Developments in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume I: Foundations

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Systems Research Institute
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ISBN 9788389475305

One-dimensional model of approximate reasoning in surgical considerations

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Abstract

Approximate reasoning is one of the most effective fuzzy systems. The compositional rule of inference founded on the logical law Modus Ponens is furnished with a true conclusion, provided that the premises of the rule are true as well. There exist different approaches to an implication, being the crucial part of the rule, but we are especially fond of the results brought by the early implication proposed by Zadeh [18, 19], which is modified in our practical model concerning a medical application. The approximate reasoning system, grounded on the extended version of Modus Ponens law, will be employed here to predict a chance of positive effects of the operation on a patient who suffers from stomach cancer. The patient's *CRP* (C-reactive proteins) symptom level, pathologically heightened, indicates the presence of a disease. When the *CRP*-value does not exceed a critical border it can be realistic to try surgery to recover the patient from his/her illness due to Do-Kyong Kim [4]. We wish to evaluate the verbal prognosis of the surgery by involving particularly designed fuzzy sets in the algorithm of approximate reasoning.

Keywords: Approximate reasoning, compositional rule of inference, Zadeh's implication, operation chance, symptom level, parametric membership functions.

1 Introduction

The technique of approximate reasoning, earliest evolved by Zadeh [18, 19] quickly found many adherents who differentiated the foundations of the theory.

Especially, the changes concerned the implication IF…THEN…ELSE…, which constitutes an important factor of the reasoning system. In [2, 5, 7] we can trace the discussion revealing definitions of the implication generated by Kleene and Denies, Willmot, Mamdani and Assilian, Larsen, Gödel et al. The trials of inserting individually created operations on fuzzy sets discern the approaches mentioned above. Even the item of compositional rule of inference was debated from separate points of views [1, 3, 6, 10, 17]. We can mention the Yager conception [17] and the Sugeno design [5] as the most original modifications of the initial version of the rule.

For a practitioner an applicable meaning of approximate reasoning is essential, especially in technique and natural sciences where vagueness of input and output is often expected. Although some technical trials of applications are remarkable, it can happen coincidentally to counterpart the approximate reasoning in medicine. The only contribution in the topic, found by the author in [9], is a discussion of the model employing a pharmacological example.

Since members of surgical staff make decisions about operations on severely-ill patients (we consider cancer) with the highest care then we wish to support these verdicts by results coming from reasoning systems. We adopt Zadeh's approach to the rule [8, 18, 19], which is modified by us and based on Lukasiewicz's definition of the fuzzy implication [1, 8, 18]. We still find this rule to be the most appealing for the reason of simply performed operations and clearly interpretable results. Then we build the own original apparatus accommodated to medical assumptions. Particular fuzzy sets that contain input data and output effects are designed in compliance with the physician's hint. The implication considers only one biological parameter *CRP* (C-reactive proteins); therefore we have named the model of approximate reasoning "one-dimensional". The choice of *CRP*, as a representative marker of cancer diseases, has been made due to the latest investigations revealing association of the index with the progression of disease in many cancer types [4, 11].

The discussion focuses around finding the objective of reasoning, i.e., the evaluation of a chance for surviving. This chance is strongly tied to the level of *CRP*, which decides about the possibility of an operation and even its type. We accomplish the discussion in Section 2. Fuzzy sets, taking place in the model, are furnished with appropriate membership degrees in Section 3. Section 4, added as a presentation of efficiency of the algorithm, reveals prognoses in cancer surgery.

2 Adoption of approximate reasoning to the operation decision

For patients, who suffer from e.g., cancer, decisions concerning their operations are made with the highest thoughtfulness. In the later or the last stage of the disease the possibility to cure the patient totally of cancer by operating him/her for tumors is rather little. As a physician does not want the patient to run the risk to suffer even more after an unnecessary operation, he ought to judge thoroughly the consequences of the surgery. The physician wants to prognosticate the operation role positively in the process of recovering; therefore we use the conception "operation chance".

We intend to involve approximate reasoning to support mathematically the extraction of the proper chance for a patient when discerning the operation role in recovery. The most decisive clinical symptom *CRP* found in an individual patient will be taken into consideration to evaluate the chance.

Let us ponder a logical compound statement [14, 15]

$$\text{IF}\,(p\,\text{AND}\,((\text{IF}\,p\,\text{THEN}\,\,q)\,\text{ELSE}\,(\text{IF}\,(\text{NOT}\,p)\,\text{THEN}\,(\text{NOT}\,q)))\,)\,\text{THEN}\,q \qquad (1)$$

whose primitive statements p and q are included in the equivalent form of (1) derived as

$$p \wedge ((p \rightarrow q) \wedge (\neg p \rightarrow \neg q)) \rightarrow q. \qquad (2)$$

The logical joint ELSE is interpreted in (2) as the conjunction $\wedge$ in compliance with the suggestions made by Lukasiewicz and Zadeh [1, 18].

The logical statement (2) is a tautology, which can be easily confirmed by the method of truth tables. We also prove that thesis q in (2) will become true if the premises p and $(p \rightarrow q) \wedge (\neg p \rightarrow \neg q)$ constitute true statements as well. In order to accomplish the last proof we utilize the method of denying the truth of the thesis q. Let $v(p)$ and $v(q)$ denote the truth values of p and q according to the convention of binary logic. If, on behalf of the proof, we assume that the thesis q is not true then $v(q) = 0$. From the previous assumption $v((p \rightarrow q) \wedge (\neg p \rightarrow \neg q)) = 1$ if $v(p \rightarrow q) = 1$ and $v(\neg p \rightarrow \neg q) = 1$. But $v(q) = 0$, which suggests that $v(p) = 0$ as well to warrant $v(p \rightarrow q) = 1$. On the other hand we have already assumed that premise p is true. As the suggestion $v(q) = 0$ leads to the contradiction "p is false" against "p is true" then we will accept $v(q) = 1$.

In accordance with the extended law *modus ponens* proposed by Zadeh [18, 19] we interpret (2) as a sentence

IF
p` (premise)
AND
(IF p THEN q) ELSE (IF (NOT p) THEN (NOT q)) (premise)
THEN (3)
q` (thesis)

provided that the semantic meaning of p and p` ($q$ and $q$` respectively) is very close.

Let p be visualized by a fuzzy set P in the universe X and let q be expressed by another fuzzy set Q in the universe of discourse Y. Analogously, the fuzzy set $P` \subset X$ constitutes a mathematical formalization of the primitive statement $p$` whereas $Q` \subset Y$ replaces formally the sense of $q$`. The modus ponens rule thus becomes

IF
$p` = P`$ (premise)
AND (4)
(IF $p = P$ THEN $q = Q$) ELSE (IF (NOT $p = CP$) THEN (NOT $q = CQ$)) (premise)
THEN
$q` = Q`$ (thesis)

The sets CP and CQ are complements of P and Q.

When making a feedback to the medical task previously outlined, we wish to use a technique of accommodating actual theoretical assertions to concrete formulations letting us evaluate the operation decision in some grades of chance.

Let S denote a symptom possessing the most decisive power in the evaluation of the operation chance. We regard S as either the complex qualitative symptom or the symptom whose intensity is assimilated with level codes. These codes, determined for both descriptions of S's complexion, form the universe X = "*symptom levels*" = $\{1,\ldots,k,\ldots,n\}$. Let us assume that level 1 is associated with the slightly heightened symptom values whereas level n indicates their critical status [14, 15].

The statement p` [14, 15]

p` = "symptom S is found in patient on level k"

is now addressed to a fuzzy set P` introduced by

$$P` = \mu_{P`}(1)/1 + \dots + \mu_{P`}(k)/k + \dots + \mu_{P`}(n)/n\,. \tag{5}$$

The sentence p built by

p = "decreasing levels of S are essential for operation chance"

is dedicated to a fuzzy set P given by

$$P = \mu_P(1)/1 + \dots + \mu_P(k)/k + \dots + \mu_P(n)/n\,. \tag{6}$$

By "decreasing levels" we mean that the values of the symptom tending to lesser numbers of levels from X prognosticate the better chance to be successfully operated when appreciating the length of survival.

Another category of elements, constituting a content of the universe Y, is determined in the model as operation chance priorities. We set chance priorities in Y = "*operation chance priorities*" = {L_0 = "*none*", L_1 = "*little*", L_2 = "*moderate*", L_3 = "*promising*", L_4 = "*very promising*"}, on condition that Y is experimentally restricted to five chance priorities only.

For sentence q

q = "operation chance can be estimated on basis of S"

a creation of a fuzzy set Q is supported by

$$Q = \mu_Q(L_0)/L_0 + \mu_Q(L_1)/L_1 + \mu_Q(L_2)/L_2 + \mu_Q(L_3)/L_3 + \mu_Q(L_4)/L_4\,. \tag{7}$$

At last, we define $q`$ containing the cumulated operation chance judgment as a statement

$q`$ = "patient with the k-level of S gets an estimated chance of being operated",

where *chance* is graded by membership degrees of the corresponding fuzzy set Q' proposed as

$$Q` = \mu_{Q'}(L_0)/L_0 + \mu_{Q'}(L_1)/L_1 + \mu_{Q'}(L_2)/L_2 + \mu_{Q'}(L_3)/L_3 + \mu_{Q'}(L_4)/L_4\,. \tag{8}$$

In the next paragraph we accomplish the discussion about an apparatus providing us with membership degrees of sets (5)–(8).

Due to *modus ponens* rule (4) we set all decision data in the scheme

IF
"symptom *S* is found in patient on level *k*" = *P*` (premise)
AND
(IF "decreasing levels of *S* are essential for operation chance" = *P* THEN "operation chance can be estimated on basis of *S*" = *Q*) ELSE (IF "decreasing levels of *S* are not essential for operation chance" = *CP* THEN "operation chance cannot be estimated on basis of *S*" = *CQ*) (premise)
THEN
"patient with the *k*-level of *S* gets an estimated chance of being operated" = *Q*` (thesis)

In conformity with [1, 8, 18] we first prognosticate a mathematical expression of the implication

(IF "decreasing levels of *S* are essential for operation chance" = *P* THEN "operation chance can be estimated on basis of *S*" = *Q*) ELSE (IF "decreasing levels of *S* are not essential for operation chance" = *CP* THEN "operation chance cannot be estimated on basis of *S*" = *CQ*)

performed as matrix *R*. Even though several approaches to membership functions of implications were made [1, 2, 5, 6, 8, 16, 18, 19] we still feel attracted by the Lukasiewicz [1, 8] conception of fuzzy implication *R* with a membership function derived as

$$\mu_R(k, L_l) = 1 \wedge (\mu_{CP}(k) + \mu_Q(L_l)) \wedge (\mu_P(k) + \mu_{CQ}(L_l)), \qquad (9)$$

$k = 1,\ldots,n$, $l = 0,\ldots,4$, for all $k \in X$ and all $L_l \in Y$.

The membership degrees of set *Q*` will be visualized after composing set *P*` with relation *R* due to Zadeh's compositional rule [18]

$$Q` = P' \circ R \qquad (10)$$

designated by the membership function

$$\mu_{Q`}(L_l) = \max_{k \in X}(\min(\mu_{P`}(k), \mu_R(k, L_l))). \qquad (11)$$

The comparisons of magnitudes of membership degrees in set *Q*` yield indications referring to judgments of the chance priorities after consideration of symptom level *k* verified in the patient.

3 Mathematical design of data sets

The decision model designed in Section 2 includes operations on fuzzy sets furnished with symbolically established membership degrees. In the current paragraph we put some life into theoretical symbols by assigning to them mathematical structures. The set *P*` a.k.a. (5) now gets assigned [14, 15]

$$\begin{aligned} P` &= \mu_{P`}(1)/1 + \cdots + \mu_{P`}(k)/k + \cdots + \mu_{P`}(n)/n \\ &= \cdots + \tfrac{n-2}{n}/(k-2) + \tfrac{n-1}{n}/(k-1) + 1/k + \tfrac{n-1}{n}/(k+1) + \tfrac{n-2}{n}/(k+2) + \cdots \end{aligned} \tag{12}$$

for the k^{th} symptom level certified in the patient examined.

Another set *P* concerning the same symptom levels in the support is found by (6) and, when assuming $\mu_P(k) = \tfrac{n-(k-1)}{n}/k$, modified as

$$P = \mu_P(1)/1 + \cdots + \mu_P(k)/k + \cdots + \mu_P(n)/n = \tfrac{n}{n}/1 + \cdots + \tfrac{n-(k-1)}{n}/k + \cdots + \tfrac{1}{n}/n, \tag{13}$$

due to the previously made assumptions, which suggest the tendency to descending values of the membership degrees in *P*. Level 1 should thus have assigned the membership degree equal to 1 as the most promising value for the operation chance prognosis.

The set *Q* is more sophisticated to design as a fuzzy set whose support consists of other fuzzy sets L_l, $l = 0,\ldots,4$, commonly defined in a symbolic chance reference set $Z = [0, 1]$. We also intend to determine the membership degrees of *Q* as some characteristic quantities from [0, 1]. Evaluation of these numbers is founded on a procedure involving a linguistic variable

"*operation chance priorities*" = {L_0 = "*none*", L_1 = "*little*", L_2 = "*moderate*", L_3 = "*promising*", L_4 = "*very promising*"}

experimentally restricted to five chance priorities only.

We first fuzzify the expressions concerning the items of the list to continue further with their defuzzification in order to attach numerical equivalents to the words from the list. Each word assists now a fuzzy set L_l, $l = 0, 1, 2, 3, 4$, whose constraint is grounded on an *s*-class mapping defined for *z* in $Z = [0, 1]$ as [12, 13, 14, 15]

$$\mu_{L_l}(z)=\mu_{L_0(l)}(z)=\begin{cases}\text{left}(\mu_{L_0(l)}(z))=\\ \text{right}(\mu_{L_0(l)}(z))=\end{cases}$$
$$\begin{aligned}&s(z,\alpha_{L_0},\beta_{L_0},\gamma_{L_0},l\cdot h), &&\text{for}\quad z\le\gamma_{L_0},\\ &1-s(z,\alpha_{L_0}+h,\beta_{L_0}+h,\gamma_{L_0}+h,l\cdot h) &&\text{for}\quad z>\gamma_{L_0}.\end{aligned} \tag{14}$$

We clarify the fact that formulas of all membership functions are derived from only one predetermined subject defining $\mu_{L_0}(z)$. The equality $\mu_{L_l}(z)=\mu_{L_0(l)}(z)$ reveals that $\mu_{L_l}(z)$ is dependent on a parameter l equal to chance priority number l, $l = 0,\dots,4$. The h unit determines a distance between α_{L_l} and $\alpha_{L_{l+1}}$ (respectively β_{L_l} and $\beta_{L_{l+1}}$ or γ_{L_l} and $\gamma_{L_{l+1}}$) for symmetric functions s.

We prepare constraints for L_0, which are affected by $\alpha_{L_0}=-0.25$, $\beta_{L_0}=-0.125$ and $\gamma_{L_0}=0$ as

$$\text{left}(\mu_{L_0}(z))=\begin{cases}2\left(\frac{z-(-0.25)}{0-(-0.25)}\right)^2 & \text{for}\quad -0.25\le z<-0.125,\\ 1-2\left(\frac{z-0}{0-(-0.25)}\right)^2 & \text{for}\quad -0.125\le z<0,\end{cases} \tag{15}$$

and

$$\text{right}(\mu_{L_0}(z))=\begin{cases}1-2\left(\frac{z-0}{0.25-0}\right)^2 & \text{for}\quad 0\le z<0.125,\\ 2\left(\frac{z-0.25}{0.25-0}\right)^2 & \text{for}\quad 0.125\le z<0.25.\end{cases} \tag{16}$$

By inserting in (15) and (16) the current value l, $l = 0,\dots,4$, and the distance h, casually determined as $h = 0.25$, we obtain a formula of the left branch of L_l

$$\text{left}(\mu_{L_l}(z))=\begin{cases}2\left(\frac{z-(-0.25+l\cdot 0.25)}{0-(-0.25)}\right)^2\\ \text{for}\quad -0.25+l\cdot 0.25\le z<-0.125+l\cdot 0.25,\\ 1-2\left(\frac{z-(0+l\cdot 0.25)}{0-(-0.25)}\right)^2\\ \text{for}\quad -0.125+l\cdot 0.25\le z<0+l\cdot 0.25,\end{cases} \tag{17}$$

and a function shaping its right branch

$$\text{right}(\mu_{L_l}(z)) = \begin{cases} 1-2\left(\frac{z-(0+l\cdot 0.25)}{0.25-0}\right)^2 \\ \text{for } \ 0+l\cdot 0.25 \le z < 0.125+l\cdot 0.25, \\ 2\left(\frac{z-(0.25+l\cdot 0.25)}{0.25-0}\right)^2 \\ \text{for } \ 0.125+l\cdot 0.25 \le z < 0.25+l\cdot 0.25. \end{cases} \tag{18}$$

Figure 1 collects plots of L_0–L_4 in conformity with different values of l included in (17) and (18).

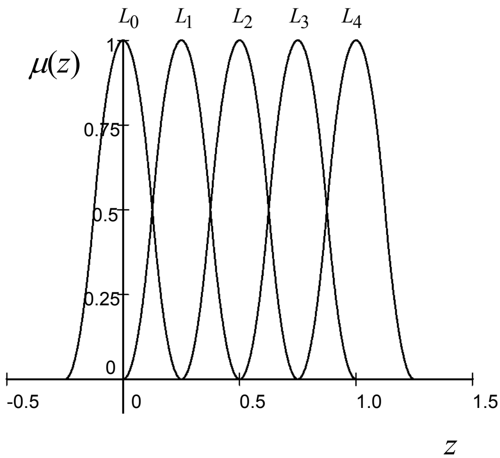

Figure 1: The terms of "*operation chance priorities*" as fuzzy sets L_0–L_4

Actually, we have an intension to emphasize the meaning of parametric nature of the L_l membership functions, which deprives the model of many distinct formulas. Apart from this advantage we focus on generating the functions that represent elegant structures mathematically expressed.

In the process of defuzzification we consider only z-values for which the sets L_0–L_4 get the status of normal sets, i.e., $z = 0$, $z = 0.25$, $z = 0.5$, $z = 0.75$ and $z = 1$. For these, another fuzzy set "*numerical operation chance*" is projected by developing its membership function in the form of

$$\mu_{\text{"numerical operation chance"}}(z) = \begin{cases} 2\left(\frac{z-0}{1-0}\right)^2 & \text{for} \quad 0 \le z < 0.5, \\ 1-2\left(\frac{z-1}{1-0}\right)^2 & \text{for} \quad 0.5 \le z < 1. \end{cases} \tag{19}$$

Via the selected z-quantities above, we tie their membership degrees calculated by means of (19) to expressions from the list in order to establish relations between words and their numerical replacements. Therefore, the set Q finally obtains a shape of

$$Q = {}^{0}\!\big/_{L_0} + {}^{0.125}\!\big/_{L_1} + {}^{0.5}\!\big/_{L_2} + {}^{0.875}\!\big/_{L_3} + {}^{1}\!\big/_{L_4}\,. \tag{20}$$

We now wish to demonstrate the action of approximate reasoning accustomed to the judgment of surgical chance.

4 Approximate reasoning-making operation chance priority in cancer surgery

In patients, who suffer from stomach cancer as the recognized diagnosis, one of the symptoms, namely, *CRP* (*C*-reactive proteins) is carefully measured and discussed with a view to make a decision about accomplishing a successful operation. The principal objectives of many studies have been to determine the preoperative serum levels of *CRP* in gastric carcinoma and to correlate them with disease status and prognosis of surviving [4, 11].

The heightened values of *CRP* (measured in milligrams per liter) are theoretically discerned in four levels stated as

1 = "*almost normal*" for $CRP < 10$,
2 = "*heightened*" if $10 \le CRP \le 20$,
3 = "*very heightened*" if $20 \le CRP \le 25$,
4 = "*dangerously heightened*" for $CRP > 25$.

Due to (13) set P is expressed as

$$P = {}^{1}\!\big/_{1} + {}^{0.75}\!\big/_{2} + {}^{0.5}\!\big/_{3} + {}^{0.25}\!\big/_{4} \tag{21}$$

in $X = \{1,\ldots,4\}$.

Suppose that an individual patient examined reveals the *CRP*-value to be 13. *CRP* is thus classified in level 2 and set P` characteristic of the patient is stated in the form of

$$P` = {}^{0.75}\!\big/_{1} + {}^{1}\!\big/_{2} + {}^{0.75}\!\big/_{3} + {}^{0.5}\!\big/_{4}\,. \tag{22}$$

according to (12).

The sets (20) and (21) together with

$$CP = 0/1 + 0.25/2 + 0.5/3 + 0.75/4 \tag{23}$$

and

$$CQ = 1/L_0 + 0.875/L_1 + 0.5/L_2 + 0.125/L_3 + 0/L_4 \tag{24}$$

generate matrix R with the entries computed in compliance with (9). R is expanded as a two-dimensional table

$$R = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{c} \begin{array}{ccccc} L_0 & L_1 & L_2 & L_3 & L_4 \end{array} \\ \begin{bmatrix} 0 & 0.125 & 0.5 & 0.875 & 1 \\ 0.25 & 0.375 & 0.75 & 0.875 & 0.75 \\ 0.5 & 0.625 & 1 & 0.625 & 0.5 \\ 075 & 0.875 & 0.75 & 0.375 & 0.25 \end{bmatrix} \end{array} \tag{25}$$

which, inserted in (10) for P` determined by (22), provides us with

$$Q` = 0.5/L_0 + 0.625/L_1 + 0.75/L_2 + 0.875/L_3 + 0.75/L_4 \, . \tag{26}$$

By interpreting the meaning of (26) we understand that there exists a promising chance for a successful result of the operation in patient whose *CRP*-index is evaluated on the second level. The most possible chance is evaluated as "*promising*" according to the highest quantity of the membership degree in Q`. No effect of the operation is evaluated with the membership degree 0.5.

We hope that the model of approximate reasoning, modified by us and adapted to the problem of operation decision, can constitute its complementary solution, especially when a decision of saving somebody's life via surgery is crucial.

5 Conclusions

Via the way of forming the text of this paper we have already come to substantial conclusions. We only summarize that we have used approximated reasoning to introduce the own initial interpretation of the system to approximate the operation chance concerning patients with heightened values of a biological index. The formulas of membership degrees and membership functions have been expanded by applying a formal mathematical design. We expect that the study makes a contribution in the domain of mathematical models projected for medical applications.

In future works we wish to examine a multi-dimensional model consisted of several symptoms that are divided in different numbers of levels. The symptoms should be included in the pattern simultaneously, which may expose some internal interactions among them. In other words, the operation chance will be a criterion that can employ many data factors. We count on finding some helpful remarks in [4, 15] to correlate biological parameters like, e.g., *CRP* and interleukin-6 (*IL-6*) to support and to extend the model of approximate reasoning in surgery.

Acknowledgements

I would like to thank Associate Professor in Medicine Henrik Forssell from the Blekinge Research Board for all helpful hints made in the subject of cancer surgery. The research done in this paper was granted by Blekinge Research Board in Karlskrona, Sweden.

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.
It may be viewed as a result of fruitful discussions held during the Eighth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2009) organized in Warsaw on October 16, 2009 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Centre for Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT – Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bistrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

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The Eighth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2009) has been meant to commence a new series of scientific events primarily focused on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Moreover, other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems are discussed.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

ISBN-13 9788389475305
ISBN 838947530-8
9 788389 475305