Grouping mechanisms for object-based vision and attention

by

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Abstract

The visual brain faces the difficult task of reconstructing a three-dimensional (3D) world from two-dimensional (2D) retinal images. In doing so, visual information is organized in terms of objects in 3D space, and this organization is the basis for selective attention, object recognition, and action planning. In complex visual scenes, both the foreground and the background are rich in features of different types, scales, *etc.* The brain must find a way to group together the features that belong to objects on the foreground, and distinguish them from features in the background.

The goal of this thesis is to understand how the neural circuits in primate cortex accomplish this task using feedback grouping mechanisms for object-based vision and attention. In Chapter 1, we introduce the background information needed to understand the physiology and previous modeling experiments. In Chapter 2, we propose a quantitative neural model of contour grouping constrained by recent physiological data. We validate the model by reproducing several experimental results, including the measure of contour-response d', as well as the magnitude and time course of neuronal responses to contours. In Chapter 3, we extend this model to natural images,

and the results are quantitatively compared with human-generated segmentations and figure-ground labels (Berkeley Segmentation Dataset). Beginning with Chapter 4, we shift our focus to the representation of 3D information in the visual system. First, we show that 3D surfaces can be represented by a feedforward, linear combination of basis functions whose response properties are similar to those of disparity-selective neurons commonly found in early visual cortex. With our model, we are able to reproduce results from a set of psychophysical experiments where attention has to be directed to surfaces. In Chapter 5, we propose a model of 3D visual saliency and show that the added depth information improves saliency prediction. Overall, this work will investigate whether feedback grouping mechanisms are fundamental for linking early feature representations to perceptual objects. The models developed will address how visual features are grouped into 2D and 3D object representations.

Primary Reader: Ernst Niebur

Secondary Reader: Rüdiger von der Heydt

Acknowledgments

As I was sitting on the boat, I was thinking about how the trip was really a metaphor for my PhD experience. I have had opportunities to steer the boat (sometimes in the wrong direction!), gone through both good and bad weather, and through it all, have had a good captain whom I can trust to guide me to the finish.

Dedication

This thesis is dedicated to my younger sister Joy, whose perseverance in the face of adversity has been my inspiration.

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2.1 Structure of the model network. Each circle stands for a population of neurons with similar receptive fields and response properties. Magenta, blue, and orange lines represent feedforward excitatory, lateral inhibitory, and feedback excitatory projections, respectively. Edges and other local features of a figure (black dashed parallelogram) activate edge cells (E), whose receptive fields are shown by green ellipses. Edge cells project to border ownership cells (B) that have the same preferred orientation and retinotopic position as the E cells they receive input from. However, for each location and preferred orientation there are two B cell populations with opposite side-of-figure preferences, in the example shown B_L whose neurons respond preferentially when the foreground object is to the left of their receptive fields and B_R whose members prefer the foreground to the right side of their receptive fields. E cells also excite other E cells with the same preferred orientation (connections not shown), as well as a class of inhibitory cells (IE) which, in turn, inhibit E cells of all preferred orientations at a given location (only E cells of one preferred orientation are shown). B cells have reciprocal, forward excitatory and feedback modulatory connections with two types of grouping cells, G_c and G_o, which integrate global context information about contours and objects, respectively. E cells also receive positive modulatory feedback from these same grouping cells. Opposing border ownership cells compete directly *via* IB cells and indirectly *via* grouping cells, which bias their activity and thus generate the response differences of opposing border ownership selective neurons. G cell populations also directly excite inhibitory grouping cells (IG; again with the indices L and R), which inhibit G_c cells nonspecifically and G_o cells in all orientations except the preferred one. Top-down attention is modeled as input to the grouping cells and can therefore either be directed towards objects (solid lines) or contours (dashed lines) in the visual field (top). 16

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