

Software for Intercriteria Analysis results visualization in the intuitionistic fuzzy triangle: Opportunities for data interpretation

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Abstract: In the current investigation a program implementation for data visualization into the intuitionistic fuzzy triangle according to the InterCriteria analysis notation is discussed. The presented software provides an opportunity for in-depth analysis of the results and flexible visualization of data obtained from the InterCriteria Analysis. An example of the software workflow is described.

Keywords: InterCriteria Analysis, Data interpretation, Data visualization, Java, Software.

2020 Mathematics Subject Classification: 03E72.

1 Introduction

InterCriteria Analysis (ICA) is an approach for decision making based on the theories of intuitionistic fuzzy sets [2] and index matrices [3]. It is used to analyze different objects according to their estimations based on the separate criteria or vice-versa [4, 11]. In the recent years ICA



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theory has been seriously investigated, and different extensions, algorithms for intuitionistic fuzzy pairs (IFPs) calculation, program implementations and applications of the proposed approach in different scientific fields are published [1, 5–7]. The ICA extensions includes variants of ICA for working with intuitionistic fuzzy data, three-dimensional data, implications, triples or ICA with weight coefficients of objects or criteria and etc. The survey of the ICA investigations is presented in [7]. Software for ICA applications are explained [9, 10, 12, 14–16]. The software used for performing ICA over datasets are InterCriteria Analysis Data (ICrAData) by Nikolay Ikonov [10, 12] and InterCriteria Decision Making (ICDM) by Deyan Mavrov [12, 14]. The first program is written in Java while the second implementation is made on C++. For the same purpose, a Matlab script with authors Peter Vassilev and Olympia Roeva was created to implement ICA [12]. Thereafter, Python scrips for modelling different operators for IFSs are proposed by Evgeniy Marinov [12]. VisicrA is the last implementation which is written in Python by Nikolay Ikonov [9, 12]. The software can perform ICA and provide facilities for results visualization. After ICA calculations the data can be presented in the form of histograms in 1D plot, 2D plot or 3D plot.

The topic of the current research work is the ICA results interpretation and visualization. The aim of the investigation is already discussed in several papers [6]. In the current investigation a program for working with ICA results is proposed. The proposed software does not perform ICA. It works with its results in the form of μ -table and ν -table. The idea is to visualize relations according to the selected indicator and data relationships according to the selected interval of the ICA scale (positive consonance, dissonance, negative consonance). The second option help us to visualize only the selected groups, clusters of data. The option for animating the process of data point drawing in the IF triangle is added. Thereafter, the user can watch the points visualization. The proposed implementation can be integrated in Java based software. The proposed ICA implementation is written in Java using Eclipse IDE [8]. The program is made using JavaFX framework that is a new technology for building graphical user interface applications (GUI) [13]. The proposed program for InterCriteria Analysis results visualization and data interpretation is presented in next section.

2 Software for InterCriteria Analysis Results Visualization and Data Interpretation in the Intuitionistic Fuzzy Triangle

The Software for InterCriteria Analysis Results Visualization and Data Interpretation in the Intuitionistic Fuzzy Triangle is written in Java using the JavaFX. JavaFX is an open source framework for desktop, mobile and embedded systems built on Java [13]. It is used for graphic user interface (GUI) implementation of the proposed software. The ICA program is designed to allow the quick visualization of the ICA results on a table of input data, which can come a text file with semicolon-separated values. The ICA implementation functionalities allow the user to visualize selected relationship or relationships between the objects or criteria by adding its intuitionistic fuzzy estimations. The input data have to include the index matrices containing the degrees of membership and degrees of non-membership. An example for the input format of the

values is presented in Notepad. A sample of the datasets for university ranking in Bulgaria for 2023 is selected [17]. The data have to be separated by semicolons (Figure 1).

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µ; International mobility; Accreditation assessment grade; Bachelor level majors; PhD programs in HEI's professional field; Doctoral-to-undergraduate an
International mobility; 0,43;0,39;0,35;0,48;0,37;0,29;0,35;0,33;0,25;0,42;0,45;0,49;0,46;0,45;0,52;0,43;0,36;0,34;0,42;0,42;0,47
Accreditation assessment grade; 0,43;0,51;0,53;0,54;0,47;0,42;0,59;0,51;0,27;0,42;0,48;0,43;0,49;0,43;0,52;0,44;0,48;0,48;0,43;0,55;0,46
Bachelor level majors; 0,39;0,51;0,49;0,51;0,26;0,40;0,46;0,44;0,27;0,37;0,39;0,38;0,42;0,25;0,53;0,41;0,48;0,43;0,43;0,52;0,50
PhD programs in HEI's professional field; 0,35;0,53;0,49;0,61;0,24;0,39;0,41;0,35;0,22;0,31;0,41;0,33;0,41;0,35;0,41;0,35;0,34;0,42;0,41;0,41;0,44
Doctoral-to-undergraduate and graduate students ratio; 0,48;0,54;0,51;0,61;0,36;0,49;0,47;0,45;0,35;0,44;0,50;0,52;0,46;0,44;0,50;0,44;0,41;0,44;0,46;0,
Total funds for science and research per student; 0,37;0,47;0,26;0,24;0,36;0,48;0,58;0,57;0,39;0,49;0,53;0,47;0,56;0,50;0,43;0,54;0,37;0,50;0,46;0,33;0,
PhD programs in the university;0,29;0,42;0,40;0,39;0,48;0,63;0,67;0,61;0,32;0,38;0,48;0,46;0,47;0,46;0,46;0,45;0,55;0,40;0,42;0,36
Papers with at least one citation (Scopus);0,35;0,59;0,46;0,41;0,47;0,58;0,63;0,79;0,48;0,42;0,43;0,37;0,59;0,44;0,44;0,55;0,55;0,56;0,67;0,49;0,44
Articles in scientific journals (Scopus);0,33;0,51;0,44;0,35;0,45;0,57;0,67;0,79;0,54;0,42;0,39;0,39;0,50;0,42;0,53;0,53;0,57;0,64;0,41;0,50;0,39
Availability of information resources;0,25;0,27;0,22;0,35;0,39;0,61;0,48;0,54;0,35;0,40;0,33;0,40;0,33;0,42;0,37;0,40;0,47;0,50;0,37;0,41;0,33
Library stock per student;0,42;0,42;0,37;0,31;0,44;0,49;0,32;0,42;0,42;0,35;0,50;0,40;0,50;0,56;0,57;0,54;0,39;0,35;0,44;0,47;0,35
Teaching floor space per student;0,45;0,48;0,39;0,41;0,50;0,53;0,38;0,43;0,39;0,33;0,50;0,46;0,65;0,52;0,46;0,70;0,35;0,41;0,47;0,30;0,43
Stock in trade (in leva per student); 0,49;0,43;0,38;0,33;0,52;0,47;0,48;0,37;0,39;0,40;0,40;0,46;0,46;0,57;0,39;0,42;0,31;0,41;0,44;0,41;0,39
Equipment (in leva per student); 0,46;0,49;0,42;0,41;0,46;0,56;0,46;0,59;0,50;0,33;0,50;0,65;0,46;0,56;0,51;0,66;0,31;0,54;0,55;0,33;0,59
Rate of library stock use; 0,45;0,43;0,25;0,35;0,44;0,50;0,47;0,44;0,42;0,42;0,56;0,52;0,57;0,56;0,41;0,52;0,33;0,46;0,48;0,34;0,44
Scholarships; 0,52;0,52;0,53;0,41;0,50;0,43;0,46;0,55;0,53;0,37;0,57;0,46;0,39;0,51;0,41;0,56;0,62;0,47;0,58;0,44;0,46
Student housing; 0,43;0,44;0,41;0,35;0,44;0,54;0,46;0,55;0,53;0,40;0,54;0,70;0,42;0,66;0,52;0,56;0,44;0,52;0,54;0,29;0,46
Foreign students; 0,36;0,48;0,48;0,34;0,41;0,37;0,45;0,56;0,57;0,47;0,39;0,35;0,31;0,31;0,33;0,62;0,44;0,56;0,56;0,39;0,43
Secondary education diploma GPA; 0,34;0,48;0,43;0,42;0,44;0,50;0,55;0,67;0,64;0,50;0,35;0,41;0,41;0,54;0,46;0,47;0,52;0,56;0,65;0,35;0,58
Graduates' insurable income; 0,42;0,43;0,43;0,41;0,46;0,46;0,40;0,47;0,41;0,37;0,44;0,47;0,44;0,55;0,48;0,58;0,54;0,56;0,65;0,20;0,70
Unemployment among graduates; 0,42;0,55;0,52;0,41;0,55;0,33;0,42;0,49;0,50;0,41;0,47;0,30;0,41;0,33;0,34;0,44;0,29;0,39;0,35;0,20;0,35
Contribution to the social security system;0,47;0,46;0,50;0,44;0,50;0,38;0,36;0,44;0,39;0,33;0,35;0,43;0,39;0,59;0,44;0,46;0,46;0,33;0,58;0,70;0,35
v; International mobility; Accreditation assessment grade; Bachelor level majors; PhD programs in HEI's professional field; Doctoral-to-undergraduate an
International mobility; 0,35;0,33;0,26;0,30;0,42;0,50;0,44;0,46;0,48;0,37;0,33;0,30;0,33;0,33;0,27;0,35;0,40;0,45;0,37;0,37;0,32
Accreditation assessment grade; 0,35;0,30;0,16;0,32;0,41;0,45;0,29;0,37;0,55;0,46;0,39;0,45;0,39;0,44;0,37;0,44;0,36;0,40;0,45;0,33;0,41
Bachelor level majors;0,33;0,30;0,14;0,29;0,56;0,41;0,36;0,38;0,48;0,44;0,42;0,44;0,40;0,56;0,29;0,41;0,30;0,38;0,39;0,29;0,31
PhD programs in HEI's professional field; 0,26;0,16;0,14;0,08;0,46;0,31;0,28;0,35;0,42;0,38;0,27;0,37;0,29;0,35;0,29;0,34;0,31;0,27;0,29;0,28;0,25
Doctoral-to-undergraduate and graduate students ratio;0,30;0,30;0,29;0,08;0,51;0,37;0,40;0,42;0,46;0,43;0,35;0,35;0,41;0,42;0,37;0,42;0,42;0,41;0,3
Total funds for science and research per student; 0,42;0,41;0,56;0,46;0,51;0,41;0,31;0,32;0,44;0,40;0,40;0,35;0,42;0,33;0,38;0,46;0,35;0,48;0,38;0,43;0,55;0,
PhD programs in the university;0,50;0,45;0,41;0,31;0,37;0,41;0,25;0,21;0,22;0,56;0,49;0,41;0,42;0,41;0,42;0,41;0,39;0,33;0,48;0,45;0,52
Papers with at least one citation (Scopus); 0,44;0,29;0,36;0,28;0,40;0,31;0,25;0,10;0,35;0,46;0,44;0,52;0,30;0,44;0,34;0,33;0,29;0,21;0,42;0,39;0,44
Articles in scientific journals (Scopus);0,46;0,37;0,38;0,35;0,42;0,32;0,21;0,10;0,29;0,47;0,49;0,50;0,39;0,46;0,36;0,35;0,28;0,24;0,48;0,39;0,50
Availability of information resources; 0,48;0,55;0,48;0,42;0,46;0,44;0,22;0,35;0,29;0,48;0,49;0,43;0,50;0,40;0,46;0,42;0,32;0,33;0,46;0,42;0,50
Library stock per student;0,37;0,46;0,44;0,38;0,43;0,40;0,56;0,46;0,47;0,48;0,37;0,49;0,39;0,32;0,32;0,35;0,46;0,54;0,45;0,41;0,53
Teaching floor space per student;0,33;0,39;0,42;0,27;0,35;0,35;0,49;0,44;0,49;0,49;0,37;0,41;0,23;0,35;0,42;0,17;0,48;0,46;0,41;0,57;0,44
Stock in trade (in leva per student); 0,30;0,45;0,44;0,37;0,35;0,42;0,41;0,52;0,50;0,43;0,49;0,41;0,43;0,31;0,50;0,46;0,54;0,48;0,44;0,48;0,49
Equipment (in leva per student);0,33;0,39;0,40;0,29;0,41;0,33;0,42;0,30;0,39;0,50;0,39;0,23;0,43;0,33;0,38;0,22;0,54;0,34;0,34;0,56;0,29
Rate of library stock use; 0,33;0,44;0,56;0,35;0,42;0,38;0,41;0,44;0,46;0,40;0,32;0,35;0,31;0,33;0,47;0,35;0,52;0,42;0,40;0,54;0,44
Scholarships; 0,27;0,37;0,29;0,29;0,37;0,46;0,42;0,34;0,36;0,46;0,32;0,42;0,50;0,38;0,47;0,33;0,23;0,41;0,31;0,44;0,42
Student housing; 0,35;0,44;0,41;0,34;0,42;0,35;0,41;0,33;0,35;0,42;0,35;0,17;0,46;0,22;0,35;0,33;0,41;0,36;0,34;0,58;0,42
Foreign students; 0,40;0,36;0,30;0,31;0,42;0,48;0,39;0,29;0,28;0,32;0,46;0,48;0,54;0,54;0,52;0,23;0,41;0,29;0,29;0,46;0,41
Secondary education diploma GPA; 0,45;0,40;0,38;0,27;0,42;0,38;0,33;0,21;0,24;0,33;0,54;0,46;0,48;0,34;0,42;0,41;0,36;0,29;0,23;0,53;0,30
Graduates' insurable income; 0,37;0,45;0,39;0,29;0,41;0,43;0,48;0,42;0,48;0,46;0,45;0,41;0,44;0,34;0,40;0,31;0,34;0,29;0,23;0,68;0,18
Unemployment among graduates; 0,37;0,33;0,29;0,28;0,32;0,55;0,45;0,39;0,39;0,42;0,41;0,57;0,48;0,56;0,54;0,44;0,58;0,46;0,53;0,68;0,53
Contribution to the social security system; 0,32;0,41;0,31;0,25;0,36;0,50;0,52;0,44;0,50;0,50;0,53;0,44;0,49;0,29;0,44;0,42;0,42;0,41;0,30;0,18;0,53;

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Figure 1. Text file containing the results of ICA, opened in Notepad

The starting screen of the software is presented in Figure 2. When the application is started the user has to select the language from the first button “EN”. The language can be set to Bulgarian or English.

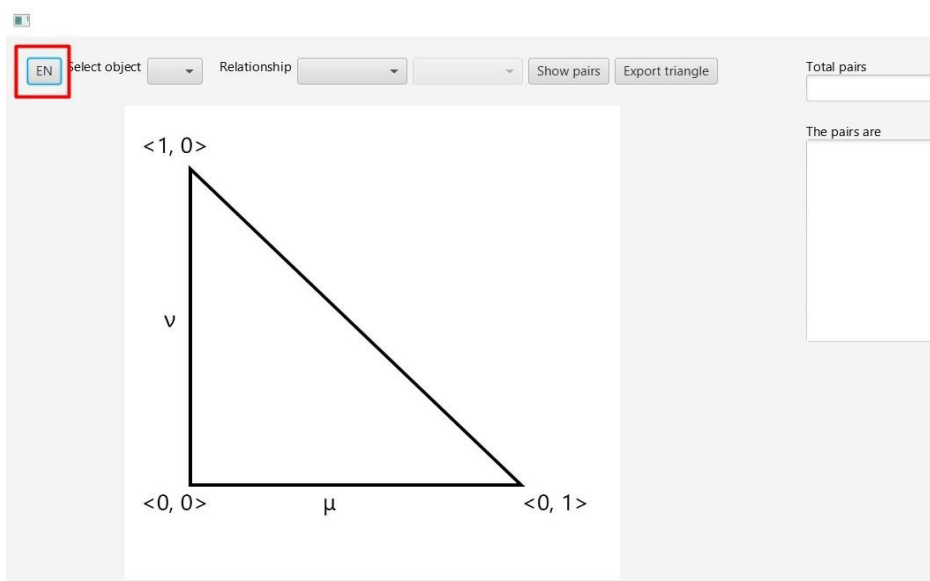


Figure 2. Set the language

The first step is to add the μ -values and the ν -values from the resulting index matrices of ICA application, containing the degrees of membership and the degrees on non-membership. The datasets are added in two controls with labels “ μ matrix” and “ ν matrix” in the upper left corner of the program’s GUI (Figure 3).

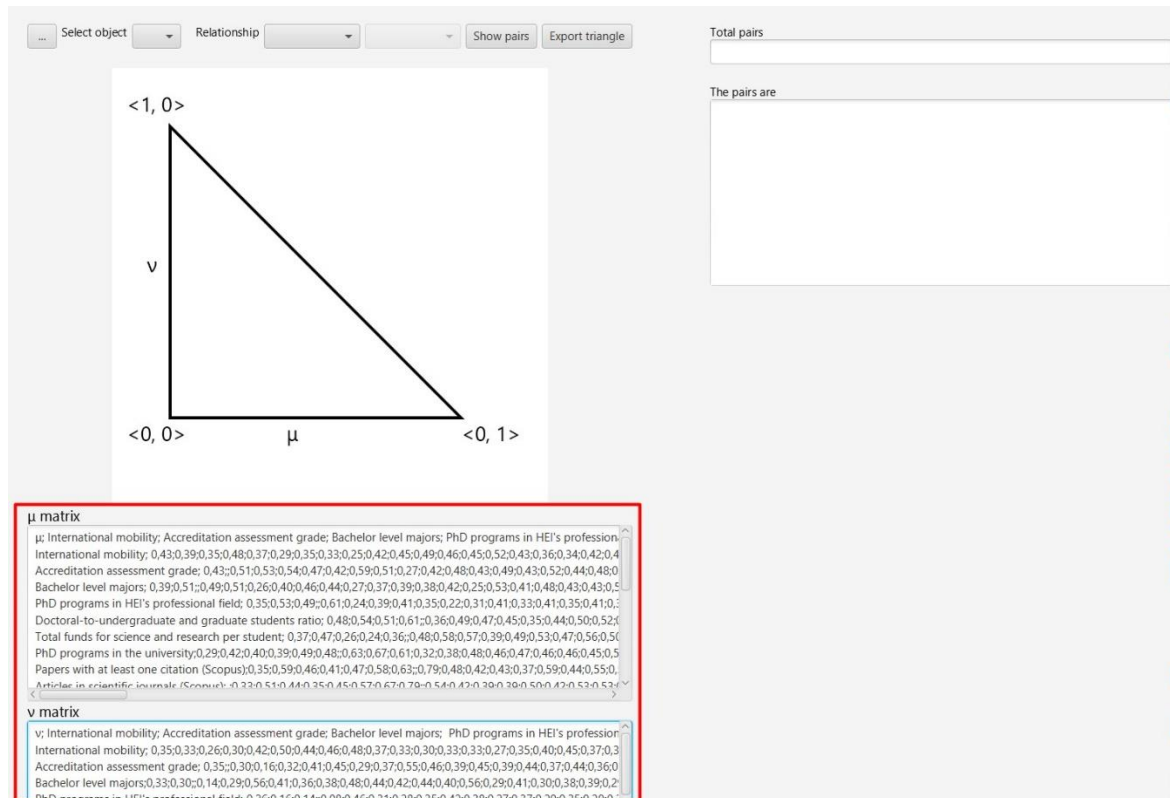


Figure 3. Loaded data: degree of membership into the μ matrix and degrees of non-membership into the ν matrix

2.1 Visualization of the results for all indicators that have all types of relationships

Thereafter the type of ICA results visualization has to be selected. In the first case the authors describe the variant of presenting results for all indicators that are assigned to all relationships intervals. The indicators of the current investigation are: international mobility; accreditation assessment grade; bachelor level majors; PhD programs in HEI's professional field; doctoral-to-undergraduate and graduate students ratio; total funds for science and research per student; PhD programs in the university; papers with at least one citation (Scopus); articles in scientific journals (Scopus); availability of information resources; library stock per student; teaching floor space per student; stock in trade (in leva per student); equipment (in leva per student); rate of library stock use; scholarships; student housing; foreign students; secondary education diploma GPA; graduates' insurable income; unemployment among graduates; contribution to the social security system.

The results of ICA are assigned to the intervals called strong positive consonance, positive consonance, weak positive consonance, weak dissonance, dissonance, strong dissonance, weak negative consonance, negative consonance, strong negative consonance. Firstly, the user has to select all indicators to include them into the results visualization in intuitionistic fuzzy triangle. This action is made by selecting option “All” from *Select Object drop-down menu* (Figure 4).

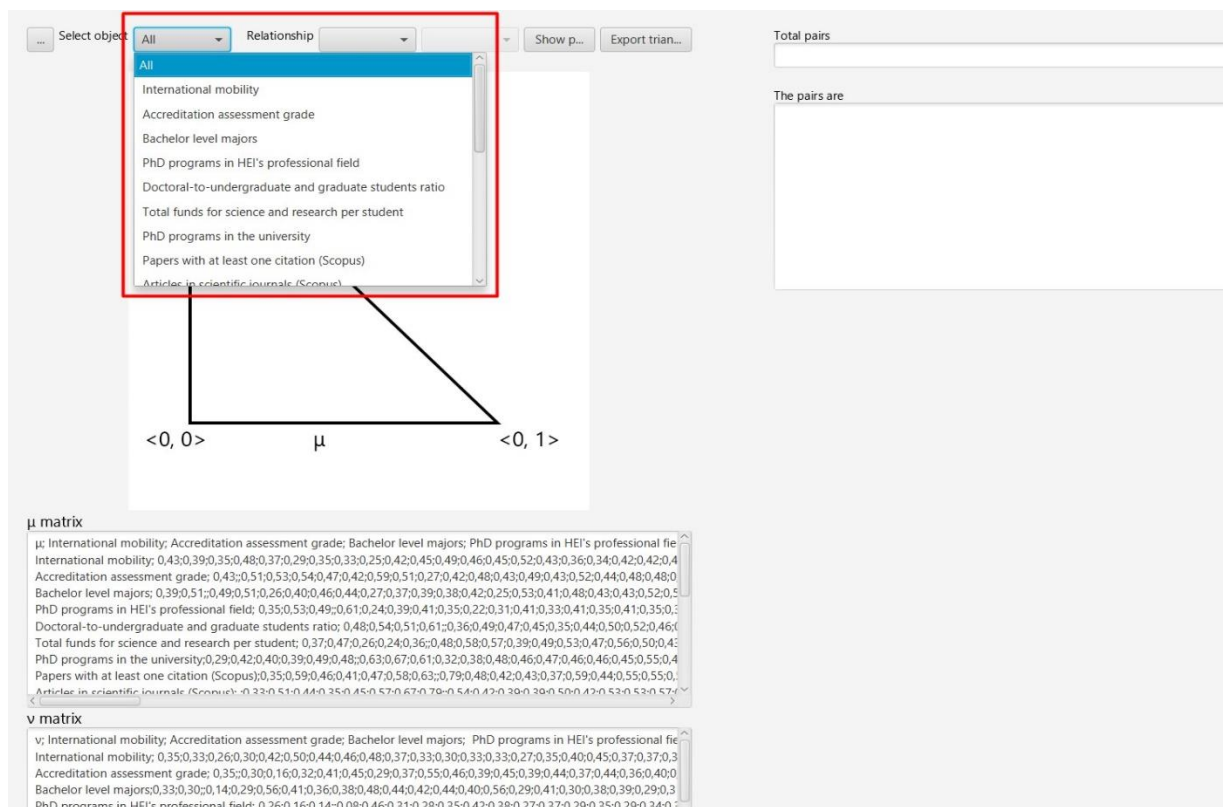


Figure 4. Choose “All” indicators to be included in the visualization

The second option that has to be chosen is the desired interval for data visualization. In this step the user has to select the type of relationships. In this example we will choose option “All” from *Relationships drop-down menu* (Figure 5).

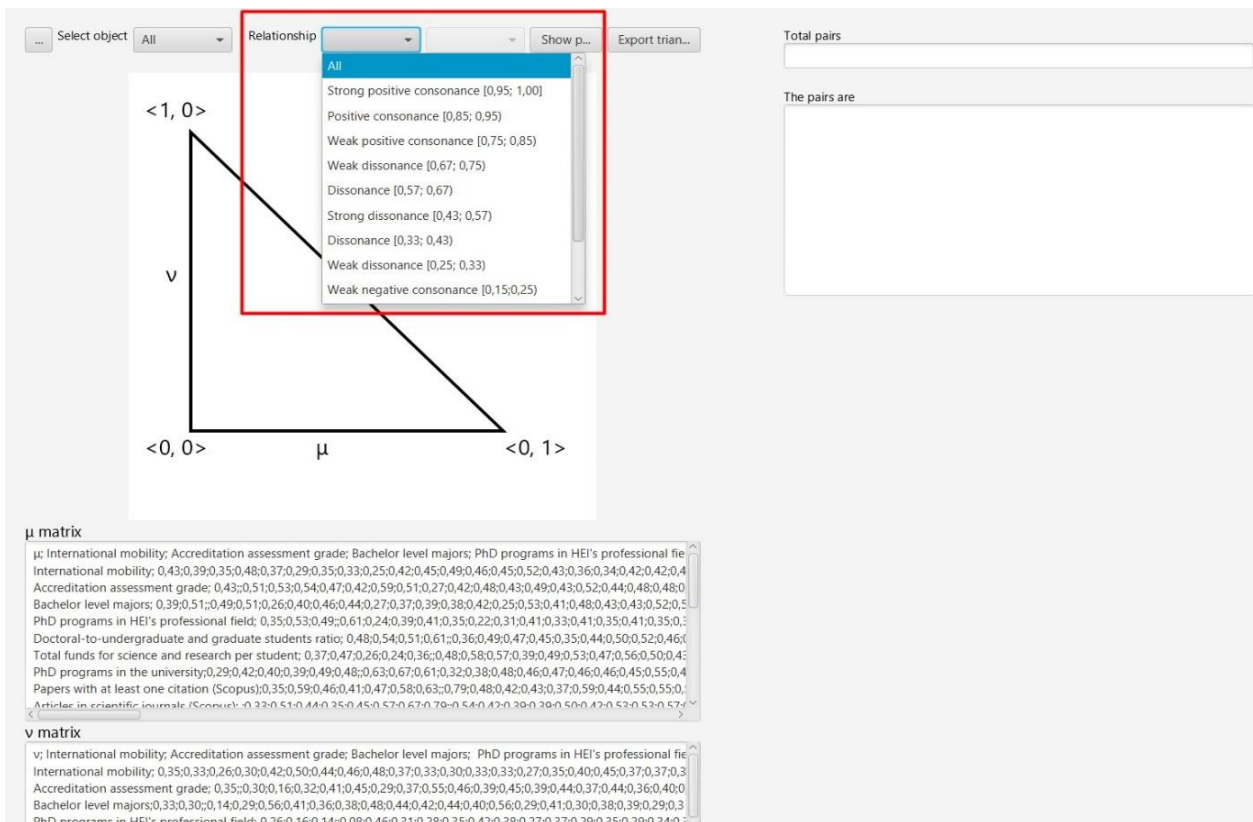


Figure 5. Choose “All” relationships to be included in the visualization

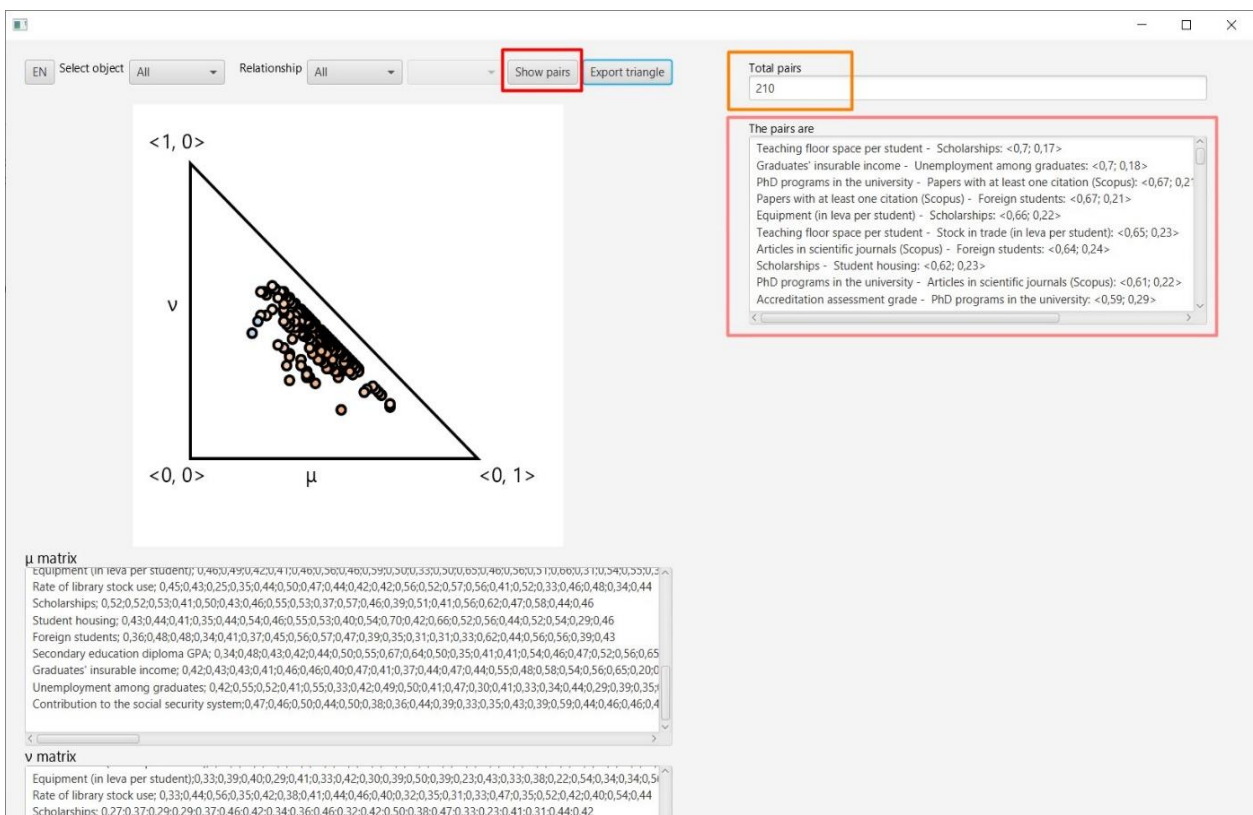


Figure 6. Visualization of all indicators that are assigned to all intervals (relationships)

In the end, the user has to start the visualization by pressing the “*Show pairs*” button (Figure 6). The intuitionistic fuzzy triangle containing the visualized data can be exported and saved using the “*Export triangle*” button (Figures 6, 7). The extension of the resultant image file is *png*.

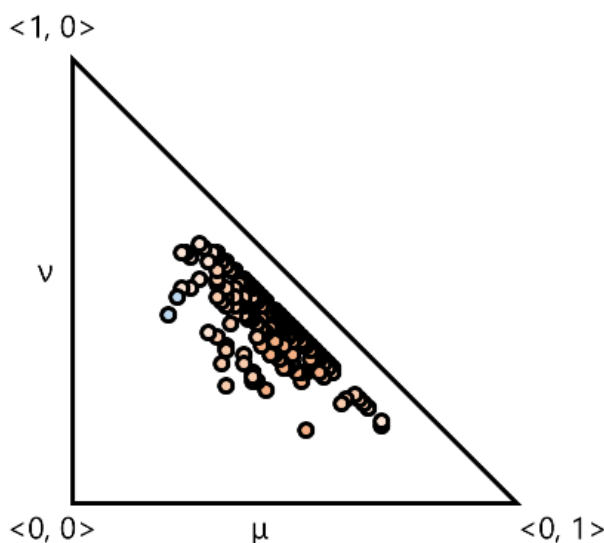


Figure 7. Exported intuitionistic fuzzy triangle

2.2 Visualization of a selected indicator assigned to all types of relationships

The functionality of selecting an indicator that is assigned to all relationships intervals is also implemented. An example of selected indicator is presented. In drop-down menu “*Select object*” the indicator “*articles in scientific journals (Scopus)*” is chosen (Figure 8).

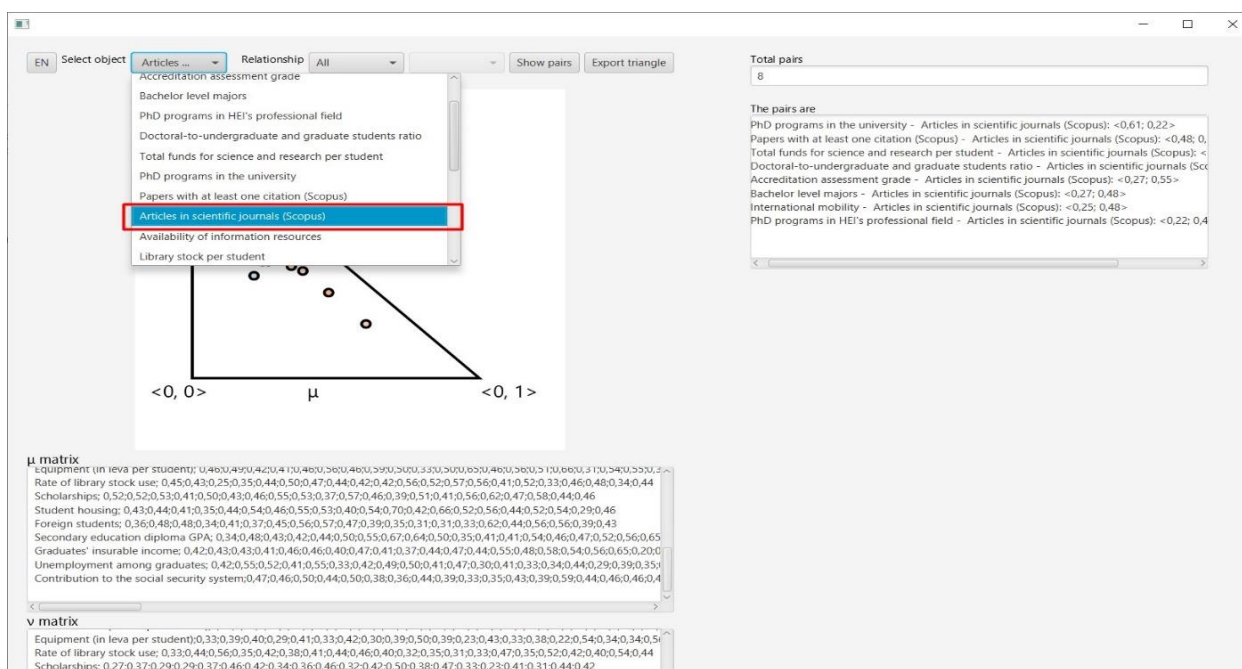


Figure 8. Selecting an indicator

The result for a selected indicator is presented in Figure 9. Points are applied one by one sequentially until all points for the indicator are displayed into the intuitionistic fuzzy triangle. Obviously, 8 pairs of indicators are found. The number is displayed in the “Total Pairs” field. The description of the pairs is presented in the “The pairs are” field.

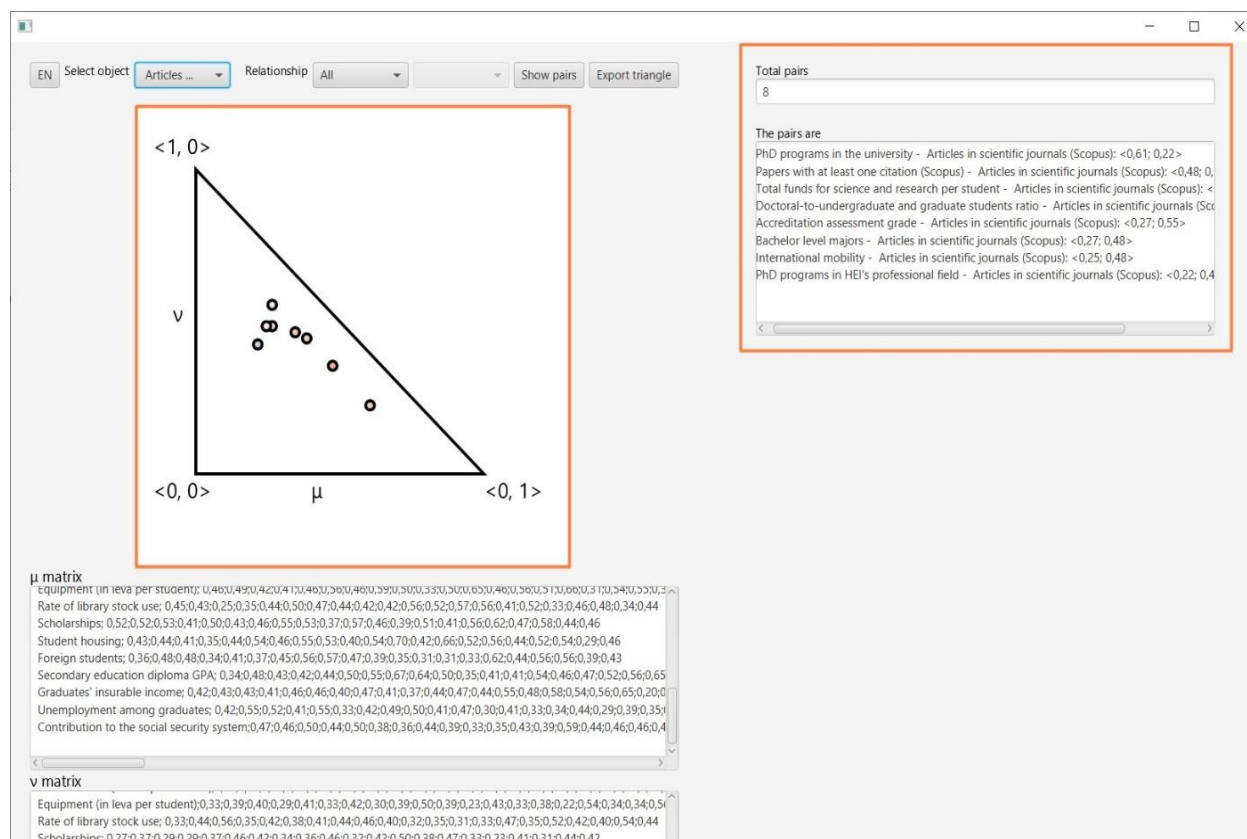


Figure 9. Results for a selected indicator

2.3 Visualization of an indicator or a set of indicators assigned to an appropriate type of relationship

In addition to the functionality of an indicator selection, the user can select in which type of relationships this indicator will be visualized. For selected indicator “articles in scientific journals (Scopus)” the user has to select an option from “Relationships” drop-down menu, for example “Weak negative consonance” (Figure 10). The indicator “articles in scientific journals (Scopus)” is included in 1 pair in weak negative consonance “PhD programs in HEI's professional field – articles in scientific journals (Scopus)”. If there are more than one pair of the indicators they will be sorted in descending order by the degree of membership and listed into the “The pairs are” field. In the same way, the user can opt to display results for all indicators whose relationships are in an appropriate interval (Figure 11). All indicators assigned in the dissonance interval are presented.

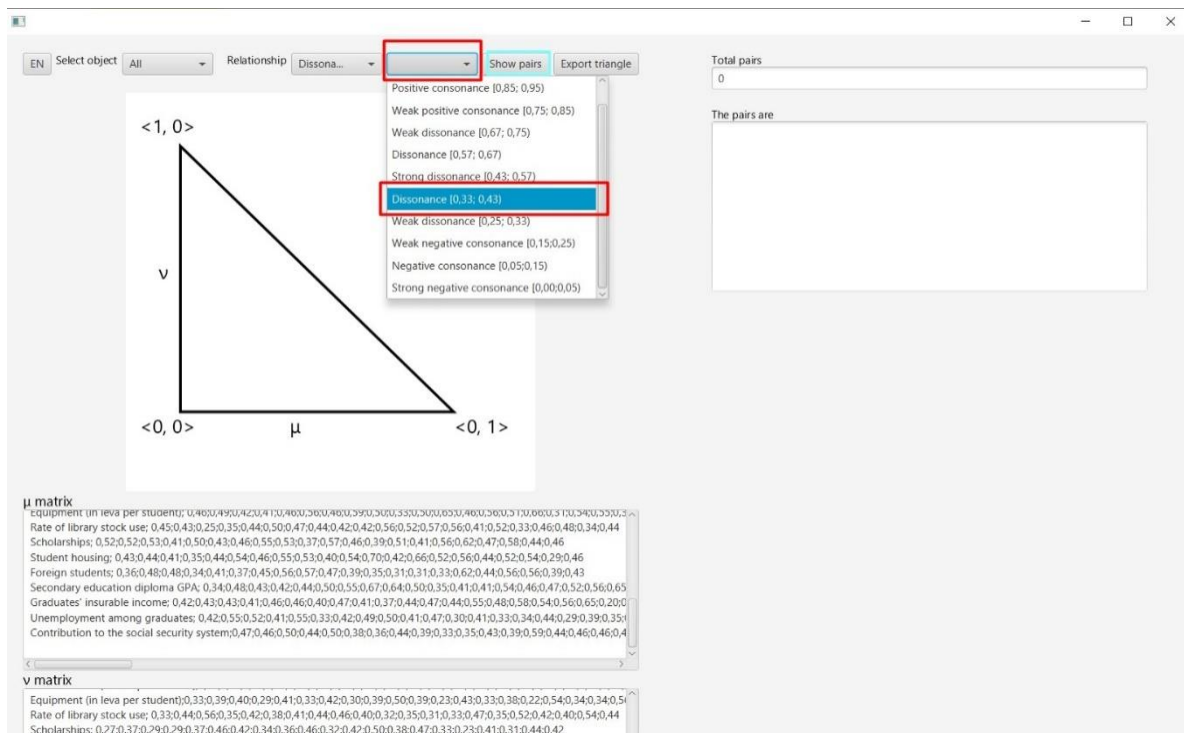


Figure 13. Selecting the indicators in dissonance [0,57; 0,67) and dissonance [0,33; 0,43)

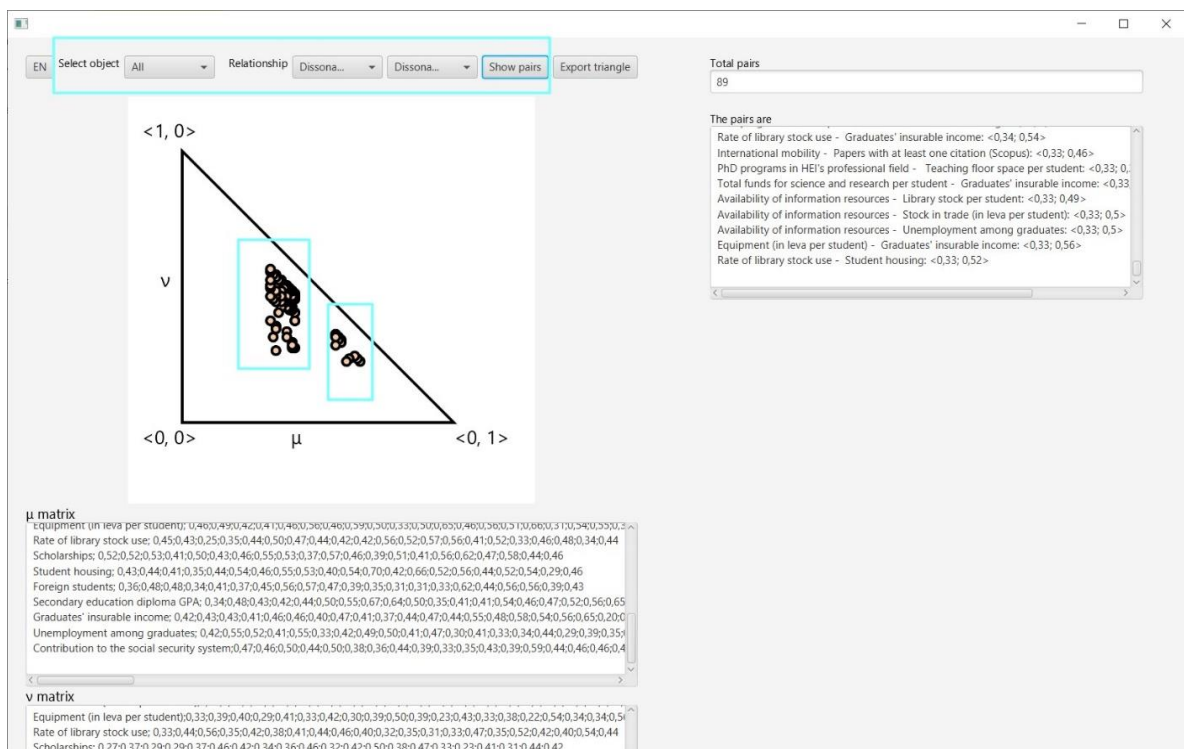


Figure 14. Indicators in dissonance [0,57; 0,67) and dissonance [0,33; 0,43)

In a similar way the user can select two different intervals of relationships. The data points for indicators are visualized one by one until all data is presented. Two groups of indicators, in dissonance and in weak negative consonance are visualized in Figure 15.

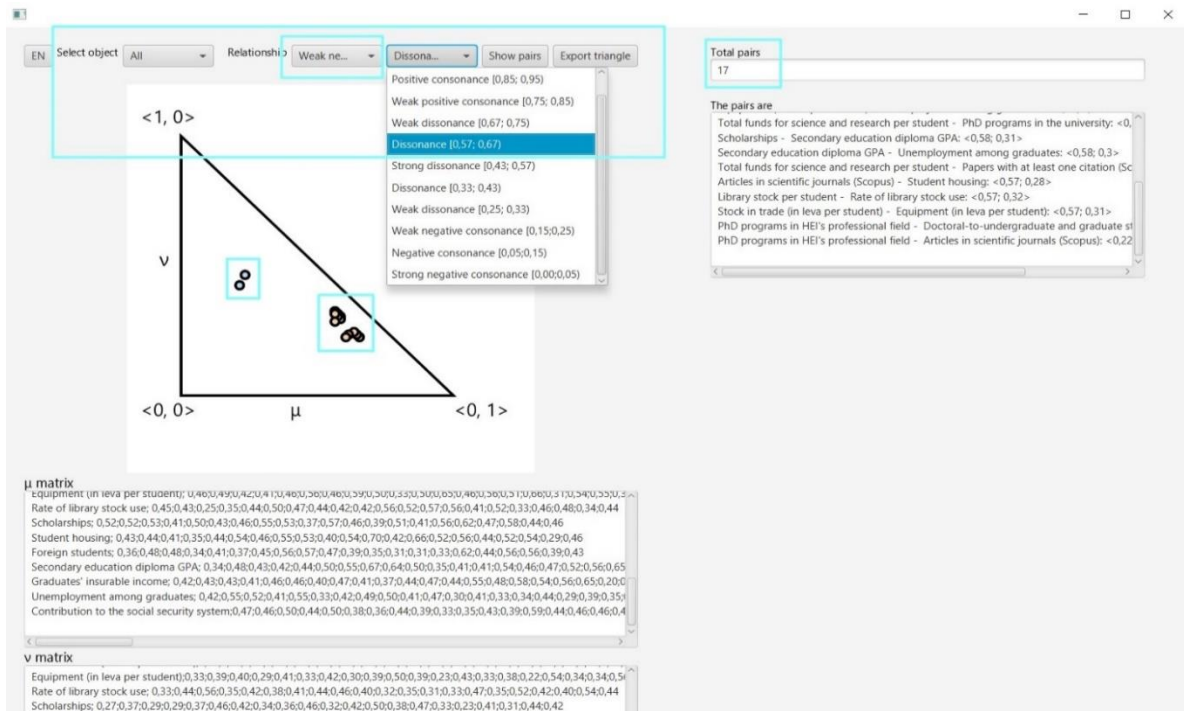


Figure 15. Indicators in dissonance and weak positive consonance

2.5 Working with the results

In the proposed program the process of working with results is implemented. Firstly, the user can clear the resulting window “The pairs are” by clicking with right button of the mouse over the white field. Then it can use the “Select All” and “Clear” options from the drop-down menu (Figure 16).

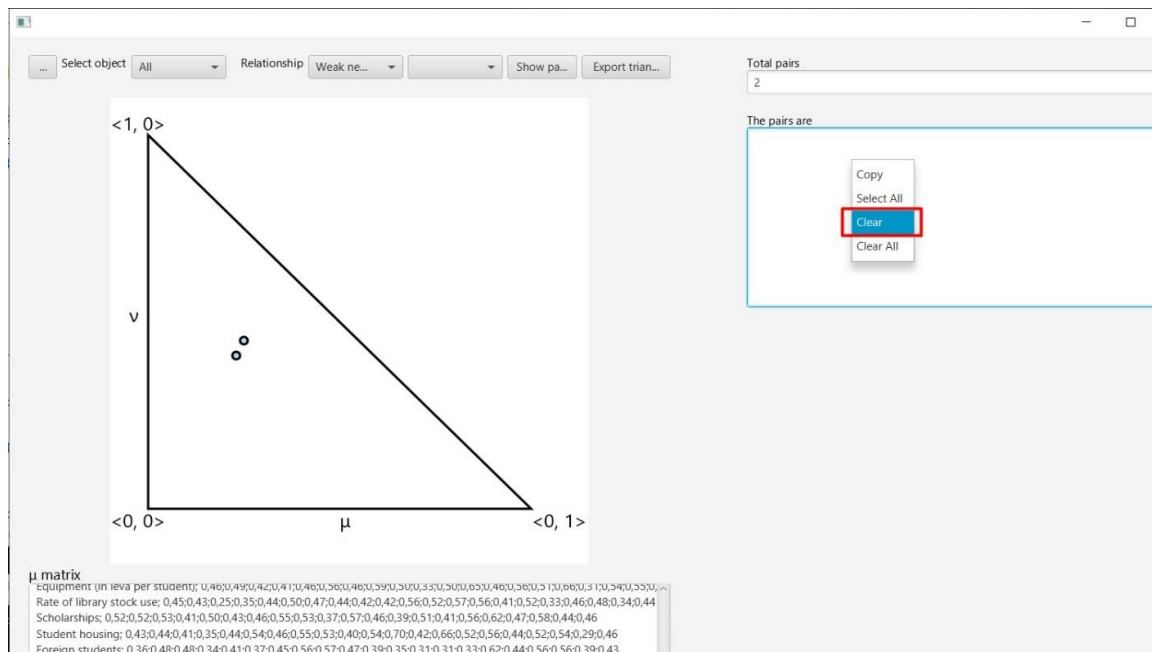


Figure 16. Clear the “The pairs are” window – select options “Select All” and “Clear” from drop-down menu

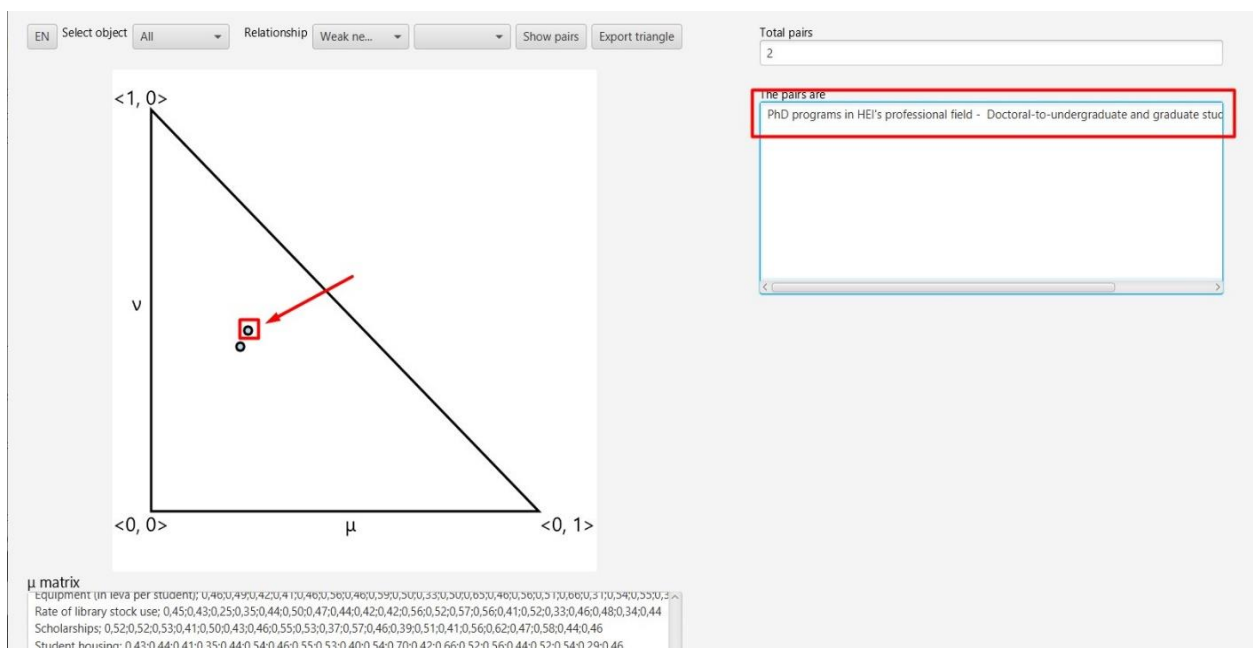


Figure 17. Visualizing the pair of indicators by selecting a data point in the IF triangle

Thereafter, depending on the selected options in “*Select object*” and “*Relationships*” menus the user can select the data point using the pointer of the mouse directly on the intuitionistic fuzzy triangle. The selected data point will appear in the “*The pairs are*” window in the form of pair of indicators (Figure 17). In similar way the user can select other data points that will be visualized in the form of pairs of indicators. The text in the window can be copied or cleaned. The working data can be cleared for other data point interpretations using the “*Clear*” option from “*Relationships*” menu and pressing “*Show pairs*” button (Figure 18).

3 Conclusion

In the current research work a program implementation providing capabilities for different types of visualizations of the ICA results into the intuitionistic fuzzy triangle is proposed. The software is build using Java and JavaFX framework. An example of program workflow is presented. The presented development allows flexible visualizations and data points interpretation according to the ICA results.

Acknowledgements

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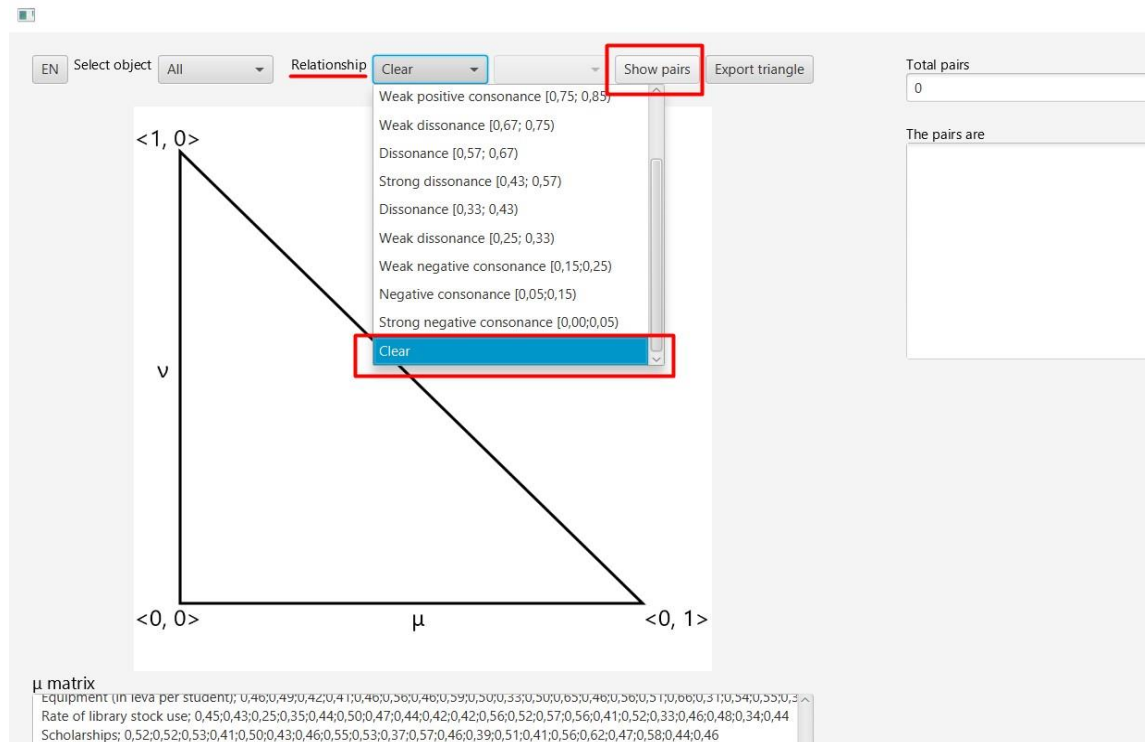


Figure 18. Clearing the working space

References

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