# Unique Hues and Colour Experience

## Mohan Matthen

## University of Toronto

### Introduction

A unique hue (also called an elemental or a pure hue) is one that is experienced as not being a mixture of other hues. For trichromatic humans, there are four unique hues—unmixed shades of blue, yellow, red, and green. These shades come in opposed pairs (Figure 1): blue is opposed to yellow in the sense that no shade is both bluish and yellowish; red is opposed to green in the same way.

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Figure 1: Colour oppositions: the white-black axis is orthogonal to the other two. (By permission of Bruce MacEvoy)

Leaving the permanently excluded opposite of each hue unsaid, we have:

Unique blue is that shade of blue that is neither reddish (in the way that mauve is reddish) nor greenish (in the way that turquoise is) [*nor whitish nor blackish*].

Unique red is that shade of red that is neither bluish (like purple) nor yellowish (like orange) [*nor whitish nor blackish*].

Similarly for unique yellow and unique green.

The reference to the achromatic elements, white and black, is usually excluded. Without their mention, shades of red on the interior of the colour solid would also count as unique. Harald Arnkill (2013, 170) explains: “When mixed with blackness, whiteness, or both, [the hues] form nuances, such as greys, browns, and olives,” not to mention pastels. The **unique hues** are colour *classes*: for instance, unique red includes all of the reddish greys, browns, and pinks that do not contain any blue or yellow*.* The structure of these classes will be explored in Sections II-IV below. The full definitions given above define the **elementary colours**; these are singular colours. Philosophers sometimes write as if the unique hues were elementary colours. They are not always clear that to capture a single colour, they need to mention the absence of black and white.

The unique hues arise out of the opponent processing of the wavelength sensitive outputs of the three types of retinal cone-cells. As we shall see, their significance is somewhat idealized in certain representations of colour. However this might be, it is indisputable that they are phenomenologically salient in the sense that most people with normal colour vision (i.e., trichromats) can, with just a little practice, be brought to make consistent judgements of uniqueness regarding sufficiently saturated colour samples. That is, trichromats can more or less reliably identify and re-identify the same colour sample as uniquely green, etc.

This *intra*subjective consistency notwithstanding,there is surprisingly large *inter*subjectivevariability among trichromats about *which* samples are so identified (Webster et. al. 2000, Kuehni 2004). Moreover, as Kuehni (*ibid*, 162) notes, individual unique hues are not rotated as a group, which means that “the perceptual distances between unique hues may vary to a smaller or larger extent by observer.” This is part of a broader phenomenological feature of colour: subjects make relatively consistent judgements about the proportions of hue elements in colours, but there are substantial inter-subjective and some systematic cross-cultural differences regarding these judgements. Looking, for example, at a piece of turquoise pottery, you may consistently judge that it is equally greenish and bluish and I may consistently judge that it is rather more bluish.

It is unlikely that the magnitude of inter-subjective variation can entirely be explained by physiological differences. Webster et al say that it might trace in part to “differences in the visual diets of observers” (*ibid*, 1554). Citing Webster’s findings, Jules Davidoff (2001) attributes inter-subjective variation to “language,” though it is unclear how he reconciles this with the fact that Webster et al were using only English-speaking subjects. (Kuehni’s 2004 metastudy does not mention language.)

Colour experience is surprisingly complex, and there are many ways of systematizing and representing how it varies. Some representations privilege the unique hues as basic dimensions of chromatic experience. This entry reviews some of the key issues that arise out of these representations and the alternatives.

### The Structure of Colour Appearance[[1]](#footnote-1)

1. The Intensive Components of Colour

In every modality, perceptual qualities are experienced as more or less intense or vivid in some fundamental respect. In touch, there are pressure, temperature, and pain; in audition, pitch and volume; foods taste more or less salty, sweet, bitter, and sour. These basic intensives play a big role in perceived similarity. In colour, this kind of variation is particularly salient. Though non-basic qualities partially determine whether two flavours or two sounds are perceived as similar (for example, two flavours might be judged similar because both are “citrusy” or “earthy”), colour similarity is almost entirely determined by simple dimensions, whether or not these dimensions correspond exactly to the unique hues.[[2]](#footnote-2)

Colour scientists have devised several different ways of systematizing colour similarity and its determinants, each appropriate for different purposes. I shall start by briefly considering *physical* (or, more accurately, *psychophysical*)colour systems, though these are not our primary concern here. These systems are componential representations of *external sources* of colour with respect to their effects on the visual system.

The CIE system represents external *light* in terms of the effects it has on the three different cone-cell types present in the retina. These cells are each sensitive to different, but overlapping, wavebands of visible light. Colour vision can differentiate two beams of light *only* *if* they differ in their effect on at least one of these cell-types. Thus, colour can be represented as a tristimulus value: one level for each cell. This basic idea is operationalized in different ways. The CIE RGB system is based on mixing lights of three primary wavelengths (700nm, 546.1nm, 435.8nm, often described, rather imprecisely, as red, green, and blue). Subjects are asked to adjust the strength of these primary lights to match a given colour—when presented with yellow, for example, they will turn red and green up and blue down. It turns out that any colour is expressible as a triplet of RGB values (e.g. greenish yellow=R235, G235, B0). (It’s a bit more complicated, but we can leave it at this.) This system is particularly useful for designing colour monitors and television screens, which use combinations of light emitting elements to produce colour.

The more commonly used CIE XYZ system is a modification of the RGB system, to reflect the fact that the three dimensions of the latter can be reduced to two variables without significant loss of information, with luminance being represented in the third dimension. The familiar horseshoe shaped representation of the spectral colours, found in many textbooks, is a luminance-constant plane in the CIE XYZ diagram.[[3]](#footnote-3)

Other systems for representing physical colour sources provide guidance to designers using paint or ink. Mixing ink for printing is different from mixing light, because ink gets its colour by selectively absorbing some wavelengths and reflecting the remainder. A mixture of inks absorbs what each component absorbs; it is thus subtractive, and the mixture reflects less than each component. A mixture of lights, by contrast, contains the wavelengths of each component and is thus additive. Subtractive mixing requires at least four primaries: standard colour printers produce nearly 3,000 different colours with cyan, magenta, yellow, and black; the Pantone system uses many more than four inks for fine matching.

The RGB and Pantone systems are based on methods of creating physical sources of colour by mixing. Although the primary concern is with how these creations look, the basic components of these systems are the lights or inks needed to produce a physical specimen of a given colour. *Perceptual* systems, by contrast, aim to systematize the intensive variation of colours as they are *experienced*. The unique hues play a fundamental role in such systems because these are *experienced* as the components of perceived colour.

1. Similarity Spaces for Colour

A similarity space is a representation of colour in terms of the basic intensives discussed above. It is a multidimensional graphic representation of qualities in which the nearness of two qualities is proportional to their similarity (Goodman 1970; Clark 1993, chapter 4; Matthen 2005, chapter 4; Raffman 2015). With colour, perceptual similarity is exceedingly difficult to map in this way. The CIE spaces represent colour, as we have seen, by the activation of the colour-sensitive cone cells. Colour *appearance* does not match the activation of the receptors. In the first place, a difference of activation levels might be too small to register. Secondly, because of opponent processing (see Hilbert, this volume), colour experience corresponds not to cone-cell activation triplets, but to *differences* of cone-cell activation—for example, yellow corresponds to a small positive difference between the output of the long-wave cone and that of the medium wave cone.

Figure 2 illustrates the difficulty with regard to just noticeable differences. It shows the plane corresponding to just noticeable differences for combinations of coloured lights of equal luminance. The figure is taken from a photograph of a three dimensional model, which was constructed from a single equal-luminance place in the CIE XYZ chromaticity diagram in such a way as to equalize just noticeable differences: the plane was printed on a flat sheet of paper, just-noticeable-difference intervals were drawn on it, and then the sheet was pinched and folded to equalize these intervals. The distance between two colours in this model inversely tracks perceptual similarity. The result is a plane that is curved in three dimensions. To get *all* the colours, variations of luminance have to be added. David Macadam (1944), who made the Figure 2 model, estimates that the totality of colours occupies a six-dimensional Euclidean solid, which cannot be drawn or physically modelled.

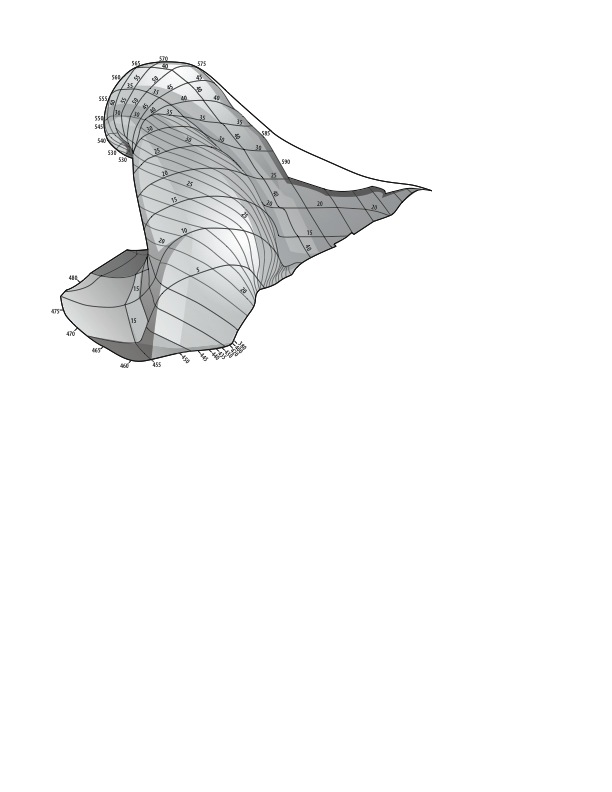


Figure 2: A chromaticity diagram that equalizes just noticeable differences. Notice that the plane is folded over at the top right, one reason why the total space in which it is embedded has dimensionality greater than 3. (From Mohan Matthen 2005: 111. Adapted from David L. Macadam (1944): 203. By permission of Elsevier.)

Different colour spaces model different aspects of colour similarity. Figure 1 takes as basic the unique hues (plus black-white) and their opposition. These give us the three axes of a simpler perceptual similarity space. This figure systematizes colour-similarity in terms of the combinations of these components. It is an idealization based on what are taken to be the underlying processes of colour vision.

1. The Unique Hues as Absolute Locations in Colour Space

The unique hues are given absolute position in colour spaces that are based on Figure 1; they mark definite phenomenal qualities, not positions specified only relative to others. To see the difference, think of a map of the world. Longstanding convention marks the Greenwich longitude as 0˚, but there is nothing qualitatively distinct about either Greenwich or the designation zero that mandates this choice. Delhi could just as easily have been marked as 0, provided that the in-betweenness relation of Greenwich-Delhi-Tokyo was maintained. By contrast, the phenomenally unmixed character of the unique hues gives them a non-arbitrary position in colour similarity space. A colour that looks reddish-yellow is naturally placed in between red and yellow; by the same token, red is naturally placed in between yellow-red and red-blue. However, yellow-red and red-blue cannot be treated as simple components of experienced colour—they are experienced as compound. It is because the unique hues are experienced as simple that they have a special place in colour similarity spaces. Maintaining in-betweenness relations is not enough. (Remember, though, the inter-personal variation in marking the poles.)

1. Colour and Colour Experience

The unique hues are experientially defined: they are the hues that *appear* unmixed or pure. This has important methodological consequences. The initial formulation of psychological theories of colour structure and underlying perceptual processes rested on the careful visual assessment of colour by 19th century theorists such as Thomas Young, Hermann von Helmholtz, and (most successfully) Ewald Hering. These men made inferences about the underlying processes of colour perception simply by reflecting on the structure of colour experience. This was a matter of principle, not of necessity. As Hering wrote:

For a systematic grouping of colours the only thing that matters is *colour* itself. Neither the qualitative (frequency) nor the quantitative (amplitude) physical properties of the radiations are relevant. (Quoted by Arnkil 2013, 168)

Hering wants to say that it is colour experience—not physical fact—that determines *perceptual* similarity spaces such as that sketched in Figure 1.

Spectral similarity is a kind of physical similarity. Colours that are spectrally similar have similar effects on us. Thus, any colour similarity space will track physical, i.e., spectral, similarity *over small regions*. This is true both of physical similarity spaces such as CIE RGB space, which indexes colours by cone-cell activation, and perceptual spaces such as those based on figure 1 and even the massively complex and weirdly shaped space of Figure 2. The *large-scale* topology of perceptual colour spaces is, however, different from that of any physical measure, and also different from one another. The axes of CIE space do not correspond to those of perceptual colour; there is no natural representation within this space of the opposition of red-green and blue-yellow, which are the opposite poles of two dimensions of hue. Moreover, there is no natural position for the unique hues—yellow is a mixture of three non-zero RGB values, though it is phenomenally experienced as unmixed. The CIE spaces provide numerical indices of all the colours we experience, but not in a way that matches colour experience.

On the other side of the coin, the perceptual spaces do not track additive mixing of lights and the subtractive mixing of paints. Here are two examples. The additive mixing of red and green *lights* yields yellow; however, red and green are experiential opposites and cannot be experientially mixed. Second, different additive or subtractive mixtures may be experienced as the same colour: such perceptually equivalent mixtures are known as *metamers*.

The NCS and Munsell systems are based on colour experience. However, these systems are constructed on slightly different principles. The Munsell system takes just noticeable differences of colour as basic, and constructs colour similarity space to preserve them. There are more just-noticeable-difference steps between red and green through blue, than in the other direction around through yellow. In consequence, the blue-yellow and red-green oppositions have no special significance in this system, which does not grant the unique hues special significance. The NCS system takes the unique hues plus whiteness and blackness as defining the basic dimensions of colour experience, and orders the colours accordingly. This difference of approach leads, as we shall see, to topological and terminological differences between the two spaces. It is good to keep this in mind: though phenomenologically salient, unique hue mixtures are only one way of systematizing colour similarity.

### Colour and Hue

Colour is experienced as hue *plus* an achromatic component. The achromatic component is differently defined in different systems. In Munsell’s system, it is called “value” and corresponds to how bright a colour looks. A saturated yellow looks a lot brighter than a saturated blue of the same luminance. (This is because yellow excites two cone cell types, while blue excites only one.) Thus, the Munsell system gives yellow a value closer to white, whereas a maximally saturated blue falls closer to black. Thus, the blue pole in Figure 1 above, which corresponds to unique blue, would be lower in Munsell space than the yellow pole.

The Swedish Natural Colour System (NCS), which is based on Hering’s system of opponent hues (Hilbert, this volume), defines the achromatic colour component as the axis of variation between white (W) and black (S for the Swedish *swart*, to distinguish it from B for blue). In this system, the hue circle consists of colours that do not contain any admixture of either white or black. Since these colours are zero white and zero black, the hue circle, figure 3, is *by definition* orthogonal to the achromatic dimension. In the NCS system, there is no way even of *saying* that yellow is brighter than blue. Correspondingly, there is no way, in the Munsell system, of saying that blue is the opposite of yellow. 180º separation in the Munsell hue circle does not correspond to exclusion.

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Figure 3: The NCS hue circle. By permission of NCS Colour AB, Stockholm [www.ncscolour.com](http://www.ncscolour.com).

Colours on the NCS hue circle have maximum chromaticness or vividness, as shown in figure 4, where the C vertex corresponds to maximal chromaticness. (“Chromaticness” is a technical term in the NCS glossary. It is different from “chromaticity,” which is a measure of colour content as a mixture of primary lights.) Chromaticness is understood experientially for each hue; its peak value attaches to the most vivid shade of that hue. It does not make sense to compare absolute chromaticness across hues. You cannot ask whether maximally chromatic yellow is more or less chromatic than maximally chromatic blue; both have chromaticness 1, by definition. Spectral colours are maximally chromatic, but the hue circle also spans purple, which is not a spectral colour. *There is no candidate for physical equivalency*—the criterion is experiential. A colour is maximally chromatic if its hue content cannot be intensified.

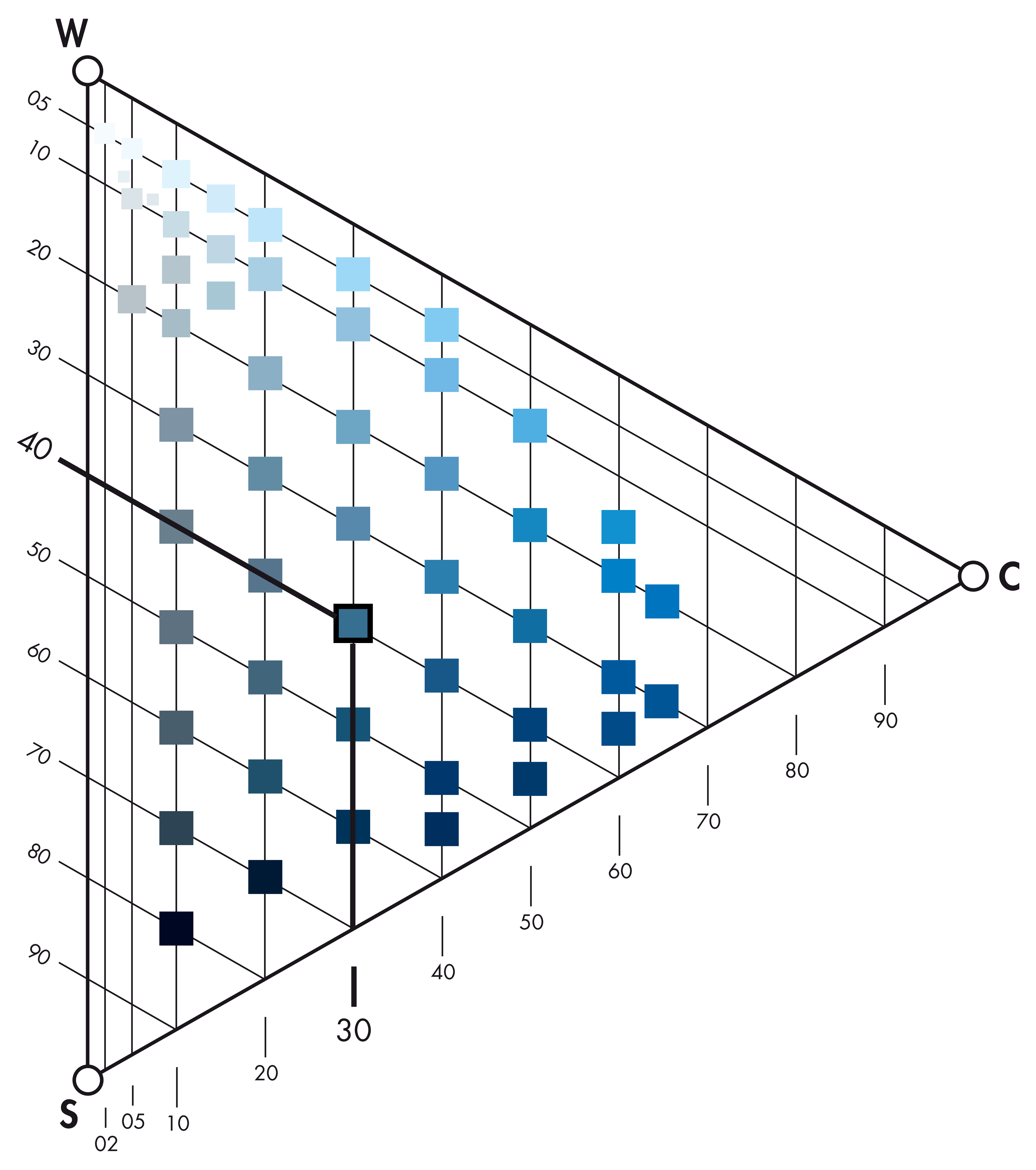


Figure 4: A vertical section of NCS space corresponding to a single radius, R90B on the hue circle, figure 3. The squares mark physical samples provided by NCS. By permission of NCS Colour AB, Stockholm [www.ncscolour.com](http://www.ncscolour.com).

Figure 4 shows what happens when a single hue (such as 10% red and 90% blue—see the marked colour on figure 3) interacts with the achromatic axis. All of the colours in Figure 4 correspond to the same mixture of the fundamental hue-components. The maximally chromatic C pole is singular—there is only one colour there. Hering says that colour is “veiled” by black and by white; in other words, adding white or adding black reduces chromaticness. Accordingly, the C-vertex contains no white and no black. In particular, the elementary colours contain no white and no black.

When white is added to a maximally chromatic colour, we move away from C toward the W pole along the upper flank of the triangle, thereby increasing the white component and reducing chromaticness, but leaving the black component constant at zero. (Again, do not confuse physical mixing of lights or inks with experiential mixing.) The lines parallel to the upper flank mark colours of the same blackness. Adding black is another way to reduce chromaticness, but in this case we move along the lower flank of the triangle from C to S, gradually increasing the black component and leaving whiteness constant at zero. Lines parallel to this lower flank (not shown in Figure 4) mark equal whiteness. NCS gives numerical values to the colours by implementing Hering’s equation:

w + s + c = 1.

The numbers along the left of Figure 4 give the blackness (s) component, and the numbers along the lower flank give chromaticness (c). The vertical lines indicate equal chromaticness.

As mentioned earlier, the NCS system is constructed on principles taken from Hering’s system of the opponent hues. It treats the maximally chromatic unique hues as pure colours. The Munsell system diverges from this by giving the chromatic elementary colours different values—as mentioned before, maximally chromatic yellow is lighter than maximally chromatic blue, and green is lighter than red. On the other hand, the Munsell system treats lightness and darkness as opposite poles of a single intensive variable. NCS is different in this regard; as Hering’s equation above shows, there is a three-way inter-dependency of white, black, and chromaticness in this system.

It should be clear that though they are based on phenomenal qualities, the colour similarity systems we have mentioned are idealizations. Even when you construct a similarity space out of a phenomenally meaningful measure such as a just noticeable difference or simplicity of experience, there is no guarantee that the axes of the space you construct will have a precise phenomenal meaning. Thus, there is a degree of idealization in such concepts as the unique hues and saturation.

### Colour as a Unity

Though colour has perceptual components, we experience each colour, whether simple or compound as *one* phenomenal whole, not as many phenomenal qualities bound together. Colours are, we might say, phenomenally unified. Figure 5 illustrates the point. The vertical lines mark colours of the same hue, but differing in lightness. Each such line is roughly equivalent to an NCS “triangle” like Figure 4, defined by a single radius on the hue circle of Figure 3. Notice how the unique hues are vertical lines in Figure 5, and triangles like that in Figure 4 in the NCS system. As we remarked at the beginning, we have to factor in the achromatic component to get a singular colour.

It is not always easy to discern sameness of hue. As Figure 5 shows, certain shades that people call yellow have the same hue content as certain shades that they call orange and certain others that they call brown. These shades differ only in lightness—i.e., in Munsell “value,” or NCS blackness/whiteness.[[4]](#footnote-4) It is very difficult to recognize that these shades are same in hue. This is a case where the components of colour are intimately mixed together: brown and orange seem like different colours, and the sameness of their components is not evident. The difference in their names is just one indication of this.[[5]](#footnote-5) If the darkness of these colours were easily separable from their hue, it would be easy to recognize brown as a blackened orange.

This said, it should also be acknowledged that in important ways, the components of colour are separable. It is certainly possible to discern hue components in colours of high chromaticness. It is easy, for example, to see that orange is yellow-red and that turquoise is a greenish blue. It is also easy to discern which of two shades of brown is more yellow and which more red. And when the difference of lightness is not too great, it is relatively easy to discern sameness of hue: an example would be a pale and a dark magenta. Moreover, the visual system itself uses the components of colour separately. The lightness or black/white component of colour is wholly or dominantly responsible for perceptions of depth and motion (Livingstone and Hubel 1988, Livingstone 2002), while fine spatial resolution depends on colour independently of lightness. This shows that even though colour is phenomenologically a unity, the visual system has some access to the separate components.



Figure 5: The Basic Colours. The pairs pink and red, and orange and brown differ little in hue. Taken from Mohan Matthen 2005: 76. Adapted from Berlin and Kay 1969: 9. By permission of Paul Kay.

Taking the unity of colour into account, *hues* are not colours—different colours can have the same hue. Accordingly, we speak of elementary *colours*, thereby including white and black alongside the four elemental hues (Arnkill 2013, 168), the latter pair being defined as possessing no hue element.

J. D. Mollon (2006), however, goes further:

Discussions of the unique hues rather seldom include white as one of the unique hues. Yet white is the mother of all unique hues, and its phenomenological purity and simplicity were historically an obstacle to the acceptance of the Newtonian theory. . . white is *neither reddish nor greenish nor yellowish nor bluish.*(*ibid*, 305; emphasis added)

Notice that the way Mollon defines it, “neither reddish not greenish nor yellowish nor bluish,” white is a class of colours that runs from pure white through various shades of gray to black. When he mentions “phenomenological purity and simplicity,” he is presumably talking about an elementary colour defined by adding “nor blackish” to the above definition. If this is right, then he should have noted that black is phenomenologically pure in just the same sense as white (it too admits none of the other unique hues). Note: The apparent disagreement with Newton came from a failure to recognize the difference between mixed light and mixed sensations. White light is a mixture of wavelengths; white is, however, an unmixed colour as far as experience goes.

Mollon’s point is significant. Is there a yellow that is unique in the same sense as white is unique? In one way of systematizing things, yes—the NCS system defines maximally chromatic unique yellow as lacking whiteness and blackness. However, yellow is lighter than its opponent blue. This comes out well in the Munsell system, which gives yellow a higher lightness value than blue. Arguably, white is pure in a way that yellow is not: pure white contains none of the hues, but the elementary colours contain non-zero lightness or darkness. (There is no way to say this in the NCS system, however—an indication of how it idealizes the Hering components of colour.)

One complication to be noted here is that white and black are contrast colours. Two complementary (but not quite equivalent) conditions are significant. First, white is the colour that reflects all of the colours of the illuminate; black is that which reflects none. Second, white is the lightest colour in any scene; black is the darkest. The visual system treats as white and black the patches in any scene that best conform to these conditions taken together. (The treatment of self-luminous objects is somewhat different.) Consequently, the white-black level of a colour patch can be raised or lowered depending on how light it is relative to a given presentation. Viewed through an isolation tube in which it is the only thing seen, a pink will appear more saturated and closer to red, and a brown will appear orange. It makes sense, therefore, to ask whether black and white are qualities of objects independently of the conditions in which they are viewed. It is beyond the scope of this entry to discuss this question.

A final point to be made here is that hue consists of a red-green and a blue-yellow component. In Figure 3, the bottom right quadrant of the figure consists of hues that vary from 100% red and 0% blue through all possible combinations of red and blue to 0% red and 100% blue at the bottom. This way of putting it, however, risks confusion by suggesting that the *colour* red is an intensive quality. *Colours* are regions in colour space such as those marked in figure 5. The colour that lies half way between red and blue in Figure 3 is, at maximum chromaticness, *magenta*. Magenta, the colour, is different from the colours we call “red” and “blue”; however, it is *reddish* and *bluish* to equal degrees. There is a difference between red-the-colour and red-the-hue-dimension.

### Does Unique Hue Have a Physiological Counterpart?

C. L. Hardin (2014) writes:

In the early 1990s . . . I asked Peter Lennie when he expected the locus of unique hues to be discovered. He then believed it would be in the next five years. It has taken twenty years, but the end appears to be in sight. . . Recently, Stoughton and Conway claimed to have found a brain locus for the unique hues. (*ibid* 379)

So far we have been emphasizing the phenomenal basis for the unique hues and their phenomenal interaction with white/black. Hardin assumes a neural basis. Mollon (2006), however, writes:

[W]hat are the unique hues? Are they determined within us, by the organization of our visual system? Or are they ecologically significant, identifying for us particular subsets of spectra in the world? Let us call answers of the former type “constitutional” hypotheses, and answers of the second type, “ecological.” *The two types of account are not necessarily exclusive, because our visual categories may have evolved to match some feature of the world.* (304, emphasis added)

Hardin’s question assumes a constitutional account; Mollon takes an ecological line.

For colour scientists, the status of the unique hues has not been settled satisfactorily. As we have repeatedly had reason to notice, they have a phenomenal basis. This phenomenal basis is inferred from subjects’ qualitative descriptions of their sensations, descriptions that are more subjective than the more usually employed judgements about the qualitative identity of sensations. There is considerable doubt in the scientific community what kind of credence should be attached to qualitative descriptions of this kind (Mollon and Jordan, 1997). Some, however, think that they are indispensable. Neitz and Neitz (2008) put it this way: “Understanding the brain requires a kind of thinking outside the main tradition of natural science: the biology has to be linked to something intangible, a private experience.”

There was considerable excitement in the early 1960s, when Russell De Valois and co-workers (De Valois, Abramov, and Jacobs 1966) found cells in precortical brain areas (specifically the lateral geniculate nucleus, LGN) that indicated opponent processes. A couple of decades later it began to become apparent that LGN is the site of spatial analysis using brightness, and that the colour-sensitive cells there do not, for the most part, correspond to the Hering red-green/blue-yellow opponencies. More complex opponent processing models were proposed as time went on; it came to be believed that the cortex extracted opponent information from the rather differently structured LGN opponent signals. Neitz and Neitz (2008) remark:

The simplest idea is [that] additional processing stages in the cortex would further transform LGN opponent signals, with the wrong spectral signatures into ones that match perception; however, even the most well thought out versions of this idea (for example [De Valois and De Valois 1993]), raise more questions than they answer. It is not clear how, and even more puzzling why, the cortex would recombine the cone signals.

In 2008, this situation changed again. Chris Tailby, Samuel Solomon, and Peter Lennie (2008) were able to identify cells in LGN that show the right spectral signature. More or less simultaneously, Cleo Stoughton and Bevil Conway (2008) reported cell populations in the inferotemporal cortex that are specific to red, green, and blue, and much more weakly to yellow. (Neitz and Neitz 2008 provide an upbeat overview from the constitutionalist perspective.) However, none of these studies are conducted in ecologically realistic situations—they are all based on single cell recordings of macaques viewing lights. And there are anomalies in the result: yellow, for example, does not evoke as pronounced a peak. As Stoughton and Conway (2009) acknowledge in response to a critical note by Mollon (2009): “It remains unclear how the brain encodes the inter-connectedness and nonlinearity of these dimensions.”

Mollon’s ecological account is even more elusive, though it rests on some intriguing phenomena. He points out, first, with regard to white objects that they reflect light that matches the illuminant. (His proposal is actually a little more complicated and a lot more interesting than this—“an achromatic surface is one that exhibits no variation in chromaticity across its surface” (2006, 306)—but we can simplify for present purposes.) Thus white has a special ecological significance. As well, he says, light from the sky is unique blue, while direct sunlight is unique yellow (both with a considerable admixture of white); thus, as he says (attributing the point to Roger Shepard), “the yellow-blue axis of human color experience corresponds to the two predominant illuminants in our world” (*ibid*, 306). This is an interesting observation, but it is unclear how it matches up with the unique hue structure of colour vision. Why, after all, is it functionally advantageous for the blue-yellow axis to match the skylight-sunlight dimension? All that Mollon offers on this point is this: “This is a rather provocative coincidence,” (*ibid*, 306)but this is not exactly an argument, much less a theory. Secondly, as Mollon admits, “It is less obvious that unique red and unique green can be directly related to properties of illuminants as such” (*ibid*,307).

It is hard to judge the current state of play. On the one hand, the “constitutional” position (that the unique hues arise from the organization of the visual system) has received dramatic new support, though this support rests on somewhat shaky quantitative analysis. On the other hand, the ecological account seems so far to rest on a few suggestive “coincidences.” Perhaps, we should content ourselves with the observation that the opponent structure of colour and colour processing has clear neurophysiological support, but the unique hues have less. This complements our earlier observation that the unique hues are somewhat idealized. (See also Jameson and D’Andrade 1997 and Valberg 2001.)

### The Variability of Unique Hue Perception

Though perceivers tend to be quite consistent with regard to which physical colours they identify as unique, there is (as we noted earlier) a certain amount of variability *among* subjects—of the total amount of variability with regard to unique hue choice, only about a third is intra-observer (Hardin 2014).

Michael Tye (2006) makes a philosophical puzzle out of this variability. Let a certain object *O* be perceived by John as uniquely blue and by Jane as greenish blue. “Intuitively,” he says, it cannot be both: to suppose otherwise “is to accept a view that is implausible from the start” (173-174). At most one of John and Jane is right. The question Tye raises is whether experiencing something differently implies experiencing it as having different (and in this case, incompatible) properties. Clearly, this is so for a single subject: if I experience the same thing colour-wise differently in similar circumstances, then I experience it as having different colours. Is the same true inter-subjectively? And how do we determine whose unique blue is the true one?

Tye acknowledges that there is no way to tell whether *O* is *truly* unique blue, but this, he insists, does not imply that there is no fact of the matter:

God knows precisely which hue chip 527 has, but we may very well never know.[[6]](#footnote-6) Our only access to the colours of things is via a single sense and the colour detectors nature has endowed us with are limited. We do not suppose that objects do not have precise lengths because of the limitations of our measuring equipment. Why suppose that the situation is fundamentally any different for the case of colour? (177-178)

The analogy with length is inconclusive. Length is the quantity that determines how long light takes to traverse an interval, that determines the gravitational force between two masses, and so on. To be wrong about length is to be wrong about this quantity. Suppose I attach the number 1 to a certain length, and you attach the number 39 to the same length. Are we disagreeing? Not necessarily, because I might be using metres and you might be using inches. Let us say, for the sake of argument, that colour is reflectance. Then, to be wrong about colour is to be wrong about reflectance. Must at least one of Jane and John be wrong about reflectance? Could it not be that the difference between them is *merely* about how their colour vision systems represent one and the same quality?

Colour experience is the product of opponent processing. Something looks bluish when the response it gets from the short-wave cone is greater than the response it gets from the long and middle wave cones. What if two subjects have differently tuned short-wave cones, so that something that looks bluish to one looks yellowish to the other? Do these experiences tell the two subjects different things about the *external* world? Byrne and Hilbert (2003) say that it is right to perceive *O* as unique blue if blue is the sole contributor to its “hue magnitude.” The problem is that “hue magnitude” means nothing in physics; Byrne and Hilbert define it by working backward from the perceptual qualities through cone responses to a physical quality/illuminant pair. Like the RGB and Pantone systems mentioned earlier, hue magnitudes are properties of external objects with respect to appearance.

The standard view of the function of opponent processing is this:

Color opponency . . . is an attempt to remove correlations in the signals of different cone cell types that are introduced by the strong overlap of the cone spectral sensitivities. [As well] naturally occurring spectra are known to be fairly smooth . . . and therefore may contribute substantially to redundancies in the cone signals. (Lee, Wachtler, and Sejnowski 2002, 2085)

The point is that there is a strong correlation in the response levels of the cone cells; to achieve maximum discrimination in such circumstance, it is functionally advantageous to throw away the common response level and keep the differences. Subtracting one response level from another is the best way to do this (Hardin 1988, 30-32).

Keep in mind that the information contained in opponent colours is exactly the same as that contained in the tristimulus values of CIE colours. Opponent processing adds no new information. The role of the opponent colour components then is merely to achieve maximum legibility—to “remove correlations in the signals of different cone cell types,” and not to extract information about external qualities. Opponent processing also arrays colours in dimensions that are easy to combine into a unified percept as described in Section IV above.

There is, therefore, a big difference between opponent processing and processing for colour constancy. The latter uses permanently stored environmental information (genetically acquired during the course of evolution) to apportion the light signals differentially to (a) the source object’s reflectance, and (b) the light incident on the source. In short, constancy processing adds information to the incident signal, while opponent processing is informationally neutral. Colour constancy processing pulls apart signals that were the same on the retina and identifies signals that were retinally different. Beyond enhancing discrimination, opponent processing does not do this: signals that are different in NCS space are different CIE space, and vice versa. Moreover, such phenomena as the mutual exclusion of the bluish and the yellowish have no physical counterpart.

The reader might think that Mollon offers us a different opinion: light from the sky is unique blue. There are two problems with this. The first is that it simply begs the question about intersubjective differences regarding unique blue: as Kuehni (2004) says, it is not justified to assume that mean unique hue values can be “considered representative of humans.” The second is that even if they are, and even if Mollon is right, the question would arise: is the sky “really” unique blue because “we” experience it that way, or is such experience “true” because the sky really is unique blue? The second position is dubious because, as noted above, blueis not a *physical* kind—it has no place in physics; it is not a term in any physical law.

In effect, Tye, Byrne, and Hilbert think that the opponent colours constitute a *physical* similarity space (though, as noted above, Byrne and Hilbert define it psychophysically). The point that emerged in sections II and III above is that it is properly defined by reference to *perceptual* systems. The visual system can be seen as doing two things with incoming light—(a) it detects what wavelength/reflectance range this light belongs to, and (b) it tags this physical property with a certain colour experience. (The point of the multistage opponency theory of De Valois and De Valois 1997 is that the second function occurs surprisingly late.) (a) is a physical measure of a particular stimulus; (b) is a correspondence between this physical measure and experience that is a permanent or acquired feature of the visual system itself. Variation with respect to (b) has been attributed to variations in cone-cell distribution and eye-colour, past visual “diet,” and language.

Suppose that a light of 510 nm, most often seen in industrial societies as green, happens to be seen by members of the Berinmo tribe in Papua New Guinea as blue. There are two possibilities here. The first is that the Berinmos’ visual system *wrongly* measures the light as belonging to the 480 nm range, and consequently as blue because (in common with industrial societies) it tags *this* range as blue. The second is that their system correctly measures the light as belonging to the 510 nm range, and tags this range as blue. In the second scenario, the same physical stimuli are tagged with different qualia—and to treat it as *wrong* is to assume that there is something non-arbitrary about such tagging. The system can be wrong about colour, but only by getting its physical characteristics wrong. As far as the Berinmo are concerned, the difference is a matter only of *how* colour is experienced (Matthen 2009). The intersubjective variability of the unique hues is due to this sort of permanent differences among visual systems. It is a shifted spectrum phenomenon (Nida-Rumelin 1996). Differences of colour qualia tagging are never about the world outside the perceiver.

*Conclusion* Colour appearance is the product of a number of underlying processes. Ewald Hering and the Swedish Natural Colour System focus on opponent colour processing as fundamental among these. The result is a codification of each colour experience as consisting of a triple of values along the three fundamental dimensions of the opponent process. Probably, this is philosophically the most neat and tidy way of systematizing colour appearance, but we should not lose sight of the facts that it is one of several alternative idealizations. It (a) simplifies the phenomenology of colour vision to some degree, (b) omits important elements of colour appearance such as perceived lightness, and (c) has not as yet been neurophysiologically validated. The unique hues are privileged in the Natural Colour System. Though they are phenomenologically salient, the above caveats apply.

Opponent colour phenomena, i.e., the phenomena that arise from the subtraction of cone-cell outputs in colour processing, have no informational value about the world outside the perceiver over and above the tristimulus representation of colours in the retina. (Or so I have argued.) The function of opponent processing is non-informational: to enhance discriminability and to format colour in a way that admits of combining distinct elements. This indicates that individual differences that relate to the opponent representation of colour—the unique hues, the proportion of hue magnitudes in perceived colour, the colour categories—have no significance regarding external reality. Some philosophers have suggested that some things in the world are uniquely blue independently of any perceptual system. This contradicts the function of opponent processing as I have presented it.

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1. Information for this and the next section has been distilled from a number of sources. I am most in debt to Hardin (1988) and Arnkill (2013). [↑](#footnote-ref-1)
2. Colour language can influence colour similarity judgements, but linguistic colour terms are not, of course, components of colour experience. Roberson, Davies, and Davidoff 2000 and Davidoff 2004 offer important experimental data, but are confused about this important distinction. [↑](#footnote-ref-2)
3. The diagram can be found on the Hyperphysics site of Georgia State University <http://tinyurl.com/nn4utgt>. [↑](#footnote-ref-3)
4. The appearance of blackness/whiteness depends on contrast with other colours present in the same scene. When these contrasts are removed by looking at brown through an isolation tube, it looks very much like orange. The component analysis of NCS is an attempt to regiment such variation. [↑](#footnote-ref-4)
5. Davidoff (e.g., 2001) would write ‘cause’ in place of ‘indication.’ [↑](#footnote-ref-5)
6. I am sure the “God knows” argument goes down well in Texas. [↑](#footnote-ref-6)