Optimal "multiplicative" interactions between local and long-range contour cues: where natural image statistics meets single neuron computation

Chaithanya Ramachandra[1], Bardia Behabadi[1], Rishabh Jain[2], Bartlett Mel[1,2]
1. Biomedical Engineering Dept, Univ. of Southern California
2. Neuroscience Graduate Program, Univ. of Southern California

Detecting object contours is a key function of the visual system, though the underlying neural operations remain poorly understood. It is generally accepted that: (1) long-range contour extraction begins in V1; (2) contour cues are propagated about the cortex by the massive network of horizontal connections between pyramidal neurons; and (3) long-range contextual inputs arriving from outside their classical receptive fields (CRF) do not drive V1 neurons by themselves, but can "multiplicatively" boost their responses to stimuli within the CRF (Kapadia et al. 1995). Two key questions remain unanswered, however: (1) What should be the form of the interaction between local and long-range contour cues to optimize contour detection, and (2) what neural mechanism(s) might mediate this interaction? To address the first question, we defined a "classical" Gabor-like oriented edge filter CRF(x), and two "contextual" filters sensitive to different aspects of long-range contour structure: M1(x) responded to aligned edge "flankers" just outside the CRF, and M2(x) consisted of an oriented filter superimposed with the CRF but at a coarser scale. Using human-labelled van Hateren images, we computed the contour probability CP = Prob(contour | CRF(x), Mi(x)) separately for both contextual modulators. We found that both M1 and M2 did in fact boost the gain of the CP function in response to increasing CRF input, providing direct support from natural contour statistics for a multiplicative CRF-extraclassical interaction. To address the second question, we compared the measured CP functions to the nonlinear interactions we observed between synaptic inputs delivered to proximal vs. distal basal dendrites in a detailed compartmental model of a neocortical pyramidal neuron using the NEURON simulation environment. We found good matches between the two sets of functions, suggesting that nonlinear synaptic integration within basal dendrites of pyramidal neurons could help mediate long-range contextual interactions in neocortex.