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Research on the ideas and models for discriminating the order parameters of complex self-organizing system: Taking the industrial convergence system of EMI and PS as example

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ABSTRACT

Complex self-organizing systems are widely exists in the social and economic fields, and most of them have the typical characteristics of complex system. The order parameter plays a very important role in the evolution process of complex self-organizing system. Therefore, the discrimination of the order parameters becomes a critical issue for revealing the development laws of the complex self-organizing system. This paper designs the ideas and models for discriminating the order parameters of complex self-organizing system based on cluster analysis and rough set theory, and carries out an empirical study for proving the correctness and effectiveness of them. The cluster analysis is used for determining the "state" of both complex self-organizing system and its macro control parameters, and building up the knowledge set which is composed of corresponding rules between their "states". And the rough set theory is used for reducing the macro control parameters of complex self-organizing system based on the knowledge set. This study shows that, the ideas for discriminating the order parameters based on the "state" of both complex self-organizing system and its macro control parameters is feasible, and the models for discriminating the order parameters of complex self-organizing system on the basis of clustering analysis and rough sets theory is particularly effective.

KEYWORDS

Order parameter; Complex self-organizing system; Cluster analysis; Rough set theory; Parameters reduction; Empirical study.

INTRODUCTION

The complex self-organizing systems are widely exists in the social and economic fields, and most of them have the typical characteristics of complex system, such as open, dynamic, adaptive, nonlinear, diversity and emergence[1,2]. These characteristics increase the research difficulty of complex self-organizing system, especially for the difficulty of discriminating its order parameters. The order parameter provides the intrinsic motivation for complex self-organizing system, and dominates the collaboration and competition among all subsystem. Furthermore, the order parameter dominates the evolution of complex self-organizing system. Generally speaking, the order parameters play a very important role in the evolution process of complex self-organizing system[3]. So, the importance of the order parameter brings an important question to us: how to discriminate the order parameters of the complex self-organizing system.

This paper sets focus on the discrimination of the order parameters of complex self-organizing system. According to the connotation of the order parameters, this paper designs ideas and models for discriminating the order parameters of complex self-organizing system based on cluster analysis and rough set theory. The outline of the paper is as follows: In section 2, the characteristics of order parameters are analyzed, and the ideas and models for discriminating the order parameters of complex self-organizing system are designed. Based on the models designed in section 2, an empirical study is carried out in section 3 for proving the correctness and effectiveness of the preceding designed research ideas and models. Section 4 gives the conclusions of this paper.

DESIGN OF THE IDEAS AND MODELS FOR DISCRIMINATING THE ORDER PARAMETER OF COMPLEX SELF-ORGANIZING SYSTEM

Ideas design for discriminating the order parameter based on its characteristics

Analysis on the characteristics of the order parameter

Self-organization theory shows that, the order parameter is the slowly changing macro control parameter of the complex self-organizing system, and it is the most prominent symbol of the transformation and qualitative leap of the complex self-organizing system. The order parameter determines not only the structure but also the evolution process of the complex self-organizing system. The order parameter has the following characteristics:

First, the order parameter is a part of "macro control parameters" of complex self-organizing system, and its "state" determines the "state" and "behavior" of the complex self-organizing system. Second, the order parameter is not only the product of collective motion of micro subsystems, but also the measurement of cooperative effect of all the micro subsystems. Third, the order parameter not only controls the subsystems' behavior, but also dominates the evolution of the complex self-organizing system.

According to the nature of the order parameter, this paper infers that: the "state" mutation of order parameter will induce the "state" mutation of the complex self-organizing system. In the other words, the "state" of order parameter determines the "state" of the complex self-organizing system, but the other variables are unable to determine the "state" of the complex self-organizing system.

Ideas design for discriminating the order parameter

Based on the analysis above, this paper designs the ideas for discriminating the order parameter of complex self-organizing system as follows:

Firstly, selecting the macro control parameters of the complex self-organizing system, and building up the knowledge set which is composed of corresponding rules between the "state" of complex self-organizing system and the "state" of its macro control parameters.

Secondly, selecting the appropriate method to establish the knowledge mining model for reducing the macro control parameters of the knowledge set which constructed in first step. In this step, the macro control parameters which are not the order parameter will be reduced.

Finally, the order parameters of the complex self-organizing system are discriminated according to the reduction results.

It is can be inferred that, there are two critical points for discriminating the order parameter of the complex self-organizing system. One is the determination of the "state" of both macro control parameters and the complex self-organizing system; another is the reduction of the macro control parameters. As we know, most data of the macro control parameters in social and economic fields are continuous variables, so it is very difficult to determine their "state" according to the data themselves. Therefore, discretization of the macro control parameters is required. However, the "state" determination of the macro control parameters by experts or scholars is not scientific and credible, because the subjective determination is influenced by the subjective factors. In order to exclude the effect of subjective factors in the "state" determination process, this paper chooses the cluster analysis to determine the "state" of the macro control parameters on the basis of related research achievements. On this basis, this paper builds up the discrimination model based on the rough set theory for mining order parameters of the complex self-organizing system.

Models design for discriminating the order parameter

Construction of the cluster analysis model

At present, the most widely used cluster analysis algorithms includes K-means[4], K-medoids[5], clarans algorithm[6], cluster algorithms based on density[7] and cluster algorithms based on grid[8]. Although these algorithms have been widely applied in many fields, they still have some shortcomings, such as sensitive to initial parameters, strongly dependent on the initialization parameters, difficult to find the optimal cluster, and sensitive to the noise etc. So, it is necessary for us to improve the traditional clustering analysis algorithm. This paper chooses traditional K-means algorithm as foundation, constructs an improved cluster analysis model for determining the "state" of both complex self-organizing system and its order parameters.

Aim at improving the traditional K-means model, this paper chooses k points as the initial cluster center from high density region of the set, and these points have furthest distance to each other. For calculating the density where the data object x_i located in, this paper defines a density parameter: set x_i as the center, the radius ε which can contain *Minpts* data objects is called density parameter. So, if the ε is bigger, the regional data density where the data object located is lower, vice versa.

By calculating the density parameters of the data objects, the points where located in high density region can be found out, and a high density point set D can be built up. By taking the maximum and minimum distance algorithm in set D, this paper chooses the data object in highest density region as the first cluster center Z_1, and chooses the high density point which is farthest from Z_1 as the second cluster center Z_2. Then, calculates the distances $d(x_i, Z_1)$ and $d(x_i, Z_2)$, $x_i \in D$. $d(x_i, Z_1)$ is the distance form x_i to Z_1 and $d(x_i, Z_2)$ is the distance form x_i to Z_2. x_i is data object from set D. Z_3 is the data objects x_i which satisfies formula (1):

$$\max(\min(d(x_i, Z_1), d(x_i, Z_2))) \quad i = 1, 2, \ldots n \quad x_i \in D \tag{1}$$

Z_m is the data objects x_i which satisfies formula (2):

$$\max(\min(d(x_i, Z_1), d(x_i, Z_2), \ldots, d(x_i, Z_{m-1}))) \quad i = 1, 2, \ldots n \quad x_i \in D \tag{2}$$

In this way, k as initial cluster center is obtained.
The K-means algorithm for optimizing the initial cluster center is described as follows:
Algorithm input: Number of clusters k and data set which contains n data objects.
Algorithm output: Minimum k clusters which satisfied the objective function.
The steps of the algorithm are like this:
Step 1: Calculate the distance between arbitrary two data objects: $d(x_i, x_j)$;
Step 2: Calculate the density parameter of each data object, delete the points which located in low density region, and build up data objects set D which located in high density region;
Step 3: Set the data object which located in highest density region as first center Z_1;
Step 4: Set the data object which is farthest from Z_1 as the second cluster center Z_2;
Step 5: Set Z_3 as the set of data object x_i which satisfies $\max(\min(d(x_i, x_j), d(x_i, Z_2))$ $(i = 1, 2, \ldots n)$, $Z_3 \in D$;
Step 6: Set Z_4 as the set of data object x_i which satisfies formula (3):

$$\max(\min(d(x_i, Z_1), d(x_i, Z_2)), d(x_i, Z_3))) \quad (i = 1, 2, \ldots n), \; Z_4 \in D \tag{3}$$

Step 7: Set Z_k as the set of data object x_i which satisfies formula (4):

$$\max(\min(d(x_i, Z_j))) \quad (i = 1, 2, \ldots n, \; j = 1, 2 \ldots k-1), \; Z_k \in D \tag{4}$$

Step 8: Start from these k cluster centers, apply the k-means cluster model, and get the cluster results.

Order parameters discrimination model based on rough set theory

The key point for discriminating the order parameters of complex self-organizing system is the reduction of the macro control parameters. The existing related research achievements show that, the rough set method is one of the most effective ways for variables reduction, and its effectiveness has been successfully proved by the application cases in the fields of science and engineering[9]. So, this paper choose the rough set as the basic theory to construct the order parameters discrimination model, and dig out the hidden order parameters of the complex self-organizing system. The order parameters discrimination model based on rough set theory is build up through the following steps:
Step 1: Description of attribute reduction algorithm. Attribute reduction based on rough set theory is a process for deleting the redundant attributes without losing any useful information. The attribute reduction set R can be expressed as:
$R = \{R : R \in C, POS_R(D) = POS_C(D)\}$, and the end condition of this algorithm is $POS_R(D) = POS_C(D)$, that is the minimum attribute set to ensure the quality of classification.

Input: Rule set $R = (U, C \cup D, V, f)$, where C is condition attribute, D is decision attribute; Output: A minimal attribute reduction set R of the rules. Calculate the core $R = core(C)$ of condition attribute C which is relative to decision attribute D by using discernibility matrix.
Step 2: Calculate the frequency of attributes: $f(a) = \lambda_{ij} / D_{ij}$, $a \in D_{ij}, i, j = 1, 2, \ldots, n$. n is the number of samples;
Step 3: Calculate the important degree $M(a)$ of each attribute $a \in E$ according to equation $M(a) = f(a) - \sum \varepsilon_{ij}$, where i is the attribute in R, j is the residual properties, ε_{ij} is the grey absolute correlation degree between the current reduction attribute and the remaining attribute, $\varepsilon_{ij} \in [0,1]$;
Step 4: Choose the maximum attribute of $M(a)$, and added into R;

Step 5: $R = R + \{a\}, E = E - \{a\}$, calculate $POS_R(D)$, if $POS_R(D) = POS_C(D)$, end the algorithm; otherwise, turn to step 2;
Step 6: Output *R*, and *R* is the order parameters set of the complex self-organizing system;
Step 7: Extract the corresponding rules of complex self-organizing system's "state" and order parameters' "state". Set X_i and Y_i represent of equivalence class in U/C and U/D in the rule set respectively, $des(X_i)$ is the description of equivalence class X_i. $des(Y_i)$ is the description of equivalence class Y_i.
The rules are defined as follows: $r_{ij} : des(X_i) \to des(Y_i), Y_i \cap X_i \neq \emptyset$

Determining factors of rules as: $\mu(X_i, Y_i) = |Y_i \cap X_i| / |X_i|, 0 < \mu(X_i, Y_i) \leq 1$. When $\mu(X_i, Y_i)$ =1, it is determined; when $0 < \mu(X_i, Y_i) < 1$, it is uncertain.

These rules are corresponding relationship between complex self-organizing system's "state" and order parameters' "state".

EMPIRICAL STUDY

By taking the industrial convergence system of equipment manufacturing industry (Referred to as the EMI for short) and producer services (Referred to as the PS for short) as example, this paper does the empirical study for proving the correctness and effectiveness of the research ideas and models designed above.

Analysis on the complex self-organizing characteristics of industrial convergence system of EMI and PS

As a typical economic system, the industrial convergence system of EMI and PS is a typical complex self-organizing system: On the one hand, the industrial convergence system exchanges material, energy and information with its environment, so it is an open system. On the other hand, there is obvious non-equilibrium between EMI and PS at industrial technology, knowledge, product and market level. And the non-equilibrium makes the industrial convergence system far from equilibrium, and cause the "fluctuations" and "nonlinear interaction" inside the system. Beside that, there is "state" mutation of the complex self-organizing system, and the convergence industry is the mutant result.

Selection of the macro control parameter of industrial convergence system

Referring to the existing related researching achievements on macro control parameters of industrial convergence system[10], this paper builds up the macro control parameters set of industrial convergence system of EMI and PS as shown in TABLE 1.

TABLE 1 : Macro control parameters set of industrial convergence system of EMI and PS

No.	Parameter	No.	Parameter	No.	Parameter
$CP\,1$	Market demand	$CP\,4$	Industry regulation	$CP\,7$	Market operation
$CP\,2$	Competition pressure	$CP\,5$	Technological innovation	$CP\,8$	Management ability
$CP\,3$	Technology diffusion	$CP\,6$	Product realization	$CP\,9$	Economic environment

Construction of knowledge set on the corresponding relationship between the "state" of complex self-organizing system and the "state" of its 9 macro control parameters

Taking the "China Statistical Yearbook 2012" and "China industrial economy statistical yearbook 2012" and other Statistical Yearbooks as data sources, this paper gets 30 groups initial data of the knowledge set on the corresponding relationship between the "state" of complex self-organizing system and the "state" of its 9 macro control parameters. On this foundation, setting the clustering parameter "numClusters" =5 which corresponding to very high, high, medium, low, very low respectively(Referred to as the VH, H, M, L, VL for short), this paper discretizes the initial data based on the improved cluster analysis model, and gets the discretized knowledge set. Based on these data, this paper chooses Genetic Algorithm to discriminate the macro control parameters of industrial convergence system according to the order parameters discrimination model which designed above, and gets 3 core sets of the macro control parameters. The core sets of the macro control parameters are shown in TABLE 2.

TABLE 2 : Core sets of macro control parameters of industrial convergence system

No.	Expression
$Core_1$	$\{CP_4, CP_5\}$
$Core_2$	$\{CP_1, CP_2, CP_4\}$
$Core_3$	$\{CP_1, CP_4, CP_5\}$

TABLE 2 shows that, the "state" of CP_1, CP_2, CP_4 and CP_5 determine the "state" of the industrial convergence system. That is to say, the order parameters of industrial convergence system are CP_1, CP_2, CP_4 and CP_5, those are market demand, competition pressure, industry regulation and technological innovation.

The comparison between the result of this study and the achievements of other related researches shows that, the discrimination results on the order parameters of industrial convergence system of EMI and PS is correct and reasonable[11,12]. In this way, the correctness and effectiveness of the methods and models which designed for discriminating the order parameters of complex self-organizing system are proved.

CONCLUSIONS

This paper set focus on the discrimination of order parameter of complex self-organizing system, and got the following conclusions through theoretical analysis, model building and empirical research: First, this paper designed the ideas for discriminating the order parameter of complex self-organizing system on the basis of cluster analysis and rough sets theory, and provided a theoretical basis for discriminating the order parameters of complex self-organizing system. Second, this paper designed the improved cluster analysis model for discretizing the continuous statistical data of both macro control parameters and the complex self-organizing system, and then determining the "state" of the complex self-organizing system and its macro control parameters. Third, this paper designed the knowledge mining model for reducing the macro control parameters of complex self-organizing system. By using this model, the core of macro control parameters is determined, and the order parameter of complex self-organizing system is discriminated at the same time. Last but not least, this paper carried out an empirical study, and proved the correctness and effectiveness of the preceding research ideas and models.

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