AN OSCILLATORY MODEL OF ATTENTION-GUIDED SELECTION OF MOVING OBJECTS

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ABSTRACT

Selective visual attention is a mechanism that gives a living organism the possibility to extract from the incoming visual information a part that is most important at a given moment and that should be processed in more detail. This mechanism is necessary due to limited processing capabilities of the visual system which does not allow rapid analysis of the whole visual scene. The models of attention can be subdivided into two main categories Traditional connectionist approach to attention modeling (Olshausen et al., 1993; Tsotsos et al., 1995, Itti and Koch, 2000), is based on a winner-take-all procedure which is implemented through a proper modification of the weights of bottom-up and top-down connections in a hierarchical neural network. An alternative approach is based on the synchronization principle realized in the frames of an oscillatory neural network (Schillen and König, 1994; Wang and Terman, 1997; Wang, 1999; Corchs and Deco, 2001; Borisyuk et al., 2003). The advantage of the latter approach is that it is compatible with modern ideas about distributed representation of visual objects in the cortex (Ishai et al., 1999), synchronization based mechanisms of feature binding (Gray, 1999; Singer 1999), and the evidence that synchronous oscillations can be a correlate of stimulus selection by attention (Steinmetz et al., 2000, Fries et al., 2001, Fries et al., 2002).

Basing on our previous results (Kazanovich and Borisyuk, 1994; Kazanovich and Borisyuk, 1999; Borisyuk et al, 2001; Kazanovich and Borisyuk, 2002), we present an oscillatory network for modeling automatic object-oriented attention. We consider here a task of dynamical object selection. The task is to select an object from the visual scene, form the attention focus on the selected object, and keep the same object in the attention focus despite continues variations of objects in the visual scene (objects movement, shape changes, etc.). The selection can be conditioned by different attributes of objects such as their context, location, and saliency. The result of selection is reflected in the activity of the elements of the network: it is higher (with greater amplitude of oscillations) for the oscillators that correspond to the object in the attention focus. The main new feature of the model is that it can work with non-stationary visual scenes whose changes may include objects location, shape, brightness, and variation of the background. The focus of attention can be changed when an abrupt (discontinuous) change of the scene takes place.

The development of the model bases on the experimental facts about the morphology, neurophysiology and functioning of the visual system and includes different levels of detail from neuronal to behavioral effects. The basic principles of system functioning include phase-locking, adaptation of the natural frequency of oscillators, and resonant response, which implies a sharp increase of the amplitude of some oscillators under synchronous stimulation by other oscillators. This new approach to neural modeling uses additional functional capabilities provided by oscillatory neural networks that cannot be implemented in traditional connectionist models. The advantage of such approach has already been demonstrated in a model of novelty detection (Borisyuk et al., 2001) and in a model of selective attention (Kazanovich and Borisyuk, 2002).The functioning of the model includes two main types of operations: the segregation of objects from the

background and the selection of an object into the attention focus. It is assumed that object/background separation and grouping the pixels or features of object according to their spatial connectivity is solved at the pre-attention level due to local coupling but attention (and global coupling) is involved when selection of individual objects is required. The important feature of global coupling used in the model is that it is realized through the Central Oscillator (CO) that has desynchronizing feedforward and synchronizing feedback connections to all the other oscillators, so-called Peripheral Oscillators (PO), of the network.

In biological terms, the model is interpreted in the following way. It is presumed that POs represent cortical columns and the CO represents the septo-hippocampal system whose final position in the pyramid of cortical convergent zones and feedforward and feedback connections give it an access to all cortical structures (Damasio, 1989). The central oscillator plays the role of a central executive of the attention system as it is suggested by Cowan (1988). The synchronization hypothesis is used for implementation of a "label" that identifies the neural assembly, coding a specified object (Gray, 1999; Singer 1999). We suppose that the focus of attention includes an object which is represented by assembly A of those POs that work synchronously with the CO (Kryukov, 1991).

The input to the network is a colored image on the plane that contains several objects. Network functioning is based on the principles of phase-locking, adaptation of the natural frequency of the CO, and the resonant influence of the CO on the oscillators from A The assemblies of POs representing different objects compete for the synchronization with the CO so that at each moment only one object wins the competition. The result of this competition is determined by saliency characteristics of objects such as size and brightness and by internal preferences (context).

We apply a 3D scheme for representation of images in the network. The input is coded as a $M*N$-matrix of pixels. Each pixel is described by K features. Each feature k can adopt L_k values. Peripheral oscillators are enumerated by indices $ijkl$ $(i = 1,\dots,M;\ j = 1,\dots,N;\ k = 1,\dots,K;\ l = 1,\dots, L_k)$. A PO P_{ijkl} receives signals from the pixel (i,j); P_{ijkl} is active if the feature k of the pixel (i,j) takes the value l.

The interaction between POs in the network is organized so that each object is represented in the network as an assembly of synchronous oscillators. Assemblies of POs corresponding to different objects are non-synchronous. Due to synchronizing connections from POs to the CO, the latter adapts its natural frequency to the frequency of the assembly A of POs that represents an object that should be selected in the attention focus. This synchronization results in the resonant increase of the amplitude of oscillations in the oscillators of A The amplitude of oscillations of other POs is shut down to a low level.

In mathematical terms the description of object features in a non-stationary scene is based on the idea of object representation by a dynamical system trajectory in multidimensional space of features. Objects are represented by different trajectories and dynamical changes in object location, shape, color, etc. are reflected by the movement of the representing point along the trajectory. In particular, this can be useful for measuring the distances between different object representations and making decision about object similarity. The continuation of a trajectory in feature phase space produces a curve in multidimensional space. In these terms attention focus formation means that the system follows the trajectory associated with the selected object. For the attended object the activity amplitudes of representing units are high. Other objects also elicit some activity in the system but this activity is low. Attention switching is implemented by jumping from one trajectory to another with a proper change of activity amplitudes.

In the presentation of this work we will give more details on the implementation of the model and describe the results of computer simulations of attention focus formation and switching.

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Keywords: Oscillatory neural network, Dynamic image, Object selection.

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