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Analysis of Translations and Algebraic Properties of Intuitionistic Fuzzy Ideals across Diverse Algebraic Systems

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Abstract:
In this paper, a detailed investigation of the rich class of Intuitionistic Fuzzy Ideals (IFIs) is carried out in different algebraic structures with their different translations with respect to the algebraic properties. Intuitionistic fuzzy sets generalize the classical fuzzy set theory from degrees of membership to degrees of both membership and non-membership, and hence provide a powerful model for uncertainty representation. Their extension and application to abstract algebra results in the introduction of intuitionistic fuzzy ideals, generalizations of the classical ideals which are used to reason under conditions of uncertainty. The study is based on the analysis of the behaviour of IFIs under the convolutional fuzzy translations within BCK and BCI-algebras, and on the examination of anti-intuitionistic fuzzy ideals through level-set-based translation mechanisms. Furthermore, Cartesian product operations of opposite IF a-translation on division HA algebras are defined and give new insights into structure relations between algebraic systems. The paper combines sophisticated decision making models and distance measure in fuzzy set theory to justify the theoretical constructs and bring out their practical implications. This work is expected to promote further progress of mathematics, decision science, engineering and computer application by integrating intuitionistic fuzzy logic and algebraic theory for better understanding of uncertainty modelling and its algebraic foundation.

Keywords: Intuitionistic fuzzy ideals, fuzzy logic, algebraic structures, BCK/BCI-algebras, HA-algebras.

1. INTRODUCTION

This introduction introduces the background and purpose of the study and gives the conceptual framework for considering the different translations and algebraic properties of intuitionistic fuzzy ideals on different algebraic systems. Due to its ability to deal with vagueness and uncertainty, fuzzy logic has been introduced as an effective analytical paradigm in many disciplines, such as engineering, artificial intelligence and decision science. Fuzzy sets are the basic components of the fuzzy logic, which generalize the classical crisp sets by introducing the concept of membership degrees. This concept is further developed through the use of intuitionistic fuzzy sets, which allow for the inclusion of an additional degree of non-membership, providing a more nuanced and realistic way of modeling uncertainty. Intuistic fuzzy ideals (IFIs) allow generalization of classical ideals and are therefore also important to capture the effects of uncertainty and vagueness in algebraic reasoning. These ideals form a flexible analytic framework to studying abstract algebraic relationships. Despite the fact that intuitionistic fuzzy ideal theory has been studied in many areas, there have not been many studies on the behavior, transformations, and properties of intuitionistic fuzzy ideal in different algebraic structures. Algebraic structures are much more general than the classical rings, lattices, semirings and go up to the residuated lattices and HA-algebras with their own operating properties and relations.

The present study tries to fill up this gap by investigating various translations and algebraic features of intuitionistic fuzzy ideals in several algebraic environments. By studying the underlying mechanisms controlling their structure and their transformations, this research is an attempt to reveal some of the basic patterns which bind the fuzzy logic and algebraic theory together. By a thorough mathematical study and conceptual evaluation, the work is aimed at a theoretical development and an insightful importance to various areas. Ultimately, this work contributes to the ongoing discourse between fuzzy logic and algebra for the sake of innovation and more connection of uncertainty modeling in abstract mathematical systems.

1.1 Background on Fuzzy Logic and Intuitionistic Fuzzy Sets

Fuzzy logic is a branch of mathematics of reasoning and decision making, where reasoning and decision making rely on imprecise and uncertain information. Fuzzy logic is not strictly binary; that is to say that rather than being a true-or-false binary proposition, fuzzy logic breaks down propositions into degrees of truth. This flexibility enables more human-like reasoning and offers an effective tool for solving complex real world problems where there are no crisp boundaries. Fuzzy logic sets are built on fuzzy sets, a generalization of classical sets which requires each element in the set to have a membership value, between the range [0,1], which determines the extent to which the element belongs to the set. Based on the intuitionistic fuzzy set theory, the intuitionistic fuzzy sets is an extension of the classical fuzzy framework, in which the concept of non-membership is incorporated into the framework. In this formulation each element is having two independent functions membership and non-membership that do not necessarily sum up to one. This double representation of hesitation margin expresses the uncertainty that is implicit in human judgment and for observable phenomena. By simultaneously describing the membership and the non-membership, IFS can more fully and realistically describe the uncertainty of a phenomenon. The general applicability of fuzzy logic makes this extension of fuzzy logic especially useful in decision-making, data analysis and pattern recognition, to name a few. Therefore, the addition of intuitionistic fuzzy logic to algebraic structures makes it possible to understand the concept of uncertainty in a more analytical way with more fine-grained tools for mathematical modeling and reasoning.

1.2 Importance of Intuitionistic Fuzzy Ideals

Ideals play an important part in algebra through the fact that they encode useful structural properties like closure under addition and multiplication. They provide a basic structure within which algebraic relations and processes can be examined, and these will be used to understand the structure and operation of algebraic structures. The classical concept is generalized by the concept of intuitionistic fuzzy ideals, which allows degrees of indeterminism, allowing more elastic and practical representation of algebraic properties in the cases where indeterminism is inherent. Intuistic fuzzy ideals: generalizing the traditional ideals by incorporating the notions of fuzzy logic, traditional ideals are reformulated to model uncertainty in algebraic systems. This generalization makes the algebraic operations and relations expressible in the spaces with incomplete or imprecise information. Intuistic fuzzy ideal is a very useful ideal in many areas of decision making, optimization, pattern recognition, etc. where it is often not possible to have exact or definite information. Intuitionistic fuzzy ideals can offer a framework that is able to support graded reasoning and variable confidence levels, allowing researchers and practitioners to analyze uncertain systems with greater accuracy. They support enlightened decision-making in ambiguous and complex environments, and contribute to effective reasoning and interpretability. Therefore, intuitive fuzzy ideals are an important development in fuzzy logic theory and algebraic modeling, which has a close connection between theoretical abstraction and practical application.

2. REVIEW OF LITREATURE

Arya and Kumar (2025) A novel framework for the evaluation of Management Information Systems (MIS) using intuitionistic fuzzy sets with VIKOR and TODIM criteria combination with Havrda-C kvat-Tsallis entropy is presented. This embedded model forms a decision making basis for complex and uncertain environments. By addressing the issue of uncertainty in MIS assessment with the incorporation of entropy-based measures, the authors are able to effectively capture uncertainty and provide more precise and reliable decision outcomes. The theoretical soundness of their model and its applicability to real-world situations is shown by testing on actual datasets from MIS. Beyond introducing methodological innovation, the work of Arya and Kumar emphasizes the enthusiasm of the entropy-based strategies and fuzzy logic in modern MIS evaluation.

Bo (2024) builds on the TODIM method by introducing the interval-valued intuitionistic fuzzy information to evaluate the quality of college English teaching which is based on VIKOR method. This is a hybrid approach that combines two prominent multi-criteria decision making techniques in order to accommodate the complexity of an educational evaluation. By mixing VIKOR in the TODIM framework, Bo develops a strong evaluation model that deals with uncertainty and interval value characteristics inherent in evaluating language learning. The realization of the model on the actual classroom evaluations demonstrates how the model is practical and relevant with a significant contribution to the development of the hybrid decision making methods of educational research.

Chen (2023) proposes a preference ranking organization method based on dual point operator which is suitable for multi criteria decision analysis under Pythagorean fuzzy uncertainty. This method provides a systematic method of ranking preferences under uncertain conditions, with the combination of fuzzy set theory and probabilistic reasoning. The efficiency of the proposed approach is shown by simulations and case studies, focusing on its capacity to allow robust decisions in complex and uncertain scenarios, such as finance, engineering, healthcare, etc. Chen's contribution updates the decision analysis by giving a framework to treat the uncertainty of Pythagorean fuzzy context.

Cheng, Xiao, and Cao (2022) a new measure of distance for intuitionistic fuzzy sets (IFS) based on similarity matrices. Recognizing the need for accurate similarity measures in pattern classification, clustering and decision making, the authors develop a measure that takes into account membership and non-membership degrees. The accuracy and robust performance of the proposed metric is verified through their empirical and comparative analyses, which also show the improvement over traditional methods. Through this work of Cheng et al., the theoretical background of the theory of intuitionistic fuzzy sets is reinforced and its applications are extended to a wide variety of computational and analytical areas.

Kokkinos, Nathanail, Gerogiannis, Moustakas, and Karayannis (2022) present a decision-support system (DSS) based on hesitant and intuitionistic fuzzy decision making for determining optimum locations for hydrogen storage stations in sustainable freight transport; Combining reluctant intuitionistic decision models with the spatial location model, the framework enables robust and informed sustainability-relevant decision making. The effectiveness of the model is validated with the help of a case study in green logistics: it is shown that the model is able to handle uncertainty and stakeholder reluctance in environmental decisions. The work represents a valuable contribution to the development of DSS methodologies since it includes the highlighting of feasibility of the intuitive and hesitant fuzzy methods for the sustainability issues faced in practice.

3. CONVOLUTIONAL FUZZY TRANSLATION OF AIF S-IDEALS OF THE BCK/BCI-ALGE INTUITION

Within the framework of BCK/BCI-algebras, for demonstrating the complex nature of the subtraction operations in these algebraic systems, the convolutional fuzzy translation of AIF S-ideals integrates the principles of abstract algebra and fuzzy logic. Modeling in BCK/BCI-algebras sometimes will be difficult due to their inherent non-linearity and diversity in their underlying structure, which includes a wide range of algebraic behaviors. Accommodating the aspects of ambiguity and uncertainty in this way, intuitionistic fuzzy logic offers an effective analytical tool for this kind of systems because of the ability to represent ambiguity and uncertainty mathematically. The purpose of convolution fuzzy translation technique is to formulate higher understanding of AIF S-ideals of BCK/BCI-algebras. To add to this, convolutional interpretations in which information is summed in a higher dimension makes it easier to elaborate a more complete algebraic relationships and functional dependencies. It is shown how to do so in a way that makes the underlying laws of subtraction operations transparent in order to support the theoretical development of algebraic intuition.

Finally the convolutional fuzzy translation of AIF S-ideals is used as a conceptual link between the abstract algebraic theory and its application. It makes algebraic behaviours more interpretable in uncertain conditions and thus provides the basis for further work in mathematical logic, information processing and computational intelligence.

3.1 Anti-Intuitionistic Fuzzy A: Level Sets − Translation

An essential outcome in regards to the qualities of intuitionistic fluffy α−translations inside the setting of hostile to intuitionistic fluffy S−ideals in the mathematical set Z. This hypothesis lays out an important and adequate condition for the intuitionistic fluffy α−translation GS α = ((μG) S α ,(wG) S α) of G = (μG, wG) to qualify as an enemy of intuitionistic fluffy S−ideal of Z. The condition specifies that GS α should fulfill specific properties if and provided that Vα(μG, t) and Mα(wG, t) arise as S−ideals of Z for components s and t inside the pictures of the participation and non-enrollment elements of G, individually, where s ≥ α.

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The verification of this hypothesis starts by accepting that GS α is without a doubt an enemy of intuitionistic fluffy S−ideal of Z, consequently inferring that (μG) S α and (wG) S α likewise qualify as hostile to fluffy S−ideals inside Z. By utilizing this presumption, the verification continues to exhibit that for components s and t inside the pictures of the enrollment and non-participation elements of G, individually, where s ≥ α, the properties of Vα(μG, t) and Mα(wG, t) as S−ideals are maintained. This entails a detailed investigation of the properties and relationships between the participation and non-enrollment degrees, with their job in characterizing S-ideal inside the logistical set Z.

The proof gives significant bits of information about the mysterious interaction between intuitionistic fluffy a-translations and antagonistic to intuitionistic fluffy S-ideals of the mathematical structures. In the luminous light of the properties of intuitionistic fluffy a-translations, this hypothesis provides us an unambiguous measure for the transformation of hostile to intuitionistic fluffy S-ideals which in turn sheds light upon the interpretation of logarithmic designs and their use in fluffy set hypothesis. Through this examination provides a necessary framework to further examination and investigation in the sphere of hypotheses of fluffy set and mathematical models.

$$(\mu_G)^S_\alpha(0) \leq (\mu_G)^S_\alpha(z)$$

for z ∈ Z, it follows that

$$\mu_G(0) + \alpha = (\mu_G)^S_\alpha(0) \leq (\mu_G)^S_\alpha(z)$$
$$= \mu_G(z) + \alpha \leq s$$

for $z \in V_\alpha(\mu_G, s)$. So $0 \in V_\alpha(\mu_G, s)$.

Let $z, x, y \in Z$ so that $(z - x) - y, x \in V_\alpha(\mu_G, s)$. Next $\mu_G((z - x) - y) \leq s - \alpha$ and $mu_G(x) \leq s - \alpha$.

i.e., $(\mu_G)^S_\alpha((z - x) - y) = \mu_G((z - x) - y) + \alpha \leq s \;\; \& \;\; \mu_G(x) + \alpha$.

But, $(\mu_G)^S_\alpha$ is a fuzzy $S-$ ideal, So, We take

$$\begin{aligned} \mu_G(z - y) + \alpha &= (\mu_G)^S_\alpha(z - y) \\ &\leq \max\{(\mu_G)^S_\alpha((z - x) - y), (\mu_G)^S_\alpha(x)\} \\ &= min\{s, s\} \leq s, \end{aligned}$$

i.e.,μG((z − x) − y) ≥ s − α so that z − y ∈ Vα(μG, s).
Therefore, Vα(μG, s) is a S−ideal of Z.
Again, since (wG) S α (0) ≥ (wG) S α (z) for z ∈ Z, it becomes that

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$$(w_G)(0) - \alpha = (w_G)^S_\alpha(0)$$
$$\geq (w_G)^S_\alpha(z)$$
$$= (w_G)(z) - \alpha.$$

For $z \in M_\alpha(w_G, t)$. Hence, $0 \in M_\alpha(w_G, t)$.

Let $z, x, y \in Z$ then $(z - x) - y,\ x \in M_\alpha(w_G, t)$.

$\mu_G((z - y) - x) \geq t + \alpha$ and $w_G(y) \geq t + \alpha$.

So $(w_G)^S_\alpha((z - x) - y) = w_G((z - x) - y) - \alpha \geq t$ and $(w_G)^S_\alpha(x) = w_G(x) - \alpha \geq t$. Since $(w_G)^S_\alpha$ is a fuzzy $S-$ ideal, therefore it gives that

$$w_G(z - y) - \alpha = (w_G)^S_\alpha(z - y) \qquad \geq min\{(w_G)^S_\alpha((z - x) - y), (w_G)^S_\alpha(x)\} \geq t.$$

Therefore Mα(wG, t) is a S− ideal of Z.
Conversely, suppose that Vα(μG, s) and Mα(wG, t) are S− ideals of Z for s ∈ Im(μG) and t ∈ Im(wG) with s ≥ α.
If there exists v ∈ Z s.t (μG) S α (0) < (μG) S αx ≤ (μG) S α (v) then μA(v) ≥ μ − α but μG(0) < μ − α.
Let G = (μG, wG) is an AIFSI of Z and let β ∈ [0, S]. Everywhere AIFSI extension H = (μH, wH) for the intuitionistic fuzzy β− translation GS β = ((μG) S q ,(wG) S β) of G, it exists α ∈ [0, S] and it is α ≥ β and B be an anti-intuitionistic fuzzy S− ideal extension for the IF GS α = ((μG) S α ,(wG) S α) of G. Let us use the example below to explain
Example. Let Z = {0, 1, 2, 3, 4} be a Cayley table BCI− algebra:

-	0	1	2	3	4
0	0	0	0	0	0
1	1	0	1	0	1
2	2	2	0	2	0
3	3	1	3	0	3
4	4	4	2	4	0

(1) Let G = (μG, wG) be an intuitionistic fuzzy subset of defined by Z

Z	0	1	2	3	4
μ_G	0.43	0.57	0.66	0.57	0.66
w_G	0.55	0.42	0.34	0.42	0.34

And G = (μG, wG) is an AIFSI of Z and s = 0.43. When we do β = 0.13, the intuitionistic fuzzy β− translation of GS β = ((μG) S β (wG) S β) of G is given by

Z	0	1	2	3	4
$(\mu_G)^S_\beta$	0.43	0.44	0.53	0.44	0.53
$(w_G)^S_\beta$	0.68	0.55	0.47	0.55	0.47

4. CARTESIAN PRODUCTS WITH RESPECT TO AN OPPOSITE IF A TRANSLATIONS OF B−IDEALS IN DIVISION HA− ALGEBRAS

Two classes of real algebras made by K. Iseki are BCK-algebras and BCI-algebras. L. A. Zadeh encouraged the possibility of fluffy sets which has been used in different regions. O. G. In 1991, Xi carried out fluffy reasoning in BCK-algebras. Differences between experts have taken a cautious look into BCI/BCK-algebras. Fluffy positive implicative standards and fluffy commutative beliefs Fluffy positive implicative standards and fluffy commutative beliefs were introduced for BCK-algebras by Y. B. Jun et al. Senapati, T.M. Bhomik, M. Mate, J. Meng et al. introduced the translation of fluffy H goals for BCK/BCI-algebras. The thoughts of IFH - and IFATH - goals are supposed to be introduced and analyzed in this work. Depiction properties of IFH-goals and IFATH-standards are gotten. We decompose the relation between the IFH beliefs (resp. IFATH-goals), both in the IFH standards (resp. IFATH-goals) and in BCI standards. We similarly prove that an IFH-ideal in BCI Polynomial math, IFH-ideal, IFATH-ideal and fluffy ideal is an IFH-ideal in BCI Polynomial math. We concentrate on the correspondence between the IFH-standards. The very smart arrangement is a fluffy BCI positive enrolment and an IFATH, in whatever point what is happening permits.

Preliminaries

Definition.

A non-empty set of Z with a stable 1 and a ÷ binate function that meets the following axioms is called a HA− algebra division.

(i) $z \div z = 1$,

(ii) $z \div 1 = z$,

(iii) $(z \div x) \div (1 \div x) = z, \forall x, z \in Z$

Example. The set of all Complex numbers is a Division BG-Algebras.

Example. Let Z = {0, 1, 2, 3, 4} by the following given Cayley table:

Table 1: Cayley table for division HA− algebra

÷	0	1	2	3	4
0	1	0	0	0	0
1	0	1	1	1	1
2	2	2	2	1	2
3	3	3	3	1	3
4	4	4	4	2	1

Cartesian Products Over a Opposite Intuitionistic Fuzzy H-Ideal

Definition. Allow Z to be a division of HA - algebras and let G and H be two inverse intuitionistic fluffy a interpretation sets. Then, coming up next is the meaning of the cartesian results of two inverse intuitionistic fluffy alpha-Interpretation sets, G and H:

Definition the Cartesian product ×1

$$G \times_1 H = \{<< z, x >, (\mu^S_{G_\alpha}(z), \mu^S_{H_\alpha}(x)), (\mu^S_{G_\alpha}(z), \mu^S_{G_\alpha}(x)) - \alpha >: x, z \in Z\}$$

Definition the Cartesian product ×2

$$G \times_2 H = \{<< z, x >, ((\mu^S_{G_\alpha}(z) + \mu^S_{H_\alpha}(x))) - ((\mu^S_{G_\alpha}(z), \mu^S_{H_\alpha}(x))), (\chi^S_{G_\alpha}(z), \chi^S_{H_\alpha}(x)) - \alpha >: x, z \in Z\}$$

Definition the Cartesian product ×3

$$G \times_3 H = \{<< z, x >, ((\mu^S_{G_\alpha}(z) + \mu^S_{H_\alpha}(x))), ((\chi^S_{G_\alpha}(z), \chi^S_{H_\alpha}(x))) - (\chi^S_{G_\alpha}(z), \chi^S_{H_\alpha}(x)) >: x, z \in Z\}$$

Definition the Cartesian product ×4

$$G \times_4 H = \{<< z, x >, \min(\mu^S_{G_\alpha}(z), \mu^S_{H_\alpha}(x)), \max(\chi^S_{G_\alpha}(z), \chi^S_{H_\alpha}(x)) >: x, z \in Z\}$$

Definition the Cartesian product ×5

$$G \times_5 = \{<< z, x >, \max(\mu^S_{G_\alpha}(z), \mu^S_{H_\alpha}(x)), \min(\chi^S_{G_\alpha}(z), \chi^S_{H_\alpha}(x)) >: x, z \in Z\}$$

Definition of gives the possibility to divide HA-algebras Z as Cartesian outcomes of Inverse Intuitionistic Fluffy a-Interpretation sets Coming up next is an orderly meaning of the Cartesian items, that is, x1, x2, x3, x4 and x5. With regards to division HA-algebras, the following definitions determine the processing of the Cartesian results of two Inverse Intuitionistic Fluffy alpha-Interpretation sets, G and H. The exact conditions and processes on applying each of the Cartesian product operations to sets G and H are explained. These concepts explain a systematic method to perform the operations of Cartesian product on Opposite Intuitionistic Fuzzy a-Translation sets, which means mathematical operations in division HA-algebras become more understandable and consistent.

5. CONCLUSION

This paper gives a complete study on the different translations and algebraic properties of Intuitionistic Fuzzy Ideals (IFIs) in various algebraic systems, such as BCK/BCI-algebras, HA-division algebras and their counterparts. By combining the conceptual richness of intuitionistic fuzzy logic which simultaneously handles membership and non-membership degrees with the structural strength of classical algebra, the work underlines the flexibility of IFIs in modelling uncertainty and imprecision in intricate mathematical and real-world situations. Presenting and analyzing the notions of convolution fuzzy translation, anti-intuitionistic fuzzy S-ideal and Cartesian product over opposite IF a-translation are added as novel mathematical tools for studying and generalizing the frontier of fuzzy algebra. Not only do these formulations maintain basic algebraic properties, but they also extend the representational strength of algebraic systems by enabling greater flexibility in modeling of ambiguity and interaction. The theoretical results and illustrative examples are enough to show that IFIs can be effectively defined, analysed and applied in different algebraic structures, thus enriching both the theory and practice. Abstract algebra and fuzzy set theory as the base of interdisciplinary applications to decision science, artificial intelligence, optimization, information systems, etc. Future research can focus on the extension of the models to dynamic systems, fuzzy topological properties, computational and machine learning methods based on the intuitionistic fuzzy algebraic structures to contribute to the modeling of reasoning under uncertainty.

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