The Human Demosaicing Algorithm

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Abstract

This talk will review work that seeks to clarify the demosaicing algorithm used by the human visual system, as well as work on how the visual system could learn the spectral classes of the cone photoreceptors in the retinal mosaic.

Summary

The human visual system shares with most digital cameras the design feature that color information is acquired via spatially interleaved sensors with different spectral properties. That is, the human retina contains three distinct spectral classes of cone photoreceptors, the L-, M-, and S-cones, and cones of these three classes are spatially interleaved in the retina. Similarly, most digital cameras employ a design with interleaved red, green, and blue sensors. In each case, generating a full color image requires application of a demosaicing algorithm that uses the available image data to estimate the values of the two cone/sensor classes not present at each cone/sensor location [1].

It is well-known that the reconstruction of information lost via interleaved spectral sampling by can lead to visible chromatic artifacts in the resulting full color image [see e.g. ref. 2, Figure 1]. Interestingly, such artifacts are rarely observed in human vision [3], suggesting that the visual system may employ a sophisticated demosaicing algorithm to deal with interleaved cone sampling. Indeed, until recently, understanding the human demosaicing algorithm has been resistant to experimental investigation because it has been difficult to demonstrate artifacts resulting from it. In 2005, however, Hofer et al. [4] reported psychophysical experiments in which an apparatus incorporating adaptive optics was used to stimulate single retinal cones and in which subjects reported the color sensations arising from such simulations. These experiments provide insight about the human demosaicing algorithm.

In the first part of this talk, I will review the measurements of Hofer et al. [4] and show how they can be understood using a model based on a Bayesian demosaicing algorithm [2, 5]. The algorithm incorporates a prior based on the statistical properties of natural color images, and takes into account the precise arrangement of the retinal cones of each observer. The model provides a parsimonious account of a number of features of the experimental data, and in particular accounts for inter-observer variation in color naming entirely in terms of measured individual differences in the arrangement of the retinal cones. That is, the responses of observers to single cone stimulation can be explained by predictions of how a Bayes optimal observer would respond to the same type of stimulation, as long as the arrangement of the cones is taken into account.

The conclusion that the human demosaicing algorithm requires that the visual system 'know' the arrangement of its cone mosaic at a fine spatial scale raises the interesting question of how such knowledge is obtained. For the L and M cones, a variety of lines of evidence suggest that the class of the cone at each retinal location is learned, rather than signaled by some sort of biochemical marker [6, 7, 8]. In the second part of the talk, I will present results that show that natural images contain sufficient statistical structure to support unsupervised learning of cone classes [see also ref. 9].

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Author Biography

David Brainard received his AB in physics from Harvard University (1982) and MS (electrical engineering) and PhD (psychology) from Stanford University in 1989. He is currently Professor of Psychology at the University of Pennsylvania and his research focuses on human color vision and color image processing. He is a fellow of the Optical Society of America and the Association for Psychological Science.