ferent colors. For example: Objects having flat spectral reflectances from near zero to 100 percent can be seen as anywhere from black via intermediate grays to white and to light emitting; they can also result in noticeably chromatic experiences of any hue. Or, certain real objects with moderately complex reflectance functions can, when seen in the same surround, result, in one white light, in a distinctly greenish color experience (olive green), whereas in another white light, there could be a distinctly reddish experience (chestnut brown), and so forth. Given the empirical fact that in a complete *Ganzfeld* (where there is no opportunity for contrast against eyelids, nose, etc.) color experiences caused by given lights disappear rapidly, the case can be made that there are no colors without contrast. With contrast present, the color of a given field depends more or less strongly on the contrasting additional fields and surrounds. (The distinction between related and unrelated colors is only a matter of the type of contrasting field.) Empirically, then, objects and lights do not result in constant or near-constant color experiences, except, again, in a fully relativized set of conditions. No such condition can be specified as standard.

Depending on the observer and the conditions of viewing, given spectral energy signatures will result in color experiences that can fall into multiple color categories. This makes it impossible to define reflectance types unambiguously. In addition, there is the problem of defining color categories: They can be defined roughly, as say green, and then encompass a considerable number of hue subcategories and related variations in intensity and lightness (for object colors). Among the subcategories for green, the only one that can psychologically be defined with little ambiguity for a given observer is the "unique green" hue (UG). There are no similarly well-defined guideposts for other greenish perceptual hue experiences (encompassing an estimated 60 just-noticeably different green object color hue steps.)

How much does reflectance of a color chip need to differ for color normal observers to see it (in given conditions of lighting and surround) as having UG hue? A complete hue circle of Munsell color chips at constant chroma and lightness has 40 chips. Of these, when viewed against an achromatic surround, some 18 contain greenness. In World Color Survey results of populations with a full complement of Hering categories, the "green" category (at value 6 and chroma 8) typically encompasses 12 Munsell chips (MacLaury 1997). In experiments to determine individual unique hues using the same kind of Munsell chips, for color-normal observers, UG is experimentally found to encompass a hue range of about 7 chips, that is, approximately 60% of the complete average hue range of "green" (Kuehni 2001 and unpublished results). Any given chip (or given reflectance) of this group is seen by 60% to over 90% of the observers as not having UG hue. And these are results where observation conditions have not been varied. Analysis of additional six sets of more recent unique hue data indicates overlaps of yellow and green ranges as well as of green and blue ranges; that is, one person's unique yellow can be another person's unique green, and comparably for green and blue.

Byrne & Hilbert (B&H) are laboring in their attempt to come up with something akin to "reflectance type" for colors caused by light as is, or after passing through a transmission filter of some sort. Light sources cannot be considered to have reflection. (What is the reflectance of the sun, and does it differ at noon and at sunset?) How can the concept of *productance* be applied to a grating onto which white light falls? For transmitting filters, reflectance plays no role, except as specular (colorless in case of white light) reflectance, and all color experience involving the filter is a result of transmitted light arriving at the eye. The authors have not succeeded in establishing a uniform concept for all three cases (reflected, transmitted, emitted) and, as they agree, the effect of light source on the color experienced from viewing an object is damaging to their case.

B&H invoke Hering's theory (but without naming him) to describe the phenomenal structure of color. This does not help, because there is (at least as yet) no unambiguous relationship between Hering primaries and cone responses. It is widely accepted that, for example, subtracted cone responses $L - M$ have no immediate relationship to unique hues, and the scientific community is still in the dark as to what is the cause of unique hue perceptions.

To make the case that colors are in the outer world, B&H must (among other things) make a clearer case for reflectance types, one that does not allow a given reflectance to fall into different reflectance types. They must explain why spectral power signatures coming to the eye should be treated differently, in regard to resulting color experience, whether they are reflected from an object, transmitted, or simply emitted (i.e., why tristimulus values cannot be the vaunted reflectance types in all cases).

Our color response is obviously triggered, in extremely relativized conditions quite reliably so, by the spectral energy signatures absorbed by the cones. Are the resulting color experiences reconstructed or just constructed? A large amount of empirical evidence makes it much more likely that color is a construction of the brain, and not a reconstruction of the world by the brain.

## Hue magnitudes and Revelation

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**Abstract:** Revelation, the thesis that the full intrinsic nature of colors is revealed to us by color experiences, is false in Byrne & Hilbert's (B&H's) view, but in an interesting and nonobvious way. I show what would make Revelation true, given B&H's account of colors, and then show why that situation fails to obtain, and why that is interesting.

Color physicalists like Byrne & Hilbert (B&H) generally reject Revelation, the thesis that the full intrinsic nature of colors is revealed to us in perceptual experience. Johnston (1992), following Russell (1912), supports Revelation and goes so far as to claim that any account that fails to render Revelation true, fails to be an account of the colors. For Johnston, though science can tell us much about how color perception works, there is nothing for science to tell us about the nature of colors that experience does not reveal. B&H are at pains to show that experience is not *inconsistent* with reflectance physicalism, but they do not say whether the content of perceptual experience tells us all that there is to know about colors. It doesn't, but given their account, that answer is not obvious.

Being committed to Revelation does not *eo ipso* commit one to rejecting reflectance physicalism. If colors are large sets of surface reflectances, Revelation is true just in case perceptual experience reveals to us the full intrinsic nature of these sets of surface reflectances. What would it be for experience to do this? Would it, for example, need to go so far as to tell us that colors are sets of *reflectances,* that is, sets of sets of reflectance magnitudes for each frequency in the visible spectrum? That seems a bit too demanding, since perception would then have to reveal the nature of photons, their wavelengths and frequencies, and so on. A more modest (and reasonable) claim is that Revelation is true if the personal-level content of an experience makes evident all of the respects in which a given shade of color is intrinsically related to all of the other shades of color.

In B&H's picture, experience represents hue in terms of hue magnitudes, which are dimensions along which determinate hues are intrinsically related to one another. The question then becomes: Do the relations between hues along the hue magnitude dimensions, **RG** and **BY**, constitute *all* of the ways in which determinate hues are intrinsically related to one another? If so, then Revelation is true of the hues, if not, then what are the intrinsic relations between the hues to which we lack perceptual access?

What it is to be a determinate hue, $red_{29}$, is to have a certain


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combination of the hue magnitudes **R**, **G**, **B**, and **Y**. A creature could perceptually represent an object as being $red_{29}$ without representing it as some combination of hue magnitudes. It is possible, that is, to represent the hues of objects without also representing them as having hue magnitudes. We, by contrast, have perceptual access to these dimensions along which hues are intrinsically related to one another. Furthermore, having a certain proportion of **R**, **G**, **B**, and **Y** is necessary and sufficient for being $red_{29}$, and so on, for all of the other determinate hues. This suggests that we have access to *all* of the dimensions along which determinate hues, as such, are intrinsically related to one another, but the suggestion is misleading.

One can have perceptual access to necessary and sufficient conditions for something being a certain hue without having perceptual access to all of the respects along which the hues are intrinsically related to one another. For example, being four-sided, having sides of equal length, and equal internal angles are necessary and sufficient conditions for being square. A creature can have perceptual access to these properties, however, without perceptual access to the property of having at least two sides. This creature lacks access to an aspect in which four-sided things are intrinsically related to all *n*-laterals, even though it has access to properties that are necessary and sufficient for being square. In B&H's view, hue perception is much like this: We have access to some, but not all of the aspects in which determinate hues are intrinsically related to one another.

Given the set of reflectances corresponding to a determinate hue, the hue magnitudes **R** and **G** tell us whether these reflectances tend to be more intense in the longer or in the middle portion of the spectrum. Likewise, **B** and **Y** tell us whether the reflectances in question tend to be more intense in the short or in the middle-to-long wavelength portion of the spectrum. The hue magnitudes tell us about how hues relate to one another in terms of relative intensities in rather coarse-grained portions of the visible spectrum.

But there are many ways in which hues relate with respect to relative intensities in finer-grained portions of the visible spectrum, to which we have no perceptual access. For example, $red_{29}$, $blue_{58}$, and many other hues relate in terms of the relative intensities of their reflectances between 500 and 525 nanometers, but we have no perceptual access to this fact, partly because we code for hues only in terms of L-, M-, and S-intensities. Early stages of the visual system code for hue in a too coarse-grained fashion for information about all of the aspects in which hues are intrinsically related to be a part of the personal-level content of perceptual states. In this sense, Revelation is false in B&H's view.

Notice, however, that a creature could be built so that it represents objects as having the same hues as we do, while it also codes for all of the aspects in which these hues are intrinsically related to one another. Likewise, a creature could be structured so that no information about the aspects in which hues are intrinsically related to one another is part of its perceptual representation of hue. We are somewhere between these two extremes, along with innumerable other coding strategies that nature could have devised for representing the determinate hues.

B&H point out that color perception has been closely associated with debates over the nature of perceptual awareness. The foregoing suggests that perceivers can be alike in the determinate hues that they represent, but differ in what it is like for them to do so. Specifically, what it is like can differ depending on what information about the ways in which the hues are intrinsically related is made perceptually available. Furthermore, the very plausibility of spectrum inversion cases may depend on the fact that humans have rather little perceptual access to the aspects in which hues are intrinsically related. A creature for whom Revelation was true would likely find it quite implausible that "what it's like to see red" could differ from person to person. B&H's work suggests that the plausibility of spectrum inversion is tied to facts about how we represent the colors, not to facts about the nature of perceptual awareness. This seems like a good reason for being wary of using the intuitive plausibility of such cases to motivate antirepresentationalist accounts of perceptual experience.

## Color as a material, not an optical, property

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**Abstract:** For all animals, color is an indicator of the substance and state of objects, for which purpose reflectance is just one among many relevant optical properties. This broader meaning of color is confirmed by linguistic evidence. Rather than reducing color to a simple physical property, it is more realistic to embrace its full phenomenology.

Evidence from ethology and linguistics suggests that, in *reality,* there is much more to color than reflectance, and therefore, defining color in terms of reflectance is an *unrealistic* narrowing of the concept. The target article does discuss the ecological approach to color, but the authors are more concerned with whether it contradicts physicalism than with what it can tell us about the function of color vision and the reality of color.

Certainly, for nonhuman species, abstract color and reflectance have little ecological relevance. With rare exceptions, such as the parrot Alex (Pepperberg 2002), nonhuman animals are not required to make abstract judgments, such as, "Is this green?" or "What color is this?" Rather, color is primarily relevant only insofar as it is correlated with the substance and state of an object.

In an evolutionary sense, one of the primary functions of color vision is to separate objects from the background. Typically, an object of interest (such as a prey species) is of a different material than the background, and therefore it will affect light differently. Some, but not all, of this difference is a result of reflectance.

Another important function of color vision is *recognition:* determining the behaviorally relevant kind of an object (food, predator, nest, etc.). For this purpose, the animal needs optical properties that are correlated with the kind of object and independent of irrelevant environmental factors, such as illumination and distance. Therefore, the nervous system constructs invariants, such as color and size constancy. Certainly, reflectance is among the invariants extracted by color vision, but there is no reason to suppose that it, as opposed to ecologically more relevant properties, is salient for most animals. This is one reason that it is so difficult to test for color vision in nonhuman species (e.g., McFarland 1987, pp. 76–77).

A third important function of color vision is to determine the (behaviorally relevant) state of an object (ripe, potable, sexually receptive, etc.). In many of these cases, the primary relevance of the surface state is as an indicator of the internal state of the object. Again, reflectance is irrelevant except as a component of a wider range of optical properties correlated with the ecologically relevant state of the object.

The foregoing is not intended to be an exhaustive list of the functions of color vision, but it should show that color vision is used to extract a range of optical properties correlated with the substance and state of an object. Certainly, color is real, but there is much more to it than reflectance.

It is also important to keep in mind that most ecologically relevant categories (such as, *edible-banana*) will be multimodal, integrating visual, olfactory, tactile, kinesthetic, and other sensorimotor properties. This suggests that it may be a mistake to consider the visual aspects of color in isolation from the nonvisual.

One might object that, although many optical properties are relevant to animals, they are not, properly speaking, color. However, linguistic evidence suggests that for humans, as for nonhuman animals, there is more to color than reflectance. The authors state their intention to treat color realism as "primarily a problem in the



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