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In memoriam

Elie Sanchez, 1944–2014

On March 6, 2014 the French mathematician, pioneer of fuzzy set theory and one of the founders of the fuzzy community, Professor Elie Sanchez, died of leukemia. He was 70 years old (Fig. 1).

After high school Elie Sanchez passed the preparatory classes “Mathématiques supérieures” and “Mathématiques spéciales” at the Lycée Thiers in Marseille, and then attended the Facultés des Sciences de Saint-Charles and the Facultés des Sciences de Luminy in the same city.

After studying mathematics at the *Laboratoire de Biomathématiques, Statistique et Informatique Médicale* of the Faculté de Médecine in Marseille in 1972, he acquired a Ph.D. in Mathematics from the Faculty of Sciences of that university with his thesis entitled *Matrices et Fonctions en Logique Symbolique* [1]. In this work he had considered Boolean matrix equations to be related to ternary logic, but shortly afterwards he switched to fuzzy logic. However, the term “fuzzy logic” did not exist before the Berkeley linguist Lakoff suggested it in 1972 [2,3].

In 1973 Elie Sanchez became familiar with the field of fuzzy sets, as he said in one of his most recent papers:

> “The first time I heard of fuzzy sets was during a seminar of Arnold Kaufmann (later on I also read an interview of L.A. Zadeh, called *“Les ensembles Flous–un concept précis”*, in *l’Informatique*, 1970) while he was presenting Zadeh’s theory and his own research. He was carrying with him the manuscript of his first book on the subject. The book was entitled “*Introduction à la Théorie des Sous Ensembles Flous. Tome I, Eléments Théoriques de Base” (Masson, Paris, 1973)*. He called them “*sous ensembles flous*”, i.e., *fuzzy subsets*, for the class of points, or objects, on which membership functions were defined was not fuzzy. This manuscript was written by hand in India ink on tracing papers. So it was one of my early influences.” [4][1]

Elie Sanchez then extended his work on Boolean matrix equations to fuzzy relation equations in his second Ph.D. thesis (in human biology from the Faculty of Medicine at the University of Méditeranée (University of Aix-Marseille II, 1974) *Equations de Relations Floues* [6]. Here he proposed an application of the principle for medical diagnosis (Fig. 2).

Zadeh had devised his max-min rule as a composition rule for fuzzy relations. He expected interesting results from the application of fuzzy relations “in transportation problems and in belief systems” [7]. Assilian and Mamdani used it in 1972 to calculate inference rule relationships once they had implemented the fuzzy IF–THEN rules for their fuzzy control algorithm as fuzzy relations [8,9]. Elie Sanchez now pursued a different direction as he later wrote in [10,p. 47]: “We plan to investigate medical aspects of fuzzy relations at some future time.” He assumed that

Fig. 1. Elie Sanchez at the IIZUKA-88 International Video-Session, KIT-NASA at the Kyushu Institute of Technology in Iizuka, Japan. Photograph taken from E. Sanchez’ private collection.

Fig. 2. Elie Sanchez and Arnold Kaufmann in France 1980.

[1] For Kaufmann’s book see [5].

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Fig. 3. Elie Sanchez and Lotfi A. Zadeh at the *IEEE Conference on Decision and Control*, Fairmont Hotel, New Orleans, Louisiana, 1977. Photograph taken from E. Sanchez' private collection.

a doctor translates his knowledge and his experience into degrees of association between symptoms and diagnoses.

Already in 1976, in a Master's thesis entitled *Medical Knowledge Network: A Database for Computer-aided Diagnosis*, Alonso Perez-Ojeda at the Department of Industrial Engineering of the University of Toronto had suggested that medical knowledge could be represented as a network in which symptoms and diseases were linked to one another by relations [11]. In order to model the "relation strength" (labeled as, e.g., "usually", "occasionally", "almost always") mathematically, he identified them with probability modifiers interpreted using frequency theory. Probably without any knowledge of Perez-Ojeda's work, Elie introduced the relationships between the set of symptoms and the set of diseases as fuzzy relations; these fuzzy relations, he found, represented the corpus of *medical knowledge*: "In a given pathology, we denote by S a set of symptoms, D a set of diagnoses, and P a set of patients. What we call "medical knowledge" is a fuzzy relation, generally denoted by R, from S to D expressing associations between symptoms, or syndromes, and diagnoses, or groups of diagnoses (Fig. 3)."[12].

Elie interpreted Zadeh's max–min rule directly to develop diagnoses. Given symptom and diagnosis sets S and D and an existing fuzzy relation $R \subset S \times D$ between them, the max–min composition may serve as an "inference rule", which makes it possible to deduce imprecise descriptions of a patient's illnesses (fuzzy sets of D) from imprecise symptom descriptions (fuzzy sets of S). With this inference rule, medical diagnoses D_j about a patient's disease can be derived by fuzzy logic from symptoms with the help of the medical knowledge represented by the fuzzy relation R.

By taking into account a set P of all patients considered and another fuzzy relation Q between P and the symptom set S, it was now possible, with the aid of the max–min composition rule, to obtain a fuzzy relation $T = Q \times R$. The fuzzy relation R can be expressed as a matrix, the entries of which can be made after interviewing doctors about their diagnostic experience. This expert medical knowledge must additionally be translated into degrees of association between symptoms and diagnoses.

Later he reported: "This work was still related to Zadeh's original fuzzy sets with [0,1]-valued membership functions. Then I extended it to L-fuzzy sets,[2] where L was a complete Brouwerian lattice. The aim was to propose the largest class of lattice-valued fuzzy sets to which the resolution methodology could apply." He published his results in an article entitled "Resolution of Composite Fuzzy Relation Equations" [10].

[2] For "L-sets" see Goguen [13].

Three years later he had turned the problem around: Instead of calculating the fuzzy relation $T = Q \times R$ from the available fuzzy relations Q and R, it was much more interesting and closer to clinical practice, at least in terms of diagnostics, to determine the fuzzy relation R from the known fuzzy relations T and Q. This would mean, of course, acquiring "medical knowledge" on the basis of knowledge about symptoms and diseases (clinical discharge diagnosis) from a patient set; in other words, to discover the relationships between symptoms and diseases.

For the volume about *Advances in Fuzzy Set Theory and its Applications* [14], he shaped this plan in two closely related papers in which he demonstrated how the max–min composition rules Zadeh had introduced could be used as a rule of inference, in particular in medical diagnostics. "Compositions of Fuzzy Relations" [15] is the first text, an abstract mathematical foundation for the second: "Medical Diagnosis and Composite Fuzzy Relations" [12] In the second article Elie Sanchez referred to the fact that medical diagnoses often had to be made without any precise analysis being possible. One or more illnesses then had to be inferred from a patient's symptoms, which most often cannot be described in any exact way. In so doing, neither the set of diseases taken into consideration nor the conclusion about the disease(s) drawn from the symptoms can be precise.

In these two (interrelated) texts in 1979, Elie then highlights how it is possible to determine the largest relation matrix R for which: $T = Q \times R$. Here, he also examined the remaining possibility, namely that of calculating the fuzzy relation Q from a given T and R. His question was: In what range can a patient's symptoms vary without the patient dropping out of the diagnosis cluster for the respective disease? This meant determining the largest relation matrix Q for which $T = Q \times R$.

Motivated by Elie's work on fuzzy relations that can be used in the medical field, in Vienna, Austria, Klaus-Peter Adlassnig fuzzified the CADIAG-I system–the *c*omputer-*a*ssisted *DIAG*nosis system that was being developed since 1968 at the department for medical computer sciences at the University of Vienna's Medical School: "Fuzzy Set Theory with its capability of defining inexact medical entities as fuzzy sets, with its linguistic approach providing an excellent approximation to medical texts as well as its power of approximate reasoning, seems to be perfectly appropriate for designing and developing Computer-Assisted diagnostic, prognostic and treatment recommendation systems." [16]

In CADIAG-II, the relationships "occurrence" and "strength of confirmation" that were considered between symptoms and diagnoses were represented as fuzzy relations with the aid of his devised mathematical ammunition. In addition, the "occurrence" of a symptom S_i in the case of a diagnosis D_j was defined as the frequency with which it occurs, while the "strength of confirmation" of the symptom was established as the importance it has for the diagnosis.

The mainframe computer on which CADIAG-II had been running was shut down in 2004; this also marked the end of the CADIAG-II system. Now, in Vienna General Hospital, the knowledge representation and inference process in the medical consultation system MedFrame/CADIAG-IV [17] and also the MONI system (Monitoring of nosocomial infections)—a database and monitoring system for surveillance of nosocomial infections [18,19]—are based on fuzzy set theory and fuzzy logic, and thus on Elie Sanchez' pioneering theoretical work.

In the 1980s, following Kaufmann's lectures, Elie gave lectures in China and Japan to introduce fuzzy sets. Fig. 4 reproduces a transparency that he used in those times. "The baldness of the human was meant to recall somebody" he wrote, when he published this illustration in [4].

At the end of the 1970s and in the 1980s, Elie Sanchez co-edited several volumes on fuzzy sets, fuzzy logic, approximate reasoning,