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Error-Correction of Recognition in the Process of Neuron Learning

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Abstract The learning process of formal neuron, error-correction of recognition through the correction of weight coefficients and neuron threshold is considered. On the first stage, initial descriptions-templates of patterns are chosen or received; on the next stage, according to the results of recognition change-correction of initial descriptions take place; if result of recognition is correct, description will not be changed, if recognition is wrong, then the error will be corrected through early developed algorithm-program module. The Error-correction algorithm is an iterative procedure where every step begins by presenting for recognition of an unknown realization and finishes according to the result of recognition through the procedures of rewarding or non-rewarding. The learning Algorithm consists of two stages: the first, formation of descriptions for the considered pattern through the realizations of initial descriptions and learning set; the second, formation of the final descriptions through the descriptions of the other patterns and their realizations. Vectors of the feature (measurement) space, elements of which are real-number values represent realizations of recognizing patterns. These vectors or even perhaps matrices are equal-dimensioned for each realization and equal to the number of features in the feature space. As needed during the learning process the evaluation of the isolated feature or the whole feature space are carried out according to the correct recognition criterion. Recognition procedure via formal neurons is simultaneously used for the description of patterns, error correction and for the realization of the feature evaluation algorithms. Compact and original description of the recognition process by the formal neuron is offered.

Keywords Neuron, Learning, Error-Correction, Recognition

1. Introduction

Most of works in respect of neuronal networks of the scientific literature describe the construction method of the net structure, however comparatively fewer numbers of works are dedicated to the error-correction throughout the recognition process. In that case when error-recognition process is discussed, e.g. error back propagation algorithm, the reasons of which are not defined and their role (contribution) in the recognition of error. In this work the method of revealing recognition error and correction, which is based on the feedback of neurons are discussed, owing to them information about error is spread, which is followed by the parameters of neurons: weighing coefficients and in case of need changes of the threshold value. Algorithm of changes is iterational and proceeds up to the time until the error recognition is corrected.

Additionally, the method of evaluation of features is described, owing to that each feature or their group under viewpoint of correct recognition is evaluated.

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2. Description of the Recognition Process by the Formal Neuron

Recognition of unknown or known set of patterns, for example realization of learning set, vectors from feature space get at the entry of recognition system, in our case neuron or neuronal network. As a result the coordinates of vectors are multiplied by the appropriate weight coefficients of the neuron. Each member of the received product is summed up by the summing element, whereof neuron reaction is received upon the realization of recognition vectors, NET number, with the help of which we establish appropriate meaning of the activation function F(NET). The meaning of the activation function is compared to Z neuron threshold. According to the comparison result the output of neuron - OUT is formed, the meaning of which is equal to zero, if the recognition is wrong, or to one if the recognition is correct.

Let us define with predicate "presentation" the appearance of recognizable vector at the input of neuron, mathematical analogue of which is graphically expressed by the symbol " $\Rightarrow\!\!\!\!\!\!\ominus\!\!\Rightarrow$ ", where symbol "⇒" expresses predicate and represents the result received through mathematical operation. This allows us to express recognition process compactly:

$$X \overset{0}{\Longrightarrow} N_e\,(W) \Rightarrow \sum_n x_n\, w_n \Rightarrow F(NET) \overset{0}{\Longrightarrow}$$
$$Z \Rightarrow OUT = \{0;1\} \qquad (2.1)$$

Where X={x_n} is a recognizable realization, Ne(W)-set of neurons with the weighing coefficients W={w}; $\sum_n x_n w_n$-summing element; n=$\overline{1;N}$; N=Card{x_n} the meaning of activation function F(NET) is defined according to NET, that is compared with the value of threshold Z of the neuron and according to the comparison the meaning of output signal OUT of neuron is defined. In particular we have:

OUT=0, if F(NET) < Z; Recognition is wrong; (2.2)

OUT=1, if F(NET) ≥ Z; Recognition is correct; (2.3)

Expression (2.2) describes the process of making decision whilst presenting unknown realization. Let us note that the conclusion of the experimenter about rightfulness and incorrectness of the recognition process, especially while realization of the learning process, might be different from the formal procedure, which we are going to discuss afterwards.

Let us denote pattern set for recognition by A, while the element of this set by A_i: $A_i \in A$, where i=$\overline{1;I}$, I=Card{A}, $X_i \in A_i$, where X_i represents A_i realization; the coordinates of vector X_i are the real numbers received via measuring the features: $X_i = x_{1i}, x_{2i}, \dots x_{ni}, \dots x_{Ni}$.

3. Description of Correct Recognition Process

Correct recognition process consists of two parts. The first, when the realization of recognizable pattern is presented to this kind of recognizing neuron, e.g. X_i realization is presented to $N_e(W)$ neuron.We consider, that in such case realization appeared at the input of "Its" type neuron. The second, one type realization e.g. X_i is presented to $N_{ej}(W_j)$ for recognition, that is "The other" type neuron. Both cases are described in (2.1) and (2.2) terms.

$$X_i \overset{0}{\Longrightarrow} N_{ei}(W_i) \Rightarrow \textstyle\sum_n x_{ni} w_{ni} = NET_i \Rightarrow$$
$$F(NET_i) \overset{0}{\Longrightarrow} Z_i \Rightarrow OUT = 1; \quad X_i \in A_i \qquad (3.1)$$
$$X_i \Rightarrow Ne_j(W_j) \Rightarrow \textstyle\sum_n x_{ni} w_{ni} = NET_{ij} \Rightarrow$$
$$F(NET_{ij}) \overset{0}{\Longrightarrow} Z_j \Rightarrow OUT = 0; \quad X_i \notin A_j \qquad (3.2)$$

Where ij=$\overline{1;I_i}$ $i \neq j$. Let us denote that in (3.1) term OUT=1, but in (3.2) OUT=0; Despite this, in both cases recognition is correct, thereby 3.1 and 3.2 differ from 2.1 and 2.2 terms.

4. Description of Incorrect Recognition Process

We might have two cases among incorrect recognition processes: the first, when any kind of realization is presented to "Its" neuron and the second one type of realization is presented for recognition to "the other's" type neuron. In order to describe the first case let us assume, that X_i is presented to Ne_i neuron, term (3.1), with the difference that the output is equal to zero;

$$X_i \overset{0}{\Longrightarrow} Ne_i \Rightarrow NET_i \Rightarrow F(NET_i) \overset{0}{\Longrightarrow} Z_i \Rightarrow$$
$$OUT = 0; \quad X_i \notin A_i \qquad (4.1)$$
$$X_i \overset{0}{\Longrightarrow} Ne_j \Rightarrow NET_{ij} \Rightarrow F(NET_{ij}) \overset{0}{\Longrightarrow} Z_j$$
$$\Rightarrow OUT = 1; \quad X_i \in A_j \qquad (4.2)$$

Where i,j=$\overline{1;I}$ terms (4.1) and (4.2) give us description of the incorrect recognition process. The aim of the following thesis is to correct this mistake. In order to achieve this aim, hereafter let us discuss in detail the process of making an error and we will work out the algorithms for its correction.

5. Error Correction Whilst Recognizing "Its" Realization

In order to examine the error made by term (4.1) let us discuss the second (last) part of the this term:

$$\textstyle\sum_n x_{ni} w_{ni} < Z_i \Rightarrow OUT = 0, \quad X_i \notin A_i \qquad (5.1)$$

There is one way to correct the error: we must change neuron weighing coefficients of so that it changed the sign of inequality $F(NET_i) < Z_i$:

$$F(NET_i) \geq Z_i \Rightarrow OUT = 1; \quad X_i \in A_i \qquad (5.2)$$

Let us discuss $F(NE\,T_i)$ value-receiving process. The function F(.) is called an activation function, which is various by different nonlinears, we choose one out of them. Activation functions have one similar function: increasing monotonously, existence of nearly linear segment (besides activation function of perceptron). So we can assume, that F(NET) function parameters, or neuron weighing coefficients are chosen in the way that, in case of any kind of change of weighing coefficients we stay on the linear segment of the activation function, so the following correlation is correct:

$$F(NET_i) = k.NET_i = k.\textstyle\sum_n x_{ni} w_{ni}, \quad k > 0;$$
$$k = const \qquad (5.3)$$

In case of term 5.3 is true k value represents scale coefficient, which is changed during the process of learning weighing coefficient. So we receive, that k=1 and accordingly instead of term 5.3, we will have:

$$F(NET_i) = \textstyle\sum_n x_n w_{ni}$$

accordingly instead of term 5.1 we will have: 5.4

$$\textstyle\sum_n x_{ni} w_{ni} < z_i \Rightarrow OUT = 0; \quad X_i \notin A_i \qquad (5.4)$$

In the process of recognition the error correction will take place if (5.1), i.e. instead of (5.4) term we will have inequality expressed by (5.2) term:

$$\textstyle\sum_n x_{ni} w_{ni} \geq Z_i \Rightarrow OUT = 1; \quad X_i \in A_i \qquad (5.5)$$

It is possible to get (5.5) inequality from inequality (4.4) $W_j = \{w_{ni}\}$ through increasing of weighing coefficients. Therefor we should grant weighing coefficients with initial meanings. Let us assume that in A_i realization set we have this type learning realization set for which the following condition is fulfilled: $\mathrm{Card}\{X_i\} = M_i$. Let us count weighing coefficients initial meanings through learning set realization (vectors) coordinates; through so-called awarding procedures:

$$w_{ni} = \frac{1}{M_i}\sum_m x_{ni}^m ;\ n = \overline{1;N};\ i = \overline{1;N} \qquad (5.6)$$

By conducting overlay procedure for any kind of neuron e.g. A_i, we take $\{w_{ni}\}$ weighing coefficients, the values of which are placed at $[\min x_{ni}; \max x_{ni}]$ range. It is possible to increase weighing coefficient step-by-step using recurrent iteration procedure and heuristically i.e. all of a sudden by adding any constant/unvarying number. We should carry out increasing i.e. awarding procedure for the weighing coefficients values of which is close or equals to max x_n, it means these characteristics are more important for the given pattern than any other. Let us discuss recurrent procedure:

$$w_{ni} = [\beta + 1] = w_{ni}[\beta] + \Delta w, \quad \beta = 1.2.3\ \ldots \quad \text{(step numbers)} \qquad (5.7)$$

If we use (5.7) iteration it will be necessary to choose Δw, that must be done by considering initial weighing coefficients. We check the recognition result of iteration at every step through the 5.5 term. We increase the number of steps until it becomes inequality 5.5 true/correct. Which corresponds to present incorrectly recognized realization for recognition for the second time. When weighing coefficients received from the previous step move unchangeably to the next step.

Those values of weighing coefficients, when inequality (5.5) becomes true, let's designate it by W_{ni}, In that case we will have:

$$\sum x_{ni}^m w_{ni}^* \geq Z_i \Rightarrow \mathrm{OUT} = 1; \quad X_i \in A_i ;$$
$$n = \overline{1;N}; \quad i = \overline{1;I}; \quad m = \overline{1;M_i} \qquad (5.8)$$

The truthfulness of 5.8 term means that the error in recognition is corrected. The change of "i "and "m" indexes show that errors can be corrected for M_i realizations of any learning set and for any pattern of A set.

The algorithm of error-correction in (5.8) term does not change correct recognition results received through changes of neuron weighing coefficients of different patterns.

Whilst changing of weighing coefficient we just use "Awarding" procedure expression (5.7); we choose equal quantities as neuron thresholds initial values:

$$Z_i = Z_j; \quad i,j = \overline{1;I};\ i \neq j \qquad (5.9)$$

Then by using (5.8) and (5.6) procedures we have an opportunity to recognize all the learning-set-realizations of pattern sets without errors, so that previously received recognition correct results stay unchanged.

6. Error Correction Whilst Recognizing Realizations of "Other's" Pattern

The process of incorrectly recognition is described by (4.1) and (4.2) terms.

Let us discuss 4.1 expression, where instead of NET_i we write its term according to 5.1.

$$\sum_n x_{ni} w_{ni} < Z_i; \qquad X_i \notin A_i \qquad (6.1)$$

Where $i=\overline{1;I}$

In order to correct the error it is necessary to change inequality signs in (6.1) term, that can be done by increasing w_{ni} weighing coefficients, i.e. with the method described in the previous paragraph.

Let's discus the right part of the (4.2) term:

$$\mathrm{NET}_{ij} = \sum_n x_{nj} w_{nj} \geq Z_j \Rightarrow X_i \in A_j;$$
$$j,i = \overline{1;I}; \quad i \neq j \qquad (6.2)$$

Threshold must be increased for correcting the error, or w_{nj} weighing coefficient decreased. Because of the fact that according to the condition, we use just "awarding" procedure, that's why we choose the procedure of increasing of the neuron threshold in the image similar to (5.7), where instead of weighing coefficient we will have the meaning of the threshold:

$$Z_i[\alpha + 1] = Z_i[\alpha] + \Delta Z; \quad \Delta Z > 0;\ i = \overline{1;I} \qquad (6.3)$$

Required value of the neuron threshold when (6.2) sign of inequality is changed in an opposite way, we will denote it with Z_i^*;

$$\sum_n x_{ni} w_{nj} < Z_i \Longrightarrow X_i \notin A_j; \quad i,j = \overline{1;I}; \quad i \neq j \qquad (6.4)$$

As the neuron pattern is one, which has one threshold, that's why if we assume the increase of the threshold of the Ne_i type neuron up to Z_i^* quantity, then we might receive errors in the recognition of "its" realizations, such opportunity especially will take place there, where the term is fulfilled: $Z_i^* > Z_i$. Precisely in order to find out those characteristics, upon which "awarding" procedure might be carried out, it is necessary to carry out the experiment of recognition for those pattern realizations for which the above mentioned inequality takes place. In case of an error we should repeat the procedure that was mentioned in the fifth paragraph.

7. Evaluation of the Features According to the Correct Recognition Criteria

For the evaluation of features basically clustering methods are used, for example "Theory of Rank Links" [1], [2], with their help the meanings of clusters are established for each pattern; also the degree of their compactness or non-compactness and etc. are established. In our case we consider recognition process by the formal neuron, but for the evaluation of features we use just the correct recognition criteria.

The correct recognition criterion implies determination of the features, changes of which provide correct recognition, or if the recognition is incorrect, corrects an error. $X_i \in A_i$ recognition process of realization by Ne_j neuron is described in 3.1 term. In the recognition process basically receiving of NET_i value, which may be used instead of

$F(NET)_i$ value (5.3 term) in order to receive final result OUT of recognition. Hereinafter we will see that changes of neuron weighing coefficients F(.) take place on the linear segment of the function (5.3 term).

According to the assumption in 5.3 term the result of recognition process is correct, if inequality is fulfilled 5.5:

$$NET_i = \sum_n x_{ni} w_{ni} \geq Z_i \Longrightarrow OUT = 1 \Longrightarrow X_i \in A_i \; ; \quad i = \overline{1;I} \qquad (7.1)$$

The value in 7.1 term NET_i consists of the sum of $x_{ni} w_{ni}$ multiplications. Let us examine each term of the sum, which consists of n element and the appropriate weighing coefficient of the learning set realization. In order to fulfil the inequality of 7.1 term the meaning/value of the multiplication must be as high as possible. As realization coordinates are important for the signs received through measuring, which could not be changed, therefore we can change just weighing coefficients, i.e. elements of W_i vector and choose w_{ni} initial meanings of weighing coefficients through learning set realization. Let us consider that $Card\{X_i\} = M_i$. If we denote elements of X set by $X_i^m \in \{X_i\}$, but X_i^m coordinates x_{ni}^m of then for the initial meanings/values of the weighing coefficients will be:

$$w_{ni} = \frac{1}{M_i} \sum_m x_{ni}^m \; ; \quad m = \overline{1; M_i} \; ; \quad i = \overline{1; I}; \quad n = \overline{1; N} \qquad (7.2)$$

By fulfilling of 7.2 term we will get vectors for each A_i pattern and neuron initial weighing coefficients. W_i set, coordinates of which w_{ni} represent objective values, as they are received through the processing of the results of features.

It is obvious that as high of w_{ni} meaning/value in 7.1 term is as high its contribution in receiving NET_i value. By this way the reliability of correct recognition will increase. In order to evaluate weighing coefficients we have to ascertain lower limit of their meanings/values, according to which we can evaluate meanings/values of the given features, i.e. their contribution in the formation of NET value. We should choose lower limit of U_i, value according to maximum meaning of the weighing coefficients of features.

$$U_i = \alpha . \max w_{ni} \; ; \quad 1 > \alpha > 0; \quad i = \overline{1, I} \qquad (7.3)$$

Where U_i is a lower limit of the meanings/values of Ne_i neuron weighing coefficients.

Definition 7.1 x_{ni} for A_i feature is important for the given pattern, if the value received by measuring of which is more or equals to a lower limit of the weighing coefficient: $x_{ni} \geq U_i$.

Let us assume that the term of 7.1 definition is fulfilled by the number of feature $N_1 \leq N$. Let us calculate new weighing coefficients according to 7.2 term.

$$\overline{W_{nt}} = \frac{1}{M_{1i}} \sum_M x_{n_i}^{m_1}; \quad m_1 = \overline{1; M_{1i}}; \quad i = \overline{1; I} \qquad (7.4)$$

Where M_{1i} constitutes a number of those realizations, where inequality of 7.1 term was fulfilled.

It is clear that $\overline{w_{ni}} \geq w_{ni}$, that's why by using w_{ni} in 7.1 term, the inequality will strengthen, which means that the reliability of correct recognition will increase. In that case when the recognition is wrong, which means that $NET_i < Z_i$, it can be corrected. In case the error is not corrected, we should use algorithm described in chapter 5. Where we will award features defined by 7.1 term. We will isolate subsets from the feature sets by (7.3) and (7.4) terms, which is important and necessary for the correct recognition of "its" realisation of the given pattern.

Let us discuss the method and algorithm for the features definition, which gives us opportunity to correct the result of the incorrect recognition, which we might have of one type, for e.g. when presenting the X_i realization for the other type Nej neuron. According to terms 7.2 we will have:

$$NET_{ij} = \sum_{n_2} x_{n_{2i}}^m \geq Z_j \Longrightarrow X_i \in A_j \; ; \quad i; j = \overline{1; I}; \quad i \neq j \qquad (7.5)$$

İn order to correct an error it is important to change the sign of 7.5 inequality reversely, so the right part of the inequality must be decreased/reduced. Reduction can be carried out in two ways: 1. w_{nj} Through the decreasing of weighing coefficients, which might cause errors. While recognizing of "Its" X_j realizations; hence we cannot use this method because according to the term we use just awarding procedure.

2. Let us discuss the method of the reduction of the sum of the weighing coefficients i.e. NET_{ij} value, which was described in (7.3) and (7.4) terms. Let us suppose that we have ascertained w_{nj} sub-level of weighing coefficients- Uj and through it let us set a definition (7.1) important features list A_j for pattern and Ne_j for neuron weighing coefficients. Let us calculate weighing coefficients according to (7.4) terms.

$$\overline{w_{nj}} = \frac{1}{M_{2j}} \sum_{n_2} x_{n_{2j}}^{m_2} \; ; \quad m_2 = \overline{1; M_{2j}}; \quad n_2 = \overline{1; N_2} \quad j = \overline{1; I} \qquad (7.6)$$

Where $x_{n_{2j}}^{m_2}$ Ne_j important features of neurons are number of those M_{2j} realizations, for which 7.3 term is fulfilled; N_2 those numbers of features, for which definition 7.1, i.e. $n_2 \geq U_j$ inequality is true.

İn order to calculate value of the definition 7.5 NET_{ij} instead of w_{nj} let us use its correlation from 7.5 terms and we will receive:

$$NET_{ij} = \sum_{n_2} x_{n_2 j} \overline{w_{nj}} \; ; \quad i; j = \overline{1; I}; \quad i \neq j; \quad N_2 \leq N. \qquad (7.7)$$

Because summing in 7.7 terms is done n_2 by index, but presumably as a rule $N_2 << N$, that's why the quantity of the components of sum 7.7 is reduced (N-N_2) by term, which might change the sign of the inequality in 7.5 terms reversely:

$$NET_{ij} < Z_i \Longrightarrow X_i \notin A_j \qquad (7.8)$$

İn that case if the sign of the inequality in 7.5, despite the attempt will not change, then we should use the procedure described in chapter 6, i.e increasing the threshold, for the compensation of which it is necessary to increase weighing coefficient. In order not to make new errors while increasing w_{ni} coefficients while recognising $\{X_j\}$ realizations, when defining features for awarding we should use the procedure described below.

Let us assume that A_i and A_j for neuron patterns Ne_i and Ne_j We have the vectors of weighing coefficients $w_i(\overline{w_i})$ and $w_j(\overline{w_j})$ calculated by the 7.2 and 7.3 terms. Let us make binary vectors Q_i and Q_j by means of them, the elements of which fulfill the term:

$$q_{ni}, q_{nj} = \{0; 1\}$$

It is obvious that vectors Q_i and Q_j will be the same dimensional as w_i and w_j vectors. Let's assume that for recognition of A_i pattern X_i realization we get an error A_j pattern on Ne_j neuron. Let us choose corresponding x_{ni} for $\overline{w_{ni}}$ as means of awarding, for which the term is satisfied.

$$q_{ni} = 1 \cap q_{nj} = 0; \quad i; j = \overline{1; I}; \quad i \neq j \quad (7.9)$$

İf when recognizing the realization X_j we get an error to neuron Ne_i, then in order to correct an error we should choose w_{nj} appropriate x_{nj}, for which the term is fulfilled:

$$q_{nj} = 1 \cap q_{ni} = 0; \quad i, j = \overline{1; I}; \quad i \neq j \quad (7.10)$$

İn both cases the inequality 7.8 will be srengthened, so that the recognition results received through 7.1 inequality will be unchanged.

8. Conclusions

The method of error-correction in the learning process of neuron and its net is described in the work. Theoretical and Applied Perspectives of learning method are elaborated. Two possibilities of making an error are mentioned and algorithmically described. First, the error which will be made through the recognition of the realizations of "Its" pattern. Second, the error which we have through the recognition of the realizations of "Other's" pattern. Both cases require the formation of different theoretical and applied means. It is proved that error can be corrected through the means of changing of neuron weighing coefficients and thresholds values. Thereby just awarding procedure is used, which provides an error–correction, in that case, if necessary measures will be received in order to avoid neuron over-filling effect.

It has been proved theoretically that correction of one error does not cause other errors.

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