



On Heterodox Non-KL Generalized Divergence Metric with Characteristics in Fuzzy Environment

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

In this paper, we suggest a novel divergence metric on a fuzzy set. Some scholars have used the fuzzy set extension and one that integrated with other theories. Axioms are proven in order to demonstrate the viability of measure. We create a way about decision-making criteria using the suggested measure and provide a workable method. We discuss the divergence metric metric for fuzzy sets in this post. The discussed properties of the proposed proposal. Multicriteria decision making is a very useful technique with a wide range of applications in the real world.

Keywords: Fuzzy set; divergence metric; decision making.

1 Introduction

The fuzzy set theory introduced by Zadeh [1] has achieved great success in a variety of domains. The actual world is full of uncertainty. When dealing with uncertainty and fuzziness, entropy is a crucial tool. Information

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theory and fuzzy theory are used to tackle problems in the study of information distribution, storage retrieval, and decision-making. Entropy is the term used to describe the measure of information theory for the first time, according to Shannon [2]. The measure of information related to the two probability distributions of discrete random variables is then evaluated by Kullback and Liebler [3], and is given as

$$D(p, q) = \sum_{i=1}^n p_i \log \frac{p_i}{q_i}$$

referred to as guided divergence. The fuzzy set theory was developed by L. Zadeh [1] and is utilised in many branches of research and industry, including image processing, pattern identification, and decision-making.

Renyi [4] introduced a new divergence metric,

$$D_\alpha(p, q) = \frac{1}{\alpha-1} \ln \sum_{i=1}^n p_i q_i^{1-\alpha}, \quad \alpha \neq 1$$

Havrda–Charvat [5] also gave a new measure of divergence metric,

$$D_\alpha(p, q) = \frac{1}{\alpha-1} (\sum_{i=1}^n p_i^\alpha q_i^{1-\alpha} - 1), \quad \alpha \neq 1$$

The definitions of closeness measure and roughly equal fuzzy sets as well as the idea of approximating fuzzy values have all been introduced in [6]. a similarity index based on the greatest difference between equivalent membership grades, was implied, along with several hazy qualities sets related to this metric were displayed. They evaluated the similarity of fuzzy value measurements .The metrics looked at in [7] include:

- (1) The measurement that is based on intersection and union procedures.
- (2) The maximal difference-based measure.
- (3) The measurement that takes into account membership grade disparities and the total.

It has been proven by earlier researchers [6-8] that a fuzzy set's entropy is a measure of its fuzziness. Zadeh was the first to suggest fuzzy entropy as a fuzziness indicator; Pal and Pal studied classical Shannon information entropy; Kosko thought about the connection between distance measurement and fuzzy entropy; and Liu put forth an axiomatic definition of entropy, distance measures, and similarity measures and discussed the connections between these three ideas. This study is significant since it may offer us some helpful information for choosing an appropriate similarity metric in fuzzy set applications.

In this research, we expand the work of [9] to further explore fuzzy value similarity measures. the matching function S that we provided in [10]. The choice of the measures to be employed in fuzzy set applications may be influenced by the fact that it has been demonstrated that some qualities are shared by various measures and that others do not hold for all of them. The definitions of o composition and composition from [11] are briefly reviewed in the coming sections.

Now, The \circ composition of the vector $a = (a_1, a_2, \dots, a_m)$, corresponding to the fuzzy subset A of U, with the matrix $R = [r_{ij}]$, corresponding to the fuzzy relation R of $U \times V$, where $U \times V = \sum_{i=1}^m \sum_{j=1}^n u_i v_j$ and is denoted by $a \circ R$ and is equal to the vector $C = (c_1, c_2, \dots, c_n)$, where

$$c_j = \cup(a_i \cap r_{ij})$$

\cap denotes the minimum operator, and \cup denotes the maximum operator. The α composition of a scalar x with a scalar y which is denoted by $x\alpha y$ is defined by

$$x\alpha y = \begin{cases} 1 & \text{if } x \leq y \\ y & \text{otherwise} \end{cases}$$

Bhandari and Pal [12] used the idea of fuzzy measure conditioning, which corresponds to Kullback and Leibler [3] probabilistic divergence metric, to develop a fuzzy distance measure between two fuzzy sets. A measure was introduced by Bhandari and Pal [12].

$$I(A, B) = \sum_{i=1}^n \mu_A(x_i) \log \frac{\mu_A(x_i)}{\mu_B(x_i)} + (1 - \mu_A(x_i)) \log \frac{(1 - \mu_A(x_i))}{(1 - \mu_B(x_i))}$$

Later, according to the exponential fuzzy entropy provided by Pal and Pal [5], Fan and Xie [13] offered discriminating of fuzzy information of fuzzy set against. A generalised divergence metric measure similar to Havrda and Charvat [5] was introduced by Kapur [14]. Along with R-norm divergence metric, Hooda and Bajaj [15] proposed a divergence metric measure. A measure of the divergence metric of two sets was provided by Bhatia and Singh [16]. Some form of fuzzy divergence metric was proposed by Tomar, Ohlan, Priya, and Tomar [17, 18]. In their article "Decision-making with Parameterized Hesitant Fuzzy Soft Set Theory," Zahari Md Rodzi and Abd Ghafur Ahmad [19] established this concept. We suggest divergence metric while keeping in mind the aforementioned literature, and certain significant properties are also investigated.

It has been demonstrated that the suggested measure is widely applicable. A brief study on the fuzzy set, measure, and divergence metric is provided in section II. A novel divergence metric measure is discussed in section III. Properties are provided together with their proof in section IV. Section V discusses how the proposed measure would be applied. The sixth segment concludes the work discussed previously.

1.1 Preliminaries

In this part, we define a few terms and notations related to divergence metric measure and fuzzy sets. We shall outline the features of the fuzzy set and its measure that will be relevant to our upcoming discussion.

Definition 1. Let $P = (p_1, p_2, \dots, p_n)$, $p_i \geq 0$ is the set of all complete finite discrete probability distribution then measure of information was defined firstly by Shannon as.

$$H(P) = \sum_{i=1}^n p_i \log p_i,$$

Definition 2. Let $X = \{x_1, x_2, \dots, x_n\}$ be universe of discourse then $A = \{ \langle x, \mu_A(x) \rangle / x \in X \}$ is called fuzzy set where $\mu_A(x_i) : X \rightarrow [0,1]$ is a membership function defined as follows

$$\begin{aligned} \mu_A(x_i) &= 0 \text{ if } x \notin A \\ \mu_A(x_i) &= 1 \text{ if } x \in A \\ \mu_A(x_i) &= 0.5 \text{ if } x \notin A \text{ or } x \in A \end{aligned}$$

Some notation for two fuzzy set

1. $A \cup B = \{ \langle x, \max(\mu_A(x), \mu_B(x)) \rangle / x \in X \}$
2. $A \cap B = \{ \langle x, \min(\mu_A(x), \mu_B(x)) \rangle / x \in X \}$
3. $A = B = \{ \langle x, \mu_A(x) = \mu_B(x) \rangle / x \in X \}$
4. $A \cdot B = \{ \langle x, \mu_A(x) \cdot \mu_B(x) \rangle / x \in X \}$
5. $A^c = \{ \langle x, \mu_A(x) = 1 - \mu_A(x) \rangle / x \in X \}$

Definition 3. Let $X = \{x_1, x_2, \dots, x_n\}$ be universe of discourse and $F(X)$ be the set of all family subset. A mapping $I: F(X) \times F(X) \rightarrow R$ is called divergence measure between fuzzy sets if

- i. $I(A: B) \geq 0$
- ii. $I(A: B) = I(B: A)$
- iii. $I(A: B) = 0$ iff $A = B$
- iv. $\text{Max}\{I(A \cup C, B \cup C), I(A \cap C, B \cap C)\} \leq I(A: B)$

Bajaj et.al. [20] define the measure of fuzzy divergence metric as

$$I_\alpha(A: B) = \frac{1}{\alpha - 1} \sum_{i=1}^n \log [\mu_A^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha}]$$

$$I_{\alpha,\beta} (A: B) = \frac{1}{1-2^{\beta-1}} \sum_{i=1}^n \left\{ \left[\mu_A^\alpha (x_i) \mu_B^{1-\alpha} (x_i) + (1 - \mu_A (x_i))^\alpha (1 - \mu_B (x_i))^{1-\alpha} \right]^{\frac{\beta-1}{\alpha-1}} - 1 \right\}$$

Entropy measure for fuzzy sets was introduced by Prakash et al. [21] as

$$H_{\alpha}^{\beta} (A) = \frac{1}{(1-\alpha)^{\beta}} \sum_{i=1}^n \left\{ \left[\mu_A^{\alpha} (x_i) + (1 - \mu_A (x_i))^{\alpha} \right]^{\beta} - 1 \right\}; \alpha > 0, \alpha \neq 1, \beta \neq 0$$

2 Our Results

2.1 New Divergence Metric Measure

In accordance with Prakash et al. [21], we suggest the following fuzzy divergence metric measure:

$$H_{\alpha,\beta} (A, B) = \frac{1}{(\alpha-1)^{\beta}} \sum_{i=1}^n \log \left\{ \left[\mu_A^{\alpha} (x_i) \mu_B^{1-\alpha} (x_i) + (1 - \mu_A (x_i))^{\alpha} (1 - \mu_B (x_i))^{1-\alpha} \right]^{\beta} - 1 \right\} \tag{1}$$

$;\alpha > 0, \alpha \neq 1, \beta \neq 0$

Theorem 1. Show that $H_{\alpha,\beta} (A, B)$ is valid measure of fuzzy divergence metric.

Proof. To show that proposed measure in (1) is valid we have to prove following axioms

1. We can clearly check in figure that $H_{\alpha,\beta} (A, B)$ is non – negative.

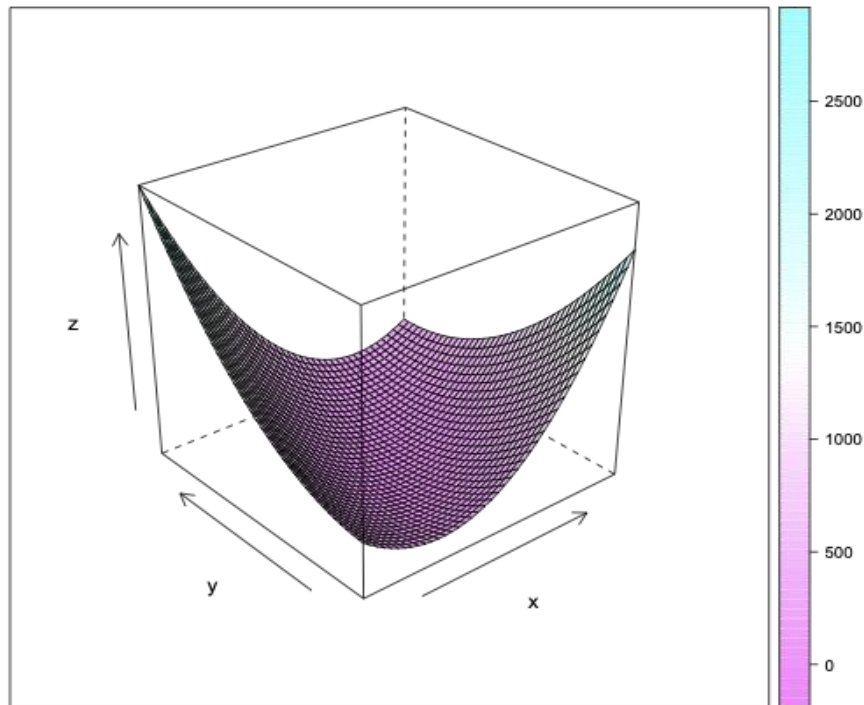


Fig. 1. $H_{\alpha,\beta} (A, B)$

2. $H_{\alpha,\beta} (A, B) \neq H_{\alpha,\beta} (B, A)$
3. $H_{\alpha,\beta} (A, B) = 0$, if $A = B$
4. We have to check the convexity of $H_{\alpha,\beta} (A, B)$

So now,

$$\frac{\partial H_{\alpha,\beta}}{\partial \mu_A(x_i)} = \left\{ \alpha\beta \left[\mu_A^{\alpha-1}(x_i)\mu_B^{1-\alpha}(x_i) + (1-\mu_A(x_i))^{\alpha-1} (1-\mu_B(x_i))^{1-\alpha} \right] \left[\mu_A^\alpha(x_i)\mu_B^{1-\alpha}(x_i) + (1-\mu_A(x_i))^\alpha (1-\mu_B(x_i))^{1-\alpha} \right]^{\beta-2} \right\}$$

$$\frac{\partial^2 H_{\alpha,\beta}}{\partial \mu_A^2(x_i)} = \left\{ \alpha(\alpha-1)\beta \left[\mu_A^{\alpha-2}(x_i)\mu_B^{1-\alpha}(x_i) + (1-\mu_A(x_i))^{\alpha-2} (1-\mu_B(x_i))^{1-\alpha} \right]^{\beta-2} + \alpha(\beta-1)\beta \left[\mu_A^{\alpha-1}(x_i)\mu_B^{1-\alpha}(x_i) + (1-\mu_A(x_i))^{\alpha-1} (1-\mu_B(x_i))^{1-\alpha} \right]^{\beta-3} \right\}$$

$$\frac{\partial^2 H_{\alpha,\beta}}{\partial \mu_A^2(x_i)} > 0 \quad \text{for } \alpha > 0, \beta > 0, \alpha \neq 1, \beta \neq 1, 2$$

Similarly we can show that

$$\Rightarrow \frac{\partial^2 H_{\alpha,\beta}}{\partial \mu_B^2(x_i)} > 0 \quad \text{for } \alpha > 0, \beta > 0, \alpha \neq 1, 2, \beta \neq 1$$

Therefore, it follows that the proposed measures are sound axiomatically.

2.2 Some Important Properties

Assume that the family of all fuzzy set of universe X, is denoted by FS(X) and A, B, C ∈ FS(X) is given

$$A = \{ \langle x, \mu_A(x) \rangle / x \in X \}$$

$$B = \{ \langle x, \mu_B(x) \rangle / x \in X \}$$

$$C = \{ \langle x, \mu_C(x) \rangle / x \in X \}$$

and we have

$$\Delta_1 = \{ x_i / x_i \in X, \mu_A(x_i) \geq \mu_B(x_i) \}$$

$$\Delta_2 = \{ x_i / x_i \in X, \mu_A(x_i) < \mu_B(x_i) \}$$

Theorem 2. Prove that proposed measure in (1) satisfies the following properties [22]:

1. $H_{\alpha,\beta}(A \cup B, A) + H_{\alpha,\beta}(A \cap B, A) = H_{\alpha,\beta}(B, A)$
2. $H_{\alpha,\beta}(A, A \cap B) = H_{\alpha,\beta}(A \cup B, B)$
3. $H_{\alpha,\beta}(A, A \cup B) = H_{\alpha,\beta}(A \cap B, B)$
4. $H_{\alpha,\beta}(A \cup B, C) + H_{\alpha,\beta}(A \cap B, C) = H_{\alpha,\beta}(A, C) + H_{\alpha,\beta}(B, C)$
5. $H_{\alpha,\beta}(A \cup B, A \cap B) = H_{\alpha,\beta}(A \cup B, B) + H_{\alpha,\beta}(B, A \cap B)$
6. $H_{\alpha,\beta}(A, A^C) = H_{\alpha,\beta}(A^C, A)$
7. $H_{\alpha,\beta}(A^C, B^C) = H_{\alpha,\beta}(A, B)$
8. $H_{\alpha,\beta}(A, B^C) = H_{\alpha,\beta}(A^C, B)$
9. $H_{\alpha,\beta}(A, B) + H_{\alpha,\beta}(A^C, B) = H_{\alpha,\beta}(A^C, B^C) + H_{\alpha,\beta}(A, B^C)$

Proof:

$$1. \left[H_{\alpha,\beta}(A \cup B, A) + H_{\alpha,\beta}(A \cap B, A) \right] = \frac{1}{(\alpha-1)\beta} \sum_{i=1}^n \log \left\{ \left[\mu_{A \cup B}^\alpha(x_i)\mu_A^{1-\alpha}(x_i) + (1-\mu_{A \cup B}(x_i))^\alpha (1-\mu_A(x_i))^{1-\alpha} \right]^\beta + \left[\mu_{A \cap B}^\alpha(x_i)\mu_A^{1-\alpha}(x_i) + (1-\mu_{A \cap B}(x_i))^\alpha (1-\mu_A(x_i))^{1-\alpha} \right]^\beta - 2 \right\}$$

$$\begin{aligned}
 &= \frac{1}{(\alpha-1)\beta} \left\{ \sum_{\Delta_1} \log \left[\left[\mu_A^\alpha(x_i) \mu_A^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_A(x_i))^{1-\alpha} \right]^\beta - 1 \right\} + \right. \\
 &\sum_{\Delta_2} \log \left\{ \left[\mu_B^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_B(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} + \\
 &\left\{ \sum_{\Delta_1} \log \left[\left[\mu_A^\alpha(x_i) \mu_A^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_A(x_i))^{1-\alpha} \right]^\beta - 1 \right\} + \right. \\
 &\left. \sum_{\Delta_2} \log \left\{ \left[\mu_B^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_B(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \right\} \\
 &= \frac{1}{(\alpha-1)\beta} \sum_{i=1}^n \log \left\{ \left[\mu_B^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_B(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\}
 \end{aligned}$$

Hence we can say that

$$H_{\alpha,\beta}(A \cup B, A) + H_{\alpha,\beta}(A \cap B, A) = H_{\alpha,\beta}(B, A)$$

$$\begin{aligned}
 2. \quad H_{\alpha,\beta}(A, A \cap B) &= \frac{1}{(\alpha-1)\beta} \sum_{i=1}^n \log \left\{ \left[\mu_A^\alpha(x_i) \mu_{A \cap B}^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_{A \cap B}(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \\
 &= \frac{1}{(\alpha-1)\beta} \left\{ \sum_{\Delta_1} \log \left[\left[\mu_A^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} + \right. \\
 &\left. \sum_{\Delta_2} \log \left\{ \left[\mu_A^\alpha(x_i) \mu_A^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_A(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \right\} \\
 3. \quad &= \frac{1}{(\alpha-1)\beta} \left\{ \sum_{\Delta_1} \log \left[\left[\mu_A^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \right\}
 \end{aligned}$$

$$\begin{aligned}
 H_{\alpha,\beta}(A \cup B, B) &= \frac{1}{(\alpha-1)\beta} \sum_{i=1}^n \log \left\{ \left[\mu_{A \cup B}^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_{A \cup B}(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \\
 &= \frac{1}{(\alpha-1)\beta} \left\{ \sum_{\Delta_1} \log \left[\left[\mu_A^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} + \right. \\
 &\left. \sum_{\Delta_2} \log \left\{ \left[\mu_B^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_B(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \right\} \\
 &= \frac{1}{(\alpha-1)\beta} \left\{ \sum_{\Delta_1} \log \left[\left[\mu_A^\alpha(x_i) \mu_B^{1-\alpha}(x_i) + (1 - \mu_A(x_i))^\alpha (1 - \mu_B(x_i))^{1-\alpha} \right]^\beta - 1 \right\} \right\}
 \end{aligned}$$

Hence we can say that

$$H_{\alpha,\beta}(A, A \cap B) = H_{\alpha,\beta}(A \cup B, B)$$

All other properties can be proved as above

3 Conclusions

We describe the divergence metric measure for fuzzy sets in this study. The discussed properties of the proposed proposal. We tested the proposed function in this research and found that it satisfies all the crucial criteria. We see that the proposed function has more application flexibility due to the presence of the argument in it. Therefore, whenever alterations are made or limiting constraints are put in place, we have produced some significant and intriguing findings that may be helpful for the generalised fuzzy divergence metric. Finally, several other significant findings are made that are helpful in statistics and information science.

Competing Interests

Authors have declared that no competing interests exist.

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