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THE CONSTRUCTION OF COMPETENCY-BASED BUSINESS GAME OPERATIONAL MODEL

Alexandr Deryabin, Lidia Shestakova, Olga Vikentyeva

Abstract: *Professional staff competences may have a substantial impact on business efficiency and performance. Therefore many modern companies train their personnel in order to develop a set of professional competences. Hence a need in development of procedures for evaluation and development of competences arises. Consequently it leads to a need of developing new software, which implements those procedures. This article considers the conceptual approach to the design of erratic competence development system elements. The article explains the concept of competence-based business game (CBG), defining it as man-machine system which allows to organize a flexible process of competence development. CBG includes technical and organizational components. Technical component forms sets of transactions, which mean the player to develop a certain level of competences. The organizational component is required to support player's activity during the game. Business game can be represented as a cybernetic system with feedback, which contains both the object of management and the management system. The game is implemented as control and operating machines accordingly. The implementation of technical component requires CBG to be divided into automate and operational models. In order to construct organizational model system analysis and domain ontology construction must be performed. Domain's (company's) business processes are represented in a form of oriented graph, traversing of which allows to develop elementary competences. Companies producing the same commodity may have different business processes. To construct competences that are applicable to similar organization, it is necessary for the graph to be a unification of every business process path. It is also possible to build a graph model of the educational management business process. This graph model must represent real management business processes of an enterprise and must reflect the logic of competence development during the learning process.*

Keywords*: competencies, active learning methods, business-game, business-process, control automat, operating automat, ontology*

ACM Classification Keywords*:* K.3 COMPUTERS AND EDUCATION: K.3.2 Computer and Information Science Education – *Information systems education*. K.4 COMPUTERS AND SOCIETY: K.4.3 *Organizational Impacts – Employment.* I.2 ARTIFICIAL INTELLIGENCE: I.2.1 Applications and Expert Systems – *Games*.

Introduction

The effectiveness of contemporary, rich with information technologies, business is largely determined by human factor. It is people with professional competences who can make a substantial contribution to the organization's performance. The problem of determining employee's competence arises every time you need to select employees that are most suitable for a particular job. Employees that are involved in the organization's business processes and have the required competences are able to make a significant impact on the results of business processes. Each company designs the structure of competences based on the role of each competence in the structure of a business process.

Recent works in the field of HR give much consideration to the procedures of competence determination and development [Крюков, 2013] as well as to the development of software that implements these procedures.

There are projects in Europe that focus on Competence-based education (CBE). Project “TenCompetence” (http://www.tencompetence.org) combines models and tools, used for creation, storage and exchange of knowledge and recourses. Project “Learning in Process” aims to create an integrated new generation system of e-learning, which will support contextual delivery of electronic educational recourses to the user. In <> [Draganidis, 2010] much attention is payed to a system’s prototype, which is based on ontology, used as a tool of competence management. The system integrates competence management with e-learning.

[Гирев, 2010] considers an intelligent system of interactive learning Stratum (http://www.stratum.ac.ru/), which provides knowledge and associated collection of interactive models, tasks and books. It also contains a built-in expert system, which automatically registers and evaluates the actions of students, and offers personal help.

Simulators deserve attention as well, due to their ability to develop professional competences. For instance, STS – Europe’s leading developer of software products in the field of project management education offer a computer simulator SimulTrain, which immerses participants in a real project’s environment and allows making management decisions while being under tight time pressure.

Dynamics of modern production and the need to constantly improve its performance and effectiveness require high-performance systems of employee competence development to be built. Consequently, the implementation of such systems creates a need in new development tools.

This article considers the conceptual approach to the design of ergatic competence development system elements. The article explains the concept of competence-based business game (CBG), defining it as man-machine system which allows to organize a flexible process of competence development.

The suggested approach extends the ideas of creating a set of development tools for active learning methods in a form of competency-based business game studio, stated in [Викентьева, 2013]. Current approach determines the structure of business game studio and depicts the set-theoretical representation of the business game design process. Business game can be represented as a cybernetic system with feedback, which contains both the object of management and the management system. The game is implemented as control and operating machines accordingly.

Technical side of CBG is constituted by two components: automate model (AM) and operational model (OM). This article considers an approach to determination of operational model structure.

The Concept of Competence-Based Business Game

Competence-based business game is an information system, which aims to give a certain level of professional competence while implementing scenarios that are determined by business-process models of the domain [Vikenteva, 2013].

Following function represents the result of a business process

$$R = f(K, M, U), \tag{1}$$

where R – business process result ;

K – level of overall employee competence;

M – quality of input materials or resources;

U – quality of business process management.

The level of overall competence K represents an integral characteristic of human recourse, which determines the result of the business process. The level of overall competence is composed from the levels of elementary competences of individual recourses. Associated with elementary business process operations:

$$K = \sum_{i=1}^{N} k_i^b \times 1/s_i \, , \tag{2}$$

where k_i^b – level of *i*-th elementary competence in the business process *b*;

s_i – complexity factor of the *i*-th elementary operation.

Each elementary competence k^b, generally, may have *l* levels, where *l* depends on the subjective opinion of educational system developers (experts) and can take up different values. Each elementary operation can have *t* levels of complexity, which also can be determined by an expert.

Statement 1. For any elementary competence k^b that supports elementary operation μ^b, there exists a test *W*, which is represented by a tuple

$$W = < w_1, w_2, \ldots w_h >, \tag{3}$$

Where w_j – *j*-th question of the test.

Statement 2. Any process (business process), performed in order to get a result in a finite number of elementary operations, can be represented by a oriented graph

$$G = < V, E >, \tag{4}$$

where G – business process graph;

V – set of graph nodes associated with elementary operations μ^b;

E – set of graph edges associated with elementary operations connections (relations).

Any elementary competence k^b can be constructed during graph *G* traversal. Traversal may be performed multiple times. The process of competence construction from now will be called the learning process.

While building a model of an organization's business process in order to use this model in the learning process it is necessary to [Викентьева, 2013]:

1. Perform system analysis of the domain and domain ontology construction

2. Build a model of educational business process G^u, using concepts and rules of ontology inference. The business process is to be represented by a graph with multiple paths but no cycles. The nodes of the graph are to represent elementary operations of primary and secondary business processes of an enterprise. Graph must have only one node that stands for the beginning of business process and only one node that stands for business process. Each node except the first and the last one must have a single input and a single output, i.e. the node's degree $\rho(v)=2$ and outdegree $\rho^-(v)=1$, indegree $\rho^+(v)=1$. Each path of the graph defines the steps that a player must make in order to execute business process completely. Each path is an alternative to other paths.

Companies producing the same commodity may have different business processes. To construct competences that are applicable to similar organization, it is necessary for the graph to be a unification of every possible business process path:

$$G^u = \bigcup_i^n G_i^B \tag{5}$$

where G^u – graph of the educational business process,

G_i^B – paths of the real business process graph.

3. Build a model of educational business process U^u, using concepts and rules of ontology inference. This graph must represent management business processes of an enterprise and must reflect the logic of competence development during the learning process. Such graph may contain cycles and various type of nodes (start node, condition node, operation node, final node) with various degree *ρ(v).*

By analogy with (5) the management business process is expressed in the following form:

$$U^u = \bigcup_i^n \left(U_i^B, U_i^L\right), \tag{6}$$

where U^u – graph of the educational management business process;

U_i^B – paths of the real management business process graph;

U_i^L – paths of the educational business process graph, which reflects the logic of competence.

A correspondence may be built between the set of graph paths of the educational business process (EBP) and the sets of competences. This correspondence may be organized in a form of traceability matrix of the EBP by the competences (competence matrix, CM).

Definition 1. A row of competence matrix determines paths in G^u and U^u, required for the construction of competence k^b The combination of these paths is to be called the CBG scenario.

Thus, CBG must consist of procedural guidelines, hardware, infoware, software, a scenario and tests to check the level of competence development [Викентьева, 2013].

Automate and Operational Models

Competence-based business games are supposed to be designed, developed and implemented within a specific environment, referred to as Competence-based Business Game Studio (CBGS) [Викентьева, 2013].

CBG is an ergatic (man-machine) information system:

$$G = \langle \psi, T \rangle, \tag{7}$$

where Ψ – elements related to human activity (teaching materials);

T – elements related to information system (hardware, software, infoware, scenario etc.).

Thus, from items (4), (5), (6) and defeinition 1 a conclusion may be drawn that competence k^b may be successfully developed only if CBG (7) adequately expresses domain concepts.

Domain must be described as ontology on the CBG development stage.

Domain ontology may be represented as [Ганюкова, 2007].

$$O =< Q, S, I >, \tag{8}$$

where Q – set of domain terms;

S – semantically meaningful relationships;

I – definitions of interpretation functions.

Ontology is a set of domain concepts, used by developers (experts) to create models of educational business processes and relations between them. Ontology permits to use the same concepts repeatedly to define different business processes of different enterprises. Moreover, it is possible to integrate several ontologies, hence describing parts of bigger domain. The use of ontologies also allows to separate domain knowledge from operational knowledge. To illustrate this let us say there is an algorithm, which describes the implementation of business process for the production of commodity *A.* The same algorithm may be then used for the production of commodity *B*, provided the latter commodities' ontology is given.

Ontology development suggests [Noy, 2001]:

- determination of ontology classes;
- organization of classes into a taxonomic hierarchy (subclass – superclass);
- determination of attributes (properties) and description of values available for these attributes;
- filling in the attributes of an instance.

If the problem may be represented within terms of result *R*, given data *D*, solution method *M*

$$Z =< R, D, M >, \tag{9}$$

then the ontology must include all alternative ways of representation of results, data, solution methods, data obtaining methods, data storage etc. Such information must be organized in structures which permit the usage of ontology. This applies both Ψ (organizational component) and *T* (technical component).

Let us take a closer look at *T*, a *CBG* component the implementation of which creates several problems such as the issue of representing student's activity and the issue of activity management according to the logic of the domain that serves the purpose of developing given level of competence.

The solution of this problem, as shown in [Викентьева, 2013], is closely related to the separation of *CBG* into automate and operational models. Automate model is built considering the scenario, the graph of the unified management process and domain ontology. Whereby, a language must be chosen that allows to implement the management algorithm. Such languages include, for example, the language of algorithm flow-charts (*AFC*).

The graph of the unified management process and domain ontology are used to develop the operational model.

Scheme for the Development of Competence k^b

The major purpose of CBG is to develop a given level of competence k^b for the Player. To reach this goal the Player interacts with the simulator (technical component *T*), which includes the automate and operational model, testing system and the traceability competence matrix of the *EBP*. In addition, the Player uses elements related to human activity Ψ (teaching materials and software application packages), which are used to support Player's activity during the game. A particular set of application packages depends on the model of the *EBP* and competence k^b. The competence matrix is used to choose a CBG scenario that allows developing given set of competences.

In Fig. 1 uses the following notation:

k^b – developed competence;

PG – procedural guidelines;

P – a player, players or a group of people who seek to develop their competences;

OM – operational model, interactive part of the CBG's hardware;

AM – automate model, management part of the CBG's hardware;

TS – testing system, that includes parts of CBGS and allows to construct testing recourses to conduct test transactions;

CM – competence matrix;

SAP – software application packages.

Let us take a closer look on the cooperation of CBG elements while developing competence k^b (Fig. 1).

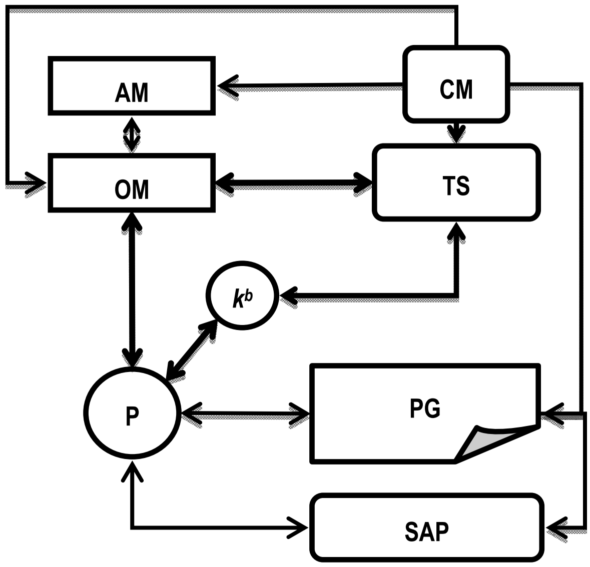

Fig. 1. Cooperation of *CBG* elements while developing competence k^b

On the stage of *CBG* elements' development competence matrix determines structural, algorithmical and functional properties of the automate model, operational model, testing system, procedural guidelines and software application packages.

Competence matrix is represented by the following relation:

$$CM = < k^b, G_i^U >, \quad (10)$$

$$CM = < k^b, U_i^U >, \quad (11)$$

where G_i^U – paths in *EBP* graph,

U_i^U – paths in the graph of the educational management business process.

Determination of CBG elements' properties is performed by imaging CM into the model of associated element. Automate model may be represented as the management algorithm in the language of algorithm flow-charts. The determination of algorithmical and structural properties of the AM in algorithm L may be represented as follows:

$$CM \rightarrow L(P, A, \Omega, \uparrow_i, \uparrow_i), \tag{12}$$

where → – imaged into,

P – test statements (the value of state register, CBG state code),

A – control signals, which determine conduction of transactions,

Ω – unconditional go-to statements,

$\uparrow i$ – transition beginning statements of the *i*-th arrow,

$\downarrow i$ – transition ending statements of the *i*-th arrow.

The algorithmical and structural properties of the operational model are determined by following imaging:

$$CM \rightarrow Q(R, TR, T), \tag{13}$$

where *Q* – function, implemented by the OM,

R – recourses,

TR – testing recourses,

T – transactions.

The “recourse” term refers to information structure, which is required to construct to CBG context and to interact with Player. Recourses may be of two kinds:

- competence development recourses *R;*
- competence evaluation recourses *TR.*

Transaction is a group of logically unified operations that works with data and is either completely processed or completely cancelled. *CBG* transaction includes:

- receiving of control signal from AM;
- choosing recourse;
- information output for the Player;
- standby and Player’s reaction input;
- processing Player’s reaction input;
- setting the state register.

Testing system includes methods and ways to construct testing recourses *TR*, information about developed competences $I(k^b)$, domain ontology *O.*

TR construction may be represented as follows:

$$CM \rightarrow TS(TR, I(k^b), O), \tag{14}$$

where *TR* – testing recourses,

$I(k^b)$ – competence information,

O – domain ontology.

PG construction may be represented as follows:

$$CM \rightarrow PG(S, In, Re, Mp), \tag{15}$$

where *S* – standards,

In – instructions,

Re – regulations,

Mp – technical guidelines.

Software application packages are chosen in accordance with the following expression:

$$CM \rightarrow SAP(P_j), \tag{16}$$

where P_j – array of SAP identification numbers.

During the game, *AM* control signal are used by elements of *OM* to construct *CBG* context as well as conduct educational or test transactions for the Player. By analyzing transaction information the Player performs actions that develop competences. *CBG* state is coded by the operational model in state register (*SR*) according to Player's reaction. This code is used by the automate model to create new control signals.

While analyzing information received from *OM* the Player may use procedural guidelines as well as software application packages.

The analysis of the process of competence k^b development along with its level evaluation is performed with the aid of test transactions sequence. These transactions are formed by the operational model either consecutively or concurrently with educational transactions.

During the game, a part of testing system is used to evaluate the level of competence, that has been developed. This part includes testing recourses which are loaded to the *OM* in advance.

Thus, following items may be distinguished:

- circuit that develops and evaluates competences, and includes player, developed competence k^b, operational model and testing system;
- circuit of *CBG* management, which includes automate and operational models;
- subsystem of player activity support, which includes procedural guidelines and software application packages.

CBG Operational Model

The game player implements a lot of sets of transactions to reach a certain level of chosen competences.

Competence development happens when the Player interacts with the technical part of CBG, main element of which is the operational model (Fig. 2).

In Fig. 2 uses the following notation:

AMI – automate model interface,

UI – user interface,

TSI – testing system interface,

CMI – competence matrix interface,

DP – diagnostic processor,

GP – gaming processor,

RS – recourse storage,

TRS – testing recourse storage,

SR – state register.

Figure 2 shows that OM is connected with CM, TS, AM and the Player. Connections are implemented with the aid of interfaces (means of interaction).

The structure of *OM* gives much attention to the state register. *SR* saves the code of *CBG* state, which refers to a number, associated with context of the game, transaction state, developed competences and Player's reaction.

AM read the state code via *AMI* analyzes it and creates an array of control signal that are then output via *AMI* to the gaming and testing processors.

According to the value of the management action gaming and testing processors conduct game or test transactions.

Recourse storage and testing recourse storage aim to store date of different type: text, multimedia, geospatial information, etc.

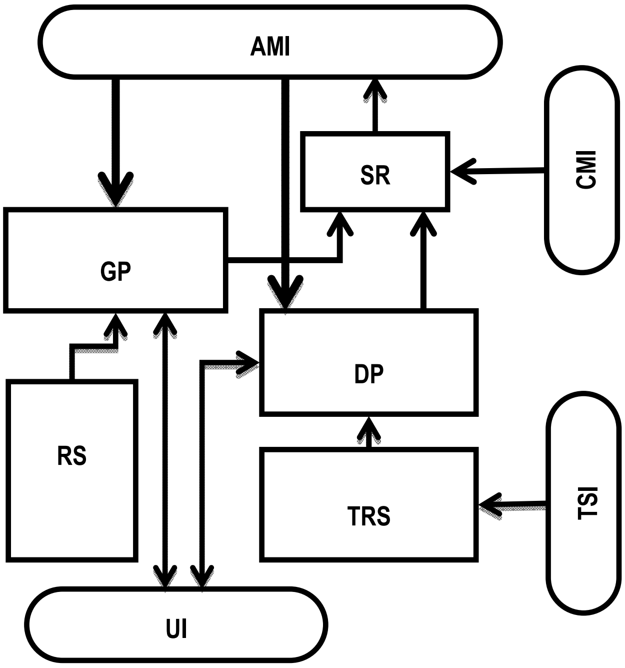

Fig. 2. Structure of CBG operating model

When conducting transactions, processors convert combinations of recourses into information structures that interact with *CBG* participant. Information, received by the Player, gives him incentives for analysis and generalization. The result of these actions represents the developed competence.

Conclusion

To effectively support organizations with qualified expert's new systems of competence development need to be introduced. Thus, article gives a description of eragtic system's structural elements. The system is a competence-based business game that aims to develop professional competences.

Domain's (company's) business processes are represented in a form of oriented graph, traversing of which allows to develop elementary competences. *CBG* uses graph models of educational and management business processes. Moving on to the *EBP* models requires system analysis and domain ontology construction to be performed.

Business game includes technical and organizational components. The implementation of technical component requires CBG to be divided into automate and operational models. Technical component forms sets of transactions, which mean the player to develop a certain level of competences.

The cooperation of *CBG* elements distinguishes a circuit of competence development and evaluation and a circuit of management. The organizational component is required to support player's activity during the game.

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A SYSTEM APPROACH TO SOLVING FORESIGHT PROBLEMS ON THE BASIS OF DELPHI METHOD

Nataliya Pankratova, Lyudmila Malafeeva

Abstract: Based on the experience of solving problems of foresight, it should be noted that the multi-factor, multi-parameter, heterogeneous and weakly structured information of the researched subject areas used at different stages of the process of foresight, leads to difficulties related to the presentation of knowledge, the construction of the survey forms, results processing and coordinated control foresight process as a whole. In order to effectively implement the process of scenario analysis it is expedient in on-line mode to develop automated tools for knowledge extraction, coordinated distribution of data flow of its processing, means in-depth analysis of the studied subject areas, taking into account all the necessary factors for the studied problem. In this article, with that said, the technique of building the information model of knowledge within a single system approach

Keywords: Delphi method, knowledge base, information model of knowledge, questionnaires, expert evaluation, the agreed expert opinion

ACM Classification Keywords: H.4.2. INFORMATION SYSTEM APPLICATION: type of system strategy **Conference topic**: Applied Program Systems

Introduction

Using the foresight methodology is based on the identification of key technologies (critical technologies) and the construction of object future scenarios, to support decision-making at the levels of government, industry or individual institutions and companies in the formation of the most effective science and technology policy and planning for its development [1]. Application of the scenario analysis to solve practical foresight problems is carried out, first of all, by bringing the methods of qualitative analysis, requiring intuition, experience and knowledge of experts in the peer evaluation in various subject areas for the solution of problems of strategic planning and decision-making.

In solving problems of foresight it is necessary to consider the details and specifics related to the necessity of obtaining and processing large volumes of diverse heterogeneous information for further analysis and decision-making at every stage of foresight. For a wide range of problems not formalized in the political, economic, social and other fields and areas of human activity expert estimation methods are the main and most acceptable way to solve them. One of the most used methods of this group is the Delphi method.

However, the complexity, lack of completeness and accuracy of the information distributed management of data flows require new tools and approaches to obtain information from the experts needed for the formation of alternative scenarios [2]. From the specified should be the need to develop automated tools and a common system approach to solving problems of foresight based on the Delphi method.

1. A system approach to solving problems of foresight based on the Delphi method

A system approach to solving problems of foresight, based on the formation of a structured knowledge base as an information platform core scenario analysis, and generation of the survey forms, formalized procedures of expert estimation based on the Delphi method and its application in the mode of on-line, is proposed (Fig. 1).

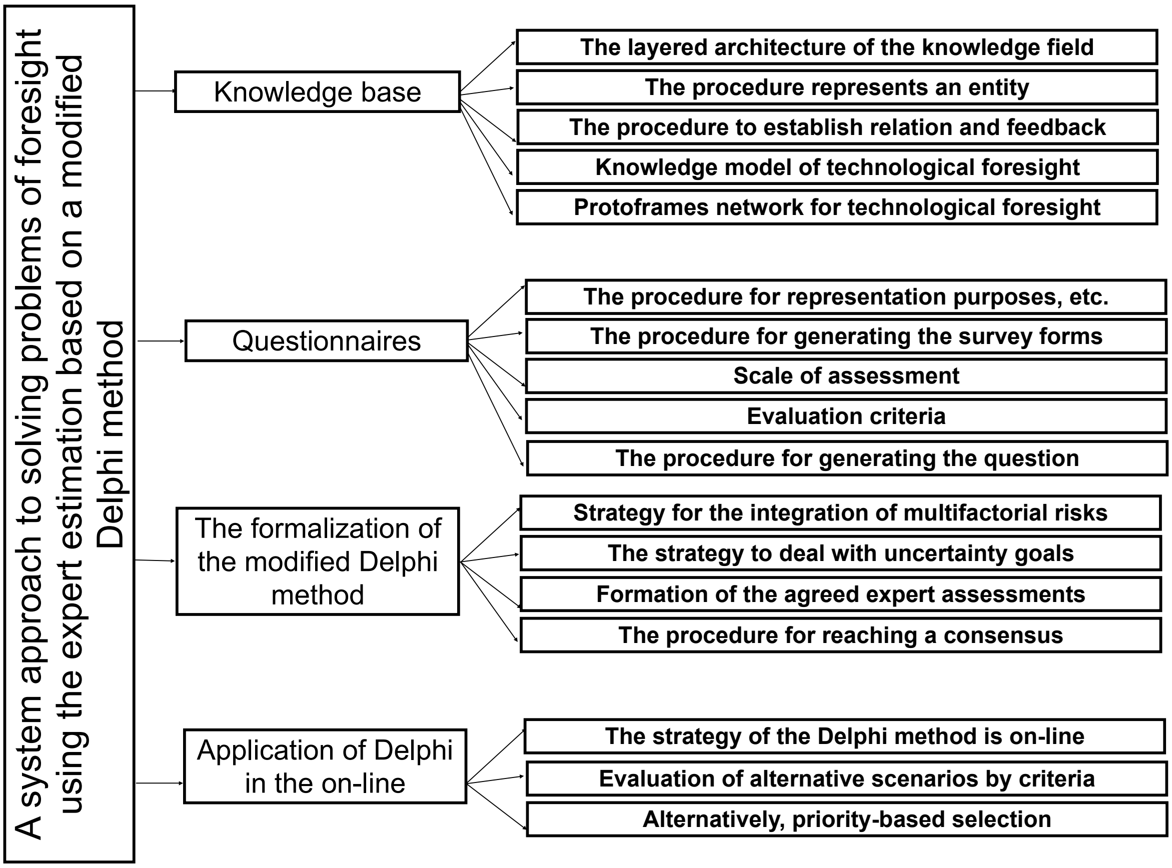

Figure 1. Block diagram of a system approach to solving foresight problems on the basis of Delphi method

Let consider the stages of strategy system approach to solving foresight problems, involving expert evaluation procedure based on the Delphi method and the creation of automated tools.

1.1. Knowledge base

In the construction of an automated tool for solving problems of foresight it is necessary to form a single information space containing homogeneous related structured data obtained from different sources: electronic documents, spreadsheets, semantic fragments extracted from text documents, etc. The proposed software of the data selection from the documents forms the basis of the data on the domain knowledge of the object. The main stages of building the knowledge base are described in [3].

In the process of building a goals tree $G = \{g_i \mid i = \overrightarrow{1, N_G}\}$ of study object O_G is seen in the complex of interrelated and interdependent problems. The procedure of describing the variants of measures sequence to achieve the objectives g_i is reduced to the procedure of describing the current context of the situation $C(T_0, S_0)$, in which there is a considered object at the current time T_0 in the current space S_0, the desired context of the situation $C(T_G, S_G)$ of the ultimate goal of the study, as well as a set of successive versions of the transitions between them $C(T_j, S_j)$, which in turn form the alternative scenarios $Sc_k = \{C(T_j, S_j) \mid j = \overrightarrow{0, N_{Gk}}\}$.

The knowledge field discussed in the relevant sections $\Pr = \{\Pr_i \mid i = \overrightarrow{1, N_{\Pr}}\}$ and levels $\Pr_i = \{L_{ij} \mid j = \overrightarrow{1, N_{\Pr_i}}\}$, the number and structure of which is limited as the scale of the network formed by the framing. The proposed architecture scales the field of knowledge objects to the desired level composition and allowing them to correlate with each other to compare the most important sections, that enables to move from a linear representation of complex plane entity to a simple hierarchical structure forming ordered knowledge based foresight features of the process [3].

In the process of formation of fields frame structures F_i, the procedure represents an entity from a field of knowledge $F_i = C_i \bigcup_{i=1}^{N_{x_i}} X_{ij}$ with the establishment of appropriate backward and forward linkages $R_i = D_{i1} \bigcup S_i \bigcup D_{i2}$, which expands the range of unique titles to choose frames and reduces the risk of duplication in the knowledge base structuring information, making the procedure more acceptable to the analyst [4,5].

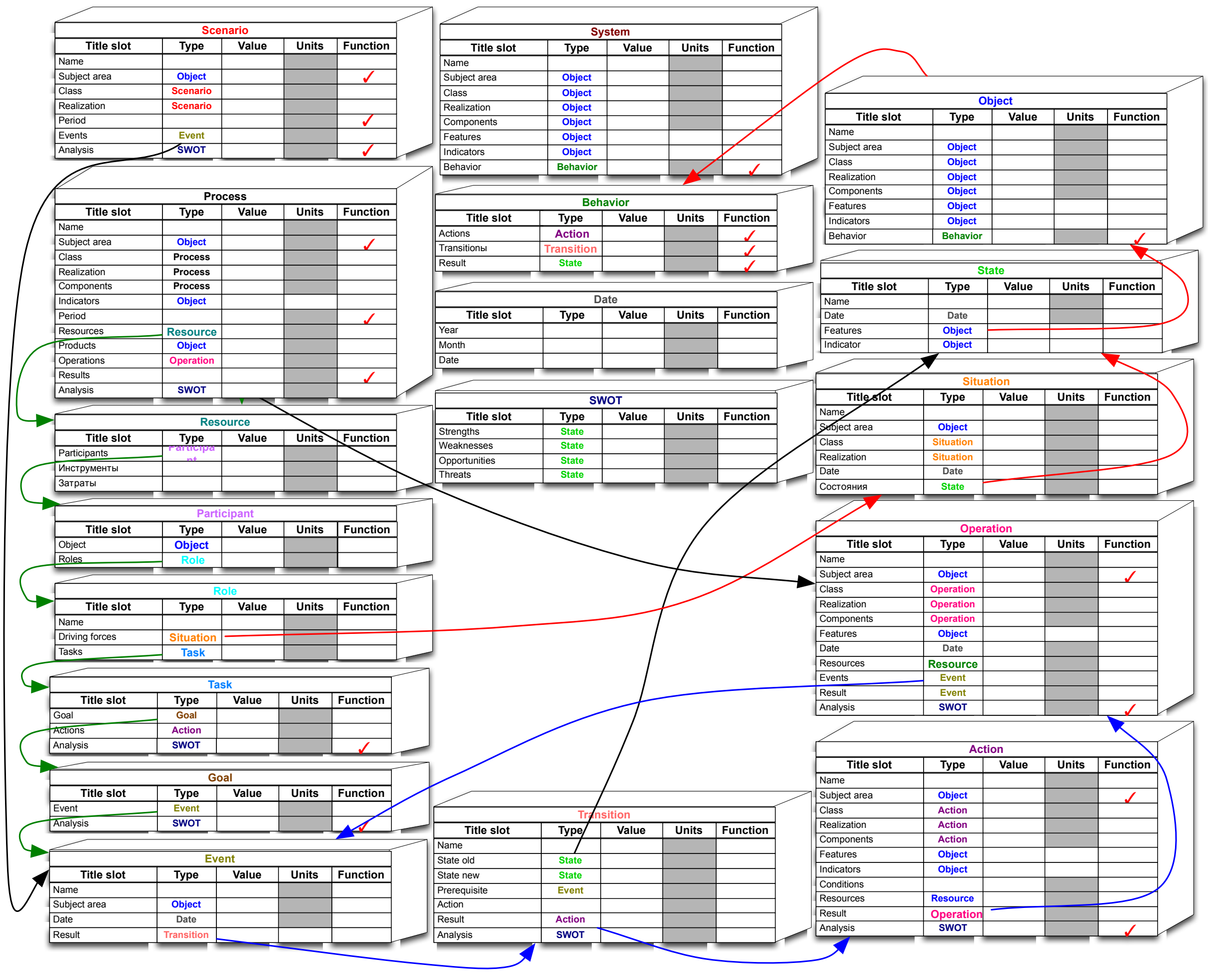

Figure 2. Frame-prototype network of technological foresight

Model of the knowledge field is defined as follows: $M =< F, R, P >$, where $F = \{F_i \mid i = \overrightarrow{1, N_F}\}$ - a lot of frames, $R = \{R_i \mid i = \overrightarrow{1, N_R}\}$ - a lot of semantic roles, $P = \{P_i \mid i = \overrightarrow{1, N_P}\}$ - finite set of relations between frames using the appropriate semantic roles where P_i is defined as: $P_i = \{F_i R_{ij} F_j \mid j = \overrightarrow{1, N_{P_i}}\}$, $\forall i = \overrightarrow{1, N_P}$.

Frame-prototype network of technological foresight, shown in Fig. 2, which is based on the information model of knowledge as a result of building the knowledge base, is represented in the form of cuts and layers containing interrelated and interdependent frames of problems, goals, situations, trends, scenarios, etc.

Frame-based approach to model building alternatives script generates quasi-dynamic knowledge control system that captures the values of a certain period of time, and allows you to build a network of transitions to create alternative scenarios for the future in accordance with the intended purpose of the study [6].

1.2. Questionnaires

In the process of solving the problems experts form possible events, conditions, solutions, evaluate the accuracy of the assumptions and hypotheses, the importance of the objectives on the basis of information given to them about the subject area, considered objects and relationships, characteristics, and performance [7]. The proposed method of construction of the survey forms for expert evaluation method based on the Delphi method helps to solve problems related to:

- Automatic generation of the survey forms the basis for research purposes;
- Correctness of the wording and presentation of the issue in order to avoid ambiguity interpretation of its meaning;
- Complete description of the context of the situation with its consequences, in which the question is asked, as well as the elimination of contextual redundancy;
- Ergonomic structure of the survey forms with a focus on the most important experts of key issues;
- Obtaining the results of the survey in the form of kid-machine interface and decision-makers;
- Inevitability of errors due to manual procedures for processing large amounts of information.

To achieve the objectives a formalization of stages of creating profiles was carried out and a module of automatic generation of the survey forms, which consists of an issue generation procedure and directly questionnaire form generation procedure was developed.

Each question in the survey form is generated from the context of the issue, the text in question and the scale of assessment:

The context of the question consists of:

1. Temporal boundaries;
2. Place;
3. Object;
4. Indicator;
5. Changes - changes from the present, affecting the rate of the object and reflect the picture in the specified time-frame and territories:
   - The name change;
   - Quality changes (degree);
   - The amount of change (scale).

Question:

Rate << Object >> << Indicator >> [and the degree of confidence in the response] for each level of << Scale >> evaluation within the context of the issue.

In order to improve the accuracy of the examination as a basis for estimating the scale 7-level scale of Miller was taken. The key indicators to determine the boundaries of the scale of estimation are:

- limiting interval $[V_{\inf};V_{\sup}]$ - the boundaries within which the indicator of an object is measured;
- General interval $[V_{\min};V_{\max}]$ - the boundaries within which the indicator of the object is under consideration.

For the evaluation of alternative scenarios of the main criteria in the construction of a 7-level scale of assessment have been taken:

- Efficiency;
- Feasibility;
- The degree of relation to the problem;
- Degree of confidence in the proposal.

Universal approach to the formation of the survey forms is to combine the different applications of the method of expert assessment based on the Delphi method in the analysis phase of the process of technological foresight that has been realized in a complex algorithmic procedures and the use of computer technology.

1.3. The formalization of the modified Delphi method

At present, in spite of the level of demand and the relevance of the Delphi method, virtually there are no mathematical formalization and the single system approach to creating coherent expert estimates.

In [8], a formalization of the process of harmonization of expert opinion in terms of fuzzy interval estimates $\overline{Q}_{np} = \{\overline{Q}_{npk} \mid k = \overrightarrow{1, K_{np}}\}$, $\overline{Q}_{npk} = \{[\overline{Q}_{npks};\overline{Q}_{npks}] \mid s = \overrightarrow{1,S}\}$ and interval metrics $\rho_{d_{npk_ik_js}} = \rho_{d_{npk_is},d_{npk_js}} = \max(|d^-_{npk_is} - d^-_{npk_js}|,|d^+_{npk_is} - d^+_{npk_js}|)$ in order to allow the interview on-line and building sound alternatives scenarios based on man-machine platform scenario analysis. The formalization of the modified Delphi method is carried out taking into account the k -expert competence χ_{npk} and confidence ν_{npks} a staged response for each s -level.

The main steps in the process of formation of the agreed expert assessments for p -th indicator n -th object on the set of interval estimates $\overline{Q}_{np}$ are [8]:

1. The calculation of the exponent of the importance $W_{np} = \{w_{npk} \mid w_{npk} = w_{np}(\overline{Q}_{npk})\}, \forall p = \overrightarrow{1, P_n}, \forall n = \overrightarrow{1,N}$:

$$w_{np}(\overline{Q}_{npk}) = (1 - \rho(\overline{Q}_{npk}, \hat{Q}))\chi_{npk} \tag{1}$$

for determination of which some steps should be carried out:

1.1. The calculation of the mathematical average $\overline{M}_{np} = \{[\overline{M}^-_{nps};\overline{M}^+_{nps}], s = \overrightarrow{1,S}\}$:

$$\overline{M}^-_{nps} = M\overline{Q}^-_{nps} = \frac{1}{K}\sum_{k=1}^{K_{np}}\overline{Q}^-_{npks} \tag{2}$$

1.2. The calculation of the integrated peer review $\overline{\overline{Q}}_{np} = \{[\overline{\overline{Q}}^{-}_{nps};\overline{\overline{Q}}^{+}_{nps}], s = \overrightarrow{1,S}\}$:

$$\overline{\overline{Q}}^{-}_{nps} = \arg\min_{\overline{Q}^{-}_{npks}}(|\,\overline{Q}_{npks} - \overline{M}^{-}_{npks}\,|)\ ;\ \overline{\overline{Q}}^{+}_{nps} = \arg\min_{\overline{Q}^{+}_{npks}}(|\,\overline{Q}_{npks} - \overline{M}^{+}_{npks}\,|) \quad (3)$$

1.3. Computation of the valuation of the span $[0;1]$:

$$K^{-}_{np} = \frac{1}{S(\overline{\overline{Q}}^{-}_{np})}\ ;\ K^{+}_{np} = \frac{1}{S(\overline{\overline{Q}}^{+}_{np})} \quad (4)$$

1.4. The calculation of the Gaussian density $\widetilde{Q}_{np} = \{[\widetilde{Q}^{-}_{nps};\widetilde{Q}^{+}_{nps}], s = \overrightarrow{1,S}\}$:

$$\widetilde{Q}^{-}_{nps} = \frac{1}{K^{-}_{np}\sqrt{2\pi\widetilde{D}^{-}}} e^{\frac{-(x_s - \overline{M}^{-})^2}{2\widetilde{D}^{-}}}\ ;\ \widetilde{Q}^{+}_{nps} = \frac{1}{K^{+}_{np}\sqrt{2\pi\widetilde{D}^{+}}} e^{\frac{-(x_s - \overline{M}^{+})^2}{2\widetilde{D}^{+}}} \quad (5)$$

1.5. The calculation of the cumulative peer review $\hat{Q}_{np} = \{[\hat{Q}^{-}_{nps};\hat{Q}^{+}_{nps}], s = \overrightarrow{1,S}\}$:

$$\sum_{s=1}^{S}\rho(\widetilde{Q}_{nps};\hat{Q}_{nps}) \to \min \quad \text{or} \quad \begin{cases} \sum_{s=1}^{S}\left(\left\| \frac{1}{K^{-}_{np}\sqrt{2\pi\widetilde{D}^{-}}} e^{\frac{-(x_s - \overline{M}^{-})^2}{2\widetilde{D}^{-}}} - \hat{Q}^{-}_{nps}\right\|\right) \to \min \\ \sum_{s=1}^{S}\left(\left\| \frac{1}{K^{+}_{np}\sqrt{2\pi\widetilde{D}^{+}}} e^{\frac{-(x_s - \overline{M}^{+})^2}{2\widetilde{D}^{+}}} - \hat{Q}^{+}_{nps}\right\|\right) \to \min \end{cases} \quad (6)$$

2. The calculation of the least remote peer review M_{np} , to determine the which one:

2.1. Build a matrix of distances between the estimates:

$$D_{np} = \{d_{npk_i k_j}\ |\ k_i, k_j \in \overrightarrow{1,K_{np}}\} \quad (7)$$

2.2. Calculate the vector sum for each row:

$$S_{np} = \{S_{npk}\ |\ S_{npk_i} = \sum_{k_j=1}^{K_{np}} d_{npk_i k_j}, k_i = \overrightarrow{1,K_{np}}\} \quad (8)$$

2.3. The minimum of the vector:

$$M_{np} = \arg\min_{k=\overrightarrow{1,K_{np}}}(S_{npk}) \quad (9)$$

3. The calculation of the confidence interval T_{np} :

$\overline{Q}_{npk} \in T_{np}$, if $\widetilde{\rho}_{npk} = \rho(M_{np},\overline{Q}_{npk})(1 - w_{npk}) < R_1^{(T_{np})}$, where $R_1^{(T_{np})}$ - a priori specified radius. (10)

4. The calculation of the indicator consistency $S^{(T_{np})}$:

$$S^{(T_{np})} = \frac{Card(T_{np})}{Card(E_{np})} \quad (11)$$

The criterion for the end of the examination procedure may be, for example, the excess indicator $S^{(T_{np})}$ a priori specified level S^*.

The main advantages and features of the interactive dialogue of the formation of the agreed expert opinion in the implementation of the Delphi method are:

opportunity to incorporate new ideas of experts;

- Opportunity to incorporate new ideas of experts;
- The focus on the views of opposition;
- Ensure coherence of confrontations (formation of consensus, which is the best option, not a choice of one of the opposites);
- Providing an incentive for creativity.

This formalization involving techniques of artificial intelligence is the basis of the computational algorithm and automated toolkit providing the peer evaluation in the on-line as part of the Information Platform scenario analysis [2].

1.4. Application of Delphi in the on-line

The strategy of the system approach in the on-line as automated tools of support of the process of foresight is shown in Fig. 3.

The block diagram shown in Fig. 3 demonstrates all the steps of the above sections from the construction of the tree of goals and building a knowledge base to automatic generation of the questionnaire forms and conduction of the expert evaluation in the on-line mode. This diagram presents the interactive conversational approach to solving problems of foresight in a unified information platform scenario analysis.

2. Example

Based on the proposed system approach to solving problems of foresight based on the Delphi method we consider a fragment of the information model of scenario analysis on the example of the situation of the livestock industry AIC Crimea (Fig. 4).

As of October 1, 2011 the livestock industry was in a state of crisis. During the first 9 months of 2011 in all categories of farms the reduction in the number of cows and milk production declines in gross were observed [9].

The problem of identification of the priority issues of the livestock industry, which led to a crisis in agriculture sector Crimea, is considered.

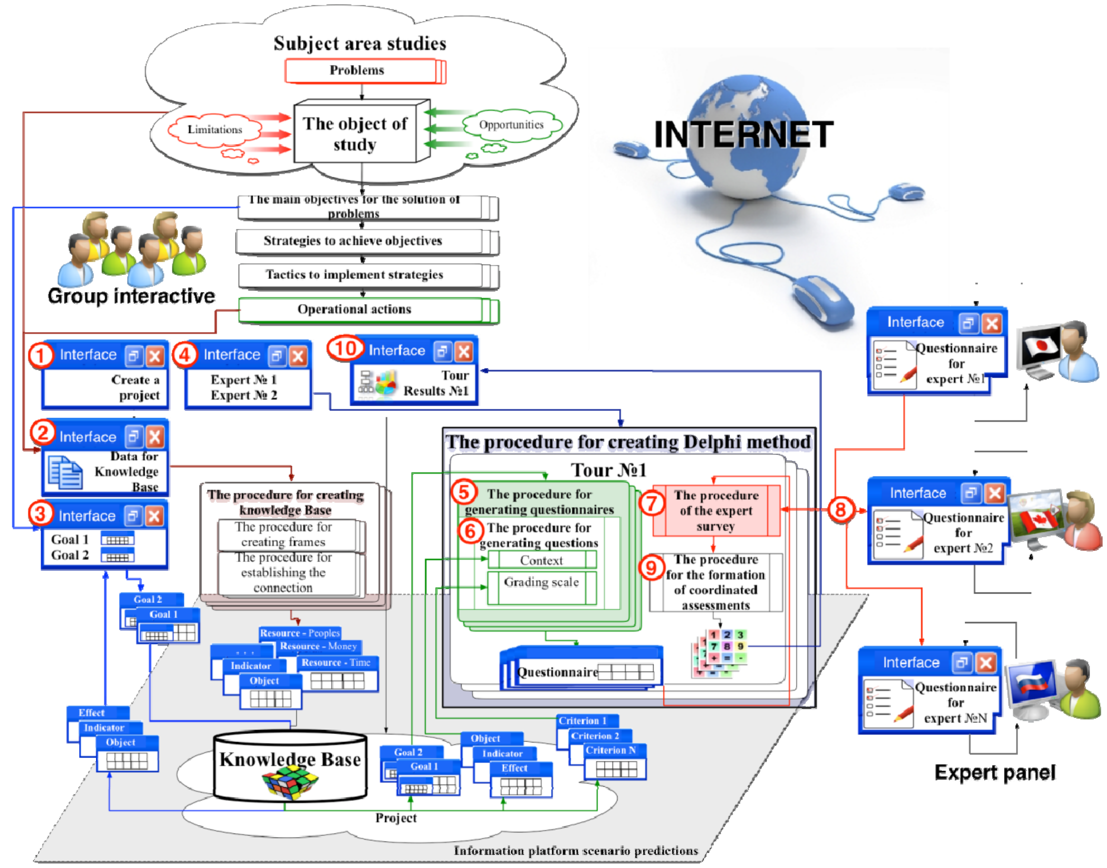

Figure 3. The block diagram of a strategy of system approach implementation in the on-line mode in the form of automated tools

Experts $E_{11} = \{E_{11k} \mid k = \overrightarrow{1,16}\}$ according to their levels of competence $\chi_{11} = \{\chi_{11k} \mid k = \overrightarrow{1,16}\}$, the values of which are presented in table 1 anonymously independently estimated object O_1 = “Challenges to overcome the crisis of the livestock industry" by criteria I_1 = “Priority” using a Miller scale with following levels $s = \overrightarrow{1,7}$:

1. The decrease in gross milk production ($x_1 \in [0;0,14]$);
2. Outdated milking equipment ($x_2 \in (0,14;0,24]$);
3. Unprofitability of the industry ($x_3 \in (0,24;0,43]$);
4. Reducing the proportion of forage crops ($x_4 \in (0,43;0,57]$);
5. Reduction in livestock ($x_5 \in (0,57;0,72]$);
6. Obsolete technical equipment ($x_6 \in (0,72;0,86]$);
7. Reducing the proportion of forage crops ($x_7 \in (0,86;1,00]$).

Thus, the generated question would be:

<u>The context of the question:</u>

Temporal boundaries: 2013-2015

Location: APK Crimea, livestock region

Object: The problems that led to the crisis

Indicator: Priority

Question:

Rate << Priority >> << breakdown-crisis of the livestock industry >> and confidence in the response for each level of << assessment scales >> in the context of the issue.

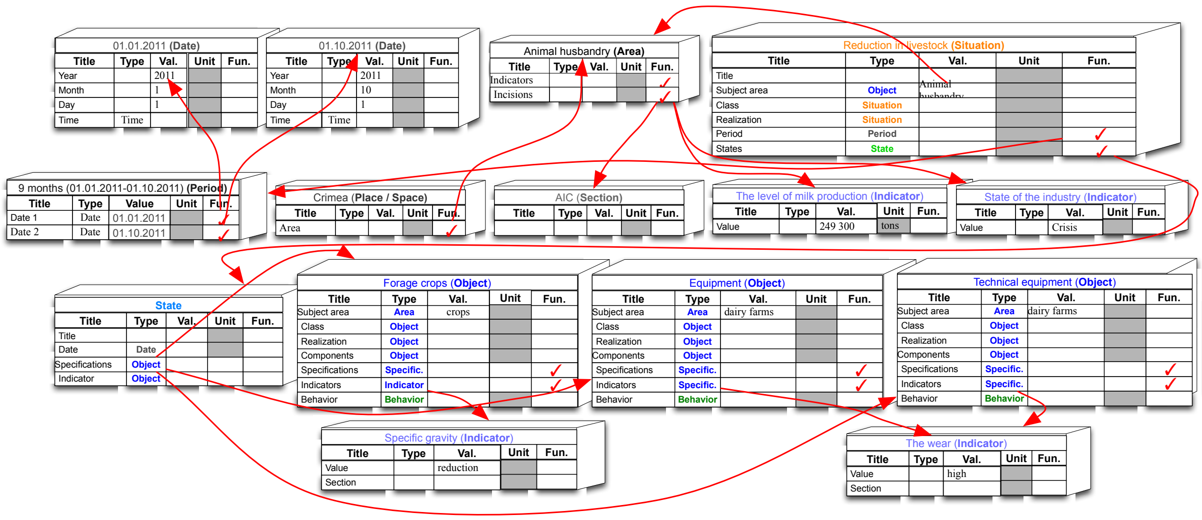

Figure 4. A fragment of the information model of prototype frames of livestock industry of Crimea

Table 1. Competence of experts

Експерт	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6	№ 7	№ 8	№ 9	№ 10	№ 11	№ 12	№ 13	№ 14	№ 15	№ 16
χ_k	0,99	0,78	0,45	0,95	0,87	0,80	0,55	0,99	0,99	0,61	0,89	0,80	0,99	0,56	1,00	1,00

The resulting point estimates are shown in table 2.

Table 2. Point expert assessments

№	Експерт	s													
		1		2		3		4		5		6		7	
		μ_{11k1}	ν_{11k1}	μ_{11k2}	ν_{11k2}	μ_{11k3}	ν_{11k3}	μ_{11k4}	ν_{11k4}	μ_{11k5}	ν_{11k5}	μ_{11k6}	ν_{11k6}	μ_{11k1}	ν_{11k1}
1	Експерт 1	0,09	0,99	0,21	0,99	0,39	0,94	0,52	0,63	0,95	0,63	0,55	0,61	0,72	0,83
2	Експерт 2	0,13	0,94	0,31	0,61	0,57	0,94	0,79	0,94	0,83	0,99	0,66	0,94	0,40	0,61
3	Експерт 3	0,14	0,61	0,33	0,63	0,58	0,83	0,77	0,63	0,76	0,61	0,56	0,61	0,31	0,94
4	Експерт 4	0,65	0,63	0,82	0,99	0,71	0,83	0,46	0,83	0,23	0,61	0,09	0,94	0,03	0,63
5	Експерт 5	0,16	0,61	0,29	0,94	0,38	0,83	0,56	0,99	0,70	0,83	0,65	0,61	0,45	0,63
6	Експерт 6	0,59	0,61	0,85	0,63	0,93	0,83	0,76	0,83	0,47	0,83	0,22	0,61	0,08	0,83
7	Експерт 7	0,09	0,83	0,21	0,63	0,35	0,61	0,43	0,94	0,57	0,63	0,66	0,63	0,56	0,83
8	Експерт 8	0,63	0,83	0,84	0,83	0,77	0,63	0,53	0,99	0,27	0,61	0,11	0,63	0,03	0,61
9	Експерт 9	0,41	0,61	0,46	0,99	0,60	0,63	0,69	0,99	0,58	0,63	0,36	0,99	0,17	0,83
10	Експерт 10	0,27	0,63	0,53	0,94	0,80	0,94	0,90	0,99	0,77	0,94	0,50	0,83	0,24	0,83
11	Експерт 11	0,77	0,61	0,84	0,61	0,66	0,83	0,39	0,83	0,24	0,94	0,13	0,63	0,05	0,99
12	Експерт 12	0,10	0,99	0,25	0,83	0,47	0,61	0,64	0,99	0,65	0,94	0,50	0,63	0,39	0,61
13	Експерт 13	0,10	0,99	0,24	0,94	0,42	0,61	0,55	0,61	0,54	0,99	0,54	0,99	0,47	0,99
14	Експерт 14	0,05	0,83	0,11	0,63	0,25	0,63	0,52	0,94	0,78	0,94	0,87	0,83	0,74	0,63
15	Експерт 15	0,37	0,83	0,61	0,63	0,74	0,99	0,67	0,63	0,45	0,61	0,31	0,94	0,19	0,63
16	Експерт 16	0,90	0,61	0,84	0,83	0,57	0,61	0,29	0,61	0,15	0,61	0,07	0,63	0,02	0,83

The agreed expert assessment in accordance with the algorithm presented in Section 1.3 is formed. According to point estimates concerning (8) the interval expert estimates are constructed (table 3).

Table 3. Interval estimates of experts

№	Експерт	1			2			3			4			5			6			7		
		d^-_{11k1}	μ_{11k1}	d^+_{11k1}	d^-_{11k2}	μ_{11k2}	d^+_{11k2}	d^-_{11k3}	μ_{11k3}	d^+_{11k3}	d^-_{11k4}	μ_{11k4}	d^+_{11k4}	d^-_{11k5}	μ_{11k5}	d^+_{11k5}	d^-_{11k6}	μ_{11k6}	d^+_{11k6}	d^-_{11k7}	μ_{11k7}	d^+_{11k7}
1	Експерт 1	0,08	0,09	0,09	0,21	0,21	0,21	0,37	0,39	0,41	0,37	0,52	0,68	0,67	0,95	1,00	0,38	0,55	0,72	0,62	0,72	0,83
2	Експерт 2	0,12	0,13	0,13	0,21	0,31	0,40	0,54	0,57	0,59	0,75	0,79	0,82	0,82	0,83	0,84	0,63	0,66	0,69	0,27	0,40	0,52
3	Експерт 3	0,10	0,14	0,19	0,23	0,33	0,43	0,50	0,58	0,66	0,54	0,77	0,99	0,52	0,76	0,99	0,39	0,56	0,73	0,30	0,31	0,33
4	Експерт 4	0,46	0,65	0,84	0,81	0,82	0,83	0,61	0,71	0,81	0,39	0,46	0,52	0,16	0,23	0,29	0,08	0,09	0,09	0,02	0,03	0,03
5	Експерт 5	0,11	0,16	0,21	0,28	0,29	0,30	0,33	0,38	0,44	0,55	0,56	0,56	0,61	0,70	0,80	0,45	0,65	0,85	0,32	0,45	0,58
6	Експерт 6	0,41	0,59	0,77	0,60	0,85	1,00	0,80	0,93	1,00	0,66	0,76	0,87	0,40	0,47	0,53	0,15	0,22	0,28	0,06	0,08	0,09
7	Експерт 7	0,08	0,09	0,10	0,15	0,21	0,27	0,24	0,35	0,46	0,42	0,43	0,45	0,40	0,57	0,74	0,46	0,66	0,85	0,48	0,56	0,63
8	Експерт 8	0,54	0,63	0,71	0,72	0,84	0,95	0,54	0,77	0,99	0,52	0,53	0,53	0,19	0,27	0,36	0,08	0,11	0,14	0,02	0,03	0,05
9	Експерт 9	0,28	0,41	0,54	0,46	0,46	0,47	0,42	0,60	0,78	0,69	0,69	0,70	0,41	0,58	0,74	0,35	0,36	0,36	0,14	0,17	0,19
10	Експерт 10	0,19	0,27	0,35	0,51	0,53	0,56	0,76	0,80	0,83	0,89	0,90	0,91	0,74	0,77	0,81	0,43	0,50	0,57	0,21	0,24	0,28
11	Експерт 11	0,53	0,77	1,00	0,58	0,84	1,00	0,57	0,66	0,75	0,33	0,39	0,44	0,23	0,24	0,25	0,09	0,13	0,16	0,05	0,05	0,05
12	Експерт 12	0,10	0,10	0,10	0,22	0,25	0,29	0,32	0,47	0,61	0,63	0,64	0,64	0,62	0,65	0,68	0,35	0,50	0,65	0,27	0,39	0,51
13	Експерт 13	0,10	0,10	0,10	0,23	0,24	0,25	0,29	0,42	0,55	0,38	0,55	0,72	0,53	0,54	0,54	0,53	0,54	0,54	0,46	0,47	0,47
14	Експерт 14	0,05	0,05	0,06	0,08	0,11	0,14	0,18	0,25	0,32	0,50	0,52	0,55	0,75	0,78	0,82	0,75	0,87	1,00	0,52	0,74	0,96
15	Експерт 15	0,32	0,37	0,42	0,43	0,61	0,79	0,74	0,74	0,75	0,47	0,67	0,87	0,31	0,45	0,59	0,30	0,31	0,33	0,13	0,19	0,24
16	Експерт 16	0,62	0,90	1,00	0,72	0,84	0,96	0,39	0,57	0,74	0,20	0,29	0,37	0,10	0,15	0,20	0,05	0,07	0,09	0,02	0,02	0,03

To calculate the parameters of importance of expert assessments the Gaussian density is determined:

The mathematical average (2) of interval expert assessments is determined:

$$\overline{M}_{11} = \{[0{,}26;0{,}42],[0{,}40;0{,}55],[0{,}48;0{,}57],[0{,}52;0{,}66],[0{,}47;0{,}64],[0{,}34;0{,}50],[0{,}24;0{,}36]\}.$$

Calculate the integrated peer-review (3)

$$\overline{\overline{Q}}_{11} = \{[0{,}28;0{,}42],[0{,}43;0{,}56],[0{,}50;0{,}66],[0{,}52;0{,}68],[0{,}52;0{,}59],[0{,}35;0{,}54],[0{,}27;0{,}33]\}.$$

Calculate the correction factor for the valuation interval (4):

$$K^-_{11} = 2{,}55 \;\; ; \;\; K^+_{11} = 1{,}94 \, .$$

A Gaussian density is determined (5) with the normalization factor:

$$\widetilde{Q}_{11} = \{[0{,}20;0{,}28],[0{,}35;0{,}47],[0{,}48;0{,}64],[0{,}52;0{,}68],[0{,}45;0{,}58],[0{,}31;0{,}40],[0{,}17;0{,}21]\}.$$

Indicators of importance according to (1) have the following meanings:

$$w_{11}(\overline{Q}_{11.1}) = 0{,}68 \quad w_{11}(\overline{Q}_{11.2}) = 0{,}60 \quad w_{11}(\overline{Q}_{11.3}) = 0{,}36 \quad w_{11}(\overline{Q}_{11.4}) = 0{,}66$$
$$w_{11}(\overline{Q}_{11.5}) = 0{,}67 \quad w_{11}(\overline{Q}_{11.6}) = 0{,}58 \quad w_{11}(\overline{Q}_{11.7}) = 0{,}40 \quad w_{11}(\overline{Q}_{11.8}) = 0{,}69$$
$$w_{11}(\overline{Q}_{11.9}) = 0{,}86 \quad w_{11}(\overline{Q}_{11.10}) = 0{,}49 \quad w_{11}(\overline{Q}_{11.11}) = 0{,}59 \quad w_{11}(\overline{Q}_{11.12}) = 0{,}65$$
$$w_{11}(\overline{Q}_{11.13}) = 0{,}80 \quad w_{11}(\overline{Q}_{11.14}) = 0{,}35 \quad w_{11}(\overline{Q}_{11.15}) = 0{,}84 \quad w_{11}(\overline{Q}_{11.16}) = 0{,}64$$

The least remote expert assessment is found by the algorithm presented in Section 1.3:

The distance matrix (7) between the estimates of the experts is constructed:

$$D_{11} = \begin{matrix} Expert1 \\ Expert2 \\ \ldots \\ Expert15 \\ Expert16 \end{matrix} \begin{bmatrix} 0,00 & 0,22 & \ldots & 0,41 & 0,65 \\ 0,22 & 0,00 & \ldots & 0,33 & 0,56 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 0,41 & 0,33 & \ldots & 0,00 & 0,37 \\ 0,65 & 0,56 & \ldots & 0,37 & 0,00 \end{bmatrix}.$$

A vector (8) from the respective rows of the resulting matrix is calculated:

$$S_{11} = [7,67 \quad 7,04 \quad \ldots \quad 7,07 \quad 8,44].$$

The value of expert estimate, which is less remote from the opinions of other experts (9), which corresponds to the expert number 13, is found:

$$M_{11} = Expert\,13(6,36).$$

In the confidence set T_{11}, calculated using (10), taking into account $R_1^{(T_{11})} = 0,25$, the experts № 1, № 2, № 4, № 5, № 6, № 8, № 9, № 11, № 12, № 13, № 15, № 16 are included. Indicator of the level of consistency (11) $S^{(T_{11})} = 0,75$, which is greater than a predetermined threshold priori $S^* = 0,7$, indicates the consistency of expert estimates in this round of expert evaluation.

The point estimate with the greatest ability to implement and with the maximum degree of confidence in the supplied reply corresponds to the level $s(Q_{11}) = 6$.

Thus, most experts agreed that "Outdated technical equipment" is the main cause of the crisis of the livestock industry of AIC Crimea and all major powers to combat the crisis should be aimed at elimination this problem.

3. Conclusion

Under the conditions of rapid development of innovative technologies the application of system approach to solving problems of foresight is a necessary component for the effective support of the process of foresight.

The information model of knowledge is a flexible toolkit for building, reporting and analysis of alternative scenarios for the future in the visual form for analytics with the purpose of further analysis and appropriate recommendations to assist in making a decision.

The application of a combination of frames and the semantic network has advantages in the description of objects, processes, events and scenarios in the database with the time-space dimension and representing each of them as an integral structure - a frame. The establishment of the forward and backward connections between the entities with the help of other entities raises the level of perception of the information by the analyst, provides a convenient machine representation for analysis and prevents the violation of structural uniformity and integrity of the database.

The architectural approach to the representation of the field of knowledge in the form of framing allows the network to scale objects to appropriate levels, allowing them to contrast and compare with each other by various sections [2]. Presentation of tier architecture according to the principle of abstraction the knowledge field makes it possible to move from a linear planar representation of complex entities to more simple, which allows you to create an ordered hierarchy of knowledge, taking into account the features of the process of foresight.

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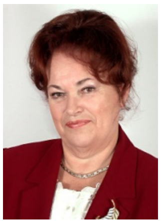

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MATRIXES LEAST SQUARES METHOD AND EXAMPLES OF ITS APPLICATION

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Abstract: *General framework of Least Square Method (LSM) generalization is represented in the paper. Namely, - generalization on vectors and matrixes case of the observation. Also, some principal examples are represented in the article. These examples illustrate the advantages of LSM in the case under consideration. General algorithm LSM with matrixes observations is proposed and described in step-by-step variant. The examples of method applications in macroeconomics and TV-media illustrate the advantages and capabilities of the method.*

Keywords: *Moore-Penrose pseudo inverse, regression, least squares method, macroeconomic indicators, media indicators, prediction.*

ACM Classification Keywords*: G.3 Probability and statistics, G.1.6. Numerical analysis: Optimization, H.1.m. Models and Principles: miscellaneous.*

Introduction

The Least Squares Method (LSM) is reliable and prevalent means to solve prediction problems in applied research and in econometrics particularly. It is used in the case when the function is represented by its observations $(x_i, y_i), i = \overline{1,N}$. Commonly used statistical form of LSM is called Regression Analysis (RA). It is necessary to say, that RA is only statistical shape for representing the link between the components $x_i, y_i, i = \overline{1,N}$ in observations $(x_i, y_i), i = \overline{1,N}$. So using RA terminology of LSM for solution of function estimating problem, and correspondingly, - prediction problem, is only the form for problem discussing.

It is opportune to note, that the LSM is equivalent to Maximum Likelihood Method for classic normal regression. Linear regression (LA) within RA has the advantage of having a closed form solution of parameter estimation problem and prediction problem. Real valued functions of vector argument are the object of investigation in RA in general and in LA in particular. Such suppositions are due to technical capabilities of technique for solving optimization problems in LSM. This technique is in the essence an investigation of extremum necessary conditions. This remark is entirely true for yet another widely used assumption, namely, full column rank assumption for appropriate matrix, which ensure uniqueness of parameter estimation. It's interesting that another technique: Moore – Penrose pseudo inverse (M-Ppi) ([Moore, 1920; Penrose,1955]) provides a comprehensive study and solution of parameter estimation problem.

Below in the article the results developing M-Ppi technique are presented. These ones enable operation with matrices as with real valued vectors and in optimization problem of LSM. And, as the consequence, the results enable designing of LSM for observations with matrix components. It is interesting to note, that such results would require the development of a full arsenal M-Ppi conception for objects in matrix Euclidean spaces. But in the case under consideration manage to use M-Ppi results for Euclidean spaces of real valued vectors to solve the problem of LSM estimation for matrixes observations. Correspondent results are also represented below as well as illustration of its applications for predicting in macroeconomics of Ukraine and in estimating of TV audience.

And the remark in conclusion. Obvious advantage of matrixes LSM, besides the explicit closed estimation form, is the fact that matrixes observations preserve relationships between the characteristics of phenomenon under consideration.

Theoretical foundation: the least squares method

The LSM in its classic version – this is a way to "restore" the numeric functions $y = f(x,\theta), x \in \mathrm{X}, \theta \in \Theta$ from parametric function family, when this function is represented by this or that collection observations $(x, y), x \in \mathrm{X}, y \in R^1$. «Restored function» $\hat{y} = \hat{f}(x,\theta) = f(x,\hat{\theta})$ is defined by choosing appropriate $\hat{\theta} \in \Theta$ (estimation of parameter). The value of parameter $\hat{\theta}$ and restored function $\hat{y} = f(x,\hat{\theta})$ I call by its estimation correspondingly.

In the version of the discrete set of observations, a collection of observations (sample) is discrete: $(x_i, y_i) : x_i \in \mathrm{X}, y_i \in R^1, i = \overline{1,N}$ and parameter is real valued vector: $\Theta \subseteq R^p : \theta^T = (\theta_0, \theta_2, ..., \theta_{p-1})$. "Recovery" can be understood in different ways:

Establish the true value of the function when the model observation is $y_i = f(x_i, \theta_0), i = \overline{1,N}, \theta_0 \in \Theta$;

Approximation of the observed values $(x_i, y_i) : x_i \in \mathrm{X}, y_i \in R^1, i = \overline{1,N}$ by a function from appropriate parametric family: by the choice of appropriate parameters $\hat{\theta} \in \Theta$. Such choice has to be done in such a way that the function $y = f(x,\hat{\theta})$ were the "best" to conform to the observation $(x_i, y_i), i = \overline{1,N}$.

Two previous versions can be combined in a model of observations, which can be described as a model of observations with errors:

$$y_i = f(x_i, \theta_0) + \varepsilon_i, i = \overline{1,N}, \theta_0 \in \Theta,$$

$\varepsilon_i, i = \overline{1,n}$ interpreted as errors of observations.

Last model of observations in the version, when $\varepsilon_i, i = \overline{1,N}$ - are the values of independent random variables is the subject of statistical theory, called regression analysis.

Problem "restoration of function" within the first model of observations can be reduced to the solution of simultaneous equations

$$\{y_i = f(x_i, \theta), i = \overline{1,N} \quad (1)$$

In the rest two cases the approximation criteria $\Im(\theta)$ are to be determined.

In the method of least squares such criterion is determined by the formula:

$$\Im(\theta) = \sum_{i=1}^{N} (y_i - f(x_i, \theta))^2, \quad (2)$$

Correspondingly, $\hat{\theta} \in \Theta$ defined as a solution of the optimization problem of LSM:

$$\begin{gathered} Arg\min_{\theta\in\Theta} \Im(\theta) = Arg\min_{\theta\in\Theta} \sum_{i=1}^{n} (y_i - f(x_i, \theta))^2 \\ \hat{\theta} \in Arg\min_{\theta\in\Theta} \Im(\theta) = Arg\min_{\theta\in\Theta} \sum_{i=1}^{n} (y_i - f(x_i, \theta))^2 . \end{gathered} \quad (3)$$

It is easily to check, that the $\theta_0 \in \Theta$ in the first model (the system of equations (1)) belongs to the set of optimization solutions:

$$\theta_0 \in \underset{\theta\in\Theta}{Arg\min}\,\Im(\theta) = \underset{\theta\in\Theta}{Arg\min}\sum_{i=1}^{N}(y_i - f(x_i,\theta))^2 .$$

Thus, the recovery function problem for the function presented by its observations in both of the forms discussed earlier is reduced to solving an optimization problem (3).

Thus, in all cases of the recovery (estimation) problem for the function, presented by its observations $(x_i, y_i), i = \overline{1,N}$, through parameter estimation $\hat{\theta}$: $\hat{f}(x,\theta) = f(x,\hat{\theta})$, $\hat{\theta}$ can be described as a solution of the optimization problem from (3) and called LSM estimation for parameter or function correspondingly:

The widespread use of LSM in solving of restoration problem for the function, presented by its observations, is determined by its very attractive feature. It is closed form solution for the parameter estimation problem. For a family of functions

$$f(x,\theta) = \sum_{j=0}^{p-1}\theta_j f_j(x)\,,\theta^T = (\theta_0,\theta_2,...,\theta_{p-1})\,,$$

$f_j(x), j = \overline{0, p-1}$ - known function of vector argument *x*

Under additional assumption *rank X=p*.

Closed formed solution in LR for optimization problem (3) \ is determined by formula

$$\hat{\theta} = (X^T X)^{-1} X^T Y, \tag{4}$$

where X – matrix determined by relation

$$X = \left(f_j(x_i)\right), i = \overline{1,N}, j = \overline{1,p-1}\,,$$

Y - vector of observed values of the function: $Y^T = (y_1,....,y_N)$.

Constraint *rank X=p*.is technical, determined only by the solution method for the optimization problem (3) and ensure uniqueness Gauss- Markov equation of the extremum necessary conditions for the functional in (2).

Functional $\Im(\theta)$ of LSM for LR turns to the form

$$\Im = || Y - X\theta ||^2 .$$

Correspondingly, and the optimization problem (3) turns to form of

$$\underset{\theta\in\Theta}{Arg\min}\,\Im(\theta) = \underset{\theta\in\Theta}{Arg\min}\,|| Y - X\theta ||^2 . \tag{5}$$

Optimization problem (5) is essential element of pseudo inverse definition X^+ of a matrix *X* by Penrose [Penrose, 1955] (M-Ppi). By this definition pseudo inverse X^+ for $Y \neq 0$ is determined as norm minimal solution of optimization problem (5):

$$X^+Y = \arg\min_{\hat{\theta}\in \underset{\theta\in\Theta}{Arg\min}||Y - X\theta||^2} || \hat{\theta} || .$$

This definition is only one from more than ten or more equivalent definitions of M-Ppi. M-Ppi technique enables comprehensive solution of optimization problem (3) in form (5) (see, for example [Кириченко, Донченко, 2005]):

$$\underset{\theta\in\Theta}{Arg\min}\,|| Y - X\theta ||^2 = X^+Y + (E_p - XX^+)R^p = \left\{\theta : \theta = X^+Y + (E_p - XX^+)\beta, \beta \in R^p\right\},$$

with M-Ppi X^+ for matrix X. For classical conditions: under condition $rankX = p$ matrix $X^T X$ invertible

$$X^{+} = (X^T X)^{-1} X^T \,,\; XX^{+} = E_p \Rightarrow E_p - XX^{+} = 0 \,,$$
$$\underset{\theta\in\Theta}{Arg\min} \| Y - X\theta \|^2 = X^{+}Y + (E_p - XX^{+})R^p = \left\{X^{+}Y\right\} = \left\{(X^T X)^{-1} X^T Y\right\}$$

Preferential use estimates from (4) and the equation of Gauss - Markov is quite restrictive in applying LSM, while advanced M-Ppi technique, as it mentioned above, enables comprehensive solution of an optimization problem (5). Such preferences of LSM users seems to be the results of habit and the fact of clarity of the source of Gauss - Markov equation as well as the fact, that M-Ppi technique require additional efforts for its mastering and applying.

Actually, directly Penrose [Penrose, 1955] pseudo inverse matrix A^{+} to $m \times n$ matrix A defined as $n \times m$-matrix, which specifies a linear operator $A^{+} : R^m \to R^n$, whose action for arbitrary $y \in R^m, y \neq 0$ is defined by

$$A^{+}y = \underset{x\in \underset{z\in R^n}{Arg\min}\|Az-y\|^2}{arg\min} \| x \|^2 \,. \tag{6}$$

So, by this definition, $A^{+}y$ associated with SLAE (system of linear algebraic equations) $Ax = y$ and defined as smallest norm solution of the optimization problem of best quadratic approximation of the right side of SLAE values of the left side:

$$\underset{x\in R^n}{Arg\min} \| y - Ax \|^2, A \in R^{m\times n}, y \in R^m \,. \tag{7}$$

The set of all solutions of the optimization problem (7) (see, for example, [Кириченко, Донченко, 2005]) is determined by relation

$$\underset{x\in R^n}{Arg\min} \| y - Ax \|^2 = A^{+}y + (E_n - A^{+}A)R^n = \left\{x : x = A^{+}y + (E_n - A^{+}A)v, v \in R^n\right\} . \tag{8}$$

M-Ppi efficiency owes singular valued decomposition (SVD) in its special tensor product form (will be denoted as SVDtp) (see, for example, [Донченко, 2011]): any $m \times n$ matrix A is represented by singularities of two matrixes $A^T A, AA^T$: by orthonormal collections of eigenvectors $v_i \in R^n, i = \overline{1,r}, u_i \in R^m, i = \overline{1,r}$ of $A^T A, AA^T$ correspondingly and common collection of correspondent nonzero eigenvalues $\lambda_1^2 \geq ... \geq \lambda_r^2 > 0, r = rankA$:

$$A = \sum_{i=1}^{r} \lambda_i u_i v_i^T \,,$$
$$u_i = \frac{Av_i}{\lambda_i}, u_i = \frac{A^T u_i}{\lambda_i}, i = \overline{1,r} \,.$$

For another definitions of SVD see, for example, [Алберт, 1977].

M-Ppi definition by SVDtp among more than a dozen other equivalent, is represented by equality:

$$A^{+} = \sum_{i=1}^{r} \lambda_i^{-1} u_i v_i^T$$

M-Ppi is even more than just a tool for working with only vector objects. It provides a means for the manipulating with matrixes. Particularly, M-Ppi technique for real valued vectors enable comprehensive solution of optimization problem type of (3) in form (5) for matrix objects:

$$\underset{X\in R^{n\times p}}{Arg\min} \| Y - AX \|_{tr}^2, Y \in R^{m\times p}, A \in R^{m\times n} \,, \tag{9}$$

where the trace norm $\| \cdot \|_{tr}$ generated by trace scalar product:

$$(C,D)_{tr} = \sum_{i,j} c_{ij} d_{ij} = trC^T D = sum\ of\ the\ diagonal\ elements\ of\ the\ matrix\ C^T D$$

Full solution of the optimization problem (9) is given by the theorem 1 below (for example, [Донченко, 2011]).

Theorem 1. For any $m \times n$ matrix A

$$\underset{X \in R^{n \times p}}{Arg\min} \| Y - AX \|_{tr}^2 = X^+Y + (E_n - A^+A)R^{n \times n} = \left\{ Z : Z = X^+Y + (E_n - A^+A)V, V \in R^{n \times n} \right\}. \quad (10)$$

As in the vector case, the solutions of matrix optimization problem (10) coincide with the set of all solutions of matrix algebraic equations relatively *X*:

$$AX = Y, A - m \times n, Y - m \times p, X - n \times p,$$

when such solutions exist.

Optimization problems and its solutions (8), (10) for, correspondingly, vector and matrix objects, namely, the problem of the best quadratic approximation of the right part of linear equation by the left one, constitute the basis for the least squares method for vector and matrix of observations. “Vectors” or “matrixes” case for observations (*x,y*) means, that both its components:, *x, y* - are simultaneously the vectors or the matrixes correspondingly under supposition that relation between them determined by the components a $m \times n$ matrix A.

Theorem 2. Let the collection of vector pairs $(x_i, y_i) : x_i \in R^n, y_i \in R^m, i = \overline{1,N}$ or matrix pairs $(X_i, Y_i) : X_i \in R^{n \times p}, Y_i \in R^{m \times p}, i = \overline{1,N}$ are an observations of linear operator, defined by $m \times n$ - matrix $A : R^{n \times p} \to R^{m \times p}$.

Then the set of LSM estimation of the operator *A*, is determined by the set of optimization problem solutions

$$\underset{A \in R^{m \times n}}{Arg\min} \Im(A)$$

with

$$\Im(A) = \begin{cases} \sum_{i=1}^{N} (y_i - Ax_i, y_i - Ax_i)^2, \ vector\ observations \\ \sum_{i=1}^{N} (Y_i - AX_i, Y_i - AX_i)_{tr}^2, \ matrix\ observations \end{cases}$$

is equivalent to optimization problem of the best quadratic approximation of the right hand part of algebraic equation $X^T A^T = Y^T$ by it left hand part respectively matrix A^T with matrices X, Y defined by the components of the observations accordingly to the relations:

$$X = \begin{cases} (x_1 \vdots ... \vdots x_N) - \ vector\ observation \\ (X_1 \vdots ... \vdots X_N) - matrix\ observation \end{cases}, \quad (11)$$

$$Y = \begin{cases} (y_1 \vdots ... \vdots y_N) - vector\ observation \\ (Y_1 \vdots ... \vdots Y_N) - matrix\ observation \end{cases}. \quad (12)$$

Proof. Indeed, It is easy to verify, that simultaneous equations: vectors $y_i = Ax_i, i = \overline{1,N}$ or matrixes $Y_i = AX_i, i = \overline{1,N}$, - in the observations model, are equivalent to matrix equations correspondingly:

$$(y_1 \vdots ... \vdots y_N) = (Ax_1 \vdots ... \vdots Ax_N) = A(x_1 \vdots ... \vdots x_N),$$
$$(Y_1 \vdots ... \vdots Y_N) = (AX_1 \vdots ... \vdots Ax_N) = A(X_1 \vdots ... \vdots X_N),$$

which follows from the definition of matrix algebra operations

Thus, in the notation (11), (12) observation models for both types of observations are represented by matrix equation $AX = Y$ with known matrixes *X,Y* and unknown matrix *A*.

Besides

$$\underset{A \in R^{m \times n}}{Arg\min} \Im(A) = \underset{A \in R^{m \times n}}{Arg\min} \| AX - Y \|_{tr}^2$$

So, equivalently

$$\underset{A\in R^{m\times n}}{Arg\min}\,\Im(A) = \underset{A\in R^{m\times n}}{Arg\min}\,||\,AX - Y\,||_{tr}^2 = \underset{A^T\in R^{n\times m}}{Arg\min}\,||\,Y^T - X^T A^T\,||_{tr}^2\,, \tag{13}$$

which proves the theorem.

Theorem 2. The set of all solutions for LSM - estimation of the linear operator by its vectors or matrixes observations is given by the relation:

$$\underset{A\in R^{m\times n}}{Arg\min}\,\Im(A), \Im(A) = \left\{A : YX^+ + V(E_n - XX^+), V \in R^{m\times n}\right\}, \tag{14}$$

Proof. The proof follows directly from theorem 1, relation (10), that describes the solution of matrix algebraic equations through obvious changes in notation and subsequent transposition using commutative property for M-Ppi for matrix and its transpose.

General algorithm of LSM with matrix observations

LSM wit matrixes observation for prediction is implemented in the usual way: by estimation of the function (operator) and using of the estimation on the appropriate argument. Observations, necessary for the estimation procedure to be applied, should be constructed on the basis of a data available. It is the first step of the algorithm proposed.

Step 1. Constructing the matrices components of observations. This step is performed on the based on statistical data by its aggregating firstly in vector and then - in matrixes $R_1, R_2, ..., R_k$. Such two – step procedure uses natural elements of phenomenon description. Vector constituents as a rule are a collection of that or those characteristics of phenomenon under consideration which corresponds to fix moments of time. These vectors constituents which correspond some “time window” are aggregated in matrix. Then the “time window” is shifted and new matrix is built, and so on.

Step 2. Constructing the observations. The matrixes $R_1, R_2, ..., R_k$ being built the observation pairs (X_j, Y_j) are built by consequence elements of $R_1, R_2, ..., R_k : (X_j, Y_j) = (R_j, R_{j+1}), j = \overline{1, k-1}$.

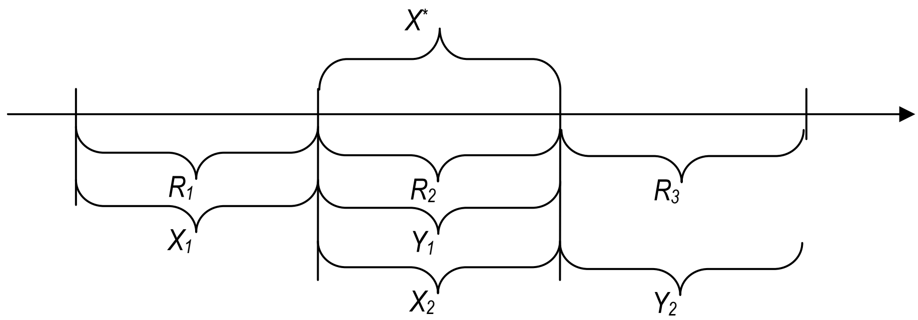

Fig. 1. Aggregated matrixes and observations

Step 3. Parametrization of the model. The relationship between matrixes elements of observations is established by matrix equation $Y = AX$ with matrix *A* as a parameter.

Step 4. LSM – estimation. The essence of this step is constructing the LSM-estimation accordingly to (14) by choosing the one with minimal norm:

$$\hat{A} = YX^+, \tag{15}$$

Step 5. Constructing the prediction formula. Prediction problem solution, based on the estimated operator $\hat{A}$ is standard: for any appropriate matrix argument *X** predicted *Y** is defined by relation $Y^* = \hat{A}X^*$.

Step 6. Calculations and the accuracy of prediction. The accuracy of prediction in economic research, as a rule, is estimated by formal criterion of accuracy called "absolute percentage error (*APE*)", defined by the relation $APE = \left|\frac{z_t - \hat{z}_t}{z_t}\right|, t = \overline{1,T}$, where z_t - the actual value of the index at the time t , $\hat{z}_t$ - prognostic value of the index at the time t .

It is generally accepted that the value of *APE* which is less than 10%, corresponds to high prediction accuracy, so, values from 10 to 20% is interpreted as good prediction accuracy, values from 20 to 50% are considered to be satisfactory, more than 50% - unsatisfactory prediction accuracy

There are some examples that illustrate the method below. Some more examples one can find in [Donchenko, Nazaraga, Tarassova, 2013].

Example 1: prediction economic indicators

In this example, the statistical data of the State Statistics Service of Ukraine was used [Ukrstat].

As described in [Харазішвілі, 2007], the regression methods most often used to predict of economic indicators in the normal way. In this example, the theory of matrixes LSM (Sections 1) was used.

In particular, Table 1 - 3 presents the value of gross domestic product (GDP), wages of employees (WE), final consumption expenditure (FCE), exports of goods and services (E) and imports of goods and services (I) for the 2007 – 1 quarter 2013 (1q2013) years (quarterly and annual data at current prices).

Table 1. The value of 5 indicators for 2007 - 2008 years (at current prices; mln.UAH)

	1 quarter 2007	2 quarter 2007	3 quarter 2007	4 quarter 2007	Total 2007	1quarter 2008	2 quarter 2008	3 quarter 2008	4 quarter 2008	Total 2008
GDP	139444	166869	199535	214883	720731	191459	236033	276451	244113	948056
WE	69078	82021	91922	108915	351936	100492	116441	121522	132009	470464
FCE	112494	130245	140935	174907	558581	161565	182154	194262	220921	758902
E	67513	79664	88491	87537	323205	88516	116640	132177	107526	444859
I	-76022	-85992	-93895	-108464	-364373	-110802	-135800	-144433	-129553	-520588

Table 2. The value of 5 indicators for 2009 - 2010 years (at current prices; mln.UAH)

	1 quarter 2009	2 quarter 2009	3 quarter 2009	4 quarter 2009	Total 2009	1 quarter 2010	2 quarter 2010	3 quarter 2010	4 quarter 2010	Total 2010
GDP	189028	214103	250306	259908	913345	217286	256754	301251	307278	1082569
WE	99206	111616	114251	126270	451343	114062	133690	139108	153791	540651
FCE	172426	188041	196074	216285	772826	194511	216027	232397	271295	914230
E	86994	95390	114962	126218	423564	112105	134553	145563	157144	549365
I	-92892	-96846	-116057	-133065	-438860	-114550	-131242	-156102	-179050	-580944

Table 3. The value of 5 indicators for 2011 – 1q2013 years (at current prices; mln.UAH)

	1 quarter 2011	2 quarter 2011	3 quarter 2011	4 quarter 2011	Total 2011	1 quarter 2012	2 quarter 2012	3 quarter 2012	4 quarter 2012	Total 2012	1 quarter 2013
GDP	261878	314620	376019	364083	1316600	293493	349212	387620	378564	1408889	301598
WE	135831	155367	158186	178727	628111	158145	180432	179944	199638	718159	165337
FCE	236580	268688	285548	314385	1105201	272970	311851	328173	356607	1269601	291388
E	156545	179626	184258	187524	707953	165810	181413	188467	181657	717347	162250
I	-173046	-187916	-202131	-215935	-779028	-186323	-215091	-214364	-219616	-835394	-180530

The use of the algorithm

1A. Indicators prediction for 2011-2012 years on the basis of 2007-2010 years.

1. Based on table 1 obvious way form a matrix of observations R_1, based on table 2 – matrix R_2, based on table 3 – matrix R_3.

2. Pair of input output matrix data (X_1, Y_1) will have the form (R_1, R_2).

3. Matrix $\hat{A}_1$ (see (15)), obtained from the equation $Y_1 = A_1 X_1$:

$$\hat{A}_1 = \begin{pmatrix} 0,472791 & 4,270925 & -0,44387 & 2,83749 & 4,410361 \\ -0,53049 & 3,940514 & -0,71641 & 2,130856 & 2,325999 \\ -0,79734 & 5,886174 & -0,49137 & 3,70521 & 4,549089 \\ 0,071931 & 0,956233 & 0,215418 & 0,572184 & 0,742387 \\ -0,34424 & 2,097631 & -1,97502 & -0,54289 & -0,95884 \end{pmatrix}$$

4. From the equation $Y^* = \hat{A}X^*$ calculate matrix predictive indicators Y^*, $X^* = X_2$.

$$\begin{pmatrix} 273694,0 & 338005,3 & 333617,9 & 337446,1 & 1282763,3 & 316432,6 & 399450,3 & 357960,9 & 337906,6 & 1411750,4 \\ 136422,5 & 169529,1 & 151972,4 & 164184,7 & 622108,7 & 167281,7 & 217282,3 & 168935,4 & 167030,4 & 720529,8 \\ 248255,2 & 306758,3 & 274580,8 & 292074,4 & 1121668,7 & 296834,3 & 377567,3 & 293639,5 & 294664,7 & 1262705,8 \\ 126419,3 & 145322,3 & 149113,3 & 159464,7 & 580319,6 & 145704,8 & 172400,0 & 172152,0 & 184595,4 & 674852,2 \\ -155678,3 & -169885,3 & -184891,2 & -192705,1 & -703159,9 & -170727,7 & -181818,3 & -200242,7 & -232626,0 & -785414,8 \end{pmatrix}$$

5. For matrices predictive indicators Y^* and actual indicators 2011 - 2012 years Y_2 calculate the matrix APE:

$$\begin{pmatrix} 4,51\% & 7,43\% & 11,28\% & 7,32\% & \mathbf{2,57}\% & 7,82\% & 14,39\% & 7,65\% & 10,74\% & \mathbf{0,20}\% \\ 0,44\% & 9,12\% & 3,93\% & 8,14\% & \mathbf{0,96}\% & 5,78\% & 20,42\% & 6,12\% & 16,33\% & \mathbf{0,33}\% \\ 4,93\% & 14,17\% & 3,84\% & 7,10\% & \mathbf{1,49}\% & 8,74\% & 21,07\% & 10,52\% & 17,37\% & \mathbf{0,54}\% \\ 19,24\% & 19,10\% & 19,07\% & 14,96\% & \mathbf{18,03}\% & 12,13\% & 4,97\% & 8,66\% & 1,62\% & \mathbf{5,92}\% \\ 10,04\% & 9,60\% & 8,53\% & 10,76\% & \mathbf{9,74}\% & 8,37\% & 15,47\% & 6,59\% & 5,92\% & \mathbf{5,98}\% \end{pmatrix}$$

In accordance with the submitted values matrix APE, error prediction GDP in 2011 (as a whole) was 2,57%, WE - 0,96%, FCE - 1,49%, E - 18,03%, I - 9,74%, error prediction GDP in 2012 (as a whole) was 0,20%, WE - 0,33%, FCE - 0,54%, E - 5,92%, I - 5,98%, and excess error 20% for some mentioned quarterly indicators can be explained by the fact that prediction is used, in particular, data the years of crisis 2008 - 2009.

1B. Indicators prediction for 2013 year on the basis of 2011-2012 years.

1. Data of 2011 year (Table 3) form a matrix R_1, data of 2012 year (Table 3) form a matrix R_2, data of 2013 year (Table 3) form a matrix R_3.

2. Pair of input output matrix data (X_1, Y_1) will have the form (R_1, R_2).

3. Matrix $\hat{A}_1$ (see (15)), obtained from the equation $Y_1 = A_1 X_1$:

$$\hat{A}_1 = \begin{pmatrix} 0,636101 & 0,151580 & -0,160623 & 1,242501 & 0,290005 \\ -0,120202 & 0,443779 & 0,343330 & 0,498337 & 0,172744 \\ 0,052472 & 0,519415 & 0,596880 & 0,282772 & -0,018491 \\ -0,033165 & -0,444692 & -0,527290 & 1,253027 & -0,944773 \\ 0,058681 & -0,274726 & 0,110891 & -1,420427 & -0,183491 \end{pmatrix}$$

4. From the equation $Y^* = \hat{A}X^*$ calculate matrix predictive indicators Y^*, $X^* = X_2$.

$$\begin{pmatrix} 318801,99 & 362421,85 & 393132,98 & 375805,98 & 1450162,79 \\ 179064,63 & 198412,63 & 202824,03 & 218113,67 & 798414,96 \\ 310804,97 & 353456,17 & 366941,54 & 391838,84 & 1423041,53 \\ 159803,61 & 174273,50 & 172762,31 & 145740,75 & 652580,17 \\ -197286,77 & -212712,68 & -218667,93 & -210819,92 & -839487,30 \end{pmatrix}$$

5. First column of the matrix of errors APE is calculated from the matrix of the forecast indicators values Y^* and actual data for 1q2013. Thereby, the prediction error of GDP (1q2013) - 5,7%, WE - 8,3%, FCE - 6,66%, E - 1,51%, I - 9,26%.

$$\begin{pmatrix} 5,70\% \\ 8,30\% \\ 6,66\% \\ 1,51\% \\ 9,28\% \end{pmatrix}$$

In general, comparing the results with the values of the relevant indicators the consensus prediction [Me], it can be argued about the competitiveness of the proposed article approach for forecasting macroeconomic indicators.

Example 2: prediction of TV audience performance

Media planning is based on the use of predictive indicators of TV audience. All players of the advertising market depend on the accuracy of TV audience indices predictive. In practice, five basic TV indicators are forecast:

- share of TV channel audience (share of the channel - sc) – this index determines the amount of viewers who watched TV from the total number of viewers at the investigated time period;
- rating of TV channel audience (ratings of the channel - rc) - this index determines the amount of TV audience, it takes into account the duration of watching TV every spectator in the analyzed period of time;
- TotalTV rating (rt) - this index determines the total size of the television audience, it takes into account individual TV time watching by every spectator in the analyzed time period;
- advertising TV audience rating of the channel (an advertisement rating - ra) - this index determines the size of TV advertising audience it takes into account the duration of advertisement viewing by every TV viewers;
- break-factor (bf)- this index determines the proportion of the audience that stays for advertising viewing.

Data description

We used five indicators data for 2013 year by months and three time slots (7:00-13:00, 13:00-19:00, 19:00-25:00).

The result of observations for this period of five television performance (audience share of channel sc, rating of channel rc, TotalTV rating rt, ratings of channel advertising ra and break-factor bf) forms the matrix of monthly observations $r(i) = \begin{pmatrix} r(i)_1 \\ r(i)_2 \\ r(i)_3 \\ r(i)_4 \end{pmatrix}, i = \overline{1,21}$.

Respectively $r(i)_1, i = \overline{1,21}$ — is the row-vector of monthly TotalTV raiting; $r(i)_2, i = \overline{1,21}$ — is the row-vector of monthly data of channel audience share; $r(i)_3, i = \overline{1,21}$ — is the row-vector of monthly data of channel rating; $r(i)_4, i = \overline{1,21}$ — is the row-vector of monthly advertising raiting data, $r(i)_5, i = \overline{1,21}$ — is the row-vector of monthly break-factor data. These monthly data vectors for a given period (in our case – 7 months) naturally organizing the matrix of observations $R(i), i = \overline{1,21}$.

Table 4. TV data perfomance by months and time slots

Period	Time slot	rt	sc	rc	ra	bf
Jan.2013	07:00 - 13:00	11,3	8,1	0,9	0,8	0,8
	13:00 - 19:00	18,9	9,1	1,7	1,3	0,8
	19:00 - 25:00	28,2	8,7	2,5	1,8	0,7
Feb.2013	07:00 - 13:00	10,9	7,4	0,8	0,6	0,8
	13:00 - 19:00	17,2	7,7	1,3	0,9	0,7
	19:00 - 25:00	27,5	8,4	2,3	1,6	0,7
Mar.2013	07:00 - 13:00	11,5	8,0	0,9	0,7	0,8
	13:00 - 19:00	17,6	8,6	1,5	1,0	0,7
	19:00 - 25:00	27,7	9,4	2,6	1,9	0,7
Apr.2013	07:00 - 13:00	9,4	8,2	0,8	0,6	0,8
	13:00 - 19:00	13,4	10,1	1,4	1,0	0,8
	19:00 - 25:00	24,7	9,9	2,4	1,8	0,7
May.2013	07:00 - 13:00	9,1	8,4	0,8	0,6	0,8
	13:00 - 19:00	13,0	10,1	1,3	1,0	0,7
	19:00 - 25:00	22,5	9,6	2,1	1,6	0,7
Jun.2013	07:00 - 13:00	8,3	7,7	0,6	0,5	0,8
	13:00 - 19:00	12,4	8,8	1,1	0,8	0,7
	19:00 - 25:00	21,6	9,4	2,0	1,4	0,7
Jul.2013	07:00 - 13:00	8,2	7,2	0,6	0,5	0,8
	13:00 - 19:00	11,9	7,9	0,9	0,7	0,7
	19:00 - 25:00	20,6	9,1	1,9	1,3	0,7

To apply the theory of pseudo inverse we use the signs of Sections 1 and construct from the observations matrix the matrix pairs of input and output data of our model. We grouped the observational data matrix $R(i), i = \overline{1,21}$ in the matrix R_1, R_2, R_3 as follows

$$
\begin{aligned}
R_1 &= (r(1)\vdots\ldots\vdots r(3)),\\
R_2 &= (r(4)\vdots\ldots\vdots r(6)),\\
R_3 &= (r(7)\vdots\ldots\vdots r(9)),\\
&\ldots\ldots\ldots\ldots\ldots\ldots\\
R_7 &= (r(19)\vdots\ldots\vdots r(21)).
\end{aligned}
$$

Then the matrix pair (X_1, Y_1), on which evaluation matrix of the model parameters $\hat{A}$ will be calculated from the matrix equation $Y = AX$, is as follows $(X_1, Y_1) = (R_1, R_2)$. The matrix pair (X_2, Y_2) is used to construct the forecast indicators matrix Y^* from the matrix equation $Y^* = \hat{A}X_2$ and accuracy estimation of prediction Y^* by the criterion of accuracy $APE = \left|\frac{Y_2 - Y^*}{Y_2}\right|$, where $(X_2, Y_2) = (R_2, R_3)$. Then

$(X_2, Y_2) = (R_2, R_3) \Rightarrow (X_3, Y_3) = (R_3, R_4)$

$(X_3, Y_3) = (R_3, R_4) \Rightarrow (X_4, Y_4) = (R_4, R_5)$

$(X_4, Y_4) = (R_4, R_5) \Rightarrow (X_5, Y_5) = (R_5, R_6)$ and so on.

The use of the algorithm

1. We constructed the matrix of monthly observations $R_1,..,R_7$ on the basis of the matrix of observations $r(i), i = \overline{1,21}$ (five basic monthly indicators in 2013(Table 4)) by grouping data.

2. A pair of input-output data matrices (X_1, Y_1) takes the form (R_1, R_2).

3. Then the matrix of estimates of the model parameters $\hat{A}$, that obtained from the equation $Y = AX \Rightarrow Y_1 = AX_1 \Rightarrow$

$$\hat{A} = \begin{pmatrix} 1.406 & -0.784 & 0.349 \\ 1.288 & -1.126 & 0.846 \\ 0.577 & -0.889 & 1.341 \end{pmatrix}$$

4. From the equation $Y^* = \hat{A}X^*$ calculate predictive indicators matrix Y^*, $X^* = X_2$.

$$\begin{vmatrix} 11,55 & 7,29 & 0,91 & 0,74 & 0,81 \\ 18,07 & 7,95 & 1,51 & 1,14 & 0,82 \\ 27,98 & 8,66 & 2,38 & 1,70 & 0,77 \end{vmatrix}$$

5. A comparison of the predictive indicators matrix Y^* and actual performance matrix Y_2 gives a matrix of errors APE:

$$\begin{vmatrix} 0,2\% & 9,2\% & 1,0\% & 1,6\% & 2,0\% \\ 2,4\% & 7,8\% & 0,3\% & 8,2\% & 15,3\% \\ 1,0\% & 8,3\% & 9,1\% & 9,3\% & 7,1\% \end{vmatrix}$$

Similarly, we have continued calculation and got a table of forecast values for five TV media indicators. In the same way we got the error matrix table APE (Table 5).

Table 5. TV data perfomance forecast фтв by month and time slot

predictive indicators matrix	Period	Time slot	rt	sc	rc	ra	bf	APE(rt)	APE(sc)	APE(rc)	APE(ra)	APE(bf)
Y_3^*	Mar.2013	07:00 - 13:00	11,6	7,3	0,9	0,7	0,8	0,2%	9,2%	1,0%	1,6%	2,0%
		13:00 - 19:00	18,1	8,0	1,5	1,1	0,8	2,4%	7,8%	0,3%	8,2%	15,3%
		19:00 - 25:00	28,0	8,7	2,4	1,7	0,8	1,0%	8,3%	9,1%	9,3%	7,1%
Y_4^*	Apr.2013	07:00 - 13:00	12,2	8,5	1,0	0,8	0,9	22,7%	3,8%	21,7%	23,3%	8,0%
		13:00 - 19:00	18,2	9,3	1,6	1,2	0,9	26,2%	8,6%	14,2%	13,5%	11,8%
		19:00 - 25:00	27,9	10,0	2,7	2,1	1,0	11,5%	0,7%	9,3%	14,9%	24,8%
Y_5^*	May.2013	07:00 - 13:00	7,8	7,9	0,5	0,5	0,9	15,7%	5,9%	42,5%	27,9%	11,4%
		13:00 - 19:00	12,0	9,5	0,9	0,7	1,1	8,7%	7,2%	51,0%	34,5%	30,5%
		19:00 - 25:00	23,6	9,0	2,1	1,6	0,9	4,9%	6,6%	1,0%	3,0%	18,0%
	Jun.2013	07:00 - 13:00	8,9	8,7	0,8	0,6	0,8	5,7%	10,8%	17,2%	16,3%	2,1%
		13:00 - 19:00	12,7	10,2	1,3	1,0	0,7	2,8%	13,0%	15,7%	16,3%	0,4%
		19:00 - 25:00	20,5	9,3	1,9	1,4	0,8	5,4%	0,2%	5,6%	1,7%	7,1%
Y_6^*	Jul.2013	07:00 - 13:00	7,6	7,3	0,6	0,5	0,8	7,6%	1,1%	5,5%	5,8%	2,3%
		13:00 - 19:00	11,6	8,2	1,0	0,7	0,8	2,8%	3,5%	3,6%	9,3%	9,0%
		19:00 - 25:00	20,7	9,2	1,9	1,4	0,7	0,3%	1,8%	2,4%	1,9%	2,4%

Y_7^*

As the *APE* errors table shows, the average annual forecast indicators error for Mar-Jul.2013 is: 5.9% – for TV channel audience share; 13.3% – for TV channel audience rating; 7.9% – for TotalTV rating; 12.5% – for TV channel advertising rating; 10.1% – for break-factor. The average prediction accuracy for all five indicators is acceptable for monthly year forecasts. However, exceeding the 10% threshold accuracy in some months is critical and shows the necessity of expert correction.

Conclusion

In the article case of matrix of observations for the arguments and values of the renewable function of the linear relationship between the components of observation has been considered.

Based on the matrixes least squares method, approach to prediction of indicators was proposed.

Testing approach with the use of statistical data of the economic and media indicators was made.

Results of prediction with available statistics were compared. The proposed approach for finding predictive values indicators is competitive.

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PARAMETRIC IDENTIFICATION FOR FOR MODEL OF A CHEMICAL HAZARDOUS SUBSTANCE CONCENTRATION USING SOFT COMPUTING

Oleg Zemlianskyi, Vitaliy Snytyuk

***Abstract**: The technology of concentration determining for a hazardous chemical substance in the pre-accident period is suggested. As a concentration model was selected neuro-fuzzy network with fuzzy inference in Tsukamoto form. Parametric optimization of concentration model is proposed to carried out using a modified method of directional optimization. There are presents the results of numerical simulations.*

***Keywords**: Chemical hazardous substance, prediction, neuro-fuzzy networks, evolutionary modeling.*

***ACM Classification Keywords**: I.2.1 Applications and Expert Systems – Industrial Automation*

Introduction

Last decade characterized by the development of information technologies as well as the growth of energy, metallurgy, chemical industry and agriculture, increased anthropogenic impact on the environment. Primarily it should be noted for the chemicals manufacturers and consumers. The increase in production volumes, competition and, consequently, decrease the rate of return, depreciation of fixed assets and investment flows behind the rate of depreciation is the cause of chemical accidents and disasters. Here are just some accidents of the last century and in recent years. In 1976 in Seveso (Italy) from the effects of chemical disaster affected more than 1,000 people, in 1978 in Suzhou (China) 3000 people were died, in 1984 in Bhopal (India) died 4035 people, in 1998 in Yaroslavl (Russia) in the affected area was more than 3,000 people, in 1989 in Jonava (Lithuania) spilled 7,000 tons of liquid ammonia, in 1991 in Mexico from the effects of chemical accident 17 people were died and 500 suffered, in 2010 in Hungary may be leaking tank of toxic waste and 10 people died, in 2012 in Latvia train derailed and 180 tons of chemicals spilled into the ground, in 2012 in Germany, there was a chemical accident with the release of chlorine and 39 people were affected, in 2007 in Ukraine was derailed train carrying yellow phosphorus, hundreds of people have been affected, in Gorlivka (Ukraine) in 2013 strait of ammonia occurred, five people died. The above are the most serious accidents, but their total number in the same period - tens or hundreds of thousands.

Modeling of chemical accidents and its features

It would be premature to assume that in the near future the number of accidents decreased. Therefore, an important problem is to minimize their negative effects which primarily include the loss of life, environmental disasters and material damage. Its solution depends on the quality of decisions, as before the accident and after it. Information basis for this is the data on accident parameters, concentration of a chemical hazardous substance (CHS) and its dynamics in the infected area. This information allows in the pre-accident period to forecast and perform scenario analysis, and in post-accident - in time to evacuate people and carry out the correct actions.

As for chemical accidents natural experiment is not possible and they occur unexpectedly due to a confluence of circumstances, modeling plays an important role. Simulation allows you to get prior information about the possible flow and nature of the accident, its parameters and its possible consequences. The simulation results are not absolute, since any real chemical accident will be different from its simulated counterpart. However, the information obtained from the simulation is the basis for forecasting, determining the possible number of victims and material damage, the basis of decision-making processes.

It is important to note that an important role is played by a pre-accident modeling of the accident effects and post-accident simulation models to clarify the earlier results. At the same time, disaster simulation time should be as small as possible, because the scale of the consequences of accidents depends on the speed of decision-making and related activities.

The main objective of modeling is to determine the concentration of CHS as function of the accident parameters, the area coordinates, the time elapsed since the accident and the construction of the respective fields of concentration. This problem is solved in the pre-accident and post-accident period. What is the source of data for modeling? In most cases, the concentration is calculated based on known techniques. But the results have low accuracy, since the common techniques are focused on ideal conditions accidents running. It is difficult or even impossible to take into account the features of construction area and its topography.

An important feature of modeling is the impossibility of results verification. If by solution of other problems of identification and optimization exist the criteria for testing the effectiveness of the proposed methods, to calculate the accuracy of the method for determining the concentration CHS requires chemical accident that physically is impossible. Therefore, many authors to test the accuracy of their results using the results of experiments on the scattering of Freon-12 in an open space in the town of Thorney Island in the UK. To their description devoted entire issue of the Journal of Hazardous Materials [Journal, 1987]. These results will be used to verify the proposed technology.

To date, the most commonly used three approaches [Makhviladze, 2002; Shatalov, 2004] to the determination of the concentration of CHS based on the use of:

• Gaussian or dispersion models;

• scattering models, in which use integrated conservation laws in the cloud as a whole during burst release, here is included the model a "heavy gas";

• models of direct numerical simulation.

Each of these models has its particular applications, advantages and disadvantages. In particular, Gaussian models are based on heuristics to determine the factors that characterize the atmospheric instability. At the same time, the behavior at CHS emissions, especially near the point of release is much more complex than can be described by models of this type. It does not take into account the induced currents and the high density of the material. Earlier have been developed models that take into account relevant features of CHS ("heavy gas") and named scattering models "heavy gas". It is known implementation of such models: a methodology for the World Bank [Manual, 1988], HGGYSTEM [Hgsystem, 1994] proposed in ISO R12.3.047-98 [ISO, 1998], the method of RD 52.04.253-90 [RD, 1991]. A common drawback of these methods is inflated real consequences of accidents.

Another disadvantage of these models is their theoretical and practical low applicability as they are directed to use in post-accident period and are general in nature. At the same time, each chemical accident has specific features and determining concentration fields CHS using these models because of the large amount of computation and the need to specify the coefficients and parameters of the accident in critical conditions is the almost impossible problem.

Models and Methods Structural and Parametric Identification

One way of solving this problem is the use of expert opinions based on experience, intuition, knowledge, results of the use of known techniques, the use of software to simulate the accidents effects, as well as climatic conditions and terrain. In such case it is necessary to determine the most likely area of infection, fiducials (the most typical characteristic of large areas) concentration point, the most possible parameters of possible accidents and form a table source data that contains database fields of the type:

$$BD_1 =< x_0,\ y_0, z_0,\ t_0,\ V,\ \nu,\ u,\ S >, \qquad BD =< x,\ y,\ z,\ t,\ C >, \tag{1}$$

where (x_0, y_0, z_0) - the coordinate of the accident point, t_0 - the accident time, V – an total emissions, ν - volume ejection speed, u - wind speed, S - the atmosphere stability by Pasqvill, (x, y, z) - coordinate of the point in which in time t the CHS concentration is equal to C. The table containing the data (1), is the basis for model receive

$$C = F(x_0,\ y_0, z_0,\ t_0,\ V,\ \nu,\ u,\ S, x,\ y,\ z,\ t), \tag{2}$$

by which the field concentration can be obtained for any contamination zone at any time.

Obviously, the model (2) can be identified structurally and parametrically using different approaches and methods. The most common is to use multiple linear regression model [Gruber, 1996]

$$C = a_0 + a_1 X_1 + a_2 X_2 + ... + a_n X_n \tag{3}$$

as the solution of the structural identification problem and least squares method (LSM) as a method of parametric identification. Simplicity of this model is its advantage, but it is important to take into account that natural processes are essentially non-linear, and the use of the model (3) is relevant only to a small time or area intervals. Rational use of non-linear multiple regression model [Snytyuk, 2008]

$$C = a \cdot f_1(X_1) \cdot f_2(X_2) \cdot ... \cdot f_n(X_n), \tag{4}$$

where $f_i(X_i) = f_i(b_{i0}, b_{i1}, ..., b_{im_i}, X_i)$ - functions which by algebraic manipulation may be converted to linear models, $b_{j0}, b_{j1}, ..., b_{jm_i}$ - the parameters, $i = \overline{1, n}$, m_i - the number of parameters in the i-th function. The advantage of this model is its non-linearity, but as the calculation of functions parameters carried out by LSM, it is necessary to check the conditions of its application. Furthermore, a function set is limited that indicate a disadvantage of a method.

One of the most accurate methods for approximate functions is the group method of data handling (GMDH) [Ivakhnenko, 1987]. The corresponding model is the Kolmogorov-Gabor polynomial

$$C = a_0 + \sum_i a_i X_i + \sum_i \sum_{j>i} a_{ij} X_i X_j + ... \tag{5}$$

The method works well on the "short" samples and limits the researcher only one of a finite set of support functions. It is quite difficult to implement, requires a considerable amount of computation. This result is very difficult to interpret.

Recently to identify tabulated dependencies using artificial neural networks (ANN) [Hickin, 2006]. It should be noted that the basic neural network architectures and training methods there are several dozen. The advantage of neural network identification is an almost complete absence of requirements to the original data. However, due to the problems of a local optimum, the network is in most cases very difficult to properly train, in addition, the result of its operation can not be interpreted.

Considering the application of these models and methods to solve the identification problem (2), we note that local solutions to their use in a limited and finite set of input data is available, but can not get a field of concentration. This conclusion is based on the inaccuracy of expert opinions, a small number of input data and a large number of parameters to be determined.

Structural identification of CHS Concentration Model

Based on the above comments and observations as the model (2) is was proposed the use of fuzzy neural network as a technology that integrates the neural network advantages and its learning capabilities, the possibility of providing expert conclusions and its interpretations. One of the first fuzzy neural networks proposed Jang (J. - SR Jang) in 1993 [Jang, 1993]. This network is called ANFIS (Adaptive - Network - Based Inference System). Traditionally used in such a network fuzzy inference in Sugeno form. However, the consequent fuzzy production rules in Sugeno form is a weighted sum of the antecedent arguments, which for our problem is unacceptable. Therefore, it was suggested that a modification of ANFIS networks with fuzzy inference in Tsukamoto form [Snytyuk, 2008]. A speciality of this form is the monotony of consequent membership functions. Let the rules would be:

P_1: if $x_1 \in A_1$, and $x_2 \in B_1$, and $x_3 \in C_1$, then $y \in D_1$;

P_2: if $x_1 \in A_2$, and $x_2 \in B_2$, and $x_3 \in C_2$, then $y \in D_2$;

P_3: if $x_1 \in A_3$, and $x_2 \in B_3$, and $x_3 \in C_3$, then $y \in D_3$,

where x_1, x_2, x_3 - the input variables, y - the resulting characteristic, A_i, B_i, C_i, D_i, - fuzzy sets with their membership functions, $i = \overline{1,3}$. A network of ANFIS is shown in Fig. 1.

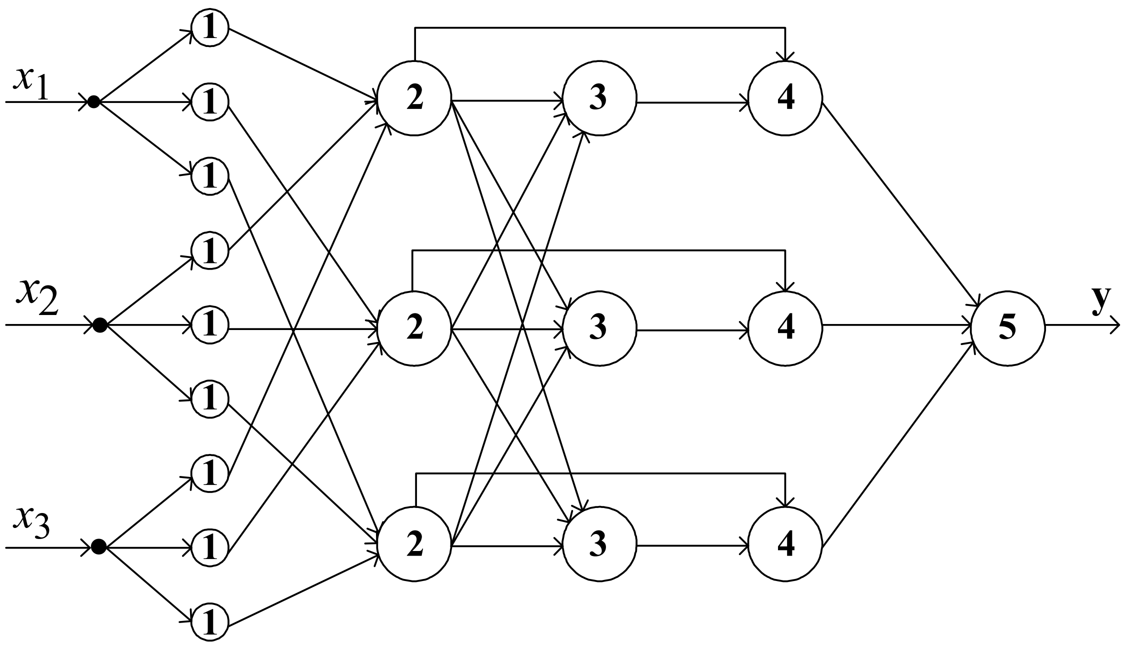

Fig. 1. ANFIS networks structure with fuzzy inference in Tsukamoto form

The input values of the network served In neurons of the first layer we find the values of membership functions

$$A_i(x_1^\circ), B_i(x_2^\circ), C_i(x_3^\circ),\ i = \overline{1,3}.$$

Thus, the number of neurons of the first layer (currently 9) coincides with the total power of set-term. In neurons of the second layer calculated values of truth measures for each rule from knowledge base:

$$\alpha_1 = A_1(x_1^\circ) \wedge B_1(x_2^\circ) \wedge C_1(x_3^\circ),$$
$$\alpha_2 = A_2(x_1^\circ) \wedge B_2(x_2^\circ) \wedge C_2(x_3^\circ),$$
$$\alpha_3 = A_3(x_1^\circ) \wedge B_3(x_2^\circ) \wedge C_3(x_3^\circ).$$

The number of neurons in this layer (there are 3) coincides with the number of rules. The same number of neurons contains the next layer and they calculated the relative importance of the rules:

$$\bar{\alpha}_1 = \frac{\alpha_1}{\alpha_1 + \alpha_2 + \alpha_3}, \quad \bar{\alpha}_2 = \frac{\alpha_2}{\alpha_1 + \alpha_2 + \alpha_3}, \quad \bar{\alpha}_3 = \frac{\alpha_3}{\alpha_1 + \alpha_2 + \alpha_3}.$$

Neurons in 4th layer perform operations

$$\bar{\alpha}_1 Z_1 = \bar{\alpha}_1 \cdot D_1^{-1}(x_1^\circ), \quad \bar{\alpha}_2 Z_2 = \bar{\alpha}_2 \cdot D_2^{-1}(x_2^\circ), \quad \bar{\alpha}_3 Z_3 = \bar{\alpha}_3 \cdot D_3^{-1}(x_3^\circ).$$

One neuron in last layer is assigned to find the sum:

$$y = \bar{\alpha}_1 Z_1 + \bar{\alpha}_2 Z_2 + \bar{\alpha}_3 Z_3.$$

As in the neurons of the first layer fuzzification is performed, it is necessary to know which of membership functions are carried out. Traditionally, learning neuro-fuzzy networks (NFN) is with using the gradient methods. This naturally requires that the membership functions are differentiable. Often are chosen a Gaussian or logistic functions. In real problems to train NFN using gradient methods is difficult and long, as each of the membership functions has, most often, two or three parameters. In the case of a large number of production rules to obtain an adequate result is almost impossible. So, if the number of input variables is ten, fifty the number of rules, the number of parameters will be several thousands. A tendency to converge the target function towards local optima does not allow for the training of NFN.

Parametric Identification of CHS Concentration Model

Since the structure of NFN is already defined by production rules, it remains to carry out its parametric identification. Assume that all membership functions are the same type of Gaussian s $\mu(z) = \exp[-(z-a)^2 / 2\sigma^2]$ selected, where a and σ - the parameters. Then the number of parameters is equal to the product of the number of input variables on the number of rules, which are expert conclusions. If the conclusions are not equal or are made various experts, the number of parameters increases, as the importance of rules and the competence of the experts are parameters.

For parameter identification we choose the evolutionary algorithms. Such a choice is based on the fact that in this case there are no requirements for membership functions are differentiable and can avoid the problem of local optima. The traditional evolutionary algorithm has the following steps:

Step 1. In accordance with the required accuracy of the outcome to determine the set of potential solutions.

Step 2. Determine the sample population of solutions and to calculate the measure of optimality of each solution.

Step 3. While the algorithm stops condition is not satisfied to perform:

Step 3.1. Select solutions from the sample population.

Step 3.2. Implement crossover and select one of these solutions.

Step 3.3. With a certain probability mutate solutions.

Step 3.4. Record the decision in the new population.

Step 3.5. If the new population is not formed, then repeat steps 3.1-3.4. Step 4. End.

A potential solution to the problem of parametric identification is as follows:

$$z = (a_1, \sigma_1, a_2, \sigma_2, \ldots, a_m, \sigma_m, \xi), \quad (6)$$

where m - the number of parameters of membership functions, ξ - more options. The value of each parameter belongs to a bounded area defined by experts. There is therefore a need to test each potential solutions to its belonging to the area of possible solutions.

Any of evolutionary algorithms, which traditionally include genetic algorithms, evolutionary strategies, genetic programming and evolutionary programming requires a considerable amount of time for its execution due to unproductive search. So on with the parameter identification problem will be based on the use of well-known method EvoMax [Snytyuk, 2012].

Adaptation of EvoMax to Parametric Identification of CHS Concentration Model

At the base of EvoMax is the idea to optimize random search of optimal solutions using evolutionary algorithms. This idea is based on the implementation of the targeted optimization using a composition of several techniques, in particular, elements of evolutionary strategies, the analytic hierarchy process and the elements of fuzzy sets theory. Let us consider a modified parameter identification method for determining concentration of CHS based on the EvoMax.

Traditionally EvoMax method is used to solve the problem of finding

$$\max_{X \in \Omega} f(X) \tag{7}$$

where $X = (x_1, x_2, ..., x_n)$, Ω - some hyperparallelepiped.

At the macro level, the proposed method will have the following steps:

Step 1. Number of iteration $e = 1$.

Step 2. Determine the initial number of potential solutions λ and generate uniformly distributed in Ω the potential solutions $z_1^e, z_2^e, \ldots, z_\lambda^e$, each of which has the form (6).

Step 3. We calculate the value of the function f at the points $z_1^e, z_2^e, \ldots, z_\lambda^e$: $f_1^e = f(z_1^e), f_2^e = f(z_2^e), \ldots,$ $f_\lambda^e = f(z_\lambda^e)$.:.

Step 4. We normalize the values f_j^e so $f_j^{ne} \in [0;1]$, $\sum_{i=1}^{\lambda} f_j^{ne} = 1$.

Step 5. Form the matrix of pairwise comparisons Saati S so. Among the normalized values of the function we find the minimum f_j^{ne}, then divide the interval $[0;1]$ in 10 intervals: $[0;0,1),[0,1;0,2),\ldots,$ $[0,9;1]$. . Then for all $h \in \{1,2,\ldots,\lambda\}$, if $f_j^{ne} \in [0,1k;0,1+0,1k)$ and $f_h^{ne} \in [0,1l;0,1+0,1l)$ where $k,l \in \{0,1,\ldots,9\}$, then $s_{jh} = l - k + 1$. Other elements of the matrix S are calculated as follows: $s_{pq} = \frac{s_{jq}}{s_{jp}}$.

Step 6. We calculate the eigenvalues of the matrix S and for the maximum eigenvalue $a_{\max}$ we find the corresponding eigenvector w. If the vector w by a variety of reasons to find is problematic its elements are approximately calculated by the formula $w_j = \frac{1}{s_{1j} + s_{2j} + \ldots + s_{\lambda j}}$. Values w_j indicate a measure of optimality (quasioptimality) potential solutions z_j^e.

Step 7. It is known [Rechenberg, 1994] that the next step should be the generation of "offspring" and the formation of a new population of potential solutions. The authors propose an evolutionary strategy to get "offsprings" as follows:

$$z_j^{e+1} = z_j^e + \xi(N(0,1)),\ j = \overline{1,\mu}, \tag{8}$$

where $\xi(N(0,1))$ - a normally distributed random variable with zero mean and unit variance, η - the number of "children" by one "parent". According to the concept of evolution by Charles Darwin $\mu > 1$, and in [Beyer, 2002] is recommended to choose $\mu \geq 7\lambda$. The last inequality is little conclusive.

We believe that to effectively finding of optimal solutions must be considered a measure of optimality w_j for potential solutions z_j^e. It will allow only more detailed investigation of the area Ω. Thus there are two hypotheses:

- if the value w_j is the bigger, then the bigger should be the value σ_j in generation of "offspring" of the potential solution z_j^e:

$$z_j^{e+1} = z_j^e + \xi(N(0,\sigma_j^e)), \tag{9}$$

which will expand the search area in the locality of a better solution, but in the least potentially optimal solutions will be the most narrowed area, including and because of its unpromising research;

- contrariwise, the bigger value w_j is the cause of in-depth study of the most promising solutions locality and the bigger value will allow a detailed study of an area distant from the unpromising potential solutions.

These two hypotheses require confirmation, both of which are heuristic, but does not contradict the theory and practice of stochastic optimization. We bow to the correctness of the second hypothesis that is confirmed in the first experiments, but requires deeper investigation.

Another problem is to determine the optimal number “offsprings” depending on the solutions optimality. Obviously, this number $N(z_j^e)$ depends on the measure of area Ω and given accuracy ε of the solution. For the case where Ω is a segment, $N(z_j^e) = g(L([a,b]))$, where $L(*)$ there is length. Determination of the value μ_j is also heuristic. In the first stage rationally believe that $\mu_j = \mu \ \ \forall i \in \{1,2,\ldots,\lambda\}$. Such conclusion is based on the second hypothesis and then for future solutions is necessary a deeper study of the locality, and for the unpromising - wider. And, both are equally important.

The most difficult is the problem of determining the variance value for each individual solutions. Obviously, σ_j^2 will depend, as in previous case, from $L([a,b])$, as well as the distance to the nearest neighbors solution. We find $d(z_j^e, z_L)$, $d(z_j^e, z_R)$ (the distance to the closest left (or point a) and right (or point b) of "neighbors" solutions). Suppose $d_{\max} = \max\{d(z_j^e, z_L), d(z_j^e, z_R)\}$, then $\sigma_j = \frac{1}{3} d_{\max}$, as by the well-known 3-sigma rule namely 10000 of 9973 points in the generation by the formula (8) belong to the interval $(x_j^e - 3\sigma_j, x_j^e + 3\sigma_j)$.

Step 8. In the previous step performed generate $\lambda \cdot \mu$ potential solutions. Find the corresponding values of the function f. From these values, and the values $f_1^e, f_2^e, \ldots, f_\lambda^e$ we determine the best λ solutions $z_1^{e+1}, z_2^{e+1}, \ldots, z_\lambda^{e+1}$ and go to step 1.

Finding the optimal solution ends on e-th iteration when in step 2 $\max_{i,j}\left|f_i - f_j\right|$ will be less than some preassigned $\delta > 0$, so $\max_{i,j}\left|z_j^e - z_i^e\right| < \varepsilon$ that it shows the convergence of the method, $i, j = \overline{1,\lambda}$. Then, the solution z_i^v which will correspond to the value $f_i^e = \max_j f_j^e$ will be a solution of the problem.

For the problem of parametric identification of CHS concentration model functions f_j would be:

$$f_j = \sum_{k=1}^{p}(C_k - F(z_j, x_{0k}, y_{0k}, z_{0k}, t_{0k}, V_k, v_k, u_k, S_k, x_k, y_k, z_k, t_k))^2, \; j = \overline{1,\lambda},$$

and the problem (7) is transformed into the problem of finding

$$\min_e \max_{i,j}\left|f_i - f_j\right|, \; i, j = \overline{1,\lambda}.$$

Thus, for the structural identification of CHS concentration model is developed a model in the form of neuro-fuzzy network with logical conclusion in Tsukamoto form. For its parameter identification is proposed to use a modified method EvoMax for directed optimization.

Experimental Verification of the Results

As mentioned above, the physical experiment for the problem is impossible, so we used the results of experiments on Torney Island. In these experiments reproduced huge emissions (exp. 07, 05, 08, 17) and a long release (exp. 45) freon-nitrogen mixtures in open space. The latter occurs when these initial data: emission volume 2000 m^3, the part in the gaseous mixture of Freon 31%, the wind speed 2 m/s, the stability of atmospheric by Pasquill was $E\left|F\right.$. In the huge emissions the gas volume was 2,000 m^3, the part of Freon in the gaseous mixture was 24%, the wind speed - 3.4 m/s, the stability of the atmosphere by Pasquill - E. These data were compared with predictions [Lisanov, 2005, Sumskoy, 2005], calculated for different techniques.

In order to forecast by the modified method EvoMaxM used expert conclusions, summarized in the table of type (1) having 54 lines. Seven lines of this table were used for the test sample. According to 47 conclusions was built neuro-fuzzy network and implemented its parametric optimization. Next, we calculated the value at a point on the axis along the direction of the wind at different distances from the accident point. The obtained values and the results of other methods for the experiment number 17 are shown in Table 1 and in Fig. 2. Comparison of the results is achieved by the mean relative deviation.

Table 1

Experience 17. Actual and predicted data for CHS concentration

X,м	40	50	70	100	140	220	500	**mean relative deviation,%**
C, % (об)	12,1	8,4	4,7	3,1	1,35	0,6	0,32	
Phast	11,2	9,5	7,5	4,2	2,4	0,95	0,18	23,43
Toxi3	11	9,5	7,6	5,7	4,3	2,5	0,6	238,2
Hgsystem	3,8	3,1	2,2	1,5	1	0,5	0,2	23,62
EvoMAxM	12,2	7,9	4,1	2,5	1,4	0,72	0,21	4,24

Forecasting and comparative analysis were also carried out for other experiences. Application of EvoMaxM allowed us to obtain predicted values with the mean relative deviation within 2,2-6,3%, which was significantly better result compared with the results of other methods.

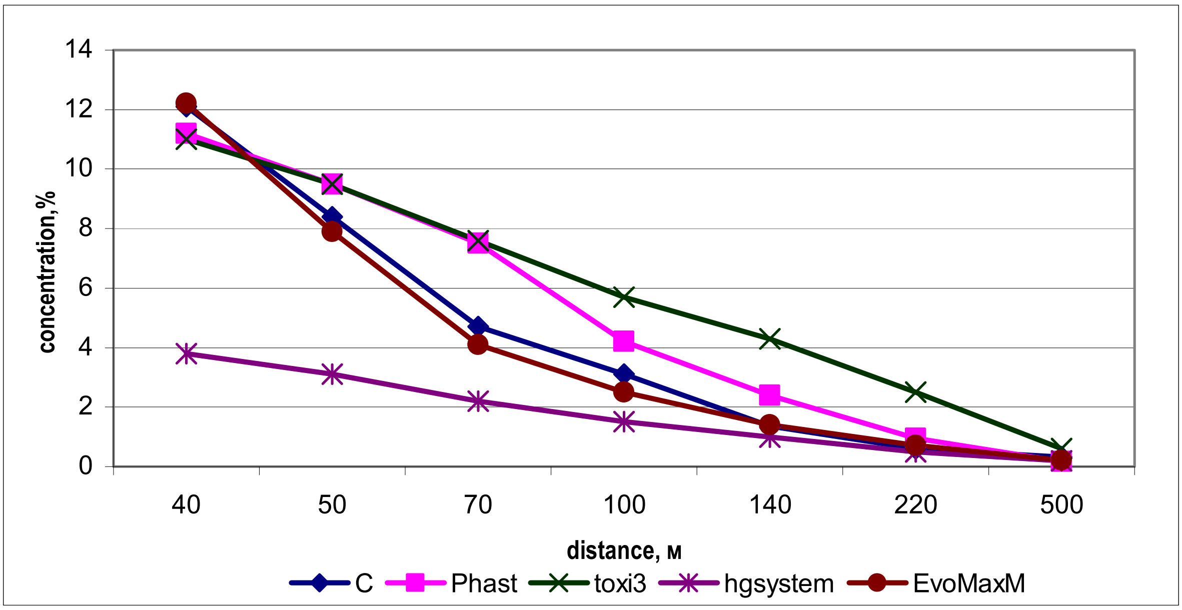

Fig. 2. Actual and predicted data for CHS concentration

Conclusion and Perspectives

In this paper proposed a method for determining the CHS concentration in the pre-accident period. It is based on use of neuro-fuzzy network as a model, which allows the processing of expert conclusions and carry out further processing and interpretation of results. Optimization of network parameters based on the use of directed optimization EvoMax, as technology accelerated search for acceptable or quasi-optimal values.

The proposed technology can be used in the post-accident period to clarify the CHS concentration fields. Given the data point measurements of CHS concentration with instruments, neuro-fuzzy network can be retrained in the shortest possible time and be used to solve the problem of forecasting the CHS concentration in all possible contamination area. In addition, this technology can be used to refine the initial values of the accident parameters, that allow to improve and objectify decision-making processes.

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THE METHOD OF ESTIMATING THE CONSISTENCY OF PAIRED COMPARISONS

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Abstract: *The equivalence of the indicators, which are used in the assessment of the consistency of paired comparisons, is investigated. It is found for which matrix of paired comparisons the usage of various indicators of consistency leads to different results regarding the permissible inconsistency, and as a consequence, to different results regarding the necessity of this matrix correction. To illustrate how critical in practical applications such contradictory results on a variety of indicators are, the examples, in which the calculation of the weights of alternatives decisions on the basis of primary and adjusted matrix of paired comparisons leads to a variety of alternatives ranking, are considered. On the basis of the conducted research the method of estimating the consistency of paired comparisons is proposed.*

Keywords: *indicators of paired comparisons matrix consistency, weak consistency, the permissible inconsistency and method of consistency estimation*

ACM Classification Keywords: *H.4.2. INFORMATION SYSTEM APPLICATION: type of system strategy*

Introduction

And as a result the matrix are constructed $D_{n\times n} = \{d_{ij} \mid i, j = 1,...,n\}$ with the properties $d_{ij} > 0$, $d_{ji} = 1/d_{ij}$.

Methods of paired comparisons are one of the components of the majority of modern methodologies of decision-making support, such as methodology of analysis of hierarchies of criteria and alternatives solutions [Pankratova & Nedashkovskaya, 2011; Saaty, 1980; Saaty & Vargas, 1987; Noghin, 2004] "line", "triangle", "square" [Totsenko, 2002], PROMETHEE [Macharis et al, 2004]. Methods of paired comparisons are used for the solution of weakly structured tasks of evaluation of decisions alternatives on the quality criterion with the involvement of experts estimates [David, 1978; Larichev &Moszkowicz, 1996; Orlov, 2004; Zhilyakov ,2006]. In particular, in the methods of analysis of hierarchies expert in pairs compares alternatives in a special fundamental scale of the relative importance.

Methods of paired comparisons are aimed at the recovery of the coefficients of relative importance (weights) $w \in R_+^n$, $\sum_{i=1}^{n} w_i = 1$ solutions alternatives on the quality criterion from the matrix of paired comparisons (MPC) $D_{n\times n}$. The calculation of these weights are most often based on the idea of minimizing the norm of MPC deviations $D_{n\times n}$ from some unknown matrix $C = (w_i / w_j)$, which in methods of paired comparisons is considered to be the best approximation of MPC $D_{n\times n}$. Matrix $C = (w_i / w_j)$ is called the consistent or theoretical. The traditional method is the one of the main vector of the weights calculation with the MPC $D_{n\times n}$ [Saaty, 1980]. Depending on the choice of the functions of the matrices norms the other methods of paired comparisons are also applied: least squares, weighted least squares, the logarithmic least squares (the method of geometric mean) and others (see the review performed in [Pankratova & Nedashkovskaya, 2011].

Take a closer look at the concept of consistency, which is one of the key methods of paired comparisons.

Inconsistency is the manifestation of the contradictions in the assessments of the experts and appears if it is necessary to compare more than three objects. MPC is called inconsistent, if $\exists i, j, k$, such that $d_{ij} \neq d_{ik} d_{kj}$. MPC is called serially or ordinally inconsistent, if $\exists$ is three of indices (i, j, k) , for which there is a cycle $a_i \succ a_j \succ a_k \succ a_i$, or in terms of elements of the MPC $(d_{ij} > 1) \wedge (d_{jk} > 1) \wedge (d_{ik} < 1)$ is performed. The reasons for inconsistencies are considered to be psychological limitations human expert [Totsenko, 2002; Xu&Da, 2003], the mistakes of experts in expressing assessments, the usage of fundamental scale of the relative importance [Zhilyakov, 2006].

For the assessment of the consistency of the MPC some indicators [Saaty, 1980; Totsenko, 2002; Aguaron & Moreno-Jimenez, 2003; Stein & Mizzi, 2007; Peláez & Lamata, 2003] and criteria [Saaty, 1980; Totsenko, 2002] are developed. They, using these indicators, allow evaluating the permissibility of the inconsistency of the MPC for its usage in the decision-making process. In this case, the actual task is to study the equivalence of the various indicators, namely if they lead to the same conclusions regarding the permissible inconsistency of the MPC in the sense of the criterion.

Expert assessments without the allowable inconsistencies are considered as controversial and, accordingly, may not be used decisions making.

The aim of this work is the assessment of the equivalence of different measures of consistency of paired comparisons and the development of appropriate method of evaluation of the consistency of the MPC, depending on the properties of the MPC.

1. Problem formulation

The definition. The matrix of paired comparisons (hereinafter MPC) is called positive, back symmetric MPC $D_{n\times n}$: $d_{ij} > 0$, $d_{ji} = 1/d_{ij}$, $i, j = 1,...,n$.

MPC are obtained in a result of the expert's implementation of paired n of elements (for example, alternatives) for the quality criterion in the scale of relations or, in the case of quantitative criteria - taking the relations of the numerical values of the alternatives according to the criterion.

The definition. MPC $\widehat{D}_{n\times n}$, for which transitivity are implemented: $\widehat{d}_{ij} = \widehat{d}_{ik}\widehat{d}_{kj}$ for $\forall i, j, k = 1,...,n$, is called strongly consistent. If $\exists\, i, j, k$, such that $d_{ij} \neq d_{ik} d_{kj}$, so such MPC is called strongly inconsistent.

The definition. MPC $\breve{D}_{n\times n}$, for which order transitivity are implemented: $(\breve{d}_{ij} > 1) \wedge (\breve{d}_{jk} > 1) \Rightarrow (\breve{d}_{ik} > 1)$, is called weak or order consistent. If $\exists\, i, j, k$, such that $(d_{ij} > 1) \wedge (d_{jk} > 1) \wedge (d_{ik} < 1)$, so the MPC is called weakly inconsistent, and the element d_{ik} - the ejection..

Statement 1. If $D_{n\times n}$ – strongly consistent MPC, so $D_{n\times n}$ – weakly consistent.

Statement 2. If $D_{n\times n}$ – weakly inconsistent МПП, so $D_{n\times n}$ – strongly consistent.

Strongly consistent MPC is very rare in the real practical problems with the expert paired comparisons of the elements, especially if the amount of the compared elements елементів n exceeds 3. Mainly, strongly consistent MPC is used as a kind of ideal MPC, it is also called theoretical, with which the specified expert or empirical MPC is compared, in the methods of calculating the local weights of the elements of the tasks of decision-making support.

For estimation of the level of inconsistency of the MPC in practical problems the indicators CR [Saaty, 1980],

GCI [Aguaron&Moreno-Jimenez, 2003], HCR [Stein & Mizzi, 2007], CI^{tr} [Peláez & Lamata, 2003], k_y [Totsenko, 2002] and criteria [Saaty, 1980; Totsenko, 2002; Aguaron&Moreno-Jimenez, 2003; Stein & Mizzi, 2007; Peláez & Lamata, 2003], which, using these indicators, allow to evaluate the admissibility of the inconsistency of the MPC for its usage in the decision-making process, are used.

Consistency indicator is connected with the method of the calculation of weights. So, the indicator CR is used with a method of the main eigenvector EM of weights calculation, the indicator GCI - with the method of geometric mean RGMM of weights calculation, the indicator HCR - with the method of arithmetic normalization of AN weights calculation.

It is known: $D_{n\times n} = \{d_{ij} \mid i, j = 1,...,n\}$ – MPC of decisions alternatives on criterion.

It is required:

- *to determine whether well-known* indicators *of consistency* CR, GCI, HCR, CI^{tr} *and* k_y *are equivalent in the sense that they lead to the same conclusions regarding the permissible inconsistency of the MPC in the sense of the criterion;*
- *to identify, how the property of weak consistency of the MPC impacts on the inconsistency permissibility of this MPC in the decision-making process;*
- *to develop the correct method of assessment of the consistency of the MPC, to calculate the weights* $w \in R_+^n$, $\sum_{i=1}^{n} w_i = 1$ *and to find the ranking of the solutions alternatives.*

First, let consider the calculation of known indicators of consistency, which are studied in the work. Then move on to the coverage of the results of the assessment of these indicators equivalence.

Traditional for methods of paired comparisons index CR is introduced for the MPC, which is a disturbance of strongly consistent MPC. Such MPC will be permissibly inconsistent in the sense of criterion (see below criterion 1), does not need the correction and can be used for the calculation of weights and decision support.

In this work the equivalence of indicators CR, GCI, HCR, CI^{tr} and k_y are estimated for MPC, which are perturbations of strongly consistent MPC, as well as for the MPC with a high level of inconsistency, namely: MPC, which have at the same time the properties of weak consistency and a strong inconsistency; weak inconsistent MPC in the condition of one or more ejections.

Research of MPC with high level of inconsistency (hereinafter such MPC are called inadmissible inconsistent or the information noise, depending on the level of inconsistency) will be necessary to develop a method of improving the consistency of this MPC.

2. Indicators and criteria of MPC consistency

Let $d_{ij} = c_{ij}\varepsilon_{ij}$, де $c_{ij} = w_i / w_j$ – the element of MPC consistency, $\varepsilon_{ij} > 0$ – the perturbation value.

Consistency relations [2] of MPC $D_{n\times n}$ is $CR(D_{n\times n}) \overset{def}{=} CI(D_{n\times n}) / MRCI(n)$, where the index of consistency $CI(D_{n\times n}) \overset{def}{=} -\sum_{i=1}^{n-1} \lambda_i / (n-1)$ – the average value of not the main eigenvalues $D_{n\times n}$ with the sign «–», after the changes $CI(D_{n\times n}) = (\lambda_{\max} - n)/(n-1)$, $\lambda_{\max}$ – the main eigenvalue $D_{n\times n}$, $MRCI(n) > 0$ – the index of random consistency - the average value of the consistency indices for randomly filled MPC dimension $n \ge 3$ (table value).

Vector of decisions alternatives weights is calculated according the method of main eigenvalue vector EM: vector of normalized weights v – the solution of the equation $Dv = \lambda_{\max} v$, normalized weights $w_i = v_i / \sum_{j=1}^{n} v_j$, $\sum_{i=1}^{n} w_i = 1$.

$GCI(D_{n\times n}) \overset{def}{=} S^2(D_{n\times n}) / d.f(n)$,where $S^2(D_{n\times n}) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} (\ln d_{ij} - \ln(v_i / v_j))^2$, $d.f(n) = n(n-1)/2 - (n-1)$ – the number of degrees of freedom, weights vector $v \in R_+^n$ – optimization problem solution $S^2(D_{n\times n}) \to \min$ with restrictions $\prod_{i=1}^{n} v_i = 1$, $v \in R_+^n$, is called <u>geometric index of consistency</u> [Aguaron & Moreno-Jimenez, 2003]. The analytical solution of the last problem $v_i = \left(\prod_{j=1}^{n} d_{ij} \right)^{1/n}$ is known as a method of geometric middle RGMM. Normalized weights: $w_i = v_i / \sum_{j=1}^{n} v_j$, $\sum_{i=1}^{n} w_i = 1$.

$HCR(D_{n\times n}) \overset{def}{=} HCI(D_{n\times n}) / MRHCI(n)$, where $HCI(D_{n\times n}) \overset{def}{=} (HM(s) - n)(n+1) / (n(n-1))$ – the harmonic index of consistency, $HM(s) = n(\sum_{j=1}^{n} (s_j)^{-1})^{-1}$ – average harmonious of values $s_j = \sum_{i=1}^{n} d_{ij}$, $MRHCI(n) > 0$ – index of random consistency – the average value of the harmonic indices of consistency for randomly filled MPC dimension $n \ge 3$ (table value), is called the <u>harmonious relations of consistency</u> [Stein & Mizzi, 2007].

The vector of decisions alternatives weights is calculated according the method of arithmetical normalization AN: vector of unnormalized weights $v_i = (\sum_{j=1}^{n} d_{ji})^{-1}$.

$CI^{tr}(D_{n\times n}) \overset{def}{=} \frac{1}{NT} \sum_{i=1}^{NT} CI^{tr}(\Gamma_i)$ – the average value of consistency indices $CI^{tr}(\Gamma_i)$ of all different transitivities of MPC $D_{n\times n}$, if $n > 3$, $CI^{tr}(D_{n\times n}) \overset{def}{=} \det(D_{n\times n})$, if $n = 3$ and $CI^{tr}(D_{n\times n}) \overset{def}{=} 0$ in other case, where $NT = n!/((n-3)!\,3!)$ – the number of different transitivities of MPC $D_{n\times n}$, if $n \ge 3$ is called <u>index of transitivities consistency</u> [Peláez & Lamata, 2003]. Transitivity Γ –the weak order on the set of the three alternatives $\{a_i, a_j, a_k\}$.

$$k_y(D_{n\times n}) = \min_{k=1,\ldots,n} (k_y(R^k))$$,where

$k_y(R^k) = \left(1 - \left(\frac{1}{n} \sum_{j=1}^{m} r_j^k \mid j - mean^k \mid - \sum_{j=1}^{m} \frac{r_j^k}{n} \ln\left(\frac{r_j^k}{n} \right) \right) \Big/ \left(G \sum_{j=1}^{m} \left| j - \frac{m+1}{2} \right| + \ln(m) \right) \right) z$ - spectral coefficient of weight spectrum $R^k = \{(r_j^k) \mid j = \overline{1,m}\}$ alternatives a_k, r_j^k - number of weights of alternative a_k, which relates to the scale division $s_j = j/m$, m - number of scale divisions, $mean^k$ - the average value of weights set of alternative a_k, $G = n / \ln(n) m \ln(m)$ - scaling coefficient, $z \in \{0,1\}$ - Boolean function, which defines the necessary and sufficient conditions for the equality to zero of spectral coefficient of consistency $k_y(R^k)$, is called <u>spectral coefficient of consistency</u> [Totsenko, 2002].

<u>*Statement 3.*</u> $CR(D_{n\times n}) \ge 0$, $GCI(D_{n\times n}) \ge 0$, $HCR(D_{n\times n}) \ge 0$, $CI^{tr}(D_{n\times n}) \ge 0$, $k_y(D_{n\times n}) \ge 0$.

The indicators CR i HCR are constructed by normalizing in accordance with measures of consistency CI i HCI values that characterize the consistency of random set MPC. Therefore, indicators CR i HCR allow assessing whether the information is in the MPC, or MPC can be considered as information noise or randomly set.

For the evaluation of allowable inconsistencies of MPC with the purpose of its use in the decision-making process two criteria are developed. Let formulate the well-known criterion of consistency 1 [Saaty, 1980], by adding to it the case of a lack of information in the MPC.

Criterion of consistency1: MPC $D_{n\times n}$:

- *strongly consistent (consistent)*, if and only if $CR(D_{n\times n})=0$, $GCI(D_{n\times n})=0$, $HCR(D_{n\times n})=0$, $CI^{tr}(D_{n\times n})=0$;
- *permissibly inconsistent (the correction of MPC is not needed)* if $CR(D_{n\times n})\le CR^{porog}$ or $GCI(D_{n\times n})\le GCI^{porog}$, або $HCR(D_{n\times n})\le HCR^{porog}$, або $CI^{tr}(D_{n\times n})\le CI^{tr\ porog}$ (depending on which indicator is used), where $CR^{porog}, GCI^{porog}, HCR^{porog}, CI^{tr\ porog}$ – the threshold values of the respective indicators;
- contains information, but it is impermissible inconsistent (you need to correct MPC), if the consistency rate exceeds its threshold value;
- *is information noise (MPC should be corrected)*, if normalized indicators $CR(D_{n\times n})\ge 1$ or $HCR(D_{n\times n})\ge 1$.

Criterion of consistency 2 [Totsenko, 2002]: MPC $D_{n\times n}$:

- *strongly consistent (consistent)*, if and only if $k_y(D_{n\times n})=1$;
- *permissibly inconsistent (the correction of MPC is not needed)*, if $k_y(D_{n\times n})\ge T_u$;
- *contains the information, , but it is impermissible inconsistent (you need to correct MPC), if* $(k_y(D_{n\times n})\ge T_0)\wedge(k_y(D_{n\times n})<T_u)$;
- *is information noise (MPC should be corrected), if* $k_y(D_{n\times n})<T_0$,

where T_0, T_u – the threshold values, which are defined, respectively, from the spectrum, which contains the minimum amount of information and a range of permissible accuracy. For a scale of [0,1] with the divisions $s_j=\{0, 0.1, 0.2, ..., 1\}$, N=11 these thresholds are equal $T_0=0.40$, $T_u=0.79$.

Consider the examples of the assessment of the MPC consistency.

Example 1. MPC $\breve{D}1_{7\times 7}$ according the definition has the properties of a weak consistency and a strong inconsistency:

$\breve{D}1_{7\times 7}$ =

1	3	8	1	5	1/3	1
1/3	1	2	1/3	1/2	1/4	1/6
1/8	1/2	1	1/4	1/2	1/8	1/7
1	3	4	1	4	1/5	1/2
1/5	2	2	1/4	1	1/4	1/4
3	4	8	5	4	1	1/4
1	6	7	2	4	4	1

Let consider if MPC $\breve{D}1_{7\times 7}$ is permissibly inconsistent according to the above-mentioned criteria of consistency. The values of MPC consistency indicators $\breve{D}1_{7\times 7}$ are equal to $CR=0.09$, $GCI=0.31$, $HCR=0.17$, $CI^{tr}=1.19$, $k_y=0.61$. Comparing them with threshold values $CR^{porog}=0.1$, $GCI^{porog}=0.37$, $HCR^{porog}=0.1$, $CI^{tr\ porog}=1.329$, $T_0=0.40$ і $T_u=0.79$ for $n=7$, come to the conclusion, that the given MPC $\breve{D}1_{7\times7}$ is permissibly inconsistent (the correction is needed) according indicators CR, GCI та CI^{tr} and is not permissibly inconsistent (correction is needed) according indicators HCR and k_y.

Thus, the use of different indicators of consistency for the MPC may lead to different results in terms of criteria.

Example 2. MPC $D2_{7\times7}$ according the definition is weakly inconsistent:

$D2_{7\times7}$ =

1	1/8	6	1/6	4	1/2	1/3
8	1	48	4/3	32	4	**3/8**
1/6	1/48	1	1/36	2/3	1/12	1/18
6	3/4	36	1	24	3	2
1/4	1/32	3/2	1/24	1	1/8	1/12
2	1/4	12	1/3	8	1	2/3
3	**8/3**	18	1/2	12	3/2	1

Comparing values of inconsistency indicators $CR(D2_{7\times7}) = 0.06$, $GCI(D2_{7\times7}) = 0.18$, $HCR(D2_{7\times7}) = 0.12$, $CI^{tr}(D2_{7\times7}) = 0.75$, $k_y(D2_{7\times7}) = 0.69$ with its thresholds values (see example.1), come to the conclusion, that MPC $D2_{7\times7}$ is permissibly inconsistent (increasing of consistency is needed) according the indicators CR, GCI та CI^{tr} and is not permissibly inconsistent (consistency increasing is required) according the indicators HCR and k_y.

Let find the ejection in the given weakly inconsistent MPC $D2_{7\times7}$, using the definition. The condition $(d_{ij} > 1) \wedge (d_{jk} > 1) \wedge (d_{ik} < 1)$ of violation of the order traransitivity on the set of alternatives is performed for $(i, j, k) = (2, 4, 7)$, so the ejection is the element $d_{ik} = d_{27} = 3/8$. It is easy to note, that after the change of this element at the back symmetric $d_{27} := 8/3$, the problem of MPC $D2_{7\times7}$ becomes strongly consistent.

The MPC of such a kind, that is weakly inconsistent with one ejection, when other elements form a very consistent transitivities, may arise during the operator error in the assessment of decisions alternatives on quantitative criteria. Evaluating the quantitative criterion, as a rule, there is a statistical information, which leads to strongly consistent MPC. However, the error of the operator may lead to the ejection in the MPC. Thus, for the weakly inconsistent MPC the use of various indicators of consistency can also lead to different results regarding the permissible inconsistencies in the sense of criteria.

3. Assessment of the equivalence of the consistency indicators *CR, GCI, HCR,* CI^{tr} and k_y of MPC

In p.2 above the examples of two MPC with different properties it is shown that the known indicators of consistency lead to different results regarding the permissible inconsistency of the MPC in the sense of criteria 1 and 2. For the assessment of the equivalence of consistency indicators CR, GCI, HCR, CI^{tr} and k_y a statistical modeling of the dependency between these indicators on MPC with different properties is carried out. Samples of 500 MPC of different levels of consistency are randomly generated. As a reference, take indicator CR, which is considered as traditional for a method of paired comparisons [Saaty, 1980], and compare with it the other indicators. For each randomly given the MPC calculate the rank, the values of transitivities indicators, as the basic elements of consistency, when the number of different transitivities of MPC is equal $NT = n!/((n-3)!\,3!)$, and also the values of the indicators CR, GCI, HCR, CI^{tr} and k_y. The calculations were carried out with the accuracy of 10^{-4}, and the conclusions were made with an accuracy of 10^{-2}. The results are presented in table 1.

Table 1. The characteristics of the MPC consistency with different properties

№	MPC consistency according the definition	Are there ejections? The number of ejections	Ranges of values of consistency indicators (for $n = 7$)					Rank of MPC	The value of MPC transitivities qualifiers
			CR	GCI	HCR	CI^{tr}	k_y		
1	Strongly consistent	No ejections	0	0	0	0	1	1	All are equal to zero
2	Perturbated strongly consistent	No ejections	[0.011; 0.100]	[0.041; 0.359]	[0.009; 0.114]	[0.129; 1.347]	[0.491; 0.845]	5, 6, 7	Take small values
3	Has the properties of strong inconsistency and weak consistency (fundamental scale)	No ejections	[0.117; 0.732]	[0.407; 2.230]	[0.039; 0.793]	[1.567; 16.480]	[0.378; 0.715]	7	Take small values within an order of the magnitude
4	Weakly inconsistent	One ejection, other elements of MPC are strongly consistent	[0.003; 3.398]	[0.012; 3.678]	[0.000; 2.825]	[0.037; 937.000]	[0.405; 1.000]	3	Equal to zero, except of a few transitivities, which correspond to a single ejection
5	Weakly inconsistent	One ejection, Other elements of MPC – perturbation of strongly consistent	[0.007; 2.633]	[0.025; 3.227]	[0.006; 1.171]	[0.076; 486.200]	[0.289; 0.845]	5, 6, 7	Take small values, with the exception of a few transitivities, which differ from others for more than an order magnitude and related the ejection
6	Weakly inconsistent (fundamental scale)	A few ejections	[0.149; 1.737]	[0.474; 4.684]	[0.071; 1.937]	[2.047; 117.200]	[0.309; 0.684]	7	There are several transitivities with large values, which differ from the others by more than an order of magnitude and related ejections

1. If the MPC is strongly consistent, so all indicators $\boldsymbol{CR}, \boldsymbol{GCI}, \boldsymbol{HCR}$, $\boldsymbol{CI^{tr}}$ and $\boldsymbol{k_y}$ equivalent and demonstrate the consistency of the MPC in the sense of criteria 1 i 2.

2. Let consider the MPC, which are the perturbation of strongly consistent MPC, when the values of perturbation are small, so that the MPC is **weakly consistent**. For such MPC observe the permissible inconsistency in the sense of criterion 1, that is the correction of the MPC is not necessary, according all indicators CR, GCI, HCR and CI^{tr} (table1), except for 3.2% of the cases, when the indicator HCR showed the need of correction. The indicator k_y and criterion 2, on the contrary, in 95% of cases have shown the necessity of the MPC correction and only in 5% of the cases - permissible inconsistency.

Let estimate the regression of the values depending on the indicator CR according the least-squares method. As the criterion of significance of the regression parameters the coefficient of determination is used. For $n = 7$ obtain: $GCI = 0.009 + 3.426 \cdot CR$ with a coefficient of determination $R^2 = 0.99$, $HCR = 0.017 + 0.516 \cdot CR$ with a coefficient of determination $R^2 = 0.27$, $CI^{tr} = -0.064 + 13.673 \cdot CR$ with a coefficient of determination $R^2 = 0.99$, $k_y = 0.782 - 1.337 \cdot CR$ with a coefficient of determination $R^2 = 0.16$.

It is known that the coefficient of determination takes its values in the interval [0,1] and the more of its value means the great importance of the regression. Thus, for perturbated strongly consistent MPC, indicators $\boldsymbol{CR}, \boldsymbol{GCI}$ *and* $\boldsymbol{CI^{tr}}$ *are equivalent.* The Indicator k_y in 95% of cases erroneously shows the necessity of MPC correction.

There are several tranzitivnosey with large values that are different from the others by more than an order of magnitude and related emissions

3. If strongly inconsistent MPC has the properties of weak inconsistency, so, analyzing the ranges of indicators changes (table.1), it can be concluded that the normalized indicators CR i HCR, as well as k_y in 99.4% of the cases, indicate the presence of information in the MPC (because $CR < 1$, $HCR < 1$ та $k_y > T_0 = 0.39$). In 97% of cases according to all indicators simultaneously MPC is impermissible inconsistent in the sense of criteria 1 and 2. The exception is 2.8% of the cases of contradictory results according to CR i HCR: CR indicates the need of the MPC correction, and HCR indicates that the correction is not required.

Regressions of the indicators, depending on the indicator CR according to the method of least squares for $n = 7$:

$GCI = 0.111 + 2.852 \cdot CR$, the coefficient of determination $R^2 = 0.99$;

$HCR = -0.035 + 0.871 \cdot CR$, коефіцієнт детермінації $R^2 = 0.50$;

$CI^{tr} = -1.866 + 22.708 \cdot CR$, the coefficient of determination $R^2 = 0.95$;

$k_y = 0.629 - 0.260 \cdot CR$, the coefficient of determination $R^2 = 0.20$.

Thus, if strongly inconsistent MPC has the property of weak consistency $\boldsymbol{CR}, \boldsymbol{GCI}$ and $\boldsymbol{CI^{tr}}$ are equivalent.

4. Let consider weakly inconsistent MPC with different quantity of ejections and various properties of elements, which are not ejections. If **the ejection is single, and other elements form strongly consistent transitivities**, for these MPC the criterion of consistency 1 operates bad, since all cases of this criterion come into action, namely, the MPC can be whether consistent (according the indicator CR in 1.8% of the cases, accuracy 10^{-2}), permissible inconsistent, that is the MPC correction is not required (according the indicator CR in 16.9% of the cases), and impermissible inconsistent (according the indicator CR in 41% of the cases) and the information noise (according the indicator CR in42.6% of the cases).

The same conclusions are true for the criterion of consistency 2: MPC can be whether consistent (1.8% of the cases, the accuracy 10^{-2}), i.e. the correction of the MPC is not required (21.6% of cases), and it is impermissible inconsistent (80.6% of the cases).

There are conflicting results according CR , HCR and k_y in the sense of the criteria 1 i 2:

- in 20.3% of the cases CR indicates the need of the MPC correction, and HCR HCR indicates that the correction is not required, in 13.7% of the cases such contradictory results have a place for CR and k_y ;
- in 2.3% of the cases the MPC are identified as such? Which are not required the correction according CR and such, which are required the correction according HCR, in 7.1% of the cases such contradictory results have a place for CR and k_y ;
- k_y , in contrast to all of the other indicators, never found the lack of information in the MPC (in all cases it was performed $k_y > T_0 = 0.39$), while in 42.6% i 6.4% of the cases CR and HCR respectively identified a total absence of information in the MPC.

Let estimate the regressions of indicators depending on the indicator CR according to the method of least squares. For $n = 7$ are obtained: $GCI = 0.324 + 1.138 \cdot CR$, коефіцієнт детермінації $R^2 = 0.97$;

$HCR = 0.050 + 0.293 \cdot CR$, coefficient of determination $R^2 = 0.46$;

$CI^{tr} = -70.649 + 191.796 \cdot CR$, coefficient of determination $R^2 = 0.84$;

$k_y = 0.776 - 0.100 \cdot CR$, coefficient of determination $R^2 = 0.57$.

Thus, if the ejection is single and other elements form strongly consistent transitivities, $\boldsymbol{CR}, \boldsymbol{GCI}$ and $\boldsymbol{CI^{tr}}$ are equivalent. These indicators operate badly, because in 18.7% of the cases it was wrongly shown, that the MPC is not required the correction, and in 42.6% of the cases the total absence of the information in the MPC was wrongly indicated. The indicator k_y operates better, because in 80.6% of the cases it was indicated the necessity of the MPC correction and never found the lack of information in the MPC.

5. If the ejection is single, and the other elements of the MPC are the perturbation of strongly consistent elements, for such MPC the criterion of consistency 1, the same as for previous MPC, operates bad, since all cases of this criterion come into action, namely, the MPC can be whether consistent (according CR in 0.4% of the cases, тthe accuracy 10^{-2}), permissibly inconsistent, it means that the MPC correction is not required (according CR in 31.4% of the cases), and impermissibly inconsistent (according CR in 54.4% of the cases) and the information noise (according CR in 17% of the cases).

The criterion 2 operates bad, since in 96.4% of the cases k_y truly indicated the existence of information in MPC and the necessity of its correction, and only in 1.8% of the cases it indicated the MPC as information noise.

The regressions of indicators depending on the indicator CR according to the method of least squares $n = 7$ are as follows:

$GCI = 0.283 + 1.300 \cdot CR$, coefficient of determination $R^2 = 0.97$,

$HCR = 0.086 + 0.186 \cdot CR$, coefficient of determination $R^2 = 0.49$,

$CI^{tr} = -23.297 + 119.071 \cdot CR$, coefficient of determination $R^2 = 0.87$,

$k_y = 0.667 - 0.080 \cdot CR$, coefficient of determination $R^2 = 0.28$.

Thus, if the ejection is single and the other elements of the MPC are the perturbation of strongly consistent elements, $\boldsymbol{CR}, \boldsymbol{GCI}$ *and* $\boldsymbol{CI^{tr}}$ *are equivalent.* These indicators operate badly, since in 31.8% of the cases it was wrongly shown, that the MPC is not required the correction. k_y Operates good, it in 96.4% of the cases showed the existence of the information in the MPC and the necessity of its correction.

6. If the ejections are a few, in 51.9% of the cases, all indicators show the presence of information and the necessity of MPC correction, and just with CR – in 60.9% of the cases, with HCR – in 56.8% of the cases, and k_y – in 99% of the cases. The lack of information is found in all three indicators CR, HCR and k_y and at the same time only in 0.7% of the cases, in terms of two indicators CR i HCR – in 40.1% of the cases, and k_y – in 1% of the cases. Regressions of the indicators depending on CR according to the method of least squares for $n = 7$ are as follows:

$GCI = 0.212 + 2.458 \cdot CR$, coefficient of determination $R^2 = 0.95$;

$HCR = -0.169 + 1.163 \cdot CR$, coefficient of determination $R^2 = 0.69$;

$CI^{tr} = -25.300 + 64.927 \cdot CR$, coefficient of determination $R^2 = 0.92$;

$k_y = 0.547 - 0.045 \cdot CR$, coefficient of determination $R^2 = 0.04$.

Thus, if the MPC is weakly inconsistent with a few ejections, $\boldsymbol{CR}, \boldsymbol{GCI}$ *and* $\boldsymbol{CI^{tr}}$ *are equivalent.*

4. Examples of calculation of local weights of decisions alternatives on the basis of primary and corrected MPC

To illustrate how critical in practical problems the found in section 3 the contradictory results of the consistency assessment are, consider examples in which the calculation of the weights of decisions alternatives on the basis of primary and corrected MPC lead to a variety of alternatives ranking.

For MPC, which have the property of weak consistency, conflicting results CR and HCR are in a small number of cases (3.2% and 2.8% of cases for different levels of weak consistency of the MPC). So let consider these contradictory results as practically unimportant and won't illustrate it here.

Let consider the weakly inconsistent MPC with different properties of the elements, which are not the ejections.

Example 3. Consider the MPC $D3_{7\times7}$, which by definition is weakly inconsistent, has the one ejection, and other elements are strongly consistent:

$D3_{7\times7}$ =

1	1/5	1/6	1/2	1/5	1/2	1/6
5	1	5/6	5/2	1	5/2	5/6
6	6/5	1	3	6/5	**1/3**	1
2	2/5	1/3	1	2/5	1	1/3
5	1	5/6	5/2	1	5/2	5/6
2	2/5	**3**	1	2/5	1	1/3
6	6/5	1	3	6/5	3	1

As noted above, the MPC of this type appear in a result of operator errors in the assessment of decisions alternatives according the quantitative criteria.

Comparing the values of the consistency indicators $CR(D3_{7\times7}) = 0.076$, $GCI(D3_{7\times7}) = 0.23$, $HCR(D3_{7\times7}) = 0.068$, $CI^{tr}(D3_{7\times7}) = 1.016$, $k_y(D3_{7\times7}) = 0.783$ with their threshold values (see table1), come to the conclusion that the MPC $D3_{7\times7}$ is permissibly inconsistent (the increasing of consistency is not required) according the indicators CR, GCI, HCR та CI^{tr} and is not permissibly inconsistenti (the increasing of consistency is required) the indicator k_y. Calculate the weights of solutions alternatives from the initial MPC $D3_{7\times7}$:

- according the method of EM: $\text{vec}^T = (0.037\ 0.183\ 0.172\ 0.073\ 0.183\ 0.133\ 0.219)$;
- according the method of RGMM: $w^T = (0.038\ 0.191\ 0.168\ 0.077\ 0.191\ 0.105\ 0.23)$;
- according the method of AN: $\text{w\_AN}^T = (0.04\ 0.198\ 0.149\ 0.079\ 0.198\ 0.099\ 0.238)$.

All methods lead to the same ranking: $a_7 \succ a_2 = a_5 \succ a_3 \succ a_6 \succ a_4 \succ a_1$.

The ejection in the given weakly inconsistent MPC $D3_{7\times7}$ according the definition is the element $d_{36} = 1/3$. After the ejection correction by changing the element at the back symmetric $d_{36} := 3$, given MPC $D3_{7\times7}$ becomes strongly consistent. So the methods of EM, RGMM, AN give equal weights: $\text{vec}^T = (0.037\ 0.185\ 0.222\ 0.074\ 0.185\ 0.074\ 0.222)$, which present another ranking of the alternatives: $a_7 = a_3 \succ a_2 = a_5 \succ a_6 = a_4 \succ a_1$.

Thus, *after the ejection correction the ranking, which differs from the ranking according the methods of EM, RGMM and AN to the MPC correction, is received.*

Example 4. Let consider weakly inconsistent MPC $D4_{7\times7}$ with single ejection, other elements of which are the perturbation of strongly consistent, in other words, they form permissibly inconsistent transistivities:

$D4_{7\times7}$ =

1	1/8	6	1/6	4	1/2	1/3
8	1	9	2	9	4	**1/3**
1/6	1/9	1	1/9	1	1/9	1/9
6	1/2	9	1	9	3	2
1/4	1/9	1	1/9	1	1/8	1/8
2	1/4	9	1/3	8	1	1/3
3	**3**	9	1/2	8	3	1

This MPC arises, for example, in the assessment of alternatives according the quality criterion in the fundamental scale, when the expert made a mistake while recording elements of the symmetric position of the MPC.

The value of the indicators are $CR(D4_{7\times7}) = 0.093$, $GCI(D4_{7\times7}) = 0.329$, $HCR(D4_{7\times7}) = 0.173$, $CI^{tr}(D4_{7\times7}) = 1.239$, $k_y(D4_{7\times7}) = 0.603$. Comparing them with the threshold values (see example1), come to the conclusion, that MPC $D4_{7\times7}$ is permissibly inconsistent according the indicators CR, GCI та

CI^{tr} and is not permissibly inconsistent (the correction is required) according the indicators HCR and k_y. Let calculate the weights of decisions alternatives from the MPC $D4_{7\times7}$:

- according the method of EM: $\mathrm{vec}^{\mathrm{T}} = (0.062\ \ 0.276\ \ 0.019\ \ 0.253\ \ 0.021\ \ 0.104\ \ 0.265)$;
- according the method of RGMM: $\mathrm{w}^{\mathrm{T}} = (0.065\ \ 0.269\ \ 0.02\ \ 0.262\ \ 0.022\ \ 0.113\ \ 0.248)$;
- according the method of AN: $\mathrm{w\_AN}^{\mathrm{T}} = (0.058\ \ 0.231\ \ 0.027\ \ 0.278\ \ 0.029\ \ 0.1\ \ 0.277)$.

All methods lead to the different ranking of alternatives. For example, ranking according the traditional method of EM is equal to $a_2 \succ a_7 \succ a_4 \succ a_6 \succ a_1 \succ a_5 = a_3$ with the accuracy 10^{-2}.

The ejection in the given MPC is the element $d_{27} = 1/3$. After changing the element at the back symmetric $d_{27} := 3$, the MPC $D4_{7\times7}$ becomes permissibly inconsistent ($CR = 0.058$, $GCI = 0.213$, $HCR = 0.025$, $k_y = 0.660$) according the all indicators, except k_y. After the ejection correction the following weights are received:

- according the method of EM: $\mathrm{vec}^{\mathrm{T}} = (0.063\ \ 0.362\ \ 0.02\ \ 0.249\ \ 0.022\ \ 0.11\ \ 0.173)$;
- according the method of RGMM: $\mathrm{w}^{\mathrm{T}} = (0.063\ \ 0.357\ \ 0.02\ \ 0.254\ \ 0.022\ \ 0.109\ \ 0.175)$;
- according the method of AN: $\mathrm{w\_AN}^{\mathrm{T}} = (0.05\ \ 0.422\ \ 0.023\ \ 0.243\ \ 0.026\ \ 0.087\ \ 0.149)$,

which set the same ranking of alternatives $a_2 \succ a_4 \succ a_7 \succ a_6 \succ a_1 \succ a_5 = a_3$, however, this ranking does not coincide with the ranking obtained from the initial MPC.

5. The method of estimating the consistency of MPC

The method of estimating the consistency of the MPC, which is proposed, is based on the results of the research of consistency indicators CR, GCI, HCR, CI^{tr} and k_y MPC, obtained in section 3. So, for MPC, which are perturbations of strongly consistent MPC in 97% of cases all indicators CR, GCI, HCR and CI^{tr} properly identified the permissible inconsistency of the MPC, and k_y for those MPC in 95% of cases erroneously shows the need of correction.

For the MPC, which has the properties of weak consistency and a strong inconsistency, in 97% of cases indicator together with all other variables correctly shows impermissible inconsistency, that is the necessity of the MPC correction.

For weakly inconsistent MPC with single ejection the CR, GCI, HCR and CI^{tr} operates bad, as erroneously show that MPC does not require the correction, if its other elements are: 1)strongly consistent or 2)perturbations of strongly consistent (18.7% and 31.8% of the cases respectively). These indicators are also mistakenly identifying the total lack of information in such MPC (42.6% and 17% of cases for 1) and (2) respectively).

In this case, the ranking of the solutions alternatives, obtained on the basis of the initial weakly inconsistent MPC, and the ranking on the basis of the corrected MPC after the change of the ejection often differs among themselves (see examples 3 and 4 above). In our opinion, the right of these two is the ranking, based on the corrected MPC. So for the weakly inconsistent MPC the indicators CR, GCI, HCR *and* CI^{tr} *cannot be used without the prior correction of ejections in this MPC.*

The indicator k_y for weakly inconsistent MPC operates better, than other elements, since in general correctly showed the presence of information in the MPC and the necessity of the correction (80% and 96.4% of the cases for 1) and (2) respectively) and practically has not revealed the lack of information in the MPC (0 1.8% of the cases for 1) and (2) respectively).

Let $D_{n\times n} = \{d_{ij} \mid i, j = 1,...,n\}$ – MPC of solutions alternatives on criteria.

The method of estimating the consistency of the MPC, that is offered, consists of the following stages:

1) Determine if $D_{n\times n}$ has the properties of weak consistency.

2) If $D_{n\times n}$ is weakly consistent, for the estimation of the permissibility of inconsistency any of the indicators CR, GCI or CI^{tr} should be used – they are equivalent – and the criterion of the consistency 1 should also be used.

3) If $D_{n\times n}$ has not the properties of weak consistency (weakly inconsistent), the ejections should be looked for in $D_{n\times n}$, and should be corrected till $D_{n\times n}$ becomes weakly consistent.

The results of simulation, shown in table1, indicate that for the getting of the ejections in the MPC, you can use the value of the determinants of its transitivities. *The proposed method of getting the ejection consists of stages*:

1). Creation of the set of MPC transitivities $\Gamma = \{\Gamma_u\} : \Gamma_u = \{d_{ij}, d_{jk}, d_{ik}\}$, $i, j, k = 1,...,n$, $i < j < k$,

$$u = 1,...,NT \text{ , } NT = \frac{n!}{(n-3)!\,3!} \text{ , } n \geq 3 \text{ .}$$

2). Calculation of the set of the transitivities determinants values: $Det = \{\det(\Gamma_u)\}$,

$$\det(\Gamma_u) = \frac{d_{ij} d_{jk}}{d_{ik}} + \frac{d_{ik}}{d_{ij} d_{jk}} - 2 \text{ .}$$

3) Selection of the maximum value of the set of determinants values:

$$\Gamma_{u^*} = \{d_{i^* j^*}, d_{j^* k^*}, d_{i^* k^*}\} = \arg\max_{u=1,...,NT} \det(\Gamma_u) \text{ .}$$

4) The transitivity Γ_{u^*} should be corrected.

Example 5. To illustrate the method of searching the ejection, using the values of MPC transitivities determinants, consider the MPC $D4_{7\times 7}$ from the example 4.

The set $Det = \{\det(\Gamma_u)\}$ for the MPC $D4_{7\times 7}$ is equal:

u	i	j	k	$\det(\Gamma_u)$
1	1	2	3	3.521
2	1	2	4	0.167
3	1	2	5	1.837
4	1	2	6	0
5	1	2	7	6.125

u	i	j	k	$\det(\Gamma_u)$
18	2	3	6	2.25
19	2	3	7	1.333
20	2	4	5	0.5
21	2	4	6	0.167
22	***2***	***4***	***7***	***10.083***

6	1	3	4	2.25
7	1	3	5	0.167
8	1	3	6	0.083
9	1	3	7	0.5
10	1	4	5	1.042
11	1	4	6	0
12	1	4	7	0
13	1	5	6	0
14	1	5	7	0.167
15	1	6	7	0.5
16	2	3	4	0.5
17	2	3	5	0
23	2	5	6	1.837
24	2	5	7	1.671
25	2	6	7	2.25
26	3	4	5	0
27	3	4	6	1.333
28	3	4	7	0.5
29	3	5	6	0.014
30	3	5	7	0.014
31	3	6	7	1.333
32	4	5	6	1.042
33	4	5	7	0.34
34	4	6	7	0.5
35	5	6	7	1.333

The maximum value of determinant, equal to 10.083, is archived in transitivity $\Gamma_{u^*} = \{d_{24}, d_{47}, d_{27}\}$. Therefore, the ejection is the element of MPC d_{27}. It should be corrected on the basis of the product $d_{24} \cdot d_{47}$.

Conclusion

In the research the assessment of equivalence of known indicators CR, GCI, HCR, CI^{tr} and k_y is carried out for the MPC with a wide range of changes of the level of consistency. The equivalence of indicators CR, GCI and CI^{tr} is shown for all researched MPC: linear regression between these indicators showed the significance of the coefficient of determination that exceed 0.95. The results for the indicators CR and GCI are consisted with known results, received in [Aguaron&Moreno-Jimenez, 2003]. However, in this work, the research was carried out for a wider range of changes of the level of consistency of the MPC. A weak linear dependence between CR and HCR (R^2 is equal to 0.27, 0.46, 0.50, 0.69 depending on the level of MPC consistency) and even less linear dependence between CR and k_y (R^2 takes the values 0.16, 0.20, 0.28, 0.04) are shown.

Such a weak linear dependence between CR and k_y can be explained by the fact that k_y is based on a completely different ideas in comparison with indicators CR, GCI, HCR and CI^{tr}. The indicator k_y in many cases leads to inconsistent results compared with CR therefore should be used carefully.

It is established, that the property of weak consistency guarantees the presence of information in the MPC.

The correct method of assessment of the consistency of the MPC depending on its characteristics is developed. If the MPC is weakly consistent, so for the assessment of the permissibility of its inconsistency any of the indicators CR, GCI або CI^{tr} and criterion of consistency 1should be used. If the MPC has not the property of weak consistency, then you need to look for ejections in this matrix, correct these ejections until the MPC becomes weakly consistent and already after that to assess the permissibility of consistency of corrected MPC according any of the indicators CR, GCI or CI^{tr}. The use of any indicators of CR, GCI, HCR and CI^{tr} and the criterion of consistency 1 to MPC, which has not the properties of weak consistency without the prior correction of the ejections, in many cases (18.7% and 31.8% of cases depending on the level of consistency) leads to erroneous vectors of weights.

The results, obtained in this work, is planned to be used in future for the development of a method of improving the MPC consistency.

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МОДЕЛЬ ОНТОЛОГИЧЕСКОГО ИНТЕРФЕЙСА АГРЕГАЦИИ ИНФОРМАЦИОННЫХ РЕСУРСОВ И СРЕДСТВ ГИС

Марина Попова

Аннотация*: В статье рассматривается разработка и применение онтологического интерфейса как эффективного средства обеспечения процессов интеграции распределённых информационных ресурсов и систем на основе использования семантических свойств. Описано представление информации в наглядной легкодоступной форме, обеспечивающее создание и использование формализованной системы знаний в конкретных предметных областях. Приведён пример агрегации онтологического интерфейса с ГИС-средой.*

Ключевые слова*: онтология, онтограф, онтологический интерфейс, геоинформационные системы (ГИС).*

ACM Classification Keywords*: I.2 ARTIFICIAL INTELLIGENCE - I.2.4 Knowledge Representation Formalisms and Methods*

Введение

Восприятие и познание окружающего мира требуют развития соответствующих методов и средств, среди которых выделяются геоинформационные системы (ГИС). ГИС могут применяться в широком спектре задач, связанных с анализом и прогнозом явлений и событий окружающего мира, с осмыслением и выделением главных факторов и причин, а также их возможных последствий, с планированием стратегических решений последствий совершаемых действий [Людвиг Фон Берталанфи, 1969]. В свою очередь, развитие геоинформационных систем связано с необходимостью совместной обработки объемов пространственной и непространственной информации, сложных процессов обработки взаимосвязанной разноплановой информации, ее интеграции и взаимодействия с другими различными по назначению системами. Дополнительные требования нахождения лучших решений, удобства, производительности, надежности и стоимости также требуют разработки и развития адекватных моделей.

Быстрый рост объемов информации, необходимость ее более качественной обработки и усвоения требуют использования методов извлечения информации и преобразования ее в такую форму, с которой будет удобно работать. Главная цель такого преобразования – возможность анализа «хаотичной» информации с помощью стандартных методов обработки данных. Более специфической целью является выявление логических закономерностей между описанными понятиями. Представленная надлежащим образом информация позволяет увидеть те дополнительные скрытые закономерности, которые не удается обнаружить другими методами.

Таким образом, актуальной является задача идентификации, поддержки и управления пространственными связями между топологическими объектами реального мира, создание новых объектов, связей, увязки новых атрибутов, визуализирующихся в виде «дружественного интерфейса».

Анализ последних исследований и публикаций

Согласно анализу современных методов и средств визуального представления информационных ресурсов в ГИС-среде [Joseph K. Berry, 2007] можно сделать вывод о том, что широко применяемым является объектный подход, при котором предметная прикладная область представляется в виде совокупности объектов, которые взаимодействуют между собой посредством передачи сообщений.

Распространенное использование ГИС создало основу для широкого применения объектно-ориентированного подхода в практике проектирования и программирования информационных систем. Указанная методология ориентирована, прежде всего, на преодоление сложностей, связанных с разработкой программных средств, созданием больших сложных систем, коллективной их разработкой, дальнейшим активным сопровождением при эксплуатации и регулярных модификациях.

Информационно-аналитическая среда ГИС-специалиста может иметь иерархическую или сетевую структуру, т.е. состоять из более специализированных сред или систем, связанных некоторыми отношениями, например, «общее-частное». Поскольку архитектура такой среды должна предоставлять гибкость, возможность для расширения функциональности и агрегации распределенных в сети информационных ресурсов, необходимо создание эргономичного интерфейса пользователя, обеспечивающего Web-доступ к ним.

Эффективным средством представления и систематизации информации являются онтологии, которые используются для формальной спецификации понятий и отношений, которые, в свою очередь, характеризуют определенную предметную область. Преимуществом онтологий как способа представления информации является их формальная структура, которая упрощает компьютерную обработку [Палагин А.В., 2005].

Будучи аналогом понятию «модель», онтология служит средством коммуникации между разработчиком и пользователем.

Использование онтологии эффективно при поиске и объединении информации из различных источников и сред, представления и интерпретации информации в процессе принятия решений. Онтологический подход обеспечивает связность информационных ресурсов и позволяет гибко работать с контекстами.

Современные интерфейсы систем представления информационных ресурсов предназначены для функционирования в гетерогенных распределенных информационных средах и поэтому основаны на методах искусственного интеллекта и парадигме Semantic Web.

На сегодняшний день одним из доминирующих решений Web-технологий, которое сводит к единой структуре как корпоративные документы и материалы, так и Интернет-ресурсы, являются портальные. Различают разные типы порталов, в зависимости от функций, которые они выполняют.

Простейший тип – информационные порталы (Information Portals), которые объединяют пользователей с информацией, обеспечивают персонифицированный доступ к ресурсам и данным с помощью классификатора, с возможностью проведения сквозного полнотекстового и атрибутивного поиска.

Порталы для совместной работы (Collaboration Portals) поддерживают различные средства взаимодействия пользователей, основанные на компьютерных технологиях. Такие порталы предоставляют информацию и обеспечивают работу группы сотрудников над определенной задачей, проектом (фактически, автоматизируют бизнес-процессы в организациях).

Экспертные порталы или порталы экспертизы (Expertise Portals) объединяют пользователей друг с другом на основе их опыта, области экспертизы и интересов. Такие системы обеспечивают подключение к экспертам на основе их знаний. Не всегда такой портал содержит нужную пользователю информацию, однако, в случае ее отсутствия может подключить пользователя к соответствующим специалистам, которые могут поделиться необходимой информацией, предоставить экспертные оценки по конкретным вопросам.

Порталы знаний (Knowledge Portals) – это интегрированные порталы, которые объединяют возможности вышеперечисленных типов и обеспечивают предоставление персонифицированной информации с учетом конкретной работы, которую выполняет каждый пользователь в определенное время [Шинкарук В.Д., 2008].

Все перечисленные свойства портальных решений (комбинирование в себе трёх типов порталов с использованием компьютерных технологий, соединяющих пользователей с информацией и пользователей друг с другом на основе таких критериев как опыт, область экспертизы, общие интересы и т.п.) имеет онтологический интерфейс. В основе такого интерфейса лежит онтология, которая условно делится на две части: первая содержит описание структуры ГИС-среды, вторая – ресурсы, описывающие выбранную предметную область.

Модель онтологического интерфейса

На сегодняшний день информационные ресурсы, используемые в процессе принятия решений, являются распределенными. Современные сетевые технологии и широкое распространение Internet предоставляют возможность доступа и использования этих ресурсов путем объединения территориально распределенных источников информации такого рода. Онтологический интерфейс позволяет визуализировать результат процессов интеграции и агрегации распределенных информационных ресурсов в процессе организации взаимодействия пользователей в легкодоступной наглядной форме.

Компьютерная онтология предметной области – это:

- иерархическая структура конечного множества понятий, описывающих заданную предметную область (ПдО);
- структура – онтограф, вершинами которого являются понятия, а дугами – семантические отношения между ними;
- понятия и отношения интерпретируются согласно общезначимым функциям интерпретации, взятых из электронных источников знаний заданной ПдО;
- определение понятий и отношений выполняется на основе аксиом и ограничений (правил) их области действия;
- существует средство формального описания онтографа;
- функции интерпретации и аксиомы описаны в нотации формальной теории.

Онтология определяет общеупотребительные, семантически значимые «понятийные единицы информации», которыми оперируют пользователи и разработчики информационных систем. В отличие от информации, закодированной в алгоритмах, онтология обеспечивает ее унифицированное и многократное использование различными группами пользователей, на разных компьютерных платформах при решении различных задач.

Онтология некоторой ПдО в общем случае формально представляется Т. А. Гавриловой и Ф. В. Хорошевским [Гаврилова Т.А., 2001] упорядоченной тройкой :

$$\mathbf{O = \langle \mathit{X}, \mathit{R}, \mathit{F} \rangle}, \quad (1)$$

где ***X***, ***R***, ***F*** – конечные множества соответственно:

X - концептов (понятий, терминов) ПдО;

R – отношений между ними;

F - функций интерпретации (определений) ***X*** и/или ***R***.

Выделяем 5 типов онтологий:

$X = \varnothing$, $R = \varnothing$, $F = \varnothing$ – неструктурированный текст;

$X \neq \varnothing$, $R = \varnothing$, $F \neq \varnothing$ – глоссарий;

$X \neq \varnothing$, $R \neq \varnothing$, $F = \varnothing$ – таксономия;

$X \neq \varnothing$, $R = \varnothing$, $F = \varnothing$ – простая онтология;

$X \neq \varnothing$, $R \neq \varnothing$, $F \neq \varnothing$ – активная онтология.

Активная онтология ($R \neq \varnothing$, $F \neq \varnothing$) – это такая онтология, в которой множества концептов и концептуальных отношений максимально полные, а к функциям интерпретации добавляются аксиомы, определения и ограничения. Описание всех компонент представлено некоторым формальным языком, доступным для их интерпретации компьютером.

$$\mathbf{O = \langle \mathit{X}, \mathit{R}, \mathit{F}, \mathit{A} (\mathit{D}, \mathit{Rs}) \rangle}, \quad (2)$$

где ***X*** = $\{x_1, x_2, \dots, x_i, \dots, x_n\}$, $i = \overline{1, n}$, $n = Card\ X$ – конечное множество концептов (понятий-объектов) заданной ПдО;

R = $\{R_1, R_2, \dots, R_k, \dots, R_m\}$, $R \subseteq X_1 \times X_2 \times \dots \times X_n$, $k = \overline{1, m}$, $m = Card\ R$ – множество концептуальных отношений между ними;

F: X×R – конечное множество функций интерпретации, заданных на концептах и/или отношениях;

A – конечное множество аксиом, состоящее из множества определений D^l_i и множества ограничений Rs^l_i для понятия X_i. Определения записываются в виде тождественно истинных высказываний, которые могут быть взяты, например, из толковых словарей ПдО. В словарях могут быть указаны дополнительные взаимосвязи понятий X_i с понятиями X_j. В множестве ограничений Rs_i могут быть заданы ограничения на интерпретацию соответствующих понятий X_i.;

D – множество дополнительных определений понятий;

Rs – множество ограничений, определяющих область действия понятийных структур.

Рассмотрим множество ограничений и множество дополнительных определений:

D = X×R×Rs – множество дополнительных определений;

Rs = $\boldsymbol{R^+ \times R}$ – множество ограничений, которое может быть рассмотрено как замыкание отношений R;

$\boldsymbol{R^+}$ – множество качеств, характеризующих элементы множества R.

Поскольку любое информационное пространство представляет собой сложную систему управления взаимодействием пользователей с информационной системой, пользователей между собой, а также является средством интеграции распределенных информационных ресурсов и процессов, то под *информационной системой* следует понимать совокупность организационных и технических средств для хранения и обработки информации с целью обеспечения информационных потребностей пользователей.

Системными компонентами являются:

- Типы данных, интерпретирующие процессы;
- Процедуры, обрабатывающие соответствующие типы данных;
- Источники, определяющие непосредственно типы данных и задающие их значение;
- Потребители или фиксирующие устройства.

Информационная система рассматривается через множество представителей - задач, которые могут быть решены с помощью информационной системы.

Задача проблемной ситуации с набором заданных целей может быть представлена в виде кортежа

$$T = <K, K^*, Aim>, \tag{3}$$

K – модель ПдО, отображающая проблемную ситуацию;

K^* – кортеж состояний ПдО, актуализирующихся на каждом шагу достижения целей;

$$K^* = <K_0, K_1, \ldots, K_i, \ldots, K_n>, \tag{4}$$

$Aim = F \times R$ – набор целей.

Таким образом, *онтологический интерфейс* имеет вид:

$$I = <K, K^*, F \times R, X, R, F, A, (X \times R \times Rs, R^+ \times R)>, \tag{5}$$

$$I = <K, K^*, Aim, X, R, F, A, (D, Rs)>, \tag{6}$$

Онтологический интерфейс – средство удобного взаимодействия пользователя с информационной системой, предназначенной для решения множества задач проблемной ситуации путем использования активной онтологии.

$$I = <T, O>, \tag{7}$$

Формально технологический базис формирования онтологического интерфейса определяется нагруженным двудольным графом.

$$G = (V_1 \cup V_2, E), \tag{8}$$

где $V_1 \cap V_2 = \varnothing$, вершины из V_1 размечены именами предикатов, а вершины из V_2 – именами аргументов;

E – множество дуг (рёбер). Дуги графа соединяют вершины, размеченные именами предикатов, с вершинами, размеченными именами аргументов.

Вершины из множества V_1 называются узлами-предикатами, вершины из V_2 – узлами-концептами, а сами предикаты – концептуальными сущностями.

Высказывания формируются на основе композиции вершин, инцидентных одному ребру.

Алгоритм формирования:

1. Определяется первая вершина (левая или правая) по направлению отношения, если оно не коммутативное;
2. Выбирается левая/правая вершина и инцидентное ребро;

3. Выбирается правая/левая вершина с инцидентным ребром, которое имеет левую/правую вершину;
4. Двудольный граф определяется как высказывание.

Вычисляется значение выражения: истинность – вершины включаются в множество объектов интерфейса, ложность – вершины не входят в этого множество.

Алгоритм формирования объектов онтологического интерфейса как множества истинных высказываний может быть представлен в общем виде нормального алгоритма Маркова [Марков А. А., 1996].

Визуализация информации в виде иерархического графа помогает пользователю:

• быстро находить нужный элемент в иерархии;

• понимать связь элемента с контекстом;

• обеспечивать возможность прямого доступа к информации при вершинах.

Сетевой граф может выступать не только средством организации информации. Расширяя его традиционные функции благодаря отражению в виде онтологического интерфейса, граф можно превратить в среду, в которой обеспечивается активная работа с распределенными информационными ресурсами.

Формирование онтологического интерфейса состоит из четырёх этапов:

1. Предварительный анализ информационных ресурсов по ПдО. Выделение концептов-понятий и объединение их по свойствам в соответствующие классы.
2. Формирование таблицы классов концептов-понятий на основе множества семантических соответствий между понятиями.
3. Построение онтографа.
4. Визуализация онтографа и формализованное описание онтологии [Стрижак О.Є., 2013].

На рис. 1 изображён фрагмент онтографа кристаллохимической классификации минералов «IMA CNMNC mineral classes» и соответствующий ей онтологический интерфейс. В данном примере экземпляры минералов входят в состав минерального класса «03 Halogenides», который в свою очередь входит в состав классификации «IMA CNMNC».

Онтологический интерфейс предназначен для визуального отображения экземпляров минералов и их принадлежности к классам в классификации, агрегации распределённых информационных источников по минералогии, а онтограф является таксономией и выполняет функции редактирования, дополнения, управления информационными ресурсами и выявления новых связей или объектов. Например, минерал пирит «Pyrite» входит в класс сульфидов «02 Sulfides and Sulfosalts» кристаллохимической классификации и в класс руд «Ores» классификации по общим признакам. С помощью онтографа был определён новый класс минералов, который можно описать как «рудные сульфиды» или «сульфидные руды» (рис.2).

Использование геоинформационных систем предоставляет дополнительные возможности визуализации данных с географической привязкой и использования многочисленных аналитических инструментов для повышения уровня эффективности принятия решений.

В геоинформационных системах классы объектов онтологии составляют слои тематической карты, а сами объекты, входящие в соответствующий класс, являются объектами слоя.

Атрибутивная информация об объектах онтологии, представленная в онтографе, отображается на карте в виде вложений. Каждая вершина онтографа имеет собственную «базу данных», содержащую информацию из распределённых информационных ресурсов, необходимую для тщательного ознакомления с выбранным объектом, которая может пополняться данными и поисковыми запросами пользователей ГИС [Попова М. А., 2013].

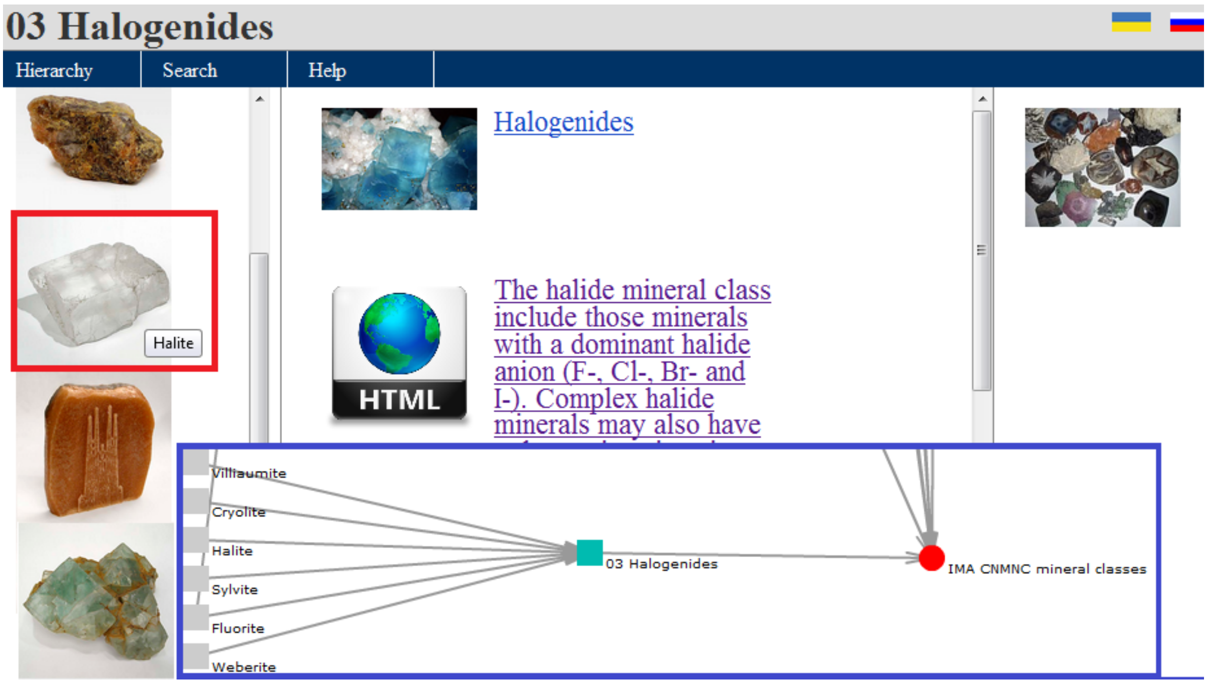

Рис. 1. Онтологический интерфейс онтографа кристаллохимической классификации минералов «IMA CNMNC mineral classes»

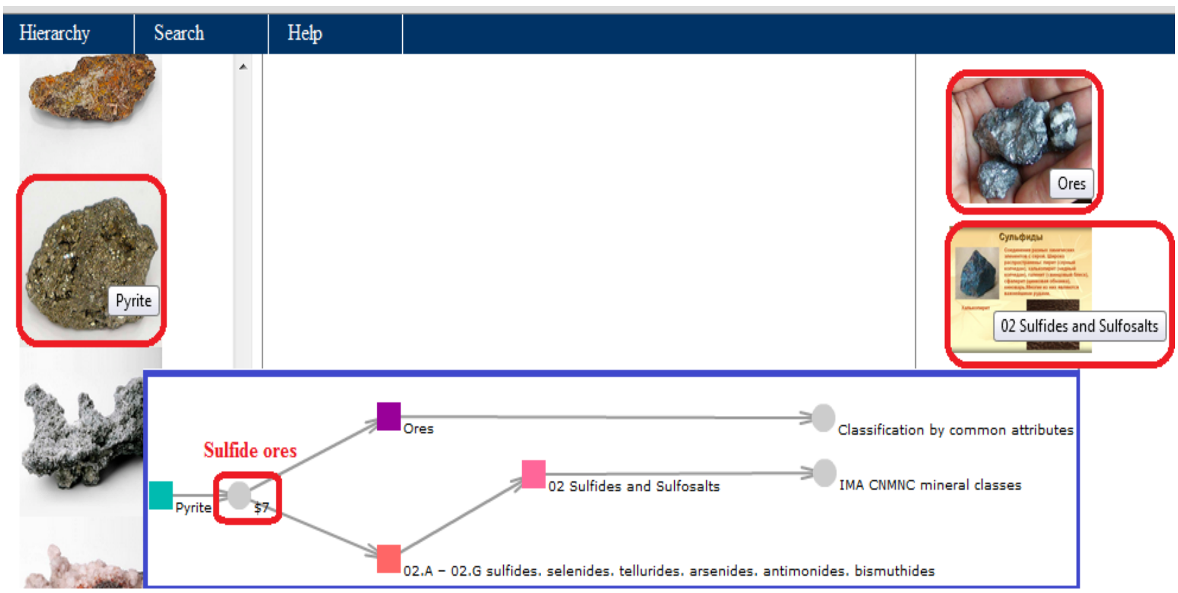

Рис. 2. Выявление нового класса объектов на примере классификаций минералов

На рис. 3 приведён пример отображения слоя «03 Halogenides» на карте, соответствующего одноименному классу онтографа «IMA CNMNC mineral classes». Все объекты, входящие в данные класс и описанные в онтографе, отображаются на карте как элементы, составляющие слой. Выбранный в онтологическом интерфейсе объект «Halite» (рис.1) наследует в ГИС-среде все свойства, заданные в онтографе.

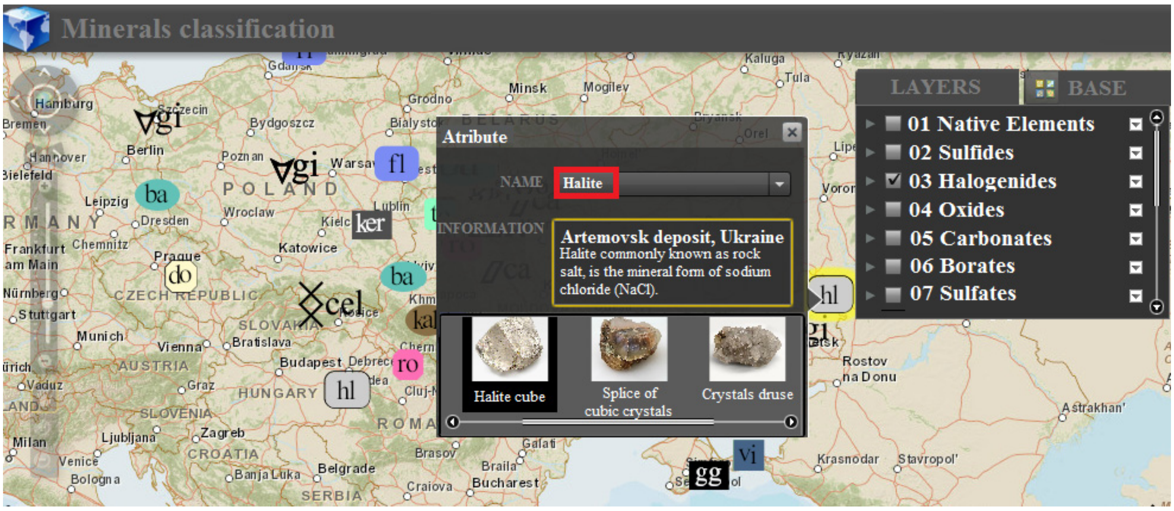

Рис. 3. Фрагмент тематической карты с отображением активного слоя класса объектов онтографа

Выводы

Использование онтологического подхода к классификации, систематизации и использованию информационных ресурсов и онтологического интерфейса для визуализации агрегации распределенных информационных моделей и систем на основе использования семантических свойств дает возможность каждому пользователю выявлять принципиально новые взаимосвязи или объекты, неизвестные ранее. Активные методы анализа проблем и поиска решений способствует смещению акцентов с пассивных методов поиска, ориентированных на передачу данных, к более широкому применеию разноформатной разнородной распределённой информации в единой аналитической среде с использованием возможностей ГИС-технологий.

Рассмотренная модель онтологического интерфейса как множества описаний процессов активизации состояний онтологии является средством управления взаимодействия пользователей с информационной системой и друг с другом, интеграции распределённых информационных ресурсов и процессов. Необходимой является разработка методов и средств контекстного расширения модели предметной области путём интеграции онтологических интерфейсов.

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METHOD OF DATA ANALYSIS BASED ON CLUSTERING IN "SYNDROMES" INDICATORS SPACE

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***Abstract**: A new data analysis method is discussed that is based on calculating syndromes by training data sets. Syndrome are defined as sub-regions in feature space where mean values of target Y deviates from mean value of Y in whole data set. Described method of syndromes construction uses boundaries found with the help of modified version of optimal valid partitioning (OVP) method. The modification is based on new validation technique that allows more effectively delete redundant regularities from output set. OVP boundaries are used to find sub-regions in features space with strong deviation of target Y from its mean by whole data set. Such sub-regions further are called syndromes. Hierarchical tree method was applied to receive clusters of objects from training dataset in space of binary indices indicating if feature description of object belongs to corresponding syndrome. Such technique allows discovering sets of objects with similar syndromes. Experiments with biomedical datasets are discussed.*

***Keywords**: Optimal partitioning, statistical validity, permutation test, regularities, gerontology.*

***ACM Classification Keywords**: H.2.8 Database Applications - Data mining, G.3 Probability and Statistics - Nonparametric statistics, Probabilistic algorithms*

Introduction

Many data analysis, forecasting or recognition methods are based on searching such sub-regions in space of explanatory variables (features) $X_1,\dots,X_n$ where levels of target variable Y deviate significantly from Y mean in data set or at least in neighboring sub-regions. Such sub-regions may be associated for example with leaves in regression trees [Breiman, 1984]. Leaves in classification trees correspond to sub-regions of feature space that contain object mainly from one of classes. Approach that is based on logical regularities must be mentioned thereupon [V.V.Ryazanov, 2003]. Logical regularities are defined as conjunctions of predicates characterizing single features. Conjunctions must be true for possibly maximal subset of one of classes in training set and must be false for objects from other classes. Logical regularity describes hyper-boxes in feature space that contain objects descriptions. At that each hyper-box contains object only from one class. Special optimization techniques allow efficiently search logical regularities. Optimal valid partitioning (OVP) ([Sen'ko, 2006; Senko,2010]) is another method that is aimed to find in feature space boundaries separating objects with different levels of target OVP implements also evaluating statistical validity of empirical regularities described by found optimal partitions with the help of permutation test. Permutation test now become popular toll to asses statistical validity ([Ernst, 2004; Gorman, 2001]). Result of OVP application in some data analysis task is set of statistically valid regularities. At section 2 new modification of OVP technique is discussed that allows eliminating from output regularities system all irredundant 2-dimensional regularities. Previous variant of OVP method allows elimination of irredundant 2-dimensional regularity R only when simple one-dimensional regularities exist for variables relevant to R. This set of regularities may be further analyzed by experts and used in forecasting algorithms. OVP technique was used in set of biomedical tasks ([Kuznetsova, 2000; Kuznetsova, 2011; Kuznetsova, 2013]).

In this paper a new additional techniques are discussed that allow receive additional useful knowledge from system of empirical regularities that were previously found with the help of OVP technique. Developed method may be used in tasks with binary target variable. At the first step boundaries of OVP regularities are used to find sub-regions in features space with strong deviation of target Y from its mean value by whole data set. Such sub-regions further are called syndromes. It must be noted that dimension of searched syndromes may be higher than 2. Represented version allows finding syndromes of dimension 3. Second stage is aimed to discover groups of objects in training set with X-descriptions belonging to the same or to the similar syndromes. Descriptions of studied objects are generated that will be further referred to as Z-descriptions. Z-description consists of set of binary indices that indicate if feature description belongs to corresponding syndrome. The discussed method is based on hierarchical cluster analysis in Z-space. Result of cluster analysis is several groups of objects with X-descriptions belonging to the same syndromes. Thus discussed method allows to evaluated structure of dataset that is relevant to target. Experiments with biomedical datasets demonstrated that method allows to outline subgroups of patients with close syndromes and to reveal systems of syndromes that simultaneously exist in sufficiently great groups.

Optimal Valid Partitioning

Let vectors of explanatory variables $X_1,\dots,X_n$ belong to $\mathbf{M} \subseteq \mathbf{R}^n$. The OVP method implement partitioning of $\mathbf{M}$ that provide for best separation of observations from dataset $\tilde{S}_t = \{(y_1,\mathbf{x}_1),\dots,(y_m,\mathbf{x}_m)\}$. Partitions are searched inside apriority defined families by optimizing of quality functional. In this paper two partitions families previously described in ([Sen'ko, 2006]) were considered: the simplest Family I includes all partitions with two elements that are divided by one boundary point; two-dimensional Family III including all partitions of two-dimensional admissible areas with no more than four elements that are separated by two boundary lines parallel to coordinate axes. Let R is partition of admissible region of explanatory variables with elements $q_1,\dots,q_r$. The partition R produces partition of dataset $\tilde{S}_t$ on subsets $\tilde{s}_1,\dots,\tilde{s}_r$, where $\tilde{s}_j$ $(j=1,\dots,r)$ is subset of observations with independent variables vectors belonging to q_j. The evaluated Y mean value for subsets $\tilde{s}_j$ is denoted as $\hat{y}(\tilde{s}_j)$. The integral quality functional $F_I(R,\tilde{S}_t)$ is defined as the sum: $F_I(R,\tilde{S}_t) = \sum_{j=1}^{r}[\hat{y}(\tilde{S}_t) - \hat{y}(\tilde{s}_j)]^2 m_j$, where m_j - is number of observations in subset $\tilde{s}_j$. Partition R_o is considered optimal among partitions from family $\tilde{R}$ if inequality $F_I(R_o,\tilde{S}_t) \geq F_I(R,\tilde{S}_t)$ is true $\forall R \in \tilde{R}$.

The initial variant PT1 is used to test null hypothesis about independence of outcome on explanatory variables related to considered regularity. Estimates of validity indices (p-values) are evaluated at random datasets that are received from dataset $\tilde{S}_t$ by random permutations of target Y relatively fixed positions of $X-$ variables. It was shown in that problem of partially false regularities arise when PT1 is used for verification of regularities that are found inside more complicated models. So additional variant of permutation test (PT2) was developed. Instead of testing null hypothesis that Y is completely independent on $X-$ variables second variant implement testing of null hypotheses that Y is independent on $X-$ variables inside sub-regions of $X-$ space related to simple regularities that were previously revealed for the same variables. However PT2 can be used for verification of regularity from family III only when simple one-dimensional valid partitions exists for at least one of two relevant explanatory variables, so additional scheme of verification was developed that will be further referred to as PT3. Suppose that R is optimal partition of explanatory variables X' and X'' admissible area that belongs to family III. Let R is described by boundary point b' for variable X' and boundary point b'' for variable X''.

Estimates of p-values are calculated separately for b' and b''.

Validity of optimal boundary $\mathbf{b}'$. To evaluate statistical validity of optimal boundary b' for variable X' we try to test null hypothesis about independence Y on X' and X'' inside subsets formed by boundary b'', At first step optimal partition $R_o(\tilde{S}_t)$ is found for initial training set $\tilde{S}_t$. Two subsets of $\tilde{S}_t$ are formed by boundary b'': subset $\tilde{S}_l = \{(y_1^l, \mathbf{x}_1^l), \ldots, (y_{m_l}^l, \mathbf{x}_{m_l}^l)\}$ includes objects from $\tilde{S}_t$ with $X' \le b''$; subset $\tilde{S}_r = \{(y_1^r, \mathbf{x}_1^r), \ldots, (y_{m_l}^r, \mathbf{x}_{m_r}^r)\}$ includes objects from $\tilde{S}_t$ with $X' > b''$. Estimate of p-value for op b' is calculated by artificial datasets that are built independently from initial datasets $\tilde{S}_l$ and $\tilde{S}_r$ by random permutation of Y values relatively fixed positions of $\mathbf{x}$ descriptions. Let generate N independent permutations of sets of numbers $\{1, \ldots, m_l\}$ and $\{1, \ldots, m_r\}$: $\{\tilde{f}_l^t = \{f_{l1}^t, \ldots, f_{lm_l}^t\},\ \tilde{f}_r^t = \{f_{r1}^t, \ldots, f_{rm_r}^t\} \mid t \in \{1, \ldots, N\}\}$. Then generated permutations are used to build random sets $\{\ \tilde{S}_{pl}^t = \{(y_{f_{l1}^t}^l, \mathbf{x}_1^l), \ldots, (y_{f_{lm_l}^t}^l, \mathbf{x}_{m_l}^l)\}, \tilde{S}_{pr}^t = \{(y_{f_{r1}^t}^r, \mathbf{x}_1^r), \ldots, (y_{f_{rm_r}^t}^r, \mathbf{x}_{m_r}^r)\} \mid t \in \{1, \ldots, N\}\}$. Optimal partition $R_o(\tilde{S}_p^t)$ is found for each $\{t \in \{1, \ldots, N\}$ by union $\tilde{S}_{pl}^t \cup \tilde{S}_{pr}^t$ that is denoted as $\tilde{S}_p^t$. Estimate of p-value is calculated as fraction of permutations with $F_I[R_o(\tilde{S}_t), \tilde{S}_t] \ge F_I[R_o(\tilde{S}_p^t), \tilde{S}_p^t]$.

Validity of optimal boundary $\mathbf{b}''$. Validation procedure for optimal boundary b'' for variable X'' is practically the same and is based test null hypothesis about independence Y on X' and X'' inside subsets formed by boundary b'.

Two-dimensional regularity from family III is considered valid at level β if to inequalities are simultaneously true: $p(b') < \beta$, X', X'', X''' $p(b'') < \beta$

Example. Figure 1 represents example of 2-dimensuonal regularity found with the help of technique described in this section. Regularity describes relationship between occurrences of ischemic stroke, polymorphism of gene coding lipoprotein lipase and α -lipoprotein level in patients after transient ischemic attack with chronic cerebral ischemia. The task is described in details in ([Kuznetsova,2013]).

Strong effect of α -lipoprotein level on ischemic stroke risk is seen for cases with H+H+ genotype..For genotypes H-H-,H+H- effect is not so expressed and is opposite by direction. Technique described above was used to calculate p-values to evaluate statistically contribution of polymorphism of gene coding LPL and α -lipoprotein level to considered regularity. It was evaluated by 2000 permutations that for LPL polymorphism p=0.005, for α - lipoprotein level p=0.001.

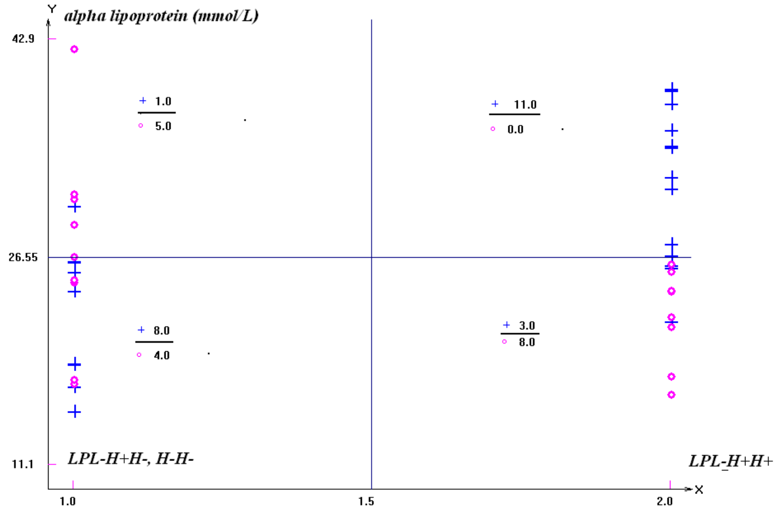

Fig. 1. Sparse diagram describing relationship between polymorphism of gene coding LPL (axis X) and α - lipoprotein level (axis Y), «o» corresponds cases after ischemic stroke, «+» corresponds cases without ischemic stroke.

Syndromes construction

OVP boundaries may be used for construction of syndromes - sub-regions in X-space where mean values of target Y significantly deviate from mean value of Y in training set $\tilde{S}_t$. Suppose that set of one-dimensional regularities $\tilde{r}^1$ and set of two-dimensional regularities $\tilde{r}^2$ were received with the help of OVP technique described in previous section. Let note that regularities from $\tilde{r}^1$ belong to family I and regularities from $\tilde{r}^2$ belong to family III.

Let optimal boundaries b', b'', b''' were found for variables X', X'', X''' with the help of OVP. Then sub-regions of $\mathbf{M}$ that are defined by inequality $X' < b'$, by pair of inequalities $X' < b', X'' < b''$ or by three inequalities $X' < b', X'' < b'', X''' < b'''$ may be examples of one-dimensional, two-dimensional or three-dimensional syndromes correspondingly.

Syndrome quality. Sub-region $q \subset \mathbf{M}$ is considered syndrome only if its quality is sufficient. At that quality of sub-region q is described with the help of functional $\mathrm{X}(q, \tilde{S}_t) = [\bar{y}(q) - \bar{Y}]^2 m(q)$, where $m(q) = |\{s_j = (y_j, \mathbf{x}_j) \in \tilde{S}_t \mid \mathbf{x}_j \in q\}|$, $\bar{y}(q) = \frac{1}{\mu(q)} \sum_{\mathbf{x}_j \in q} y_j$, $\bar{Y} = \frac{1}{m} \sum_{j=1}^{m} y_j$ So sub-region q is considered syndrome if $\mathrm{X}(q, \tilde{S}_t) > T_q$ where T_q is initially specified threshold.

Sets of boundaries. It must be noted that for some variables several boundaries may be calculated. Suppose that $\tilde{b}_i$ is set of boundaries for variable X_i that is relevant to regularity r_i^1 from $\tilde{r}^1$ and set of regularities $\tilde{r}_i^2$

from $\tilde{r}^2$. Set $\tilde{b}_i$ consists of boundary for X_i in regularity r_i^1 and regularities from $\tilde{r}_i^2$. Let $\tilde{I}_b$ is set of numbers of variables that are relevant to $\tilde{r}^1$ or $\tilde{r}^2$.

Let describe a necessary condition for family $\tilde{\mathbf{Q}}_l$ of l-dimensional sub-regions of $\mathbf{M}$ to be syndromes family. Suppose that $\tilde{J}$ is set of maps from $\{1,\ldots,l\}$ to $\tilde{I}_b$. Each sub-region $q \in \tilde{\mathbf{Q}}_l$ is characterized:

a) by J_q from $\tilde{J}$;

b) by vector of boundaries $\mathbf{b}(q) = [b_1(q),\ldots,b_l(q)]$, where boundary $b_i(q)$ is taken from $\tilde{b}_{J(i)}$;

c) and by vector of indices $\boldsymbol{\beta}(q) = [\beta_1(q),\ldots,\beta_l(q)]$, where $\beta_i(q) \in \{-1,1\}$.

It is considered that vector $\mathbf{x} = (x_1,\ldots,x_n) \in \mathbf{R}^n$ belongs to q if following inequalities are simultaneously satisfied:

$$x_{J_q(i)}\beta_i(q) < b_i(q),\ i = 1,\ldots,l \tag{1}$$

Structure of dependencies existing in data may be evaluated more exactly by calculating all syndromes with dimension less or equal *k*.

Necessary condition. Let subset q of $\mathbf{M}$ is *l*-dimensional syndrome. Then inequalities (1) must be simultaneously satisfied for any $\mathbf{x} \in q$. Thus simultaneous satisfying of inequalities (1) may be discussed as necessary condition for $q \in \mathbf{M}$ to be syndrome.

As it was mentioned above quality of $q \in \mathbf{M}$ must be sufficient. So inequality $\mathrm{X}(q,\tilde{S}_t) > Tr$ must be satisfied also. But demand of sufficient quality is not single.

For some syndrome with dimension greater than 1 high quality is achieved by some subset of relevant variables. At that another relevant variables are actually irredundant. So additional condition must be used that make it possible to delete irredundant multidimensional syndromes from final syndromes set. Let $\tilde{\mathbf{Q}}_1,\ldots,\tilde{\mathbf{Q}}_k$ are families of $\mathbf{M}$ sub-regions satisfying necessary condition. At that dimension of sub-regions from $\tilde{\mathbf{Q}}_l$ is equal l, $l = 1,\ldots,k$. Following conditions are sufficient for each sub-region from families $\tilde{\mathbf{Q}}_1,\ldots,\tilde{\mathbf{Q}}_k$ to be syndrome.

Sufficient conditions. Let $q_1,\ldots,q_k$ is set of syndromes, where q_l belongs to family $\tilde{\mathbf{Q}}_l$, $l \le k$. Besides $q_l \supset q_{l+1}, l = 1,\ldots,k-1$. Then inequalities

$$h_l \mathrm{X}(q_l,\tilde{S}_t) < \mathrm{X}(q_{l+1},\tilde{S}_t), l = 1,\ldots,k-1$$

must be simultaneously satisfied, where $h_l > 1$ is penalty multiplier.

So to find all syndromes with dimension not less than *k* it is sufficient to enumerate all sub-regions that are defined by inequalities (1) and to select sub-regions satisfying conditions (2).

Following procedure may be used of construct all possible syndromes. At initial stage penalty multipliers $h_1,\ldots,h_{l-1}$ are selected.

At first step all one-dimensional syndromes are built by enumerating of all one-dimensional sub-regions satisfying necessary condition and evaluating inequality $\mathrm{X}(q,\tilde{S}_t) > T_q$. At step $k \geq l > 1$ all l -dimensional syndromes are built by enumerating of all l-dimensional sub-regions satisfying necessary condition and evaluating for each q_l if sufficient condition $h_{l-1}\mathrm{X}(q_{l-1},\tilde{S}_t) < \mathrm{X}(q_l,\tilde{S}_t)$ is true for any pair (q_{l-1},q_l) where q_{l-1} is syndrome with dimension l that was built at previous step. Search is finished when all $k-$ dimensional syndromes are found.

Clustering method

A set of syndromes $\tilde{\mathbf{Q}}$ defines map from $\mathbf{M}$ to binary hypercube $\mathbf{B}^N$ of dimension $N = |\tilde{\mathbf{Q}}|$. Let $\tilde{\mathbf{Q}} = \{q_1,\ldots,q_N\}$. Binary vector $\mathbf{z}(\mathbf{x}) = [z_1(\mathbf{x}),\ldots,z_N(\mathbf{x})]$ is constructed by vector $\mathbf{x} \in \mathbf{M}$ with the help of simple rule: $z_i(\mathbf{x}) = 1$ if $\mathbf{x} \in q_i$ and $z_i(\mathbf{x}) = 0$ otherwise, $i = 1,\ldots,N$. Our goal is to find groups inside $\tilde{S}_t$ with similar syndromes. Such task may be reduced to search of groups with close z-descriptions. To achieve this goal hierarchical clustering technique is used.

Let ρ is semi-metrics that is defined at $\mathbf{B}^N$. We may use for example standard Hemming metrics. In this study we use semi-metrics $\rho(\mathbf{z}',\mathbf{z}'') = |\{i \mid z_i' = 1, z_i'' = 1, i = 1,\ldots,N\}|$. In other words we is defined as fraction of z-variables that are equal 1 in descriptions Let $G' = \{\mathbf{z}_1',\ldots,\mathbf{z}_{m_1}'\}$ and $G'' = \{\mathbf{z}_1'',\ldots,\mathbf{z}_{m_2}''\}$ are sets of z-descriptions of objects from $\tilde{S}_t$. Distance between G' and G'' is defined as

$$\boldsymbol{\rho}(G',G'') = \frac{1}{m'm''}\sum_{i=1}^{m'}\sum_{i'=1}^{m''}\rho(\mathbf{z}_i',\mathbf{z}_{i'}'').$$

Initially a threshold T_{cl} is chosen, At first step z-description of each object from $\tilde{S}_t$ is considered cluster. So at first step stage we have set of m clusters $\tilde{G}^0 = \{G_1^0 = \{s_1\},\ldots,G_m^0 = \{s_m\}\}$. Mutual distances between clusters are calculated and minimal distance $\mathrm{P}_{\min}^0$ is selected. Then pair of clusters $(G_{i_b'}^0, G_{i_b''}^0\}$ satisfying equality $\boldsymbol{\rho}(G_{i_b'}^0, G_{i_b''}^0\} = \mathrm{P}_{\min}^0$ is selected. In case $\mathrm{P}_{\min}^0 < T_{cl}$ new cluster $G_{i_b'}^0 \cup G_{i_b''}^0$ is added to $\tilde{G}^0$ and pair of clusters $(G_{i_b'}^0, G_{i_b''}^0\}$ is removed. Thus we receive new set of clusters $\tilde{G}^1 = \{G_1^1,\ldots,G_{m-1}^1\}$.

At step k-1 we have clusters $\tilde{G}^k = \{G_1^k,\ldots,G_{m-k}^k\}$. The same procedure that was used for set $\tilde{G}^0$ is repeated for set $\tilde{G}^k$. Pair of clusters $(G_{i_b'}^0, G_{i_b''}^0\}$ satisfying equality $\boldsymbol{\rho}(G_{i_b'}^0, G_{i_b''}^0\} = \mathrm{P}_{\min}^0$ is selected and new cluster $G_{i'_b}^{k-1} \cup G_{i''_b}^{k-1}$ is added to $\tilde{G}^{k-1}$ and pair of clusters $(G_{i'_b}^{k-1}, G_{i''_b}^{k-1}\}$ is removed. Thus we receive new set of clusters including $G_{i'_b}^{k-1} \cup G_{i''_b}^{k-1}$.

Procedure is finished when a) at some step there are no such two clusters that inequality $\mathbf{P}_{\min}^{0} < T_{cl}$ is true for distance between them, b) all objects are put to one clusters. At that case (b) corresponds to absence of cluster structure at level T_{cl}. So it is necessary to select higher level $T'_{cl} > T_{cl}$ to asses cluster structure.

Each cluster G may be characterized by set of syndromes $\tilde{\mathbf{Q}}_G^k \subseteq \tilde{\mathbf{Q}}^k$. Subset $\tilde{\mathbf{Q}}_G^k$ is searched by a threshold T_{cov} that is selected by user. Let $q \in \tilde{\mathbf{Q}}^k$ and $G_q = \{s_j \in G \mid \mathbf{x}_j \in q\}$. Syndrome q belongs to $\tilde{\mathbf{Q}}_G^k$ only when $|G(q)|/|G| > T_{\text{cov}}$.

Let note that set $\tilde{\mathbf{Q}}_G^k$ may be characterized by set of inequalities $IP(\tilde{\mathbf{Q}}_G^k) = \{x_{J_q(i)}\beta_i(q) < b_i(q) \mid i = 1,\ldots,l(q), q \in\}$. So group $IP(\tilde{\mathbf{Q}}_G^k)$ may be considered as short description of group G.

Experiment with biomedical data

Performance of developed technique in gerontology task was evaluated. Effect of clinical and genetic factors on life duration was studied in patients from Moscow population with chronic cerebral ischemia. Two groups of patients were compared by wide set of clinical, biochemical, genetic and instrumental indices: group of 123 long-livers older than 89 (average age 91.0), group of 235 patients of middle and old age (all younger 90).

At the initial stage OVP method was used to search one-dimensional regularities from model I. Valid regularities (p<0.02) were found for 41 variables. Found boundaries and threshold $T_q = 5$ were used to calculate syndromes with dimension 1-3. Thus 56 one-dimensional, 34-two-dimensional and 506 three-dimensional syndromes were found.

Three compact clusters were outlined with the help of technique described in previous section at $T_{cl} = 0.17$.

First cluster $G\text{I}$ includes 227 patients: 216 patients from group I and 11 patients from group II. Thus it may be considered that first cluster represents majority of patients with age <90. This cluster is characterized by set $\tilde{\mathbf{Q}}_{G\text{I}}^3$ that includes 18 syndromes selected according $T_{\text{cov}} = 0.9$. In other words each of syndromes from $\tilde{\mathbf{Q}}_{G\text{I}}^3$ exists for not less than 90% of patients from first cluster. Table 1 includes all inequalities from set $IP(\tilde{\mathbf{Q}}_{G\text{I}}^3)$ that describe at least 1 syndrome from $\tilde{\mathbf{Q}}_{G\text{I}}^3$.

Table 1.

Glucose >6,4 mmol/L	Aspartate transaminase(AST)> 15,5 units
Diastolic pressure> 72,5 mmHg	Hemoglobin > 115 g/L
Whole protein > 68,5 g/L	Cholesterol > 4,795 mmol /L

Second cluster $G\text{II}$ includes 27 patients older 89 and no patients younger 90. This cluster is characterized by set $\tilde{\mathbf{Q}}^3_{G\text{II}}$ that includes 47 syndromes selected according $T_{\text{cov}} = 1$. This cluster is characterized by such indicators as angina pectoris (II-III functional classes), coronary atherosclerosis, and third stage of chronic cerebral ischemia. It is necessary to note that more than 80% of patients from $G\text{II}$ have B1B2 and B2B2 genotypes of Cholesteryl ester transfer protein (TaqIB polymorphism).

Second cluster does not include patients with systolic arterial pressure below 164,5 diastolic pressure below 90. Patients from second cluster do not have ischemic stroke. Table 2 includes all inequalities from set $IP(\tilde{\mathbf{Q}}^3_{G\text{II}})$ that describe at least 1 syndrome from $\tilde{\mathbf{Q}}^3_{G\text{II}}$.

Table 2.

systolic pressure. < 164,5 mmHg	morbus hypertonicus –no	angina pectoris (II-III fc)- yes
diastolic pressure < 90 mmHg	Ischemic stroke-no	coronary atherosclerosis – yes
B1B2 and B2B2 genotypes of CETP	Smoking –no	CCI – III stage– yes

Third cluster $G\text{III}$ includes 7 patients from group II and systolic arterial pressure higher 164.5. All patients have H-H- genotype of lipoproteinlipaze - LPL (HindIII polymorphism).

Table 3 includes all inequalities from set $IP(\tilde{\mathbf{Q}}^3_{G\text{III}})$ that describe at least 1 syndrome from $\tilde{\mathbf{Q}}^3_{G\text{III}}$.

Table 3.

Systolic pressure. >164,5 mmHg.	General cholesterol>5,0 mmol/L	angina pectoris (II-III fc) -yes
Diastolic pressure > 90 mmHg	Ischemic stroke-no	coronary atherosclerosis – yes
genotype H-H- of LPL	Smoking - no	CCI – III stage– yes

Conclusion

Thus new method of intellectual data analysis was developed that is combination of optimal valid partitioning technique and hierarchical clustering. The method allows discovering in multidimensional feature space sub-regions corresponding to one of target classes (syndromes).

Binary descriptions of objects indicating to what syndromes initial feature descriptions belong are generated at the second stage. Hierarchical cluster analysis is used to discover compact groups in binary descriptions space. So method allows discovering groups of objects that belong to similar syndromes.

Biomedical application was discussed that is aimed to find features related to life duration in patients with chronic cerebral ischemia. It was shown that almost all patients younger 90 were put to one compact cluster in binary descriptions space. At that two clusters were revealed include patients долгожителей only. These two clusters differ by genetic parameters and systolic pressure levels. It is possible that influence of arterial pressure on life duration is also associated with polymorphism of genes that are related to lipid metabolism: gene of lipoproteinlipaze, Developed method may be used in task of biomedical data analysis.

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MATRIX FEATURE VECTORS AND HU MOMENTS IN GESTURE RECOGNITION

Volodymyr Donchenko, Andrew Golik

***Abstract**: This paper covers usage of matrix feature vectors and Hu moments in recognition of tactile sign language. The paper also provides comparative characteristic of both approaches and a variant of formation of feature vectors in matrix form. It is suggested to use orthogonal and ellipsoidal compliance distances for matrix feature vectors and numerical intervals for Hu moments.*

***Keywords**: gesture recognition, Hu moments, orthogonal projectors, ellipsoidal distance, SVD – decomposition, pseudoinverse.*

***ACM Classification Keywords**: I.2 Artificial Intelligence, I.4 Image Processing and Computer Vision, I.5 Pattern Recognition, G.1.3 Numerical Linear Algebra.*

Introduction

This article draws parallels between usage of Hu moments and matrix feature vectors in gesture recognition. Specific case of the mentioned task was chosen for implementation and testing: finger recognition of sign language. Hu moments are well-known numeric characteristics that can be obtained for image of gesture and effectively used for gesture recognition. They are so wide-used because Hu moments are invariant under translation, changes in scale and rotation. However, such power requires corresponding level of responsibility. We usually consider all the moments at the same time as feature vector that can be used for clustering. This approach has a lot of leaks which are covered in the paper.

In order to find more stable and effective solution matrix feature vectors are suggested. Usage of matrices as representatives of the object which is analyzed is “natural” technique. Gestures are presented with images (or sequence of images) that in early stages of processing of input data are captured from a webcam or other recording device. A variant of conversion of the images to matrices is suggested in the article.

Two variants of compliance distances are suggested, namely ellipsoidal and orthogonal distances. Ellipsoidal distance is based on a "minimal ellipse" that "covers" learning sample of class. Orthogonal distance is based on Cartesian grouping operators and orthogonal projectors.

Clustering with usage of compliance distances that are based on pseudoinverse and SVD-decomposition can be successfully applied to numeric vectors. However, as mentioned above learning sample consists of matrices. One of the main purposes of the research was to transfer properties of pseudoinverse and SVD-decomposition to the space of matrix feature vectors.

Results of recognition program that was implemented using C# and EmguCV environments justify an introduction of mentioned approaches, especially, compliance distances that are based on orthogonal projectors.

Overview of Hu moments

Image moment is a certain particular weighted average of the image pixels' intensities, or a function of such moments, usually chosen to have some attractive property or interpretation. Simple properties of the image which are found via image moments include area, its centroid, and information about its orientation.

For a 2D continuous function $f(x,y)$ the moment of order $(p+q)$ is defined as

$$M_{pq} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} x^p y^q f(\mathrm{x},\mathrm{y}) dxdy$$

for $p,q = 0,1,2,\ldots$ Adapting this to greyscale image with pixel intensities $I(\mathrm{x},\mathrm{y})$, raw image moments M_{ij} are calculated by

$$M_{ij} = \sum \sum x^i y^j I(\mathrm{x},\mathrm{y})$$

In some cases, this may be calculated by considering the image as a probability density function, i.e., by dividing the above by

$$\sum_x \sum_y I(\mathrm{x},\mathrm{y})$$

A uniqueness theorem (Hu [1962]) states that if $f(x,y)$ is piecewise continuous and has nonzero values only in a finite part of the x,y plane, moments of all orders exist, and the moment sequence (M_{pq}) is uniquely determined by $f(x,y)$. Conversely, (M_{pq}) uniquely determines $f(x,y)$. In practice, the image is summarized with functions of a few lower order moments.

Simple image properties derived via moments include:

- Area (for binary images) or sum of grey level: M_{00}
- Centroid: $\{\mathrm{x},\mathrm{y}\} = \{\mathrm{M}_{10}/\mathrm{M}_{00}, \mathrm{M}_{01}/\mathrm{M}_{00}\}$

Central moments are defined as

$$M_{pq} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} (\mathrm{x}-\overline{x})^p (\mathrm{y}-\overline{y})^q f(\mathrm{x},\mathrm{y}) dxdy$$

where $\overline{x} = \frac{M_{10}}{M_{00}}$ and $\overline{y} = \frac{M_{01}}{M_{00}}$ are the components of the centroid.

If $f(x,y)$ is a digital image, then the previous equation becomes

$$M_{pq} = \sum_x \sum_y (\mathrm{x}-\overline{x})^p (\mathrm{y}-\overline{y})^q f(\mathrm{x},\mathrm{y})$$

$$\mu_{pq} = \sum_m^p \sum_n^q \binom{p}{m} \binom{q}{n} (-\overline{x})^{(\mathrm{p}-\mathrm{m})} (-\overline{y})^{(\mathrm{q}-\mathrm{n})} M_{mn}$$

Central moments are translational invariant.

Information about image orientation can be derived by first using the second order central moments to construct a covariance matrix.

$$\mu'_{20} = \mu_{20} / \mu_{00} = M_{20} / M_{00} - \overline{x}^2, \mu'_{02} = \mu_{20} / \mu_{00} = M_{02} / M_{00} - \overline{y}^2, \mu'_{11} = \mu_{11} / \mu_{00} = M_{11} / M_{00} - \overline{x}\overline{y}$$

The covariance matrix of the image $I(x,y)$ is now

$$\mathrm{cov}\left[I(\mathrm{x},\mathrm{y})\right] = \begin{bmatrix} \mu'_{20}\mu'_{11} \\ \mu'_{11}\mu'_{02} \end{bmatrix}.$$

The eigenvectors of this matrix correspond to the major and minor axes of the image intensity, so the orientation can thus be extracted from the angle of the eigenvector associated with the largest eigenvalue. It can be shown that this angle Θ is given by the following formula:

$$\Theta = \frac{1}{2} \arctan\left(\frac{2\mu'_{11}}{\mu'_{20} - \mu'_{02}} \right)$$

The above formula holds as long as:

$$\mu'_{11} \neq 0$$

The eigenvalues of the covariance matrix can easily be shown to be

$$\lambda_i = \frac{\mu'_{20} + \mu'_{02}}{2} \pm \frac{\sqrt{4\mu'^2_{11} + (\mu'_{20} - \mu'_{02})^2}}{2}$$

and are proportional to the squared length of the eigenvector axes. The relative difference in magnitude of the eigenvalues is thus an indication of the eccentricity of the image, or how elongated it is. The eccentricity is

$$\sqrt{1 - \frac{\lambda_2}{\lambda_1}}$$

Moments n_{ij} where $i + j \geq 2$ can be constructed to be invariant to both translation and changes in scale by dividing the corresponding central moment by the properly scaled (00)th moment, using the following formula.

$$n_{ij} = \frac{\mu_{ij}}{\mu_{00}^{1+\frac{i+j}{2}}}$$

It is possible to calculate moments which are invariant under translation, changes in scale, and also rotation. Most frequently used are the Hu set of invariant moments:[6]

$$I_1 = \eta_{20} + \eta_{02}$$

$$I_2 = (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2$$

$$I_3 = (\eta_{30} + 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2$$

$$I_4 = (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2$$

$$I_5 = (\eta_{30} - 3\eta_{12})(\eta_{30} - \eta_{12})\left[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2\right] + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})\left[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2\right]$$

$$I_6 = (\eta_{20} - \eta_{02})\left[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2\right] + 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03})$$

$$I_7 = (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12})\left[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2\right] - (\eta_{30} - 3\eta_{12})(\eta_{21} + \eta_{03})\left[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2\right]$$

The first one, I1, is analogous to the moment of inertia around the image's centroid, where the pixels' intensities are analogous to physical density. The last one, I7, is skew invariant, which enables it to distinguish mirror images of otherwise identical images.

A general theory on deriving complete and independent sets of rotation invariant moments was proposed by J. Flusser[7] and T. Suk.[8] They showed that the traditional Hu's invariant set is not independent nor complete. I3 is not very useful as it is dependent on the others. In the original Hu's set there is a missing third order independent moment invariant:

$$I_8 = \eta_{11}\left[(\eta_{30} + \eta_{12})^2 - (\eta_{03} + \eta_{21})^2\right] - (\eta_{20} - \eta_{02})(\eta_{30} + \eta_{12})(\eta_{03} + \eta_{21})$$

Matrix feature vectors

First stage of gesture recognition problem consists of capturing images from a webcam or other recording device, followed by finding and highlighting on the resulting image hand and its contour. This contour gives fairly complete information that can be used for gesture identification.

There are several ways to analyze a contour of hand, for example, as series of interrelated points. In addition, there are a number of numerical characteristics that can be calculated for the contour: moments, Freeman chains etc. We are going to talk about representation of gesture contour in matrix form. Transition to matrix form begins with finding the smallest rectangle covering a contour of hand on an image.

Having its coordinates, we can cut it from an image and convert into binary matrix. However, standardization problem of dimension of such matrices is urgent because it depends on many factors: size of hand of a person, a distance from hand to recording device, etc. Possible solution of this problem is a construction of “characteristic” matrix: capturing images of contour of hand and its subsequent compression or stretching to standard size with conversion into matrix form according to certain rules. However, if we consider gesture recognition problem specific variant of scaling is required. An example that clearly demonstrates a need for changes in the above mentioned algorithm of standardization is shown in Figure 3.

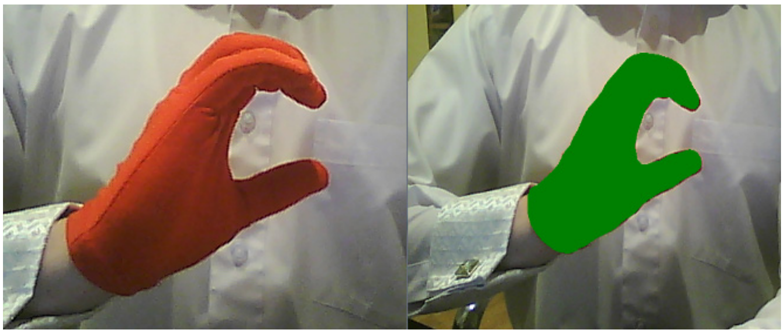

Figure 1. Image of gesture that is captured from a webcam. A contour of hand is found and highlighted

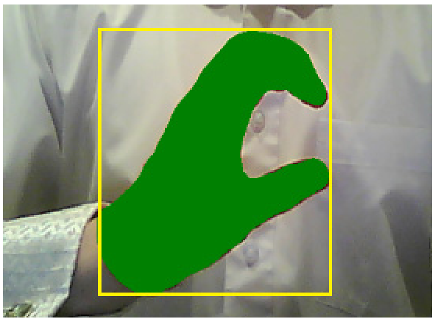

Figure 2. The smallest rectangle covering a contour of hand

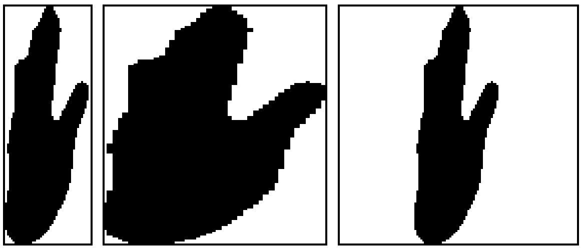

Figure 3. Different variants of standardization of an image.

There are 3 parts of Figure 3: the first - minimal rectangle covering a gesture, the other two - variants of its standardization. Suppose that square of certain size was chosen as a standard. In this case, after stretching an image we will get results that are presented in the second part of Figure 3. It is not difficult to see that in this case an image of a gesture largely lost its informative value, because the ratio of width and height, which is important in this problem, was changed. More correct approach is illustrated in the third part of Figure 3. In this case additional empty areas were placed on the left and right from the image. The size of these areas is identical and found in such way that a resulting image conforms to the standards.

It is suggested to do a transition from an image to the matrix on the next stage. We remind that RGB is a format of presentation of color, as a combination of red, green and blue colors. Having results of experiments we set the legitimate values of RGB, which allow to make decision: whether a pixel should be examined as meaningful or not. The transformation of an image consists of replacement of pixels which satisfy the set of legitimate values of RGB by 1 and all other by 0. Finally we get a matrix that consists of 0 and 1. The matrix can be called a “characteristic” matrix. Its image can be reproduced in a black-an-white form which is natural for binary matrices.

The standardized «characteristic» matrices for the images of gestures can be used for recognition of signs of tactile language. A binary characteristic matrix is obtained as the result converting process.

Ellipsoidal and orthogonal compliance distances

After forming feature vectors on the stage of clustering there is a necessity for comparison of the vectors, establishment of the so-called compliance distance between them. Possibility of usage of ellipsoidal and orthogonal distances is considered in the article.

The main feature of the mentioned distances is that while training the system, they work not with one etalon, but with a set of etalons (for the different environmental conditions).

Ellipsoidal distance is built by facilities of pseudoinverse for different variants of linear operators. Such distance leans against conception of «minimum ellipses of grouping». Actually, we talk about ellipses that «cover» each of training sets by a «minimum» and «optimum» rank. Ellipsoidal distance is built for matrices as matrices of linear operators between matrix Euclidian spaces by facilities of pseudoinverse for the mentioned spaces. They are implemented, as well as in the case of vector Euclidian spaces, through the so-called «groupings operators» of theory of pseudoinverse. Such operators are determined after the matrix of operator A that is operator between vector Euclidian spaces, and is defined by expressions:

$$R(A) = A^{+}A^{+T}, R(A^{T}) = (A^{T})^{+}(A)^{T+T} = A^{+T}A^{+}$$

The principle role of grouping operators is that they allow us to build the «minimum ellipses of grouping»: ellipsoids which contain all vectors of set $a_k, k = \overline{1,n}$ and are optimum in certain sense. Optimum lies in following: all axis of the ellipse are formed by the orthonormal set of vectors, sum of squares of projections on which is maximal, and the squares of lengths of proper axis coincide with the proper sums of squares of projections. More precisely next four theorems have place [4].

Theorem 1 For an arbitrary set of vectors $a_k \in R^m, k = \overline{1,n}$, solution of optimization problem of search of maximum sum of squares of projections on subspace that is formed by the normalized vector $u \in R^m : \|u\| = 1$ is a vector u_1 from singularity (u_1, λ_1^2) of singular decomposition of matrix $A = (a_1 \vdots \ldots \vdots a_n)$:

$$u_1 = \arg \min_{u \in R^m : \|u\| = 1} \sum_{k=1}^{r} \| \Pr_u a_k \|^2$$

$$\min_{u \in R^m : \|u\| = 1} \sum_{k=1}^{r} \| \Pr_u a_k \|^2 = \lambda_1^2$$

Theorem 2 For arbitrary set of vectors $a_k \in R^m, k = \overline{1,n}$, solution of optimization problem of search of maximum sum of squares of projections on subspace that is formed by normalized vector $u \in R^m : \|u\| = 1$ is a vector u_1 from singularity (u_1, λ_1^2) of singular decomposition of matrix $A = (a_1 \vdots \ldots \vdots a_n)$:

$$u_k = \arg \min_{u \in R^m : \|u\| = 1, u \perp L(u_1, \ldots, u_k)} \sum_{k=1}^{r} \| \Pr_u a_k \|^2$$

$$\min_{u \in R^m : \|u\| = 1, u \perp L(u_1, \ldots, u_k)} \sum_{k=1}^{r} \| \Pr_u a_k \|^2 = \lambda_{k+1}^2$$

$$k = \overline{1, r-1},$$

where $(u_k, \lambda_k^2), k = \overline{1,r}$ as well as in the previous theorem of singularity of singular decomposition of matrix which is formed from the elements of the researched set of vectors.

Theorem 3 For arbitrary set of vectors $a_k \in R^m, k = \overline{1,n}$

$$a_k^T R(A^T) a_k \le r_{\max}^2 < r$$

$$r_{\max}^2 = \max_{k=\overline{1,n}} a_k^T\ R(A^T) a_k ,$$

Where, as well as in two previous theorems, A is a matrix that is formed from the vectors of a set as its columns. Ellipsoid of theorem 3 groups the vectors of set according to the central location of the ellipse of grouping: based on an ellipse which has center at origin. In practical applications center of ellipse is mean value $\bar{a}$ of elements from the set:

$$\bar{a} = \frac{1}{n} \sum a_k$$

In this case a grouping operator is built based on a matrix $\tilde{A}$ which is formed from centered average vectors from the set $\tilde{a}_k : \tilde{a}_k = a_k - \bar{a}, k = \overline{1,n}$. Consequently following theorem has place.

Theorem 4 For arbitrary set of vectors $a_k \in R^m, k = \overline{1,n}$ we have following inequalities

$$(a_k - \bar{a})^T R(\tilde{A}^T)(a_k - \bar{a}) \le \tilde{r}_{\max}^2 \le r, k = \overline{1,n}$$

$$r_{\max}^2 = \max_{k=\overline{1,n}} \tilde{a}_k^T R(\tilde{A}^T) \tilde{a}_k$$

As a set of vectors the training sets of classes are used $Kl_l, l = \overline{1,L}$. As compliance distances (namely their squares): functional $\rho^2(x, Kl_l), x \in R^m, l = \overline{1,L}$ according to minimum value of which sorting is performed, - it is possible to use the minimum ellipses of grouping. It means that compliance distances are determined as following:

$$\rho^2(x, Kl_l) = (x - \bar{a}_l)^T \frac{R(\tilde{A}_1^T)}{\tilde{r}_{1\max}^2}(x - \bar{a}_l), x \in R^m,\ l = \overline{1,L}$$

Such ellipsoidal distance is used for characteristic matrices.

Together with ellipsoidal compliance distance orthogonal distance is offered in the article. It gives ability to carry properties of pseudoinverse and SVD– decomposition in case of matrix feature vectors.

$R^{(m\times n),K}$ is Euclidian space $m \times n$ of matrix corteges of length K $\alpha = (A_1 \vdots \ldots \vdots A_K) \in R^{(m\times n),K}$ with «natural» component-wise scalar multiplication:

$$(\alpha, \beta) = \sum_{k=1}^{K} (A_k, B_k)_{tr} = \sum_{k=1}^{K} trA_k^T B_k$$

$$\alpha = (A_1 \vdots \ldots \vdots A_K), \beta = (B_1 \vdots \ldots \vdots B_K) \in R^{(m\times n),K}$$

$\wp_\alpha : R^K \to R^{m\times n}$ linear operator between corresponding Euclidian spaces, that is set by a matrix cortege $\alpha = (A_1 \vdots \ldots \vdots A_K) \in R^{(m\times n),K}$ and determined by matrix cortege operations according to expression:

$$\wp_\alpha y = \sum_{k=1}^{K} y_k A_k, \alpha = (A_1 \vdots \ldots \vdots A_K) \in R^{(m\times n),K}, y = \begin{pmatrix} y_1 \\ \cdots \\ y_K \end{pmatrix} \in R^K$$

Theorem 5 [5] Conjugate $\wp_\alpha^*$ of the operator $\wp_\alpha : R^K \to R^{m\times n}$ is a linear operator, which obviously, operates in reverse to $\wp_\alpha$ direction: $\wp_\alpha^* : R^{m\times n} \to R^K$ and is determined by expression:

$$\wp_\alpha^* X = \begin{pmatrix} trA_1^T X \\ \cdots \\ trA_K^T X \end{pmatrix}$$

Proof

Indeed,

$$\left(\wp_\alpha y, X\right)_{tr} = \left(\sum_{k=1}^{K} y_k A_k, X\right)_{tr} = \sum_{k=1}^{K} y_k \left(A_k, X\right)_{tr} = \sum_{k=1}^{K} y_k \left(trA_k^T X\right) = \left(y, \begin{pmatrix} trA_1^T X \\ \cdots \\ trA_K^T X \end{pmatrix}\right)$$

This proves the theorem.

Theorem 6 [5] Multiplication of two operators is a linear operator $\wp_\alpha^* \wp_\alpha : R^K \to R^K$ which is given by a matrix (we will identify it with the operator), which is determined by expression:

$$\wp_\alpha^* \wp = \begin{pmatrix} trA_1^T A_1, \ldots, trA_1^T A_n \\ \cdots \\ trA_n^T A_1, \ldots, trA_n^T A_n \end{pmatrix} \quad (1)$$

Notice that matrix that is defined by expression (1) is the matrix of Gramm of elements $A_1, \ldots, A_K$ of matrix cortege $\alpha = (A_1 \vdots \ldots \vdots A_K)$, that specifies operator $\wp_\alpha$.

Proof

Indeed,

$$\wp_\alpha^* \wp_\alpha y = \wp_\alpha^* (\wp_\alpha y) = \begin{pmatrix} trA_1^T \sum_{i=1}^{n} A_i y_i \\ \cdots \\ trA_n^T \sum_{i=1}^{n} A_i y_i \end{pmatrix} = \begin{pmatrix} tr \sum_{i=1}^{n} A_1^T A_i y_i \\ \cdots \\ tr \sum_{i=1}^{n} A_n^T A_i y_i \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^{n} trA_1^T A_i y_i \\ \cdots \\ \sum_{i=1}^{n} trA_n^T A_i y_i \end{pmatrix} = \begin{pmatrix} trA_1^T A_1, \ldots, trA_1^T A_n \\ \cdots \\ trA_n^T A_1, \ldots, trA_n^T A_n \end{pmatrix} \begin{pmatrix} y_1 \\ \cdots \\ y_n \end{pmatrix} = (tr(A_i^T A_j))y$$

This proves the theorem.

A singular decomposition for a matrix (1) is obvious: it is symmetric and non-negatively defined matrix. It is determined by the set of singularities $(v_i, \lambda_i^2), i, j = \overline{1, r}$: by the orthonormal set of vectors $\| v_i \| = 1, v_i \perp v_j, i \neq j; i, j = \overline{1, r}; \lambda_1 > \lambda_2 > \ldots > \lambda_r > 0$ which are own for an operator $\wp_\alpha^* \wp_\alpha : R^K \to R^K$: $\wp_\alpha^* \wp_\alpha v_i = \lambda_i^2 v_i, i = \overline{1, r}$. Defined by singularities $(v_i, \lambda_i^2), i = \overline{1, r}$ matrices $U_i \in R^{m \times n} : U_i = \frac{1}{\lambda_i} \wp_\alpha v_i, i = \overline{1, r}$ are the elements of set of singularities $(U_i, \lambda_i^2), i = \overline{1, r}$ of the operator $\wp_\alpha \wp_\alpha^*$. Singular decomposition of cortege operator: singularities of two operators: $\wp_\alpha^* \wp_\alpha, \wp_\alpha \wp_\alpha^*$, determine the singular decomposition of operator $\wp_\alpha$.

Theorem 7 [5] (singular decomposition of cortege operator)

$$\wp_\alpha = \sum_{k=1}^{K} \lambda_k U_k v_k^T.$$

Variant of singular decomposition: taking into consideration the expression $U_i \in R^{m \times n} : U_i = \frac{1}{\lambda_i} \wp_\alpha v_i, i = \overline{1, r}$ n and its investigation, we have

$$\wp_\alpha = \sum_{k=1}^{K} \lambda_k U_k v_k^T = \sum_{k=1}^{K} \left(\wp_\alpha v_k\right) v_k^T$$

Remark of general character: the general variant of the theorem about singular decomposition is needed. This statement should touch general Euclidian spaces. It needs to be formulated for linear operators on general Euclidian spaces.

Theorem 8 [5] For an arbitrary linear operator $\wp_E : E_1 \to E_2$ on the pair of Euclidian spaces $(E_i, (,)_i), i = 1,2$ there is a set of singularities $(v_i, \lambda_I^2), (u_i, \lambda_I^2) i = \overline{1,r}, r = rank \wp_E$ of operators $\wp_E^* \wp$, $\wp \wp_E^*$ accordingly with the general set of own numbers $\lambda_I^2, i = \overline{1,r}$ that

$$\wp_E x = \sum_{i=1}^{r} u_i \lambda (v_i, x)_1, \wp_E^* y = \sum_{i=1}^{r} v_i \lambda (u_i, y)_2$$

In addition following expressions have place:

$$u_i = \lambda_I^{-1} \wp v_i, i = \overline{1,r}$$

$$v_i = \lambda_I^{-1} \wp_E^* u_i, i = \overline{1,r}$$

Basic operators of PDO theory are for cortege operators: a pseudoinverse by svd-decomposition.

According to svd-determination, PDO of cortege operator is set by following expression [5]:

$$\wp_\alpha^+ = \sum_{k=1}^{K} \lambda^{-1} v_k \left(U_k, \cdot\right)_{tr} = \sum_{k=1}^{K} \lambda^{-2} v_k \left(\wp_\alpha v_k, \cdot\right)_{tr}$$

The orthogonal projectors of base subspaces of operator and, accordingly, - grouping operators are determined after svd-presentation of cortege operator in standard way.

Theorem 9 Operators marked as $P(\wp_\alpha^*), P(\wp_\alpha)$ and determined by expressions:

$$P(\wp_\alpha^*) = \sum_{k=1}^{r} U_k \left(U_k, \cdot\right)_{tr}$$

$$P(\wp_\alpha) = \sum_{k=1}^{r} v_k \left(v_k, \cdot\right) = \sum_{k=1}^{r} v_k v_k^T$$

are orthogonal projectors $P_{L_{\wp_\alpha}}, P_{L_{\wp_\alpha^*}}$ on subspaces $L_{\wp_\alpha}$, $L_{\wp_\alpha^*}$ of possible values of operators $\wp_\alpha$, $\wp_\alpha^*$ accordingly:

$$P(\wp_\alpha^*) = P_{L_{\wp_\alpha}}, P(\wp_\alpha) = P_{L_{\wp_\alpha^*}}$$

These subspaces are the linear shells of the corresponding orthonormal sets:

$$L_{\wp_\alpha} = L(U_1, ..., U_r), \ L_{\wp_\alpha^*} = L(v_1, ..., v_r)$$

Proof

Proof is the same as in the case of linear operators between Euclidian spaces of numerical vectors: symmetry and idempotence is simply checked up for both operators. Similarly obvious are assertions that $U_k \in L_{\wp_\alpha}$, $v_k \in L_{\wp_\alpha^*}$, and consequently from reasoning of dimension $L_{\wp_\alpha} = L(U_1, ..., U_r)$, $L_{\wp_\alpha^*} = L(v_1, ..., v_r)$. In addition, as follows from determination $P_{L_{\wp_\alpha}}, P_{L_{\wp_\alpha^*}}$ the last spaces are spaces of possible values for them accordingly. Finally, note, that subspace on which an orthogonal projector carries out the orthogonal projection can be described, in particular, as a space of possible values for it.

Theorem 10 Operators $Z(\wp_\alpha^*), Z(\wp_\alpha)$ which are complements to the identical operator of orthogonal projectors $P(\wp_\alpha^*), P(\wp_\alpha)$ accordingly:

$$Z(\wp_\alpha^*) X = X - P(\wp_\alpha^*) X, \quad Z(\wp_\alpha) = E_K - P(\wp_\alpha),$$

are orthogonal projectors on the kernels of operators accordingly.

Proof

Firstly, proof follows from the fact that for $\wp_\alpha^*$, $\wp_\alpha$ each of operators $Z(\wp_\alpha^*), Z(\wp_\alpha)$ is symmetric and idempotent. In addition they are orthogonal projectors on the orthogonal adding to subspaces

$L_{\wp_\alpha} = L(U_1,...,U_r)$, $L_{\wp^*_\alpha} = L(v_1,...,v_r)$ accordingly. Namely, these orthogonal complements are the kernels of operators $\wp^*_\alpha, \wp_\alpha$ accordingly.

Theorem 11 Square of distance $\rho^2(X, L_{\wp_\alpha})$ from arbitrary $m \times n$ matrix X to linear subspace $L_{\wp_\alpha}$ that is the set of possible values of cortege operator $\wp_\alpha$ is given by formula:

$$\rho^2(X, L_{\wp_\alpha}) = (X, Z(\wp^*_\alpha)X)_{tr} = \| X \|^2 - \sum_{k=1}^{r} (X, U_k)^2_{tr}$$

Proof

Indeed,

$\rho^2(X, L_{\wp_\alpha}) = \| X_{L_{\wp_\alpha}^{\perp}} \|^2$ in decomposition $X = X_{L_{\wp_\alpha}} + X_{L_{\wp_\alpha}^{\perp}}$ by decomposition $R^{m\times n} = L_{\wp_\alpha} + L_{\wp^*_\alpha}$.

Obviously, $X_{L_{\wp_\alpha}^{\perp}} = Z(\wp^*_\alpha)X$ so:

$$\rho^2(X, L_{\wp_\alpha}) = \| X_{L_{\wp_\alpha}^{\perp}} \|^2 = \| Z(\wp^*_\alpha)X \|^2_{tr} = \left(Z(\wp^*_\alpha)X, Z(\wp^*_\alpha)X_{tr} \right) = \left(X, Z(\wp^*_\alpha)Z(\wp^*_\alpha)X_{tr} \right)_{tr} = \left(X, Z(\wp^*_\alpha)X_{tr} \right)_{tr}$$

As an orthonormal set $U_i, i = \overline{1,r}$ is an orthonormal base in $L_{\wp_\alpha} = L(U_1,...,U_r)$ and $(X, U_i)_{tr}, i = \overline{1,r}$ is the co-ordinates of decomposition $X_{L_{\wp_\alpha}}$ by this orthonormal base, then $\| X_{L_{\wp_\alpha}} \|^2 = \sum_{i=1}^{r} (X, U_i)^2_{tr}$.

It remains to notice that according to the theorem of Pythagoras in an abstract variant $\| X \|^2 = \| X_{L_{\wp_\alpha}} \|^2 + \| X_{L_{\wp_\alpha}^{\perp}} \|^2$, and consequently:

$$\| X_{L_{\wp_\alpha}^{\perp}} \|^2 = \| X \|^2 - \| X_{L_{\wp_\alpha}} \|^2 = \| X \|^2 - \sum_{k=1}^{r} (X, U_k)^2_{tr}$$

The theorem is well-proven.

Theorem 12 A square of distance $\rho^2(X, L)$ of arbitrary $m \times n$ matrix X to linear subspace $L = L(A_1,...,A_K)$, which is the linear hull of set $m \times n$ matrices $A_1,...,A_K$ is determined by formula:

$$\rho^2(X, L) = \rho^2(X, L_{\wp_\alpha}) = (X, Z(\wp^*_\alpha)X)_{tr} = \| X \|^2 - \sum_{k=1}^{r} (X, U_k)^2_{tr}$$

for a cortege operator $\wp_\alpha$, formed by a set $A_1,...,A_K$: $\wp_\alpha = (A_1,...,A_K)$.

Proof

Proof follows from the fact that subspaces $L = L(A_1,...,A_K)$ and $L_{\wp_\alpha}$ coincide between itself.

Theorem 13 A square of distance $\rho^2(X, \Gamma(a, L))$ of arbitrary $m \times n$ matrix X to the hyper plane $\Gamma(\bar{a}, L)$:

$$\bar{a} = \frac{1}{K} \sum_{k=1}^{K} A_k, L = L(\tilde{A}_1,...,\tilde{A}_K), \tilde{A}_k = A_k - \bar{a}, k = \overline{1,K},$$

formed by set of $m \times n$ matrices $A_1,...,A_K$ is given by the formula:

$$\rho^2(X, \Gamma(\bar{a}, L)) = (X - \bar{a}, Z(\wp^*_{\tilde{\alpha}})(X - \bar{a}))_{tr} = \| X - \bar{a} \|^2 - \sum_{k=1}^{r} (X - \bar{a}, \tilde{U}_k)^2_{tr}$$

where cortege operator $\wp_{\tilde{\alpha}}$ is determined by expression $\wp_{\tilde{\alpha}} = (\tilde{A}_1,...,\tilde{A}_K)$, and $\tilde{U}_i, i = \overline{1,r}$ orthonormal set of eigenmatrices of operator $\wp^*_{\tilde{\alpha}}$.

Proof

Proof is obvious because of $\rho^2(X, \Gamma(\bar{a}, L)) = \rho^2(X - \bar{a}, L)$ and previous theorem.

Parallels between matrix feature vectors and Hu moments

Hu moments are invariant under translation, changes in scale and rotation. Mentioned properties can be effectively used in gesture recognition because it is quite convenient to be able to check if two objects are similar to within rotation or scale etc. The problem is that each gesture has quite strict rules that allow person to show corresponding gesture correctly. In other words it can be acceptable to consider rotation while checking object similarity but only in some interval. However, Hu moments do not allow us to do that and finally they consider objects similar too often so results become not satisfactory. It does not mean that Hu moments are not effective, but it is difficult to use all their advantages for gesture recognition especially on huge set of gestures.

Matrix feature vectors with ellipsoidal or orthogonal compliance distance is used with learning samples. Learning sample is obtained for each gesture and consists of a set of matrices. The matrices correspond to different images of gestures under different environmental conditions. Dictionary of gestures is used in the process of clustering. After converting initial image into the characteristic matrix, this matrix, using one of the compliance distances considered in the article, is checked for closeness to every element from the dictionary. Element that appears to be “the nearest” in the terms of the compliance distance is accepted as a result.

The main goal of both Hu moments and matrix feature vectors is to recognize gestures in different environment: angle of demonstration, distance from hand to recording device etc. However, matrix feature vectors are more stable because they consider not all possible rotations of gestures while comparing them, but only those which are placed in learning set and correspond only to correct demonstrations of gesture. Matrix feature vectors do not have such redundancy as Hu moments have.

Testing and results

Testing of gesture recognition was conducted on the set of dactyls. Specially developed program module formed a training set (base of standards) for every element from the dictionary, using characteristic matrices. Depending on system configuration, ellipsoidal or orthogonal distance was used.

For implementation of programmatic part of task C# was chosen. There is a shell of library “Open CV” for this environment, called Emgu CV. It includes a rich toolkit which allows working with the data flow that is obtained from recording device in real-time. In addition, it contains a number of functions and classes which can be effectively applied to recognition.

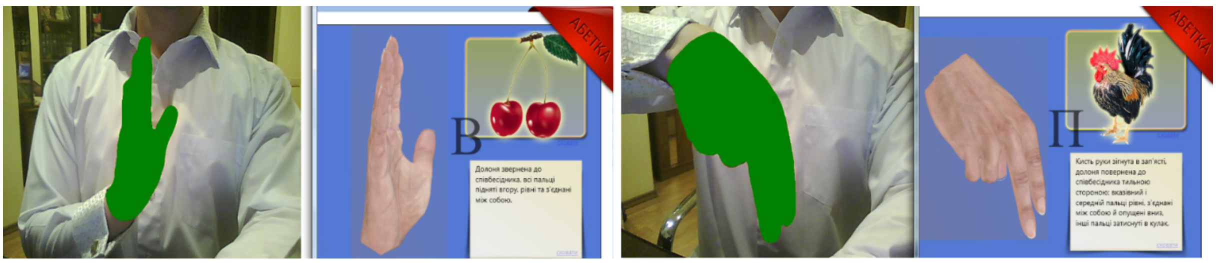

Figure 4. Examples of gesture recognition

Hu moments show the best performance with usage of numerical intervals. Each Hu moment for each gesture was considered separately. After practical part (testing and configuration) appropriate numerical intervals for each Hu moment was found. All in all, we found a set of intervals for each gesture. Size of this set corresponds to amount of Hu moments.

While recognition for initial characteristic matrix we find values of Hu moments and for each gesture check if the values meet corresponding numerical intervals. If all the values get to the intervals then corresponding gesture is marked as "possible solution". This approach does not guarantee that every time there will be only one "possible solution", but it is stable enough to be used on practice.

Matrix feature vectors can be used separately or together with Hu moments. Results of testing show that the best variant is to use them on a set of mentioned above "possible solutions" which are found using Hu moments. In this case quality of recognition is really high. The only problem that cannot be solved using suggested approaches appears when gestures look really similar and we need information not only about contour of hand, but about position of each finger.

Figure 5. Illustration of problem with same contour but different finger positions

Figure 5 illustrates the problem. It cannot be solved at this stage, because current solution does not check if fingers are before or behind a palm. Algorithms of a skeletization could be a good choice for this case.

Conclusion

Prospective direction is usage of multilevel clustering, where different technics and algorithms are applied stage-by-stage. Suggested matrix feature vectors and the compliance distances can make a basis of one of such stages. It is a good option to use matrix feature vectors after checking numerical intervals for Hu moments. Although the proposed compliance distances require a subsequent study and optimization, but even on current stage for gesture recognition of tactile language, mathematical results that are illustrated in the applications shows the capacity.

All in all in this article were considered problems of classification tactile language. Note, that matrices are natural representatives of objects in the mentioned task. Development of mathematical apparatus of pseudoinverse for analysis of such objects on the basis of theory of pseudoinverse for matrix Euclidian spaces was proposed.

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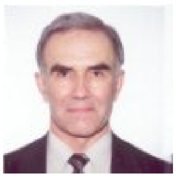

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ABOUT AN APPROACH TO MODEL DEVELOPMENT OF MAN-COMPUTER INTERACTION

Arseniy Bakanov, Nina Bakanova, Tasho Tashev

Abstract: *In this paper are presented the results of investigations concerning development of methodic for extraction of expert knowledge in the process of man-computer interaction with intellectual information system. During the investigations a model is developed describing the interaction process with the intellectual information system, the process of criteria formation for evaluation of the alternatives also the process of decision making. One of the problems concerning the model developed herein is extraction of original heuristics applied by the experts in the process of decision making.*

Keywords*: decision making, knowledge retrieval, man-computer interaction, modeling.*

ACM Classification Keywords*: H.4.2 Types of Systems - Decision support*

Introduction

Information and telecommunication technologies change before our own eyes human environment which is now impossible without ubiquitous electronics devices. Intellectual information media is a natural development of the electronic, intelligence and communication technologies.

We will consider that the presence of an intellectual agent in a media makes this media intellectual. Under the term intellectual agent we will understand any program (program-apparatus module) executing monitoring of the surrounding media which is capable of learning and is acting in this media and their behavior is rational because their actions aim a specific goal.

The problem of interaction between the man and the intellectual information media in particular the system of decision making support is one of most significant in the contemporary world. This problem has many aspects the most important of which is connected with the investigation of processes of intelligence interaction between the man and the system. During the examination of these processes the man is considered as a subject and the system for decision making as a tool.

The significance of the investigation of man – intellectual system interaction model is a result of the importance of the part that intellectual systems play in the everyday life and the impact that they have on the life regardless their direct or indirect involvement. The increased number of social nets, intelligence and communication systems and the increased number of their users also shows the importance of this type of investigation.

To problems of interaction between man and intellectual information system (for example decision making support or expert system) are dedicated many papers, between them those of Anderson, Bobrow, Charniak, Luger, Kahneman, Minsky, Tversky, Zadeh, also Velichkovskii, Larichev, Petrovskii, Podinovskii and other famous scientists. In the process of interaction with the intellectual intelligence system (IIS) the man has to consider of great amount of factors and to solve problems connected with multi-criteria choice. For a human system multi-criteria problems are a very complicated type of problems (Петровский А.Б., 2004). The presence of many criteria leads to overload of the human system, making man to use different often original heuristics in order to solve a specific problem (Ларичев О. И., 1987).

Original heuristics extraction used by man in the process of interaction with the intellectual – the goal of the herein developed model.

In this paper are presented investigation results leading to development of a methodic of extraction of expert knowledge in the process of man-computer interaction with the information system. During the investigations a model is developed describing the interaction process with the intellectual intelligence system, the process of criteria formation for evaluation of the alternatives also the process of decision making. One of the problems concerning the model developed herein is extraction of original heuristics applied by the experts in the process of decision making.

Human-computer interaction modeling

We will briefly describe information interaction in the terms of the present model.

Using the devices of information reflection (in our case monitor) information is sent to a man. The man receives information, actually an image of it that is not every time adequate to the emitted information. Under term information model we will consider a set of qualitative and quantitative characteristics of information sent to man by devices for information reflection. As a result of sensing information inside the man is created subjective conceptual model. The conceptual model is a dynamical synthesis of information sensed and the information already available till the given moment. The conceptual model is usually representation not of the individual object but of the whole situation itself.

In the frames of the discussed model the interaction between the man and the intellectual information media is a process of reaching specific goal which consists of a sequence of actions that have to be executed in order to full field the task. The term action means a functional element of human activity with a well defined goal.

In the suggested model interaction between man and intellectual media is described using information theory as well as game theory. From the game theory point of view the process of interaction of the man with intellectual information media is presented as a closed system capable of transition from one state to another and every transition lead to decreasing of the uncertainty (Вентцель Е.С., 2005), i.e. entropy of the system. From the game theory point of view man-computer interaction can be considered as a game which starts from some (initial) state and consists of a sequence of steps at which each of gamers makes a choice between several possibilities. The game ends which some result (profit). By representing man-computer interaction as a game we are given the possibility to describe and design man-computer interaction using the mathematical apparatus of the game theory. This way, using the mathematical apparatus of the information theory and as well as the game theory we are able present the model of man-computer interaction with the intellectual information media. Let introduce a function that describes the interaction of the observer with the intellectual information media $F(dI,T,S)$ where I – information matrix (information presented, information received, information retrieved), determined in particular using the mathematical apparatus of the information theory, d – some coefficient characterizing the subjective confidence to the presented information, T – time matrix determined according to the memory model suggested by Alan Baddeley (Baddeley, 2009), S – set of strategies considering cognitive and style particularities of decision making of the individual him/herself, determined by using the mathematical apparatus of the game theory and mathematical psychology..

This function makes possible to take into account the interconnections between the mathematical apparatus of the information theory, the memory model by Baddeley and also set of strategies considering cognitive and style particularities of decision making of the individual him/herself.

Experiment description

In accordance with the goal of this paper an experimental investigation is executed of the interaction between the man and the intellectual information media on the example of the interaction between a man and a decision making support system. During the experiment is modeled the work of people making decisions (the decision maker). The work of the decision maker is to be acquainted with the document – by reading the text on the monitor a to make a decision where it belongs i.e. where to send the document – department or other part of the organization where the document has to be sent for further retrieval.

It is necessary to say that in the organizations every day is received a mass of documentation and a mistake of the decision maker will not only lead to a mistake during the document retrieval and execution but to the document bad execution and even not execution if it enters the wrong department. For the work with documents (even entering) in big organization are used electronic document flow systems (Баканова Н. Б., 2007). In this system can be added a program module that plays the role of the making decision support system. This module provides the initial retrieval of the document text colors the basic words and visualizes the structure of the document. In the frames of the experiment the aim is to investigate the process of decision making as a part of the problem of document sorting by experts i.e. people with experience as a decision maker as well as novices i.e. people with no experience as a decision maker. During the investigation some of the decisions are reaches with and some without making decision support system. Two groups of peoples take part in the investigations:

1) Experts i.e. people with experience as a decision maker;

2) Novices i.e. people with no experience as a decision maker – students from the high schools in Moscow.

The investigations are executed using equipment capable of following the trajectory of the eyes of the user in the process of reading of information as well as in the process of making the decision (www.smivision.com). Alongside with this experiment are executed investigation of the cognitive style – impulsive/reflective (Холодная, 2002), also the style of self regulative behavior by methodic of Morosanova (Моросанова, Индина, 2011). To the examined persons is presented some document that consists of text and after the reading it a decision has to be made concerning a choice between several alternatives (a decision concerning the document sorting). To the tested are presented documents that are preliminary retrieved by the decision making support systems as well as documents without retrieval. If the document is retrieved the text structure is determined and a content analysis is provided using a specially designed thesaurus (Figure 1).

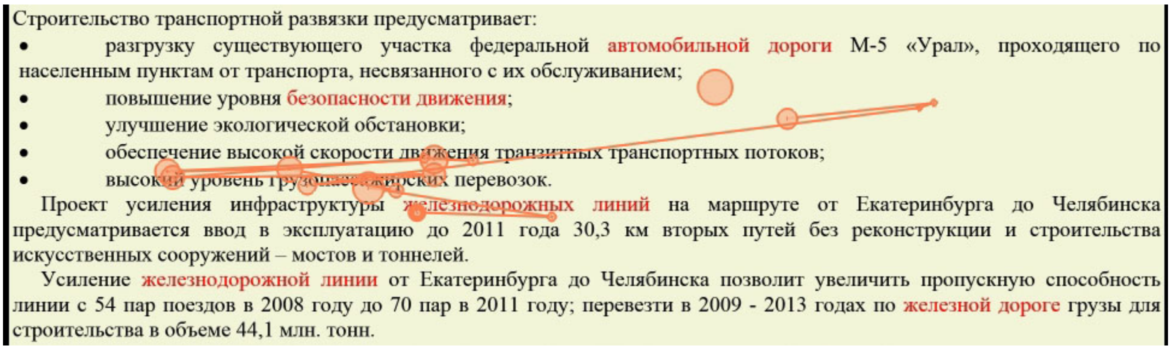
As a result of the retrieval the text structure is visualized and the basic words are colored (Баканов А.С., 2009). The succession of the texts (with or without retrieval) on the monitor is changed in order to avoid the possibility that the tested person is accustomed to a given type of text and this person makes a decision. The investigator observes and fixes (also in *.mpeg format) the trajectory of the examined person eyes in process of text reading as well as in the process of decision making. On the stage of decision making to the tested are presented (also on the monitor) questions of two types. The first type questions are questions presented in the following order:

1) Choose alternatives (from a list) to which a given document/text belongs;

2) Choose alternatives (from the chosen before) to which the chosen document mostly belongs;

3) Choose only one alternative (from the chosen before).

This way in the process of answering to the questions of type one in order showed above the structure of the mental representations of the user, formed during the reading of the given document, is revealed (Figure 2).


Строительство транспортной развязки предусматривает:

- разгрузку существующего участка федеральной автомобильной дороги М-5 «Урал», проходящего по населенным пунктам от транспорта, несвязанного с их обслуживанием;
- повышение уровня безопасности движения;
- улучшение экологической обстановки;
- обеспечение высокой скорости движения транзитных транспортных потоков;
- высокий уровень грузопассажирских перевозок.

Проект усиления инфраструктуры железнодорожных линий на маршруте от Екатеринбурга до Челябинска предусматривается ввод в эксплуатацию до 2011 года 30,3 км вторых путей без реконструкции и строительства искусственных сооружений – мостов и тоннелей.

Усиление железнодорожной линии от Екатеринбурга до Челябинска позволит увеличить пропускную способность линии с 54 пар поездов в 2008 году до 70 пар в 2011 году; перевезти в 2009 - 2013 годах по железной дороге грузы для строительства в объеме 44,1 млн. тонн.

Figure 1. A fragment of the text with the determined basic words and the gaze tracking of the expert in the process of the text reading

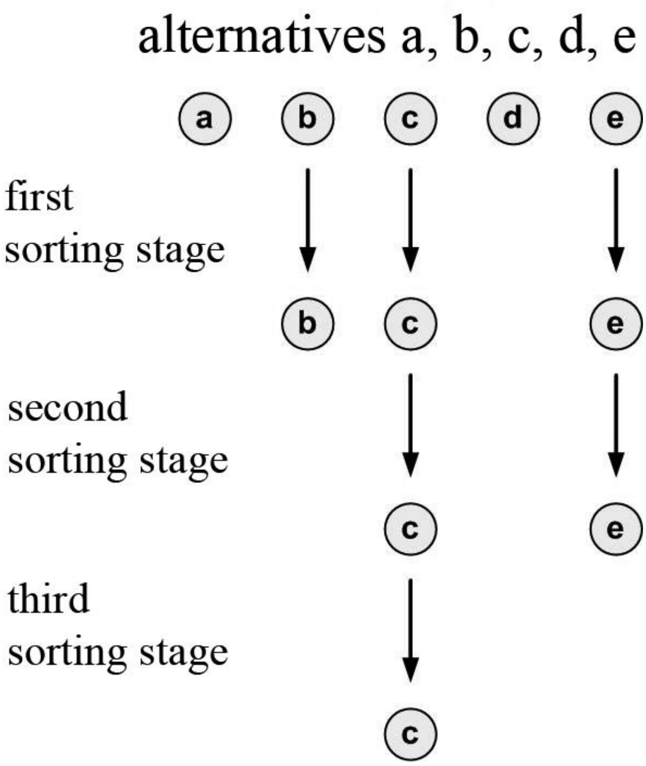


Figure 2. Sorting scheme. The process of choosing one alternative

There are a lot of definitions of the term mental representation (Брушлинский А.В., Сергиенко Е.А., 1998) so we will use the following definition: mental representation - subjective image of the objective reality, reflection of the inner and outer world in the consciousness of the person or applicable to our investigation the subjective image of the document/text in the consciousness of the tested person.

While answering to the questions of the type two (also presented on the monitor) the examined has to evaluate using numbers the rate to which a given document/text is close to the chosen alternative. The trajectory of the eyes of tested during the experiment is fixed by the observer.

Except from the eyes trajectory, the observer checks the time for needed for the text reading, the diameter of the people, the speed of the eyes movement, the for the decision making after the reading of a text with or without colored basic words.

Experiment results

The expert are considerably better at sorting documents when their structure is preliminary determined (15313 ms with and 21328 ms without preliminary retrieval respectively); in the same time for the novices the preliminary retrieval is not very helpful (24322 ms и 25757 ms respectively).

The solution of the problems type two - quantitative evaluation i.e. estimate in number the rate at which the document/text is close to the chosen alternative is slightly slower for the experts in comparison with the preliminary retrieval but the number of the correct answer is bigger in comparison with the cases without retrieval (12528 ms и 11226 ms respectively).

The most important in the process of text reading by the tested are criteria on which is based the decision of the tested in the process of interaction with the intellectual information media.

During the investigation the following correlations are determined:

- Answering time for the question about quantitative estimation of the alternatives with experience – positive correlation;
- Confidence coefficient for decision making with experience – negative correlation;
- Confidence coefficient for decision making with style field dependent/field independent– negative correlation;
- Basic words coefficient with style field dependent/field independent– positive correlation;
- Confidence coefficient for decision making with style synthetic/analytic – negative correlation.

At the present moment the investigations continue.

Conclusions

In the frames of the executed investigation is developed a model describing the process of interaction with the intellectual information system, process of the criteria formation for alternative evaluation and process of decision making.

The applied in the investigation device for following of the trajectory of the user’s gaze gives a possibility to reveal original heuristics used by experts for task solving in the process of interaction with the intellectual system.

Availability gaze tracking system allows their usage in the system for control decision support, increasing their efficiency.

Introduction of such a device in the information system allows receiving quickly and in real time feedback from the user which allows adjusting the system to the user, to extract knowledge in the process of work etc.

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