NEURAL NETWORK MODEL AS A POSSIBLE TOOL FOR MODELING OF CONFIDENCE IN SENSORY JUDGMENTS[1]

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ABSTRACT

Developed neural network approach is directed to modeling of decision making and confidence in human sensory judgments. It is implied that mathematical methods choosen for modeling of behaviour have to be corresponded to real brain neurons activity. In order to meet this requirement a simple correlational algorithm is suggested for adaptive stochastic adjustment of weights of a formal neuron.

BASIC CONCEPTIONS

At present two main classes of decision theories are distinguished which provide basis for quantitative models of confidence (*Con*). One class includes models developed in Signal Detection Theory (SDT) framework (see Baranski, Petrusic (1998) and references there in). They assume that confidence is based on a distance between a sampled observation and a decisional criterion. In addition any sensory effect received in each observation is considered to be single.

Another class includes stochastic models assuming that each observation is consisted of a number of sequential elementary samples of a sensory difference value in "greater-less-same-task". They are cumulated in a single store (random walk models – Link, Heath, 1975; Heath, 1984) or in two or three stores (accumulator model – Vickers et al., 1979, 1998; Smith, Vickers, 1988; doubt-scaling model – Baranski, Petrusic, 1998), which cumulate positive and negative values of a sensory difference and sensory impression of stimuli equality separately. *Con* is a result of stochastic cumulation of evidence in favour of competing alternatives (Audley, 1960). Evidence means exceeding of sensory effect of one of stimuli compared, regarding a sensory effect of the other stimulus. Positive values of these effects difference point that the first stimulus is greater, while negative values – that the second one is greater. An advantage of these models as compared to SDT ones is connected with capacities of the

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formers to describe temporal characteristics of sensory decisions in addition to their accuracy and *Con*.

Vickers et al. (1979, 1998), Smith, Vickers (1988) have developed a conception of modeling of *Con* in sensory judgments known to be the most deep and successful. Rating of *Con* they suggested seems to reflect a psychological nature of *Con* more correctly than a number of vacillations among alternatives (Audley, 1960, Usher, Zakai, 1993) and in more general form than exclusive latent time of choosing of a selected alternative (Usher, Zakai, 1993).

Assuming a single store in Heath's (1984) model means that a relative difference is cumulated between evidences in favour of each decision, while a value of each evidence can't be estimated separately. This assumption restricts capacities of this model to describe sensory decisions in comparison with Vickers et al. (1979, 1998) model, which implies two stores and therefore has such a capacity. However it seems to be difficult to compare data obtained on the base on random walk model and accumulator model directly, since these models use different basic conceptions. To stop a cumulation process on the base of a settled value of evidence in favour of an alternative chosen is not the same as to stop it on the base of a settled value of *Con* regarding accuracy of this alternative choice. An appropriate compromise is suggested below concerning the prolonged discussion between random walk and accumulator models, which combines advantages of the both models.

Specificity of this class of models is connected with the fact that their basic conceptions imply the symmetry of the both stimuli compared. At the same time such symmetry may be destroyed, say, in the case of successive presentation of stimuli. In this case functioning of memory mechanisms has to be taken in account in the model.

Moreover, empirical evidence was obtained, which does not correspond to the both classes of models considered. It was found that brain structures activation level fluctuates in the course of sensory performance and discrimination ability fluctuates correspondingly, i.e. values of sensory effects are modulated by this fluctuation (Gusev, Shapkin, 1991). No model considered takes in account such a modulation. A basic conception seems to be added by some assumption about brain's solving of this problem, in order to overcome this limitation. One of the possible ways to do it is moving to another level of stimuli representation in the nervous system. A level of neurons activity expressed in spikes is not unique but there is a level of synaptic connections among neurons as well. Fluctuations of neurons activity may influence on a rate of change of their synaptic weights, but most probably not on a value of such weights.

It seems that the third class of models may be distinguished, which are based on neural network models of memory. These are an adaptive filter model for recognition (Heath, Fulham, 1988) and a model for decision making considered as a choice between multiattribute alternatives (Usher, Zakay, 1993). Though the latter model does not consider sensory judgments specially, it may be included into the third class conditionally since it concerns *Con* in decisions made.

A model suggested by Gregson (1999) is kept aloof. It is based on algebra of nonlinear psychophysical dynamics and represents *Con* to be a nonlinear dynamic cascaded process.

Heath and Fulham (1988) have suggested a special algorithm, which provides remembering of new stimuli and habituation to repeated presentation of the same stimulus. The authors represent a process of memory matrix revision by using of adaptive adjustment, which is widely spread in radio engineering (Widrow, Stirns, 1989). An adjustment of weight matrix is provided by a stochastic approximation of an iteration method of the steepest descent. Such an iterative approach is very attractive for a practical using when it is needed to solve a problem in a real time (i.e. very quickly) and to use very modest device while an accuracy of the solution may be not very high. A neural network also looks as "a very modest device" which has to work in a real time. Therefore we made an attempt to simplify this model and to show that fluctuations of neurons activity do not influence on decision making and estimation of *Con*.

MATHEMATICAL MODEL

Let's consider a representation of a real sensory stimulus in a human perceptual space. Assume that it is described by m-dimensional vector $(x_1,x_2, ...,x_m)^T$ which has components corresponded to main parameters of the stimulus mental representation.

In order to use the standard mathematical theory of linear adaptive adder (Widrow, Stirns, 1989), let's introduce for a k-th time moment: $\mathbf{X_k}=(x_1,...,x_{i-1},x_{i+1},...,x_m)^T$ - a vector of given input signals and $\mathbf{W_k}=(w_1,...,w_{i-1},w_{i+1},...,w_m)^T$ - a current vector of weights of an i-th neuron (Fig.1).

In this case a current output of the adder in the k-th moment will be equal to:

$$y_k = \mathbf{W_k^T X_k = X_k^T W_k} \qquad (1)$$

When denoting a desired output of the adder $\varphi^{-1}(x_i)$ as d_k we may obtain an error in the moment k:

$$\varepsilon_k = d_k - y_k = d_k - \mathbf{W_k^T X_k} = d_k - \mathbf{X_k^T W_k} . \qquad (2)$$

A matrix model (Heath, Fulham, 1988) represents a neural network (i.e. neurons and their interconnections) in a wholistic and therefore concrete and rigidly given matrix form. It implies that neurons and all links between them are the same. A possibility was described to derive more flexible and detailed vector model without loss of it's accuracy and generality (Shendyapin, 1999).

In this case an iterative process for a weight vector is simpler than in the matrix case:

$$\mathbf{W_{k+1} = W_k} + 2\mu\varepsilon_k \mathbf{X_k^*} . \qquad (3)$$

A corresponding scheme of an adjustment of a neuron weights is shown in the Fig.1. Simplicity of the model received allows believe that a neuron own activity will be enough for the model realizing. It's quite probable that a neuron is able to weight input signals, add and subtract them and carry out a correlation processing.

It was shown (Widrow, Stirns, 1989) that mean weights are converged towards correct solution. Since a gradient estimation is used in the method of the steepest descent instead of a real gradient, it may be interpreted as an adding some noise to a real gradient. In it's turn a noise of a gradient induces a noise component of a weight vector during adaptation process and a stabilized regime as well. Some error is caused by this noise. The error was shown to be proportional to μ - a feedback coefficient (Widrow, Stirns, 1989). Therefore the error may be made as small as needed by reducing μ-value.

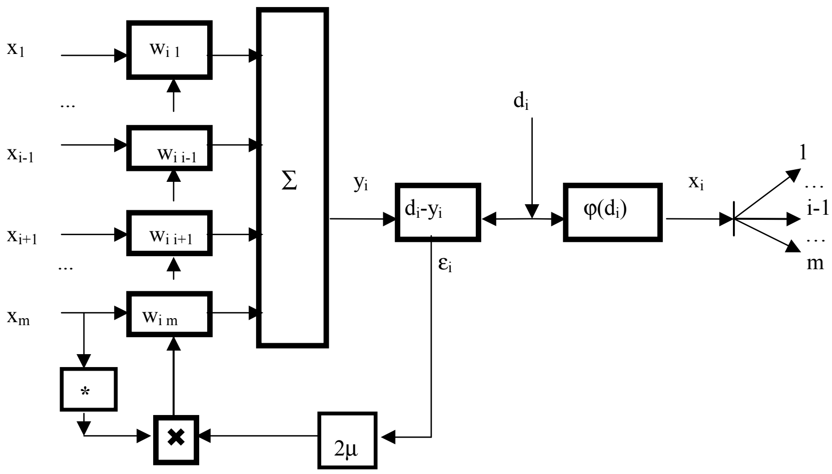

Fig.1. A scheme of weights adjustment for an i-th neuron in the adaptive vector model.

APPLICATION OF THE MODEL TO SENSORY JUDGMENTS

We consider two competing versions of the dynamic approach to sensory judgments modeling. They are an adaptive filter model (Heath, Fulham, 1988), which implies memory mechanisms functioning and hence belongs to neural network paradigm, and accumulator model (Vickers et al., 1979, 1998; Smith, Vickers, 1988) which gives more clear conceptual representation of human decision making and feeling of *Con* regarding it's accuracy.

Suggested adaptive vector model develops Heath and Fulham (1988) work. It was proved that neuron weights are proportional to a value of a stimulus varying parameter. If a stimulus having a parameter *S* was presented first and induced a sensory effect *s,* then a neuron weights became proportional to *s* as a result of remembering. If a stimulus having a parameter *V* was presented after that and induced a sensory effect *v*, then a neuron weights become proportional to *v* in the course of their adjustment. A difference between current and final neuron weights are used in our model for representation of evidence in favour of a selected alternative in decision making, according to Vickers et al. (1979, 1998). Since a process of neuron synaptic weights adjustment is a somatic one then we may assume that it does not depend on fluctuations of the brain activity significantly.

It may be thought that the model suggested will allow combine advantages of random walk and accumulator models. Computer simulation of the model is under way.

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