Advancing Dynamic Binding Theory: Implementation of Complex Concepts

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Different features of a visual stimulus are processed by spatially disparate neuronal populations [2]. In order to generate a holistic perception of an object in the visual field, responses of neurons activated by this object have to be associated with one another. Synchronization of single spikes or oscillatory modulated neuronal activity is considered a primary candidate mechanism for this purpose. Many experiments (reviewed by [3]) show that neurons tend to synchronize their activity if stimulated by the same object. They do much less so if they receive the same stimulation, but from different objects.

On a more general account we can say that the perception of an object (e.g., a vertical red bar) is composed from the activation of more primitive concepts (e.g., 'redness', 'verticality') and call it a complex concept. A fundamental property of concepts is that they are compositional and decomposable. Compositionality, especially with respect to perception, has not, to a sufficient extent, been taken into regard in the context of dynamic binding, yet.

Our modeling study suggests that dynamic binding can account for the compositionality of visual perception. The model network (introduced in [1]) reflects the recurrent interactions between excitatory and inhibitory neurons in layer 2 and 3 of the primary visual cortex. We analyzed the dynamics of the network by computing the principal modes and the time course of the associated order parameters. While principal modes are constant over time, order parameters are the weight of each mode in the network state for each point in time. This can be seen as complete separation of spatial information, contained in the principal modes, from temporal information in the the order parameters.

In [1] we found that principal modes hold different interpretations of a stimulus, and hence represent different epistemic possibilities (see figure 1b). Here we concentrate on the order parameters. Figure 1c shows that the oscillation of the order parameter with the highest eigenvalue (blue curve) constitutes an envelope for the oscillation of the one with the second largest (green). We regard this as a mechanism for the representation of part-whole relations, which is a fundamental requirement of many complex concepts. At the same time it is the key to hierarchical binding. We hypothesize, therefore, that neural synchronization is not only a mechanism for binding representations of attributes of one and the same object together to form the representation of the object with its attributes. Beyond that it is general enough to also bind together the representations of the parts of an object to form the representation of the object with its parts.

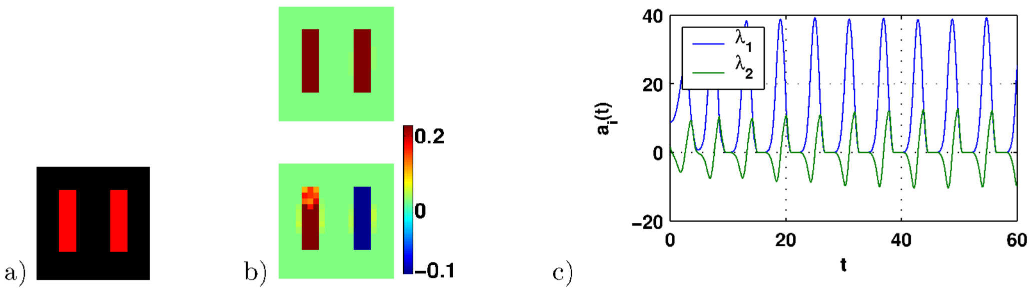

Figure 1: **a)** A stimulus consisting of two vertical bars. **b)** Principal modes with two largest eigenvalues (top to bottom). The vectors were reshaped and color-coded to facilitate visual inspection of the contribution of each principal mode to the overall network activity. The first principal mode (top panel) shows that the oscillators activated by the two bars make the same positive contribution to the activity. It accounts for the synchronization of the two regions and can be interpreted as a mode in which the two bars are seen as a single object. In the second mode (lower panel), the contributions in the two regions have opposite signs. This accounts for a residual phase difference between the oscillations in the two regions which can be interpreted as representing two separate objects. **c)** Time course of the order parameters: $a_1(t)$ is an envelope of $\pm a_2(t)$.

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