

IMAT3406 - Fuzzy Logic and Knowledge Based Systems

Fuzzy Inference System

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1 Introduction

For this project there has been a software requirement of an automated ‘smart home’ system that assists in control of a house’s heating system. The implementation should include a fuzzy inference system (FIS) that determines the temperature setting of a room within the house, based upon multiple sensorial and temporal inputs. These inputs will include the day of the year (used to determine the current season), the time of the day, the temperature measured outside in degrees celsius ($^{\circ}\text{C}$), and the current amount of sunlight (lux). These inputs will then be passed into the FIS that will calculate an output that describes the level that the heating system should adjusted to (as a percentage).

The proposed model for the proposed FIS will use a collection of fuzzy ‘if-then’ rules that determine how the system will react to different scenarios throughout the year, such as adjusting heating to higher levels in the winter and lower levels in the summer. These ‘if-then’ rules are then used to determine the level of membership that each input has to a specific fuzzy set, for example determining how ‘warm’ the input temperature of 3°C is (in this case it would have no level of membership as we do not consider 3°C to be ‘warm’). This technique is known as the Mamdani fuzzy inference method; “Mamdani fuzzy systems use fuzzy sets as rule consequent” (Zeng et al. 2000).

An alternative to the Mamdani model would be the Sugeno model. Whereas Mamdani produces an output that is a membership level of a fuzzy set, Sugeno produces an output that is a constant or linear weighted mathematical expression. However, as Al-Jarrah and Abu-Qdais outlined, Mamdani is “the most suitable model when encoding experts opinion in which their consequences are expressed as linguistic variables” (Al-Jarrah and Abu-Qdais 2006). As the specification for this project required the use of “expert knowledge to determine the temperature setting of a room”, we can see that this requires an experts opinion to map consequences as a temperature setting, therefore identifying that Mamdani is the most suitable model for the project.

With the fuzzy model defined, we must then select an appropriate defuzzification method to extract a real temperature output from the fuzzified information. This will be chosen later in the paper, after the testing phase, as we will test our model with five different defuzzification methods to identify the most appropriate and reliable method for the system.

2 Methodology

2.1 Input Variables

As described in the introduction, the FIS will use a multitude of sensorial and temporal inputs to provide all relevant information for the system to make an accurate calculation when adjusting the heating system.

2.1.1 Day of the Year

The day of the year will be provided to the FIS as an integer between 1 and 365. The FIS will use the value provided and calculate the level of membership the current day has to a 'season'. The function used to produce the fuzzy sets is the Gaussian function that will provide a symmetric curve shape, peaking in the middle of the season. This contradicts most peoples perceptions of a season, as traditionally seasons have specific start and end dates. However we know that if we had a specific cut off date, as tradition suggests, the next day realistically will not actually have a drastic change in outdoor temperature, but using the traditional cut off system would result in a drastically different output temperature from one day to the next. For this reason the Gaussian function was selected to provide a smooth transition between seasons.

- **Start of Winter** - The start of Winter is considered to peak on January 1st, the start of the year.
- **Spring** - The Spring season peaks on April 1st, the first quarter of the year.
- **Summer** - The Summer season peaks on July 2nd, exactly half way into the year.
- **Autumn** - The Autumn season peaks on October 1st, three quarters into the year.
- **End of Winter** - The start of Winter is considered to peak on December 31st, the end of the year.

2.1.2 Time of the Day

The current time of the day will be provided to the FIS as an integer between 0 and 1440 as a measurement of minutes (1440 minutes being 24 hours). The time of the day will then be used to calculate the level of membership the current time has to a 'time of day category'. Similarly to the seasons in the previous input variable, the time of day is implemented using a Gaussian function to provide a smooth transition between the categories. Again, this may seem contradictory to what people traditionally interpret (as one would instantly say that midday is over as soon as 12:01pm hits), however this smooth transition provides a more reliable output when calculated using the FIS and avoids sudden changes in output temperature.

The categories for time of day include:

- **Start of Midnight** - Peaking at 12am.
- **Dawn** - Peaking at 5am.
- **Morning** - Peaking at 9am.
- **Midday** - Peaking at 12pm.
- **Evening** - Peaking at 5pm.
- **Night** - Peaking at 9pm.
- **End of Midnight** - Peaking at 12am.

2.1.3 Outside Temperature

The temperature measured outside of the house will also be provided to the FIS, allowing the system a point of reference as an acceptable temperature given how hot it actually is outside of the system itself. The recorded temperatures (provided in degrees Celsius), will then be fuzzified into six different sets that cover values from -25°C to 40°C . Unlike the previous two inputs, these sets are defined using trapezoidal rules, allowing us to specify specified values that a temperature stops being part of a set. As there is a lower range (65°C) compared to the two previous inputs (365 days & 1440 minutes), it is easier to manually define sets and ensure that the transition is smooth based on our own knowledge, ensuring that no part of the 65°C range is left uncategorised.

- **Freezing** - Starting at -25°C and continuing till -10°C , then decreasing until 0°C .
- **Cold** - Starting at -10°C , peaking at 0°C , continuing fully until 3°C , then decreasing until 10°C .
- **Mild** - Starting at 3°C , peaking at 10°C , continuing fully until 15°C , then decreasing until 20°C .
- **Warm** - Starting at 15°C , peaking at 22°C , continuing fully until 25°C , then decreasing until 28°C .
- **Hot** - Starting at 25°C , peaking at 28°C , continuing fully until 30°C , then decreasing until 32°C .
- **Boiling** - Starting at 30°C , peaking at 32°C , continuing fully until 40°C .

2.1.4 Sunlight

The sunlight is provided to the system as an integer measurement of ‘lux’, a unit that describes luminosity. Using values provided by Microsoft, we see that the categories for lux measurement range from pitch black (0 lux) to direct sunlight (100,000 lux) (Microsoft 2015).

Studying the values provided by Microsoft, we can quickly identify that the amount of categories that they provide is somewhat cumbersome, but may still be collated to provide a smaller subset of categories.

- **Pitch Black**

Starting at 0 lux, continuing to 300 lux, then decreasing till 400 lux. On the table provided by Microsoft, this includes categories ‘Pitch Black’, ‘Very Dark’, ‘Dark Indoors’, and ‘Dim Indoors’.

- **Clear**

Starting at 350 lux, increasing until 400 lux, continuing to 5000 lux, then decreasing till 5100 lux. On the table provided by Microsoft, this includes categories ‘Normal Indoors’, and ‘Bright Indoors’.

- **Cloudy**

Starting at 4900 lux, increasing until 5000 lux, continuing to 30,000 lux, then decreasing till 30,100 lux. On the table provided by Microsoft, this includes categories ‘Dim Outdoors’, and ‘Cloudy Outdoors’.

- **Direct Sunlight**

Starting at 29,000 lux, increasing until 30,000 lux, continuing to 100,000 lux. On the table provided by Microsoft, this corresponds to the ‘Direct Sunlight’ category.

2.2 Output Variable

As described in the introduction, the output from the FIS will be a fuzzy set that describes a percentage of how much the heating should be on. Similarly to the first two input variables, the fuzzy sets that define the heating options are created using a Gaussian function to provide a smooth transition between heating options, ensuring that there is not a sudden jump when transitioning from one heating setting to the next.

- **Off** - 0%
- **Low** - 25%
- **Medium** - 50%
- **High** - 75%
- **Full Power** - 100%

2.3 Ruleset

With the fuzzy sets defined, we must now be able to fuzzify the input data and select how it will fall into a specific set. This will be accomplished with the ‘if-then’ fuzzy rules that the Mamdani model provides.

The list of rules, shown in Appendix A, provides the system with the ability to make decisions for the output based on the inputs it is provided with. The logic the FIS uses allows us to apply specific effects when a set of criteria have been met. For example, if at any time the system has been told that it is ‘boiling’ outside, the FIS will respond by turning the heating to the ‘off’ setting.

A full outline of the rules is shown below:

- **Global Rules**

These rules apply globally to the system and have only one specific criteria. They cover scenarios in which the system has detected it is freezing outside (between -25°C and 0°C) or when it is boiling (between 30°C and 40°C). The system will react by either turning the heating to maximum in the case of freezing, or minimum in the case of boiling.

- **Winter Rules**

The winter rules apply only when the system is told that the current season is winter. It will react by checking the current temperature outside and increasing its own temperature if appropriate.

- **Summer Rules**

In a similar but opposite fashion to the winter rules, the summer rules check for higher temperatures and lower the output temperature when appropriate.

- **Spring/Autumn Rules**

These rules apply only when it is spring or autumn. They are identical but opposite rules, as spring can be seen going from a cold season to a warm one, whereas autumn is the opposite.

- **Energy Conservation Rules**

The final set of rules allow the system to conserve energy when it is possible. This is achieved by turning the heating off during hours that the people in the house would typically be asleep, as we would not need to heat the house when the owners are in their beds. However, once dawn occurs it will then slowly begin to heat the house, elevating the output more so when morning hits. This ensures that the homeowners will not wake up to a house that is still freezing cold.

2.4 Testing

For the testing section we will use a variety of different input data, stored within an excel spreadsheet file, that the system will interpret and parse accordingly. This data will then be processed through the FIS which will then apply one of the five defuzzification methods that MATLAB offers. These include the middle, smallest, and largest of maximum, as well as the centroid and bisector methods.

After testing is complete, we will be able to assess and identify the most appropriate defuzzification method, as well as rectify any issues that occurred with specific input data during testing.

The full test results can be found in Appendix B.

2.5 Defuzzification Method

Looking at the test results and the outputs they produce, we can observe that MOM, SOM, and LOM all produce an output with very steep and sharp changes. This would provide the system with sudden changes and not provide a smooth transition when specifying the temperature setting.

Both the Centroid and Bisector defuzzification methods provide a much smoother transition in settings than the previously assessed methods, however the Centroid method seems to provide the most appropriate and accurate output results and has therefore been chosen as the defuzzification method for the system.

3 Conclusion

Overall the product performs very well and applies to the specification given. The implementation shows the success of a test driven development environment that allowed us to make key decisions for the system before deployment. This allowed us to assess and identify the most appropriate choices for the product before it being rolled out to users. The use of academic literature also helped to ensure that the choices being made, prior to development, were informed and in the best interest of the project's success.

Given further development time, testing could be expanded and the effectiveness of the Sugeno model could be explored. However, due to time constraints and with the assistance of academic advice, it was not explored in this report.

Further rules could also be added to the system to deal with extraordinary circumstances, however the addition of more rules would have increased the product's overall complexity and require a much larger set of test data. As a result of this, further time would have been taken from development in order to test the system correctly, therefore the set of rules was kept to a low, manageable number that also provides a good representation of the system's performance. Real life data could prove useful in future testing, using data from days of the year that actually occurred in the real world, as opposed to data that was simply simulated.

Appendices

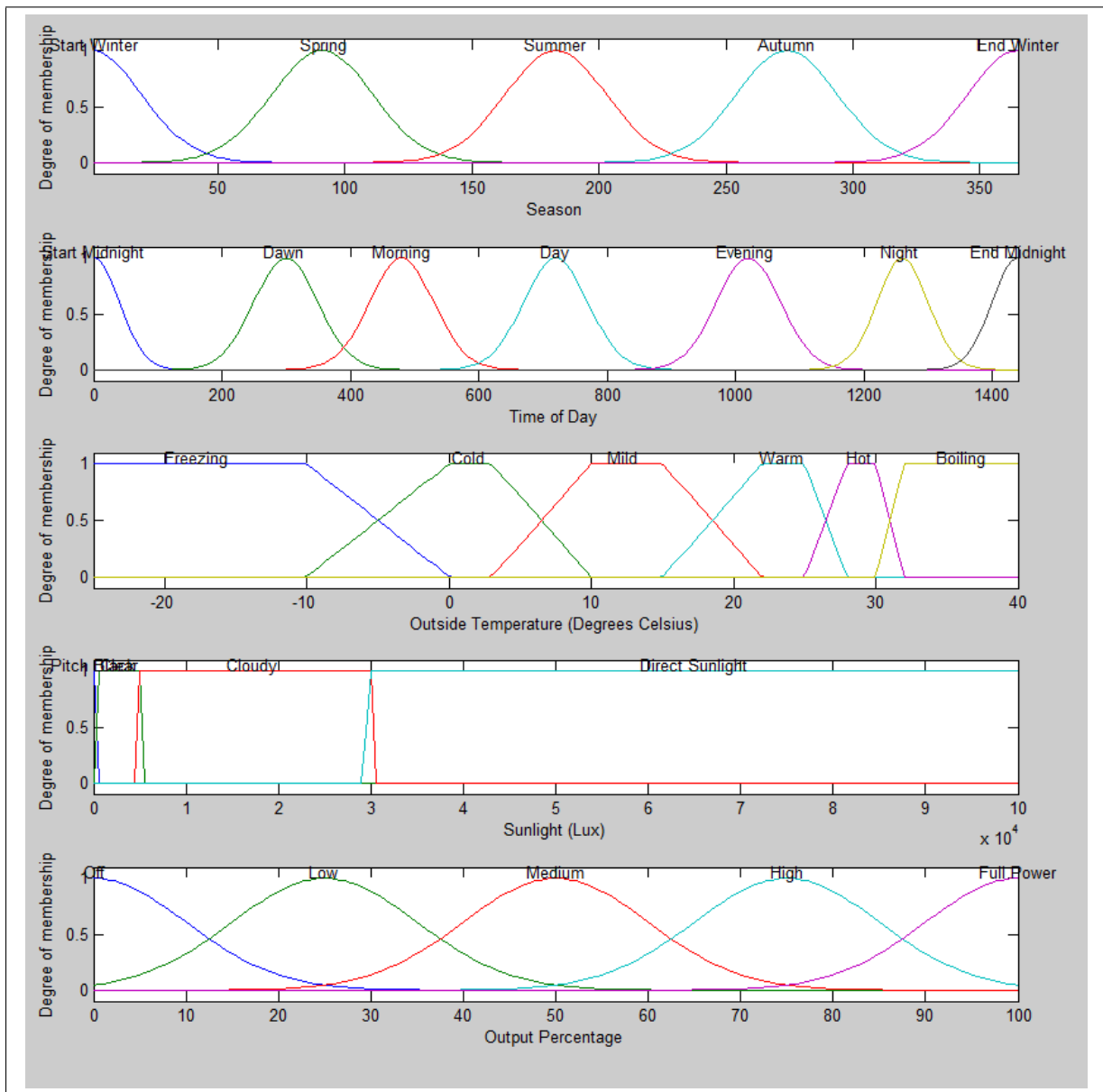
A Ruleset

```
1 % Global rules
2 boiling_rule = [ 0 0 6 0 1 1 0 ]; % Whenever it is boiling, turn heating off
3 freezing_rule = [ 0 0 1 0 5 1 0 ]; % Whenever it is freezing, turn heating to
   full power
4
5 % Winter Rules
6 start_of_winter_freezing = [1 0 1 0 5 1 2]; % During the start of Winter when
   the temperature is freezing, set output to Very High
7 end_of_winter_freezing = [5 0 1 0 5 1 2]; % During the end of Winter when the
   temperature is freezing, set output to Very High
8
9 % Summer Rules
10 summer_hot = [3 0 5 0 1 1 2]; % During the Summer, or whenever it is Hot, set
   output to Very Low
11 summer_warm = [3 4 4 0 2 1 1]; % During the Summer, when it is Warm, set output
   to Low
12
13 % Spring Rules
14 spring_end_midnight = [2 1 2 1 4 1 1]; % At the end of midnight in Spring, when
   temperature is Cold and there is no light, set output to High
15 spring_start_midnight = [2 7 2 1 4 1 1]; % At the start of midnight in Spring,
   when the temperature is Cold and there is no light, set output to High
16 spring_mild_morning = [2 3 3 2 3 1 1]; % During the morning in Spring, when the
   temperature is Mild and it is a clear day, set output to Medium
17 spring_warm_midday = [2 4 4 2 2 1 1]; % At midday in Spring, when the
   temperature is Warm and it is a clear day, set output to Low
18 spring_mild_evening = [2 5 3 2 3 1 1]; % During the evening in Spring, when the
   temperature is Mild and it is a clear day, set output to Medium
19
20 % Autumn Rules
21 autumn_end_midnight = [4 1 2 1 4 1 1]; % At the end of midnight in Autumn, when
   the temperature is Cold and there is no light, set output to High
22 autumn_start_midnight = [4 7 2 1 4 1 1]; % At the start of midnight in Autumn,
   when the temperature is cold and there is no light, set output to High
23 autumn_mild_morning = [4 3 3 2 3 1 1]; % During the morning in Autumn, when the
   temperature is Mild and it is a clear day, set output to Medium
24 autumn_warm_midday = [4 4 4 2 2 1 1]; % At midday in Autumn, when the
   temperature is Warm and it is a clear day, set output to Low
25 autumn_mild_evening = [4 5 3 2 3 1 1]; % During the evening in Autumn, when the
   temperature is Mild and it is a clear day, set output to Medium
26
27 % Energy Conservation Rules
28 energy_conserve_rule_start_midnight = [ 0 1 0 0 1 1 1 ];
29 energy_conserve_rule_end_midnight = [ 0 7 0 0 1 1 1 ];
30 energy_conserve_rule_dawn = [ 0 2 0 0 1 1 1 ];
```

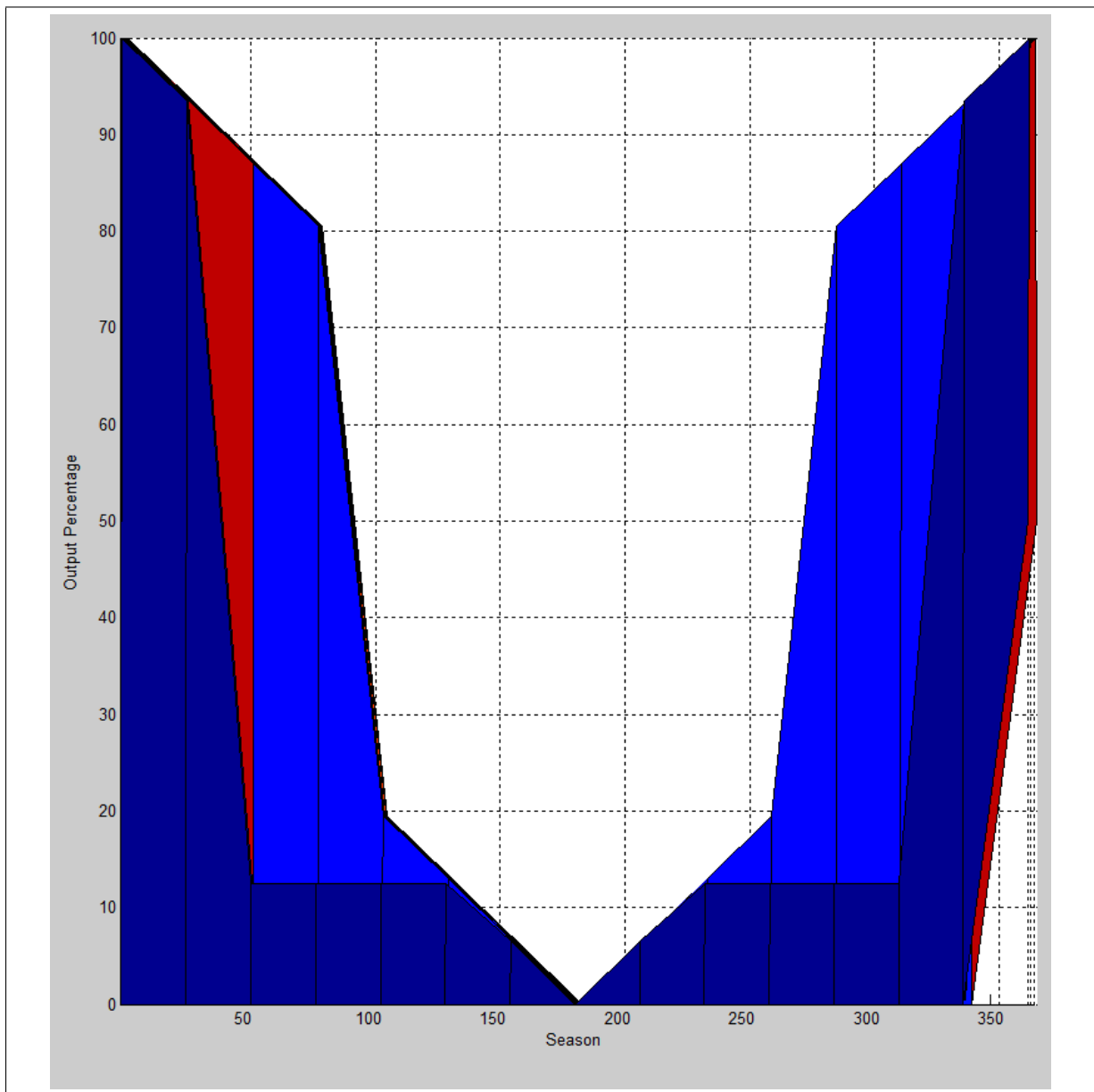
B Test Results

Rule	Input Variables				Output Variables				
	Day	Time	Temp.	Light	MOM	SOM	LOM	Centroid	Bisec.
boiling	183	1200	40	3,500	0	0	0	7.67	6
freezing	1	1200	-25	0	100	100	100	92.33	94
summer_hot	183	1200	28	3,500	0	0	0	7.67	6
summer_warm	183	1200	24	3,500	0	0	0	7.67	6
start_of_winter	365	0	-25	0	50	0	100	50	50
end_of_winter	365	1200	-25	3,500	100	100	100	92.33	94
spring_midnight	91	0	0	0	37.5	0	75	51.78	68
spring_morning	91	540	5	3,500	50	35	65	50	50
spring_midday	91	720	15	3,500	77.5	55	100	52.98	57
spring_evening	91	1020	5	3,500	50	35	65	50	50
autumn_midnight	274	0	0	0	37.5	0	75	51.78	68
autumn_morning	274	540	5	3,500	50	35	65	50	50
autumn_midday	274	720	15	3,500	50	0	100	50	50
autumn_evening	274	1020	5	3,500	50	35	65	50	50

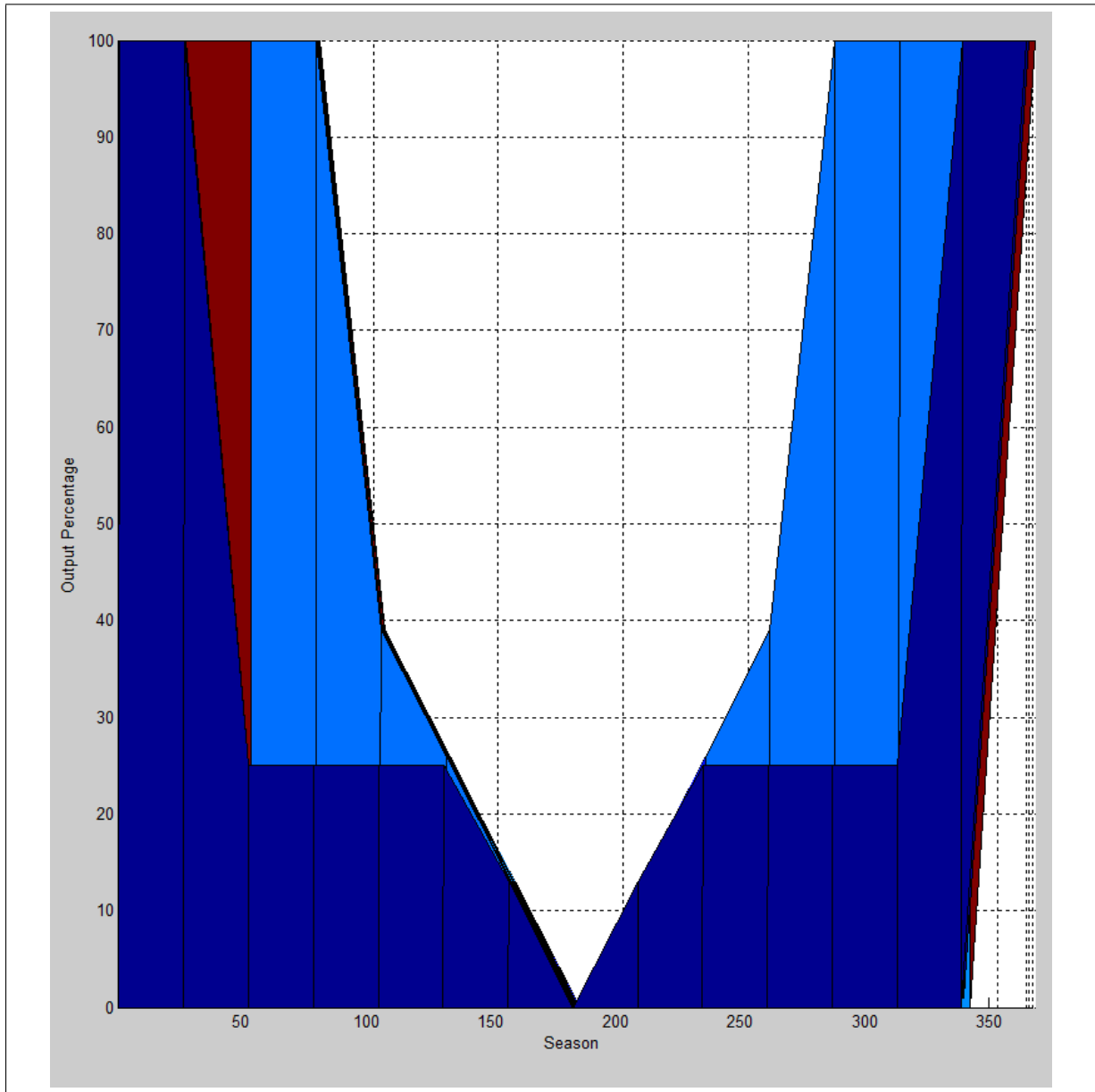
C Fuzzy Sets



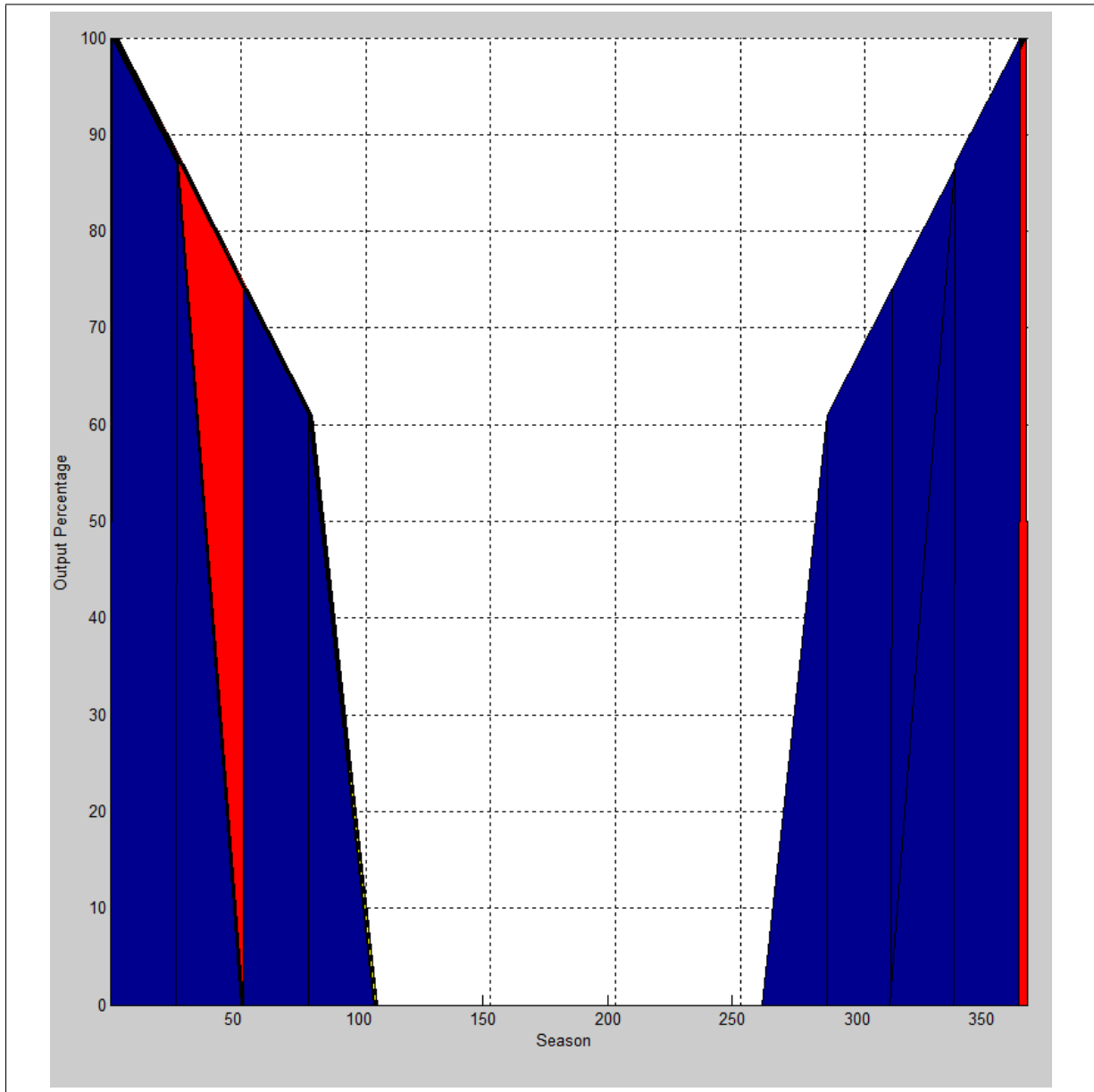
D Middle of Maximum Defuzzification Method



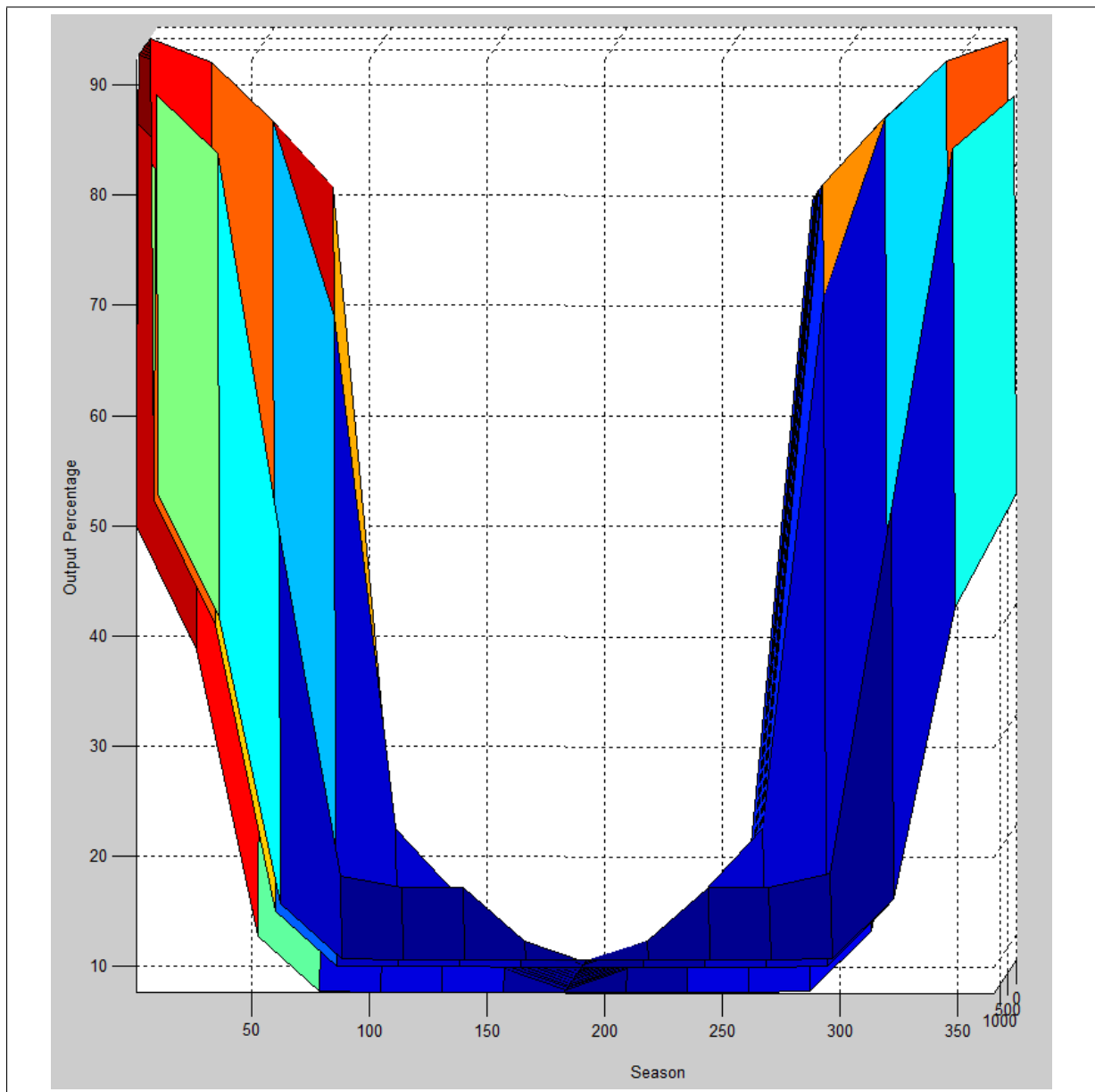
E Largest of Maximum Defuzzification Method



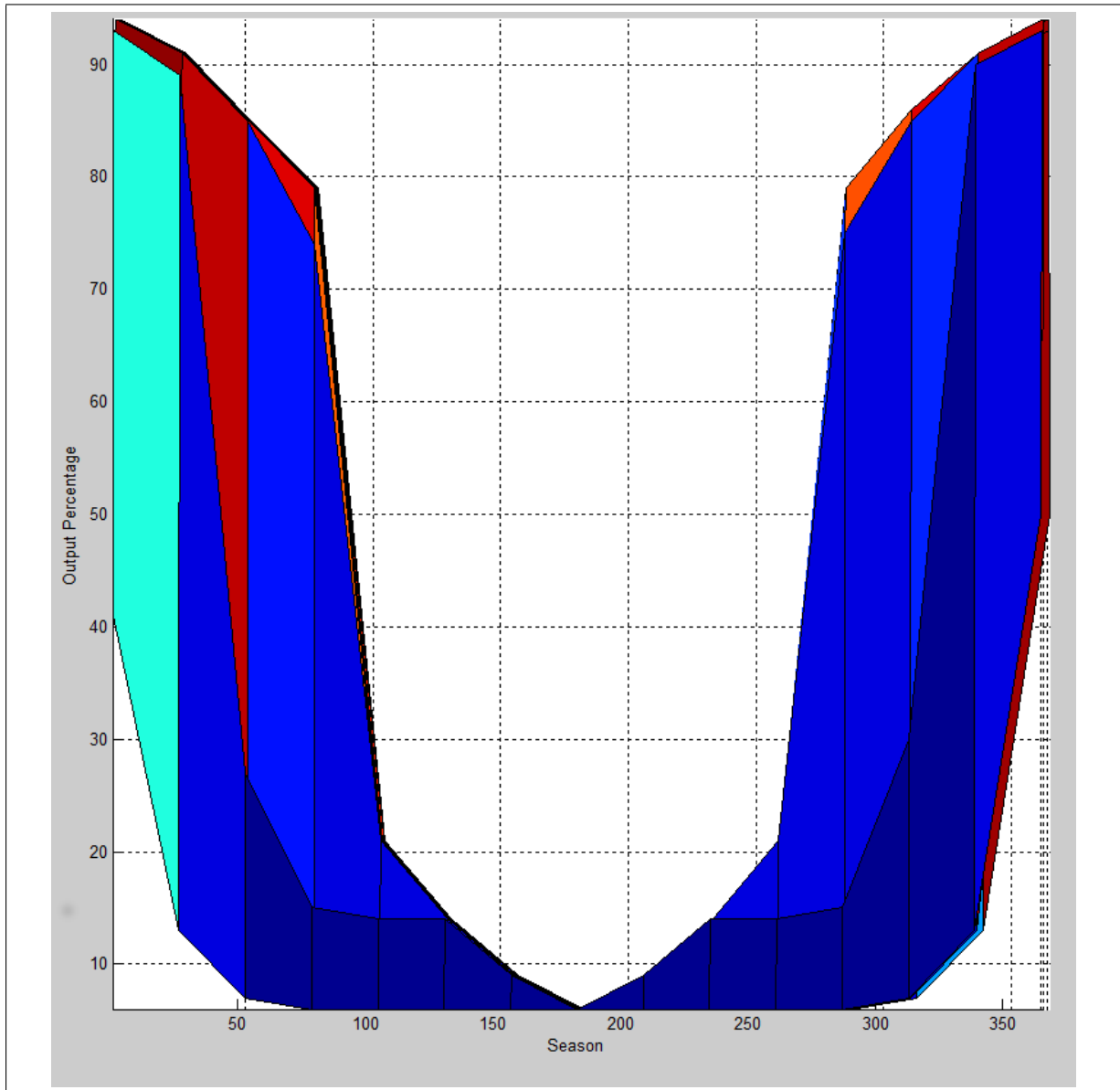
F Smallest of Maximum Defuzzification Method



G Centroid Defuzzification Method



H Bisector Defuzzification Method



References

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Acronyms

- FIS** fuzzy inference system. 1–6
- LOM** largest of maximum. 6, 8
- MOM** middle of maximum. 6, 8
- SOM** smallest of maximum. 6, 8