PALACKÝ UNIVERSITY OLOMOUC

FuzzME 2.3

User Guide

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FuzzME is a software tool for creating fuzzy models of multiple-criteria evaluation and decision-making. It can also be used for solving fuzzy classification problems. This user guide summarizes functions of the software and describes the steps of creating a model in this software.

Contents

Software description

FuzzME is a tool for creating fuzzy models of multiple-criteria evaluation and decision making. It was developed at the Faculty of Science at Palacký University Olomouc by Mgr. P. Holeček, doc. RNDr J. Talašová, CSc., RNDr. O. Pavlačka Ph.D. and Mgr. I. Bebčáková, Ph.D.

In the FuzzME software, both quantitative and qualitative criteria can be used. For the aggregation of partial evaluations, any of the following methods can be utilized:

- Fuzzy weighted average,
- Fuzzy OWA operator,
- Fuzzified WOWA operator,
- Fuzzy Choquet integral,

- Fuzzy expert system.

The software makes it possible to evaluate a set of alternatives and, subsequently, compare them according to the centers of gravity of their evaluations.

The name of the software itself is an abbreviation of "**Fuz**zy Methods of **M**ultiple **C**riteria **E**valuation". The FuzzME is available in Czech and English versions.

Apart from multiple criteria evaluation, the FuzzME can be also used to solve fuzzy classification problems. Such a problem is then described by a fuzzy rule base and it is solved by one of two available methods - Single Winner or Voting by Multiple Fuzzy Rules.

In the following text, it is expected that the user is familiar with the theoretical background and the methods that are used in FuzzME.

Installation

Hardware and software requirements

The FuzzME has the following software requirements:

- Microsoft Windows XP, or newer,
- Microsoft .NET framework 2.0, or newer.

The Microsoft .NET framework is required by FuzzME. It is pre-installed on all computers with Windows Vista, Windows 7, and Windows 8. However, it is possible that users with the older Windows XP will have to install this component manually. In this case, the .NET framework can be downloaded from the Microsoft website.

The minimal hardware requirements are as follows:

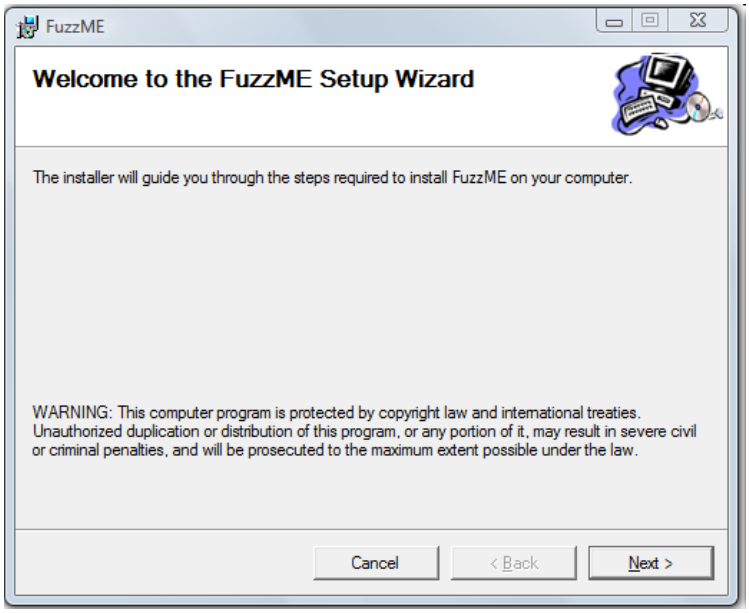
- screen resolution at least 1024 x 768 pixels,
- the other hardware requirements are the same as the hardware requirements of Windows XP.

Installation

The installation should be started automatically after the CD is inserted. If this function is disabled in the Windows, you can start the installation manually. To do that, open the CD in Windows Explorer and double-click on the file *setup.exe*.

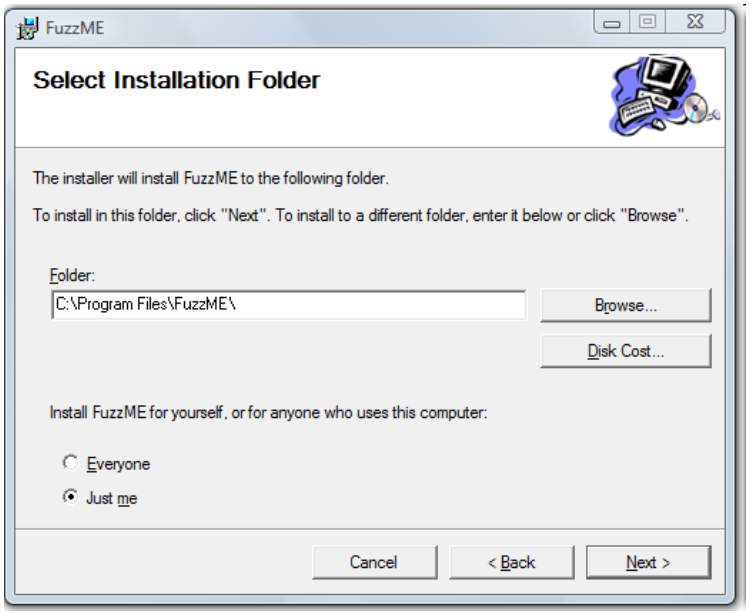
The installer first checks if the .NET framework is installed on the computer. If this component is missing, the installer will attempt to download it and install it from the web. For the installation of the .NET framework, administrator rights and internet access are required. If the installer will not be able to download the component automatically, you should download .NET framework manually from the Microsoft website, or find and install it from Windows Update service. However, the .NET framework is packed together with Windows Vista and the newer versions, so it has already been installed on most of the computers.

On the first screen, the installer displays the basic information. Continue by clicking on *Next*.



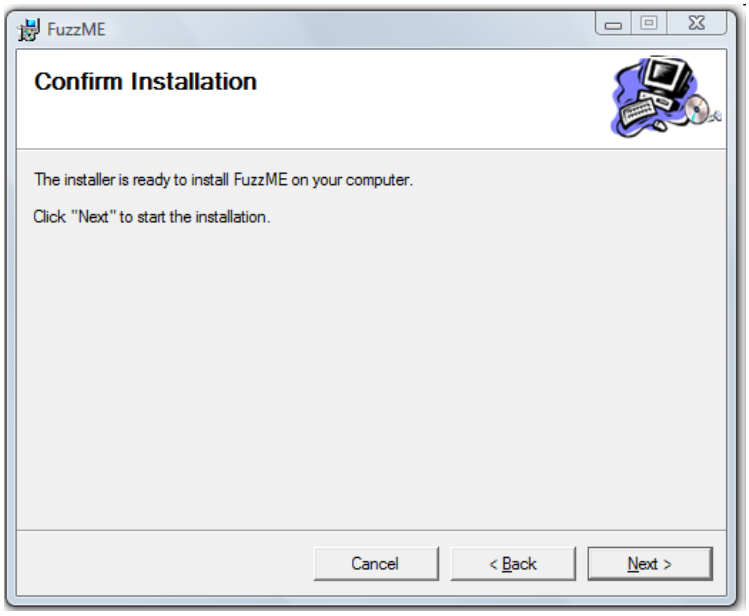
Installation – step 1

On the second screen, you can change the location where FuzzME should be installed. Proceed by clicking on *Next*.



Installation – step 2

Start the installation by clicking on *Next* button. After successful installation, you should see the FuzzME shortcut on the desktop and in the Start menu.



Installation – step 3

Note: It is also possible to use FuzzME without installing it your computer. In this case, simple double-click on the *FuzzME.exe* file in the Windows Explorer. On Windows XP, it is possible that .NET framework is missing on the computer. In this case, an error message will appear when the FuzzME is started. To solve this problem, you have to install the .NET framework first.

Note: FuzzME is developed and tested on the Windows operating system. To use FuzzME on Linux, you have to install .NET framework for Linux by Project Mono. Since the FuzzME is developed for Windows, it cannot be guaranteed that all function will work properly on Linux.

Uninstallation

If the software was installed properly, it can be uninstalled from the Windows in the following way:

1. Click on *Start*, *Control Panel*, and then double-click on *Add or Remove Programs* (the name differs depending on the operation system version).
2. Select FuzzME from the list.
3. Click on Remove.

Note: It is also possible to use FuzzME without installing it on the computer. In this case, simply delete the program folder to remove the software.

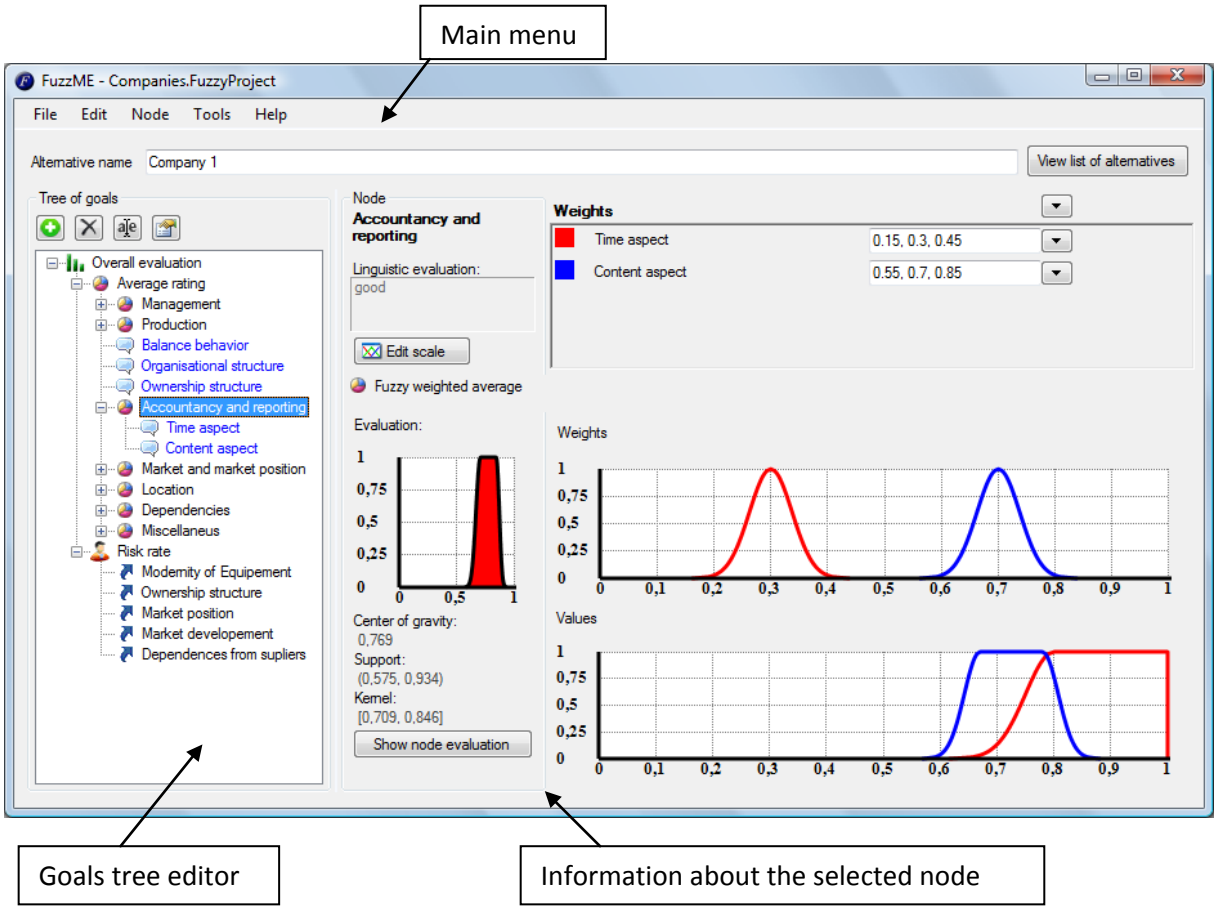
Launching the FuzzME

After the installation, the FuzzME can be launched by double-clicking on its icon on the desktop or in the Start menu. FuzzME can be also launched by double-clicking on the file *FuzzME.exe* in Windows Explorer.

Main window

Main window

The main window of the program is divided into several parts.



On the left side of the window, there is a goals tree editor. In this editor, the structure of the goals tree is displayed and can be modified. The user can select a node of the tree by clicking on it.

On the right side of the windows, the information about the selected node is displayed. The user can see the node name, evaluation of the partial goal corresponding to the node, and other node parameters. The parameters differ according to the type of the selected node.

The top part of the main window is occupied by the main menu and the name of the selected alternative.

Main menu

The main menu contains the following items.

File

- **New** – It creates a new empty project.
- **Open** – It opens a project.
- **Save** – The edited project is saved into a file.
- **Save As** –The edited project is saved into a file under the name selected by the user.

- **Recent Projects** – Contains the list of recently opened projects. They can be opened again by clicking on them.
- **Import** – This item shows a dialogue for import of the alternatives and their criteria values into FuzzME.
- **Export** – This menu item contains dialogues for export of the data from a FuzzME project. It makes it possible to export alternatives (their names together with their criteria values) or the final evaluations of the alternatives. If a fuzzy expert system node is selected then there is a possibility to export the fuzzy rule base into format used by Matlab.
- **Exit** –The program is closed by clicking on this item.

Edit

- **Cut Node** –The selected node is copied into the clipboard and then removed from the goals tree.
- **Copy Node** – The selected node is copied into the clipboard so that it could be pasted later into another node of the tree, or into a different project.
- **Paste Node** – A node is pasted from the clipboard. It will be pasted as a child node of the selected node.

Note: When the list of alternatives is opened, the Edit menu contains items for clipboard operations with the alternatives instead. The names and meaning of these items are similar and therefore will not be mentioned here.

Node

This menu is displayed only when the goals tree is visible.

- **Add Subnode** – A new node will be created (as a child node of the selected node).
- **Delete** –The selected node will be deleted.
- **Rename** – It makes it possible to change the name of the node. The user can type a new name. The editing is ended by pressing *Enter* or canceled by pressing *Esc*.
- **Change type** – It makes it possible to change the type of the node. A dialog with all supported node types is displayed to the user.
- **Other node operations** – This menu contains some less frequently used operations. They are described in the sections Goals Tree Editor and Link to another criterion.
- **Edit Linguistic Scale** – It displays the linguistic scale editor. The user can create a new scale for the selected node or edit the existing one.
- **Scale Type** – In this menu, user can choose one of the linguistic scale types. This choice will be used to obtain the linguistic description for the evaluation of the node.
- **Weights** – The menu contains items specific for nodes that require weights as a parameter. The items of this menu allow saving the weights into a file, and vice versa, loading them from a file. There are also items for creating the weights.
- **FNV-fuzzy measure** – The menu is specific for the fuzzy Choquet integral node. See Choquet integral for more information.
- **Rule Base** – The menu is specific for the fuzzy expert system node. See Fuzzy expert system for more information.
- **Show Node Evaluation** – It opens a window with details on the evaluation of the selected node.

- **Compare inputs and result** – It opens a window where all input values and the output value of the selected node are displayed.
- **Compare results for various inputs** – For the selected node, it allows to visualize the changes of its evaluation depending on various input values.

Alternative

This menu is displayed only when the alternative list is visible.

- **Add** – A new alternative is created.
- **Edit** – The selected alternative is edited.
- **Delete** – The selected alternative is deleted.
- **Delete All** – All alternatives in the project are deleted.
- **Show Alternative Evaluation** – It opens a window with details on the evaluation of the selected alternative.
- **Recompute All Evaluations** – It clears all caches for evaluations and it performs the evaluation of all the alternatives in the project again.
- **Find** – The function can be used to find an alternative by its name.
- **Sort by Name** – The alternatives list will be ordered by the alternative names.
- **Sort by Evaluation** – The alternatives list will be ordered by the alternative evaluation (according to the centers of gravity).

Tools

- **Mode** – This item switches between the goals tree view and the alternative list view. It can be also accomplished by pressing *F7* key.
- **Project Statistics** – It opens a window with basic information about the opened project (e.g. the number of nodes and the number of alternatives).
- **Options** – It opens a window with the program settings.

Help

- **User Guide** – It opens this user guide.
- **Mathematical Methods used in FuzzME** – It opens a paper with some basic information on the mathematical model and methods used in FuzzME.
- **About** – It shows a window with basic information about the FuzzME (e.g. current version number).

How to create a model in FuzzME

A model in FuzzME is described by a goals tree. The tree has to be designed and all required parameters for the nodes have to be set.

Steps of creating the model

A model is created in the following steps:

1. **Designing the structure of the goals tree** – First, the expert defines the structure of the goals tree. All the nodes are created and named properly.

2. **Designing the linguistic scales for tree nodes** – A linguistic scale is required for qualitative criteria and for the fuzzy expert system. This step is not mandatory for other node types, however, it is highly recommended.
3. **Defining type of each node in the goals tree** – The expert determines the type of each node in the goals tree. The nodes at the end of the branches are criteria. The expert chooses if the criterion is qualitative or quantitative (or alternatively a link to another criterion can be defined). The rest of the nodes are aggregating nodes. The expert has to choose the aggregation method that will be used.
4. **Setting parameters of the node** – Finally the expert sets parameters for each node. The parameters depend on the node type, which was chosen in the previous step. For example, normalized fuzzy weights have to be set for fuzzy weighted average.

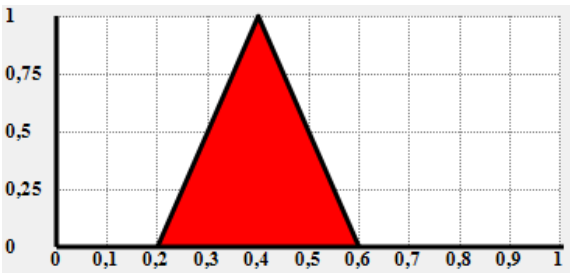
When those steps are performed, the model is created. The expert can proceed to evaluation of the alternatives. This process is done by the following steps:

1. **Adding or importing the alternatives** – The alternatives can be added either manually or they can be imported, e.g., from Excel.
2. **Evaluation of the alternatives** – When a new alternative is added, its evaluation is calculated automatically. The expert can have the alternatives ordered according their evaluations.
3. **Export of the results** – It is possible to export the evaluation results, e.g. into Excel, for their further analyze, or for their presentation.

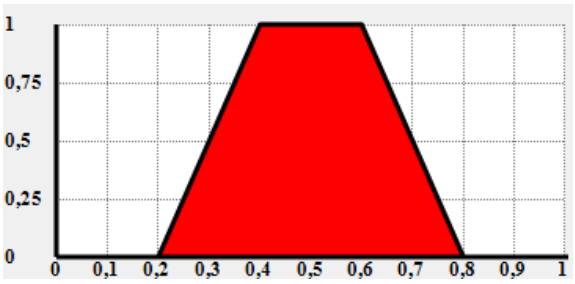
Using fuzzy numbers in FuzzME

Different mathematical software products use different notations for fuzzy numbers. For example in Matlab, a space is used to separate the significant points of fuzzy numbers. The fuzzy numbers in FuzzME are written by the user as a **list of the significant points separated by comas**. This notation is used in the whole software. There is always possibility to use a real number or an interval, as they are the special cases of fuzzy numbers. The notation should be clearer from the following examples.

Notation	Meaning
0.8	A real number 0.8.
0.2, 0.4	An interval 0.2 to 0.4.
0.2, 0.4, 0.6	A triangular fuzzy number
0.2, 0.4, 0.5, 0.6	A trapezoidal fuzzy number, whose support is (0.2, 0.6) and whose kernel is [0.4, 0.5].



A triangular fuzzy number.

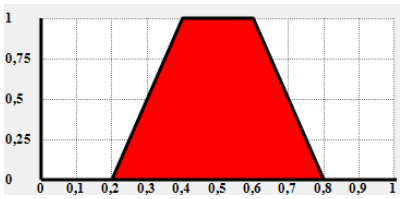


A trapezoidal fuzzy number.

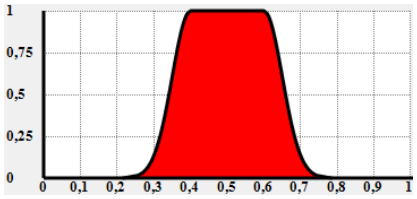
Note: Because the numbers are the significant values, they are always in ascending order. Otherwise, the fuzzy number is not valid and a warning can appear. An example of such an invalid notation of fuzzy number can be “0.1, 0.3, 0.2”.

Input box for fuzzy numbers

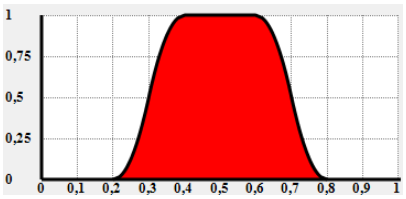
There are several membership functions that can be used. The membership function type can be chosen from the drop-down box on the right-hand side. The chosen type influences the shape of the membership function. The different membership function types can be seen in the following figures.



Linar fuzzy number.



Gaussian fuzzy number.



Quadratic fuzzy number.

Note: The FuzzME works with piecewise linear fuzzy numbers. They are used to approximate more complex fuzzy numbers (e.g. Gaussian or Quadratic). The preciseness of this approximation (and other calculations with fuzzy numbers) depends on the number of used α-cuts, which can be set in *Options*.

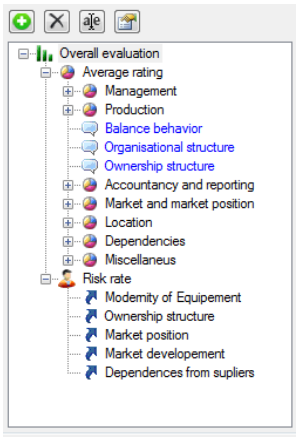
Note: The user can set which character should be used to separate significant points in the *Options*. It is possible to use either a comma (default), or a space (as in the Matlab).

A fuzzy number can be also edited in the Fuzzy number editor in FuzzME. This can be done by clicking with the right mouse button on an input box for fuzzy numbers and selecting *Show in Fuzzy Number Editor*. Now you can edit the individual significant points and see the characteristics of the edited fuzzy number (e.g. center of gravity, uncertainty, etc.). You can also choose the number of α-cuts that will be displayed (from the menu *View*). Another interesting feature is creating the fuzzy number by drawing it by mouse. This can be done by choosing *Edit | Design the Fuzzy Number by Drawing* from the main menu. Then press the left mouse button and start drawing the fuzzy number into the graph. The FuzzME checks the condition common for all fuzzy numbers, so the left part of its membership function has to be non-decreasing and its right-part has to be non-increasing. Release the mouse button when you have finished the drawing. The original fuzzy number will be replaced with the drawn one.

Designing the goals tree

Creating the structure of the goals tree

The structure of the goals tree is displayed on the left side of the main window. In this step, the structure is designed and the names are given to the nodes.



The user can do the following operation:

- **Select node** – The node is selected simply by clicking on it. In the right-hand part of the main windows, the node details are displayed.
- **Add node** – When a new node should be added, the user select one of the nodes in the goals tree first. The new node will be a child node of the selected one. Then, the user can either click on the corresponding icon, or choose *Node | Add subnode* from the main menu. After that, it is possible to type name of the node. The editing of the node name is ended by pressing *Enter*.

  Note: It is not possible to add a child node to a criterion since the criteria should always be the terminal nodes.

  Note: Initially, the new nodes have undefined type (which is signalized by a red question mark icon). The type can be selected in the right-hand part of the main windows. The type can be also changed later.
- **Delete node** – The user can delete a node by selecting it and clicking on the corresponding icon or choosing *Node | Delete* from the main menu. If the node has any child nodes, they will be deleted, too.
- **Rename node** – To rename a node, the user selects it and then clicks on the corresponding icon or chooses *Node | Rename* from the main menu (or presses *F2* key). The new name can be typed and subsequently confirmed by pressing *Enter*.
- **Moving the node** – The node can by copied or moved to another place in the goals tree. This can be performed by standard drag & drop technique (i.e. left mouse button is held, the mouse pointer is moved to the new location and then the mouse button is released). The node can be also copied through clipboard. The user selects the node of interest, chooses *Edit | Copy node* from the menu, selects place, where the node should be copied and, finally, chooses *Edit | Paste node* from the menu.

- **Choosing another node type for the node** – The type of each node can be changed any time. To do that, user selects the node and then clicks on the corresponding icon or chooses *Node | Change type* from the main menu.
- **Making a node to be a root of the goals tree** – Sometimes the expert needs to choose another node to be the root of the goals tree. This can be accomplished by selecting the node and choosing *Node | Other Node Operations | Make Selected Node to Be Root* from the main menu. This function can be also handy, when the expert wants to extend the goals tree and add a node above the current root node. In this case a new node is added anywhere and then selected as the new root of the tree.

Designing a linguistic scale for the nodes

Linguistic scales and linguistic approximation in FuzzME

Linguistic scales are used for the linguistic approximation in FuzzME. The scale has to be defined for all qualitative criteria (since they are evaluated verbally). It also has to be defined for fuzzy expert system and its child nodes (the fuzzy rule base used in the fuzzy expert system is defined verbally). For the other nodes, it is not necessary to define such a scale, however it is highly recommended. If the scale is defined, the user can see also the linguistic evaluation of the node.

On the right-hand side of the window, just under the node name, the linguistic evaluation of this node is displayed. Under this evaluation, there is an *Edit scale* button, which opens the Linguistic Scale Editor and makes it possible to create or edit the linguistic scale for the selected node.

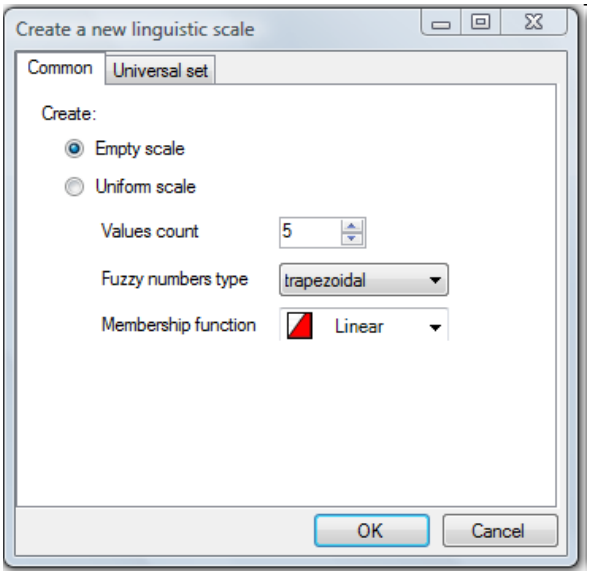
After the scale is defined, the user can set the mode of the linguistic approximation for the given node. The mode can be selected in the *Node | Scale Type* menu. There are three possibilities:

1. **Simple** – Only terms from the scale will be used.
2. **Extended** – The scale is extended by terms in form “A to B”, where A and B are the elementary terms from the original scale.
3. **Scale with Intermediate Values** - The scale is extended by terms in form “between A and B”, where A and B are the elementary terms from the original scale.

Linguistic Scale Editor

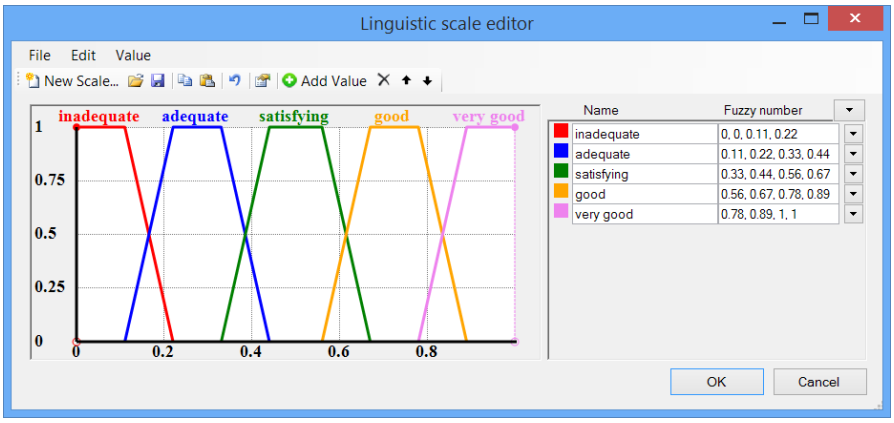
The linguistic scale for the selected node can be edited in the Linguistic Scale Editor. The editor can be opened by clicking on *Edit scale* button or by choosing *Node | Edit Linguistic Scale* from the main menu.

If the scale has not been created yet, a dialog for creating a new scale appears. The user can create a uniform scale with a minimal effort. It is necessary to fill in just the number of scale items. The user can also select the required shape of the fuzzy numbers which model the scale items. The dialog is then confirmed by clicking on *OK*.



Note: The scale is defined on the interval 0 to 1 by default. For more advanced users, there is a possibility to change this universe. On the *Universe* tab in the previous dialog, they can modify the minimal value, the maximal value and the scale type.

After the scale is created, the main window of the Linguistic Scale Editor appears.



On the left side of the window there is a graphical representation of the scale items. On the right side, there is a list of the scale items – their names and fuzzy numbers, which model them. When a new scale is created, its items are named “a”, “b”, “c”, etc. by default. The user should edit this texts and give them proper names (e.g. “inadequate”, “average”, “good”, etc.).

The user can perform the following operation with the linguistic fuzzy scale and its items. All of them are accessible through the main menu:

- **Create a new scale** – A new scale for the selected node is created. This can be done from the main menu by selecting *File | New scale*.
- **Open the scale from a file** – The scale for the selected node is imported (loaded) from a file. This can be done from the main menu by selecting *File | Open*.

- **Save the scale into a file** – The edited scale is exported (saved) into a file by clicking on *File | Save*.
  Note: This option can be handy if you want to use the same (or very similar) linguistic scale for multiple nodes of the goals tree. You just have to design the scale once and save it to a file. Then, open the Linguistic Scale Editor for the other nodes and load this scale.
  Note: This function serves for exporting the fuzzy scale, not saving the changes made in the edited fuzzy scale. The changes for the currently edited scales are saved simply by clicking on the *OK* button of the Linguistic Scale Editor.
- **Edit scale universal set** – This function opens a dialog for setting the scale universal set (which is the interval 0 to 1 by default). All the values of the scale will be recalculated so that they would fit the new universal set.
- **Undo** – This function undo the last modification of the scale made by the user (it returns one step back)
- **Copy scale into the clipboard** – The edited scale is copied into the clipboard (*Edit | Copy scale*). This makes it possible to use the same scale for different nodes without saving it into a file.
- **Paste scale from the clipboard** – The fuzzy scale is pasted from the clipboard (*Edit | Paste scale*).
- **Add a new value to the scale** – A new value is added to the linguistic scale (*Value | Add value*, or the corresponding button on the toolbar). The value appears in the list on the right-hand side of the window. The user has to fill the name of the value and the fuzzy number that models the value.
- **Delete the value** – The selected (edited) value of the linguistic scale is deleted (*Value | Delete value).*
- **Move the value up or down in the list** – The value is moved one position up or down in the list (*Value | Move up*, or *Value | Move down).*

The editor can be closed and the changes are confirmed by clicking on OK. By clicking on Cancel, the editor is closed and the changes are not saved. If one of the fuzzy numbers is not set by the user properly, a warning appears. See Using fuzzy numbers in FuzzME for more information on the correct notation of the fuzzy numbers in FuzzME.

Specifying the criteria

Setting type of a criterion

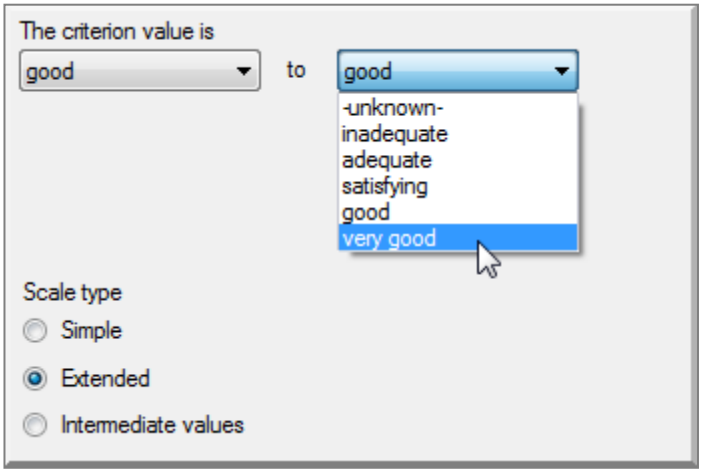
After the structure of the goals tree is designed and the linguistic fuzzy scales are defined, the user can set the type for all the criteria. The criteria are at the ends of the goals tree branches. There are two possible types – qualitative and quantitative criteria. Besides that, the user can also create a link to another already defined criterion.

First, select the node in the goals tree. If the type of the node was not chosen yet, a dialog with the supported types appears in the right-hand part of the main windows. Choose qualitative criterion, quantitative criterion or link to another node by clicking on the corresponding button in the dialog. The type of the criterion can be changed in the future.

Then, set the parameters specific for the selected criterion type.

Qualitative criterion

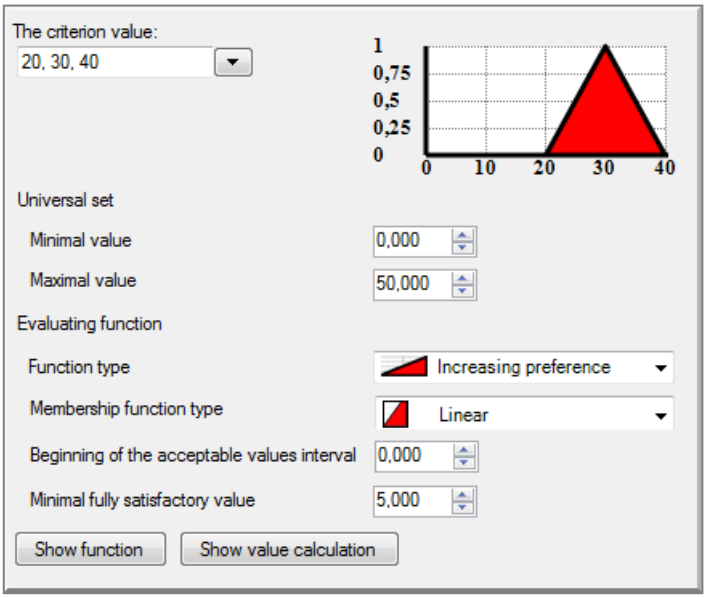
According to qualitative criteria, the alternatives are evaluated verbally. The expert chooses the best fitting term from the linguistic scale. Make sure that the linguistic scale was defined for the qualitative criterion.



The dialog for a qualitative criterion contains drop-down box (or boxes) where the value of the criterion for the selected alternative is chosen. Underneath them, the user can set the type of the used scale – simple, extended, or a scale with intermediate values. For more details, see Linguistic fuzzy scales and linguistic approximation in FuzzME.

Quantitative criterion

For a quantitative criterion, its evaluating function has to be defined.



The dialog contains the following items:

- **Criteria value** – The value of the criterion for the selected alternative. The value can be fuzzy or it can be a real number.
- **Universal set** – The universal set for the selected criterion, which determines the minimal and the maximal possible values of this criterion.
- **Evaluating function** – To define the evaluating function, the user chooses the type of the function first. The type can be
    - **Increasing preference** - The greater values of the criterion, the better.
    - **Decreasing preference** - The lower values of the criterion, the better.
    - **Preference of selected values** – The user can specify a value (or interval of values) which are fully satisfactory and the values which are not satisfactory at all.
    - **Other** – The shape of the function is set manually (in form of a fuzzy number). For advanced users only.

  Next, the user sets the parameters which differ according to the selected type of the evaluating function (for example "Minimal fully satisfactory value of the criterion"). The user can also choose type of the evaluating function (Linear, Gauss and Quadratic).

There are two buttons at the bottom of the dialog

- **Show function** – The graph of the evaluating function is displayed.
- **Show value calculation** – The graphical representation of the criteria evaluation calculation is displayed. The image depicts the calculation of the value according to the extension principle.

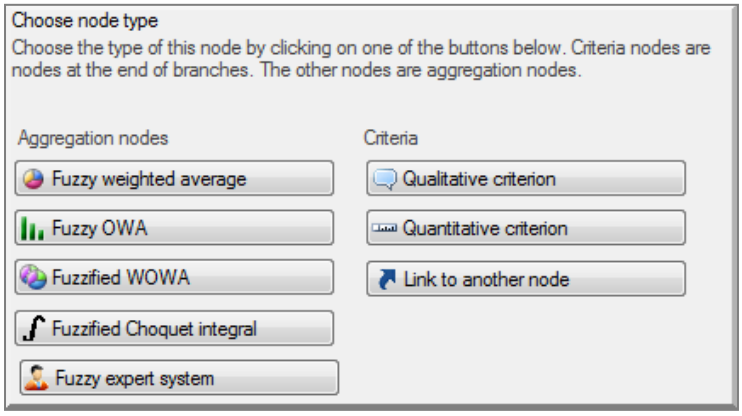
Link to another criterion

On some rare occasions, it is necessary to use one criterion multiple times in the same goals tree. In this case, the criterion is defined just once and then a link to this criterion is used. The user selects the linked criterion from the drop-down list. The node will always have the same evaluation as the linked criterion.

The aggregation nodes

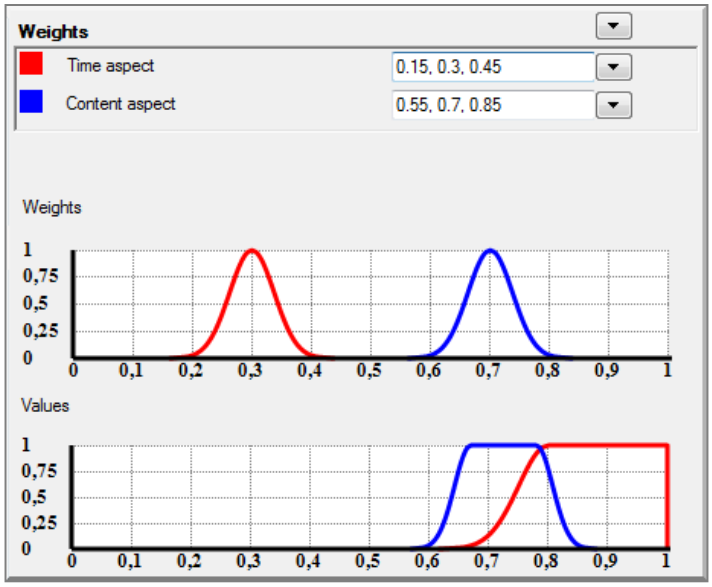
Setting type of an aggregation node

Setting the type of an aggregation node is done in the same way as setting the type of a criterion. First, select the node in the goals tree. If the type of the node was not chosen yet, a dialog with the list of supported types appears in the right-hand part of the main windows. The user chooses the appropriate node type by clicking on the corresponding button in the dialog. The supported aggregation types are: fuzzy weighted average, fuzzy OWA operator, fuzzified WOWA operator, fuzzy Choquet integral and fuzzy expert system. The type of any node can be changed in the future.



Fuzzy weighted average

For fuzzy weighted average, the normalized fuzzy weights have to be set. Each weight is expressed by a fuzzy number (a real number as a special case of a fuzzy number can be also used).



The FuzzME checks all the conditions that the fuzzy weights have to satisfy. If they do not do that, one of the following warnings appears:

- **Weights are not set** – This warning is displayed when the node has just been created and the weights have not been set yet.
- **The weights are not correct** – One or more of the weights are not correct fuzzy numbers. Check if they are written in the correct format. See Using fuzzy numbers in FuzzME for more information.
- **The weights are not normalizable** – The given estimations of the fuzzy weights cannot be used to derive normalized fuzzy weights. They are not on the interval [0, 1] or their kernels do not satisfy the condition for normalization (it must be possible to select a real normalized weights within the kernels of the fuzzy weights).

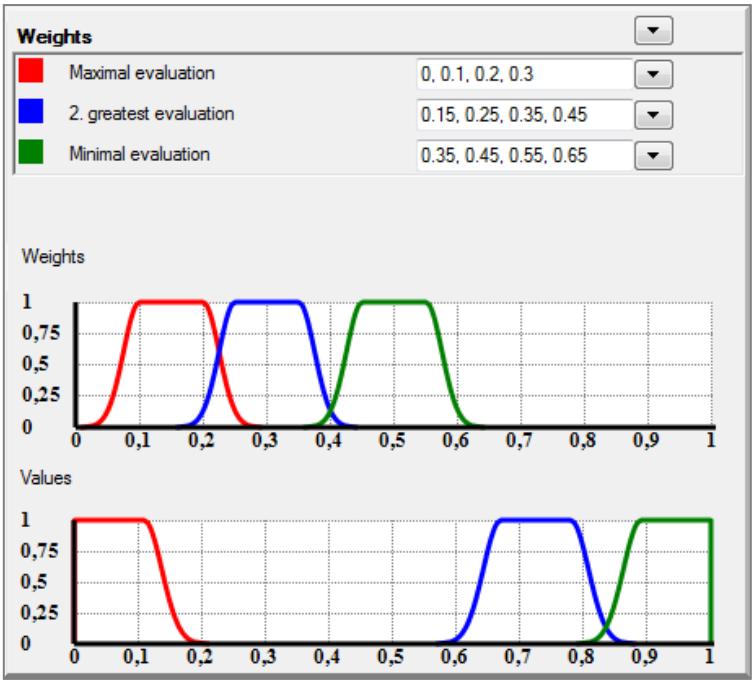
- **The weights are not normalized** – The given estimations of the fuzzy weights were set correctly, but they do not form normalized fuzzy weights, yet. To derive normalized fuzzy weights from these estimations, click on the *Derive normalized fuzzy weights* button.

The weights and the input values for the fuzzy weighted average are depicted at the bottom of the dialog. The following operations can be done with the normalized fuzzy weights:

- **Load weights from a file** – The weights can be loaded from a file by selecting *Node | Weights | Open* from the main menu.
- **Save weights into a file** – The weights can be saved into a file so that they could be used for another node or in a different goals tree (*Node | Weights |Save as)*.
- **Create uniform weights** – A real uniform weights are created (*Node | Weights | Create uniform weights*).
- **Edit support and kernel length** – This function can be used to fuzzify existing real weights. First, real weights have to be set. Then this dialog is opened (*Node | Weights | Edit support and kernel length*) and length of the support and kernel of the weights is set.

Fuzzy OWA operator

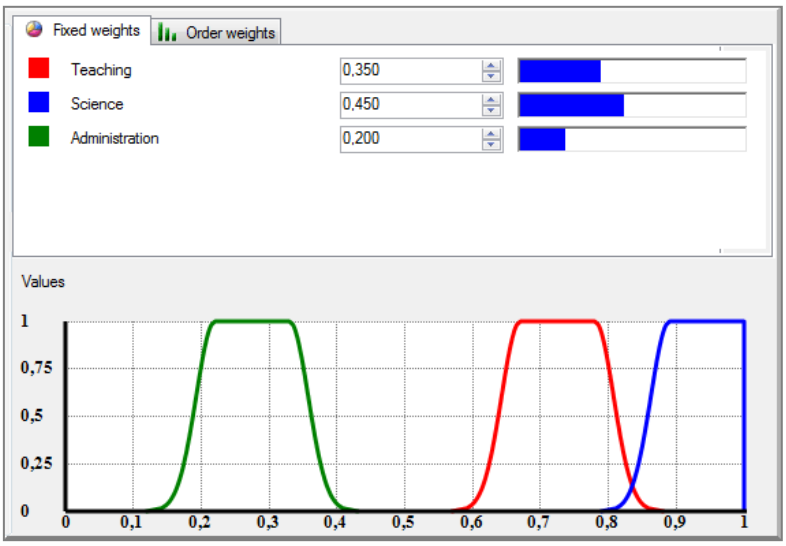
For fuzzy OWA operator, the normalized fuzzy weights are required. The process of their setting is identical as in the case of fuzzy weighted average. Therefore the description of the dialog will be



skipped (it differs only in labels for the weights). See Fuzzy weighted average for more information.

Fuzzified WOWA operator

Fuzzified WOWA operator utilizes two sets of weights – fixed weights and order weights. For each of them, there is one tab.



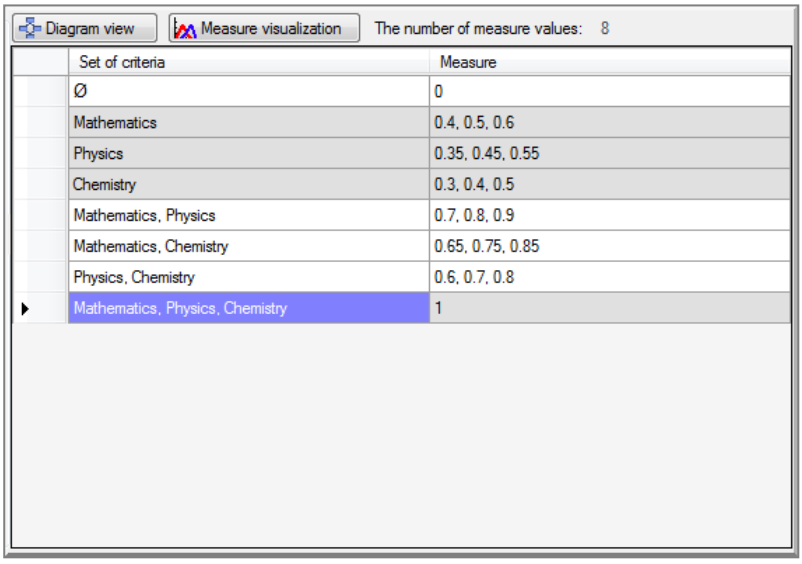
The weights are real number and their sum must equal one for both of the sets. If the sum is not equal one, a warning appears. The user can click on *Normalize* button which modifies the value of the last weight so that the sum would be equal to one.

It is possible to save the weights into a file, load them from a file, or create uniform weights. All these operations with weights are described in the section Fuzzy weighted average.

Fuzzy Choquet integral

For fuzzy Choquet integral, a FNV-fuzzy measure must be defined. The user can see all subsets of criteria (or child nodes) and their measure. Each row in the table represents one value of the FNV-fuzzy measure. The value is a fuzzy number (a real number, as a special case of a fuzzy number, can be also used).

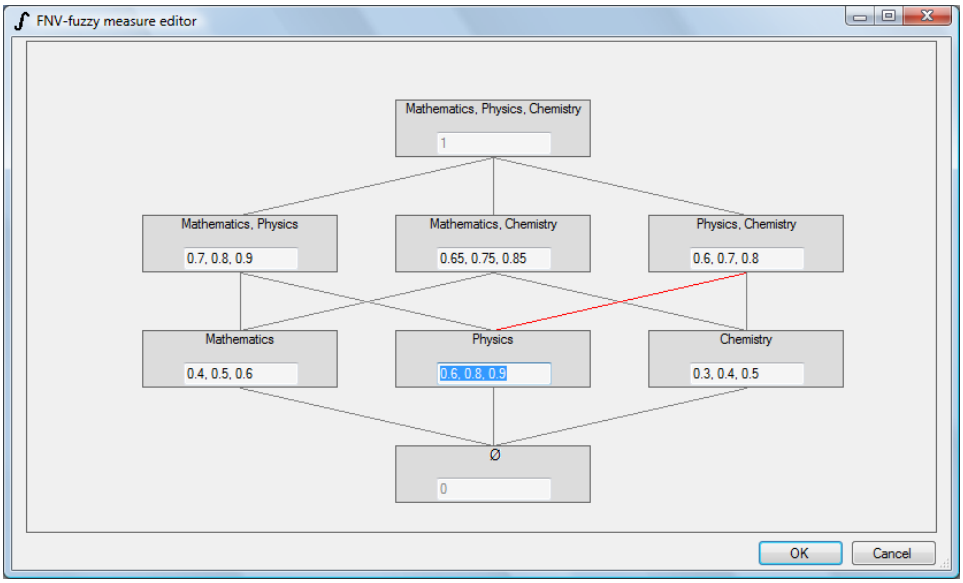
Note: For n child nodes, the FNV-fuzzy measure has 2^n values. If the number of the child nodes of the selected node is high, the software can be slow.



The FNV-fuzzy measure is required to satisfy the monotonicity condition. Otherwise, an icon of an exclamation mark is shown next to the measure values that do not meet the condition.

Besides the table view, there are two more ways of displaying the FNV- fuzzy measure in FuzzME:

- **Diagram view** – The measure is displayed in form of a diagram. This view is convenient for small number of measure values (otherwise it can become too big and therefore slow and difficult to interpret). If the condition of monotonicity is not satisfied, the user can see easily where exactly it is broken. This is signalized by a red line. The diagram view can be opened by clicking on the *Diagram view* button or by selecting *Node | FNV-fuzzy measure | Diagram view*.
- **Measure visualization** – All measure values are presented as a set of images. The visualization can be opened by clicking on the *Measure visualization* button or by selecting *Node | FNV-fuzzy measure | Measure visualization* from the main menu.



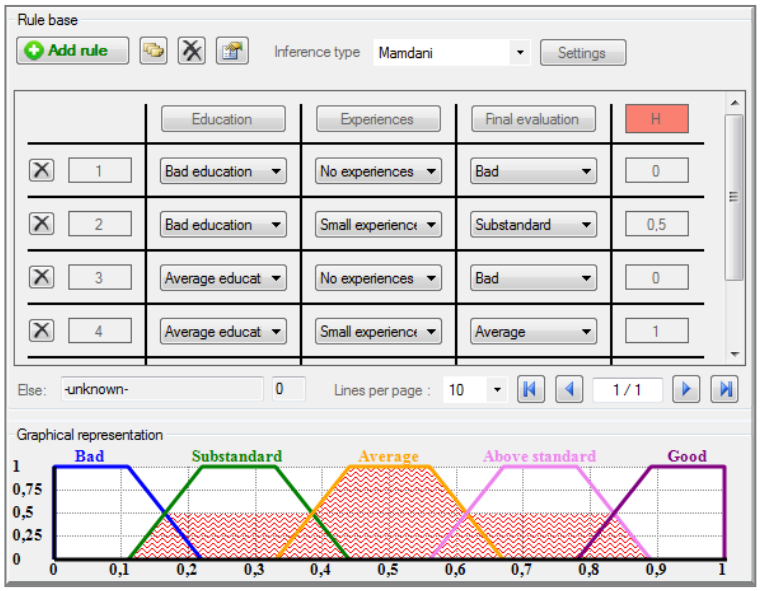
Fuzzy expert system

The fuzzy expert system in the FuzzME can be used either for a fuzzy evaluation or for a fuzzy classification. Multiple inference algorithms are supported. The user can choose the Mamdani, Sugeno-WA, or Sugeno-WOWA inference algorithms for the purposes of fuzzy evaluation. For fuzzy classification, Single Winner or Voting by Multiple Fuzzy Rules algorithms can be applied.

First, the expert has to define a fuzzy rule base for the fuzzy expert system. Then an appropriate inference algorithm is chosen. Because the fuzzy rule base is defined linguistically, a linguistic fuzzy scale has to be defined for the fuzzy expert system node and all its child nodes first.

The fuzzy rule base is presented in the form of a table. Each row of the table represents one rule from the base. The rules are in form of "if - then". In each column, except for the last one, there is a value of a criterion or a child node (if-part). In the last column, there is the result (then-part of the rule). The number next to the rule (denoted in the software as *H*) is the degree in which was the

given rule fired. If the number of rules is high, they are divided into the several pages. The arrow icons under the table can be used to move to the next or to the previous page.



The user can use the following function:

- **Add rule** – By clicking on the *Add rule* button, a new rule is added at the end of the base. The user then selects the values for of the child nodes and the value for the result from drop-down boxes.
- **Delete rule** – Clicking on the black cross icon on the left-hand side of any rule will cause that the rule will be deleted.
- **Edit rule** – Any values of the rule can be modified directly by choosing a new one from the drop-down box. The values in each drop-down box are the linguistic values of the fuzzy scale defined for the corresponding node.
- **Edit linguistic scale** – The linguistic scales can be edited quickly by clicking on the button with the criterion name in the header of the table.
- **Clear base** – All rules will be deleted. This function is available from the menu *Node | Rule base | Clear base*.
- **Criteria combinations** – This function offers a quick way of creating the fuzzy rule base (*Node | Rule base | Criteria combinations*). A new rule base will be created. Each rule in this base represents each possible combination of the input values. Then, the expert just has to select the result (output) value for each rule, or to delete the rule (e.g. if such a combination of input values cannot occur).
- **Adjust the fuzzy expert system settings** – A dialog with the fuzzy expert system settings is opened (*Node | Rule base | Fuzzy Expert System Settings*). The items in this dialog are described in following text of this section.
- **Show fuzzy expert system details** – A window with additional information is opened (*Node | Rule base | Show Fuzzy Expert System Details*). The user can see there, e.g., the total number of rules and the number of fired rules.
- **Open** – The rule base can be loaded from a file (*Node | Rule base | Open*).

- **Save as** – The rule base is saved into the file so that it can be used in another fuzzy expert system (*Node | Rule base | Save As*).
- **Export into Matlab** – The fuzzy expert system created in FuzzME can be exported into Matlab. Select *File | Export | Export Expert System into Matlab*.

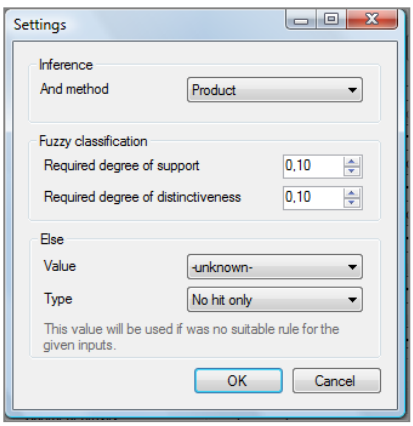
The fuzzy rule base can be created either by adding the rules one-by-one (*Add rule* button), or by generating the whole fuzzy rule base, so that it would contain all possible combination of the input values (*Create combinations* functions) and choosing the output values for the new rules.

After the fuzzy rule base is created, the expert chooses the inference type from a drop-down box at the top of the dialog. If Sugeno-WOWA algorithm is selected, a *Weights* button appears. Clicking on the button opens a window where the weights for the Sugeno-WOWA can be set.

At the bottom of the dialog, there is a graphical representation of the output linguistic fuzzy scale. The displayed information depends on the selected inference algorithm. In case of Sugeno and Sugeno-WOWA, the numbers above the scale values express the resulting weights for the Sugeno inference. If the Mamdani inference is selected, the result of the inference (fuzzy set) is highlighted in the image. In case of Single Winner or Voting by Multiple Fuzzy Rules classification algorithms, the number of votes for each of the classes is displayed.

The user can adjust the behavior of the fuzzy expert system by clicking on the *Settings* button (or by choosing *Node | Rule base | Fuzzy Expert System Settings*). In the window, the user can adjust the following settings:

- **And-Method** – The t-norm that will be used for modeling of the "and". The supported methods are the *minimum* and the *product*.
- **Fuzzy Classification** – The parameters concerning the fuzzy classification. For more information see the section **Fuzzy classification in FuzzME**.
- **Else** – The else-value is the value that will be used if no rule can be applied for the given input. By default, the *unknown* value (i.e. the whole interval [0, 1]) is used but the user can choose another one. The *type* determines in which situation this value will be used. If "no hit only" is selected, the value will be used only if no rule was fired at all. If "rule" is selected, it will be added as a separate rule that will be fired in the degree one minus the maximal of the degrees in which the rest of the rules was fired.



Analyze the aggregation behavior

In the FuzzME, there are functions that make it easy to understand the behavior of the selected aggregation method and to set the proper parameters:

Compare inputs and results

This function displays all the input values and the aggregation result in the same image. Select the node of interest and choose *Node | Compare inputs and result* from the menu.

Compare results for various inputs

This function demonstrates how the result of the aggregation will be affected if some of the input values change. Select the node of interest in the goals tree and choose *Node | Compare results for various inputs* from the main menu. The user can select up to two criteria of interest for which the analysis should be performed.

For the two selected criteria, the user sets their minimum value, their maximum value and the number of values (this will represent the number of rows or columns in the table). The table below then shows the evaluation of this partial goal when the values of the two selected criteria are changing from the selected minimum value to the maximum one and the values of the other criteria remain unchanged.

The table rows represent the different (crisp) values of the first criterion and the columns represent the different values of the second one. In the corresponding cell, there is the resulting evaluation. The user can select which characteristic of the resulting evaluation should be displayed. One of the following options can be chosen:

- Center of gravity;
- Uncertainty amount - crisp numbers have uncertainty equal to zero, if the evaluation represents the value *unknown* (i.e. the whole interval [0, 1]), its uncertainty will be one;
- Middle of kernel - the center of the fuzzy evaluation kernel;
- Lowest of kernel - the lowest value of the fuzzy evaluation kernel;
- Highest of kernel - the highest value of the fuzzy evaluation kernel;
- Middle of support - the center of the fuzzy evaluation support;
- Lowest of support - the lowest value of the fuzzy evaluation support;
- Highest of support - the highest value of the fuzzy evaluation support;
- All significant points - all four main significant points of the fuzzy evaluation, delimited by the coma, will be displayed.

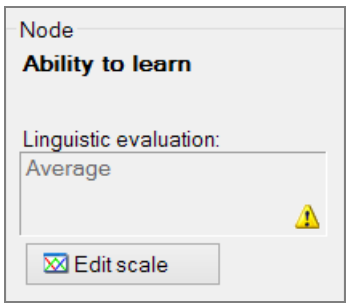
The table can be copied, i.e., to Excel and saved for purpose of the further analysis.

Clicking on the *Plot in Matlab* button makes it possible to plot the content of the table in the Matlab. The evaluation function can be visualized this way, which can be very valuable for the expert in the analysis of the model. When the user clicks on the button, a dialogue appears. The user selects in the dialogue where should be the M-file generated by the FuzzME saved. The FuzzME opens this M-file in the Matlab automatically.

For generating the graph of the evaluation function, it is recommended to set a reasonable number of values for the first and the second criterion. It is recommended to use more than 10 values for each criterion; otherwise the graph is too rough. On the other hand, more than 20 values for each criterion involve a larger number of calculations and it could take some time.

Analyze the linguistic approximation behavior

In the middle part of the main window, the linguistic description of the evaluation in the selected goals tree node is displayed. It can look as in the following image.

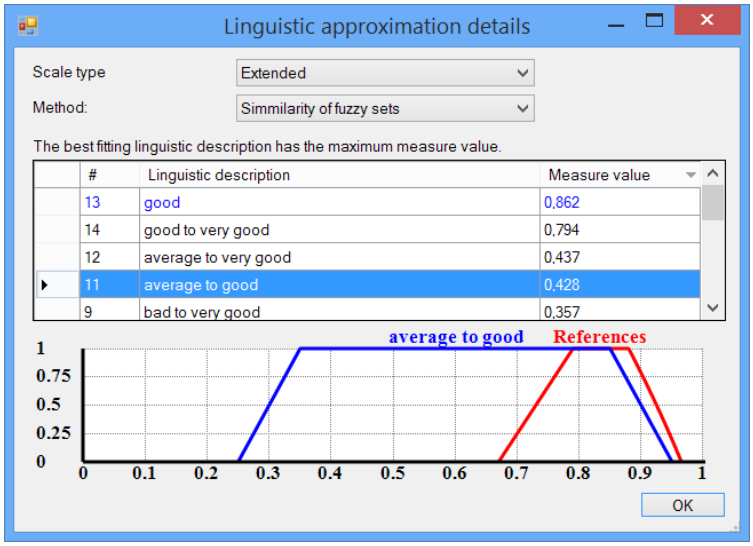


In the image, an exclamation mark icon is dispayed. It signalizes that there are also other linguistic descriptions that are as closed to the fuzzy evaluation as the displayed linguistic description. The decision maker should therefore examine also these alternative linguistic descriptions.

By clicking on the linguistic description, a new dialogue is opened showing the details on the linguistic approximation for this partial evaluations.

The dialogue makes it possible to select the used linguistic scale type and also the linguistic approximation method. Then all possible linguistic descriptions are listed together with the value that measures how well does the linguistic description fit the partial evaluation (it is the similarity or distance - depending on the selected method). The best-fitting term is highlighted by the blue color. By clicking on the header of the table, the values can be ordered (e.g. if you click on the header of the last colemn, the values are ordered according to how well they fit they the particular partial evaluation).

By clicking on any of the values in the table, the meaning of selected term (blue) and the actual value of the partial evaluation (red) are dispayed graphically. This makes it possible to check how well does the meaning of the linguistic term correspond to the partial evaluation of interest.

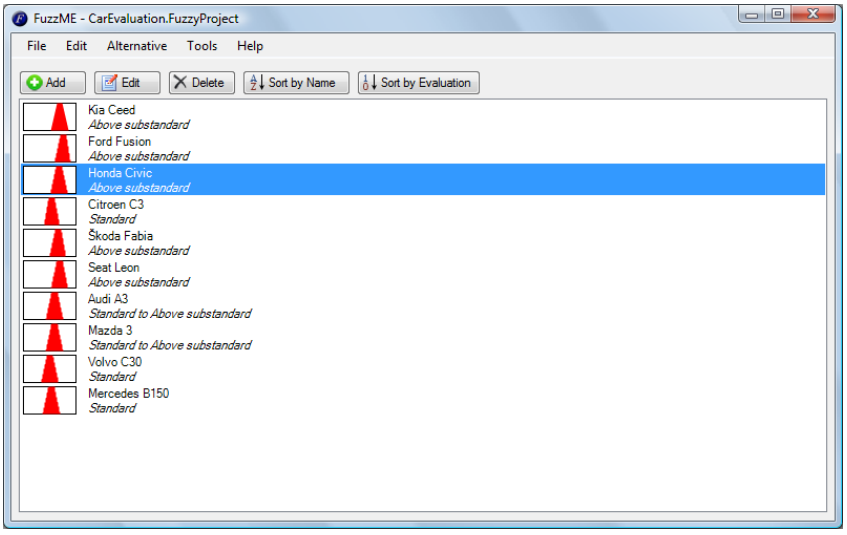


List of alternatives

Managing the alternatives

When the goals tree has been designed, the expert can proceed to evaluation of the alternatives. The user can open the list of the alternatives, by clicking on the button *View list of alternatives* or from the menu *Tools | Mode | List of alternatives*.

For each alternative in the list, there is its name and the graphical representation of its evaluation (which is a fuzzy number). If a linguistic scale has been defined for the root node of the goals tree, a linguistic evaluation of the alternative is displayed under the alternative name.



The user can do the following operations with alternatives:

- **Add alternative** – To create a new alternative, the user clicks on *Add* button or selects *Alternative | Add* from the menu. A new alternative is created and the window is switched to the alternative editing mode. In this mode, the user should fill in the alternative name first.

Then it is necessary to click on each criteria node in the goals tree and fill in the value of the criterion for this alternative. If some of these values are not known, the user can leave there the default value, which is "- *unknown* -". When the alternative name and the criteria values have been filled, the user can return back to the list of alternatives by pressing *View list of alternatives* button.

- **Edit alternative** – The alternative can be edited by double-clicking on it (or by pressing *Edit* button or selecting *Alternative | Edit*). The window is switched to the alternative editing mode. Subsequently, the user can modify the alternative name or the values of its criteria. This is done in the same way as in the case of adding an alternative. Finally, the user can return back to the list of alternatives by pressing *View list of alternatives* button.
- **Delete alternative** – The user selects the alternative in the list by clicking on it. Then the selected alternative is deleted by pressing *Delete* button, *Del* key on the keyboard, or by selecting *Alternative | Delete* from the menu.
- **Delete all alternatives** – All alternatives can be deleted from the menu *Alternative | Delete All*. At least one alternative always has to be in the list. That is why there is one default alternative after the deletion.
- **Show alternative evaluation** – The basic information about the alternative evaluation is displayed directly in the list of alternatives. To obtain more detailed information, select *Alternative | Show alternative evaluation*.
- **Recompute all evaluations** – The evaluations of the alternatives are calculated automatically after the change of the goals tree or values of an alternative. These evaluations are cached for better speed. However, it is possible to clear this cache and calculate the evaluations again by selecting *Alternative | Recompute All Evaluations*.
- **Find** – This function searches for an alternative by its name (*Alternative | Find* from the menu or *Ctrl+F7*).
- **Sort alternatives by name** – The alternatives are ordered according to the alphabetical order of their names (click on *Sort by Name* button or select *Alternative | Sort by Name*).
- **Sort alternatives by evaluation** – The alternatives are ordered according to the centers of gravity of their evaluations (click on *Sort by Evaluation* button or select *Alternative | Sort by Evaluation*). The alternatives with the best evaluations are displayed at the top of the list.
- **Copy, Cut, Paste** – The alternative can be copied to the clipboard and pasted into another project. Click on the alternative with the right mouse button. Then select the operation from the context menu. Keep on mind that if the alternative is copied into another project with different criteria, the criteria values need not to be transferred properly.
- **Import of the alternatives** – The alternative names and their criteria values can be imported, e.g., from Excel. See section Import of the alternatives.
- **Export of the alternatives or their evaluations** – See section Export for more information.

Import of the alternatives

It is not necessary to add all of the alternatives manually. They can be imported from another software product such as Microsoft Excel or Microsoft Access. The FuzzME supports CSV (comma separated values) files for the import.

To import data from the Excel, the Excel table should have the following format:

- The first row is the header with the criteria names (starting from the second column because the first one is occupied by the alternative names).
- The other rows represent the alternatives. In the first column of each row, there is a name of the alternative. In the rest of the columns, there are the criteria values for this alternative (each value in a separate cell).

Example of an Excel file in the suitable format can be seen in the following picture.

	A	B	C	D	E	F	G	H	I
1	Alternative name	Operating costs	Spare parts costs	Additional safety elements	Steering booster	ABS	Luggage capacity	Air-conditioning	Design
2	Kia Ceed	19000, 31000, 44000	High	Yes	Yes	Yes	340	Yes	above standard-good
3	Ford Fusion	20000, 33000, 35000	Low	Yes	Yes	Yes	337	Yes	average-above standard
4	Honda Civic	20000, 32000, 44000	Medium	Yes	Yes	Yes	415	Yes	good-excellent
5	Citroen C3	17000, 31000, 43000	Medium	No	Yes	Yes	305	Yes	average
6	Škoda Fabia	13000, 31000, 37000	High	Yes	Yes	No	300	No	above standard-good
7	Seat Leon	21000, 34000, 47000	Medium	Yes	Yes	Yes	292	Yes	good-excellent
8	Audi A3	26000, 39000, 52000	High	Yes	Yes	Yes	360	Yes	good-excellent
9	Mazda 3	19000, 33000, 45000	High	Yes	Yes	Yes	346	Yes	average-above standard
10	Volvo C30	24000, 38000, 52000	High	Yes	Yes	Yes	233	Yes	excellent
11	Mercedes B150	19000, 33000, 40000	High	Yes	Yes	Yes	554	Yes	excellent

To import data from the Excel into the FuzzME, the CSV file have to be created first:

1. Open a spreadsheet file of interest in Excel
2. Choose *Save As* from the *File menu* in the Excel.
3. There is the *Save As Type* drop-down list at the bottom of the dialog box. Choose the *CSV (Semicolon delimited)* option.
4. Close the Excel

Note: The CSV files contain basically only the data (text in the cells) without any additional information about colors, formatting, etc. That is why they are easy to process and a lot of software products (such as Matlab) support export of the data into this format.

Finally, import this CSV file into the FuzzME:

1. Open a project in FuzzME where the alternatives should be imported.
2. Select *File | Import | Import alternatives* form the main menu.
3. In the dialog, click on *Browse* and select the CSV file you have created in Excel. Keep on mind that there are two formats – standard (data are separated with a comma) and Excel (data are separated with a semicolon). You should select the correct format from the drop-down list in this dialog. Confirm the dialog by clicking on *Open*. Move to the next step by clicking on *Next* button.
4. In the next step, you have to link each criterion (on the left) with the column in the CSV file (on the right). You have to choose format in which the criteria values are written:
    a) **Value is a fuzzy number** – Values of all the criteria were written as fuzzy numbers (i.e. the list of significant points separated by commas) in Excel (for example “0, 0.1, 0.2”).
    b) **Value is a scale item index** – Value of the qualitative criteria were written as an index of the scale item in Excel. For example, let us consider that the scale for a criterion has items “poor”, “average” and “good”. Then the value “2” denotes the second item of the scale (“average”). The value “2-3” denotes “average to good” and the value “2/3” means “between average and good”. The value “0” denotes the “unknown”

value. The algorithm in FuzzME is very flexible. It is possible to use the scale item names (e.g. “poor”) instead of their indices (e.g. “1”) in the Excel.

5. Click on *Done* to start the import. The number of imported alternatives will be displayed and the dialog can be closed.

Export of the data

Export of the evaluations

The evaluations can be exported into a CSV file. This file can be then opened in Excel by double-clicking on it in Windows Explorer. To export the evaluations, select *File* | *Export* | *Export Evaluations* from the main menu.

Choose a name for the new CSV file, and specify its type. The type can be either standard CSV (values separated by a comma), or Excel CSV (values separated by a semicolon). Click on *Save* to start the export.

Export of the alternatives

The alternatives names and their criteria values can be exported into a CSV file. Select *File* | *Export* | *Export alternatives* from the main menu.

Choose a name for the new CSV file, and its type. The type can be either standard CSV (values separated by a comma), or Excel CSV (values separated by a semicolon). Click on *Save*. In the following dialog, the parameters for the export can be specified. The appropriate values of these parameters depend on the software that you want to use later for processing the CSV file. Click on *OK* to start exporting.

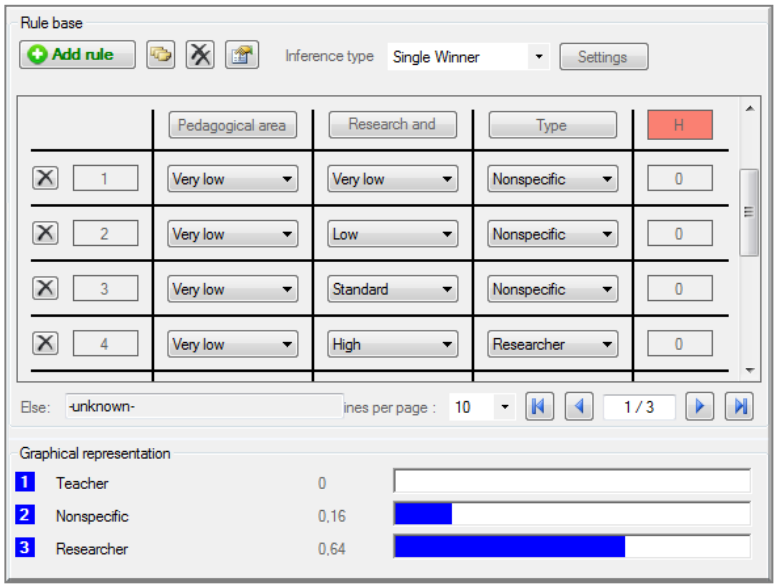
Fuzzy classification in FuzzME

Although the main function of the FuzzME is multiple-criteria fuzzy evaluation, it can be used also for fuzzy classification. Two fuzzy classification algorithms are available – Single Winner and Voting by Multiple Fuzzy Rules. The result will be the best fitting class for the object. The classification is described by a fuzzy rule base.

First, the goals tree is designed in the same way as it was described in the section **Designing the goals tree**. The root node of the tree will be a fuzzy expert system, since a fuzzy rule base will be used for description of the classification.

Next, define a linguistic fuzzy scale for the root node (the one with the fuzzy expert system). Create for example a uniform scale. Each item of the scale represents one class. Select suitable name for each of the items (classes). The fuzzy numbers used for modeling of the scale items are unimportant since the scale is nominal one. They serve just as numeric identifiers of the classes. You can use any mutually different numbers (or fuzzy numbers).

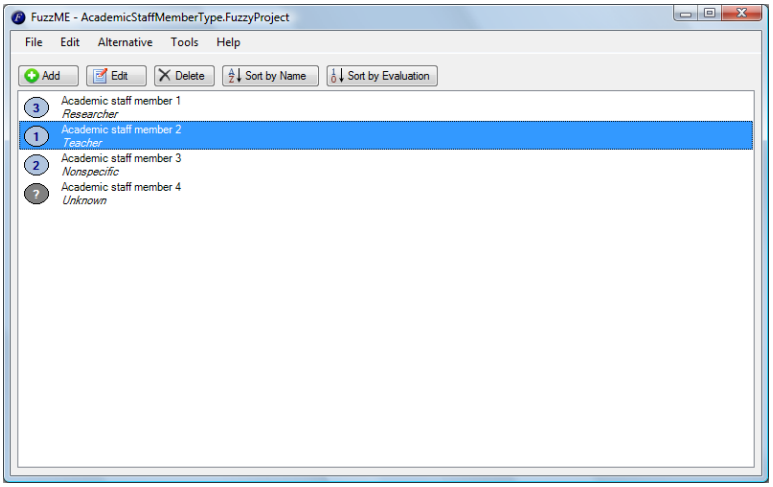
In the following step, define the fuzzy rule base. For each of the rules, select the corresponding class on the right-hand of the rule. Finally, instead of the Mamdani or Sugeno inference, select one of the mentioned classification algorithms. When one of them is selected, FuzzME will treat the project as a fuzzy classification project.



The FuzzME also supports the cases where the object cannot be classified. You can adjust the parameters for determining which objects cannot be classified. To do so, click on the *Settings* button, or select *Node | Rule Base | Fuzzy Expert System Settings* from the menu. There are two parameters:

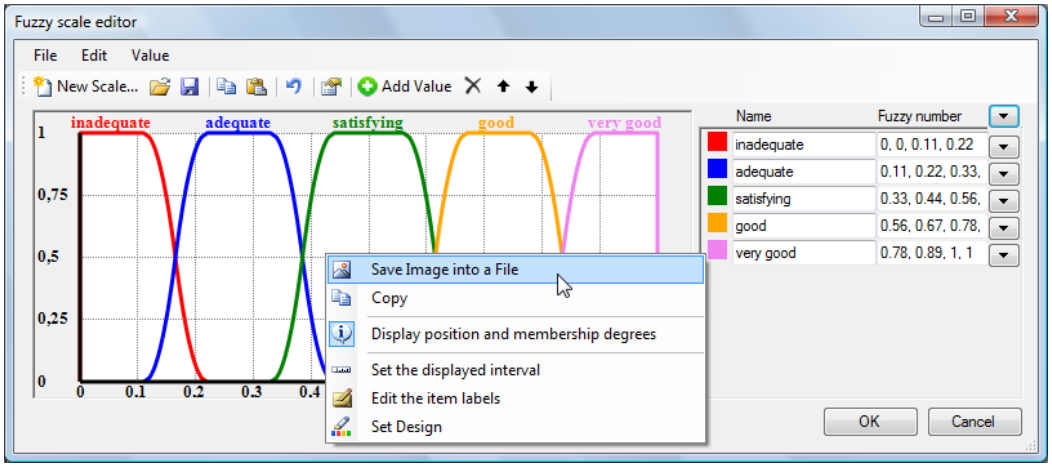
- **Required degree of support** – This parameter represent the minimal required number of votes for the class, i.e. one of the rules should be fired at least in this degree. Otherwise, the object will be marked as unclassifiable. The higher value, the more unclassifiable objects – value 1 means that the rule that proposed the winner class must be fully fired
- **Required degree of distinctiveness** – The greater value of this parameter, the greater difference in the number of votes for the best fitting class and for the second best fitting one will be required. The value 1 means, that the no other classes than the winner one can be proposed.

Notice a few changes when the FuzzME is used for the fuzzy classification. In the fuzzy rule base editor, the output fuzzy scale is no more displayed. Instead, there is a list of the classes and the "numbers of votes", which they received. In the alternatives list, there is the number of the class in front of each object, or a question mark if the given object cannot be classified.



Graphics in FuzzME

All the graphics created in FuzzME can be customized and saved as an image into a file. The parameters for the graphics can be set in the *Options* on the *Graphics* tab (see Tab Graphics).



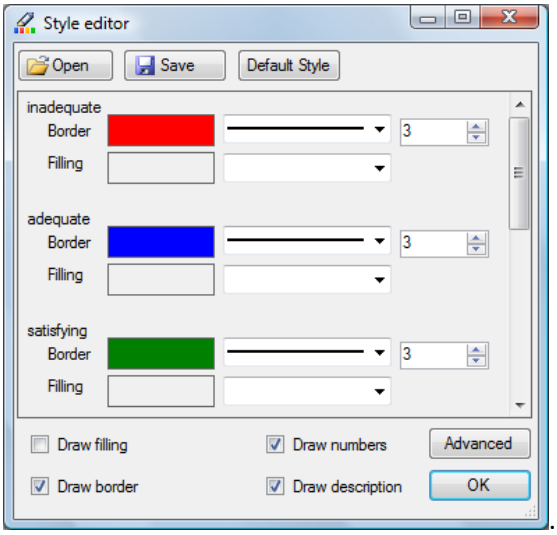
For any image displayed in FuzzME, the user can use the following functions. They are available from the context menu (click on the image with the right mouse button to open it):

- **Save the image into a file** – Any image displayed in the FuzzME can be saved into a file. Click on the image with the right mouse button. A context menu appears. Select "*Save Image into a File*" from the context menu. Choose the name of the new file and the format of the image. The supported bitmap formats are png, gif, bmp and jpg. It is recommended to use the png format.

  The FuzzME can save the image also as a vector graphics either in the svg format, or in the Metapost. Free converters available on the Internet can be used to convert the svg image to eps, or pdf. Because of the characteristics of the vector graphics, the image need not to look exactly as in the screen (different font can be used, the texts might be slightly misplaced). The current version does not support some advanced graphical settings for the vector graphics (e.g. hatching in the Metapost).

  Save the image by clicking on the *Save* button.

- **Copy image to the clipboard** - By selecting *Copy* from the context menu, you can copy any image created in the FuzzME to the clipboard. The copied image can be then pasted e.g. to the Word or another software.
- **Turn on/off the displaying of the membership degrees** – If this option is turned on, a small box is displayed when the user moves the mouse over the image. In the box, there is the *x* (corresponding to the mouse position) and the membership degrees of the *x* for all of the fuzzy numbers displayed in the image. The option can be turned on or off by clicking on *Display position and membership degrees* in the context menu.
- **Set displayed interval** – Before the image is saved into a file or copied to the clipboard it can be useful to specify which interval will be displayed in the image. This can be done by selecting *Set the displayed interval* from the context menu.
- **Edit the fuzzy number labels** – Sometimes the labels of the fuzzy numbers can be overlapping because they are too long. This can be fixed by selecting new (shorter) labels for the fuzzy numbers (choose *Edit the Item Labels* in the context menu). The purpose of this function is just to make the image more appealing before it is saved or copied. The new labels are not persistent, the original labels will be reloaded when the image is redrawn again (e.g. when another node is selected).
- **Modify the colors and style of the image** – Click on the image with the right mouse button and select *Set Design* from the context menu. For each fuzzy number that is displayed, you can set the border (color, line style and line width) and the filling (color and the filling style). You can enable or disable drawing of the numbers at the axes, or descriptions. You can also save the style into a file and open it later. If you click on *Advanced*, a window with additional options appears. In the window, you can set the font for the descriptions (its style, size and color) and the font for the numbers. You can also set the background color or modify the properties of the axes in this dialog. The styles are saved into a configuration file so they will be used until they are changed. The default style can be restored later by selecting *Tools | Options* from the main menu, choosing *Graphics* tab and clicking on the *Set Default Style* button.



Note: The node names can contain upper and lower indices. They are written it the same notation as in TeX:

- For a lower index use "_". If the index should be more than one character long, it must be enclosed into curly brackets. So a node with the name "A_1" will be drawn as an A with an index 1. Another example of this notation can be: "W_{something}".
- For an upper index use "^". Again, if the index has more than one character, it must be enclosed into curly brackets. Examples: "A^1", "A^{something}".

This behavior is advantageous if you want to use the images generated by FuzzME in a scientific paper, where the names in the image must correspond with the rest of the text. The same notation for upper and lower indices can be used in the function *Edit the fuzzy number labels.*

Options

The settings can be opened by selecting *Tools | Options* from the main menu. There are three tabs – *Common*, *Fuzzy Numbers*, and *Graphics*.

Tab Common

On the *General* tab, the following options can be set:

- **Language** – The software is available in the Czech and English versions. After the language is changed, the FuzzME needs to be restarted. If the *Autodetect language* checkbox is checked, the preferred language will be detected automatically from the language of the operating system.
- **List of alternatives** – The user can switch between the simple and advanced view. In the simple view, only alternative names are displayed without any additional information so it is convenient for slower computers.

Tab Fuzzy Numbers

On the *Fuzzy Numbers* tab, the following settings can be adjusted:

- **Format** – This option specifies which character will be used to delimit the significant points of fuzzy numbers. The default value is a comma (then a fuzzy number can be written by the user e.g. as "0.1, 0.2, 0.3"). However, the user can select also a space as a delimiter instead (e.g. "0.1 0.2 0.3"). This can be handy especially for users which are used to Matlab syntax.
- **Preciseness** – The user can choose the number of α-cuts that will be used for the calculations. The more α-cuts, the better preciseness. The fewer α-cuts, the better calculations speed.

Tab Graphics

On this tab, the user can set the parameters for the graphics in FuzzME:

- **Saved image size** – The resolution of the graphics saved into a file (see **Graphics in FuzzME**). If *Default* is selected, the images will have the same resolution as the graphics on the screen.

- **Styles** – The style (e.g. colors) of the graphics can be modified in the Style Editor (see **Graphics in FuzzME**). In this dialog, the user can select whether the modified style should be saved or if the default style should be always used.
- **Painting** - The user can select the graphics quality. If the *standard quality* is selected, the fuzzy numbers are drawn by a series of lines (as in the FuzzME 2.1 and former versions). Selecting the *high quality* causes that the membership functions of fuzzy numbers will be drawn in the usual mathematical style. This is especially suitable if the images should be used in scientific publications. The difference can be seen best on functions that are not continuous.

  The next checkbox in this group of settings allows the user to select whether the entire membership function should be drawn or if only parts where it is non-zero should be plotted. The first way is recommended if the image is to be published in a paper. However, if the image contains more than one fuzzy number, the membership functions overlays in the parts where they are zero. This may be rather confusing and the latter way of drawing is recommended in these cases.

Frequently Asked Questions (FAQ)

The program could not be started. An error occurs during its start.

Probably, .NET framework is not installed on the computer. This component is required by the FuzzME. See Hardware and software requirements and Installation for more information.

Which format should be used when setting a fuzzy number?

The fuzzy numbers are described by their significant values. The significant values are **separated by comas**. There is also a possibility to select another character as a delimiter of the significant points. In the numbers, the decimal point is used. See Using fuzzy numbers in FuzzME for more information.

Where can I download the latest version?

The latest version can be downloaded from http://www.fuzzme.net/.