What is Colour?

Ross Littlewood, Jan 2016.

Customary language uses colour reference as if the property of colour was fully determined by physical properties inherent in objects. Colour perception is therefore regarded as the processes through which observers discover pre-existing facts about the world. The observer need not be an infallible judge, but errors in observation do not negate the assumption that colour is a physical property of objects. This assumption has been called 'colour objectivism' (Hardin 1988), and I will argue it is false. To explain why, I will need to discuss some uncomfortable facts about visual perception.

The first is that our colour perceptions are more fallible than we usually acknowledge. In Fig. 1 there is a strong impression that parts A and B are different colours but a Photoshop cut out of each presented against a neutral background at the left of the page shows they are the same.

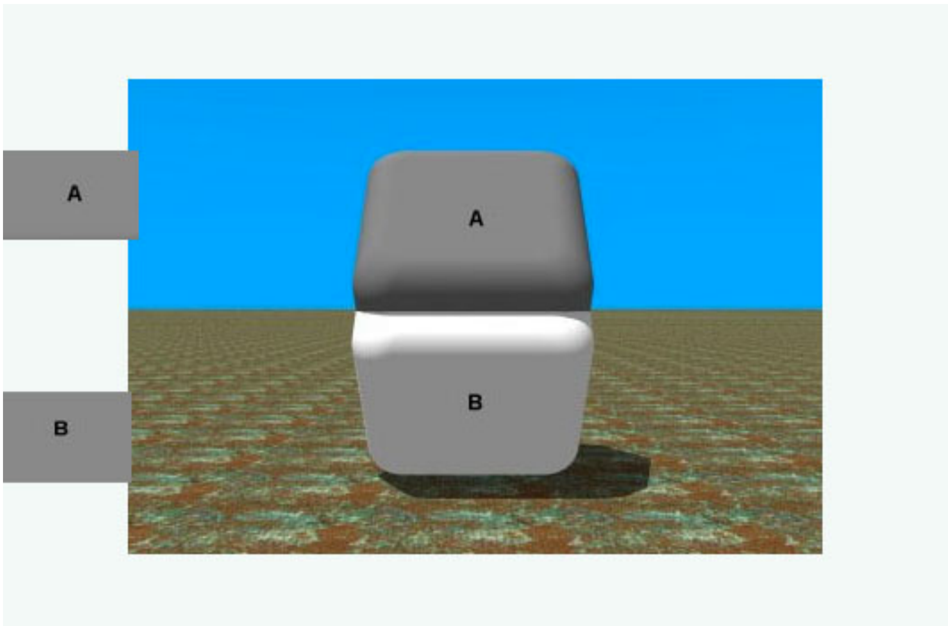

Fig. 1 (Modified from http://brainden.com/color-illusions.htm)

Fig 2 appears to show different coloured dogs but a Photoshop analysis reveals they are also the same. The explanation of these errors of judgment is that simultaneous colour contrast biases our perceptions.

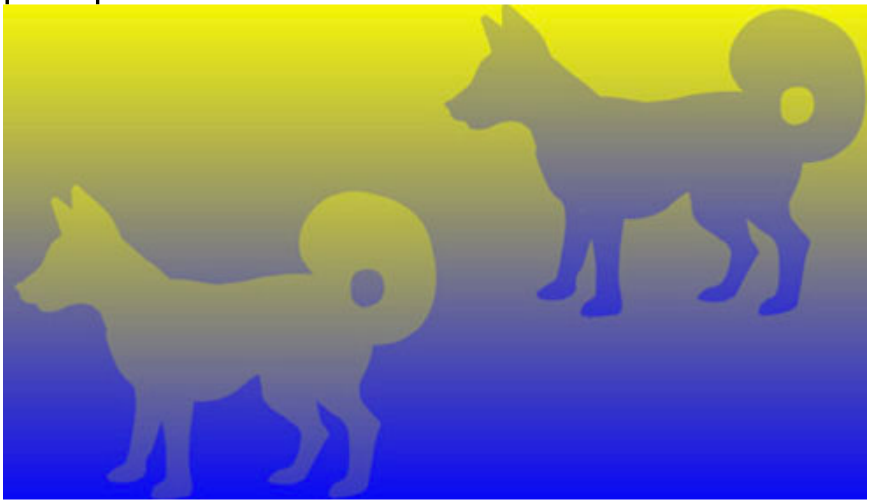

Fig.2 (from http://brainden.com/color-illusions.htm)

The second uncomfortable fact is that the colour categories we refer to in language, both socially and 'internally' when thinking about colour, function linguistically as culturally contingent heuristics. Heuristics are rapidly accessible mental shortcuts. They place our perceptions into broad categories, which simplifies communication and decision-making. Knowing the colour of fruit informs us if we should eat it but tells us very little about the pigments on its surface. Berlin and Kay (1969) established that humans from a wide range of cultures can distinguish the same 11 colour categories named in English, but their methodology had a Eurocentric bias and ignored several examples of culturally contingent colour difference. For example, Spanish, Italian and Russian have a separate colour name for light and dark blue, whereas English does not. The Dani tribe of Western New Guinea has only two colour names in their language (Heider, 1972), and other tribal groups in New Guinea and Africa have been found to conflate light blue with grey. It has been claimed that the paucity of colour names in Homeric and Biblical texts suggests that colour perceptions may have altered during social development (Gladstone 1858). In particular, it is claimed that blue is seldom mentioned, however it is well known that the Phoenicians traded extensively with both the ancient Greeks and the Levantine tribes, and amongst their most valuable goods were purple and blue dyes. Homer's 'wine dark sea' is a perfectly good description of the colour of the Mediterranean reflecting an orange-red sunset. Even a Universalist about language could accept that there is historical and anthropological evidence for differences in colour naming between cultures, and also differences in the apparent importance of the identification of colour as a heuristic for object identification. There is no inconsistency between the beliefs that all perceptually intact humans are in principle capable of perceiving a similar number of colour differences across the visible spectrum and the belief that colour reference in language is largely socially determined.

The third uncomfortable fact is that any categorical colour perception can be elicited by an almost infinite variety of spectral distributions (defining physically different stimuli). It is possible to produce indistinguishable 'colour samples' from completely different spectral components, such as additive and subtractive primaries. Indistinguishable colours comprised of dissimilar spectral distributions are called metamers. The waveforms in Fig. 3 represent the spectral reflectance from a series of paints, but it is very difficult to predict the colour category from any of the spectral distributions, or to be certain which different waveforms will produce different colour perceptions.

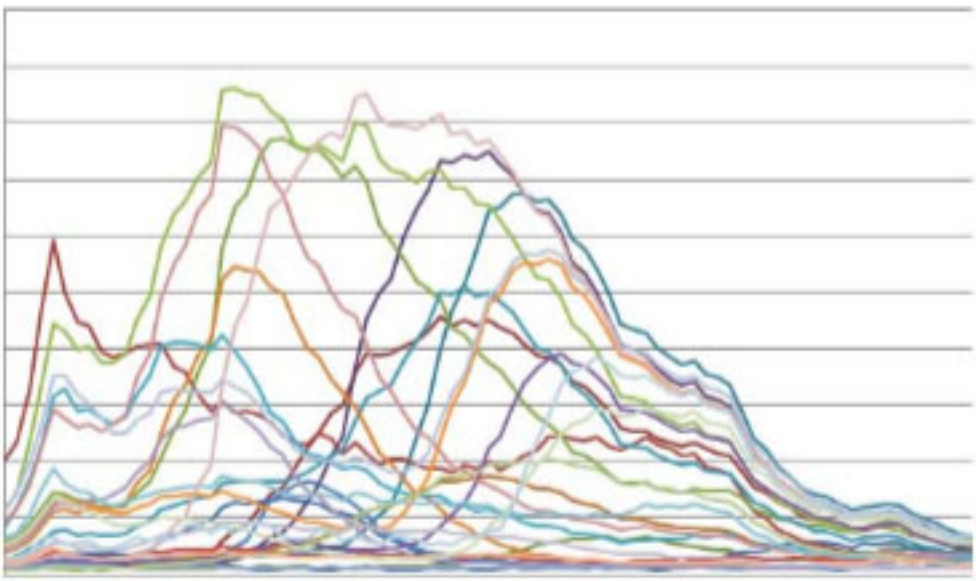

Fig. 3. Spectral Distribution Curves (from http://www.ebajapan.jp/assets/pdf/hiroshima_baba.pdf)

The fourth uncomfortable fact for objectivism is colour constancy. If an observer identifies a yellow banana in a background of other fruit it is possible to manipulate the illuminating wavelengths on the fruit so that the spectral emission from the banana closely matches that of a green apple nearby. Under controlled viewing conditions observers may still report the banana as yellow and the apple as green. This phenomenon was the subject of some interesting experiments by Edwin Land who popularized his own theory of colour vision called retinex theory (1977).

The fifth problem for objectivism is the Helmholtz-Kohlrausch effect, in which fully saturated spectral colours appear more luminous than an equiluminant white. "Objective" colour saturation is perceived "subjectively" as a hybrid phenomenon comprised of both luminance and chroma.

These problems for objectivism should encourage us to look elsewhere for the origins of colour. Perhaps the essence of what we mean by colour is the response pattern of our three cone receptor types. A moment's reflection will show that this cannot be true. For any single type of light receptor the response varies with the amount of light energy absorbed, regardless of wavelength. A green receptor responds equally to a yellow of low intensity or a blue of greater intensity, even though it has a peak sensitivity at 530 nanometers. We refer to the three receptor types as different because they have different peak sensitivities, but for each class of receptor the only difference the wavelength makes to their response is the relative magnitude. There is no in principal way that the response of any class of light receptor could provide the basis of colour consciousness unless luminance was fixed. Combining two cone types broadens the response curve but still fails to provide a qualitatively different response in proportion to wavelength. Adding a third receptor type simply broadens the response curve further. We need to look beyond the receptors for an explanation of 'colour.'

The next step in visual processing is signal opponency. If the green cone response is subtracted from the red then the resulting 'opponent' signal can be compared to the luminance, or 'yellow' response, when red and green are summated. This is thought to occur within the retina as a result of neural processing. When the blue cone response is subtracted from the yellow response a further qualitatively different chromatic sensitive signal is created. This process is called opponent processing and was first proposed by Hering in 1878 (Baumann 1992). Opponency produces spectrally responsive signals but it does not produce a set of categorically distinct colour differences. The red /green opponent output from the retina travels via 'parvocellular' fibers to the cerebral cortex, and the blue / yellow opponent output via 'koniocellular' fibers, that do not mix or combine their signals, even as they terminate in the striate cortex. There are also 'magnocellular' fibers that transit luminance signals with high temporal resolution that is useful for movement perception.

When these nerve fibers pass through the occipital cortex they appear as white 'striae' (streaks) within the grey matter at the occipital lobe of the brain, giving this region its name - 'striate cortex.' The different signal types (parvo, konio, and magno-cellular) are separated into separate 'columns' that lie parallel to one another within the striate cortex. Shape, location, brightness, colour, edge orientation, movement, and other object features are processed in parallel columns of nerves; but at different speeds. Given that the colour signal is still anatomically separate from the rest of the object features the overall perception lacks unity at this point. It seems problematic to claim that the striate cortex could functionally attach colour to object perceptions if the colour signal is not united with the other visual processes. The main colour processing area of the striate cortex is called V4, but brain cells in that area respond more to chromatic contrast than to particular hues. It seems that even at this level of parallel processing we have still not found the neural correlate of colour.

The search continues. From the striate cortex the visual signal travels through a 'ventral stream' to the inferior posterior temporal lobe, and via a 'dorsal stream' to the superior and medial posterior parietal cortex. The dorsal stream determines where an object is in relation to an internal 'map' of the visual field - each of us has our own egocentric map of the world located in our heads, and it seems that vision operates by locating 'nested volumes' within this egocentric array, before attributing meaning or judgments to the objects of regard. ventral stream determines what an object is, and is located close to Wernicke's area; a part of the brain necessary to the interpretation of meaning in language. Functional magnetic resonance imaging (fMRI) suggests that an area beneath the posterior part of the brain called the lingual gyrus, and an area on the inferior surface of the posterior temporal lobes called the fusiform gyrus, together form the 'colour center' of the brain (Lueck et al 1989). Neurons in these areas have strongly colour receptive fields. Damage to these areas causes cerebral achromatopsia (loss of colour consciousness). The dorsal stream has connections to V4 but there are more colour coded connections in the ventral stream, consistent with the belief that the temporal lobe makes categorical judgments about object perceptions, but for any collection of visual signals to be apprehended as an object prior processing is required.

You may be familiar with this hoary philosophical chestnut; if a tree falls in a wood and there is no one there to hear it fall, does it make a sound? One answer is that it creates an acoustic signal but sound by definition only exists in the brain of a conscious subject who detects the signal and processes it. The problem with colour is somewhat analogous, but differs importantly in that chromatically contingent perceptions have culturally determined references. A rapid mental shortcut for labeling objects and ensuring they are categorised consistently is called a heuristic. Colour is a socially determined set of heuristic labels that arise after object processing in the brain of a conscious observer.

A solitary 'red' pixel in a blackened room is not first of all a sample of redness. It is first of all a luminance target with a specific egocentric location and extension. Secondary characteristics of texture, stability, colour, etc are judgments about a subconscious 'precategorical icon.' Objects are not recognised for what they are before we map them into our subconscious as objects. Colour seems to be part of the process of judging objects, not a way of determining a facts about their essence. We are all aware that objects enter consciousness with an exclusive 'colour identity' – they are never both red and green at the one time. This fact does not mean that 'colour' must be in the raw signal. It is just as plausible to believe that colour emerges subconsciously from processing and is added as part of object identification. That hypothesis would explain many of the colour illusions that puzzle us. Colour is a pragmatically useful label used by socially connected individuals to consistently reference chromatic contrast within a social discourse. The truth about what perceptions match what colours are truths that exist within social discourse before we are born. There is no physical machine, colour chart, or scientific test that can determine the boundary between pink and red. That is socially determined, and is not reducible to biological or scientific facts. The view that I have been arguing for here is a species of 'colour subjectivism.'

In 2015 there was a debate in social media about the colours in the dress below (Fig. 4). As opposing groups debated about their perceptions it was interesting to note how little each side was willing to compromise in the face of 'scientific' objectivity.

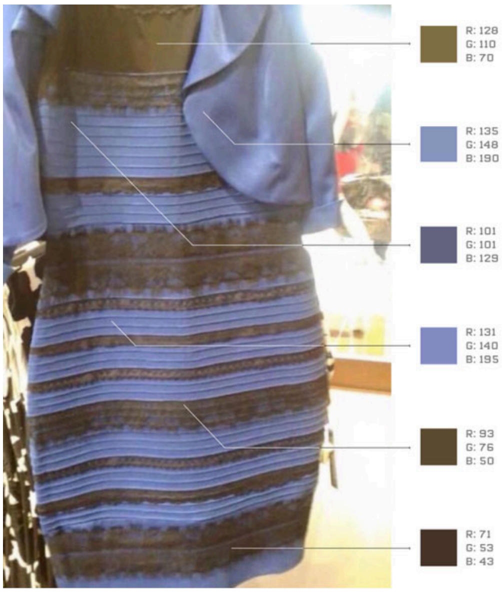

Fig. 4. Coloured dress (from http://www.wired.com/2015/02/science-one-agrees-color-dress/).

"The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead: his eyes are closed." – Albert Einstein

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