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Maykel Leyva-Vazquez

Florentin Smarandache

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Resolucion de sistemas de ecuaciones lineales neutrosóficas mediante computación simbólica.

Solving neutrosophic linear equations systems using symbolic computation.

Maikel Leyva-Vázquez¹, Florentin Smarandache²

¹Universidad Politecnica Salesiana, Guayaquil Ecuador. Email: mleyvaz@gmail.com

²Mathematics & Science Department, University of New Mexico. 705 Gurley Ave., Gallup, NM 87301, USA. e-mail: fsmarandache@gmail.com

Resumen. En este trabajo, aplicamos el concepto de números neutrosóficos para resolver un sistema de ecuaciones lineales neutrosóficas que utilizan la computación simbólica. Además, utilizamos Jupyter, que es apoyado en el Colaborador de Google para realizar el cómputo simbólico. La biblioteca simbólica de Python se utiliza para realizar el proceso de computación neutrosófica. Los sistemas de ecuaciones lineales neutrosóficas se resuelven a través de la computación simbólica en Python. Se ha desarrollado un estudio de caso para la determinación del tráfico vehicular con indeterminación. Este rey de la computación abre nuevas formas de tratar la indeterminación en problemas del mundo real.

Palabras claves: Computación neutrosófica, sympy, google colaborativo, número neutrosófico, ecuaciones lineales Neutrosóficas.

Abstract. In this paper, we apply the concept of neutrosophic numbers to solve a systems of neutrosophic linear equations using symbolic computation. Also, we utilize Jupyter, which is supported in Google Colaboratory for performing symbolic computation. The sympy library of Python is used to perform the process of neutrosophic computation. Systems of neutrosophic linear equations are solved through symbolic computation in Python. A case study was developed for the determination of vehicular traffic with indeterminacy. This kind of computation opens new ways to deal with indeterminacy in real-world problems.

Keywords: neutrosophic computing, sympy, google colaboratory, neutrosophic number, neutrosophic linear equations

INTRODUCCIÓN

The word Neutrosophy means knowledge of neutral thought, and this third / neutral represents the main distinction, i.e., the neutral/indeterminate / unknown part (in addition to "truth" / "belonging" and "falsehood" Components of "non-belonging" that appear in the fuzzy logic / set). Neutrosophic logic (NL) is a generalization of Zadeh's fuzzy logic (FL), and especially of Atanassov's intuitionistic fuzzy logic (IFL), and other multi-valued logics, see Figure 1 and [1].

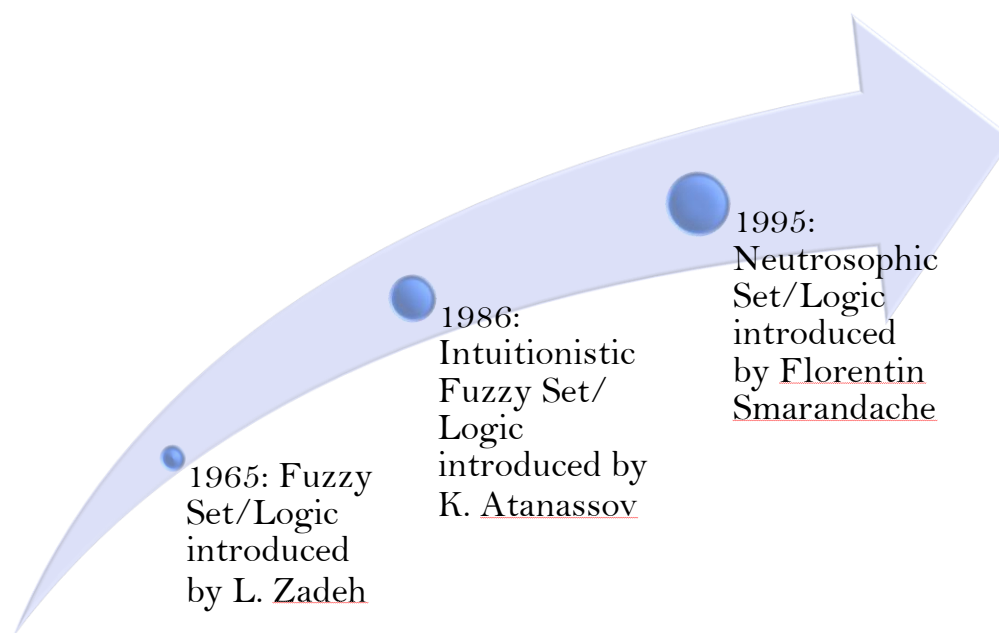


Figure 1. Neutrosophy and its fundamental antecedents ([1]).

Let U be a universe of discourse, and M a set included in U . An element x of U which is denoted with respect to M as x (T, I, F) and belongs to M according to the Neutrosophic Set as follows: it is $t\%$ true in the set, $i\%$ indeterminate (unknowns) in the set, and $f\%$ false, where t varies in T , i varies in I and f varies in F . Statically T, I, F are subsets, but dynamically T, I, F are functions/operators that depend on many known or unknown parameters [2, 3].

Neutrosophic sets generalize the fuzzy sets (especially the fuzzy and fuzzy intuitionist sets), the paraconsistent sets. It allows dealing with a more significant number of situations that occur in real-life [4].

2. PRELIMINARY

A *statistical neutrosophic number* is a number given in the following form ([5]):

$$N = d + i \quad (1)$$

Where d is the *determined part* and i is the *indeterminate part*, see [6]. For example: $a = 8.6 + i$ if $i \in [3, 3.4]$ the number is equivalent to $a \in [11.6, 12]$.

Additionally, a *neutrosophic matrix* is a matrix such that the elements $a = (a_{ij})$ have been replaced by elements in $\langle R \cup I \rangle$, where $\langle R \cup I \rangle$ is a *neutrosophic ring*, see [7].

A *neutrosophic graph* is a kind of graph in which at least one arc is a *neutrosophic arc*, see [8]. The weights associated with the arcs have the following meanings: 0 = “no connection between nodes”, 1 = “connection between nodes”, I = “indeterminate connection (unknown if it is or not)”. The *neutrosophic adjacency matrix* is an adjacency matrix with at least one neutrosophic arc. Such notions are not used in fuzzy theory, an example of which is shown below:

$$\begin{pmatrix} 0 & 0 & I \\ I & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$

Further, we shall describe practical implementations of this approach. *Google Colaboratory* is a web application that allows us to create and share documents containing source codes, equations, visualizations, and illustrative texts, as shown in Figure 2.



Figure 2. Google Colaboratory

Jupyter allows us to interact with several programming languages; in this case, Python is used. Python is a simple and powerful programming language with access to a great variety of useful libraries.

3. NEUTROSOPHIC COMPUTING AND SYMPY

SymPy can be used for computational works with neutrosophic numbers in Python language. It is a library written in Python language with the purpose of bringing together all the features of a computer algebra system, which is easily extensible and maintains the code as simple as possible ([9]).

Here we propose a calculus that is based on interval-valued arithmetic and accordingly, a de-neutrosification process is required [10] to obtain a representative numeric value. Thus, $I \in [0,1]$ is replaced by its maximum and minimum values.

In this case we employ the mpmath library and the mpi type [11]. The mpi type deals with intervals of a pair of mpf values. Interval arithmetic uses conservative rounding, so that, if an interval is interpreted as the numerical uncertainty with respect to a single-valued number, any sequence of interval operations will produce intervals that contain the result of applying the same sequence of operations to a precise number, see Figure 3.

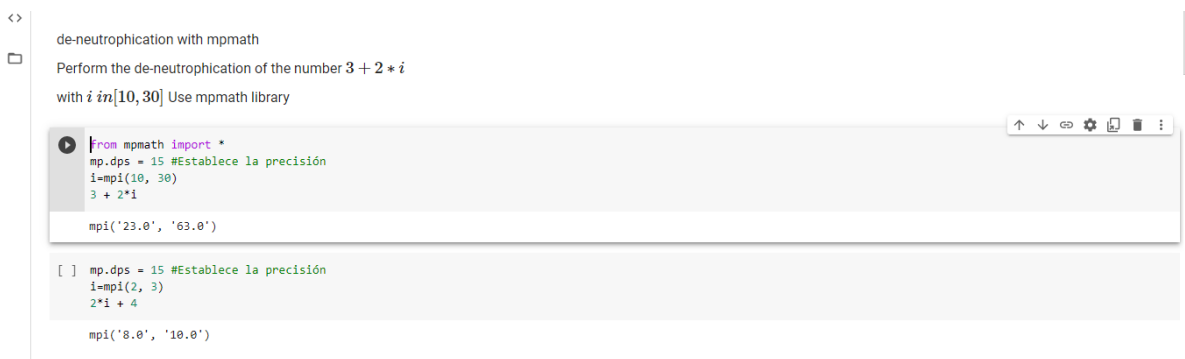


Figure 3. Working with Neutrosophic Numbers

In this case systems of neutrosophic linear equations can be solved, see [12]. For example, given the following system of equations:

$$3x+8y = 1+i \tag{2}$$

$$4x + 7y = 8+i \tag{3}$$

It is solved as follows, see Figure 4:

```

[ ]
<> from sympy import Matrix, solve_linear_system
    from sympy.abc import x, y
    i = var('i')
    system = Matrix(( (1, 4, 2+i), (-2, 1, 14+i)))
    solve_linear_system(system, x, y)

{x: -i/3 - 6, y: i/3 + 2}

```

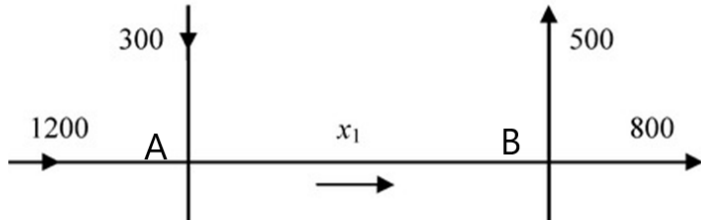


Figure 4. Solution to a system of linear equations with Neutrosophic Numbers, by using Colaboratory.

An example of application in a real-life problem is a system of linear equations that determines the flow of traffic at different intercepts, see Figure 5

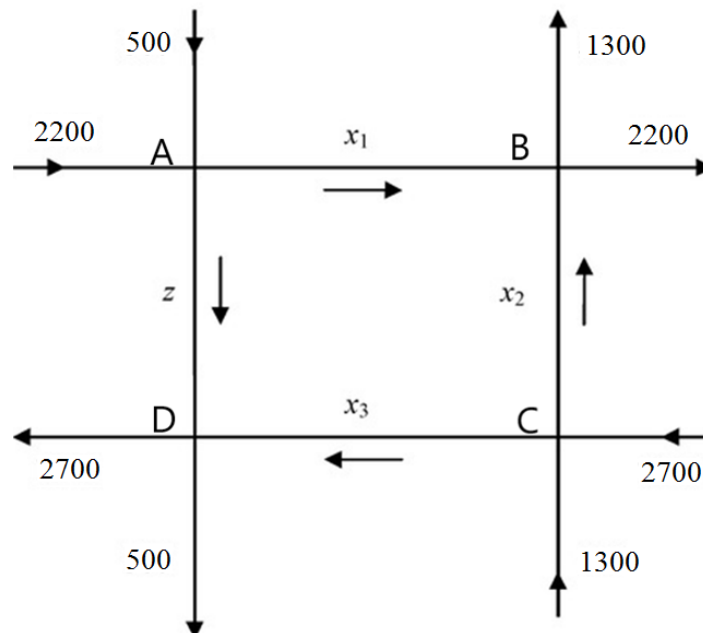


Figure 5. Schematic representation of the Vehicle Flow ([12]).

At each intercept, the outflow must be equal to the inflow.

$$\text{Intercept A: } 2700 = x_1 + z$$

$$\text{Intercept B: } 3500 = x_1 + x_2$$

$$\text{Intercept C: } 4000 = x_2 + x_3$$

$$\text{Interception D: } 3200 = x_3 + z$$

If $z = 500$.

Then the system of equations is as follows:

$$x_1 = 2200$$

$$x_1 + x_2 = 3500$$

$$x_2 + 2x_3 = 6700$$

The solution for this system is the following:

$$x_1 = 2200$$

$$x_2 = 1300$$

$$x_3 = 2700$$

```
[ ] from sympy import Matrix, solve_linear_system
from sympy.abc import x, y, z

system = Matrix(( (1,0,0, 1100), (1, 1, 0, 1300), (0, 1, 2,3400)))

solve_linear_system(system, x, y, z)

{x: 1100, y: 200, z: 1600}

▶ from sympy import Matrix, solve_linear_system
from sympy.abc import x, y, z

system = Matrix(( (1,0,0, 1100-i), (1, 1, 0, 1300), (0, 1, 2,3400-i)))

solve_linear_system(system, x, y, z)

{x: -i + 1100, y: i + 200, z: -i + 1600}
```

Figure 6. A solution of the vehicular flow with indetermination.

In the case of $z = 500+i$.

Then the system of equations is:

$$x_1 = 2200 - i$$

$$x_1 + x_2 = 3500$$

$$x_1 + 2x_3 = 6700 - i$$

The solution for this system is:

$$x_1 = 2200 - i$$

$$x_2 = 1300 + i$$

$$x_3 = 2250$$

This kind of computation allows opening new ways to compute using indeterminacy in different real-world problems [13-19].

CONCLUSIONES

In this paper, the concept of neutrosophic numbers was used to solve linear equations. The tool Jupyter supported by Google Colaboratory is utilized. The Sympy library is applied to perform the neutrosophic computation process. Neutrosophic linear equation systems are solved by symbolic python computation. A case study is developed for the determination of vehicular traffic with indetermination.

Future works include the development of new applications in different areas of engineering and science like neutrosophic statistics and multicriteria. Other areas of future work include the development of new tools for neutrosophic computing.

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