Data Complexation: Synergic Methods

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Abstract: - In the hierarchy of system theories, the top level is occupied by synergetics – the science of cooperative processes [1,2]. This is an integral science that allows us to move to a holistic understanding of nature, technology and society based on a single synergetic concept. Unlike general systems theory, synergetics studies cooperative, coherent and self-consistent processes that arise in complex systems. If cybernetics develops management methods in which the system functions in a predetermined manner to achieve a goal, then synergetics organizes a process characterized by self-government and self-organization in accordance with the goal. Here, complex processes develop not under centralized influences, but through the collective interaction of components. Cooperation of components allows the use of reserve capabilities of the system and significantly increases the degree of emergence (system effect). Of course, the transition to a holistic, synergetic concept requires new scientific and applied research that reflects cooperative, synergetic phenomena in the relevant subject areas of knowledge [1]. Therefore, the problem considered in this article is relevant.

Key-Words: - synergetics, data complexation, degrees of freedom reducers, degrees of freedom discriminators, functional system, expert assessments

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1 Introduction

Among the subject areas, biology turned out to be the most receptive to the ideas of synergetics. According to P.K. Anokhin [3], when a biological organism feels the need to achieve a certain result, it develops a special functional system to realize this need. The content of the result (goal) is formed by the system in the form of some model before the result itself appears. If it is sufficient, the body moves on to the formation of another functional system with another useful result, which represents the next stage in the universal continuum of goals. If the result is insufficient, then the activating mechanisms are stimulated, an active selection of new components occurs, a change in the degrees of freedom of existing synaptic organizations is created, and, finally, after several trials and errors, a sufficient adaptive result is found.

The main quality of a biological self-organizing system is that it continuously and actively enumerates the degrees of freedom of many components, often even in micro-intervals of time, in order to include those that bring the organism closer to obtaining the desired result.

According to Anokhin's own definition., "a system can only be called such a complex of selectively involved components, in which the interaction and relationship acquire the character of cooperation of components to obtain a fixed useful result" [3]. The identified fundamental property of interaction is a clearly expressed and universally manifested synergistic process in biological systems [1].

The stated provisions of the theory of P.K. Anokhin are organically combined with the theory of dominance by A.A. Ukhtomsky [4] (dominant is the center of excitation of spatial structures of the brain). The process of creating a functional system through dominant excitation indirectly leads to purposeful activity. A dynamically changing focus (center) of excitation, structured according to the mechanism of a functional system, is an integral part of this dominant system. The synergetic theory of the dominant functional system is, in particular, the ideological basis for a formalized description of the operator's activity in the human-machine system [5].

The synergetic concept of data integration (fusion) is actively used to extract maximum information from the existing set of various data characterizing a process or object in a wide variety of subject areas. Let us give some examples from the field of space research.

The work [6] describes a method for automatically classifying the state of forests based on aerospace survey materials based on the synergetic principle of data fusion. If, as a result of the primary classification, two or more different decisions are obtained regarding the class affiliation of an object, then the summary decision is formed by a synergetic rule. First, the entire set of solutions obtained (a component of the synergetic system) is examined, after which the "weight" of some increases and others decreases. Then the most informative (dominant) spectral channels of the sensor are determined, and based on their readings the correct decision is made.

In [7], a complex for remote sensing of the Earth is described, including optical, infrared and radar sensing equipment. This combination of channels for obtaining information of different physical nature provides new opportunities for solving various practical problems. A similar approach is described in article [8]. In [9], the task of integrating signals from navigation fields of various physical natures (radio navigation fields such as GPS, geophysical fields, the field of stars and bodies of the Solar System, etc.) was posed.

2 Problem Formulation

To achieve the goal, the synergetic system must have the required number of degrees of freedom. This corresponds to Ashby's law [10], known in cybernetics, about necessary diversity, only the concept of "diversity" is specified in the concept of "degrees of freedom" of the system, since it is the degrees of freedom that serve as the source of possible diversity. When synthesizing a synergetic system, one must first create excess degrees of freedom, which determine additional possibilities in the properties of the future system, and then overcome (reduce) these degrees of freedom using the dominant mechanism during the functioning of the system. To achieve this goal, "degrees of freedom reducers" are introduced into the synthesized system using a special control law [1].

Unlike conventional synergetic systems, integration systems, as a rule, do not have an excessive number of data acquisition channels. The number of degrees of freedom is a priori limited and the essence of the problem is to extract the maximum amount of available information under these restrictions. In the above examples, the action of the "degrees of freedom reducers" led to the cutting off of less informative ones and to the selection of one or more of the most informative (dominant) channels for obtaining data in the current situation, on the basis of which the desired solution was formed.

With this approach, some useful nuances contained in the pruned channels do not take part in the solution search process, i.e. some information is lost. Figuratively speaking, from the entire ensemble of data, one or several dominant "soloists" are artificially singled out, whose sound lacks those overtones that give the performance special value.

When synthesizing a synergetic system for data integration, it is advisable to abandon the concept of a dominant and, instead of "degrees of freedom reducers," include mechanisms that allow all channels for obtaining data to participate in the formation of a solution with weights corresponding to the degree of their information content in the current situation ("degrees of freedom discriminators"). As a result, all available information will be used properly, and the "sound" of the data ensemble will be coherent and voluminous.

To illustrate the proposed approach, consider the problem of integrating data from expert assessments. If a certain quantitative value cannot be measured directly, then heuristic methods are usually used to determine it. They are based on an individual opinion (postulate) expressed by a specialist (expert) about the value being assessed, based on his professional experience. The main disadvantage of postulation is subjectivity and the possibility of arbitrariness. The procedure of the expert assessment method allows us to reduce this drawback.

3 Problem Solution

The method consists in the fact that to assess a certain quantitative characteristic, the postulates of not one, but several persons (experts) competent in this matter are used. It is assumed that the "true" value of a quantitative characteristic unknown to us is within the range of expert estimates and the "generalized" collective opinion is more reliable. An unknown quantitative characteristic is considered as a random variable, the distribution law of which is reflected in the expert's postulate. To establish the final assessment, the statements of all experts are studied together and processed as a kind of initial statistical material. Processing should be done using the concepts of mathematical statistics.

When solving problems of expert assessment, it is necessary to take into account that the number of experts is usually limited, and the degree of their competence in this matter may vary. Failure to take these circumstances into account reduces the reliability and accuracy of the required estimates. An interesting analogy is given by Olaf Helmer: “We receive information about current events using various instruments, sometimes inaccurate, and we do not refuse this information, taking into account only the degree of its accuracy and reliability. Expert specialists can also be considered as a kind of “device” that gives information about the likelihood of certain upcoming events or hypotheses that explain current events. One should only try to determine the degree of accuracy and reliability of this information, just as is done for other measuring instruments" [11]. Continuing this analogy, we can say that the task of processing expert statements is similar to the task of integrating instruments with different accuracy classes.

It is natural to assume that the accuracy and reliability of the expert assessment procedure will increase significantly if the statements of each expert are perceived with a coefficient (weight) depending on the degree of his competence in this matter. This weight can be established either on the basis of assessments of the expert’s previous activities, or according to self-assessment, or taking into account the qualifications, erudition, position or academic title of the expert. A more reliable procedure is one in which the expert’s competence is assessed directly in the process of solving a specific problem.

Let's consider one way to take into account the heterogeneity of the composition of experts when assessing certain numerical indicators. For simplicity, let us analyze the situation when m experts (the number of degrees of freedom in the future synergetic data integration system) evaluate a single indicator, assigning it a certain number on a certain rating scale. As a result, we obtain an array of initial data of expert assessments, which in our case is represented as a column matrix

$$A = \begin{Vmatrix} \alpha_1 \\ \alpha_2 \\ \dots \\ \alpha_j \\ \dots \\ \alpha_m \end{Vmatrix}, \quad m \geq 3. \qquad (1)$$

Since it is not yet known which expert to trust more, we first assume that the degree of confidence in the statements of all experts is the same and when averaging their estimates are accepted with one coefficient $k_j^I=1$, $j \in [1,m]$. As a result of averaging, the average score is obtained

$$\alpha^I = \frac{1}{m}\sum_{j=1}^{m} k_j^I \alpha_j = \frac{1}{m}\sum_{j=1}^{m} 1 \cdot \alpha_j = \frac{1}{m}\sum_{j=1}^{m} \alpha_j.$$

Let's call it the estimate of the first iteration. The averaging operation in matrix form is the multiplication of the matrix of expert assessments on the left by a unit m-row matrix (summing vector)

$$E = \begin{Vmatrix} 1 & 1 & \dots & 1 \end{Vmatrix}$$

and dividing the product by the number of experts:

$$\alpha^I=(1/m)EA.$$

Now we have information about the average assessment α^I, with which we can compare the assessments of individual experts α_j from matrix (1). Naturally, the difference between the average assessment (majority opinion) and the assessment made by an expert can serve as the basis for changing the weighting coefficient with which the statement of a given expert is perceived. For those experts whose assessment at the first iteration is closer to the average, it is advisable to increase the coefficient k_j and, conversely, for experts whose assessments are far from the average, it should be lowered. Our procedure omits those relatively rare cases in which the “truth” turns out to be on the side of the minority. Let's introduce a measure (degrees of freedom discriminator)

$$\delta_j^{II} = \left| \alpha^I - \alpha_j \right|, \; j \in [1,m],$$

which serves as a quantitative expression of the degree of incompetence of the j-th expert at the second iteration. It is advisable to select coefficients k_j^{II} that would represent functions inversely proportional to δ_j^{II}:

$$k_j^{II}=a/\delta_j^{II}, \; a=\text{const}, \quad (2)$$

given that

$$\sum_{j=1}^{m} k_j^{II} = m. \qquad (3)$$

Solving the system of equations (2) and (3), we eliminate the unknown proportionality coefficient *a* and obtain

$$k_j^{II} = \left(m \big/ \delta_j^{II} \right) \Big/ \sum_{t=1}^{m} \left(1 \big/ \delta_t^{II} \right).$$

After this, averaging is carried out at the second iteration, taking into account the competence of experts based on the results of the first iteration.

$$\alpha^{II} = \frac{1}{m} \sum_{j=1}^{m} k_j^{II} \alpha_j. \qquad (4)$$

By introducing the row matrix

$$K^{II} = \left\| k_1^{II} \quad k_2^{II} \quad \ldots \quad k_j^{II} \quad \ldots \quad k_m^{II} \right\|,$$

we present expression (4) in matrix form

$\alpha^{II}=(1/m)K^{II}A.$

The third iteration process begins with establishing the measure

$$\delta^{III} = \left| \alpha^{II} - \alpha_j \right|, j \in [1, m],$$

etc. Iterative procedure

$\alpha^{(g)}=(1/m)K^{(g)}A,\ g\in[1,h],\ K^{I}=E$

continues until a stop condition is met

$$\left| \alpha^{(h)} - \alpha^{(h-1)} \right| \le \varphi,$$

where φ is a given small value. The result of the described iterative procedure is to obtain a refined estimate $\alpha=\alpha^{(h)}$, determined taking into account the heterogeneity in the composition of the experts. In practical cases, the iterative process converges in 3-4 iterations. Note that in this case, as the value of φ decreases, the estimate based on the principle of "degrees of freedom discriminators" asymptotically degenerates into an estimate based on the principle of "degrees of freedom reducers."

To increase the accuracy of measurements when studying the parameters of the motion of small celestial bodies, a bistatic configuration of radar systems is used. Information from each of n receiving antennas, separated over considerable distances, is processed and compared with each other so that the resulting signal is the most reliable.

We consider the problem of information processing in bistatic radar as calculating a refined estimate θ^* of the parameter θ of the distribution $f(x/\theta)$ of a random variable X based on statistical material of a limited volume $x=x^{(n)}=(x_1, x_2, \ldots , x_n)$ – degrees of freedom of the synergetic data integration system.

To solve this problem, we use the Bayesian approach [12,13]. A priori information is used that the unbiased estimate of the parameter θ, considered as a random variable, is distributed according to the same law as X. Minimizing the risk function with a quadratic loss function gives an expression for the optimal estimate as the a posteriori mathematical expectation of the parameter θ, calculated from a given vector observations:

$$\theta^* = \int_{-\infty}^{+\infty} \theta f(\theta|x) d\theta \Big|_{x=x^{(n)}}.$$

The proposed technique provides for an individual approach to each realization of a random variable (weighting in accordance with the posterior probability of its occurrence) – a discriminator of degrees of freedom, which eliminates information loss when calculating the required estimates from a small sample. This makes it possible to best take advantage of the bistatic configuration of radar measurements.

4 Conclusion

Synergetic methods of data integration are proposed, which make it possible to obtain the maximum amount of available information with a limited number of channels. Instead of degree-of-freedom reducers, it is proposed to use the mechanism of degree-of-freedom discriminators, which makes it possible for all channels, to the extent of their information content in the current situation, to take part in the development of a cooperative solution.

From the examples considered, it is clear that synergetic methods of data integration are consonant with the ideas of mathematical statistics with limited sample sizes. Therefore, in the future it is planned to conduct a study of some synergistic aspects of mathematical statistics. In terms of application, it is planned to study the possibility of using the weighted least squares method to increase the convergence speed of the dual programming method described in [14].

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