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# **Simplful**

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## A USER-FRIENDLY PYTHON LIBRARY FOR FUZZY LOGIC

Simpful is a Python library for fuzzy logic reasoning, designed to provide a simple and lightweight API, as close as possible to natural language. This page presents detailed documentation on the classes and methods implemented in it.

### 1.1 Installation

You can install Simpful with

```
pip install simpful
```

### 1.2 Additional information

If you want to check out some examples or need more information on the usage of the library, please visit our [GitHub repository](#), or check our published article [here](#).

#### 1.2.1 simpful module

##### simpful.simpful module

**class** `simpful.simpful.AutoTriangle` (*n\_sets=3, terms=None, universe\_of\_discourse=[0, 1], verbose=False*)

Bases: `simpful.simpful.LinguisticVariable`

Creates a new linguistic variable, whose universe of discourse is automatically divided in a given number of fuzzy sets. The sets are all symmetrical, normalized, and for each element of the universe their memberships sum up to 1.

##### Parameters

- **n\_sets** – (integer) number of fuzzy sets in which the universe of discourse must be divided.
- **terms** – list of strings containing linguistic terms for the fuzzy sets (must be appropriate to the number of fuzzy sets).
- **universe\_of\_discourse** – a list of two elements, specifying min and max of the universe of discourse.
- **verbose** – True/False, toggles verbose mode.

**class** `simpful.simpful.FuzzySystem` (*operators=None, show\_banner=True, sanitize\_input=False, verbose=True*)

Bases: `object`

Creates a new fuzzy system.

### Parameters

- **operators** – a list of strings, specifying fuzzy operators to be used instead of defaults. Currently supported operators: ‘AND\_PRODUCT’.
- **show\_banner** – True/False, toggles display of banner.
- **sanitize\_input** – sanitize variables’ names to eliminate non-accepted characters (under development).
- **verbose** – True/False, toggles verbose mode.

**Mamdani\_inference** (*terms=None, subdivisions=1000, aggregation\_function=<built-in function max>, ignore\_errors=False, ignore\_warnings=False, verbose=False*)

Performs Mamdani fuzzy inference.

### Parameters

- **terms** – list of the names of the variables on which inference must be performed. If empty, all variables appearing in the consequent of a fuzzy rule are inferred.
- **subdivisions** – the number of integration steps to be performed for calculating fuzzy set area (default: 1000).
- **aggregation\_function** – pointer to function used to aggregate fuzzy sets during Mamdani inference, default is max. Use Python sum function, or simpful’s `probor` function for sum and probabilistic OR, respectively.
- **ignore\_errors** – True/False, toggles the raising of errors during the inference.
- **ignore\_warnings** – True/False, toggles the raising of warnings during the inference.
- **verbose** – True/False, toggles verbose mode.

**Returns** a dictionary, containing as keys the variables’ names and as values their numerical inferred values.

**Sugeno\_inference** (*terms=None, ignore\_errors=False, ignore\_warnings=False, verbose=False*)

Performs Sugeno fuzzy inference.

### Parameters

- **terms** – list of the names of the variables on which inference must be performed. If empty, all variables appearing in the consequent of a fuzzy rule are inferred.
- **ignore\_errors** – True/False, toggles the raising of errors during the inference.
- **ignore\_warnings** – True/False, toggles the raising of warnings during the inference.
- **verbose** – True/False, toggles verbose mode.

**Returns** a dictionary, containing as keys the variables’ names and as values their numerical inferred values.

**add\_linguistic\_variable** (*name, LV, verbose=False*)

Adds a new linguistic variable to the fuzzy system.

### Parameters

- **name** – string containing the name of the linguistic variable.

- **LV** – linguistic variable object to be added to the fuzzy system.
- **verbose** – True/False, toggles verbose mode.

**add\_rules** (*rules, verbose=False*)

Adds new fuzzy rules to the fuzzy system.

**Parameters**

- **rules** – list of fuzzy rules to be added. Rules must be specified as strings, respecting Simplful’s syntax.
- **sanitize** – True/False, automatically removes non alphanumeric symbols from rules.
- **verbose** – True/False, toggles verbose mode.

**add\_rules\_from\_file** (*path, verbose=False*)

Imports new fuzzy rules by reading the strings from a text file.

**aggregate** (*list\_variables, function*)

Performs a fuzzy aggregation of linguistic variables contained in a FuzzySystem object.

**Parameters**

- **list\_variables** – list of linguistic variables names in the FuzzySystem object to aggregate.
- **function** – pointer to an aggregation function. The function must accept as an argument a list of membership values.

**Returns** the aggregated membership values.

**get\_firing\_strengths** (*input\_values=None*)

If “input\_values” is not provided, it returns a list of the firing strengths of the the rules, given the current state of input variables. “input\_values” is an optional argument, in the form of a dictionary containing a list of input states for each variable. In this second case, it returns a 2D list of firing strengths of the given states.

**Parameters** **input\_values** – dictionary where the keys are names of linguistic variables and the values are a list of input values for that variable.

**Returns** a list containing rules’ firing strengths, or a 2D list containing rules’ firing strengths for each given input state.

**get\_fuzzy\_set** (*variable\_name, fs\_name*)

Returns a FuzzySet object associated to a linguistic variable.

**Parameters**

- **variable\_name** – name of the linguistic variable.
- **fs\_name** – linguistic term associated to the fuzzy set.

**Returns** a FuzzySet object.

**get\_fuzzy\_sets** (*variable\_name*)

Returns the list of FuzzySet objects associated to one linguistic variable.

**Parameters** **variable\_name** – name of the linguistic variable.

**Returns** a list containing FuzzySet objects.

**inference** (*terms=None, subdivisions=1000, aggregation\_function=<built-in function max>, ignore\_errors=False, ignore\_warnings=False, verbose=False*)

Performs the fuzzy inference, trying to automatically choose the correct inference engine.

**Parameters**

- **terms** – list of the names of the variables on which inference must be performed. If empty, all variables appearing in the consequent of a fuzzy rule are inferred.
- **subdivisions** – the number of integration steps to be performed for calculating fuzzy set area (default: 1000).
- **aggregation\_function** – pointer to function used to aggregate fuzzy sets during Mamdani inference, default is max. Use Python sum function, or simpful’s probor function for sum and probabilistic OR, respectively.
- **ignore\_errors** – True/False, toggles the raising of errors during the inference.
- **ignore\_warnings** – True/False, toggles the raising of warnings during the inference.
- **verbose** – True/False, toggles verbose mode.

**Returns** a dictionary, containing as keys the variables’ names and as values their numerical inferred values.

**plot\_variable** (*var\_name, outputfile="", TGT=None, highlight=None, ax=None, xscale='linear'*)

Plots all fuzzy sets contained in a linguistic variable. Options for saving the figure and draw on a matplotlib ax are provided.

#### Parameters

- **var\_name** – string containing the name of the linguistic variable to plot.
- **outputfile** – string containing path and filename where the plot must be saved.
- **TGT** – a specific element of the universe of discourse to be highlighted in the figure.
- **highlight** – string, indicating the linguistic term/fuzzy set to highlight in the plot.
- **ax** – a matplotlib ax where the variable will be plotted.
- **xscale** – default “linear”, supported scales “log”. Changes the scale of the xaxis.

**produce\_figure** (*outputfile="", max\_figures\_per\_row=4*)

Plots the membership functions of each linguistic variable contained in the fuzzy system.

#### Parameters

- **outputfile** – string containing path and filename where the plot must be saved.
- **max\_figures\_per\_row** – maximum number of figures per row in the plot.

**set\_constant** (*name, value, verbose=False*)

Sets the numerical value of a linguistic variable to a constant value (i.e. ignore fuzzy inference).

#### Parameters

- **name** – name of the linguistic variables to be set to a constant value.
- **value** – numerical value to be set.
- **verbose** – True/False, toggles verbose mode.

**set\_crisp\_output\_value** (*name, value, verbose=False*)

Adds a new crisp output value to the fuzzy system.

#### Parameters

- **name** – string containing the identifying name of the crisp output value.
- **value** – numerical value of the crisp output value to be added to the fuzzy system.
- **verbose** – True/False, toggles verbose mode.



**set\_output\_function** (*name, function, verbose=False*)

Adds a new output function to the fuzzy system.

#### Parameters

- **name** – string containing the identifying name of the output function.
- **function** – string containing the output function to be added to the fuzzy system. The function specified in the string must use the names of linguistic variables contained in the fuzzy system object.
- **verbose** – True/False, toggles verbose mode.

**set\_variable** (*name, value, verbose=False*)

Sets the numerical value of a linguistic variable.

#### Parameters

- **name** – name of the linguistic variables to be set.
- **value** – numerical value to be set.
- **verbose** – True/False, toggles verbose mode.

**class** simplful.simplful.LinguisticVariable (*FS\_list=[], concept=None, universe\_of\_discourse=None*)

Bases: object

Creates a new linguistic variable.

#### Parameters

- **FS\_list** – a list of FuzzySet instances.
- **concept** – a string providing a brief description of the concept represented by the linguistic variable (optional).
- **universe\_of\_discourse** – a list of two elements, specifying min and max of the universe of discourse. Optional, but it must be specified to exploit plotting facilities.

**draw** (*ax, TGT=None, highlight=None, xscale='linear'*)

This method returns a matplotlib ax, representing all fuzzy sets contained in the linguistic variable.

#### Parameters

- **ax** – the matplotlib axis to plot to.
- **TGT** – show the memberships of a specific element of discourse TGT in the figure.
- **highlight** – string, indicating the linguistic term/fuzzy set to highlight in the plot.
- **xscale** – default “linear”, supported scales “log”. Changes the scale of the xaxis.

**Returns** A matplotlib axis, representing all fuzzy sets contained in the linguistic variable.

**get\_universe\_of\_discourse** ()

This method provides the leftmost and rightmost values of the universe of discourse of the linguistic variable.

**Returns** the two extreme values of the universe of discourse.

**plot** (*outputfile="", TGT=None, highlight=None, xscale='linear'*)

Shows a plot representing all fuzzy sets contained in the linguistic variable.

#### Parameters

- **outputfile** – path and filename where the plot must be saved.

- **TGT** – show the memberships of a specific element of discourse TGT in the figure.
- **highlight** – string, indicating the linguistic term/fuzzy set to highlight in the plot.
- **xscale** – default “linear”, supported scales “log”. Changes the scale of the axis.

**exception** `simpful.simpful.UndefinedUniverseOfDiscourseError` (*message*)

Bases: `Exception`

`simpful.simpful.probor` (*m\_list*)

Performs aggregation of membership values using the probabilistic OR operation.

**Parameters** *m\_list* – list of membership values to aggregate.

**Returns** the aggregated membership value.

`simpful.simpful.prod` (*m\_list*)

Performs aggregation of membership values using the product operation.

**Parameters** *m\_list* – list of membership values to aggregate.

**Returns** the aggregated membership value.

## 1.2.2 fuzzy sets module

### `simpful.fuzzy_sets` module

**class** `simpful.fuzzy_sets.CrispSet` (*a, b, term*)

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a new crisp set.

**Parameters**

- **a** – left extreme value of the set.
- **b** – right extreme value of the set.
- **term** – string representing the linguistic term to be associated to the crisp set.

**set\_params** (*a=None, b=None*)

Changes parameters of the crisp set.

**Parameters**

- **a** – left extreme value of the set.
- **b** – right extreme value of the set.

**class** `simpful.fuzzy_sets.Crisp_MF` (*a, b*)

Bases: `simpful.fuzzy_sets.MF_object`

Creates a crisp membership function.

**Parameters**

- **a** – left extreme value of the set.
- **b** – right extreme value of the set.

**class** `simpful.fuzzy_sets.DoubleGaussianFuzzySet` (*mu1, sigma1, mu2, sigma2, term*)

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a new double Gaussian fuzzy set.

**Parameters**

- **mu1** – mean of the first distribution.
- **sigma1** – standard deviation of the first distribution.
- **mu2** – mean of the second distribution.
- **sigma2** – standard deviation of the second distribution.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** (*mu1=None, sigma1=None, mu2=None, sigma2=None*)  
Changes parameters of the double Gaussian fuzzy set.

#### Parameters

- **mu1** – mean of the first distribution.
- **sigma1** – standard deviation of the first distribution.
- **mu2** – mean of the second distribution.
- **sigma2** – standard deviation of the second distribution.

**class** `simplful.fuzzy_sets.DoubleGaussian_MF` (*mu1, sigma1, mu2, sigma2*)  
Bases: `simplful.fuzzy_sets.MF_object`

Creates a double Gaussian membership function.

#### Parameters

- **mu1** – mean of the first distribution.
- **sigma1** – standard deviation of the first distribution.
- **mu2** – mean of the second distribution.
- **sigma2** – standard deviation of the second distribution.

**class** `simplful.fuzzy_sets.FuzzySet` (*points=None, function=None, term="", high\_quality\_interpolate=False, boundary\_values=None, verbose=False*)

Bases: `object`

Creates a new fuzzy set.

#### Parameters

- **points** – list of points to define a polygonal fuzzy sets. Each point is defined as a list of two coordinates in the universe of discourse/membership degree space.
- **function** – function to define a non-polygonal fuzzy set. Supports pre-implemented membership functions `Sigmoid_MF`, `InvSigmoid_MF`, `Gaussian_MF`, `InvGaussian_MF`, `DoubleGaussian_MF`, `Triangle_MF`, `Trapezoidal_MF` or user-defined functions.
- **term** – string representing the linguistic term to be associated to the fuzzy set.
- **high\_quality\_interpolate** – True/False, toggles high quality interpolation for point-based fuzzy sets. Default value is set to False.
- **boundary\_values** – list of two membership values for point-based fuzzy sets. The first and second value are used to fill in values at the left-side and right-side of the fuzzy set, respectively. If None (default value), fuzzy sets will be considered as shouldered.
- **verbose** – True/False, toggles verbose mode.

**get\_term** ()

Return the linguistic term associated to this fuzzy set.

**get\_value** (*v*)

Return the membership value of *v* to this Fuzzy Set.

**Parameters** **v** – element of the universe of discourse.

**Returns** The membership value of *v* to this Fuzzy Set.

**get\_value\_cut** (*v*, *cut*)

Return the membership value of *v* to this Fuzzy Set, capped to the cut value.

**Parameters**

- **v** – element of the universe of discourse.
- **cut** – alpha cut of the fuzzy set.

**set\_points** (*points*)

Changes points of the point-based fuzzy set.

**Parameters** **points** – a list of points to define a polygonal fuzzy sets. Each point is defined as a list of two coordinates in the universe of discourse/membership degree space.

**class** `simpful.fuzzy_sets.GaussianFuzzySet` (*mu*, *sigma*, *term*)

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a new Gaussian fuzzy set.

**Parameters**

- **mu** – mean of the distribution.
- **sigma** – standard deviation of the distribution.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** (*mu=None*, *sigma=None*)

Changes parameters of the Gaussian fuzzy set.

**Parameters**

- **mu** – mean of the distribution.
- **sigma** – standard deviation of the distribution.

**class** `simpful.fuzzy_sets.Gaussian_MF` (*mu*, *sigma*)

Bases: `simpful.fuzzy_sets.MF_object`

Creates a Gaussian membership function.

**Parameters**

- **mu** – mean of the distribution.
- **sigma** – standard deviation of the distribution.

**class** `simpful.fuzzy_sets.InvGaussianFuzzySet` (*mu*, *sigma*, *term*)

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a new inversed Gaussian fuzzy set.

**Parameters**

- **mu** – mean of the distribution.
- **sigma** – standard deviation of the distribution.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** (*mu=None, sigma=None*)

Changes parameters of the inversed Gaussian fuzzy set.

**Parameters**

- **mu** – mean of the distribution.
- **sigma** – standard deviation of the distribution.

**class** `simplful.fuzzy_sets.InvGaussian_MF` (*mu, sigma*)

Bases: `simplful.fuzzy_sets.MF_object`

Creates an inversed Gaussian membership function.

**Parameters**

- **mu** – mean of the distribution.
- **sigma** – standard deviation of the distribution.

**class** `simplful.fuzzy_sets.InvSigmoidFuzzySet` (*c, a, term*)

Bases: `simplful.fuzzy_sets.FuzzySet`

Creates a new inversed sigmoidal fuzzy set.

**Parameters**

- **c** – universe of discourse coordinate of inflection point.
- **a** – steepness of the curve.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** (*c=None, a=None*)

Changes parameters of the inversed sigmoidal fuzzy set.

**Parameters**

- **c** – universe of discourse coordinate of inflection point.
- **a** – steepness of the curve.

**class** `simplful.fuzzy_sets.InvSigmoid_MF` (*c=0, a=1*)

Bases: `simplful.fuzzy_sets.MF_object`

Creates an inversed sigmoid membership function.

**Parameters**

- **c** – universe of discourse coordinate of inflection point.
- **a** – steepness of the curve.

**class** `simplful.fuzzy_sets.SigmoidFuzzySet` (*c, a, term*)

Bases: `simplful.fuzzy_sets.FuzzySet`

Creates a new sigmoidal fuzzy set.

**Parameters**

- **c** – universe of discourse coordinate of inflection point.
- **a** – steepness of the curve.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** (*c=None, a=None*)

Changes parameters of the sigmoidal fuzzy set.

**Parameters**

- **c** – universe of discourse coordinate of inflection point.
- **a** – steepness of the curve.

**class** `simpful.fuzzy_sets.Sigmoid_MF` (*c=0, a=1*)

Bases: `simpful.fuzzy_sets.MF_object`

Creates a sigmoidal membership function.

**Parameters**

- **c** – universe of discourse coordinate of the inflection point.
- **a** – steepness of the curve.

**class** `simpful.fuzzy_sets.SingletonSet` (*pairs, term*)

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a set composed of singletons.

**Parameters**

- **pairs** – a list of pairs [x, y], where x is an element of the universe of discourse and y its membership degree.
- **term** – string representing the linguistic term to be associated to the singletons set.

**set\_params** (*pairs=None*)

Changes the pairs of the singletons set.

**Parameters pairs** – a list of pairs [x, y], where x is an element of the universe of discourse and y its membership degree.

**class** `simpful.fuzzy_sets.Singleton_MF` (*pairs*)

Bases: `simpful.fuzzy_sets.MF_object`

Creates a membership function composed of singletons.

**Parameters pairs** – a list of pairs [x, y], where x is an element of the universe of discourse and y its membership degree.

**class** `simpful.fuzzy_sets.TrapezoidFuzzySet` (*a, b, c, d, term*)

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a new trapezoidal fuzzy set.

**Parameters**

- **a** – universe of discourse coordinate of the leftmost vertex.
- **b** – universe of discourse coordinate of the upper left vertex.
- **c** – universe of discourse coordinate of the upper right vertex.
- **d** – universe of discourse coordinate of the rightmost vertex.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** (*a=None, b=None, c=None, d=None*)

Changes parameters of the trapezoidal fuzzy set.

**Parameters**

- **a** – universe of discourse coordinate of the leftmost vertex.
- **b** – universe of discourse coordinate of the upper left vertex.

- **c** – universe of discourse coordinate of the upper right vertex.
- **d** – universe of discourse coordinate of the rightmost vertex.

**class** `simpful.fuzzy_sets.Trapezoidal_MF` ( $a=0, b=0.25, c=0.75, d=1$ )

Bases: `simpful.fuzzy_sets.MF_object`

Creates a normalized trapezoidal membership function. Requires  $a \leq b \leq c \leq d$ .

#### Parameters

- **a** – universe of discourse coordinate of the leftmost vertex.
- **b** – universe of discourse coordinate of the upper left vertex.
- **c** – universe of discourse coordinate of the upper right vertex.
- **d** – universe of discourse coordinate of the rightmost vertex.

**class** `simpful.fuzzy_sets.TriangleFuzzySet` ( $a, b, c, term$ )

Bases: `simpful.fuzzy_sets.FuzzySet`

Creates a new triangular fuzzy set.

#### Parameters

- **a** – universe of discourse coordinate of the leftmost vertex.
- **b** – universe of discourse coordinate of the upper vertex.
- **c** – universe of discourse coordinate of the rightmost vertex.
- **term** – string representing the linguistic term to be associated to the fuzzy set.

**set\_params** ( $a=None, b=None, c=None$ )

Changes parameters of the triangular fuzzy set.

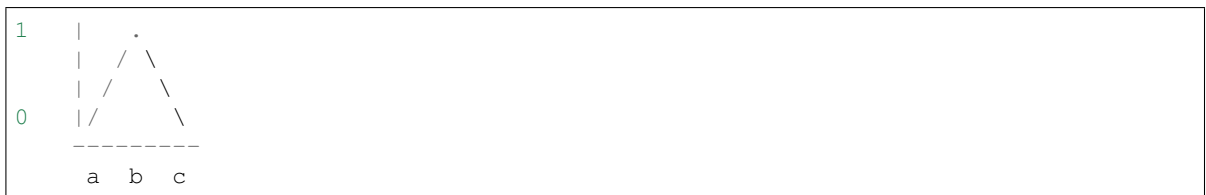
#### Parameters

- **a** – universe of discourse coordinate of the leftmost vertex.
- **b** – universe of discourse coordinate of the upper vertex.
- **c** – universe of discourse coordinate of the rightmost vertex.

**class** `simpful.fuzzy_sets.Triangular_MF` ( $a=0, b=0.5, c=1$ )

Bases: `simpful.fuzzy_sets.MF_object`

Creates a normalized triangular membership function. Requires  $a \leq b \leq c$  and the semantics is the following:



#### Parameters

- **a** – universe of discourse coordinate of the leftmost vertex.
- **b** – universe of discourse coordinate of the upper vertex.
- **c** – universe of discourse coordinate of the rightmost vertex.

## 1.2.3 fuzzy aggregation module

### simpful.fuzzy\_aggregation module

**class** simpful.fuzzy\_aggregation.**FuzzyAggregator** (*verbose=False*)

Bases: object

Creates a new fuzzy aggregation object.

**Parameters** **verbose** – True/False, toggles verbose mode.

**add\_variables** (*\*args*)

Adds variables and their fuzzy sets to perform fuzzy aggregation.

**Parameters** **\*args** – ‘FuzzySet’ objects, whose ‘term’ argument is the name of the variable.

**aggregate** (*variables=None, aggregation\_fun='product'*)

Performs fuzzy aggregation.

**Parameters**

- **variables** – list of variables names to be aggregated. If empty, all added variables are aggregated.
- **aggregation\_fun** – pointer to a fuzzy aggregation function or string name of an implemented aggregation method. Default method is “product”. Currently implemented methods: product, min, max, arit\_mean

**Returns** Numerical result of the aggregation, as provided by the aggregation function.

**set\_variable** (*name, value*)

Sets the numerical value of a variable to be aggregated.

**Parameters**

- **name** – name of the variables to be set.
- **value** – numerical value to be set.



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