Designing and Tuning a Fuzzy Inference System

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Introduction

The task in this coursework was to build a Fuzzy Inference System (FIS) that gives advice to doctors when a patient needs to be referred to a hospital for emergency using two simple metrics: the patient's temperature and the severity of their headache. After some research, it was concluded that both abnormally low or high core body temperatures (extreme hypothermia or hyperthermia) are very serious health issues even in the absence of other symptoms, while a headache is a less serious problem on its own. However, when temperature deviates from normal values, combined with a headache, might indicate a more severe health issue and the patient should seek medical attention as soon as possible. The FIS that was implemented is using this rule of thumb to provide advice based on the available biological data.

To evaluate the constructed inference systems two methods were used. The first one was to look at the 3D output surface of the system. Although there is a built-in function in the fuzzy toolkit that generates the output surface, it was hard to evaluate the FIS, as it would only show the surface from one angle, and the colours were misleading. Therefore, a modified version of the function was created that uses the library rgl, which provided an interactive 3D plot of the surface. Furthermore, the colouring was changed so that the contours of the surface could be seen from any angle, and another parameter was added to improve the resolution of the generated plot. The trade-off is that the evaluation of the FIS would take longer when generating high-resolution 3D plots. However, this was acceptable as this modification provided a way to iterate over many different configurations, and it made it easy to get a quick overview of the FIS' performance. The aim of this method was to look at the transitions in output values when the input values only change slightly.

The second method was to calculate the root-mean-square error (RMSE) of a FIS. This was done by establishing a few predefined target input-output value pairs. These value pairs were set by following the basic ruleset described before. As opposed to the first method, the main goal here was to evaluate the performance of the FIS in edge cases, such as extreme hypothermia combined with a severe headache.

Initial Experiments

Only considering temperatures

The first FIS that was created only utilised the temperature metric to produce an output (rules in Appendix 1). The reasoning behind this is that this provided a way to get familiar with the API of the Fuzzy Toolkit and to create a stepping stone that can be improved upon. Since not every patient is the same and therefore different temperature values can be considered normal for different patients, an arbitrary scale of

0 to 10 (0 – hypothermia, 5 – normal, 10 – hyperthermia) was utilised. This way the system's normal temperature range can be adjusted based on each patient's medical records (this task might be automatized by another FIS). To create this FIS five terms were used to represent the input variable temperature (very low, low, normal, high, very high), three terms for the input variable headache (low, mild, severe), and three terms for the output variable urgency (low, medium, emergency). The membership functions were Gaussian, spread out evenly both for temperature and urgency. Trapezoidal membership functions were used for headache, as this representation seemed more in line with the semantic meaning of the terms assigned to represent this variable. An additional membership function was added to both variables, undefined, which allowed to create rules that only depend on one variable.

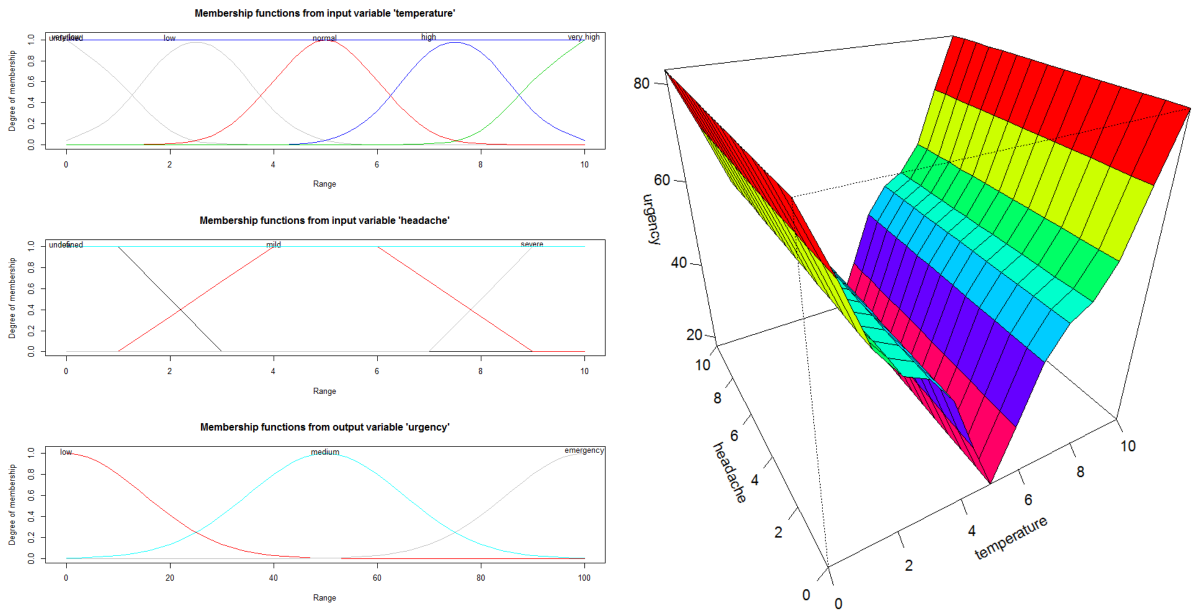

Figure 1 Membership values and output surface of FIS1

It is easy to see that this was not the most performant FIS, with a RMSE of about 30. However, it proved to be a great starting point as this showed the general shape of the output surface that was to be achieved.

Adding headache dependent rules

The next obvious step was to add some rules that use headache values in combination with temperature. Rules were added, so that it would make for a gradual increase with respect to the headache value (Appendix 2). However, the rules for extreme temperature deviation were left intact as this condition is severe enough on its own, to justify immediate medical attention.

The resulting output surface is shown on the right. This FIS performed a lot better than the initial, with a RMSE of about 17. The main issue with the output is that it underestimates the seriousness of a severe headache but it overestimates the seriousness of temperature deviation.

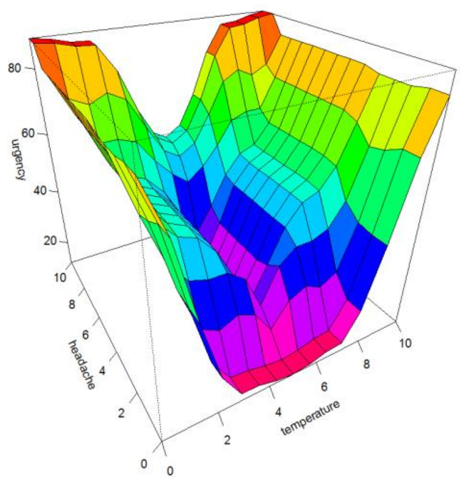

Figure 2 Using headache dependent rules

Extending headache terms

To improve the granularity of the previous FIS two more headache terms were introduced to the system (very low, very severe), and the membership functions were changed to Gaussian as it seemed easier to distribute the terms evenly with this function type, as opposed to trapezoidal ones. The rules were updated to work with the extended number of terms (Appendix 3). The resulting FIS is shown below.

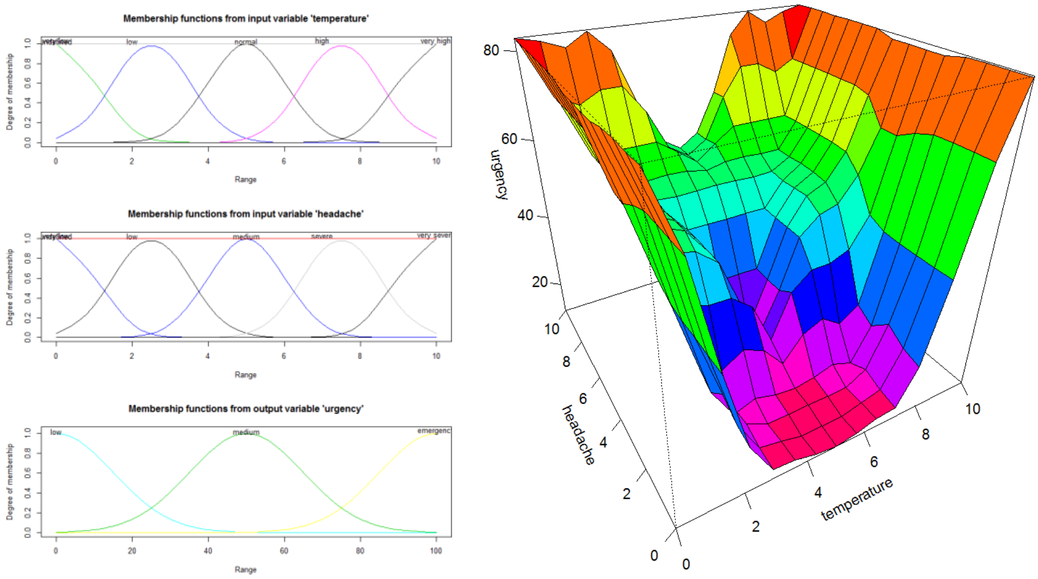

Figure 3 Result of adding two extra headache terms

Even though the RMSE performance got better, decreasing to 15.5, the overall shape of the surface remained the same, and therefore this change would not resolve the under/overestimation problem of the previous system.

Adding more output terms

After the last attempt, it became clear that the overall granularity of the system could only be improved if more output terms are added. Two more terms were added to urgency (very low, high), and the rules were changed accordingly, to represent a gradual increase in severity (Appendix 4).

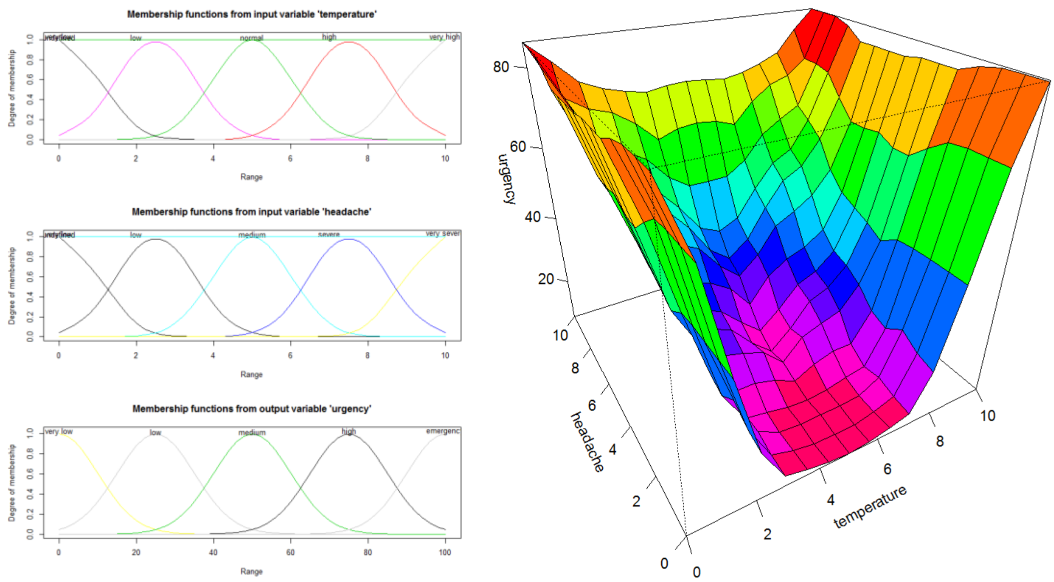

Figure 4 FIS with five output terms

Not surprisingly, this solution provided great results, reducing the RMSE to 14. Although, this FIS is very close to what the requirements suggest, it is still quite problematic. The main issue is that the most serious conditions only reach about 83 when defuzzified, which would indicate a less serious problem, as the target output should reach values close to 100. Furthermore, the normal state (i.e. temperature: 5, headache: 0), gets 8, which again should be somewhat lower. An ideal FIS would have a much sharper transition towards edge cases.

Tweaking membership functions

To improve on the last FIS several more or less successful experiments were conducted. Most of these experiments only changed a few parameters in the FIS, like adjusting rule weights, or slightly adjusting membership function parameters. In one such experiment, the headache terms were changed to utilise triangle membership functions. In the other two variables, the Gaussian shoulder functions were adjusted to reach the value of 1 faster, that is, to make them look like exponential functions. Furthermore, the low and high functions in temperature were moved further from normal, as the term normal tends to cover a wider range of temperatures than the other two. All of these adjustments were made to provide a better representation of the semantics of the terms they stand for.

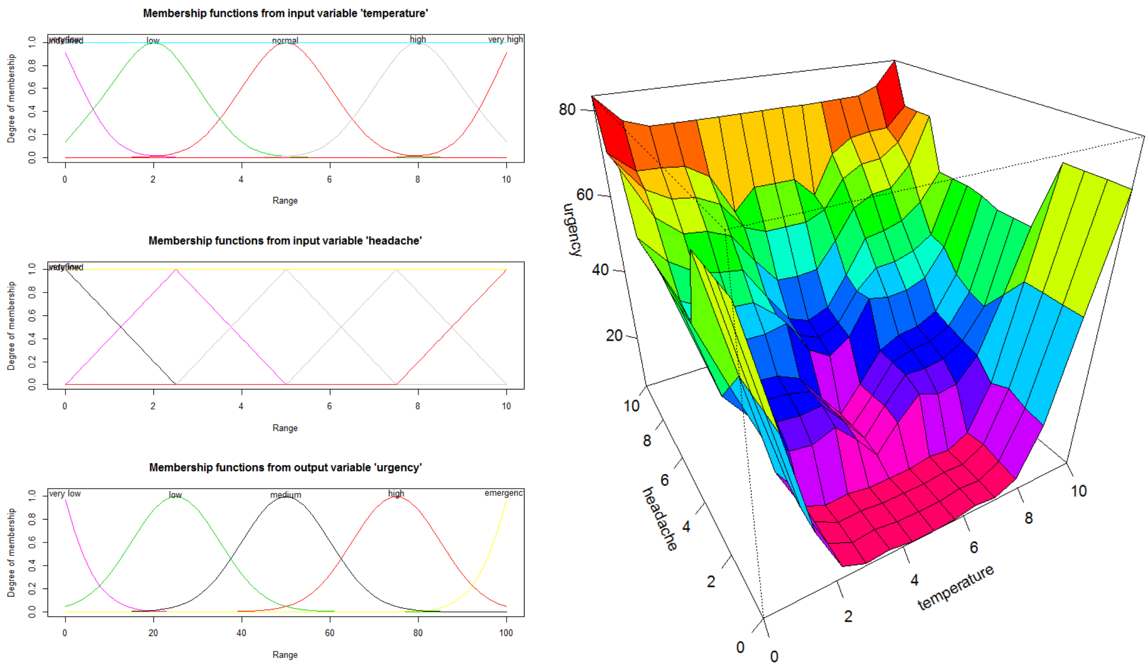

Figure 5 FIS resulting from adjusting membership functions

Surprisingly, these adjustments did not prove to be useful, increasing the RMSE to 22.5. Nevertheless, a few more experiments were carried out on this FIS, as some parts of it were very convincing, such as the high urgency for very severe headaches and the steep curves for extreme temperatures. However, the rules were lacking, as the system ranks a very wide range of values as not urgent at all.

Adjusting rules

By adjusting the rules to consider headaches with a higher impact (Appendix 5), the surface on the right was achieved. Even though this solution has a better RMSE (17), the surface still does not fit the requirements established at the start. The issue here is that this system would give a score of 56 urgency for someone with a body temperature of 22 °C, but only a slight headache (probably only a slight headache because the person is barely conscious). Another issue is that normal values have been completely eradicated, as even small deviations from normal values would be scored at least 20 on the urgency scale. After some other adjustments on rule weightings, and other small parameters, the surface still would not fit the set requirements.

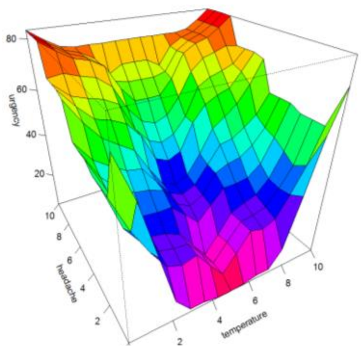

Figure 6 Increased headache weighting

Final FIS – adjusting the defuzzification method

On the brink of giving up, and reverting the FIS to two commits earlier, the only remaining parameters of the system were adjusted, which defines how the FIS converts the values of the membership functions to crisp values. After experimenting with several methods of applying AND, OR, implication and defuzzification one solution stood out. This system uses the bisector method for defuzzification and product instead of minimum for implication. The built-in and custom 3D surface of the resulting FIS is shown below.

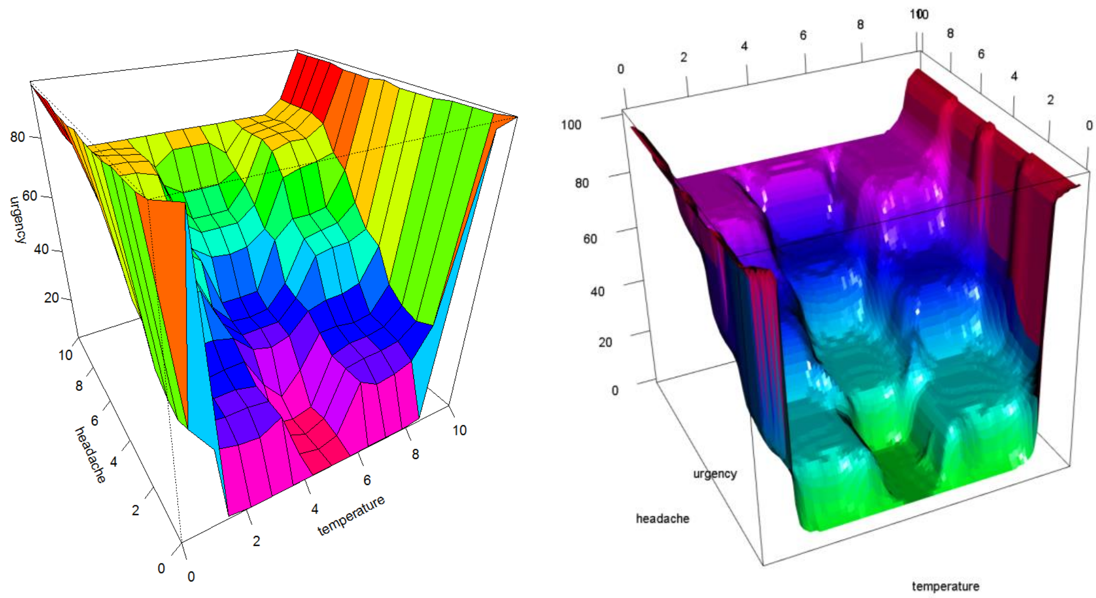

Figure 7 Two different representations of the final FIS

The performance of this FIS was outstanding, reducing the RMSE to only 3. The reason why this final version performs so well is that it classifies the most serious conditions with a score of 96, which is closer to the target score of 100 than any other system produced. Furthermore, it scores the normal condition with only 3, which again is the closest to the target of 0. However, this system is still not perfect as it has an output surface that resembles a checkerboard. Sometimes this is desirable, but in this scenario, a more gradual transition might be preferred. Nevertheless, this shortcoming is acceptable, as this behaviour is similar to what humans do, that is, the system classifies a set of values into categories of urgency, but still providing a clear transition between classes.

SUMMARY

For this coursework, a Fuzzy Inference System was developed that gives advice to doctors on the seriousness of the patients' condition based on the patient's headache and temperature deviation. A simple ruleset was established based on research that was used as the requirements to develop the FIS. Then the method of iterative development was utilised to create the system that matches these requirements. To evaluate each iteration, the FIS' output was compared with some predefined target values, and its 3D surface was analysed. Using this method it was shown how starting from a quite simple structure that only takes the temperature deviation into account a performant classifier was developed.

Appendix

Appendix 1: Temperature only rules

IF temperature is very low THEN urgency is emergency
IF temperature is low THEN urgency is medium
IF temperature is normal THEN urgency is low
IF temperature is high THEN urgency is medium
IF temperature is very high THEN urgency is emergency

Appendix 2: Rules with three headache terms

IF temperature is very low THEN urgency is emergency
IF temperature is low AND headache is low THEN urgency is low
IF temperature is low AND headache is mild THEN urgency is medium
IF temperature is low AND headache is severe THEN urgency is emergency
IF temperature is normal AND headache is low THEN urgency is low
IF temperature is normal AND headache is mild THEN urgency is medium
IF temperature is normal AND headache is severe THEN urgency is emergency
IF temperature is high AND headache is low THEN urgency is low
IF temperature is high AND headache is mild THEN urgency is medium
IF temperature is high AND headache is severe THEN urgency is emergency
IF temperature is very high THEN urgency is emergency

Appendix 3: Rules with five headache terms

IF temperature is very low THEN urgency is emergency
IF temperature is low AND headache is very low THEN urgency is low
IF temperature is low AND headache is low THEN urgency is low
IF temperature is low AND headache is mild THEN urgency is medium
IF temperature is low AND headache is severe THEN urgency is medium
IF temperature is low AND headache is very severe THEN urgency is emergency
IF temperature is normal AND headache is very low THEN urgency is low
IF temperature is normal AND headache is low THEN urgency is low
IF temperature is normal AND headache is mild THEN urgency is low
IF temperature is normal AND headache is severe THEN urgency is medium
IF temperature is normal AND headache is very severe THEN urgency is medium
IF temperature is high AND headache is very low THEN urgency is low
IF temperature is high AND headache is low THEN urgency is low
IF temperature is high AND headache is mild THEN urgency is medium
IF temperature is high AND headache is severe THEN urgency is medium
IF temperature is high AND headache is very severe THEN urgency is emergency
IF temperature is very high THEN urgency is emergency

Appendix 4: Rules with five urgency terms

IF temperature is very low THEN urgency is emergency
IF temperature is low AND headache is very low THEN urgency is very low
IF temperature is low AND headache is low THEN urgency is very low
IF temperature is low AND headache is mild THEN urgency is low
IF temperature is low AND headache is severe THEN urgency is medium
IF temperature is low AND headache is very severe THEN urgency is high
IF temperature is normal AND headache is very low THEN urgency is very low
IF temperature is normal AND headache is low THEN urgency is very low
IF temperature is normal AND headache is mild THEN urgency is very low
IF temperature is normal AND headache is severe THEN urgency is low
IF temperature is normal AND headache is very severe THEN urgency is high
IF temperature is high AND headache is very low THEN urgency is very low
IF temperature is high AND headache is low THEN urgency is very low

IF temperature is high AND headache is mild THEN urgency is low
IF temperature is high AND headache is severe THEN urgency is medium
IF temperature is high AND headache is very severe THEN urgency is high
IF temperature is very high THEN urgency is emergency

Appendix 5: Adjusted headache weighting

IF temperature is very low THEN urgency is emergency
IF temperature is low AND headache is very low THEN urgency is very low
IF temperature is low AND headache is low THEN urgency is low
IF temperature is low AND headache is mild THEN urgency is medium
IF temperature is low AND headache is severe THEN urgency is high
IF temperature is low AND headache is very severe THEN urgency is high
IF temperature is normal AND headache is very low THEN urgency is very low
IF temperature is normal AND headache is low THEN urgency is very low
IF temperature is normal AND headache is mild THEN urgency is low
IF temperature is normal AND headache is severe THEN urgency is medium
IF temperature is normal AND headache is very severe THEN urgency is high
IF temperature is high AND headache is very low THEN urgency is very low
IF temperature is high AND headache is low THEN urgency is low
IF temperature is high AND headache is mild THEN urgency is medium
IF temperature is high AND headache is severe THEN urgency is high
IF temperature is high AND headache is very severe THEN urgency is high
IF temperature is very high THEN urgency is emergency