BMC Neuroscience

BioMed Central

Oral presentation

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Modeling self-organizing tri-chromatic color selective regions in primary visual cortex

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from Sixteenth Annual Computational Neuroscience Meeting: CNS*2007
Toronto, Canada. 7–12 July 2007

Published: 6 July 2007

BMC Neuroscience 2007, **8**(Suppl 2):S24 doi:10.1186/1471-2202-8-S2-S24

How does the brain represent and process color in the primary visual cortex (V1)? Experimental evidence from macaque monkey suggests that cells selective for color are organized into small, spatially separated blobs in V1. This organization is strikingly different from that of orientation and ocular dominance maps, which consist of large, spatially contiguous patterns.

In this paper, a self-organizing tri-chromatic model of V1 is constructed using natural color image input. Neurons in the modeled V1 are initially unselective, and develop multi-lobed ON/OFF receptive fields through Hebbian learning of retinal responses to visual patterns. The model develops realistic color-selective receptive fields, color maps, ocular dominance columns, and orientation maps. Color-selective blobs are located inside ocular dominance columns, and lateral connections link cells with similar orientation preferences, matching previous experimental results. Further, the model makes a number of predictions for future experiments, including:

1. The color map has three types of color-selective blobs and a unique cortical activation pattern exists for each of the pure color hues.

2. The usual blob-like organization for color emerges as long as the training images have a higher brightness contour gradient compared to the hue contour gradient, and the inputs are highly correlated between the eyes. Otherwise the color blobs regularly extend across borders of ocular dominance stripes (contrary to macaque results).

3. Neurons in areas where red and green patches are near each other respond to both red and green, causing them to maximally prefer yellow, even though there are no yellow photoreceptors in the retina.

4. Cells selective for color connect to other cells with similar chromatic preferences: Blue-selective neurons connect to blue selective neurons, red-selective to other red-selective neurons, and so forth.

Thus the model replicates the known data on the organization of color selectivity in V1, gives a detailed explanation for how this structure develops and functions, and provides concrete predictions that can be tested in future experiments. These findings suggest that a single self-organizing system may underlie the development of orientation selectivity, eye preference, color selectivity, and lateral connectivity in the primary visual cortex.