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A HYBRID METHOD, COMBINING HIERARCHIC AND COGNITIVE MODELS, FOR THE MODELING AND SIMULATION OF COMPLEX SYSTEMS

Abstract

Complex decision making in a complex, dynamic environment is often a very difficult task. Investigation into huge amount of multivariate data is needed to extract and manipulate information distributed within, so that decision making can be soundly sustained.

Keywords:
cognitive models, hierarchical structure, fuzzy numbers, cognitive map.

1. INTRODUCTION

Decision support systems built for this purpose should have advanced features such as:

- Good explanation facilities, preferably presenting the decision rules used;
- Dealing with vague, fuzzy information, as well, as with crisp information;
- Dealing with contradictory knowledge, e.g. when two experts predict different trends in the stock market;
- Dealing with large data bases with a lot of redundant information, or coping with lack of data.
- Hierarchical organization, i.e., they can involve different levels of processing, comparing different possible solutions, using alternatives, sometimes in a recurrent way.

Techniques of computational intelligence, such as artificial neural networks, fuzzy logic systems, genetic algorithms, advanced statistical methods, along with traditional statistical and financial analysis methods, have been widely applied on various problems in finance and economics. Firs of all, it must be noticed, that in the field, like economics, the expert's knowledge is always used. This expert's knowledge is the basis of each economic decision support system. Rule-based system and fuzzy rule-based system in particular have been used in financial and economic decision making. The main advantage of rule-based systems is that their functioning is based on expert rules. The main disadvantage is that these systems are not flexible enough to react to changes in the data. It is proposed to decompose the data domain involved into two parts: the fuzzy hierarchy of the purposes and tasks, which is changed only in a crisis situation, and a cognitive map of the situation, which is changed at each receipt of new information in the system.

2. THE HYBRID METHOD

The structure of the hierarchy of the purposes and tasks holds the main factors of the involved data domain and the links between these factors, which stay invariant. This hierarchical structure is determined by the experts of this domain. Only in the crises situations this structure can be changed, but these changes must be controlled by the expert's rules. The development of the hierarchy is made by the experts, they select the main factors and determine they levels and the links between them. The meta-levels of the structure are the following: first level is the level of the global aim; the others are levels of the criteria, which determine the global aim. The last level is the level of factors with a set of values. The links in the hierarchy define the dependency between the upper level element's realization and the corresponding underlying level element's realization.

After hierarchy construction, the elementary estimations should be made by experts. The elementary estimation consists on the getting for certain vertex $i \in V_m$ paired estimations $_{jk}^{(i)}$ of the arcs weights $(i, j) \in W$, $j \in \Gamma_i = \{k \mid (i, k) \in W\}$. Paired estimations show, in how many times the contribution of the object j is more than the contribution of the object k in the achievement of the object i aim; $j, k \in \Gamma_i$. The proposed method of the hierarchy analysis allows to get the experts estimations as exact ($r_{jk}^{(i)} \in R_+$ - nonnegative numbers), interval ($r_{jk}^{(i)} = [a_{jk}^{(i)}, b_{jk}^{(i)}] \subset R$ - intervals) or fuzzy numbers ($r_{jk}^{(i)} = \{(t, \mu_{jk}^{(i)}(t)) \mid t \in R_+\}$ – closed convex fuzzy sets on R_+). The last case includes the linguistic estimates and two previous cases. Thereby, we get as a result of an elementary estimation a binary relation $R^{(i)} = \{((j,k), r_{jk}^{(i)}) \mid j, k \in \Gamma_i\}$ on the objects set Γ_i, which gives the intensity of the objects superiority. After getting the estimations, we must average them. In each of the elementary estimations may participate several experts, so for some pairs (j, k) of the objects $j, k \in \Gamma_i$ different experts s can assign different estimations $r_{jk}^{(i)s}$ (s – expert's number). The procedure of the expert estimation averaging consists in the determination of the mean geometric estimation. The result of the pairs estimations average in the i elementary estimation – exact, interval or fuzzy relation $R_{(i)}$ – is used in the determination of the weights $y_{i,j}$, of all the arcs $(i, j) \in W$, coming out of the vertex i. The arcs weights satisfy the following condition:

$$\sum_{j \in \Gamma_i} y_{ij} = 1; \quad y_{ij} \ge 0, \quad \forall\, i \in \Gamma_i$$

If there are several objects on the first level y_1, then the "zero" elementary estimation is made, it means, that the pair comparison of the objects importance coefficients must be made. As a result of the "zero" estimation, the importance coefficients of the first level objects are determined. After the elementary estimations results processing, the importance coefficients z_j of the objects $j \in V_1$ of the first level of the hierarchic structure are determined. And also the weights y_{ji} of all the arcs $(i, j) \in W$ are determined (the coefficients of the relative importance of the vertex $Y_{ji}^{(s)}$ for the vertex $Y_i^{(s-1)}$ of the nearest upper level, where s – is a level number. The weights of the underlying level objects are determined by the recurrence from top to bottom recalculation of the objects weights (objects importance coefficients):

$$z_i = \sum_{j \in \Gamma_i^{-1}} y_{ji} z_j, \; i \in V_2,$$

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$$z_i = \sum_{j \in \Gamma_i^{-1}} y_{ji} z_j \text{ , } i \in V_M$$

$$(\Gamma_i^{-1} = \{j \mid (j, i) \in W\}).$$

Directly influenced factors are situated on the hierarchy last level. The realization of these factors (they represent the factors with a set of taken values), spreading upwards on consecutively located levels of the factors hierarchical structure, will bring into the realization of all above located factors and, finally, - to the achievement of the global aims of the considered complex object development. Last level's factors are also independent and have no links between each other. Obviously, in reality, the actions have the links between each other. That why, the hierarchic model is insufficient. To allow this contradiction, we will use the cognitive model.

The cognitive model allows analyzing the currant situation state. The current situation state model is presented by the graph, which is called a cognitive map. To each node of the map corresponds a function f_i , which is called a factor. In each moment of time a factor takes on a value from a linear ordered set. These sets are called scales. The factor's value is also called factor's expression rate. If these values are measurable in impartial scores, then they form a quantitative scale. But, more typical for the natural systems is the case, where factor's expression rate can not be measured directly and can only be estimated by the expert as a linguistic value. The set of these values must be also ordered and forms a linguistic scale. Hereinafter f_i will denote the name of the factor i. Its value in the moment of time t will be denoted as $x_i(t)$. The vector $X(t) = (x_1(t), x_2(t), ..., x_n(t))$ of all the factors values in the moment t forms a situation state at the moment t.

The variable w_{ij}, assigned to the branches (f_i, f_j), is numerical and can take on all real values. It is called link's weight (f_i , f_j) and characterizes the intensity of the influence of the factor f_i on the factor f_j. The variables w_{ij} whole is given by the contiguity matrix of the graph W = $||w_{ij}||$. Variable value w_{ij}, i.e. the influence intensity fi on f_j generally depends on the factor f_i *value*. But, practically, the branches weights are changed seldom, that why they can be considered as constant. A cognitive model is established, if

- Set of situation factors $F=\{f_i\}$; is established
- Linguistic (Z_i) and numerical (X_i) scales are established and also the reflection $Z_i \rightarrow X_i$ is given
- Established cause-and-effect relations between factors, which are given by the contiguity matrix of the oriented graph W=$|w_{ij\,sl}|$.
- The initial incremental vector of the situation factors $P(t)= (p_1(t), p_2(t), ..., p_n(t))$ is defined.

The task is to find the incremental vector of the situation factors $P(t), P(t+1), ..., P(t+n)$ and the situation states $X(t), X(t+1), ..., X(t+n)$ in successive discrete moments of time $t, t+1, ..., t+n$. This task is accomplished with the aid of some matrix algorithms (for example, the algorithm of the transitive closure).

The factors of both models represent the same situation in the involved data domain, but their sense differs. The factors in the hierarchy represent the main aim to reach and the criteria of the general aim realization. The last hierarchy level contains the concrete actions, which can confront with the factors in the cognitive model. The cognitive model's factors represent the concrete actions and the links between them. But, we can simply take the factors from the last hierarchical level and consider them as cognitive factors. The factors on the last level are the concrete actions which exert influence on the upper factors. And the cognitive model gives all the actions of the situation. It exist a univocal correspondence between a subset of cognitive factors and the set of the last level's hierarchical factors. Each factor in the cognitive has its value, which is defined in each moment of time from the cognitive map. Each factor in the hierarchy has only the importance coefficient, which shows the contribution of this factor in the realization of the global aim, but doesn't have the concrete quantitative value. The synthesis of both models occurs independently from each other, for their synthesis different expert estimations are required. After this synthesis, we need to compare the corresponding factors. To construct the correspondence between the factors it is proposed to use the expert's rule-based algorithm.

3. CONCLUSION

The situation modeling in the fuzzy environment, like sociology, economics etc requires first of all the expert's knowledge. All the fuzzy data domain modeling systems are built with the expert's participation. The proposed method gives the possibility to distinguish the global aims and the backbone factors of the situation. Also the method allows to follow up the situation state and to have the values of the situation factors in each moment of time.

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