Development of an effective adaptive forecasting system based on the combination of neural network and genetic algorithm

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Abstract. The paper is presented an effective adaptive forecasting system based on combining mathematical modeling tools, including neural networks and genetic algorithm. The construction of the neural network structure that is best relative to the selected criterion makes it possible to improve the procedure for finding a solution to the problem in terms of a number of parameters. Each individual in the genetic algorithm is encoded as a vector with data on the number of neurons on the intermediate layers of the neural network. The evolution of the population occurs in the genetic algorithm, information in the chromosomes changes as a result of the probabilistic application of genetic operators. As a result, such a structure of the neural network is formed, at which the convergence to a given level of error of 1.0% is the fastest. Applied calculations were carried out on the monthly statistical data of investments in human capital (education, healthcare and culture) of the Udmurt Republic. The proposed adaptive system, applied to the construction of forecasts of socio-economic indicators, can be used in the construction of development strategies both at the regional level and at the country level.

1. Introduction
Forecasting methods are algorithms for processing available information in order to build future trends in the studied processes and phenomena. The field of application of forecasting methods imposes its own limitations on them, makes them take into account the peculiarities and overcome possible difficulties in building forecasts. Mathematical analysis and forecast of socio-economic processes and phenomena take place, as a rule, in conditions of the insufficient initial statistical information, in the presence of constant variations in the external environment, under the influence of a large number of unaccounted factors. Also, when constructing mathematical forecasts of socio-economic processes, there are factors that are difficult to formalize. Thus, we can conclude that when modeling socio-economic processes, the complexity lies in the presence of a large number of implicit mathematical relationships. Nevertheless, it is a qualitative forecast that is the key to building socio-economic strategies and making rational management decisions.

At present, it is known that the tools of neural network modeling and forecasting can effectively establish implicit mathematical relationships [1, 2]. Neural networks are widely used to solve the most demanded data mining tasks [3, 4]. The advantage of using neural networks in predicting socio-economic processes is the stability of the results obtained against frequent changes in the environment.

One of the most important question is the choice of neural network structure. Modern neural networks are composed of perceptron. The perceptron was proposed in 1957 by the American neurophysiologist
F. Rosenblatt as a result of studying the nervous system of a living organism. Before F. Rosenblatt, the theory of neural networks was identified in 1943 in the work “A Logical Calculus of Ideas Immanent in Nervous Activity” by American’s neurophysiologist W. McCulloch and mathematician W. Pitts. The work shows that any logical function can be implemented using a neural network. The foundation on which the theory of neural networks is based was completed thanks to the research of the Finnish scientist in the field of artificial neural networks T. Kohonen, the American neurobiologist and mathematician S. Grossberg. The result of their research was the possibility of building and using multilayer networks.

In 1974, the American sociologist P. Verboros developed neural network algorithms for training multilayer neural networks, including both the learning process by back propagating errors and recurrent neural networks. Neural networks can have completely different structures. The structure of a neural network affects the speed of its learning and increases the adaptive properties of the computational algorithm. The process of choosing the optimal neural network structure is well presented in the researches [5-7].

The article is discussed the structure of multilayer fully connected network. The construction of the neural network structure is determined by the work of a genetic algorithm.

The genetic algorithm is heuristic method. The genetic algorithm is implemented mechanisms that resemble biological evolution. These mechanisms include random selection, combination and variation of the required parameters to solve the problems of mathematical modeling and optimization [8]. The terms used in the description of genetic algorithms are borrowed from genetics: a population (a finite set of individuals), respectively, individuals included in the population (represented as chromosomes), chromosomes – ordered gene sequences, etc.

The combined using of neural network approaches to modeling socio-economic processes and genetic algorithms for constructing the topology of a neural network makes it possible to obtain an effective adaptive forecasting system.

2. Adaptive forecasting system based on combining neural networks and genetic algorithm

An individual in the population of the genetic algorithm is represented as a vector, whose coordinates are data on the number of neurons on the hidden layers of the neural network. The initial initialization of the population is specified in a non-uniform way – each individual represents a random structure of the neural network \( \{k_1, k_2, \ldots, k_m\} \), where \( k_m \) is the number of neurons on the \( m \)-layer. In the course of the genetic algorithm, the evolution of the population occurs by changing the chromosomes information, due to the probabilistic use of genetic operators of selection, crossing and mutation. There are many selection methods in genetic algorithms (roulette method, tournament selection, rank selection) [9].

We applied a tournament selection, in accordance with which we select \( m_i \) individuals from the population (the \( m_i \) value is the size of the tournament). Further, among these \( m_i \) individuals, we determine the individual with the best fitness function value. This operation continues until the required number of parents is reached to form the next generation. When constructing the structure of a neural network, the applied genetic algorithm also is used the crossing operator. It is a one-point operator that selects a break point within a chromosome with the subsequent exchange of information located behind this point. Also, the proposed genetic algorithm is used the mutation operator, which produces a random change in only one of the genes of the chromosome [10].

The practical using of the genetic operators of crossing and mutation is of a probabilistic nature: a certain fixed number is set – the probability \( p_f \in [0;1] \). Next, a random number \( p \) is generated. If \( p \leq p_f \), then the action specified by the operator is performed. For the crossing operator is \( p_c \in [0,5;1] \), the mutation operator is \( p_m \in [0;0,1] \). An algorithm for solving the problem of determining the best structure of neural network using genetic algorithm is shown in figure 1.
The optimization function of determining the best structure of the neural network is specified as the training time of the neural network up to an error level of 1.0%. Accordingly, the best is the structure of the neural network with the minimum training time. The condition for the termination of the algorithm is the condition that the found “best” chromosome does not change for several generations in a row (more than 25-30 generations in the algorithm). The search for the best structure of neural network is carried out in all directions of changing its organization (both towards simplification and towards complication).

To adjust the parameters and check the accuracy of the developed algorithm, it was tested. Table 1 shows the parameters of the genetic algorithm for determining the best structure of the neural network.

| №  | Parameter                  | Testing range | Value change step | Selected parameter value |
|----|----------------------------|---------------|-------------------|--------------------------|
| 1  | \(N\) – population size   | \([5:100]\)   | 5                 | 35                       |
| 2  | \(m_t\) – tournament size | \([2:10]\)    | 1                 | 4                        |
| 3  | \(p_c\) – crossing probability | \([0.5:1.0]\) | 0.05              | 0.9                      |
| 4  | \(p_m\) – mutation probability | \([0.01:0.1]\) | 0.01              | 0.07                     |

**Figure 1.** Algorithm for selection the best structure of a neural network using genetic algorithm.
Union mathematical modeling tools based on neural networks and mathematical modeling tools based on a genetic algorithm makes it possible, by combining the strategies of these methods, to create an effective adaptive system that makes it possible to make forecasts for the short and medium term.

Let’s consider the application of the adaptive forecasting system proposed by the authors to forecast of investment in human capital in the Udmurt Republic. Investments in education, healthcare and culture are accepted as the main investments [11]. It is these three components that form in a full-fledged way the economic category of human capital, which participates on a par with productive capital in a generalized social product (gross regional product) [12].

Thus, when implementing the constructed algorithm of the adaptive forecasting system, known statistical data on monthly budget and private investments in human capital (in education $J_1(t)$, in healthcare $J_2(t)$, and in culture $J_3(t)$) are selected as input, and also the values of the gross regional product $Y(t)$ of the Udmurt Republic from 2000 to 2019 [13]. The output data of the algorithm of the adaptive forecasting system are the predicted monthly volumes of investment in human capital ($\tilde{J}_1(t+\tau)$, $\tilde{J}_2(t+\tau)$ and $\tilde{J}_3(t+\tau)$, where $\tau$ is the time lag).

The initial statistical information is divided into a training set and a retro-forecast section (test set). On the training set, the neural network is trained using the backpropagation algorithm [14]. On the test set, the choice of the time lag for forecasting is carried out on the basis of the average relative error [15]. After 28 generations of genetic algorithm (label 3 in figure 2), the termination condition is met and the best neural network structure is found. The training times for other structures of the neural network are shown in figure 2 by labels 1 and 2.

![Figure 2](image1.png)

**Figure 2.** Dependence of training time the "best" neural network ($T$) from generation ($G$) in genetic algorithm.

![Figure 3](image2.png)

**Figure 3.** Learning error of three-layer neural network ($E$) from iteration number ($M$).

In the case of using a neural network with the best structure, fewer iterations are required to converge to the required error level of 1.0%.

The implemented algorithm makes it possible to select the best neural network structure, which convergence to given level of error $E$ is the fastest (see figure 3).

Figure 4 is showed the structure of a three-layer neural network used to solve the set problem of forecasting investments in the human capital of the region.
3. Solution of the problem of forecasting investment processes by using the developed toolkit

Figures 5, 6, 7 present the results of short-term forecasting of investments in education, healthcare and culture of the Udmurt Republic, obtained by using a trained neural network with a lag $\tau = 12$ months.

![Figure 4](image_url)

**Figure 4.** Three-layer neural network, which used to predict investments into human capital.

![Figure 5](image_url)

**Figure 5.** Monthly budget and private investments in education of the Udmurt Republic for the period 2000-2019 and forecast to 2025, billion rubles.

![Figure 6](image_url)

**Figure 6.** Monthly budget and private investments in healthcare of the Udmurt Republic for the period 2000-2019 and forecast to 2025, billion rubles.

![Figure 7](image_url)

**Figure 7.** Monthly budget and private investments in culture of the Udmurt Republic for the period 2000-2019 and forecast to 2025, billion rubles.

The average relative error is calculated on the retro-forecast section for the period of 2000-2019 for the three components of the human capital of the Udmurt Republic and is not exceed 1.0%.
4. Conclusion
This research is presented an efficient adaptive forecasting system built on the basis of combining mathematical modeling tools based on neural networks and mathematical modeling tools on a genetic algorithm. This system is applied to forecast socio-economic processes, in particular, the process of investing in human capital of the regional economy. The genetic algorithm made it possible to search for the best structure of a multilayer fully connected neural network from the point of view of optimality criterion – the time spent on convergence of the neural network to a given level of error of 1.0%.

Applied calculations were carried out on statistical data of the Udmurt Republic region. Based on monthly statistics for the period 2000-2019 forecast of the dynamics of investments until 2025 in the components of the human capital of the region – education, healthcare and culture were built. The proposed adaptive system, applied to the construction of forecasts of socio-economic indicators, can be used in the construction of development strategies on regional and country level.

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