Applied Soft Computing 42 (2016) 410–422

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Optimal allocation of information granularity in system modeling through the maximization of information specificity: A development of granular input space

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ARTICLE INFO

Article history:
Received 1 August 2015
Received in revised form 12 January 2016
Accepted 1 February 2016
Available online 11 February 2016

Keywords:
Fuzzy models
Information granules
Granular input space
Global sensitivity
Interval arithmetic

ABSTRACT

In this study, we introduce a concept of a granular input space in system modeling, in particular in fuzzy rule-based modeling. The underlying problem can be succinctly formulated in the following way: given is a numeric model, develop an efficient way of forming granular input variables so that the corresponding granular outputs of the model achieve the highest level of specificity. The rationale behind the formulation of the problem is offered along with several illustrative examples. In conjunction with the underlying idea, developed is an algorithmic framework supporting an optimization of the specificity of the model exposed to granular inputs (data). It is dwelled upon one of the principles of Granular Computing, namely an optimal allocation of information granularity. For illustrative purposes, the study is focused on information granules formalized in terms of intervals (however the proposed approach becomes equally relevant for other formalism of information granules). Some comparative analysis with the existing idea of global sensitivity analysis is also carried out by contrasting the essential differences among the two approaches and analyzing the results of computational experiments.

1. Introduction

Granular Computing has vividly demonstrated its advantages in modeling and solving complex problem [1,2], for instance, human-centric systems. Human-centered information processing engages a fundamental concept of information granules. In system modeling, Granular Computing contributes in numerous ways to system modeling [2–7]. Those contributions, resulting in some *granular* models, could be classified as falling into one of the general groups of approaches:

1.1. Granular space of parameters in system modeling

A constructed model being endowed with numeric parameters is augmented in the sense its parameters are made granular, viz. information granules are spanned over the numeric values of the parameters. These information granules can be realized as intervals, fuzzy sets, rough sets, etc. The key objective of this construct is to make the resulting granular model to become more in rapport with the real world. Information granularity is sought as a vital design asset and an allocation (distribution) of information granularity is realized in such a way so that a criterion of coverage (inclusion) of data in information granules produced by the granular model is maximized. The approaches falling under this rubric help develop models at higher level of abstraction.

1.2. Granular input space in system modeling

Here our focus is on the construction of inputs of the model in the form of information granules with an objective of gaining a better insight into the nature and the role of individual input variables they play in the model. The investigations dealing with the exploration the granular input space and its construction are the subjects of this study.

1.3. Hybrid granular parameter and input space in system modeling

This approach constitutes a combination of the two outlined above as both the parameters of the model and the inputs are made

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http://dx.doi.org/10.1016/j.asoc.2016.02.001
1568-4946/

granular. In this sense, we are engaged in the formation and the optimization of the granular space of parameters as well as the granular input space.

The granular input space plays a vital role. It becomes obvious that different input variables exhibit a different impact on the outputs of the model. A quantification of this impact relates to some sensitivity analysis. Here we formulate the problem in the setting of information granules. We are interested in the following problem: if we make some input variable to become an information granule, what is its impact on the granularity of the result? Assuming that we have at our disposal a certain level of information granularity (regarded as a useful design asset), the problem is: how this asset becomes distributed (allocated) across all input variables so that the granular output exhibits the highest level of information granularity as possible? In this setting information granules and their level of information granularity (specificity) are important design characteristics to be optimized. Intuitively, one may anticipate that in this allocation exercise, an input variable whose impact on the output is quite limited, comes as an information granule of low specificity. The opposite holds true in case of any input variable, which significantly exhibit the output of the model. Here to retain a high specificity of the output results, this input variable has to be kept quite specific. It is important to note that information granules associated with the certain input variable is a tangible, easily interpretable and practically sound outcome of the process of allocation of information granularity. Consider that we have some limited resources to acquire input data and an acquisition of the input variables comes with a certain cost. The precision of the acquired input variable is related with the granularity of the variable: higher granularity implies higher precision (specificity) of the variable. Our intent is to distribute the resources so that the quality of the granularity of the result produced becomes maximized, viz. its specificity is the highest one.

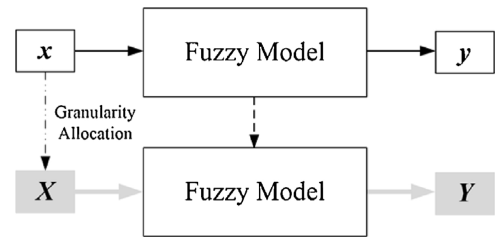

Fig. 1. The concept of granular input space in fuzzy model systems.

The objective of this study is to establish a systematic way of allocation information to input variables by solving a certain optimization problem of specificity maximization. An overall view of the optimization framework is schematically visualized in Fig. 1. We proceed with an existing fuzzy model (which is a numeric mapping $y = f(\boldsymbol{x})$) and establish a way of allocating information granularity across the input variables (making them granular (denoted here by $\boldsymbol{X}$) so that the granular output of the fuzzy model $Y = f(\boldsymbol{X})$ exhibits the highest level of specificity. In essence, the optimization problem boils down to a development of a *granular* input space.

In this study, we concentrate on Takagi–Sugeno (T–S) fuzzy rule-based models. The rationale behind this choice is as follows. Rule-based model of this form are commonly encountered in fuzzy modeling and its applications [10–12,17]. There is a plethora of well-established design practices including population-based optimization techniques [13,14] and ensuing verification mechanisms.

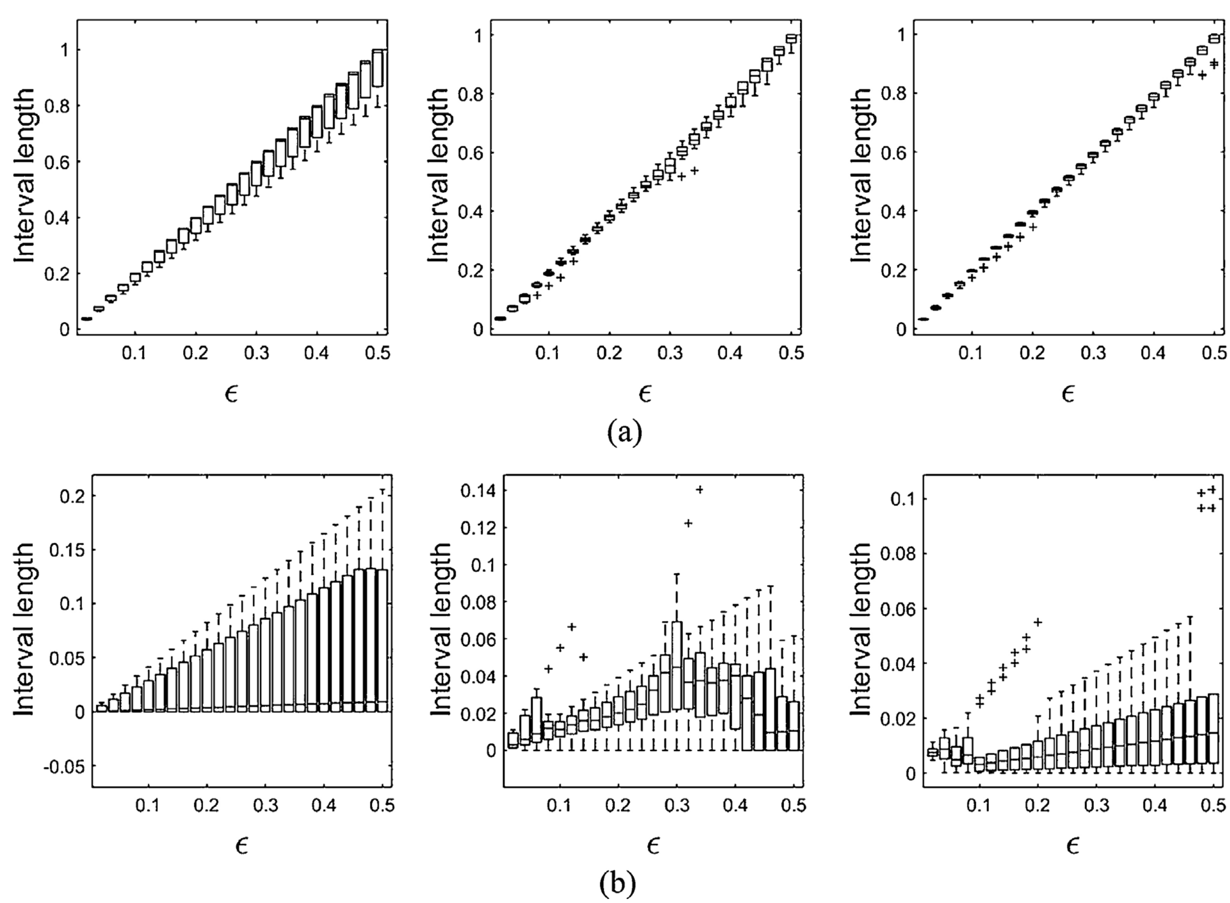

Fig. 2. Optimal allocation of information granularity across input variables: (a) input $\boldsymbol{x}_1$, (b) input $\boldsymbol{x}_2$; $m = 2.0$; (left figure) $c = 2$, (middle figure) $c = 5$, (right figure) $c = 9$.