Notes on Intuitionistic Fuzzy Sets
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Designing and developing Intuitionistic Fuzzy Logic Toolbox in MATLAB: Membership and non-membership functions gallery

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Abstract: The authors have designed and developed algorithms for pattern recognition and clustering techniques using intuitionistic fuzzy (IF) sets, IF operators, IF logic (IFL) – shortest path in networks using IF graphs and IF hypergraphs – video processing using temporal IF sets, RGB image representation through IF index matrices, and molecular structure representation through IF directed hypergraphs. The three major steps involved in the above-said modeling processes via IFSs are (i) intuitionistic fuzzification, (ii) modification of membership and non-membership values (using IF logic/operators/rules/relations) and (iii) intuitionistic defuzzification. While developing these algorithms, parameter tuning was one of the major limitations, and hence specific values were assigned to complete the running process. To overcome this, it is necessary to introduce a toolbox in MATLAB so that the users can select the appropriate tools and parameterize them. Hence, in the long process of contributing a full-pledged intuitionistic fuzzy logic toolbox, namely IFL Toolbox in MATLAB, the membership and non-membership functions gallery has been developed initially, as one of the modules which is the foundation for any IFL control system.

This module contains functions, codes, examples and figures/graphs, which will be available on the MATLAB creation page. The proposed module is compared with the existing fuzzy logic toolbox in MATLAB and verified.
Keywords: Membership and non-membership gallery, IFL Toolbox.
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1 Introduction

Georg Cantor's Set theory provides a logical foundation for various mathematical domains such as mathematical analysis, topology, rings and vector spaces. It assumes crisp, well-defined relationship between elements. However, the uncertainty in the real world cannot be dealt with by set theory. As technology progresses, the demand for effective tools to manage uncertainty and imprecision in decision-making grows more evident. The limitations of classical set theory led to the emergence of fuzzy set theory, pioneered by Lotfi A. Zadeh in the 1960s.

Fuzzy Logic emerged as a tool for dealing with uncertainty by allowing degrees of membership between 0 and 1 in other words allowing an element to belong to a set to a certain degree, rather than strictly being a member or non-member. However, as the complexity of real-world problems grew, the limitations of traditional fuzzy logic became evident.

To overcome this, intuitionistic fuzzy sets were introduced by Krassimir T Atanassov in the year 1983 as a way to handle incomplete and imprecise information. While fuzzy sets involve membership and non-membership degrees, intuitionistic fuzzy sets include an additional component called the *hesitation degree*. The hesitation degree represents the level of uncertainty or non-determinacy regarding whether an element belongs to the set or not, [2].

MATLAB, a high-performance programming language and environment, has been a go-to platform for researchers and engineers in various disciplines. Hence, the authors got motivated to contribute a toolbox in MATLAB using intuitionistic fuzzy sets namely the *Intuitionistic Fuzzy Logic Toolbox (IFL Toolbox)*. The toolbox will consist totally eight modules in which the first module **M1**, Fuzzification functions is discussed in this paper. This toolbox aims to provide a gallery of intuitive and customizable membership and non-membership functions, allowing researchers, practitioners, and educators to easily experiment with and understand the behavior of intuitionistic fuzzy sets. By offering a range of functions with diverse shapes and characteristics, users can tailor the toolbox to suit their specific application requirements, facilitating the development of more accurate and context-aware intuitionistic fuzzy logic systems, [8].

The paper "Designing and developing image editing tools in MATLAB using intuitionistic fuzzy sets" presents a commendable exploration into the realm of image editing algorithms, utilizing the innovative framework of intuitionistic fuzzy sets which plays a major as a motivation for this paper, [9].

The design and development of the membership and non-membership functions gallery in MATLAB provide users with a user-friendly interface for visualizing and selecting appropriate functions for their intuitionistic fuzzy logic systems. The book, often referenced in this context, is likely to have explored various aspects of intuitionistic fuzzy logic, providing theoretical foundations and practical insights. Understanding and building upon the concepts presented in Atanassov's work becomes crucial in the development of a MATLAB toolbox dedicated to intuitionistic fuzzy logic (IFL).

2 Review of literature

Krassimir T Atanassov authored the book "Intuitionistic Fuzzy Sets: Theory and applications" which is a more comprehensive and complete report on intuitionistic fuzzy set theory, also the first book on intuitionistic fuzzy sets [2].

Even though, IFS is an object of intensive research, the theory is far from being complete, there are few unsolved open problems given by K. T. Atanassov in page numbers 287–291 of [2]. Some of the open problems are chosen by the authors which are mentioned below with some of their references to work on them in the near future.

(i) Problem 9: What other applications do IFS have?
In [4], the use of fuzzy information for re-learning in the expert system is considered. It is concerned briefly with fuzzy learning algorithm, which may be used in such systems. An exact description of any real physical situation is virtually impossible. Therefore, it is necessary to develop schemes which deal analytically with decision processes. In [7], the framework is formulated all classified with fuzzy set theory and applications. Similarly, the other applications of IFSs can also be studied.

(ii) Problem 22: To develop the general theory of IF systems.
In [13], the authors introduced the use of fuzzy sets and fuzzy logic for the approximation of functions and modeling of static and dynamic systems and also it contains MATLAB programs implementing some of the examples. This gives motivation to develop video processing toolbox using temporal IFSs.

(iii) Problem 26: To develop statistical and probabilistical tools for IFSs and IFLs.
In [5], an important distinction is made, in the interpretation of the weights, between degrees of truth and degrees of uncertainty; the former can be assumed to behave in a fully compositional way while the latter cannot. Rule-based inference systems where fuzzy set operations are used for propagating and combining 'certainty factors', are briefly discussed. Hence, the development of statistical tools for IFSs and IFLs is essential.

(iv) Problem 27: To develop algorithms for intuitionistic defuzzification and comparison.
Fuzzy sets can be viewed as a convenient way for expressing a rank-ordering over a set of possible words, or equivalently, of possible interpretations. [6] deals with the comparison of two fuzzy set-based logics such as similarity logic and possibilistic logic. In [14], the author introduced a parameterized family of defuzzification operators called the Semi LInear DEfuzzification (SLIDE) method. Also, it suggests an algorithm for learning of

the parameter from a data set. Therefore, it is necessary to introduce intuitionistic defuzzification functions in IFL Toolbox.

IFSs were introduced as more generalized additional tools for fuzzy sets particularly in dealing with uncertain or vague information. Further, in complex-decision making scenarios, IFSs provide a more expressive framework to capture decision-making process. Hence, it is opportune to introduce the Intuitionistic Fuzzy Logic (IFL) Toolbox in MATLAB, where the IFL controller serves as the foundational framework for modeling processes utilizing IFSs.

In [12], the steps involved in intuitionistic fuzzy logic controller are discussed as follows:

(i) *Intuitionistic fuzzification:*
Intuitionistic fuzzification is a process that converts crisp, precise values into degrees of membership, non-membership and hesitation. It assigns degrees of membership to elements based on their resemblance to a given linguistic term or concept. This step captures the degree to which an element belongs to the intuitionistic fuzzy set. In addition to membership degrees, intuitionistic fuzzification assigns degrees of non-membership to elements,
representing the extent to which elements do not belong to the intuitionistic fuzzy set. It also incorporates a measure of hesitancy, representing the level of uncertainty or indecision in assigning membership and non-membership degrees to elements.

(ii) *Modification of membership and non-membership values:*
In this step, users can adjust the membership values assigned to elements to reflect their degree of belongingness to an intuitionistic fuzzy set. The modification of non-membership values allows users to account for uncertainty and ambiguity more effectively. Users can also modify hesitancy values to reflect their confidence level in the assigned degrees. Higher hesitancy values indicate greater uncertainty, whereas lower the values, higher the confidence.

(iii) *Intuitionistic defuzzification:*
Intuitionistic defuzzification involves the process of extracting crisp values from intuitionistic fuzzy sets. Consider the membership, non-membership, and hesitation degrees modified in step 2 and use appropriate defuzzification techniques extract reliable and informative crisp values from intuitionistic fuzzy sets, thus enhancing the effectiveness of fuzzy logic-based systems in real-world applications.

Fuzzy image processing system enhance the contrast of the image only using membership values. But in intuitionistic fuzzy image processing, both the membership and non-membership values are used. These functions not only capture the degree to which each pixel belongs to specific intensity levels but also account for the uncertainty and ambiguity associated with non-membership and hesitancy which is applied to improve the enhancement of the output images.

The fuzzy logic toolbox (FLT) in MATLAB is a comprehensive software package that provides a wide range of tools which are useful in various domains such as control systems, decision making and pattern recognition. Even though, FLT provides a range of basic tools for building fuzzy inference systems, it needs support for more advanced techniques. The toolbox offers a variety of predefined membership functions and inference methods but, the options for customization options for the users is limited.

3 Mathematical background: Preliminaries

3.1 Basic definitions

The following definitions and results are the prerequisites for the better understanding of contents of the paper.

Definition 3.1. *An intuitionistic fuzzy set* A in X is defined as an object of the form

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

where the functions $\mu_A : X \to [0, 1]$ and $\nu_A : X \to [0, 1]$ define the degrees of membership and non-membership of the element $x \in X$ respectively, and for every $x \in X$ in A, $0 \leq \mu_A(x) + \nu_A(x) \leq 1$ holds.

Definition 3.2. *Membership function* for an intuitionistic fuzzy set A on the universe of discourse X is defined as $\mu_A : X \to [0, 1]$, where each element $x \in X$ is mapped to a value between 0 and 1. The value $\mu_A(x)$, for $x \in X$, is called the membership value or degree of membership.

Definition 3.3. *Non-membership function* for an intuitionistic fuzzy set A on the universe of discourse X is defined as $\nu_A : X \to [0, 1]$, where each element $x \in X$ is mapped to a value between 0 and 1. The value $\nu_A(x)$, for $x \in X$, is called the non-membership value or degree of non-membership.

Definition 3.4. The value of $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ is called the *degree of non-determinacy (or uncertainty)* of the element $x \in X$ to the intuitionistic fuzzy set A.

Note.

- *Membership degree* $\mu_A(x)$: This represents the degree to which an element x belongs to the set A. It's a value between 0 and 1.
- *Non-membership degree* $\nu_A(x)$: This represents the degree to which an element x does not belong to the set A. It's also a value between 0 and 1.
- *Hesitation degree* $\pi_A(x)$: This represents the degree of uncertainty or hesitation in assigning the element to either the set or its complement. It is a value between 0 and 1.

3.2 Geometric interpretation of IFS

There exist, so far, seven different geometric interpretations of IFSs. The most relevant of them are given in the Figure 3.1 and Figure 3.2 [2].

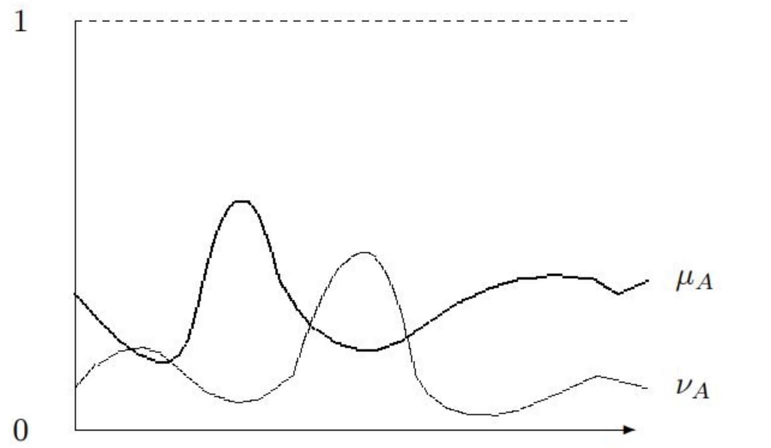

Figure 3.1. The standard geometric interpretation of IFS (most widely accepted)

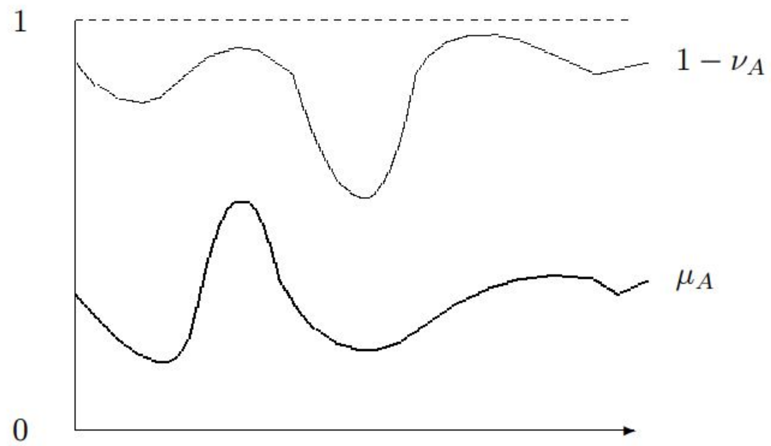

Figure 3.2. An analogue of the standard geometric interpretation of IFS

3.3 Types of intuitionistic fuzzification and defuzzification functions

The following are the definitions of types of intuitionistic fuzzification and defuzzification functions.

- Table 3.1 provides the definitions of nine types of intuitionistic fuzzification functions [12]
- Table 3.2 provides the definitions of seven types of intuitionistic defuzzification functions [11]

Table 3.1. Types of intuitionistic fuzzification functions

Type	Membership function	Non-membership function	About parameters
Triangular	$\mu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ \left(\frac{x-a}{b-a}\right) - \epsilon & \text{if } a < x \leq b \\ \left(\frac{c-x}{c-b}\right) - \epsilon & \text{if } b < x < c \\ 0 & \text{if } x \geq c \end{cases}$	$\nu_A(x) = \begin{cases} 1-\epsilon & \text{if } x \leq a \\ 1-\left(\frac{x-a}{b-a}\right) & \text{if } a < x \leq b \\ 1-\left(\frac{c-x}{c-b}\right) & \text{if } b < x < c \\ 1-\epsilon & \text{if } x \geq c \end{cases}$	a - Lower limit of x; b - Value between lower and upper limit of x; c - Upper limit of x
Trapezoidal	$\mu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ \left(\frac{x-a}{b-a}\right) - \epsilon & \text{if } a < x < b \\ 1-\epsilon & \text{if} b \leq x \leq c \\ \left(\frac{d-x}{d-c}\right) - \epsilon & \text{if } c < x < d \\ 0 & \text{if } x \geq d \end{cases}$	$\nu_A(x) = \begin{cases} 1-\epsilon & \text{if } x \leq a \\ 1-\left(\frac{x-a}{b-a}\right) & \text{if } a < x < b \\ 0 & \text{if} b \leq x \leq c \\ 1-\left(\frac{d-x}{d-c}\right) & \text{if } c < x < d \\ 1-\epsilon & \text{if } x \geq d \end{cases}$	a - Lower limit of x; b - Lower support limit of x; c - Upper support limit of x; d - Upper limit of x
R	$\mu_A(x) = \begin{cases} 0 & \text{if } x \geq d \\ \left(\frac{d-x}{d-c}\right) - \epsilon & \text{if } c < x < d \\ 1-\epsilon & \text{if } x \leq c \end{cases}$	$\nu_A(x) = \begin{cases} 1-\epsilon & \text{if } x \geq d \\ 1-\left(\frac{d-x}{d-c}\right) & \text{if } c < x < d \\ 0 & \text{if } x \leq c \end{cases}$	a and $b: -\infty$; c - lower limit; d - upper limit
L	$\mu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ \left(\frac{x-a}{b-a}\right) - \epsilon & \text{if } a < x < b \\ 1-\epsilon & \text{if } x \geq b \end{cases}$	$\nu_A(x) = \begin{cases} 1-\epsilon & \text{if } x \leq a \\ 1-\left(\frac{x-a}{b-a}\right) & \text{if } a < x < b \\ 0 & \text{if } x \geq b \end{cases}$	a - lower limit; b - upper limit ; c and $d: +\infty$
Gaussian	$\mu_A(x) = e^{-\frac{(x-m)^2}{2k^2}} - \epsilon$	$\nu_A(x) = 1 - e^{-\frac{(x-m)^2}{2k^2}}$	m - middle value of x; k - width≥ 0

Contd.

Type	Membership function	Non-membership function	About parameters
Bell	$\mu_A(x) = 1 - \epsilon - \frac{1}{1+\left\|\frac{x-c}{a}\right\|^{2b}}$	$\nu_A(x) = \frac{1}{1+\left\|\frac{x-c}{a}\right\|^{2b}}$	a - positive parameter; b - positive value and control the slopes at the crossover points; c - locates the center of the curve
Sigmoidal	$\mu_A(x) = \frac{1}{1+\exp(-a(x-c))} - \epsilon$	$\nu_A(x) = 1 - \frac{1}{1+\exp(-a(x-c))}$	a - determines the steepness of the function (If a is positive, the function is open to the right, whereas if it is negative it is open to the left); c - the distance from the origin
S-shaped	$\mu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon & \text{if } a < x \leq \frac{a+b}{2} \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon & \text{if } \frac{a+b}{2} \leq x < b \\ 1 - \epsilon & \text{if } x \geq b \end{cases}$	$\nu_A(x) = \begin{cases} 1 - \epsilon & \text{if } x \leq a \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2 & \text{if } a < x \leq \frac{a+b}{2} \\ 2\left(\frac{x-a}{b-a}\right)^2 & \text{if } \frac{a+b}{2} \leq x < b \\ 0 & \text{if } x \geq b \end{cases}$	a and b - extremes of the sloped portion of the curve
Z-shaped	$\mu_A(x) = \begin{cases} 1 - \epsilon & \text{if } x \leq a \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2 & \text{if } a < x \leq \frac{a+b}{2} \\ 2\left(\frac{x-a}{b-a}\right)^2 & \text{if } \frac{a+b}{2} \leq x < b \\ 0 & \text{if } x \geq b \end{cases}$	$\nu_A(x) = \begin{cases} 0 & \text{if } x \leq a \\ 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon & \text{if } a < x \leq \frac{a+b}{2} \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon & \text{if } \frac{a+b}{2} \leq x < b \\ 1 - \epsilon & \text{if } x \geq b \end{cases}$	a and b - extremes of the sloped portion of the curve

Table 3.2. Types of intuitionistic defuzzification functions. Here a, b, c, d, c_1, c_2 and ϵ are arbitrary constants and $C(y)$ is the crisp value

Type	Defuzzification function#
Triangular	$C(y) = \begin{cases} \leq a & \text{if } y = 0 \\ a + (b-a)(y+\epsilon) - \sqrt{\mu * (c_1 - \gamma)} & \text{if } 0 < y \leq \frac{x-a}{b-a} - \epsilon \\ (b-a)(y+\epsilon) + c - \sqrt{\mu * (c_2 - \gamma)} & \text{if } \frac{x-a}{b-a} - \epsilon \leq y < \frac{c-x}{c-b} - \epsilon \\ \geq c & \text{if } y = 0 \end{cases}$
Trapezoidal	$C(y) = \begin{cases} \leq a & \text{if } y = 0 \\ a + (b-a)(y+\epsilon) - \sqrt{\mu * (c_1 - \gamma)} & \text{if } 0 < y \leq \frac{x-a}{b-a} - \epsilon \\ b \leq x \leq c & \text{if } y = 1 - \epsilon \\ (c-d)(y+\epsilon) + d - \sqrt{\mu * (c_2 - \gamma)} & \text{if } 1 - \epsilon < y < \frac{d-x}{d-c} - \epsilon \\ \geq d & \text{if } y = 0 \end{cases}$
R-trapezoidal	$C(y) = \begin{cases} \leq c & \text{if } y = 1 - \epsilon \\ (c-d)(y+\epsilon) + d - \sqrt{\mu * (c_1 - \gamma)} & \text{if } 1 - \epsilon < y < \frac{d-x}{d-c} - \epsilon \\ \geq d & \text{if } y = 0 \end{cases}$
L-trapezoidal	$C(y) = \begin{cases} \leq a & \text{if } y = 0 \\ a + (b-a)(y+\epsilon) - \sqrt{\mu * (c_2 - \gamma)} & \text{if } 0 < y \leq \frac{x-a}{b-a} - \epsilon \\ \geq b & \text{if } y = 1 - \epsilon \end{cases}$
Gaussian	$C(y) = \begin{cases} \left(m - k\sqrt{-2\log(y+\epsilon)}\right) - \sqrt{\mu * c_1 * \gamma} & \text{if } x \leq m \\ \left(m + k\sqrt{-2\log(y+\epsilon)}\right) + \sqrt{\mu * c_2 * \gamma} & \text{if } x > m \end{cases}$
S-shaped	$C(y) = \begin{cases} \leq a & \text{if } y = 0 \\ a + \frac{(b-a)\sqrt{y+\epsilon}}{\sqrt{2}} + (\mu * (c_1 - \gamma))^2 & \text{if } 0 < y \leq 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon \\ b - \frac{(b-a)\sqrt{1-(y+\epsilon)}}{\sqrt{2}} + (\mu * (c_2 * \gamma))^2 & \text{if } 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon \leq y < 1 - 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon \\ \geq b & \text{if } y \geq 1 - \epsilon \end{cases}$
Z-shaped	$C(y) = \begin{cases} \leq a & \text{if } y = 1 - \epsilon \\ a + \frac{(b-a)\sqrt{1-(y+\epsilon)}}{\sqrt{2}} + (\mu * (c_1 * \gamma))^2 & \text{if } 0 < y \leq 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon \\ b - \frac{(b-a)\sqrt{y+\epsilon}}{\sqrt{2}} + (\mu * (c_2 - \gamma))^2 & \text{if } 1 - 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon \leq y < 2\left(\frac{x-a}{b-a}\right)^2 - \epsilon \\ \geq b & \text{if } y = 0 \end{cases}$

Calculation of defuzzification values is explained by numerical examples in [11].

4 Description of IFL Toolbox

The advancement of IF set theory has been substantial, facilitating the development of numerous algorithms across various domains. These algorithms encompass image and video processing, clustering techniques, shortest path determination in networks, RGB image analysis, molecular structure representation, among others. Parvathi Rangasamy and her team of research scholars have notably contributed to the theoretical expansion and practical application of IF set theory through the design and refinement of such algorithms.

Motivated by the need for consistent and readily available tools to address the aforementioned computational challenges, Parvathi Rangasamy and Kaviranjanii G embarked on an ambitious journey to construct algorithms that address the inherent uncertainties and imprecisions pervasive in real-world data. This initiative, aptly named as intuitionistics fuzzy logic toolbox (IFL toolbox), serves as a repository of specialized functions tailored to cater to the intricacies of IF logic and set operations. By freely disseminating this toolbox on the MATLAB File Exchange page, the authors have extended their contribution to the broader scientific community, facilitating easier access to essential computational resources.

The creation of the IFL Toolbox not only underscores the significance of IF set theory in contemporary computational research but also underscores the commitment of the authors to fostering advancements in this field. This resource stands poised to streamline the implementation of IF-based algorithms, thereby promoting further exploration and innovation across a spectrum of application domains.

4.1 About the IFL Toolbox

It is proposed to contribute the following modules for Intuitionistic Fuzzy Logic Toolbox:

- (M1) Intuitionistic fuzzification functions
- (M2) Intuitionistic defuzzification functions
- (M3) Contrast intensification of images
- (M4) Dilation and concentration of images
- (M5) RGB image representation
- (M6) Video processing
- (M7) Shortest path in networks

More such modules can be included, in future, depending upon requirement. Within the scope of this paper, a concerted effort is made to develop the Module 1,*intuituionistic fuzzification functions*, marking the inception of a pivotal step towards enhancing the model's effectiveness.

4.2 Module 1: Intuitionistic fuzzification functions

This module is composed of

- (i) Functions
- (ii) Syntax/coding
- (iii) Examples
- (iv) Figures/Graphs

(i) *Functions* give a list of nine types of intuitionistic fuzzification functions to determine the membership and non membership values. The appearance of the window is displayed in Figure 4.1.

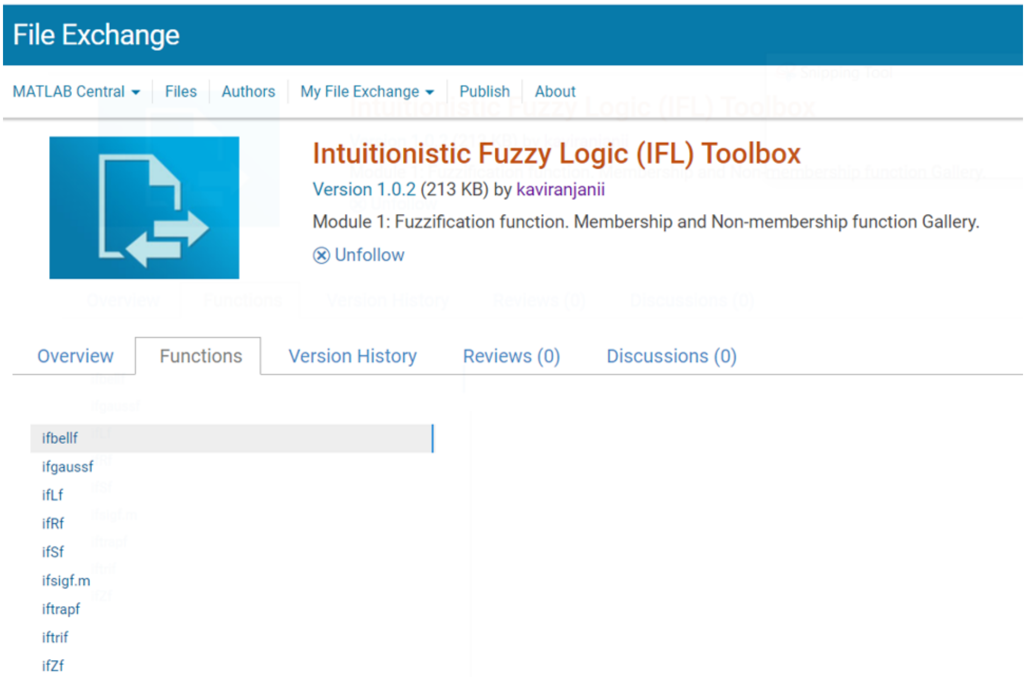

Figure 4.1. Intuitionistic fuzzification function gallery

(ii) *Syntax/coding:* Here, MATLAB codes for respective functions is available with the explanation of parameters. For example, the coding and the parameters for *itrif* is available in the toolbox as shown in Figure 4.2 and Figure 4.3.

Figure 4.2. Code for intuitionistic fuzzy triangular function

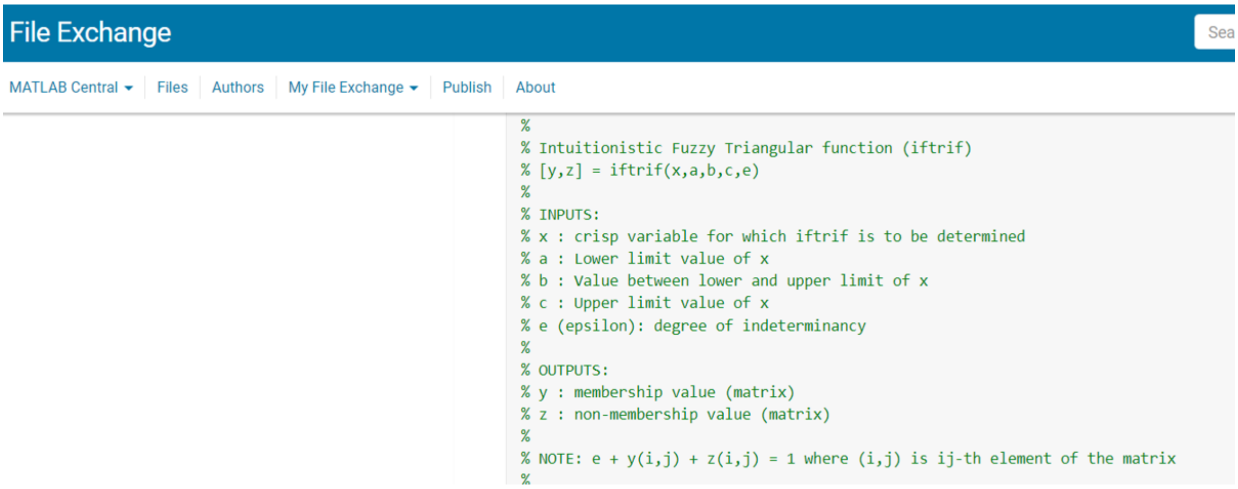

Figure 4.3. Parameters for intuitionistic fuzzy triangular function

(iii) *Examples:* Along with the codes, the application of the intuitionistic fuzzy triangular function (*iftrif*) is illustrated. Assume that the room temperature varies from -5°C to $+5$°C in a particular day. The membership and non-membership values corresponding to the linguistic variable *approximately 0°C* with the parameters $a = -5, b = 0, c = +5$ and $e = 0.2$ (depends on the model) are calculated. The function is defined as $[y, z]$ = *iftrif*$(-5 : 5, -5, 0, 5, 0.2)$.

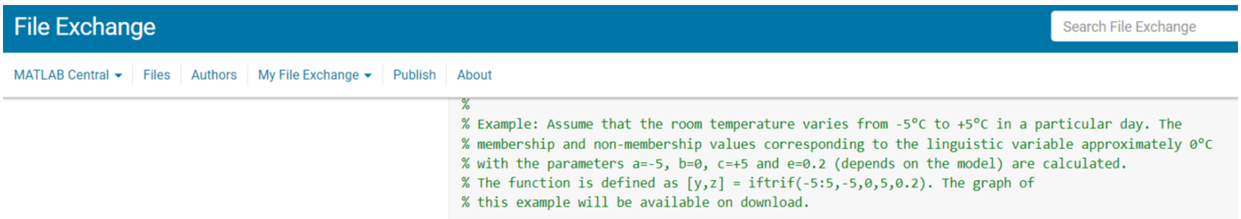

Figure 4.4. Example

(iv) *Figures/Graphs* displays the diagrammatic representation of membership and non-membership functions. Graphs depicting examples corresponding to each function are available on download of the toolbox. The graph of *iftrif* for *approximately 0°C* is given in Figure 4.5.

In the similar way, all options are defined and explained in IFLToolbox for other eight of fuzzification functions. Further, the working of intuitionistic defuzzification functions will be discussed at length in the immediate next paper by authors.

5 Conclusion

In this paper, the development and implementation of the IFL Toolbox in MATLAB is presented, which serves as a comprehensive resource for intuitionistic fuzzy logic (IFL) practitioners. Through the toolbox, users gain access to a diverse gallery of membership and non-membership functions, facilitating the modeling and analysis of complex systems under uncertainty. By providing a user-friendly interface and a wide range of functionalities, the toolbox empowers

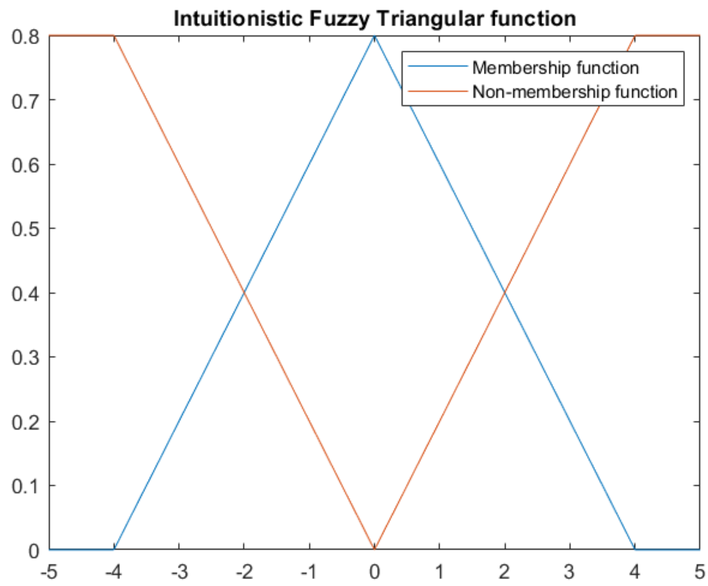

Figure 4.5. Membership and non membership functions of linguistic variable *approximately 0°C*

researchers and practitioners to effectively apply IFL concepts in various domains, including decision-making, pattern recognition, and control systems. The proposed IFL Toolbox not only streamlines the process of designing and implementing IFL-based algorithms but also promotes the advancement of intuitionistic fuzzy logic theory and its practical applications. Future work may focus on expanding the toolbox's capabilities, integrating additional features, and enhancing its compatibility with emerging MATLAB versions to further enrich the IFL research landscape and empower users in tackling real-world challenges effectively. The toolbox is available at `https://in.mathworks.com/matlabcentral/fileexchange/162506-intuitionistic-fuzzy-logic-ifl-toolbox`

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