Towards Medical Neutrosophic KRP Systems

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Abstract

The development of computer systems for representation, storage and processing the knowledge related to a domain or specific field is a strong requirement nowadays, mainly for medical diagnosis and computer assisted therapy. The management of imprecision measurements, paradoxical data, and unconventional inference techniques is possible using the neutrosophic paradigm.

This paper describes the neutrosophic algebraic numbers and illustrates their usage in developing knowledge representation and processing systems. Finally, some ideas on medical diagnosis systems are presented.

Keywords: neutrosophic numbers, neutrosophic logic, knowledge representation and processing, medical informatics

1. Introduction

Knowledge Representation and Processing (KRP) Systems are frameworks for implementing expert systems to operate on different fields. To be effective, an appropriate KRP system for a domain must meet the following functionalities: 1) Knowledge acquisition and preprocessing (in order to optimize its structure); 2) Storing and retrieving knowledge in / from a knowledge base; 3) Query processing; 4) Producing knowledge following judgments on existing knowledge, and 5) Providing a user interface that ensures the introduction and extraction of knowledge pieces.

Knowledge acquisition, filtering, and processing deals with real challenges when experience imprecision measurements, paradoxical data, and unconventional inference techniques. To manage such situations, Smarandache, see (Smarandache F., 2007), introduced the degree of indeterminacy/neutrality (I) as a new component since 1995, in order to extend both fuzzy (Zadeh, 1965) and intuitionistic fuzzy (Atanassov, 1998) concepts. In the following we are interested in using real neutrosophic numbers. Initially, integer neutrosophic systems were introduced in 2003 by Vasantha Kandasamy & Smarandache, see (Vasantha Kandasamy, 2006). Recently, operations on real neutrosophic numbers were introduced and their augmented value was demonstrated in (Smarandache, 2016), and (Mohammed Saeed, 2018).

In order to process imprecise measurements, an indeterminacy component is necessary to be added. Formally, a real neutrosophic number in algebraic format, written as $a + bI$, has a as the *determinate* (the *known*) part, and b as the *indeterminate* part, and I is the indeterminacy operator with $I^2 = I$, $I + I = 2I$, and $I - I = 0$. The following properties are important for supporting knowledge representation and processing under neutrosophic assumptions:

- If n is any positive integer then $I^n = I$, $xI+yI = (x+y)I$, $0I = 0$, both $1/I$, and I/I are undefined.
- If $x = a + bI$, and $y = c + dI$ are two real neutrosophic numbers, then:
  1) $x + y = (a + c) + (b + d)I$,
  2) $x - y = (a - c) +(b - d)I$,
  3) $\lambda x = \lambda a + \lambda bI$ (with λ a real number),
  4) $xy = ac + (ad + bc + bd)I$,
  5) $x/y = u + vI$, when defined, with $u = a/c$, and $v = (bc - ad) / (c(c + d))$,
  6) $x^2 = a^2 + (2ab + b^2)I$.
- If a, and $a + b$ are such that $\sqrt{a}$, and $\sqrt{a+b}$ are both defined, then $\sqrt{a+bI} = u + vI$, where $u + vI \in \{t_1, t_2, t_3, t_4\}$, with $t_1 = (\sqrt{a}, -\sqrt{a}+\sqrt{a+b})$, $t_2 = (\sqrt{a}, -\sqrt{a}-\sqrt{a+b})$, $t_3 = (-\sqrt{a}, \sqrt{a}+\sqrt{a+b})$, and $t_4 = (-\sqrt{a}, \sqrt{a}-\sqrt{a+b})$.

A partial order on the set of real neutrosophic numbers, denoted by [≤], can be defined according to the following rules:

1. $a + bI \equiv c + dI$ if and only if $a = c$ and $b = d$.
2. If $a < c$ then $a + bI$ [≤] $c + dI$,
3. If $a = c$, and $b \leq d$ then $a + bI$ [≤] $c + dI$.

Another useful model, called real neutrosophic quadruple number, is an entity of the form (a, bT, cI, dF), written as $a+bT+cI+dF$, where T, I, F have their usual neutrosophic logic meanings and a, b, c, d are real numbers. The component a is the known part and $bT+cI+dF$ is the unknown part. Following (Smarandache, 2015), in a pessimistic model (*formally:* $T<I<F$), is assumed that $TI = IT = I$, $TF = FT = F$, $IF = FI = F$, $TT = T^2 = T$, $II = I^2 = I$, $FF = F^2 = F$, $0T = 0I = 0F = 0$.

The following properties are important for supporting knowledge representation and processing under quadruple neutrosophic format:

- If $x = a_1 + b_1T +c_1I +d_1F$, and $y = a_2 + b_2T +c_2I +d_2F$, then $x + y = (a_1+a_2) + (b_1+b_2)T + (c_1+c_2)I + (d_1+d_2)F$, $x - y = (a_1-a_2) + (b_1-b_2)T + (c_1-c_2)I + (d_1-d_2)F$, $xy = a_1a_2 + (a_1b_2 + a_2b_1 + b_1b_2)T + (a_1c_2 + a_2c_1 + c_1c_2 + c_1b_2 + c_2b_1)I +.(a_1d_2 + a_2d_1 + b_1d_2 + b_2d_1 + c_1d_2 + c_2d_1 + d_1d_2)F$.
- If $x = a_1 + b_1T +c_1I +d_1F$, and m is a real number (scalar) then $mx = ma_1 + mb_1T +mc_1I +md_1F$.
- If $x = a_1 + b_1T +c_1I +d_1F$, $y = a_2 + b_2T +c_2I +d_2F$, and m and n are real scalars, then $m(x + y) = mx + my$, $(m + n)x = mx + nx$, $(mn)x = m(nx)$, $-x = -a_1 - b_1T - c_1I - d_1F$.

An optimistic (*formally:* $T>I>F$) quadruple model is based on assumptions: $TI = IT = T$, $TF = FT = T$, and $IF = FI = I$. If $x = a_1 + b_1T +c_1I +d_1F$, and $y = a_2 + b_2T +c_2I +d_2F$ then , $xy = a_1a_2 + (a_1b_2 + a_2b_1 + b_1b_2+ c_1b_2 + c_2b_1+ d_1b_2 + d_2b_1)T + (a_1c_2 + a_2c_1 + c_1c_2+ c_1d_2 + c_2d_1)I +.(a_1d_2 + a_2d_1$

+ d_1d_2)F. Depending on the real situation under modelling, an optimistic or a pessimistic model can be selected.

2. Neutrosophic KRP systems architecture

According to (Mohammed Saeed, 2016), any architectural model of a generic KRP system must contain at least five interconnected components M_i, *i* in *{1, 2, 3, 4, 5}*. The module M_1 takes user data or interpretations that, based on analytics processes (to reject or accept for representation - suitability in the field of the problem) will trigger segmentation procedures, extraction of features, and will constitute structures appropriate to knowledge base storage M_2.

The knowledge acquisition, which is a representative process of the component M_1, follows four steps: defining and extracting information, conceptualizing, formalizing, and implementing. The first phase is dedicated to extracting information from publications (books, magazines, audio-video materials) and from experts in the field, in an informal manner, usually through descriptions and records. In the second phase the interpretation of the information, the identification of the concepts and the relations between them takes place. The third phase, one of the formalization, will identify the most appropriate representation and will specify the syntax and the semantics of the representation. Finally, implementation of formal representation takes place in a language appropriate for computerized processing. The M_2 module - Knowledge Base - contains knowledge pieces that have been acquired by human experts in close association with the problem area and that describe certain situations, real facts, rules, etc. Generally, within a dedicated KRP system, the knowledge base uses the data stored in a database DB (specific to the problem), the M_2 module having the task of indicating how intelligently the data stored in the DB is processed on the basis of knowledge specific to solving problems in the particular area.

The module M_3 takes facts from the knowledge base and sends them directly to the user or sends them to the resolver (Module M_4) to "derive" using the resolution principle new knowledge that it will be delivered to the user or recorded in the knowledge base (the case of automated learning).

The module M_4 is the inference engine. This can be a program (or a microprogrammed integrated circuit) that has general inference mechanisms for processing knowledge using the most diverse reasoning methods. Following the judgments made, it is possible to make changes to the pieces of knowledge. Some rules will be removed or replaced with others. Practically, the module M_4 has a rule-based system (RBS). The RBS is a static set of knowledge, the inference engine is the one to dynamically discover new knowledge by consulting the bases of rules, bases of facts, and other bases relevant to the problem under consideration.

To increase inferential engine efficiency, KRP systems can use rulebooks. The rulebook is a data structure that memorizes, according to a particular format, the rules, usually in the form of an indexed list. The item on the first position will be the first used (fact, rule). The list position is based on a priority indicator set by the KRP analyst or based on the efficiency of the inference algorithm in the context of conflict resolution. Basically, it is a kind of sorting method, usually downward after the priority pointer, and when the same priorities the order is set in relation to the conflict resolution strategy. Moreover, the module M_4 must provide the user with information on how to obtain the solution (the reasoning steps).

The human machine interface is represented by the module M_5. This module provides the user interface and allows access to information and knowledge recorded or provided by various components of the KRP system. The module M_5 provides multiple access levels: regular user, knowledge base administrator (field specialist), database administrator (specialist in problem solving for a specific type of activity), and KRP system administrator.

The technical implementation of a KRP system can appeal to various components (plug-ins) that are independent of the data, facts, or rules needed to solve concrete problems.

Any framework of neutrosophic KRP systems should consider the following components (Mohammed Saeed, 2018): 1) The *Input module* (oriented to crisp data); 2) The *Neutrosophication*

Unit (able to convert crisp data to neutrosophic representation; 3) The *Neutrosophic Knowledge Base* (storing facts/rules and their associated degrees in TIF format: T - truth, I - indeterminacy, F - falsehood); 4) The *Neutrosophic Inference Engine* (based on neutrosophic logic); 5) The *Deneutrosophication Unit* used to convert from neutrosophic representations to crisp values, and 6) The *Output module* (crisp data visualization).

The neutrosophic unit preprocesses crisp input data to identify valid cases, invalid cases, and ambiguous cases.

The items in the knowledge base are described by algebraic (including quadruples) neutrosophic numbers, or TIF - values, with T - degree of membership, I - degree of indeterminacy, and F - degree of non-membership, when working with neutrosophic sets or TIF-neutrosophic numbers.

Example 1. Let $x_1, x_2, ..., x_k$ be a number of repeated measurements of the indicator x. Let a = min $\{x_i \mid i = 1, 2, ..., k\}$, $c = max\{x_i \mid i = 1, 2, ..., k\}$, and $b = c\text{-}a$. The indicator x can be described by the neutrosophic number $x = a + bI$. Hence, the sequence 1, 1, 1, 2, 2, 2, 3 can be described by 1+2I.

Example 2. Let $x_1, x_2, ..., x_k$ be a number of repeated measurements of the indicator x. Let $a = min \{x_i \mid i = 1, 2, ..., k\}$, e is the *median* of the measurements, $b = e - a$, f is the *third quartile* of the measurements, $c = f - e$, $h = max \{x_i \mid i = 1, 2, ..., k\}$, and $d = h\text{-}f$. The indicator x can be described by the neutrosophic number $x = a + bT+cI+dF$. The sequence 1, 1, 1, 2, 2, 2, 3 can be described by 1 + 1T+0I+1F.

Example 3. The sequence 1, 1, 1, 2, 2, 2, 3, 10 can be described by 1 + 1T + 1I + 7F.

The neutrosophic knowledge base is composed by facts and their neutrosophic level of validity, and by rules described in a *t*-neutrosophic norm format. Various neutrosophic logic operators, t-norms, and t-conorms in neutrosophic frameworks can be found in (Albeanu, 2013) and (Albeanu, 2014).

The neutrosophic inference engine uses neutrosophic logic operators, and provides the final result after evaluating the implication operator. According to the operators, the result is a neutrosophic entity, in general in TIF - format.

Let X (resp. Y) be the data input (resp. output) domain and $A_1, A_2, \ldots, A_n$ (resp. $B_1, B_2, \ldots, B_n$) be neutrosophic sets of X (resp. Y). Let t be a neutrosophic triangular norm and RB the rule base (set of neutrosophic rules): If x is A_i (T, I, F) then y is B_i (T, I, F), i = 1, 2, …, n. The final evaluation can be obtained by $\perp$(t(x is A_i, y is B_i), i = 1, 2, …, n), taking into account the components T, I, and F for every set.

The deneutrosophication unit is responsible with filtering membership/validity information in order to provide a center of gravity, or a particular mean of data. If the result is a neutrosophic number in quadruple format, the associated robust crisp value is the median. If $x = a + bT + cI + dF$, then median $e = a + b$. Another robust crisp value is the interquartile based indicator $m = a + 3b/4 + c/2$.

If the result is a TIF entity (given by three functions $T(x), I(x),$ and $F(x)$), then a indicator function is computed $H(x) = pT(x) +qI(x) + r(1\text{-}F(x)),$ where p, q, and r are positive parameters generated according to the importance/risk of components. Finally, for the function H is applied any defuzzification method: *center of gravity*, *center of area* etc.

3. Towards medical neutrosophic KRP systems

It is large accepted that obtaining and applying "Medical Knowledge" are essential tasks to assure a high quality health care system. According to (Boegl et al., 2004), "the nature of the relationships between symptoms, physical signs, laboratory data, clinical findings, and diagnostic hypotheses can be characterized as a collection of empirical facts, statistical data, scientific cause–effect structures, and human experience." Computer systems like MYCIN (Shortlife, 1976) and ONCOCIN (Shortlife, 1986) are only some well-known classical medical expert systems. More aspects can be discovered in the included references on medical informatics.

A medical diagnosis problem, however, often has to manage a large amount of uncertain, inconsistent, or indeterminate data. This remark emphasized the necessity to use fuzzy, intuitionistic fuzzy, or neutrosophic KRP systems for medical diagnosis, where for every patient (the crisp universe P), a set of symptoms (findings) are stored based on neutrosophic numbers. A set of diseases (and associated therapies) is known by the system according to a rule base depending on the symptoms.

Applicability of neutrosophic science in medical informatics was considered in (Ansari et al., 2011). Also, (Ali et al., 2017) developed a neutrosophic recommender system for medical diagnosis based on algebraic neutrosophic measures.

In (Boegl et al., 2004) there are identified two subtypes of medical concepts to be considered by a KRP. One type is related to medical entities: findings, diseases, and therapies. Other type is represented by medical data that describes quantitative medical concepts such as results from physical examinations, various measurements including laboratory data: complete blood count (CBC), blood chemistries and electrolytes, urinalysis (UA) etc.

An algebraic KRP system will convert every sequence of crisp data to neutrosophic numbers or linguistic variables modeled by triangular or trapezoidal neutrosophic numbers with membership functions for the TIF components. The system should differentiate between males and females in order to establish an adequate result.

A medical KRP system implements medical algorithms (based on “decision trees”) that are useful for a partial diagnose based on the most appropriate laboratory tests. In the following, let us use the neutrosophic numbers in a+bI format associated to normal values of CBC items: Hemoglobin (g/dl) = 13.5+3I (male) and 12 + 3I (female), Hematocrit (%) = 41+9I (male) and 36+8I (female), RBC’s (x10^6/ml) = 4.5+I (male) and 4+0.9I (female), MCV = 80+20I, MCH = 26+8I. When consider the Electrolytes, the common values can be converted to Calcium (mg/dL) = 8.8+1.5I, Chloride (mEq/L) = 95+12I, Magnesium (mEq/L) = 1.6+0.8I, Phosphate (mg/dL) = 2.5+2I, Potassium (mEq/L) = 3.5+1.7I, Sodium (mEq/L) = 135+12I.

If the file of a patient p contains repeated measurements on some item, then a representation $a+bT+cI+dF$ can be given, when analyzing the data sequence by descriptive statistics, as described above.

Also, the degree of imprecision in the quantitative measurement of any item is given by the magnitude of the coefficient of variation, expressed usually as a percent, obtained from multiple measurements of the item using the formula: (STDEV/MEAN)×100; where MEAN and STDEV are the mean and standard deviation of the values obtained from the multiple measurements of an item. As described in the first section, the coefficient of variation can be computed in a neutrosophic framework by appropriate operations.

In the medical world, KRPs are developed for specific oriented subjects. The available knowledge from experts is converted to suitable models and inference rules in order to build an efficient tool. Both single and multi decision criteria can be used to establish diseases and associated therapies for patients. The above presentation is a preliminary investigation and in depth developments should be developed for specific medical fields.

4. Conclusions

The usage of neutrosophic numbers, neutrosophic logical operators and the inference procedures in order to build knowledge representation and processing systems is presented in general case, and examples oriented to medical diagnosis and computer assisted therapy shown new applications of neutrosophy. The present investigation can be extended to cover more neutrosophic models, including neutrosophic intervals for medical KRP systems.

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