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Using Neural Network Mathematical Models to Solve Pedagogical Problems

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ABSTRACT
This article describes the process of creating neural network mathematical models to solve such pedagogical problems as predicting the results of project activities of schoolchildren and developing recommendations for selecting a perspective project task; predicting student attendance based on their personal qualities, aims and lesson schedules; modelling the activities of student interns (musicians and future music teachers) related to their decision to attend theoretical classes, etc. The following stages of creating neural network forecasting systems are considered: formalization of the task, the formation of training examples, designing a neural network, its training and testing. To create neural network systems that implement mathematical models, special software was developed using a high-level cross-platform programming language Python.
Keywords: *artificial neural networks, intelligent systems, neural network mathematical modelling, pedagogical tasks*

1. INTRODUCTION

Today a modern man lives in increasingly complex systems and he himself presents an evolving self-organizing cognitive system. With increasing complexity of the system difficulties in understanding and predicting its behaviour (predicting risks, efficiency, etc.) are also increasing, in fact, in applying mathematical methods to describe complex systems and their behaviour, and the complexity of the systems can exceed the capabilities of their modelling using computers [1], [2], [3]. The use of neuroinformation technologies allows to change the approach to the methodology of constructing computer mathematical models. It is possible on their basis to build computer mathematical models without thinking about the objective laws of subject areas, proceeding only from empirical data and the experience presented by training examples. Neural network models "extract themselves" the laws of the objective world and allow them to be effectively used to solve a wide range of practical problems [4]. This approach is especially effective for constructing mathematical models and data mining in poorly formalized subject areas, such as, for example, pedagogy, sociology, medicine, music, etc.
Intelligent systems are human-machine systems that can not only imitate the intellectual capabilities of a person, but also enhance them thanks to cognitive reasoning and the performance of a computer with a comfortable intelligent interface. Currently, in the scientific literature and the media there are many reports of successful experience in using neural networks to create predictive systems. In the field of medicine, experience has been gained in using neural networks for diagnosing diseases (the works of O. I. Larichev, E.V.Naryzhny, who created a predictive system in the field of clinical diagnostics, became famous), cardiodiagnostics, diagnosis of cancer, analysis of genomic DNA sequences [5]. According to V.A.Bajanov "the latest achievements of neuroscience begin to shed new light on the nature of music and musical creativity, to reveal the features of musical development and education" [6]. The need to use neuroscience in pedagogy has been expressed by many scientists (V.A. Moskvin, V.D. Eremeeva, T.P. Khrizman). At the end of the 20th century, it became possible to realize more widely the achievements of neuropsychology and neurobiology in pedagogical practice.
In the field of pedagogy, one can set the task of creating prognostic systems based on the design, training, optimization and use of neural network models for the study and solution of pedagogical problems, such as:
- prediction (and development of recommendations) of a person's abilities for a certain type of activity (business, high achievement sports, research, composing musical works, etc.) based on a model of human activity [4];
- implementation of a model of meta-project training based on the idea of creating a situation of constructive chaos by a teacher in a study group [7];
- analysis (with the subsequent possibility of improvement) of control and measuring materials on control and measuring materials for their compliance with the stated topic and level of difficulty for a reliable assessment of students' academic achievements in the subject through the use of adaptive testing [8];

- forecasting the results of project activities of schoolchildren (and development of recommendations for the selection of a promising project task) [9];
- prediction of attendance by students of training sessions based on their personal qualities, goals and schedules (and the development of recommendations for changing the schedule in order to improve class attendance);
- prediction of social success and professional self-realization of a teacher, etc.

2. THE CREATION OF NEURAL NETWORK PROGNOSTIC SYSTEMS

Artificial neural networks (ANN) are information structures that underlie the functioning of some computer programs. Such networks consist of simple elements of the same type (neurons), interconnected in a certain way, the functionality of which is similar to most of the elementary functions of a biological neuron. Communication can be strong (significant) and weak (insignificant until absent), which in artificial neural networks is characterized by a weighting coefficient of coupling (w). Each neuron is characterized by its current state (excited or inhibited), which is determined by the activation function. The ANN can be visualized in the form of a directed graph, the vertices of which will correspond to neurons, and the arcs connecting the vertices will correspond to synaptic connections or weights (Fig. 1).

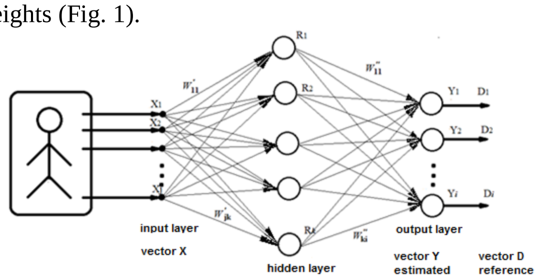

Figure 1 The scheme of the neural network

ANNs have a number of valuable properties, including the ability to learn, retrain, analyse incoming information, process a large amount of data presented on different scales, filter out unnecessary information, make forecasts, process signals in parallel, due to the combination of a large number of neurons into layers. The task of a neural network is to transform information in the required manner. For this, the network is pre-trained. During training, ideal (reference) values of the pairs <inputs-outputs> are used. For training, the so-called training algorithm is used. An unconfigured neural network is not able to display the reference behaviour. The training algorithm modifies individual neurons of the network and the weights of its connections in such a way that the behaviour of the network corresponds to the reference (model) behaviour [7].
The creation of neural network prognostic systems is carried out in the processes of: *formalizing the task, forming training examples, designing a neural network, its training and testing*. The realized neural network of the domain can be used to conduct computational experiments and find answers to the questions posed.
Formalization of the task includes determining the goals of modelling, establishing the input and output parameters of the models (corresponding to the set pedagogical problems), as well as determining the structure (composition and length) of the input vectors X and the output vectors D (depending on the pedagogical tasks being solved). In the capacity of the components of the input vector X, it is important to choose significant parameters - those that have a significant effect on the result. The output vector D is formed so that its components make it possible to obtain answers to all the questions posed.
In the *formation of training examples*, the contents of the input and output vectors are selected. As a result, many pairs $\{X_q; D_q\}$ (q = 1, ..., Q is the number of training examples), where such a pair makes up an example characterizing the subject area. It is advisable to normalize the numerical information prepared for input into the neural network - bring it to the range [0,1] or [−1,1]. The whole set of examples is divided into training L and testing T. To calculate the minimum allowable volume of the training set, the following formula is recommended: $Q = 7 N_x + 15$, in which N_x is the number of input parameters of the neural network model [8].
Network design. The structure of the neural network is selected in accordance with the recommendations:
- the number of inputs should coincide with the number of input parameters, i.e. with the dimension of the vector X, which is determined by the conditions of the problem being solved;
- the number of neurons of the output layer should coincide with the number of output parameters, i.e. with the dimension of the output vector D, which is also determined by the conditions of the problem;
- the number of hidden layers of the perceptron, according to the Hecht-Nielsen theorem, must be at least one, and neurons in the hidden layers must have a sigmoid activation function [10];
- the number of neurons in the hidden layers can be approximately estimated by the Hecht-Nielsen formula [10];
- along with the training set of examples L, the testing set of examples T is introduced.

The goal of *training a neural network* is to select the synaptic weights w_{ij} so that for each input vector X_q of the set of training examples, the neural network produces a calculated vector Y_q that is minimally different from the given output vector D_q. This goal is achieved by using the developed neural network learning algorithms (in particular, for classical neural networks with hidden layers - back error propagation algorithm).
Testing (and optimization) of the network. The generalization properties of the neural network are checked using a testing set of examples, i.e., those examples that were not used in training the network. Optimization consists in selecting the most suitable

network structure for this task - the number of hidden layers, the number of hidden neurons, the number of synaptic connections, as well as the type and parameters of the activation functions of neurons. This operation is performed if the difference between the components of the reference output vector D_q and the calculated output vector Y_q is unacceptably large.

*Intelligent analysis of pedagogical problems b*y the *method of neural network mathematical modelling*. A neural network mathematical model reacts to a change in input parameters in the same way as a domain itself would behave. Therefore, by conducting computational experiments on the model, the goals of modelling are achieved and answers to the questions are formulated.

Implementation of ANN. There are many special programs for designing and working with neural networks, called neurosimulators, neuroimitators and neuropackages. Many of these programs have functions for automatical optimizing neural networks.

3. NEURAL NETWORK PROGNOSTIC SYSTEMS FOR SOLVING PEDAGOGICAL PROBLEMS

Let us consider the process of creating neural network predictive systems using examples of systems for solving pedagogical problems.

3.1. Prediction of the results of project activities of schoolchildren

Example 1. Prediction of the results of project activities of schoolchildren (and the development of recommendations for the selection of a prospective project task).

To form the input vector X and the output calculation vector Y (and, accordingly, the output reference vector D), their dimensions, and the contents of each component, it is necessary to analyse the studied area, relying on typical samples of its implementation. We will observe how the teacher makes the choice of project assignments “favourable” for students. The term “favourable” project assignment means that the topic of the assignment will interest the student, that the student has a range of knowledge and skills sufficient to complete the project assignment, that the student’s personal characteristics (determination, perseverance, ability to analyse, etc.) will allow him to cope with the intended volume of analytical and / or experimental work.

The teacher forms a record in which he fixes the name, the name of the class / group; and then, as a rule, finds out the interests and activity of the student (for example, if the student is engaged in extra-curricular activities within further education or electives, whether he/she participated in competitions and how successfully); listens to the wishes of the student in relation to the scientific field within which he intends to carry out the project; gets acquainted with the results of educational activities for previous periods of training; finds out how diligent (for example, regarding homework) and discipline (for example, if he missed classes for no good reason, or received comments for bad behaviour). You can also take into account sociability (person-person, person-nature, person-sign, person-machine), the type of temperament of the student (choleric, sanguine, phlegmatic, melancholic) and other data that determine the characteristics of a person and, therefore, affect the likelihood of systematic purposeful work (collective or individual) on the project task.

As a result, the teacher accumulates several parameters characterizing the personality of the learner and the history of his educational activity, having processed which with the help of his knowledge and pedagogical experience, the teacher draws a conclusion about the likelihood of successful completion of the project task, and then formalizes and presents the student with the content of the project activity. These are the initial parameters - input for human analysis or input for calculation by a neural network, defining vector X.

In the output vector D, the possible results of the project activity should be encoded, taking into account the components of the integrated assessment (for example, whether the research goal has been achieved; whether the research tasks are specified and solved; whether literature analysis has been performed within the scope of the project task topic; whether the results are presented in the form of an explanatory note, whether the oral report was successful in the process of defending the project; what is the share of the student’s personal contribution to solving the problem in the case of a collective project, etc.). In the case of using the dichotomous scale 0 and 1, the output vector of the neural network D will consist of many units (corresponding to the implemented components of the integrated assessment) and one or more zeros (if the corresponding component of the integrated assessment is not implemented). You can evaluate and, accordingly, encode the implementation of the components of a comprehensive assessment on a five- or one-hundred-point scale. The dimension of the vector D can be significantly reduced if we restrict ourselves to evaluating the result of the project. Then the output vector of the neural network D will consist of many zeros and one unit.

3.2. Prediction of attendance of training sessions by students

Example 2. Prediction of attendance by students of training sessions based on their personal qualities, goals and lesson schedules (and the development of recommendations for changing the schedule in order to improve class attendance).

The decision of students to attend training sessions in a situation prevailing at a particular time depends on their personal characteristics, which can be identified using questionnaires. Among personal characteristics, it is advisable to consider, for example, the following:

- self-organization (ability to resist weaknesses);
- psychotype (extrovert, introvert, ambivert);
- temperament (choleric, sanguine, phlegmatic, melancholic);
- responsibility (or irresponsibility) of the student in relation to the implementation of public assignments;
- the prevalence of the desire to acquire new knowledge in the learning process over the desire to acquire a document on the availability of this knowledge as a result of study (or vice versa);
- the student's assessment of the importance of their own time in terms of the appropriateness of time's transport costs, depending on the expected duration of the classes (for example, only one pair in the class schedule or the presence of "windows");
- concern over the state of one's own health in terms of the intention to attend (or not attend) training sessions;
- a sphere of subject interests (programming, computer games, theoretical foundations of computer science);
- the aim is to combine study with professional activity (or not), etc.

These are the input parameters of the vector X used for calculation by a neural network.

In the output vector D, the results of attendance by the students surveyed by training sessions (for example, in specialized disciplines) taken from group journals of the dean's office should be encoded. The empirical data obtained as a result of the questionnaire and from the data of the dean's office are reduced to a dichotomous scale of yes to no and are used to design and train a neural network.

To create neural network forecasting systems that solve pedagogical problems, special software was developed using a high-level cross-platform Python programming language. During the development of a computer program, it became necessary to import standard modules and additional libraries, such as a pickle module for serializing and deserializing objects, a random module for generating pseudo random numbers, for the exact calculation of the exponent of a number, etc. Empirical data obtained as a result of questioning the students, are the basis for training the neural network, which is carried out iteratively, i.e., the data are reused. For storing data, a dictionary was formed, where the key was the name of the student, and the value is the data of personal characteristics and performance / attendance journals. The dictionary is stored as a file, the data are processed using the methods of the standard pickle module: the dump() method for writing serialized objects to a file and the load() method for extracting from the file. The program is presented in a Python-file, an interactive menu has been implemented to view training examples and weights of the current iteration, to start the learning process and write the values of the synaptic weights of the next iteration into a file for testing.

3.3. Modelling the activities of student interns

Example 3. Modelling the activities of student interns (musicians and future music teachers) related to their decision to attend academic classes.

This task was formulated in the development of the pedagogical problem solved by the ANN, described in Example 2. Teachers working with students in the system of cultural institutions and education are well aware that more musicians and future music teachers will be interested in disciplines related to mastering patterns of the art that they have mastered for many years in the process of performing activities. The interest in theoretical disciplines is weakly expressed among students, respectively, hence problems arise with visiting and mastering the content of such disciplines. However, the curriculum of any educational program in music education necessarily includes disciplines of theoretical and methodological training, which greatly increases the possibility of expanding the methodological experience of future music teachers.

Weak interest and, accordingly, attendance of the educational discipline of the methodological orientation "Music Education in Russia and China" was noted in the group of Chinese trainee students studying under the educational program "Musical education" at Ural State Pedagogical University (USPU). Students mastered the program of two undergraduate courses at the University of Baicheng, then studied for two years at the Institute of Music and Art Education of USPU, while simultaneously actively mastering the Russian language. Due to the identified problem, music teachers and educators teaching information technology at the university were interested in developing a forecasting system for solving a diagnostic problem - selecting foreign students for an internship at a Russian university under the educational program "Musical education". To develop such an ANN, some personality characteristics and professional knowledge, skills obtained during the questioning of a group of trainee students from China used in the input vector X were revealed:
- the student's assessment of the importance of performing or methodological preparation of a music teacher for professional activities (the importance of both components is equal);
- the degree of expression of student's interest in the profession of a music teacher (interest in learning new techniques and technologies in Russian and Chinese pedagogy of music education);
- a positive assessment by the student of the importance of theoretical and methodological knowledge for professional activity;
- the student's presence (or absence) of a desire to test certain theoretical and methodological knowledge in the process of their own pedagogical practice (assumptions about the inclusion of acquired methodological knowledge in the content of music lessons at school and music classes within clubs);

- the student's presence (or absence) of a desire to study methodological literature (reading methodical articles and books in Chinese, followed by a brief summary in Russian);
- the student's ability to identify "bottlenecks" in methodological training and to design ways to obtain the missing knowledge;
- the presence (or absence) of the student's desire to compose message presentations on the specifics of music education in China at its various levels.

In the output vector D, the results of attendance by the students of the theoretical and methodological studies were coded. The developed ANN, which allows to predict the orientation of students (future music teachers) in mastering the academic disciplines of the theoretical and methodological orientation, is supposed to be used in the selection of foreign students for internship at USPU.

4. CONCLUSION

Neural network forecasting systems have been developed at Ural State Pedagogical University, they provide the intellectual analysis of pedagogical problems. You can change some of the input parameters and observe how the values of the output vector Y change. Thus, the laws of the subject area can be identified and the tasks of predicting the future properties of the simulated object and its optimization can be solved, among the tasks of pedagogy as well.

REFERENCES

[1] Pozner, M. (2008), "Development of attention systems in humans", Computers, brain, cognition: advances in cognitive sciences ["Razvitiye sistem vnimaniya u cheloveka", Kompyutery, mozg, poznaniye: uspehi kognitivnyh nauk], Nauka, Moscow, pp. 93-106.

[2] Simon, G. A. (2008), "The structure of complexity in the developing world", Computers, brain, cognition: advances in cognitive sciences [Struktura slozhnosti v razvivayuschemsya mire", Kompyutery, mozg, poznaniye: uspehi kognitivnyh nauk], Nauka, Moscow, pp. 21-27.

[3] Chuprikova, N. I., Volkov E. V. (ed.), (2013), Differentiation-integration theory of development: Philosophical interpretation and application to psychology, linguistics, and education: Abstracts of second conference [Differentsyonno-integrirovannaya teoriya razvitiya: Filosofskoye osmysleniye I primeneniye v psihologii, yazykoznanii i pedagogike: tezisy dokladov Vtoroy nauchno-prakticheskoy konferentsii], (4th March 2013, Moscow), Institute of Psychology RAS, Moscow, 45 p.

[4] Yasnitsky, L. N. (2016), Intelligent systems, Laboratory of knowledge [Intellektualniye sistemy, Laboratoriya znaniy], Moscow, 221 p.

[5] Larichev, O. I., Naryzhny E. V. (2008), "Computer modeling of procedural knowledge", Computers, brain, cognition: advances in cognitive sciences ["Kompyuternoye modelirovaniye protsedurnymi znaniyami", Kompyutery, mozg, poznaniye: uspehi kognitivnyh nauk], Nauka, Moscow, pp. 235-251.

[6] Bazhanov, V. A., Kraeva A. G. (2017), "Music in the focus of modern neuroscience" ["Muzyka v fokuse sovremennoy neyronauki"], Vestnik Tomskogo gosudarstvennogo universiteta. Filosofiya. Sotsiologiya. Politologiya, No. 40, pp.7-21.

[7] Gorbatyuk, V. F. (2017), "Training of self-organizing systems of natural intelligence (review based on the results of the monograph)" ["Obucheniye samoorganizuyuschihsya system yestestvennogo intellekta (obzor po rezultatam monografii)"], Pedagogicheskiye nauki. No. 1, pp. 51-68.

[8] Goryushkin, E. I. (2009), The use of neural network technologies in adaptive testing in computer science at a university: thesis abstract [Ispolzovaniye neyrosetevyh tehnologiy v adaptivnom testirovanii po informatike v vuze: avtoref. dis. ... kand. ped. nauk], Kursk, 24 p.

[9] Lapenok, M. V., Lozinskaya, M. A. (2019), "Cognitive approach to teaching intellectual modeling of pedagogical problems", Cognitive research in education: Collection of scientific articles of the VII International scientific-practical conference, ["Kognitivniy podhod k obucheniyu intellektualnomu modelirovaniyu pedagogicheskih problem, Sbornik nauchnyh statey VII Mezhdunarodnoy nauchno-prakticheskoy konferentsii "Kognitivniye issledovaniya v obrazovanii"], Yekaterinburg, pp. 248-254.

[10] Hecht-Nielsen, R. (1987), Kolmogorov's Mapping Neural Network Existence Theorem, IEEE First Annual Int. Conf. on Neural Networks, San Diego, V. 3, pp. 11-14.