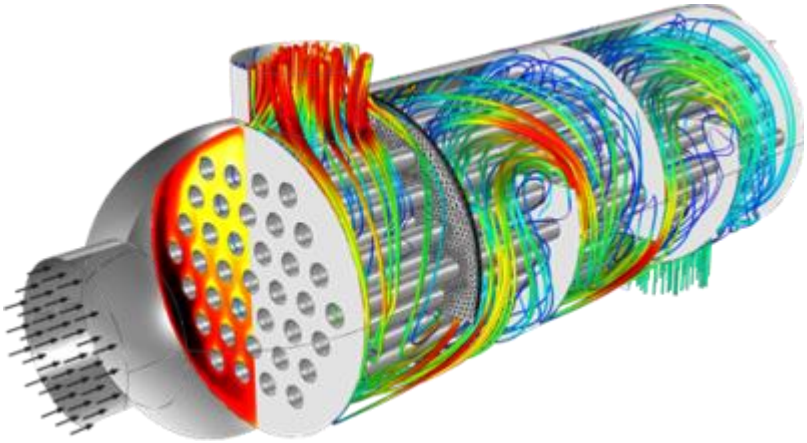
STAFFORDSHIRE UNIVERSITY

# Artificial Intelligence and Machine Learning

## Machine Learning
## Fuzzy Interference Systems
## Coursework 2



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MATLAB

Timothée A.Milhomme --- Artificial Intelligence and Machine Learning --- Academic Year 2020-2021

# Abstract

This report is produced in the module Artificial Intelligence and machine learning at Staffordshire University during the first semester of the academic year 2020-2021 and supervised by C GOONAWARDANE. We will in a first time compare 3 different types of fuzzy clustering to choose the best one. Then we will discuss the difference between the Mamdani and the Sugeno method. Finally, we will do the study of heat exchanger with fuzzy logic. In a fist time we will use a triangular method with both and Mamdani and Sugeno method and secondly with a bell curve method with both Mamdani and Sugeno too. We will analyse and discuss the results of all this methods.

## Contents

# Introduction Research Questions

## Different types of Fuzzy clustering methods

Hard clustering is the method of partitioning point into their respective cluster, each point can be placed in only cluster. When we talk about Fuzzy clustering or soft clustering, we intend that each point can be placed in different clusters with a membership coefficient. In the end we assign the point with the highest membership coefficient into the corresponding cluster [1].

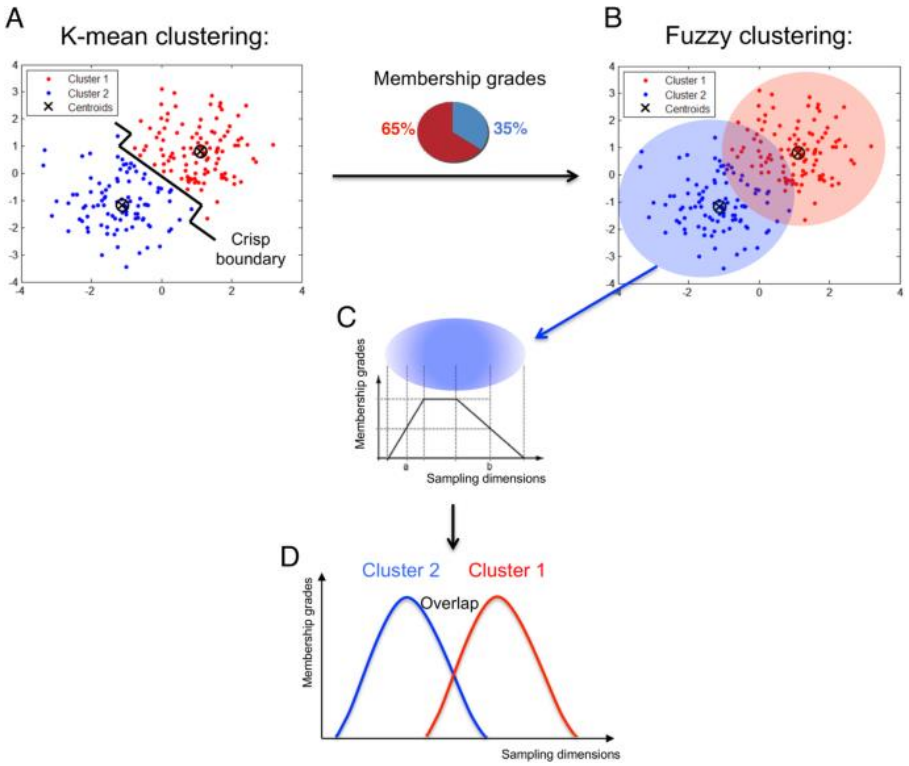


*Figure 1 Difference between hard and soft clustering*

The two classical types of fuzzy clustering are fuzzy c-means [1] (FCM) and Gustafson-Kessel (G-K) algorithm. The two method are alike in the way that they are computing the measured distance to assign the point to each cluster. They are different in the way of computing. FCM uses a norm-inducing identity matrix while G-K compute ethe cluster covariance matrix. There is a third method based on the G-K algorithm, this method doesn't assume the number of clusters and iteratively guess them from 2 to K the maximum number of clusters set by the user.

## Best clustering method

The iterative version of Gustafson-Kessel (G-K) algorithm is overall better than the two other method. The first reason is the GK as a better flexibility toward the input type of data. While not being always the more precise its easy to have a good result with this method without too much pre-processing of the data set. Secondly the iterative method is better because it tries all the possible number of cluster t find the best one. Having an intuition in this field is good but if its possible to try all the possibilities its better. It is important to overestimate the number of maximum clusters, it takes more time but most of the time better result are found.

## Mamdani and Sugeno

### Mamdani

This method was created to build a control system used to synthesize some worded rules from a human operator, by outputting a fuzzy set for each rule. The big advantages of this system are that it is intuitive, well-suited to human input, the results are easily interpretable, and the appearance is widespread.[2]

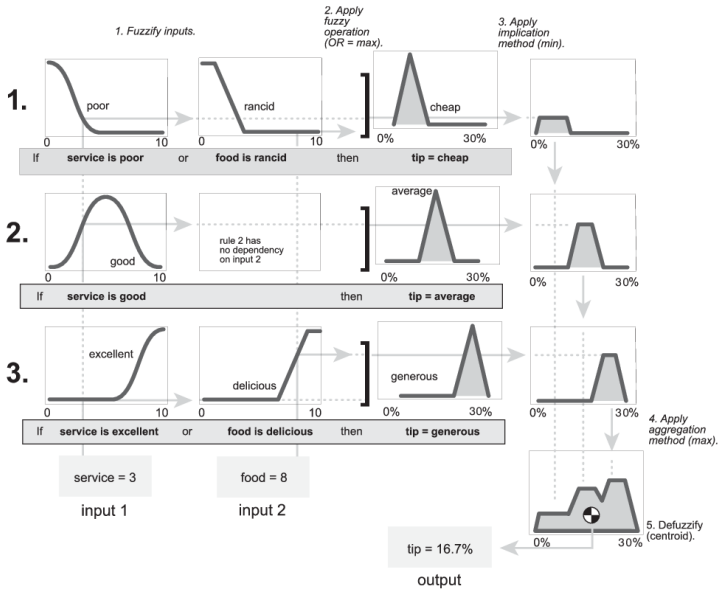


*Figure 2 Mamdani Method*

### Sugeno

The output of the Sugeno fuzzy inference is a singleton constant or linear input of the input values. The computation of this process is more efficient than the Mamdani fuzzy inference system. This technique works better with linear methods like PID (Proportional Integral Derivative). This method is highly customizable and optimizable. The output will be guaranteed to be a surface continuity. TO sum up this method is better for mathematical analysis.[2]

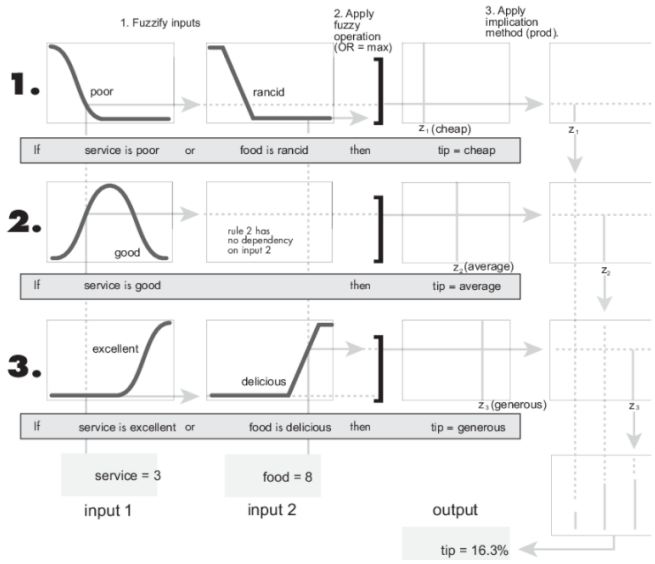


*Figure 3 Sugeno Method*

# First method

In this first part will, ty to solve le following problem:

$$0 < AU \leq 20{,}000 \qquad 1{,}000 < w \leq 2{,}000, \qquad 0 < \Delta T \leq 10$$

The following rules of inference were observed:

**Rule 1:**
If $w$ is (large flow rate) **and** $\Delta T$ is (small approach)
then $AU$ is (large heat exchanger)

**Rule 2:**
If $w$ is (small flow rate) **or** $\Delta T$ is (large approach)
then $AU$ is (small heat exchanger)

**Rule 3:**
If $w$ is (small flow rate) **and** $\Delta T$ is (small approach)
then $AU$ is (large heat exchanger)

## Fuzzification

### Mamdani (1M)

We will consider the following assumptions:

The small approach of ΔT is **smallApp $\epsilon$ [0;5]** and the large is **largeApp $\epsilon$ [5;10]**.

The small flow rate of w is **smallflowrate $\epsilon$ [1000;1500]** and the large is **largeflowrate $\epsilon$ [1500;2000]**.

The small Heat Exchanger AU is **smallHE $\epsilon$ [0;10000]** and the large **largeHE $\epsilon$ [10000;20000]**.

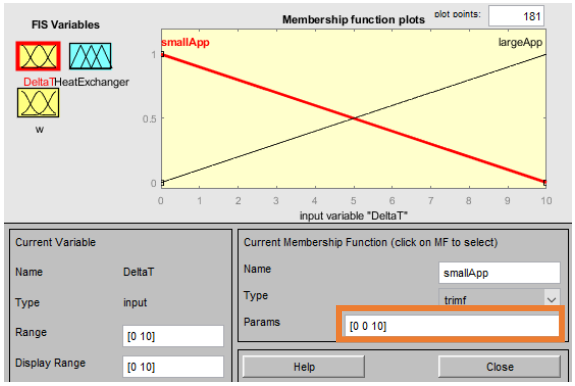


*Figure 5 Membership function temperature 1M*

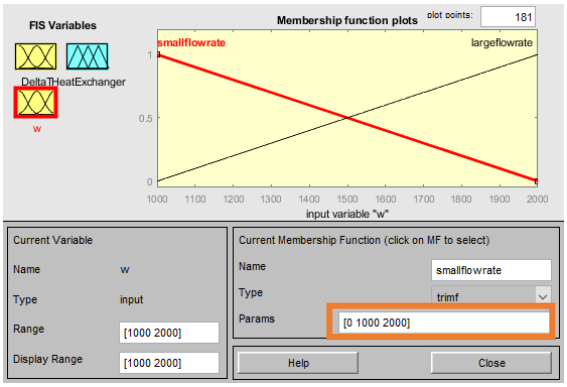


*Figure 4 Membership function mass flow rate 1M*

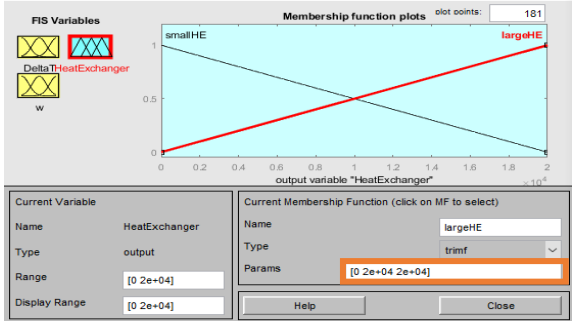


*Figure 6 Membership function heat exchanger 1M*

The membership function used here is the simplest one in Mamdani called triangular membership function. We define 3 the three points of the triangle, the first and the last are the base and the middle one is the top. Here the chosen parameters are circle in orange. The range of each values is the one defined by the problem.

## Sugeno (1S)

For the Sugeno the input is the same the only difference is for the output. We don't define a triangular function to determine the answer but a linear vector in which the data will be contained. The difference will be in the computing, this method is way more customizable, but we will leave the default values for now.

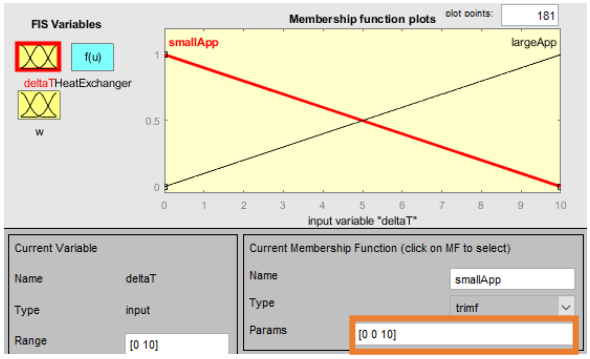


*Figure 8 Membership function temperature 1S*

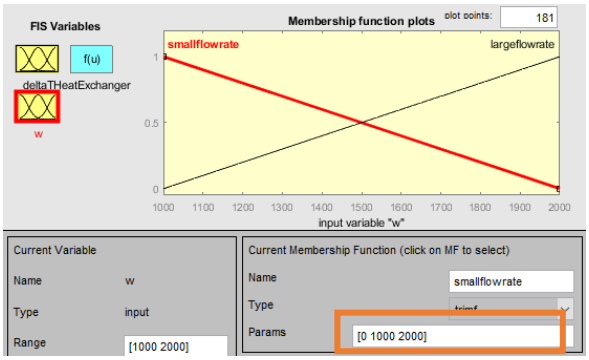


*Figure 7 Membership function mass flow rate 1S*

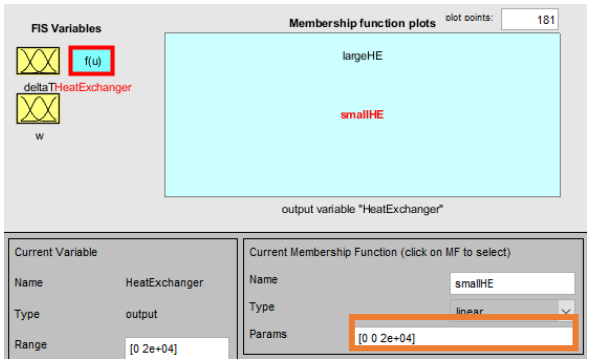


*Figure 9 Membership function heat exchanger 1S*

## Rule Evaluation

This part is the most trivial one because its really verbal we just need to input the rules of the problem in the interface, there is no tricks and the this is the same for both Sugeno and Mamdani.

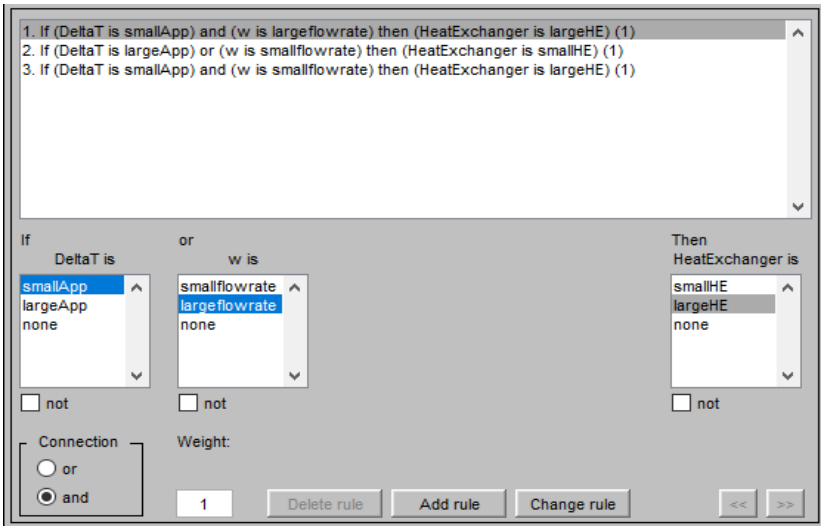


*Figure 10 Rule evaluation*

## Aggregation of the rule outputs

The goal of this part is to unify all the outputs of all the rules. This where MATLAB is very useful because the Fuzzy tool does all the work automatically. It takes all the membership function and all the rules to compute the maximum degree of membership of all the set. Finally, it adds all the membership coefficient together.

## Defuzzification

This part translates all the result found in the fuzzy set into understandable result. We input the value founded in the aggregation of the rule and find the percentage of belonging to a set using the centre of gravity method. This method was seen in class and the formula is:

$$COG = \frac{\int_a^b \mu_A(x)\, x\, dx}{\int_a^b \mu_A(x)\, dx}$$

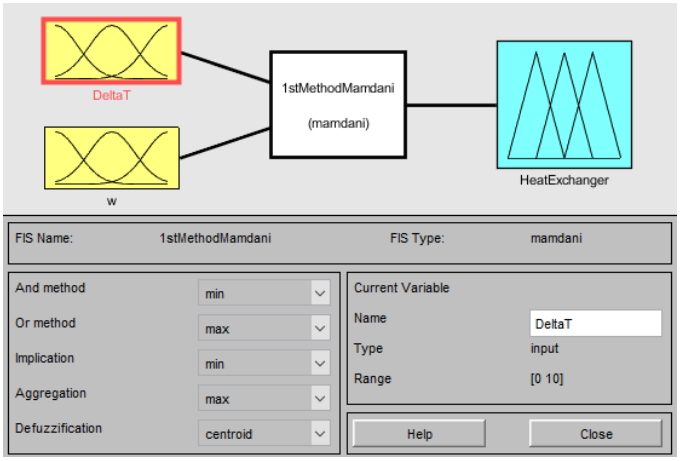


*Figure 11 Mamdani method of defuzzification*

# Second method

## Fuzzification

### Mamdani (2M)

The process here is the same than in the first method the only difference is the way of inputting and outputting the data here we use a bell function which is smoother.

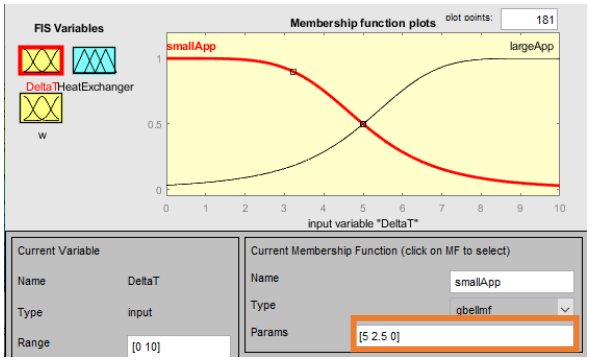


*Figure 13Membership function temperature 2M*

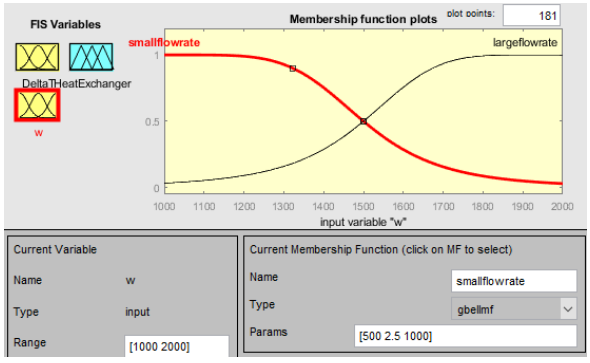


*Figure 12 Membership function mass flow rate 2M*

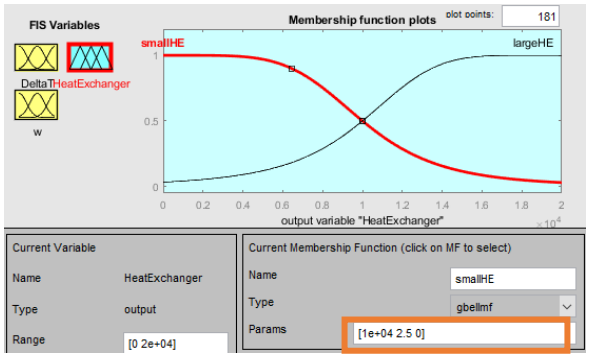


*Figure 14Membership function heat exchanger 2M*

To obtain this bell curve the sum of first and the last parameter must be equal to the point where the curves meet. Then the middle parameter is the tangent of the bell curve at its centre point. This allow to choose how steep the curve is.

## Sugeno (2S)

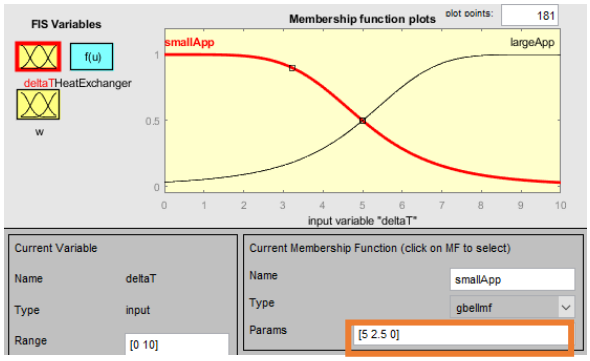


*Figure 16Membership function temperature 2S*

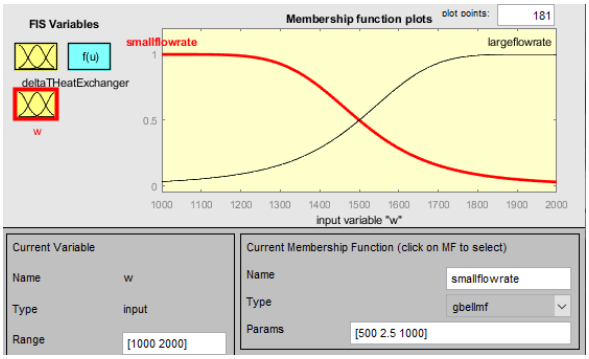


*Figure 15 Membership function mass flow rate 2S*

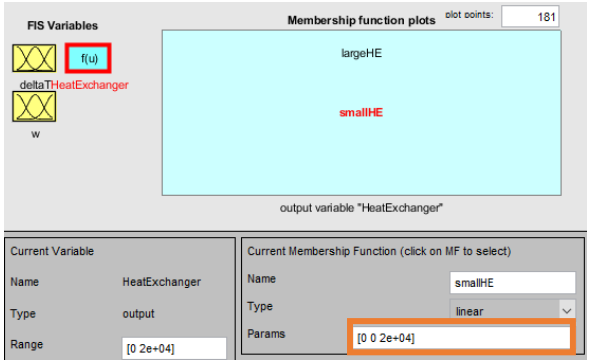


*Figure 17Membership function heat exchanger 2S*

Nothing different here we choose linear to find a result close to the Mamdani result. I don't understand why there is no representation of the curves.

## Analysis and comparison of the results

To test each model, we used the values of temperature 6.5K and 1300kg/s for the flow rate.

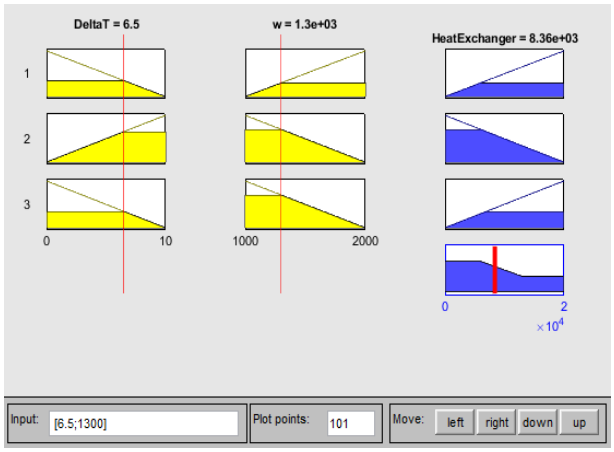


*Figure 24 Rule Viewer 1M*

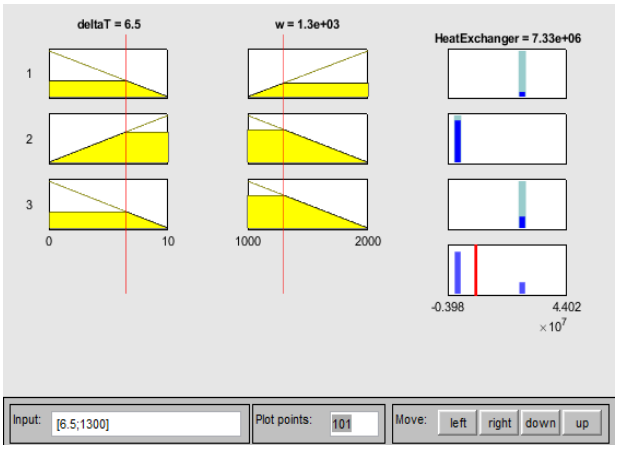


*Figure 25 Rule Viewer 1S*

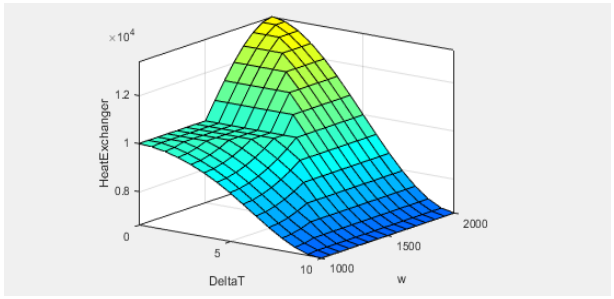


*Figure 23 Surface Viewer 1M*

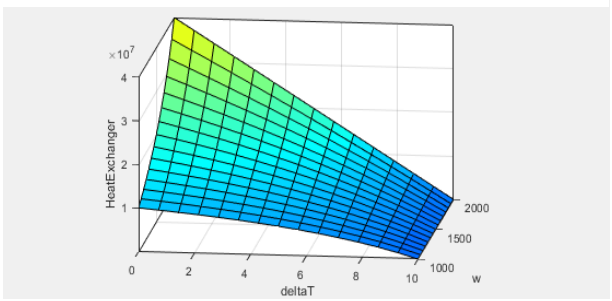


*Figure 22 Surface Viewer 1S*

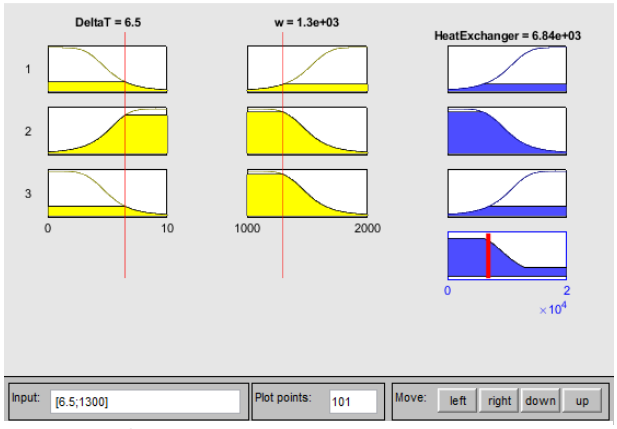


*Figure 21 Rule viewer 2M*

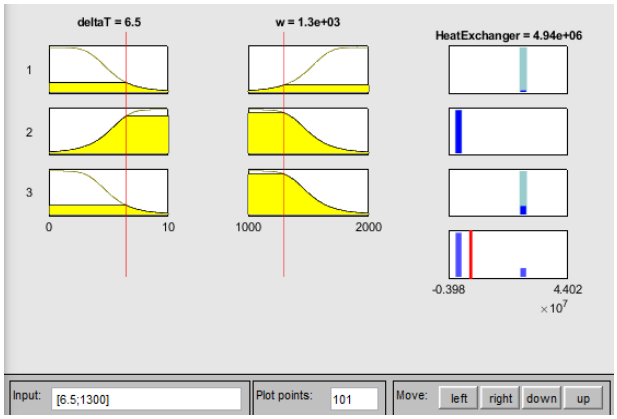


*Figure 19 Rule viewer 2S*

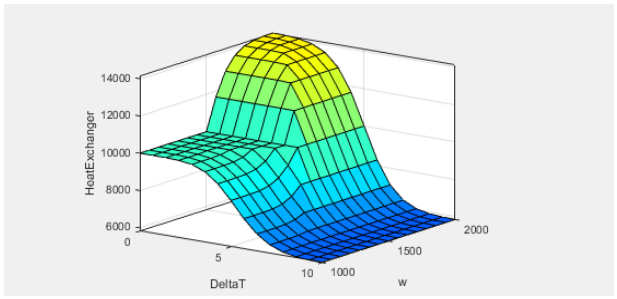


*Figure 20 Surface Viewer 2M*

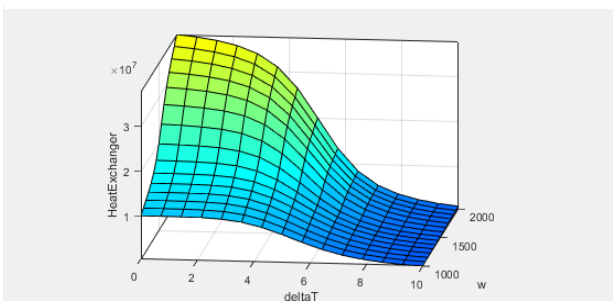


*Figure 18 Surface viewer 2S*

We can observe that the calculation of the centre of gravity is trivial understand in the rule viewer, the presentation makes it clear to see the summing of the rules. I don't understand the result of the Sugeno calculation. The details of this method are to complex for our understanding but produce some smoother results which could be useful in some application. If we look at the surface viewer of the first method, we can see it's a bit sharp for the Mamdani one and too smooth for the Sugeno.

We can also see that the result of the second method is smoother than the first one this is due to the bell curve pricing some smoother outcome, than the triangular input. The Sugeno method is still to smooth. It would be interesting to dive more precisely into the details of the Sugeno method because the result is supposed to be more precise when the all the parameters are master well. It would also be worth it to study the Anfis properties to realise a complete Sugeno method.

## Conclusion

To complete fuzzy logic is a way to study clustering in a different approach. A little bit more intuitive than the hard clustering and a bit less mathematical. Nonetheless the results are good, and it can become more and more mathematical if we go in the details of the Sugeno. We saw that the result of fuzzy logic must be balanced between smooth and accurate to estimate a model precisely. This method is quite visual, and we can understand it rapidly the result are also very visual which help to understand.

# Bibliography

[1] Comparison of Fuzzy Clustering Methods and Their Applications to Geophysics Data, Hindawi, 11th April 2010, by Carl A. Nelson et al.

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[2] Mamdani and Sugeno Fuzzy Inference Systems

https://uk.mathworks.com/help/fuzzy/types-of-fuzzy-inference-systems.html