

OBJECT SELECTION BY AN OSCILLATORY NEURAL NETWORK

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Consecutive selection of objects (CSO) is a classical task in the theory of neural networks that appears in relation to feature binding and attention problems. It can be formulated in the following way: the dynamics of a neural network (that implements CSO) should be organised so that neuronal assemblies, coding different objects presented simultaneously, consecutively increase and decrease their activity. Thus at each moment of time the activity of the assembly corresponding to a selected object is significantly higher than the activity of all the other network elements. The sequence in which objects are selected may be deterministic (with or without repetition of the same object in a cycle of selection of all the presented objects) or random. We describe a new solution to CSO that is based on phase-locking procedure in an oscillatory neural network with a special architecture of connections, the so-called network with a central element.

Traditional approaches to CSO (Tsotsos et al., 1995; Ritz et al., 1994; Wang & Terman, 1997) imply that the information about the correspondence between objects and network elements is coded in terms of connection weights. This results in application of two types of neural network architectures: the networks with all-to-all (global) connections and the networks with local connections. The drawback of the former is the exponential growth of the number of connections with the increase of the input information. The latter is suitable under assumption about retinotopic organization of the input. Such an assumption is valid for the primary areas of the visual cortex but it is not fulfilled in the associative areas and the entorhinal cortex. Therefore, on later stages of information processing it is impossible to identify the features of a separate object relying on the compact location of the corresponding neuronal assemblies.

We present a solution to the CSO task in the frames of an oscillatory neural network with fixed connection strengths (and without any predefined local topology of connections), where all the interaction between the elements of the network is carried out through a single element (Kryukov, 1991, Kazanovich & Borisyuk, 1994, 1999). The network is comprised of the central oscillator (CO) and n peripheral oscillators (PO) which have feedforward and feedback connections to the CO. There are no connections between peripheral oscillators, therefore the whole number of connections in the network is $2n$.

It is presumed that each object from the set of simultaneously presented objects is coded in the network by a group of POs (the groups belonging to different objects do not overlap). For simplicity we suppose that all groups have the same size s . If k is the number of presented objects, then $n = ks$.

The current state of an oscillator is described by three variables: the phase, the amplitude of oscillations, and the natural frequency of the oscillator. The values of these variables

change in time according to prescribed rules of interaction between POs and the CO. The main mechanism of oscillator interaction is postulated as phase-locking.

We suppose that all oscillators in a group have the same constant natural frequency (chosen from an interval of admissible frequency values). Initial phases of oscillators in one group are randomly distributed in a narrow range (l, r) ($r - l \ll \pi$). These assumptions are based on the synchronization hypothesis which states that the information related to an object is coded by synchronous activity of oscillators representing this object (Singer & Gray, 1995). Identical values of natural frequencies and the similarity of oscillator's phases are used as a "label" that allows the identification of an object. Any two objects, if presented simultaneously, should be coded by different values of natural frequencies of oscillators or by non-overlapping intervals of initial phase values. Such an approach to object coding in phase-frequency domain improves the object separation capabilities of the system under conditions when both phase and frequency ranges are restricted.

In biological terms, the model is interpreted in the following way. It is assumed that POs are constituted of locally interacting populations of excitatory and inhibitory neurons of the cortex. The CO is represented by the septo-hippocampal system whose final position in the pyramid of cortical convergent zones (Damasio, 1989) and feedforward and feedback connections to the associative areas and the entorhinal cortex give it a direct or indirect access to nearly all the cortical structures. The network can be considered as a model of object oriented attention (attention of the type "what"). We suppose that the focus of attention includes an object which is represented by the group of POs that work synchronously with the CO. Consecutive attention focusing on different objects facilitates novelty detection and memorization of new and significant objects in short term memory.

CSO is implemented by the following dynamics of the network. The CO consecutively synchronizes its activity with one or another group of POs. Just after network initialisation and start, the CO synchronises the group of oscillators whose phase-frequency characteristics are most similar to those of the CO. The oscillators that are synchronised by the CO significantly increase the amplitude of their oscillations (switching to the state of resonance with the CO). The activity of other oscillators is temporarily inhibited.

After spending some time in a resonant state, the group of oscillators is forced to decrease its amplitudes to a low level. This state of low-level activity is kept for a long enough period of time to give the CO an opportunity to synchronize its activity with another group of oscillators, etc.

The described dynamics are implemented by using the principles of the resonance and phase-locking formulated elsewhere (Borisjuk et al., 2001). The first problem that should be solved for implementation of such dynamics is to restrict the synchronization of oscillators at any time to exactly one group of POs which results in a narrow phase-locking range of the CO. On the other hand, the CO should have the capability to synchronize the groups of POs with different natural frequencies located in a relatively large range. This difficulty is overcome by letting the CO to adapt its natural frequency to the current value of CO's frequency. Due to such adaptation, the CO tunes to the nearest natural frequency of the POs of one of the groups.

Another problem appears due to necessity to discriminate the groups of oscillators with similar natural frequencies but different intervals of phase values. In phase-locking systems, the result of synchronization is usually independent of initial phases. Therefore there is danger that all oscillators with the same natural frequencies will be synchronized in one cluster. Such type of synchronization can be avoided by a special choice of the interaction function: this function should rapidly decay if phase difference between the CO and a PO exceeds a certain threshold. In this case the CO rapidly adapts its phase to the nearest average phase of oscillators of one of the groups. After that the oscillators of this group are

synchronized by the CO and switch to a resonant state while the interaction of the CO with oscillators of other groups becomes weak (hence they are not able to synchronize with the CO).

An additional mechanism, “tiredness from the resonance”, is used to switch the synchronization of the CO from one group of POs to another group. Namely, we presume that if a PO has spent a long enough time T_r in a resonant state (with the amplitude of oscillations permanently exceeding a threshold), this oscillator loses the capability to work with a high amplitude, so the amplitude of its oscillations exponentially decays to a low level (this level is chosen so that this oscillator cannot control the dynamics of the CO anymore). The PO is kept in that state of low activity during a given time interval T_p . This time is used by the CO to phase-lock other groups of oscillators. After the time T_p has passed, the PO recommences its normal activity starting with the amplitude that it had at the moment of network initialisation.

Computer experiments show that the model successfully implements CSO, separately synchronizing the groups of oscillators that differ by phases or by natural frequencies on the values about 0.3-0.4. Depending on the parameter T_p , the network can make a repetition-free cycle of selection of all objects (if T_p is large enough) or to select objects with repetitions (if T_p is smaller than the time of selection of all presented objects). Non-deterministic order of selection is possible if T_p is made random.

The presented model of CSO is not provided with the capability of memorizing objects or sequences of events but this capability can be easily included in the network functionality by adding a second layer (a chain of oscillators or groups of oscillators) with operation principles formulated in (Borisyuk & Hoppensteadt, 1999, Borisyuk et al., 2001). In this two-layer construction the network for CSO will be used as the input to the second layer, where memorization is performed. It is important that at any moment the second layer will receive the information about one object, which prevents erroneous binding of features of different objects in the memorized pattern.

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