Coding the Presence of Visual Objects Independent of their Identity by a Multi-Level Neural Network with Feedback

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INTRODUCTION AND GOAL. Visual cortical areas V1, V2 and V4 are known to encode contours. Zhou et al. [1] showed that a large percentage of V1, V2 and V4 neurons in monkeys can also respond specifically to a contour belonging to an object. This border ownership (**BO**) coding recorded is present within milliseconds of response onset and is largely invariant to changes in object size. We are interested in the neural mechanisms of BO-coding, and more generally, in mechanisms of coding in the presence of visual objects, independent of their identity.

MODEL. In our model form invariance increases with each of the three areas through feed-forward convergence. In Area 1 (Fig.1) the classical receptive fields (**cRF**) have orientation specific simple-cell properties. Area 2 neurons respond to convex contours. Neurons of the highest area (Area 3) detect the presence of an object and its position in a visual scene, invariant of its form. Area 1a and 1b neurons receive the same input only differing in its latency. In the lowest area (Area 1b) there are pairs of mutually inhibiting neurons encoding converse relative positions of object presence at each position and for every orientation. Such BO-neurons receive modulatory feedback from the highest area. Thereby they are provided with information about object presence and location required for BO-encoding.

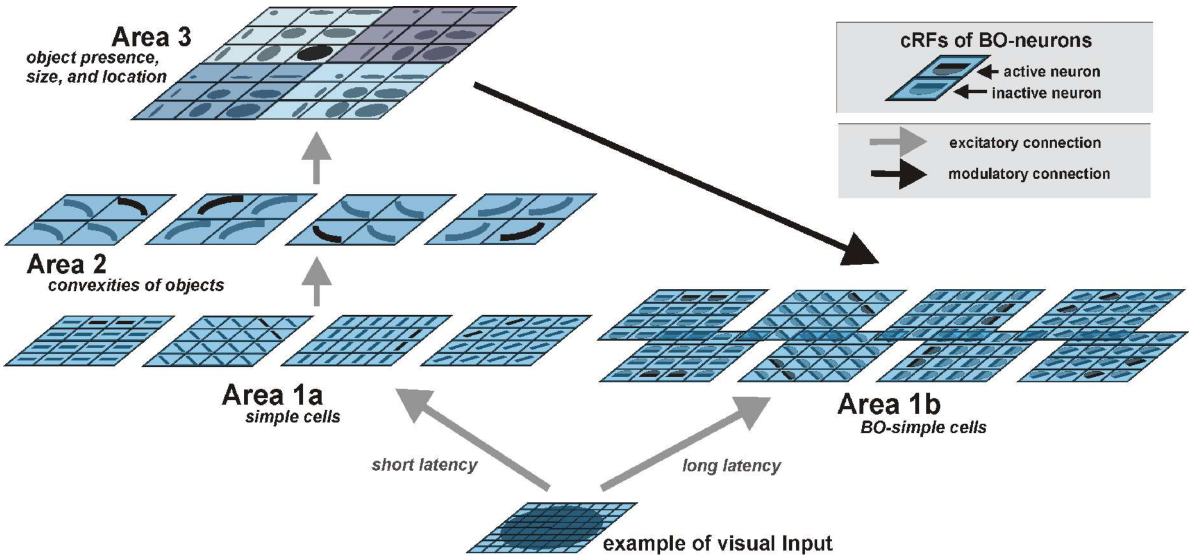

Fig.1: *Network architecture with antagonisitic border ownership neurons in Area 1b. Through feed-forward convergence cRF size increases with each area. Area 3 provides modulatory feedback to Area 1b. Neurons activated by exemplary disc stimulus are highlighted in black.*

Intra-areal connections support encoding of Gestalt properties and object detection. In both Area 1a and 1b neighboring neurons with curvilinear arranged cRFs modulate each other with Gaussian distribution of coupling strength, encoding the Gestalt property of good continuation. Area 1a neurons encoding a convex contour segment converge on the same Area 2 neuron. Thus, Area 2 neurons encode the Gestalt property of convexity. Area 2 neurons encoding complementing convexities facilitate each other and neurons encoding contradicting convexities inhibit each other, further supporting convexities. The convergence of complementing Areas 2 convexity detectors in Area 3 resemble the Gestalt property of closed contour, since Area 3 neurons encode the presence of objects with closed contours. In the highest area, neurons encoding objects sharing edges inhibit each other. Further, in all areas neurons inhibit each other locally.

RESULTS. The activity of a BO-neuron is raised when it is part of an object and lowered if its antagonistic BO-neuron is activated (Fig.2). There is no change in activity of BO-neurons through feedback, when encoding an edge not belonging to any object (resembling the monkey data [1]). In addition, figure-ground segregation is markedly improved by these properties, thus aiding possible further processing. Depending on feedback strength and inhibitory effects, the model allows a wide range of feedback-effects from slight modulation to suppression of everything not belonging to objects detected.

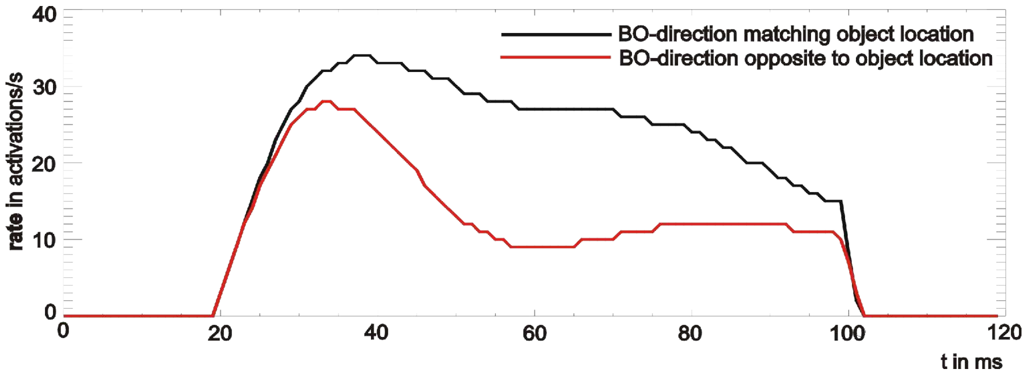

Fig.2: *Antagonistic border-ownership neurons in Area 1b coding the same position and orientation but opposite BO-directions.One BO-neuron (black) receives modulatory feedback and inhibits its antagonist (red/grey).*

DISCUSSION. Our model shows how a neural network with fast inter-areal feed-forward and feedback (according to measurements [2]) can support the presence of visual objects in lower visual cortical areas. This can explain BO-properties found in monkey visual cortex [1], especially the fast responses of BO-neurons independent of stimulus size - impossible to account for by the relatively slowly conducting intra-areal connections having lateral delays dependent on object size [2]. The model uses the known time-delay between fast magnocellular (to Area 1a) and slow parvocellular (to Area 1b) input. The model resembles biologically plausible mechanisms: The convergence throughout cortical areas in the dorsal visual pathway, with layers first encoding simple Gestalt properties, then location of parts of objects or even entire objects. Through the explicit representation of objects our model performs more robust, especially with complex stimuli, than models not detecting object presence [3]. Our model further demonstrates that fast feedback connections can play a crucial role in figure-ground segregation, improving the signal-to-noise ratio of visual object representations in early visual areas. Through modulation of BO-neurons these are able to prevail against less active neurons not belonging to the encoded object's contour in their surround through inhibition.

[1] Zhou, Friedman, von der Heydt (2000) J. of Neuroscience 20:6594-6611
[2] Bullier (2001) Brain Research Reviews 36:96-107
[3] Nishimura, Sakai (2004) Neurocomputing 58-60:843-848