Creation of applied intelligent system for diagnostics of cognitive and emotional-volitional sphere of post-stroke patients at different stages of rehabilitation treatment

A Yankovskaya¹, V Obukhovskaya ²³ and D Nazmetdinova²
¹ Department of Software Engineering, National Research Tomsk State University, Tomsk, Russia
² Department of Genetic and Clinical Psychology, National Research Tomsk State University, Tomsk, Russia
³ Department of Fundamental Psychology and Behavioral Medicine, Siberian State Medical University, Tomsk, Russia

E-mail: ayyankov@gmail.com

Abstract. In this paper, we describe the creation of the medical diagnostic intelligent system, which is used for the analysis of cognitive and emotional-volitional sphere of post-stroke patients at different stages of rehabilitation treatment (IS DICEV). The applied IS DICEV is constructed with the help of intelligent instrumental software IMSLOG and is based on test methods of the pattern recognition, fault-tolerant mixed diagnostic tests. The use of the applied IS DICEV will allow revealing various kinds of regularities in the cognitive and emotional-volitional sphere of post-stroke patients, as well as finding diagnostic decisions and justifying those using graphical tools. These goals are very important for tracking the dynamics of rehabilitation treatment.

1. Introduction
Currently, there is no doubt in the urgent need to develop intelligent systems (IS) in the field of medicine, psychology, biology, ecobiomedicine and a number of other areas [1-13]. In particular, it is very important to create an applied IS of diagnostics of cognitive and emotional-volitional sphere of post-stroke patients at different stages of rehabilitation treatment (DICEV). Cerebrovascular injury (stroke) is the second leading cause of death in the world, third leading cause of disability and affects people at the peak of their productive life [14-16]. This problem is an interdisciplinary one. We are considering a development of applied IS based on new information technologies and cognitive graphics tools (CGT) for high-quality diagnostics of a large number of post-stroke patients. Applied IS should be created taking into account modern methods of clinical psychology, psychiatry, sociology and methods of discrete mathematics, mathematical logic, pattern recognition, reliability, soft computing, system analysis, and statistics.

2. Problem area description
Post-stroke and concomitant cognitive and emotional-volitional disorders are socially significant problems now days. Current incidence of acute cerebral circulation disorders in Russia is 3 cases per 1,000 population per year. As result, 80 % of patients lose their ability to work, and 44 % die within 5 years after a stroke [17].
The relevance of diagnostics of the cognitive and emotional-volitional spheres of post-stroke patients, the rapid development of information technologies had intensified research on diagnostic IS based on various methods of pattern recognition [1–3, 9]. A number of applied IS are worth mentioning here: for adapting to cognitive decline «Autominder» [4]; to remember the sequence of everyday actions «COACH» [5]; for a diagnosis of mental disorders [6]; for diagnosing and making decisions about depression [7]; for a therapeutic estimation of the quality of actions performed by patients with cognitive disabilities «AMPS» [8]. Significant results were presented by Russian scientists B.A. Kobrinsky [9], L.V. Kan, Y.M. Kuznetsova and N.V. Chudova [10], A.E. Yankovskaya [2, 3, 12, 18].

The relevance of the proposed approaches to the creation of applied IS DICEV is caused by the need not only to diagnose, but also to determine the dynamics of the cognitive status, emotional and volitional sphere of patients at different stages of rehabilitation treatment. Violation of the cognitive and emotional-volitional spheres leads to severe psychological, social and somatic consequences and possible disability [14–17]. It is necessary to develop timely and rapidly diagnostic decision-making, as well as justify these decisions using CGT take into account the consequences of stroke. Unfortunately, we are not aware about any published attempts to construct similar applied IS.

The work performed by A.E. Yankovskaya on the IS creation to reveal various kind of regularities and decision-making of a diagnostic, therapeutic, organizational and managerial nature, including clinical psychology and medicine was a prerequisite for the applied IS DICEV creation. IS were constructed on the basis of intelligent instrumental software (IIS) IMSLOG using a matrix method of presenting data and knowledge, test methods for pattern recognition, fault-tolerant irreduntant unconditional diagnostic tests and fault-tolerant mixed diagnostic tests, making and substantiating decisions using CGT [2, 3, 19], as well as fuzzy and threshold logic [11, 12].

We did analyze the current research state in the field of creating applied IS has shown that in decision-making and justification on the diagnostics of cognitive and emotional-volitional sphere of post-stroke patients at different stages of rehabilitation treatment. It is reasonable to use test methods of pattern recognition and create applied IS DICEV using fuzzy and threshold logic. This system is destined for revealing various regularities between the parameters (features) of cognitive and emotional-volitional sphere: capacity of short-term and long-term memory; capacity, distribution and switching of attention; the motivation for recovery; the symptoms of anxiety and depression.

The purpose of study is revealing various kinds of regularities in the cognitive and emotional-volitional sphere of post-stroke patients at different stages of rehabilitation treatment, as well as finding diagnostic decisions and justifying those using CGT. It is proposed to achieve this goal by creating the applied IS DICEV, which will be constructed on the base of IIS IMSLOG [13].

3. Matrix representation of data and knowledge

The applied DICEV is based on the IIS IMSLOG [13] using the matrix model of data and knowledge representation, including an integer matrix of description Q and a distinction matrix R [2]. The rows of the Q matrix correspond to training objects (patients with ischemic stroke in the early recovery period and with the consequences of ischemic stroke). Columns Q matrix correspond to characteristic features (CF) of cognitive and emotional-volitional sphere. The qij element of the Q matrix sets the value of the j-th feature for the i-th object. If the value of some feature is not significant, then this fact is indicated by a dash in the corresponding element of the matrix Q. For each CF zij (j = {1,2,...,m}) integer value or interval of change of its values are specified.

The rows of the matrix R are assigned to the rows of the matrix Q, the columns of the matrix R are assigned to the classification features (CLF), which partition the learning objects into equivalence classes [2]. The set of all non-repeating rows of the distinction matrix is mapped to the set of selected patterns represented by a one-column matrix R', whose elements are the numbers of the patterns.

This model allows to represent not only the data, but also the knowledge of experts, since one row of the Q matrix can specify in an interval form (using the dash "-" symbol) a subset of objects characterized by the same final decision, given by the corresponding row of the matrix R. An example
of a data and knowledge matrix representation (with the exception of interval values of features) is shown in Figure 1.

$$Q = \begin{pmatrix}
z_1 & z_2 & z_3 & z_4 & z_5 & z_6 & z_7 & z_8 & z_9 & z_{10} & z_{11} & k_1 & k_2 \\
1 & 4 & 6 & 3 & 2 & 2 & 1 & 2 & 3 & 4 & 1 & 1 & 2 \\
4 & 4 & 5 & 2 & 3 & 2 & 4 & 7 & 8 & 3 & 4 & 1 & 2 \\
3 & 4 & 5 & 3 & 3 & 2 & 4 & 5 & 3 & 4 & 1 & 3 & 1 \\
3 & 4 & 4 & 1 & 4 & 4 & 2 & 3 & 1 & 5 & 1 & 4 & 2 \\
2 & 4 & 2 & 1 & 6 & 3 & 4 & 5 & 2 & 3 & 1 & 5 & 2 \\
2 & 4 & 5 & 1 & 3 & 4 & 3 & 1 & 2 & 1 & 6 & 2 & 1 \\
1 & 4 & 3 & 2 & 5 & 2 & 1 & 2 & 3 & 4 & 1 & 3 & 3 \\
3 & 4 & 2 & 2 & 6 & 2 & 2 & 3 & 3 & 2 & 1 & 8 & 1 & 3 \\
5 & 4 & 2 & 2 & 6 & 3 & 5 & 6 & 2 & 4 & 1 & 9 & 3 & 2 \\
4 & 4 & 6 & 1 & 2 & 5 & 5 & 6 & 1 & 4 & 2 & 10 & 3 & 2 \\
\end{pmatrix}$$

$$R = \begin{pmatrix}
1 & 2 \\
1 & 2 \\
1 & 2 \\
2 & 1 \\
2 & 1 \\
2 & 1 \\
2 & 1 \\
2 & 1 \\
3 & 2 \\
4 & \\
\end{pmatrix}$$

$$R' = \begin{pmatrix}
1 & 2 \\
1 & 2 \\
1 & 2 \\
2 & 1 \\
2 & 1 \\
2 & 1 \\
2 & 1 \\
2 & 1 \\
3 & 2 \\
4 \\
\end{pmatrix}$$

**Figure 1.** Data and knowledge matrix representation.

According to the above given matrix model, we represent the data and knowledge in the considered area by the matrices $Q$ and $R$. The rows of the matrix $Q$ represent various combinations of CF values. Following CF are included:

- $z_1-z_{10}$ – number of correctly reproduced words (number of CF - 10),
- $z_{11}-z_{21}$ – number of correctly reproduced words after a time interval (number of CF - 10),
- $z_{22}-z_{47}$ – finding objects in the correct order (number of CF - 25),
- $z_{48}-z_{55}$ – intrapersonal recovery factor (number of CF - 7),
- $z_{56}-z_{73}$ – interpersonal recovery factor (number of CF - 7),
- $z_{74}-z_{77}$ – recovery control factor (number of CF - 3),
- $z_{78}-z_{85}$ – symptoms of anxiety (number of CF - 7),
- $z_{86}-z_{93}$ – symptoms of depression (number of CF - 7).

We have proposed 7 CIF for the diagnostic matrix $R$:

1st CIF – the capacity of short-term memory (3 values: 1 – low; 2 – medium; 3 – high);
2nd CIF – the capacity of long-term memory (3 values: 1 – low; 2 – medium; 3 – high);
3rd CIF – the capacity of attention (3 values: 1 – low; 2 – medium; 3 – high);
4th CIF – the distribution of attention (3 values: 1 – low; 2 – medium; 3 – high);
5th CIF – the attention switching (3 values: 1 – low; 2 – medium; 3 – high);
6th CIF – the motivation for recovery (2 values: 1 – intrapersonal; 2 – interpersonal);
7th CIF – the symptoms of anxiety and depression (3 values: 1 – absence of reliably expressed symptoms; 2 – subclinical expressed anxiety and depression; 3 – clinically expressed anxiety / depression).

The number of rows of matrices $Q$ and $R$ is 1,000 (taking into account that not all combinations are possible) – which equals to the patient number. We note that matrix $Q$ is added by columns, each column matches the patient’s identification features (full name, age, gender, educational status, position). The number of columns of $Q$ is 93 (excluding identification features). The number of columns of $R$ is 7.

The database and knowledge will be created on the base of: 1) results of a study of 1,000 patients diagnosed with ischemic stroke in the early recovery period and with the consequences of ischemic stroke, who are being treated in neurological clinics; 2) knowledge of highly qualified experts about patients, their features of cognitive and emotional-volitional spheres; 3) amnestic disease history data.

4. A brief description of the mathematical foundations of building applied intelligent system

Applied IS DICEV is based on the original matrix model of data and knowledge representation [2], convergence of several sciences and scientific fields [18], mathematical apparatus for revealing various kinds of regularities [2, 3], test logical-combinatorial methods of pattern recognition [2], construction of irredundant unconditional (fault-tolerant (FT), if necessary) diagnostic tests (DT) [11], mixed (FT, if
necessary) DT [11], the procedure of voting on a variety of tests, decision-making and justification of decision-making with the use of CGT [2, 3, 13, 19].

The regularities in knowledge are represented as the following subsets of features [2]:

1) constant (taking the same value for all patterns);
2) stable (constant inside the pattern, but not constant overall);
3) uninformative (not distinguishing any pair of objects of different patterns);
4) unessential (not included in any non-redundant DT);
5) obligatory (included in all irredundant unconditional diagnostic tests (IUDT));
6) pseudo-obligatory (not obligatory but included into all IUDTs that are involved in decision-making);
7) alternative (in inclusion in DT);
8) dependent (in the sense of including subsets of distinguishable pairs of objects);
9) weighting coefficients of CF (distinguishing objects from different classes (patterns));
10) IUDT weighting coefficients;
11) all minimal and all (or part - at a large feature space) irredundant distinguish subsets of features, which are, in fact, the minimum DT and IUDT.

In the presence of measurement errors of certain features or their entry, original test methods for pattern recognition, FT IUDT and FT mixed DT are used. These tests implement the optimal combination of unconditional and conditional components; procedure of voting on a set of decision rules; final decision-making and its justification using CGT [2, 11, 18, 19].

Regularities in clinical psychology are under development. The following regularities had been revealed on the matrices Q and R as is shown in Fig. 1:

1) z2 is a constant feature.
2) z3, z4, and z5 are obligatory features included in the kernel.
3) Features z3 and z5 are included in the first group of alternative features.
4) Features z1 and z8 are included in the second group of alternative features.
5) The feature z7 depends on the feature z8.
6) The feature z11 depends on the features z1, z4, z6, and z7, z8, and z9.
7) 12 minimal DT: z1z3z4z5z7z8, z1z3z4z5z7z9, z1z3z4z5z7z10, z1z3z4z5z6z8, z1z3z4z5z8z9, z1z3z4z5z6z10, z1z3z4z5z9z10, z3z4z5z7z8z9, z3z4z5z7z9z10, z3z4z5z8z9z10.

The framework of the paper does not allow us to present the remaining regularities.

For the construction of applied IS DICEV we use the diagnostic scheme of psychological questionnaires. This scheme is aimed at diagnostics: a) peculiarities of cognitive sphere – the capacity of short-term and long-term memory; the capacity, distribution and switching of attention in accordance with dynamic of the level (low, mid, high); b) peculiarities of emotional-volitional sphere – motivation for recovery, symptoms of anxiety and depression.

Taking into account the degree of amplification (severity) of symptoms (features) significantly affects the result of making reliable decisions. The analysis of feature values will allow to determine the dynamics of patients' condition at different stages of rehabilitation treatment. It makes possible to diagnose the patient condition more accurately and interprette it better.

Applied IS DICEV implements the following functions:

1) entering personal subject data;
2) extracting features for identify peculiarities of cognitive and emotional-volitional sphere of post-stroke patients at different rehabilitation treatment stages;
3) making final diagnostic decisions;
4) justification of decision-making with the use of CGT;
5) the formation of a conclusion on diagnostic decisions.

Applied IS DICEV allows to diagnose main indicators and deficits of the cognitive and emotional-volitional spheres based on the obtained results analysis. We suggest using 93 CF, corresponding to the peculiarities of the cognitive and emotional-volitional spheres, the absence or low indicators of which indicate that the subject has a disorder (deficit).
The construction of the applied IS DICEV will be based on the IIS IMSLOG [13], in which an intelligent interface using CGT is user interaction oriented.

5. Construction of applied intelligent system
The construction of an applied IS DICEV is carried out in 5 stages (first four of which are based on IIS IMSLOG [13]):

1) a) systematization and structuring of data and knowledge, b) determining the functional composition of applied IS DICEV, its architecture and methods most suitable for revealing regularities in data and knowledge, c) making decisions relatively cognitive and emotional-volitional sphere of post-stroke patients at different stages of rehabilitation treatment;
2) layout of the required configuration of the applied IS DICEV by connecting corresponding software modules to the core (with automatic registration);
3) a) creation of a knowledge base module by means of a knowledge analysis module and optimization of the knowledge base, b) processing a knowledge module to revealing regularities by which a set of decision rules is formed, which is used later by the decision module and justification of decisions using CGT;
4) configuration of the applied IS DICEV for specific customer;
5) installation of the system at customer location.

The mathematical apparatus and the justification of decision-making are presented in publications [2, 3, 11, 18, 19], the IIS IMSLOG is given in [13], development and investigation of the applied IS on the base IIS IMSLOG are described in publications [11, 12]. The construction of the applied IS DICEV is based on IIS IMSLOG. We present in Figure 2 only the block scheme of the final decision.

![Figure 2. The block scheme of the final decision using the applied IS DICEV.](image)

The application of the applied IS DICEV will allow specialists to make diagnostic decision quickly and efficiently, as well as justify these decisions using CGT. It will improve the quality of the rehabilitation treatment.

6. Conclusion
For the first time, a matrix model for the representation of data and knowledge in the field of rehabilitation of post-stroke patients was proposed. Original structuring of data and knowledge was developed. For the first time, applied IS DICEV constructed on the base of IIS IMSLOG is aimed to make decisions and justify them using CGT efficiently, quickly and in a timely manner. Applied IS DICEV allows diagnosing the significance of features of post-stroke disorders based on simplified diagnostic criteria, as well as to evaluate the dynamics of indicators of cognitive and emotional-volitional spheres at different stages of rehabilitation treatment.

There is good reason to believe that the applied IS DICEV will ensure the reliability and quality of results; reduce time and financial costs; and allow timely to inform medical specialist about the state of the cognitive and emotional-volitional spheres of post-stroke patients at different rehabilitation treatment stages. Corresponding research will be carried out on the base of neurological clinics. The inclusion of the applied IS DICEV in geographic information systems will allows significantly extending their capabilities.

In the future research we plan to include the mathematical apparatus of fuzzy and threshold logic in order to expand the capabilities of the applied IS DICEV.

Acknowledgment
The reported study was funded by RFBR, project number 18-013-00937, project number 19-313-90057.

References

[1] Zhuravlev Y I, Ryazanov V V and Senko O V 2006 Recognition. Mathematical methods. Software system, practical solution (Moscow: Phasis) p 159
[2] Yankovskaya A E 2011 Logical tests and Cognitive Graphic Tool (LAMBERT Academic Publishing) p 92
[3] Yankovskaya A E 1994 Test recognizing medical expert systems with elements of cognitive graphics Computer Chronicle 8/9 61–83
[4] Pollack M E, Brown L, Colbry D, McCarthy C E, Orosz C, Peintner B, Ramakrishnan S and Tsamardinos I 2003 Autominder: an intelligent cognitive orthotic system for people with memory impairment Robotics and Autonomous Systems 44 273–282
[5] Morris P, Muscettola N and Vidal T 2001 Dynamic Control of Plans with Temporal Uncertainty Proc. of the 17th Int. Joint Confr.on Artificial Intelligence (San Francisco: Morgan Kaufmann Publishers) 1 pp 494–499
[6] Bouaiachi Y, Khaldi M and Azmani A 2014 Neural network-based decision support system for pre-diagnosis of psychiatric disorders Proc. of Information Science and Technology (Third IEEE Intern. Colloquium, 20-22 Oct. 2014) pp 102–106
[7] Ekong V E, Inyang U G and Onibere E A 2012 Intelligent Decision Support System for Depression Diagnosis Based on Neuro-fuzzy-CBR Hybrid Modern Applied Science 6/7 79–88
[8] LoPresti E F, Michailidis A and Kirsch N 2004 Assistive Technology for Cognitive Rehabilitation: State of the Art. Neuropsychological Rehabilitation 14 (1-2) 5-39
[9] Kobrinsky B A 2016 Fuzziness in clinical medicine and the need for its reflection in expert systems Doctor and information technology 5 6–14
[10] Kan L V, Kuznetsova Y M and Chudova N V 2010 Expert systems in the field of psychodiagnostics Artificial intelligence and decision making 2 26–35
[11] Yankovskaya A E and Yamshanov A V 2016 An Accelerated Parallel Algorithm for Constructing the Nonredundant Matrix of Implications during the Construction of Fault-Tolerant Nonredundant Diagnostic Tests Automatic Documentation and Mathematical Linguistics 50(6) 223-236
[12] Yankovskaya A E, Kornetov A N, Il’inskikh N N and Obukhovskaya V B 2017 An Expansion of Intelligent Systems Complex for Express-Diagnostics and Prevention of Organizational Stress,
Depression, and Deviant Behavior on the Basis of the Biopsychosocial Approach *Pattern Recognition and Image Analysis* 4 783–788

[13] Yankovskaya A E, Gedike A I, Ametov R V and Bleikher A M 2003 IMSLOG-2002 Software Tool for Supporting Information Technologies of Test Pattern Recognition *Pattern Recognition and Image Analysis* 13(4) 650–657

[14] Global Health Estimates. Geneva: World Health Organization; 2012. Available from: http://www.who.int/healthinfo/global_burden_disease/en/

[15] Johnson W, Onuma O, Owolabi M and Sachdeva S 2016 Stroke: a global response is needed *Bull World Health Organ* 94 634–634

[16] Nazmetdinova D L and Obukhovskaya V B 2020 Features of the cognitive and emotional-volitional spheres of patients with post-stroke neurological disorders at different stages of rehabilitation treatment *Psychologist* 19 1-15

[17] Koval’chuk V V, Bogatyreva M D and Minnullin T I 2014 Modern aspects of rehabilitation of stroke patients *Zh. Nevrol. Psikhiatr. Im. S. S. Korsakova* 6 101-105

[18] Yankovskaya A E 2010 Analysis of data and knowledge based on the convergence of several sciences and scientific fields *Collection of reports of the 8th international conference Intellectualization Information Processing* (Moscow: MAX Press) pp 96–199

[19] Yankovskaya A 2019 2-Simplex Prism as a Cognitive Graphics Tool for Decision-Making // *Encyclopedia of Computer Graphics and Games* (Switzerland: Springer Nature) p 13