Fuzzy Rule-Based Machine Learning in Process Modeling

BODENHOFER Ulrich

Software Competence Center Hagenberg
A-4232 Hagenberg
AUSTRIA

The optimization of technical processes requires a sufficient understanding of the interrelations in a process. More specifically, this means that a model of the given process is needed. Traditional methods for modeling technical processes are based on analytical relationships that are either explicit formulas derived from knowledge in physics, chemistry or engineering science or given as solutions of systems of differential equations. In practice, however, one is often confronted with processes that are too complex to be sufficiently captured by an analytical model or — although it would be possible in principle — the development of a full-fledged analytical model is too costly.

Machine learning often offers a reasonable alternative. Under the term "machine learning", we usually subsume a class of methods for identifying relationships from data. In contrast to statistical regression, machine learning methods do not assume a predefined underlying parametric model, but uses other forms of representing relationships, most often with universal approximation properties. This description would also comprise neural networks. The given contribution, however, is devoted to a different class of machine learning methods — rule-based methods based on fuzzy logic, i.e. methods that create fuzzy systems (fuzzy if-then rules) from data. Rule-based approaches have the advantage that they additionally offer valuable insights into the process. Classical rule-based methods based on Boolean logic, however, are not able to model continuous numerical relationships. The use of fuzzy logic bridges the gap between interpretable rules on the one hand and continuous numerical modeling on the other hand. Fuzzy rule-based machine learning, therefore, offers valuable interpretable insights into the process while still being able to provide a continuous numerical process model.

The given contribution gives an overview of fuzzy rule-based machine learning methodologies that were specifically developed for the process modeling domain. We start from a general language for fuzzy rule-based machine learning that includes ordering-based modifiers [1, 3]. This language is both expressive and allows to easily maintain interpretability of the linguistic expressions [2]. Based on this language, we discuss FS-ID3, a fuzzy rule-based method for decision tree induction [5], FS-FOIL, a fuzzy rule-based inductive learning method [6, 7], and RENO, a numerical method for optimizing interpretable fuzzy systems [4, 8]. Finally, we give an overview of successful industrial applications of fuzzy rule-based machine learning in paper production, injection molding, and other domains.

References

[1] U. Bodenhofer. The construction of ordering-based modifiers. In G. Brewka, R. Der, S. Gottwald, and A. Schierwagen, editors, *Fuzzy-Neuro Systems '99*, pages 55–62. Leipziger Universitätsverlag, 1999.

[2] U. Bodenhofer and P. Bauer. A formal model of interpretability of linguistic variables. In J. Casillas, O. Cordón, F. Herrera, and L. Magdalena, editors, *Interpretability Issues in Fuzzy Modeling*, volume 128 of *Studies in Fuzziness and Soft Computing*, pages 524–545. Springer, Berlin, 2003.

[3] U. Bodenhofer, M. De Cock, and E. E. Kerre. Openings and closures of fuzzy preorderings: Theoretical basics and applications to fuzzy rule-based systems. *Int. J. General Systems*, 32(4):343–360, 2003.

[4] M. Burger, J. Haslinger, U. Bodenhofer, and H. W. Engl. Regularized data-driven construction of fuzzy controllers. *J. Inverse Ill-Posed Probl.*, 10(4):319–344, 2002.

[5] M. Drobics and U. Bodenhofer. Fuzzy modeling with decision trees. In *Proc. 2002 IEEE Int. Conf. on Systems, Man and Cybernetics*, pages 90–95, Hammamet, Tunisia, October 2002.

[6] M. Drobics, U. Bodenhofer, and E. P. Klement. FS-FOIL: An inductive learning method for extracting interpretable fuzzy descriptions. *Internat. J. Approx. Reason.*, 32(2–3):131–152, 2003.

[7] M. Drobics, U. Bodenhofer, and W. Winiwarter. Mining clusters and corresponding interpretable descriptions — a three-stage approach. *Expert Systems*, 19(4):224–234, 2002.

[8] J. Haslinger, U. Bodenhofer, and M. Burger. Data-driven construction of Sugeno controllers: Analytical aspects and new numerical methods. In *Proc. Joint 9th IFSA World Congress and 20th NAFIPS Int. Conf.*, pages 239–244, Vancouver, July 2001.