Model and Algorithm of Artificial Immune System for the Recognitions of Single Symbol and their Comparison with Existing Methods

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Abstract: The present paper is devoted to the creation of a model and algorithm of an artificial immune system (AIS). In the description of the proposed artificial immune system model and algorithm the terminology from the natural immune system is preserved. The adopted concept of B-cells are responsible for producing antibodies, a special class of complex proteins on the surface of B-lymphocytes, capable of binding to certain types of molecules (antigens) is used. The full set of antigenic receptors of all B-cells is a plurality of antibodies that can be produced by the organism. The proposed model is considered for realization of the problem of single symbols recognition. The uniform algorithm of realization of the artificial immune system for solving problems of recognition (recognition of single symbols) is developed, and its improved distributed version, using the concept of decentralized nature of immune system, is carried out. Accuracy of calculations is compared to that for other methods, particularly to neural networks. The program product involving the algorithms is developed, and computing experiments for each considered task are made.

Key-Words: artificial immune system, model, algorithm, lymphocytes, affinity, object-oriented model, immune network, immune memory

1 Introduction

Genetic programming [1] is the oldest method of automatic program creation by means of genetic algorithm, developed by American computer scientist J. R. Koza. This method is based on computer language *LISP*, which is able to manipulate symbolic expressions. During existence of GP the numerous processes such as: data fitting, logical expressions synthesis, robot trajectory optimization, synthesis of a program for artificial ant movement, system identification, etc. were executed.

The description of the first artificial immune system models appeared in the work of Farmer, Packard, and Perelson [1]. It is the most recent concept that has been transformed to informatics from biology. The very basis of the artificial immune systems was created only in the middle of the 1990s. In 1994, Kepkhart [2] described the negative selection algorithm. The first collective monograph on artificial immune systems was published in 1999 [3]. Later in 2000s appeared some other models of artificial immune systems, however the majority of them have been dealing with the concept of only one type of cells, namely, *B-lymphocytes*, without taking into consideration such features of immune systems as *distribution* and *decentralization*.

The natural immune system is a complex system consisting of several parts with different functionality [16]. The immune system uses multilevel protection against external hostile antigens with the help of nonspecific (congenital) and specific (acquired) protective mechanisms. The main role of the immune system is to classify the cells and molecules as "friends" and "foes". The immune system recognizes a variety of different antigens, from viruses to parasitic worms, and distinguishes them from the genuine cells. Recognition of the antigens is complicated by their adaptation and evolutionary development of new methods of successful infecting of the host's organism. When the foreign cell is detected, it is further classified and, depending on the result, the immune system triggers the protective mechanism with the purpose to destroy the foreign molecules.

Let us consider the human immune system, what it consists of and how it functions. The human organism supports a great number of immunocompetent cells, circulating throughout the body. The immune system cells, which play the key role in the acquired immunity, are lymphocytes that are a subtype of leukocytes. The most part of lymphocytes are responsible for the specific acquired immunity since they are capable of recognizing the infectious antigens inside and outside the cells, in tissues or in blood. Other cells, phagocytes, are auxiliary cells, are capable of destroying foreign molecules or cells. The lymphocytes are divided into B-lymphocytes and T-lymphocytes. All lymphocytes are formed in the bone marrow, and T-lymphocytes additionally undergo a stage of differentiation in the thymus. Both B- and T-cells carry on their surfaces receptor molecules that recognize specific proteins. The receptors represent a "counterimpression" of a certain part of a foreign molecule capable of joining it. In this one cell may only contain receptors of one antigen type [15,16].

Among T-lymphocytes are distinguished T-helpers that can strengthen or suppress the B-cells reaction to the stimulus; T-killers responsible for destroying the genuine cells of the organism infected by viruses and other pathogenic intracellular microorganisms [16]. B-cells are responsible for producing antibodies, a special class of complex proteins on the surface of B-lymphocytes, capable of binding to certain types of molecules (antigens). The full set of antigenic receptors of all B-cells is a plurality of antibodies that can be produced by the organism.

When the antigen gets into the organism, just a small number of the immune system cells can recognize it. Such recognition stimulates the processes of reproduction and differentiation of lymphocytes, resulting in creation of clones of identical cells. Such process (called "clone reproduction") forms a large population of cells specific to this concrete antigen of cells, which results in destruction or neutralization of the antigen. After that, a part of the formed cells is stored in the immune memory. As a result, subsequent impact of this or similar antigen leads to a faster immune response (secondary response).

There are two main variants of the immune response: *Humoral*, using B-cells and their products, and *Cellular*, where T-cells participate. Both immune responses correspond to similar sequences of organism protection stages: activation, division, differentiation, secretion, immune attack, suppression and memory, yet they are executed differently. For the regulation of both Humoral and Cellular responses T-helpers are important, which either enhance or suppress the immune response.

The natural immune system is of great interest for informatics, because it can process large data volumes and its calculations have highly parallel and distributed character [3]. The goal of this paper is to present the development of the model and algorithm of an artificial immune system (AIS) and to compare the accuracy of calculations to that for other methods, especially to neural networks. The proposed model is considered for realization of the problem of unit symbols recognition. The structure of the paper is:

1. Introduction.
2. Model of an Artificial Immune System.
3. Model of an Artificial Immune System for the Problem of Symbol Images Recognition.
4.Description of the Adopted Immune Network in the Problem of Symbol Images Recognition
5. Algorithm of Realization of Artificial Immune System for the of Symbol Images Recognition.
5.1 Result accuracy. Test examples, comparison with the existing methods
5.2. A program complex of realization of the offered algorithms
6.Conclusion
7. References

2. Model of an Artificial Immune System

We suggest the mathematical statement of artificial immune systems, which could be presented as a set of the following elements [14]:

$$IIS = \langle L, G, A, m, S \rangle$$

where:

- *IIS* is the artificial immune system;
- *L* is the space of all possible lymphocytes; in so

doing a lymphocyte can represent a line, a list of coordinates, or an expression tree;

- G is a set of all possible antigens; in so doing G can be a line, a matrix of logical values, and/or a list of values of a function in the known points;

- $A: L \times G \to [0,1]$ is the given measure of affinity which assigns to each lymphocyte and each anti-gen a certain number from the segment [0, 1] (this number shows how "well" this lymphocyte reacts on the given anti-gen);

- $\mu: L \to L$ is the mutation operator which is applied to a certain lymphocyte for the improvement of its recognition properties;

- $S: A \subset L \to B \subset A \subset L$ is the selection operator leaving the best lymphocytes in the current immune system, supporting the network size.

Then algorithm could be presented as a sequence of the following steps:

- Step 1 is to create initial immune system – $\mathrm{Im}\,System \subset L$.

In this step, the given number of admissible lymphocytes for a particular problem is generated randomly to form an initial system.

- Step 2 is to get $g \in G, \forall l \in \mathrm{Im}\,System : a_l = A(l, g)$.

In this step, the affinity (fitness) of all lymphocytes of the current immune system is calculated (using the corresponding antigens approach to all lymphocytes).

- Step 3 is to define the best lymphocyte $l^* = \arg\max(a_l)$.

- Step 4 is to apply the mutation operator $M = \{\mu(l), l \in Im\,System\}$ to lymphocytes.

The mutation operator can be applied not to all lymphocytes, but to a certain subset (more frequently to those possessing the higher value of affinity). The mutation operator makes equal small changes in the value or structure of the lymphocyte.

-Step 5 is to utilize the selection operator for preserving the network size; the selection operator selects and keeps lymphocytes with the greatest values of affinity (from the current set of lymphocytes and from the set of the mutated lymphocytes obtained in step 4).

$Im\,System = S(Im\,System \cup M)$;

-- Step 6 is to decide whether l^* matches the given criteria or the maximum number of iterations is achieved. If yes, then go to the exit, otherwise return to Step 2.

Summarizing, it could be noted that the immune system solves a problem of optimizing the function, which represents the affinity. For various technical tasks this model and algorithm would change, depending on a given problem.

3. Model of an Artificial Immune System for the Problem of Symbol Images Recognition

The algorithm of artificial immune systems can be used for the recognition of symbol images, thus the problem of the single symbol recognition is considered first.

Initial data in this problem is a single symbol image. The input information is a file with an image in supported format (.bmp, .jpg). In order not to restrict the set of images, let's assume that they may be of any color and size. On the other hand, the algorithm reads an image as the matrix of Boolean values. Thus, we face the problem of image pre-processing, i.e. its scaling and binarization [4,5].

At first the color image set in the RGB format needs to be converted into the gray scale image (utilizing the procedure described in [4,5]). This procedure will give us the image with 256 tones of gray. Then it needs to be converted into the two-color image. Binarization of the image represents the process of image transformations consisting of the gradation of one color (gray) to a bitmap, i.e., the image with each pixel can have only two colors (in our case it is black and white colors). The result of such conversions is the desired image representation.

To solve the problem of binarization, let's utilize the Otsu method [4], which is the most effective from all the methods of global binarization both by its quality (mistakes up to 30% or less) and by processing speed. This method adopts the histogram of values distribution of raster image pixel brightness. The histogram is constructed according to the values $p_i = n_i / N$, where $\boldsymbol{N}$ is a number of image pixels, and n_i is a number of pixels with the brightness of i -level. The brightness range is divided into two classes by means of brightness threshold value of k- level**,** where k is the integer value from 0 to 255. Relative frequencies refer to each class. By means of these formulas we will obtain η - threshold, which is a border between two classes, those shades, which are less than a threshold value, will be referred as 0, while the others will be assigned to 1.

Moreover all images to be recognized should be reduced to pre-assigned dimensions. For the solution of this problem, we will use the scaling algorithm based on the Brezenkhem algorithm [5]. Thus, from the image of arbitrary size it is possible to obtain the transformed image of the desired size. First, we need to define the borders of the rectangular area occupied by the symbol image itself. Then, if the detected size of this area does not coincide with the desired size, the scaling operation needs to be performed again.

As a result of all these transformations, we will obtain the matrix of given dimensions, consisting of logical values, representing a recognizable image.

4. Description of the Adopted Immune Network in the Problem of Symbol Images Recognition

Classification of separate cells and molecules is the most important property of the natural immune network. Conditionally it is possible to allocate two types of such classification, namely: simple analysis “friend vs. foe” and more detailed analysis of those cells and molecules, which were classified as “foes”. We suggest adopting the principle of the detailed analysis of “foes” in artificial immune system model for solving the problem of symbol images recognition, where images will play the role of antigens, and artificial prototype of immune system on the basis of reaction of *B*-lymphocytes will define the type of these antigens. However this problem has some significant peculiarities. Let us state the most important of them. Unlike in the case of natural immune system, the amount of antigens in the given problem is small and known in advance. With this in mind, a certain antigen can be assigned to each artificial lymphocyte, to which this lymphocyte will react. This allows us to simplify the procedure of finding the quantity of lymphocytes i.e. recognizing the symbol images configuration.

In the natural immune system the classification is happening with the help of chemical reactions. For the artificial immune system we suggest the following network organization and lymphocytes representation:

- Step 1 - preprocessing of the image. The monochrome image can be presented as $M \times N$ matrix of Boolean values in which ‘true’ occupies those places which correspond to black pixels and actually format the image.

- Step 2 - representation of the *B*-lymphocytes concept. A concept of lymphocyte from the natural immune system can be presented in the artificial immune system concept as an array of P couples of numbers. Each of such couples represents the pixel coordinates in the image. However, we will use a bit more complicated conceptual representation of the lymphocyte, namely a lymphocyte in which the information about those pixels that should be white (blank) is still stored. Thus, our lymphocyte contains two lists of coordinates; one of which stores coordinates of black pixels and the other stores coordinates of white pixels. Then number S may be presented as a sum $S=S1+S2$, where $S1$ is a number of black pixels of the input image (antigens) which are defined by coordinates from the first list of the lymphocyte, and $S2$ is a number of white pixels of the input image (antigens) which are defined by coordinates from the second list of the lymphocyte. The structural model of the lymphocyte is given in Fig. 1

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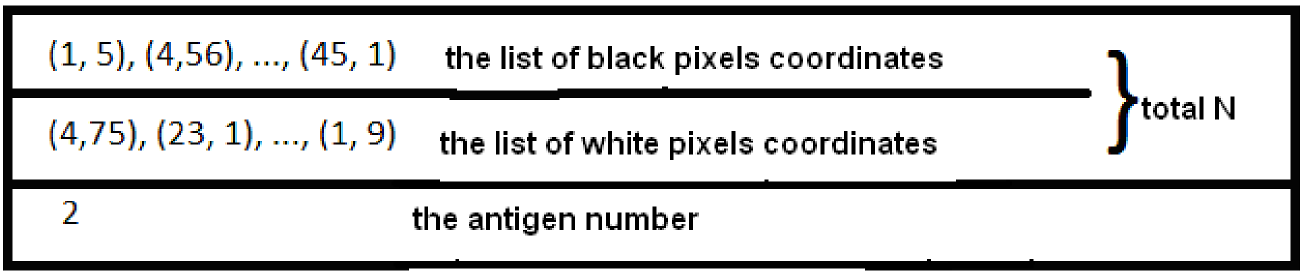

Fig. 1 Structural model of a lymphocyte

-Step 3 - calculation of the affinity. Lets introduce a certain number $S<P$ in order to describe the lymphocyte reaction on the antigen, as well as the affinity measure to this antigen for each according to the following formula: $f = S / N$, where N is the number of pixels in both lists of the lymphocyte (the number of pixels, about which the lymphocyte stores information).

- Step 4 – composition of the network. To simplify the natural immune system model we suggest considering only B-lymphocytes for classification of each antigen. T-lymphocytes in this artificial system will not be considered.

5. Algorithm of Realization of Artificial Immune System for the of Symbol Images Recognition

As in the most pattern recognition algorithms, our algorithm consists of two main parts: training and actual work. Training in the algorithm, which uses the immune system, is a trainer-free process: the tested system is trained to perform an objective task without intervention from an experimenter. In this problem, this type of training is adopted, because descriptions of the set of objects (of the training selection) are known, and the system is required to detect the internal relationships, dependencies, regularities that exist between these objects.

Thus the actual recognition is reduced to the following:

1) The image to be recognized is settled in the form of pre-processed Boolean matrix values.

2) The array with numbers of antigens is created and filled with zeros.

3) For all lymphocytes of a network, the affinity to the particular antigen is calculated. If it is greater than some threshold value (i.e. the lymphocyte reacts to this antigen), then an array element with the index equal to the number of the antigen (assigned to the lymphocyte during its creation) is increased to a number value, depending on affinity.

4) In the resulting array the maximal element is located. As the array represents affinity values (of objective function), then having chosen among all its elements the maximum one, we could define the number of the antigen to which the immune system accumulates the greatest affinity. Its index will be that answer of the immune network.

As a strategy to control the number of lymphocytes in the artificial immune system, we suggest two of the following actions:

1) Make each lymphocyte to store a time mark when it was last time activated, i.e. when its affinity to the presented antigen was greater than the threshold. The weak points of this action is that if images for recognition feed unevenly, for example, one did not feed for a long time, all lymphocytes corresponding to this image will be removed from the network and its recognition will become impossible. To improve this we suggest keeping the part of the training sampling for checking the generated on the training step lymphocytes. Those lymphocytes, which will remain inactive during the checking, are to be removed.

2) To add to the network composition a lymphocyte specially trained to react to the image that gives enough confidence for the answer after it has been fed for recognition, i.e. in the array responsible for an answer description during the recognition process, one number defining the image class is larger than all others (or dominates in any other way).

It is obvious that in above described algorithm the following simplification in comparison with functioning of the natural immune system is used, namely the quantity of various types of antigens is known in advance, unlike in biology.

The algorithm consists of two main parts: training and actual action. Training in the algorithm using the immune system is a trainer-free process: the tested system is trained to carry out an objective without intervention from an experimenter. In this problem, this type of training is adopted because descriptions of a set of objects (the training selection) are known, and the system should find the internal interrelations, dependences, and/or relationships existing between these objects.

Actually the recognition is reduced to

1) The image to be recognized is settled in the form of a Boolean matrix values;

2)The array with numbers of anti-genes is created and filled with zero.

3) For all lymphocytes of a network, affinity particular anti-gene is calculated. If it is more than some threshold value, i.e., the lymphocyte reacts to this anti-gene, then an array element with the index equal to the number of the anti-gene is increased by a value depending on affinity.

4) In the resulting array, the maximal element should be found. As the array represents values affinity (goal function), then having chosen among all its elements the maximum one we could define the number of the anti-gene, to which the immune system possesses the greatest affinity. Its index will be the answer of an immune network.

As the strategy to control the number of lymphocytes of the immune system, two actions are suggested:

1) Each lymphocyte stores a time mark when it was last time activated, i.e., its affinity to the presented anti-gene was higher than the threshold. If images for recognition move unevenly, for example, one did not move for a any long time, all lymphocytes corresponding to this image will be removed from the network, and its recognition will become impossible. For the solution of this problem, it is possible to leave part of the training selection for

checking the lymphocytes generated on a training step. Inactivated lymphocytes should be removed.
2) After submission of the image for recognition, if the confidence in the answer is enough, i.e. in the array responsible for an answer description during recognition, one number defining the image class is larger than others, then the lymphocyte trained especially for response to this image is added to the network structure.

It is obvious that in this algorithm the following simplification in comparison with functioning of the natural immune system is used, namely: the quantity of various types of anti-genes is known in advance, unlike to biology.

5.1, Result accuracy. Test examples, comparison with the existing methods

For solving the problem of comparison of functioning of various algorithms for hand-written symbols recognition the data from MNIST database (Mixed National Institute of Standards and Technology database) were used [6-11].

Here is the test example aiming on the result accuracy proof. The set of symbols for training consists of 60,000 images of handwritten digits from 0 to 9. The size of each image is 28 by 28 pixels, each character is scaled to this size. The color image is 255 shades of gray, where white is background and black color is the symbol itself.

As a test sample a set of 10,000 characters of the same size is used.

For the solution of this problem the artificial immune system with the following parameters is used:

1) The lymphocyte size is 200 pixels.
2) The threshold value of affinity (at which it is considered that the lymphocyte reacted to the given image) is equal to 0.8.
3) The amount of the training selection is 60000 symbols.
4) The amount of test selection is 10000 symbols.
5) During the training for each fed image 80 lymphocytes reacting to it are generated.

After the training of the artificial immune network using the above-stated parameters, on the test set the algorithm showed the accuracy of 3.04 (Table 1). Data is taken from works [7-11].

Now let us compare the training efficiency of multilayered neural networks and artificial immune systems. For that we will consider the following training set: $\{(x(n), d(n))\}_{n=1}^{N}$. Into the backward propagation of errors algorithm the images from this training set are fed, and for each of them, sequentially, forward and backward passes are performed [13].

Forward pass: let the training example be represented by a pair $(x(n), d(n))$, where $x(n)$ is an input vector and $d(n)$ is the desired network response. Induced local field of neuron *j* of layer *l* is calculated by formula:

$$v_j^l(n) = \sum_{i=o}^{l} w_{ji}^l(n) y_i^{l-1}(n)$$

Where $y_i^{l-1}(n)$ is the output signal of neuron *i* located in preceding layer *l* – 1; is the synaptic weight of link of neuron *j* of layer *l* with neuron *j* of layer *l* – 1. For $i = o : y_0^{l-1}(n) = 1,$ while (n) is the threshold applied to neuron *j* of layer *l*. If sigmoidal function is used, them the output signal of neuron *j* of layer *l* is expressed as follows:

$y_j^l(n) = \varphi(v_j(n))$

If neuron *j* is situated in the first hidden layer (*l* = 1), then $y_j^{(o)} = x_j(n)$, φ, is the function of activation of neuron.

Where $x_j(n)$ is the *j*-th element of input vector *x(n)*. If neuron *j* is situated in output layer (*l* = *L*), then $y_j^{(L)} = x_j(n)$. The error signal is calculated as follows:

$$e_j(n) = d_j(n) - o_j(n)$$

Where $d_j(n)$ is the *j*-th element of the vector of desired response *d*(*n*); o_j is output value of neuron network.

Backward pass: local gradients of network nodes are calculated by formula

$$\delta_j^l = \begin{cases} e_j^l(n)\phi_j'(v_j^l(n)) \ \ for\,output\ layer\,L \\ \phi_j'(v_j^l(n))\sum_k \delta_k^{l+1}(n)\delta_j^{l+1}(n)\ \ for\,hidden\ layer\ l \end{cases}$$

Change of synaptic weights of layer *l* of the network is performed in accordance with generalized delta rule

$$w_{ji}^l(n+1) = w_{ji}^l(n) + \alpha[w_{ji}^l(n-1)] + \eta\delta_j^l(n)y^{l-1}_j(n)$$

Now, let us calculate the number of operations for each image out of the training set. Change of weights will affect all weights of the network; let us indicate the number of operations for their calculation as W_{weights}, and note that the computational complexity is linear in *W*: *0(W).*

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Table 1. Comparative accuracy of various recognition methods

Method	*Percentage of correctly recognized images of the test set*
Linear classifier (neural network with the 1st level)	12.0
K of the nearest neighbors, Euclidean distance	5.0
Method of principal components and quadratic classifier	3.3
Method of reference vectors (Gaussian kernel)	1.4
Two-layer neural network, 300 neurons in the hidden layer	4.7
Two-layer neural network, 1000 neurons in the hidden layer	4.5
Three-layer neural network, 300 and 100 neurons in the hidden layer respectively	3.05
Three-layer neural network, 500 and 150 neurons in the hidden layer respectively	2.95
Six-layer neural network with the number of neurons 784-2500-2000-1500-1000-500-10, parallel version functioning on video accelerators	0.35
Artificial immune system	3.04

Also, for each neuron in the network its induced cal eld and local gradient will be calculated; let us indicate this number of operations as $W_{neurons}$.

And, since the training is performed interactively (by epochs), for each sample out of the training set these operations will be performed not once, but several times, until the algorithm reaches the stop criteria. As the stop criteria is used reaching by gradient vector Euclidean norm of sufficiently small values, or a sufficiently small absolute intensity of changes of mean square error during the epoch. What is to be considered as "sufficiently small" shall be determined prior to starting the algorithm. Let us indicate the average number of iterations of the back propagation of error algorithm to one element of the training set as N_{iter}. It can be notices that $N_{iter} > 1$ in the general case, since the multilayer turns out that the average number of operations for one training example is: $E_{example} = N_{iter} * (W_{weights} + W_{neurons})$.

While the total number of operations can be calculated by formula: $E = N * E_{example} = N * N_{iter} * (W_{weights} + W_{neurons})$

Let us consider the three-layer neural network with 300 and 100 neurons with the hidden layers respectively. Since the example of the rendered image is 28 by 28 pixels, the system has 784 inputs. Thus, we have that

$W_{weights} = 784 * 300 + 300 * 100 + 100 * 10 = 266\ 200$

$W_{neurons} = 2 * (300 + 100 + 10) = 820$

$E_{example} = N_{iter} * (468\ 500 + 1320) = 469\ 820 * N_{iter}$

In an artificial immune system, the training depends on two parameters: the number of pixels about which the information is stored by lymphocyte (N_{pixels}) and the number of lymphocytes created for each rendered image out of training set (N_{lymph}). For each pixel the generation of two random numbers is required, so we multiply lymphocyte (N_{pixels}) and training set (N_{lymph}). by 2. Then, the number of operations for one sample out of the training set is equal to: $E_{example} = 2 * N_{pixels} * N_{lymph}$

For the considered immune system $N_{pixels} = 200$, $N_{lymph} = 80$, $E_{example} = 32000$, which is 8 times less than that of the neural network with 300 and 100 neurons and 14 times less than that of the neural network with 500 and 150 neurons. It should also be noted that the artificial immune system does not have a notion of the number of iterations (epochs), unlike the immune networks.

5.2. A program complex of realization of the offered algorithms

If we look at the structure of a program complex more in detail [12], we'll see that it involves the subsystem for solving the problem of recognition of single symbols, which is used programming language C# and consists from the following modules:

1. *The recognition module*, which comprises classes of lymphocytes, artificial immune system, and affinity calculation methods.
2. *The pre-processing module*, which realizes algorithms for binarization of the image and scaling.
3. *The module of preservation* and loading of already trained artificial immune system from the file.
4. *The module of the user's graphic interface*.

6 Conclusion

The generic approach involving models and algorithms is developed to formalize the research on the basis of artificial immune systems. The main results are the following:

1. The uniform model is developed for the solution of recognition problems (single symbols recognition) on the basis of artificial immune system, using the fact that one of the main problems of the immune system is to recognize harmful organisms and molecules.
2. The uniform algorithm of realization of the artificial immune system is developed for solving problems of recognition (recognition of single symbols), and its improved distributed version using decentralized nature of the immune system is carried out.
3.The program product involving the algorithms described above developed, and computing experiments for each considered task are made.

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