ICrAData – Software for InterCriteria Analysis

Nikolay Ikonomov[1*], **Peter Vassilev**[2], **Olympia Roeva**[2]

[1]*Department of Analysis, Geometry and Topology*
Institute of Mathematics and Informatics, Bulgarian Academy of Sciences
Acad. G. Bonchev Str., Bl. 8, 1113 Sofia, Bulgaria
E-mail: nikonomov@math.bas.bg

[2]*Department of Bioinformatics and Mathematical Modelling*
Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences
Acad. G. Bonchev Str., Bl. 105, 1113 Sofia, Bulgaria
E-mails: peter.vassilev@gmail.com, olympia@biomed.bas.bg

[*]*Corresponding author*

Received: September 19, 2017 **Accepted: February 12, 2018**

Published: March 31, 2018

Abstract: *In this paper, we consider the InterCriteria Analysis (ICrA), which is based on the index matrices and intuitionistic fuzzy sets. We demonstrate the application of ICrA using the software ICrAData. ICrAData implements five different algorithms for InterCriteria relations calculation, namely: μ-biased, Unbiased, ν-biased, Balanced and Weighted. The software ICrAData displays results in two panels – matrix and graphical view, and the results can also be exported in various formats: matrices, vectors, and graphics. In the matrix view, the column data can be sorted in ascending or descending order. The graphic view has options for resizing the intuitionistic fuzzy triangle, showing a grid and assigning different colours to the points. Moreover, a selected point in the graphic is outlined in the matrix view, and vice-versa. In the present paper some of the ICrAData software functionalities are illustrated by an example.*

Keywords: *Intercriteria analysis, ICrAData, Software.*

Introduction

The InterCriteria Analysis (ICrA) has been developed with the goal to gain additional insight into the nature of criteria involved in a multicriteria problem, and discover on this basis existing relations between the criteria themselves [6]. It is based on the apparatus of the index matrices [3], and the intuitionistic fuzzy sets [2, 4, 5] and can be applied to decision making in different areas of knowledge.

The approach has been discussed in details in a number of papers devoted to different areas of application [1, 9, 15, 19, 20]. Some of the works use the authors' Matlab realization of the ICrA algorithm [15,16,18], but most of them utilize the specialized software developed by Mavrov for application of ICrA and presented in [13, 14]. The software of Mavrov "takes two matrices of input data and outputs the intuitionistic fuzzy pairs that describe the intercriterial relationship as two tables. The application can work with Microsoft Excel workbooks or text files and provides ways to transfer the output data to other programs. It can also include functionality to display graphics of the output data" [13]. In [14] additional graphical interpretation of the results of ICrA in the intuitionistic fuzzy interpretational triangle, has been implemented.

While the software presented in [13, 14] has a user friendly interface and is easy to use, it suffers from several limitations: the software only works under Windows; the copied data has to be compatible with Microsoft Excel, and in this regard imposes restriction on the number of objects (placed in columns).

In this paper, a new cross-platform software implementing ICrA, called ICrAData, is proposed. ICrAData has no limitation on the number of objects and has many additional functionalities compared to the software of Mavrov. Moreover, five different algorithms (μ-biased, Unbiased, ν-biased, Balanced and Weighted) for intercriteria relations calculation are implemented in ICrAData, in accordance with the current development of the ICrA theory [7, 16].

The paper is organized as follows: in Section 2 is presented the background of the InterCriteria Analysis, in Section 3 the software ICrAData and implemented algorithms for InterCriteria relation calculation are described. The concluding remarks are given in Section 4.

Intercriteria analysis background

We briefly outline the theoretical background of ICrA. Based on [6], an Intuitionistic Fuzzy Pair (IFP) [2] is obtained as an estimation of the degrees of "agreement" and "disagreement" between two criteria applied to different objects. An index matrix [3] with index sets consisting of the criteria with elements IFPs corresponding to the "agreement" and "disagreement" between the respective criteria is then constructed.

Let O denote the set of all objects $O_1, O_2, \ldots, O_n$ being evaluated, and $C(O)$ be the set of values computed by a given criteria C to the objects, i.e.,

$$O \stackrel{\text{def}}{=} \{O_1, O_2, O_3, \ldots, O_n\},$$
$$C(O) \stackrel{\text{def}}{=} \{C(O_1), C(O_2), C(O_3), \ldots, C(O_n)\}.$$

Let $x_i = C(O_i)$. Then the following set can be defined:

$$C^*(O) \stackrel{\text{def}}{=} \{\langle x_i, x_j\rangle | i \neq j \,\&\, \langle x_i, x_j\rangle \in C(O) \times C(O)\}.$$

In order to find the "agreement" of two criteria, the vector of all internal comparisons of each criteria, which fulfill exactly one of three relations R, $\overline{R}$ and $\tilde{R}$ is constructed. That is, for a fixed criterion C and any ordered pair $\langle x, y\rangle \in C^*(O)$ it is true:

$$\langle x, y\rangle \in R \Leftrightarrow \langle y, x\rangle \in \overline{R}, \tag{1}$$
$$\langle x, y\rangle \in \tilde{R} \Leftrightarrow \langle x, y\rangle \notin (R \cup \overline{R}), \tag{2}$$
$$R \cup \overline{R} \cup \tilde{R} = C^*(O). \tag{3}$$

Further, we consider R, $\overline{R}$ and $\tilde{R}$ to be >, < and =, respectively. From the above it is clear that only a subset of $C(O) \times C(O)$ needs to be considered for the effective calculation of the vector of internal comparisons, since from Eqs. (1)-(3) it follows that if the relation between x and y is known, then so is the relation between y and x. Thus of interest are only the lexicographically ordered pairs $\langle x, y\rangle$. Denote for brevity: $C_{i,j} = \langle C(O_i), C(O_j)\rangle$. Then for a given criterion C, the vector with $n(n-1)/2$ elements is obtained:

$$V(C) = \{C_{1,2}, C_{1,3}, \ldots, C_{1,n}, C_{2,3}, C_{2,4}, \ldots, C_{2,n}, C_{3,4}, \ldots, C_{3,n}, \ldots, C_{n-1,n}\}.$$

Let $V(C)$ is replaced by $\hat{V}(C)$, where its k-th component ($1 \leq k \leq n(n-1)/2$):

$$\hat{V}_k(C) = \begin{cases} 1, \text{ iff } V_k(C) \in R, \\ -1, \text{ iff } V_k(C) \in \overline{R}, \\ 0, \text{ otherwise.} \end{cases}$$

When comparing two criteria C and C', the degree of "agreement" $\mu_{C,C'}$ is determined as the number of matching non-zero components of the respective vectors (divided by the length of the vector for normalization purposes) and depending on the implemented algorithm, possibly by the number of matching zero components. The degree of "disagreement" $\nu_{C,C'}$ is the number of components of opposing signs in the two vectors, but may also be influenced by the matching zero components, depending on the chosen algorithm [16].

It is obvious (from the way of calculation) that for $\mu_{C,C'}$ and $\nu_{C,C'}$ we have $\mu_{C,C'} = \mu_{C',C}$ and $\nu_{C,C'} = \nu_{C',C}$. Also, $\langle \mu_{C,C'}, \nu_{C,C'} \rangle$ is an IFP. In the most of the obtained pairs $\langle \mu_{C,C'}, \nu_{C,C'} \rangle$, the sum $\mu_{C,C'} + \nu_{C,C'} = 1$. However, there may be some pairs, for which this sum is less than 1. The difference $\pi = 1 - (\mu_{C,C'} + \nu_{C,C'})$ is considered as a degree of "uncertainty".

Currently five different algorithms are proposed. The algorithms μ-biased, Unbiased, ν-biased and Balanced are developed in [16], based on ideas in [7]. The Weighted algorithm is proposed later in [17]. Here we give short description of the algorithms below:

- **μ-biased**: This algorithm follows the rules presented in [7, Table 3], where the rule $=,=$ for two criteria C and C' is assigned to $\mu_{C,C'}$.
- **Unbiased**: This algorithm follows the rules in [7, Table 1], where the rule $=,=$ is not assigned to $\mu_{C,C'}$ or $\nu_{C,C'}$. It should be noted that in such case a criterion compared to itself does not necessarily yield $\langle 1,0 \rangle$.
- **ν-biased**: In this case the rule $=,=$ for two criteria C and C' is assigned to $\nu_{C,C'}$. It should be noted that in such case a criteria compared to itself does not necessarily yield $\langle 1,0 \rangle$.
- **Balanced**: This algorithm follows the rules in [7, Table 2], where the rule $=,=$ for two criteria C and C' is assigned a half to both $\mu_{C,C'}$ and $\nu_{C,C'}$. It should be noted that in such case a criteria compared to itself does not necessarily yield $\langle 1,0 \rangle$.
- **Weighted**: The algorithm assigns the rule $=,=$ proportionally to $\mu_{C,C'}$ and $\nu_{C,C'}$, resulting in intuitionistic fuzzy pairs.

ICrAData software

The ICrAData software is written in the Java programming language [11], and it requires installation of Java Virtual Machine from [12]. After installing the software from [10], the software can be started by the executable file "ICrAData.jar".

The input data has to be a matrix with minimum size 3×3, as presented in Eq. (4). The column separator can be tab, comma or semicolon. Each value can be a natural or a real number, and the decimal separator can be point or comma.

$$\begin{array}{c|cccc} & O_1 & O_2 & \dots & O_m \\ \hline C_1 & C_1(O_1) & C_1(O_2) & \dots & C_1(O_m) \\ C_2 & C_2(O_1) & C_2(O_2) & \dots & C_2(O_m) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & C_n(O_1) & C_n(O_2) & \dots & C_n(O_m) \end{array} \qquad (4)$$

The criteria names can be specified with `#criterianames: A,B,C,D`, the object names – `#objectnames: X,Y,Z,W,V`. These criteria names are used for the column names in the matrices, the object names will be used in a future version of the program, for matrix transposition.

As an illustration we provide the following sample data matrix:
6;5;3;7;6
7;7;8;1;3
4;3;5;9;1
4;5;6;7;8

Copy this data and paste it into the left panel of the ICrAData window. The data written in the left panel can be saved from the button "Save File", and can be saved with different file name with "Save Copy". Afterwards, the saved files can be opened using the "Open File" option. When the data has been loaded, select the button "Analysis".

All five algorithms (μ-biased, Unbiased, ν-biased, Balanced and Weighted), mentioned in the the previous section, are implemented in ICrAData software. They can be selected from the drop-down menu. After changing the algorithm, select "Analysis" to make the new calculations and display the results. The numeric results are displayed in the central panel as two matrices ($\mu_{C,C'}$ and $\nu_{C,C'}$), the corresponding graphic – in the right panel.

In the primary view the central panel contains the result matrices for $\mu_{C,C'}$ and $\nu_{C,C'}$ (see Fig. 1). A secondary view can be selected, which displays the ordered pair $\langle \mu_{C,C'}, \nu_{C,C'} \rangle$ in the upper matrix and the Euclidean distance from each pair to $\langle 1,0 \rangle$ in the lower matrix (see Fig. 2) as proposed in [8]. There is also an option to change the decimal digits being displayed, the default is 4 digits. Calculations are done in double precision, which is around 16 decimal digits.

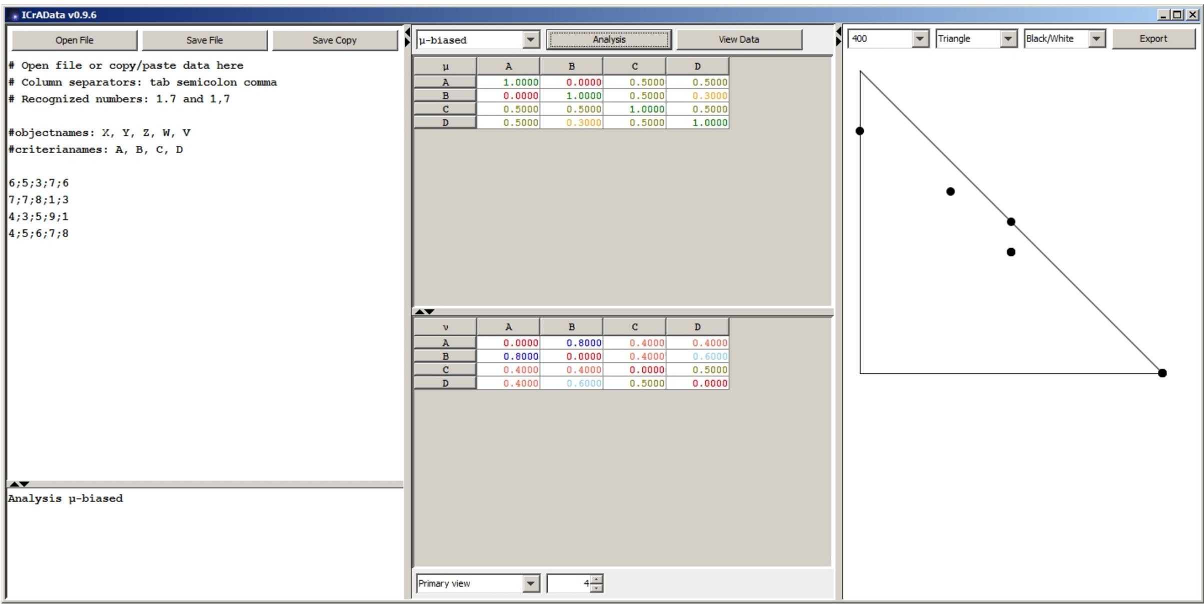


Fig. 1 ICrAData user interface – primary view

All points in the form of pairs $\langle \mu_{C,C'}, \nu_{C,C'} \rangle$, which are the result from the analysis, are displayed on the right panel as points in the intuitionistic fuzzy triangle with vertices $\langle 0,0 \rangle$, $\langle 0,1 \rangle$, $\langle 1,0 \rangle$ – corresponding to logical constants uncertainty, falsity and truth, respectively. Several options can be selected above the graphic: size of the graphic, grid lines and color of the points. The graphic can also be exported as a PNG image. Selecting a point from the graphic (with the mouse) highlights the corresponding cells in the matrices, and vice-versa – selecting a cell highlights the point.

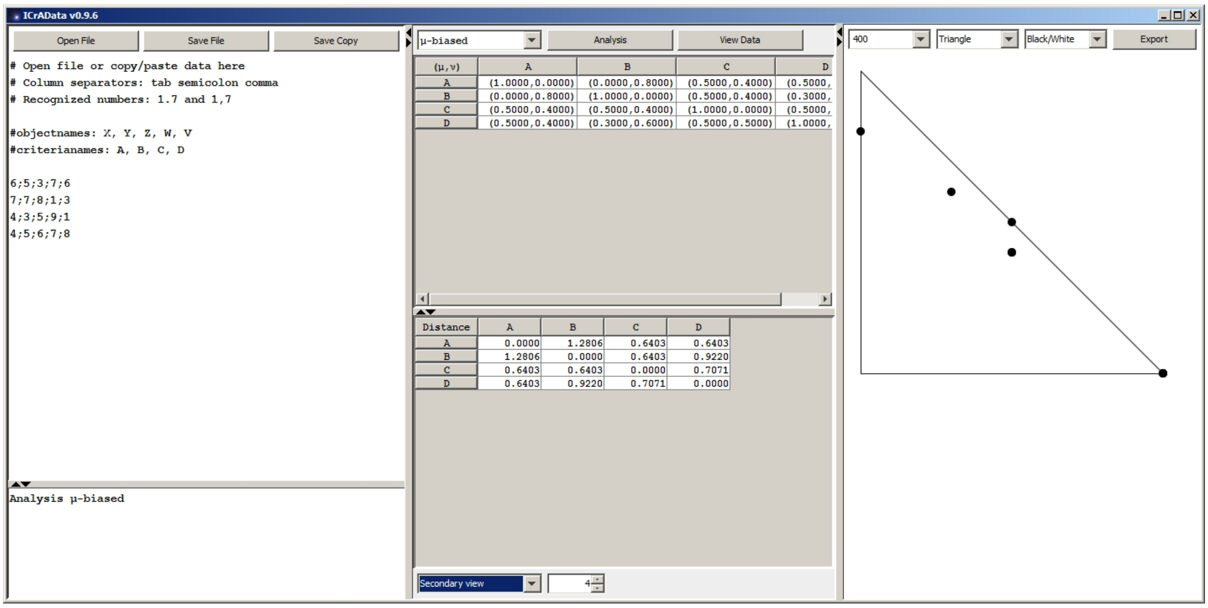


Fig. 2 ICrAData user interface – secondary view

All data can be viewed and exported by selecting the button "View Data". There are options for choosing the displayed matrix or vector, the column separator, the decimal digits separator and the number of decimal digits displayed. The upper triangular matrices from the resulting matrices for $\mu_{C,C'}$ and $\nu_{C,C'}$, as well as the distance matrix, can be exported as vectors, which is useful for data comparison with other software.

We will illustrate the algorithms with an example. Let us have the indexed matrix from Eq. (4). The criteria matrix, created from the index matrix, is:

$$\begin{array}{c|cccccc}
 & (1\text{-}2) & (1\text{-}3) & \ldots & (1\text{-}n) & (2\text{-}3) & \ldots \\ \hline
C_1 & C_1(O_1)-C_1(O_2) & C_1(O_1)-C_1(O_3) & \ldots & C_1(O_1)-C_1(O_n) & C_1(O_2)-C_1(O_3) & \ldots \\
C_2 & C_2(O_1)-C_2(O_2) & C_2(O_1)-C_2(O_3) & \ldots & C_2(O_1)-C_2(O_n) & C_2(O_2)-C_2(O_3) & \ldots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
C_n & C_n(O_1)-C_n(O_2) & C_n(O_1)-C_n(O_3) & \ldots & C_n(O_1)-C_n(O_n) & C_n(O_2)-C_n(O_3) & \ldots
\end{array}.$$

The following index matrix corresponds to the sample data given above:

$$\begin{array}{c|ccccc}
 & O_1 & O_2 & O_3 & O_4 & O_5 \\ \hline
C_1 & 6 & 5 & 3 & 7 & 6 \\
C_2 & 7 & 7 & 8 & 1 & 3 \\
C_3 & 4 & 3 & 5 & 9 & 1 \\
C_4 & 4 & 5 & 6 & 7 & 8
\end{array}. \tag{5}$$

The criteria matrix obtained from the index matrix Eq. (5) has the following form:

$$\begin{array}{c|cccccccccc}
 & (1\text{-}2) & (1\text{-}3) & (1\text{-}4) & (1\text{-}5) & (2\text{-}3) & (2\text{-}4) & (2\text{-}5) & (3\text{-}4) & (3\text{-}5) & (4\text{-}5) \\ \hline
C_1 & 1 & 3 & -1 & 0 & 2 & -2 & -1 & -4 & -3 & 1 \\
C_2 & 0 & -1 & 6 & 4 & -1 & 6 & 4 & 7 & 5 & -2 \\
C_3 & 1 & -1 & -5 & 3 & -2 & -6 & 2 & -4 & 4 & 8 \\
C_4 & -1 & -2 & -3 & -4 & -1 & -2 & -3 & -1 & -2 & -1
\end{array}. \tag{6}$$

Now we create a new matrix, called sign matrix, which takes the sign of each value of the criteria matrix Eq. (6):

	(1-2)	(1-3)	(1-4)	(1-5)	(2-3)	(2-4)	(2-5)	(3-4)	(3-5)	(4-5)
S_1	1	1	-1	0	1	-1	-1	-1	-1	1
S_2	0	-1	1	1	-1	1	1	1	1	-1
S_3	1	-1	-1	1	-1	-1	1	-1	1	1
S_4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

. (7)

Depending on the algorithm used, from the rows of the signed matrix Eq. (7), we obtain a symmetric matrix. Therefore we only need to consider the matrix of the following form:

	C_1	C_2	C_3	C_4
C_1	$S_1\#S_1$	$S_1\#S_2$	$S_1\#S_3$	$S_1\#S_4$
C_2	-	$S_2\#S_2$	$S_2\#S_3$	$S_2\#S_4$
C_3	-	-	$S_3\#S_3$	$S_3\#S_4$
C_4	-	-	-	$S_4\#S_4$

, (8)

where $S_i\#S_j$ denotes the result of comparison between the i-th and j-th rows of Eq. (7).

The comparison rules used in interpreting Eq. (8) generate the $\mu_{C,C'}$ and $\nu_{C,C'}$ matrices, obtained as an end result of ICrA. Further, we explain the different steps in obtaining the resulting matrices $\mu_{C,C'}$ and $\nu_{C,C'}$ Eq. (8).

- μ**-biased** algorithm

  We use the following rules for the matrix μ_{C_i,C_j}: $0 = 0$, $1 = 1$, $-1 = -1$, and the following for the matrix ν_{C_i,C_j}: $-1 \neq 1$, $1 \neq -1$. The comparison $0 \neq 0$ is not considered.

  We count the equal values of the signed matrix Eq. (7) and assign them to μ_{C_i,C_j}. In the same manner, the different values are assigned to ν_{C_i,C_j}. Finally, the obtained μ_{C_i,C_j} and ν_{C_i,C_j} values are normalized in [0, 1] interval by dividing by the all counted elements. As a result we obtain the following matrices:

μ_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	1	0	0.5	0.5
C_2	-	1	0.5	0.3
C_3	-	-	1	0.5
C_4	-	-	-	1

,

ν_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0	0.8	0.4	0.4
C_2	-	0	0.4	0.6
C_3	-	-	0	0.5
C_4	-	-	-	0

.

- **Unbiased** algorithm

  We use the following rules for the matrix μ_{C_i,C_j}: $1 = 1$, $-1 = -1$, and the following for the matrix ν_{C_i,C_j}: $-1 \neq 1$, $1 \neq -1$. The comparisons $0 = 0$ and $0 \neq 0$ are not considered.

μ_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	$\boxed{0.9}$	0	0.5	0.5
C_2	-	$\boxed{0.9}$	0.5	0.3
C_3	-	-	1	0.5
C_4	-	-	-	1

,

ν_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0	0.8	0.4	0.4
C_2	-	0	0.4	0.6
C_3	-	-	0	0.5
C_4	-	-	-	0

.

  Here and further, to highlight the difference between μ-biased and the other algorithms, the differing values of μ_{C_i,C_j} and ν_{C_i,C_j} are enclosed in a box.

- **ν-biased** algorithm

  We use the following rules for the matrix μ_{C_i,C_j}: $1 = 1$, $-1 = -1$, and the following for the matrix ν_{C_i,C_j}: $0 \neq 0$, $-1 \neq 1$, $1 \neq -1$. The comparison $0 = 0$ is not considered.

μ_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0.9	0	0.5	0.5
C_2	-	0.9	0.5	0.3
C_3	-	-	1	0.5
C_4	-	-	-	1

ν_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0.1	0.8	0.4	0.4
C_2	-	0.1	0.4	0.6
C_3	-	-	0	0.5
C_4	-	-	-	0

- **Balanced** algorithm

  Based on μ-biased and ν-biased algorithms, the μ_{C_i,C_j} and ν_{C_i,C_j} values are obtained in the following way:

$$\mu_{C_i,C_j}^{\text{Balanced}} = \frac{\mu_{C_i,C_j}^{\mu\text{-biased}} + \mu_{C_i,C_j}^{\nu\text{-biased}}}{2}, \quad \nu_{C_i,C_j}^{\text{Balanced}} = \frac{\nu_{C_i,C_j}^{\mu\text{-biased}} + \nu_{C_i,C_j}^{\nu\text{-biased}}}{2}.$$

  Therefore, the comparisons $0 = 0$ and $0 \neq 0$ are evenly assigned to μ_{C_i,C_j} and ν_{C_i,C_j}.

μ_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0.95	0	0.5	0.5
C_2	-	0.95	0.5	0.3
C_3	-	-	1	0.5
C_4	-	-	-	1

ν_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0.05	0.8	0.4	0.4
C_2	-	0.05	0.4	0.6
C_3	-	-	0	0.5
C_4	-	-	-	0

- **Weighted** algorithm

  We construct the following matrix P:

$$P_{i,j} = \mu_{C_i,C_j}^{\text{Unbiased}} + \nu_{C_i,C_j}^{\text{Unbiased}}.$$

  Further, we obtain μ_{C_i,C_j} and ν_{C_i,C_j} as follows:

$$\mu_{C_i,C_j}^{\text{Weighted}} = \begin{cases} \mu_{C_i,C_j}^{\text{Unbiased}} + \dfrac{\mu_{C_i,C_j}^{\text{Unbiased}}}{P_{i,j}}(1 - P_{i,j}) = \dfrac{\mu_{C_i,C_j}^{\text{Unbiased}}}{P_{i,j}}, & \text{if } P_{i,j} \neq 0, \\ \dfrac{1}{2}, & \text{otherwise,} \end{cases}$$

$$\nu_{C_i,C_j}^{\text{Weighted}} = \begin{cases} \nu_{C_i,C_j}^{\text{Unbiased}} + \dfrac{\nu_{C_i,C_j}^{\text{Unbiased}}}{P_{i,j}}(1 - P_{i,j}) = \dfrac{\nu_{C_i,C_j}^{\text{Unbiased}}}{P_{i,j}}, & \text{if } P_{i,j} \neq 0, \\ \dfrac{1}{2}, & \text{otherwise,} \end{cases}$$

  where $P_{i,j}$ denotes the element in the i-th row and j-th column of matrix P.

  We recall the matrices from the Unbiased algorithm:

μ_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0.9	0	0.5	0.5
C_2	-	0.9	0.5	0.3
C_3	-	-	1	0.5
C_4	-	-	-	1

ν_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0	0.8	0.4	0.4
C_2	-	0	0.4	0.6
C_3	-	-	0	0.5
C_4	-	-	-	0

Then the matrix P is:

$P_{i,j}$	C_1	C_2	C_3	C_4
C_1	0.9	0.8	0.9	0.9
C_2	-	0.9	0.9	0.9
C_3	-	-	1	1
C_4	-	-	-	1

The resulting μ_{C_i,C_j} and ν_{C_i,C_j} matrices obtained from the Weighted algorithm are as follows:

μ_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	1	0	0.5556	0.5556
C_2	-	1	0.5556	0.3333
C_3	-	-	1	0.5
C_4	-	-	-	1

ν_{C_i,C_j}	C_1	C_2	C_3	C_4
C_1	0	1	0.4444	0.4444
C_2	-	0	0.4444	0.6667
C_3	-	-	0	0.5
C_4	-	-	-	0

It is important to note that the sum of the respective elements of μ_{C_i,C_j} and ν_{C_i,C_j} is equal to one.

We have now presented the algorithms both from theoretical and practical point of view. We have used the default example given in the software to illustrate in detail the different algorithms implemented in ICrAData, which are used in the application of the ICrA approach.

Conclusion

In this paper, a new cross-platform software for ICrA approach, ICrAData, is proposed. The software is written in the Java programming language and is able to easily handle large numbers of objects and criteria within a reasonable time. In ICrAData five different algorithms for intercriteria relations calculation, namely μ-biased, Unbiased, ν-biased, Balanced and Weighted, are implemented. The choice of the particular algorithm depends mainly on the initial set of data for ICrA.

This paper has demonstrated that ICrAData software is user friendly and should be a valuable addition to users working in the field of application of ICrA approach.

Authors' contributions

N. Ikonomov designed and wrote the software. P. Vassilev and O. Roeva tested ICrAData and optimized the program. All authors took an active part in manuscript writing, reading, and approved the final manuscript.

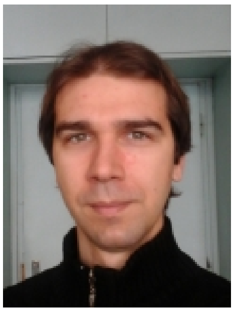
Acknowledgements

This work is partially supported by the National Science Fund of Bulgaria under Grants No. DFNI-I-02-5/2014 "InterCriteria Analysis: A New Approach to Decision Making" and No. DFNI-DN-02-10/2016 "New Instruments for Knowledge Discovery from Data, and Their Modelling".

References

1. Angelova N., K. Atanassov, B. Riecan (2015). Intercriteria Analysis of the Intuitionistic Fuzzy Implication Properties, Notes on Intuitionistic Fuzzy Sets, 21(5), 20-23.
2. Atanassov K. (2012). On Intuitionistic Fuzzy Sets Theory, Springer, Berlin.
3. Atanassov K. (2014). Index Matrices: Towards an Augmented Matrix Calculus, Studies in Computational Intelligence, 573.
4. Atanassov K. (2016). Intuitionistic Fuzzy Sets, VII ITKR Session, Sofia, 20-23 June 1983, Reprinted: International Journal Bioautomation, 20(S1), S1-S6.
5. Atanassov K. (2016). Review and New Results on Intuitionistic Fuzzy Sets, Mathematical Foundations of Artificial Intelligence Seminar, Sofia, 1988, Preprint IM-MFAIS-1-88, Reprinted: International Journal Bioautomation, 20(S1), S7-S16.
6. Atanassov K., D. Mavrov, V. Atanassova (2014). InterCriteria Decision Making: A New Approach for Multicriteria Decision Making, Based on Index Matrices and Intuitionistic Fuzzy Sets, Issues in Intuitionistic Fuzzy Sets and Generalized Nets, 11, 1-8.
7. Atanassov K., V. Atanassova, G. Gluhchev (2015). InterCriteria Analysis: Ideas and Problems, Notes on Intuitionistic Fuzzy Sets, 21(1), 81-88.
8. Atanassova V. (2015). Interpretation in the Intuitionistic Fuzzy Triangle of the Results, Obtained by the InterCriteria Analysis, 9th Conference of the European Society for Fuzzy Logic and Technology (EUSFLAT), 1369-1374, doi: 10.2991/ifsa-eusflat-15.2015.193.
9. Bureva V., E. Sotirova, S. Sotirov, D. Mavrov (2015). Application of the InterCriteria Decision Making Method to Bulgarian Universities Ranking, Notes on Intuitionistic Fuzzy Sets, 21(2), 111-117.
10. InterCriteria.net – ICrAData Software, http://intercriteria.net/software/ .
11. Java Platform SE 8, API Documentation, https://docs.oracle.com/javase/8/docs/api/ .
12. Java Virtual Machine, https://java.com/ .
13. Mavrov D. (2015). Software for InterCriteria Analysis: Implementation of the Main Algorithm, Notes on Intuitionistic Fuzzy Sets, 21(2), 77-86.
14. Mavrov D., I. Radeva, F. Capkovic, L. Doukovska (2015). Software for InterCriteria Analysis: Graphic Interpretation within the Intuitionistic Fuzzy Triangle, Proceedings of 5th International Symposium on Business Modeling and Software Design, 279-283.
15. Pencheva T., M. Angelova, P. Vassilev, O. Roeva (2016). InterCriteria Analysis Approach to Parameter Identification of a Fermentation Process Model, Advances in Intelligent Systems and Computing, 401, 385-397.
16. Roeva O., P. Vassilev, M. Angelova, J. Su, T. Pencheva (2016). Comparison of Different Algorithms for InterCriteria Relations Calculation, Proc. of the IEEE 8th International Conference on Intelligent Systems, 567-572.
17. Roeva O., P. Vassilev, N. Ikonomov (2018). A New Algorithm for InterCriteria Relation Calculation, Studies in Computational Intelligence, in press.
18. Roeva O., P. Vassilev, S. Fidanova, M. Paprzycki (2016). InterCriteria Analysis of Genetic Algorithms Performance, Studies of Computational Intelligence, 655, 235-260.
19. Sotirov S., E. Sotirova, P. Melin, O. Castillo, K. Atanassov (2016). Modular Neural Network Preprocessing Procedure with Intuitionistic Fuzzy InterCriteria Analysis Method, Advances in Intelligent Systems and Computing, Vol. 400, Springer, Cham, 175-186.
20. Todinova S., D. Mavrov, S. Krumova, P. Marinov, V. Atanassova, K. Atanassov, S. G. Taneva (2016). Blood Plasma Thermograms Dataset Analysis by Means of InterCriteria and Correlation Analyses for the Case of Colorectal Cancer, International Journal Bioautomation, 20(1), 115-124.

Assist. Prof. Nikolay Ikonomov, Ph.D.
Email: nikonomov@math.bas.bg



Nikolay Ikonomov received his Ph.D. degree in Mathematics from the Institute of Mathematics and Informatics of the Bulgarian Academy of Sciences in 2016. At present he is an Assistant Professor at Institute of Mathematics and Informatics, Bulgarian Academy of Sciences. He has specialized in implementing mathematical algorithms in computer software.

Assist. Prof. Peter Vassilev, Ph.D.
Email: peter.vassilev@gmail.com

Peter Vassilev has an M.Sc. degree (2009) in Applied Mathematics from the Technical University – Sofia and Ph.D. degree (2013) from the Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences. At present he is a Senior Assistant Professor at the Institute of Biophysics and Biomedical Engineering – Bulgarian Academy of Sciences. He has more than 40 publications. His current scientific interests are in the area of bioinformatics, artificial intelligence and algorithms.

Assoc. Prof. Olympia Roeva, Ph.D.
Email: olympia@biomed.bas.bg

Olympia Roeva received M.Sc. degree (1998) and Ph.D. degree (2007) from the Technical University – Sofia. At present she is an Associate Professor at the Institute of Biophysics and Biomedical Engineering – Bulgarian Academy of Sciences. She has more than 100 publications, among those 10 books and book chapters, with more than 400 citations. Her current scientific interests are in the fields of modelling, optimization and control of biotechnological processes, metaheuristic algorithms, intuitionistic fuzzy sets and generalized nets.