H 14: Theories of Colour Vision

Theories of colour vision

Trichromatic theory

The presence of three types of "colour" receptors in the retinal layer confirmed the ideas that had been proposed in the trichromatic theory of human colour vision. This states that the magnitudes of three stimuli determine the perception of a colour and not the detailed distribution of light energy across the visible spectrum.

The concept is illustrated in Figure 1. If these stimuli are the same for two different light distributions, then the colour appearance of the lights will be the same, irrespective of their spectrum.

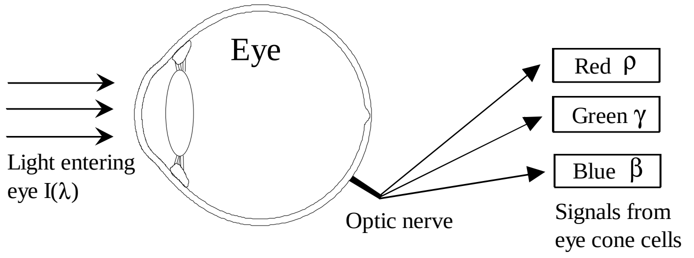

Figure 1: Signals from the eye cone cells

The theory is also known as the ***Young-Maxwell-Helmholtz theory*** after the three scientists who made significant contributions to its development. The trichromatic theory is important since it forms the basis of most methods of expressing colour in terms of numbers and of the methods of reproduction of coloured images.

Thomas Young (1801)

Proposed that the eye perceived colour in terms of three principle or primary colour stimuli. He initially suggested that these were red, yellow and blue, but later amended this to red, green and violet.

Helmholtz (1852)

Helmholtz appears to have been the first person to recognise the difference between "additive colour mixing" and "subtractive colour mixing".

Additive colour mixing

Describes the creation of a range of colours by the mixing of light from two, or more, coloured light sources. It is known as additive because each source adds light of selected wavelengths to the mixture. The most familiar example of colour reproduction by additive colour mixing is colour television. All the colours seen on the screen are produced by the combination of light emitted by red, green and blue phosphors on the screen.

Subtractive colour mixing

Describes the creation of a range of colours by the mixing of two or more materials that absorb (subtract) light of selected wavelengths from the incident illumination, usually white light. The most familiar example of colour reproduction by subtractive colour mixing is colour photography. All the colours seen on are produced by the absorbing different amounts of the red, green and blue bands of light from the white light incident photographic image.

Partitative colour mixing

The impression of continuous colour tones obtained by half-tone printing is by a combination of the additive and the subtractive colour mixing processes, this has the special name of partitative colour mixing.

James Clerk Maxwell (1860)

Made recognised the fact that most, but not all, colours could be obtained by mixing together appropriate amounts of red, green and blue (or violet) lights for example by shining them onto a projection screen. He proposed that the amounts of light from three standard sources required to match the colour appearance of an object would provide a complete specification of the colour of that object.

Maxwell was the first to demonstrate a method of colour photography, he reproduced the coloured image by mixing together appropriate amounts of red, green and blue light using three overlapping images projected onto a screen.

The trichromatic theory does not explain all the facts concerning colour vision, but it was an important step in the investigation of colour sensations. The theory, coupled with the concept of colour matching equations, led to the first internationally agreed method of numerically specifying colour. Numerical methods of describing colour are used to communicate colour information without the need for physical samples. Ideally, the numbers should by easily interpreted in terms of attributes such as lightness, chroma or hue.

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Opponent theory

The opponent theory arose from the ideas of ***Hering*** and deals with the interpretation of colour stimuli, and describes a second stage in the colour vision process. The first trichromatic stage describes the generation of three colour stimuli; the second stage describes the subsequent interpretation of these stimuli.

Psychological primaries

Hering pointed out that we normally describe a colour in terms of four unique hues

Red, Yellow, Green and Blue.

All other hues may be described in terms of one or two terms drawn from these four. For example orange is a not a unique hue since it can be described as a reddish yellow, in a similar way purple is not unique since it can be described as a reddish blue. The hues red, yellow green and blue are unique, as they cannot be described in any other terms.

Opponent pairs

The four unique hues of red, green, yellow and blue, when taken together with white and black form, a group of six basic colour properties.

Red and green are not only unique hues but are also psychologically opponent colour sensations. A colour will never be described as having both the properties of redness and greenness at the same time; there is no such colour as a reddish green.

In the same way, yellow and blue are an opponent pair of colour perceptions.

The six properties can be grouped into two opponent pairs, red/green and yellow/blue and the luminance property of white/black.

The second stage of colour vision is thought to arise from the action of neurons and in particular by inhibitory synapses. Figure 2 illustrates the signal pathways and the processing required accounting for the properties described in the opponent theory.

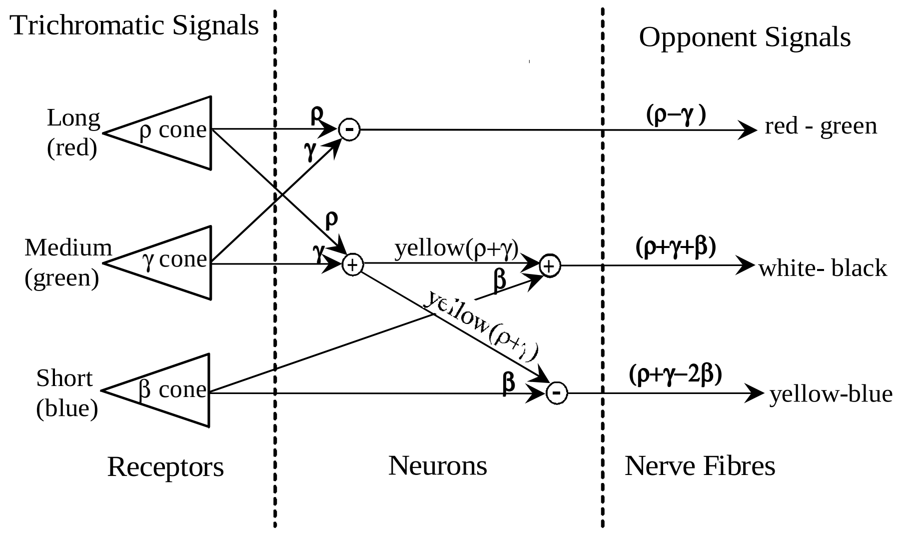

Figure 2: A set of signal paths consistent with the two stages of colour vision

Colour appearance models

The concepts of the two-stage model of colour vision, trichromatic followed by opponent, accounts for the visual appearance of a surface when viewed under a ***specific set*** of reference conditions. At first consideration, this does not seem to be much of a limitation, as it imposes no difficulties provided we are only considering surface colours such as painted or printed panels. However, the rapid growth in the need for the cross-media representation of colour information, such as that depicted by Figure 3, has caused the limitation to become a problem.

Figure 3 shows three stages in the production of a design for a printed item of sportswear. Imagine that instrumental measurements give L* a* b* values for the printed materials that are an acceptable match to the L* a* b* of the corresponding areas on the CAD monitor display. Will the colour appearance of areas of the printed materials match the appearance of the corresponding areas of the monitor display?

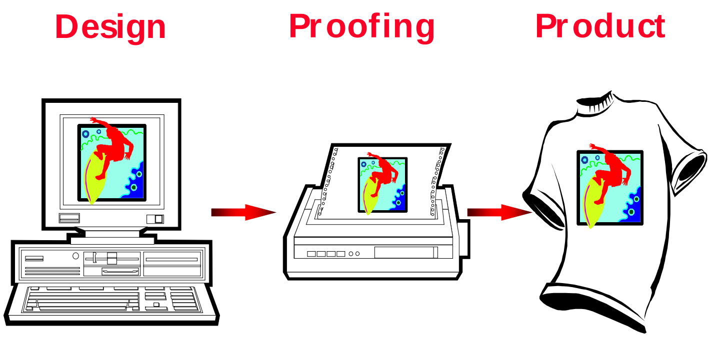

Figure 3: Three stages in the production of sportswear

The increasing use of computer based methods for creating design for fabrics and print, has led to the demand that the colour of the printed product has the same appearance as that displayed on the computer display monitor. This can be achieved with the aid of an “Appearance Model”.

Principles of appearance modelling

An appearance model considers the way in which the visual system senses light, the way adaptation changes the visual signals and how the adapted signals are combined for transmission to the brain. Hunt introduces this version of an appearance model as being:

> ***“...sufficiently simple to make it feasible for modelling, while making it possible to include the most important factors that affect colour appearance.”***

A schematic diagram showing the relationships between the three stages, sensing, adaptation and combination, is shown in Figure 4.

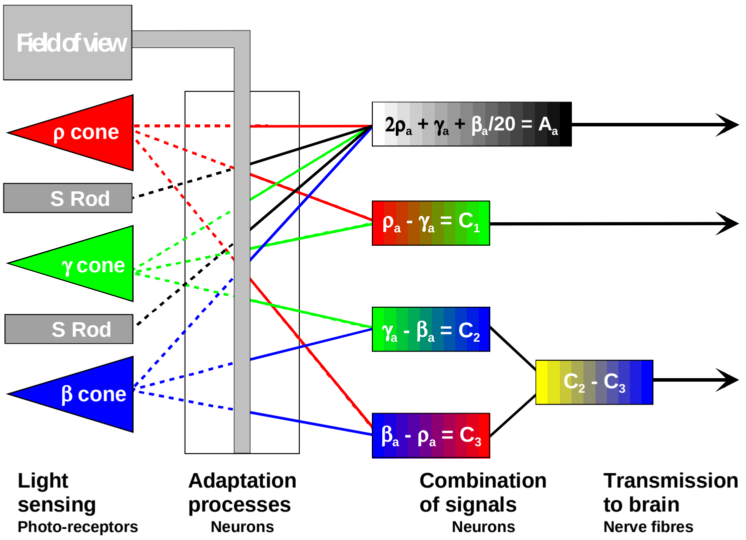

Figure 4: Stages of the visual process that occur in the retina

Light sensing

The first stage in the visual process is the sensing of light by the rod and cone photosensitive elements.

- rgandb are the visual stimuli of the long, medium and short wavelength sensitive cones respectively.
- S is the visual stimulus of the rod cells.

Adaptation

The second stage in the visual process transforms the visual stimulus of cells in the central element to take into account interactions with the signals coming from cells in the other areas of the retina. One of the most common examples is chromatic adaptation that acts so that a white object is perceived as white under a wide range of illumination conditions.

Combination
The third stage in the visual process is the addition and subtraction of the adapted signals to generate a luminance channel and several opponent channels. The combined signals are interpreted by the brain in terms of the attributes of colour appearance attributes such as hue, lightness and chroma.

- A is an achromatic channel that passes luminosity information only.
- C_1, C_2, and C_3 are the colour opponent channels that pass (red – green), (green – blue) and (blue- red) information respectively.

Such models are capable of predicting, and compensating for the simultaneous contrast effect.

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