Poster-Paper-Submission (2 pages) for the ICCM meeting 2003 in Bamberg (Germany)

Abstract

Title: Attentional effects in a model of two reciprocally connected visual areas

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Abstract:

Even when creating a biologically realistic model for an apparently very simple cognitive task like seeking a certain object in the visual field, one is confronted with severe problems concerning binding of distributed representations. In this work we present simulation results from a model of two reciprocally coupled visual cortical areas. One area is a peripheral visual area where local object features are represented, the other is a more central visual area where whole objects are recognized. In our model, correct binding is achieved by the simultaneous switching of the activation state of corresponding neuron groups. We relate our simulations to neurophysiological findings concerning attention and biased competition, and demonstrate how these findings can be explained very naturally by assuming different kinds of bindings between neuron groups in different areas as produced by our model. While the binding is fluctuating in the absence of attention, it becomes static by the attentional bias. This leads us to several predictions for neurophysiological experiments.

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Attentional effects in a model of two reciprocally connected visual areas

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Even when creating a biologically realistic model for an apparently very simple cognitive task like seeking a certain object in the visual field and subsequently pointing to it, one is confronted with severe problems concerning binding of distributed representations.

For example, the selection of one object when multiple objects are present in the visual field can be modeled as shown in Figure 1, where the task is to look for a plum. In a primary visual area (e.g., V1) features of different objects (e.g., plum and apple) are represented. This area is reciprocally connected to two further areas where whole objects and their corresponding positions (e.g. left upper and right lower corner) are represented separately (what/where paths), but only one object and position at the same time. Binding must occur between corresponding representations in all three areas. This can be achieved by the reciprocal inter-areal synaptic connections which together with other neuron-intrinsic mechanisms (like habituation) temporally synchronize activity of corresponding neuron groups (Knoblauch & Palm 2001, 2002) similarly as postulated by the temporal correlation hypothesis (Singer & Gray 1995). In order to select one object (plum) in the presence of distractors (apple), excitation from a further cortical area may act as an attentional bias which initiates the transmission of information exclusively about the desired object to higher cortical areas (like the object and position areas) and suppresses the information about distractors.

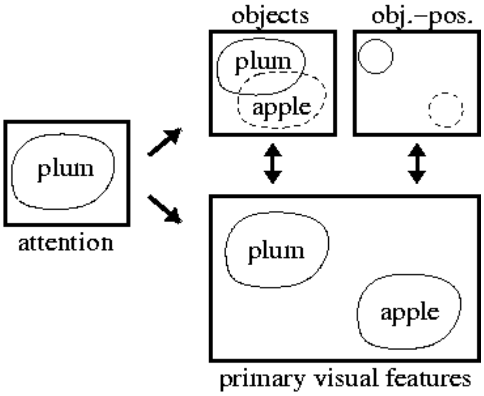

Figure 1: Model of cortical areas involved in selecting one certain object (plum) when also a distractor (apple) is present in the visual field.

We simulated a model similar to Fig.1 consisting of two reciprocally connected cortical areas, a peripheral visual area and a more central visual object area, where the representations in the object area can be biased by attentional excitation from a third cortical area (cf. Knoblauch & Palm 2002). This model can reproduce single unit data as observed in neurophysiological experiments (Reynolds & Desimone 1999). In these experiments single neurons are stimulated using two stimuli in the receptive field of the neuron, a preferred and a poor stimulus. When presenting only the preferred stimulus, the neuron exhibits a strong response, while the response is weak, if only the poor stimulus is presented. Interestingly, for the superposition of the two stimuli, the response lies between the responses for the single stimuli indicating a competition between the two stimuli. If now attention is directed to one of the two stimuli, the response of the neuron is as if only the attended stimulus were present.

As can be seen in Figure 2, our model replicates this behavior at least qualitatively. We used two learned stimuli, a rectangle and an ellipse (instead of a plum or an apple) and recorded from a neuron in the object area as indicated (Fig.2A). Fig. 2B shows a neuron response in the absence of external attention. Presenting only the ellipse the PSTH shows strong activation with rates above 40 spikes/sec. Presenting only the rectangle, the response remains around 10 spikes/sec, i.e. the ellipse is the preferred stimulus and the rectangle the poor stimulus. Stimulating with the superposition of the ellipse and the rectangle the response is around 25 spikes/sec, well between the two previous responses.

If now the external attention is directed to the ellipse, the response is very similar as if stimulating only with the ellipse (Fig. 2C). Correspondingly, if attention is directed to the rectangle, the response is similarly weak as if only the rectangle were presented.

When repeating the analysis using recordings from the peripheral area one observes that the effect of attention is weaker than in the central area. This effect is also

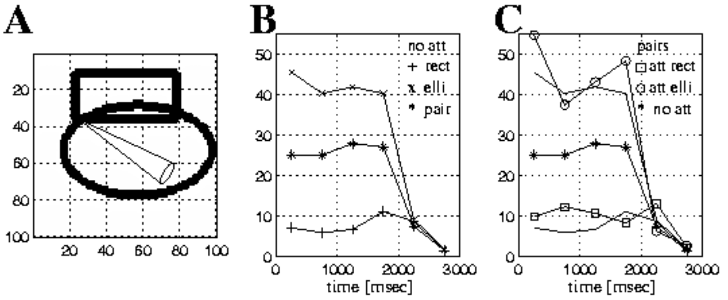

Figure 2: Single neuron PSTH (peri-stimulus-time-histogram) response under different attentional conditions when stimulating with one object or two objects simultaneously (see text).

found in neurophysiological experiments (e.g. V2 vs. IT). The interpretation is that the degree of competition depends on RF (receptive field) size (Reynolds & Desimone 1999) which is known to be larger for higher areas. In other words, two stimuli represented by two neuron groups at a cortical location will compete due to common unspecific local inhibition only if the RFs of the neurons overlap at least partially.

In experiments as well in our simulations attention seems to act as a kind of filter: if two objects are present, the response of the neuron is as if only the attended object were in the RF (Reynolds and Desimone 1999). One could try to explain these findings by assuming a simultaneous activation of the two assemblies representing the two objects. Then inhibitory activity would be greater than for single stimuli and therefore account for the observed response intermediate between the response for preferred and poor stimulus. However, in this case it is surprising that additional excitation by attention accounts almost exactly for the loss of activity by the additional inhibition in the two stimulus case, as it seems to be in experiments.

Our model explains this filter property more elegantly: When looking to unaveraged single trials (in contrast to the PSTHs of Fig.2 or the experiments) one observes that the described effects can be explained by different kinds of binding (Fig.3) While without attention binding fluctuates, i.e. phases of enhanced activity (fast states) are split up between the two competing stimuli, attention produces a bias towards one stimulus such that the binding is static again, as if only one object were present in the visual field.

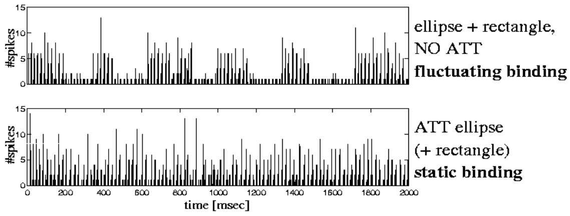

Figure 3: Single-trials (summed over all neurons representing the ellipse). Same experiment as in Fig.2.

From our model we can infer several predictions for experiments. For example the switching of the assemblies should be reflected in local field potentials of mass recordings (e.g. optical imaging) as well as in membrane potentials of single neurons, and the variance between single trial recordings should be higher for two competing stimuli without attention than for the case of only one (attended) stimulus. Actually, recent neurophysiological findings already point in this direction (Anderson et al. 2000; Tsodyks et al. 1999).

In summary, we have proposed a biologically realistic model which is capable of variable binding (Knoblauch & Palm 2001, 2002; cf., Shastri & Ajjanagadde 1993). In future work this will be extended to perform the full sensory-motor loop of a simple cognitive task like reacting to a spoken order to point to a certain object in the visual field.

Acknowledgments

This work was partially supported by the MirrorBot project of the European Union, and by the Volkswagen foundation (VW-I/77 355).

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