Title: Cone fundamentals, colour matching functions and individual differences

Speaker: Andrew Stockman

Abstract:

Colour perception depends on a complex sequence of serial and parallel processes but at its initial stage it is relatively simple. At its input it depends on the activations of just three photoreceptor types: the long- (L), middle- (M) and short- (S) wavelength-sensitive cones, each of which responds to light univariantly (*i.e.*, with regard only to the number of photons absorbed). Consequently, a knowledge of how well each type responds to different wavelengths—the three cone spectral sensitivities—allows us to predict pairs of lights that should appear the same to the normal or "standard" human observer. The CIE has sanctioned the cone spectral sensitivity estimates of Stockman and Sharpe (2000) and their associated measures of luminous efficiency (Sharpe *et al.*, 2005, 2011) as "physiologically-relevant" standards for colour vision (CIE, 2006). These discrete tabulated cone spectral sensitivities—often referred to as "cone fundamentals"—are specified for 2 and 10-deg vision for the mean "standard" observers with wild-type (normal) photopigment genotypes and with average ocular transparencies. The LMS fundamentals can be easily transformed into colour matching functions (CMFs) for any other sets of primaries, such as XYZ (CIE, 2015) or RGB.

While it is important to be able to define the mean CMFs, it is becoming increasingly important in colour applications to be able to predict the CMFs of individual observers many of which differ substantially from the mean functions. Partly to facilitate this computationally, we have developed formulae that account for the three cone spectral sensitivities, their underlying photopigment spectra and the macular and lens pigment optical density spectra as continuous functions of wavelength from 360 nm to 850 nm with minimal error. These continuous functions enable individual differences to be easily calculated and allow the straightforward generation of non-standard cone spectral sensitivities (and other colour matching functions) with different macular, lens and photopigment optical densities, and with spectrally shifted L- and M-cone photopigments such as those found in red-green colour vision deficient observers.

In a recent series of experiments, we have successfully used these continuous functions to analyse colour matching data obtained with a new 11-primary LED-driven colour matching device (LEDMax) and have been able to identify the causes of the individual variations in the matches.

References: Stockman and Sharpe, *Vision Research* (2000) 40, 1711-1737. Sharpe *et al.*, *Journal of Vision* (2005) 5, 948-968; *Color Research & Application* (2011) 36, 42-46. CIE (2006) 170-1:2006; (2015) 170-2:2015.

Biography:

Andrew Stockman is the Steers Professor at the Institute of Ophthalmology at University College London and is a part-time Qiushi Chair Professor at the College of Optical Science and Engineering, Zhejiang University. His research areas include color vision, rod vision, visual adaptation, temporal sensitivity, and clinical psychophysics. He may be best known for his work with Ted Sharpe on spectral sensitivities and luminous efficiency. He runs the widely used colour database at http://www.cvrl.org and is Editor-in-Chief of Color Research and

Application. In 2016 he received the Colour Group GB Newton medal, and in 2018 the Inter-Society Color Council Macbeth Award.