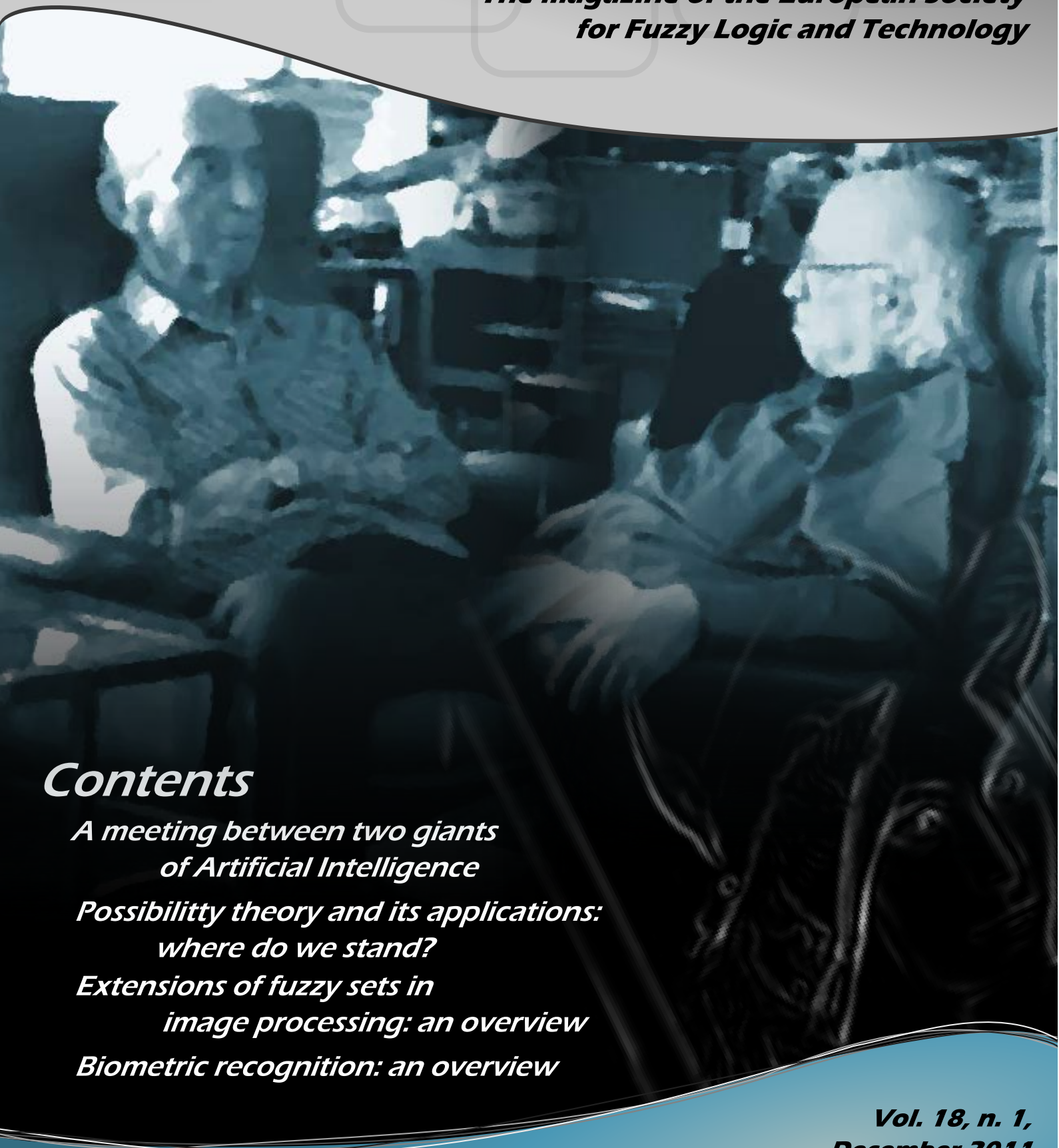
EUSFLAT
EUROPEAN SOCIETY FOR FUZZY LOGIC AND TECHNOLOGY

# Mathware & Soft Computing

*The magazine of the European Society for Fuzzy Logic and Technology*



## Contents



**Vol. 18, n. 1, December 2011**

EUROPEAN SOCIETY FOR FUZZY LOGIC AND TECHNOLOGY

# Mathware & Soft Computing

The magazine of the European Society for Fuzzy Logic and Technology



Volume 18, number 1
December 2011

**Dep. Legal: B-35.642-94**
**ISSN 1134-5632**

## Hot Topics



## Scientific Reports



## Eusflat Life



## World Echoes

# *Message from the Editor-in-Chief*

Humberto Bustince

When the new year is about to begin, we start this scientific adventure: the new Mathware&Soft Computing electronic magazine. Following the Mathware&Soft Computing journal, and also linked to the European Society for Fuzzy Logic and Technology (EUSFLAT), this magazine is born with the vocation of reaching at researchers in the soft computing community as well as those others that may find of interest fuzzy techniques, in particular, and soft computing, in general. That's why, apart from proper scientific papers, we also want to include overviews, surveys and works that, from a general point of view, allow scientists in different fields to understand the history, the fundamental treated questions or the challenges in specific subjects that, due to their nature, can be interesting for a wide audience.

We are going to publish two issues per year that will be available at the webpage

`http://giara.unavarra.es/msc`

We count on the collaboration of readers. A link will be soon available at the webpage cited above to upload works. For the moment, for the next issue, scientific collaborations, news, etc... can be sent before May 1, 2012 to the following addresses:

- bustince@unavarra.es
- magazine@eusflat.org

Purely scientific works will of course be submitted to a peer-reviewing process. However, and due to the characteristics of our magazine, we hope that this reviewing will be faster than in some other more specialized journals.

We have the pleasure of opening this first issue with an exceptional document: A talk between professors Lofti A. Zadeh and Ronald R. Yager that took place last September, 12 at Zadeh's home. It is not so common to have the possibility of enjoying an open discussion between two science giants. The complete video of the interview can be found at: `http://giara.unavarra.es/msc/index.php/interview`

We have also intended to include in a prominent place of this first issue a tribute to professor Da Ruan, who passed away suddenly last summer, and who had so many friends inside and outside from the EUSFLAT community. Some of these friends have contributed with their words to this obituary.

Regarding the scientific contents, in this first issue there are three overviews. The first one, about possibility theory, has been written by D. Dubois and H. Prade. The second one focuses on the present use of fuzzy extensions in several image processing problems. The third one introduces the state of the art of biometric recognition, from a general point of view.

We have also devoted a complete section in the magazine to the EUSFLAT association. We present its official journal,"International Journal of Computational Intelligence Systems", the minutes from the last assembly and a review on the last conferences that are associated to EUSFLAT. Finally, book reviews, several announcements and some news complete this issue.

As any new thing, this proposal still requires of some last minute touches. In particular, the web page is not wholly functional for the moment, although we expect everything will be working along next months.

We are open to any suggestion, comment or contribution anybody wants to make. From here we already thank them beforehand.

Before concluding, as editor-in-chief, I want to thank to all the people who have contribute to this issue, and, in particular, to the assistant editors: Javier Fernandez, Aranzazu Jurio and Daniel Paternain. They are actually who have made possible that this work goes ahead, and without them nothing would have been possible.

Welcome to the new Mathware&Soft Computing magazine.

Humberto Bustince
Editor-in-Chief

# *Message from the President*

Javier Montero

It has taken some time to close the old *Mathware & Soft Computing* journal and launch the new *Mathware & Soft Computing* magazine. As agreed at Dortmund assembly (June 29, 2010), this magazine is keeping the journal title adding the subtitle *The European Society for Fuzzy Logic and Technologies Magazine*, and including among other features past EUSFLAT Newsletter and reports coming from EUSFLAT Working Groups and other reputed researchers. Humberto Bustince, magazine Director, has been working hard with his team to launch an attractive first issue that I am sure we all will enjoy, starting from the enlightening interview to Lotfi A. Zadeh conducted by Ron Yager specially for the EUSFLAT magazine. Our new magazine was formally presented at the last General Assembly, held in Aix-les-Bains (July 21, 2011). With this letter I am particularly inviting you to actively collaborate within our EUSFLAT magazine, providing reports and any other interesting material. This new EUSFLAT magazine keeps an obvious reference to other successful magazines in related fields, adapted to our small but growing scientific society.

In addition to such a major achievement, our colleague Jorge Casillas is about to launch a new EUSFLAT Web page, which from his recent experience as EUSFLAT Treasurer is expected to help EUSFLAT management and improve Ulrich Bodenhofer past work, acknowledged during the EUSFLAT 2011 General Assembly as the third EUSFLAT honorary member.

In this EUSFLAT 2011 general assembly we also acknowledged the first Best Student Paper Award and the Best Ph.D. Thesis Award. We have introduced a new category of "Committer" EUSFLAT membership you might be interested in, and created a new "Leadership" EUSFLAT Award. All these awards will hopefully help EUSFLAT to get more visibility, and based upon the prestige of the EUSFLAT members and the activities of our Working Groups, our association will become more and more attractive. Let me stress once again the traditional support we give to young researchers by means of our student grants program.

Today we are 298 members from 31 countries, but we are showing to be a life and active community, that offers a number of relevant advantages to their members, please help us to spread the advantages of joining EUSFLAT:

- Electronic full-text access to the International Journal of Computational Intelligence Systems (IJCIS)
- Reduced subscriptions of selected journals
- Reduced registration fees for the biannual EUSFLAT Conference and other EUSFLAT-supported conferences
- Possibility to join (or even establish) a EUSFLAT Working Group
- Participation in EUSFLAT Assemblies (once a year; of course, including the right to vote in EUSFLAT Board Elections)
- Eligibility to be candidate in EUSFLAT Board Elections
- Stay informed by the free EUSFLAT Magazine and a moderated mailing list
- Access to a network of hundreds of leading researchers in fuzzy logic and related technologies
- Special reductions if you join another main close associations like HFS, NAFIPS, NSAIS, SIGEF and ACIA, or simply if you attend their conferences
- Additional benefits for student members:
  - Eligibility to apply for a EUSFLAT Student Grant
  - Eligibility for receiving a Best Student Paper Award at a EUSFLAT conference or a Best Ph.D. Thesis Award.

Beside all the above good news, as President of EUSFLAT I have to express my most sincere condolences for our EUSFLAT board member Da Ruan, who unexpectedly passed away last July 31. Da will be deeply missed mainly as a good friend, but also because his taught work within the fuzzy community. According to EUSFLAT bylaws, his duties within EUSFLAT board will be addressed by the EUSFLAT Board till the next General Assembly. Atlantis Press has nominated Luis Martinez and Jie Lu, both EUSFLAT members, as Coeditors-in-Chief for our official journal, the *International Journal of Computational Intelligence Systems*. The 2010 JCR impact factor of this journal was 1.471, second fourth within both subject categories "Computer Science, Artificial Intelligence" and "Computer Science, Interdisciplinary Applications". Please do not forget to consider this journal for your best papers.

The next EUSFLAT General Assembly will be scheduled during the IPMU conference (Catania, July 9-13, 2012), as already agreed with the IPMU local organizers, see http://www.ipmu2012.unict.it/.

Looking forward to meet you at Catania,

Javier Montero
President of EUSFLAT

INTERVIEW

# A meeting between two giants of Artificial Intelligence

Interview between Lofti A. Zadeh and Ronald R. Yager

The interview that we present here between L.A. Zadeh and R.R. Yager is an informal talk with two great scientific personalities of our time that, from our point of view, constitutes an exceptional document. This talk took place at Zadeh's home in Berkeley, where R.R. Yager travelled from NY on September 10-12, 2011.

Before starting with the interview itself, we would like to thank professors L.A. Zadeh and R.R. Yager for accepting our proposal. We also want to thank Asli Celikilmaz and Shahnaz Shahbazova for their colaboration, since without it this meeting and its transcription would have not been possible.

## Personal life: motivation for travelling

**R.Y. I want to go back a little bit into your old personal life. You were a student somewhere in some foreign, way away place in Iran and Azerbaijan, which is very far away. What made you want to come to the United States to go to school?**

L.Z. I was born in Baku, Azerbaijan, which in 1921, was a part of the Soviet Union. So my language was the Russian language. But things became difficult in the Soviet Union and my parents, Iranian citizens, returned to Iran. They placed me in an American missionary school and during that period I developed this ambition to go to the United States. When I completed this American college I entered University of Teheran, which again was an all together different world. The influence was primarily French and all of our text books were French text books. I received Bachelor's degree in 1942, when there were

**Lofti A. Zadeh with his parents**

**Lofti A. Zadeh with his family**

American troops in Iran. I got to know quite a few Americans because I spoke English and my father had a business of building supplies and things of this kind, so I became some sort of intermediary and my income was high at that time. But then I thought that, if I stayed there, I'd have a good life. But it would be a life of doing nothing basically. But I had always been interested in science since I can remember myself, since the age of six, so I came to the United States, not as a student but as an immigrant, because I decided that this is the country where I want to spend the rest of my life.

**I came to the United States, not as a student but as an immigrant, because I decided that this is the country where I want to spend the rest of my life**

So, while I was in Teheran, I applied for admission to MIT and I was admitted. And the reason why I was admitted, I think, was that at MIT there were not that many students. At war time younger people were in the Army. And I entered MIT in September 1944 and I must tell you that MIT compared to University of Teheran was very easy. It was more rigorous the kind of training that I got at the University of Teheran, which was in the French tradition. But there were all kinds of subjects that I was not exposed to while I was at the University of Teheran. When I came to MIT, it was exciting not only in terms of the people but things I never heard of before. But the training I got at the University of Teheran was excellent training. Life in the

United States today is orders of magnitude more difficult than it was when I started my teaching career at Columbia University. My salary was $2,500 a year as an instructor. At that time graduates of MIT, master's degree, were getting $50 a week, but New York Times was 5 cents, subway was 5 cents, brand new car $1500. It was a different world. You submitted a proposal to aid the staff, a two page proposal asking for $20.000 and with probability 95,9 you got the $20.000. Money was so easy to get because a lot of work was supported by the Defense Department. Just to give you an example, Air Force was begging MIT to accept money to do research, but MIT didn't want that. So MIT eventually, grudgingly, agreed to set up Lincoln Laboratories. Lincoln Laboratories, yes, sort of separate from MIT. So National Science Foundation (NSF) came into existence at about the same time that I started my teaching career. The budget of NSF (National Science Foundation) initially was 15 million dollars. Today it is 3,4,5, or 6 billion dollars.

**R.Y. I guess it was a better world to be a younger person in than it is today.**

L.Z. Yes.

## People influencing Zadeh's Career

**R.Y. The first thing that interests me was you were around in a very exciting period, after WWII, when there were a lot of giants around. Who were some of the people who impressed you during that period?**

L.Z. I was a graduate student at MIT from 1944, when I came to the United States, to 1946. In that period, many things classified during the war were being declassified and radiation laboratory and computers were being born. One personality that impressed me very much at the time was Norbert Wiener. He was extremely absentminded,

**Norbert Wiener**

but he authored a famous monograph on prediction theory, which was highly classified but then it was declassified. And there were many other people: Pitts, original thinker, McCulloch... It was also, more or less, the beginning of the cold war, the famous speech by Churchill started the whole thing. There was the feeling that there would be a technological competition. The Government was going to put a lot of money in support of research. So, in this respect, I consider myself to be fortunate. I was there

**It was not the world of Laplace Transforms and Fourier Transforms. It was a world of "bits" of "channels", of "entropy", of things that nobody talked about before Shannon did**

when those things were happening. And one event that was particularly significant for me was Shannon's Information Theory. I heard his first lecture, in 1946. At that time I was at Columbia University, in New York and I was extremely impressed by what Shannon had to say. It was a different world, a digital world. It was not the world of Laplace Transforms and Fourier Transforms, which is Norbert Wiener's world. It was a world of "bits" of "channels", of "entropy", of things that nobody talked about before Shannon did. So I would say that among the most significant events at that time was Shannon's developing "Information Theory", not that the information theory by itself had so many applications, but the entry into the digital world.

**R.Y. When they come to have some different view of measured information.**

L.Z. Right

**R.Y. Is there any particular person that directly influenced your career?**

L.Z. I would say that the person who influenced me most was Professor Ernst Guillemin. I took his course on Circuit Theory and his courses were models of clarity and precision. My taste for system theory began with my exposure to Guillemin's concept and techniques. Actually, I was somewhat critical of the world that Guillemin lived in. And, as a student, I sometimes argued with him saying that the world that he was describing, synthesis of different kinds of networks, was too idealized, it was a world in which there are no non-linearities, there were no dying areas, no noise, no nothing. And I did express my view at that time, to the effect that eventually computers would be used to do circuit analysis. That real

**I would say that the person who influenced me most was Professor Ernst Guillemin. My taste for system theory began with my exposure to Guillemin's concept and techniques**

world circuits are too complicated for the kind of theory that Guillemin was presenting to his students. So, on one hand I was very deeply influenced and on the other hand I wasn't quite on the same wavelength. And the reason why I was more influenced by Guillemin is because many of the other professors at MIT at that time were not really research oriented, they were primarily teachers. Guillemin, in addition to being a very influential person, was an extremely fine person. So in many respects he was a role model. Professors at MIT at that time were very dedicated people, and they were not really a part of the world that was coming into existence at that time. We were very innocent in many ways.

**R.Y. Another place where you spent some time was the very historical place of Princeton Institute for Advance Study at Princeton. This is a place with many giants. Could you reflect a little bit upon your experience there?**

L.Z. I was at Columbia University from 1946 to 1959. I received my Master's Degree from MIT in 1946 but I did not stay at MIT to work toward the PhD degree because my parents came to the United States to settle in New York and I wanted to be close to them. So I was extremely fortunate in getting a job at Columbia University as an instructor. If I had gotten a job at, say, City College, I

**F.l.t.r.: Joseph Weizenbaum, Ed Fredkin, John McCarthy and Claude Shannon**

would be a big zero today because after I have to teach 15-20 hours a week there would be no time for research. Columbia was not like that. Its engineering school was not in good shape but the derivatives were positive: new people, new ideas. My main field of interest was System Theory. In 1954 I wrote a paper called "System Theory". I think I was the first to use that term, "System Theory". While I was at Columbia I was very close to the Department of Mathematical Statistics, and in particular to Herb Robins, who at that time was Chair of the Department. We became very close friends. He was also a close friend

**In that time Robert Oppenheimer was the director of the Institute, an extremely interesting place where you had people who were among the smartest people in the world**

of Deane Montgomery, a prominent mathematician, and at the request of Herb Robins, he recommended me for visiting membership of the Institute. I missed seeing Von Neumann in 56-57, and I missed seeing Einstein. They were not there during the war. In that time Robert Oppenheimer was the director of the Institute, an extremely interesting place where you had people who were among the smartest people in the world. I was the only non-mathematician, but they assumed that I was a mathematician. But to be accepted in that world the primary requirement is that you be able to gossip. Not to talk about theorem XYZ but if some professor ran away with his student or somebody was having an affair with somebody else. This is the sort of things that people talked about at lunch. Every morning, there was a van that picked up people and bring them to the Institute and Gödel was one of them. So every morning I was in this van with him but he never opened his mouth. I never had a chance to talk with him. There were people like that. Quine was also there, and Kreisel, who had extremely fascinating seminars, logic, probability theory and various other things. While I was there, I also audited a course at Princeton given by Kleene, the leading logician.

## Transition towards fuzzy logic

**R.Y. At some point you make a transition from this electrical engineering world to a whole different world. At least, the tools are different, you're talking about sets, you're talking about logic. Could you say a little bit about your transition?**

L.Z. That's a really good question. As I already said, my field in systems analysis was basically the field of linear systems. And as I already mentioned, under the influence of Ed Moore's work, I moved towards the concept of state and its associated concepts. And finite state machines are close to computers. I was always interested in computers but when I was growing up they were not in existence. Even though I was not close to the world of computers, nevertheless, I felt that that was the world of the future.

**Even though I was not close to the world of computers, nevertheless, I felt that that was the world of the future**

In 1950 I wrote a paper called "Thinking machines, a new field in electrical engineering" and that was 6 years before Artificial Intelligence Center (AI) was born. Incidentally, I talked about "electronic director of admissions" in that paper. In 1965, looking 15 years ahead, Trustees of Columbia University decided to disband the office of admissions and replace it with electronic office. Then I described what would be the rule based system. Take a students record and various active parameters and the new correction of rules "if this or that, then..." so I described it a rule based system there. So I was sort of gravitated


**Lofti A. Zadeh at his desk in 1937**

towards that. In 1959 I came to Berkeley. Then I taught on one hand finite state systems, on the other hand something having to do with linear systems. Then, in 1963, I was appointed as Chair of the department. And that was the period when computer science began to become visible and a war started between electrical engineering and computer science at UC Berkeley. I was for pushing computer science with electrical engineering, but Professor Abr

**Then, in 1963, I was appointed as Chair of the department. And that was the period when computer science began to become visible and a war started between electrical engineering and computer science at UC Berkeley**

Topp, who was the director of the Computer Center at that time, was pushing for a separate department. So I was pushing computers in EE, hiring various people and starting programs, so I became much closer to that world than I was prior to my becoming Chair of the department. But again my involvement was not of the kind where I really did something with computers, it was sort of administrative. In 1967 we changed the name to Electrical Engineering and Computer Science. The first department to change its name and I put myself in the back for persuading the people in the department to go along with it. Many people were opposed to it. My term as Chair came to an end in 1968 and I decided to do something about it. So I took a medical leave, half of which I spent at IBM Research Laboratory and half at MIT's Project Lab. In that period I retrained myself and when I came back to the Department in 1968 I no longer taught courses in systems analysis, I began to teach elementary courses in programming and not so elementary courses in computer languages. And that changed the direction of my life. But the war between computer science and EE continued. Eventually the Department of Computer Science which was set up in 1967, was disbanded and the people in the department were absorbed in EECS. At that point the division of Computer Science was formed in EECS, I moved into that division.

## Inspiration for fuzzy sets

**R.Y. I was around with students in a time when The State Space approach was coming in. A very interesting period. Let me ask another question. Is there any direct inspiration you could account for your development of fuzzy sets?**

L.Z. Not really. I tried to persuade Herb Robins, my eminent friend, just to do something. I also tried to persuade Dick Bellman, who was my best friend. But both of them were busy with their own problems. But I felt increasingly that something was lacking. Linear system theory could not deal with unsharpness of class boundaries. So

**So I must say that my developing of the concept of fuzzy sets to a considerable degree was also a matter of luck**

in my 1961 paper called "From Circuit Theory to System Theory" I do say that we need something, we need fuzzy concepts. It was always in the back of my mind. The idea occurred to me in 1964 and the paper was published in 1965. At that time I was Chair but I never really stopped thinking about or participating in conferences and writing. I never became one hundred percent administrator. So I must say that my developing of the concept of fuzzy sets to a considerable degree was also a matter of luck.

And had I not developed the concept, today I would not really be sort of initiator of something that has followers. I think that this is an important criteria. There are many many people in academic world who try this position of prominence but they never develop a following, so there is no legacy. They pass away, they're forgotten.

**Richard E. Bellman**

**R.Y. That brings up something I was going to talk you about later but I'll bring it up now. In some regards, "fuzzy sets" is "fuzzy sets", there is no real "Zadeh's fuzzy sets" sure and I've always thought that perhaps something with your name as Zadeh's extension principle. Could you comment about how you feel about something like that?**

L.Z. I think that if you look at history of many fields, in particular mathematics, you'll find that some names stay because they are associated with some concept. And in some cases people have done a lot but somehow the name did not get attached to something. One thing to which my name got attached to some degree, and I am pleased with that, is "extension principle". It didn't get attached to "fuzzy sets" or "fuzzy logic" but people know that it is associated with Zadeh and that is good enough for me.

## Interaction with AI community

**R.Y. At the same time you started introducing fuzzy sets, the whole field of artificial intelligence was arising in some way dealing with very similar issues . Could you comment a little about your interaction with the AI community?**

L.Z. I've always been close to the AI community. So I knew quite well the people that are considered to be leaders like Minsky, McCarthy and I still have a close relationship with them. But at the same time, I was not

completely in-tuned with the directions. AI was very based on logic and too varied logic. AI came into existence in 1956 so, in 1965 when my paper with fuzzy sets appeared, there was something in AI but it was very much too varied logic oriented. I was out of sympathy with that. So when I started fuzzy sets I felt that it was important for AI to broaden itself and to consider other logical systems, in particular fuzzy logic. And my conviction was, and remains, that AI should be based on fuzzy logic.

**Marvin Minsky and John McCarthy**

I realize, of course, that this statement would be rejected out of hands by the AI community. The AI community is still very happy with two valued logic, but the time will come when things will change. Let me give you an example. The founders of AI, above all McCarthy and Minsky, were very logic oriented. Probability was a bad word in AI until Judea Pearl began to write something on "probability theory" and it is thanks to him that probability made its way into AI. Logic oriented AI is not used that much nowadays, it has never really found that many applications. People talk about non-monotonic logic and today non-monotonic logic is largely neglected. But at that time they thought they could apply it to common sense reasoning. You have to use fuzzy logic to deal with common sense reasoning. So I still maintain,

**In many many cases, animosity is based on unfamiliarity. And if it is based on unfamiliarity, then the best thing is to be gracious about it**

I contend that AI has to be based on fuzzy logic. Now if I had said in the mid 60's that probability theory should be a part of AI, people would strongly disagree with me. But eventually probability theory was accepted and the same thing with fuzzy logic. So then it may take five years, ten, fifteen years but eventually they will say "Perhaps Zadeh was not quite as stupid as we thought he was".

## Clash with probabilistic approaches

**R.Y. At best, I think the people in the logical approach to AI didn't pay attention to fuzzy sets, very frankly. But now on the other hand, the people in the probabilistic domain have been much more aggressive and challenging fuzzy. It has been more of a kind of almost like a hostility.**

L.Z. Yes. Because there isn't that much competition between fuzzy set theory and logic, Von Neumann's logic but there is between probability theory and fuzzy logic.There shouldn't be. But there are many people in probability theory who view fuzzy logic as a competitor and so there is a natural tendency to knock your competitor as part of American tradition. And so what has become very popular is "bayesianism". But basically bayesianism is equated to probability theory. It is not but that's the way it is equated. And so you are right. I have frequently encountered that kind of hostility and I don't want to mention names but no long ago I had an exchange with somebody and he was extremely hostile towards fuzzy logic. And hostile in an aggressive way.

**So when I started fuzzy sets I felt that it was important for AI to broaden itself and to consider other logical systems, in particular fuzzy logic**

**R.Y. In this regard maybe you could provide some advice to some people. Over the years now you have overcome a lot of animosity and a lot of resistance to your ideas and you persevered over these years. Could you make some advice for people who may find themselves in a similar position?**

L.Z. Well I think there are two kinds of animosities. One is when you really know a person well and you don't like that person. The other kind of animosity is when you don't know the person but for some reason, you don't like that person because of race, color or whatever. So if you deal with the first kind, it is difficult because there is some sort of an intrinsic concept. But in many many cases, in my experience, animosity is based on unfamiliarity. And if it is based on unfamiliarity, then the best thing is to be gracious about it. So if somebody says that "I don't believe in what you're doing" say "Thank you, I appreciate what you said" and so forth.

**Lofti A. Zadeh received the Honda Prize in 1989**

If there is something you really don't agree with, you can say "well I agree with you almost completely but in some minor ways, I view things a little bit differently". And then you proceed to talk about it. Another thing is to say "you know what? I agree with everything that you did not say." That stops it. But my experience's been this: that there were quite a few cases where initially my relationship was not good. Not that I felt badly about the person, but that person did not like me. But I did not respond unkind

and eventually we became good friends. And the most sort of prominent example of that is my relationship Professor John R. Ragazzini at Columbia University. When I started as Columbia University Instructor I was asked to be his assistant and I could see that he doesn't

**I take a general benign view of people because I was fortunate to grow up in an environment in which almost everybody that I was in contact with was good**

like me. And eventually we became the best friends. I must tell you something about myself. I take a general benign view of people. And the reason why I take a benign view of people is because I was fortunate to grow up in an environment in which almost everybody that I was in contact with was good. It's hard for me to think of situations or circumstances where this was not the case. So I think that you tend to be benign if that's your experience and conversely if you grow up in situations in which you deal with crooks, and thieves and murderers and various other things then you're not going to be benign.

## Membership grades

**R.Y. Throughout the history of fuzzy sets, the essential question that comes up when you introduce them to people is the question of membership grade. And this becomes the first heard of, the one that has to come over.**

L.Z. There are many situations when people get exposed to this concept. Fuzzy logic and fuzzy sets are used all over the place. But they're used in situations in which these membership functions are declared. In other words, designer interacts not with the human but with the machine. You design fuzzy logic transmission. But right from the very beginning this was a question that arose and I gave a talk where there was somebody with an idea. He was a linguist and this is the first question that he asked. "Where do you get the membership functions from?" "These are context-dependent, tall to one person is not the same as tall to another person". But I can tell you, "if somebody is 5,10, to what degree is this person tall?" People can ask questions like that. Particularly today we get more and more questions from 0 to 10. Now humans have a remarkable capability to, what I call, graduate perceptions. So I can elicit it from you by asking a series of questions "to what degree is 5,10 tall?" "to what degree is 5,8 tall?" "To what degree is 6,5 tall?" Out of that, I'll get you a membership function.

**R.Y. There is another situation which is becoming much more important nowadays. It is not declarative and it is not learning. There is an Internet and fuzzy sets is clearly a tool. But isn't it you're getting information that is being said and you have no source that you can come and say "what do you mean by this?" How do you suggest that one can get the fuzzy membership grades in that environment?**

**Lofti A. Zadeh with Ebrahim Mamdani and some of his students**

L.Z. Let's consider the problem of natural language and understanding. I recently began to talk about a z-mouse. With it you can easily do that. With the z-mouse you have a mark, called an f-mark on the computer screen and you enter your perception of a number on that scale. Now the f-mark is not a point, it's some fuzzy thing. Fuzziness in that context means that you are not completely sure what the value is. So if I ask you "to what degree do you like Obama?, you use the f-mouse to put a mark but not a point. Meaning that hey I'm not completely sure here to what degree I like Obama. So you get this membership function, but it will not be a sequence of points. It will be these f-marks. So what it boils down to is that if there is nobody that you can turn to and ask to define the meaning of "tall", humans have perceptions of "tall" so that if somebody asked you to what degree is so and so tall you would be able to answer that question. Now, and that brings me to the definition of "understanding". We do not have that but at some time in the future, perhaps far away, we could have a system such that the images that are in our brain can be seen on the screen. At that point we will say that this is really "understanding". It is not understanding in the sense it's used there, natural language processing. It's understanding in the sense in which people really understand.

**We do not have that the definition of understanding but some time in the future, perhaps far away, we could have a system such that the images that are in our brain can be seen on the screen. At that point we will say that this is really "understanding"**

## Computing with words

**R.Y. In some ways, as I see it, I want to find the exact term. Your ways in fuzzy sets sometimes it's not mainstream and somehow you're an outsider**

**in some sense because the approach that you follow is a constraint approach. And the other approach in fuzzy sets in most places is one of building up. They're using information rules for building up**

L.Z. If you look at the papers that I've written or I am writing so forth they're not really the mainstream. But I think that doesn't bother me because I think that it'll take time but eventually, people will warm up to it. For example, I've been very much in computing with words and not that many people have followed me. But with the passage of time, more and more people will do. Now I'm very interested in mathematics dealing with computational problems which are stated in a natural language". My contention is that mathematics cannot, but I can come up with a system that's based on computing with words. And it opens a new vista for mathematics.

## Extended fuzzy sets

**R.Y. My initial appeal to fuzzy sets has always been that people use fuzziness to simplify things. Now in this regard, I find very appealing when you talked about extended fuzzy sets. Somehow my understanding of extended fuzzy sets is that you don't really need membership grades.**

L.Z. When we talk I say "tall", "short" and so forth. I don't give a membership function. And yet, you understand what I'm saying. If I say "Raise your arm.", you do it. That's fuzzy. You don't know what's the degree of membership in this and this. If we were dealing with a machine, a robot, then we would have to precisiate it. But humans understand many things without the membership function being specified. So an extended fuzzy set or extended logic is a logic in which you deal with fuzzy sets but the membership functions are not specified.

**Humans understand many things without the membership function being specified. So an extended fuzzy set or extended logic is a logic in which you deal with fuzzy sets but the membership functions are not specified.**

**R.Y. In natural language, for example, people have talked about possibility theory as one way of working. Another way is probability.**

L.Z. You need both. In my recent work I'm using the concept of "restriction" which is the same as "generalized constraint". If information is provided by restricting you have to find other ways to find information. Suppose you have a number X and then you say that the probability that X is large is small. I give you some information about X but it is not possibilistic, it is not probabilistic, it is a mixture of the two. What is the probability that "John is tall". So you have a mixture of probability and possibility so I am not saying that you should not use probability theory, no, I'm saying that, let's say, 60% is possibility and 40%, 20% it might be probability and 20% it might be mixture of the two.

**Contrary to my expectation, fuzzy set theory had a much harder time getting accepted within the humanistic sciences than hard sciences and engineering**

## Control

**R.Y. In your early work, you were closer to control work. You never really wrote a paper on fuzzy control. Is there any reason why you have never really got too much involved in fuzzy control per se?**

L.Z. When I wrote my first paper on fuzzy sets, my expectation was that fuzzy set theory would be used primarily in fields in which conventional system theory techniques didn't work. In the grounds of humanities, law, biological systems or, in general, human-centered systems. But, contrary to my expectation, fuzzy set theory had a much harder time getting accepted within the humanistic sciences than hard sciences and engineering. I began to see that there were applications in systems analysis. So my first, short paper on that subject was the 1972 paper called "A rationale for fuzzy control" where I

## Lofti A. Zadeh and the fuzzy community

**Left:** Lofti A. Zadeh receiving his 15th honorary doctorate on January 2003 with Erich Peter Klement. **Right:** Vilém Novák, Irina Perfilieva and Michal Baczyński with Lofti A. Zadeh during 6th Fuzzy Days in Dortmund at May 1999.

indicated why fuzzy set theory may be used in control planning. But I was never really control theorist. So in 1974-75 Mamdani and Assilian published their famous paper on linguistic synthesis and their work was based on my 1973 paper "On the concept of linguistic variable" and fuzzy if-then rules. In any case, in response to your question I never really tried to push control, because this was not really my cup of tea. But I think that the concept of a linguistic variable and fuzzy if-then rules opened the door to fuzzy control.

**I never really tried to push control, because this was not really my cup of tea. But I think that the concept of a linguistic variable and fuzzy if-then rules opened the door to fuzzy control.**

## Soft Computing

**R.Y. There have been a few related ideas, things like soft computing, things like gradual computing. Could you comment on how you see those all in one picture, the relationship between soft computing, fuzzy sets, gradual computing?**

L.Z. Let me first comment on soft computing. There has always been a sort of nationalistic feeling, particularly within AI or methodologies which are sort of AI oriented, in particular neural computing, evolutionary computing, probabilistic computing, fuzzy logic and so forth. There is a tendency to raise your banner and say "this is the only correct methodology". I thought we should not fight with each other.

**I think that the principal methodologies would be fuzzy logic, neural computing, evolution computing and probabilistic computing. And I think that students should be exposed not just to one of these methodlogies, but to all of them**

So I said "let us form a partnership. Let's put these things together so that they won't be fighting with each other. So that they'd be reinforcing each other." And I thought that the principal methodologies would be fuzzy logic, neural computing, evolution computing and probabilistic computing. And I thought that students should be exposed not just to one of these things but to all of them, because it is obvious that the student who is trained only one kind of AI is not going to be as well equipped to solve relation problems as somebody who knows all of them. Now let me give you one example. In the late 90's Jim Bezdek came up with the term "computational intelligence", which is basically the same as "soft computing". I took on that term not just because it is more sexy but because AAAI took it backed it for some exercise. And AAAI is a powerful organization, the most powerful scientific organization in the world. So today computational intelligence is more popularly used than soft computing.

**The reason why fuzzy logic is not applied as widely in the United States as it is in Europe is that not many people know what it is, because there are not many universities in which you have courses of it**

What is happening now is there is some sort of a competition between computational intelligence and AI. I think that most of the real world applications of AI actually are applications of computational intelligence, so I think that with the passage of time computational intelligence will go faster than AI. The reason why fuzzy logic is not applied as widely in the United States as it is in Europe is that not many people know what it is, because there are not that many universities in which you have courses in fuzzy logic. I want to tell you something else, because this has to do with causality. We don't really have a theory of causality. In particular we do not have a theory of "multicausality". For example, suppose I am a manufacturer of raincoats. I want to increase my sales. So what do I do? I increase the advertising budget by 20%. Six months later my sales go up by 10%. Was the increase of sales caused by the

## Lofti A. Zadeh and the fuzzy community

**Left:** Lofti A. Zadeh with James Keller and James Bezdek at Eusflat-LFA Conference 2005 in Barcelona. **Right:** Javier Montero, Humberto Bustince, Tomasa Calvo and Luis Magdalena with Lofti A. Zadeh when he received the Honorary Doctorate by the Technical University of Madrid in 2007.


increase in the advertising budget? I say there is no theory that can tell you whether or not this is due to the increase in the advertising budget. You cannot survey people who bought the raincoat and find out whether they bought it because of advertising. Let me give you an example. Suppose that I increase the advertising budget by 20% and the sales went down 10%.Then, should I say that it was the wrong thing to do?. But it may be that they went down by 10% because there was no rain. So if I had not increased the advertising budget, the sales would have gone down by 30%.

**We don't really have a theory of causality. In particular we do not have a theory of "multicausality"**

**R.Y. How do you know?**

L.Z. Nobody can tell what would have happened, there is no solution to this quosel. Whenever you have multicausality, you cannot sort out what caused and to what degree.

**R.Y. This is just something I think we have talked about before. You're very conservative, in the sense that instead of trying to say "here is the solution", you try and say there's no solution. Your views in many things are conservative in that sense. In decision-making for example, it is required doing something even if you're not certain.**

L.Z. Well, actually. What I say is frequently misinterpreted. I am not saying "we cannot do anything about it", I am saying "we cannot consider it a theory". So surely we do things all the time and make decisions with multiple causes. In medicine we do it all the time. But we cannot construct a theory. So when Judea Pearl tells me that he had a theory, I said "no, you don't have a theory". When Joe Hackman tells me "I have a theory", I say "you don't have a theory" When somebody asks me "Can you construct a theory?" I say "No, I cannot construct a theory". What we do is based on perceptions.

## Future of fuzzy sets

**R.Y. What would you like to see happen in the field of fuzzy sets and soft computing in the future. Do you have any vision?**

L.Z. I have almost always had the feeling that natural languages are important. So my first paper was in 1961 but my first big cite in fuzzy was in 1969. In 1971 "Quantitative fuzzy semantics" was my first paper in which natural language was there. I feel that in fuzzy logic not enough people have been interested in natural languages. And in the case of natural languages, not enough people have been interested in fuzzy logic. I've always felt that some people who are really prominent in the field of fuzzy logic they disapproved of my talking about computing with words. What I think is that natural language can be serious. It is a new whole field to find solution of problems which are stated in natural language.

**I see that in very many cases things are described in natural language. And that's why I say that fuzzy logic, in large measure, is really computing with words**

But it's not just a matter of theory it is a matter of common sense reasoning. How do you make decisions, when the information that you have is described in natural language? People do that all the time. But how do you construct a theory of that? I've never been really satisfied with decision theories, with maximum expected utility, prospect theory. They're not sufficient, they're realistic. In fact, probabilities are imprecise. But now instead of saying "imprecise" I say "probabilities are described in a natural language". And so, when I wrote my first paper in which I used computing with words, I did see that in very many cases things are described in natural language. And that's why I say that fuzzy logic, in large measure, is really computing with words.

## Lofti A. Zadeh and the fuzzy community

**Left:** Lofti A. Zadeh receiving a prize in the year of the 40th anniversary of the first paper on fuzzy sets at the Eusflat-LFA 2005 Conference in Barcelona. **Right:** Pilar Sobrevilla and Ana del Amo with Lofti A. Zadeh in the NAFIPS 2005 in Michigan.

## Perseverance

**R.Y. I have noticed many occasions years ago you would be coming to some conference. You come thousands of miles, and come and speak for ten or twenty minutes to a room maybe with ten people in it. Could you say something about perseverance?**

L.Z. I think I have that quality. When things don't work out the way I would like them to work out I tell myself "Don't give up". So I think I have this quality and it has helped me tremendously because very many people have a tendency to give up. One, two, three tries and that just discourages them.

**R.Y. Is there any advice? For me it is a very interesting quality.**

L.Z. Yes, I think it's an important quality but I think that in one's life luck plays a tremendously important role. In my own life there were two or three critical points. One such point was getting the job at Columbia University. And there were two or three instances where it could have gone this way and it could have gone that way.

## About writing papers

**R.Y. A more personal question. Could you say something on how you write a paper?**

L.Z. I do quite a bit of thinking after I get into bed, for one hour or two hours. The way I write it up then basically is based on having something in my mind before I start writing, rather than just doing it extemporaneously whenever. So there are two periods: one is when I go to bed and the other one, when I get up, early in the morning.

**The way I write is basically based on having something in my mind before I start writing, rather than just doing it extemporaneously whenever**

But I must also say the time that I devote to thinking about technical problems is quite high. I think it is much higher than what normally would be the case.

Exception of some nights, I am always thinking about something. And this is something that I have not trained myself to do, it's something that comes naturally. When I am sort of falling asleep, I think not so much about how much money will I make if I start this company or that company but I think about various technical problems.

**In many cases people are concerned not so much with trying to explain, but trying to impress people. And you impress people by not being understandable**

**R.Y. I've read some of the work by Freud "Civilization and It's Discontents" and I have always found something similar in your work and Freud's, in the simplicity. Your writing is very easy to read. Do you purposely think about the simplicity?**

L.Z. My experience is that most things are basically much simpler than they appear to be. They appear to be complicated because they are not well explained. But I always had the feeling that if I understand something, I can do a good job with the explanation. And in many cases when I ask somebody a question, and that person cannot explain it to me, it is because that person did not really understand the subject well. There are some exceptions. There are subjects which are intrinsically complex like relativity theory, like some subjects in mathematics like measure theory. But outside of things of this kind most subjects are not really that complex. So it is unfortunate that in many cases, people are concerned not so much with trying to explain, but trying to impress people. And you impress people by not being understandable.

## Education

**R.Y. You were a teacher for a long time so I think you have a lot of experience with education. As more and more our education is moving towards sort of "on-line", no longer classroom, do you have any thoughts on that?**

L.Z. I have somewhat mixed feelings about it. We have

### Lofti A. Zadeh and the fuzzy community

**Left:** Lofti A. Zadeh with Pilar Sobrevilla and Piero Bonissone in FUZZ-IEEE 2001 Conference, in Melbourne (Australia). **Right:** Eduard Montseny and Lofti A. Zadeh at the Eusflat-LFA Conference 2005, in Barcelona.

technological progress but we should not assume that technological progress is always positive. Let me give you some examples to the contrary. Previously you called something and you got a human operator. Today you call a place, you don't get a human, they say press this or press that, and in some cases they say "all our operators are busy". It takes you fifteen minutes, you go crazy waiting for a human to answer because it doesn't fit the standard things. What I'm trying to say is, that in many cases, it is a matter of efficiency. It is cheaper to use machines than to use humans. But when it comes to education, the best kind of education that I've experienced was a course at Princeton, taught by Kleene, a world renowned logician. There were about five or six people taking the course. We were seated at a round table and Kleene asked us what we thought about this or that. No examinations, no homeworks, nothing. But this was the Socratic sort of thing. High salary, small number of students and he always taught just one course, so you can calculate how expensive it was, per student, to have a course. Compare that with on-line courses, distance courses, where you never get a human being in there and you never have a chance to ask some questions.

**R.Y. And people who teach these courses don't even know anything about it because all you have to do is just put up the stuff.**

L.Z. I would hate if I had to spend my time on doing this sort of a thing.

## Proudness

**R.Y. Ninety years, you look back on your career now, what do you feel the most proud of?**

L.Z. There are some people who are proud of themselves and I say I never shared that feeling. I say that to a considerable extent I consider myself to be lucky in getting into fuzzy sets. But it was a matter of luck and I can't use the word proud. But if you ask me to point out something which I'm most pleased with, I would say it'd be fuzzy set theory. And within that, linguistic variable, fuzzy if-then rules, and more recently computing with words and right now, this mathematical solution of computational problems stated in natural languages. I think this maybe will be more important, not in terms of real world problems, not with computer and similar products, but in terms of theory. I am also pleased with the fact that this occurred to me at this age, you see, at the age of ninety, where most people are really underground or similar.

**If you ask me to point out something which I'm most pleased with, I would say it'd be fuzzy set theory**

**R.Y. Pleased is a better word. On the other side of the coin, if you look back on your life, is there anything that you would have done differently?**

L.Z. Not really, there's always something but even in the case of my heart attack in 2008, it sounds a little strange, but in some sense I am glad that I had it, at that time. If I did not have my heart attack in 2008 I would have it later. Where? Somewhere in the plane. So I was lucky that it happened when I was at home and Ausley and Neilcare and family, we were supposed to have dinner that night. So I consider myself lucky that I had a heart attack at that time. Now I did, I think, too much traveling.

**R.Y. That's for sure, Lofti. Anyone who knows you would say that.**

---

We would like to thank Rudolf Seising, Eduard Montseny, Pilar Sobrevilla and Michal Baczyński for the pictures that illustrate this interview. All the rigths are by the authors.

More information about Zadeh can be found in: *Seising, Rudolf: The Fuzzification of Systems. The Genesis of Fuzzy Set Theory and Its Initial Applications - Developments up to the 1970s (Studies in Fuzziness and Soft Computing, Vol. 216) Berlin, New York, [et al.]: Springer 2007.*

The video record of the interview and a complete transcription are available at `http://giara.unavarra.es/msc/index.php/interview`.

## Ronald R. Yager

We want to thank Ronald R. Yager, who has been the real author of this interview. With more of 500 published works, there are a lot of contributions by Prof. Yager to Artificial Intelligence. However, the most important one is probably the definition and study of OWA (Ordered Weighted Aggregation) operators, that allow to calculate the mean of different values taking into account the relative valued assigned to each of them and the way they are ordered. These operators as specially well-fitted for the describing and treating linguistic values in the frame of computing with words.

Prof. Yager has received many awards along his career. Between them, we can mention the FLINS gold medal and the Computational Intelligence Society Fuzzy Pioneer award. He is still very active, taking part in conferences and workshops in all the world.

IN MEMORIAM

# EUSFLAT board member Da Ruan: Obituary

## By Professor Dr. Etienne E. Kerre

Midsummer 2011. Da prepared an extensive delicious Chinese dinner for his family and some friends. Everybody enjoyed the pleasant evening. But suddenly Da felt unwell: a heart failure made a dramatic end to his life and left us behind with memories about this remarkable friend and colleague.

Da was born and grown up in Shanghai, China. In 1983 he obtained a Bachelor of Science degree in Computational Mathematics from Fudan University, one of the top 4 universities in China. Due to excellent study results he became an asistant of this university. In 1987 he got a grant from the Chinese government to study abroad. In that way Da became my first Chinese PhD student, an intelligent and hardworking young researcher, capable to tackle new problems in the nascent mathematics of fuzziness. Da successfully defended his PhD on "A critical study of widely used fuzzy implication operators and their influence on the inference rules in fuzzy expert systems" in December 1990 with Dr Han Zimmermann and late Dr Phillippe Smets among the members of the jury.

**As PhD student, he was an intelligent and hardworking researcher, capable to tackle new problems in the nascent mathematics of fuzziness.**

In 1991 till his death Da became a permanent staff member of the Belgian Nuclear Research Center in Mol, Belgium. Among the long list of activities and initiatives Da has taken in that research center I will only mention two of them: first the development of a time-dependent three-dimensional finite-element diffusion cone TRANSFUSION for nuclear oil well logging applications, and second the building of a fuzzy logic control demo model that has been extended for on-line experiments at the BR1 nuclear reactor in Mol. Due to these advanced and daring applications of fuzzy logic Da has been hired as principal investigator by the International Atomic Energy Agency in Vienna to develop a fuzzy logic based intelligent tool for uncertainty analysis for nuclear safeguards applications as well as to develop an adaptive fuzzy controller for the TRIGA Mark III reactor in Mexico.

**Da was very concerned and full of love for his family in Belgium ( his wife Greet and two sons Alexander and Nicolas) and in China ( his parents, brother and sister)**

Da has also been an excellent researcher with more than 100 papers in internationally high ranked journals such as Fuzzy Sets and Systems, Information Sciences, Journal of Global Optimization, Journal of Multiple Valued Logic and Soft Computing, Journal of Computational Intelligence Systems, Journal of Intelligent Systems, Journal of Intelligent Systems, Journal of Approximate reasoning, Journal of Uncertainty, Fuzziness and Knowledge-Based Systems. Soft Computing, Mathware and Soft Computing. His main topics of research were: fuzzy implications, decision support systems, risk evaluations, lattice-valued logics and reasoning with fuzzy if-then rules.

But Da will ever be remembered for his excellent service to our fuzzy community. First of all he edited close to 20 special issues for several international journals. Secondly he edited 36 books on computational intelligence, mathematics of fuzziness and intelligent decision making systems. He has been a referee for about 25 international journals. Moreover in 2007 he launched as editor-in-chief the International Journal of Intelligence Systems (with already an impact factor of 1.471 in 2010!) as well as the book series "Computational Intelligence Systems".

**Da has been an excellent researcher with more than 100 papers in internationally high ranked journals. He will ever be remembered for his excellent service to our fuzzy community**

However his major scientific achievement was the founding of FLINS, an acronym for Fuzzy Logic and Intelligent technologies in Nuclear Science. Every 2 years from 1994 on Da organized the international FLINS conference that could count on a continually growing number of participants. Da was always proud to have the prestigious proceedings of this conference ready at the start of the conference.

**We will miss Da so much as an excellent friend, full of kindness and unconditional helpfulness**

Because of his excellent CV Da became a guest professor at several universities in Belgium ( Ghent and Hasselt), Australia ( UTS in Sydney) and China ( Shanghai Electricity and Power university, Shanghai Maritime university, Shanghai university, Xihua university in Chengdu, Southwest Jiaotong university in Chengdu): he was a beloved teacher, Ph D promoter and research guide. Looking at these achievements one can hardly imagine the amount of energy Da has put into his scientific activities. But Da was also very concerned and full of love for his family in Belgium ( his wife Greet and two sons Alexander and Nicolas) and in China ( his parents, brother and sister). Many of us have experienced his passion against well-prepared Chinese food.

We will miss Da so much, not only as a perfect organizer of meetings, not only as an indefatigable editor of special issues of journals and books, not only as an intelligent mind to develop high technological control devices... but most importantly as an excellent friend, full of kindness and unconditional helpfulness. Thank you Da!

## By Professors Dr. Luis Martínez, Dr. Jie Lu and Dr. Javier Montero

Our colleague Da Ruan, member of the EUSFLAT board since the last EUSFLAT general assembly, unexpectedly passed away on 31 July, 2011 from heart failure at the early age of 50 years. His death was a shock to all of us. He will be very sadly missed. Da Ruan was a leading member of the global fuzzy logic community, an appreciated EUSFLAT member, and Editor in Chief of the EUSFLAT official journal, the International Journal of Computational Intelligence Systems.

Da Ruan's untimely passing has created much sadness in our research community and poses an irreparable loss to the fuzzy logic research field. He was very energetic, full of brilliant ideas, and always enthusiastic about his research, teaching and collaboration. A number of Web pages have been created around the world to honour Da Ruan's memory (see, e.g., http://decide.it.uts.edu.au/DaRuan/Da_Ruan.html, which contains many world-class researchers' messages in tribute to Da's scientific work and his excellent character; see also http://www.sckcen.be/fr/Nouvelles/In-Memoriam-Da-Ruan). He was well liked and highly regarded, as evidenced by the messages of tribute.

Da Ruan was a principal research scientist at the Belgian Nuclear Research Centre (SCKoCEN). He received a PhD in Mathematics from Ghent University, Belgium in 1990. His major research interests were in the areas of mathematical modelling, computational intelligence methods, uncertainty analysis, decision support systems and AI applications to information management, cost/benefit analysis, nuclear safety and security related fields. He published 90 peer-reviewed journal articles, two text books, and 20 research books on artificial intelligence, decision support systems, and intelligent information systems and applications.

**Da Ruan was a leading member of the global fuzzy logic community, an appreciated EUSFLAT member and Editor in Chief of the EUSFLAT official journal**

Da Ruan received an honorary doctoral degree from the Nuclear Power Institute of China for his research achievements, including intelligent control for nuclear reactors in 1995. He served as a member of the editorial board of Fuzzy Sets and Systems (Elsevier), as regional editor for the European International Journal of Intelligent Automation and Soft Computing (TSI Press, Albuquerque, NM), as co-editor-in-chief of the International Journal of Nuclear Knowledge Management (Interscience Publishers, Geneva), as editor-in-chief of the International Journal of Computational Intelligence Systems (Atlantis Press, Paris), and as editor of the book series on Intelligent Information Systems and for the proceedings series of Computer Engineering and Information Science (World Scientific,

Web pages to honour Da Ruan's memory

- http://decide.it.uts.edu.au/DaRuan/Da_Ruan.html
- http://www.sckcen.be/fr/Nouvelles/In-Memoriam-Da-Ruan

Singapore). He was a guest Professor at the Dept of Applied Math and Computer Science in Ghent University and at the Dept of Applied Economics in Hasselt University, respectively, in Belgium and an Adjunct Professor in the Faculty of Information Technology at University of Technology, Sydney in Australia. He had recently spent two months at Complutense University of Madrid, under the programme of Distinguished Visitors from this University.

**He will be very sadly missed. His passing poses an irreparable loss to the fuzzy logic research field**

Da Ruan chaired the international conference series FLINS on Applied Computational Intelligence from 1994. A Memorial Da Ruan Best Paper Award at each FLINS edition is expected to be acknowledged from now on.

**He was very energetic, full of brilliant ideas, and always enthusiastic about his research, teaching and collaboration**

A more complete biography, written by his friend and Ph.D. advisor Etienne Kerre, can be found in Fuzzy Sets and Systems 185:1-4 (2011). A Springer book entitled A tribute to Prof. Dr. Da Ruan is expected to appear in 2012.

"Since I have got the sad news about Da my mood has been really down because I have not only lost a brilliant researcher that supported me whenever I needed but also I have lost a close friend that shared me many nice and important moments in my life. I have realized that during more than seven years we have been collaborating Da has been a key factor to my research career. So from these lines I just want to say that I am going to miss him a lot and I will be thankful to him forever. Thanks a lot for being our friend Da."

SCIENTIFIC REPORTS

# Possibility Theory and its Applications: Where Do we Stand?

Didier Dubois and Henri Prade, IRIT-CNRS, Université Paul Sabatier, 31062 Toulouse Cedex 09, France

## Abstract

This paper provides an overview of possibility theory, emphasizing its historical roots and its recent developments. Possibility theory lies at the crossroads between fuzzy sets, probability and non-monotonic reasoning. Possibility theory can be cast either in an ordinal or in a numerical setting. Qualitative possibility theory is closely related to belief revision theory, and common-sense reasoning with exception-tainted knowledge in Artificial Intelligence. Possibilistic logic provides a rich representation setting, which enables the handling of lower bounds of possibility theory measures, while remaining close to classical logic. Qualitative possibility theory has been axiomatically justified in a decision-theoretic framework in the style of Savage, thus providing a foundation for qualitative decision theory. Quantitative possibility theory is the simplest framework for statistical reasoning with imprecise probabilities. As such it has close connections with random set theory and confidence intervals, and can provide a tool for uncertainty propagation with limited statistical or subjective information.

## 1. Introduction

Possibility theory is an uncertainty theory devoted to the handling of incomplete information. To a large extent, it is comparable to probability theory because it is based on set-functions. It differs from the latter by the use of a pair of dual set functions (possibility and necessity measures) instead of only one. Besides, it is not additive and makes sense on ordinal structures. The name "Theory of Possibility" was coined by Zadeh [142], who was inspired by a paper by Gaines and Kohout [91]. In Zadeh's view, possibility distributions were meant to provide a graded semantics to natural language statements. However, possibility and necessity measures can also be the basis of a full-fledged representation of partial belief that parallels probability. It can be seen either as a coarse, non-numerical version of probability theory, or a framework for reasoning with extreme probabilities, or yet a simple approach to reasoning with imprecise probabilities [74].

After reviewing pioneering contributions to possibility theory, we recall its basic concepts and present the two main directions along which it has developed: the qualitative and quantitative settings. Both approaches share the same basic "maxitivity" axiom. They differ when it comes to conditioning, and to independence notions. Then we discuss prospective lines of research in the area.

## 2. Historical Background

Zadeh was not the first scientist to speak about formalising notions of possibility. The modalities *possible* and *necessary* have been used in philosophy at least since the Middle-Ages in Europe, based on Aristotle's and Theophrastus' works [22]. More recently they became the building blocks of Modal Logics that emerged at the beginning of the XXth century from the works of C.I. Lewis (see Hughes and Cresswell [31]). In this approach, possibility and necessity are all-or-nothing notions, and handled at the syntactic level. More recently, and independently from Zadeh's view, the notion of possibility, as opposed to probability, was central in the works of one economist, and in those of two philosophers.

**G. L. S. Shackle** A graded notion of possibility was introduced as a full-fledged approach to uncertainty and decision in the 1940-1970's by the English economist G. L. S. Shackle [127], who called *degree of potential surprise* of an event its degree of impossibility, that is, the degree of necessity of the opposite event. Shackle's notion of possibility is basically epistemic, it is a "character of the chooser's particular state of knowledge in his present." Impossibility is understood as disbelief. Potential surprise is valued on a disbelief scale, namely a positive interval of the form $[0, y^*]$, where $y^*$ denotes the absolute rejection of the event to which it is assigned. In case everything is possible, all mutually exclusive hypotheses have zero surprise. At least one elementary hypothesis must carry zero potential surprise. The degree of surprise of an event, a set of elementary hypotheses, is the degree of surprise of its least surprising realisation. Shackle also introduces a notion of conditional possibility, whereby the degree of surprise of a conjunction of two events $A$ and $B$ is equal to the maximum of the degree of surprise of $A$, and of the degree of surprise of $B$, should $A$ prove true. The disbelief notion introduced later by Spohn [130] employs the same type of convention as potential surprise, but using the set of natural integers as a disbelief scale; his conditioning rule uses the subtraction of natural integers.

**D. Lewis** In his 1973 book [109] the philosopher David Lewis considers a graded notion of possibility in the form of a relation between possible worlds he calls *comparative possibility*. He equates this concept of possibility to a notion of similarity between possible worlds. This non-symmetric notion of similarity is also comparative, and is meant to express statements of the form: *a world $j$ is at least as similar to world $i$ as world $k$ is.* Comparative similarity of $j$ and $k$ with respect to $i$ is interpreted as the comparative possibility of $j$ with respect to $k$ viewed from world $i$. Such relations are assumed to be complete pre-orderings and are instrumental in defining the truth conditions of counterfactual statements. Comparative

possibility relations $\geq_\Pi$ obey the key axiom: for all events $A, B, C$,

$$A \geq_\Pi B \text{ implies } C \cup A \geq_\Pi C \cup B.$$

This axiom was later independently proposed by the first author [42] in an attempt to derive a possibilistic counterpart to comparative probabilities. Independently, the connection between numerical possibility and similarity was investigated by Sudkamp [131].

**L. J. Cohen** A framework very similar to the one of Shackle was proposed by the philosopher L. J. Cohen [32] who considered the problem of legal reasoning. He introduced so-called *Baconian probabilities* understood as degrees of provability. The idea is that it is hard to prove someone guilty at the court of law by means of pure statistical arguments. The basic feature of degrees of provability is that a hypothesis and its negation cannot both be provable together to any extent (the contrary being a case for inconsistency). Such degrees of provability coincide with necessity measures.

**L. A. Zadeh** In his seminal paper [142] Zadeh proposed an interpretation of membership functions of fuzzy sets as possibility distributions encoding flexible constraints induced by natural language statements. Zadeh articulated the relationship between possibility and probability, noticing that what is probable must preliminarily be possible. However, the view of possibility degrees developed in his paper refers to the idea of graded feasibility (degrees of ease, as in the example of "how many eggs can Hans eat for his breakfast") rather than to the epistemic notion of plausibility laid bare by Shackle. Nevertheless, the key axiom of "maxitivity" for possibility measures is highlighted. In two subsequent articles [143, 144], Zadeh acknowledged the connection between possibility theory, belief functions and upper/lower probabilities, and proposed their extensions to fuzzy events and fuzzy information granules.

## 3. Basic Notions of Possibility Theory

The basic building blocks of possibility theory were first described in the authors' book [62], then more extensively in [67] and [105]. More recent accounts are in [74, 61][1]. Let $S$ be a set of states of affairs (or descriptions thereof), or states for short. A possibility distribution is a mapping $\pi$ from $S$ to a totally ordered scale $L$, with top 1 and bottom 0, such as the unit interval. The function $\pi$ represents the state of knowledge of an agent (about the actual state of affairs) distinguishing what is plausible from what is less plausible, what is the normal course of things from what is not, what is surprising from what is expected. It represents a flexible restriction on what is the actual state with the following conventions (similar to probability, but opposite to Shackle's potential surprise scale):

- $\pi(s) = 0$ means that state $s$ is rejected as impossible;
- $\pi(s) = 1$ means that state $s$ is totally possible (= plausible).

If $S$ is exhaustive, at least one of the elements of $S$ should be the actual world, so that $\exists s, \pi(s) = 1$ (normalisation). Distinct values may simultaneously have a degree of possibility equal to 1.

Possibility theory is driven by the principle of minimal specificity. It states that any hypothesis not known to be impossible cannot be ruled out. A possibility distribution $\pi$ is said to be at least as specific as another $\pi'$ if and only if for each state of affairs $s$: $\pi(s) \leq \pi'(s)$ (Yager [141]). Then, $\pi$ is at least as restrictive and informative as $\pi'$.

In the possibilistic framework, extreme forms of partial knowledge can be captured, namely:

- Complete knowledge: for some $s_0, \pi(s_0) = 1$ and $\pi(s) = 0, \forall s \neq s_0$ (only $s_0$ is possible)
- Complete ignorance: $\pi(s) = 1, \forall s \in S$ (all states are possible).

Given a simple query of the form "does event $A$ occur? where $A$ is a subset of states, the response to the query can be obtained by computing degrees of possibility and necessity, respectively (if the possibility scale $L = [0, 1]$):

$$\Pi(A) = \sup_{s \in A} \pi(s); \; N(A) = \inf_{s \notin A} 1 - \pi(s).$$

$\Pi(A)$ evaluates to what extent $A$ is consistent with $\pi$, while $N(A)$ evaluates to what extent $A$ is certainly implied by $\pi$. The possibility-necessity duality is expressed by $N(A) = 1 - \Pi(A^c)$, where $A^c$ is the complement of $A$. Generally, $\Pi(S) = N(S) = 1$ and $\Pi(\emptyset) = N(\emptyset) = 0$. Possibility measures satisfy the basic "maxitivity" property $\Pi(A \cup B) = \max(\Pi(A), \Pi(B))$. Necessity measures satisfy an axiom dual to that of possibility measures, namely $N(A \cap B) = \min(N(A), N(B))$. On infinite spaces, these axioms must hold for infinite families of sets.

Human knowledge is often expressed in a declarative way using statements to which belief degrees are attached. It corresponds to expressing constraints the world is supposed to comply with. Certainty-qualified pieces of uncertain information of the form "$A$ is certain to degree $\alpha$" can then be modeled by the constraint $N(A) \geq \alpha$. The least specific possibility distribution reflecting this information is [67]:

$$\pi_{(A,\alpha)}(s) = \left\{ \begin{array}{cc} 1, & \text{if } s \in A \\ 1 - \alpha & \text{otherwise} \end{array} \right\} \quad (1)$$

This possibility distribution is a key-building lock to construct possibility distributions. Acquiring further pieces of knowledge leads to updating $\pi_{(A,\alpha)}$ into some $\pi < \pi_{(A,\alpha)}$.

Apart from $\Pi$ and $N$, a measure of *guaranteed possibility* can be defined [71, 54] : $\Delta(A) = \inf_{s \in A} \pi(s)$. It estimates to what extent *all* states in $A$ are actually possible according to evidence. $\Delta(A)$ can be used as a degree of evidential support for $A$. Uncertain statements of the form "$A$ is possible to degree $\beta$" often mean that all realizations of $A$ are possible to degree $\beta$. They can then be modeled by the constraint $\Delta(A) \geq \beta$. It corresponds to the idea of observed evidence. This type of information is better

[1] See also *http://www.scholarpedia.org/article/Possibility_theory*.

exploited by assuming an informational principle opposite to the one of minimal specificity, namely, any situation not yet observed is tentatively considered as impossible. This is similar to closed-world assumption. The most specific distribution $\delta_{(A,\beta)}$ in agreement with $\Delta(A) \geq \beta$ is :

$$\delta_{(A,\beta)}(s) = \left\{ \begin{array}{cc} \beta, & \text{if } s \in A \\ 0 & \text{otherwise.} \end{array} \right\}$$

Acquiring further pieces of evidence leads to updating $\delta_{(A,\beta)}$ into some wider distribution $\delta > \delta_{(A,\beta)}$. Such evidential support functions do not behave with the same conventions as possibility distributions: $\delta(s) = 1$ means that $S$ is guaranteed to be possible, because of a high evidential support, while $\delta(s) = 0$ only means that $S$ has not been observed yet (hence is of unknown possibility). Distributions $\delta$ are generally not normalised to 1, and serve as lower bounds to possibility distributions $\pi$ (because what is observed must be possible). Such a bipolar representation of information using pairs $(\delta, \pi)$ may provide a natural interpretation of interval-valued fuzzy sets [77]. Note that possibility distributions induced from certainty-qualified pieces of knowledge combine conjunctively, by discarding possible states, while evidential support distributions induced by possibility-qualified pieces of evidence combine disjunctively, by accumulating possible states.

Possibility theory has enabled a typology of fuzzy rules to be laid bare, distinguishing rules whose purpose is to propagate uncertainty through reasoning steps, from rules whose main purpose is similarity-based interpolation [72], depending on the choice of a many-valued implication connective that models a rule. The bipolar view of information based on $(\delta, \pi)$ pairs sheds new light on the debate between conjunctive and implicative representation of rules [88]. Representing a rule as a material implication focuses on counterexamples to rules, while using a conjunction between antecedent and consequent points out examples of the rule and highlights its positive content. Traditionally in fuzzy control and modelling, the latter representation is adopted, while the former is the logical tradition. Introducing fuzzy implicative rules in modelling accounts for constraints or landmark points the model should comply with (as opposed to observed data) [93]. The bipolar view of rules in terms of examples and counterexamples may turn out to be very useful when extracting fuzzy rules from data [57].

Notions of conditioning and independence were studied for possibility measures. Conditional possibility is defined similarly to probability theory using a Bayesian-like equation of the form [67]

$$\Pi(B \cap A) = \Pi(B \mid A) \star \Pi(A).$$

However, in the ordinal setting the operation $\star$ cannot be a product and is changed into the minimum. In the numerical setting, there are several ways to define conditioning, not all of which have this form, as seen later in this paper. There are also several variants of possibilistic independence [35, 34, 46]. Generally, independence in possibility theory is neither symmetric, nor insensitive to negation. For Boolean variables, independence between events is not equivalent to independence between variables.

An important example of a possibility distribution is the fuzzy interval, which is a fuzzy set of the real line whose cuts are intervals [62, 67]. The calculus of fuzzy intervals is an extension of interval arithmetics based on a possibilistic counterpart of a computation of random variable. To compute the addition of two fuzzy intervals $A$ and $B$ one has to compute the membership function of $A \oplus B$ as the degree of possibility $\mu_{A\oplus B}(z) = \Pi(\{(x, y) : x + y = z\})$, based on the possibility distribution $\min(\mu_A(x), \mu_B(y))$. There is a large literature on possibilistic interval analysis; see [58] for a survey of XXth century references.

## 4. Qualitative Possibility Theory

This section is restricted to the case of a finite state space $S$, supposed to be the set of interpretations of a formal propositional language. In other words, $S$ is the universe induced by Boolean attributes. A plausibility ordering is a complete pre-order of states denoted by $\geq_\pi$, which induces a well-ordered partition $\{E_1, \cdots, E_n\}$ of $S$. It is the comparative counterpart of a possibility distribution $\pi$, i.e., $s \geq_\pi s'$ if and only if $\pi(s) \geq \pi(s')$. Indeed it is more natural to expect that an agent will supply ordinal rather than numerical information about his beliefs. By convention $E_1$ contains the most normal states of fact, $E_n$ the least plausible, or most surprising ones. Denoting by $\max(A)$ any most plausible state $s_0 \in A$, ordinal counterparts of possibility and necessity measures [42] are then defined as follows: $\{s\} \geq_\Pi \emptyset$ for all $s \in S$ and

$$A \geq_\Pi B \text{ if and only if } \max(A) \geq_\pi \max(B)$$

$$A \geq_N B \text{ if and only if } \max(B^c) \geq_\pi \max(A^c).$$

Possibility relations $\geq_\Pi$ are those of Lewis [109] and satisfy his characteristic property

$$A \geq_\Pi B \text{ implies } C \cup A \geq_\Pi C \cup B$$

while necessity relations can also be defined as $A \geq_N B$ if and only if $B^c \geq_\Pi A^c$, and satisfy a similar axiom:

$$A \geq_N B \text{ implies } C \cap A \geq_N C \cap B.$$

The latter coincide with epistemic entrenchment relations in the sense of belief revision theory [92, 69]. Conditioning a possibility relation $\geq_\Pi$ by an non-impossible event $C >_\Pi \emptyset$ means deriving a relation $\geq_\Pi^C$ such that

$$A \geq_\Pi^C B \text{ if and only if } A \cap C \geq_\Pi B \cap C.$$

The notion of independence for comparative possibility theory was studied in Dubois et al. [46], for independence between events, and Ben Amor et al. [11] between variables.

### 4.1 Nonmonotonic Inference

Suppose $S$ is equipped with a plausibility ordering. The main idea behind qualitative possibility theory is that the state of the world is always believed to be as normal as possible, neglecting less normal states. $A \geq_\Pi B$ really means that there is a normal state where $A$ holds that is at least as normal as any normal state where $B$ holds. The dual case $A \geq_N B$ is intuitively understood as "$A$ is at least as certain as $B$", in the sense that there are states

where $B$ fails to hold that are at least as normal as the most normal state where $A$ does not hold. In particular, the events accepted as true are those which are true in all the most plausible states, namely the ones such that $A >_N \emptyset$. These assumptions lead us to interpret the plausible inference $A \mid\approx B$ of a proposition $B$ from another $A$, under a state of knowledge $\geq_\Pi$ as follows: $B$ *should be true in all the most normal states were* $A$ *is true*, which means $B >_\Pi^A B^c$ in terms of ordinal conditioning, that is, $A \cap B$ is more plausible than $A \cap B^c$. $A \mid\approx B$ also means that the agent considers $B$ as an accepted belief in the context $A$.

This kind of inference is nonmonotonic in the sense that $A \mid\approx B$ does not always imply $A \cap C \mid\approx B$ for any additional information $C$. This is similar to the fact that a conditional probability $P(B \mid A \cap C)$ may be low even if $P(B \mid A)$ is high. The properties of the consequence relation $\mid\approx$ are now well-understood, and are precisely the ones laid bare by Lehmann and Magidor [108] for their so-called "rational inference". Monotonicity is only partially restored: $A \mid\approx B$ implies $A \cap C \mid\approx B$ holds provided that $A \mid\approx C^c$ does not hold (i.e. that states were $A$ is true do not typically violate $C$). This property is called *rational monotony*, and, along with some more standard ones (like closure under conjunction), characterizes default possibilistic inference $\mid\approx$. In fact, the set $\{B, A \mid\approx B\}$ of accepted beliefs in the context $A$ is deductively closed, which corresponds to the idea that the agent reasons with accepted beliefs in each context as if they were true, until some event occurs that modifies this context. This closure property is enough to justify a possibilistic approach [52] and adding the rational monotonicity property ensures the existence of a single possibility relation generating the consequence relation $\mid\approx$[15]. Possibility theory has been studied from the point of view of cognitive psychology. Experimental results [124] suggest that there are situations where people reason about uncertainty using the rules or possibility theory, rather than with those of probability theory.

Plausibility orderings can be generated by a set of if-then rules tainted with unspecified exceptions. This set forms a knowledge base supplied by an agent. Each rule "if $A$ then $B$" is understood as a constraint of the form $A \cap B >_\Pi A \cap B^c$ on possibility relations. There exists a single minimally specific element in the set of possibility relations satisfying all constraints induced by rules (unless the latter are inconsistent). It corresponds to the most compact plausibility ranking of states induced by the rules [15]. This ranking can be computed by an algorithm originally proposed by Pearl [118].

## 4.2 Possibilistic Logic

Qualitative possibility relations can be represented by (and only by) possibility measures ranging on any totally ordered set $L$ (especially a finite one) [42]. This absolute representation on an ordinal scale is slightly more expressive than the purely relational one. When the finite set $S$ is large and generated by a propositional language, qualitative possibility distributions can be efficiently encoded in possibilistic logic [90, 59, 75]. A possibilistic logic base $K$ is a set of pairs $(\phi, \alpha)$, where $\phi$ is a Boolean expression and $\alpha$ is an element of $L$. This pair encodes the constraint $N(\phi) \geq \alpha$ where $N(\phi)$ is the degree of necessity of the set of models of $\phi$. Each prioritized formula $(\phi, \alpha)$ has a fuzzy set of models (described in Section 3) and the fuzzy intersection of the fuzzy sets of models of all prioritized formulas in $K$ yields the associated plausibility ordering on $S$.

Syntactic deduction from a set of prioritized clauses is achieved by refutation using an extension of the standard resolution rule, whereby $(\phi \vee \psi, \min(\alpha, \beta))$ can be derived from $(\phi \vee \xi, \alpha)$ and $(\psi \vee \neg\xi, \beta)$. This rule, which evaluates the validity of an inferred proposition by the validity of the weakest premiss, goes back to Theophrastus, a disciple of Aristotle. Possibilistic logic is an inconsistency-tolerant extension of propositional logic that provides a natural semantic setting for mechanizing non-monotonic reasoning [17], with a computational complexity close to that of propositional logic.

Another compact representation of qualitative possibility distributions is the possibilistic directed graph, which uses the same conventions as Bayesian nets, but relies on an ordinal notion of conditional possibility [67]

$$\Pi(B \mid A) = \left\{ \begin{array}{cc} 1, & \text{if } \Pi(B \cap A) = \Pi(A) \\ \Pi(B \cap A) & \text{otherwise.} \end{array} \right\}$$

Joint possibility distributions can be decomposed into a conjunction of conditional possibility distributions (using minimum) in a way similar to Bayes nets [14]. It is based on a symmetric notion of qualitative independence $\Pi(B \cap A) = \min(\Pi(A), \Pi(B))$ that is weaker than the causal-like condition $\Pi(B \mid A) = \Pi(B)$ [46]. Ben Amor and Benferhat [12] investigate the properties of qualitative independence that enable local inferences to be performed in possibilistic nets. Uncertainty propagation algorithms suitable for possibilistic graphical structures have been studied [13].

Other types of possibilistic logic can also handle constraints of the form $\Pi(\phi) \geq \alpha$, or $\Delta(\phi) \geq \alpha$ [75]. Possibilistic logic can be extended to logic programming [1, 10], similarity reasoning [2], and many-valued logic as extensively studied by Godo and colleagues [38].

## 4.3 Decision-theoretic foundations

Zadeh [142] hinted that "since our intuition concerning the behaviour of possibilities is not very reliable", our understanding of them "would be enhanced by the development of an axiomatic approach to the definition of subjective possibilitiesÉ in the spirit of axiomatic approaches to the definition of subjective probabilities". Decision-theoretic justifications of qualitative possibility were devised, in the style of Savage [125] more than 10 years ago. On top of the set of states, assume there is a set $X$ of consequences of decisions. A decision, or act, is modeled as a mapping $f$ from $S$ to $X$ assigning to each state $S$ its consequence $f(s)$. The axiomatic approach consists in proposing properties of a preference relation $\succeq$ between acts so that a representation of this relation by means of a preference functional $W(f)$ is ensured, that is, act $f$ is as good as act $g$ (denoted $f \succeq g$) if and only if $W(f) \geq W(g)$. $W(f)$ depends on the agent's knowledge about the state of affairs, here supposed to be a possibility distribution $\pi$ on $S$, and the agent's goal, modeled by a utility function

$u$ on $X$. Both the utility function and the possibility distribution map to the same finite chain $L$. A pessimistic criterion $W_\pi^-(f)$ is of the form:

$$W_\pi^-(f) = \min_{s\in S} \max(n(\pi(s)), u(f(s)))$$

where $n$ is the order-reversing map of $L$. $n(\pi(s))$ is the degree of certainty that the state is not $s$ (hence the degree of surprise of observing $s$), $u(f(s))$ the utility of choosing act $f$ in state $s$. $W_\pi^-(f)$ is all the higher as all states are either very surprising or have high utility. This criterion is actually a prioritized extension of the Wald maximin criterion. The latter is recovered if $\pi(s) = 1$ (top of $L$) $\forall s \in S$. According to the pessimistic criterion, acts are chosen according to their worst consequences, restricted to the most plausible states $S^* = \{s, \pi(s) \geq n(W_\pi^-(f))\}$. The optimistic counterpart of this criterion is:

$$W_\pi^+(f) = \max_{s\in S} \min(\pi(s)), u(f(s))).$$

$W_\pi^+(f)$ is all the higher as there is a very plausible state with high utility. The optimistic criterion was first proposed by Yager [139] and the pessimistic criterion by Whalen [138]. These optimistic and pessimistic possibilistic criteria are particular cases of a more general criterion based on the Sugeno integral [97] specialized to possibility and necessity of fuzzy events [142, 62]:

$$S_{\gamma,u}(f) = \max_{\lambda\in L} \min(\lambda, \gamma(F_\lambda))$$

where $F_\lambda = \{s \in S, u(f(s)) \geq \lambda\}$, $\gamma$ is a monotonic set function that reflects the decision-maker attitude in front of uncertainty: $\gamma(A)$ is the degree of confidence in event $A$. If $\gamma = \Pi$, then $S_{\Pi,u}(f) = W_\pi^+(f)$. Similarly, if $\gamma = N$, then $S_{N,u}(f) = W_\pi^-(f)$.

For any acts $f, g$, and any event $A$, let $fAg$ denote an act consisting of choosing $f$ if $A$ occurs and $g$ if its complement occurs. Let $f \wedge g$ (resp. $f \vee g$) be the act whose results yield the worst (resp. best) consequence of the two acts in each state. Constant acts are those whose consequence is fixed regardless of the state. A result in [82, 83] provides an act-driven axiomatization of these criteria, and enforces possibility theory as a "rational representation of uncertainty for a finite state space $S$:

**Theorem 1** *Suppose the preference relation $\succeq$ on acts obeys the following properties:*

1. *$(X^S, \succeq)$ is a complete preorder.*
2. *There are two acts such that $f \succ g$.*
3. *$\forall A, \forall g$ and $h$ constant, $\forall f, g \succeq h$ implies $gAf \succeq hAf$.*
4. *If $f$ is constant, $f \succ h$ and $g \succ h$ imply $f \wedge g \succ h$.*
5. *If $f$ is constant, $h \succ f$ and $h \succ g$ imply $h \succ f \vee g$.*

*then there exists a finite chain $L$, an $L$-valued monotonic set-function $\gamma$ on $S$ and an $L$-valued utility function $u$, such that $\succeq$ is representable by a Sugeno integral of $u(f)$ with respect to $\gamma$. Moreover $\gamma$ is a necessity (resp. possibility) measure as soon as property (4) (resp. (5)) holds for all acts. The preference functional is then $W_\pi^-(f)$ (resp. $W_\pi^+(f)$).*

Axioms (4-5) contradict expected utility theory. They become reasonable if the value scale is finite, decisions are one-shot (no compensation) and provided that there is a big step between any level in the qualitative value scale and the adjacent ones. In other words, the preference pattern $f \succ h$ always means that $f$ is significantly preferred to $h$, to the point of considering the value of $h$ negligible in front of the value of $f$. The above result provides decision-theoretic foundations of possibility theory, whose axioms can thus be tested from observing the choice behavior of agents. See [49] for another approach to comparative possibility relations, more closely relying on Savage axioms, but giving up any comparability between utility and plausibility levels. The drawback of these and other qualitative decision criteria is their lack of discrimination power [47]. To overcome it, refinements of possibilistic criteria were recently proposed, based on lexicographic schemes [89]. These new criteria turn out to be representable by a classical (but big-stepped) expected utility criterion. Qualitative possibilistic counterparts of influence diagrams for decision trees have been recently investigated [98].

More recently, possibilistic qualitative bipolar decision criteria have been defined, axiomatized [48] and empirically tested [23]. They are qualitative counterparts of cumulative prospect theory criteria of Kahneman and Tverski [133].

## 5. Quantitative Possibility Theory

The phrase "quantitative possibility" refers to the case when possibility degrees range in the unit interval. In that case, a precise articulation between possibility and probability theories is useful to provide an interpretation to possibility and necessity degrees. Several such interpretations can be consistently devised: a degree of possibility can be viewed as an upper probability bound [70], and a possibility distribution can be viewed as a likelihood function [60]. A possibility measure is also a special case of a Shafer plausibility function [126]. Following a very different approach, possibility theory can account for probability distributions with extreme values, infinitesimal [130] or having big steps [16]. There are finally close connections between possibility theory and idempotent analysis [113]. The theory of large deviations in probability theory [123] also handles set-functions that look like possibility measures [117]. Here we focus on the role of possibility theory in the theory of imprecise probability.

### 5.1 Possibility as upper probability

Let $\pi$ be a possibility distribution where $\pi(s) \in [0, 1]$. Let $\mathbf{P}(\pi)$ be the set of probability measures $P$ such that $P \leq \Pi$, i.e. $\forall A \subseteq S, P(A) \leq \Pi(A)$. Then the possibility measure $\Pi$ coincides with the upper probability function $P^*$ such that $P^*(A) = \sup\{P(A), P \in \mathbf{P}(\pi)\}$ while the necessity measure $N$ is the lower probability function $P_*$ such that $P_*(A) = \inf\{P(A), P \in \mathbf{P}(\pi)\}$ ; see [70, 36] for details. $P$ and $\pi$ are said to be consistent if $P \in \mathbf{P}(\pi)$. The connection between possibility measures and imprecise probabilistic reasoning is especially promising for the

efficient representation of non-parametric families of probability functions, and it makes sense even in the scope of modeling linguistic information [136].

A possibility measure can be computed from nested confidence subsets $\{A_1, A_2, \ldots, A_m\}$ where $A_i \subset A_{i+1}, i = 1 \ldots m-1$. Each confidence subset $A_i$ is attached a positive confidence level $\lambda_i$ interpreted as a lower bound of $P(A_i)$, hence a necessity degree. It is viewed as a certainty-qualified statement that generates a possibility distribution $\pi_i$ according to Section 3. The corresponding possibility distribution is

$$\pi(s) = \min_{i=1,\ldots,m} \pi_i(s) = \left\{ \begin{array}{cc} 1 & \text{if } u \in A_1 \\ 1-\lambda_{j-1} & \text{if } j = \max\{i : s \notin A_i\} > 1 \end{array} \right\}$$

The information modeled by $\pi$ can also be viewed as a nested random set $\{(A_i, \nu_i), i = 1, \ldots, m\}$, where $\nu_i = \lambda_i - \lambda_{i-1}$. This framework allows for imprecision (reflected by the size of the $A_i$'s) and uncertainty (the $\nu_i$'s). And $\nu_i$ is the probability that the agent only knows that $A_i$ contains the actual state (it is not $P(A_i)$). The random set view of possibility theory is well adapted to the idea of imprecise statistical data, as developed in [94, 103]. Namely, given a bunch of imprecise (not necessarily nested) observations (called focal sets), $\pi$ supplies an approximate representation of the data, as $\pi(s) = \sum_{i:s\in A_i} \nu_i$.

The set $\mathbf{P}(\pi)$ contains many probability distributions, arguably too many. Neumaier [116] has recently proposed a related framework, in a different terminology, for representing smaller subsets of probability measures using two possibility distributions instead of one. He basically uses a pair of distributions $(\delta, \pi)$ (in the sense of Section 3) of distributions, he calls "cloud", where $\delta$ is a guaranteed possibility distribution (in our terminology) such that $\pi \geq \delta$. A cloud models the (generally non-empty) set $\mathbf{P}(\pi) \cap \mathbf{P}(1-\delta)$, viewing $1-\delta$ as a standard possibility distribution. The precise connections between possibility distributions, clouds and other simple representations of numerical uncertainty is studied in [39].

## 5.2 Conditioning

There are two kinds of conditioning that can be envisaged upon the arrival of new information $E$. The first method presupposes that the new information alters the possibility distribution $\pi$ by declaring all states outside $E$ impossible. The conditional measure $\pi(. \mid E)$ is such that $\Pi(B \mid E) \cdot \Pi(E) = \Pi(B \cap E)$. This is formally Dempster rule of conditioning of belief functions, specialised to possibility measures. The conditional possibility distribution representing the weighted set of confidence intervals is,

$$\pi(s \mid E) = \left\{ \begin{array}{cc} \frac{\pi(s)}{\Pi(E)}, & \text{if } s \in E \\ 0 & \text{otherwise.} \end{array} \right\}$$

De Baets et al. [33] provide a mathematical justification of this notion in an infinite setting, as opposed to the min-based conditioning of qualitative possibility theory. Indeed, the maxitivity axiom extended to the infinite setting is not preserved by the min-based conditioning. The product-based conditioning leads to a notion of independence of the form $\Pi(B \cap E) = \Pi(B) \cdot \Pi(E)$ whose properties are very similar to the ones of probabilistic independence [34].

Another form of conditioning [73, 37], more in line with the Bayesian tradition, considers that the possibility distribution $\pi$ encodes imprecise statistical information, and event $E$ only reflects a feature of the current situation, not of the state in general. Then the value $\Pi(B \mid\mid E) = \sup\{P(B \mid E), P(E) > 0, P \leq \Pi\}$ is the result of performing a sensitivity analysis of the usual conditional probability over $\mathbf{P}(\pi)$ (Walley [135]). Interestingly, the resulting set-function is again a possibility measure, with distribution

$$\pi(s \mid\mid E) = \left\{ \begin{array}{cc} \max(\pi(s), \frac{\pi(s)}{\pi(s)+N(E)}), & \text{if } s \in E \\ 0 & \text{otherwise.} \end{array} \right\}$$

It is generally less specific than $\pi$ on $E$, as clear from the above expression, and becomes non-informative when $N(E) = 0$ (i.e. if there is no information about $E$). This is because $\pi(\cdot \mid\mid E)$ is obtained from the focusing of the generic information $\pi$ over the reference class $E$. On the contrary, $\pi(\cdot \mid E)$ operates a revision process on $\pi$ due to additional knowledge asserting that states outside $E$ are impossible. See De Cooman [37] for a detailed study of this form of conditioning.

## 5.3 Probability-possibility transformations

The problem of transforming a possibility distribution into a probability distribution and conversely is meaningful in the scope of uncertainty combination with heterogeneous sources (some supplying statistical data, other linguistic data, for instance). It is useful to cast all pieces of information in the same framework. The basic requirement is to respect the consistency principle $\Pi \geq P$. The problem is then either to pick a probability measure in $\mathbf{P}(\pi)$, or to construct a possibility measure dominating $P$.

There are two basic approaches to possibility/probability transformations, which both respect a form of probability-possibility consistency. One, due to Klir [106, 96] is based on a principle of information invariance, the other [84] is based on optimizing information content. Klir assumes that possibilistic and probabilistic information measures are commensurate. Namely, the choice between possibility and probability is then a mere matter of translation between languages "neither of which is weaker or stronger than the other (quoting Klir and Parviz [107]). It suggests that entropy and imprecision capture the same facet of uncertainty, albeit in different guises. The other approach, recalled here, considers that going from possibility to probability leads to increase the precision of the considered representation (as we go from a family of nested sets to a random element), while going the other way around means a loss of specificity.

**From possibility to probability** The most basic example of transformation from possibility to probability is the Laplace principle of insufficient reason claiming that what is equally possible should be considered as equally probable. A generalised Laplacean indifference principle is then adopted in the general case of a possibility distribution $\pi$: the weights $\nu_i$ bearing the sets $A_i$ from the nested

family of levels cuts of $\pi$ are uniformly distributed on the elements of these cuts $A_i$. Let $P_i$ be the uniform probability measure on $A_i$. The resulting probability measure is $P = \sum_{i=1,\ldots,m} \nu_i \cdot P_i$. This transformation, already proposed in 1982 [63] comes down to selecting the center of gravity of the set $\mathbf{P}(\pi)$ of probability distributions dominated by $\pi$. This transformation also coincides with Smets' pignistic transformation [129] and with the Shapley value of the "unamimity game" (another name of the necessity measure) in game theory. The rationale behind this transformation is to minimize arbitrariness by preserving the symmetry properties of the representation. This transformation from possibility to probability is one-to-one. Note that the definition of this transformation does not use the nestedness property of cuts of the possibility distribution. It applies all the same to non-nested random sets (or belief functions) defined by pairs $\{(A_i, \nu_i), i = 1, \ldots, m\}$, where $\nu_i$ are non-negative reals such that $\sum_{i=1,\ldots,m} \nu_i = 1$.

**From objective probability to possibility** From probability to possibility, the rationale of the transformation is not the same according to whether the probability distribution we start with is subjective or objective [86]. In the case of a statistically induced probability distribution, the rationale is to preserve as much information as possible. This is in line with the handling of $\Delta$-qualified pieces of information representing observed evidence, considered in section 3; hence we select as the result of the transformation of a probability measure $P$, the most specific possibility measure in the set of those dominating $P$ [84]. This most specific element is generally unique if $P$ induces a linear ordering on $S$. Suppose $S$ is a finite set. The idea is to let $\Pi(A) = P(A)$, for these sets $A$ having minimal probability among other sets having the same cardinality as $A$. If $p_1 > p_2 > \cdots > p_n$, then $\Pi(A) = P(A)$ for sets $A$ of the form $\{s_i, \ldots, s_n\}$, and the possibility distribution is defined as $\pi_P(s_i) = \sum_{j=i,\ldots,m} p_j$, with $p_j = P(\{s_j\})$. Note that $\pi_P$ is a kind of cumulative distribution of $P$, already known as a Lorentz curve in the mathematical literature [112]. If there are equiprobable elements, the unicity of the transformation is preserved if equipossibility of the corresponding elements is enforced. In this case it is a bijective transformation as well. Recently, this transformation was used to prove a rather surprising agreement between probabilistic indeterminateness as measured by Shannon entropy, and possibilistic non-specificity. Namely it is possible to compare probability measures on finite sets in terms of their relative *peakedness* (a concept adapted from Birnbaum [21]) by comparing the relative specificity of their possibilistic transforms. Namely let $P$ and $Q$ be two probability measures on $S$ and $\pi_P$, $\pi_Q$ the possibility distributions induced by our transformation. It can be proved that if $\pi_P \geq \pi_Q$ (i.e. $P$ is less peaked than $Q$) then the Shannon entropy of $P$ is higher than the one of $Q$ [55]. This result give some grounds to the intuitions developed by Klir [106], without assuming any commensurability between entropy and specificity indices.

**Possibility distributions induced by prediction intervals** In the continuous case, moving from objective probability to possibility means adopting a representation of uncertainty in terms of prediction intervals around the mode viewed as the "most frequent value". Extracting a prediction interval from a probability distribution or devising a probabilistic inequality can be viewed as moving from a probabilistic to a possibilistic representation. Namely suppose a non-atomic probability measure $P$ on the real line, with unimodal density $p$, and suppose one wishes to represent it by an interval $I$ with a prescribed level of confidence $P(I) = \gamma$ of hitting it. The most natural choice is the most precise interval ensuring this level of confidence. It can be proved that this interval is of the form of a cut of the density, i.e. $I_\gamma = \{s, p(s) \geq \theta\}$ for some threshold $\theta$. Moving the degree of confidence from 0 to 1 yields a nested family of prediction intervals that form a possibility distribution $\pi$ consistent with $P$, the most specific one actually, having the same support and the same mode as $P$ and defined by ([84]):

$$\pi(\inf I_\gamma) = \pi(\sup I_\gamma) = 1 - \gamma = 1 - P(I_\gamma)$$

This kind of transformation again yields a kind of cumulative distribution according to the ordering induced by the density $p$. Similar constructs can be found in the statistical literature (Birnbaum [21]). More recently Mauris et al. [81] noticed that starting from any family of nested sets around some characteristic point (the mean, the median,...), the above equation yields a possibility measure dominating $P$. Well-known inequalities of probability theory, such as those of Chebyshev and Camp-Meidel, can also be viewed as possibilistic approximations of probability functions. It turns out that for symmetric unimodal densities, each side of the optimal possibilistic transform is a convex function. Given such a probability density on a bounded interval $[a, b]$, the triangular fuzzy number whose core is the mode of $p$ and the support is $[a, b]$ is thus a possibility distribution dominating $P$ regardless of its shape (and the tightest such distribution). These results justify the use of symmetric triangular fuzzy numbers as fuzzy counterparts to uniform probability distributions. They provide much tighter probability bounds than Chebyshev and Camp-Meidel inequalities for symmetric densities with bounded support. This setting is adapted to the modelling of sensor measurements [115]. These results are extended to more general distributions by Baudrit et al., [7], and provide a tool for representing poor probabilistic information. More recently, Mauris [114] unifies, by means of possibility theory, many old techniques independently developed in statistics for one-point estimation, relying on the idea of dispersion of an empirical distribution. The efficiency of different estimators can be compared by means of fuzzy set inclusion applied to optimal possibility transforms of probability distributions. This unified approach does not presuppose a finite variance.

**Subjective possibility distributions** The case of a subjective probability distribution is different. Indeed, the probability function is then supplied by an agent who is in some sense forced to express beliefs in this form due to rationality constraints, and the setting of exchangeable bets. However his actual knowledge may be far from

justifying the use of a single well-defined probability distribution. For instance in case of total ignorance about some value, apart from its belonging to an interval, the framework of exchangeable bets enforces a uniform probability distribution, on behalf of the principle of insufficient reason. Based on the setting of exchangeable bets, it is possible to define a subjectivist view of numerical possibility theory, that differs from the proposal of Walley [135]. The approach developed by Dubois, Prade and Smets [87] relies on the assumption that when an agent constructs a probability measure by assigning prices to lotteries, this probability measure is actually induced by a belief function representing the agent$\tilde{O}$s actual state of knowledge. We assume that going from an underlying belief function to an elicited probability measure is achieved by means of the above mentioned pignistic transformation, changing focal sets into uniform probability distributions. The task is to reconstruct this underlying belief function under a minimal commitment assumption. In the paper [87], we pose and solve the problem of finding the least informative belief function having a given pignistic probability. We prove that it is unique and consonant, thus induced by a possibility distribution. The obtained possibility distribution can be defined as the converse of the pignistic transformation (which is one-to-one for possibility distributions). It is subjective in the same sense as in the subjectivist school in probability theory. However, it is the least biased representation of the agent$\tilde{O}$s state of knowledge compatible with the observed betting behaviour. In particular it is less specific than the one constructed from the prediction intervals of an objective probability. This transformation was first proposed in [64] for objective probability, interpreting the empirical necessity of an event as summing the excess of probabilities of realizations of this event with respect to the probability of the most likely realization of the opposite event.

**Possibility theory and defuzzification** Possibilistic mean values can be defined using Choquet integrals with respect to possibility and necessity measures [65, 37], and come close to defuzzification methods [134]. A fuzzy interval is a fuzzy set of reals whose membership function is unimodal and upper-semi continuous. Its $\alpha$-cuts are closed intervals. Interpreting a fuzzy interval $M$, associated to a possibility distribution $\mu_M$, as a family of probabilities, upper and lower mean values $E^*(M)$ and $E_*(M)$, can be defined as [66]:

$$E_*(M) = \int_0^1 \inf M_\alpha d\alpha; \quad E^*(M) = \int_0^1 \sup M_\alpha d\alpha$$

where $M_\alpha$ is the $\alpha$-cut of $M$.

Then the mean interval $E(M) = [E_*(M), E^*(M)]$ of $M$ is the interval containing the mean values of all random variables consistent with $M$, that is $E(M) = \{E(P) \mid P \in \mathbf{P}(\mu_M)\}$, where $E(P)$ represents the expected value associated to the probability measure $P$. That the "mean value" of a fuzzy interval is an interval seems to be intuitively satisfactory. Particularly the mean interval of a (regular) interval $[a, b]$ is this interval itself. The upper and lower mean values are linear with respect to the addition of fuzzy numbers. Define the addition $M+N$ as the fuzzy interval whose cuts are $M_\alpha + N_\alpha = \{s+t, s \in M_\alpha, t \in N_\alpha\}$ defined according to the rules of interval analysis. Then $E(M+N) = E(M) + E(N)$, and similarly for the scalar multiplication $E(aM) = aE(M)$, where $aM$ has membership grades of the form $\mu_M(s/a)$ for $a \neq 0$. In view of this property, it seems that the most natural defuzzication method is the middle point $\hat{E}(M)$ of the mean interval (originally proposed by Yager [140]). Other defuzzification techniques do not generally possess this kind of linearity property. $\hat{E}(M)$ has a natural interpretation in terms of simulation of a fuzzy variable [28], and is the mean value of the pignistic transformation of $M$. Indeed it is the mean value of the empirical probability distribution obtained by the random process defined by picking an element $\alpha$ in the unit interval at random, and then an element $s$ in the cut $M_\alpha$ at random.

## 6. Some Applications

Possibility theory has not been the main framework for engineering applications of fuzzy sets in the past. However, on the basis of its connections to symbolic artificial intelligence, to decision theory and to imprecise statistics, we consider that it has significant potential for further applied developments in a number of areas, including some where fuzzy sets are not yet always accepted. Only some directions are pointed out here.

1. Possibility theory also offers a framework for preference modeling in constraint-directed reasoning. Both prioritized and soft constraints can be captured by possibility distributions expressing degrees of feasibility rather than plausibility [51]. Possibility offers a natural setting for fuzzy optimization whose aim is to balance the levels of satisfaction of multiple fuzzy constraints (instead of minimizing an overall cost) [53]. Qualitative decision criteria are particularly adapted to the handling of uncertainty in this setting. Applications of possibility theory-based decision-making can be found in scheduling [50, 128, 29, 30]. Possibility distributions can also model ill-known constraint coefficients in linear and non-linear programming, thus leading to variants of chance-constrained programming [102]. Besides, the possibilistic logic setting provides a compact representation framework for preferences, which is more expressive than the CP-net approach [104].

2. Quantitative possibility theory is the natural setting for a reconciliation between probability and fuzzy sets. An important research direction is the comparison between fuzzy interval analysis [58] and random variable calculations with a view to unifying them [68]. Indeed, a current major concern, in for instance risk analysis studies, is to perform uncertainty propagation under poor data and without independence assumptions (see the papers in the special issue [100]). Finding the potential of possibilistic representations in computing conservative bounds for such probabilistic calculations is certainly a major challenge [99]. Methods for joint propagation of pos-

sibilistic and probabilistic information have been devised [9], based on casting both in a random set setting [6]; the case of probabilistic models with fuzzy interval parameters has also been dealt with [8]. The active area of fuzzy random variables is also connected to this question [95].

Other applications of possibility theory can be found in fields such as data analysis [137, 132, 24], database querying [25], diagnosis [27, 26], belief revision [18], argumentation [4, 3], case-based reasoning [56, 101], learning [120, 121], and information merging [19] (taking advantage of the bipolar representation setting which distinguishes between positive information of the form $\Delta(\phi) \geq \alpha$ and negative information expressing impossibility under the form $N(\phi) \geq \alpha \Leftrightarrow 1 - \Pi(\neg\phi) \geq \alpha$ [20]).

## 7. Some current research lines

A number of on-going works deal with new research lines where possibility theory is central. In the following we outline a few of those:

- *Formal concept analysis*: Formal concept analysis (FCA) studies Boolean data tables relating objects and attributes. The key issue of FCA is to extract so-called concepts from such tables. A concept is a maximal set of objects sharing a maximal number of attributes. The enumeration of such concepts can be carried out via a Galois connection between objects and attributes, and this Galois connection uses operators similar to the $\Delta$ function of possibility theory. Based on this analogy, other correspondences can be laid bare using the three other set-functions of possibility theory [45, 41]. In particular, one of these correspondences detects independent subtables [79]. This approach can be systematized to fuzzy or uncertain versions of formal concept analysis.

- *Generalised possibilistic logic* Possibilistic logic, in its basic version, attaches degrees of necessity to formulas, which turn them into graded modal formulas of the necessity kind. However only conjunction of weighted formulas are allowed. Yet very early we noticed that it makes sense to extend the language towards handing constraints on the degree of possibility of a formula. This requires allowing for negation and disjunctions of necessity-qualified proposition. This extension, still under study [78], puts together the KD modal logic and basic possibilistic logic. Recently it has been shown that non-monotonic logic programing languages can be translated into generalized possibilistic logic, making the meaning of negation by default in rule much more transparent [85]. This move from basic to generalized possibilistic logic also enables further extensions to the multi-agent and the multi-source case [76] to be considered. Besides, it has been recently shown that a Sugeno integral can be also represented in terms of possibilistic logic, which enables us to lay bare the logical description of an aggregation process [80].

- *Qualitative capacities and possibility measures.* While a numerical possibility measure is equivalent to a convex set of probability measures, it turns out that in the qualitative setting, a monotone set-function can be represented by means of a family of possibility measures [5, 43]. This line of research enables qualitative counterparts of results in the study of Choquet capacities in the numerical settings to be established. Especially, a monotone set-function can be seen as the counterpart of a belief function, and various concepts of evidence theory can be adapted to this setting [119]. Sugeno integral can be viewed as a lower possibilistic expectation in the sense of section 4.3 [43]. These results enable the structure of qualitative monotonic set-functions to be laid bare, with possible connection with neighborhood semantics of non-regular modal logics.

- *Regression and kriging* Fuzzy regression analysis is seldom envisaged from the point of view of possibility theory. One exception is the possibilistic regression initiated by Tanaka and Guo [132], where the idea is to approximate precise or set-valued data in the sense of inclusion by means of a set-valued or fuzzy set-valued linear function obtained by making the linear coefficients of a linear function fuzzy. The alternative approach is the fuzzy least squares of Diamond [40] where fuzzy data are interpreted as functions and a crisp distance between fuzzy sets is often used. However, fuzzy data are questionably seen as objective entities [110]. The introduction of possibility theory in regression analysis of fuzzy data comes down to an epistemic view of fuzzy data whereby one tries to construct the envelope of all linear regression results that could have been obtained, had the data been precise[44]. This view has been applied to the kriging problem in geostatistics [111]. Another use of possibility theory consists in exploiting possibility-probability transforms to develop a form of quantile regression on crisp data [122], yielding a fuzzy function that is much more faithful to the data set than what a fuzzified linear function can offer.

# References

[1] T. Alsinet, L. Godo: Towards an automated deduction system for first-order possibilistic logic programming with fuzzy constants. *Int. J. Intell. Syst.*,17, 887-924, 2002.

[2] T. Alsinet, L. Godo: Adding similarity-based reasoning capabilities to a Horn fragment of possibilistic logic with fuzzy constants. *Fuzzy Sets and Systems*, 144, 43-65, 2004.

[3] T. Alsinet, C. Chesñevar, L. Godo, S. Sandri, G. Simari: Formalizing argumentative reasoning in a possibilistic logic programming setting with fuzzy unification. *Int. J. Approx. Reasoning*, 48, 711-729, 2008.

[4] L. Amgoud, H. Prade. Reaching agreement through argumentation: A possibilistic approach. *Proc. of the 9th Int. Conf. on Principles of Knowledge Representation and Reasoning (KR'04)*(Whistler, BC, Canada), AAAI Press, 175-182, 2004.

[5] G. Banon, Constructive decomposition of fuzzy measures in terms of possibility and necessity measures. *Proc. VIth IFSA World Congress*, São Paulo, Brazil, vol. I, 217-220, 1995.

[6] C. Baudrit, I. Couso, D. Dubois. Joint propagation of probability and possibility in risk analysis: Towards a formal framework. *Inter. J. of Approximate Reasoning*, 45, 82-105, 2007.

[7] C. Baudrit, D. Dubois, Practical representations of incomplete probabilistic knowledge *Computational Statistics & Data Analysis*, 51 86-108, 2006.

[8] C. Baudrit, D. Dubois, N. Perrot, Representing parametric probabilistic models tainted with imprecision. *Fuzzy Sets and Systems*, 159, 2008, 1913-1928.

[9] C. Baudrit, D. Guyonnet, D. Dubois, Joint propagation and exploitation of probabilistic and possibilistic information in risk assessment, *IEEE Trans. Fuzzy Systems*, 14, 593-608, 2006.

[10] K. Bauters, S. Schockaert, M. De Cock, D. Vermeir, D., Possibilistic answer set programming revisited. *Proc. 26th Conf. on Uncertainty in Artificial Intelligence (UAI'10)*, Catalina Island, 48-55, 2010.

[11] N. Ben Amor, K. Mellouli, S. Benferhat, D. Dubois, H. Prade, A theoretical framework for possibilistic independence in a weakly ordered setting. *Int. J. Uncert. Fuzz. & Knowl.-B. Syst.* 10, 117-155, 2002.

[12] N. Ben Amor, S. Benferhat, Graphoid properties of qualitative possibilistic independence relations. *Int. J. Uncert. Fuzz. & Knowl.-B. Syst.* 13, 59-97, 2005.

[13] N. Ben Amor, S. Benferhat, K. Mellouli, Anytime propagation algorithm for min-based possibilistic graphs. *Soft Comput.*, 8, 50-161, 2003.

[14] S. Benferhat, D. Dubois, L. Garcia and H. Prade, On the transformation between possibilistic logic bases and possibilistic causal networks. *Int. J. Approximate Reasoning*, 29:135-173, 2002.

[15] S. Benferhat, D. Dubois and H. Prade, Nonmonotonic reasoning, conditional objects and possibility theory, *Artificial Intelligence*, 92: 259-276, 1997.

[16] S. Benferhat, D. Dubois and H. Prade Possibilistic and standard probabilistic semantics of conditional knowledge bases, *J. Logic Comput.*, 9, 873-895, 1999.

[17] S. Benferhat, D. Dubois, and H. Prade, Practical Handling of exception-tainted rules and independence information in possibilistic logic *Applied Intelligence*, 9, 101-127,1998.

[18] S. Benferhat, D. Dubois, H. Prade and M.-A. Williams. A practical approach to revising prioritized knowledge bases,*Studia Logica*, 70, 105-130, 2002.

[19] S. Benferhat, D. Dubois, S. Kaci, H. Prade, Bipolar possibility theory in preference modeling: Representation, fusion and optimal solutions. *Information Fusion*, 7, 135-150, 2006.

[20] S. Benferhat, D. Dubois, S. Kaci, H. Prade, Modeling positive and negative information in possibility theory. *Int. J. Intell. Syst.*, 23, 1094-1118, 2008.

[21] Z.W. Birnbaum On random variables with comparable peakedness. *Ann. Math. Stat.* 19, 76-81, 1948.

[22] I. M. Bocheń, *La Logique de Théophraste*. Librairie de l'Université de Fribourg en Suisse. 1947.

[23] J.-F. Bonnefon, D. Dubois, H. Fargier, S. Leblois, Qualitative heuristics for balancing the pros and the cons, *Theory and Decision*, 65, 71-95, 2008.

[24] C. Borgelt, J. Gebhardt and R. Kruse, Possibilistic graphical models. In G. Della Riccia et al. editors, *Computational Intelligence in Data Mining*, Springer, Wien, pages 51-68, 2000.

[25] P. Bosc and H. Prade, An introduction to the fuzzy set and possibility theory-based treatment of soft queries and uncertain of imprecise databases. In: P. Smets, A. Motro, eds. *Uncertainty Management in Information Systems*, Dordrecht: Kluwer, 285-324, 1997.

[26] S. Boverie et al. Online diagnosis of engine dyno test benches: a possibilistic approach *Proc. 15th. Eur. Conf. on Artificial Intelligence*, Lyon. Amsterdam: IOS Press, 658-662, 2002.

[27] D. Cayrac, D. Dubois and H. Prade, Handling uncertainty with possibility theory and fuzzy sets in a satellite fault diagnosis application. *IEEE Trans. on Fuzzy Systems*, 4, 251-269, 1996.

[28] S. Chanas and M. Nowakowski, Single value simulation of fuzzy variable, *Fuzzy Sets and Systems*, 25, 43-57, 1988.

[29] S. Chanas and P. Zielinski, Critical path analysis in the network with fuzzy activity times, *Fuzzy Sets and Systems*, 122, 195-204, 2001.

[30] S. Chanas, D. Dubois, and P. Zielinski, Necessary criticality in the network with imprecise activity times. *IEEE transactions on Man, Machine and Cybernetics*, 32:393-407, 2002.

[31] B.F. Chellas *Modal Logic, an Introduction*, Cambridge University Press, Cambridge, 1980.

[32] L. J. Cohen, *The Probable and the Provable*. Oxford: Clarendon, 1977.

[33] B. De Baets, E. Tsiporkova and R. Mesiar Conditioning in possibility with strict order norms, *Fuzzy Sets and Systems*, 106, 221-229, 1999.

[34] L.M. De Campos and J.F. Huete. Independence concepts in possibility theory, *Fuzzy Sets and Systems*, 103, 127-152 & 487-506, 1999.

[35] G. De Cooman, Possibility theory. Part I: Measure- and integral-theoretic groundwork; Part II: Conditional possibility; Part III: Possibilistic independence. *Int. J. of General Syst.*, 25: 291-371, 1997.

[36] G. De Cooman and D. Aeyels, Supremum-preserving upper probabilities. *Information Sciences*, 118, 173 -212, 1999.

[37] G. De Cooman, Integration and conditioning in numerical possibility theory. *Annals of Math. and AI*, 32, 87-123, 2001.

[38] P. Dellunde, L. Godo, E. Marchioni: Extending possibilistic logic over Gödel logic. *Int. J. Approx. Reasoning*, 52, 63-75, 2011.

[39] S. Destercke D.Dubois, E. Chojnacki, Unifying practical uncertainty representations Ð Part I: Generalized p-boxes. *Inter. J. of Approximate Reasoning*, 49, 649-663, 2008; Part II: Clouds. *Inter. J. of Approximate Reasoning*, 49, 664-677, 2008.

[40] P. Diamond (1988) Fuzzy least squares. *Information Sciences*, 46, 141-157

[41] Y. Djouadi, H. Prade: Possibility-theoretic extension of derivation operators in formal concept analysis over fuzzy lattices. *Fuzzy Optimization & Decision Making* 10, 287-309, 2011.

[42] D. Dubois, Belief structures, possibility theory and decomposable measures on finite sets. *Computers and AI*, 5, 403-416, 1986.

[43] D. Dubois Fuzzy measures on finite scales as families of possibility measures, *Proc. 7th Conf. of the Europ. Soc. for Fuzzy Logic and Technology (EUSFLAT'11)*, Annecy, Atlantis Press, 822-829, 2011.

[44] D. Dubois Ontic vs. epistemic fuzzy sets in modeling and data processing tasks, *Proc. Inter. Joint Conf. on Computational Intelligence*, Paris, pp. IS13-IS19.

[45] D. Dubois, F. Dupin de Saint-Cyr, H. Prade: A possibility-theoretic view of formal concept analysis. *Fundam. Inform.*, 75, 195-213, 2007.

[46] D. Dubois, L. Farinas del Cerro, A. Herzig and H. Prade, Qualitative relevance and independence: A roadmap, *Proc. of the 15h Inter. Joint Conf. on Artif. Intell.*, Nagoya, 62-67, 1997.

[47] D. Dubois, H. Fargier. Qualitative decision rules under uncertainty. In G. Della Riccia, et al. editors, *Planning Based on Decision Theory*, CISM courses and Lectures 472, Springer Wien, 3-26, 2003.

[48] D. Dubois, H. Fargier, J.-F. Bonnefon. On the qualitative comparison of decisions having positive and negative features. *J. of Artificial Intelligence Research*, AAAI Press, 32, 385-417, 2008.

[49] D. Dubois, H. Fargier, and P. Perny H. Prade, Qualitative decision theory with preference relations and comparative uncertainty: An axiomatic approach. *Artificial Intelligence*, 148, 219-260, 2003.

[50] D. Dubois, H. Fargier and H. Prade: Fuzzy constraints in job-shop scheduling. *J. of Intelligent Manufacturing*, 6:215-234, 1995.

[51] D. Dubois, H. Fargier, and H. Prade, Possibility theory in constraint satisfaction problems: Handling priority, preference and uncertainty. *Applied Intelligence*, 6: 287-309, 1996.

[52] D. Dubois, H. Fargier, and H. Prade, Ordinal and probabilistic representations of acceptance. *J. Artificial Intelligence Research*, 22, 23-56, 2004

[53] D. Dubois and P. Fortemps. Computing improved optimal solutions to max-min flexible constraint satisfaction problems. *Eur. J. of Operational Research*, 118: 95-126, 1999.

[54] D. Dubois, P. Hajek and H. Prade, Knowledge-driven versus data-driven logics. *J. Logic, Lang. and Inform.*, 9: 65–89, 2000.

[55] D. Dubois, E. Huellermeier Comparing probability measures using possibility theory: A notion of relative peakedness. Inter. J. of Approximate Reasoning, 45, 364-385, 2007

[56] D. Dubois, E. Huellermeier and H. Prade. Fuzzy set-based methods in instance-based reasoning, *IEEE Trans. on Fuzzy Systems*, 10, 322-332, 2002.

[57] D. Dubois, E. Huellermeier and H. Prade. A systematic approach to the assessment of fuzzy association rules, *Data Mining and Knowledge Discovery*, 13, 167-192, 2006

[58] D. Dubois, E. Kerre, R. Mesiar, H. Prade, Fuzzy interval analysis. In: D. Dubois and H. Prade, editors, *Fundamentals of Fuzzy Sets*. Boston, Mass: Kluwer, pages 483-581, 2000.

[59] D. Dubois, J. Lang and H. Prade, Possibilistic logic. In D.M. Gabbay, et al, editors, *Handbook of Logic in AI and Logic Programming*, Vol. 3, Oxford University Press, pages 439-513, 1994.

[60] D. Dubois, S. Moral and H. Prade, A semantics for possibility theory based on likelihoods, *J. Math. Anal. Appl.*, 205, 359-380, 1997.

[61] D. Dubois, H.T. Nguyen, H. Prade, Fuzzy sets and probability: misunderstandings, bridges and gaps. In D. Dubois and H. Prade, editors, *Fundamentals of Fuzzy Sets*. Boston, Mass: Kluwer, pages 343-438, 2000

[62] D. Dubois, H. Prade, *Fuzzy Sets and Systems: Theory and Applications*. New York: Academic Press, 1980.

[63] D. Dubois, H. Prade, On several representations of an uncertain body of evidence. In: M. Gupta, E. Sanchez, editors, *Fuzzy Information and Decision Processes*, North-Holland: Amsterdam, pages 167-181,1982.

[64] D. Dubois, H. Prade Unfair coins and necessity measures: a possibilistic interpretation of histograms, *Fuzzy Sets and Systems*, 10(1), 15-20, 1983.

[65] D. Dubois and H. Prade, Evidence measures based on fuzzy information, *Automatica*, 21: 547-562, 1985.

[66] D. Dubois and H. Prade, The mean value of a fuzzy number, *Fuzzy Sets and Systems*, 24: 279-300, 1987.

[67] D. Dubois and H. Prade, *Possibility Theory*, New York: Plenum, 1988.

[68] D. Dubois and H. Prade, Random sets and fuzzy interval analysis. *Fuzzy Sets and Systems*, 42: 87-101, 1991.

[69] D. Dubois and H. Prade, Epistemic entrenchment and possibilistic logic, *Artificial Intelligence*, 1991, 50: 223-239.

[70] D. Dubois and H. Prade, When upper probabilities are possibility measures, *Fuzzy Sets and Systems*, 49:s 65-74, 1992.

[71] D. Dubois, H. Prade: Possibility theory as a basis for preference propagation in automated reasoning. *Proc. of the 1st IEEE Inter. Conf. on Fuzzy Systems (FUZZ-IEEE'92)*, San Diego, Ca., March 8-12, 1992, 821-832.

[72] D. Dubois and H. Prade, What are fuzzy rules and how to use them. *Fuzzy Sets and Systems*, 84: 169-185, 1996.

[73] D. Dubois and H. Prade, Bayesian conditioning in possibility theory, *Fuzzy Sets and Systems*, 92: 223-240, 1997.

[74] D. Dubois and H. Prade, Possibility theory: Qualitative and quantitative aspects. In: D. M. Gabbay and P. Smets P., editors *Handbook of Defeasible Reasoning and Uncertainty Management Systems*, Vol. 1., Dordrecht: Kluwer Academic, 169-226, 1998.

[75] D. Dubois, H. Prade. Possibilistic logic: A retrospective and prospective view. *Fuzzy Sets and Systems*, 144, 3-23, 2004.

[76] D. Dubois, H. Prade. Toward multiple-agent extensions of possibilistic logic. *Proc. IEEE Inter. Conf. on Fuzzy Systems (FUZZ-IEEE'07)*, London, July 23-26,187-192, 2007.

[77] D. Dubois, H. Prade. An overview of the asymmetric bipolar representation of positive and negative information in possibility theory. *Fuzzy Sets and Systems*, 160, 1355-1366, 2009.

[78] D. Dubois, H. Prade: Generalized possibilistic logic. *Proc. 5th Inter. Conf. on Scalable Uncertainty Management (SUM'11)*, Dayton, Springer, LNCS 6929, 428-432, 2011.

[79] D. Dubois, H. Prade. Possibility theory and formal concept analysis: Characterizing independent sub-contexts to appear in *Fuzzy Sets and Systems*.

[80] D. Dubois, H. Prade, A. Rico. A possibilistic logic view of Sugeno integrals. *Proc. Eurofuse Workshop on Fuzzy Methods for Knowledge-Based Systems (EUROFUSE 2011)*, Sept. 21-23, Régua, Portugal, (P. Melo-Pinto, P. Couto, C. Serôdio, J. Fodor, B. De Baets, eds.), Advances in Intelligent and Soft Computing, vol. 107, Springer-Verlag, Berlin, 2011, 19-30.

[81] D. Dubois, L. Foulloy, G. Mauris, H. Prade, Probability-possibility transformations, triangular fuzzy sets, and probabilistic inequalities. *Reliable Computing*, 10, 273-297, 2004.

[82] D. Dubois, H. Prade and R. Sabbadin, Qualitative decision theory with Sugeno integrals In [97], 314-322, 2000.

[83] D. Dubois, H. Prade and R. Sabbadin, Decision-theoretic foundations of possibility theory. *Eur. J. Operational Research*, 128, 459-478, 2001

[84] D. Dubois, H. Prade and S. Sandri On possibility/probability transformations. In R. Lowen, M. Roubens, editors. *Fuzzy Logic: State of the Art*, Dordrecht: Kluwer Academic Publ.,103-112, 1993.

[85] D. Dubois, H. Prade, S. Schockaert. Rules and meta-rules in the framework of possibility theory and possibilistic logic. *Scientia Iranica*, 18 (3), 566-573, 2011.

[86] D. Dubois, H. Prade and Smets, New semantics for quantitative possibility theory. *Proc. 6th Europ. Conf. on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU'01)*, Toulouse, Sept. 19-21, LNAI 2143, Springer-Verlag, 410-421, 2001.

[87] D. Dubois, H. Prade and P. Smets, A definition of subjective possibility, *Badania Operacyjne i Decyzije* (Wroclaw) 4, 7-22, 2003.

[88] D. Dubois, H. Prade, and L. Ughetto. A new perspective on reasoning with fuzzy rules. *Int. J. of Intelligent Systems*, 18 : 541-567, 2003.

[89] H. Fargier, R. Sabbadin, Qualitative decision under uncertainty: Back to expected utility, *Artificial Intelligence* 164, 245-280, 2005.

[90] H. Farreny, H. Prade, Default and inexact reasoning with possibility degrees. *IEEE Trans. Systems, Man and Cybernetics*, 16(2), 270-276, 1986.

[91] B. R Gaines and L. Kohout, Possible automata. *Proc. Int. Symp. Multiple-Valued logics*, Bloomington, IN, pages 183-196, 1975.

[92] P. Gärdenfors, *Knowledge in Flux*, Cambridge, MA.: MIT Press, 1988.

[93] S. Galichet, D. Dubois, H. Prade. Imprecise specification of ill-known functions using gradual rules. *Int. J. of Approximate reasoning*, 35, 205-222, 2004.

[94] J. Gebhardt and R. Kruse, The context model. I*Int. J. Approximate Reasoning*, 9, 283-314, 1993.

[95] M. Gil, ed., Fuzzy Random Variables, Special Issue, *Information Sciences*, 133, 2001.

[96] J. F. Geer and G.J. Klir, A mathematical analysis of information-preserving transformations between probabilistic and possibilistic formulations of uncertainty, *Int. J. of General Systems*, 20, 143-176, 1992.

[97] M. Grabisch, T. Murofushi and M. Sugeno, editors, *Fuzzy measures and Integrals Theory and Applications*, Heidelberg: Physica-Verlag, 2000.

[98] W. Guezguez, N. Ben Amor, K. Mellouli, Qualitative possibilistic influence diagrams based on qualitative possibilistic utilities. *Europ. J. of Operational Research*, 195, 223-238, 2009.

[99] D. Guyonnet, B. Bourgine, D. Dubois, H. Fargier, B. Côme, J.-P. Chilès, Hybrid approach for addressing uncertainty in risk assessments. *J. of Environ. Eng.*, 129, 68-78, 2003.

[100] J.C. Helton, W.L. Oberkampf, editors (2004) Alternative Representations of Uncertainty. *Reliability Engineering and Systems Safety*, 85, 369 p.

[101] E. Huellermeier, D. Dubois and H. Prade. Model adaptation in possibilistic instance-based reasoning. *IEEE Trans. on Fuzzy Systems*, 10, 333-339, 2002.

[102] M. Inuiguchi, H. Ichihashi, Y. Kume Modality constrained programming problems: A unified approach to fuzzy mathematical programming problems in the setting of possibility theory, *Information Sciences*, 67, 93-126, 1993.

[103] C. Joslyn, Measurement of possibilistic histograms from interval data, *Int. J. of General Systems*, 26: 9-33, 1997.

[104] S. Kaci, H. Prade, Mastering the processing of preferences by using symbolic priorities in possibilistic logic. *Proc. 18th Europ. Conf. on Artificial Intelligence (ECAI'08)*, Patras, July 21-25, 376-380, 2008.

[105] G. J Klir and T. Folger *Fuzzy Sets, Uncertainty and Information*. Englewood Cliffs, NJ: Prentice Hall, 1988.

[106] G. J. Klir, A principle of uncertainty and information invariance, *Int. J. of General Systems*, 17: 249-275, 1990.

[107] G. J. Klir and B. Parviz B. Probability-possibility transformations: A comparison, *Int. J. of General Systems*, 21: 291-310, 1992.

[108] D. Lehmann, M. Magidor, What does a conditional knowledge base entail? *Artificial Intelligence*, 55, 1-60, 1992.

[109] D. L. Lewis, *Counterfactuals*. Oxford: Basil Blackwell, 1973.

[110] K. Loquin, D. Dubois, Kriging and epistemic uncertainty: A critical discussion. In: *Methods for Handling Imperfect Spatial Information*, (R. Jeansoulin, O. Papini, H. Prade, S. Schockaert, eds.), Springer-Verlag, STUDFUZZ 256, 269Ð305, 2010.

[111] K. Loquin, D. Dubois, A fuzzy interval analysis approach to kriging with ill-known variogram and data, to appear in *Soft Computing*, 2012.

[112] A. W. Marshall and I. Olkin, *Inequalities: Theory of Majorization and its Applications*, Academic Press, New York, 1979.

[113] V. Maslov, *Méthodes Opératorielles*, Mir Publications, Moscow, 1987.

[114] G. Mauris Possibility distributions: A unified representation of usual direct-probability-based parameter estimation methods Int. J. of Approximate Reasoning, 52:1232-1242, 2011.

[115] G. Mauris, V. Lasserre, L. Foulloy, Fuzzy modeling of measurement data acquired from physical sensors. *IEEE Trans. on Measurement and Instrumentation*, 49: 1201-1205, 2000.

[116] A. Neumaier, Clouds, fuzzy sets and probability intervals. *Reliable Computing*, 10, 249-272, 2004.

[117] H. T. Nguyen, B. Bouchon-Meunier, Random sets and large deviations principle as a foundation for possibility measures, *Soft Computing*, 8:61-70, 2003.

[118] J. Pearl, System Z: A natural ordering of defaults with tractable applications to default reasoning, *Proc. 3rd Conf. Theoretical Aspects of Reasoning About Knowledge*. San Francisco: Morgan Kaufmann, pages 121-135, 1990.

[119] H. Prade, A. Rico, Possibilistic evidence, *Proc. 11th Europ. Conf. on Symbolic and Quantitative Approaches to Reasoning with Uncertainty (ECSQARU'11*, Belfast, UK, June 29-July 1, Springer, LNAI 6717, 713-724, 2011.

[120] H. Prade, M. Serrurier, Introducing possibilistic logic in ILP for dealing with exceptions. *Artif. Intell.* , 171, 939-950, 2007.

[121] H. Prade, M. Serrurier, Bipolar version space learning. *Int. J. Intell. Syst.*, 23,1135-1152, 2008.

[122] H. Prade, M. Serrurier. Maximum-likelihood principle for possibility distributions viewed as families of probabilities. *Proc. IEEE Inter. Conf. on Fuzzy Systems (FUZZ-IEEE'11)*, Taipei, 2987-2993, 2011.

[123] A. Puhalskii, *Large Deviations and Idempotent Probability*, Chapman and Hall, 2001

[124] E. Raufaste, R. Da Silva Neves, C. Mariné Testing the descriptive validity of possibility theory in human judgements of uncertainty. *Artificial Intelligence*, 148: 197-218, 2003.

[125] L.J. Savage *The Foundations of Statistics*, New York: Dover, 1972.

[126] G. Shafer, Belief functions and possibility measures. In J.C. Bezdek, editor, *Analysis of Fuzzy Information Vol. I: Mathematics and Logic*, Boca Raton, FL : CRC Press, pages 51-84, 1987.

[127] G. L. S. Shackle *Decision, Order and Time in Human Affairs*, 2nd edition, Cambridge University Press, UK, 1961.

[128] R. Slowinski and M. Hapke, editors (2000) *Scheduling under Fuzziness*, Heidelberg: Physica-Verlag, 2000.

[129] P. Smets (1990). Constructing the pignistic probability function in a context of uncertainty. In: M. Henrion et al., editors, *Uncertainty in Artificial Intelligence*, vol. 5, Amsterdam: North-Holland, pages 29-39, 1990.

[130] W. Spohn, A general, nonprobabilistic theory of inductive reasoning. In R.D. Shachter, et al., editors, *Uncertainty in Artificial Intelligence*, Vol. 4. Amsterdam: North Holland. pages 149-158, 1990.

[131] T. Sudkamp, Similarity and the measurement of possibility. *Actes Rencontres Francophones sur la Logique Floue et ses Applications* (Montpellier, France), Toulouse: Cepadues Editions, pages 13-26, 2002.

[132] H. Tanaka, P.J. Guo, *Possibilistic Data Analysis for Operations Research*, Heidelberg: Physica-Verlag, 1999.

[133] A. Tversky and D. Kahneman. Advances in prospect theory: cumulative representation of uncertainty. *J. of Risk and Uncertainty*, 5, 297-323, 1992.

[134] W. Van Leekwijck and E. E. Kerre, Defuzzification: criteria and classification, *Fuzzy Sets and Systems*, 108, 303-314, 2001.

[135] P. Walley, *Statistical Reasoning with Imprecise Probabilities*, Chapman and Hall, 1991.

[136] P. Walley and G. De Cooman, A behavioural model for linguistic uncertainty, *Information Sciences*, 134,1-37, 1999.

[137] O. Wolkenhauer, *Possibility Theory with Applications to Data Analysis*. Chichester: Research Studies Press, 1998.

[138] T. Whalen Decision making under uncertainty with various assumptions about available information. *IEEE Trans. on Systems, Man and Cybernetics*, 14: 888-900, 1984.

[139] R. R. Yager, Possibilistic decision making. *IEEE Trans. on Systems, Man and Cybernetics*, 9: 388-392, 1979

[140] R. R. Yager, A procedure for ordering fuzzy subsets of the unit interval, *Information Sciences*, 24,143-161, 1981.

[141] R. R. Yager, An introduction to applications of possibility theory. *Human Systems Management*, 3, 246-269, 1983.

[142] L. A. Zadeh, Fuzzy sets as a basis for a theory of possibility, *Fuzzy Sets and Systems*, 1, 3-28, 1978.

[143] L. A. Zadeh. Fuzzy sets and information granularity. In: M.M. Gupta, R. Ragade, R.R. Yager, eds., *Advances in Fuzzy Set Theory and Applications*, Amsterdam: North-Holland, 1979, pages 3-18.

[144] L. A. Zadeh. Possibility theory and soft data analysis. In: L. Cobb, R. Thrall, eds., *Mathematical Frontiers of Social and Policy Sciences*, Boulder, Co.: Westview Press, pages 69-129, 1982.

SCIENTIFIC REPORTS

# Extensions of Fuzzy Sets in Image Processing: An Overview

M. Pagola, E. Barrenechea, H. Bustince, J. Fernandez, M. Galar, A. Jurio, C. Lopez-Molina, D. Paternain, J. Sanz, Universidad Publica de Navarra, Spain
P. Couto, P. Melo-Pinto, University of Trás-os-Montes and Alto Douro, Portugal

## 1. Introduction

Computer vision systems are made up of several stages in which they try to extract the information of the image. The stages and the purpose of its algorithms, depends on the application of the artificial vision system. Usually the systems are split in three main stages. The first stage is devoted to noise filtering, smoothing or contrast enhancement (it's also known as preprocessing or low level vision), the second stage is devoted to image segmentation, to split objects or regions according to their characteristics (intermediate level vision). Third stage involves the understanding of the scene (high level vision).

Uncertainty is present in every process of computer vision, therefore fuzzy techniques have been widely use in almost any of the processes. Extensions of fuzzy sets are not as specific as their counter-parts of fuzzy sets, but this lack of specificity makes them more realistic for some applications. Their advantage is that they allow us to express our uncertainty in identifying a particular membership function. This uncertainty is involved when extensions of fuzzy sets are processed, making results of the processing less specific but more reliable. Many authors based on this advantage proposed different image processing algorithms using extensions of fuzzy sets. This work presents a valuable review for the interested reader of the recent works using extensions of fuzzy sets in image processing. The chapter is divided as follows: first we recall the basics of the extensions of fuzzy sets, i.e. Type-2 fuzzy sets, Interval-valued fuzzy sets and Atanassov's Intuitionistic fuzzy sets. In sequent sections we review the methods proposed for noise removal (section 3), image enhancement (section 4), edge detection (section 5) and segmentation (section 6). There exist other image segmentation tasks such as video de-interlacing, stereo matching or object representation that are not described in this work.

## 2. Extensions of fuzzy sets

From the beginning it was clear that fuzzy set theory [48] was an extraordinary tool for representing human knowledge. Nevertheless, Zadeh himself established (see [49]) that sometimes, in decision-making processes, knowledge is better represented by means of some generalizations of fuzzy sets. A key problem of representing the knowledge by means of Fuzzy sets is to choose the membership function which best represents such knowledge.

Sometimes, it is appropriate to represent the membership degree of each element to the fuzzy set by means of an interval. From these considerations arises the extension of fuzzy sets called *theory of interval-valued fuzzy sets*, that is, fuzzy sets such that the membership degree of each element of the fuzzy set is given by a closed subinterval of the interval $[0,1]$. Hence, not only vagueness (lack of sharp class boundaries), but also a feature of uncertainty (lack of information) can be addressed intuitively.

These sets were first introduced in the 1970s. In May 1975 Sambuc (see [37]) presented in his doctoral thesis the concept of an interval-valued fuzzy set named a $\Phi$-fuzzy set. That same year, Zadeh [49] discussed the representation of type 2 fuzzy sets and its potential in approximate reasoning.

The concept of a *type 2 fuzzy set* was introduced by Zadeh [49] as a generalization of an ordinary fuzzy set. Type 2 fuzzy sets are characterized by a fuzzy membership function, that is, the membership value for each element of the set is itself a fuzzy set in $[0,1]$.

Formally, given the referential set $U$, a type 2 fuzzy set is defined as an object $\overline{\overline{A}}$ which has the following form:

$$\overline{\overline{A}} = \{(u, x, \mu_u(x)) | u \in U, x \in [0,1]\},$$

where $x \in [0,1]$ is the primary membership degree of $u$ and $\mu_u(x)$ is the secondary membership level, specific to a given pair $(u,x)$.

One year later, Grattan-Guinness [27] established a definition of an interval-valued membership function. In that decade interval-valued fuzzy sets appeared in the literature in various guises and it was not until the 1980s, that the importance of these sets, as well as their name, was definitely established.

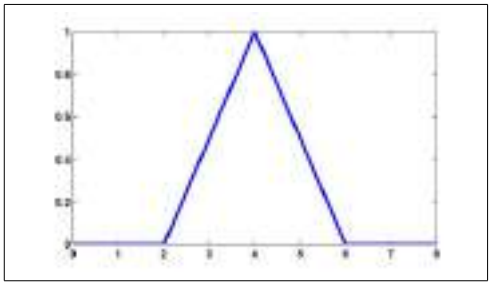


**Fig1. Fuzzy membership function.**

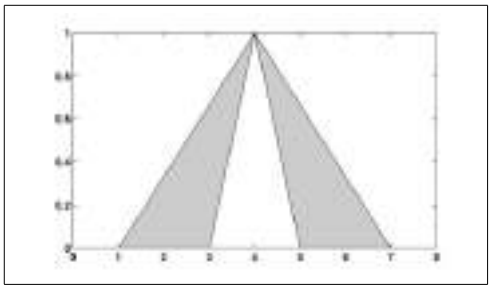


**Fig2. Interval valued fuzzy membership function. Lower bound and upper bound**

A particular case of a type 2 fuzzy set is an *interval type 2 fuzzy set* (see [31]–[32]). An interval type 2 fuzzy set $\overline{\overline{A}}$ in $U$ is defined by

$$\overline{\overline{A}} = \{(u, A(u), \mu_u(x))|u \in U, A(u) \in L([0,1])\},$$

where $A(u)$ is a closed subinterval of $[0,1]$, and the function $\mu_u(x)$ represents the fuzzy set associated with the element $u \in U$ obtained when $x$ covers the interval $[0,1]$; $\mu_u(x)$ is given in the following way:

$$\mu_u(x) = \begin{cases} a \text{ if } \underline{A}(u) \leq x \leq \overline{A}(u) \\ 0 \text{ otherwise} \end{cases},$$

where $0 \leq a \leq 1$. It turns out that an interval type 2 fuzzy set is the same as an IVFS if we take $a = 1$.

Another important extension of fuzzy set theory is the theory of Atanassov's intuitionistic fuzzy sets ([1], [2]). Atanassov's intuitionistic fuzzy sets assign to each element of the universe not only a membership degree, but also a nonmembership degree, which is less than or equal to 1 minus the membership degree.

An Atanassov's intuitionistic fuzzy set (A-IFS) on $U$ is a set

$$\hat{A} = \{(u, \mu_{\hat{A}}(u), \nu_{\hat{A}}(u))|u \in U\},$$

where $\mu_{\hat{A}}(u) \in [0,1]$ denotes the membership degree and $\nu_{\hat{A}}(u) \in [0,1]$ the nonmembership degree of $u$ in $\hat{A}$ and where, for all $u \in U$, $\mu_{\hat{A}}(u) + \nu_{\hat{A}}(u) \leq 1$.

In [1] Atanassov established that every Atanassov intuitionistic fuzzy set $\hat{A}$ on $U$ can be represented by an interval-valued fuzzy set $A$ given by

$$\begin{aligned} A: \quad & U \to L([0,1]) \\ & u \to [\mu_{\hat{A}}(u), 1 - \nu_{\hat{A}}(u)], \qquad \text{for all } u \in U. \end{aligned}$$

Using this representation, Atanassov proposed in 1983 that Atanassov's intuitionistic fuzzy set theory was equivalent to the theory of interval-valued fuzzy sets. This equivalence was proven in 2003 by Deschrijver and Kerre [20]. Therefore, from a mathematical point of view, the results that we obtain for IVFSs are easily adaptable to A-IFSs and vice versa. Nevertheless, we need to point out that, conceptually, the two types of sets are totally different. This is made clear when applications of these sets are constructed (see [43]).

In 1993, Gau and Buehrer introduced the concept of *vague sets* [26]. Later, in 1996, it was proven that vague sets are in fact A-IFSs [6].

A compilation of the sets that are equivalent (from a mathematical point of view) to interval-valued fuzzy sets can be found in [21]. Two conclusions are drawn from this study:

1.- Interval-valued fuzzy sets are equivalent to A-IFSs (and therefore vague sets), to grey sets (see [19]) and to $L$-fuzzy set in Goguen's sense with respect to a special lattice $L([0,1])$.

2.- IVFSs are a particular case of probabilistic sets (see [23]), of soft sets (see [3]), of Atanassov's interval-valued intuitionistic fuzzy sets and evidently of Type 2 fuzzy sets.

## 3. Noise Reduction

In this section we focus on gray scale images and the use of fuzzy logic theory extensions for noise removal.

Many applications of image processing perform image noise removal before any further processing such as segmentation, enhancement, edge detection or compression. Noise removal is a crucial task for most applications mainly for two reasons:

- Digital images are often corrupted by impulse noise during image acquisition, image transmission and image processing due to a number of imperfections present in these tasks environments.
- The noise can critically affect any image post-processing decisively compromising their performance.

For these reasons, noise removal is one of the most important steps for most image processing applications, regarding the overall performance of the applications and, is still a challenging problem in image processing.

When using fuzzy sets for noise removal, since their memberships are crisp values, it is not possible to know which one is the best membership function and, different membership functions will lead to different processing results. On the other hand, when using type-2 fuzzy sets, since their membership functions are also fuzzy, provides us with a more efficient way of dealing with uncertainty and, consequently, a more robust way of determining the membership functions.

In their work, Sun and Meng [39], make the assumption that, since impulse corruption is usually large compared with the strength of the signal, then the noise corrupted pixels have intensity values that are near the saturated values (lower and upper limits of the gray scale used). Based on this assumption, a inverted ladder membership function is used as initial membership function from which the type-2 fuzzy set is constructed (Fig. 3).

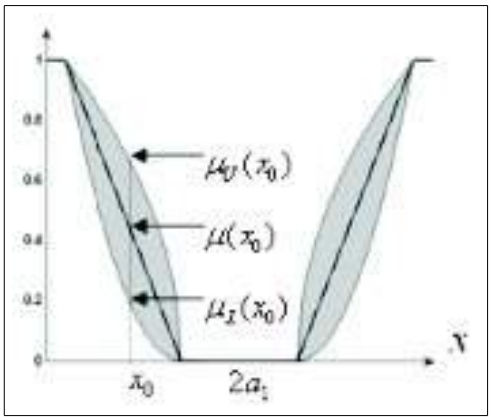



**Fig3. Type-2 Fuzzy Set constructed from the initial ladder membership function**

After defining the inverted ladder membership function based on parameters $a$, $a_1$ and $a_2$, the lower and upper limits of the type-2 fuzzy set are obtained using the following equations:

$$\mu_U(x) = [\mu(x)]^{\frac{1}{\alpha}}$$
$$\mu_L(x) = [\mu(x)]^{\alpha}$$

where $\alpha \in (1, 2]$.

After the construction of the type-2 fuzzy set, the probability of a pixel been corrupted by impulse noise (PPC) is represented by the centroid-type-reduction [46] of the set. This way, the larger PPC means the bigger probability of the pixel been corrupted and, the less PPC means the less probability. Finally, a threshold of corruption is established in such way that if the pixel's PPC is bigger than the threshold its restored value is the mean of the pixels intensities in the subimage ($n \times n$ filtering window centered at the pixel) and, if the pixel's PPC is less than the threshold it maintains its intensity.

Tulin, Basturk and Yuksel [42] proposed a type-2 fuzzy operator for detail preserving restoration of impulse noise corrupted images, that processes the pixels contained in a $3\times3$ filtering window and outputs the restored value of the window center pixel. The proposed operator is structure that combines four type-2 neuro-fuzzy filters, four defuzzifiers and a postprocessor. Each one of the type-2 NF filters are identical and accept the center pixel and two of its neighborhoods (processing the horizontal, vertical, diagonal and reverse diagonal pixel neighborhoods of the filtering window) and produces an output that represents the uncertainty interval (i.e., lower and upper bounds) for the center pixel restored value in the form of a type-1 interval. Each combination of the inputs of the filter and their associated type-2 interval Gaussian membership functions is represented by a rule in the form:

$$if(X_1 \in M_{i1})and(X_2 \in M_{i2})and(X_3 \in M_{i3}), then$$
$$R_i = k_{i1}X_1 + k_{i2}X_2 + k_{i3}X_3 + k_{i4}$$

There are $N$ fuzzy rules in the rulebase where, $R_i$ denotes the output of the $i$th rule ($N$ rules, $i = 1, 2, \cdots N$) and $M_{ij}$ denotes the $i$th Gaussian membership function of the $j$th input (3 inputs, $j = 1, 2, 3$) and is defined as follows:

$$M_{ij}(u) = \exp\left[-\frac{1}{2}(\frac{u - m_{ij}}{\sigma_{ij}})\right]$$

where $m_{ij}$ and $\sigma_{ij}$ are the mean and the standard deviation of the membership function, respectively.

Note that the membership functions $M_{ij}$ (Fig. 4) are interval membership functions with their boundaries characterized by upper and lower Gaussian membership functions (see [42]).

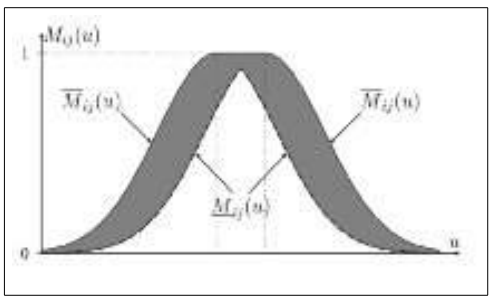



**Fig4. Type-2 interval Gaussian membership function**

The optimal values for the parameters of each one of the type-2 interval Gaussian membership functions are obtained by training using the least squares optimization algorithm. Finally, the output of each NF filter is the weighted average of the individual rules outputs.

The defuzzifier blocks convert the input fuzzy sets coming from the corresponding type-2 NF filters into a scalar value by performing centroid defuzzification (the centroid is the center of the type-1 interval fuzzy set).

The output of the defuzzifier blocks are four scalar values that are to be the candidates for the filtering window center pixel restored value. The postprocessor converts the four candidates into a single output value by discarding the lowest and the highest values and averaging the remaining two values.

In [42] Tulin, Basturk and Yuksel proposed an extension of this operator where the the original neighborhood topologies (horizontal, vertical, diagonal and reverse diagonal pixel neighborhoods) are extended to 28 possible neighborhood topologies corresponding to a filtering operator with 28 NF filters, 28 defuzzifiers and a postprocessor. However, authors emphasized that, for most filtering applications, one does not have to use all of these neighborhood topologies.

In this new operator, the NF filters and the defuzzifiers work in the same way as in the original operator. The way the new postprocessor produces the output value from the scalar values obtained at the outputs of the defuzzifiers is different from the original one. The postprocessor calculates the average of its inputs and truncates it to a 8-bit integer number, which is the output of the operator.

Wang, Chung, Hu and Wu [45] proposed a interval type-2 fuzzy filter for Gaussian noise suppression while maintaining the original structure of the image. Based on interval type-2 fuzzy sets is constructed a selective feedback fuzzy neural network (SFNN) suitable for image representation. In reality, this SFNN is a universal approximator that works as a filter for Gaussian noise suppression that preserves the fine structure of the image from the theoretical viewpoint.

First, the image is fuzzified in using linguistic concepts in such way that the gray scale interval is equally divided in $K_0$ partitions. Each one of these partitions is described with a Gaussian shape and its membership function obtained by drawing all the Gaussians having mean and standard deviation.

The proposed SFNN has five components: two neurons in the input layer (since, the input is a 2-D digital image), three hidden layers and the output layer. Since, a digital image can be viewed as a continuous 2-D function and, according to the structure of the SFNN (see [45]) it can be used to approximate a continuous function, the SFNN is used to express a digital image and, a Gaussian noise filter is designed based on it. For each one of the $K_0$ partitions a optimal gray level is computed in a small operating window (mean of the pixels in the window) and, the window gray level which is nearest to the optimal gray level is selected as the optimal gray level in the operating window.

After the operating window slides over the whole image, the mean absolute error of the input image and the

output image (filtered image) are calculated and if the difference between these two values is less than a small positive number the process stops; otherwise the gray levels of the input image are replaced by the gray levels of the output image and the process is restarted.

In [4], Bigand and Colot, use IVFS entropy to take into account the uncertainty present in the image noise removal process. Their motivation is to assess, and ultimately remove, the uncertainty of the membership values using the length of the interval in an IVFSs (the longer the interval, the more uncertainty).

For each pixel, the uncertainty of a precise FS is modeled by the closed intervals delimited by the upper ($\mu_U(x)$) and lower ($\mu_L(x)$) membership functions defined as follows:

$$\mu_U(x) = [\mu(x; g, \sigma)]^{\frac{1}{2}}$$

$$\mu_L(x) = [\mu(x; g, \sigma)]^2$$

where $\mu(x; g, \sigma)$ is a Gaussian fuzzy number defined as:

$$\mu(x; g, \sigma) = \exp\left[-\frac{1}{2}(\frac{x-g}{\sigma})^2\right]$$

Then, in order to be used as a criterion to automatically find fuzzy region width and thresholds for segmentation of noisy images, the entropy (which they wrongly called index of ultrafuzziness) of each one of the constructed IVFSs is calculated as follows:

$$\Gamma(x) = \frac{1}{M.N}\sum_{g=0}^{G-1}[h(x).(\mu_U(x) - \mu_L(x))]$$

where $G$ is the number of gray levels of a $M \times N$ image.

This entropy is used to obtain a image homogram (in the same way as proposed by Cheng [18] using FSs) since, according to the authors, $\Gamma$ represents the homogeneity distribution across intensities of the considered image. This homogram is used to find all major homogeneous regions while filtering noise in such way that, if a pixel belongs to one of these regions then the pixel is noise-free else pixel is noisy.

Finally, using a $3\times3$ filtering window, the median filter is applied to all the pixels identified as noisy pixels.

**Discussion** Efficient noise removal in corrupted images is still a challenging problem in image processing mostly due to the imperfection/uncertainty inevitably present in noisy environments. The main idea of these works is to take into account the total amount of the imprecision/uncertainty present in the process of image noise filtering by means of the use of fuzzy sets extensions namely, interval-valued fuzzy sets and type-2 fuzzy sets.

All the presented filters inherit the advantages of fuzzy sets extensions theory, where an extra degree of fuzziness provides a more efficient way of dealing with uncertainty than with ordinary fuzzy sets.

Hence, using fuzzy sets extensions in noise filtering seems to bee a very promising idea that can lead to the design of efficient filtering operators.

## 4. Enhancement

In image enhancement, the main goal is to produce a new image that endows more accurate information for analysis than the original one. In this context, fuzzy logic extensions are used to represent and manipulate the uncertainty involved in the image enhancement process. Both type-2 fuzzy sets and A-IFSs approaches presented in this section, are able to model and minimize the effect that the uncertainty has in the image enhancement problem.

**Image Enhancement using Type-2 Fuzzy Sets** In [22], Ensafi and Tizhoosh proposed a type-2 fuzzy image enhancement method based on extension of the locally adaptive fuzzy histogram hyperbolization method [41], improving its performance by extending it from a type-1 to a type-2 method where the additional third dimension of the type-2 sets gives more degrees of freedom for better representation of the uncertainties associated with the image.

First, based on the value of homogeneity $\mu_{Homo}$, the image is divided into several sub-images.

$$\mu_{Homo} = \left(1 - \frac{g_{maxLocal} - g_{minLocal}}{g_{maxGlobal} - g_{minGlobal}}\right)^2$$

Setting the minimum and maximum local window sizes to 10 and 20 respectively and, using a fuzzy if-then-else rule, the local window size surrounding each supporting point is calculated.

The type-2 fuzzy set is obtained by blurring the type-1 fuzzy set defined by the membership function $\mu(g_{mn})$ of each gray level.

$$\mu(g_{mn}) = \frac{g_{mn} - g_{min}}{g_{max} - g_{min}}$$

Where $g_{mn}$ represents the pixel gray level and, $g_{min}$ and $g_{max}$ represent the image minimum and maximum gray levels respectively.

The type-2 fuzzy set is constructed defining the upper and lower membership values using interval-valued fuzzy sets in the following way:

$$\mu_{UPPER}(x) = (\mu(x))^{0.5} \quad \mu_{LOWER}(x) = (\mu(x))^2$$

And, the proposed type-2 membership function is defined by:

$$\mu_{T2}(g_{mn}) = (\mu_{LOWER} \times \alpha) + (\mu_{UPPER} \times (1 - \alpha))$$

with $\alpha = \frac{g_{Mean}}{L}$.

where, $L$ is the number of gray levels and $g_{Mean}$ the mean gray value of each sub-image.

Finally, using the $\mu_{T2}$ values, the new gray levels of the enhanced image are calculated using the following expression with $\beta = 1.1$:

$$g'_{mn} = \left(\frac{L \times 1}{e'^1 \times 1}\right) \times \left[e'^{\mu(g_{mn})^\beta} - 1\right]$$

**Image Enhancement using A-IFSs Entropy** In [44], Vlachos and Sergiadis studied the role of entropy in A-IFSs for contrast enhancement. Different concepts of entropy on A-IFss and their behavior are analyzed in the context of image enhancement.

In this work, image enhancement is regarded as a entropy optimization problem within an A-IFS image processing framework where, in the first stage the image is transferred into the fuzzy domain and sequentially into the A-IFS domain, where the proposed processing is performed. Finally, the inverse process is carried out in order to obtain the processed image in the gray-level domain.

Therefore, an intuitionistic fuzzification scheme for constructing an A-IFS for representing the image, based on entropy optimization, was proposed. First, the image ($N \times M$ pixels having $L$ gray-levels) is represented in the fuzzy domain by $A$.

$$A = \{\langle g_{ij}, \mu_A(g_{ij})\rangle | g_{ij} \in 0, \times, L-1\}$$

with, $i \in \{1, \times, M\}$ and $j \in \{1, \times, N\}$.

A optimal derivation of a combination of membership and non-membership functions that model the image gray-levels is achieved by maximizing the intuitionistic fuzzy entropy of the image (i.e., maximum intuitionistic fuzzy entropy principle).

First, the membership function $\mu_A(g)$ of the fuzzified image is calculated.

$$\mu_A(g) = \frac{g - g_{min}}{g_{max} - g_{min}}$$

The A-IFS for representing the image,

$$\hat{A} = \left\{\langle g, \mu_{\hat{A}}(g;\lambda), \nu_{\hat{A}}(g;\lambda)\rangle | g \in 0, \times, L-1\right\}$$

is then constructed, by means of $\mu_A(g)$, using the following expressions:

$$\mu_{\hat{A}}(g,\lambda) = 1 - (1 - \mu_A(g))^{\lambda}$$

and

$$\nu_{\hat{A}}(g,\lambda) = (1 - \mu_A(g))^{\lambda(\lambda+1)}$$

where $\lambda$ is obtained using an optimization criterion that is formulated as follows:

$$\lambda = \arg \max_{\lambda \geq 1} \{E(\hat{A};\lambda)\}$$

Where $E$ is an entropy measure. Entropies proposed by Burillo and Bustince [5] and by Szmidt and Kacprzyk [38] where used.

The defuzzification is made using the *maximum index of fuzziness intuitionistic defuzzification* [43] by selecting a parameter $\alpha$ in the following way:

$$\alpha = \begin{cases} 0, & \text{if } \alpha' < 0 \\ \alpha', & \text{if } 0 \leqslant \alpha' \leqslant 1 \\ 1, & \text{if } \alpha' > 1 \end{cases}$$

where

$$\alpha' = \frac{\sum_{g=0}^{L-1} h_A(g)\pi_{\hat{A}}(g;\lambda)(1 - 2\mu_{\hat{A}}(g;\lambda))}{2\sum_{g=0}^{L-1} h_A(g)\pi^2_{\hat{A}}(g;\lambda)}$$

with $h_A$ being the histogram of the fuzzified image $A$.

Finally, the new intensity gray levels $g'$ are obtained through the expression:

$$g' = (L-1)\mu_{D_\alpha(\hat{A})}(g)$$

where

$$\mu_{D_\alpha(\hat{A})}(g) = \alpha + (1-\alpha)\mu_{\hat{A}}(g;\lambda) - \alpha\nu_{\hat{A}}(g;\lambda)$$

**Discussion** In their work, Ensafi and Tizhoosh [22] demonstrated that using type-2 fuzzy logic a better image contrast enhancement is achieved than with its type-1 counterpart.

In Vlachos and Sergiadis approach [44], A-IFSs are used as a mathematical framework to deal with the vagueness present in a digital image by means of the A-IFS extra degree of freedom that allows a flexible modeling of imprecise and/or imperfect information present in images, better than classical fuzzy sets. They concluded that the different notions of intuitionistic fuzzy entropy used [5, 38] treat images in different ways, making the selection of the appropriate entropy measure to be application-dependent.

## 5. Edge Detection

In the ideal case, the result of applying an edge detector to an image may lead to a set of connected curves that indicate the boundaries of objects, the boundaries of surface markings as well curves that correspond to discontinuities in surface orientation. Thus, applying an edge detector to an image may significantly reduce the amount of data to be processed and may therefore filter out information that may be regarded as less relevant, while preserving the important structural properties of an image.

**Fig 6. Example image**

**Fig7. Example of edge detection**

One of the seminal works of edge detection was Canny's [15]. Its aim was to discover the optimal edge detection algorithm. In this situation, an optimal edge detector means:

- Good detection - the algorithm should mark as many real edges in the image as possible.
- Good localization - edges marked should be as close as possible to the edge in the real image.
- Minimal response - a given edge in the image should only be marked once, and where possible, image noise should not create false edges.

Some fuzzy approaches to edge detection already exist and perform quite well (see [28]). Why then work with an extension of fuzzy sets? A classical definition of what an edge within an image should be is: *a significantly change in the intensity of adjacent neighboring pixels.* To state a specific threshold on how large the intensity change between two neighboring pixels must be, is not a simple task and obviously depends on the scene, illumination etc. So it's clear that extensions of fuzzy sets can be used to deal with this uncertain concept.

In the literature of extensions of fuzzy sets applied to edge detection there exist three different approaches. In the first one the main idea is to assign each pixel of the image with an interval, and then measuring its entropy decide if it's edge or not. In the second approach a interval type fuzzy system is used to classify pixels and, in the third approach AIFSs are used to deal with the uncertainty of edge pattern matching.

**First approach [12]:** Consider the fact that edge detection techniques attempt to find pixels whose intensity (gray level) is very different from those of its neighbors. An element of f (image) belongs to an edge if there is a big enough difference between its intensity and its neighbors' intensities. (Notice that this definition is intentionally fuzzy in its own right). The method begins assigning an IVFS to each matrix f and therefore each element has associated an interval as membership degree. The lower and upper bounds of this interval are determined by the concepts of tn-processing and sn-processing

**Definition 1** *([10]) Consider a matrix $f \in \mathcal{M}$, any two t-norms $T_1$ and $T_2$ in $[0,1]$, and a positive integer $n$ less than or equal to $\frac{N-1}{2}$ and $\frac{M-1}{2}$. We define the tn-processing of $f$ as follows:*

$$g^n_{T_1,T_2} : \mathcal{M} \to \mathcal{M}_n \text{ given by}$$
$$g^n_{T_1,T_2}(f(x,y)) = \mathop{T_1}_{\substack{i=-n\\j=-n}}^{n} (T_2(f(x-i,y-j), f(x,y)))$$
$$\text{with } n \le x \le N-(n+1), n \le y \le M-(n+1)$$

In this case it is said that we use a submatrix of order $(2n+1)\times(2n+1)$.

**Definition 2** *([10]) Let $n$ be an integer number greater than zero. We define the IVn matrix associated with $f \in \mathcal{M}$ as the interval-valued fuzzy set $G^n$ given by*

$$G^n = \{((x,y), G^n(x,y) = [g^n_{T_1,T_2}(f(x,y)), g^n_{S_1,S_2}(f(x,y))] \in L([0,1]))|x \in X, y \in Y\}$$

*being $g^n_{T_1,T_2}$ and $g^n_{S_1,S_2}$ the tn-processing and the sn-processing given by Definition 1.*

Obviously, we can also associate with each matrix $f$ the following interval-valued fuzzy set $\mathbf{f} : \mathbf{f} = \{((x,y), \mathbf{f}(x,y) = [f(x,y), f(x,y)] \in L([0,1]))|x \in X, y \in Y\}$.

The following definition associates with the IVFS $G^n$ a fuzzy set whose membership function is the length of the intervals in $G^n$.

**Definition 3** *([10]) Given a matrix $f \in \mathcal{M}$ and its corresponding $G^n$. We call W-matrix of $f$, a new matrix obtained by assigning to each of its elements the corresponding interval length of $G^n$. It is denoted as $W(G^n)$. Therefore $W(G^n) = \{((x,y), W(G^n)(x,y) = g^n_{S_1,S_2}(f(x,y)) - g^n_{T_1,T_2}(f(x,y)))|(x,y) \in X \times Y\} \in FSs(X \times Y)$.*

Every matrix $f$ is thus associated with an interval-valued fuzzy set $G^n$ and a fuzzy set $W(G^n)$.

The normalized entropy of $G^n$ is given by the following expression:

$$\mathcal{E}_{\mathcal{N}}(G^n) = \frac{\sum_{\substack{n\le x\le N-(n+1)\\ n\le y\le M-(n+1)}} g^n_{S_1,S_2}(f(x,y)) - g^n_{T_1,T_2}(f(x,y))}{(N-2\cdot n)\times(M-2\cdot n)} \quad (2)$$

It is logical to relate those elements of $G^n$ whose membership degree intervals are large to the location of the edge. This fact leads us to establish the following:

The normalized entropy of $G^n$ establishes the average length of the intervals that represent the membership function of the elements. A large entropy implies that the intervals are large, meaning that the difference between $g^n_{T_1,T_2}$ and $g^n_{S_1,S_2}$ tends to be large for each element. In such a matrix there are many changes in intensity, and a higher proportion of elements belong to an edge. Conversely, a small entropy implies that few elements of the matrix belong to an edge. The normalized entropy of $G^n$ therefore indicates the *proportion of elements* that are part of an edge.

**Definition 4** *We say that an element $(x,y)$ belongs to the bright zone edge if it satisfies the following two items:*

(*i*) $f(x,y) \geq \frac{g^n_{\vee,\vee}(f(x,y))+g^n_{\wedge,\wedge}(f(x,y))}{2} = K_{0.5}(G^n(x,y))$, *and*

(*ii*) *its interval has sufficient length.*

To identify elements of $G^n$ with a long enough interval to belong to an edge, we start by considering two intensity values $p$ and $q$ whose values are yet to be determined. For the moment, we simply require $p \leq q$ and $p, q \in [0,1]$ (in a binary image, we would have $p = 0$ and $q = 1$). From these two values we base on the following rule to obtain the edges:

(a) *If $W(G^n(x,y)) \geq q$, then the element belongs to an edge.*

(b) *If $p \leq W(G^n(x,y)) < q$, then we need a way of distinguishing elements that belong to the edge from those that do not belong.*

(c) *If $W(G^n(x,y)) < p$, then the element $(x,y)$ generally does not belong to the edge.* Such elements can be considered, however, if very few elements satisfy conditions (a) and (b).

From previous rule is proposed the following algorithm, in which relevant pixels are added to the edge by means of different actions (please see [12]).

**(BZ1)** *Calculate the IVn matrix $G^n$ and its associated W-matrix (by means of $g^n_{\wedge,\wedge}$ and $g^n_{\vee,\vee}$).*

**(BZ2)** *Calculate $p$ and $q$, then construct the sets $G^n_p$, $G^n_{p,q}$ and $G^n_q$.*

**(BZ3)** *Calculate the entropies $\mathcal{E}_{\mathcal{N}}(G^n_p)$, $\mathcal{E}_{\mathcal{N}}(G^n_{p,q})$ and $\mathcal{E}_{\mathcal{N}}(G^n_q)$.*

**(BZ4)** *Calculate $\mathbf{T}_{\wedge,\wedge}(\mathbf{f}, G^n)$.*

**(BZ5)** *Calculate $\mathcal{E}_{\mathcal{N}}(\mathbf{T}_{\wedge,\wedge}(\mathbf{f}, G^n)^n_p)$, $\mathcal{E}_{\mathcal{N}}(\mathbf{T}_{\wedge,\wedge}(\mathbf{f}, G^n)^n_{p,q})$ and $\mathcal{E}_{\mathcal{N}}(\mathbf{T}_{\wedge,\wedge}(\mathbf{f}, G^n)^n_q)$.*

**(BZ6)** *Execute **(Action1)**, **(Action2)** or **(Action3)**.*

**(BZ7)** *Sum the binary images obtained in (BZ6).*

**(BZ8)** *Clean and thin the lines.*

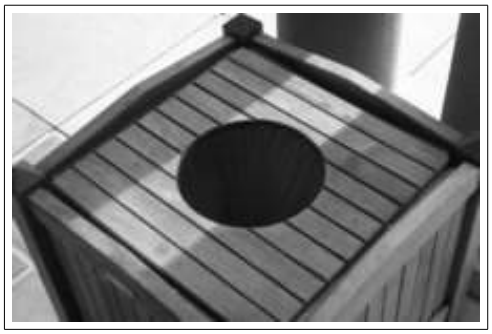


**Fig 8. Example image**

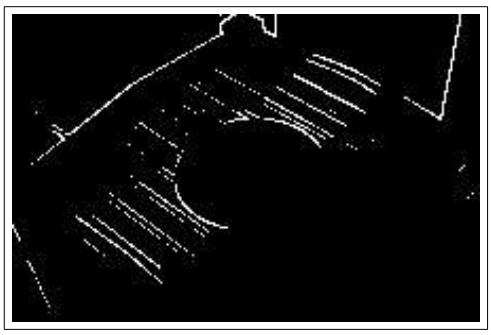


**Fig 9. Edge image after Action 1**

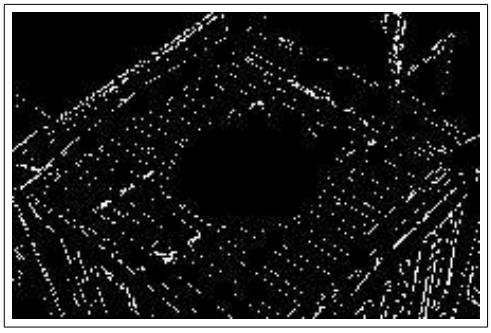


**Fig 10. Edge image after Action 2**

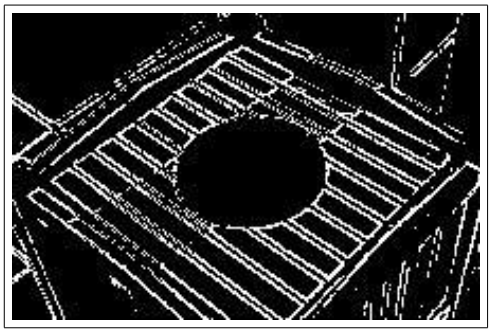


**Fig 11. Edge image after Action 3**

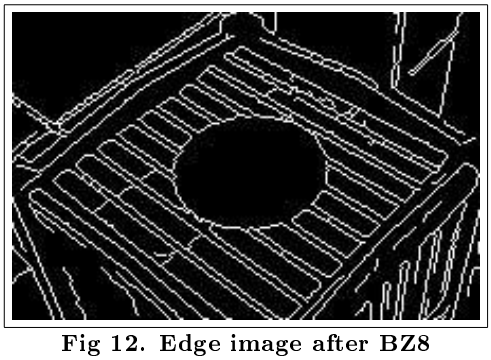


**Fig 12. Edge image after BZ8**

**Second approach [33, 34]**: the goal is to design a system which makes it easier to include edges in low contrast regions, but which does not favor false edges by effect of noise. Because of this specifications the authors design an Interval type 2 fuzzy system.

The system has 4 inputs and one output that is the degree of edginess of each pixel.

The input variables are the gradients with respect to x-axis and y-axis, to which they call DH and DV respectively. The other two inputs are the pixels filtered when

convolute two masks to the original image. One is a high-pass filter and the other a low-pass filter. The high-pass filter HP detects the contrast of the image to guarantee the border detection in relative low contrast regions. The low-pass filter M allow to detect image pixels belonging to regions of the input were the mean gray level is lower. These regions are proportionally more affected by noise, supposed uniformly distributed over the whole image.

Seven interval valued fuzzy rules allow to evaluate the input variables, so that the obtained image displays the edges of the image in color near white (HIGH tone), whereas the background was in tones near black (tone LOW).

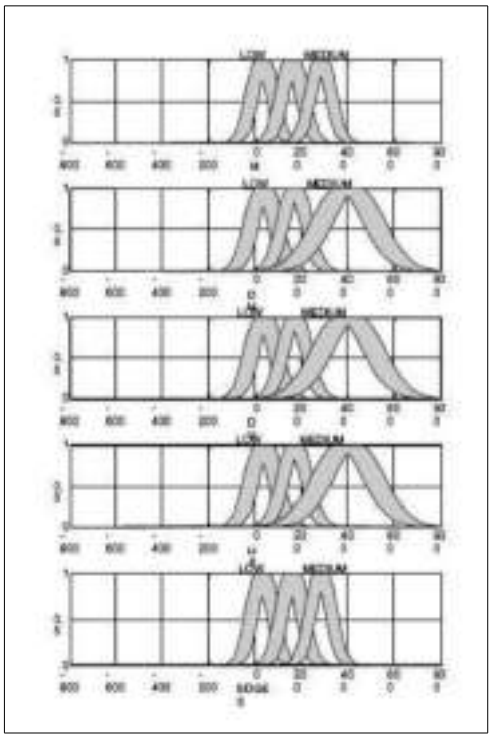


**Fig 13. Interval valued membership functions designed for the input variables and the output variable: Degree of "edginess".**

1. If (DH is LOW) and (DV is LOW) then (EDGES is LOW)
2. If (DH is MEDIUM) and (DV is MEDIUM) then (EDGES is HIGH)
3. If (DH is HIGH) and (DV is HIGH) then (EDGES is HIGH)
4. If (DH is MEDIUM) and (HP is LOW) then (EDGES is HIGH)
5. If (DV is MEDIUM) and (HP is LOW) then (EDGES is HIGH)
6. If (M is LOW) and (DV is MEDIUM) then (EDGES is LOW)
7. If (M is LOW) and (DH is MEDIUM) then (EDGES is LOW)

**Third Approach [16]:** the authors propose an intuitionistic fuzzy divergence to deal with the uncertainty in an edge pattern matching scheme. The intuitionistic fuzzy set takes into account the uncertainty in assignment of membership degree known as hesitation degree.

The main idea behind template edge matching is to detect tipical intensity distributions that are usually in edges. The authors propose the following algorithm to deal with uncertainty present in the matching process by means of an intuitionistic divergence.

- Step 1. Form 16 edge-detected templates.
- Step 2. Apply the edge templates over the image by placing the center of each template at each point (i,j) over the normalized image.
- Step 3. Calculate the intuitionistic fuzzy divergence (IFD) between each elements of each template and the image window and choose the minimum IFD value.
- Step 4. Choose the maximum of all the 16 minimum intuitionistic fuzzy divergence values.
- Step 5. Position the maximum value at the point where the template was centered over the image.
- Step 6. For all the pixel positions, the max-min value has been selected and positioned.
- Step 7. A new intuitionistic divergence matrix has been formed.
- Step 8. Threshold the intuitionistic divergence matrix and thin.
- Step 9. An edge-detected image is obtained.

Experimental studies reveal that, for edge detection the result is completely dependent on the selection of hesitation constant and thereby by the hesitation degree (also called the intuitionistic fuzzy index). The intuitionistic method detects the dominant edges clearly, while removing the unwanted edges.

## 6. Segmentation

Image segmentation is a critical and essential component of image analysis and/or pattern recognition system and is one of the most difficult tasks in image processing, that can determine the quality of the final result of the system.

The goal of image segmentation is the partition of an image in different areas or regions.

**Definition 5** *Segmentation is grouping pixels into regions such that*

1. $\cup_{i=1}^{k} P_i$ = *Entire image* ($\{P_i\}$ *is an exhaustive partitioning).*
2. $P_i \cap P_j = 0, i \neq j$ ($\{P_i\}$ *is an exclusive partitioning).*
3. *Each region* $P_i$ *satisfies a predicate; that is, all points of the partition have some common property.*
4. *Pixels belonging to adjacent regions, when taken jointly, do not satisfy the predicate.*

There exist three different approaches using fuzzy methods:

- Histogram thresholding.
- Feature space clustering.
- Rule based systems.

There exist different works that use extensions of fuzzy sets within the three approaches. The most commonly studied method is thresholding with extensions of fuzzy sets. The first work on this topic was made by Tizhoosh [40].

One of the earlier papers of fuzzy thresholding is [36] in 1983. The idea behind the fuzzy thresholding is to first transfer the selected image feature into a fuzzy subset by means of a proper membership function and then select and optimize a global or local fuzzy measure to attain the goal of image segmentation.

In [36] the authors used the S-function to fuzzify the image. They minimize the entropy in such a way that the final segmented image is the one which has less doubtful pixels.

Said membership functions represent the brightness set within the image. The basic idea of using this membership function is that, if we take the value of a parameter as the threshold value, the dark pixels should have low membership degrees, and on the contrary, brighter pixels should have high membership degrees. The pixels with membership function near 0.5 should be the ones that are not clearly classified. Therefore the set with less entropy is the set with less amount of pixels with uncertain membership (around 0.5).

In 2005 Tizhoosh [40] presented a paper that uses Interval type 2 fuzzy sets in image thresholding (we must point out that he tries to use type 2 fuzzy sets, however in the paper he only uses Interval Type 2 fuzzy sets). His study is based on the modification of the classical fuzzy algorithm of Huang and Wang [29], so that he applies an $\alpha$ factor as interval generator to the membership function. Starting from a membership function, Tizhoosh obtains an interval valued fuzzy set that "contains" different membership functions and is useful for finding the threshold of an image.

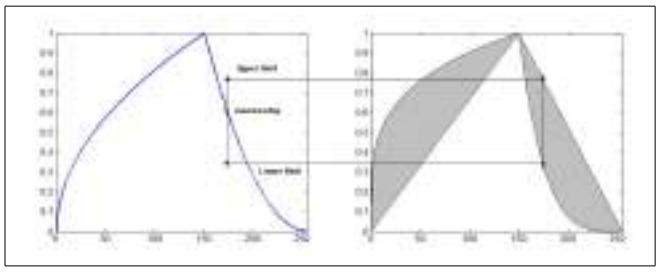


**Fig.14 Threshold as a fuzzy number used by Tizhoosh. Transformation of a FS into a IVFS.**

He assigns each intensity with the following interval of membership, $\mu_U$ and $\mu_L$ being the upper and lower membership degrees:

$$\begin{aligned} \mu_L(g) &= \mu(g)^{\alpha} \\ \mu_U(g) &= \mu(g)^{1/\alpha} \end{aligned} \tag{3}$$

With $\alpha \in (1, \infty)$, and therefore $0 \leq \mu_L(q) \leq \mu_U(q) \leq 1$. Sometimes parameter $\alpha$ can be interpreted as linguistic edges.

Tizhoosh's idea for proposing his algorithm is to *"remove the uncertainty of membership values by using type II fuzzy sets"*.

Vlachos and Sergiaidis [43] also propose a modification of Tizhoosh's algorithm, using Atanassov's intuitionistic fuzzy sets (see [1]). Their basis are membership functions similar to Huang's but, instead of minimizing the entropy, the algorithm minimizes the divergence with set $\hat{\mathbf{1}}$ (see [17]). The structure of the intuitionistic algorithm is the same as Tizhoosh's. The construction of the intuitionistic fuzzy sets is done in the following way:

$$\begin{aligned} \mu_{\hat{A}}(g,t) &= \lambda \mu_A(g,t) \\ \nu_{\hat{A}}(g,t) &= (\hat{1} - \lambda \mu_A(g,t))^{\lambda} \end{aligned} \tag{4}$$

With $\lambda \in [0,1]$, being $\hat{A}$ an intuitionistic fuzzy set, and the divergence:

$$\begin{aligned} D_{IFS}(\hat{A}, \hat{1}, t) = \sum_{g=0}^{L-1} h_A(g) \Bigg( & \mu_{\hat{A}(g,t)} ln \frac{2\mu_{\hat{A}}(g,t)}{1+\mu_{\hat{A}}(g,t)} \\ & + \nu_{\hat{A}}(g,t) ln 2 + ln \frac{2}{1+\mu_{\hat{A}}(g,t)} \Bigg) \end{aligned} \tag{5}$$

Tizhooh's algorithm is applied directly to color segmentation using RGB in [35]. Moreover in [47] it's used to segment color image skin lesions.

But there exist an improvement of Tizhoosh algorithm, that arises from the selection of the membership functions. It was proved, that the membership functions that best represent the image are the ones used in [25, 29], that represent how similar the intensity of each pixel is to the mean of the intensities of the object or to the mean of the intensities of the background. By defining the functions in this way, the set with lowest entropy is the set that contains the greatest number of pixels around the mean of the intensities of the background and the mean of the intensities of the object.

Starting form the idea of obtaining the uncertainty from the information given by the user, we have proposed several approximations using A-IFS [8, 9] (where the key point is to calculate the intuitionistic index) and also using interval valued fuzzy sets [7] (where the key point is to calculate the lengths of the intervals). These works lead us to introduce the concept of an ignorance function to try to model the lack of knowledge from which experts may suffer when determining the membership degrees of some pixels of an image Q to the fuzzy set representing the background of the image, $Q_B$, and to the fuzzy set representing the object in the image, $Q_O$.

The classical fuzzy thresholding algorithm is modified due to the user should pick two functions, one to represent the background and another one to represent the object. We have chosen this representation since, in this way, the expert is able to get a better representation of the pixels for which he is not sure of their membership to the object

or the background. In Fig. 15 we show two membership functions, one to represent the background and the other to represent the object.

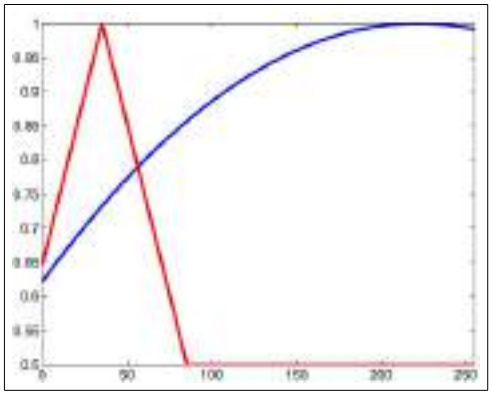


**Fig 15. Two different membership functions to represent the background and the object with t=150**

As we have already said in the previous paragraph, we are going to represent the images by means of two different fuzzy sets. For this reason, in our proposed algorithm we introduce the concept of *ignorance function* $G_u$. Such functions are a way to represent the user's ignorance for choosing the two membership functions used to represent the image (object and background). Therefore, in our algorithm we will associate to each pixel three numerical values:

- A value for representing its membership to the background, which we will interpret as the expert's knowledge of the membership of the pixel to the background.
- A value for representing its belongingness to the object, which we will interpret as the expert's knowledge of the membership of the pixel to the object.
- A value for representing the expert's ignorance of the membership of the pixels to the background or to the object. This ignorance hinders the expert from making an exact construction of the membership functions described in the first two items and therefore it also hinders the proper construction of step $(a)$ of the fuzzy algorithm. The lower the value of ignorance is, the better the membership function chosen to represent the membership of that pixel to the background and the one chosen to represent the membership to the object will be. Evidently, there will be pixels of the image for which the expert will know exactly their membership to the background or to the object but there will also be pixels for which the expert is not able to determine if they belong to the background or to the object.

Under these conditions, if the value of the function of ignorance $(G_u)$ for a certain pixel is zero, it means that the expert is positively sure about the belongingness of the pixel to the background or to the object. However, if the expert does not know at all whether the pixel belongs to the background or to the object he must represent its membership to both with the value 0.5, and under these conditions we can say that the expert has *total* ignorance regarding the membership of the pixel to the background and the membership of the same pixel to the object.

In [13] a methodology is proposed to construct Ignorance functions.

Ignorance functions can be constructed from t-norms as the miimum or te product or other functions like the geometric mean that are not t-norms. We have proposed several ways to construct IVFSs from a fuzzy membership function and an ignorance function.

In [13] it's proved that solution provided by the IVFS algorithm is better than the solution provided by the fuzzy algorithm when wrong membership functions are chosen and for special type of images (ultrasound images) the ignorance functions are useful for fast segmentation.

**Clustering:** A very common method for segmenting images is clustering. The most studied algorithm for this purpose is the Fuzzy Cluster Means (FCM), which aims to find the most characteristic point of each cluster, considered its centroid, and the membership degree of every object to each cluster. Some authors have adapted this algorithm to type-2 fuzzy sets. In [30] Hwang et al. try to define and manage the uncertainty of fuzzifier $m$ in FCM. They define the lower and upper interval memberships using two different values of $m$. To manage appropriately the uncertainty defined in an interval type-2 fuzzy set through all steps of FCM, they update cluster centers employing type reduction and defuzzification methods using type-2 fuzzy operations.

In [24] Jurio et al. transform the original image into an interval valued fuzzy set and adapt the FCM to it. In order to do that, we calculate the distance between each pattern and each cluster by the interval-valued restricted equivalence function.

**Fuzzy rule based systems:**

Data driven methods have also used in image segmentation. Starting from man made segmentations as ground truth data, machine learning algorithms have been used to create intellingent systems devoted to segment similar images as the trainig ones. Neural networks are the most common, and also fuzzy rule based systems have provided good results.

In [14] we introduce an application of interval-valued systems to the segmentation of prostate ultrasound images. The system classifies each pixel as prostate or background. The input variables are the values of each pixel in different processed images as proximity, edginess and enhanced image. The system has 20 rules and is trained with ideal images segmented by an expert.

## 7. Final remarks and future trends

As a brief resume of the conclusions of all the works reviewed using extensions of fuzzy sets in image processing, authors claim that the motivation of using extensions is their capability to deal with uncertainty present in all image processing steps. Looking to the results presented we can say that this research line is really promising. However we have found two points that we must notice:

1. All works that have been revised use interval type 2 fuzzy sets, although in the title are presented as

type-2 fuzzy sets. This occurs maybe due to the complexity of dealing with real type-2 fuzzy sets or due to the fact that it's really difficult to define a type-2 fuzzy set.

2. Works dealing with intuitionistic fuzzy sets, do not use the complete information given by the intuitionistic fuzzy sets. The non-membership does not represent anything. Authors use the hesitation index $\pi$ but as we have seen in the introduction it is equivalent to the length of an interval in IVFS. A really important conclusion is that all works can be done using Interval valued fuzzy sets. Therefore a problem of notation and work visibility is derived.

Hence future research, form the extensions point of view, must focus on problems that definition and computation of general type 2 fuzzy sets are tractable. Also, finding applications or image representations in which membership and non-membership can be generated independently in order to use all of the power of A-IFSs, should be researched.

From the point of view of image processing algorithms point of view, extensions of fuzzy sets can also be used in video summarization or content image retrieval.

**Acknowledgements:** This work has been partially supported by POCI 2010 (Programa Operacional Ciencia e Investigacao 2010), and by the Spanish Ministry of Education and Science under project referenceS TIN2010-15055 and TIN2011-29520.

# References

[1] Atanassov K.: Intuitionistic fuzzy sets. Fuzzy Sets and Systems, **20**, 87-96 (1986)

[2] Atanassov K.: Intuitionistic Fuzzy Sets. Theory and Applications, Physica-Verlag, Heidelberg (1999)

[3] Basu K., Deb R., Pattanaik P.K.: Soft sets: an ordinal formulation of vagueness with some applications to the theory of choice. Fuzzy Sets and Systems, **45**, 45–58 (1992)

[4] Bigand A. and Colot O.: Fuzzy filter based on interval-valued fuzzy sets for image filtering, Fuzzy Sets and Systems, (2009) doi:10.1016/j.fss.2009.03.010,

[5] Burillo P., Bustince H.: Entropy on intuitionistic fuzzy sets and on interval-valued fuzzy sets. Fuzzy Sets and Systems, **78**, 305–3016 (1996)

[6] Bustince H. , Burillo P.: Vague sets are intuitionistic fuzzy sets. Fuzzy Sets and Systems, **79**, 403–405 (1996)

[7] Bustince H., Pagola M., Barrenechea E., Orduna R.: Representation of uncertainty associated with the fuzzification of an image by means of interval type 2 fuzzy sets. Application to threshold computing. Proceedings of Eurofuse Workshop: New Trends in Preference Modelling, EUROFUSE,(Spain), 73-78 (2007).

[8] Bustince H., Mohedano V., Barrenechea E., Pagola M.: An algorithm for calculating the threshold of an image representing uncertainty through A-IFSs, Proceedings of Information Processing and Management of Uncertainty in Knowledge-Based Systems, IPMU, Paris, 2383–2390 (2006)

[9] Bustince H., Barrenechea E., Pagola M., Orduna R.: Image Thresholding Computation Using Atanassov's Intuitionistic Fuzzy Sets, Journal of Advanced Computational Intelligence and Intelligent Informatics, **11**(2), 187–194 (2007)

[10] H. Bustince, E. Barrenechea, M. Pagola, R. Orduna: Construction of interval type 2 fuzzy images to represent images in grayscale. False edges, Proceedings of IEEE International Conference on Fuzzy Systems, London, 73-78 (2007)

[11] H. Bustince, D. Villanueva, M. Pagola, E. Barrenechea, R. orduna, J. Fernandez, J. Olagoitia, P. Melo-Pinto, and P. Couto,: Stereo Matching Algorithm using Interval Valued Fuzzy Similarity, FLINS 2008 - 8th International FLINS Conference on Computational Intelligence in Decision and Control, Spain ,1099-1104 (2008)

[12] H. Bustince, Barrenechea E, M. Pagola and J. Fernandez: Interval-valued fuzzy sets constructed from matrices: Application to edge detection, Fuzzy Sets and Systems, (2009) doi:10.1016/j.fss.2008.08.005

[13] H. Bustince, , M. Pagola, E. Barrenechea, J. Fernandez, P. Melo-Pinto, P. Couto, H.R. Tizhoosh and J. Montero: Ignorance functions. An application to the calculation of the threshold in prostate ultrasound images, Fuzzy Sets and Systems, (2009) doi:10.1016/j.fss.2009.03.005

[14] H. Bustince, G. Artola, M. Pagola, E. Barrenechea, H. Tizhoosh,: Sistema neurodifuso intervalo-valorado aplicado a la segmentacion de imagenes de ultrasonidos, XIV Congreso Español Sobre Tecnologias y Logica Fuzzy, Spain (2008)

[15] J. Canny: A computational approach to edge detection, IEEE Transactions on Pattern Analysis and Machine Intelligence, **8**, 679-698 (1986)

[16] Tamalika Chaira, A.K. Ray: A new measure using intuitionistic fuzzy set theory and its application to edge detection. Applied Soft Computing, **8**(2), 919-927 (2008)

[17] Chaira T. , Ray A. K.: Segmentation using fuzzy divergence. Pattern Recognition Letters, **24**, 1837-1844 (2003)

[18] Cheng H., Jiang X. and Wang J.: Color image segmentation based on homogram thresholding and region merging. Pattern Recognition, **35**(2), 373-393 (2002)

[19] Deng J.L.: Introduction to grey system theory, Journal of Grey Systems, **1**, 1–24 (1989)

[20] Deschrijver G., Kerre E.E.: On the relationship between some extensions of fuzzy set theory. Fuzzy Sets and Systems, **133**(2), 227–235 (2003)

[21] Deschrijver G., Kerre E.E.: On the position of intuitionistic fuzzy set theory in the framework of theories modelling imprecision. Information Sciences, **177**, 1860–1866 (2007)

[22] Ensafi P. and Tizhoosh H., Type-2 fuzzy image enhancement, Lecture Notes in Computer Science, 3656, 159-166, (2005)

[23] Hirota K.: Concepts of probabilistic sets, Fuzzy Sets and Systems,**5**, 31–46 (1981)

[24] Jurio A., Bustince H., Barrenechea E., Pagola M., Paternain D., Ignorance-based fuzzy clustering algorithm. In 9th International Conference on Intelligent Systems Design and Applications, Pisa, Italia, 2009.

[25] Forero M.G.: Fuzzy thresholding and histogram analysis, Fuzzy Filters for Image Processing, Eds: M. Nachtegael, D. Van der Weken, D. Van de Ville, E.E. Kerre, Springer, 129-152, (2003)

[26] Gau W.L., Buehrer D. J.: Vague sets. IEEE Transactions on Systems, Man and Cybernetics, **23**(2), 751–759 (1993)

[27] Grattan-Guinness I.:Fuzzy membership mapped onto interval and many-valued quantities. Z. Math. Logik Grundlag. Mathe., **22**, 149–160 (1976)

[28] M.M. Gupta, G.K. Knopf, P.N. Nikiforuk: Edge perception using fuzzy logic, in Fuzzy Computing M.M. Gupta and T. Yamakawa (Editors) Elsevier Science Publishers, 35-51 (1988)

[29] Huang L.K., Wang M.J.: Image thresholding by minimizing the measure of fuzziness, Pattern recognition, **28**(1), 41-51 (1995)

[30] Cheul Hwang, Frank Chung-Hoon Rhee: Uncertain Fuzzy Clustering: Interval Type-2 Fuzzy Approach to $C$-Means, IEEE Transactions on Fuzzy Systems, **15**(1):107-120, (2007)

[31] Mendel J.M., John R. I.: Type-2 fuzzy sets made simple. IEEE Transactions on Fuzzy Systems, **10**(2), 117–127 (2002)

[32] Mendel J.M.:Uncertain Rule-Based Fuzzy Logic Systems, Prentice-Hall, Upper Saddle River, NJ (2001)

[33] Mendoza, O., Melin, P., Licea, G.: Fuzzy Inference Systems Type-1 and Type-2 for Digital Images Edge Detection. Journal of Engineering Letters, 15(1), 45-52 (2007)

[34] Mendoza, O., Melin, P., Licea G.: A new method for edge detection in image processing using interval type-2 fuzzy logic, In Proceedings of Granular Computing, 151-156 (2007)

[35] Tehami, S., Bigand, A., Colot, O., Color Image Segmentation Based on Type-2 Fuzzy Sets and Region Merging, LECTURE NOTES IN COMPUTER SCIENCE, 4678, (2007)

[36] Pal S. K., King R. A. and Hashim A. A.: Automatic grey level thresholding through index of fuzziness and entropy.Pattern Recognition Letters. **1**(3), 141-146 (1983)

[37] Sambuc R., Function Φ-Flous, Application a l'aide au Diagnostic en Pathologie Thyroidienne, These de Doctorat en Medicine, University of Marseille (1975)

[38] Szmidt E. and Kacprzyk J.:Entropy and similarity of intuitionistic fuzzy sets. In: Proc. Information Processing and Management of Uncertainty in Knowledge-Based Systems, Paris, France, 2375-2382 (2006)

[39] Sun Z. and Meng G.: An image filter for eliminating impulse noise based on type-2 fuzzy sets. In: ICALIP 2008. International Conference on Audio, Language and Image Processing, 1278-1282 (2008)

[40] Tizhoosh H.R.: Image thresholding using type-2 fuzzy sets, Pattern Recognition, **38**, 2363–2372 (2005)

[41] Tizhoosh H., Krel G. and Muchaelis B.:Locally Adaptive Fuzzy Image Enhancement, In: Computational Intelligence, Theory and Applications, proceedings of 5th fuzzy days, 272-276 (1997)

[42] Tulin Yildrim M., Basturk A. and Emin Yuksel M.:A Detail-Preserving Type-2 Fuzzy Logic Filter for Impulse Noise Removal from Digital Images, In Proc. FUZZIEEE, U.K., 751-756 (2007)

[43] Vlachos I. K. and Sergiadis G. D.: Intuitionistic fuzzy information - Applications to pattern recognition. Pattern Recognition Letters, **28**, 197-206 (2007)

[44] Vlachos I. and Sergiadis G.: The Role of Entropy in Intuitionistic Fuzzy Contrast Enhancement, Lecture Notes in Computer Science, Foundations of Fuzzy Logic and Soft Computing, 104-113 (2007)

[45] Wang S.T., Chung F.L., Hu D.W. and Wu X.S.: A new Gaussian noise filter based on interval type-2 fuzzy logic systems, Soft Computing, **9**, 398-406 (2005)

[46] Wei S. and Zeng-qi S.: Research on Type-2 Fuzzy Logic System and its application, Fuzzy Systems and Mathematics, **19**, 126-135 (2005)

[47] M. Emin Yuksel, Senior Member, IEEE, and Murat Borlu, Accurate Segmentation of Dermoscopic Images by Image Thresholding Based on Type-2 Fuzzy Logic, IEEE Transactions on Fuzzy Systems, (2009) doi: 10.1109/TFUZZ.2009.2018300

[48] Zadeh L.A.: Fuzzy sets, Information Control, **8**, 338–353 (1965)

[49] Zadeh L.A.: The concept of a linguistic variable and its application to approximate reasoning – I. Information Sciences, **8**, 199–249 (1975)

[50] Zhonggui Sun; Guangwu Meng: An image filter for eliminating impulse noise based on type-2 fuzzy sets, ICALIP 2008, International Conference on Audio, Language and Image Processing, 1278-1282, (2008)

SCIENTIFIC REPORTS

# Biometric Recognition: An Overview

Raul Sanchez-Reillo, University Group for Identification Technologies, Carlos III University of Madrid, Spain, rseillo@ing.uc3m.es

## Abstract

Biometric Recognition is reaching a certain level of maturity, being deployed to cover the user identify or authenticate users in a variety of applications. Several modalities are applicable nowadays for recognizing humans (e.g. fingerprint, face, iris, signature or vascular), while others are still under development (e.g. gait, ear or keystrokes). But even in those modalities considered mature, there are still open issues that require further research, especially when considering their deployment in applications that handle large sets of population. This paper will provide a short overview to this technology, highlighting the current state of the art and the steps forward being demanded nowadays.

## Introduction

Applications such as physical access control, access to on-line services, access to use restricted infrastructure, or even National Security, have a common need: recognizing persons. As it is well known, this can be solved by using: a) some secret knowledge by the citizen (e.g. passwords); b) the belonging of a certain token (e.g. credit cards, National ID cards or passports); and/or c) the biological or behavioural characteristics of the user (e.g. fingerprints, facial image or handwritten signature). This third option is what is called Biometrics, and has the advantage of recognizing an individual, not from what he/she knows or belongs, but from what he/she really is.

This definition of Biometrics [1], together with the interest of searching for solutions towards reducing international crime, led to the erroneous idea that Biometrics is a primary security technology, and treated as direct way to improve the security of systems and applications. The fact that biometric modalities do also have some limitations, both in performance and in resistance to fraudulent attacks, has created a certain level of disappointment and lack of trust in the technology.

The truth is that the most important characteristics of Biometric Recognition, is that it provides a mean to identify and/or authenticate persons that is more closely related to the human way of performing such operation.

**The most important characteristics of Biometric Recognition, is that it provides a mean to identify and/or authenticate persons that is more closely related to the human way of performing such operation**

This can be used to increase the level of comfort and usability of systems at different sectors of the population. By gaining comfort and usability, citizens will use the technology without introducing bad practices that are intended to help their everyday life. For example, banks indicate their clients that PIN codes of their credit cards have to remain secret and that those credit cards shall be kept within the hands of the cardholder. But unfortunately, a significant number of citizens do not follow these instructions. Some users, due to their lack of ability to remember passwords, keep the PIN code written on a paper within the same wallet where the card is stored. If a pickpocket steals the wallet, he/she gains immediate access to the financial services of such users. Other users prefer to keep the PIN codes secret, but they use the same PIN code in several applications, regardless wheter some of those applications may be secure enough. This can also be a help for an attacker, gaining knowledge of the PIN code in the non-secured application, and then using it in all other applications. Furthermore, there are citizens that, for convenience, prefer to tell the PIN code and even give the card to some relatives (e.g. to allow their children or partners to get money from the ATM without being bothered).

All these examples, are only a small portion of the use cases that draw unsecured behaviour of the citizen, mostly by their need of having a more adaptable and comfortable way of using the available services. By using Biometric Recognition in a convenient way, these bad practices can be partially or completely removed, improving indirectly the security of the whole system. Therefore, it is much better to consider Biometrics as a convenience technology, than a security technology.

**By using Biometric Recognition in a convenient way, these bad practices can be partially or completely removed, improving indirectly the security of the whole system**

Throughout this paper, a short description about the technology inside biometric systems will be provided, as well as a discussion about the most relevant modalities existing nowadays. This will lead us to present the existing gaps in the technology, as well as the efforts that the research community are applying to close those gaps.

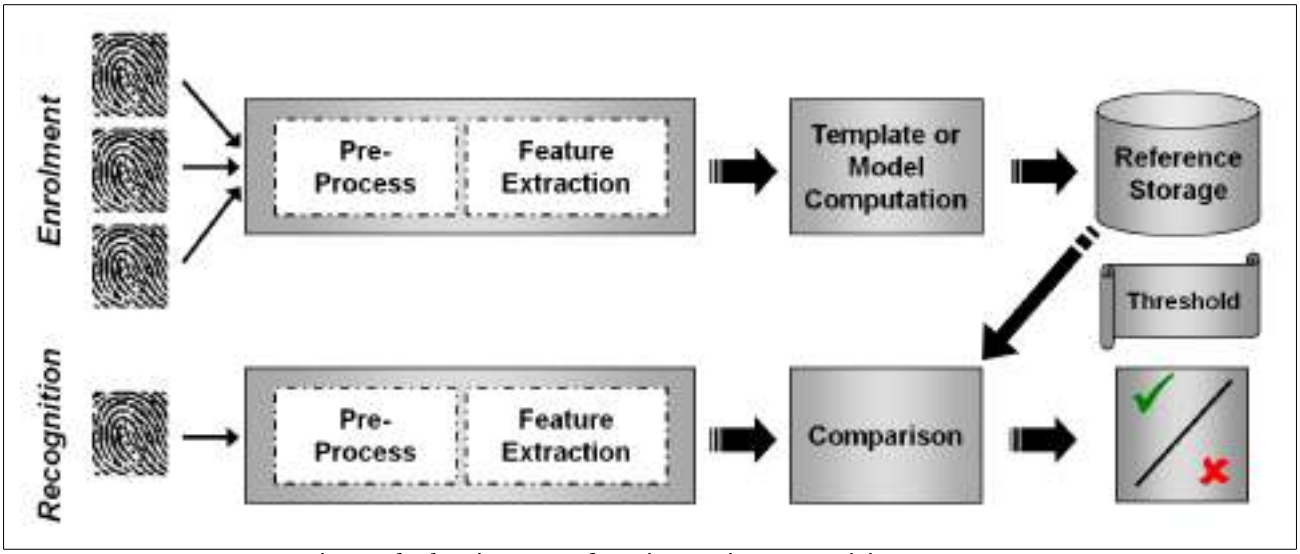



**Fig1. Block Diagram of a Biometric Recognition system**

## Biometric Recognition Technology

Biometric Recognition can be deployed following two different kinds of schemes, which solve two different groups of applications. The **Identification scheme** is that one when the sample taking from the user is compared with all templates previously stored in the database. This is the typical situation of a forensic analysis where a latent fingerprint acquired from a crime scene is compared with all fingerprints stored in the police database of all registered criminals.

On the other hand, when using the **Authentication scheme** (also called Verification scheme) the sample captured is only compared with the template previously stored of that same user. Therefore it is needed to claim the identity of the user to be authenticated at the time as the biometric sample is acquired. This scheme can be applied to any of the everyday life applications that authenticate persons by using passwords or tokens (such as credit cards).

Independently of which scheme is used, Biometrics Recognition is based on the same principles that any Pattern Recognition technology. Figure 1 shows how a biometric system is based on two phases.

**Independently of which scheme is used, Biometrics Recognition is based on the same principles that any Pattern Recognition technology**

The first one is the Enrolment phase, where some biometric samples from the user to be registered are acquired. From those samples, a biometric reference is calculated (i.e. a biometric template or a biometric model) and stored within the system. In the case of an Identification system, it will be stored in a database, while in an Authentication system it may be even stored in a secure token carried by the user (e.g. a smart card). Once the user is enrolled in the system, he/she can use the system in its Recognition phase, where once again, a sample from the user is acquired, and compared with biometric references.

In any of the two phases, from the sample acquired by the sensor till the comparison or template calculation stage, some signal processing blocks have to be followed. Those blocks depend completely on the biometric modality used, but they can be classified into two main blocks. The first one is a pre-processing block, where all information in the sample that does not carry relevant information is removed (e.g. locating the sample within the image or signal and removing background information). This is needed to reduce computational needs in further stages. The second block is the feature extraction block, where those features that are characteristic of the user but not of the whole population (i.e. those discriminative features) are extracted to allow identification.

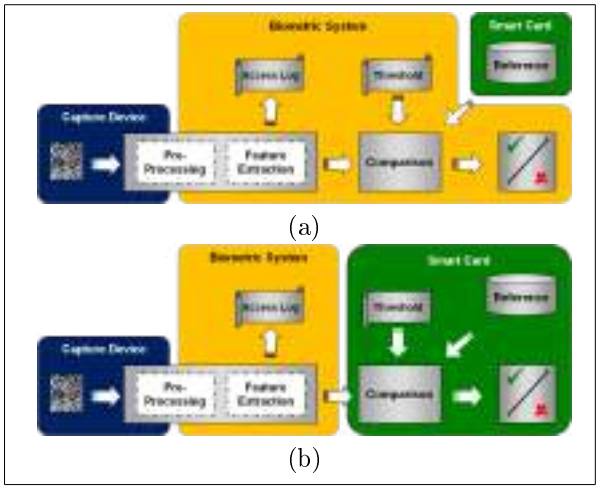


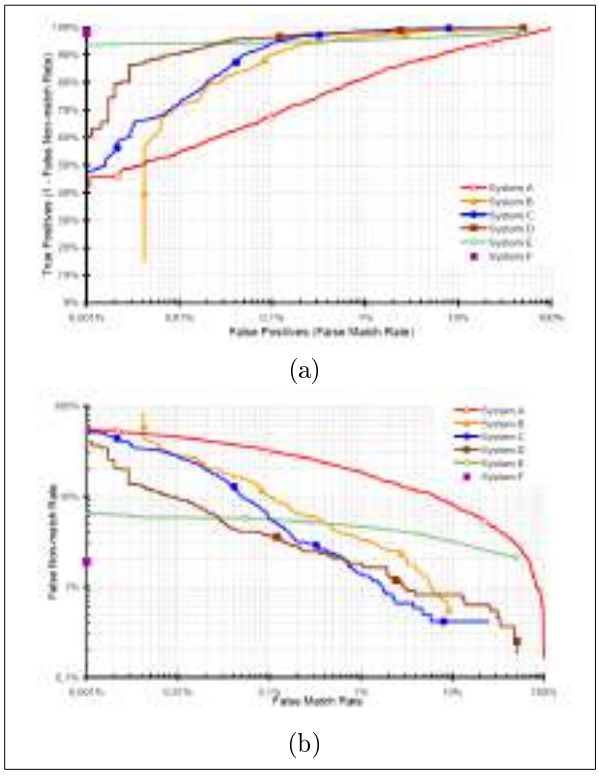

**Fig.2 Two approaches for implementing an Authentication system: a) Store on Card; b) Comparison on Card**

In addition to these two blocks, there is another block in parallel to both of them, which is in charge or analysing the quality of the sample or the processing done, so as to decide if the quality is not good enough and, in such case, discarding the sample. Discarding low quality samples will mean an error in the acquisition stage (e.g. a Failure to Acquire), but not an error in the comparison stage (i.e. a False Match or a False Non-Match).

As it has been previously mentioned, when the biometric system is to be implemented following an Authentication scheme, the user can carry his/her own biometric reference in a secure device, such as a smart card. In such a case two possibilities may exist. The first one is that the biometric reference is stored in the smart card, being read by the biometric system (under security mechanism), as to be able to compare the sample with the reference stored. The other possibility is that the smart card does the comparison itself, not releasing ever the biometric reference of the user. This second approach is more secure, but it also demands a more expensive smart card. Figure 2 shows graphically these two approaches.

**The main difference between comparing passwords and comparing biometric samples, is that in the former case an exactness comparison is done while in the latter a similarity analysis is done**

In order to end this short introduction to the technology of Biometric Recognition technology, let's talk about the comparison stage. The main difference between comparing passwords and comparing biometric samples, is that in the former case an exactness comparison is done (i.e. any single difference will consider that two passwords do not match), while in the latter case a similarity analysis is done (i.e. a percentage of how the two samples are alike is given, and the decision is done using a threshold decided after a probabilistic study).



(a)

(b)

**Fig.3 Examples of graphical representation of error rates (images taken from ISO/IEC 19795-1): a) ROC curve; b) DET curve**

The use of this probabilistic analysis in Biometrics, leads to two kinds of error rates, as two samples are never identical and there is always the probability of having two samples from the same user that are less similar than the threshold used (i.e. False Non-Match) or two samples from different users that present a similarity above the threshold decided (i.e. a False Match). By counting these errors, two error rates are computed: False Non-Match Rate (FNMR) and False Match Rate (FMR), which when applied to an operational system are referred as False Rejection Rate (FRR) and False Acceptance Rate (FAR).

These two error rates evolve in a complementary way, as changing the threshold to lower one of them, will immediately increase the other one. Therefore performance of Biometric Recognition systems are usually described by using curves such as the ones shown in Figure 3.

## Biometric Modalities

Biometrics can be applied to a great variety of parts of the body, extracting different features from each of them. Each of these specific implementations of Biometric Recognition is called **modality**. There are several well know modalities, such as fingerprint, iris, face, voice and handwritten signature, while others are less known such as vascular or palmprint.

**Biometrics can be applied to a great variety of parts of the body, such as fingerprint, iris, face, voice, handwritten signature, vascular or palmprint**

Having such a variety, it is typical to compare all modalities in search for the best one. In order to do so, several parameters can be considered:

- **Universality:** That tells the percentage of the population that presents extractable features for that modality. This percentage can depend not only on the physical availability of that part of the body, but also on the adaptation of the population conditions to the acquisition device. For example, universality of fingerprints depend on the amount of population with one available finger, but also on the percentage of the population that may have eroded fingerprints (e.g. carpenters) that make its capture not possible with certain kind fingerprint sensors.
- **Uniqueness:** The probability of two citizens within the population not presenting the same biometric features. This is directly related to the discriminative power of the features extracted in the biometric modality.
- **Stability:** Whether the extracted features remain stable throughout time, weather conditions, health status, age, etc.
- **Acquisition simplicity:** If there are acquisition methods that are easily to use by an average citizen within the target population. This is directly related to the usability level achieved, and therefore inversely related to the user rejection to use the system.
- **Performance:** i.e. the error rates achieved by the modality.

- **User acceptance:** This can be affected by the usability of the system, but also on other conditions, such as cultural behaviour, police implications, etc.

- **Resistance to fraudulent use:** Whether the modality and its commercial systems can recognize attacks such as spoofing, replay attacks, etc.

- **Cost.**

- And **any other parameter** that may impact on the successful deployment of the technology, such as adaptation to the scenario where the system is to be used.

It is important to note from the very beginning that there is not a single biometric modality that is better than the rest in all cases. With so many parameters, it is impossible that one modality is the best one in each of the different parameters, for all different scenarios.

**It is important to note that there is not a single biometric modality that is better than the rest in all cases**

For example, there is the common believe that speaker recognition (i.e. voice) is quite bad because of the lack of stability of the samples and the poor recognition rates achieved. But when considering an application over the phone, such as telephone banking, speaker recognition is the most natural way of identifying the user, as the citizen will talk with normality and the acquisition device is already in the hands of the user (i.e. the phone). This is a simple example where it can be seen that an a priori bad modality, can be considered the best one in certain scenarios.

From the great range of biometric modalities, only the most relevant ones are being briefly described in this paper.

**Speaker Recognition** is a modality that has been scientifically studied for more than 3 decades now (e.g. [2]). There are a huge number of methods to extract features and to compare features from samples. Some of these methods depend on the text corresponding to the utterance provided (text-dependent approaches), while some others are considered to be text-independent (i.e. the speaker is allowed to say whatever sentence he/she likes). Speaker recognition systems, in order to avoid replay attacks, even using text-dependent approaches, have a parallel process of recognizing the text uttered by the user. This is done to check if the pronounced is corresponding to a certain text claim requested by the system. Obviously, this claimed text change every time the system is used to avoid attacks. Unfortunately parameters such as age, stress, health conditions, surrounding noise, etc. are not yet isolated from the extracted features. This drawback provides one of the most important challenges of this technology, as the stability of the features is quite low.


**Fig.4 Fingerprint samples taken from the Fingerprint Verification Competition 2004 [3]**

**Fingerprints** are one of the most known biometric modalities [3]. Having been scientifically studied for more than a century, it is based on studying the structure that the skin ridges and valleys present at the finger tips. The universality of this modality is well studied and it is extremely high, being considered by police forces as the primary positive identification method since the beginning of the $20^th$ century. On the drawback point of view, this police implication is the reason behind the rejection of this modality by certain groups of population. Also, the high performance of this modality may be reduced by using capture device that are not adapted to the variability of the scenario or the population; typically when using cheap semiconductor sensors.

**Fig.5 A face recognition system for web applications (image taken from [5])**

**Facial Recognition** presents characteristics similar to those told about Speaker Recognition [4]. It is a modality that has been also studied for decades, but the lack of stability due to age, surgery operations, complements such as glasses or piercings, changes in look especially related to the hair and beard, or different kinds of makeup,

leads to present high error rates. Even illumination and facial expression present real challenges to this modality. Current advances in this modality, as well as the use of 3D capture devices, have improved greatly its performance.

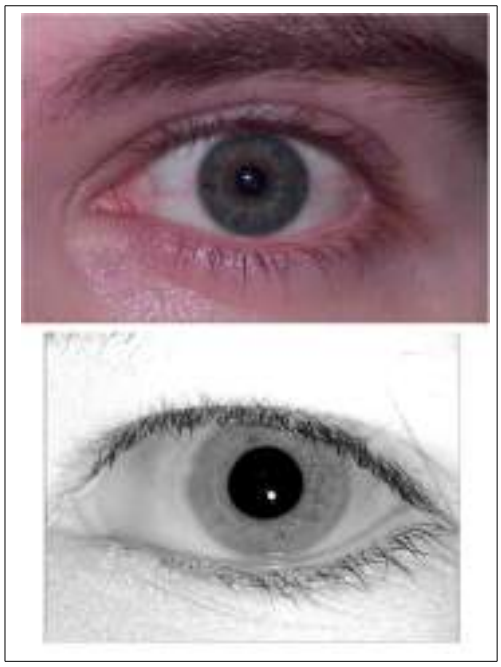


**Fig.6 Examples of iris images in visual and infrared ranges**

**Iris Pattern** is a relatively recent modality, being published by John G. Daugman in 1993. It is based on acquiring an infrared image (i.e. a photograph or a video sequence) of the human eye, and from that, removing all pixels out of the boundary of the iris and the sclera, and inside the boundary of the iris and the pupil [6]. Then that portion of the image is processed using multi-resolution techniques in order to extract features of the texture of the iris (i.e. not about the shape or the colour). Its performance is even higher than the one for fingerprints, presenting some inherent anti-spoofing mechanisms. Unfortunately its cost is too high for most of current applications.

**Handwritten Signature** is one of the oldest biometric modalities. It is a biometric trait that is not only used for recognizing the identity of the signer, but also to acknowledge or accept the content of the manuscript being signed. Some decades ago, this biometric modality entered the automation process, and technology allowed using capturing devices that do not only acquire the signature graph, but also the movements of the signer. This leads to the creation of two different modalities from this same biometric trait. When analyzing only the graph created, the modality is called static signature, or off-line signature. When analyzing the movements of the signer when signing, the modality is called dynamic signature, or on-line signature. On-line signature provides better performance, but needs special tablets or other kind of devices that are able to capture and register the movement of the pen while signing. Although error rates are still far from those of fingerprint or iris, the usability and familiarity of the modality for the average user is one of its greatest advantages. Also, it can be immediately implemented in any of the traditional systems where handwriting signatures are used, even complementing the use of the paper with the acquisition of electronic information.

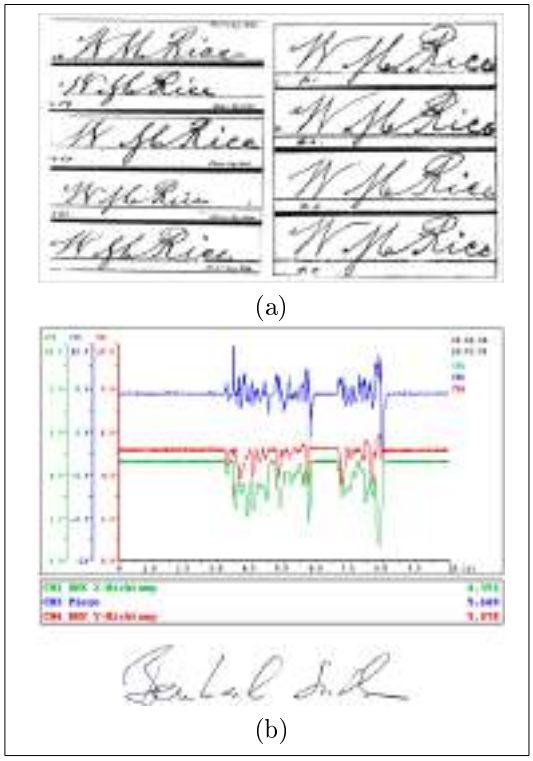



**Fig.7 Samples for handwritten signature: a) Off-line signatures used in a trial in 1900; b) Representation of on-line signature signals (image taken from http://cis-research.eu/node/130)**

And the last modality to be mentioned in this paper is **Vascular Biometrics**, i.e. acquiring information about the pattern of the veins in a particular part of the body [7]. This is a very recent modality, but its usability, price and performance have made it to gain popularity and acceptance. Typically the part of the body used is the hand or a finger, and the image is captured by using infrared photography, which is able to emphasize the image of the superficial veins under human skin. Although further tests should be carried out, the current results obtained by independent tests have shown a performance quite close to fingerprints, with a higher level of universality and usability. Further works should consolidate this modality among the most reliable ones.

## Gaps and Current R&D Lines

Biometric systems are currently out in the market and in position to be used. But this does not mean that all work in Biometrics is already done. There are a lot of R&D lines open with great amount of resources being applied worldwide.

**Biometric systems are currently out in the market and in position to be used but there are a lot of R&D lines open with great amount of resources being applied worldwide**

The most immediate R&D Lines is to improve the performance of each of the modalities, either to reduce

error rates, or to adapt the solution to cheaper sensors. The most important issue for this research line is how the improvement in performance is validated, because performance improvement depend on the database used for the evaluation. Also, it is important that those evaluation are done by independent third parties that can provide un-biased results. Related to this need, there have been a number of independent public contests for some of the modalities previously mentioned [8], as well as some independent laboratories available.

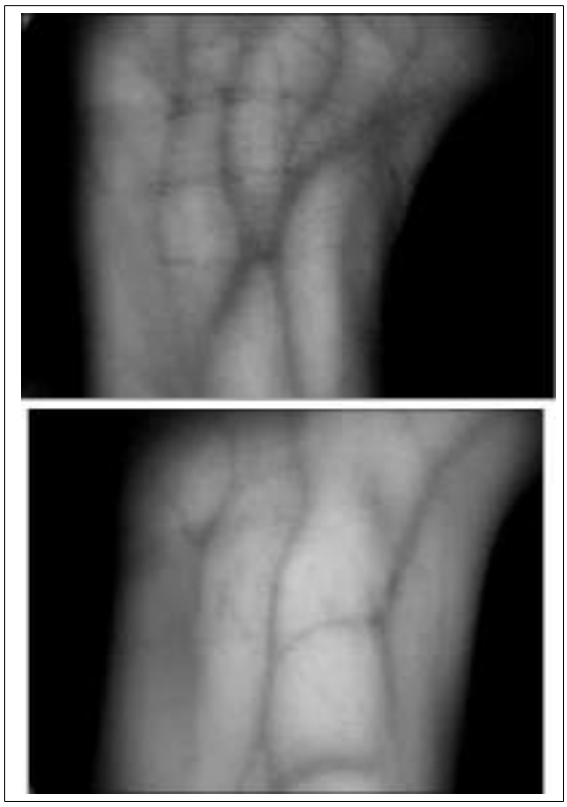


**Fig.8 Samples of vascular patterns of human wrists**

Another current need is to evaluate usability of biometric systems, in order to measure that level of usability achieved, and therefore being able to improve it. Now that biometric systems are being deployed, a lot of unexpected situations are found, especially when biometric systems are installed in scenarios different from those initially used for their design (e.g. using an office-based system to be used by engineers, in an outdoor scenario with average population). Studying the usability of biometric systems is even harder than studying the usability of other computer-based tools, as the interaction of the user may also affect the error rates achieved by the system. Therefore, works like those in [9] are devoted to detect the casuistic that users and biometric system will face, and their impact in the performance of the system.

Another important factor, as it has been mentioned slightly above, is the impact of the scenario and/or platform used when deploying the biometric system. The influence of the environmental conditions (e.g. humidity, temperature, surrounding light and/or noise, etc.) can lead to strong deviations in the performance of the system [10]. Furthermore, implementing the biometric solution in a certain kind of platform (e.g. mobile devices), may bring new challenges that can affect the error rates achieved, compared to the initial reference platform (e.g. a PC-based implementation).

**The influence of the environmental conditions (e.g. humidity, temperature, surrounding light and/or noise, etc.) can lead to strong deviations in the performance of the system**

Currently both, research institutions and industry, are approaching platforms that could ease the access of the technology to end-users. This means that studying the way these solutions may be implemented in devices such as tablets or smart phones is a hot topic nowadays.

Although it has been mentioned at the beginning of this paper, Biometrics should not be considered as a security tool. But it is clear that biometric systems are many times used in contexts where evaluating the level of security is an important need. In this line, the direct application of Common Criteria (http://www.commoncriteriaportal.org/), the world reference specification of how security shall be evaluated in Information Technology systems, is not an easy task. In addition to the fact that biometric systems may be attacked from several points [11] (see Fig. 9), the dependence of Biometrics on statistical results brings new challenges. It has to be noted that biometric performance depends not only on algorithms, but on the sensors used, the usability, the user attitude or even the environmental conditions.

**Biometric systems are many times used in contexts where evaluating the level of security is an important need. But performance depends not only on algorithms, but on the sensors used, the usability, the user attitude or even the environmental conditions.**

Last but not least, another hot topic for the R&D community is the analysis and detection of spoofing attacks (i.e. using artificial fingers [12], parts of a dead body, etc.). Each biometric modality suffers from its own vulnerabilities. Therefore there are several R&D groups and companies are researching in methods to detect this kind of attacks, and develop countermeasures against them. This kind of studies are, in most cases, confidential, due to the potential impact on the commercial projection of a determined product, or even their influence in National Security, when Biometrics is used for certain applications such as Immigration Control.

## Conclusions

Biometric Recognition is entering a certain level of maturity, being able to use its current products in several applications and scenarios. As any other technology, Biometrics presents its own advantages and disadvantages and further work is needed to reduce the number of disadvantages to a minimum. But from the advantages point of view, Biometrics provides a way to recognize individuals closer to the way that human beings recognize each other. Therefore it is a technology with a high potential for improving comfort and usability in a large range of products,

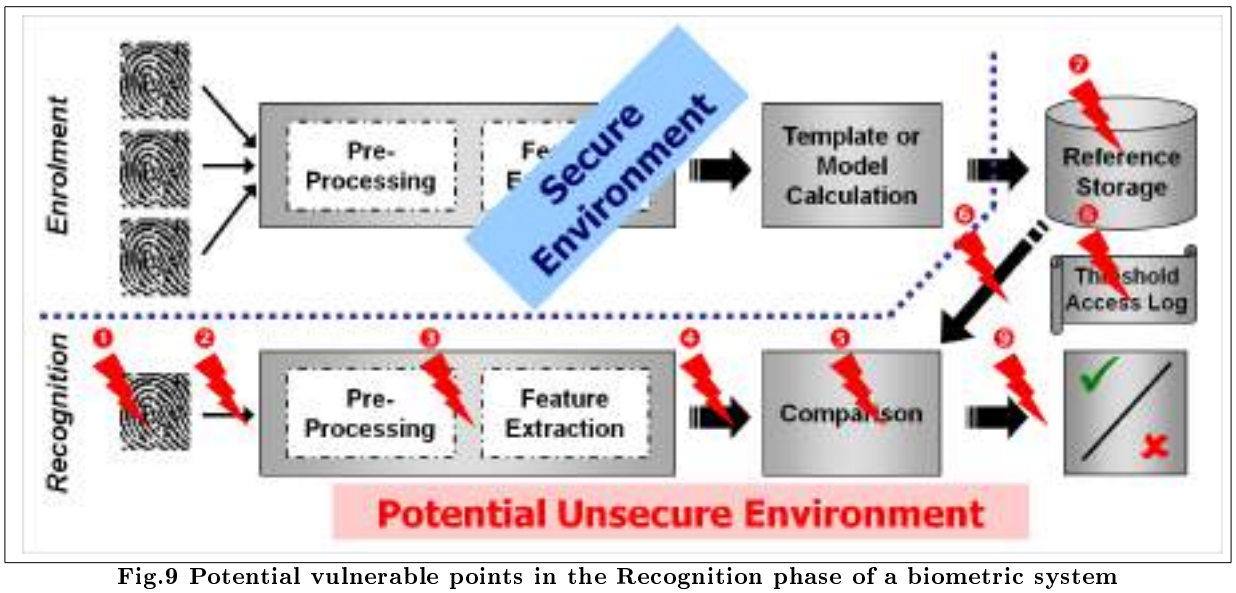



**Fig.9 Potential vulnerable points in the Recognition phase of a biometric system**

especially when the average citizen is targeted (i.e. a citizen that may not have any technological background or interest in using the system). This characteristic of being a convenient technology can, indirectly, improve the security level achieved by current systems, by removing most of the bad practices that users have nowadays.

## References

[1] Jain, A. K.; Flynn, P.; Ross, A. A.; Handbook of Biometrics; Springer; 2008.

[2] Reynolds, D. A.; An overview of automatic speaker recognition technology; IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), pages IV-4072 - IV-4075, 2002.

[3] Maltoni, A.; Maio D.; Jain, A. K.; Prabhakar S.; Handbook of Fingerprint Recognition; Springer; 2009.

[4] Li, S. Z.; Jain, A. K.; Handbook of Face Recognition; Springer, 2011.

[5] Cognitec Systems GmbH, http://www.cognitec-systems.de/Applications-for-convenience-a.17.0.html

[6] Daugman, J.; Probing the Uniqueness and Randomness of IrisCodes: Results From 200 Billion Iris Pair Comparisons; Proceedings of the IEEE, vol. 94, no. 11, pages 1927 - 1935; 2006.

[7] Kumar, A.; Prathyusha, K.V.; Personal Authentication Using Hand Vein Triangulation and Knuckle Shape, IEEE Transactions on Image Processing, vol. 18, no. 9, pages 2127 - 2136; 2009.

[8] Petrovska-Delacrétaz, D.; Chollet, G.; Dorizzi, B.; Guide to Biometric Reference Systems and Performance Evaluation; Springer; 2009.

[9] Kukula, E.P.; Sutton, M.J.; Elliott, S.J.; The Human-Biometric-Sensor Interaction Evaluation Method: Biometric Performance and Usability Measurements; IEEE Transactions on Instrumentation and Measurement, vol. 59, no. 4, pages 784 - 791; 2010.

[10] Sanchez-Reillo, R.; Fernandez-Saavedra, B.; Liu-Jimenez, J.; Kwon, Y.-B.; Changes to vascular biometric system security & performance; IEEE Aerospace and Electronic Systems Magazine, vol. 24, no. 6, pages 4 - 14; 2009.

[11] Ratha, N.K., Connell, J.H.B.R.M.; Enhancing security and privacy in biometrics-based authentication systems; IBM Systems Journal 40(3), 614-634; 2001.

[12] Matsumoto, T.; Matsumoto, H.; Yamada, K.; Hoshino, S.; Impact of Artificial "Gummy" Fingers on Fingerprint Systems; Proceedings of SPIE, vol. 4677, Optical Security and Counterfeit Deterrence Techniques IV; 2002.

WORKING GROUPS

# The EUSFLAT Working Group on Philosophical Foundations

Rudolf Seising, Settimo Termini, Enric Trillas.
European Centre for Soft Computing (ECSC), Mieres (Asturias), Spain

The EUSLAT working group on Philosophical Foundations was launched at September 13, 2007 in the assembly of EUSFLAT in Ostrava (Czech Republic). The proposal, given by Rudolf Seising (coordinator of this working group since that time) was approved by the assembly in the Congress Hall of the hotel Imperial, Ostrava. The other coordinators of this working group were/are Enric Trillas (2007-2009) and Settimo Termini (since 2009)[2].

**I. Workshop on Soft Computing in Humanities and Social Sciences, ECSC, Mieres, March 5-6, 2009**

It was the aim of the founders of this working group to motivate philosophers, educators, and scientists, to approach the roots of Soft Computing, as well as its results in real applications. To this end, this working group should initially consist in:

- A forum for the analysis of the grounds and methodologies of Soft Computing and, in particular, of Fuzzy Logic and Computing with Words/Meanings, where new points of view could be openly and quickly discussed, and from which some scientific work/publications could follow up.
- Among new possible points of view we indicate also the one of investigating whether the relationships between Fuzzy sets and Soft Computing on one side and Humanities and Social Sciences on the other side could indicate ways of interaction between disciplines different from the "simple" application/use of theoretical results and techniques of a discipline to problems of another discipline.
- Efforts to create an adequate environment to interest educators, and specially High School teachers, to approach Fuzzy Logic, in principle only to lengthen their horizons of knowledge.
- The organization of special sessions in those conferences where it might be possible to spread off the knowledge of Soft Computing to new areas of either research or direct application of its methods.

To realize our aims the working group organized and operated many activities during the last four years: workshops and seminars and other scientific meetings, courses and sessions:

- Workshop on Soft Computing in Humanities and Social Sciences at the ECSC in Mieres (Asturias), Spain, March 5-6, 2009[3].
- International Seminar on Soft Computing in Humanities and Social Sciences at the ECSC in Mieres (Asturias), Spain, September 10-11, 2009[4].
- First International Symposium on Fuzzy Logic, Philosophy and Medicine and the First International Open Workshop on Fuzziness and Medicine took place in March 23-25, 2011 at the ECSC in collaboration with the support of an anonymous donator, the International Fuzzy Systems Association (IFSA), the European Society for Fuzzy Logic and Technology (EUSFLAT), the Hospital Universitario Central de Asturias and Springer-publisher[5].

**Introductory talk of Prof. Dr. Kazem Sadegh-Zadeh at the First International Symposium on Fuzzy Logic, Philosophy and Medicine ECSC, Mieres, March 23, 2011**

[2] www.eusflat.org/research/phil.htm
[3] www.softcomputing.es/schss2009/en/program.php
[4] www.softcomputing.es/schss2009/en/home.php
[5] www.softcomputing.es/metaspace/portal/3/189-news-andevents?one_article=1&mtsp_nocache=yes&pms=1,157,189007,view,normal,0&id_html_article=671&back_ipg=189

In the years 2010 and 2011 we started two new formats of scientific events in our area.

**Audience in the First International Symposium on Fuzzy Logic, Philosophy and Medicine and First International Open Workshop on Fuzziness and Medicine, ECSC, Mieres, March 23-25, 2011.**

A new format of scientific conversation meetings is called ´´Saturday Scientific Conversations" (SSC). The SSC 2010 took place under the heading ´´Philosophy, Science, Technology and Fuzzy Logic" in Gijon, in the Asturias region of Spain, in May 15, 2010. It was organized by the ECSC under the sponsorship of the Government of Asturias and CajAstur Savings Bank. Four speakers, the mathematician Enric Trillas (Mieres, Spain), the physicist Settimo Termini (Palermo, Italy), the physicist Gianpiero Cattaneo (Milan, Italy) and the historian and philosopher of science Rudolf Seising (Mieres, Spain) contributed to these very interesting conversations and discussions on "Philosophy, Science, Technology, and Fuzzy Logic". This first edition received the participation of 15 young researchers coming from many European countries[6].

**The speakers of the First SSC in Gijon, May 15, 2010: f.l.t.r.: Rudolf Seising (hidden), Gianpiero Cattaneo, Settimo Termini and Enric Trillas**

The SSC 2011 was organized in Palermo, in the Sicily island of Italy in May 14, 2011 and the four speakers who contributed to these interesting conversations and discussions on the topic "Thinking and Fuzzy Logic" were: again Enric Trillas, Settimo Termini and Rudolf Seising, and also the electrical engineer Claudio Moraga (Mieres, Spain). This edition was organized for 22 young researchers coming from many European countries under the sponsorship of Centro Interdipartimentale per le Tecnologie della Conoscenza, Consiglio Nazionale delle Ricerche Istituto di Cibernetica "E. Caianiello" and Facoltà di Scienze MM FF NN, Dipartimento di Matematica ed Informatica[7].

We also established a new format of teaching in our area that we call "CRF". CRF is a course for "Reflecting on fuzziness (CRF)". Our first version that occurred from September 12 to October 14, 2011 the European Centre for Soft Computing (ECSC) had the subtitle "Philosophy, Science, Technology".

**Three of the speakers of the Second SSC in Palermo, May 14, 2011: f.l.t.r.: Enric Trillas, Settimo Termini and Claudio Moraga.**

CRF is a philosophical tendency intensive course for few students, and to reflect, to speculate, to think on fuzziness and Fuzzy Sets in different areas. The CRF is mainly intended for people interested in the evolution of scientific and technological ideas and CRFstudents should reflect on new ideas in modern science and technology. The program of the CRF was built up of five parts that corresponded with two lectures of 1.5 hours by the professors, plus several joint seminars of two hours each. The five parts were: Reflections on the History of Fuzzy Sets and Systems by Rudolf Seising, Reflections on Fuzzy Logic versus Classical Logic by Enric Trillas, Reflections on Fuzzy Control by Luis Argüelles, Reflections on Neuro-fuzzy and Evolutive Systems by Claudio Moraga and Reflections on Computing with Words and Perceptions Gracián Triviño.

[6] http://ssc.unipa.it/SSC_2011/Past_Edition.html
[7] http://ssc.unipa.it/SSC_2011/2011.html

In addition, and during each one of these parts, some recognized researchers of different age and background addressed the students with some of his/her personal scientific, technological or intellectual contributions and personal scientific experiences, and attended his/her questions: Sergio Damas, Itziar García-Honrado, Gabriella Pasi, Adolfo Rodriguez de Soto, Enrique Ruspini, Michio Sugeno and Enric Trillas.

**The five students of the first CRF and the "complementary lecturer Itziar Garcia-Honrado (at the desk); f.l.t.r. Fabio D'Asaro (Palermo, Italy), Anett Hoppe (Magdeburg, Germany), Martin Pereira Fariña (Santiago de Compostela, Spain), Oscar Cosido (Santander, Spain) and Begoña Menendez Lopez (Oviedo, Spain).**

Five students from Italy, Germany and Spain have been accepted and all five students passed the first CRF successfully. The next CRF is planned to take place in the ECSC in Spetember 2012.

On April 29, 2011 the Foundation for the Advancement of Soft Computing (by means of the ECSC) and Cajastur Savings Bank, organized the First "lfredo Deano" Seminar on Ordinary Reasoning, to be held in the Cultural Center "Muralla Romana" of Gijon (Spain).

This seminar, coordinated by Prof. Alejandro Sobrino (Santiago de Compostela), was open to experts and non experts in the field of logic and it aims to become an invitation to know some modern attempts to extract the underlying logic inherent to various aspects of ordinary reasoning, as the imprecision, the time or the use of cases in the argumentation. It also intends to be a discussion forum in which attendees can discuss the shortcomings, achievements and challenges ahead in the fascinating world of how to accomplish a computer that is able to simulate the characteristics of ordinary reasoning[8]. The final goal is to pay tribute to Alfredo Deaño, who became the first Spanish logician that disseminated the logic of ordinary language in his famous book: Introduction to Formal Logic (1974).

**Speakers at the Round Table in the first "Alfredo Deaño" Seminar, April 26, 2011.**

Finally, we should note that two years ago Alejandro Sobrino and Martin Pereira (University of Santiago de Compostela) launched the series of the Newsletter Philosophy & Soft Computing with articles, book reviews and interviews concerning the area of Soft Computing to Humanities and Social Sciences, especially Philosophy. The first volume appeared in 2009 and was published in the ECSC web[9]. The next four volumes did appear in 2010 and 2011[10].

**Audience in the Second SSC in Palermo, May 14, 2011.**

Our view on the relations of Soft Computing disciplines to Humanities and Social Sciences led also to the formation of new ´´areas" for paper submissions in relevant international conferences:

- a new area "Fuzzy Logic in Social Sciences" was established to the 2009 IFSA World Congress and 2009 EUSFLAT Conference July 19-23, in Lisbon, Portugal[11] and
- a new area "Uncertainty and Social Sciences" was established to the 13th International Con-

[8] http://www.softcomputing.es/metaspace/portal/3/328-alfredo-dea%C3%B1oseminar?pms=1,7,293003,view,normal,0
[9] http://docs.softcomputing.es/public/NewsletterPhilosophyAndSoftComputingNumber_1.pdf
[10] http://docs.softcomputing.es/public/NewsletterPhilosophyAndSoftComputingNumber_2.pdf
[11] http://ifsa2009.ist.utl.pt/index.php?option=com_content&view=article&id=59&Itemid=63
[12] http://www.mathematik.uni-marburg.de/~ipmu2010/areaChairs.html

ference on Information Processing and Management of Uncertainty in Knowledge-Based Systems (IPMU-2010), Conference Center Westfalenhallen, Dortmund, Germany, June 28 - July 2, 2010[12].

**Audience in the Secnd SSC in Palermo, May 14, 2011.**

Our members could organize some special sessions for such conferences:

- Special session "The Meaning of Information, Cognition, and Fuzziness" at the North American Fuzzy Information Society Annual Conference (NAFIPS-09), University of Cincinnati, Ohio, USA, June 14-17, 2009.
- Special session "Philosophical, Sociological and Economical Thinking" at the 2009 IFSA World Congress und 2009 EUSFLAT Conference July 19-23, Lisbon, Portugal, 2009.
- Special session "Uncertainty, Vagueness and Fuzziness in Humanities and Social Sciences" at the 13th International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems (IPMU-2010), Conference Center Westfalenhallen, Dortmund, Germany, June 28 - July 2, 2010.
- Special session "Fuzzy Sets and Systems and the Soft Sciences" at the FUZZ-IEEE part of this 2010 IEEE World Congress on Computational Intelligence (WCCI 2010), IEEE World Congress on Computational Intelligence, Centre de Convencions Internacional de Barcelona, Spain, July 18-23, 2010.
- Special session "Soft Computing in Soft Sciences" at the 2011 World Conference on Soft Computing - A Better Future Using Information and Technology, (WConSC 2011), May 23-26, 2011, San Francisco, California, USA.
- Special session "Thinking - Language - Meaning" at the conference EUSFLAT-LFA 2011, July 18-22, 2011, Aix-Les-Bains, France.

In the following publications many of the contributions have been written by members of our working group:

- R. Seising (Ed.) Views on Fuzzy Sets and Systems from Different Perspectives. Philosophy and Logic, Criticisms and Applications (Studies in Fuzziness and Soft Computing. Vol. 243), Springer, 2009. 18
- Seising, Rudolf, Veronica Sanz (eds.): Soft Computing in Humanities and Social Sciences (Studies in Fuzziness and Soft Computing. Vol. 273), Springer 2012.19
- "Special Issue on Fuzzy and Quantum Systems" appeared in the International Journal of General Systems as Vol. 40, No. 1 in January 2011. The next four appearing publications that are linked with our working group are:
- Seising, Rudolf and Marco Tabacchi (eds.): Fuzziness and Medicine: Philosophical Reflections and Application Systems in Health Care. A Companion Volume to Sadegh-Zadeh's Handbook on Analytical Philosophy of Medicine, (Studies in Fuzziness and Soft Computing), Springer 2012.
- Seising, Rudolf, Enric Trillas, Settimo Termini and Claudio Moraga (eds.): On Fuzziness, Springer 2012.
- Luigi Colazzo, Mario Fedrizzi, Andrea Molinari, Rudolf Seising (eds.): Fuzzy Approaches to e-Learning Systems, Springer, 2012.

Finally, we are preparing the following publications

- Seising, Rudolf and Enric Trillas (eds.): History and Philosophy of Fuzziness, Springer, 2012.
- "Special Issue on oft Computing in Humanities and Social Sciences" in the International Journal of Fuzzy Sets and Systems to appear in the year 2012.

The prosperity of activities of the EUSFLAT Working Group on Philosophical Foundations shows that there is lively interest in reflecting on the philosophical foundations of science and technology and especially of soft computing methodologies. In the future we hope to take notice that the methods of Soft Computing will be part of research projects in philosophy, education science, economics, linguistics, political sciences, life sciences, law and arts. It is our aim to spread off the knowledge of SC to the areas of the "soft sciences"!

JOURNAL HIGHLIGHTS

# International Journal of Computational Intelligence Systems

The official publication of the *European Society for Fuzzy Logic and Technologies* (EUSFLAT)


The International Journal of Computational Intelligence Systems is the official publication of the European Society for Fuzzy Logic and Technologies (EUSFLAT) from July 1st 2010. So taking advantage of the launch of the new EUSFLAT magazine it is included a call for papers to all EUSFLAT members.

This journal was launched by Prof. Da Ruan in 2008 to reinforce the long-term collaboration, originated from FLINS Conferences since early 90s, among computational intelligence researchers all over the world, mainly Europe and China. The journal was included in the Science Citation Index (SCI), and Current Contents/Engineering Computing & Technology beginning with Volume 1 (issue 1), 2008. This international journal on computational intelligence research, developments and applications is devoted to:

## Aims and scope

The International Journal of Computational Intelligence Systems aims at covering state-of-the-art research and development in all fields where computational intelligence is applied. The journal publishes original papers on foundations and new developments of computational intelligence with an emphasis on applied research, including current and potential applications of methods and techniques derived from computational intelligence research.

The journals seeks original contributions in the area of applied computational intelligence research in general, with a focus on applications using new, emerging technologies originating from computational intelligence research. Applications may range from information technology and (nuclear) energy supply to environmental, societal and security related topics. Papers submitted to International Journal of Computational Intelligence Systems will all be double peer reviewed. Recognizing the importance of a fast publication of papers, the journal commits is committed to publishing a paper within 4 months after submission (unless major revisions of the paper are needed). For this, we aim at an average review time of 20 weeks for a paper. Also, the journal applies the principle of 'rolling publication', so as soon as a paper has been accepted it will be published on-line.

Topics to be considered include, but are not limited to:

## Methodologies

* Fuzzy logic
* Neural networks
* Genetic algorithms
* Probabilistic computing
* Hybrid methods
* Chaos theory
* Rough set theory
* Evidence theory
* AI and expert systems
* Machine learning
* Interactive computational models

## Domains of application

* Decision support systems
* Process and system control, System identification and modeling, and Optimization
* Signal or image processing, Pattern recognition
* Condition monitoring, Fault diagnosis, and Systems integration
* Internet tools, Human-machine interface
* Time series prediction, Noise analysis, Real time systems
* Robotics
* Virtual reality, Telecommunications
* Consumer electronics, Industrial electronics, (nuclear) Power and energy
* Data mining, Data visualization, Intelligent information retrieval, and Autonomous reasoning
* E-science and technology
* Risk analysis and safety related issues

Original research papers within the scope of IJCIS are invited for submission to the editor-in-chief:

**Prof. Dr Jie Lu**
Faculty of Engineering and Information Technology
University of Technology
Sydney, Australia

**Prof. Dr Luis Martinez**
Computer Sciences Department
Universidad de Jaén
Jaén, Spain

More information at: http://www.atlantis-press.com/publications/ijcis

REPORT

# Minutes of the Assembly of the European Society for Fuzzy Logic and Technology

In Aix-Les-Bains (France), the 21st of July 2011, at 17:00, the assembly of EUSFLAT, presided by the President of the Society, Professor Javier Montero, congregates in the Centre des Congrès Aix Les Bains in order to develop the following agenda:

## 1. EUSFLAT Board Report

### News

- IFSA has a new president (2011-2013) Oscar Castillo (Mexico) and a new elected president (President 2013-2015) Christer Carlsson (Finland).
- EUSFLAT signs bilateral agreements with other societies: HFS, NAFIPS, NSAIS, SIGEF, ACIA (Catalan AI Association, agreement renewed). The main features of the agreements are as follows: mutual discounts in membership fees, mutual discounts in association conferences, permanent link in web sites. Having in mind the positive outputs of the agreements, we encourage the society members to propose other strategic agreements!
- The President proudly informs about the EUSFLAT influence and active presence in IFSA, namely about:
  - BERNARD DE BAETS and RADKO MESIAR became new IFSA Fellows;
  - ENRIC TRILLAS was awarded the IFSA Award 2011 (life time academic achievement);
  - LUIS MAGDALENA was elected as the IFSA Secretary;
  - JAVIER MONTERO was elected as the IFSA Vice President;
  - ALBERTO FERNÁNDEZ, MARÍA J. DEL JESÚS, FRANCISCO HERRERA obtained the L.A. Zadeh Prize 2011 (Best Paper Award) for the following paper Hierachical fuzzy rule based classification systems with genetic rule selection for imbalance data-sets, International Journal of Approximate Reasoning 50:561-577, 2009;
  - OSCAR CORDÓN, SERGIO DAMAS, OSCAR IBÁÑEZ et al. obtained the IFSA 2011 Outstanding Application of Fuzzy Technology award for the "Forensic identification system using craneofacial superimposition based on fuzzy sets";
  - J. TINGUARO RODRÍGUEZ, CAMILO FRANCO et al. obtained the IFSA 2011 Conferece Best Paper Award.
- Finally, with respect to IFSA, the President reminded the L.A. Zadeh's 50.000 euro donation to IFSA that can be used in order to support conferences (Best papers Awards, Student grants, etc.) or in order to support specific educational activities. Please apply to IFSA! (Directly or by means of EUSFLAT).
- Other successes of EUSFLAT members and other acknowledgements:
  - FRANCISCO HERRERA - Soft Computing - Mamdani Award 2010 (European Centre for Soft Computing);
  - FRANCISCO HERRERA, ENRIQUE HERRERA-VIEDMA, LUIS MARTINEZ - 2010 IEEE CIS Transactions on Fuzzy Systems Outstanding Paper Award for the following paper: A fuzzy linguistic methodology to deal with unbalanced linguistic term set IEEE TFS 16:354.370, 2008 (acknowledged at Fuzz-IEEE'11, Taipei, Taiwan);
  - OSCAR CORDÓN - 2011 IEEE Computational Intelligence Society Outstanding Early Career Award (The first such award conferred by Computational Intelligence Society);
  - EUROPEAN CENTER FOR SOFTCOMPUTING (LUIS MAGDALENA, Director) - 2012 IEEE Computational Intelligence Society Outstanding Organization Award.

### Memberships

- EUSFLAT has (by July 12 + EUSFLAT 2011 and WILF 2011 members) 287 members from 28 countries, 124 from Spain, 22 from the Czech Republic, 12 from Italy, 11 from France as well as from Germany, etc. It is the second highest number since 2005 which was highly influenced by the EUSFLAT+LFA 2005 conference (171 conference members and "only" 164 regular members wile in 2011 we have 236 regular members).
- It is important to note, that last three years the number of members does not oscilate between odd and even years as it used to be in the past (267 in 2009, 263 in 2010 and 287 in 2011) and thus, we may observe a kind of stabilization of the community.
- Positive influence had and hopefully will have mainly the recuriting campaing (automatic emails to past members, kind personal invitations to relevant researchers, conference agreements etc.) and the web management (plans for significant improvements).

### Publications

- Mathware & Soft Computing has not been accepted for the coverage by ISI and thus, during the last EUSFLAT Assembly at Dortmund it has been decided to close the journal. Final volume will be published by September 2011.
- The title "Mathware & Soft Computing" will be carried by the new Magazine of the European Society for Fuzzy Logic and Technologies (Editor-in-Chief - HUMBERTO BUSTINCE).
- This EUSFLAT Magazine will contain mainly: News and Opinions; Scientific Reports; Applied papers and collaborations with companies; Information about/from Working Groups and finally Departments (Newsletter, Book reviews, Conferences etc.). Invitation to collaborate on this project!
- The President presented the report from Da Ruan, Editor-in-Chieff of the society journal Int. J. Computational Intelligence Systems. He stressed the increasing impact factor (from 0.312 in 2009 to 1.471 in 2010), acceptance rate less than 30

### EUSFLAT 2011

- Report from Sylvie Gallichet, the Local Chair - 184 submitted papers, 156 of them accepted; 174 participants, 15 special sessions, 13 EUSFLAT student travel grants; proceedings will be submitted for coverage in EI/Compendex, Scopus, ISI.
- All EUSFLAT Working Groups organized special sessions. Thanks to them! Call to launch new working groups in key missing topics.
- There will be 1 or 2 special issues (on specific topics) of IJCIS with post-conference extended contributions.
- Great thanks to all local organizers for an amazing job with EUSFLAT 2011!

## 2. Conference endorsement

There was a plenty of endorsed events since January 2010. A higher category of the endorsement (EUSFLAT supported conference) is being launched, as agreed during the last EUSFLAT assembly at Dortmund. AGOP, ESTYLF, FLINS, FSTA, ISCAMI and WILF are among the first supported (or intended to be supported) conferences. Call to apply!

## 3. EUSFLAT Sections

Some national CS associations are interested to create a federation of such national associations. But an international society such as EUSFLAT may hardly become a member of a federation of national associations. Article 27 of the EUSFLAT statutes enables to form Sections. Solution under study!

## 4. EUSFLAT awards

- Proposal for the EUSFLAT Honorary Member (so far Francesc Esteva and Enric Trillas): ULRICH BODENHOFER. Approved!
- Besides the Honorary membership, the President presents the proposal to launch EUSFLAT "SCIENTIFIC EXCELLENCE" AWARD - an acknowledgement of research excellence within Europe (in a broad sense and including all EUSFLAT members even oustide Europe). Scientific Excellence Award Commission consists of all EUSFLAT Presidents (F. Esteva, L. Magdalena, U. Bodenhofer, J. Montero) and Previous Awardees Any EUSFLAT member may nominate a candidate. Approved!

## 5. EUSFLAT projects

- Launching FL & SC wiki repository.
- Educational material being collected by the IEEE CIS, http;//ieee-cis.org/edu/ reminded.

## 6. Membership fees

- EUSFLAT proposes to declare Honorary members as EUSFLAT Life-Members and to pay their annual fees. Approved!
- EUSFLAT proposes to establish EUSFLAT Committer Membership for those who want to support the society by twice higher membership fees. This would be a privileged membership that would be approved by the board based on strict scientific criteria. Approved!
- In order to activate collaborative institutions and donations, the Bylaws revision will be soon initiated, together a complete updating of some weird sentences.
- Increasement of regular fee by 10EUR will not be needed (M&SC publication costs saved). Two-year membership and research group membership are still analyzed in order to avoid encountering potential problems.

## 7. Treasury report

- 2010 Treasury Report - main issues January 1: 18,313.46EUR; 2010 Incomes: 8,884.66EUR; 2010 Expenses: 2,502.44EUR; Surplus: 6,382.22EUR; December 31: 24,695.68EUR
- 2011 Expected Budget - main issues January 1: 24,695.68EUR; 2011 Incomes: 10,975.00EUR; 2011 Expenses: 10, 218.00EUR; Surplus: 757.00EUR; December 31: 25,452.68EUR

- 2012 Proposed Budget - main issues January 1: 25,452.68EUR; 2012 Incomes: 7, 500.00EUR; 2012 Expenses: 9,320.00EUR; Surplus: -1820.00EUR; December 31: 23,632.68EUR

Comments: There is no need to increase fee (regular = 40EUR, student = 20EUR, both include IJCIS access). Starting from 2012, web & administrative support will increase expenses for 1500EUR/year. Budget of 4500EUR is planned to be spent for student grants in 2012 (300EUR each grant).

2010 Treasury report, 2011 Expected budget and 2012 Proposed budget were approved!

## 8. EUSFLAT 2013

The candidate for EUSFLAT 2013 is Milano-Bicocia in Italy, dates to be announced (2nd or 3rd week in September). The candidature is presented by GABRIELA PASI, the local Conference Chair. The candidature approved!

## 9. EUSFLAT 2015

The candidate for EUSFLAT 2015 is Oviedo in Spain, LUIS MAGDALENA will act as a Local Chair, dates to be announced. Thus, the conference is supposed to be organized as a joint EUSFLAT-IFSA event. The candidature is presented by Oscar Cordón. Amogn other promised features, Oscar Cordón mentioned low registration fees and that student and regular participants will be trated in the same way. The candidature approved!

## 10. Honorary membership acknowledgement to Enric Trillas

Honorary membership (awarded in Dortmund 2010) to Enric Trillas was acknowledged. Oscar Cordón pronounced a short speech on behalf of the bearer.

## 11. EUSFLAT 2010 Best Ph.D. Thesis Award

The Jury, consisting of EUSFLAT Honorary members, awarded OSCAR IBAÑEZ for his PhD thesis Forensic identification by craniofacial superimposition using soft computing. The winner was awarded a diploma and 200EUR (including 1 year membership).

## 12. EUSFLAT 2011 Conference Best Student Paper Award

The jury comsisting of the EUSFLAT Board (whenever no conflict of interests) awards the following three dinstinguished papers:

- Carlos Lopez-Molina: "Generation of fuzzy edge images using trapezoidal membership functions"
- Ali Fallah Tehrani: "Choquistic Regression: Generalizing Logistic Regression using the Choquet Integral"
- Martin Víta: "Filters in algebras of fuzzy logics"

Based on the paper itselves as well as related presentations, the EUSFLAT 2011 Best Student Paper Award goes to MARTIN VÍTA for the paper "Filters in algebras of fuzzy logics" (co-authored by Petr Cintula). This winner also gets a Diploma plus 200EUR including 1 year membership.

## 13. New Board election

Prof. Javier Montero informs that the follwing only list of candidates has been submitted for the new board:

- President:
  Javier MONTERO, Spain
- Vice President:
  Gabriella PASI, Italy
- Secretary:
  Martin ŠTĚPNIČKA, Czech Republic
- Treasurer:
  Edurne BARRENECHEA, Spain
- Recruiting:
  Valentina E. BALAS, Romania
- EUSFLAT Magazine:
  Humberto BUSTINCE, Spain
- Web Coordination:
  Jorge CASILLAS, Spain
- BISC & IFSA News:
  Asli CELIKYILMAZ, USA
- Calls & Forum:
  Oscar CORDÓN, Spain
- Grants:
  Bernard DE BAETS, Belgium
- Conference Liaison:
  Marcin DETYNIECKI, France
- Working Groups:
  Eyke HÜLLERMEIER, Germany
- Outreach activities:
  Radko MESIAR, Slovak Republic
- Conference Endorsement:
  Dragan RADOJEVIC, Serbia
- Special IJCIS Issues:
  Da RUAN, Belgium
- Awards:
  Eulalia SZMIDT, Poland

The list of candidates has been elected for the new board!

## 14. Other matters

- Next EUSFLAT General Assembly will be held at IPMU 2012 Conference in Catania, Italy, July 9-13, 2012.
- Irina Perfilieva asked about some details the EUSFLAT Newsletter and the M&SC Magazine. These questions were answerred by Humberto Bustince with stressing the fact that the old Newsletter content will be part of the new M&SC Magazine.
- The Assembly started as scheduled at 18:00, July 21, 2011 and ended at 19:30, July 21, 2011.

Acting as secretary, I certify all of this.
Aix-Les-Bains, July 21, 2011.
Martin Štěpnička

CONFERENCE REPORTS

# 7th EUSFLAT Conference and 17th LFA meeting

Sylvie Galichet, Polytech Annecy-Chambery, Universite de Savoie

**Radko Mesiar receiving the IFSA Fellowship by hands of Javier Montero and Janusz Kacprzyk**

The 7th biannual EUSFLAT Conference and the 17th annual LFA meeting, held on July 18 - 22, 2011 in Aix-les-Bains, France. The European Society for Fuzzy Logic and Technology (EUSFLAT) and the steering committee of the rencontres francophones sur la Logique Floue et ses Applications (LFA) have decided to organize a joint event, EUSFLAT-LFA 2011, for mutually promoting each other and bringing together an outstanding diversity of people and teams. This decision has been fruitful and the conference at Aix-les-Bains has been a great event with more than 200 participants.

EUSFLAT-LFA 2011 has provided a stimulating forum for scientists and students to share the excitement of disseminating the latest research findings in fundamental issues of fuzzy set theory. The conference has also allowed an effective exchange of knowledge and experience amongst researchers active in various theoretical and applied areas of fuzzy systems, soft computing and intelligent systems.

**Oscar Ibañez receiving the best Ph.D. Thesis award**

It has been our pleasure as chairpersons to organize this meeting, prepare its technical program, and be involved in the making of the proceedings (on line access at `http://www.atlantis-press.com/publications/aisr/eusflat-11/`).

This would have been impossible without the help of many people, especially the members of the international program committee and the organizers and co-organizers of the special sessions and above all, the authors! Without their contribution, this year's conference would have not existed. We thank them all for their help and hope everyone has appreciated the result of their combined effort.

EUSFLAT-LFA 2011 received a total of 184 submissions from over 31 countries from five continents. Each paper was reviewed by two reviewers. Papers submitted for the 15 special sessions were peer-reviewed with the same criteria used for regular papers. At least one reviewer, not involved in the organization of the special session, was selected by the conference chairs. Based on the outcome of the review process and recommendations of the members of the program committee, 156 papers were accepted for inclusion in the conference program. We are very grateful to the numerous referees that helped us evaluate papers and build up the program. We really believe we succeeded in proposing homogeneous sessions. The technical program brought together an outstanding diversity of papers that has made for an exciting conference.

**F.l.t.r. Javier Montero, Ali Fallah Tehrani (distinguished student paper), Bernard De Baets, Martin Vita (best student paper award) and Carlos Lopez-Molina (distinguished student paper)**

Our warm thanks go to the five plenary speakers who kindly accepted sharing their expertise with the attendees: A. Appriou, M. Baczynski, O. Cordon, A.J. Ijspeert and M. Sugeno.

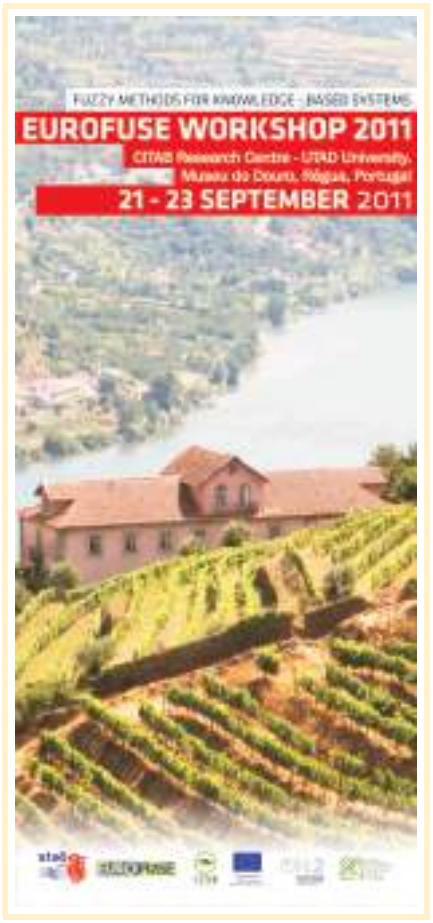
We are also grateful to the institutions which have helped the organization of the EUSFLAT-LFA 2011 conference: Région Rhône Alpes, Université de Savoie, Polytech Annecy-Chambéry, Laboratoire LISTIC.

We hope you enjoyed the conference as well as the location at Aix-les-Bains, an historical Savoie's city between lake and mountains (where it is something raining !)

CONFERENCE REPORTS

# EUROFUSE Workshop 2011

P. Melo-Pinto and P. Couto, Centre for the Research and Technology of Agro-Environmental and Biological Sciences. UTAD University, Portugal




Fuzzy Methods for Knowledge-Based Systems, held in the Museu do Douro, Régua - Portugal, in September 21-23, 2011. (http://www.citab.utad.pt/eurofuse2011) EUROFUSE was established in 1998 as the EURO (the Association of European Operational Research Societies) Working Group on Fuzzy Sets, a successor of the former European Chapter of IFSA (the International Fuzzy Systems Association). The working group is coordinated by Bernard De Baets (KERMIT, Ghent University, Belgium) and János Fodor (Óbuda University, Hungary). EUROFUSE 2011 was the last of a series of EUROFUSE workshops, including the successful EUROFUSE 1999 (Budapest, Hungary), EUROFUSE 2000 (Mons, Belgium), EUROFUSE 2001 (Granada, Spain), EUROFUSE 2002 (Varenna, Italy), EUROFUSE 2004 (Warsaw, Poland), EUROFUSE 2005 (Belgrade, Serbia), EUROFUSE 2007 (Jaen, Spain) and EUROFUSE 2009 (Pamplona, Spain).

This edition was organised by Pedro Melo-Pinto and Pedro Couto. The theme of the workshop was "Fuzzy Methods for Knowledgebased Systems". The aims of the workshop were to establish the New Trends in the field and to bring together researchers and practitioners in an informal atmosphere. For this reason, the number of participants was limited and all presentations were plenary.

Fuzzy logic play a key role in knowledge-based systems. Knowledgebased systems support decision making activities in an intelligent way. They account for inputs of different nature, such as symbolic and numerical data, and are expressed in various representation formats. The workshop included contributions from fuzzy logic and knowledge-based systems such as preference representation and modelling, aggregation operators, knowledge extraction, decision making and extensions of fuzzy sets. At the same time, it addressed implementations of such systems in different areas, such as image processing and communication. EUROFUSE 2011 had three distinguished keynote speakers: Francisco Herrera (Granada, Spain), Radko Mesiar (Bratislava, Slovakia) and José Luis Garcia Lapresta (Valladolid, Spain). The three day program consisted of a total of 37 lectures with 70 participants from 10 countries.

### Promoters and Chairs

Pedro Melo-Pinto (CITAB-UTAD, Portual)
Pedro Couto (CITAB-UTAD, Portual)
Bernard De Baets (Kermit-UGent, Belgium)
János Fodor (Obuda University, Hungary )

### Organizing Comittee

Carlos Serodio (CITAB-UTAD, Portual)
Pedro Mestre (CITAB-UTAD, Portual)
Joao Matias (CM-UTAD, Portugal)
Rita Ribeiro (Uni-Nova-Univ. Nova de Lisboa, Portugal )

CONFERENCE REPORTS

# 27th Conference on Uncertainty in Artificial Intelligence (UAI 2011)

Lluis Godo, Artificial Intelligence Research Institute (IIIA) of the Spanish National Research Council (CSIC)


The 27th Conference on Uncertainty in Artificial Intelligence (UAI 2011) was held at the Campus Roger de Lluria of the Universitat Pompeu Fabra, in Barcelona, Spain, July 14-17, 2011. It was colocated with another major scientific event, the celebration of the IJCAI'11 Conference (http://www.ijcai-11.org), the most important conference on Artificial Intelligence, that took place immediately after, from July 18 to 22, also in Barcelona.

The general chair of UAI 2011 was Peter Grünwald (CWI and Leiden University, NL), and the program co-chairs were Avi Pfeffer (Charles River Analytics, US) and Fabio G. Cozman (Universidade de Sao Paulo, Brasil). The local organisers were Lluís Godo, Tommaso Flaminio and Enrico Marchioni, researchers from IIIA-CSIC (Barcelona, Spain), and members of EUSFLAT.

UAI conferences are organized annually under the support of the Association for Uncertainty in Artificial Intelligence (AUAI) www.auai.org. The AUAI is a non-profit organization focused on the UAI's annual conference and, in general, in promoting research in pursuit of advances in knowledge representation, learning and reasoning under uncertainty. Over the years, the UAI community has developed techniques that have been widely integrated into general Artificial Intelligence curricula and adopted in many fields outside of Artificial Intelligence. The meeting is now a premier international conference on issues relating to representation and management of uncertainty within the field of Artificial Intelligence. UAI has a wide scope that includes modeling, inference, learning and decision making under uncertainty, with an interest both in theory and in applied work. This time UAI 2011 also hosted the 8th Bayesian Modelling Applications Workshop, a focused forum for interchange among those interested in real world applications of graphical models and Bayesian networks.

UAI-2011 had over 200 participants of all around the world, and it had a record of submissions, 285 regular papers were submitted and 96 were accepted (24 for plenary presentation and 72 for poster presentation). The program consisted of three full and intensive days of technical presentations and four invited talks distinguished speakers: James M. Rehg (Georgia Institute of Technology), Hod Lipson (Cornell University), Karl Friston (University College London), and Colin Howson (University of Toronto). Besides, UAI 2011 also hosted a tutorial day, on July 14th. Three tutorials were given on this day: Ilya Shpitser (Harvard University) reviewed "Causal Inference: from Effects of Interventions to Learning and Inference with Partial Observability"; Milind Tambe and Christopher Kiekintveld (University of Southern California and University of Texas at El Paso) discussed "Game Theory for Security: Lessons Learned from Deployed Applications"; and Pedro Domingos and Kristian Kersting (University of Washington and Fraunhofer IAIS) presented material on "Combining Logic and Probability: Languages, Algorithms and Applications".

Two awards were given to two outstanding technical contributions. The UAI 2011 Microsoft Best Paper Award was given to the paper Sum-Product Networks: A New Deep Architecture by Hoifung Poon and Pedro Domingos, and the UAI 2011 Google Best Student Paper Award was given to the paper Generalised Wishart Processes by Andrew Wilson and Zoubin Ghahramani.

For more information, one can consult the conference website http://www.auai.org/uai2011. The proceedings of the conference can also be freely consulted in `http://uai.sis.pitt.edu/displayArticles.jsp?mmnu=1&smnu=1&proceeding_id=27`.

NEWS

## Book Review: Soft Computing in Humanities and Social Sciences

Eds: Rudolf Seising and Veronica Sanz. Studies in Fuzziness and Soft Computing, Vol. 273, Springer 2012.


**From the Preface:**

The field of Soft Computing in Humanities and Social Sciences is at a turning point. Not very long ago, the very label seemed a little bit odd. Soft Computing is a technological field while Humanities and Social Sciences fall under the other pole of the "two cultures" defined by C.P. Snow in 1959. In the recent years, however, this has changed. The strong distinction between "science" and "humanities" has been criticized from many fronts and, at the same time, an increasing cooperation between the so-called "hard sciences" and "soft-sciences" is taking place in a wide range of scientific projects dealing with very complex and interdisciplinary topics.

In the last fifteen years the area of Soft Computing has also experienced a gradual rapprochement to disciplines in the Humanities and Social Sciences, and also in the field of Medicine, Biology and even the Arts, a phenomenon that did not occur much in the previous years (to the surprise of the very founder of the field, Lotfi Zadeh). The collection of this book presents a generous sampling of the new and burgeoning field of Soft Computing in Humanities and Social Sciences, bringing together a wide array of authors and subject matters from different disciplines. Some of the contributors of the book belong to the scientific and technical areas of Soft Computing while others come from various fields in the humanities and social sciences such as Philosophy, History, Sociology or Economics.

The six sections in which the volume is divided represent some of the most relevant topics that have result from fruitful exchanges taken place on this topic in the last years in several workshops, seminars and special sessions. These are only an example of what the interesting encounter and conversations between Soft Computing and the Humanities and Social Sciences can yield in the future.

**The authors:**

Rudolf Seising received a Ph.D. degree in philosophy of science and a postdoctoral lecture qualification (PD) in history of science from the Ludwig Maximilians University of Munich. He is an Adjoint Researcher at the European Centre for Soft Computing in Mieres (Asturias), Spain.

Veronica Sanz earned a Ph.D. in Philosophy at the University Complutense of Madrid (Spain). At the moment she is a Postdoctoral Researcher at the Science, Technology and Society Center in the University of California at Berkeley.

---

NEWS

## Fuzzy Logic Tools (FLT) released

Thematic Group of Intelligent Control, Spanish Comittee of Automatic

After a hard work of redesign and documentation, the 1.0 version of Fuzzy Logic Tools (FLT) has been released. The software is available for the Scientific and Academic Community.

FLT is a C++ framework for storage, analysis and design of fully general multiple-input multiple-output (MIMO) Takagi-Sugeno fuzzy control systems, without constraints in the order of either the inputs or the output vectors. This software is based on work done in the PhD of Antonio Javier Barragán Piña, but has been expanded new methods developed as a result of the investigation of Control and Robotics Group from the Universuty of Huelva. Also, the code has been documented and some errors have been corrected.

FLT has been written in C++, and is free to GPLv3.
Official FLT page on Sourceforge:
`http://sourceforge.net/projects/fuzzylogictools/`
Online documentation (HTML):
`http://uhu.es/antonio.barragan/FLTHelp/`
Fuzzy Logic Tools Reference Manual (PDF):
`http://uhu.es/antonio.barragan/FLTHelp/Fuzzy_Logic_Tools_Reference_Manual_v1.0.pdf`

José Manuel Andújar
Coordinator of the Thematic Group of Intelligent Control of the Spanish Comittee of Automatic

NEWS

## Ph.D. Thesis defended by José Antonio Sanz

Group of Artificial Intelligence and Approximate Reasoning, Public University of Navarra, Spain

José Antonio Sanz Delgado defended his PhD Thesis entitled Linguistic fuzzy rule-based classification systems using interval-valued fuzzy sets and tuning of the degree of ignorance the last 15th of July. His supervisors are the PhD Humberto Bustince Sola (Public University of Navarre), the PhD Francisco Herrera Triguero (University of Granada) and the PhD Alberto Fernández Hilario (University of Jaén).

In the Thesis it is studied the behaviour of Interval-Valued Fuzzy Sets (IVFSs) applied on linguistic fuzzy classification systems. Specifically, this work faces two of the main problems that can provoke a lack of accuracy in these systems, namely:

- The ignorance (lack of information) related to the definition of the membership functions used to model the linguistic labels;
- The initial values assigned to the parameters of the system may not be perfectly adapted to the context of each specific problem.

The aim of the Thesis is to improve the initial performance of methods belonging to different kinds of fuzzy techniques by applying:

- IVFSs in order to model the ignorance degree associated with the assignment of punctual values as membership degrees of the elements to the set;
- A genetic tuning approach to optimize the values of the parameters of the system.

In the core of the memory it is presented an incremental methodology in which we can find:

- Some IVFSs construction methods based on weak ignorance functions.
- Different extensions of the fuzzy reasoning method in order to take into account the ignorance degree throughout the inference process.
- Several genetic tuning approaches so as to optimize distinct system's parameters like the degree of ignorance that each IVFS represents or the lateral position of the membership functions, among others.

All the methodologies are tested over wide collections of data-sets and their quality is supported by means of appropriate statistical comparisons with respect to the most suitable classification methods in each case.

This Thesis has led to the development of four papers: the two first ones have been already published in the International Journal of Information Sciences and in the International Journal of Approximate Reasoning and the two remainder ones are still in publication process.

NEWS

## Ph.D. Thesis defended by A. Javier Barragán awarded

Department of Electronic, Computer Science and Automatic Engineering, University of Huelva, Spain

**A. Javier Barragán (right) receiving the best Ph.D. thesis award by the hands of Ramón Galán (left)**

The thesis titled "Synthesis of stable fuzzy control systems by design" defended by Antonio Javier Barragán and supervised by José Manuel Andújar was awarded with the Best Ph.D. Thesis in Intelligent Control award by the Spanish Comittee of Automatic of 2009-2010.

The main goal of this Thesis is to establish a methodology for designing fuzzy controllers as general as possible, so as to ensure the stability control system in closed loop. Similarly, countries willing to contribute to the formalization of fuzzy systems with tools that allow analysis of these systems according to the theory of nonlinear control accepted by the scientific community. To this end, the memory is organized into seven chapters, is summarized below:

Chapter 1 is a description of the structure of the Thesis and the chapters in it. It also lists the major innovations of the Thesis and conducts an analysis of the scientific performance of it.

Chapter 2 introduces the fuzzy logic and its applications through a historical journey, with special emphasis on control applications.

The chapter 3 addresses the need for a model of the plant so we can study the fuzzy logic system from a formal point of view. This model is studied from the perspective of the model state. This model defines the fuzzy state of the plant to get the equivalent mathematical model, and proposes an extension of the state vector to simplify their representation. Then, a similar study conducted with both the controller and the closed loop system, resulting in both cases the equivalent mathematical model. In all cases, some algorithms are proposed to calculate such mathematical models. Then, each stage of the modeling process are studied for identify a system from input / output through the application of fuzzy models. In the parameters' identification phase a new hybrid methodology are proposed.

In chapter 4 the linearization is solved without any simplification of the system element blur, blur of a model completely, without limitation on the number of rules, nor the size of the state and control vectors, nor the type membership function, allowing the mixing of different membership functions. Then the jacobian matrix is solved for a fuzzy control system in general terms. Subsequently deals with the obtaining of states of equilibrium through a methodology based on numerical methods, we proposed the use of the jacobian matrix to accelerate the convergence and improve the accuracy.

Chapter 5 is focused on the design of fuzzy controllers from two approaches: 1) heuristic, based on knowledge of an operator, and 2) formally, through a study of system stability. This chapter proposes a design methodology based on three steps: identification of the plant and the same representation as a fuzzy state model, this study from the fuzzy model obtained, and design of a fuzzy controller which guarantees the stability of the closed loop system. To enable the completion of the third section we propose a new stability theorem based on Lyapunov theory. Finally, an algorithm design is presented.

In chapter 6 a fuzzy controller for a crane container is designed carrying the knowledge of an expert. Then, the design methodology proposed in the chapter 5 is presented using 3 examples, which are made with all the necessary steps: identification of the plant, extraction of their states of equilibrium and study the local stability of the same, and design a fuzzy controller that stabilizes the plant.

Finally, chapter 7 presents the conclusions arising from the Thesis, then, the subjects left the way open to be resolved in future works are shown.

---

NEWS

## WORKSHOP Data and Uncertainty held in UTAD, September 20, 2011

### Centre for the Research and Technology of Agro-Environmental and Biological Sciences, UTAD University, Portugal


The event aimed to address various aspects present in the process of modeling the uncertainty inherent to all kinds of experimental data. Uncertainty is always present in any measurement resulting in errors in experimental data. These errors are quantitatively estimated by uncertainty making it a very important concept that all scientists should take into consideration when reporting results from their scientific activity.

The Workshop had three distinguished invited speakers: Humberto Bustince from the Public University of Navarra, Pamplona, Spain, that gave the lecture entitled "Image Processing and Fuzzy Logic", Javier Montero from Complutense University of Madrid, Spain, with the lecture "Stop blaming Uncertainty" and João Paulo Carvalho from the IST, Technical University of Lisbon, Portugal with the lecture "Identification and classification based on approximate estimations of Top-K values in data streams".

NEWS

# Open postdoc positions at the University of Ostrava

## Centre of Excellence IT4Innovations Division of the University of Ostrava, Institute for Research and Applications of Fuzzy Modeling

Due to the new project "Strengthening research teams at the University of Ostrava", the Centre of Excellence IT4Innovations Division of the University of Ostrava announces two newly open postdoc positions:

Open position 1: Postdoc at the Department of Theoretical Research Research topic: Mathematical fuzzy logic in narrow sense (FLn): higher-order fuzzy logic (fuzzy type theory, fuzzy class theory) with the focus on:

- Theory of fuzzy relations and fuzzy functions
- Theory of fuzzy numbers and fuzzy intervals
- Theory of fuzzy measures and fuzzy quantifiers

Duration (covered by the project): July 2012 - June 2015
Possible prolongation of the contract: Yes
Mentor: Prof. Vilem Novák
Sallary: 45,000 CZK per month (approx. 1,800 EUR per month)

Open position 2: Postdoc at the Department of Applied Research

Research topic: Data-mining or data-processing with the focus on one or preferably more of the following fields:

- Automatic image recognition
- Digital image feature extraction
- Applications of fuzzy methods and mathematical morphology methods on image processing
- Applications of fuzzy methods on data-mining tasks (e.g. linguistic association mining)
- Applications of soft computing methods on time series analysis and predictions

Duration (covered by the project): July 2012 - June 2015
Possible prolongation of the contract: Yes
Mentor: Prof. Irina Perfilieva
Sallary: 45,000 CZK per month (approx. 1,800 EUR per month)

All details and the official application form are published on: `http://irafm.osu.cz/en/c126_job-opportunities/`

CALLS

## $4^{th}$ FuzzyMAD Encontuer in Madrid (Spain) 20th December 2011

Department of Statistics and Operational Research I, Complutense University of Madrid, Spain

The fourth edition of the FuzzyMAD encounter will be held in 2011, December 20th. FuzzyMAD pursues a collaborative framework for researchers working in Madrid and having interests in Fuzzy Logic and its applications. This meeting is open to any student and researcher willing to establish contact with fuzzy researchers within Madrid, a town that sometimes makes our life too busy. With this objective, FuzzyMAD is usually scheduled between 11:00 and 16:00 giving time for some short invited Ph.D. student presentations, poster session for presentation of research groups meanwhile we have a buffet, and a round table after a strategic invited talk. This year our invited speaker is Luis Magdalena, head of the European Centre for Soft Computing. Five hours of intense communication for 50 researchers coming from most relevant research institutions located in Madrid.

---

CALLS

## First International Competition of Time Series Forecasting (ICTSF)

Dear colleagues,
we are pleased to invite you to the First International Competition of Time Series Forecasting (ICTSF) `http://www.caos.inf.uc3m.es/~jperalta/ICTSF/`

Forecasting problem:

Forecast a dataset of 8 time series from a web bookshop data as accurately as possible, using methods from computational intelligence and applying a consistent methodology. The data consists of 8 time series with different time frequencies, that could include yearly, quarterly, monthly, weekly, daily and hourly data.

Objectives:

We seek to evaluate the accuracy of computational intelligence (CI) methods in time series forecasting with multiple frequencies. We seek to determine progress in modelling CI for forecasting & to disseminate knowledge on "best practices" across time series of different frequencies. The contestants will use a unique consistent methodology for all time series.

Methods:

The prediction competition is open to all methods of computational intelligence, incl. feed-forward and recurrent neural networks, fuzzy predictors, evolutionary & genetic algorithms, decision & regression tress, support vector regression, hybrid approaches etc. used in all areas of forecasting, prediction & time series analysis, etc.

Publication of results:

All those submitting predictions will be invited to participate in sessions at the 2012 IEEE Evolving and Adaptive Intelligence Systems (IEEE EAIS) Madrid, Spain. This conference will provide awards by dataset for students and non-students.

The DEADLINE is the 10th of January of 2012.

We look forward to your predictions and also to your participation in the IEEE-EAIS 2012 conference.

Kind regards & best of luck! Juan Peralta Donate, Paulo Cortez and Martin Štěpnička

---

CALLS

## XVI Spanish Conference on Fuzzy Logic and Technologies (ESTYLF 2012) in Valladolid (Spain) 1-3 February 2012

University of Valladolid


The XVI Spanish Conference on Fuzzy Logic and Technologies (ESTYLF 2012) will take place in the Conference Palace Conde Ansurez of Valladolid (Spain) on February 1-3, 2012. As in previous editions, this conference is open to any people interested in fuzzy logic and its applications and it intends to be a discussion forum in which new results can be presented, ideas can be discussed and projects related to this research area can be exposed.

Several Special sessions will be organized, covering many different topics from very theoretical ones up to applied ones, all of them related to fuzzy theory. A non exhaustive list of topics would cover Fundamentals of fuzzy logic, uncertainty modelling, acquisition and representation of knowledge, approximate reasoning, decision making, fuzzy databases, data mining, web intelligent systems, fuzzy control, hybrid systems, computing with words...

Two plenary talks are planned: The first one will be given by Prof. Bernard De Baets, and the second one by Prof. Oscar Cordón. Moreover, a forum on the technical and scientific collaboration between the University and the enterprises will take place during the Conference

CALLS

## 11th International Conference on Fuzzy Set Theory and Applications (FSTA 2011) in Liptovský Ján (Slovak Republic) January 30-3 February 2012

Eleventh Conference on Fuzzy Set Theory and Applications will take place under the auspices of the Faculty of Civil Engineering of the Slovak Technical University in Bratislava, the Armed Forces Academy of General Milan Rastislav Štefánik in Liptovský Mikuláš and Working Group for Fuzzy Set Theory and Applications by Slovak Mathematical and Physical Association, in co-operation with EUSFLAT.

### Language

The official language will be English. Simultaneous interpretation will not be available.

### Scientific Programme

The Conference Scientific Programme will consist of special invited plenary lectures, invited and contributed parallel sessions. Rooms will be provided for workshops and special invited sessions during the conference.

### Invited Plenary Speakers

H. Bustince, Spain
D. Dubois, France
J. Fodor, Hungary
R. Ghiselli Ricci, Italy
M. Navara, Czech Republic
M. Stepnècka, Czech Republic
J. Talasová, Czech Republic
J. Vejnarová, Czech Republic

### Venue

Lectures and sessions will take place at the Hotel Sorea Máj in Liptovský Ján. The opening ceremony will begin on Monday morning, January 30, 2012 at 9 a.m. The conference is expected to end on Friday afternoon, February 3, 2012.

### Social and cultural events

The Organizing Committee will prepare a short excursion, concert and a reception for the participants and accompanying persons. The conference will be held in Liptovský Ján - a tiny village with well-preserved Renaissance manor houses that is about 12 km from Liptovský Mikuláš. It is situated at the entrance to the Jánska Valley - the longest valley in the Low Tatra Mountains with excellent conditions for winter and summer sports. The Jánska Valley is a starting point for visiting different parts of the central Slovakia. There are several possibilities to go for individual trips to the High or Low Tatras.

CALLS

## Seminar on New Trends on Intelligent Systems in Granada (Spain) 16-17 February 2012

Department of Computer Science and Artificial Intelligence, University of Granada, Spain

### General information about the seminar:

The Seminar is conceived as a workshop in our Master-PhD Program in Computer Science. It is scheduled during two days, with four invited talks. Each invited talk lasts for approximately one hour plus 20 minutes of questions and discussion. There will also be a final roundtable where lecturers participate in a discussion on current topics related to the future of Intelligent Systems, or the implications in our society.

The expected audience is Master students, who have finished five years of studies in Computer Science, and Ph.D. students, who are involved in our Ph.D. Program. Additionally, professors and researches coming from several places of Spain, also attend to the Seminar. It is held in a big auditorium, with a participation of about 100 persons each day.

The seminar is addressed to Master students. Therefore, the talks are mainly focused on topics at the Master level such as current trends, research challenges, state of the art, industry applications, etc. The idea is that the Seminar is not a very specialized research conference, but

a forum where a Master student could find an overview and challenges of some interesting research fields.

More information at: http://docto-si.ugr.es/seminario

Lecturers (by alphabetical order):

**Eyke Hüllermeier.** *Fuzzy Logic in Machine Learning*
Knowledge Engineering & Bioinformatics Lab
Marburg University (Germany)
**Ora Lassila.** *Semantic Web*
Nokia Mobile Solutions (USA)
**Pietro Lio.** *BioInformatics*
Cambridge Computational Biology Institute
Cambridge University (UK)
**Nikhil R. Pal.** *Sensor/Feature selection in a connectionist framework*
Electronics and Communication Sciences Unit (ECSU)
Indian Statistical Institute (India)

Former Lecturers (by alphabetical order) at the Seminar since 2004:

Ajith Abraham, Ricardo Baeza-Yates, Bernadette Bouchon-Meunier, Philipp Cimiano, Carlos Coello, Fabio Crestani, Stefan Decker, Pedro Domingos, Didier Dubois, Robert Fuller, Toshio Fukuda, Janusz Kacprzyk, James Keller, Laszlo Koczy, Rudolf Kruse, Mounia Lalmas, Christian Lemaitre, Jay Liebowitz, Vicenzo Loia, Simon Lucas, Anders L. Madsen, Marcelo Madeiros, Javier Montero, Enrico Motta, Witold Pedrycz, Henri Prade, Da Ruan, Enrique H. Ruspini, Alesandro Saffiotti, Philippe Smets, Austin Tate, Enric Trillas, Xindong Wu and Ronald Yager.

About Granada:

Granada is one of the most beautiful cities in Spain. In 30 minutes you can reach the snow-covered mountains (with one of the best skiing resorts in Spain) and in 40 minutes you can also swim at the Tropical's coast.

Its Albayzin's neighbourhood, together with the famous Alhambra Arabian palace is protected by UNESCO (http://whc.unesco.org/pg.cfm?cid=31&id_site=314). The Alhambra is, in fact, one of the most visited monuments in Europe and it competed against other monuments around the Earth to belong to the new 7 wonders of the world (http://www.new7wonders.com) (although, unfortunately it was not elected...) As a curiosity, the American Institute of Mathematics is going to replicate it for his new building at California (new: http://www.ams.org/notices/200511/fea-aim.pdf , video: http://video.google.com/videoplay?docid=-6956424081422740268)

You can find more information about Granada at http://granadainfo.com/english.htm

---

CALLS

## Logic, Algebra and Truth Degrees 2012 in Kanazawa (Japan) 10-14 September 2012

### EUSFLAT working group on Mathematical Fuzzy Logic

The third official meeting of the EUSFLAT Working Group on Mathematical Fuzzy Logic will be held on 10-14 September 2012 in Kanazawa, Japan. The conference is organized by Research Center for Integrated Science, Japan Advanced Institute of Science and Technology.

Mathematical Fuzzy Logic is a subdiscipline of Mathematical Logic which studies the notion of comparative truth. The assumption that 'truth comes in degrees' has proved to be very useful in many, both theoretical and applied, areas of Mathematics, Computer Science and Philosophy.

Researchers interested in presenting a paper can submit a 2-4 pages abstract at http://www.easychair.org/conferences/?conf=latd2012

Deadline for submissions: 22 April 2012

Conference Web Site: http://www.jaist.ac.jp/rcis/latd12/

Programme Committee:

- Stefano Aguzzoli (University of Milano, Italy)
- Matthias Baaz (Vienna University of Technology, Austria)
- Petr Cintula (Academy of Sciences, Czech Republic)
- Carles Noguera (CSIC, Spain)
- Hiroakira Ono (JAIST, Japan), Chair
- James Raftery (University of KwaZulu-Natal, South Africa)
- Constantine Tsinakis (Vanderbilt University, USA)

Invited Speakers:

- Rostislav Horcik (Academy of Sciences, Czech Republic)
- Emil Jerabek (Academy of Sciences, Czech Republic)
- Daniele Mundici (University of Florence, Italy)
- Greg Restall (University of Melbourne, Australia)
- Luca Spada (University of Salerno, Italy)

CALLS

## $13^{th}$ International Student Conference on Applied Mathematics and Informatics ISCAMI 2012 in Malenovice (Czech Republic) 10-13 May 2012

University of Ostrava and Slovak University of Technology

It is already the 13th International Student Conference on Applied Mathematics and Informatics (ISCAMI) that bears the traditions originating from International Student Conferences for Undergraduate and Graduate Students of Applied Mathematics initially organized in Bratislava, Slovakia.

ISCAMI 2012 is organized jointly by the Department of Mathematics of Faculty of Civil Engineering of the Slovak University of Technology in Bratislava and by the Centre of Excellence IT4Innovations - Division of the University of Ostrava - Institute for Research and Applications of Fuzzy Modeling (IRAFM) again in Malenovice, a beautiful village situated on the root of the highest peak in Beskydy mountains near Ostrava. And we are again happy and proud that the conference, as the only student conference, is marked as EUSFLAT endorsed event, for which we are grateful to EUSFLAT.

Participants will be invited to submit post-conference papers into special issues of chosen reviewed journals. Let us recall, that in previous years, we have used e.g. the following journals: Kybernetika (JCR), Neural Network World (JCRI), Acta Polytechnica Hungarica (JCR), Acta Universitatis Matthiae Belii and Acta Mathematica Universitatis Ostraviensis.

ISCAMI 2012 brings a new quality that consists in being organized jointly with the 1st Summer School on Applied Mathematics and Informatics that will be composed of several interesting tutorials given by leading scientists and fabulous teachers from distinct fields on the border of applied mathematics and informatics (F. Klawonn from Wolfenbüttel in Germany; Petr Sosík from Opava in the Czech Republic and Christian Moewes from Magdeburg in Germany).

Due to the support of the A-Math-Net Applied Mathematics Knowledge Transfer Network - an ESF project reg. nr. CZ.1.07/2.4.00/17.0100 we will be able to support most of the participants as well as invited tutorial speakers with providing them with a free participation without paying any registration fees.

CALLS

## $75^{th}$ meeting of the European Working Group in Multiple Criteria Decision Aid in Tarragona (Spain) 12-14 April 2012

Intelligent Technologies for Advanced Knowledge Acquisition, Universitat Rovira i Virgili, Spain

The next 75th meeting of the European Working Group on Multiple Criteria Decision Aiding wants to strenghen its relation to the AI community in general, and specially to soft computing. The workshop is organized by Dr. Aida Valls and the research group ITAKA at URV.

We propose as main topic: "Multiple Criteria Decision Aiding and Artificial Intelligence: connections and challenges".

We cordially invite you to participate at this meeting, which will be held on April, 2012 from Thursday 12 to Saturday 14, at the Universitat Rovira i Virgili, in Tarragona (Catalonia, Spain).

Together with the presentations, we will have a round table discussion about the following two topics:

1. Advantages and drawbacks of expressing preferences in a linguistic scale in decision making.

2. Are the multicriteria decision aid methods scalable to large sets of data?

At the moment I can announce the participation of the following people in the round table:

- Prof. Jose Luis Garcia-Lapresta
- Prof. Salvatore Greco
- Prof. Vicenç Torra

If you are intereted in attending to this workshop, please send the forms attached to the organizers before January 20, 2012. Additional information can be found at: `http://deim.urv.cat/~itaka/CMS4`

We are looking forward to seeing you at Tarragona.

CALLS

## 6th International Conference on Soft Methods in Probability and Statistics in Konstanz (Germany) 4-6 October 2012

### Scope

The aim of SMPS 2012 is to serve as a forum for discussing new trends that enlarge the statistical and uncertainty modeling traditions towards the handling of incomplete, subjective or fuzzy information.

### Topics

SMPS 2012 invites submissions of papers dealing with a variety of topics in soft methods in probability and statistics, which include, but are not limited to: Analysis of Censored/Incomplete/Fuzzy Data, Random Sets, Fuzzy Random Variables/Random Fuzzy Sets, Fuzzy Regression Methods, Triangular Norms and Copulas, Imprecise Probabilities, Dempster-Shafer Theory, Robust Methods, Clustering and Classification, Graphical Models, Machine Learning, Heuristic Optimization, Soft Computing and Statistics, Statistical Software for Imprecise Data, Applications in Biology, Economics, etc.

### Dates

Submission of papers: March 18, 2012
Notification of acceptance: April 29, 2012
Submission of final versions: May 21, 2012
Conference: October 4-6, 2012

### Proceedings

The final version of the papers accepted for presentation after the reviewing process will be published in an edited volume of the series "Advances in Intelligent and Soft Computing" (Springer-Verlag).

### Conference Venue

In 2012 the SMPS conference will be held at the University of Konstanz. Konstanz is a city with approximately 80,000 inhabitants located at the western end of Lake Constance in the south-west corner of Germany, bordering Switzerland. Its large old town center comprises many ancient buildings and narrow alleys. The city skyline is dominated by the majestic cathedral, several other churches and three towers as remnants of the city wall, one of which marks the place of the former medieval bridge over the Rhine river.

### Flower Island Mainau

Mainau is an island in Lake Constance. It is maintained as a garden island and a model of excellent environmental practices. It is one of the main tourist attractions of Lake Constance. Beside flowers there is a park landscape with beautiful views of the lake. Also, the conference dinner will take place on this island.

### Invited Speakers

**Christian Borgelt**, principal researcher at the European Centre for Soft Computing, is well known in the data mining community for a large number of free implementations of data mining algorithms. He has published around 100 papers in conferences, workshops, books and journals, co-authored four books and co-edited three conference proceedings as well as one special journal issue.

**Lawrence O'Higgins Hall**, professor of computer science at the University of South Florida, is renowned for outstanding scientific achievements in approximate reasoning, data mining and pattern recognition. He is a former president of the IEEE Syst., Man, Cybern. Society, and a fellow of the IEEE. He has served on the NAFIPS board and on the administrative committee of the IEEE CI Society and the IFSA. He has published over 60 journal papers and numerous conference papers.

**Hannu T. Toivonen**, professor of computer science at the University of Helsinki, is renowned for outstanding scientific achievements in knowledge discovery, pattern and link discovery, data mining, analysis of scientific data, search and exploration of networked information, with applications in bioinformatics, and in international collaboration. He has published numerous papers in conferences, workshops, books and journals, co-authored books and co-edited several conference proceedings.

CALLS

# 14th International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems IPMU 2012 in Catania (Italy) 9-13 July 2012


The IPMU conference is organized every two years with the focus of bringing together scientists working on methods for the management of uncertainty and aggregation of information in intelligent systems. This conference provides a medium for the exchange of ideas between theoreticians and practitioners in these and related areas.

In 2012 the conference will be held at the Economics Faculty of University of Catania. Catania is one of the main economic, touristic and educational centre in Sicily, being an important hub of the technological industry, thus gaining the nickname of the "European Silicon Valley". Catania is renowed all over the world for the wonderful strength of Etna, the snow-covered peaks, the crystal clear sea of the Ionian coast, the historical and archaeological heritages, the baroque churches and palaces and the urban design (the downtown area is a World Heritage Site, along with the Val di Noto), the enogastronomic traditions and music, the innate warmth and hospitality culture of the people. From Catania, within a day, you can easily reach a lot of other important cities with touristic attractions and important archeological rests such as Taormina, Syracuse, Piazza Armerina and Agrigento.

Topics and Scope of the Conference

Theory, Methods and Tools: Uncertainty, Bayesian and Probabilistic Methods, Information Theory, Measures of Information and Uncertainty, Evidence and Possibility Theory, Utility Theory, Fuzzy Sets and Fuzzy Logic, Rough Sets, Multiple Criteria Decision Methods, Aggregation Methods, Knowledge Representation, Approximate Reasoning, Non-classical Logics, Default Reasoning, Belief Revision, Argumentation, Ontologies, Uncertainty in Cognition, Graphical Models, Knowledge Acquisition, Machine Learning, Evolutionary Computation, Neural Networks, Data Analysis.

Application Fields: Intelligent Systems and Information Processing, Decision Support, Database and Information Systems, Information Retrieval and Fusion, Image Processing, Multi-Media, Agents, Pattern Recognition, Medicine and Bioinformatics, Finance, Software Engineering, Industrial Engineering.

The deadline for paper submission is january 15, 2012 (extended deadline). All submissions will be peer-reviewed on the basis of originality and scientific quality, and authors will be notified about acceptance or rejection by February 25, 2012.

The conference proceedings will be published by Springer-Verlag (LNAI/CCIS series).

Next EUSFLAT General Assembly will be held at IPMU 2012 Conference in Catania, Italy.