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Informatik

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Nr. 2/2011

Arbeitsberichte aus dem Fachbereich Informatik

Universität Koblenz-Landau • Campus Koblenz • Universitätsstraße 1 • 56070 Koblenz
Telefon +49 261 287-0 • http://www.uni-koblenz.de

Arbeitsberichte des Fachbereichs Informatik

ISSN (Print): 1864-0346
ISSN (Online): 1864-0850

Herausgeber / Edited by:

Der Dekan:
Prof. Dr. Zöbel

Kontaktdaten der Verfasser

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Oleg V. Kryuchin, Alexander A. Arzamastsev, Klaus G. Troitzsch

Abstract

This paper describes parallel algorithms for training artificial neural networks. Possible levels of parallelity are presented. Experiments for checking the efficiency of algorithms are discussed.

Keywords: artificial neural networks, computer clusters, parallel algorithms.

1 Introduction

1.1 Background and aims

Nowadays artificial neural networks (ANN) are used in different branches of science [8]. Especially they occur in such sciences as psychology, sociology and economics. The reason why they are used in these sciences is the peculiarity of the objects of these sciences as these objects cannot be easily defined by simple rules. The usage of artificial neural networks can cost a lot of time because neural network models have a complex structure and many parameters. One possible solution of this problem is using parallel algorithms and computer clusters.

The aim of this paper is to improve the efficiency of the deveopment of ANN-models by means of parallel algorithms. To achieve this aim, several tasks have to be solved. These tasks are the analysis of software products appropriate for using ANN, the development of parallel algorithms of training ANNs, the development of an information system with parallel algorithms of training ANNs and the development of numerical experiments to check the efficiency of these algorithms.

1.2 Current products

Nowadays there are no neural networks simulators for computer clusters. There are simulators for single PCs (JavaNNS, NeuroShell, NNC, Mathlab neural network tools etc.) but they cannot be executed on computer clusters. There are tools for computer clusters (T-System etc.) but they do not consider the specific requirements of neural networks simulation. And there are hardware solutions (Nimfa and etc.) which do not use computer clusters and cannot be configured for concrete task. So there are not products which bring together the technologies of artificial neural networks and of parallel algorithms.

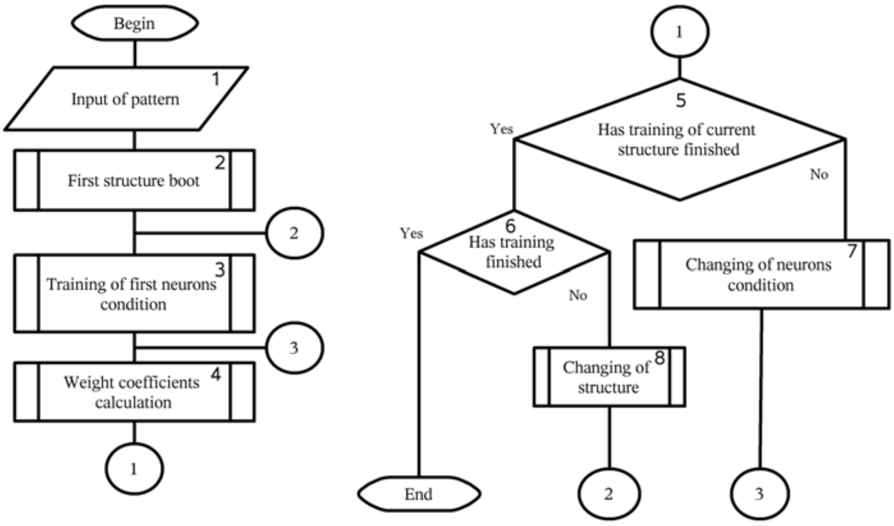
2 Training neural networks

The main task in trining a neural network is the minimization of a target function (1).

$$\varepsilon = \sum_{i=0}^{N-1} \sum_{j=0}^{P-1} (d_{i,j} - F(\vec{x}_i, \vec{w}, \vec{\mu})_j)^2 \tag{1}$$

where $\vec{x}$ is input pattern, $\vec{d}$ is output pattern, F is ANN output value calculation function, $\vec{w}$ are weight coefficients, $\vec{\mu}$ are activation functions, N is pattern row count and P is ANN output neurons count.

This main task consist of three levels: the level of changing the structure, the level of changing the activation functions of the neurons and the level of changing the weight coefficients. Figure 1 shows the general algorithm of training artificial neural networks.


Begin
1
Input of pattern
2
First structure boot
2
3
Training of first neurons condition
3
4
Weight coefficients calculation
1
1
5
Has training of current structure finished
Yes
No
6
Has training finished
Yes
No
7
Changing of neurons condition
8
Changing of structure
End
2
3

Pic. 1: The scheme of training of artificial neural network.

It is possible to develop parallel algorithms of training on each level:

- on the level of calculaing the value of the target function,
- on the level of updating the weight coefficients,
- on the level of searching the neuron activation function,
- on the level of training the structure.

Each of these will be discussed in the next section.

3 Parallel calculation on different levels

3.1 Parallel calculation of the value of the target function

If there are n processors and the pattern consists of N rows then each processor can calculate the inaccuracy for part of the pattern (equation 3) for processor number k and equation 2 for the zero (lead) processor. Then the zero processor sums up (formula 4). So the lead processor sends M rows to each processor, calculates the inaccuracy by $\hat{M}$ rows, receives the inaccuracies from the other processors and calculates the result. Values of M and $\hat{M}$ are calculated by formulas 5–6 [3].

$$\varepsilon_0 = \sum_{i=0}^{\hat{M}-1} \sum_{j=0}^{P-1} (d_{i,j} - F(\vec{x}_i, \vec{w}, \vec{\mu})_j)^2 \qquad (2)$$

$$\varepsilon_k = \sum_{i=0}^{M} \sum_{j=0}^{P-1} (d_{i+(k*M)+\hat{M},j} - F(\vec{x}_{i+(k*M)+\hat{M}}, \vec{w}, \vec{\mu})_j)^2, \quad k > 0 \qquad (3)$$

$$\varepsilon = \frac{1}{N} \sum_{k=0}^{n-1} \varepsilon_k \qquad (4)$$

$$M = \begin{cases} \left[\frac{N}{n}\right], & N \; mod \; n = 0; \\ \left[\frac{N}{n-1}\right], & N \; mod \; n \neq 0; \end{cases} \qquad (5)$$

$$\hat{M} = \begin{cases} M, & N \; mod \; n = 0; \\ N - M(n-1), & N \; mod \; n \neq 0; \end{cases} \qquad (6)$$

3.2 Parallel training of weight coefficients

There are different methods for the level of updating weight coefficients training. These are the method of full scanning, the Monte-Carlo method and several gradient methods. Each method uses unique parallel training.

3.2.1 Method of full scanning

This method searches all variants of weight coefficients values. So the value of the i-th weight coefficient in the I-th iteration is calculated by formula (7). The method iterates I_F times (the value of I_F is calculated by formula (9)).

$$w_i^{(I)} = l_0^{down} + s_i \times \left(\left[\frac{I}{\hat{s}(i)} \right] \; mod \; \left(\left[\frac{l_i^{up} - l_i^{down}}{s_i} \right] + 1 \right) \right) \qquad (7)$$

$$\hat{s}(i) = \begin{cases} 1, & i = l_w - 1; \\ \prod_{j=i+1}^{l_w-1} \left(\left[\frac{l_j^{up} - l_j^{down}}{s_j} \right] + 1 \right), & i < l_w - 1; \end{cases} \qquad (8)$$

$$I_F = \prod_{i=0}^{l_w-1} \left(\left[\frac{l_j^{up} - l_j^{down}}{s_j} \right] + 1 \right) \qquad (9)$$

Here l_i^{up}, l_i^{down} are the upper and lower limits of the i-th weight coefficient, s_i is the step of the i-th scanning of the weight coefficient, and l_w is the weights count.

If there are n processors then each nonzero processor iterates J_F times (formula (10)) ,and the lead processor iterates $\hat{J}_F$ times (formula (11)).

$$J_F = \begin{cases} \left[\frac{I_F}{n}\right], & I_F \; mod \; n = 0; \\ \left[\frac{I_F}{n-1}\right], & I_F \; mod \; n \neq 0; \end{cases} \qquad (10)$$

$$\hat{J}_F = \begin{cases} J_F, & I_F \; mod \; n = 0; \\ I_F - J_F(n-1), & I_F \; mod \; n \neq 0; \end{cases} \tag{11}$$

3.2.2 Monte-Carlo method

In this method, the weight coefficients are initialised with random values $\vec{r} = (r_0, r_1, \ldots, r_{l_w - 1})$. In each iteration each processor generates k points $\vec{w}_k^{(I)}$ of weight coefficients in the neighbourhood of $\vec{w}^{(I-1)}$ and calculates the inaccuracy $\varepsilon_k^{(I)}$ for each of these points. Then the zero processor chooses the minimum inaccuracy ($\varepsilon^{(I)} = \min\limits_k(\varepsilon_k^{(I)})$). If this inaccuracy is less than the current inaccuracy then the new coefficients will be set to network [5].

3.2.3 Gradient methods

Gradient methods are based on the calculation of a gradient vector and change the values of the weight coefficients in the opposite direction:

$$\vec{w}^{(I)} = \vec{w}^{(I-1)} - \vec{s}^{(I)} \nabla \varepsilon^{(I)} \tag{12}$$

Here $\nabla \varepsilon = (\frac{\partial \varepsilon}{\partial w_0}, \frac{\partial \varepsilon}{\partial w_1}, \ldots, \frac{\partial \varepsilon}{\partial w_{l_w - 1}})$ is the gradient.

This is the general idea but different gradient methods (for example QuickProp and RPROP) can use other similar formulas.

In these algorithms the vector of weight coefficients is divided into n parts and each part is located on a different processor. The lead processor calculates $\hat{N}_w$ weight coefficients, and the other processors calculate $\hat{l}_w$. The values of $\hat{l}_w$ and $\hat{N}_w$ are calculated by formulas (13)-(14) [3].

$$\hat{l}_w = \begin{cases} \left[\frac{l_w}{n}\right], & l_w \; mod \; n = 0; \\ \left[\frac{l_w}{n-1}\right], & l_w \; mod \; n \neq 0; \end{cases} \tag{13}$$

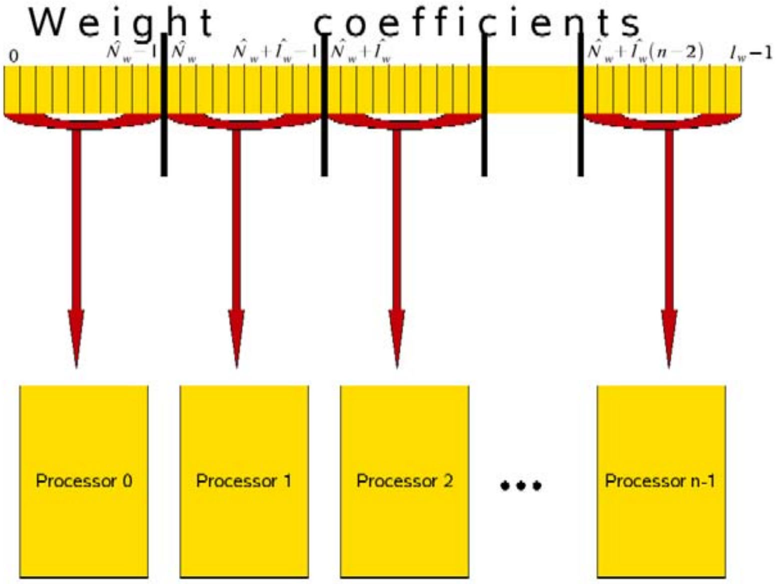
$$\hat{N}_w = \begin{cases} \hat{l}_w, & l_w \; mod \; n = 0; \\ l_w - \hat{l}_w(n-1), & l_w \; mod \; n \neq 0; \end{cases} \tag{14}$$

3.3 Parallel search of the neuron activation function

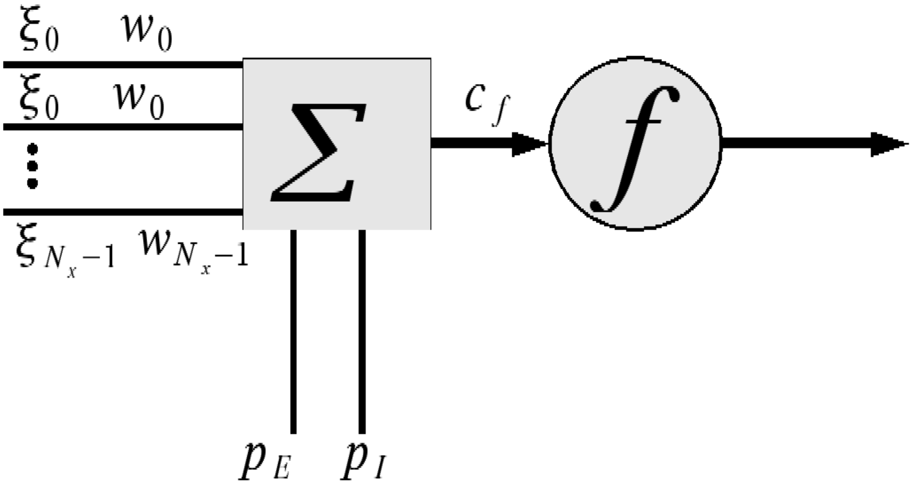
A universal mathematics neuron consists of two parts — an adder and an activation function (pic. 3). An adder calculates the sum of products of input signal values and weight coefficients. The output neuron value is calculated by formula (15). So a neuron has several search parameters — two impulses (internal and external), the activation function coefficient(s) and the type of activation function. Several types of functions (for example threshold functions) need some other parameters.

$$y = f\left(c_f\left(\sum_{i=0}^{N_x - 1}(\xi_i w_i) + p_I + p_E\right)\right) \tag{15}$$

Here c_f is the coefficient of activation function, p_I, p_E are the internal and the external impulse (appendant weights), $\vec{\xi}$ contains the input signals, N_x is the count of input signals, and f is a function of some type.



Pic. 2: The location of weight coefficients on processors.



Pic. 3: Universal mathematics neuron.

Training the activation function consists of searching all these parameters. It needs a full scanning of all variants. It symbolizes all possible values of the i-th activation neuron function as $\vec{\nu}_i$ (first function value is $\vec{\nu}_{i,0}$) and size of this vector as $N(\vec{\nu}_i)$. So there will be I_μ iterations (this is calculated by formula (16)), and the activation function value of the i-th neuron in the I-th iteration is calculated by formula (17).

$$I_\mu = \prod_{i=0}^{l_\mu-1} N(\vec{\nu}_i) \tag{16}$$

$$\mu_i^{(I)} = \nu_{\iota,i}, \quad \iota = \left[\frac{I}{\hat{s}(i)}\right] \; mod \; N(\vec{\nu}_i) \tag{17}$$

$$\hat{s}(i) = \begin{cases} 1, & i = l_\mu - 1; \\ \prod_{j=i+1}^{l_\mu - 1} N(\vec{\nu}_j), & i < l_\mu - 1; \end{cases} \tag{18}$$

Here l_μ is the number of neurons.

If there are n processors then each nonzero processors iterates J_μ times (formula (19)), and the lead processor iterates $\hat{J}_\mu$ times (formula (20)).

$$J_\mu = \begin{cases} \left[\frac{I_\mu}{n}\right], & I_\mu \ mod\ n = 0; \\ \left[\frac{I_\mu}{n-1}\right], & I_\mu \ mod\ n \neq 0; \end{cases} \tag{19}$$

$$\hat{J}_\mu = \begin{cases} J_\mu, & I_\mu \ mod\ n = 0; \\ I_\mu - J_\mu(n-1), & I_\mu \ mod\ n \neq 0; \end{cases} \tag{20}$$

3.4 The parallel training of the neural network for its structure

Usually in the beginning the structure is minimal, and then new neurons and layers are appended and inserted. Input neurons count is equal input pattern size and output neurons count depends from output pattern size. In the beginning the structure has one hidden layer witch consists of one neuron (if it is possible for using structure type). After training for structure (selection of activation functions and weight coefficients) the inaccuracy value is checked. If this value is large then a new neuron is added in the hidden layer and the network is again trained for structure. Such an operation is repeated until adding neurons leads to a depreciation of the inaccuracy . After this a new hidden layer with one neuron is added. The training finishes after the inaccuracy is below a threshold value (or when some other stopping criterion is met) [1].

The lead processor builds the structure and sends it to some free processor, and this processor begins to search activation functions and weight coefficients. After the end of the training this processor sends the structure back to the zero processor and receives a new structure. This process continues until a stop constraint is executed.

4 Estimating the performance of parallel algorithms for ANN training

If a serial training algorithm spends t hours, then the time expense of an ideal parallel algorithm τ_I is calculated by formula (21). But ideal time expense is impossible because such effect is possible only in particular cases. So the real time expense of parallel training is calculated by formula (22).

$$\tau_I = \frac{t}{n} \tag{21}$$

Here n is the number of processors.

$$\tau_R = \frac{t}{n} + \Phi(n) \tag{22}$$

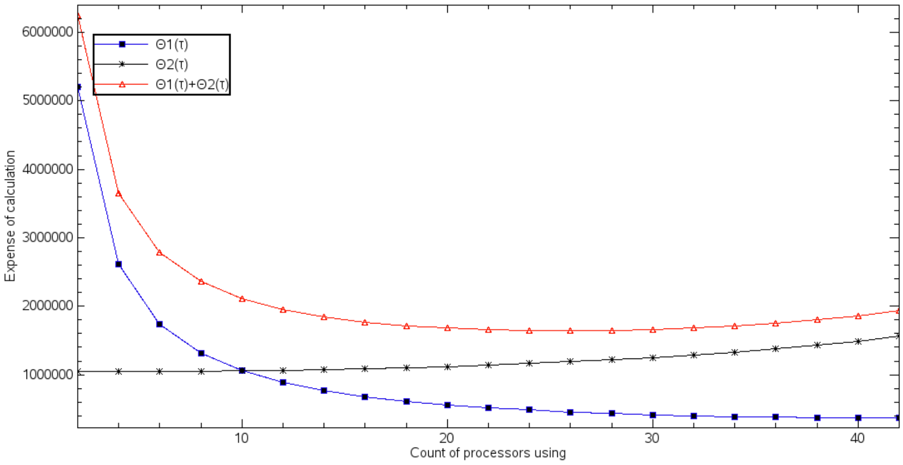
Here $\Phi(n)$ is the time expense for preparing and sending data.

So the efficiency coefficient may be calculated by formula (23).

$$\alpha = \frac{t}{\tau_R n} \tag{23}$$

where t, τ_R is the time expense of serial and parallel algorithms, and n is the numbver of processors.

The increase of the number of processors involves a speedup of training. But after several moments the time expenses begin to rise. The reason for this is the large time expense for transferring data from one processors to some other. So there is an optimal number of processors for each task. This count depends on the expense of calculation waiting ($\Theta_1(\tau)$ in pic. 4) and the expense of computer cluster using ($\Theta_2(\tau)$ in pic 4). The value $\Theta_1(\tau) + \Theta_2(\tau)$ in pic 4 shows the total expense.



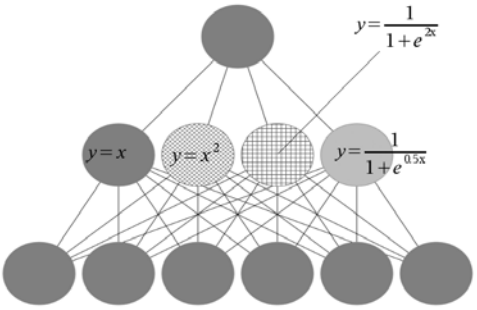
Pic. 4: Dependence of expense from processors count.

5 Experiments

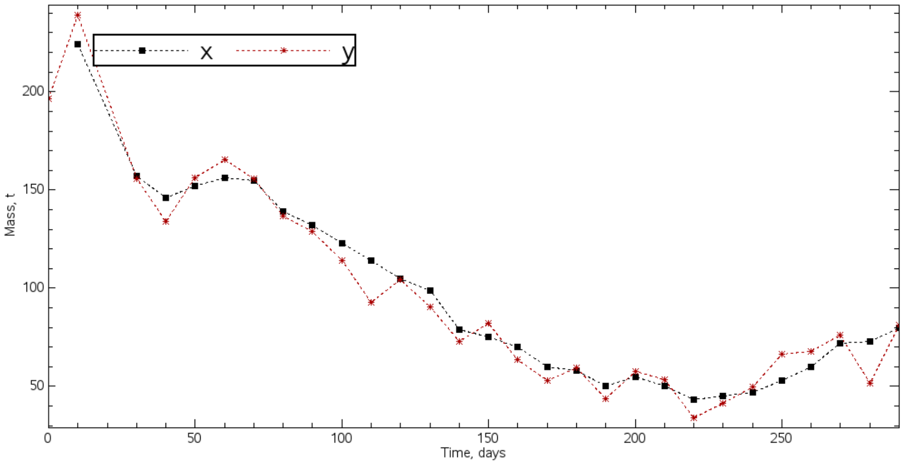
For checking the efficiency of parallel algorithms several experiments were done. All experiments were done on the computer cluster of Tambov State University, on the computer cluster of Tambov State Technical University and on the computer cluster of Moscow Calculation Center. ANN models were built by serial and parallel algorithms (using 4, 6 and 8 processors) and coefficient of efficiency was calculated. There were gradients training algorithms and there were two levels – the level of target function value calculation and the level of weight coefficients calculation.

5.1 Caught shrimp mass forecasting

The first experiment is forecasting the mass of caught shrimp. This experiment uses a multilayer perceptron [6]. Pic. 5 shows the obtained ANN structure and pic 6 shows the empirical and predicted values of shrimp mass. The values of the efficiency coefficient can be found in table 3.



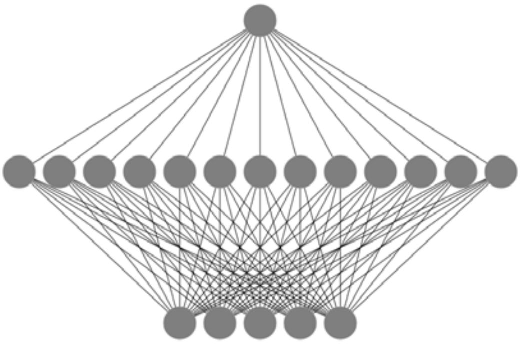
Pic. 5: ANN structure in the experiment on forecasting caught shrimp mass.



Pic. 6: Empirical (x) and forecast (y) values of the mass of caught shrimp.

5.2 Air temperature forecasting

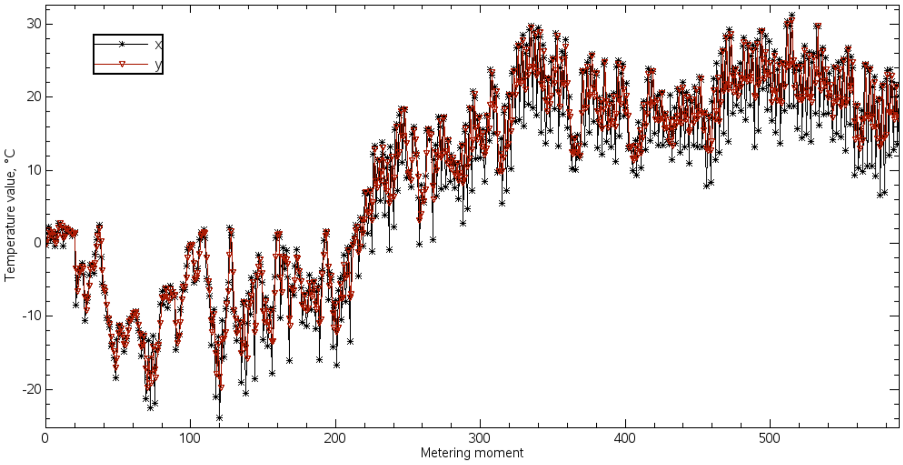
The second experiment is the forecast of the air temperature in Tambov (Russia)[7]. The values are shown in pic. 8, the structure is shown in pic. 7, and the coefficients of efficiency are shown in table 2.



Pic. 7: ANN structure in forecasting of air temperature.

Tab. 1: Coefficient of efficiency values for the experiment on forecasting caught shrimp mass

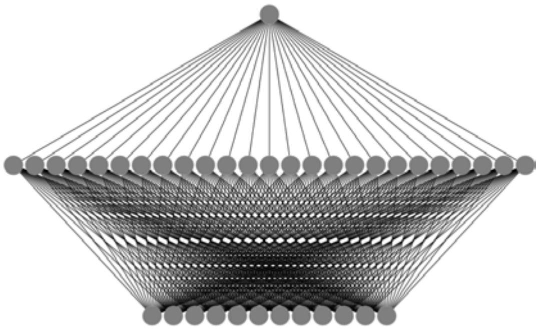
	Cluster TSU	Cluster TSTU	Cluster MCC
α_{wG} (4 proc)	0.9235	0.9199	0.9297
α_{wG} (6 proc)	0.9221	0.9157	0.9291
α_{wG} (8 proc)	0.9204	0.9105	0.9283
α_{ε} (4 proc)	0.8921	0.8822	0.9091
α_{ε} (6 proc)	0.8906	0.8793	0.9079
α_{ε} (8 proc)	0.8891	0.8769	0.9067



Pic. 8: Empirical (x) and forecast (y) values of air temperature.

5.3 Forecast of currency exchange rates

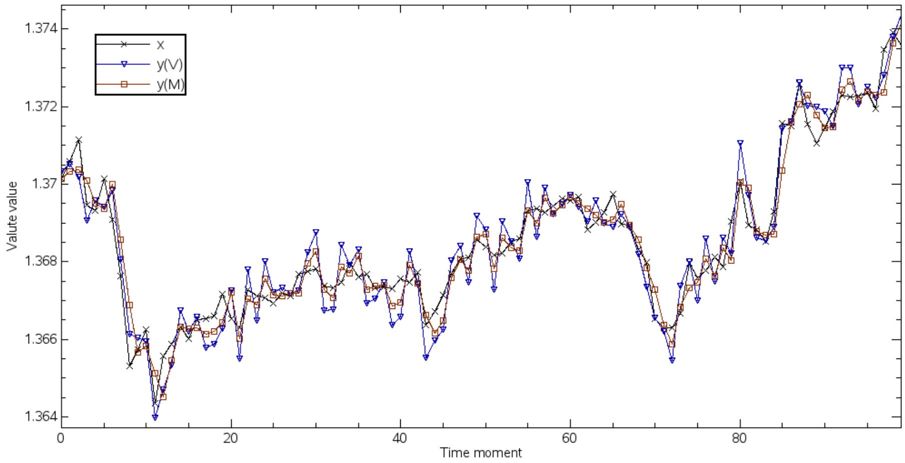
The third experiment is the forecasting of exchange rates between Euro and US dollar. This experiment uses a multilayer perceptron (MLP) and a Volterry network [4]. Values are shown in pic. 9, the MLP-structure is shown in pic. 10, and coefficients of efficiency are shown in table 3.



Pic. 9: ANN structure in forecasting of currency exchange rates.

Tab. 2: Coefficient of efficiency values for experiment of air temperature in Tambov

	Cluster TSU	Cluster TSTU	Cluster MCC
α_{wG} (4 proc)	0.9312	0.9287	0.9401
α_{wG} (6 proc)	0.9304	0.9273	0.9393
α_{wG} (8 proc)	0.9297	0.9259	0.9387
α_{ε} (4 proc)	0.9124	0.8974	0.9199
α_{ε} (6 proc)	0.9112	0.8951	0.9182
α_{ε} (8 proc)	0.9103	0.8936	0.9169



Pic. 10: Empirical exchange rates (x), exchange rates forecast by multilayer perceptron (y(M)) and by Volterry (y(V)).

5.4 Social object modeling

The last experiment is social object simulation. Social object here is the dependence of schoolboys' professional ability on their personal characteristics [2]. Coefficients of efficiency are shown in table 4.

6 Conclusion

So this paper brings together the technology of artificial neural networks and the technology of parallel algorithms. Aning information system with parallel algorithms of ANN training was developed. The theoretical expressions of defining of efficiency of parallel algorithms were deduced, and numerical experiments for check the efficiency of these algorithms were done.

Tab. 3: Coefficient of efficiency values for experiment of forecasting currency exchange rates

	Cluster TSU	Cluster TSTU	Cluster MCC
α_{wG} (4 proc)	0.9319	0.9281	0.9438
α_{wG} (6 proc)	0.9302	0.9271	0.9392
α_{wG} (8 proc)	0.9293	0.9261	0.9389
α_{ε} (4 proc)	0.9127	0.8975	0.9202
α_{ε} (6 proc)	0.9111	0.8949	0.9181
α_{ε} (8 proc)	0.9101	0.8932	0.9165

Tab. 4: Coefficient of efficiency values for the experiment of social object simulation

	Cluster TSU	Cluster TSTU	Cluster MCC
α_{wG} (4 proc)	0.9212	0.9103	0.9396
α_{wG} (6 proc)	0.9212	0.9103	0.9391
α_{wG} (8 proc)	0.9211	0.9098	0.9373
α_{ε} (4 proc)	0.9129	0.8977	0.9205
α_{ε} (6 proc)	0.9114	0.8951	0.9188
α_{ε} (8 proc)	0.9103	0.8935	0.9169

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