5

Conclusions

All along the explanation we have been summarizing the most important aspects of this work. Nevertheless, in this chapter we will review the most important conclusions without getting into details, which have also been explained in the thesis.

First, we will provide a brief summary of the work. Then we will comment the strong and the weak points of the methodology proposed, which have been observed when applying the method to many different examples. Finally we suggest some details for further research in order to improve some deficiencies or to improve its performance.

5.1 Results

We have proposed a methodology to deal with the development of fuzzy rule based systems from input-output data. For years this problem was solved without taking into account the intelligibility of the models. Here we have proposed an alternative which has tried to solve different problems:

- The intelligibility and the accuracy of a model are not complementary. In general the more intelligibility the less accuracy (or the more accuracy the less intelligibility). Furthermore they depend on each person because human's capacity to work with linguistic models obviously varies from one to another. In this sense we demanded a solution which could define the trade-off between accuracy and intelligibility. We have solved it with the definition of the whole method's basic parameter, the *desired error* (ε), which is considered in several steps of the solution.

- Anyway we also demanded a hierarchical solution which could be debugged by users in order to change some of the optional parameters the method accepts: the grid of universes of scope, the statistics parameters when computing the optimal β, the fact of including mid fuzzy sets if the fuzzy curves are close to odd functions, the criteria to stop the process, the alternatives when computing the possible output sets for each rule, the alternatives when clustering these possible output sets, the optional parameters inside these alternatives like the *compact factor* which is defined in the Chiu's clustering method as r_β/r_α which may be increased if we require less clusters, ...

- Furthermore the method had to be simple enough in order to be more optimal than other alternatives in terms of computational cost.

We have studied in detail how we could satisfy all these requirements, concluding that the final method we have proposed provides intelligible models in a reasonable time, which can also be tuned by users according to each problem and person.

The whole method has been developed with efficient solutions in terms of computational costs, which furthermore, satisfy most of the commonly accepted criteria concerning intelligibility. In this sense we have argued the decisions by addressing to these criteria before accepting every solution.

This methodology has been tested through several examples, from which we have concluded that, in general, it obtains similar results to others which are focused on accuracy but it also assures most of the intelligibility criteria commonly proposed in the literature. In this sense, we have shown how this method can be considered not only to obtain a model from input-output data but also to *explain* how a more complex model works. Furthermore, we have compared the computational cost in order to verify the fact that this is a very efficient solution in comparison with most of the other alternatives.

5.2 Strong and weak points

From the previous comments we conclude that the strong points of the methodology in comparison with the most popular alternatives are:

- The fact of providing models with a method that assures most of the intelligibility criteria and consequently, models which must be easily understood by users.

- The fact of adapting the trade-off between intelligibility and accuracy, basically through the definition of an only one mandatory parameter, the *desired error* (ε).

- The fact of facilitating several options in order to convert the general solution into the necessary solution for each problem and person.

- The fact of computing the models with efficient operations in terms of the necessary time to obtain the result.

Nevertheless this solution fails in some cases.

- The first problem arises if we work with few samples because in general then we can not assure satisfactory models. This is due to either the poor statistics of the β parameter or the wide grid that is considered for each variable. Anyway this problem may be solved in some cases by changing some of the method's parameters in spite of not being easy if one is not used to doing it.

- The second problem appears from the fact of working with only one input variable every time if we have *bad distributed samples*. This concept refers to the phenomenon of the values of the input we are considering appearing like a shadow when they are plotted, in order to show their relation with the system, making it very difficult to obtain its fuzzy curve. This phenomenon can be observed with the system plotted in figure 5.1 which is called the peaks function[1].

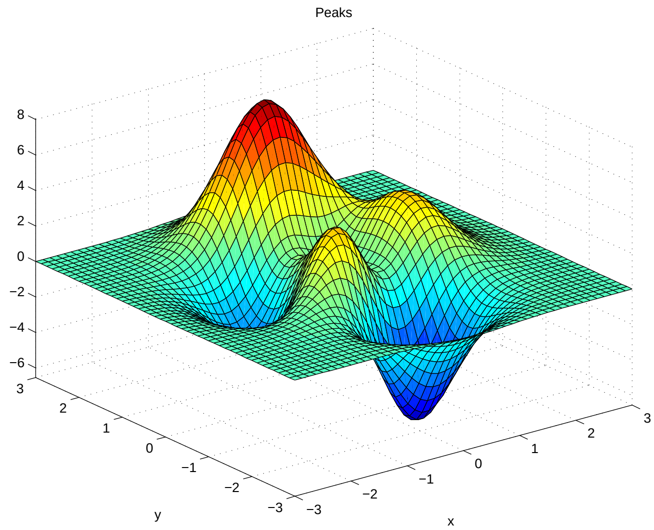

Figure 5.1: Peaks function.

[1]This function is defined in Matlab by translating and scaling Gaussian distributions.

This function is computed as:

$$z = \begin{array}{rl} + & 3(1-x)^2 \exp\left(-x^2-(y+1)^2\right) - \ldots \\ - & 10(\frac{x}{5}-x^3-y^5) \exp\left(-x^2-y^2\right) - \ldots \\ - & \frac{1}{3} \exp\left(-(x+1)^2-y^2\right) \end{array} \tag{5.1}$$

Observe in figure 5.2 how the samples that will be considered when computing the fuzzy curve for the input x are slightly symmetrical with $z = 0$. In this case the fuzzy curve may result too much flat independently of its β parameter and then the linearization process may be degraded. This does not happen with the variable y from which the method would give easily its optimal fuzzy curve.

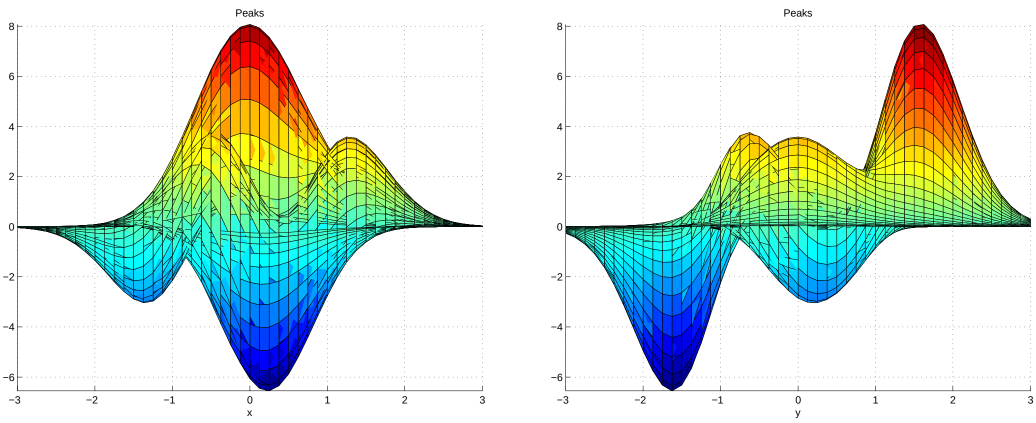

Figure 5.2: Distribution of the samples for each input.

- The third problem appears when the method requires many input partitions in order to satisfy the *desired error* and consequently when the model has too many rules. In this case its global intelligibility decreases, that is the understanding of the whole system. The fact is that this methodology assures intelligible rules but not intelligible models, if all the rules must be considered as a whole definition. Fortunately there are some studies today which try to compact a large number of rules by applying linguistic modifiers to some fuzzy sets.

Obviously these problems will be the basis for further research.

5.3 Suggestions for further research

Like many scientific works this thesis has proposed answers to specified questions and by doing so, many other problems arise.

- We are interested in including some techniques in order to simplify the final rule matrix and thus, to obtain a global intelligible definition of the system and not only intelligible local rules. Here we may start with some of the interesting advances proposed in the introduction.

- We would like to include some techniques able to discern the more relevant input variables in the explanation of the process in order to optimize the number of variables involved in the solution. This problem is usually solved with decision trees like in [48].

- We are studying how an optimal linear-piecewise approximation relating the inputs and the outputs may be obtained directly from the input-output data and thus, we could avoid the use of fuzzy curves in order to improve the computational cost. We are thinking about the use of principal curves for this purpose [56, 19].

- We are also interested in building a method which works in a similar way to the one we have proposed but by computing all the input variables together in order to solve those cases of *bad distributed samples.* Nevertheless then we will probably have to accept a very complex computation that will increase the necessary time to obtain each solution.

- We must adapt the method to the working with categorical variables and not only with numerical variables. Anyway this adaptation seems easy by associating a number to each possible category and by working with a proper grid of its universe of scope.

- We are interested in applying this method which seems to be very fast in order to model systems in real time.

Work must go on ...