Spatial frequency and visual persistence: Cortical reset

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Abstract—Psychophysical studies show that the duration of visual persistence increases with spatial frequency of gratings. Previous theories ascribe this finding to differences between the spatial and temporal properties of sustained and transient pathways. This paper proposes an alternative account that explains persistence as a side-effect of excitatory feedback in neural circuits for contour extraction. Mechanisms to break excitatory feedback include inhibitory reset signals at stimulus offset. Simulations demonstrate how gratings with lower spatial frequency generate stronger inhibitory reset signals, thereby resulting in shorter persistence for lower spatial frequencies. Additional simulations account for interactions of spatial frequency with stimulus duration, effects of adaptation, and properties of residual traces, as opposed to visual persistence.

INTRODUCTION

Brief visual stimuli often seem to last much beyond their physical duration so that stimuli as brief as 5 ms seem to last more than 300 ms (e.g. Bowen et al., 1974). The duration of persistence is related inversely to stimulus duration (Bowen et al., 1974), inversely to stimulus intensity (Bowen et al., 1974), inversely to proximity of a nearby stimulus (Farrell et al., 1990), and directly to stimulus spatial frequency (Meyer and Maguire, 1977).

Francis et al. (1994) accounted for all of these factors, except spatial frequency, with a neural network model of visual perception. In the model, persistence is the result of lasting neural responses that derive from excitatory feedback in cortical neural circuits. Mechanisms embedded in the neural circuits inhibit lasting responses generated by a stimulus, thereby preventing neural responses from persisting too long. One mechanism was lateral inhibition, which had spatial properties that accounted for inverse-proximity effects. A second mechanism

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created reset signals at stimulus offset that actively inhibited subsequent responses generated by the stimulus. Increases in stimulus duration and luminance increased the strength of the reset signals and thereby decreased persistence, in agreement with the psychophysical data.

This article shows how simulations of the model that include filters of multiple sizes account for the relationship between persistence and spatial frequency. Simulations of the model account for the following psychophysical data:

- **Spatial frequency**: for bar and sine gratings, visual persistence is directly related to spatial frequency. Likewise, persistence is inversely related to the size of a single bar (Meyer and Maguire, 1977, 1979).

- **Frequency and duration**: high frequency gratings show a strong inverse relationship between persistence and stimulus duration. Low frequency gratings have a weaker inverse duration effect (Meyer and Maguire, 1981).

- **Pretest adaptation**: for a high frequency grating with short durations, pretest adaptation to that grating reduces persistence. Persistence is unchanged for gratings of long duration, and for low frequency gratings (Meyer and Maguire, 1981).

- **Residual traces**: when observers judge the offset of any residual trace of the target grating, the duration of the trace is inversely related to spatial frequency (Long and Sakitt, 1981).

In the model, the effects of stimulus duration, spatial frequency, adaptation, and residual traces depend on the behavior of cortical reset signals. The next section briefly describes the model and the mechanisms underlying visual persistence.

**MULTIPLE SCALES IN THE BOUNDARY CONTOUR SYSTEM**

The model, called the Boundary Contour System (BCS), consists of a large set of individual neurons with excitatory and inhibitory connections that promote computations necessary for visual perception. Since Grossberg (1994) recently reviewed the BCS model and described its relations to other parts of visual perception and to parts of visual cortex, this paper will only describe the model in general terms. The BCS' functional purpose is to identify the location and orientation of stimulus edges or boundaries. It accomplishes this by first feeding a visual image to simple cells, where each has a receptive field tuned to changes in luminance at a specific location and orientation. Signals from these cells contribute to complex cells that become insensitive to the direction of luminance change, but remain sensitive to orientation and position. These complex cells then feed into a series of cooperative and competitive hypercomplex cell stages that selects a consistent pattern of cell activations.

To aid contour detection, BCS complex cells pool responses from multiple scales. For the BCS model such pooled responses play an important role in computations of shading (Grossberg and Mingolla, 1987) and disparity (Grossberg, 1987, 1994,