Here we combined fuzzy rules with wavelet transform, collaborating with **Szilvia Nagy**, and as a result, the necessary measurement quantity for good pre-assessment of the band width of telecomm wire pairs could be essentially reduced.

We also ventured in the area of community networks, first with Alex Tormasi and a group of other students, then, with one of my most junior students, **Gergely Posfai**, where recommendation systems could be improved by applying fuzzy elements.

The long line of students, postdocs and collaborators could be continued, but at the end of this subjective story I intend to deal with our involvement in the international fuzzy community and its institutions.

As I mentioned it above, in 1975 I joined the EURO WGFS. Later it was substituted by EUSFLAT, which is still the major European organization for fuzzy researchers. Although I was there when the idea of founding EUSFLAT was coined, later it came to some disputes: Should the HFA remain independent while EUSFLAT is already in existence? The Hungarian fuzzy community decided for yes.

At the IFSA WC in Istanbul in 2003, at the end of my presidency. Dan Ralescu, Bernadette Bouchon-Meunier and Kaoru Hirota are also in the picture.

Soon after the EURO WGFS IFSA was founded, and I got invitations to the IFSA congresses - unfortunately I was not allowed to go. It was only in 1987 that I could attend the 3rd WC in Tokyo, but ever since I was present at every IFSA congress. Already in the early 1990-s I became very much interested in IFSA and in 1995 I was elected a Vice President. This was the time of transitions as IFSA changed from a society of individuals into an association of societies. I was involved in the formulation of the new bylaws, and later in the establishment of various IFSA awards. The logo of IFSA was designed by me and a long gone Hungarian artist who also made the IFSA Award plaque in bronze. Later, Tom Gedeon and I designed colors to the logo while I stayed at the UNSW in Sydney. This logo is still in use in an unaltered form.

After four years of service as VP I was elected President Elect in 1999. When in 2001 I took over the President's position, dark clouds gathered over IFSA. The organization had never been registered officially in any country of the world, the account always moved with the Treasurer from country to country... and suddenly we faced anti-terrorism laws, which prevented the transfer of money without a good explanation. NAFIPS and some other member organizations insisted on the registration of IFSA as a non-profit

organization – while SOFT and a few others declared, they would leave IFSA if it became an official association, because of the additional costs. I was very proud when I proposed the compromise solution that is still working nowadays: having two IFSAs, one registered, and one keeping the original loose structure. In 2003 I could hand over presidency with the feeling of having done a good job!

When I finished my 10 years' service in IFSA I suggested my good friend **Imre Rudas** to be elected as Treasurer. Imre has not yet been mentioned in this history, but in fact he wrote a lot of papers on fuzzy operations, robotic applications, and many other topics in the field [37]. He had also co-authored papers with almost all Hungarian fuzzy researchers, having a very collaborative personality. So, we also had a few papers together, especially with my former student Rita Lovassy, where various fuzzy operations were investigated from the point of view of how to build the best neural networks from them. Imre made the Hungarian Fuzzy Association very active, and started a series of annual conferences in Hungary and neighboring countries with a Hungarian minority, thus involving many scientists who had had little opportunity without those events to appear at an international event. Imre became Rector of Obuda University and made it to a fuzzy and intelligent systems research and events hub.

At last I want to mention that the Hungarian fuzzy community has been also rather active in the IEEE. At first the SMC Society, later the NN Council and its successor, the CIS attracted many of us. In 1992 the first FUZZ-IEEE was held in San Diego, and I attended it, traveling from Korea to the USA. Janos Fodor was also there. Ever after, I have attended all FUZZ-IEEE conferences, also the ones in the frame of WCCI-s... Janos stopped traveling much, so later often I was the only Hungarian participant, sometimes however attending with my students. It was however not so in 1998 when in Anchorage we had a delegation of four Hungarian participants, apart from me, my sister **Annamaria Koczy Varkonyi**, who had also published quite a few fuzzy related papers [38]. Peter Varlaki and our one time co-author, Antal Penninger attended the meeting.

In 2004 I even organized one FUZZ-IEEE in Budapest, with quite a success. In the next year I was elected AdCom member of CIS, and after two periods, I was delegated to the Systems Council of IEEE as the representative of CIS for two subsequent years. Imre Rudas has been active in the Industrial Electronics Society until recently, being a member of the Board of Directors, and holding other positions.

We are still organizing our respective conferences mostly annually. 9

years ago I started the annual Gyor Symposium on Computational intelligence that evolved in the meantime into the European Symposium on Computational Intelligence and Mathematics (ESCIM), jointly chaired by Jesus Medina from Cadiz and Janusz Kacprzyk from Warsaw, having a strong focus on fuzzy mathematics and applications. Imre annually hosts the CINTI (IEEE International Symposium on Computational Intelligence and Informatics) meetings in Budapest, which this year had its 17th issue. I must mention a personal remark: When I reached 60, a special one day Symposium within CINTI was dedicated to my own and my group's work on fuzzy, with a special separate volume of the proceedings – a really kind present from old friend Imre Rudas!

At the FUZZ-IEEE congress in Anchorage (1998) with the Hungarian participants surrounding Lotfi: Peter Varlaki, my sister Annamaria Koczy Varkonyi, myself and Antal Penninger

We are still active, we are working on many aspects of fuzzy science, mathematical and theoretical, modeling and algorithmic issues, and many applications from engineering to decision support, from management to legal modeling – but gradually a new generation takes over, and it is fine so!

References

1.　L T Kóczy: Some questions of the theory of fuzzy sets, Dept. of Process Control, Tech. Univ. of Budapest, 1974

2.　J. C. Fodor and M. R. Roubens: Fuzzy preference modelling and multicriteria decision support, Springer, 1994

3.　J. C. Fodor: Contrapositive symmetry of fuzzy implications, Fuzzy Sets and Systems, 69: (2) 141-156, 1995

4.　C. Carlsson and R Fuller: On possibilistic mean value and variance of fuzzy numbers, Fuzzy Sets and Systems, 122: (2) 315-326, 2001

5.　R Fuller and P Majlender: An analytic approach for obtaining maximal entropy OWA operator weights, Fuzzy Sets and Systems, 124: (1) 53-57, 2001

6.　R. Fuller; J. Mezei; P. Varlaki: An improved index of interactivity for fuzzy numbers, Fuzzy Sets and Systems, 165: (1) pp. 56-66, 2011

7.　R Fuller; I. Harmati; P. Varlaki: On Probabilistic Correlation Coefficients for Fuzzy Numbers Aspects of Computational Intelligence: Theory and Applications: Heidelberg; London; New York: Springer Verlag, 2013, pp. 249-263

8.　P Földesi, J Botzheim, L T Kóczy: Eugenic Bacterial Memetic Algorithm for Fuzzy Road Transport Traveling Salesman Problem, INT J INNOV COMPUT I, Vol 7 No 5 (B), 2011 pp. 2775-2798 (IJICIC)

9.　J. Dombi: Eine allgemeine Klasse von Fuzzy-operatoren, die De Morgan Klasse und eine Operator-induzierte Klasse von Fuzziness-Massen, Rhein-Westfalische Technische Hochschule Aachen, Institut für Wirtschaftswissenschaften, 79/03, 1979

10.　J. Dombi: Pliant Arithmetics and Pliant Arithmetic Operations, Acta Polytechnica Hungarica 6:5, 19-4, 2009

11.　L Gál; R Lovassy; I J Rudas; L T Kóczy: Learning the optimal parameter of the Hamacher t-norm applied for fuzzy-rule-based model extraction, Neural Comput & Applic 24: 133-142, 2014

12.　L Gál, R Lovassy, L T Kóczy: Function Approximation Performance of Fuzzy Neural Networks Based on Frequently Used Fuzzy Operations and a Pair of New Trigonometric Norms, WCCI 2010 IEEE World Congress on Computational Intelligence, Barcelona, Spain, July 18-23, 2010 pp. 1514-1521

13.　L T Kóczy: Fuzzy graphs in the evaluation and optimization of networks, FUZZY SET SYST 46: (3) 307-319, 1992

14.　[7] M Kovacs: Linear programming with centered fuzzy numbers, An. Univ. Sci. Budapest, Sect. Comput. 12, 1991 pp. 159-165

15.　L T Kóczy, M Hajnal: A new fuzzy calculus and its application as a pattern recognition technique, 3rd Int. Congr. of Cybernetics and Systems, Bucharest, pp. 511-549, 1975

16.　L T Kóczy: About the fuzzy description of relative position of patterns (2), Proc. 2nd 1FSA Congress, Tokyo, 416-419, 1987

17.　L T Kóczy: On the description of relative position of fuzzy patterns, PATTERN RECOGN LETT 8: (1) 21-28 (1988)

18.　K Ozawa, K Hirota, L T Kóczy, K Ohmori: Algebraic fuzzy flip-flop circuits, FUZZY SET SYST 39: (2) 215-226, 1991

19. L T Kóczy, K Hirota: Ordering, distance and closeness of fuzzy sets, FUZZY SET SYST, 59: (3) 281-293, 1993

20. L T Kóczy, K Hirota: Approximate reasoning by linear rule interpolation and general approximation, INT J APPROX REASON 9: (3) 197-225, 1993

21. L T Kóczy, K Hirota, L Muresan: Interpolation in hierarchical fuzzy rule bases, J INTELL FUZZY SYST 1: (2) 77-84, 1999

22. S. Jenei: Structure of left-continuous triangular norms with strong induced negations. (II) Rotation-annihilation construction, Journal of Applied Non-Classical Logics, 11: (3-4) 351–366, 2001

23. S. Jenei and F. Montagna: A general method for constructing left-continuous t-norms, Fuzzy Sets and Systems, 136: (3) 263–282, 2003

24. L T Kóczy, M Sugeno: Explicit functions of fuzzy control systems, INT J UNCERTAIN FUZZ 4: 515-535, 1996

25. S Kovács, L T Kóczy: Shape of fuzzy conclusion generated by linear interpolation of trapezoidal if...then... rules, TATRA MT MATH PUBL 6: 83-93, 1995

26. A Chong, TD Gedeon, LT Kóczy, KW Wong: Subspace identification with cylindricity-based clustering for hierarchical fuzzy system construction, AUST J INTELL INFORM PROCCESS SYST 7: (2), 2002

27. B S U Mendis, T D Gedeon, L T Kóczy: Flexibility and Robustness of Hierarchical Fuzzy Signature Structures with Perturbed Input Data, 11th International Conference: Information Processing and Management of Uncertainty in Knowledge-based Systems, (IPMU) Paris, pp. 2552-2559, 2006

28. E P Klement, L T Kóczy, B Moser: Are fuzzy systems universal approximators?, INT J GEN SYST 28: (3) 259-282, 1999

29. D Tikk, L T Kóczy: Takagi-Sugeno-Kang-type controllers with a bounded number of rules are nowhere dense, Information Processing and Management of Uncertainty (IPMU), Paris, pp. 643-648, 1998

30. L T Kóczy, D Tikk: Fuzzy systems, Typotex, Budapest, 2000. 2nd improved ed. Typotex, 2012

31. P Baranyi, L T Kóczy, T D Gedeon: A Generalized Concept for Fuzzy Rule Interpolation, IEEE T FUZZY SYST 12: (6) 820-837, 2004

32. K Balazs and L. T. Koczy: Constructing dense, sparse and hierarchical fuzzy systems by applying evolutionary optimization techniques. Applied and Computational Mathematics, 11(1):81–101, 2012

33. K Balazs and L. T. Koczy: Hierarchical-interpolative fuzzy system construction by genetic and bacterial memetic programming approaches. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 20(supp02):105–131, 2012

34. C Pozna; N Minculete; R-E Precup; L T Kóczy; Á Ballagi: Signatures: Definitions, operators and applications to fuzzy modeling, Fuzzy Sets and Systems vol. 201, (2012) pp. 86-104

35. A. Buruzs; F. M. Hatwagner; L. T. Koczy: Fuzzy Cognitive Maps and Bacterial Evolutionary Algorithm Approach to Integrated Waste Management Systems. J. of Advanced Computational Intelligence and Informatics 18:(4) pp. 538-548, 2014

36. F. M. Hatwagner; E Papageorgiou; L. T. Koczy: A Concept Reduction Approach for Fuzzy Cognitive Map Models in Decision Making and Management, Neurocomputing (to appear)

37.   Rudas I, Bitó J, Tar J: An Advanced Robot Control Scheme Using ANN and Fuzzy Theory Based Solutions, ROBOTICA 14: pp. 189-198, 1996

38.   O Takacs, A R Varkonyi-Koczy, P Varlaki: Non-exact Complexity Reduction of Generalized Neuro-Fuzzy Networks, 10th IEEE Int. Conf. on Fuzzy Systems, FUZZ-IEEE 2001, Melbourne, Australia, pp. 980-983, 2001