Visual Associative Memory With Omitted Inhibitory Synaptic Connections: Is it Still able To Improve The Quality of Distorted Images?

P. V. Maximov, V. V. Maximov
Institute for Problems of Information Transmission, Russian Academy of Sciences,
127994, GSP-4, Bolshoi Karetny per. 19, Moscow, Russia
e-mail: pmaximov@iitp.ru
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A possibility of novelty filters on modifiable synapses to improve the quality of optically distorted images was investigated by simulation. Inhibitory synapses were shown to be essential for mechanisms of adaptation to a priori unknown distortions.

In the paper [1] we have proposed an explanation of the orientation-contingent colour after-effect, or the McCollough effect (ME) in the framework of associative memory and novelty filter. The ME is generally obtained when after the exposure for a few minutes to alternating coloured gratings, say, red vertical and green horizontal ones, subjects perceive similarly oriented achromatic gratings as tinted with complementary hues. In the course of "adaptation" the colour grid patterns are supposed to be stored in the memory. When testing with an achromatic grid, the associative image of the grid with the same orientation is recalled from the memory and subtracted from the input image, leaving in the resulting image only novel feature, namely, a complementary colour of the grid. A computational model of the filter is based on a neural network with modifiable synapses and consists of (i) an input layer of two (left and right eyes) square matrices with two analog receptors (red and green) in each pixel, (ii) an isomorphic associative neural layer, each analog neuron being synaptically connected with all receptors of both eyes except a receptor of the same position, (iii) an output layer (novelty filter). Modification of synaptic efficacies complies with the Hebbian-like learning rule. Computer simulations illustrate that after several presentations of coloured gratings the model displays persistent ME which is slowly destroyed by subsequent presentations of random pictures. After the adaptation, synaptic connections of the associative neurons with receptors show clear colour specific grid pattern of alternating excitatory and inhibitory stripes.

The same scheme of the novelty filter on modifiable synapses was found [2] to eliminate cross-correlation between the input signals and can serve as an efficient adaptive instrument for correction of a priori unknown optical distortions (such as defocusing and astigmatism), which causes a strong correlation of signals in adjacent receptors. In fact, during simulated adaptation to random pictures the outputs of the network become uncorrelated. Receptive fields of the associative neurons (their synaptic connections with receptors) acquire a structure of concentric excitatory and inhibitory zones. This improves spatial frequency resolution, results in enhancement of edges and makes a diffuse retinal image of a spot appreciably sharpened.

In light of these results, it has been supposed that the real visual system possesses some adaptive mechanism, similar in its properties to the novelty filter, localised at the early stages of visual information processing (possibly even in the retina) and intended to tune to unknown optical distortions, while long-term illusions similar to the ME may occur under special experimental conditions as a by-product of this mechanism. Unfortunately, this similarity is only qualitative, since it is hard to realise the novelty filter of our model directly on real neurons. In particular, in our model each synaptic weight may possess both positive and negative values. Real synapses may be either excitatory or inhibitory. Some mechanism could change the synaptic efficacies of the synapses, but it could not change their type.

Therefore one may expect that the neural network of the novelty filter in the real visual system should use either appreciably more complex synaptic circuitry (with both types of synaptic connections) or similar structure, but with synapses of only one type. In the second case the filter can be expected to solve the problems worse.

In this paper we examined the capabilities of the restricted model where all synaptic weights were nonnegative. It was shown that despite the restriction the novelty filter simulates the McCollough effect and corrects optical distortions to some extent.

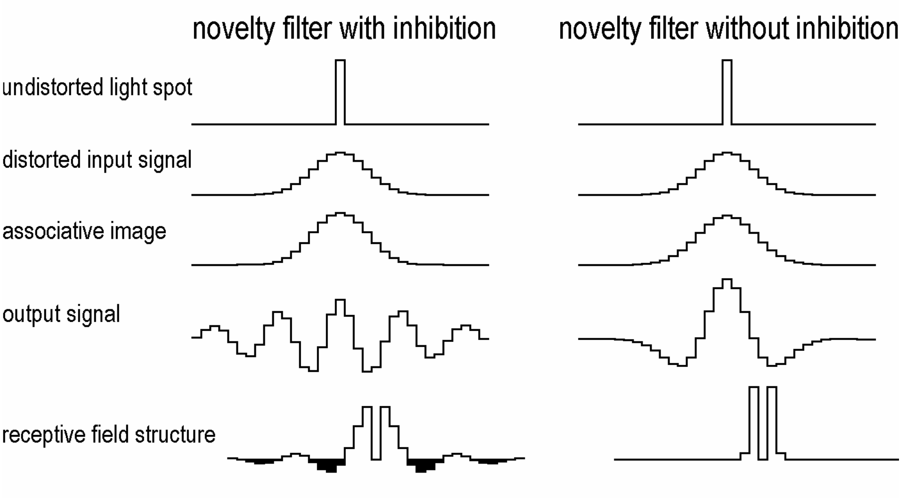

Fig. 1

Unlike the ME, optical distortions could be simulated with a one-dimensional retina (that permits to save time and space). For these reasons new one-dimensional versions of a model of the novelty filter were built according to the scheme described above. A modification rule of the version with inhibition (where each synaptic weight might be both positive and negative) remained the same, while that of the version without inhibition possessed nonlinearity giving nonnegative synaptic weights only. An optical system was supposed to possess bad spatial resolution and blurred an initially undistorted image. Fig. 1 illustrates the results of experiments with these models of the novelty filter after equally long adaptation to random pictures (where signals in all pixels were initially uncorrelated). In both cases the responses of these models to the blurred light spots are shown. The first four curves show the spatial distribution of signal intensity at different stages of the models. The receptive field structures for one of the associative neurons, acquired in the course of adaptation, are shown for each version of the filter in the last line, where negative weight deflections are filled in black for clarity. It can be seen that in both cases high spatial frequencies are emphasized in the output signal, and sizes of the spots are smaller. However, as distinct from the model with inhibition in the model without inhibition this improvement always was less considerable, and a final structure of the receptive field of associative neurons proved to be independent on the quality of the optical system. As a result, in any case the adaptation to random pictures gives the same result, what makes an adaptive properties of such a novelty filter quite useless.

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1. P.V. Maximov, V.V. Maximov, *Perception*, **26**, Suppl., 19, (1997).
2. P.V. Maximov, *Proceedings of the IEEE AIS'03 and CAD-2003*, **1**, 597-602, (2003).