Neutrosophic Logic and Its Scientific Applications

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Chapter 38
Neutrosophic Logic and Its Scientific Applications

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Abstract The scientific term neutrosophy was first coined by Florentin Smarandache a few years ago. The origins, attribute, extent of neutralities and their interactions with other ideational spectra, and indeterminacy are all investigated in this discipline of study. Neutrosophic logic, a group of many-valued systems which can be regarded as an extension of fuzzy logic, is one of the new theories based on the fundamental principles of neutrosophy. Neutrosophy logic is a new branch of logic that addresses the shortcomings of fuzzy and classical logic. Some of the disadvantages of fuzzy relations are failures to handle inconsistent information and the high processing cost of completing a non-linear program. In neutrosophic sets, truthfulness and falsity are independent, whereas in intuitionistic fuzzy sets, it is dependent. The neutrosophic logic has the ability to manipulate both incomplete and inconsistent data. So, there is a need for research into the use of neutrosophic logic in different domains from medical treatment to the role of a recommender system using new advanced computational intelligent techniques. In this study, we are discussing about basic concepts of neutrosophic logic, fuzzy logic's drawbacks and advantages of using neutrosophic logic, and also the comparison between neutrosophic logic, intuitionistic and interval-valued fuzzy systems, and classical logic on different factors like uncertainty and vagueness.

38.1 Introduction

One of A.I.'s prominent issues and challenges is simulating uncertainty for addressing realistic situations. Managing uncertainties, particularly indeterminate circumstances where it is not true or false, is the utmost goal for decision-makers. As a result, new approaches to attribute interpretation are emerging, like fuzzy logic, intuitionistic,

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interval-valued fuzzy, and neutrosophic models. The fuzzy logic system was first introduced by Prof. L.A. Zadeh in 1965. It is used to deal with the concept of partial truth, where the truth value can be somewhere between true and false. It is one of the soft computing methods for simulating real-world uncertainties. In classical logic, on the other hand, the truth values of variables are either 0 or 1. Models that are fuzzy, intuitionistic fuzzy, or imprecise are constrained because they cannot express indeterminacy and contradiction, which is a very important feature of human thought. Florentin Smarandache proposed the theory of neutrosophic logic since fuzzy logic is unable to exhibit indeterminacy on its own [1]. Neutrosophic logic (NL) is a set of logic that generalizes fuzzy logic, paraconsistent logic, intuitionistic logic, etc. The first part of neutrosophic logic is the degree of membership (T), the middle part is indeterminacy (I), and the third part is the degree of non-membership of each set element.

The rest of the chapter is organized as follows: Sect. 38.2 describes about the overview of the neutrosophic logic system and its basic concepts. Section 38.3 presents the relationship between neutrosophic logic, classical logic, and fuzzy logic, and Sect. 38.4 describes about differences between the two logic systems. Section 38.5 tells about the advantages of neutrosophic logic over fuzzy logic. Section 38.6 differentiates between different expert systems. Section 38.7 describes the different inference systems of different expert systems. Section 38.8 shows the applications of neutrosophic logic and Sect. 38.9 comprises the conclusion and future work.

38.2 Background

38.2.1 Crisp Logic (Classical Logic)

It is similar to Boolean logic (either 0 or 1). True (1) or false (0) is the outcome of a statement. Fuzzy logic, on the other hand, captures the degree to which something is true.

38.2.2 Fuzzy Logic

Fuzzy logic is a type of many-valued logic with membership degrees ranging from 1 to 0. The fuzzy set theory proposed by fuzzy logic states that a fuzzy set is a collection of ordered pairs represented by

$$A = \{(y, \mu_A(y)) | y \in U\}$$

where $\mu_A(y)$ = membership function in fuzzy set A,

U = universe of discourse.

There is partial membership in the situation of fuzzy sets. The membership function, with a value ranging from 0 to 1, is used to calculate the degree of uncertainty of the fuzzy set's elements. The truth value of variables in fuzzy logic can be any real number between 0 and 1, both inclusive [2].

38.2.3 Intuitionistic and Paraconsistent Logic

Paraconsistent logic refers to a branch of logic that studies and develops "inconsistency-tolerant" logic systems that reject the idea of explosion, whereas intuitionistic logic includes the general principles of logical reasoning which have been derived by logicians from intuitionistic mathematics.

38.2.4 Neutrosophic Logic

The term "neutrosophic logic" refers to a logic in which the proposition's parameters are defined as follows:

1. Truth (T), percentage of truth
2. Falsehood (F), percentage of falsity
3. Indeterminacy (I), the condition or percentage of being indeterminate

where truth, indeterminacy, and falsehood are standard or non-standard real subsets of]0,1 + [, that is not inherently connected.

The total value of the elements in single-valued neutrosophic logic is:

1. $0 \le t + i + f \le 3$, when each of these elements is self-contained.
2. $0 \le t + i + f \le 2$, when two elements are interdependent, but the final part is unaffected.
3. $0 \le t + i + f \le 1$, when all three elements are interconnected.

There is scope for inadequate information (total < 1), paraconsistent and conflicting information (total > 1), or complete information (total = 1) when three or two of the T, I, F components are independent. If all three aspects of truth, indeterminacy, and falsity are interconnected, one can offer partial (total < 1) or entire (total = 1) information in the same way.

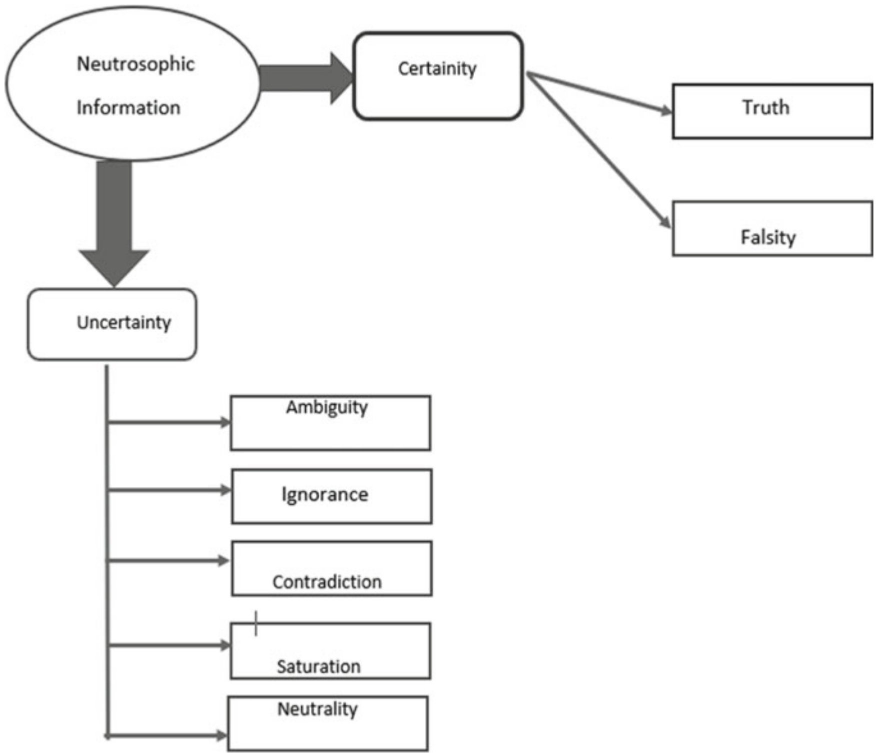

Fig. 38.1 Neutrosophic data

38.2.5 Neutrosophic Data

Neutrosophic data consists of certainty and uncertainty data. Certainty data is further subdivided into truth and falsity. In the case of uncertainty data, it consists of ambiguity, ignorance, contradiction, saturation, and neutralities (Fig. 38.1).

38.3 Relationship Between Neutrosophic and Fuzzy Logic

38.3.1 Neutrosophic System Equation

$$X \circ R = Y$$

where

$X \Rightarrow$ Neutrosophic data.
$Y \Rightarrow$ Neutrosophic output/information.

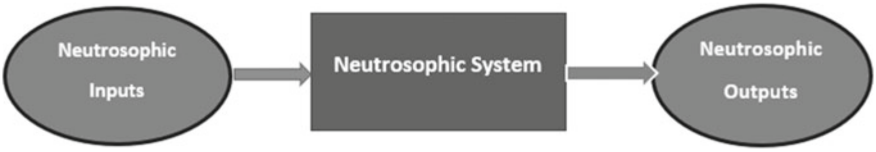

Fig. 38.2 Neutrosophic system equation

$R \Rightarrow$ Neutrosophic rules.
$\circ \Rightarrow$ Inference Mechanism.

Below is a block diagram of a neutrosophic system along with various I/O neutrosophic processors. The neutrosophic system is at the core and can interact with all of the processors (Fig. 38.2).

The neutrosophic system works on the principle of the neutrosophic system equation '$X \circ R = Y$'. The neutrosophic data 'X' is input to the neutrosophic system, where R is the collection of neutrosophic rules that the system utilizes to obtain the output. The output obtained is neutrosophic information 'Y'. The neutrosophic knowledge is obtained by extracting knowledge from neutrosophic data. As a result, after implementing the decision support system procedure on neutrosophic data, the neutrosophic decision is the endpoint. The decision support system processes the data required for solving the computational tasks. The task of launching the I/O program is assigned by the decision support system. It collects neutrosophic data and displays neutrosophic outputs. The interface between the neutrosophic system and the devices is based on the decision support system. It entails a series of events that execute I/O operations before storing the results as neutrosophic output [3].

38.3.2 Neutrosophic Logic Data Processing

Neutrosophic data consists of certainty and uncertainty data. The neutrosophic system processes neutrosophic data into neutrosophic information (based on the neutrosophic system equation). Neutrosophic information is converted into neutrosophic knowledge. This knowledge helps in decision-making which is known as neutrosophic decision. The whole is known as neutrosophic data processing (Fig. 38.3).

38.3.3 Representation of Neutrosophic Set

See Fig. 38.4.

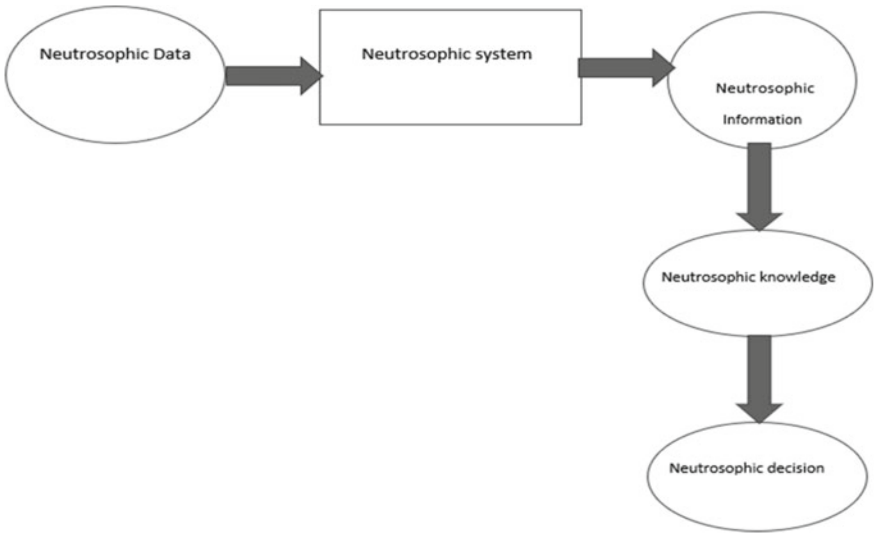

Fig. 38.3 Neutrosophic data processing

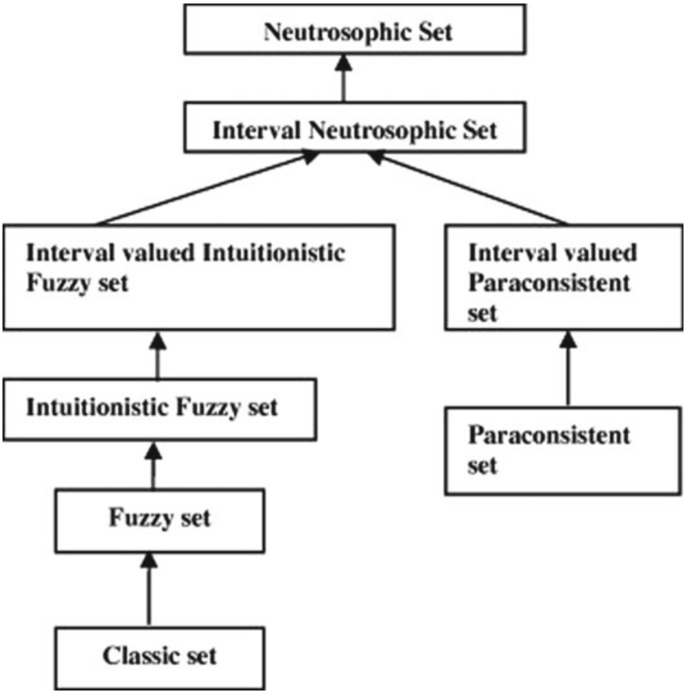

Fig. 38.4 Relation between neutrosophic set and other sets

38.3.3.1 Classical Set

These sets are sets with crisp boundaries. These sets are a collection of distinct objects.

38.3.3.2 Neutrosophic Set

It is a collection that contains triplets with distinct membership values for true, false, and indeterminacy (T, I, F).

38.3.3.3 Interval Neutrosophic Set

It is a neutrosophic set (A) that satisfies the following condition**:**

For each point z in Z, $T(z)$, $I(z)$, $F(z) \subseteq [0, 1]$.

where degree of membership T, indeterminacy membership function I, and degree of non-membership F are parameters that describe an interval neutrosophic set A in Z.

38.3.3.4 Intuitionistic Fuzzy Set

Atanassov presented a fuzzy set that more correctly quantifies uncertainty and allows for detailed modelling of the problem based on existing knowledge and observations which is known as an intuitionistic fuzzy set. An intuitionistic fuzzy set's extend version or generalization is the neutrosophic set [4].

38.3.3.5 Paraconsistent Set

If a logical consequence relation is not explosive, it is considered para consistent. If any arbitrary conclusion is implied by any arbitrary contradiction, a logical consequence connection is explosive [5].

Because the fuzzy set concentrates solely on the membership degree of members of the fuzzy set, it ignores unpredictability and indeterminacy that characterize the real world. The neutrosophic set is a subset or generalization of the intuitionistic fuzzy set. It successfully and efficiently illustrates real-world problems by taking into account all components of the situation (i.e. falsity, indeterminacy, truthiness) [6], as depicted in Fig. 38.5.

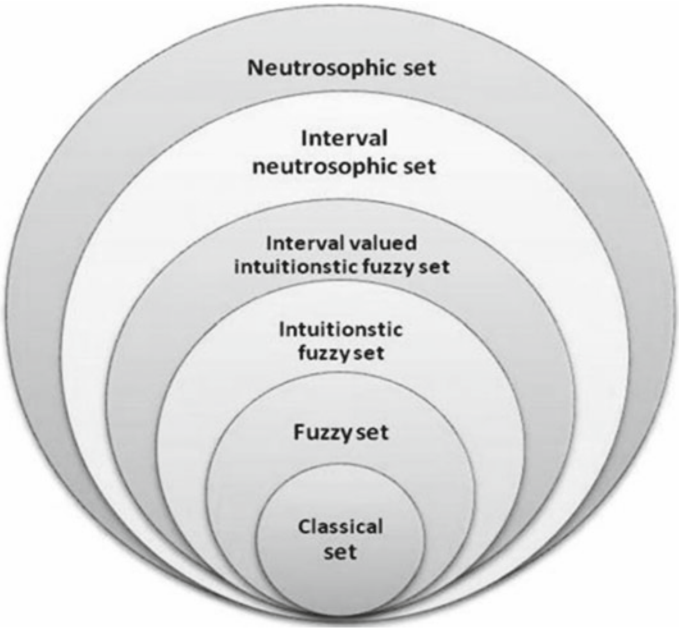

Fig. 38.5 From crisp sets to neutrosophic sets

38.4 Difference Between Fuzzy and Neutrosophic Logic

All three measurements (truth, falsehood, and indeterminacy) are independent in neutrosophic sets. We have inadequate information as a result of how one influences the other in decision-making, and their sum is less than 1. The total of the membership and non-membership components should be equal to 1 because they are based on the intuitionistic fuzzy set. If membership increases in the case of intuitionistic fuzzy, then certainly, the sum of the other two measures will decrease [7].

The neutrosophic logic has the ability to manipulate both incomplete and inconsistent data. Only imperfect information can be handled by fuzzy relations or intuitionistic fuzzy relations. The neutrosophic theory is more versatile and valuable than all other logic. It is more flexible.

The combination of qualifying probabilities can result in fuzzy probabilities that are either insufficiently exact or insufficiently informative. But the factor of indeterminacy plays a vital role in favouring neutrosophic logic systems over fuzzy logic systems [8].

In general, fuzzy logic inference reduces to the answers for a non-linear program; hence, finding strategies to solve such programs can be computationally expensive. To get inference from fuzzy if–then rules which have characteristics of fuzzy probability, there are currently no inexact, low-cost techniques. In addition, we do not have a good

Table 38.1 Relation between fuzzy, intuitionistic fuzzy, and neutrosophic logic

Uncertainty models	Uncertainty types			
	Vagueness	Imprecision	Ambiguity	Inconsistency
Fuzzy	Yes			
Intuitionistic fuzzy	Yes	Yes		
Neutrosophic	Yes	Yes	Yes	Yes

way to infer from possibility-qualified rules within a branch. This is a significant flaw in fuzzy logic (Table 38.1).

38.5 Advantages of Neutrosophic Logic Over Fuzzy Logic

- The fuzzy logic deals with inconsistencies, whereas neutrosophic logic deals with both inconsistencies and incompleteness.
- Although fuzzy logic ensures a particular element's multiple belongingness to multiple classes to varying degrees, it cannot capture neutralities due to indeterminacy. Furthermore, data representation employing fuzzy logic is constrained by the requirement that an element's membership and non-membership values sum to 1 [9].
- According to Leibniz's theory, the following definitions of absolute truth (true in all possible universes) and relative truth (truth in at least one world) are stated. In contrast to neutrosophic logic, the terms of absolute truth and relative truth are defined as NL (absolute truth) $= 1^+$ and NL (relative truth) $= 1$. Neutrosophic theory, on the other end, offers a means for dealing with data-driven indeterminacy [10].
- Due to its capacity to overcome indeterminacy difficulties, neutrosophic logic unlike other logic is a better indicator of the real information.
- Similarly, other allied logic like Lukasiewicz logic considered three values (1, 1/2, 0). All values are constrained between 0 and 1 only. A value less than 0 or an extension beyond 1 is not allowed. But in the case of neutrosophic logic, all values are possible.
- Neutrosophic theory's ability to deal with all aspects of a problem, including conflicts, can be combined with other types of sets such as rough sets, soft sets, and bipolar sets due to its hybrid behaviour. Therefore, we are seeing various uses of the neutrosophic theory which is increasingly being applied in various fields including medical diagnostics, data analysis, analysis of images, pattern recognition, aggregation, and cancer treatment.

Table 38.2 Difference between neural network, fuzzy, and neutrosophic logic

	Neural network	Fuzzy logic	Neutrosophic logic
Definition	It is a system that is based on the biological neurons of the human brain to perform computations	It is a style of reasoning and decision-making that is similar to human reasoning	It is a philosophical discipline concerned with the origin, nature, and scope of neutralities
Flexibility	This system cannot easily be modified	This system can easily be modified	It is more flexible
Training	It trains itself by learning from the data set	Everything must be defined explicitly	Everything must be defined explicitly
Inconsistencies, uncertainness	It deals with uncertainness	It deals with inconsistencies	Neutrosophic logic deals with both inconsistencies and incompleteness
Usage	It helps to perform predictions	It helps to perform pattern recognition	It helps to solve indeterminacy problems
Complexity	It is complex than fuzzy logic	It is simpler than a neural network	It is simpler than fuzzy logic
Learning	It is based on learning	It is not based on learning	It is not based on learning
Knowledge	Difficult to extract knowledge	Knowledge can easily be extracted	Knowledge can easily be extracted

38.6 Comparison Among Different Expert Systems

See Table 38.2.

38.7 Inference Systems of Different Expert Systems

38.7.1 Fuzzy Inference System

Fuzzy inference systems are widely used computing frameworks responsible for transforming the mapping from an input (in the case of fuzzy categorization, features are inputs) to an output (in the case of fuzzy categorization, classes are outputs), as shown in Fig. 38.6. Its concept is based on fuzzy if–then rules, fuzzy set theory, and fuzzy reasoning. It is made up of three parts: input fuzzification, knowledge-based system, and output defuzzification. The fuzzy knowledge base contains a collection of fuzzy production rules as well as membership functions defined in fuzzy sets. During fuzzification, the crisp input is converted to a fuzzy output using membership functions from the fuzzy knowledge base. There are some common defuzzification

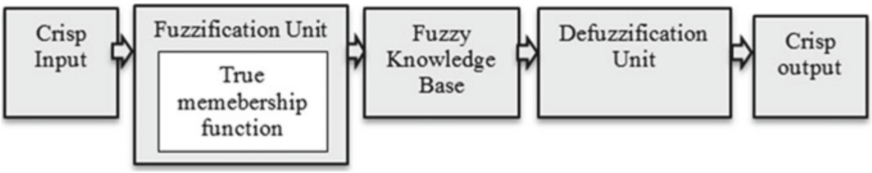

Fig. 38.6 Fuzzy inference system

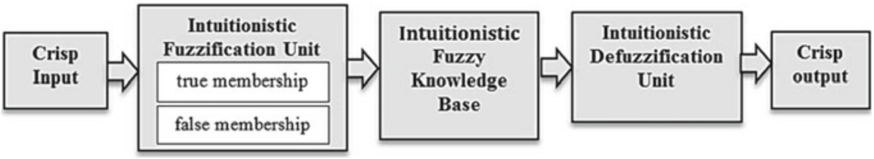

Fig. 38.7 Intuitionistic fuzzy inference system

techniques like centroid, bisector, and maximum methods in which crisp output is generated from the fuzzy output [7].

38.7.2 Intuitionistic Fuzzy Inference System

A single value between zero and one represents an element's membership in a fuzzy set. However, because there is a hesitating degree, the degree of non-membership of an element is not equal to a difference between 1 and the degree of membership. For imitating human imprecise decision-making, an intuitionistic fuzzy set is appropriate. Figure 38.7 depicts the intuitionistic fuzzy inference system. The fuzzy knowledge base stores the true and false membership functions of intuitionistic fuzzy sets, as well as a set of intuitionistic fuzzy production rules.

38.7.3 Neutrosophic Inference System

The neutrosophic inference system is made up of three parts: a neutrosophication unit that receives crisp input and distributes suitable membership functions, a neutrosophic knowledge base which is present in the central portion of the inference system that connects the input to output variable, and a deneutrosophication unit that takes neutrosophic values and transforms them to crisp values [11] (Fig. 38.8).

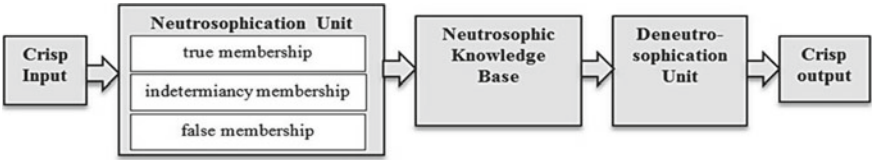

Fig. 38.8 Neutrosophic inference system

38.8 Applications of Neutrosophic System

Neutrosophic applications in different sectors have been rapidly developing in all directions, particularly since the publication of numerous scientific journals and studies on neutrosophic logic. In neutrosophic logic, new theories, methodologies, and algorithms have been rapidly developed. Due to the neutrosophic set's hybridization nature, it can combine with other possibilities of sets is one of the most noticeable developments in neutrosophic theory. Examples of such sets are bipolar set, rough set, soft set, and hesitant fuzzy set. Different hybrid structures introduced in recent works, such as bipolar neutrosophic set, single-valued neutrosophic rough set, single-valued neutrosophic hesitant fuzzy set, rough neutrosophic set, and so on, have found wide application in different sectors. Data analytics, decision-making, cancer treatment, automobiles, medical, social science, and other fields have all benefited from the use of the neutrosophic set [8]. One of the most promising uses of the neutrosophic logic framework could be assisting doctors in better classification of Alzheimer's disease, potentially leading to earlier treatment.

In Table 38.3, we provided details of neutrosophic techniques and their applications in different sectors like healthcare and the medical industry through some prominent scientific journals and articles.

In Paper 1, it was discovered that the role of the neutrosophic logic tool was critical. It was able to properly forecast breast cancer detection in patients in the majority of cases, and more than 80% of the time when predicting the onset of breast cancer [12].

Another example of how neutrosophic logic could help individuals with neurological diseases is Alzheimer's disease. In paper 2, the authors have released a study describing a new A.I. system based on neutrosophic systems that could identify Alzheimer's disease up to six years sooner than current diagnostic procedures. It designed the method by using thousands of brain images to train a machine learning algorithm, making it one of the clearer Alzheimer's detection techniques now available. The AI system based on neutrosophic logic outperformed human clinicians in recognizing patterns of scans of the brain, an indicator that can suggest brain sickness [13].

According to the findings in Paper 3, the algorithm could assist in diagnosing breast cancer by earlier detection than the traditional method in many situations. The findings point to the potential use of neutrosophic logic in mammography to

Table 38.3 Applications of neutrosophic logic in different domains

S. No.	Sources	Year of publication	Selected applications	Methodology
1	Thermogram breast cancer prediction approach based on Neutrosophic Sets and Fuzzy C-Means Algorithm, Tarek Gaber, Gehad Ismail	2015	Breast cancer treatment	Using neutrosophic set, FFCM, and morphological operators, the system first extracted ROI. The SVM was then used to detect normal and abnormal breasts using many variables (statistical, texture, and energy)
2	A recommender system for Alzheimer Patients in Sultanate of Oman using Neutrosophic Logic	2020	Alzheimer's disease early detection	Patients and clinicians can use the recommendations to determine the seriousness of Alzheimer's disease at the different stages of therapy
3	Breast cancer detection using neutrosophic logic, S. Sivaranjani, K. Kaarthik	2019	Breast cancer treatment	Neutrosophic logic designed to better model and predict breast cancer was able to outperform radiologists, in some cases with an ability to detect tiny malignant tissues that would otherwise go unnoticed
4	Analysing age group and time of the day using interval-valued neutrosophic sets, S. Broumi, M. Lathamaheswari	2020	Analysing and forecasting patterns	This paper uses an interval-valued neutrosophic set with thorough description and pictorial depiction to analyse age groups and time (day or night)
5	Hong-yu Zhang, Jian-qiang Wang, Xiao-hong Chen, "Interval neutrosophic sets and their application in multi-criteria decision making problems"	2014	Multi-criteria decision-making problems	Presented a multiple attribute group decision-making approach

(continued)

Table 38.3 (continued)

S. No.	Sources	Year of publication	Selected applications	Methodology
6	Smarandache, Florentin; Leyva-Vázquez, Maikel (2018): Fundamentals of neutrosophic logic and sets and their role in artificial intelligence	2018	Artificial intelligence	Neutrosophic logic is used in A.I. to get better results with greater precision and automation results
7	Challenges and future directions in neutrosophic set-based medical image analysis Deepika Koundal, Bhisham Sharma	2019	Medical imaging	Neutrosophic logic models outperformed traditional machine learning techniques in detecting patterns and discriminative features in brain imaging
8	Applications of neutrosophic logic to robotics: An introduction, F. Smarandache, and L. Vlădăreanu	2011	Robotics	The paper begins with a brief discussion of a robot's mathematical dynamics, followed by a method for bringing neutrosophic science to robotics
9	Comparison of neutrosophic approach to various deep learning models for sentiment analysis, Mayukh Sharma, Ilanthenral Kandasamy, W.B. Vasantha	2021	Sentiment analysis	Deep learning has been applied in a variety of real industrial applications as well as classification difficulties. Neutrosophic theory depicts neutrality and indeterminacy parameters clearly
10	COVID-19 Vaccine: A neutrosophic MCDM approach for determining the priority groups, Ibrahim M. Hezam, Moddassir Khan Nayeem, Abdelaziz Foul	2021	COVID-19 vaccines	The process is involved in identifying priority groups for receiving COVID vaccines using age and job criteria

diagnose breast cancer earlier, as well as the ability to build AI for other clinical fields with better results [14].

According to paper 4, neutrosophic logic is appropriate for this research since it parallels human behaviour in terms of forecasting age and time (or day-night). Membership values of truth, indeterminacy, and falsehood may be exact numbers or interval numbers, based on human intelligence. This paper uses an interval-valued neutrosophic set with a thorough description and pictorial depiction to analyse age groups and time (day or night). Another relevant area described in the paper is fuzzy logic and the representation of uncertainty, as well as its application to complex systems. These causal models are tools that can assist you to make better decisions regarding uncertainty [15].

In real-world scientific and technical applications, interval neutrosophic sets are useful for dealing with data that is unclear, imprecise, incomplete, or inconsistent. However, because there is not enough research on interval neutrosophic sets, a relatively young branch of neutrosophic sets, there is not enough to go on. The available literature, in particular, does not mention aggregation operators or a multi-criteria decision-making strategy for interval neutrosophic sets. Based on the related research achievements in interval-valued intuitionistic fuzzy sets, the operations of interval neutrosophic sets are defined in paper 5. And the approach to compare interval neutrosophic sets was proposed in the paper. As a result of the proposed operators, a multi-criteria decision-making approach is constructed. The process discussed in the paper includes the ranking of all options that may be calculated using the comparison approach, and the best one can be simply found [16].

For applying the machine learning model, traditional machine learning approaches require a centralized database with direct access to patient data. Such methods are affected by various factors such as rules and regulations, the privacy of patient's data, information security, data ownership, and the overhead to hospitals of developing and maintaining these centralized databases. The application of neutrosophic theory in A.I. is growing in popularity since it is thought to provide the best outcomes. Robotics, autonomous decisions, satellite image classification, healthcare problems, neutrosophic cognitive maps, linear and non-linear programming, and neutrosophic cognitive maps have all used neutrosophic logic, sets, probability, and statistics in the expansion of A.I. (artificial intelligence) tools and methodologies. This wide range of applications of neutrosophic theory in various fields such as A.I. (artificial intelligence) has raised new concerns and brought creative solutions to pressing issues [17].

Medical technicians face a difficult problem in effectively predicting medical imaging scans since the data is extremely complicated and the links between different types of data are poorly understood. Neutrosophic logic models outperformed traditional machine learning techniques in detecting patterns and discriminative features in brain imaging. According to paper 7, neutrosophic logic takes medical imaging to the next level. Thanks to a potent mix of artificial intelligence, neutrosophic logic, and 3D medical imaging, substantial advances in imaging have been made in the last five years [18].

Scaling has become impossible without robots, and solutions can now be deployed with remarkable speed and low downtime. Advances in robotic autonomy, which use various machine learning approaches to improve the robot's ability to recognize, diagnose, and respond to unanticipated conditions, determine the pace and speed of scientific advancement in artificial intelligence. The application of neutrosophic logic in robotics is one of the strategies outlined in paper 8. The paper begins with a brief discussion of a robot's mathematical dynamics, followed by a method for bringing neutrosophic science to robotics. Robotics is the study and development of devices that perform physical activities in an automated manner. The integration of neutrosophic systems has resulted in a new generation of robots that can collaborate with humans and execute a variety of jobs in challenging conditions. Drones, disaster-response robots, and robot aides in home health care are just a few examples [19].

According to paper 9, deep learning has been applied in a variety of real industrial applications as well as classification difficulties. Neutrosophic theory depicts neutrality and indeterminacy parameters. Due to the presence of these factors, it is used for sentiment analysis [20].

Authorities must identify priority groups for COVID-19 vaccine dose allocation through different deep learning techniques, according to the findings in Paper 10. The four primary criteria based on age, health status, women's status, and the type of job are defined in this paper. All of the findings show that healthcare workers, persons with pre-existing medical conditions, elderly, essential employees, and pregnant and nursing moms should be the first to receive the vaccine dosage [21].

38.9 Conclusion and Future Work

As big data analytics, artificial intelligence, machine learning (ML), deep learning, and other technologies are being increasingly widely used in fields such as medical, robotics, smart homes, and automobiles, researchers are actively seeking innovative approaches to training different algorithms which will be effective and give accurate and precise results across different sectors. The neutrosophic system is among the most effective methods which are widely accepted in several research fields. Because of greater accuracy and precise results, neutrosophic techniques are preferred over other deep learning techniques, but there is a need for research in this field. Furthermore, the neutrosophic system can solve more complex issues in decision-making because due to the presence of three truth-membership, indeterminacy, and falsity membership components. As a result, the neutrosophic system, unlike the fuzzy logic system, is more generalized and indeterminacy tolerant in its functioning. So, neutrosophic logic is a generalized form of fuzzy logic and intuitionistic logic. In this paper, we discussed different possible scenarios of uses of neutrosophic logic in the field of medical treatment, breast cancer, artificial intelligence, and robotics. We also discussed about neutrosophic system equation ($X \circ R = Y$). After the study, we have identified some improvements which are left for future work. Different performance factors and criteria discussed here can also be used in future models to rank and evaluate the performance of models. In conclusion, the study presents that the role of neutrosophic logic in decision-making is very important and vital. Further researches are recommended in the above directions.

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