Colourfulness of colour images of natural scenes: Multidimensional scaling

surface, even though the spectra of both illuminants are unknown. As follows from the work of Maloney and Wandell, 1986 *Journal of the Optical Society of America A* **3** 29–33) we show that, if illuminants and reflectances are described well by two-dimensional and three-dimensional linear models, it is possible to solve for colour constancy at a shadow edge. If the linear model only approximates real cone responses then the attainable colour constancy is dependent on the magnitude of the chromaticity shift between directly illuminated and shadowed cone response vectors—the greater the chromaticity shift the better the colour constancy. Although there are other theories of colour constancy in which multiple illuminants are assumed, ours is unique in that it works with a single reflectance (the most plausible circumstance), as opposed to two (Tsukada and Ohta, 1990, in *Proceedings of the Third International Conference on Computer Vision*, IEEE Computer Society) or three (D'Zmura and Iverson, 1993 *Journal of the Optical Society of America A* **10** 2148–2165) reflectances. We carried out simulation experiments to evaluate our method. In line with our theoretical arguments, the degree of colour constancy attained is directly linked to the chromaticity shift between direct and shadow illuminants. Good colour constancy is possible with fairly small colour shifts.

◆ **The interaction of colour and motion in figure–ground segregation**
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We studied how motion and colour interact in figure–ground segregation by determining whether noise in one cue interferes with the segmentation signal carried by the other (cue interference) and whether segmentation is enhanced when the two cues concur (cue concurrence). Observers viewed an array 6.5 deg square of 1000 randomly positioned dots in which the target was a vertical band of dots appearing to the left or right of midline and distinguished from the background dots by a different distribution either of speeds, of colours, or of both. The stimulus design ensures that the task cannot be performed by local-motion or colour-contrast detection. The stimulus was displayed for 100 ms, and was followed after 150 ms by a 1 s mask of moving dots with random speeds and colours. In the motion-isolation case, target and background dots had the same uniform colour, with nonzero luminance contrast. The speed distributions of the background, and target dots were each Gaussian, with different means and standard deviations. Thresholds for correctly locating the target were measured as a function of the difference in target and background distributions. In the colour-isolation case, the target and background dots were held static, while their chromaticities were drawn from different Gaussian distributions. Thresholds were similarly determined as a function of the colour-segmentation signal. In the cue-interference case, motion noise was added to the colour signal (or vice versa) by assigning target and background dots speeds (or colours) drawn from the same nonuniform distribution. We found that thresholds for segmentation by motion were significantly increased by colour noise (for example, by roughly 10% for a colour-noise distribution of 50% red, 50% green). Thresholds for segmentation by colour were likewise increased by motion noise. In the cue-concurrence case, when subthreshold segmentation signals for colour and motion were combined, performance was boosted above threshold, beyond that predicted by probability summation. The results suggest that colour and motion signals interact at early stages, before a global segmentation based on either is decided.

◆ **Colourfulness of colour images of natural scenes: multidimensional scaling**
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It was found that the perceptual quality of the images of natural scenes depended upon their subjective colourfulness when the images were transformed by varying of chroma (Fedorovskaya et al, 1993 *Proceedings of the 1st IS&T/SID Colour Imaging Conference* 37–41). The transformations were done over the colour-point distributions in the CIELUV colour space, where each colour point represented one pixel of a corresponding image. On the basis of the unidimensional scaling of colourfulness it has been demonstrated that colourfulness can be represented as a linear combination of average chroma and variability of chroma. However, such a representation held only within each scene; there was no regular rule to compare different scenes even with significantly different average chroma of the original images. Multidimensional scaling of the colourfulness reveals the relations of different scenes regarding this perceptual attribute. It highlights several factors influencing subjective impression of colourfulness. These factors can possibly be interpreted as a combination of average chroma and variability of chroma, an overall lightness, and representation of hues. The data obtained are compared with those of cluster analysis performed over colour-point distributions in CIELUV colour space.