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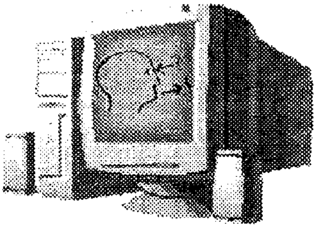

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Application of Cognitive Graphics Means for Decision-Making and Substantiation of Decisions in Intelligent System

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Abstract. In this paper is offered a method of decision-making and its substantiation with application of means cognitive graphics on the base of a 3 -simplex. A used unusual matrix model of data and knowledge representation is described. Mathematical foundations of a 3 -simplex construction are proposed. Three ways for visualization and substantiation of the decision-making are offered. These ways are based on 3-simplex development (transformation) in a set of 2-simplexes.
Keywords. Cognitive graphics, decision-making and its substantiation, matrix model of data and knowledge representation, regularities in the data and knowledge, n-simplex.

1 Introduction

Since 80th years of the XX century cognitive graphics has begun to develop as scientific direction associated with decision-making and its substantiation in intelligent systems (ISs). The world famous scientists D.A. Pospelov [3], A.A. Zenkin [18] had made a significant contribution in cognitive science development. Namely D.A.Pospelov suggested idea about synthesis of two directions based on a metaphor of the left and right hemisphere which has giant recognition field [4, 5].

Decision-making and its substantiation in ISs with using various means of cognitive graphics invariances to problem fields, is oriented on various qualification users and is possessed of various potential of intelligent energy, are presented in publications [6–12, 14, 17]. The idea of combination various cognitive means, which have or do not have a mapping in usual reality in representation of information structures, regularities revealing and decision-making and its substantiation into intelligent systems are partly reflected in publications [7, 9, 11, 17].

By the present moment large quantities of subsystems for decision-making and its substantiation with using cognitive graphical means including using 2-simplex are implemented in subsystems presented in [6, 8, 10, 12–14].

However for practical purposes it may be necessary for reference of the object under investigation to the pattern at considering a larger number of patterns.

If the total number analyzable patterns are more than 3 in 2-simplex then two closest patterns to decision-making are selected and all another are jointed into a single pattern [8]. In a s ituation when it is necessary to refer the object under investigation to one of 3 considered patterns is offered to use development of the 3-simplex (regular tetrahedron) in the set of 2-simplexes (regular triangle) in this paper.

In the paper visualization of decision-making results and its substantiation on the base of development (transformation) of a 3-simplex in the set of four 2-simplexes is given. Data and knowledge representation is described. The main concepts and definitions are given. The idea of a decision-making is described shortly. Mathematical bases of mapping object under investigation in the n-simplex, visualization of a 3-simplex in the form set of 2-simplexes development are proposed.

2 Representation Data and Knowledge

We use unusual matrix model [6, 8] for represented the data and knowledge (learning sample consisting of object discriminations). The model includes an integer discrimination matrix (***Q***) and an integer distinction matrix (***R***).

Rows of discriminations matrix ***Q*** is mapping objects from learning sample of a problem field. Columns of discriminations matrix ***Q*** is mapping characteristic features, which in aggregate describe each object. The element q_{ij} of the matrix ***Q*** determine the value j-th feature for i-th object. Rows q_i of the matrix ***Q*** is mapping object s_i ($i \in \{1, \ldots, l\}$) where l is number of learning objects. A dash ("–") in the respective element of the matrix ***Q*** shows that the value of the feature is not significant to the object. We give the range of values for each feature z_j ($j \in \{1, 2, \ldots m\}$).

Each row of the matrix ***R*** corresponds to the row of the matrix ***Q*** having the same index. Columns of the matrix ***R*** is mapping of distinction levels that represent classification features. Classification features define the different mechanisms of objects partition into equivalence classes (mechanisms of classification). The element r_{ij} of matrix ***R*** sets a belonging i-th object to one of the selected classes at j-th mechanism of classification. The number of class is used for indication of the object belong to this class. The set of all nonrepeating rows of the matrix R is compared to the number of selected patterns presented by the one-column matrix ***R'*** whose elements are the numbers of patterns. Elements of a pattern are the objects presented by rows of a discriminations matrix ***Q***, compared to identical rows of a distinctions matrix ***R***.

This model allows us to represent not only data but the expert knowledge, as one row of the matrix ***Q*** can be represented as a subset of objects in the interval form, which are characterized with the same final decisions, for the relevant rows of the matrix ***R***.

For further survey we use the definitions and concepts described in [6, 8].

Description object under investigation is set by a values population of features which number, as a rule, is essential less numbers of the characteristic features.

A diagnostic test (DT) is a set of features that distinguishes any pair of objects that belong to different patterns.

The diagnostic test is called “irredundant” (dead-end [19]) if it includes an irredundant amount of features.

An irredundant unconditional diagnostic test (IUDT) is characterized by simultaneously representation of all features of the object under investigation included in test, while decision-making.

Regularities are subsets of features with particular, easy-to-interpret properties that affect the distinguishability of objects from different patterns that are stably observed for objects from the learning sample and are exhibited in other objects of the same nature and weight coefficients of features that characterize their individual contribution [16] to the distinguishability of objects and the information weight given, unlike [2], on the subset of tests used for a final decision-making.

These subsets can include constant (taking the same value for all patterns), stable (constant inside a pattern, but non-constant), non-informative (not distinguishing any pair of objects), alternative (in the sense of their inclusion in DT), dependent (in the sense of the inclusion of subsets of distinguishable pairs of objects), unessential (not included in any IUDT), obligatory (included in all IUDT), and pseudo-obligatory (which are not obligatory, but included in all IUDT involved in decision-making) features, as well as all minimal and all (or part, for a large feature space) irredundant distinguishing subsets of features that are essentially minimal and irredundant DTs, respectively. The weight coefficients of characteristic features are also included in regularities [16], as well as the information weight of characteristic features determined on the subset of tests used for a find decision-making.

The irredundant an implications matrix [6, 8] is constructed under matrixes $\boldsymbol{Q}$ and $\boldsymbol{R}$. The implications matrix of sets discernibility of objects from different patterns for a problem decision about belonging of the object to this or that pattern (to a class at the fixed mechanism of classification). On irredundant the implications matrix of with application of logical-combinatorial algorithms come to light various regularities and are constructed irredundant the coverings column [6, 8] setting as a matter of fact all IUDT.

Decision-making on belonging of object under investigation to one or another pattern on everyone IUDT within the framework of the logical-combinatorial approach of a pattern recognition is performed out with use of threshold value of conditional degree of proximity of the object under investigation to the considered pattern. This threshold value is calculated on the base on admissible error in percentage of recognition preassigned by the user [8].

Definition of a membership object x under investigation to pattern k is defined on the base of coefficient of conditional degree of proximity a_k of recognizable object under investigation to the pattern k [8], calculated by the formula:

$$a_k = \frac{S_k^x}{S_k},$$

где x – object under investigation,

k – pattern,

S_k –coefficient of interclass similarity (similarity of objects inside the pattern),

S_k^x –coefficient of similarity object x under investigation with class (pattern) k.

The coefficient of interclass similarity S_k is defined as the ratio of the sum in pairs similarity (number of the equal values of the same name of features) of objects inside a class (pattern) to number of pairs objects of this class (pattern).

The similarity coefficient S_k^x of object under investigation with class (pattern) is defined as the ratio of the sum of a similarity of the given object with all objects the class (pattern) to the number of objects of this class (pattern).

3 Mathematical foundation of mapping of object under investigation in the n-simplex

The theorem given in the publications [1, 8] is the foundation for decision-making and its substantiation with cognitive means in the form n-simplex

Theorem. Suppose $a_1, a_2, \ldots, a_{n+1}$ is any set of simultaneously not equal to zero numbers where n - dimension of a correct simplex. Then there is one and only one such point that $h_1{:}h_2{:}\ldots{:}h_{n+1} = a_1{:}a_2{:}\ldots{:}a_{n+1}$,, where h_i ($i \in \{1,2,\ldots,n\}$) – distance from this i-th point to the side [1].

At n=3 the coefficient a_i ($i \in \{1,2,3,4\}$) represents a degree of conditional proximity of object under investigation to i-th pattern. By virtue of the fact that the 3-simplex possesses property of the distances (h) sum constancy from any point to its sides and of preservation property of ratios h1/a1=h2/a2=h3/a3=h4/a4 then distances h1, h2, h3, h4 are calculated on the base of coefficients a_i ($i \in \{1,2,3,4\}$) and normalisation operation from the following relations

$$\begin{cases} h = \sum_{i=1}^{4} h_i \\ h = \alpha \sum_{i=1}^{4} a_i \\ \dfrac{h_1}{a_1} = \dfrac{h_2}{a_2} = \dfrac{h_3}{a_3} = \dfrac{h_4}{a_5} \end{cases}$$

by the formula

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$$h_i = \frac{h \cdot a_i}{\sum_{i=1}^{4} a_i},$$

where α – scaling coefficient.

Outstanding importance for the person making a decision has not only a disposition of object under investigation among other objects of learning sample but also knowledge of some numerical characteristics of observable objects, for example, the entry of object under investigation in the admissible error of recognition preassigned by the user. If the object under investigation fall into field of a similarity not exceeding error of decision-making with some pattern (class) then the point mapping given object in a 3-simplex should not beyond the bounds, marking an admissible error. These boundaries are marked with use of an interior and exterior correct tetrahedron (3-simplex).

4 Visualization of a 3-simplex in the form development a set of the 2-simplexes

Application cognitive graphics raises considerably quality of the decision-making and its substantiation.

Coefficients a_i ($i \in \{1,2,3,4\}$) and distances h_i ($i \in \{1,2,3,4\}$) are calculated for visualization of the object under investigation among other objects of learning sample for four typical patterns (classes).

We will represent 3-simplex in the form of the development consisting from the set of 2-simplexes (for example Figure 1) because creation of cognitive means is difficult and time consuming. The admissible error of recognition is represented a dotted line on Figure 1 in each 2-simplex in the form of an interior and exterior correct triangle.

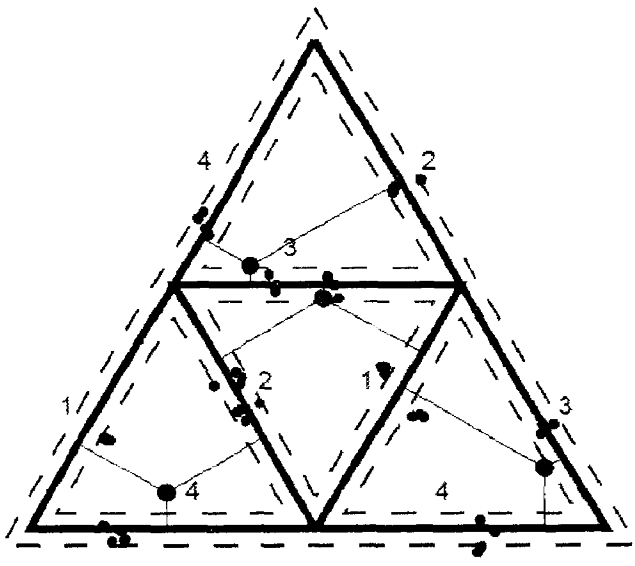

Figure 1. The first way of knowledge visualization

Sides of 2-simplex are pointed in different colours. Each colour is associated with the certain pattern. The side of 2-simplex is compared to the pattern which is the closest to the object under investigation is represented by the green colour, the second pattern with respect to similarity is presented by violet colour, the third pattern with respect to similarity is presented grey colour, the fourth pattern pattern with respect to similarity is presented by brown colour.

We present three ways visualization of knowledge for the learning sample and for the object under investigation on aforementioned development. We present all objects of the learning sample and the object under investigation in form of points. The objects location for visualization is calculated with use of transformation of characters space which describes this object in patterns space.

It's necessary to note that right now the subsystem of knowledge visualization is implemented so that learning sample is generated by the pseudo random way and so results for each example of visualization are different.

The first way of knowledge visualization is presented with use an equilateral triangle. This equilateral triangle includes four 2-simplexes inside (Figure 1).

Each side of a central 2-simplex is the common side with one of sides of an adjacent triangle.

This way of visualization gives the compact picture consisting from four 2-simplexes. This way of visualization is obvious if the number of patterns does not exceed four.

The difference of relative distances from object under investigation to the same pattern in all 2-simplexes and coincidence of the internal boundary of the admissible error of the central 2-simplex with the exterior boundary of the admissible error of the adjacent with it of 2-simplexes (Figure 1) are lacks of the first way of visualization.

The second way of knowledge visualization is more detailed. This way is given on Figure 2.

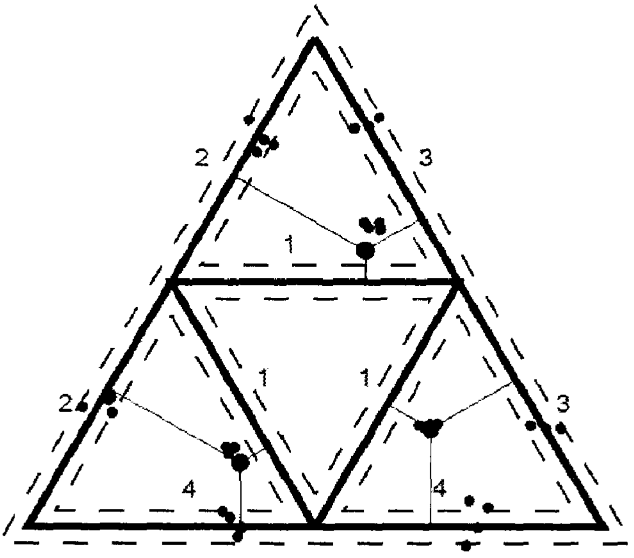

Figure 2. The second way of knowledge visualization

The second way of visualization not uses the central 2-simplex for representation of knowledge. The central 2-simplex represents edge which is the closest to the object under investigation in the 3-simplex. Three exterior 2-simplexes are used for visualization of knowledge relatively three patterns difference every 2-simplex. One from a patterns is the closest to the object under investigation is coincided to other of sides of the central 2-simplex (Figure 2) and two other of sides are combination of the two patterns from three remained patterns. The knowledge is represented so that it is easy to see extent of similarity of the object under investigation to the selected pattern in different combinations of remaining patterns on the one picture.

The second way of representation of knowledge is less loaded by the information and is mapping object under investigation more by visual relative to the pattern which is the closest to the object under investigation. The second way of visualization has one of lacks inhering to the first way of the visualization, namely difference of relative distances from object under investigation to the same pattern in all 2-simplexes

The third way of knowledge visualization is more detailed and is presented on the Figure 3. One side of the central 2-simplex of the third way of visualization is represent two patterns. This way is expediently to use at the number of patterns which is considered is equal 4.

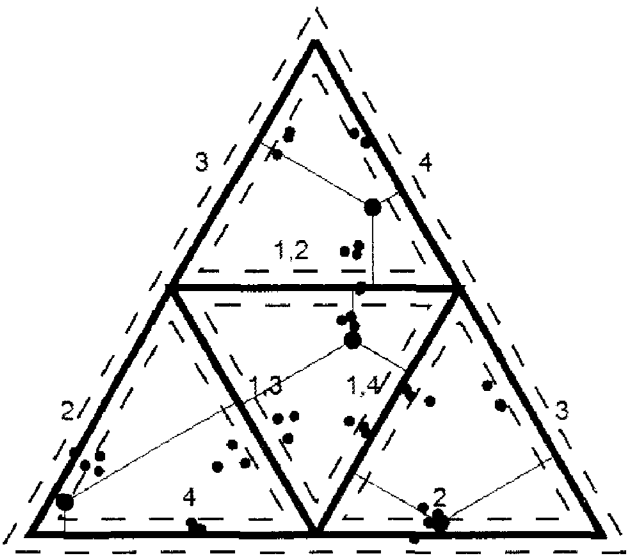

Figure 3. The third way of knowledge visualization

Difference of the third way from previous ways consists that each side of the central 2-simplex is represented two patterns. There and so the relative relation of distances h_i $(i \in \{1,2,3,4\}$ don't keeped for central 2-simplex. The relative relation of distances h_i $(i \in \{1,2,3,4\}$ is keeped for exterior 2-simplexes. Preservation of relative distances h_i $(i \in \{1,2,3,4\}$ allows the person making a decision to observe the object under investigation at equal conditions. Unlike the second way the third way of visualization possesses other the lack inhering the first way, namely coincide of the internal boundary of the admissible error of the central 2-simplex with the exterior boundary of the admissible error of the adjacent with it of 2-simplex.

Above described cognitive means on the base of development of the 3-simplex in sets of three 2-simplexes are offered to use for decision-making and its substantiation based on test methods of a pattern recognition [8] with use of optimising of the logical-combinatorial transformations.

The assignment of the object under investigation to the pattern is defined on the base of formulas described in section 3.

Applied intelligent systems are constructed on the base of the intelligent instrumental software (IIS) IMSLOG [15]. IIS IMSLOG is intended for regularities revealing, decision-making and its substantiation with use means graphic, including cognitive means.

5 Conclusion

Application of cognitive graphics means based on development of the 3-simplex into sets of 2-simplexes for decision-making and its substantiation in intelligent systems is suggested.

Three ways of development of the 3-simplex into set of 2-simplexes are given. All ways consist from set of four 2-simplexes, but the second way uses only three 2-simplexes for visualization. The suggest ways of visualization allow increasing quality of decision-making and getting more substantiation.

The mathematical base of object under investigation mapping in n-simplex are described.

The matrix way of data and knowledge representation used in intelligent systems based on test methods of pattern recognition, decision-making using graphical means including cognitive means is given.

Advisability for intelligent subsystem of cognitive means visualization based on 3-simplex construction in IIS IMSLOG [15] is given. The applied intelligent subsystem on the base of IIS IMSLOG as well as IIS IMSLOG has been devised in Laboratory of Intelligent Systems of Tomsk State University of Architecture and Building.

Future investigation is connected with implement subsystem for decision-making and its substantiation based on above-mentioned cognitive means.

Future the progress is directed on implement cognitive means based on 3-simplex in IIS IMSLOG. This allows to research object into space of four patterns and to observe 3-simplex with different initial points of observation that will increase the quality of decision-making in space of four patterns.

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