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## Significant Differences Between Neutrosophic Sets and Fermatean Neutrosophic Sets

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### Abstract

In contemporary data analysis and decision-making, managing ambiguity, imprecision, and uncertainty is essential. Advanced frameworks like neutrosophic sets and Fermatean neutrosophic sets were created to tackle these issues. By adding three distinct membership functions to express truth, indeterminacy, and falsity, neutrosophic sets expand fuzzy set theory and provide a thorough method for handling inconsistent and incomplete data. On the other hand, Fermatean neutrosophic sets offer a more flexible and nuanced depiction of uncertainty by adding a cubic sum constraint on the membership degrees. This paper analyses the theoretical underpinnings of both sets, contrasts their strengths and weaknesses and structures, and employs real-world examples to illustrate how they might be used in actuality. While Fermatean neutrosophic sets are used in project management, autonomous vehicle navigation, and financial investment decisions, neutrosophic sets have been tested in medical diagnosis, sentiment analysis, and environmental risk monitoring. By emphasising each framework's advantages and appropriateness for various decision-making scenarios, the comparison analysis sheds light on how advantageous they are in real-world circumstances involving complicated unpredictability.

**Keywords:** Fermatean Neutrosophic Set; Neutrosophic Set; Comparision; Real-Life Examples.

## 1 | Introduction

Making intelligent choices frequently necessitates sophisticated techniques for coping with imprecise, unclear, and unreliable data in today's complex and uncertain world. In order to effectively handle these complications, conventional set theories—including fuzzy sets—have been expanded. A particular extension that uses three separate membership functions—truth, indeterminacy, and falsity—to thoroughly describe many facets of uncertainty is the neutrosophic set, which originally was suggested by Florentin Smarandache. By using a cubic sum rule for the membership degrees, Fermatean neutrosophic sets offer an even more adaptable framework, enabling a more complex depiction of uncertainty and indeterminacy.

Although, several theories address uncertainty in ambiguous situations, but they often fall short of handling all cases, emphasizing the need for further advancements. The Fermatean Neutrosophic Set (FNS) as well as Neutrosophic Set (NS) serves as a generalized framework, covering fuzzy, intuitionistic fuzzy, Pythagorean fuzzy, spherical fuzzy, and Fermatean fuzzy sets, and can also simplify into these forms, making it highly



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versatile for managing various uncertainties. However, there is a pressing need for a systematic study that directly compares neutrosophic sets (NS) and Fermatean neutrosophic sets (FNS) in terms of their structural boundaries and real-world decision-making performance, so as to clearly establish the specific conditions under which FNS's added flexibility yields genuine advantages over conventional NS, rather than simply assuming this superiority based on theoretical generalization alone. This study addresses that gap through a direct theoretical and applied comparison of NS and FNS across medical diagnosis, sentiment analysis, project management, and autonomous vehicle navigation.

This paper delves into the theoretical underpinnings of neutrosophic and Fermatean neutrosophic sets, comparing their structures and capabilities. Further, aims to demonstrate the usefulness and benefits of these advanced set theories utilizing real-world examples from a variety of domains, including medical diagnosis, sentiment analysis, project management, and autonomous car navigation. By highlighting each framework's unique advantages, this comparison seeks to shed light on how well-suited each is for different decision-making situations with intricate uncertainty.

Based on the findings illustrated in the following papers given below the results are utilized.

| Resarchers           | Year | Refrence | Findings                                                                                                |
|----------------------|------|----------|---------------------------------------------------------------------------------------------------------|
| Zadeh, L. A.         | 1965 | [1]      | Introduction to Fuzzy Sets                                                                              |
| Atanassov, K. T.     | 1986 | [2]      | Intuitionistic Fuzzy Sets                                                                               |
| Smarandache F.       | 1999 | [3]      | Unifying Field in Logics                                                                                |
| Smarandache, F.      | 2005 | [4]      | Neutrosophic Set, a generalization of the intuitionistic fuzzy sets                                     |
| Wang, H. et al       | 2012 | [5]      | Single Valued Neutrosophic Sets                                                                         |
| Yager, R. R.         | 2013 | [6]      | Pythagorean Fuzzy Subsets                                                                               |
| Jansi. et al         | 2019 | [7]      | Correlation Measure for Pythagorean Neutrosophic Sets with T and F as Dependent Neutrosophic Components |
| Senapati, T          | 2020 | [8]      | Fermatean fuzzy sets                                                                                    |
| Antony Crispin et.al | 2021 | [9]      | Fermatean Neutrosophic Sets                                                                             |
| Broumi, et .al       | 2022 | [10]     | Theory and Applications of Fermatean Neutrosophic Graphs                                                |
| Broumi, S. et .al    | 2022 | [11]     | Interval-valued fermatean neutrosophic graphs                                                           |
| Karak, M.et al       | 2023 | [12]     | A Solution Technique of Transportation Problem in Neutrosophic Environment                              |

## 2 | Preliminaries

**Definition 2.1** [1]: Let  $X$  be a nonempty set. A fuzzy set  $A$  drawn from  $X$  is defined as

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

Where  $\mu_A : X \rightarrow [0,1]$  is the membership function of the fuzzy set  $A$ .

**Definition 2.2** [2]: Let  $X$  be a universe. An intuitionistic fuzzy set  $A$  on  $X$  can be defined as follows:

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

Where  $\mu_A : X \rightarrow [0,1]$  and  $\nu_A : X \rightarrow [0,1]$  such that  $0 \leq \mu_A(x) + \nu_A(x) \leq 1$  for any  $x \in X$  Where,  $\mu_A(x)$  and  $\nu_A(x)$  is the degree of membership and degree of non-membership of the element  $x$  respectively.

**Definition 2.3** [3]: Let  $X$  be a universe set. A Neutrosophic Set (NS)  $A$  in  $X$  is characterized by a truth membership function  $T_A$ , an indeterminacy membership function  $I_A$  and a falsity membership function  $F_A$  where  $T_A$ ,  $I_A$  and  $F_A$  are real standard elements of  $[0,1]$ . It can be written as

$$A = \{\langle x, (T_A(x)) + (I_A(x)) + (F_A(x)) \rangle : x \in X, T_A, I_A, F_A \in ]-0, 1+[ \}$$

There is no restriction on the sum of  $(T_A(x))$ ,  $(I_A(x))$  and  $(F_A(x))$ , and

$$0^- \leq (T_A(x)) + (I_A(x)) + (F_A(x)) \leq 3^+$$

**Definition 2.4** [4]: Consider  $X$  be a set that is not empty (universe).  $A$  is a neutrosophic set on  $X$  is of the form:

$$A = \{ \langle x, T_A(x), I_A(x), F_A(x) \rangle | x \in X \}$$

where  $T_A(x), I_A(x), F_A(x) \in [0, 1]$ ,  $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 2$ , for every  $x$  in  $X$ .  $T_A(x)$  is the degree of membership,  $I_A(x)$  is the degree of indeterminacy and  $F_A(x)$  is the degree of non-membership. Here  $T_A(x)$  and  $F_A(x)$  are dependent components and  $I_A(x)$  is an independent component.

**Definition.2.5** [9]: Let  $X$  be a non-empty set (universe). A Fermatean neutrosophic set (FNS)  $\tilde{S}$  on  $X$  is an object of the form:

$$\tilde{S} = \{ \langle s, (T_{\tilde{S}}(s), I_{\tilde{S}}(s), F_{\tilde{S}}(s)) \rangle | s \in X \}$$

where,  $T_{\tilde{S}}(s), I_{\tilde{S}}(s), F_{\tilde{S}}(s) : X \rightarrow [0, 1]$ ,  $0 \leq T_{\tilde{S}}^3(s) + F_{\tilde{S}}^3(s) \leq 1$ ,  $0 \leq I_{\tilde{S}}^3(s) \leq 1$

then

$$0 \leq T_{\tilde{S}}^3(s) + I_{\tilde{S}}^3(s) + F_{\tilde{S}}^3(s) \leq 2 \forall s \in X$$

$T_{\tilde{S}}(s)$  is the degree of membership,  $I_{\tilde{S}}(s)$  is the degree of indeterminacy and  $F_{\tilde{S}}(s)$  is the degree of non-membership. Here  $T_{\tilde{S}}(s)$  and  $F_{\tilde{S}}(s)$  are dependent components and  $I_{\tilde{S}}(s)$  is an independent component.

### 3 | Substantial Difference between Neutrosophic Sets and Fermatean Neutrosophic Sets

Let's consider other type of examples of both neutrosophic sets and Fermatean Neutrosophic sets and highlight their differences:

#### 3.1 | Neutrosophic Sets Example

Consider a neutrosophic set representing the concept of "temperature" in a room. We define the elements of the set as the temperature values in Celsius at different locations within the room.

For each temperature value, we assign degrees of truth, indeterminacy, and falsity to represent the uncertainty associated with the temperature measurement. For instance:

- **Truth:** Degree to which the temperature value is accurate based on the thermometer used.
- **Indeterminacy:** Degree of uncertainty due to factors like sensor accuracy, air circulation, or measurement errors.
- **Falsity:** Degree of discrepancy between the measured temperature and the actual temperature.

In this example, a neutrosophic set allows us to express the uncertainty inherent in temperature measurements across different locations in the room. For instance, a window-side reading is assigned ( $T = 0.7$ ,  $I = 0.2$ ,  $F = 0.1$ ), satisfying  $0 \leq T + I + F \leq 3$ , where  $T$  represents thermometer accuracy,  $I$  represents uncertainty from air circulation, and  $F$  represents deviation due to sunlight exposure.

#### 3.2 | Fermatean Neutrosophic Sets Example

Let's consider a Fermatean Neutrosophic set representing the concept of "weather conditions" in a region. We define the elements of the set as different weather conditions such as sunny, rainy, cloudy, and windy.

For each weather condition, we assign membership, non-membership, and indeterminacy values to represent the degree of belongingness to that weather condition, the degree of not belongingness, and the degree of uncertainty respectively. For instance:

- **Membership:** Degree to which a weather condition belongs to a specific category based on meteorological data and observations.
- **Non-membership:** Degree to which a weather condition does not belong to a specific category.
- **Indeterminacy:** Degree of uncertainty or ambiguity in categorizing the weather condition.

By taking into account variables like transitional weather patterns or insufficient knowledge, a Fermatean Neutrosophic set in this case enables us to convey the uncertainty in categorising weather situations into distinct groups.

In this example, a Fermatean neutrosophic set allows us to express the uncertainty inherent in categorizing weather conditions across different observations in the region. For instance, a transitional weather state is assigned ( $T = 0.75$ ,  $I = 0.4$ ,  $F = 0.55$ ), satisfying  $0 \leq T^3 + I^3 + F^3 \leq 2$  — a cubic bound that allows high, conflicting membership and non-membership values a neutrosophic set can't as naturally represent.

## 4 | Real-Life Examples

### 4.1 | Medical Diagnosis: Sentiment Analysis

#### Neutrosophic Sets

##### **Scenario:**

A doctor diagnosing a patient with symptoms that match multiple conditions (e.g., flu, COVID-19, or a common cold).

##### **Neutrosophic Set Representation:**

**Truth Membership (T):** The probability that the patient has the flu based on observed symptoms.

**Indeterminacy Membership (I):** Uncertainty due to overlapping symptoms with other diseases and lack of complete information.

**Falsity Membership (F):** The probability that the patient does not have the flu.

**Example Values:**  $T=0.7$ ,  $I=0.4$ ,  $F=0.3$ .

#### Fermatean Neutrosophic Sets

##### **Scenario:**

Three doctors are diagnosing a patient whose symptoms could indicate various conditions (e.g., flu, COVID-19, or a common cold). Therefore, we are assigning a neutrosophic value to the patient, resulting in three sets of truth, indeterminacy, and falsity memberships.

##### **Neutrosophic Set Representation:**

**Truth Membership (T):** The probability that the patient has the flu based on observed symptoms.

**Indeterminacy Membership (I):** Uncertainty due to overlapping symptoms with other diseases and lack of complete information.

**Falsity Membership (F):** The probability that the patient does not have the flu.

**Example Values:**

Doctor 1:  $T=0.8, I=0.5, F=0.6$ .

Doctor 2:  $T=0.9, I=0.7, F=0.7$ .

Doctor 3:  $T=0.7, I=0.5, F=0.8$ .

Based on the values provided, we are focusing on the maximum value to ensure the patient's recovery. The maximum values of  $T$ ,  $I$ , and  $F$  are selected because they preserve the most cautious expert judgment, appropriate given the high clinical cost of false negatives, and this operation remains theoretically valid as the resulting aggregated triple stays closed under the FNS constraint ( $T^3+I^3+F^3 \leq 2$ ).

Therefore, we obtain the values as follows:

$$T= 0.9, I= 0.7, F= 0.8 \text{ (where } T^3+I^3+F^3 \leq 2 \text{ but } T+I+F > 2).$$

In this example, a Fermatean Neutrosophic set enables us to express the uncertainty in classifying medical diagnoses into specific categories, considering factors such as multiple potential conditions and incomplete information. By using a Fermatean Neutrosophic set, we can compare and integrate the reviews of three doctors to achieve a more accurate diagnosis.

## 4.2 | Sentiment Analysis

### Neutrosophic Sets

#### **Scenario:**

Analyzing customer reviews for a product to determine overall sentiment.

#### **Neutrosophic Set Representation:**

**Truth Membership (T):** The degree to which a review is positive.

**Indeterminacy Membership (I):** Ambiguity in the review text (e.g., mixed emotions or unclear statements).

**Falsity Membership (F):** The degree to which a review is negative.

**Example Values:**  $T=0.6, I=0.3, F=0.3$

### Fermatean Neutrosophic Sets

#### **Scenario:**

Evaluating the general attitude of four customer reviews of a product. There are four sets of truth, indeterminacy, and falsity memberships as a result of providing each consumer a neutrosophic value..

#### **Neutrosophic Set Representation:**

**Truth Membership (T):** The degree to which a review is positive.

**Indeterminacy Membership (I):** Ambiguity in the review text (e.g., mixed emotions or unclear statements).

**Falsity Membership (F):** The degree to which a review is negative.

#### **Example Values:**

customer 1:  $T=0.6, I=0.5, F=0.7$ .

customer 2:  $T=0.8, I=0.7, F=0.2$ .

customer 3:  $T=0.5, I=0.8, F=0.5$ .

customer 4:  $T=0.4, I=0.8, F=0.7$ .

To ensure good product quality, we are concentrating on the greatest value based on the customer review values. As the outcome, we conclude with the following values:

$$T=0.8, I=0.8, F=0.7 \text{ (where } T^3+I^3+F^3 \leq 2 \text{ but } T+I+F > 2).$$

In this case, we may represent the ambiguity in grouping the product's quality into several categories by considering elements like insufficient information and many possible situations using a Fermatean Neutrosophic set. To get a more accurate evaluation of customer feedback, we may compare and combine the reviews of four consumers using a Fermatean Neutrosophic set.

### 4.3 | Decision-Making

#### Neutrosophic Sets

Scenario:

Deciding whether to proceed with a new project based on incomplete data.

Fermatean Neutrosophic Set Representation:

**Truth Membership (T):** Confidence level that the project will succeed based on current information.

**Indeterminacy Membership (I):** Uncertainty due to unknown market conditions or incomplete project specifications.

**Falsity Membership (F):** Confidence level that the project will fail.

Example Values:  $T=0.9, I=0.8, F=0.1$ .

#### Fermatean Neutrosophic Sets

Scenario:

Deciding whether to proceed with a new project based on incomplete data with two neutrosophic values.

**Fermatean Neutrosophic Set Representation:**

**Truth Membership (T):** Confidence level that the project will succeed based on current information.

**Indeterminacy Membership (I):** Uncertainty due to unknown market conditions or incomplete project specifications.

**Falsity Membership (F):** Confidence level that the project will fail.

**Example Values:**

Decision maker 1:  $T=0.7, I=0.8, F=0.6$ .

Decision maker 2:  $T=0.8, I=0.9, F=0.7$ .

To ensure the new project, we are concentrating on the highest value based on the values of the decision makers. Consequently, we reach the following findings:

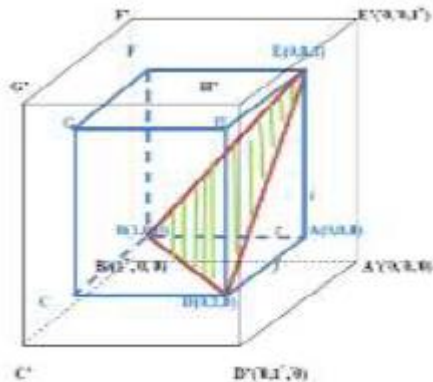
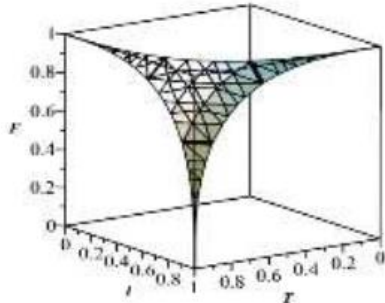
$$T=0.8, I=0.9, F=0.6 \text{ (where } T^3+I^3+F^3 \leq 2 \text{ but } T+I+F > 2).$$

In this scenario, considering variables like various possible circumstances and insufficient knowledge, a Fermatean Neutrosophic set allows us to describe the ambiguity in categorizing decision-making into distinct groups. To get a more accurate value, we can compare and combine the assessments of two decision-makers using a Fermatean Neutrosophic set.

## 5 | Comparison between Fermatean Neutrosophic Sets and Neutrosophic Sets

Both neutrosophic sets and Fermatean neutrosophic sets are frameworks designed to deal with imperfect knowledge, vagueness, and uncertainty. Fermatean neutrosophic sets offer an extended structure inside the framework of neutrosophic sets, which provide a wide method to capturing these ambiguities. This is a thorough comparison of the two:

| Properties                | Neutrosophic Sets                                                                                                                                               | Fermatean Neutrosophic Sets                                                                                                                                                                                                                                |
|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Membership Function       | Truth Membership (T):<br>$T_S(s) \in [0,1]$                                                                                                                     | Truth Membership (T):<br>$T_S(s) \in [0,1]$                                                                                                                                                                                                                |
|                           | Indeterminacy Membership (I): $I_S(s) \in [0,1]$                                                                                                                | Indeterminacy Membership (I): $I_S(s) \in [0,1]$                                                                                                                                                                                                           |
|                           | Falsity Membership (F):<br>$F_S(s) \in [0,1]$                                                                                                                   | Falsity Membership (F): $F_S(s) \in [0,1]$                                                                                                                                                                                                                 |
| Independence of Component | The values of $T_S(s)$ , and $F_S(s)$ are dependent of each other. $I_S(s)$ is dependent.                                                                       | The values of $T_S(s)$ , and $F_S(s)$ are dependent of each other. $I_S(s)$ is dependent.                                                                                                                                                                  |
|                           | $0 \leq T_S(s) + F_S(s) \leq 1$ , and $0 \leq I_S(s) \leq 1$ can be any value within the range $[0,1]$ .                                                        | $0 \leq T_S^3(s) + F_S^3(s) \leq 1$ , and $0 \leq I_S^3(s) \leq 1$ can be any value within the range $[0,1]$ .                                                                                                                                             |
|                           | $F_S(s) \leq 1 - T_S(s)$                                                                                                                                        | $F_S^3(s) \leq 1 - T_S^3(s)$                                                                                                                                                                                                                               |
|                           | $0 \leq T_S(s) + I_S(s) + F_S(s) \leq 2$                                                                                                                        | $0 \leq T_S^3(s) + I_S^3(s) + F_S^3(s) \leq 2$                                                                                                                                                                                                             |
| Flexibility               | Neutrosophic sets can handle incomplete, inconsistent, and indeterminate information.                                                                           | The cubic relationship allows for more nuanced and detailed modeling of uncertainty.                                                                                                                                                                       |
|                           | They provide a robust framework for modeling real-world problems where data uncertainty is a significant factor.                                                | It provides a more comprehensive range of membership values, making it useful for complex decision-making scenarios.                                                                                                                                       |
| Applications              | Widely used in artificial intelligence, decision-making, information processing, and other fields requiring handling of uncertain and inconsistent information. | Similar to neutrosophic sets, but especially useful in scenarios requiring a higher degree of flexibility and nuance in modeling uncertainty and indeterminacy.<br>Applied in fields like decision-making, medical diagnosis, and complex system analysis. |
| Mathematical Structure:   | Use the sum of truth, indeterminacy, and falsity components, which can range from 0 to 2.                                                                       | Use the cubic sum condition $0 \leq T_S^3(s) + I_S^3(s) + F_S^3(s) \leq 2$ allowing more flexible and nuanced representation.                                                                                                                              |

|                                        |                                                                                                                                                      |                                                                                                                                       |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| <b>Flexibility and Expressiveness:</b> | Provide a broad framework suitable for handling general uncertainty and inconsistency.                                                               | Offer enhanced flexibility due to the cubic constraint, allowing for more detailed and refined uncertainty modeling.                  |
| <b>Handling of Uncertainty:</b>        | Suitable for general cases of uncertainty, indeterminacy, and inconsistency.                                                                         | Particularly effective in scenarios requiring a more nuanced approach to uncertainty, benefiting from the relaxed cubic relationship. |
| <b>Distance measure in MCDM</b>        | In Neutrosophic set, Similarity measure is an important tool in MCDM problems, which can be used to measure the difference between the alternatives. | In Fermatean neutrosophic set Similarity measure gives a more reliable then NS.                                                       |
| <b>CODAS technique</b>                 | Neutrosophic set gives accurate result                                                                                                               | Fermatean neutrosophic set gives more accurate result when compared to neutrosophic set in the case of dependence.                    |
| <b>Region</b>                          | For smaller region Neutrosophic set gives reliable result.                                                                                           | For bigger region Fermatean neutrosophic set gives a reliable result                                                                  |
| <b>If and only if Condition</b>        | Neutrosophic set dose not satisfies Fermatean neutrosophic set condition.                                                                            | Fermatean neutrosophic set satisfies neutrosophic set condition.                                                                      |
| <b>Graphical Representation</b>        |                                                                   |                                                   |

## 6 | Neutrosophy and Neutrosophic Logic Usages

- Multispace, multistructure, and transdisciplinarity.
- Analysing complex systems using qualitative causal reasoning.
- Topologies that is neutrosophic.

- Neutrosophic set-based vector reinforcement machine.
- Neutrosophic cognitive maps are employed as a decision support aid in knowledge-based institutions.
- Inaccurate answer to queries. Synthesis Neural Networks Implementing Bagging and Interval Neutrosophic Sets.
- Lithofacies tagging utilizing well log data employing quantification of uncertainty, interval neutrosophic sets, and neural networks.
- Rethinking the Decision Matrix Technique using an inference method based on indefiniteness.

## 7 | Conclusion

This study compared neutrosophic sets (NS) and Fermatean neutrosophic sets (FNS) both theoretically and across four real-world domains—medical diagnosis, sentiment analysis, project management, and autonomous vehicle navigation. While NS bounds uncertainty linearly ( $0 \leq T+I+F \leq 3$ ), FNS relaxes this through a cubic constraint ( $0 \leq T^3+I^3+F^3 \leq 2$ ), enabling it to represent high, conflicting degrees of membership and non-membership that NS cannot naturally accommodate, as seen in our medical diagnosis and sentiment analysis cases. NS, meanwhile, remains effective and computationally simpler for problems with more moderate, clearly separable uncertainty, such as structured project management. These findings give practitioners a practical basis for choosing between the two frameworks according to the severity and complexity of uncertainty in their specific application.

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## Conflicts of Interest

The authors declare no conflict of interest.

## Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

## Author Contributions

All authors contributed equally to this study.

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