

Color realism and color science

Alex Byrne

Department of Linguistics and Philosophy, Massachusetts Institute of Technology, Cambridge, MA 02139

abyrne@mit.edu mit.edu/abyrne/www

David R. Hilbert

Department of Philosophy and Laboratory of Integrative Neuroscience, University of Illinois at Chicago, Chicago, IL 60607

hilbert@uic.edu www.uic.edu/~hilbert/

Abstract: The target article is an attempt to make some progress on the problem of color realism. Are objects colored? And what is the nature of the color properties? We defend the view that physical objects (for instance, tomatoes, radishes, and rubies) are colored, and that colors are physical properties, specifically, types of reflectance. This is probably a minority opinion, at least among color scientists. Textbooks frequently claim that physical objects are not colored, and that the colors are “subjective” or “in the mind.” The article has two other purposes: First, to introduce an interdisciplinary audience to some distinctively philosophical tools that are useful in tackling the problem of color realism and, second, to clarify the various positions and central arguments in the debate.

The first part explains the problem of color realism and makes some useful distinctions. These distinctions are then used to expose various confusions that often prevent people from seeing that the issues are genuine and difficult, and that the problem of color realism ought to be of interest to anyone working in the field of color science. The second part explains the various leading answers to the problem of color realism, and (briefly) argues that all views other than our own have serious difficulties or are unmotivated. The third part explains and motivates our own view, that colors are types of reflectances and defends it against objections made in the recent literature that are often taken as fatal.

Keywords: Color; color vision; comparative vision; ecological view; inverted spectrum; mental representation; perception; physicalism; qualia; realism; similarity

1. The problem of color realism

Color is the subject of a vast and impressive body of empirical research and theory. A lot is known about the physical properties of objects that are responsible for the appearance of color: photoreceptors in the eye; color processing in the visual system; the genetics of color vision; the various defects of color vision; the variations in color vocabulary and categories across cultures; color constancy; the variation in apparent color with viewing conditions; color vision in animals; and about the evolution of color vision.¹ Unsurprisingly, the fine details are often subject to vigorous dispute, for example, whether or not macaque cortical area V4 is a color center (Heywood et al. 1995; Schiller 1996; Zeki 1990); and sometimes the fundamental assumptions of a particular sub-field are questioned (e.g., Saunders & van Brakel 1997 on color categories). But, by and large, the field of color science commands a broad consensus.

Rather strikingly, however, there are some basic and important issues missing from this agreeable picture. What is redness? A physical property of some sort – for example, a certain way of reflecting light? Or is it a disposition to produce certain sensations in certain perceivers? Or is redness a *sui generis* property about which not much can be said? Further, do those objects like tomatoes, strawberries, and radishes that appear to have this property really have it? In other words, are objects, like tomatoes, red? Color scientists, philosophers, and other cognitive scientists with opinions on the matter strongly disagree about the answers to these questions.²

In fact, the most popular opinion, at any rate among color scientists, may well be the view that *nothing* is colored – at least not physical objects in the perceiver’s environment, like tomatoes. For example:

We know from psychophysical and neurophysiological investigations that color is created somewhere in the brain, although the exact location of this process is still unknown, and we even have no idea what entities the sensations called color are. . . . In short, colors appear only at a first naïve glance to be located in objects. (Backhaus & Menzel 1992, p. 28)

ALEX BYRNE is Associate Professor of Philosophy at the Massachusetts Institute of Technology. He has published widely in the fields of philosophy of mind, metaphysics, and philosophy of language, including much joint work with David Hilbert on color. He recently edited (with Robert Stalnaker and Ralph Wedgwood) *Fact and Value: Essays on Ethics and Metaphysics* for Judith Jarvis Thomson.

DAVID HILBERT is Associate Professor of Philosophy and member of the Laboratory of Integrative Neuroscience at the University of Illinois at Chicago. He has worked extensively on color; recent publications include “Color and the inverted spectrum” (with Mark Kalderon), in *Color Perception: Philosophical, Psychological, Artistic, and Computational Perspectives*, ed. S. Davis, and *Readings on Color*, Vols. 1,2 (edited with Alex Byrne).

And in a well-known passage, Semir Zeki writes:

The results described here . . . suggest that *the nervous system, rather than analyze colours, takes what information there is in the external environment, namely, the reflectance of different surfaces for different wavelengths of light, and transforms that information to construct colours*, using its own algorithms to do so. In other words, it constructs something which is a property of the brain, not the world outside. (Zeki 1983, p. 764, emphasis in original)

Finally, in an excellent recent textbook on vision, Stephen Palmer claims that:

Color is a *psychological* property of our visual experiences when we look at objects and lights, not a *physical* property of those objects or lights. (Palmer 1999b, p. 95, emphasis in original)

And:

There may be *light* of different wavelengths independent of an observer, but there is no *color* independent of an observer, because color is a psychological phenomenon that arises only within an observer. (Palmer 1999b, p. 97, emphasis in original)³

Although contemporary color science would be quite unrecognizable to Galileo, this is one respect in which he is perfectly up to date:

I think that tastes, odors, colors, and so on are no more than mere names so far as the object in which we place them is concerned, and that they reside only in the consciousness. Hence, if the living creatures were removed, all these qualities would be wiped away and annihilated. (Galileo, in Drake 1957, p. 274)⁴

This target article is an attempt to make some progress on the problem of *color realism* (Boghossian & Velleman 1991): Are objects colored? And what is the nature of the colors? In particular, we defend the view that objects are colored, and that colors are physical properties, specifically, types of reflectance (Byrne & Hilbert 1997a; Hilbert 1987; see also Armstrong 1999; Jackson 1998; Lewis 1997; Matthen 1988; Tye 1995; 2000).

The article has two other purposes: First, to introduce an interdisciplinary audience to some distinctively philosophical tools that are useful in tackling the problem of color realism and: Second, to clarify the various positions and central arguments in the debate. We hope that our discussion will at least remove some obstacles to progress in research, even if our conclusion is not accepted. The article is therefore very much in the spirit of Block's (1995) *BBS* article "On a confusion about a function of consciousness."

The article is in three main parts. The first part explains the problem of color realism and makes some useful distinctions. These distinctions are then used to expose various confusions that often prevent people from seeing that the issues are genuine and difficult, and that the problem of color realism ought to be of interest to anyone working in the field of color science. The second part explains the various leading answers to the problem of color realism, and (briefly) argues that all of them except physicalism have serious difficulties or are unmotivated. The third part explains and motivates our own view, that colors are types of reflectances, and defends it against objections made in the recent literature that are often taken as fatal.

1.1. The problem of color realism explained

If someone with normal color vision looks at a tomato in good light, the tomato will appear to have a distinctive prop-

erty – a property that strawberries and cherries also appear to have – and which we call "red" in English. The problem of color realism is posed by the following two questions. First, do objects like tomatoes, strawberries, and radishes really have the distinctive property that they appear to have? Second, what is this property? (Of course, there are parallel questions for the other colors that objects appear to have.)

It is important to emphasize that a negative answer to the first question is a genuine theoretical option. As we all know, it does not follow from the fact that an object *visually appears* to have a certain property that the object has that property. The study of visual illusions is well-established; a visual illusion is precisely a case where an object visually appears to have a property it does not in fact have. For example, in the Ponzo and Müller-Lyer illusions, lines that are of the same length appear to be of different lengths. There are also *color* illusions, for instance produced by changes in illuminants, or by simultaneous contrast. An example of the latter kind of color illusion is neon color spreading, in which a region that is in fact white appears pink (Nakayama et al. 1990; Van Tuijl & de Weert 1979). A negative answer to the first question amounts to the view that color illusions are the rule, not the exception. This might seem odd, but it is not incoherent.

The problem of color realism concerns various especially salient properties that objects visually appear to have. It does not concern, at least in the first instance, color language or color concepts. The issue is not how to define the words "red," "yellow," and so on. Neither is it about the nature of the *concept* RED (where concepts are either taken to be mental representations used in thought and inference [Fodor 1998], or the semantic contents of such representations [Peacocke 1992]). Of course, it is natural to suppose that there are intimate connections between a certain salient property that tomatoes appear to have, the word "red" and the concept RED; in particular, the word "red" refers to this property, and the concept RED is a concept of this property. Some scientists and philosophers would argue for more intimate connections between color experiences and color vocabulary and concepts.⁵ But the present point is simply that the problem of color realism is primarily a problem in the theory of perception, not a problem in the theory of thought or language.

Consider an analogy. From the point of view of the biologist, the word "food" is applied by ordinary people in a somewhat arbitrary way. According to them, the synthetic cooking oil Olestra, which has no nutritional value at all, is a food, but vitamin tablets and beer are not. An investigation of how ordinary people use the word "food" is not particularly relevant to biology. What is relevant is an investigation into the sorts of substances human beings can digest, whether or not the biological category of the digestible lines up exactly with the folk category of food. *The problem of color realism is like the investigation of what humans can digest, not the investigation of the folk category of food.* The enquiry concerns certain properties that objects visually appear to have, not how ordinary people use color words, or how they conceptualize color categories.⁶

A final point of clarification: Although the main focus of the problem of color realism is on human color vision, any satisfactory solution must address the issue of color vision in non-human animals. We shall say something about this later, in section 3.3.

1.2. The representational content of experience

It is helpful to put the problem of color realism in terms of the *representational content* (“content” for short) of color experience. When someone has a visual experience, the scene before her eyes visually appears a certain way: for example, it might visually appear to a subject that there is a red bulgy object on the table. The proposition *that there is a red bulgy object on the table* is part of the content of the subject’s experience. In general, the proposition that *p* is part of the content of a subject’s visual experience if and only if it visually appears to the subject that *p*. Propositions are bearers of truth and falsity: the proposition that there is a red bulgy object on the table is true just in case there *is* a red bulgy object on the table, and false otherwise. A subject’s visual experience will be illusory (at least to some extent) if a proposition that is part of the content of her experience is false. Likewise, a subject’s visual experience will be *veridical* (at least to some extent) if a proposition that is part of the content of her experience is true.⁷

The representational content of a subject’s experience specifies the way the world appears *to the subject*. So the content of an experience is content at the personal level – it is not subpersonal content. If the proposition that there are such-and-such edges, blobs, and bars is part of the content of an early stage of visual processing, it does not follow that that proposition is part of the content of the subject’s visual experience.

As discussed in the previous section, Backhaus and Menzel, Zeki, Palmer, and Galileo hold the view that nothing – at any rate no physical object like a tomato – is colored. Some of these theorists might well disown the apparatus of representational content as explained above (indulging in some anachronism, Galileo probably would). But assuming – as we shall – that this apparatus provides a useful and relatively innocuous way of framing the debate, the view that no physical objects are colored is equivalent to the view that the contents distinctive of color experiences (for example, that there is a red bulgy object on the table) are uniformly false.

The problem of color realism, then, concerns the representational content of color experiences. Is this content – for example, that there is a red bulgy object on the table – sometimes true? And what is the property red that figures in the content of such experiences?

So, on pain of changing the subject, it is not an option, as Matthen (1992) urges, “to maintain, paradoxically perhaps, that it is not color that is the content of color vision, but some other physical quantity” (p. 46). Colors, at any rate in the sense in which they concern us in this article, are (at least) *properties represented by certain kinds of visual experiences*. According to Thompson et al. (1992), “That color should be the content of chromatic perceptual states is a criterion of adequacy for any theory of perceptual content” (p. 62), and we agree.⁸

Enough has been said, we hope, to make it clear that the problem of color realism is not a *recherché* philosophical issue of little concern to working color scientists, solvable if at all by *a priori* reasoning from the armchair. The problem concerns the kinds of properties that are represented by visual experiences, and so inextricably involves empirical research into animal visual systems.⁹

1.3. Useful distinctions and common confusions

When someone looks at a tomato in good light, she undergoes a visual experience. This experience is an *event*, like an explosion or a thunderstorm: it begins at one time and ends at a later time. The *object* of the experience is the tomato, which is not an event (tomatoes don’t occur). The *content* of the experience includes (we may suppose) the proposition that there is a red bulgy object on the table. The color property represented by the experience is the property red. If the experience is veridical, then the object of the experience has the color property represented by the experience: in other words, if the experience is veridical, the tomato is red.

1.3.1. Sense data. A long tradition in philosophy has it that the subject’s visual awareness of the tomato is mediated by the awareness of something else, an object called a *sense datum* (Moore 1953, Ch. 2; Price 1950, Ch. 1; Russell 1912, Ch. 1). Afterimages provide the easiest way to introduce the idea. Consider the experience of a red circular afterimage, produced by fixating on a green circular patch for a minute or so, and then looking at a white wall. It is perennially tempting to suppose that there *is* something red and circular that the perceiver is aware of. If there is, then because there is nothing red and circular in the world external to the perceiver, there must be something red and circular in the perceiver’s internal world – something mental, presumably, since nothing in the brain is red and circular. This red circular thing is a *sense datum*. Sense data are supposed to be not only present in the case of afterimages, but in cases of normal vision as well: the perception of a tomato, as well as the afterimage experience, involves a red circular sense datum.

Sense data have been under heavy attack in analytic philosophy since the 1950s, in our opinion rightly so. We are not going to rehash this debate here, but are simply going to assume that the arguments against sense data are successful (Armstrong 1961, Ch. 3; Pitcher 1971, Ch. 1; Sellars 1956). But we should say something about the afterimage example. Afterimages are simply illusions, as Smart pointed out many years ago (Smart 1959). When one has an experience of a red circular afterimage, the content of the experience is – to a first approximation – that there is a red circular patch at a certain location. But this proposition is simply false. There is no red circular patch – not even in some internal mental realm.

1.3.2. Properties of an experience versus represented properties. A classic confusion is the conflation of the properties of an experience with the properties represented by the experience (Harman 1990). An experience of a tomato is an event, presumably a neural event of some kind, and although it represents the property red, the experience is certainly not red, any more than the word “red,” which refers to the property red, is itself red. If anything is red it is the *tomato*.

Failure to attend to this distinction can make it seem obvious that color is some sort of *mental* or *psychological* property, rather than a property of physical objects like tomatoes. This sort of mistake is probably one of the main reasons why many textbooks state that color is produced by the brain, or is in the mind; it may well also underlie the *International Lighting Vocabulary* definition of “hue” as a

certain “attribute of visual sensation” (CIE 1970, 45-25-215).

1.3.3. Color versus conditions necessary for its perception. In order for a household thermostat to detect that the temperature is below 65°F, the thermostat dial must be set correctly. It does not follow that the property of being below 65°F is in any interesting sense dependent on, or relative to, thermostats or their settings. No one is likely to make this mistake of confusing *temperature* with *conditions necessary for the detection of temperature*. But an analogous mistake is for some reason often made in the case of color. (We will give a particularly nice illustration of this in sect. 3.1.3 below.)

The presence of perceivers and the occurrence of certain mental events are obviously necessary for the perception of color. Just as in the thermostat example, it does not follow that the colors themselves are in any interesting sense dependent on, or relative to, perceivers or mental events. To think it did would be to confuse conditions necessary for the perception of color with color itself.

1.3.4. Subjective, objective, phenomenal, and physical color. As mentioned earlier, there are some relatively uncontroversial color illusions, for example, spreading effects (Bressan 1995; Van Tuijl & de Weert 1979) and the appearance of chromatic colors on rotating discs painted with an achromatic pattern (Festing et al. 1971; Karvellas et al. 1979). Sometimes the claim of illusion is put by saying that “subjective” or “illusory” colors are “produced in the visual system” by objects like the discs (the contrast being with the “objective” colors that objects like tomatoes appear to have). This is not a happy way of speaking, for two reasons. The first is that the color properties do not come in two varieties, “subjective” (“illusory”) and “objective,” as the terminology suggests: there is just *one* property of being red. Rather, the distinction here is really between two kinds of objects: those that look to have colors they do not have (perhaps the discs), and those that look to have colors they do have (perhaps tomatoes). The second reason why the terminology is unhappy is that it suggests that “subjective” colors are somehow “in the mind.” What is certainly “in the mind” – at any rate if this expression is not taken too seriously – are *visual experiences* of colored discs, or red tomatoes. The colors, however, are not in the mind, even if the experience is an illusion (on this point, recall the distinction between properties of an experience and represented properties in sect. 1.3.2 above).¹⁰

Now consider this passage:

The physicist uses the term [“color”] to refer to certain phenomena in the field of optics. Hence, the physicist, when confronted with the task of measuring the color of a material, measures the relevant optical properties of the material. Physiologists and psychologists employ the term in . . . another sense. They are interested primarily in understanding the nature of the visual process, and use the term, on occasion, to denote sensation in the consciousness of a human observer. (MacAdam 1985, pp. 3–4)

The first part of MacAdam’s distinction is straightforward: that the optical properties of an object are responsible for its appearance of color – sometimes called *physical color*. Colorimetry is largely concerned with physical color; and so the *chromaticity* and *purity* of a light source can be said to be measures of its physical color.

Since nothing but confusion can come from using color terms to “denote sensations,” the second part of MacAdam’s distinction needs some adjustment. On the one hand, the things distinguished are intended to be “sensations.” On the other hand, color terms are supposed to be an appropriate way of denoting the things distinguished. We cannot have both. If we stress “sensations,” then the things to be distinguished are *certain kinds of visual experiences* (e.g., an experience of a tomato in good light). If we stress the appropriateness of color terms, then the things to be distinguished are *certain salient properties represented by those experiences* (e.g., the salient surface property the tomato visually appears to have). These properties are sometimes called *phenomenal colors*, or *colors-as-we-see-them*.

There is, then, a perfectly good distinction between physical color and phenomenal color – although it must be emphasized that this is not a distinction between properties of objects like tomatoes and properties of sensations. Using this terminology, the problem of color realism explained above concerns phenomenal color. What are the phenomenal colors? Do the objects that appear to have phenomenal colors really have them? Accordingly, whenever “color” occurs unmodified in this article, it means phenomenal color.

But here’s the important point: rather paradoxically, a distinction may turn out not to distinguish anything! At the start of enquiry, one would want to make a distinction between salt and sodium chloride, or the butler and the murderer, even though it may turn out that salt *is* sodium chloride or that the butler *is* the murderer. It may similarly turn out with phenomenal color and (a kind of) physical color. Although care must be taken to make this distinction at the outset, perhaps phenomenal and physical color are one and the same (see sect. 2.4 below).

2. Theories of color

We now briefly review the main contenders for solutions to the problem of color realism, noting some of their main problems.¹¹

2.1. Eliminativism

We have already met eliminativism in the quotations given at the beginning. It is the view that nothing is colored – not, at any rate, ordinary physical objects like tomatoes. An eliminativist might be a kind of *projectivist*, and hold that some things are colored (e.g., sensations, neural states, or sense data), which we then mistakenly take for properties of objects like tomatoes (Boghossian & Velleman 1989; 1991; Jackson 1977). Indeed, the projectivist view is the most straightforward interpretation of the quotations from Backhaus and Menzel, Zeki, and Palmer. This position is extremely unpalatable, however, because either the objects that the projectivist says are colored don’t have the right colors, if indeed they have any color at all (sensations, neural states), or else they are highly dubious entities (sense data).

The most defensible kind of eliminativism is simply the view that absolutely nothing is colored. Eliminativism (about color) is then comparable to eliminativism about witches or phlogiston. The eliminativist about witches says that there simply aren’t any, not – as a “projectivist” about witches would have it – that there are witches but we mistakenly think they are women.¹²

The main line of argument for eliminativism proceeds by

claiming that science has straightforwardly shown that objects like tomatoes do not in fact have colors. The surface of a tomato has a reflectance, various microphysical properties, and is disposed to affect perceivers in certain ways. No other properties of the tomato are required to explain causally our experiences when we look at the tomato. In particular, the alleged color of the tomato does no work in causally explaining our experiences. But since a perceptible property must do this kind of causal work, this implies that we cannot perceive the color of tomato; and if we cannot perceive the color of the tomato, there is no reason to suppose that it has any color (cf. Jackson 1977, pp. 121–27; Johnston 1992; Mackie 1976, Ch. 1).

This argument does issue a powerful challenge to those who think that tomatoes *are* red, but that this property is not to be identified with a reflectance, a microphysical property, or a disposition to affect perceivers (see the discussion of *primitivism* in sect. 2.3 below). However, it begs the question against someone who *identifies* redness with (say) a reflectance.

Hence, the case for eliminativism crucially depends on showing that colors cannot be identified with properties of objects that do causally explain our perceptions of color. According to us this cannot be shown, at least not across the board: the objections against identifying colors with physical properties do not succeed.

2.2. Dispositionalism

Dispositionalism is the view that colors are dispositions (powers, tendencies) to cause certain visual experiences in certain perceivers in certain conditions; that is, colors are *psychological* dispositions.¹³ (Strictly speaking we should add that, according to dispositionalism, at least sometimes our perceptions of color are veridical. This qualification should also be added to the three other views discussed below.)

Dispositionalism is a position often associated with the seventeenth century English philosopher John Locke (1689/1975, Bk. II, Ch. viii). Locke, like other seventeenth century philosophers, drew a distinction between *primary* and *secondary* qualities. Primary qualities have been characterized in a number of different (and often incompatible) ways, but the core idea is that they comprise a set of fundamental properties in terms of which all material phenomena can be explained. For Locke, the primary qualities included shape, size, motion, and solidity (and determinates of these determinables, e.g., being a square, or being one yard long). Because objects have certain primary qualities, they are disposed to affect perceivers in certain ways; these dispositional properties are the secondary qualities. In this Lockean terminology, dispositionalism is the view that colors are secondary qualities.

A simple version of dispositionalism is this: yellowness = the disposition to look yellow to typical human beings in daylight. Dispositionalism has been much discussed by philosophers, although no consensus has been reached.¹⁴ It is sometimes tacitly accepted, although rarely explicitly formulated, by color scientists.¹⁵

One traditional objection to dispositionalism is that “certain perceivers” and “certain conditions” cannot be specified in a principled way (Hardin 1993, pp. 67–82). This certainly is a difficulty, but in our view the fundamental problem with dispositionalism is that it is unmotivated. It is

certainly plausible that – qualifications and caveats aside – green objects are disposed to look green. However, it is equally plausible that – qualifications and caveats aside – square objects are disposed to look square. It is not very tempting to conclude from this that squareness *is* a disposition to look square. Why should it be any more tempting in the case of color? The dispositionalist, in our view, has failed to answer what we might call *Berkeley’s Challenge*, namely, to explain why perceivers should be mentioned in the story about the nature of color, but not in the story about shape.¹⁶

2.3. Primitivism

According to primitivism, objects are colored, but the colors are not dispositions to affect perceivers, or physical properties (Campbell 1993; Hacker 1987; Stroud 2000; Yablo 1995).¹⁷ What are the colors then? No especially informative answer is forthcoming. According to the primitivist, the colors can usefully be compared with irreducible physical properties, like the property of being electrically charged. Given the reductive cast of mind in cognitive science, it is not surprising that primitivism is generally the preserve of philosophers.

Like eliminativism, primitivism is quite unmotivated if there are already perfectly good candidates to be the color properties, for instance, physical properties of some sort. The basic argument for primitivism, then, is similar to the argument for eliminativism: the alternatives must be dispatched first. Thus if, as we shall argue, the case for eliminativism does not get off the ground, neither does the case for primitivism.

2.4. Physicalism

Physicalism is the view that colors are physical properties of some kind, for example, microphysical properties (Armstrong 1968, Ch. 12; Jackson 1998, Ch. 4; Jackson & Pargetter 1987; Lewis 1997; Smart 1975) or reflectances (Armstrong 1999, Ch. 3; Byrne & Hilbert 1997a; Dretske 1995, Ch. 3; Hilbert 1987; Matthen 1988; Tye 1995, pp. 144–50; 2000, Ch. 7).¹⁸

There are two main challenges to physicalism. First, it is argued that physicalism cannot account for the apparent similarities and differences between colors. In other words, the physicalist cannot explain the structure of *phenomenal* color space (Boghossian & Velleman 1991).

Second, and connectedly, it is argued that physicalism cannot account for the phenomenological observations that provided the inspiration for the opponent-process theory of color vision. For example, it is argued that physicalism cannot explain why orange is a binary hue (every shade of orange is seen as reddish and yellowish), while yellow is a unique hue (there is a shade of yellow that is neither reddish nor greenish) (Hardin 1993).

We do not think these objections work. In section 3.2 below, we shall give a physicalistically acceptable account of both similarity and opponency.¹⁹

2.5. The ecological view

In an important article, Thompson et al. (1992) have developed an “ecological view” of color, inspired by Gibson (1979). The view is best expressed in Thompson (1995a),

and so we shall focus on this book (see also Thompson et al. 1992; Varela et al. 1991). According to the ecological view, “a proper account of the ontology of colour and of chromatic perceptual content should be *relational* and *ecological*” (Thompson 1995a, p. 243, our emphasis).

By “relational,” Thompson means that the colors are *relational properties*. A relational property is the property of bearing a specific relation to a specific thing (or things). For example, being a sibling (or, in an alternative notation, x is a sibling) is a relational property, because it is the property of bearing the two-place relation x is a sibling of y , to someone.²⁰ Dispositions are also relational properties: for example, the property of being disposed to look red to humans is the property of bearing the two-place relation x is disposed to look red to y , to human beings. So, as Thompson notes (p. 243), dispositionalism is also a relational theory of color. Thompson himself thinks that colors are kinds of dispositions to affect perceivers, although he emphasizes that his brand of dispositionalism is quite different from the traditional sort. The really distinctive part of his position is supposed to be its “ecological” character. But what does this amount to? According to Thompson:

For a relational account to be philosophically satisfying and naturalistic it must be ecological. The world outside the perceiver must be considered as an environment, rather than a neutral material universe. And the perceiver must be considered as an active exploring animal, rather than a passive spectator that simply receives sensations from physical impressions. (p. 244; see also pp. 177–78)

There is a way of reading this passage on which “ecological” doesn’t add very much to “relational.” As a piece of methodology, it is surely true that an investigation of color vision should not limit itself to laboratory situations in which subjects are highly constrained behaviorally, and visual stimuli are also severely limited. There is nothing here for a physicalist or anyone else to disagree with.

Clearly something stronger is intended. What is wrong with the theories of color we have considered so far is supposed to be that “the animal and its environment are treated as fundamentally separate systems. The distal world is specified in advance and provides a source of input that is independent of the animal” (p. 222). What “ecological” is intended to add to “relational” is (at least) the claim that the environment and the perceiver are not “fundamentally separate systems” (p. 222) – they are “inherently interdependent” (p. 245).

We find this addition to a large degree obscure. Thompson’s main illustration is the possibility that color vision in various species coevolved with the colors of plants and other animals. Perhaps trichromatic vision in primates coevolved with colored fruits (Mollon 1989): it is mutually advantageous for the fruits to be seen by the primates (the primates get food and the fruits get their seeds dispersed). If so, then the colors of the fruits in the primates’ environment is partly explained by the primates’ color vision, as well as conversely. The trouble is that this sort of dependence between color vision and the colors of objects does not constrain the nature of the colors in any interesting way: coevolution is not in any tension with physicalism, for example.²¹ The easiest way of seeing this is to consider a parallel case. Imagine that a popular car company designs its cupholders to accommodate cups from a popular coffee company. The initial fit could be a little more snug, so some time later the coffee company makes a small adjustment in

the size of its cups. Yet more improvement is possible, hence the next generation of cupholders is amended accordingly; and so on. The cupholders therefore “coevolve” with the shape of the cups. But this obviously does not show much of anything about the nature of shapes; in particular, it doesn’t show that shapes are nonphysical properties.

So, as far as we can make out, the ecological view boils down to something not much different from traditional dispositionalism (for a similar criticism see Whitmyer 1999). Moreover, it is somewhat less developed, because Thompson tells us very little about how the “ecological-level” dispositions are to be specified. Evidently the “particular perceivers” and “particular viewing conditions” (Thompson 1995a, p. 245) should be specified in a number of different ways to accommodate, among other things, color vision across species (p. 246), but Thompson does not supply any of the details.

2.6. Digression on naturalistic theories of content

A lot of philosophical ink has been spilt on the problem of “naturalizing semantics” or the “symbol grounding problem” (Harnad 1990). This is the problem of providing a naturalistically acceptable account of mental representation. If a language of thought theory is assumed (Fodor 1975; 1987; 1990; Rey 1997), the particular form the problem takes is this: What are the sufficient (or, better, necessary, and sufficient) conditions, storable in a non-psychological and non-semantic vocabulary, for a simple predicate F in Mentalese to refer to a property P ? (The problem takes a correspondingly different form for other accounts of mental representation.) For example, one guiding idea is that representation is a matter of causal covariation of some kind (Stampe 1977). In the language of thought example, and greatly oversimplifying, F refers to P if tokens of F in the brain are caused by the instantiation of P .²²

Now, one way of settling the question of color realism would be via some naturalistic theory of content. Suppose for illustration that a causal covariational account were correct, and that property P causally covaried in the right way with experiences of tomatoes for P to be the surface property of tomatoes represented by those experiences. Then P would be the property red. If P turned out to be a type of reflectance (a not implausible eventuality), then physicalism would have been established.

Unfortunately, none of these theories is well-enough developed to allow this sort of argument to be formulated in the required detail. And in any case we do not actually find any of these theories convincing. But it is worth noting that many of them – particularly the causal covariation sort – are quite hospitable to physicalism.

Unless and until the problem of naturalizing semantics is solved, a defense of physicalism, in particular, must rely heavily on plausibility considerations. In what follows we are not pretending to demonstrate the truth of physicalism; we will be satisfied if we make it a credible hypothesis.

3. Physicalism defended

3.1. Reflectance physicalism

Any plausible version of physicalism will identify the colors with physical properties implicated in the causal process that underlies the perception of color (see Fig. 1 below). In

its simplest form, this process involves a constant illuminant interacting with a matte surface (with fixed reflecting characteristics) to produce reflected light which enters the eye.²³ Although the causal chain extends from the illuminant to the stimulus via the object, it is of course the object that looks colored (more strictly, its surface), and so the relevant physical property must be a property of objects (more strictly, surfaces). We can narrow the field further by noting that the color vision of human beings and many other organisms exhibits approximate *color constancy* (Jameson & Hurvich 1989; Werner et al. 1988); for instance, tomatoes do not seem to change color when they are taken from a sunny vegetable patch into a kitchen illuminated with incandescent light. Assuming that our perceptions of color are often veridical, we therefore need a physical property of objects that is largely *illumination-independent* – a physical property that an object can retain through changes in

illumination. This last constraint rules out properties an object has only if it is actually reflecting light of a specific character – for instance, light with a certain wavelength-energy distribution (spectral power distribution), or wavelength composition. Finally, we need a property that human visual systems could plausibly recover from the responses of the three kinds of cone photoreceptors. The property that initially suggests itself is *surface spectral reflectance*: the proportion of incident light the object is disposed to reflect at each wavelength in the visible spectrum.²⁴ This property is a property of objects that appear colored, it is (largely) illumination-independent, and much empirical work has been devoted to showing how it might be recovered from receptor responses (D’Zmura 1992; Finlayson 1996; Maloney & Wandell 1986; Funt et al. 1991). For illustrations of the reflectance functions of various common objects, see Figure 2 below.

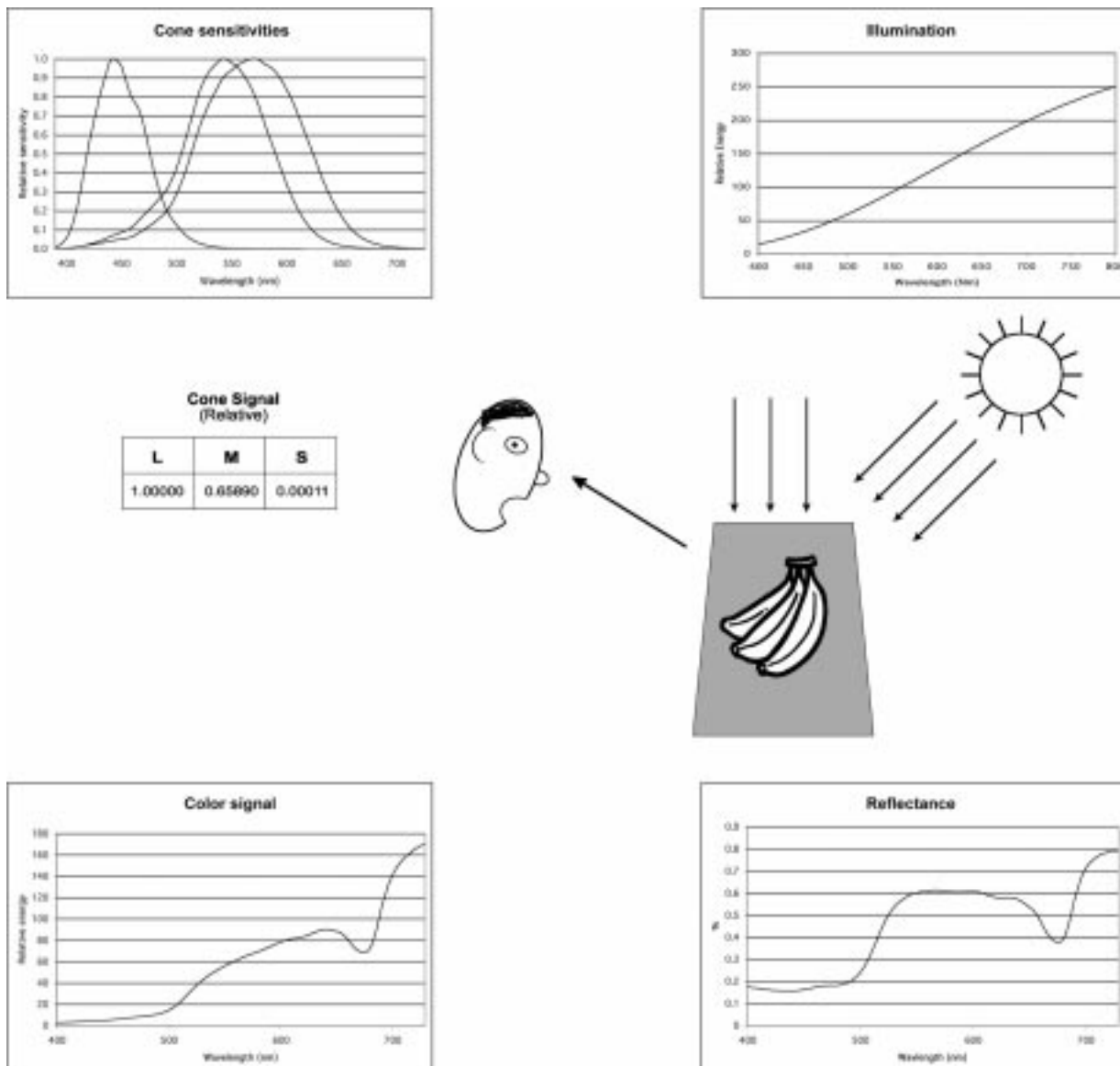


Figure 1. The causal process leading to color vision.

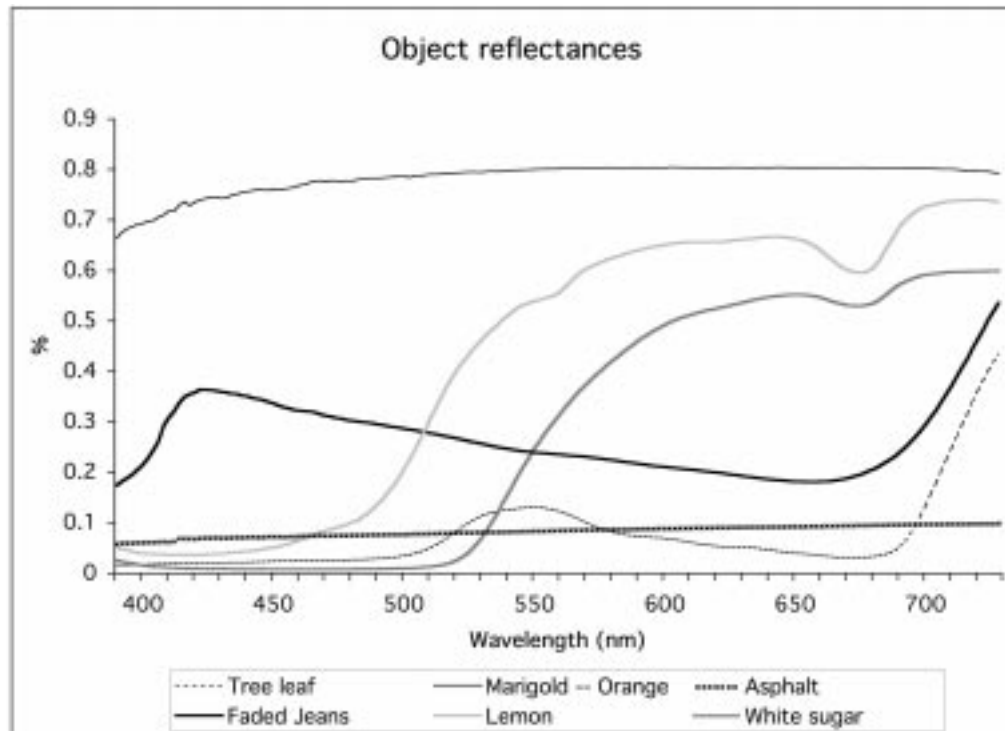


Figure 2. Spectral reflectances for some common objects. (Data courtesy of Eastman Kodak Company via <http://www.cns.nyu.edu/ftp/ltn/SSR/kodak/>)

An illuminant such as sunlight falls on an object, in this case a bunch of bananas. (For clarity, the spectral power distribution of CIE illuminant A is given, rather than that of daylight or sunlight.) The light reaching the eye (the color signal) represents the illuminant as transformed by the reflectance of the object. This light then stimulates the three cone types to generate the cone signal. This process is repeated for each region in the visual field and the cone signals collectively contain all the information available to the visual system regarding the colors of the objects in the visual field. (For simplicity, we represent this process only for one region.)

Now this basic suggestion, that colors are reflectances, is open to three immediate objections, in addition to the charge that physicalism of any variety cannot account for color similarities. We will address these objections in turn, in the following three sections. In order to reply to the first two (although not the third), the basic suggestion will need to be elaborated and modified.²⁵

3.1.1. The problem of metamers. The first objection starts from the phenomenon of *metamerism*: objects with quite different reflectances can match in color under a given illuminant.²⁶ Two such objects are a *metameric pair* with respect to that illuminant. Metamerism is a consequence of the fact that all the information available for perception of color derives from just three receptor types with broad spectral sensitivity. If the light reaching the eye from two objects produces the same response in each of these three receptor types, then they will appear to have exactly the same color no matter how their reflectances differ. (See Fig. 3 below.) There are reasons for thinking that metameric

pairs are uncommon for natural objects (Cohen 1964; Maloney 1986), although contemporary color technology produces many approximate perceptual matches between physically distinct objects. Consequently there is some uncertainty as to the practical (as opposed to theoretical) significance of metamerism for animals inhabiting their natural environments. In any case, it is sometimes argued that the mere possibility of metameric pairs poses a serious obstacle to any attempt to identify colors with reflectances (Dedrick 1996; Hall 1996; Hardin 1993, pp. 63–64).

If we say that a color is *determinate* if and only if no normal human observer can, in normal circumstances, discriminate (on the basis of color) between two objects that appear to have that color,²⁷ then the problem can be put as follows. Determinate colors cannot be identified with specific reflectances because there will typically be (indefinitely) many reflectances that result in the appearance of a given determinate color, and no motivation for choosing between them.

This objection is correct, as far as it goes. But it can be defused by making a slight change that was required in any event. Notice that even if we ignore metamerism, there is already a problem with *determinable* colors – red, green, purple, and so forth. Typically two purple objects will have different reflectances. The solution to this problem is clear: we can identify the determinable colors with reflectance-types (or sets of reflectances) rather than with the specific reflectances themselves. For example, the property purple, on this modified account, is a type of reflectance rather than a specific reflectance. As a bonus, this proposal also solves the problem of metamers (and so it is not really an additional problem): both determinable and determinate colors

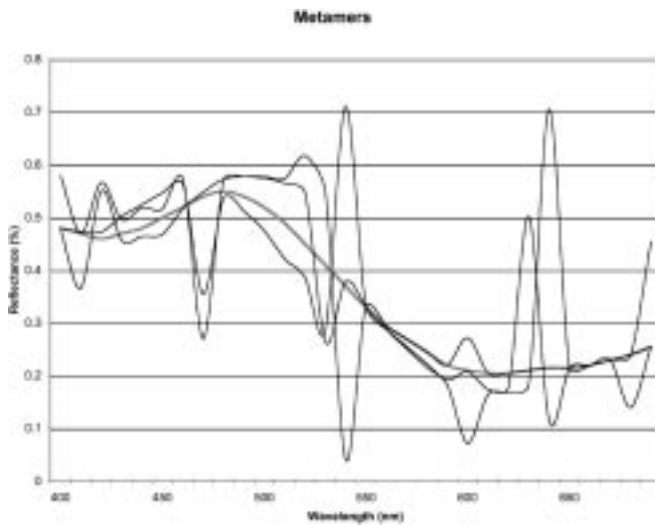


Figure 3. Reflectances of four objects that look alike. Objects with these spectral reflectance curves would match in color for the CIE 1931 standard observer when viewed under illuminant C.

are reflectance-types. Metameric surfaces are, according to the revised theory, the same in determinate color in spite of their physical differences (Byrne & Hilbert 1997a; Hilbert 1987).²⁸

As is well known, the relation between reflectance and apparent color is in some ways more complicated than the relation between simple physical magnitudes and some other perceptible properties (e.g., length). The various reflectances that are perceptually equivalent (with respect to a given illuminant) are not just minor variants of each other. Surfaces with grossly different reflectances can perceptually match even under fairly normal illuminants (see again Fig. 3). So the reflectance-types that we identify with the colors will be quite uninteresting from the point of view of physics or any other branch of science unconcerned with the reactions of human perceivers. This fact does not, however, imply that these categories are unreal or somehow subjective (Hilbert 1987). It is just a plain matter of fact that an object has a particular type of reflectance, and this fact need not depend in any interesting way on the existence of creatures with color vision. No doubt fire engines would not have had that distinctive reflectance-type if humans had not evolved color vision, but rubies and garnets would still have had it – even if humans had never evolved at all.

There is a useful comparison here with the CIE 1931 Standard Observer. Given a fixed illuminant, the Standard Observer allows reflectances to be sorted into types (in particular, equivalence classes: two reflectances will be in the same class if and only if their tristimulus coordinates relative to the illuminant are identical). Although tristimulus coordinates are derived from the color matching behavior of human beings, that a particular reflectance has a certain set of coordinates is not dependent on the existence of perceivers, human or otherwise. If humans had never evolved at all, reflectances would still have had tristimulus coordinates. Further, like the types reflectance physicalism identifies with the colors, the types of reflectances generated by the Standard Observer will seem a motley jumble to a physicist, precisely because they are psychophysically inspired.

We should emphasize that tristimulus coordinates in the CIE system are not suitable to specify the reflectance-types that a plausible version of reflectance physicalism will identify with the colors. The coordinates vary with illumination, do not capture perceived similarity relations, and are tied to very specific and (outside the laboratory) uncommon viewing conditions. Similar points apply to other standard colorimetric systems. A further issue arises in the case of color appearance models. Plausible versions of physicalism (and, indeed, *any* defensible view of color) will allow that *some* (perhaps very few) color perceptions are illusory – even under good viewing conditions. The goal of color appearance models is, on the other hand, to provide a computational procedure allowing the perfect prediction of color appearance on the basis of physical measurements. If a color appearance model were taken as the basis of color categories, it would not admit the possibility of error or illusion. Thus, a model that classified reflectances on the basis of color *appearance* would not necessarily be classifying them on the basis of *color*.

3.1.2. Colored lights, filters, and volumes. Reflectance physicalism as we have described it so far has been tailored to the colors of objects with opaque surfaces that do not emit light. But of course these are not the only things that appear colored. Many apparently colored objects are translucent or transparent, for instance, glasses of beer, the previously mentioned examples of rubies and garnets, and filters like amber sunglasses. The perceived color of such objects is significantly, and frequently almost entirely, determined by their transmittance characteristics. In addition, light sources provide some paradigmatic instances of colored things: stoplights, like tomatoes, grapefruit, and limes, are red, yellow, and green. Again, the perceived color of a light source often has little to do with its reflectance characteristics. So, the second objection is that reflectance physicalism seems committed to describing the perceived color of many ordinary things as illusory. Admittedly, occasional color illusions come with the territory, but this sort of widespread illusion is hard to swallow.²⁹

One possible reply is to claim that the colors come in several flavors: *surface* colors, *volume* colors, and *illuminant* colors.³⁰ On this proposal, surface colors are reflectances, while volume colors are some other physical property and illuminant colors yet a third. Such a move would be quite unacceptable, however. Opaque objects, translucent objects, and light sources can look the same in respect of color. Therefore, the natural inference is that there is a single property that vision represents all these objects as having – a conclusion supported by common speech, as well as by what is known about the extraction of color information by the visual system.

Fortunately, though, another reply is available. Earlier, we gave a standard definition of reflectance: the proportion of incident light the object is disposed to reflect at each wavelength in the visible spectrum. However, we could just as well have characterized reflectance slightly differently, in terms of the light that would *leave* the object, rather than the light that the object would *reflect*. For clarity, let us adopt some new terminology, and say that the *productance* of a surface is its disposition to produce (i.e., reflect or emit or transmit) a specific proportion of incident light. For opaque non-luminous surfaces this will be equivalent to the original definition of reflectance in terms of reflected light.

For surfaces that emit or transmit light, however, the productance and the reflectance will sharply diverge. Characterizing physicalism in terms of productance rather than reflectance will allow us to account for all the problem cases just mentioned. We will consider light sources first, and then turn to translucent or transparent objects.³¹

The light leaving the surface of an (opaque³²) light source consists of two components: the light reflected and the light emitted. Because of this fact, productances are always *relative to an illuminant*.

To see this, consider a simple example involving a surface that emits monochromatic light of wavelength λ with intensity e , reflects fraction r of light with wavelength λ , and emits or reflects no other light. Assume also, as is true of many light sources, that the intensity of the emitted light does not depend on the intensity of the illuminant. Consider an illuminant I_1 whose intensity at λ is i_1 . Then, with this choice of illuminant, the productance is measured by the ratio $(ri_1 + e)/i_1$. However, with another choice of illuminant I_2 , whose intensity at λ is i_2 , the productance is measured by the ratio $(ri_2 + e)/i_2$. These ratios will of course be different if i_1 and i_2 are different: increasing the illuminant decreases the productance. Hence, *relative to I_1* , the productance of the surface is measured by $(ri_1 + e)/i_1$. In other words, the productance of the surface (relative to I_1) is its disposition, when illuminated by I_1 , to produce light that is $(ri_1 + e)/i_1$ of I_1 at wavelength λ , and zero at all other wavelengths. Similarly for I_2 . This relativity of productances to illuminants is illustrated in Figure 4 below.

Two points are worth noting. First, for surfaces that do not emit light we can ignore the relativity of productances to illuminants, because the productance functions for different illuminants will be the same. Second, since the sum of the intensities of the emitted and reflected light at a wavelength λ can exceed the intensity of the incident light at λ , some productance functions for a light source may have values greater than one.

Although productances are *relative to illuminants*, it is important to stress that the productance of a surface is *illumi-*

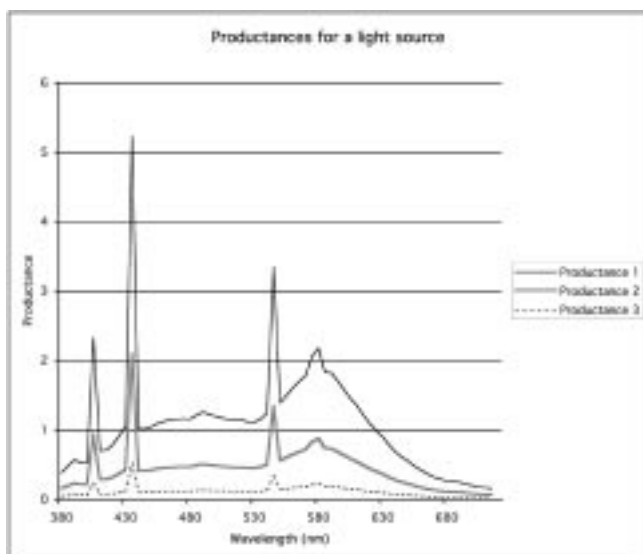


Figure 4. The productance of a standard fluorescent light source with respect to three (increasing) levels of a daylight (D65) illuminant.

nation-independent – that is, independent of the actual illuminant. The surface of a stoplight or tomato has a certain productance relative to an illuminant I , and it has this productance independently of the light that is in fact illuminating it. Hence, it has a certain type of productance independent of the actual illumination. The ordinary person thinks that some stoplights are red at night, and that tomatoes are red in a closed refrigerator, and the revised version of physicalism characterized in terms of productance agrees.

Turning now to translucent or transparent objects, it might seem that the change from reflectance to productance does not solve all our problems. Suppose we take a thin filter and measure the ratio of the light produced by its facing surface to the light incident on the surface, at each wavelength. Assuming the filter is not backlit, this procedure will not take into account the transmitting characteristics of the filter, and therefore the result will not appropriately correlate with its perceived color. So, if this is the right way to measure “the ratio of the produced light to the incident light,” and thus productance, then “productance physicalism” will not accommodate the colors of objects that transmit light. However, there is no special reason – other than convenience for certain technical purposes – to take the “incident light” to be incident just on the *facing* surface. In the case of the filter, we could take the reflectance to be measured by the usual ratio, but with the entire filter (i.e., its front and back) uniformly illuminated. In the case of the productance of an opaque surface, this procedure will make no difference. It will, though, take the transmitting characteristics of filters into account, which is just what we want. Since translucent or transparent volumes like glasses of beer can be thought of as composed of layers of filters, we do not need to add anything else to provide for their colors.

(Because none of what follows hinges on the complexities just raised, for simplicity we will henceforth ignore productance and return to the initial characterization of physicalism in terms of reflectance.)

3.1.3. Related and unrelated colors. The distinction between *related* and *unrelated* colors is frequently employed in the empirical study of color vision (Fairchild 1998, pp. 105–106). Unrelated colors are colors that are seen in isolation from other colors, typically against a black or other neutral background. Related colors, by contrast, are colors seen against a background of other colors. Take the case of brown. Brown is only ever seen as a related color: an object is never seen as brown unless some other (lighter) color is visible at the same time. If an object looks brown against a light background then it will look orange against a dark one. This fact, and the terminology of “related color,” might suggest that brown, unlike colors that can be seen as unrelated, is a relational property, in particular one involving a relation between an object and its surround. And if brown is this sort of relational property, then it cannot be a reflectance: whether or not an object has a given reflectance does not depend at all on the surround.

However, if we avoid the confusion mentioned in section 1.3.3 above, between the conditions necessary for perception and what is perceived, there should be no temptation to think of brown as being a relational property different in kind from other colors. The conditions necessary to see an object as brown involve a relation between the object and its surround, but this is perfectly compatible with our claim that brown is a type of reflectance.³³

In support of this point it is worth observing that viewing objects in isolation is not an ideal condition for extraction of reflectance information. Because the light reaching the eye from a surface does not by itself contain information that uniquely specifies the reflectance of that surface, proposals for how the human visual system achieves approximate color constancy typically involve making use of light from the entire scene.³⁴ Consequently, the perception of unrelated colors will often be illusory. If this is right, then the fact that brown is only ever seen as a related color tells us nothing about the nature of brown. It merely illustrates the fact that color perception works better under some conditions than others.

So, although the distinction between related and unrelated colors is important to understanding and modeling the mechanisms of color vision, it is no threat to reflectance physicalism.

3.2. The phenomenal structure of the colors.

The colors stand to each other in a complex web of similarity relations. (Here we will concentrate exclusively on similarities between the *hues*.) For example, purple is more similar to blue than to green; and the numerous shades of red are more or less similar to each other. Relations of hue similarity also have an *opponent* structure. Red is opposed to green in the sense that no reddish shade is greenish, and vice versa; similarly for yellow and blue. Further, there is a shade of red (“unique red”) that is neither yellowish nor bluish, and similarly for the three other *unique hues* – yellow, green, and blue. This is nicely shown in experiments summarized by Hurvich (1981, Ch. 5): a normal observer looking at a stimulus produced by two monochromators is able to adjust one of them until he reports seeing a yellow stimulus that is not at all reddish or greenish. In contrast, every shade of purple is both reddish and bluish, and likewise for the other three *binary hues* (orange, olive, and turquoise). The binary hues are sometimes said to be “perceptual mixtures” of the unique hues.

These facts form the basis of an objection to physicalism. (As we are defending reflectance physicalism, we will take this as the specific target.) The supposed problem can be vividly illustrated by displaying representative instances of the reflectance-types that, on a view like ours, are the properties purple, blue, and green (see Fig. 5 below).

There does not seem to be an obvious respect in which the first reflectance-type is more similar to the second than it is to the third. Neither does there seem to be anything in the reflectance-types corresponding to the difference between the unique and binary hues: any reflectance-type that a physicalist might identify with purple, for instance, will not in any intelligible sense be a “mixture” of the reflectance-types that are identified with red and blue. If physicalism cannot respect the fact that purple is more similar to blue than to green, and the fact that purple is a binary hue, then physicalism is Hamlet without the prince – it strips the hues of their essences, and so cannot be a satisfactory theory of color at all.

Thus Hardin writes:

If we reflect on what it is to be red, we readily see that it is *possible* for there to be a red that is unique, i.e., neither yellowish nor bluish. It is equally apparent that it is *impossible* for there to be a unique orange, one that is neither reddish nor yellowish . . . If yellow is identical with *G*, and orange is identical with

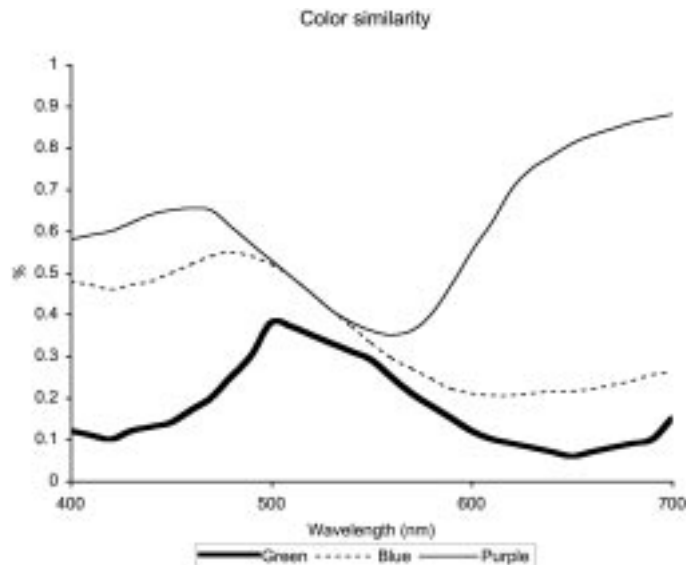


Figure 5. Spectral reflectance curves typical of purple, blue, and green objects.

H, it must be possible for there to be a unique *G* but impossible for there to be a unique *H*. If hues are physical complexes, those physical complexes must admit of a division into unique and binary complexes. No matter how gerrymandered the physical complex that is to be identical with the hues, it must have this fourfold structure, and, if objectivism [i.e., physicalism] is to be sustained, once the complex is identified, it must be possible to characterize that structure on the basis of physical predicates alone. (Hardin 1993, p. 66)

And:

The unitary-binary structure of the colors as we experience them corresponds to no known physical structure lying outside of nervous systems that is causally involved in the perception of color. This makes it very difficult to subscribe to a color realism that is supposed to be about red, yellow, green, blue, black, and white – that is, the colors with which we are perceptually acquainted. (Hardin 1993, p. 300, n. 2)

Following Hardin, Thompson et al. claim that:

Light waves or surface spectral reflectances do not stand in relations to each other that can be described as unique or binary, or for that matter opponent or nonopponent, balanced or unbalanced, saturated or unsaturated, and so forth. There simply is no mapping from such physical properties to the properties of color that is sufficient to establish the objectivist [i.e., physicalist] identification. (Thompson et al. 1992, p. 16)³⁵

Complaints against physicalism along these lines are also endorsed by Boghossian & Velleman 1991; Johnston 1992; Thompson 1995a.

One reply is to concede that physicalism cannot recover similarity relations and the binary/unique distinction, but nonetheless insist that this is not a fatal defect (Matthen 1999, pp. 67–68).³⁶ However, such heroism is not required. In our view, the phenomena of color similarity and opponency show us something important about the *representational content* of color experience – about the way the color properties are encoded by our visual systems. And once we have the basic account of the content of color experience on the table, it will be apparent that there is no problem here for physicalism.

3.2.1. The content of color experience revisited. So far, we have been assuming that the content of a typical experience of looking at a green object includes the *proposition* that the object is green or, to be a little more realistic, that the *object* is green₃₁ (suppose “green₃₁” is a determinate shade of green). In any case, the assumption so far has been that color experiences *simply attribute color properties to objects*.

The right picture is more complicated, however. (Remember that we are presently focusing on hue, ignoring saturation and lightness.) It is natural to say, and subjects *do* say, that one colored chip has “more blue” and “less red” in it than another, that a certain yellow chip has “no red and no orange” in it, that any orange chip has “some red and some yellow” in it, and so forth. If subjects are asked to estimate the “relative amounts of hues” in a stimulus (for example 40 percent red, 60 percent yellow), not only do they seem to understand the instruction, but they give similar answers (Sternheim & Boynton 1966; Werner & Wooten 1979).³⁷

This is puzzling. Red, yellow, green, and blue are *properties*, and it does not make any sense to say that one object has *more* of a property than another object, or a *relative amount* of a property. An object either has a property or it doesn't.

We suggest that the way to connect this talk with the content of visual experience is to recognize that visual experience represents objects as having *proportions of hue-magnitudes*. This needs some explaining.³⁸

For our purposes, a *magnitude M* is a set of properties M , the members of which are the *values* of M , together with a *ratio scale* S_M . The ratio scale S_M is simply an equivalence class of functions from the members of M to the real numbers, with the equivalence relation holding between functions f and g if there is a positive real number n such that for all x , $f(x) = ng(x)$. Thus, the magnitude *length* in the intuitive sense can be identified with the magnitude L , which comprises the set L of all particular length properties (being two inches long, being six inches long, being three miles long, . . .) plus a ratio scale S_L which includes the function that takes a length property l to the number that specifies l in meters, and so also includes the function that takes l to the number specifying l in feet.³⁹

The values of a magnitude M are just properties, and so an individual a can be represented as having one of these properties. For present purposes, the crucial fact is that such a representation might encode information about the scale of M , or it might not. As an example of the former and richer kind of representation, consider the sentences “ a is three feet long” and “ b is two feet long.” They jointly encode the information that a is longer than b : someone who knew that a is three feet long and that b is two feet long would be able to conclude that a is longer than b . Now imagine that stick x and stick y are three feet and two feet long, respectively. The sentence “ a is the actual length of stick x ” is true just in case a is three feet long, and similarly for the sentence “ b is the actual length of stick y .” These sentences are examples of the latter and weaker kind of representation. They do not encode the information that a is longer than b , even though, of course, if they are true, then a is longer than b .

Suppose now we have two magnitudes, say “height” H and “width” W . Think of the values of H and W as properties had by suitably oriented rectangles, and call the sum of

a rectangle's width and height (picking some unit of measurement) its *size*. The sentence “ a 's height is 25 percent of its size” does more than simply attribute a certain property to the rectangle a , just as “ a is three feet long” does more than attribute a certain property to a . Someone who knew both that a 's height is 25 percent of its size and that b 's height is 20 percent of its size could conclude that b is a “skinnier” rectangle than a . We can mark this fact about the extra information encoded by saying that sentences like “ a 's height is 25 percent of its size” represent an object *as having proportions of the magnitudes H and W*.

Our proposal is that objects are represented *as having proportions of “hue” magnitudes*, just as, in the example of sentences like “ a 's height is 25 percent of its size,” the rectangle a is represented as having certain proportions of the magnitudes H and W .⁴⁰ We need four hue-magnitudes, R , Y , G , and B (set aside for the moment the question of just what these magnitudes are). An object will possess certain values of these magnitudes; call their sum (picking some unit of measurement) the object's *total hue* (analogous to a rectangle's *size* in the previous example). The idea is that if an object is perceived as orange, then it is represented as having a value of R that is approximately 50 percent of its total hue, and similarly with Y : say, a 60 percent proportion of R and a 40 percent proportion of Y . If an object is perceived as purple, it is seen as having R and B in a similar proportion, say a 55 percent proportion of R and 45 percent proportion of B . If an object appears blue, it is seen as having a high proportion of B and a relatively low proportion of either R or G , and so on.⁴¹

To a first approximation, then, if someone with normal color vision looks at a tomato, the representational content of her experience is not simply that the tomato is red₂₉ (suppose “red₂₉” is a determinate shade of yellowish-red). Rather, the content is, for example, that the tomato has a value of R that is 80 percent of its total hue, and a value of Y that is 20 percent of its total hue. (Recall from section 1.2 that the content of experience is personal level content: it specifies the way the world appears *to the subject*.)

This is, of course, no more than a *very simplified model* of the representational content of color experience insofar as it concerns hue. However, as we shall shortly explain, if something roughly like it is correct, we can give an appealing account of the similarity relations between the hues, and the binary/unique distinction.

3.2.2. The fit with opponent-process theory. As should come as no surprise, there is a nice fit between the claim that hues are represented as proportions of hue-magnitudes, and opponent-process theory (Hurvich & Jameson 1957; Lennie & D'Zmura 1988). However, it should be emphasized that there is nothing in the magnitude proposal that *requires* the truth of opponent-process theory, let alone the simplified version of it we will use for the purposes of illustration.⁴²

The basic idea of opponent-process theory is that the outputs of the three cone-types are transformed into two opponent chromatic signals and one nonopponent achromatic signal. Letting the cone outputs for the long, medium, and shortwave cones be L , M , and S , in the simplified version of the theory the red-green signal is $L-M$, the yellow-blue signal is $(L+M)-S$, and the achromatic signal is $L+M$.

Focusing on the two chromatic signals, if $L-M > 0$ then the red-green signal produces a “red response,” and pro-

duces a “green response” if $L-M < 0$. Similarly, the yellow-blue signal produces a “yellow response” if $(L+M)-S > 0$, and a “blue response” if $(L+M)-S < 0$. Hence, the experience of unique red is produced when the red-green signal is positive ($L-M > 0$) and the yellow-blue signal is zero ($(L+M)-S = 0$).

The opponent hues when (additively) mixed cancel each other. For example, a greenish light when mixed with an appropriate intensity of reddish light will appear neither greenish nor reddish. Suppose we have two greenish lights, I_1 and I_2 , and that the second requires more of the same reddish light in order to produce a light that is neither greenish nor reddish. Then (according to opponent-process theory), the “green response” produced by I_2 is greater than that produced by I_1 . By using such a psychophysical cancellation technique, the responses of the opponent channels by wavelength (chromatic response functions) can be experimentally determined. (For an accessible textbook presentation, see Hurvich 1981, Ch. 5.)

However, it is not altogether clear how to interpret opponent-process theory. What does it mean to say, for example, that a stimulus produces both a “red” and “yellow” response? Typically, the explanation is left at an intuitive level: a stimulus that produces both a “red” and “yellow” response is one that looks to be a “combination” or a “mixture” of red and yellow. This may be metaphorically illuminating, but it is not theoretically satisfying.⁴³ Our proposal offers a way to fill the gap: such a stimulus is visually represented as having a (non-extreme) proportion of both the red- and yellow-magnitudes.

Moreover, opponent-process theory fills a gap in the magnitude proposal. It provides a functional account of how the visual system could derive information about the proportions of hue-magnitudes in a stimulus from the cone outputs.

3.2.3. Similarity and the binary/unique distinction revisited. If the magnitude proposal is along the right lines, then we can explain the similarity relations among the hues and the binary/unique distinction, in terms of the content of color experience.

Take similarity first, and in particular the fact that purple is more similar to blue than to green. Objects that appear blue are represented as having a high proportion of **B** (and a lower proportion of either **G** or **R**); objects that appear purple are represented as having a roughly equal proportion of **B** and **R**, and objects that appear green are represented as having a high proportion of **G** (and a lower proportion of either **Y** or **B**). There is therefore a perceptually obvious respect in which blue is more similar to purple than to green. Namely, there is a hue-magnitude (**B**) that all blue-appearing objects and purple-appearing objects, but not all green-appearing objects, are represented as having.

The reason why a binary hue like orange appears to be a “mixture” of red and yellow is that any object that appears orange is visually represented as having some proportion of both **R** and **Y**. On the other hand, an object can appear green and be represented as having a value of **G** that is 100 percent of its total hue. That is why green (and yellow, red, and blue) are said to be “unique” hues.

In this way, the phenomena of color similarity and opponency can be explained on the assumption that visual experiences represent objects as having proportions of hue-magnitudes. Hence, if there is a physicalist account of the

hue-magnitudes, then color similarity and opponency do not pose any difficulty for physicalism. So we must now show that there is such an account.

There are reasons independent of the present claim about hue-magnitudes to identify the colors with reflectance-types, as we argued above in section 3.1. It is legitimate, then, to work backwards and ask – under the assumption that colors are reflectance-types – if there are any obvious physicalistically acceptable candidates to be the hue-magnitudes.

Consider light with a fixed spectral power distribution. Let us say that the light’s *L-intensity* is the degree to which it stimulates the L-cones, its *M-intensity* is the degree to which it stimulates the M-cones, and its *S-intensity* is the degree to which it stimulates the S-cones. (This is, of course, imprecise, but will do for our purposes.⁴⁴) Now take unique red. Assuming that colors are reflectance-types, and simplifying for illustration, an object is unique red if and only if, under an equal energy illuminant, it would reflect light with a greater L-intensity than M-intensity, and with an S-intensity equal to the sum of its L- and M-intensities (recall that we are ignoring complications introduced in sect. 3.1.2 above). Assuming that the magnitude proposal is correct, an object that looks unique red is represented as having some value of **R** that is 100 percent of its total hue (and is therefore represented as having *no* proportion of **Y** or **B**). Putting reflectance physicalism and the magnitude proposal together, an object has some value of **R** if and only if, under an equal energy illuminant, it would reflect light with a greater L-intensity than M-intensity – the greater the difference, the higher the value of **R**. And similarly for the other magnitudes. An object has some value of **G** if and only if, under an equal energy illuminant, it would reflect light with a greater M-intensity than L-intensity. An object has some value of **Y** (**B**) if and only if, under an equal energy illuminant, it would reflect light the sum of whose M- and L-intensities is greater (lesser) than its S-intensity – the greater the difference, the higher the value of **Y** (**B**).

3.3. Evolution and animal color vision

Color vision is very widely distributed among animals. Some degree of color vision appears to be the default condition for all the major groups of vertebrates and is also common among invertebrates (Jacobs 1981; 1993; Menzel 1979). As one would expect, color vision systems vary widely across species. Using just the most basic classification, some organisms are dichromats, others (including human beings) are trichromats, and still others tetra- or pentachromats⁴⁵ (Bowmaker et al. 1997; Jacobs 1981; 1993). So some organisms possess color vision that is in certain respects more highly developed than the human standard. Different organisms also use their color vision for different purposes, for instance foraging, communication (in particular sexual signaling), and detection of predators (Lythgoe 1979; McFarland & Munz 1975; Menzel & Shmida 1993; Thompson et al. 1992). Given the prevalence of color vision and its deep theoretical relations to color, it is something of a scandal that hardly any philosophical accounts of color so much as mention the existence of color vision in non-human animals.

Moreover, it might seem that elementary considerations concerning color vision in other species and its evolution shows that reflectance physicalism is at best unmotivated,

and at worst straightforwardly false. One objection starts by pointing out that reflectance-types have no primary ecological significance. What matters in foraging, for example, is locating edible material, not detecting reflectances. Given the dubious ecological significance of reflectance-types – the objection continues – it is unlikely that there was selection for a visual subsystem devoted to extracting and encoding information about these properties. Further, there is a good deal of empirical evidence that color vision was selected for – it did not arise as a by-product of selection for other visual functions. The pigment types involved in color vision have been studied in a large number of organisms and they display a good deal of fit with what is known about the organisms' visual environments (Bowmaker et al. 1994; Lythgoe 1979; McFarland & Munz 1975). Therefore – the objection concludes – reflectance physicalism is incompatible with very plausible hypotheses about the evolution of color vision.

This objection relies on the assumption that selection cannot act to produce detectors for properties that lack primary ecological significance for an organism. Notice that spatial properties, like shape, are equally suspect if this reasoning is correct.⁴⁶ However, it is incorrect. Consider an analogous argument: there could not be selection for flight because there is no advantage to the organism merely to move through the air rather than on the ground. Here the mistake is clear. Flying contributes to an organism's fitness by enabling it do other things better, for example, finding mates or food. In addition, flying contributes to an organism's fitness in multiple ways, making it inappropriate to describe it simply as, say, a mechanism for evading predators. Thus, to return to the color case, it is mistaken to argue that animals cannot have mechanisms devoted to extracting and coding information about reflectance-types because these mechanisms are not of primary ecological significance for the animal. If there is a correlation between reflectances and more ecologically significant properties, then selection for the mechanisms may well occur. Although the selection pressures driving the evolution of color vision are still a subject of controversy, plausibly it at least partly involves the use of color vision for object discrimination, detection, and recognition (Jacobs 1981; 1990; Mollon 1989).

Another objection begins by claiming that not all organisms with color vision appear to be using it to detect reflectance-types: some seem to use their color vision to respond to illuminant characteristics and not surface features at all (Hatfield 1992; Matthen 1999; Thompson 1995a; 1995b; Thompson et al. 1992). For instance, some fish have color vision specialized for detecting contrast between other objects and the background illumination. Therefore – the objection concludes – since color is whatever is detected by color vision, colors cannot be reflectance-types.⁴⁷

This objection relies on what is admittedly the standard conception of color vision: an organism has color vision if and only if it is capable of discriminating some spectrally different stimuli independently of brightness. Equivalently, an organism has color vision if and only if there is at least one pair of wavelengths that the organism is capable of discriminating for every value of their relative intensity (Jacobs 1981). This criterion has the great virtue of being closely connected with the underlying physiology. A necessary condition for being able to make discriminations based on spectral (as opposed to luminance) differences is the possession of at least two types of photoreceptors with dif-

fering spectral sensitivity characteristics. Hence, by using this criterion, it is possible to get significant information about an organism's color vision based on physiological as opposed to behavioral tests.

However, although useful and important, this criterion does not tell us what sort of properties are extracted from the visual stimulus and represented by the color vision system. Two organisms who both pass the discrimination test could be using their shared machinery to represent quite different types of properties – perhaps luminances in one case and reflectances in the other. So, if color vision is thought of as a system for visually representing certain properties – paradigm instances of which are represented by the *human* visual system, – then the criterion based on wavelength discrimination is not adequate. Moreover, in the context of the problem of color realism, this is how we should think of color vision. Hence, if it turns out that certain salient properties represented by the human visual system are reflectance-types, then organisms with visual systems that do not represent reflectance-types cannot have color vision in the sense relevant to this article.⁴⁸ For our purposes, the standard discriminatory criterion is necessary but not sufficient for possession of color vision (Hilbert 1992).

Even given this more restrictive conception of what it is to possess color vision, very many non-human organisms will plausibly possess it. These include most old-world primates, many birds, many shallow water fish, and invertebrates such as bees. The reflectances represented will depend on the details of the visual system in question: human color and bee color vision, for instance, presumably represent quite different reflectance-types. Since a single surface falls under many different reflectance-types (in fact, infinitely many), there need not be any conflict between color appearances across species. Goldfish and human beings see objects as having different colors, but reflectance physicalism gives no reason to suppose that if one species is right, then the other must be wrong.

Thus, contrary to initial appearances, the facts about the types and distribution of color among non-human organisms fit nicely into the framework of reflectance physicalism.

3.4. Variation in normal color vision

There is a surprising amount of variation in the color vision of people classified on standard tests – for example, the Farnsworth-Munsell 100-Hue Test – as having “normal” color vision. Hurvich et al. (1968) found that the location of “unique green” for spectral lights among 50 subjects varied from 490 to 520nm. This is a large range: 15nm either side of unique green looks distinctly bluish or yellowish. Earlier color matching data used to construct the CIE standard observers showed similar variation between individual subjects (Wyszecki & Stiles 1982, pp. 425–35). A large part of this variation is due to differences in macular and lens pigments, but some of it is due to differences in photopigments. A more recent study of color matching results among 50 males discovered that they divided into two broad groups, with the difference between the groups traceable to a polymorphism in the L-cone photopigment gene (Winderickx et al. 1992). The maximum points of the absorption spectra of the resulting two photopigments were found to differ by 5nm (Merbs & Nathans 1992). Because

the L-cone photopigment genes are on the X chromosome, the distribution of the two photopigments varies significantly between men and women (Neitz & Neitz 1998).

In addition to variation between subjects, there is also variation within subjects. Color matching depends on visual angle (Stiles 1937). The degeneration of the lens with age makes it yellower, producing a shift in perceived hue, with purple objects looking significantly redder (Fairchild 1998, p. 5). Color perception can vary between the right and left eyes due to differences in the optical density of the macula (Fairchild 1998, p. 7).

These facts give rise to an obvious problem, which C. L. Hardin nicely expresses as follows:

[Imagine that all of the] hue chips manufactured by the Munsell Company covering [the] 5 Blue-Green to 2.5 Green range were randomly spread out before you to be separately viewed on a dark gray background in North Daylight. One of them would be your considered choice for unique green. Your colleague might make a different choice. If so, which of the chips is unique green? (Hardin 1993, p. 80, endnote omitted)

According to Hardin, “if this question is to be answered at all, it can be answered only by convention. We might, for example, decree that the most frequently chosen chip is to be unique green. But we could decide otherwise” (p. 80).

Hardin’s answer to his own question is a little odd. Suppose a certain chip looks to you to be unique green. Convention has nothing to do with this: what makes it the case that the chip looks unique green are facts about your visual system and its interaction with the chip, and these are not matters of convention or decision. Now consider the question of whether the chip *is* as it *looks*. Convention has nothing to do with this either: it is entirely a matter of how things are with the chip. If the chip *is* unique green, then the answer is yes; if not, no.

We suspect that Hardin’s eliminativism is influencing his answer. Even if, as Hardin thinks, *nothing* is red, blue, yellow or green (let alone unique green), color terminology has great practical value. For various pragmatic reasons, it would not be a good idea to speak the literal truth and to refuse to apply color expressions – for example, “unique green” – to anything. So how should we use this expression? Obviously the answer to *this* question is a matter of convention: the question calls for a *decision*, not a statement of fact. But this is not the question that Hardin is officially asking, although the two might be easily confused. By his own lights, what Hardin should have said in answer to his official question is that – as a plain matter of non-conventional fact – *neither* chip is unique green.

If this answer – that neither chip is unique green – is correct, then we are in trouble. For, since we may fairly suppose that if *anything* is unique green, one of the chips is unique green, the proper conclusion is that *nothing* is unique green. And if nothing is unique green, it is hard to see why other shades of green, or of any other color, are any better off. The natural terminus of this line of thought is therefore that *nothing* has any color, that is, that eliminativism is true. So we do not have here a problem solely for physicalism, but rather for *any* realist theory of color.

But what is the problem, exactly? What the facts about individual differences in color vision show is that, under the twin assumptions (a) that objects do not have many different colors simultaneously (e.g., if a chip is unique green, it is not also bluish-green), and (b) that if objects really are colored (e.g., a certain chip is unique green), then there is

widespread misperception of the determinate colors: Many people will misperceive a chip that is in fact unique green as slightly bluish-green, for instance. If this can be turned into a good argument against color realism then two things must be established. First, that the conclusion, widespread misperception of the determinate colors, is unacceptable. If this is right, then we have to reject either (a) or (b). Second, to complete the argument it must be established that (b) is the culprit.

We think this argument fails at the first stage, because the conclusion is not unacceptable. First, note that the conclusion is not especially astonishing or at odds with apparently obvious facts. The conclusion is not that people rarely see objects as having the colors they actually have, but that they rarely see objects as having the *determinate colors* they actually have. It is consistent with the conclusion that people typically see green objects as green, orange objects as orange, and so forth. Second, note that similar conclusions hold for other perceptible properties, for example, spatial properties. For a concrete case consider aniseikonia; a moderately common ophthalmological condition in which the size (or shape) of the retinal image differs between the two eyes.⁴⁹

One effect of aniseikonia is that the orientation of surfaces in the horizontal plane is misperceived because of the binocular distance errors introduced by the difference in magnification. The result is that a significant fraction of the population is unable to perceive correctly whether or not a surface is oriented perpendicular to the line of sight (in the horizontal dimension). Since this is just one of many common deficits of spatial vision, we can safely say that people rarely see objects as having exactly the spatial properties that they really have. This observation does not lend support to the conclusion that objects do not really possess spatial properties.

There is one final worry, which can be brought out by noting that in the shape case we have independent tests for whether someone is perceiving a shape correctly. In the color case, there is no such test. As things stand, the best evidence for a Munsell chip’s having a certain color is that the majority of those with normal color vision see the object as having that color. The lack of an independent test is partly due to the fact that colors are not perceived by any other sensory modality, and partly due to the fact that we have no acceptable naturalistic theory of the content of color experience (see sect. 2.6 above). In addition, colors as such do not figure significantly in the data or theories of any sciences other than those concerned with animal behavior. Attributions of properties such as shape are constrained by the role of those properties in a network of causal relations. Since there is no chip that the majority will pronounce to be unique green, we have no good reason to believe, of any chip, that it is unique green. So, someone might argue, it follows that we have no good reason to believe that there are any unique green chips. Doesn’t this contradict what a typical physicalist or color realist will want to say?

Yes, it does. But the argument is fallacious. From the fact that we have no good reason to believe, of any chip, that it is unique green, it does not follow that we have no good reason to believe that there are any unique green chips. That would be like arguing that we have no good reason to believe that Professor Plum has been murdered, on the ground that there is no particular person who is clearly the culprit.⁵⁰

3.5. The inverted spectrum

The “inverted spectrum” thought experiment (Locke 1689/1975, Bk. II, Ch. xxvii, para. 15) is well-known. Here is a neutral way – begging no important questions – of describing the basic setup. We have two perceivers, Invert and Nonvert. Nonvert’s color vision is the same as yours (assuming you have normal color vision). Now take some (roughly) symmetric transformation T of the psychological color solid, say a reversal of the red-green axis, or a reversal of the red-green, yellow-blue, and black-white axes (for useful discussion see Palmer 1999a). Imagine Nonvert is looking at some scene S , say a radish against a background of lettuce leaves. The *inversion* of S is a scene which differs from S only in the colors that objects appear to have to Nonvert: if the color of an object o is C , then the color of o in S is $T(C)$. Concentrate on what it is like for you (i.e., Nonvert, in effect) to look at colored objects. Now here is the important part: what it is like for *Invert* to look at a scene S is just the same as what it is like to *Nonvert* to look at the inversion of S .

Invert and Nonvert, in the hypothetical circumstance described, are said to be *spectrally inverted* with respect to each other. So far, we have no controversial argument, just a description of what certainly seems to be a possibility, although perhaps only a far-fetched one.

The inverted spectrum turns up in a variety of different philosophical disputes. Only one of these has some relevance to physicalism about color; however, some short discussion of the irrelevant ones is necessary to prevent confusion.

Some arguments based on the inverted spectrum start by adding further stipulations to the basic inverted spectrum case. Three stipulations are of particular importance (here it is not necessary to spell them out with much precision). The first is that Invert and Nonvert are *behaviorally* alike, in the sense that they are alike in how they are disposed to move their bodies and utter sounds. The second, that they are *functionally* alike (their brains have the same inner causal structure). The third, that Invert and Nonvert are *physically* alike (they are “molecule-for-molecule” replicas of each other). “Behavioral” and “functional” are usually understood so that these three stipulations are in ascending order of strength: physical sameness implies functional and behavioral sameness, functional sameness implies behavioral sameness, while none of the converse implications holds.

Now suppose – controversially – that one of these three enriched inverted spectrum cases is genuinely possible; for example, the one about sameness of functional organization. Take Invert and Nonvert, both looking at the same scene. They are functionally identical. But they are plainly mentally distinct. Therefore, there has got to be more to mental life than functional organization, and so the popular position in philosophy and cognitive science known as *functionalism* is thereby refuted (Block & Fodor 1972).

It is important to see that this kind of debate has nothing to do with physicalism about color. Physicalism about color is not a thesis about the nature of the mind, or mental states: It is a thesis about certain properties that objects like tomatoes visually appear to have. Physicalism about color is compatible with practically any view about the nature of mind: that mental properties are not identical to physical properties, that the mind is some kind of computer, that the mind

is an immaterial substance directing the movement of the body via the pineal gland, or whatever.⁵¹

Now consider a quite different inverted spectrum argument, one that is relevant to physicalism about color. For this argument, we just need the original Invert/Nonvert example: we do not need the controversial suppositions that Invert and Nonvert are behaviorally, functionally, or physically identical. Imagine that Invert and Nonvert have been “inverted” with respect to each other since birth. They both use their color vision to navigate the world and identify objects. They are part of the same linguistic community: they both call blood “red,” and grass “green,” and so forth. Now – the argument continues – it would be implausible to hold that either Invert or Nonvert is systematically *misperceiving* the colors of objects. Surely, when Invert and Nonvert are both looking at a tomato, their visual experiences both represent it as *red*. But, of course, Invert’s and Nonvert’s experiences, when they each look at the tomato, are very different: what it’s like for Invert to look at a tomato is not the same as what it’s like for Nonvert to look at a tomato. In other words, there is more to “what it’s like” to undergo an experience than the experience’s representational content, and so the position in philosophy known as *representationism* or *intentionalism* is thereby refuted.⁵² Here is essentially the same conclusion put in the terminology of Block’s much-discussed *BBS* article (Block 1995): there is more to *phenomenal consciousness* than *access consciousness*.

We can now see why it was necessary to describe the initial inverted spectrum case with what might have seemed excessive circumspection. One might think the obvious description of Invert’s condition is that radishes look green to him and lettuces look red. We did not put it that way, because this would have begged the question against positions like Block’s: that radishes look green to Invert is precisely what Block *denies* (at any rate, if Invert has been “inverted” for some time).

The present section and the previous one raise similar issues: The actual variation in normal color vision discussed in the previous section can be thought of as an extremely mild case of spectrum inversion. One might therefore use actual variation to run an empirically-based argument against representationism, of exactly the same kind as the argument based on the hypothetical example of Invert and Nonvert (Block 1999).

As it happens, we do not accept these arguments against representationism. We have argued elsewhere that representationism (about color experience) is correct (Byrne & Hilbert 1997a).⁵³ Therefore we think, *pace* Block, that the right description of Invert is that radishes *look green* to him. But our purpose is not to engage in this dispute here. Rather, we want to explain just what (slight) relevance it has to physicalism about color.

Suppose, first, that Block is right and that *phenomenism* – the view opposed to representationism – is correct. There is no obvious threat to physicalism here, and indeed Block is a physicalist about color. But the phenomenist physicalist does have a particular problem of his own. Intuitively, color similarity and the binary/unique distinction are inextricably bound up with “what it’s like” to see colored objects. Since the phenomenist thinks that “what it’s like” is not wholly a matter of the representational content of color experience, he will think that color similarity and the binary/unique distinction are not wholly a matter of representational

content either. Therefore, a physicalist about color who also denies representationism will have to tell a somewhat different story about the binary/unique distinction and color similarity than the one we gave above in section 3.2. However, in the absence of an argument that a phenomenist *cannot* solve this problem and consistently remain a physicalist, this is no great objection.⁵⁴

Suppose, on the other hand, that Block is wrong and that representationism is correct. Here, it might be thought, there is an obvious threat to physicalism, and indeed to any realist theory of color, on the basis of the following argument. For all we know, various kinds of spectrum inversion that are hard to detect behaviorally are widespread (Block 1990; Palmer 1999a). So, for all we know, perhaps only a small segment of the population actually sees objects as having their true colors! To insist that objects *are* colored while admitting that maybe most people completely *mis-perceive* the colors of objects would be a weak and unmotivated form of realism. Much better – the argument concludes – to say that *nothing* has any color.

In response, we deny the sceptical premise: that, for all we know, spectrum inversion is widespread. The epistemological issues are far too complex to be discussed here (for a review of some relevant literature see Pryor 2001). We will have to rest with admitting that while there is a case to be made *for* the sceptical premise, there is an equally persuasive argument *against* it. For, surely we *do* know that *tomatoes look red to most people*; only a general sceptic about our knowledge of others' mental states would deny it. But now it follows, given representationism, that we do know that spectrum inversion is *not* widespread (Byrne 1999). This is hardly enough to establish that the sceptical premise is false, but it is enough to show that the matter is far from straightforward.

It might be replied that spectrum inversion is not just a remote possibility suggested by the overactive imaginations of philosophers, but a live empirical one. It has been argued that, given the genetic basis of protanopia and deuteranopia, cases of "pseudonormal vision" should occur in the human population (Piantanida 1974; see also Boynton 1979, pp. 356–58; Nida-Rümelin 1996). A normal subject has L-cones containing the photopigment erythrolabe, and M-cones containing the photopigment chlorolabe – a pseudonormal subject would have the photopigments switched round. If the subject's visual pathways were unchanged, a pseudonormal subject would be red-green spectrally inverted.⁵⁵ There are three points to be made in reply. First, even if pseudonormal vision actually occurs, its frequency will be very low (Piantanida gives an estimate of 14 in 10,000 males); thus the possibility of pseudonormal vision does not show that spectrum inversion might be widespread. Second, there is in any case no reason to suppose that pseudonormal genes would preserve normal visual pathways: the opponent channels might be switched as well, in which case pseudonormal subjects would not be red-green spectrally inverted. Third, there is evidence that for the M- and L-cones the development of the retinal circuitry for the red-green opponent channel is insensitive to which pigment the cone contains. In other words, pseudonormal subjects would just be normal subjects (Dacey 2000; de Valois & de Valois 1993; Mullen & Kingdom 1996).

To summarize. Some "inverted spectrum" arguments are

irrelevant to physicalism about color; those that are relevant do not pose a clear danger to physicalism.

4. Conclusion

Physicalism is not a particularly popular theory of color. Sometimes philosophers malign it as the product of a "scientific" ideology that unthinkingly takes science as the touchstone of what is real. Some color scientists would complain that physicalism does not respect science *enough*. Proper attention to the facts of color vision, they would say, shows that colors are really "in the brain."

We have tried to counteract this tendency, by showing that physicalism – reflectance physicalism, in particular – has the resources to deal with common objections, and can be smoothly integrated with much empirical work. At the very least, physicalism should be taken more seriously by color scientists.

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NOTES

1. Physics: Nassau 1983; photoreceptors: Lamb 1999; Merbs & Nathans 1992; Schnapf & Schneeweis 1999. Color processing: Dacey 2000; Gegenfurtner & Sharpe 1999, Chs. in Parts II and III. Genetics: Nathans et al. 1986a; 1986b; 1992. Color vision defects: Kaiser & Boynton 1996. Vocabulary and categories: Berlin & Kay 1969; Hardin & Maffi 1997; MacLaury 1997. Color constancy: Arend & Reeves 1986; Jameson & Hurvich 1989; Kraft & Brainard 1999. Dependence on viewing conditions: Fairchild 1998. Animal color vision: Jacobs 1981; 1993; Menzel 1979. Evolution of color vision: Bowmaker 1998; Jacobs 1990; Mollon 2000; Yokoyama 1999.

2. For a representative sampling of the contemporary philosophical dispute, see Byrne & Hilbert 1997b; for a variety of views in cognitive science see the commentaries to Palmer 1999a; Saunders & van Brakel 1997; Thompson et al. 1992.

3. There are many other examples from textbooks; here are five: "[O]bjects themselves have no color . . . Instead, color is a psychological phenomenon, an entirely subjective experience" (Sekuler & Blake 1985, p. 181); "'Redness' cannot be measured with a physical measuring instrument because it is a creation of our visual system" (Goldstein 1989, p. 140); "The illusion that color is an inherent property of an object is enhanced by our remarkable ability to use language to communicate about the perceived color of things . . . color is ultimately subjective" (Kaiser & Boynton 1996, p. 486); "At this point in time our ideas concerning the nature of color are still largely speculative. For now, the most convincing account, in conflict with few if any facts, is that color is identical to a particular brain state" (Kuehni 1997, p. 26); "[W]ithout the human observer there is no color" (Fairchild 1998, p. xv).

4. Many other seventeenth century scientists and philosophers shared Galileo's view, for instance Boyle, Newton, and Descartes.

5. An example from science: It is a common view that the phenomenology of color experience has a large influence on color vocabulary (Berlin & Kay 1969; MacLaury 1997). For an example from philosophy, see the following note.

6. Admittedly some philosophers – in particular Jackson (1998)

and Lewis (1997) – will disagree, at least with our emphasis. They agree that the problem of color realism concerns properties that objects appear to have, but according to them the only way to solve it is to analyze our “folk concept” of color. For present purposes we need not pursue this disagreement.

7. We are here indulging in a great deal of simplification and skating over a number of important issues about the content of perceptual experience that have been extensively discussed in the philosophical literature, which we can afford to ignore here. For some of these issues, see Evans 1982; McDowell 1994; Peacocke 1983; 1992; a useful collection is Crane 1992.

8. Strictly speaking, *color* is not the content of visual experience; rather the content is a *proposition* to the effect that an object has a color.

9. It perhaps should be emphasized that our use of the philosophical jargon of “representational content,” “propositions,” and the like, does not commit us to any particular doctrines about the nature and form of perceptual representation. In particular, it does not commit us to the view that perceptual representations are linguistic. We *are* assuming that perceptual states embody putative information about the world external to the organism – but this is of course a widespread assumption in cognitive science. Our statement of the problem of color realism is not intended to involve any other assumptions that a typical theorist of vision might find tendentious, although it doubtless involves unfamiliar terminology.

10. Of course, we are not disputing that “subjective” color effects are importantly different from “objective” or normal color perception. We simply want to resist the misleading connotations of this terminology.

11. For another review, from a more philosophical standpoint, see the introduction to Byrne & Hilbert 1997b.

12. This kind of eliminativism is defended in Hardin (1984; 1993); see also Averill (1992), Clark (1996), Landesman (1989), Mackie (1976), and Maund (1995).

13. Reflectances are also dispositions – dispositions to reflect certain proportions of the incident light (see sect. 3.1 below). Because they are not *psychological* dispositions, however, the view that identifies colors with reflectances is not, in our terminology, a version of dispositionalism.

14. For explanation of the various varieties, see Byrne and Hilbert (1997b, pp. xx–xxii); for defenses of dispositionalism, see Evans (1980), Johnston (1992), Langsam (2000), McDowell (1985), McGinn (1983); for criticism, see Boghossian and Velleman (1989), Byrne (2001a), Hardin (1993, Ch. 2), Hilbert (1987), and Stroud (2000, Ch. 6).

15. Cf. Sekuler & Blake 1985, p. 182: “So to refer to a ‘red sweater’ is incorrect, strictly speaking. To be correct you should describe it as a sweater that when seen in daylight can evoke a sensation most humans call ‘red.’” This is not quite dispositionalism, because Sekuler and Blake are eliminativists: they think that the sweater *isn’t* red. Rather, their view seems to be that the disposition to produce certain sensations is a scientifically respectable *surrogate* for redness. Although objects like sweaters and tomatoes do not have the property red, they *do* possess the dispositional surrogate. Locke arguably held a view of just this sort (see, e.g., Smith 1990).

16. The philosopher George Berkeley claimed that Locke’s arguments “may with equal force, be brought to prove the same thing of extension, figure, and motion” (Berkeley 1710/1998, Pt. I, para. 15).

17. For a position that combines elements from primitivism and dispositionalism, see McGinn 1996.

18. Since psychological dispositions might (in some views) turn out to be physical properties, the official distinction between physicalism and dispositionalism is not exclusive. This is a complication that is best ignored.

19. These versions of physicalism are analogous to type-type identity theories in the philosophy of mind. There is a related theory of color that is analogous to (“role state”) functionalism in the

philosophy of mind: orange (say) is the “higher order” property of having some property or other that realizes a certain functional role. Dispositionalism is a kind of color functionalism (of the “role state” sort); other kinds are possible, although as far as we know they are never discussed. Some theories of color are analogous to “realizer state” functionalism: Orange (say) is the property that in fact realizes a certain functional role, not the higher order property of having the role realized. These theories are varieties of physicalism that are also dispositional in spirit. See Cohen (2000; 2001), Jackson (1998), Jackson and Pargetter (1987), and McLaughlin (1999; 2003). On the identity theory and functionalism in the philosophy of mind, see, for example, Kim (1996).

20. In fact, drawing the relational/non-relational distinction is by no means as straightforward as this explanation makes out. Fortunately, we can ignore the complications here.

21. What is essentially this point is made by a number of commentators to Thompson et al. 1992), in particular Broackes (1992) and Levine (1992).

22. Other theories of representation appeal to a biological notion of function (Dretske 1995; Millikan 1984) or to the “conceptual/functional role” of inner symbols (Block 1986).

23. Throughout we will adopt the idealization of ignoring the *specular* (mirror) component of the reflectance. The component of the reflectance that is of interest to us is the *body reflectance*, which carries more information about the material properties of the reflecting surface. We will also ignore the complications posed by fluorescence, and the transmitting characteristics of the medium between the object and the eye.

24. For some materials, especially diffracting ones, the reflectance measured in some directions varies greatly from the reflectance measured in others. In the standard account of reflectance – the one adopted here – it is the average of the reflectance measured in all directions (i.e., the average, over all directions δ , of the object’s *reflectance factor* at δ). Because reflectances are not direction-dependent, this has the result that on the theory of color proposed below, objects like peacocks’ tails will often produce color illusions. For precise definitions of “reflectance” and “reflectance factor,” see Judd and Wyszecki (1975, p. 463).

25. There is one objection to reflectance physicalism that we will not consider, partly because it is really more of a friendly amendment, and partly because it would take us too far into metaphysics. The objection is this: The colors should be identified with the “categorical bases” of dispositions to reflect light, not with the dispositions (reflectances) themselves, on the ground that the colors are causally efficacious and dispositions are not. For a clear presentation of the argument, see Jackson 1998, Ch. 4.

26. If two objects have different reflectances there will be some illuminant under which the objects do *not* match.

27. This definition is intended merely to sharpen the problem of metamers. A more precise definition would have to give more details about “normal human observers,” “normal circumstances,” and what “discrimination” amounts to (because discrimination is a statistical matter, the boundary between discrimination and non-discrimination is somewhat arbitrary). In addition, this account of determinate color would be difficult to apply in practice.

28. This solution to the problem of metamers neither contradicts (nor implies) the view defended by one of us that, in addition to reflectance-types, the specific reflectances are also examples of colors, although not colors that humans perceive (Hilbert 1987).

29. We will only discuss the colors of light *sources*, not the color of light itself. On one view, light is not colored because it is invisible: instead, it is part of the causal process that leads to the visibility of other things. We need not address this complicated issue here.

30. That is, the reply is to identify the various modes of color appearance (of which there are more than the three we list) with different color properties. Katz (1935) provides a still useful description of the modes of color appearance, while Fairchild (1998, pp. 168–72) gives a convenient recent summary.

31. Notice that in ordinary life, the distinction between light sources and light transmitters is somewhat arbitrary. The top stop light is a red light source but it consists of a red filter in front of a more or less white light source. A tinted windshield might transmit much more light than the stop light emits but it is classified as a filter. Part of what underlies this distinction is that the stop light is treated as a unified object while we conceptually separate the sun and the windshield. Since the revised definition of reflectance gives a unified treatment to all these phenomena, we need not concern ourselves here with how to draw these lines.

32. Some light sources are translucent, for instance “light sticks,” which contain liquids that are luminescent when mixed.

33. For some related points, see Tye (2000, pp. 150–62).

34. There is little agreement as to the actual set of scene features that are used by the human visual system to achieve approximate color constancy. Proposals include features such as the average background (equivalent background), specularities, and local contrast. A useful review is found in Kaiser and Boynton (1996, pp. 507–22) and two recent examples of attempts to assess the contribution of these and other factors are Kraft and Brainard (1999); Yang and Maloney (2001).

35. It will become clear that if our account works for the binary/unique distinction, then no special problem is posed by, say, saturation. We will therefore not spend time discussing the other distinctions mentioned by Thompson et al.

36. We should add that Matthen does not endorse physicalism in the paper just cited (a change from his earlier reflectance physicalism, Matthen 1988). He calls his currently favored position *pluralistic realism*, which to a first approximation might be characterized as the view that color experience represents a variety of different properties (including but not limited to reflectances); the only thing these properties have in common is that they are all detectable by a wavelength-sensitive perceptual system.

37. The Natural Color System (NCS) is derived from subjects’ judgments about the proportion of the four unique hues in a stimulus. See Sivik (1997).

38. For a more “philosophical” treatment, see Byrne (2003a), on which this section is based.

39. Note that temperature is not happily thought of as a magnitude in the above account because the usual temperature scale (i.e., that equivalence class whose members include the Centigrade function that takes the temperature property of boiling water to the number 100, and the Fahrenheit function that takes this property to the number 212) is an interval scale, not a ratio scale (there is no privileged zero point). This problem could easily be fixed by broadening the definition of a magnitude, but there is no need to do it here.

40. We are not endorsing the claim that there is a single representation of color that is used for all purposes. For example, we take no stand on the question of whether the representation of colors relevant to explicit judgments of similarity and difference is the same as the representation used for visual search (Boynton & Olson 1990; D’Zmura 1991).

41. There is a formal parallel between our proposal and the *spectral hue coefficients* (the ratio, at any given wavelength, of each chromatic response – red, green, blue, yellow – to the total chromatic response; for the details, see Hurvich (1981, pp. 70–71)).

42. Although opponent-process theory is very influential it is not without its detractors. For a recent very critical review see Saunders and van Brakel (1997). We are not here endorsing opponent-process theory, but merely showing that our account of color similarity is consistent with it.

43. Two non-metaphorical ways of explaining the sense in which orange is a “mixture” of red and yellow are non-starters. First, orange objects are not both red and yellow. Rather, they are both reddish and yellowish. Second, orange objects are not composed of smaller red objects and yellow objects, as a bouquet might be composed of red and yellow flowers.

44. Further precision is pointless because we are not pretend-

ing to give an exact physical characterization of the colors. Given some more precise definition of “L-intensity,” the L-intensity of light reaching the eye from an object could be calculated from the spectral power distribution of the reflected light and the spectral sensitivity of the L-cones (ignoring the pre-receptor media).

45. This classification is in terms of the number of spectrally different photoreceptor types contributing to color vision.

46. This is not, of course, a novel observation. Gibson (1979) made it (and produced the mistaken inference). (See also Thompson et al. 1992.)

47. It should be noted that the primary literature is often less definitive about the function of color vision than the secondary literature sometimes implies.

48. It is not our contention that color scientists have been making a mistake or have been confused in relying on the discriminatory criterion in their work. If it is the basic physiological mechanisms of color vision (and their evolution) that is of interest, then the discriminatory criterion is perfectly adequate (and much easier to apply than alternatives). As is often pointed out, for other purposes it is appropriate to supplement the discriminatory criterion with, for example, the requirement that some kind of opponent process transformation be present (Thompson et al. 1992).

49. Bennett and Rabbetts (1998, p. 273) give an estimated incidence of 3–5 percent. It is likely to be much higher among cognitive scientists since one common cause is spectacles (as opposed to contact lenses) with lenses of unequal power. Personal observation suggests that academia is one of the last strongholds of spectacle wearing, and unequal refractive errors for the two eyes are quite common.

50. Thus we are prepared to countenance “unknowable color facts” – that a certain chip is unique green, for instance. And so should any color realist who accepts some assumptions that are (we think) highly plausible.

51. This is a bit of a rhetorical overstatement. Different theories of mind offer different accounts of perception, and of course some of these will be less hospitable to physicalism about color than others.

52. For a classic and sophisticated presentation of the argument, see Block (1990; see also Block 1986; 1998; 1999; 2000; Peacocke 1983; Shoemaker 1982).

53. For extended defenses of representationism see Byrne (2001b), Dretske (1995), Lycan (1987; 1996), and Tye (1995; 2000). Although it might not be immediately apparent, representationism is also defended in Dennett (1991).

54. Admittedly, there are some difficulties – perhaps not insuperable – in combining phenomenism with physicalism (Boghossian & Velleman 1991).

55. As Ross (1999) points out, this argument depends on the claim that “internalism” about the phenomenal character of experience is correct: that phenomenal character is determined by the intrinsic state of the subject’s brain, not what environment the brain happens to be in. Internalism is the usual view, but it has been denied, notably by Dretske (1995).

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Perceptual variation and access to colors

Edward Wilson Averill

Philosophy Department, Texas Tech University, Lubbock, TX 79409.
edward.averill@ttu.edu <http://www.philosophy/ttu.edu>

Abstract: To identify the set of reflectances that constitute redness, the authors must first determine which surfaces are red. They do this by relying on widespread agreement among us. However, arguments based on the possible ways in which humans would perceive colors show that mere widespread agreement among us is not a satisfactory way to determine which surfaces are red.

Byrne & Hilbert (B&H) defend their reflectance physicalism against two perceptual variation arguments: One uses variations in normal perceivers (sect. 3.4), the other uses inverted spectrum variations (sect. 3.5). However, there are more powerful perceptual variation arguments.

Let us grant the authors, for the sake of argument, that a determinable color – red, green, blue, and so on – is identical to a set of spectral reflectance curves. (To simplify things, I ignore productance.) How can we determine which set of spectral reflectance curves constitutes redness? The authors point out, in section 3.4, that there is no test for determining the colors of things that is independent of the colors that objects appear to have to a majority of us. (In this way, colors are unlike shapes.) So, presumably, the authors assume that the red surfaces are the surfaces that contemporary humans generally agree are red, because they look red to us under good viewing conditions. For example, ripe tomatoes are red. Redness is the set of reflectance curves of those surfaces we agree are red. The reflectance curves for the other determinable colors are to be identified in a similar way. Let us grant that widespread agreement exists among us as to which surfaces are red, although there will be disagreement about borderline cases. The assumption I want to challenge is this: The surfaces that contemporary humans agree (or would agree) are red, really *are* red. An implication of this assumption is that, if another group of observers were to identify a different set of surfaces as red (there was widespread agreement among these observers as to which surfaces are red and which are not red), then that group would be wrong. Consider such a group.

Suppose some humans were to evolve so that the pigment of the M-cone cells in their retinas had a slightly different absorption curve. More specifically, suppose the M-cone cells were to become less sensitive in the 540-nm to 600-nm range, but otherwise their eyes were like ours. The M-different humans would see some objects that look yellow to us – such as gold (the impure gold used in jewelry) – as red. Like us, the M-different humans would reach widespread agreement as to which surfaces were red, and which were not, based on the way that these surfaces look to them under good viewing conditions. If the M-different humans were to use the authors' assumption that the determinable colors are sets of spectral reflectances, they would identify redness as a set of spectral reflectances, not the set that we identify as redness. For example, the M-different humans would say that the spectral reflectance curve of gold is in the set that constitutes redness. Who is right? I submit that there is no principled reason for saying that one group is correct and the other is wrong. (For other versions of this point, see Averill 1992 and Matthan 1999.)

Perhaps some arguments that appeal to a possibility get under-

mined if the possibility is either physically impossible or remote. The possibility just imagined seems to be physically possible, but how remote is it? If humans were to survive for another 10 million years (a remote possibility?), is it likely that some of the pigments in their cone cells would change so as to cause them to see some things as having a different color from the color we see those things as having? If it were likely, would the possibility of M-different humans, or something like them, still be remote? Even if it would still be remote, does this undermine the above argument? I think not. The fundamental point is this: Given the assumption that redness is identical to a set of spectral reflectances, we have no access to redness that allows us to compare the surfaces that we agree are red with the surfaces that really are red. For this reason, we do not know whether the surfaces we agree to be red are really red. Or, if we do know that the surfaces we agree are red really are red, then redness is not identical to a set of spectral reflectances. The possibility of M-different humans brings out these points about our access to redness. The remoteness of the possibility is irrelevant.

The authors seem to take a somewhat different tack with determinate colors than they do with determinable colors. In section 3.4, they point out that, because there is no common agreement about what surfaces are unique green, there is no way we can determine which surfaces are unique green – and similarly for many other determinate colors. Are they claiming that there is no way “at present” or “no way in theory” to accurately identify the determinate colors? The authors liken the situation to a detective not knowing who murdered Professor Plum, which suggests that there is, in theory, a way of finding out which reflectances constitute unique green. If this is right, then they owe us an account of how the nature of unique green could be established in theory. Again, it seems to me that the authors do not take seriously the problem of explaining how we either know, or could find out, what the sets of reflectance curves are for the different colors.

A satisfactory realism with respect to Xs (material objects, colors, universals, etc.) must either set out an account of how we do (or could in theory) have access to Xs, or explain why it is rational to believe in Xs that we cannot have access to. The authors appear to embrace the first alternative, although somewhat differently for determinable and determinate colors. My objection is that they do not fully address the access problem in either case. Of course, it is open to the authors to hold that there is no way of finding out the true nature of the colors. This would be color realism without access to the real.

Perceptual objects may have nonphysical properties

Aaron Ben-Ze'ev

Department of Philosophy, University of Haifa, Haifa, Israel.

benzeev@research.haifa.ac.il <http://research.haifa.ac.il/~emotions/>

Abstract: Byrne & Hilbert defend color realism, which assumes that: (a) colors are properties of objects; (b) these objects are physical; hence, (c) colors are physical properties. I accept (a), agree that in a certain sense (b) can be defended, but reject (c). Colors are properties of perceptual objects – which also have underlying physical properties – but they are not physical properties.

Byrne & Hilbert (B&H) argue that colors are properties of physical objects and hence, that colors are physical properties. I agree that colors are properties of objects having physical aspects, but this does not mean that colors are physical properties. A crucial issue neglected in B&H's considerations is the distinction between various levels of description.

Any given event may be described by referring to various levels of description, such as the physical, chemical, biological, psychological, and sociological. At each level there are self-contained

emergent wholes that have their own properties and parts. Each level of description has both unique properties and properties common to a few other levels. Although the division of the world into various levels depends to some extent on our cognitive system, it is not necessarily arbitrary. The differences between the various levels are real.

In many discussions, “real” is identified with “physical” and “unreal” with “mental” (or “subjective”). Thus, B&H identify their color realism with the claim that colors are properties of physical objects. I believe that this identification is inadequate, as “real” and “unreal” are level-dependent (and even context-dependent) attributes: Something may be real on one level of description and unreal on another.

What is the ontological status of the perceptual environment? Naïve realism, or physicalism, assumes that perceptual qualities exist independently of the perceiver, whereas extreme subjectivism assumes they are properties of the perceiver. I believe that both views are inadequate (Ben-Ze’ev 1993).

A quantitative compromise between these views is to divide the perceptual environment into two parts: One in which naïve realism is correct, and one in which the subjectivist view holds true. The distinction between primary and secondary qualities is just such a solution. I consider it necessary to make a qualitative distinction between the viewpoint within the perceptual environment – this is the perceiver’s viewpoint – and the viewpoint about the perceptual environment as a whole. From the perceiver’s viewpoint, colors are real properties of objects; however, outside the perceptual environment, for example, in the physical world, colors are not necessarily properties of objects.

In an important sense, all perceived qualities are subject-dependent rather than being properties of an independent physical world. In the course of its progress, science is moving further away from perceptual content. The world described by physics is becoming less and less available to perceptual awareness. Physics does not copy perceptual properties, but rather substitutes them with physical entities. The physical world exists on a different level of description than the perceptual environment, but its existence does not make the perceptual environment less real.

When we speak of a perceptual environment, we presuppose a context involving a perceiver. B&H criticize the ecological approach to color perception, but it is not merely an accidental connection that caused color vision to co-evolve with the colors of plants – the connection is a necessary conceptual one. To paraphrase Kant’s terminology: The *a priori* conditions of a possible perceptual experience in general are, at the same time, conditions of the possibility of perceptual objects (Kant 1787/1965, p. A111). Similarly, Gibson argues: “the words *animal* and *environment* make an inseparable pair. Each term implies the other. . . . an environment implies an animal (or at least an organism) to be surrounded” (Gibson 1979, p. 8). To be sure, organisms are “not in the environment as coins are in a box” (Dewey 1922, p. 272). The perceiver and the perceptual environment exist as a pair, just as a father and his son exist as a pair. The very same man existed before his son was born, but then another aspect was added to him: that of being a father. In the same way, the physical world existed before the emergence of perceptual systems, but then another level of description, the perceptual one, was added (Ben-Ze’ev 1993, p. 95).

This approach is a type of critical realism. Its realistic aspect is expressed in the assumption that there are objects whose existence is independent of any existing subject. This is not naïve realism, because it admits to the constructive nature of the perceptual environment.

B&H seem to argue that: (a) colors are properties of objects; (b) these objects are physical; hence, (c) colors are physical properties. It is true that colors are properties of objects, but those are perceptual, rather than physical objects. Perceptual objects can be also described on the physical level, and in this sense may be described as physical properties as well. However, not all properties emerging on the perceptual level are present on the physical level

as well. Color, I believe, is one such property. Indeed, physicists do not use color terms in their explanations. This does not imply that colors are not real at a different level of description.

The relational, or subjective, nature of the perceptual environment does not imply – as B&H seem to fear – that veridical perception cannot be distinguished from perceptual illusions. When we ascribe some property to a perceptual object, this ascription can be mistaken. In this sense, it makes no difference whether these objects are physical or mental. The fact that Madame Bovary is a fictional figure does not imply that we can say anything we choose to about her; within the context of her story, there are certain claims that are true and others that are clearly false. Similarly, ascribing certain colors to a given perceptual object may be true or false. A context-dependent property is not tantamount to an arbitrary property.

Contrary to the B&H’s claim that “Physicalism about color is compatible with practically any view about the nature of mind” (sect. 3.5), color physicalism is not compatible with views such as those of Kant, Gibson, and the one presented here, which assume that the cognitive nature of the mind in general, and the perceptual system in particular, implies the relational and constructive nature of the perceptual environment.

To sum up, perceptual objects are indeed colored as B&H say. These objects can also be described at a physical level of description. This, however, does not mean that colors are physical properties. Eliminating the perceptual, or more generally, the psychological level of description may make our explanations less problematic, but also less adequate.

“Color realism” shows a subjectivist’s mode of thinking

Michael H. Brill

American Institute of Physics, College Park, MD 20740-3842.
mbrill@aip.org

Abstract: Byrne & Hilbert (B&H) assert that reflectances embody the reality of color, but metamerism smears the authors’ “real” color categories into uselessness. B&H ignore this problem, possibly because they implicitly adopt a sort of subjectivism, whereby an object is defined by the percepts (or more generally by the measurements) it engenders. Subjectivism is unwieldy, and hence prone to such troubles.

Byrne & Hilbert (B&H) defend the position that color inheres in the spectral reflectance of an object. This reflectance realism is a parody of the position taken by investigators into color constancy – and therefore needs a reply from that scientific quarter. Color-constancy theories all posit searches for illuminant-invariant quantities based on a restricted set of expected reflectances, but any such strategy must fail if *all possible* reflectances are allowed. The problem is especially acute for metameric reflectances, which have different spectra that match under one light but not under another. Color matches made under a particular light cannot be resolved into different percepts by visual computation. Thus, an object’s color cannot depend only on reflectance, but must also depend on the incident light. Color constancy is at best an imperfectly realized goal.

How do B&H deal with metameric reflectances? In section 3.1.1, they “identify the determinable colors with reflectance-types (or sets of reflectances) rather than with the specific reflectances themselves. . . . As a bonus, this proposal also solves the problem of metamers . . . : both determinable and determinate colors are reflectance-types.”

What do B&H mean by “reflectance type”? One might try to interpret a reflectance type as a metameric equivalence class of reflectances (i.e., all the reflectances that match under a particular light). But changing the light breaks some reflectance-matches (color matches of reflectance) and cements other ones. Thus, the

light, as well as the object, must jointly determine these classes – and hence, *a fortiori*, must jointly determine the color.

No matter how one defines reflectance type, reflectance realism seems to demand that the “type” label inhere in a reflectance and be independent of the illuminant. However, the “typing” must not give different labels to reflectances that are indistinguishable under any given light. With metamerism lurking as a possibility, one must include in any type all reflectances that could possibly match a certain reflectance *R* under any light. This is too large a class for a single color label, as I am confident the authors will acknowledge. Of course, differences between observer color matches add an analogous dimension to the problem of assigning reflectance types.

If the authors retreat from this consequence by positing that not all reflectances belong to color categories, they must decide which reflectances do and which do not – an unsatisfying prospect at best.

Why would B&H continue to defend reflectance realism in the face of such a logical problem? The answer, I think, is that these authors believe in the existence of real-object categories that are inverse maps from the sensorium, independent of such conditions as differences in illuminant spectra or in observers’ color-matching functions. The road to such faith is a well-worn path, the epistemological tenet of *subjectivism*. This tenet “limits knowledge to conscious states and elements” (Webster 1993). According to a subjectivist, an object is the ensemble of all its percepts (e.g., color percepts under different lights, or, more ineffably, color percepts from an object regardless of the light).

There is a problem inherent in the authors’ implicit subjectivism. Declaring that the “reality” of a reflectance is derivable from the color percepts it engenders is analogous to saying that the entire three-dimensional content of an object is captured in a large number of photographs of that object. It is far more reasonable to admit that “color equals light + object + viewer,” as has been more customary since the time of the ancient atomists (e.g., Democritus in the fifth century BC). Atomists’ “simulacra” are messengers to the eye, similar in role to the modern “illuminant” (Lindberg 1976). By positing a reality that has more dimensions than are accessible to the color perceiver, one can avoid defining an object from its percepts and thereby limiting prediction of the object’s behavior in the physical world (e.g., when illuminated with a different light).

I have said that subjectivism is a well-worn path. In making this assertion, I adopt H. Lindner’s slightly nonstandard interpretation that includes physical measurements among the percepts that are the substrate of subjectivism. In Lindner’s words:

I do not charge Relativity and Quantum Theory with a naïve psychological or perceptual subjectivity. Epistemological subjectivism assumes the observer’s accurate account of his experiences and measurements, including instrumented measurements, within his CS [coordinate system], even as recorded by mini-observers at every point of his CS. (Lindner 2003)

Interpreting subjectivism in this surprising but revealing way, it becomes clear that even relativity and quantum theorists have accepted the premise that an object *is* the ensemble of all its percepts (e.g., reference-frame views). Relativity crawls from one reference frame to another in an attempt to hang reality on such a subjectivistic framework, even though the reference frames fall apart over long distances in curved space: Any coordinate grid defining a reference frame gets tangled up with itself remote from the observer (Brill 1989). In quantum theory, the perceiver is necessary for the “collapse of the wave packet” that *determines* the reality. For example, the life or death of Schrödinger’s cat is not decided until someone looks in the box containing the cat. But is the packet fully collapsed if another observer who observes the first observer has not yet collapsed *his* wave-packet (LeGuin 1982)? The last word has yet to be written about this awkwardness.

In view of these difficulties, it isn’t surprising that, despite the subjectivism required in formal exposition, physicists and engi-

neers informally use objective metaphors that transcend the perceptions of objects: for example, the “mollusk” metaphor for curved spacetime (Einstein 1920, Ch. 28). It would be hard to imagine a different state of affairs, for example, a photointerpreter who does not believe in a three-dimensional ground-truth that predicates all the two-dimensional images he views. Nor should color be made to inhere in objects, which thereby become tacit extensions of our sensorium.

Ecological considerations support color physicalism

James J. Clark

Centre for Intelligent Machines, McGill University, Montréal, Québec
H3A-2A7, Canada. clark@cim.mcgill.ca
<http://www.cim.mcgill.ca/~clark>

Abstract: We argue that any theory of color physicalism must include consideration of ecological interactions. Ecological and sensorimotor contingencies resulting from relative surface motion and observer motion give rise to measurable effects on the spectrum of light reflecting from surfaces. These contingencies define invariant manifolds in a sensory-spatial space, which is the physical underpinning of all subjective color experiences.

The arguments for physicalism provided in the target article can be strengthened by considering the ecological aspects of surface reflectance. Humans develop and live in a complex visual environment, and this complexity should not be ignored in developing theories of color perception. There are a number of physical processes governing the spectra of light reflecting from surfaces that become important in nontrivial environments. These physical processes result in significant asymmetries that rule out many of the philosophical arguments against a physicalist view of color (Myin 2001).

For example, the problems caused by metamers vanish when surface interreflections (Gilchrist & Ramachandran 1992) are examined. Consider a V-shaped concavity formed from a folded surface with a given reflectance spectrum, illuminated by a diffuse light source. The spectrum of the light reflected from the surface will be a complicated nonlinear function of the surface reflectance spectrum (Langer 1999). Suppose we take a second concavity with the same shape as the first, with a surface reflectance spectrum that is different but metameric to the first. Because of the nonlinear effects of interreflection, the spectrum of the light reflected from the second concavity will, in general, be different from that reflected from the first. Thus, even though two different planar surface patches observed in isolation may appear to have the same color, when the same surfaces are observed in nontrivial environmental arrangements (e.g., folded into concavities), the differences between them become apparent. As mentioned in the target article, it is clear that the human visual system takes the visual neighborhood into account when perceiving constancy of color across illuminant spectra changes. Bloj et al. (1999) have shown that humans can likewise discount the effect of interreflection on perceived color when information as to relative surface orientation is available.

We contend that the human visual system identifies invariances in the sensory input corresponding to particular qualities such as color. These invariances are revealed through active experience in a complex environment. Experience allows the visual system to form statistical models and make predictions of the sensory effect of different motor acts and different environmental contexts on a given phenomenal quantity. In mathematical terms, one can consider the invariances inherent in image formation as defining manifolds in an abstract space defined by sensory and environmental degrees of freedom. It is the identification of a particular sensory input with a specific submanifold that corresponds with the asso-

ciated mental contents. The submanifold is defined by physical laws, and therefore, the associated mental contents are dictated by physical reality. The brain, in this view, gathers evidence for a particular submanifold corresponding to a stable physical quantity. Many neurobiologists are beginning to believe that the brain is particularly designed to be able to learn and recognize such invariant manifolds (Seung & Lee 2000).

The apparent problems of the phenomenal structure of color can be handled by the manifold approach, as the particular invariant submanifold that the brain actually makes explicit depends on the specific circuitry of the brain. *The phenomenal contents themselves are dictated by the physical reality, but the ones that are actually experienced depend on the precise wiring of the brain.* For example, consider the problem of color similarity. We will approach this by first examining the submanifold (in the space of all possible sensory inputs and ecological configurations) corresponding to a surface with a particular reflectance characteristic. This submanifold is determined by purely physical processes and represents invariant properties of the light reflecting from the surface (e.g., what happens to the reflected light when another surface is brought close to it). The sensory apparatus and neural processes in the brain concerned with the perception of hue respond, however, only to a two-dimensional subset of this high-dimension color submanifold. They will still respond in a way that reflects the physical laws of sensorimotor and ecological contingency, but will be insensitive to many details. One can think of the brain as responding to a projected version of the high-dimension surface spectrum manifold. The specifics of the coordinate system used to represent the two-dimensional subset depend on the precise details of the neural implementation and will vary from person to person. Unique hues correspond to extreme values of these coordinates (i.e., red-green for one coordinate axis, and blue-yellow for the other). Binary hues correspond to linear combinations of the unique hues.

Now, this choice of coordinates is arbitrary, as one could conceive of a brain that would use a different coordinate system to represent color. Thus the subjective experience would be different, much as the subjective experience of a color-blind person in viewing green grass is different from that of a normally sighted person. But this does not mean that the subjective experiences do not have a physical source. On the contrary, both the color-blind and normally sighted observers are merely perceiving different aspects of the same physical structure, the sensorimotor/ecological submanifold.

My view of physicalism is very much in keeping with the recent proposals of O'Regan and Noë (2001a). In their theory, color is determined by physical laws that describe how the sensory input is affected by motor acts of the observer, what they refer to as "sensorimotor contingencies." They add that color is also determined by the ways in which the sensory input generated by a colored patch depends on how the patch affects, and is affected by, its environment. I refer to these ecological laws as the "ecological contingencies" of color. The role of the brain in my view is to extract, through neural circuits that are hardwired or developed through experience, the sensorimotor and ecological contingencies associated with a given phenomenon. The fact that the brain may only be able to extract a subset of all the contingencies does not eliminate the inherent connection to the physical world.

In summary, I suggest that the consideration of ecological and sensorimotor contingencies associated with the reflectance of light from surfaces leads to a natural elaboration of the physicalist theory of color being expressed in the target paper.

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Perceptual variation, realism, and relativization, or: How I learned to stop worrying and love variations in color vision

Jonathan Cohen

Department of Philosophy, University of California, San Diego, La Jolla, CA 92093-0119. joncohen@aardvark.ucsd.edu
<http://aardvark.ucsd.edu/~joncohen/>

Abstract: In many cases of variation in color vision, there is no nonarbitrary way of choosing between variants. Byrne & Hilbert insist that there is an unknown standard for choosing, whereas eliminativists claim that all the variants are erroneous. A better response relativizes colors to perceivers, thereby providing a color realism that avoids the need to choose between variants.

Byrne & Hilbert (B&H) discuss variations in color vision (sect. 3.4) mainly in the context of blocking the eliminativist's argument from these phenomena to the conclusion that nothing is colored. I want to concede realism about color, but use the same phenomena to raise a distinct yet related set of challenges for B&H.

We can raise these challenges by reflecting on the case of variation B&H adapt from Hardin (1993). You and your colleague view a range of Munsell chips under relevantly similar perceptual circumstances, but you disagree about which of the chips is unique green: Chip C1 looks unique green to you, and fails to look unique green (say it looks bluish green) to your colleague, whereas chip C2 looks unique green to her but not to you. Now consider chip C1, and ask: Is C1 unique green?

By hypothesis, consulting the perceivers (you and your colleague) will not provide a determinate answer, since they are divided over the question. (The assumption that there are only two such observers is inessential; one can easily expand the number of perceivers without thereby generating a consensus about C1's color.) What we need, then, is a standard for whether something is unique green that is *independent* of the reports of perceivers. Unfortunately, as B&H point out, "in the color case, there is no such [independent] test" (sect. 3.4) to which we can turn. (B&H blame the lack of an independent test partly on "the fact that colors are not perceived by any other sensory modality" (sect. 3.4). But I do not see why a further sense modality for perceiving colors would necessarily provide the sort of independent test we need. Suppose we had such an additional modality for perceiving colors. It is possible that: [1] that modality might not lend support to either of the conflicting visual representations of color; [2] that modality might lend support to both of the conflicting representations. In either case, it would not arbitrate disputes among visual representations in the way that B&H imagine.)

B&H recognize that an independent standard is needed to answer our question about the chip, and that no such independent standard is available. But this does not alarm them; by way of analogy, they point out that even if we lack decisive evidence about the guilt of a particular suspect, this does not lead us to believe that no one murdered Professor Plum. Presumably, the intended force of the analogy is that, even if we lack an independent standard that would certify one of the ways C1 looks as *the* veridical representation of the chip's color, there may nonetheless be an unknown fact of the matter about which representation is veridical.

But the analogy is unconvincing, because the background beliefs we bring to the inquiry are far less informative in the case at hand than they are in the case of Professor Plum. For, our belief that Professor Plum has been murdered is sustained in the face of our lack of dispositive evidence about individual suspects only because of certain sorts of general background beliefs, and these are notably absent in the case of the missing standard for color perception.

In the case of Professor Plum, beliefs of two general kinds are relevant: (1) Our independently well-supported beliefs about how people move and behave imply that the good Professor would not have ended up in his present unhappy state (keeled over in the

ballroom, knife protruding from his back) had some person or other not murdered him. (2) We have no trouble understanding how someone could be the murderer of Professor Plum without our having decisive evidence of his guilt. Here, belief (1) creates a presumptive prejudice to the effect that Professor Plum was murdered, and belief (2) explains away potential counter-considerations engendered by our lack of evidence about specific individuals. This combination of beliefs, then, leads us to think that there is a fact of the matter about who murdered Plum, even if that fact of the matter is beyond our ken.

Contrast the case of the wanted independent standard for color perception. Here our general background beliefs both fail to establish a presumptive prejudice in favor of an independent but possibly unknown standard, and fail to override the counter-considerations engendered by our lack of evidence. Indeed, the failure of several hundred years of systematic efforts directed at articulating standards of this kind establishes a presumptive case *against* their existence. (The history of these efforts is recounted in Hardin 1993, pp. 67–82; see also Cohen 2003.) As such, B&H's view that there is an epistemically unavailable standard strikes me as a piece of unwarranted optimism.

Suppose that, as I suspect, there is no well-motivated independent standard to arbitrate between the two representations of C1's color. Must we, then, endorse color eliminativism? Like B&H, I hope to avoid this outcome: Eliminativism amounts to such a radical revision of our pretheoretical views about the world that it should be regarded as a position of last resort. (As usual, Hume [1762/1986] is eloquent on this point: "Philosophy scarce ever advances a greater paradox in the eyes of the people, than when it affirms that snow is neither cold nor white: fire hot nor red" [letter to Hugh Blair of 4 July 1762, printed in *Mind*, October 1986].)

Luckily, there are noneliminativist ways of accepting the absence of a perceiver-independent standard for C1's color. Namely, we can hold that the alternative representations of C1's color (the way it looks to you, the way it looks to your colleague) are *both* veridical. There are a number of ways of fleshing out this suggestion, but one of the most popular is to construe colors as relativized to perceivers. (The dispositionalist view B&H consider [and reject as unmotivated] in section 2.2 is one account of this type, although there are a number of others. Consequently, the point I am pressing is one way of providing the motivation for such views that B&H think is lacking.) In the case at hand, this would amount to saying that C1 exemplifies both of these color properties: unique green to you, and bluish green to your colleague. This view both frees us from having to answer the otherwise pressing, but apparently unanswerable, question of whether C1 is unique green or not, and explains why past efforts to answer it have failed (namely, according to this view, there is no nonarbitrary reason for preferring either choice over the other). This is all to the good: Hard cases make bad law.

The view I am recommending is a species of realism, in that it insists that colors are real (not merely apparent) properties of objects. (A number of authors have objected that such views unacceptably preclude erroneous color attributions [e.g., see Hilbert 1987, p. 8, and Matthen 2001]. For a response to this objection, see Cohen 2000; 2003.) However, unlike B&H's preferred form of realism, it accommodates the data about perceptual variation without requiring either hard choices or unwarranted optimism. As such, I believe this view is a more attractive alternative for those in the market for a realist account of color.

True color only exists in the eye of the observer

Frans W. Cornelissen,^a Eli Brenner,^b and Jeroen Smeets^b

^aLaboratory of Experimental Ophthalmology, School for Behavioral and Cognitive Neurosciences (BCN), University of Groningen, 9700 RB Groningen, The Netherlands; ^bDepartment of Neuroscience, Erasmus Medical Center, 3000 DR Rotterdam, The Netherlands.

f.w.cornelissen@med.rug.nl brenner@fys.fgg.eur.nl
smeets@fys.fgg.eur.nl http://www.eur.nl/fgg/neuro/people/smeets

Abstract: The colors we perceive are the outcome of an attempt to meaningfully order the spectral information from the environment. These colors are not the result of a straightforward mapping of a physical property to a sensation, but arise from an interaction between our environment and our visual system. Thus, although one may infer from a surface's reflectance characteristics that it will be perceived as "colored," true colors only arise by virtue of the interaction of the reflected light with the eye (and brain) of an observer.

Color vision evolved as a means for organisms to gain information about the world from the light reflected (and occasionally emitted) by surfaces. Color vision enables organisms to detect and recognize objects on the basis of spectral as well as intensity (luminance) differences. Reflectance characteristics can provide useful information about an object, such as whether a banana is ripe or not. If it looks yellow, the banana is likely to be ripe. But is the banana really yellow? In a sense it must be, because we are very consistent in categorizing surfaces by their color. On the other hand, we are known to misjudge reflectance properties when the illumination is unusual, or in the case of metamers. This supports the notion that the goal of visual processing is to provide fast and adequate, and not necessarily the best (Brenner & Smeets 2001), estimates of physical properties. In the case of color vision, the estimate should be sufficiently reliable for judging whether, for example, bananas are ripe under natural lighting conditions.

The segregation of reflectance properties into colors is not an arbitrary association between surface reflectances and color names that is learned during development (Brenner et al. 1985; 1990; Diet et al. 1987), but is determined by the spectral sensitivity of the cones and the way their outputs are combined during subsequent neural processing. Most of the variance in natural reflection and illumination spectra can be accounted for by using a set of only three basis functions (for an overview, see Lennie & D'Zmura 1988). Thus, crude sampling with three adequate types of sensors (the cones) would allow us to discriminate between most of the different spectral reflectances present in our environment. In the course of evolution, our ancestors presumably acquired cones with spectral sensitivities that were suitable for the existing visual environment and their own behavioral needs (Regan et al. 2001). In our opinion, the colors that we perceive are the outcome of the way that our visual system uses the signals of the three cone types to make order of the spectral (and in particular, the reflectance) information present in the environment. Thus, we can agree with Byrne & Hilbert (B&H) that colors are related to physical properties (i.e., reflectance spectra), but not in the way they propose, because we will argue that colors only exist in connection to an observer.

For our visual system, a fundamental problem that occurs when estimating a surface's properties is that the spectral composition of the light reaching the eye is the product of the surface's reflectance and the spectral content of the illuminant. For spectral information to be useful, one must be able to distinguish surface properties from those of the illumination. Humans and many other animals can somehow recognize colors under a wide range of illuminations (Arend & Reeves 1986; Bauml 1999; Cornelissen & Brenner 1995; Dorr & Neumeier 1996; Foster & Nascimento 1994; Foster et al. 1997; Ingle 1985; Land & McCann 1971; Lucassen & Walraven 1996; Troost & De Weert 1991; Werner et al. 1988). That they are able to do so, can be attributed to the ingenuity of their color vision systems, which, in many ways, can be understood to be a collection of "tricks." Cone adaptation is a trick

that reduces the sensitivity to longer-term spectral biases in the visual environment (Von Kries 1905). An emphasis on the ratio between the stimulation of different kinds of cones (color opponency), rather than on the cone responses themselves, is a trick that makes color vision independent of the level of illumination (Brenner & Cornelissen 1991; Foster et al. 1997; Jameson & Hurvich 1961). Comparisons between the stimulation at different spatial locations (spatial opponency) is a trick that makes color vision less dependent on the chromaticity of the illumination (Brenner & Cornelissen 1991; Brenner et al. 1989; Walraven et al. 1987).

Relying on such tricks has its consequences. For example, biases in the chromatic content of neighboring surfaces influence a surface's apparent color by chromatic induction (Brenner et al. 1989; Cornelissen & Brenner 1991; Walraven 1973). Perhaps that is why the influence of the color of neighboring surfaces is reduced if the scene is very colorful (Brenner & Cornelissen 2002). The use of tricks such as those mentioned above means that not only the cones themselves, but also the subsequent connectivity, will influence the way that the spectral composition of the light reaching the eye is transformed into perceived colors.

In the target article, B&H argue that colors are real physical surface properties. We maintain that the colors that we perceive arise from interactions between our visual system and the spectral information in the environment, and therefore cannot be physical properties of the surfaces alone. B&H (section 3.4, para. 10) in a way come close to this conclusion when they point out that we have no unbiased and independent means to determine an object's "physical color" because only human (and perhaps animal) responses can be used to determine it. This ultimately reduces the idea, that objects are colored, to an untestable belief. We are less pessimistic about the possibilities of studying the perception of surface colors, because we see color vision as a systematic interaction between our visual system and the light that reaches our eyes when reflected from surfaces in our surroundings. Thus, bananas are yellow (at least for human observers) because our visual system responds to them in a certain way.

To provide an analogy somewhat akin to one presented by B&H (sect. 1.1, para. 4), we point out that whether a specific substance can be considered to be "food" depends on whether the organism in question can digest it. Grass is food to a cow, because its stomach and intestines can digest it. For us, grass is not food, because we cannot digest it. Thus, being food is not a property of the grass. There is no food without an organism that can eat it. *Color is like food in this respect*. Whether a particular reflectance spectrum becomes a color depends on the presence of an organism with a suitably equipped visual system. Colors can therefore only arise by virtue of an eye and brain of an observer. Whether this implies that colors should be considered to exist only "in the mind" is a matter of taste.

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Orange laser beams are not illusory: The need for a plurality of "real" color ontologies

Lieven Decock^a and Jaap van Brakel^b

^aFaculty of Philosophy, Tilburg University, 5000 LE Tilburg, The Netherlands;

^bInstitute of Philosophy, University of Leuven, 3000 Leuven, Belgium.

l.decock@uvt.nl Jaap.Vanbrakel@hiw.kuleuven.ac.be

Abstract: Reflectance physicalism only provides a partial picture of the ontology of color. Byrne & Hilbert's account is unsatisfactory because the replacement of reflectance functions by productance functions is ad hoc, unclear, and only leads to new problems. Furthermore, the effects of color contrast and differences in illumination are not really taken seriously: Too many "real" colors are tacitly dismissed as illusory, and this for arbitrary reasons. We claim that there cannot be an all-embracing ontology for color.

Byrne & Hilbert's (B&H's) color realism, grounded in reflectance physicalism, only provides a partial picture of the ontology of color as we know it. Many aspects of human color vision are neglected or sidestepped in their account. This sort of critique is not new, but B&H's responses to earlier critiques (e.g., Campbell 1993) are not satisfactory.

Since reflection is not the only physical process underlying color perceptions, what the authors call "productances" are introduced to modify surface reflection functions into more general functions, so that processes like absorption, emission, and so forth. (Nassau 1983) can be taken into account. However, the idea of productance functions remains sketchy. At no point in the target article is the precise relation between productance and color given. If, as B&H say, "productances are always *relative to an illuminant*" (sect. 3.1.2, emphasis in original), *prima facie* color is no longer an independent property or disposition of a surface. If the productance of a surface is relative to the illuminant, it becomes unclear what the color of the surface is. Is it to be equated with the productance function or with the productance function relative to an illuminant? If the productance function is presented as $p(\lambda, I)$, that is, a binary function taking as domain pairs of wavelengths and illuminants, and as range the positive real numbers (since values larger than 1 are possible), then it is not clear whether the color of the surface should be identified with the binary function $p(\lambda, I)$ with variable I , or with the simple function $p(\lambda, I_a)$ for a given illuminant I_a . On the first horn of the dilemma, the direct correspondence between physical color and perceived color is broken, because in a given situation, one would not perceive "the" color of a surface, but only one aspect of the color of a surface. On the second horn, some surfaces no longer have a unique color, because for each illuminant I_a , the simple function $p(\lambda, I_a)$ will be different. With this option, the relation between perceived and physical color is restored, but at a high cost. The advantage of reflectance physicalism over the wavelength conception of color (Hilbert 1987, p. 7) would be that overall illumination could be neglected, because of color constancy. But if illumination plays an essential role in how the color of a surface is perceived, we may as well take the light that reaches the eye as the "real" physical base on which color perception supervenes.

Also the role of contrast effects is underestimated. In section 3.1.3, B&H discuss related and unrelated colors. They reject the objection that brown cannot be a surface color, because unrelated colors that are seen under laboratory conditions are less normal than related colors. However, the problem of contrast effects is much more serious. Even if a surface is presented in a surrounding containing all the other colors that are normally necessary for its perception, still its perceived color can change dramatically by local changes in the colors surrounding it. By means of contrast effects one can make any surface look like almost any color (Whittle 2002). Hence, it may be more appropriate to regard the color of a surface as being a relation between its reflectance function and the reflectance functions of the background and surrounding surfaces, again undermining B&H's basic ontological claim that a perceived color can be identified with the surface reflectance or productance function of an isolated object.

And there are other limitations. Sometimes, perceived colors are totally unrelated to the reflection function of the surface or volume one is looking at. Take, for example, the color of an orange laser beam. It has a very vivid color. However, if we interpret this phenomenon according to B&H's theory, the object one is looking at is a cylinder of air. But the reflectance function of this cylinder is totally unrelated to the perceived color. Hence, B&H would have to say that the vivid orange is, in fact, an illusory appearance. A more appropriate way of regarding this case is by claiming that one is seeing the color of the laser beam rather than the color of a cylinder of air. A similar case is the projection of a film on a white screen. Again, the perceived colors are totally unrelated to the normal reflection function of the screen. Should we therefore conclude that one does not see colored figures on the screen? Again, the troublemaker in these examples is the assumption that colors

are properties of surfaces (or volumes) alone, whereas many real colors arise through differences in illumination parameters.

The gist of all this is that B&H's reflectance physicalism is forced to curtail the domain of "real" color severely, and dismiss many important color phenomena as illusory or nonstandard. The limitations imposed involve a large degree of arbitrariness, and the proposal contains ad hoc additions such as productances. Therefore, the claim that reflectance physicalism is the most appropriate ontology for color is not substantiated. The intuition behind it, namely, that color is *primarily* (but not *exclusively*) a property of external objects, is plausible and deserves the elaboration that B&H have given it. But there is more to color than someone with normal color vision looking at a (ripe) tomato in good light.

At a more general level, we suggest that it is not possible to come up with a final all-embracing ontology for color (see also Matthen 1999); none of the proposals B&H discuss and dismiss will do, including their own proposal. To think that color is (physically, ontologically) one thing (or nothing at all) has been part of the philosopher's dream for a long time. However, what in colloquial English is called color, is a very complex function of human beings and what their environments afford, and it is not plausible that this can be described with a single ontology, if only because there is not one scientific theory of color perception that explains the color of all perceived colors.

The quest for a single ontology for color is a result of a mistaken view of ontology. Ontology should be regarded as the handmaiden of epistemology (Decock 2002; Quine 1953). In color science, one has to work with a range of overlapping theories to explicate various aspects of color vision. Ontologies for specific theories can be given, but a universal or global ontology for colors can only be imposed by "not saving the phenomena." We suggest that the ontologies of color are relative to the theoretical framework one is working in and that a plurality of plausible ontologies can be proposed, serving different aims. As to color vision, one will have to live with "radical ontological pluralism" (Dupré 1993, p. 94).

Productance physicalism and a *posteriori* necessity

Don Dedrick

Department of Philosophy and Institute of Cognitive Science, University of Louisiana at Lafayette, Lafayette, LA 70504-3770. dpd@louisiana.edu
<http://www.ucs.louisiana.edu/~dpd9999>

Abstract: The problem of nonreflectors perceived as colored is the central problem for Byrne & Hilbert's (B&H's) physicalism. Vision scientists and other interested parties need to consider the motivation for their account of "productance physicalism." Is B&H's theory motivated by scientific concerns or by philosophical interests intended to preserve a physicalist account of color as a *posteriori* necessary?

Near the end of a preliminary section of the target article B&H inform us that

a distinction may turn out not to distinguish anything! At the start of enquiry, one would want to make a distinction between salt and sodium chloride, or the butler and the murderer, even though it may turn out that salt is sodium chloride or that the butler is the murderer. It may similarly turn out with phenomenal color and (a kind of) physical color . . . perhaps phenomenal and physical color are one and the same. (sect. 1.3.4, para. 5)

The philosopher Saul Kripke (1980) initiated a useful way to talk about cases like these. The identities in question are necessary *and a posteriori*. They are necessary because salt is sodium chloride, and a *posteriori* because determining the identity takes some empirical work, that is, a discovery by science. One further point about Kripke's concept: the necessity it prescribes is neither logical (does not involve, say, tautology) nor is it physical (does not in-

volve a law of nature). Instead, it names a metaphysical necessity that concerns the way things are in themselves: The *thing*, salt, is the *thing*, sodium chloride in, as philosophers say, all possible worlds. Is the claim that color = reflectance an instance of a *posteriori* necessity? B&H do not discuss this matter in the target article, though they advocate necessity in an earlier work (Byrne & Hilbert 1997, p. 267).

To say that color = reflectance is a *posteriori* necessary is to say that, whereas one can discover that colors are reflectance classes, one cannot discover that colors may be something else other than, or as well as, reflectances. Suppose science determines that color is something else. Then reflectance physicalism is false. Suppose it is sometimes something else. Then there are two ways to go that are of interest here: (1) One can give up metaphysical necessity and hold that colors are contingently a number of things. (2) One can hold that, on those occasions where "color" is something other than reflectance, it is not color (and that it is color on the occasions where it is reflectance).

The authors approach the problem of animal color vision via (2): "If it turns out that certain salient properties represented by the human visual system are reflectance-types, then organisms with visual systems that do not represent reflectance-types cannot have color vision in the sense relevant to this article" (sect. 3.3, para. 6). This will strike some as cognitive imperialism – especially since it is virtually certain that other animals represent properties other than surfaces (Jacobs 1981; Matthen 1999; Thompson 1995a). But note: If the color = reflectance is a *posteriori* necessary, then you cannot discover that colors are not reflectances. There are difficult issues here, but as the authors make clear, human color vision and related vision systems serve as "paradigm instances" (sect. 3.3, para. 6) for color in general, and, as such, place constraints on what we may consider as color. This would not be the case if a color = physical-color identity were contingent. Were that so, it would be an empirical and conceptual question as to what counts as "color vision." This is not the view that B&H hold.

However one feels about the idea of limiting color vision to animals that represent reflectances, that view will be implausible if, for paradigm instances, color is not reflectance. We can hardly deny color vision to certain animals on the basis that their "colors" are not reflectances, if color = reflectance does not hold for the paradigms. This brings us, in a roundabout way, to (1): the idea that one can give up necessity and hold that colors are contingently a number of things. This possibility arises most clearly for things that are, *prima facie*, not reflectors but perceived as colored. To understand how seriously B&H treat this issue, consider the fact that their theory of color should properly be called "productance physicalism" (sect. 3.1.2, para. 8), where productance is designed to accommodate reflectors and nonreflectors. They have, in other words, subsumed the vision-scientific concept of reflectance within a novel category of "productances." Some will view this concept as *ad hoc*, others, possibly, as a contribution to vision science. B&H seem uncertain. The number of occasions the phrase "productance physicalism" appears in their text is: just one (see sect. 3.1.2, para. 8); for the remainder of their article, they revert to "reflectance."

The real difficulties for B&H's physicalism do not come from metamers, or from facts about color appearance, nor from opponent-process theory. For these cases, the authors only need to show that their physicalism is consistent with certain perceptual facts and/or models of perceptual processing. These facts and models are grounded in perceptual systems (and thus concern, directly, color appearance). In B&H's physicalism, color content is external to perceptual systems. Thus, perceptual issues can offer no direct challenge. To put this another way: There is no reason to think that the facts of color appearance should be incompatible with physicalism. One is going to need some account of how the external interacts with the internal, and no specific type of account seems required. The problem of nonreflectors perceived as colored (treated as productances) is different. Here, the fact of the matter is that some colored things are not reflectors. If reflectance physicalism cannot be emended to become productance physical-

ism, we overturn the necessity of color = reflectance and end up with color as different sorts of thing. If this is the case, then the claim that other animals do not have color vision – because they represent properties other than reflectances – will be unmotivated. Thus, it will become a very contingent question as to what counts as color vision and what it is that is represented in color experience.

The problem of nonreflectors perceived as colored is the central problem for B&H's physicalism. This being so, vision scientists and other interested parties need to consider the motivation for productance. Is B&H's theory motivated by scientific concerns (the "a posteriori") or by philosophical interests that are intended to preserve the necessary *a posteriori* interpretation of color = reflectance (or, rather, color = productance)? The philosophical and the empirical are not so disparate as one might think (as the target article clearly demonstrates), but this is still a question worth asking.

Imprecise color constancy versus color realism

Brian V. Funt

School of Computing Science, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada. funt@sfu.ca
<http://css.sfu.ca/members/funt.html>

Abstract: Byrne & Hilbert's thesis, that color be associated with reflectance-type, is questioned on the grounds that it is far from clear that the human visual system is able to determine a surface's reflectance-type with sufficient accuracy. In addition, a (friendly) suggestion is made as to how to amend the definition of reflectance-type in terms of CIE (Commission Internationale de l'Eclairage) coordinates under a canonical illuminant.

Suppose, as Byrne & Hilbert (B&H) suggest, that one purpose of the human visual system is to determine surface spectral reflectance-types. Is it possible for the visual system to compute reflectance-type accurately from the available cone inputs? If so, does it? B&H presume it does and give the example that a red tomato in the garden will look the same in the kitchen. However, such thought experiments are very risky. Put the same tomato in a laboratory light booth and change the illumination from daylight to tungsten, and one observes a pronounced change in the tomato's appearance. It will still be red, but quite a different quality of red.

Human color constancy under a change of illuminant is only approximate. Various studies have been conducted quantifying the error in human color constancy (e.g., Brainard et al. 1997; Worthey 1985) and in computational models (Barnard et al. 2002). B&H take as a premise that color constancy is almost perfect: "Assuming that our perceptions of color are often veridical, we therefore need a physical property of objects that is largely *illumination-independent*" (target article, sect. 3.1, para. 1). If color constancy were perfect, then it would be much easier to agree that color might be identified with reflectance-type. However, should we associate color with a physical property when the visual system is only able to estimate the property imprecisely?

Whatever the mechanism of color perception, it is clear that it involves significant post-receptor processing of more than the cone responses at a single retinal location. Color constancy models (Finlayson et al. 2001; Forsyth 1990; Funt et al. 1999; Land & McCann 1971), while differing in many ways, all have in common the use of signals from many locations. In addition, cone signals taken over time may be part of the computation. If the visual system is estimating reflectance-type, then the estimate is almost certainly subject to some variability, depending on the visual context in which the reflectance-type occurs. Are we simply to set aside all such variation as color illusion?

B&H may prefer to ignore the difference between a reflectance-type and an estimate of reflectance-type; however, understanding this difference is one of the main subjects of color science. The magnitude of the color shifts is significant enough that it is of great practical importance to be able to predict how people will perceive a color of a surface as the viewing conditions change. Colors in a photographic print, for example, may look correct under one viewing condition but incorrect in another. A theory of color perception restricted to the concept of reflectance-type alone will be unable to account for these differences.

Although not expressed in the terminology of "reflectance-type" and "estimate of reflectance-type," the color science community regularly distinguishes between these two concepts of color. The former is the domain of colorimetry, the latter of color appearance models. The word "color" is used in both colorimetry and appearance modeling, but everyone is aware that its meaning depends on the context. Perhaps it would help to have two different terms, but it does not help to claim that only one is the definition of color.

I turn now to B&H's choice of "reflectance-type" as a description of the physical property corresponding to color. They first introduce surface spectral reflectance as being the physical property corresponding to color, then backtrack to say that it is the equivalence class of reflectances, and then further backtrack to "productances."

Clearly, surface spectral reflectance (a major simplification of a surface's bidirectional reflectance distribution function) is a physical property, but it is not one which "human visual systems could plausibly recover from the responses of the three kinds of cone photoreceptors" (target article, sect. 3.1, para. 1). Typically, spectral reflectance measurements are made at 4 nanometer intervals across the range of 380–780 nanometers. This results in 101 measurements. Putting the issue of the illumination conditions aside, the cones, on the other hand, provide only three measurements based on weighted averages of the incoming spectrum. The visual system measures, therefore, only a three-dimensional subspace of the much-higher-dimensional space of reflectances.

It might be argued that finite-dimensional linear models based on the statistics of typical reflectances allow full spectra to be reconstructed from the cone signals. However, such reconstructed spectra are still restricted to a three-dimensional subspace formed from linear combinations of the basis reflectances. Furthermore, the model's weights are equivalent to the original cone signals, in that they differ from them only by a 3-by-3 linear transformation. In other words, it is futile to expect the human visual system to "plausibly recover" the full surface spectral reflectance function. At best, it can recover a 3-parameter approximation.

B&H acknowledge the problem that the cones provide information only about a three-dimensional subspace reflectance space in their discussion of "determinable colors," which they then equate with "reflectance-types." They write, "We can identify the determinable colors with reflectance-types (or sets of reflectances) rather than with specific reflectances themselves" (sect. 3.1.1, para. 3). They do not explicitly state what test defines membership in the equivalence class of reflectances of the same reflectance-type. This might not be so irksome if they did not disparage CIE tristimulus coordinates as "not suitable to specify the reflectance-types" (sect. 3.1.1, para. 6). However, one straightforward way to define a reflectance-type is: the set of reflectances producing identical CIE tristimulus values XYZ (or equivalently CIE $L^*a^*b^*$) under some fixed illuminant specifically chosen to be the standard (often called "canonical") illuminant. The canonical illuminant need not be physically realizable, and so could be chosen to be equal-energy white.

Reflectance-type and CIE tristimulus values measured relative to a canonical illuminant (call these CIE-C coordinates) are equivalent; however, CIE-C coordinates more accurately reflect the 3-parameter type of information that the visual system could plausibly extract about surfaces. B&H object to CIE tristimulus values on the basis that the "coordinates vary with illumination, do not capture perceived similarity relations, and are tied to very specific

and (outside the laboratory) uncommon viewing conditions” (sect. 3.1.1, last para.). By specifying a canonical illuminant, CIE-C coordinates overcome the first objection. Because they are mathematically equivalent to reflectance-type, they are no better or worse relative to similarity relations. Similarly, they can be extended to productances. The laboratory conditions objection is unfounded in any case. Of course, the CIE color matching functions were determined under special viewing conditions; nonetheless, given the standard matching functions, determining the tristimulus values of a given reflectance under a canonical illuminant is a matter of straightforward calculation.

Whether the physical property to be associated with color in a physicalist approach is B&H’s reflectance-type or a 3-parameter illumination-independent specification such as CIE-C, there remains a significant gap between the property and the precision with which the visual system can determine it.

Do metamers matter?

Martin Hahn

Philosophy Department, Simon Fraser University, Burnaby, British Columbia
V5A 1S6 Canada. mhahn@sfu.ca

Abstract: Metamerism is a rather common feature of objects. The authors see it as problematic because they are concerned with a special case: metamerism in standard conditions. Such metamerism does not, however, pose a problem for color realists. There is an apparent problem in cases of metameric light sources, but to see such metamers as problematic is to fail to answer Berkeley’s challenge.

What makes the existence of metamers problematic for the color realist? According to Bryne & Hilbert (B&H), two objects are metamers insofar as they have different reflectances yet “match in [apparent] color under a given illuminant” (target article, sect. 3.1.1, para. 1). Metamers, claim B&H, are rare. But at least for this definition, this is false. Walk into any room full of objects and turn down the lights. Long before the “given illuminant” is too low for us to see at all, all the objects will match in hue. Similarly, in the parking lot, under low-pressure sodium lights, all cars appear to have the same color. And then there is the notorious case of metameric socks: The navy blue and black ones form metameric pairs in the early morning light of my bedroom. Metamerism, or what one might call common metamerism, can result from either of two facts: Our ability to accommodate to changes in illumination is less than perfect, and, under some illuminants, no mechanism could preserve color constancy.

Such a wide variability of causes of identical color appearances seems intolerable, so the standard way color realists define colors is by their appearance under just one illuminant – standard conditions. Objective red is the SSR of those objects that appear red to normal observers under standard conditions – daylight, for example, or perhaps white light. The only troublesome metamers are then the sets of objects of quite different reflectances that are indistinguishable to normal observers in standard conditions. Such metamers could be distinguished by their appearance if only we had different color systems, most notably if we had more than three cones. Fortunately, standard-condition metamers are very rare in nature, so the problem of such uncommon metamers is perhaps not a practical one.

The problem is that the same determinate color can be identified with any number of different metameric SSRs, and the choice between them is arbitrary. B&H’s proposed solution is to take determinate colors to be reflectance *types* rather than reflectances. A fully determinate shade of red is, in fact, a perceptual equivalence class of reflectances, those that a normal human trichromat cannot distinguish in standard conditions. Colors are fully objective; color types, both determinate and determinable, are anthropocentric.

But is a solution needed? Suppose the color sophisticates at Toyota develop a new paint, Metameric Blue. In daylight, Metameric Blue appears just the same as another Toyota color, Mundane Blue. At sunset, Metameric Blue cars take on a sophisticated silver-blue tint. In Toyota brochures, Metameric Blue and Mundane Blue are listed as two standard color choices. How else would one list them? Moreover, if standard condition metamers became widespread, we would carefully check our potential new cars, laptops, and cellular phones under the appropriate illuminants before we chose them.

The moral of the story: If what counts as a determinate color is a matter of which SSRs are indistinguishable to a normal observer, then indistinguishability under standard conditions is the wrong criterion. If we can distinguish one SSR from another under at least one illuminant, we have two determinate colors. This goes for determinables as well: To be red is not just to look a certain way in standard conditions. It is to look the right way (red!) across a range of conditions. The cosmetics industry has long known this. A red lipstick which, in candlelight, looks slightly orange is really an orangey red, even if the difference between it and one that appears pure red in candlelight is below JND under standard conditions. That’s why cosmetics’ counters have those silly mirrors. Statistically, white light gives us the best chance of discriminating between the SSRs of objects. But there will be pairs of SSRs that are only distinguishable if we skew the SPD of the illuminant so as to increase the signal-to-noise ratio in the relevant part(s) of the spectrum. The proper solution to the problem of metamers – common and uncommon – is thus to simply accept that the same color will have different appearances in different conditions. For something to be blue, it must look just the way blue things ought to look in green light, blue light, white light, and, indeed, no light at all.

Still, there are the metameric pairs of psychophysics – those produced by triplets of light sources – that are genuinely indistinguishable. Here, there are no alternate illuminants to distinguish them, so we have pairs of quite different SPDs being classed as the same determinate color by normal observers after all.

Is this a problem for the objectivity of colors? Only if real colors are tied to apparent colors in a way that no other objective property is. Apparent colors are connected to real ones, according to B&H, because of the way the question of realism is posed. If all of our perceptual judgments of color turned out to be false, there would be no real colors. Should someone claim that physical properties of kind C are colors, but all our color judgments were false about those properties, the person would be changing the subject. But these points are perfectly general: They are not confined to “secondary” properties or even to perceptual ones. If a person claimed that being in debt was a certain kind of property humans can have, property D, but *none* of our judgments of indebtedness turned out to be true for his theory, he would be changing the subject. He would not be talking about indebtedness. And if there was *nothing* in the world that made a large portion of debt judgments true, indebtedness would be an “illusion.” This is what happened to phlogiston, and to say that phlogiston turned out to be oxygen is indeed to change the subject.

That some, or even most, of our perceptual judgments of color turn out to be true is thus a minimal condition of color realism. Such a minimal condition is also true, for example, of the property of shape. But for a shape to be determinate is not for it to be indistinguishable to normal human observers under some (or even all) conditions. That every actual shape is determinate (i.e., of a fully determinate type, as B&H point out) is a basic fact about the world. It is not a fact about our perceptual acuity. Shapes go all the way down to, for example, waveforms of light. There is nothing at all puzzling about differences in shape that we cannot perceive, or perhaps even detect, with our best instruments. This is what it means for a property to be truly objective: It is independent of observers; or recognition-transcendent, as we philosophers like to say.

Thus, if colors are objective like shapes, and if indeed they are

SSRs, then determinate colors are just determinate SSRs. In tying determinate colors to what normal perceivers can distinguish, B&H have, in their own words “failed to answer what we might call *Berkeley’s Challenge*, namely, to explain why perceivers should be mentioned in the story about the nature of color, but not in the story about shape” (sect. 2.2, last para.).

Parallels between hearing and seeing support physicalism

Stephen Handel^a and Molly L. Erickson^b

^aDepartment of Psychology; ^bDepartment of Audiology and Speech Pathology, University of Tennessee, Knoxville, TN 37996. shandel@utk.edu merickso@utk.edu web.utk.edu/~aspweb/faculty/Erickson/default.html

Abstract: There are 2,000 hair cells in the cochlea, but only three cones in the retina. This disparity can be understood in terms of the differences between the physical characteristics of the auditory signal (discrete excitations and resonances requiring many narrowly tuned receptors) and those of the visual signal (smooth daylight excitations and reflectances requiring only a few broadly tuned receptors). We argue that this match supports the physicalism of color and timbre.

The correspondences between the perceptual properties of hearing and seeing are not simply one to one, but one to many. Consider color: the intuitively obvious correspondence would be color to pitch. Each “pure” color and “pure” pitch can be associated with a single wavelength, and it seems natural to associate colors with pitches and vice versa. Moreover, although there are not complementary pitches or metamers, there are pitch intervals (octaves and fifths) that have unique perceptual relationships leading to the circle of fifths and spiral representations of pitch height (frequency) and pitch chroma (octaves) (see Shepard 1982).¹ However, we believe that a richer correspondence exists between vi-

sual color and auditory timbre.² Here color and timbre belong to objects. Color and timbre constancy allow perceivers to break the sensory world into coherent objects in spite of variations due to surface illumination or due to excitation frequency and intensity. Without source timbre, there would be no connections among sounds. We are using the term timbre in a nontraditional way. By the ANSI (American National Standards Institute) definition, timbre is that quality that distinguishes two sounds at the same pitch and loudness, and therefore, each sound-producing object produces a set of timbres across pitch and loudness. Yet, timbre must necessarily be a property of the source (e.g., a flute, a Barbra Streisand) that allows the listener to segment the varying acoustic signals into stable sources.

If we accept the match between color and timbre, then we can argue that there are fundamental parallels between the production of color and the color receptors in the retina, and the production of sound and the auditory receptors (hair cells) in the cochlea. Such a parallel does not prove that color is the spectra due to the surface reflectance, or that timbre is the spectra due to the sound body resonances. But the fact that the visual and auditory sensory systems are specifically “tuned” to the different type of sensory energy for each sense does buttress both contentions and weakens the argument that sensory qualities are arbitrary constructions.

Both color and timbre are conceptualized as source/filter models, although it is the fundamental differences between both the auditory and visual sources, and filters, that are crucial to our argument. What is common to both hearing and seeing is the independent “multiplication” of the source excitation energy by the filter response. At this point we can imagine a second source/filter process: the resulting frequency spectra becomes the source and the sensitivity curve for the receptors becomes the filter. The excitation of each receptor is based on the multiplication at each frequency of the filtered source excitation by the receptor sensitivity: presumably the firing rate is a function of that sum across frequency (see Fig. 1 in the target article).

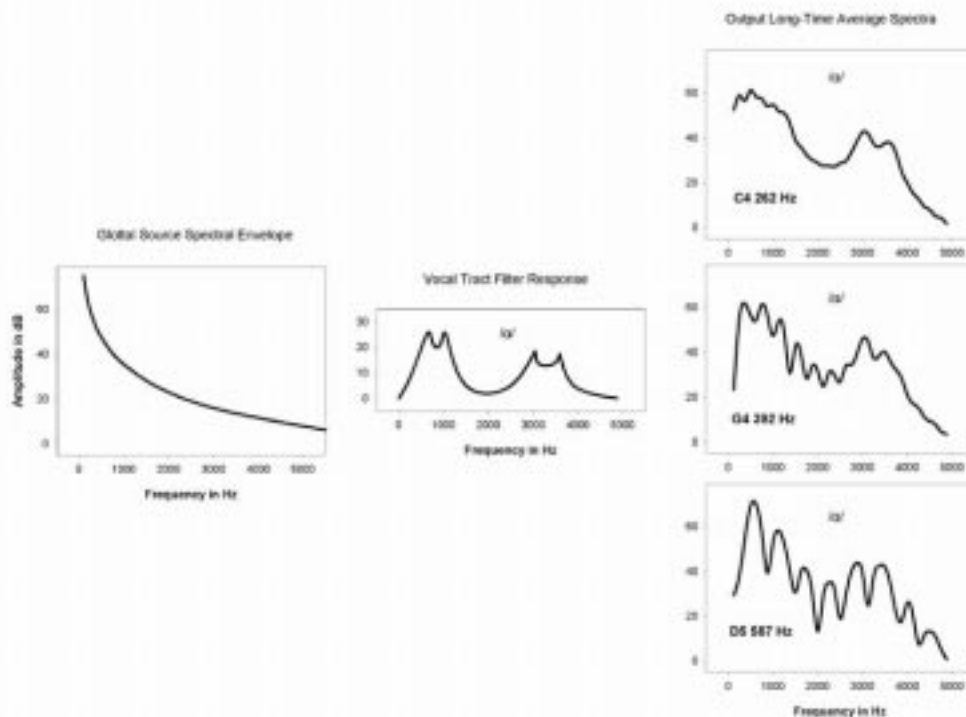


Figure 1 (Handel & Erickson). Representation of the source-filter model for the human voice. Output long-term average spectra are shown based on source frequencies of 262 Hz, 392 Hz, and 587 Hz.

Consider vision first. What we want to explain is why only a small number of cones are necessary. The source excitation will be due to direct sunlight, skylight, and reflected light from other objects, and the resulting excitation spectra of natural light at different times of day and locations is continuous and relatively smooth. Judd et al. found that the different excitations could be reproduced using different amounts of three independent functions: one function to represent the overall illumination level, one function to represent the blue-yellow contrast, and one function to represent the red-green contrast. The surface reflectance (the filter) is due to embedded particles that reflect the incident light. Somewhat surprisingly, the reflectance functions of most materials also are continuous and smooth, as illustrated in Figure 2 of the target article. Using diverse surfaces, most studies have found that the reflectance spectra can be reproduced with 3 to 7 independent functions (Wandell 1995) and that the first three functions usually represent (1) illumination, (2) red/green, and (3) blue/yellow contrasts. The fact that both the illumination and reflectance functions can be represented by a small number of independent functions suggests that only a small number of receptors would be necessary to recover the illumination-independent color. However, even with three functions for both illumination and reflection there is not an explicit solution for trichromatic vision: there are six unknowns but only three data points from the cones. Maloney (1999) and Hurlbert (1998) present alternative simplifying assumptions that yield a solution for reflectance.

Now consider timbre. What we want to explain here is why there are roughly 2,000 sound receptors in the inner ear. The source excitation (e.g., bowing or plucking a violin, vocal fold vibration) occurs at discrete and typically harmonic frequencies, and the energy at each frequency depends on the precise ways the excitation is initiated. Bowing generates a different pattern of amplitudes than plucking, and the amplitudes of the higher harmonics are relatively greater at more intense excitation levels. The sound body resonances (the filters) also occur at discrete frequencies based on the shape and material of the sound body. In the case of the human voice, resonance peaks termed formants occur at frequencies determined by vocal tract shape and size, so the radiated sound usually contains multiple peaks at widely spread frequencies separated by regions of low amplitude (Fig. 1). What this means is that neither the source spectra nor the filter spectra can be modeled by a small number of independent linear functions, and timbre depends on the distribution of individual vibrations across frequency. To distinguish among different timbres (i.e., different sound objects) therefore requires many receptors, necessarily tuned to narrow frequency bands to pick up the resonance peaks; and that is what is found in the peripheral auditory system. The perceptual dimensions underlying similarity judgments between pairs of timbres are based on the amplitude pattern of the spectra. The dimensions include the spectral centroid (i.e., the weighted average of the frequencies), the number and frequency range of the harmonics, and the variance of the harmonics, particularly across the duration of the sound (Erickson, in press). All of these require a fine-grained analysis of the spectrum.

We believe this correspondence between the physical characteristics of light and sound and the characteristics of the visual and auditory sensory receptors support Byrne & Hilbert's (B&H's) contention that colors are physical properties, and support the analogous contention that timbres are physical properties.

NOTES

1. It is surprising that books rarely point out that sound waves are as "pitchless" as light rays are colorless. We suspect that writers are lulled by the correlation between frequency and pitch, which is not found for colors.

2. It is interesting that vocal pedagogues use the terms color and timbre interchangeably when referring to the quality of a voice (see Vennard 1967).

Byrne and Hilbert's chromatic ether

C. L. Hardin

Syracuse, NY 13210. chardin1@twcny.rr.com

Abstract: Because our only access to color qualities is through their appearance, Byrne & Hilbert's insistence on a strict distinction between apparent colors and real colors leaves them without a principled way of determining when, if ever, we see colors as they really are.

Hue differences are differences in quality. Spectral power differences are quantitative. This renders any putative identification of hues with spectral power distributions problematic. If the identification is to be made persuasively, it must be possible to show how hues – or hue magnitudes – can be mapped into spectral power distributions in a principled fashion. Byrne & Hilbert (B&H) propose to do this by relating hue magnitudes to relative cone response. For example, a light with a spectral power distribution that stimulates L-cones more than M-cones ("L-intensity") is to be denominated "reddish," whereas a light with a spectral power distribution that stimulates M-cones more than L-cones ("M-intensity") is to be deemed "greenish."

This talk of "L-intensity" or "M-intensity" sounds as if it were subject-independent, but it isn't. Not only do individuals differ in their opponent systems, the balances between opponent systems in a given individual are subject to shifts depending on luminance level, stimulus size and duration, and state of adaptation. If one could find a plausible specification of "L-intensity," "M-intensity," and "S-intensity" based on spectral power distributions alone, one could speak of the accuracy or inaccuracy of a person's visual estimates of hue magnitude, just as one speaks of the accuracy or inaccuracy of a person's estimate of length or weight. We can, indeed, measure the ability that people have to resolve wavelength differences precisely because we have an independent way to measure wavelengths. But without such an independent measure, it is simply nonsense to speak of the accuracy with which someone estimates hue magnitudes. All we can do is determine the extent to which people agree or differ in their hue magnitude estimates.

B&H attempt to blunt this sort of criticism by appealing to the well-worn distinction between something's being *F* and our ability to know or gain epistemic access to *F*. For example, in discussing simultaneous contrast, they distinguish between an object's *appearing* brown and its *being* brown. "If an object looks brown against a light background then it will look orange against a dark one" (target article, sect. 3.1.3, para. 1). However, "the fact that brown is only ever seen as a related color tells us nothing about the nature of brown. It merely illustrates the fact that color perception works better under some conditions than others" (sect. 3.1.3, para. 4).

So under what conditions does "color perception work better" (presumably, come closer to showing us the colors of objects "as they are")? Is there, for example, a background that is best suited for displaying the "true colors" of a set of Munsell chips? One would look in vain in the literature of color technology for an answer to such a question, not because it is hard to answer, or unanswerable, but because it is ill-conceived. As every practitioner knows, the choice of background is as much a function of one's purposes, as it is of the particular, empirically accessible, characteristics of the materials at hand.

Because they insist on a distinction between apparent colors and real colors, while acknowledging that access to color qualities can only be gained through color appearance, B&H are forced to a damning admission: "Thus we are prepared to countenance 'unknowable color facts' – that a certain chip is unique green, for instance. And so should any color realist who accepts some assumptions that are (we think) highly plausible" (target article, note 50).

There is at least a whiff of ether here, the electromagnetic ether whose undulations were supposed to be the mechanical basis of electromagnetic phenomena. The null result of the Michelson-Morley experiment left one with two choices: Regard the earth's

motion through the ether as an unknowable fact, or else dispense with the ether altogether. Empirical science opted for the second course. Have B&H opted for a chromatic ether?

In favor of an ecological account of color

Scott Huettel,^a Thomas Polger,^b and Michael Riley^c

^aDepartments of Psychiatry and Neurobiology, and Brain Imaging and Analysis Center, Duke University Medical Center, Durham, NC 27710;

^bDepartment of Philosophy, University of Cincinnati, Cincinnati, OH 45221-0374; ^cDepartment of Psychology, University of Cincinnati, Cincinnati, OH 45221-0376. scott.huettel@duke.edu

<http://www.biac.duke.edu/people/faculty/huettel.asp>

thomas.polger@uc.edu <http://homepages.uc.edu/~polgertw>

michael.riley@uc.edu

<http://homepages.uc.edu/~rileym/pmdl/RileyLab>

Abstract: Byrne & Hilbert understate the difficulties facing their version of color realism. We doubt that they can fix reflectance types and magnitudes in a way that does not invoke relations to perceivers. B&H's account, therefore, resembles the dispositional or ecological accounts that they dismiss. This is a good thing, for a dispositional account is promising if understood in an ecological framework.

We do not see that Byrne & Hilbert's (B&H's) account succeeds in identifying colors with observer-independent features of the world. Although the reflectance of a surface is observer-independent, reflectances alone are insufficient to explain color relations. B&H thus identify colors, not with reflectances, but instead with sets of reflectances. But, because every reflectance is a member of infinitely many sets, with which sets are colors identified? B&H identify a determinate color with such a set of reflectances that no normal human observer can, in normal circumstances, discriminate (on the basis of reflectance) between two surfaces that share that reflectance set. This introduces the familiar problems of relations to observers, which pose challenges for physicalism. And, the resulting motley set of reflectances, B&H admit, "will be quite uninteresting from the point of view of physics or any other branch of science unconcerned with the reactions of human perceivers." They continue, "This fact does not, however, imply that these categories are unreal or somehow subjective (Hilbert 1987)" (target article, sect. 3.1.1, para. 4). Yes and no.

Consider the set of all things that are more than two feet and less than three feet away from the authors of this commentary. Is this set subjective or real? Each member of the set exists quite independently of the authors, as does the set if sets exist at all. But the membership of the set depends on the authors, for it changes as we move about. Similarly, whereas reflectances and sets of reflectances are observer-independent properties or entities, the fact that particular reflectances belong to the set of reds is not observer-independent; instead it depends on what reflectances are discriminable to certain observers, under certain circumstances, and so forth. This sounds very much like a dispositional account.

Even if B&H can successfully sever sets of reflectances from the perceptual equivalence relations that fixed their membership, they will still need to show that these sets can explain familiar observations concerning color relations. In particular, they must explain away data that seem to show that the physicalist account cannot address the color relations that characterize color spaces. B&H's elaborated theory says that vision represents objects as constituted from the values of four hue magnitudes, red, yellow, green, and blue. We don't know to what the magnitudes correspond, why there are four rather than more or fewer, or why these four are hue magnitudes rather than saturation or texture magnitudes. We doubt that these questions can be answered in an observer-independent manner. If not, B&H's account turns out to be similar to the dispositional or ecological accounts they dismiss.

It is seductive to think of simple physical properties of objects as being isomorphic with our experiences of them. As B&H note,

squareness seems to be an intrinsic property, and not perceiver-relative. Yet, perceived shape depends on orientation and context, just as perceived reflectance depends on the surrounding scene, orientation, illumination, and object identity (e.g., Lotto & Purves 1999). Similarly, haptically perceived heaviness does not depend simply on an object's mass; it depends on the spatial layout or distribution of an object's mass (Turvey et al. 2001). This does not show that objects do not have properties such as shape, but it may be reason to resist the identification of perceived shape with the properties represented by perceived shape. The punchline is that we must be cautious about naively assuming that our experiences resemble the world.

If physicalism cannot explain color perception, what framework should take its place? We favor a dispositional account that makes use of ecological relations. Central to this account is the mutuality of animal and environment, as illustrated by the concept of affordances, which are behavioral possibilities of a given object or environment for a given animal (Gibson 1966; 1979/1986). Affordances capture the relation of an animal's action capabilities to the environment. Visually perceived affordances for climbability, for instance, are based on the intrinsic scaling of environmental properties (step height) by perceiver properties (leg length), as shown by Warren (1984). The perception of affordances in terms of naturally scaled environmental properties highlights the importance of animal-environment mutuality: Affordances are always relative to perceivers.

This can be appreciated in the context of Turvey's (1992) dispositional account of affordances. Turvey argued that an affordance is a disposition of an environment that is actualized in the presence of a complementary disposition of an animal (an effectivity, i.e., an action capability of a particular animal). Turvey (1992, p. 180) offered the following analysis of affordances:

Let W_{pq} (e.g., a person-climbing-stairs system) = $j(X_p, Z_q)$ be composed of different things, Z (person) and X (stairs). Let p be a property of X and q be a property of Z . Then p is said to be an affordance of X and q is the effectivity of Z (i.e., the complement of p), if and only if, there is a third property r such that

- (i) $W_{pq} = j(X_p, Z_q)$ possesses r
- (ii) $W_{pq} = j(X_p, Z_q)$ possesses neither p nor q
- (iii) Neither Z nor X possesses r .

In this analysis, j is a function that expresses the joining of animal (Z) and environment (X). Each possess a complementary disposition q (an effectivity) and p (an affordance) to form W_{pq} . That joining results in the actualization r of the previously latent dispositions. By itself, p is not an affordance; it can only be an affordance for some creature. In the absence of the animal, p is a disposition, that is, a real possibility to be actualized as an affordance in the presence of an animal with dispositional property q . Property p is only an affordance with respect to animal property q when X and Z are joined.

We think that B&H's approach to color perception is, in fact, a dispositional account, because it cannot explain color vision without invoking properties of perceivers. A dispositional account positioned in an ecological framework carries considerable appeal, but it does not open the door to sense data or any of the other unnatural baggage of traditional subjective accounts of color. Nor does it deny that colors are real features of the world, and that they are the properties that are represented in color vision. Dispositional properties are relational, but nonetheless genuine. Salt really is water-soluble. Twigs, but not trees, are movable for birds. The world contains circles, and it contains cup-holders. The relational property that is the ratio of a stair's riser height to a person's leg length is no less a real, substantive property than stair height or leg length. Gibson (1979/1986, p. 129) said that the concept of "affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy." An ecologically motivated, dispositional account of color vision may do just that.

Color and content

Frank Jackson

Philosophy Program, Australian National University, ACT 0200, Australia.
frank.jackson@anu.edu.au

Abstract: Those who identify colours with physical properties need to say how the content of colour experiences relate to their favoured identifications. This is because it is not plausible to hold that colour experiences represent things as having the physical properties in question. I sketch how physical realists about colour might tackle this item of unfinished business.

I agree with Byrne & Hilbert (B&H) that we should identify colours with physical properties. I also agree with them that we should be representationalists about colour experience, and I think their way of generalizing the reflectance theory is very attractive. But there is a pressing problem, concerning combining representationalism about colour experience with physical realism about colour, that goes unaddressed in their article.

What should a physical realist say about the content of colour experience? First up, the answer seems obvious. The experience of something looking red represents that thing as being red. If red is identical with physical property Y, it follows that the experience of something looking red must represent that thing as being Y. This answer makes the representation of colour a *very* different matter from the perceptual experience of shape. We do not need to carry out an investigation into which property objects have when they are represented as looking square (or feeling square). But physicalists about colour, who identify the content of colour experience with the physical properties that they identify with the colours, must say that the situation is very different with colour experience. Detailed investigation will be mandatory for colour experience. Until we find out which colours are which physical properties, we do not know how our colour experiences are representing things as being.

Could physicalists about colour think of this as one of the interesting differences between the experience of colour and the experience of shape, rather than as something counterintuitive? The trouble is that the attractive idea behind representationalism about perceptual experience in general, be it of shape, colour, motion, or whatever, is that how things are being represented to be decides what an experience is like. This means that if we do not know how colour experiences represent things as being until we know which physical properties are identical with which colours, we do not know what it is like to have colour experiences. This is very hard to believe.

I think representationalists about experience in general, and colour experience in particular, who also espouse physical realism about colour, have to offer an account of the content of colour experience that does two things together: It gives an account of the content, which avoids the consequence that the content depends on which colours are which physical properties, and at the same time shows how this account is consistent with identifying the colours with physical properties. Doing the second requires showing how representationalists, who are also physical realists, can explain why the following argument fails.

Premise 1. Red is the colour the experience of red represents things as having. (Axiomatic for representationalists.)

Premise 2. Red = reflectance Y, for example. (Physicalism or physical realism about colour.)

Conclusion. The experience of red represents things as being Y.

As far as I can see, the only way to turn the trick is to follow Australian materialists (e.g., Armstrong 1968, Ch. 12; Smart 1959). Here is the idea without the detail: Colour experiences represent the things we see as having properties playing certain roles. The experiences do not represent the properties playing the roles *qua* the properties they are – reflectances, for example; rather, they represent that *there are* properties playing the roles. The roles may be in part causal, but it is plausible that a major part of how colour experiences represent things to be, is as having visually ac-

cessible commonalities with various colour exemplars (like blood or pillar boxes in England, in the case of experiences of red). There is a nice question as to how we might spell this out without wrongly making it part of the representational content that the exemplars are the colour they are, which we won't discuss.

How does this suggestion undermine the troublesome argument? It tells us that to represent that *x* is red is to represent that *x* has the (not too disjunctive) property that plays such and such a role. Physicalists can then identify the property that plays such and such a role with Y, without having to conclude that to represent that *x* is red is to represent that *x* is Y. Having the property that plays such and such a role is not the same property as the property which in fact plays the role. This is an old theme in discussions of Australian materialism, but the focus here is on properties of our surroundings, not states of our brains.

The above is support for the kind of position that B&H take, but it means that there is a major question that needs resolution before we can close the book on physicalism about colour. How precisely should we spell out the role that the colours play; the role we need in order to account for the representational content of colour experience in a way that allows physical identifications of the colours, while avoiding the bad result that colour experiences represent things as having the physical properties in question?

Why not color physicalism without color absolutism?

Zoltán Jakab^a and Brian P. McLaughlin^b

^aDepartment of Psychology, Center for Cognitive Science, Rutgers University, Piscataway, NJ 08854-8020; ^bDepartment of Philosophy, Rutgers University, New Brunswick, NJ 08901. zjakab@rci.rutgers.edu
brianmc@rci.rutgers.edu

Abstract: We make three points. First, the concept of productance value that the authors propose in their defense of color physicalism fails to do the work for which it is intended. Second, the authors fail to offer an adequate physicalist account of what they call the hue-magnitudes. Third, their answer to the problem of individual differences faces serious difficulties.

Introduction. By our lights, color physicalism is the only viable brand of color realism: If surfaces and volumes really have colors – as opposed to merely visually appearing to have them – then colors are physical properties. On this point, then, we are in firm agreement with Byrne & Hilbert (B&H). Here, however, we will focus on points of disagreement.

1. Light emitters and light transmitters. As B&H note, their initial proposal – that colors are types of spectral reflectance properties – faces an immediate problem: The spectral reflectance properties of translucent surfaces and surfaces emitting light have little to do with their colors. In response, the authors claim that color physicalists should therefore appeal to a broader notion than that of spectral reflectance, the notion of productance. Although we see no obstacle to physicalists constructing an umbrella notion that covers light reflectors, light emitters, and light transmitters, B&H's account of productance won't do.

B&H tell us that the productance values of a surface or light source are measured by the following ratio: $(\mathbf{r}(\lambda)I(\lambda) + E(\lambda))/I(\lambda)$, or equivalently, $\mathbf{r}(\lambda) + E(\lambda)/I(\lambda)$ for each wavelength λ between 400 and 700 nm. $I(\lambda)$ is the intensity of the illumination at wavelength λ ; $E(\lambda)$ is the intensity of the surface's emission at λ ; and $\mathbf{r}(\lambda)$ is its reflectance at λ .

The trouble is that in cases involving light-emission in the total absence of external illumination (e.g., the case of a fire-fly emitting light in the total absence of external illumination), this formula for productance value is either undefined or yields an infinite value. In such a case, the external illumination I is zero at every visible wavelength, while E , the surface's emission, is

nonzero at some visible wavelengths. Thus, to calculate the formula $r(\lambda) + E(\lambda)/I(\lambda)$, we would have to divide by zero for any wavelength λ at which there is emission but no external illumination. And in cases in which the emission stays constant while the external illumination goes to zero at every visible wavelength, the productance values go to infinity at the wavelengths of emission. Suffice it to note that it is hard to see how this notion of productance value could be sensibly interpreted so that the color of a surface emitting light in the total absence, or near total absence, of external illumination could be identified as a type of productance.

2. The phenomenal structure of colors. As B&H point out, color physicalism must be squared with the perceived similarity relationships among the hues, and with the fact that hues, as we perceive them, admit of a unique/binariness distinction. For this reason, they introduce the notion of a hue magnitude, telling us that there are four such magnitudes: **R**, **Y**, **G**, and **B**. According to their proposal, when an object looks unique red, it is represented as having 100% of **R**. And when an object looks purple, it is represented as having “**R** and **B** in a similar proportion, say a 55 percent proportion of **R** and a 45 percent proportion of **B**” (target article, sect. 3.2.1, para. 8).

For hue magnitudes to do the intended work, they must be physical properties of surfaces. To locate the hue magnitudes among such properties, B&H appeal to L-intensities, M-intensities, and S-intensities of color signals. The L-intensity of a color signal is the degree to which it would stimulate the L-cones; M- and S- intensities are interpreted analogously. They tell us that: “an object has some value of **R** if and only if, under an equal energy illuminant, it would reflect light with a greater L-intensity than M-intensity – the greater the difference, the higher the value of **R**” (sect. 3.2.3, last para.)

B&H tell us that LMS-intensities can be derived from color signals and cone sensitivities. The natural suggestion here is that LMS-intensities can be so derived by taking the product of the color signal and the cone sensitivity functions.¹ But then their theory makes mistaken predictions. On any of the standard procedures for estimating the S-, M-, and L-cone excitations for unique red surfaces, $S < (L + M)$, contrary to B&H’s prediction that $S = (L + M)$.² This is because human color processing is such that the $S = (L + M)$ equilibrium points of the LMS space fail to map onto the blue-yellow equilibrium points of “phenomenal” color space – the color space generated by color-discriminations or multidimensional scaling data (Izmailov & Sokolov 1991; Jameson, forthcoming; MacLeod & Boynton 1979; Maloney 1999; Wuerger et al. 1995).³ The same objection applies to the case of unique greens and achromatic grays; for the latter, the B&H proposal mistakenly predicts that $S = (L + M)$. Note, moreover, that many purplish surfaces excite the S-cones less than the L- and M-cones together.

3. Variation in normal color vision. As B&H note, on any of the standard criteria for normality, there is widespread variation in how surfaces would look in determinate color to normal perceivers in normal circumstances; and there is, as well, considerable variation in how they would look in various determinable colors.⁴ Given this widespread variation, B&H are prepared to maintain that there is widespread color illusion among normal perceivers in normal circumstances.

This position is not forced on them by their adherence to color physicalism. It is open to a color physicalist to maintain that a physical property is a color only relative to a type of perceiver and type of circumstance of visual observation.⁵ Thus, for instance, a color physicalist could hold that a physical property P is unique green for one type of perceiver in one type of circumstance, and bluish-green for another type of perceiver in that same type of circumstance. (Compare the fact that something can be digestible for one type of digestive system but not for another.) So when the surface looks unique green to the one type of perceiver in the circumstance in question and bluish-green to the other, neither perceiver is misperceiving the color of the surface. Color physicalists need not be color absolutists.

But B&H embrace color absolutism. They claim that color is like shape with respect to independence of experience. As they acknowledge, however, there are independent tests for determining whether a normal perceiver is misperceiving the shape of a surface, but in the case of color, “there is no such test” (sect. 3.4).

Given the fact that there is considerable variation in normal color vision as concerns unique green and the very serious possibility that there will be no independent test, B&H tell us that they are “prepared to countenance ‘unknowable color facts’ – that a certain chip is unique green, for instance” (target article, note 50). In so countenancing this, they are committed to countenancing that we cannot know what physical property unique green is. Moreover, for the same reason, they should be prepared to countenance that it is unknowable what physical properties the determinate colors are.

Given the lack of widespread variations as concerns red, blue, green, and yellow, B&H may think that, mere philosophical skepticism aside, there is no reason to doubt that we can know what physical properties red, blue, green, and yellow are. But it is hard to see why counting heads matters. As B&H note, the distribution of two L-cone photopigment variants varies significantly between males and females. Suppose that, as a result, a surface that would look some color C to the majority of normal color perceivers would look some other color C* to a minority (where neither C nor C* is a determinable of the other). The situation could be reversed through selective breeding.

As B&H correctly note, “physicalism about color is compatible with practically any view about the nature of mind” (sect. 3.5, para. 6). We believe, however, that it is their commitment to a particular theory of mind, a brand of representationalism, that leads them to color absolutism. They embrace the twofold view that the phenomenal character of a color experience supervenes on the content of the experience, and that the content of a color experience includes a color as a component. Commitment to color physicalism is, we believe, itself a reason to reject this brand of representationalism.

NOTES

1. The estimation of L-cone excitation is the product of the color signal and the L-cone sensitivity function, integrated over the 400–700 nm interval, and similarly for M- and S-cone excitations.

2. In addition, the difference between S and (L + M) is substantial.

3. See especially Figure 2 in McLeod & Boynton (1979). The $b = (r + g)$ points (i.e., the $S = (L + M)$ points) in the square-shaped McLeod-Boynton chromaticity diagram constitute the top horizontal edge of the diagram, and only the violet end of spectrum loci fall near there. Reds fall near the bottom right corner of the diagram.

4. Here we use “determinate color” and “determinable color” as these terms are defined by Byrne & Hilbert.

5. See McLaughlin (2000; 2002; 2003) for a defense of this relativist brand of color physicalism.

Olive green or chestnut brown?

Rolf G. Kuehni

Charlotte, NC 28226. rkuehni@carolina.rr.com

Abstract: Reflectance and spectral power functions are poor predictors of color experiences. Only in completely relativized conditions (single observer, non-metameric set of stimuli, and single set of viewing conditions) is the relationship close. Variation in reflectance of Munsell chips experienced by color-normal observers as having a unique green hue encompasses approximately sixty percent of the complete range of hues falling under the category “green”; and in recent determinations of unique hues, ranges of yellow and green as well as green and blue unique hues overlap.

Among the many empirical facts of color experiences is the following: Unless seen in fully relativized conditions (in regard to color-normal observer, isomeric stimuli, and surround), specific visual spectral energy signatures can be experienced as many dif-

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 be-

tween 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

John Kulvicki

Department of Philosophy, Washington University, Saint Louis, MO 63130.
jkulvick@artsci.wustl.edu

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, red₂₉, is to have a certain

combination of the hue magnitudes **R**, **G**, **B**, and **Y**. A creature could perceptually represent an object as being red₂₉ 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 red₂₉, 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, red₂₉, blue₅₅, 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

Bruce J. MacLennan

Department of Computer Science, University of Tennessee, Knoxville, TN 37996-3450. maclellan@cs.utk.edu
<http://www.cs.utk.edu/~mclennan>

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

theory of perception, not a problem in the theory of thought or language" (target article, sect. 1.1, para. 3), but this begs the question of whether color, in any important sense, can be so treated. They distinguish the problem of color realism from the investigation of color as a folk category, but the possibility remains that the folk category is the only (ecologically) real category.

To see this, we can look at the prescientific color terminology. I apologize for spending so much space on ancient color terms, but there are advantages to looking at languages that are not our own, and at early color terms, whose meanings are uncontaminated by assumptions about a linear color spectrum.

For example, Latin *color*, which means appearance and complexion as well as color, comes from an Indo-European root that means to cover or conceal; that is, *color* originally refers to "that which covers" an object (Watkins 2000, s.v. kel-²). Further, the primary meaning of ancient Greek *chrōma* is skin, and only secondarily, complexion and color (Liddell et al. 1968, s.v. chrōma). It comes from the Indo-European root *ghrêu-*, which also gives Greek *chrōs* (Watkins 2000, s.v. ghrêu-), which means skin, flesh, body, and only secondarily, the complexion and color of the skin (Liddell et al. 1968, s.v. chrōs). Again, we see that the concept of color refers to surface appearance, especially as an indicator of internal state (as in complexion). Similar observations apply to words for specific colors.

Ancient Greek color terminology is notoriously complex (e.g., vol. 1 of Maxwell-Stuart 1981 is devoted to one word, *glaukos*). Consider *porphureos*, commonly translated "purple"; it is famous as the royal color, the unauthorized use of which could be interpreted as treason (Gage 1993, p. 25). In addition to purple, lexicons list its meanings as: dark red, crimson, and russet (Liddell & Scott 1889, s.v.). Therefore, we can see why Homer uses it to describe blood – but why is the stormy sea *porphureos* (*Iliad*, I.482)? And why the rainbow (*Iliad*, XVII.547)? As Liddell & Scott (1889, s.v.) remark, "the word does not imply any definite color." Rather, for Homer's audience, the word referred first to the gleaming, glancing play of light on disturbed water, and by extension to any shimmering, lustrous, lurid, or glittering play of color; "royal purple" had this quality (Cunliffe 1924, s.v.; see also Gage 1993, pp. 16, 25–26, for more on *porphureos*).

Another, but especially informative, example is *chlōros*, nominally translated "green." We are not surprised that wood and seawater may be described as *chlōros*, but why is it applied to sand, people, cheese, fish, flowers, fruit, gold, tears, and blood (Liddell et al. 1968, s.v.)? The core meaning is revealed by its Indo-European root *ghel-*², which means to shine, and by extension, any bright material (Watkins 2000, s.v.). However, in ancient Greek, the meaning is further extended to include the moist (as in green wood), living, fresh (or unsalted), freshly cut or picked, blooming, unripe, and so forth (Liddell et al. 1968, s.v. chlōros). Thus, we understand how cheese, fish, flowers, fruit, and blood can be *chlōros*.

Here we come close to the crux of the matter: These supposed color terms have semantic fields that refer to a range of ecologically relevant appearances (correlated with underlying properties, such as freshness), which correspond only loosely with reflectance types. If we try to reduce the meanings of such terms to a narrow physical property, such as reflectance, we will be ignoring much of their meaning.

One may assume that color is primarily a simple, abstract physical property, such as surface spectral reflectance, and that all the rest is inessential complication, connotation, association, and other psychosocial baggage, but I think the evidence points in the opposite direction. Color is fundamentally concrete, material, and deeply embedded in the lives, ecologies, and evolutions of the organisms that perceive it. Abstraction comes later, if at all, from an attempt to give a simple scientific description of the phenomena. This is the reason that color does not enter into any fundamental physical theories: It is not a physical, but a psychobiological, category.

Much of the difficulty with color arises from trying to reconstruct a folk concept as a scientific or philosophical concept. This

is unnecessary. We have or can define the scientific concepts that we need, such as surface spectral reflectance and productance. Further, the attempted reconstruction is counterproductive, for it diverts us from the interesting and important task of elucidating the rich and concrete phenomenology of color as it is actually experienced by humans and other animals.

Surface color perception in constrained environments

Laurence T. Maloney

Department of Psychology and Neural Science, New York University, New York, NY 10003. laurence.maloney@nyu.edu

Abstract: Byrne & Hilbert propose that color can be identified with explicit properties of physical surfaces. I argue that this claim must be qualified to take into account constraints needed to make recovery of surface color information possible. When these constraints are satisfied, then a biological visual system can establish a correspondence between perceived surface color and specific surface properties.

I shall now remind you, that I did not deny, but that colour might in some sense be considered a quality residing in the body that is said to be coloured.
– Robert Boyle (1663; quoted in Wade 1998)

Boyle does not exclude the possibility that colors correspond to objective properties of surfaces, but is evidently perplexed as to what these *intrinsic colors* (Shepard 1992) might be. For many types of surfaces, light-surface interaction can be described by a *bidirectional reflectance density function*, $S(\lambda, \mathbf{v}, \mathbf{l})$, defined for each small surface region. This bidirectional reflectance density function (BRDF) is the probability that a photon of wavelength λ , arriving at the surface from direction \mathbf{l} , will be re-emitted in direction \mathbf{v} toward the viewer. The physical world \mathbf{W} is, for our purposes, the collection of all physically possible BRDFs.

So far as we know, a normal, trichromatic observer assigns just three independent surface color descriptors $\boldsymbol{\mu} = (\mu_1, \mu_2, \mu_3)$ to each surface patch. These color descriptors, by definition, determine color appearance, and we can make inferences concerning them by studying the observer's performance in experiments. If these descriptors are determined by the BRDF of the corresponding surface, as Byrne & Hilbert (B&H) suggest, then the net effect of color visual processing can be summarized as a mapping, $\chi : S(\lambda, \mathbf{v}, \mathbf{l}) \rightarrow \boldsymbol{\mu}$ from BRDFs to color descriptors. The domain of the mapping χ is the physical world \mathbf{W} and its range is all possible color descriptors.

Of course, color visual processing in a biological organism begins with the excitations of retinal photoreceptors that depend as much on the light incident on a surface as on the spectral properties of the surface itself. To be able to summarize the effect of this visual processing by the mapping $\chi : S(\lambda, \mathbf{v}, \mathbf{l}) \rightarrow \boldsymbol{\mu}$ is a claim about color visual processing, and a very strong one. It entails that the visual system described by the mapping χ would have perfect color constancy. It is also a claim that is complicated by two factors.

The first is that we, currently, have no clear idea of what \mathbf{W} , the collection of all physically possible BRDFs, contains. Consequently, the claim that color visual processing can be summarized by the mapping χ is open to disproof with each newly discovered actual or possible surface.

The second complication is that we do not need to discover new BRDFs to call into question the existence of the mapping χ . It is relatively easy to arrange experimental circumstances to produce large failures in color constancy:

If changes in illumination are sufficiently great, surface colors may become radically altered . . . [W]eakly or moderately selective illuminants with respect to wavelength leave surface colors relatively unchanged . . .

but a highly selective illuminant may make two surfaces which appear different in daylight indistinguishable, and surfaces of the same daylight color widely different. (Helson & Judd 1936)

Without further qualification, we cannot identify color descriptors with specific aspects of the BRDFs of actual or possible surfaces.

The likely reaction to this claim is to cry foul. The human visual system is not capable of reliably estimating surface properties under “any possible circumstances” that an experimenter dreams up. Instead, it has a natural operating range or “environment” and, within this environment, it can reliably estimate color descriptors that correspond to surface properties. This environment is a list of constraints on lighting, surface BRDFs, scene layout and complexity, and perhaps more. When these constraints are satisfied (“the visual system is in its operating environment”) then color descriptors reliably correspond to identifiable surface properties.

Of course, we do not yet know what this environment is, if it exists at all. The first piece of evidence in favor of its existence is that, under some circumstances, human observers do exhibit a high degree of color constancy (Brainard 1998; Brainard et al. 1997). It is not implausible that some refinement of the conditions of these experiments could lead to even better constancy (Maloney 2002; Yang & Maloney 2001).

The second is that three measurements of the BRDF across the human visible spectrum can be used to construct remarkably accurate approximations to the BRDFs of many naturally-occurring surfaces, suggesting that an environment with BRDFs in 1:1 correspondence to color descriptors would not be far from the world we know (Maloney 2003).

The third piece of evidence is circumstantial. Recent attempts to model human surface color perception typically begin with strong assumptions about the environment in which the algorithm will operate (see reviews in Hurlbert 1998; Maloney 1999). There seems to be no other way to attack the problem.

Maloney (1999; 2003) discusses the hypothesis that there is a specific idealized “environment” for human surface color perception over which a human observer would see changes in surface colors, if and only if, the BRDFs of surfaces changed. The work reviewed suggests that such an environment must be different from the world we live in, but it need not be very different.

The implications of this hypothesis is that B&H’s claim is likely false if it is interpreted as a strict claim about the actual or possible physical environment, **W**. Yet, in a different, idealized environment, very near to our own, but with a somewhat simplified physics and chemistry, our color vision might be able to establish a correspondence between color descriptors and specific properties of BRDFs, as proposed by B&H. If there is such an environment, and we can determine exactly what it is, we will certainly have a better understanding of human color vision and its limitations. We will also be in a better position to explain Robert Boyle’s discomfort in ascribing colors to surfaces. If there are idealized philosophers in this idealized environment, they would be wrong to consider color as anything other than a perceptual correlate of objective surface properties, the intrinsic colors of surfaces.

Color nominalism, pluralistic realism, and color science

Mohan Matthen

Department of Philosophy, University of British Columbia, Vancouver, B.C.
V6T 1Z1 Canada. mohan.matthen@ubc.ca
<http://www.philosophy.ubc.ca/faculty/matthen/>

Abstract: Byrne & Hilbert are right that it might be an objective fact that a particular tomato is unique red, but wrong that it cannot simultaneously be yellowish-red (not only objectively, but from somebody else’s point of view). Sensory categorization varies among organisms, slightly among conspecifics, and sharply across taxa. There is no question of truth or falsity concerning choice of categories, only of utility and disutility. The appro-

priate framework for color categories is Nominalism and Pluralistic Realism.

The brain actively transforms the retinal image by means of the multilayered process that ultimately culminates in visual consciousness. From the fact that our consciousness of color is the result of such a transformation – from the fact that using its own algorithms, the nervous system transforms wavelengths differentiating information captured from the external environment – many scientists conclude that color is constructed by the brain, and is not a property of physical things.

This is puzzling in two ways. First, Galileo and Descartes (to name two cases) were not aware of visual processing; they assumed that visual sensation is the “perception of light and color” faithfully transmitted from the retinal image. Yet, they also held that color is a confabulation of vision, not a real property of things. Second, our visual consciousness of size, shape, motion, and so forth, also result from transformations of the retinal image. But contemporary visual scientists are not tempted to say that size, shape, and motion are mere constructs of the brain. So one might suspect that the target article misdiagnoses the *irrealism* of color scientists, where irrealism is the decidedly odd position that tomatoes are not red. We need to get to the bottom of this.

Byrne & Hilbert (B&H) endorse the following propositions: (1) The representational content of a subject’s experience specifies the way the world appears to *the subject* (sect. 1.2, their emphasis). (2) The properties that figure in the representational content of color experiences are “types of reflectance.”

It seems to follow that when a certain object looks red to me, it appears to me (the subject) that it has a certain reflectance – for, by (1) and (2) above, my color experience “specifies” that the object in question has this reflectance. But this conclusion is obviously false. That is, it is obviously false that, simply on the basis of color experience, any proposition about reflectance becomes apparent to the (naïve) subject.

Let us distinguish, therefore, between representational content and trigger feature. The *trigger feature* of a perceptual state is the environmental property that *normally* causes a particular perceptual state to occur (however you might understand “normally”). Single-cell recordings are concerned with trigger features: They correlate distal stimulus features with the activity of single cells in sensory pathways. One can inquire after the trigger feature of conscious color experience. Let us concede that reflectances (or productances, as B&H define them) are the trigger features of color experience – this is all that the color constancy and illumination independence of section 3.1 can demonstrate. The conclusion that reflectances figure in representational *content* is still unwarranted. Color experience does not “specify the world” in terms of reflectance.

Now here is the crucial point. Color experience specifies the world in terms of categories like yellow and red and the relations between them. These categories result from visual processing, specifically opponent processing; they are not (as the phenomenon of metamerism shows) physically unified categories; they are physically definable, but only by bringing in systemic idiosyncrasies like cone-cell tuning and opponent processing. By contrast, properties like shape, size, and motion *are* categories of physics; here there is a much closer correspondence between representational content and definable physical properties that are system-independent. This is the truth that the visual scientists, quoted in section 1 of the target article, are after, though they misstate the point. (It is perhaps clearer in Galileo, Descartes, and Locke.) The important point to fasten upon is not that things look colored because the signal emanating from them has been processed by the visual system. *All* visual appearance results from visual processing; this does not distinguish color from anything else. The important point is that color *categories* and their interrelationships result from visual processing. It is these idiosyncratically manufactured categories that figure in representational content.

There might be minor differences between my visual process and yours. Perhaps the peak sensitivity of my long-wave cones is slightly displaced from that of yours. This has the consequence that your unique red category is a bit different from mine. Does this mean that one of us must be wrong about whether an external object, like a tomato, is unique red? No. The situation resembles that of an equivocation in what each of us means by “food.” You exclude beer; I don’t. We disagree about how to describe beer, but this does not mean that one of us is right and the other wrong. Once what each of us means by “food” is spelled out, there might be no substantive difference between us. Both of us might be right. The same is true for color categories. We cannot sensibly ask: “Which of us is right in describing this tomato as unique red?” There is no basis for answering such a question. In philosophical terminology, this amounts to a kind of *nominalism* about color categories. Nominalism about categories does not imply irrealism about external objects, or about the subsumption of external objects under these categories. The tomato really is unique red in my visual system’s “sense,” and really isn’t in yours. However, nominalism does imply that saying that something is unique red is a subjective way of capturing a truth about that thing, which cannot be objectively justified as being against other modes of description.

Minor differences between organisms of the same species do not seriously affect the ways in which they are adapted to the environment, or the communication between them. For, as B&H note, disagreement among humans is mostly about determinate shades, not broader categories like green or blue. When we consider organisms that belong to widely separated biological taxa, the differences may be quite sharp. Thus, it may be completely misleading to talk of the pigeon’s or the salmon’s color space in terms of primate color categories like “yellow,” “red,” and so forth. Their color categories are different from ours. Nevertheless, their categories, and ours, capture objective truths about the environment – truths difficult to measure against one another, truths subjectively presented, but truths for all that. This is the position I call Pluralistic Realism – see note 36 of the target article.

Clarifying the problem of color realism

Barry Maund

Department of Philosophy, School of Humanities, The University of Western Australia, Crawley, WA 6009, Australia. jbmaund@arts.uwa.edu.au

Abstract: “The problem of color realism” as defined in the first section of the target article, is crucial to the argument laid out by Byrne & Hilbert. They claim that the problem of color realism “does not concern, at least in the first instance, color language or color concepts” (sect. 1.1). I argue that this claim is misconceived and that a different characterisation of the problem, and some of their preliminary assumptions makes their positive proposal less appealing.

The crucial part of this interesting paper is the first section “The problem of color realism explained” in which the authors provide a characterisation of color realism and a set of distinctions and proposals for avoiding confusion. This section is crucial because it shapes the whole discussion. However, it leads the authors to overlook the possibility that there might be an objective property which is *represented* in experience but *represented as* a different kind of property, one that is conceptualised in a certain way. I cannot argue for the latter, but I wish to challenge some of the assumptions that Byrne & Hilbert (B&H) make.

For instance, the problem of color realism is said to concern “various especially salient properties that objects visually appear to have”:

It does not concern, at least in the first instance, color language or color concepts. The issue is not how to define the words “red,” “yellow,” and so on. Neither is it about the nature of the *concept* RED. (target article, sect. 1.1, para. 3, emphasis in original)

The authors go on to say that the problem of color realism is primarily a problem in “the theory of perception, not a problem in the theory of thought or language.” But here they are operating with a false dichotomy. They overlook the strong possibility that the problem is about both perception and thought (i.e., thought about perception), and more specifically, that perception operates through concepts.

If color realism is a question about a certain property, or set of properties, then we have to specify what these properties are – which poses a problem. I cannot see how one can do that without first of all identifying a certain concept of color. We surely have to identify a certain concept that conceptualises color as a certain kind of property. This of course is what B&H themselves actually do when they say that the kind of property which they are interested in, is that “which we call ‘red’ in English” (sect. 1.1). In other words, it only makes sense to raise the question of color realism, if we have first of all identified a certain concept of color. To do so of course does not rule out the possibility that colors are reflectances as B&H suggest, but to work out whether or not they are, we need to understand how the ordinary concept of color operates.

There are various possibilities that would allow us to identify colors with reflectances (at least in principle): One is, that the ordinary color terms operate in the way Thomas Reid (1970) suggests. Reid held that colors in physical bodies are unknown qualities that underpin the “appearances” that colored objects induce in perceivers. But he did not think that what colors are is entirely different from the way they are conceptualised; for he held that as far as ordinary language and ordinary perceivers are concerned, colors are conceptualised as “unknown qualities” – ones which appear in certain ways. Our color names apply to the unknown qualities and not to “the appearances for which we do not have names.”

Another way the terms operate is as David Lewis (1997) suggests. That is, the term “red” names a certain property, one that satisfies a range of platitudes assumed by ordinary language users. One of the key platitudes is that colors are the properties that cause us to perceive things as colored.

Either way, it is possible that, given the way our color terms operate, they are understood to apply to certain qualities that play a certain role in the way colored objects appear. Hence, it is possible – at least in principle – that colors are, say, reflectances. Reid’s proposal seems to be to be just bizarre. That leaves the authors with using something like Lewis’s proposal. Color realism might just work, but the problem is that the set of color platitudes might be such that no physical properties (or no plausible candidate) satisfies them. If so, color realism is false, at any rate for colors as they are ordinarily conceptualised.

I would have thought that the way colors are ordinarily conceptualised fits the way they are thought of in the “Manifest Image”: they are intrinsic, perceiver-independent, manifest properties. In these respects they are like other visually perceptible properties such as shape, size, and number.

Perhaps I am wrong, but B&H need to argue about the concept: they simply cannot say that they are interested in the property and not in the concept.

The importance of the ordinary concept of color seems to be implicitly acknowledged by B&H in the next section (sect. 1.2, “The representational content of experience”) where they provide another characterisation of color realism, one expressed in terms of “representational content”:

When someone has a visual experience, the scene before her eyes visually appears in a certain way: for example, it might visually appear to a subject that there is a red bulgy object on the table. The proposition that there is a red bulgy object on the table is part of the content of the subject’s experience. (sect. 1.2, emphasis in original)

B&H stress that this kind of content is content at the personal level, that is, it is content for the subject, and not for some sub-personal system. On the face of it, this content is conceptual content; and in talking about the representational content of color ex-

periences, we are talking about the concept of color, just as we are talking about the concepts “bulgy object” and “table.” Hence, the issue of color realism concerns that concept. Of course, B&H might respond and say that the sort of representational content they are thinking of is nonconceptual content, and that the color property that enters this content is different from the one that the ordinary concept ostensibly identifies; but then they would have solved the problem by changing the subject.

B&H also reject sense data, aligning themselves with the many attacks that have featured in analytical philosophy since the 1950s, and specifically with the criticisms of Armstrong, Sellars, and Pitcher. I do not think that this is adequate. Those attacks are mounted against only certain versions of sense data, and not the strongest; moreover, they make questionable assumptions about epistemology or about how they characterise their opposing views. I do not think that any of these attacks count against such a theory as defended by, for example, Howard Robinson (1994). This is important, since at least one of the major opposing theories of perceptual experience – and of color experience in particular – is that which postulates qualia, that is, qualia in the strong sense denied by critics such as Dennett. Qualia take over many of the features of sense-data (in one of the various senses of that term); hence, I do not think that qualia can be set aside as easily as B&H suppose.

Can a physicalist notion of color provide any insight into the nature of color perception?

Rainer Mausfeld and Reinhard Niederée

Institute for Psychology, University of Kiel, D-24098 Kiel, Germany.
(mausfeld;niederée)@psychologie.uni-kiel.de

Abstract: Byrne & Hilbert (B&H) conceive of color perception as the representation of a physical property “out there.” In our view, their approach does not only have various internal problems, but is also apt to becloud both the intricate and still poorly understood role that “color” plays within perceptual architecture, and the complex coupling to the “external world” of the perceptual system as an entirety. We propose an alternative perspective, which avoids B&H’s misleading dichotomy between a purely subjective and a realist conception of “color.”

Byrne & Hilbert (B&H) make an impressive attempt to render our common-sense concept of “color out there” into a physical concept, thereby taking into account a broad range of phenomena and conceptual issues. They take seriously, and attempt to make rigorous, the widely accepted, but rarely ever clearly spelled-out, idea that there is a simple intrinsic relation between perceived surface color and surface reflectance. They propose a unitary physicalistic approach to “color” that also embraces aspects of colored lights, filters, and volumes. For us as color scientists, raising such issues is a laudable endeavor, since many of these issues tend to be bypassed by color science. However, from our point of view, their approach fails in various respects, both internally and from a broader theoretical perspective on perception. To some extent, this is because of the fact that their reading of current color research reflects unfortunate theoretical distortions that color science itself has brought forth. In failing, their target article is very useful, as it is apt to bring to the fore conceptual flaws and theoretical lacunae in our present theoretical picture of color perception.

To begin with, we will briefly indicate some of the internal problems of B&H’s approach. First, a fundamental requirement for a metaphysically sound realist concept of “colors out there” would be that one should be able to clearly specify the meaning of two objects having the *same* (“determinate,” i.e., individual) color. In their attempt to do this for surfaces, B&H choose the obvious option to refer to the concept of metamerism of surfaces with respect

to an illuminant. That means that their notion of equality is not only relative to the species, type of observer, and so forth (on account of the way metamerism is defined), but also to the specification of the illuminant (even for a *single* observer). Even with respect to trichromatic human observers only, this either implies that there is a plenitude of different color concepts, or that one has to identify the “true” normal illumination, normal observer, and so on. It is not clear to us how this can be done in a nonarbitrary way (the options of simply referring to vague everyday notions of “normality” is insufficient). We agree with B&H that a relational approach to color is not an appropriate response to this problem either.

Second, although it is a theoretical requirement to integrate light sources into the picture, the attempt to find a *single* property “color” appears to us inherently problematic. In any case, the ad hoc formula for what B&H call “productance” (sect. 3.1.2) is inappropriate. For instance, according to their formula, the productance of a light source approaches infinity as the incident illumination approaches zero. This has a number of unwarranted consequences, one of them being that in complete darkness any two light sources (extending across the entire spectrum) would both have an infinite productance, and hence should have the same color.

One could, of course, try to meet the (well-known) objection of arbitrariness by providing constraints or additional criteria for what should count as a correct specification of the concepts involved. B&H indeed try to establish a corresponding meta-criterion, which – in the absence of a suitable external physical standard (as available with respect to, for example, the attribute of size) – has to be perceiver-dependent. B&H require that: (1) the number of “illusions” according to that criterion be minimal, and (2) that their concept not be trivialized by simply identifying the perceived color with the “true physical color” (implying that there would be no illusions at all). Unfortunately, this meta-criterion is so vague that it is compatible with a great variety of specifications, and hence, a multitude of possibilities for classifying color percepts and color judgments into “veridical” and “nonveridical” ones.

So, in the end, one is left with arbitrary attempts to normatively and prescriptively introduce an ideal language for a discourse about “color out there.” No doubt, this is a possible game one can play. Within certain technical domains, corresponding colorimetric standards may even be useful for practical purposes. We feel, however, that this strategy – as well as various rivaling philosophical approaches, for example, relational ones – and the enduring disputes they inevitably give rise to, obscure core issues concerning scientific inquiries into the nature of perception and evade the deep philosophical challenges centering around the relation between perception and “reality.” As far as we can see, merely refining elements within the framework pursued by B&H does not resolve these empirical and conceptual difficulties. Rather, we believe these are due to the fundamental inappropriateness of the perspective as a whole.

A central presumption on which B&H’s approach rests, basically amounts to a local mapping theory of perception, according to which: (a) a percept can essentially be reduced to its “content,” which in turn can be identified with a corresponding proposition about an external physical state, and (b) each percept can individually be classified as either illusionary or veridical. Furthermore, they postulate that (c) there is only a single physical property that is truly represented through color vision. These presumptions can be called into question on empirical and theoretical grounds.

First, in conjunction with (a) and (b), presumption (c) conflicts with the impressive empirical evidence that shows that there is a much more complex internal perceptual architecture of “color,” and thus a more complex relation to external physical properties (e.g., Ekröll et al. 2002; Katz 1935; Mausfeld 2003). Properties of this architecture are mirrored, for instance, in phenomenal experiences of two colors at the same location, which can hardly be mapped back to a single physical property (e.g., a white

wall under red illumination). What indeed remains to be explained is the theoretically important and often neglected fact that, at a phenomenological level, perceived “surface colors,” “illumination colors,” or “light source colors” have something in common at all. We do not believe that presumption (c) is empirically appropriate or heuristically helpful in this regard. In our view, this fact, instead, reveals a poorly understood key feature of the internal logic of the perceptual system (which we conjecture can be understood in terms of continuity, stability, and ambiguity management).

Second, and more important, already presumptions (a) and (b) seem to be profoundly misleading. In contrast, we believe that, in its core aspects, the relation of the internal organization of perception and the relevant external physical aspects seems to be analogous to the following situation, as discussed in the philosophy of science. Consider two theories, T1 and T2, possibly based on different theoretical primitives, with T1 being the presently best theory of a domain and T2 a practically useful (and often older) theory, which, however, according to T1 cannot be strictly true. It is not uncommon in this situation that T2 cannot be reduced to T1, in the sense that one cannot generally express the “content” of descriptions of states of the world in terms of T2 (briefly, T2-propositions) one-by-one in terms of T1-propositions; and thus it is not guaranteed that one can assign truth-values to individual T2-propositions on the basis of T1.

We think that these considerations provide a useful metaphor for the situation at issue. T1-propositions would then correspond to physical descriptions of states of the world, whereas T2-propositions would correspond to perception-based descriptions. T2, in particular, includes prelinguistic structural properties of the perceptual system yielding perceptual categories in which phenomenal experience is cast, such as “surface color” and “illumination color.”¹ These have to be understood here, not as physical concepts, but as concepts *internal* to the visual system, playing the role of theoretical terms, as it were. Furthermore, T2 includes linguistic and corresponding interpretative capacities that underlie our folk-physics of “color.” The structure of common-sense reasoning about “color” is thus determined by T2. An essential feature of T2 is that it allows for incoherence and vagueness and does not require a clear-cut notion of two objects having the same color.

If our analogy is basically correct, then B&H’s goal of reducing important parts of T2 to T1 cannot lead to an appropriate understanding of the relation between color perception and physics. By the same token, the common-sense concept of illusion cannot, and need not, be translated into a metaphysically sound dichotomy of veridicality versus illusion defined for all situations. What would be needed instead is an analysis (1) of T2, that is, of the actual principles that underlie the “construction” of the world-as-perceived, and (2) of what makes this “construction” useful, that is, functional aspects relating T2 and T1.² For such investigations, a clear-cut physicalist concept of “color out there” is not needed.³ What is needed instead are, first of all, better explanatory theories of the role various forms of “color” play within the structure of representational primitives.

NOTES

1. For an adequate explanatory account of the visual system, one has to acknowledge that “color” is *not* an autonomous and unitary perceptual attribute that can be investigated more or less in isolation from other aspects of our perceptual architecture.

2. The difference in perspective is highlighted by B&H’s asymmetrical treatment of the ideal red-green inverts/nonverts, color perception of the former (arbitrarily, we think) being counted as illusory. Both in view of (1) and (2), these perceptual systems would have to be treated as equivalent, and hence a corresponding asymmetrical assignment of truth values would be pointless.

3. As should be obvious from the above analogy, this does by no means imply that color perception is “purely subjective” (though, of course, our phenomenal color experiences – in a different sense of the word – are subjective).

An account of color without a subject?

Erik Myin

Department of Philosophy, Centre for Logic and Philosophy of Science, Free University Brussels (VUB), B1050 Brussels, Belgium. emyin@vub.ac.be
<http://homepages.vub.ac.be/~emyin/>

Abstract: While color realism is endorsed, Byrne & Hilbert’s (B&H’s) case for it stretches the notion of “physical property” beyond acceptable bounds. It is argued that a satisfactory account of color should do much more to respond to antirealist intuitions that flow from the specificity of color *experience*, and a pointer to an approach that does so is provided.

The authors are absolutely right in defending a view on color in which color perception is aimed at the world “out there” rather than at a private “construction in our heads.” To the arguments against “eliminativism” and “projectivism,” one could add that construing all color perception as illusory seems to invoke the conceptually incoherent category of an abnormal case that has no normal case but only exceptions.

However, the message might not come across to the color science community, because it comes in a joint package with a rather austere exercise in philosophical correctness, which leads to a view of color in which too many intuitions about color can’t find a home, and in which quite a few empirical facts can only be fitted given much theoretical/conceptual maneuvering.

The intuitive motivation for the antirealist option of constructing color as being “in the mind,” seems to derive from two sources. A first source concerns the seeming importance of the specific evolutionary, physiological, cultural, and so forth make-up of color perceivers in determining which colors are perceived. Second, there are intuitions about the ways in which conscious color experience seems to be different from the physical properties that cause color. The latter set of intuitions includes the seeming arbitrariness of the precise qualitative nature of the experience (the way an experience of “red” feels) with respect to whatever physical properties that cause them (e.g., the reflectance profile of a red surface).

Now, the authors certainly go to great pains to address the first source. Basically, their strategy consists of “physicalizing”: re-describing matters such that aspects of color perception, apparently determined by physiological or cultural aspects, become “physical” properties. So they enrich their “physicalist” ontology with “reflectance types” to take into account the role of color categorization. Presumed facts about opponent processing are taken care of by the forging of the “physical” properties of hue-magnitudes. It has to be granted that this rescues “physicalism,” but only by stretching the notion of “physical property” to a degree that seems hard to swallow, precisely because of the implicit reliance, in the definition of these properties, on the physiological and cultural aspects of perceivers. The authors might reply that the latter aspects only concern conditions under which the physical properties of reflectance type and hue-magnitude are observed, just as the setting of the thermometer that is necessary for the perception of the physical property of temperature (sects. 1.3.3 and 3.1.3). However, the analogy with temperature doesn’t work (and just assuming it works, is question begging), precisely because temperature is a much more robust property, which is *not* necessarily defined in terms of the specifics of thermometers.

The second source of antirealist intuitions is hardly addressed at all. All that is implied is that the usual question: “Why does this or that neural process that correlates with the experience of red come with *this* specific quality?” is transformed into “Why is it that this neural process, which has as representational content that there is something out there with the reflectance type of red, come with *this* specific quality?” As long as people will approach color from this perspective, they will be tempted, from their inability to fit together in their minds the objective and the experiential properties, to adopt antirealist views according to which the experiential property is not something “out there.”

It seems that any palatable philosophical account of color will

have little appeal if this “qualitative aspect” of color is not given its due. Elsewhere it has been argued that the recently proposed sensorimotor contingency theory of visual perception can provide the basis for such an account (Myin & O’Regan 2002; O’Regan & Noë 2001a). According to the sensorimotor contingency theory, perception, including color perception, is a matter of finding out – through active exploration – that certain sensorimotor regularities obtain, where the latter concern ways in which stimulation changes in relation to the perceiver’s motion. This view is fully compatible with the idea that *what* is perceived (*through* the acknowledgment of sensorimotor regularities) is color out there. But the view has the advantage, vis-à-vis B&H’s “physicalism,” that it connects with experience, by tracking experience as had by an active person, who only makes contact with color when it is actively explored through a specific visual apparatus (and possibly a specific cultural education).

To see how this approach is able to deal with the issue of “arbitrariness,” consider its account of tactile “softness,” as, for example, felt by manually exploring a damp sponge. Though softness is clearly grounded in material properties of objects, the *experience* of softness can only be understood by reflecting on how softness is apprehended.

In the sensorimotor account, the experience of softness comes about through a specific pattern encountered in a sensorimotor exploration, including such facts as that if one pushes on a soft object, it yields. It seems difficult to raise the arbitrariness worry here, because there seems to be an intimate and intuitive link between this pattern of exploration and the experience of softness. The sensorimotor account of color, by accounting for color experience along much the same lines, contains the promise to deal with the “arbitrariness” worry – and therefore with “Berkeley’s challenge” (sect. 2.2) as well. (For work on color along these lines, see also Myin 2001 and Pettit 2003.)

Moreover, the sensorimotor account, by emphasizing an exploring subject, gets a grip on experience because it allows us to think of the experiencer as being conscious, *just as we are*. As stressed by various theorists (Merleau-Ponty 1945; Wittgenstein 1953, p. 281), the more a creature is similar to us in its physiology, culture, and in the way it acts and speaks, the more we feel invited to model its experience as being similar to our own. Now this implies that the degree to which an account of color will be perceived as doing justice to experience, will be proportional to the degree in which it stresses such physiological, cultural, and other “projection-inviting” factors – exactly the opposite of the “physicalizing” strategy put forth by B&H.

It is likely that B&H would catalogue the approach advocated here as an ontologically impure mixture of *physicalism-cum-dispositionalism*, even if much of the point of it is to reject the usefulness of carving up the space of possibilities along these lines (this might lead B&H to label it as *primitivism*).

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Spatial position and perceived color of objects

Romi Nijhawan

School of Cognitive and Computing Sciences, University of Sussex-Brighton, East Sussex, Falmer BN1 9QH, United Kingdom. romin@cogs.susx.ac.uk
<http://www.cogs.susx.ac.uk/users/romin/>

Abstract: Visual percepts are called veridical when a “real” object can be identified as their cause, and illusions otherwise. The perceived position and color of a flashed object may be called veridical or illusory depending on which viewpoint one adopts. Since “reality” is assumed to be fixed (inde-

pendent of viewpoint) in the definition of veridicality (or illusion), this suggests that “perceived” position and color are not properties of “real” objects.

Any account of color perception is incomplete without delineation of plausible processes that translate the response of neurons into experienced color. Many vision scientists and philosophers believe that there is a great gap in our understanding of how this translation works for any visual experience, let alone the experience of color. Meanwhile, dogmatic positions on whether perceived color is a property of physical objects or of the observer’s nervous system are unreasonable. Byrne & Hilbert (B&H) are therefore correct in attempting to weaken the current dogma that color is entirely a psychological phenomenon. However, the authors would have made a similar mistake if their view, that perceived color is a property of physical objects, were to become dominant.

B&H draw attention to the classic confusion in which the properties represented by an experience are attributed to the properties of the experience (Harmon 1990). Consider the red color of a strawberry. The experience of red is based on a neural event, which represents the property red, but the event itself is not red anymore than the word “red” is itself red. Thus, if the observer’s experience (or the neural event on which the experience is based) is not red, and the experience represents the property red, then where is the property that is represented by the experience? The authors claim that the only possibility is that the perceived red is a physical property of the strawberry. However, on the assumption that the known behavior of neurons is necessary (but not sufficient) for color perception, the process that is necessary and sufficient for color perception may be expected to be physically proximal with the neurons, and causally linked to their activity. Thus, it might seem more correct to say that the perception of color results within the observer’s nervous system. Just as the authors correctly point out logical problems with this position, I outline an approach that poses problems for the claim that color is a property of physical objects.

B&H answer the question “do physical objects have the color that they appear to have?” in the affirmative. Consider the perception of the complementary after-image, say the perception of a red disk following adaptation to a green disk. Since the after-image of the red disk is an illusion (there is no physical disk), the authors treat this result as orthogonal to their question. However, consider the case of a prism that optically displaces the image of a red disk. The observer will see the disk viewed through the prism in a position that is not the disk’s physical position, so this qualifies as an illusion and could be similarly dismissed. Extension of such an argument would lead to dismissal of cases of individuals wearing corrective lenses viewing colored objects. If, however, processes early in the visual pathway are considered, then the after-image case, the prism displacement case, and the “normal” viewing case are all similar. So, a theory of color perception needs to explain all of these situations, not just cases where perceived color can be identified with physical input.

Consider the following experiments where perception clearly contradicts physical input: A moving green bar appears against a black background (see Fig. 1, left panel; movement direction given by bold arrow). A thin flashed red bar is superimposed on the wider moving bar. This display is seen in two views. In the “snapshot” view (with no seen motion), with appropriate intensities of the red bar and the green bar, observers see the thin flashed bar as overlapping the wide moving bar and its color as yellow (additive color mixing; see Fig. 1 right panel, top). However, in the “extended” view, when the green bar is seen as moving, the flashed bar is perceived against the black background in a position trailing the moving bar, and the color of the flash is seen as red (see Fig. 1 right panel, bottom). Thus, despite the superimposed physical light, the colors do not “mix” if the green and red objects are seen in non-overlapping positions (Nijhawan 1997). In a second experiment, the observer makes smooth pursuit eye-movement past a stationary green bar visible against a black background. A flashed red bar is superimposed on the stationary bar. Once again,

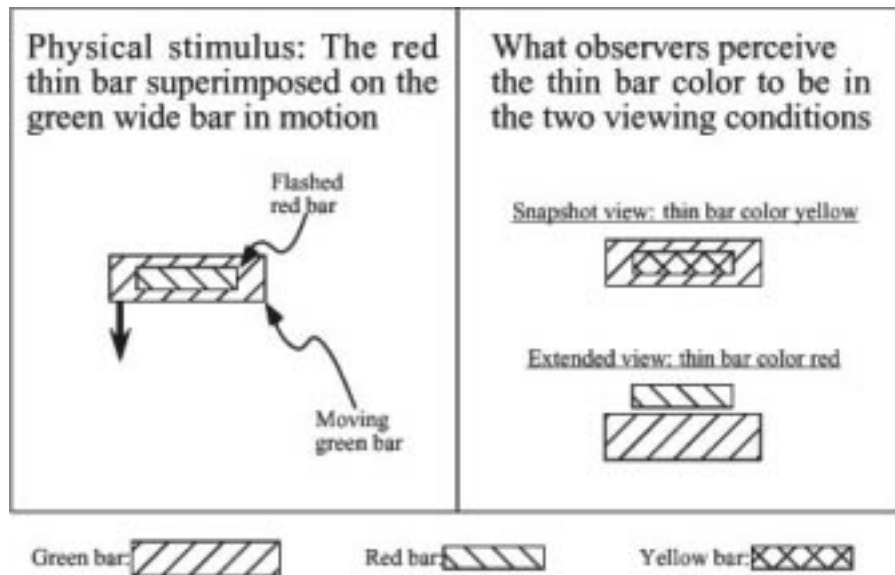


Figure 1 (Nijhawan). The left panel shows the physical stimulus at the instant the thin bar is flashed. The bold arrow shows the direction of motion of the green bar. The right panel shows what the observers perceive in the “snapshot” and the “extended” views. For simplicity, the background, which was black in the actual experiment, is shown as white.

the flashed red bar appears off the stationary green bar, in a position shifted in the direction of pursuit, and the color of the shifted bar is seen as red instead of yellow (Nijhawan et al. 1998).

The authors may argue that the above results are based on flashed objects, which are highly unnatural stimuli. Consider, however, stimuli with the time profile of a brief flash (abrupt onset followed quickly by offset) more generally; such stimuli are common for the tactile system, and have contributed to its evolution. It has been suggested that visual systems with image forming eyes have evolved from the more primitive touch based systems (Gregory 1967; Samat & Netsky 1981). This view is consistent with the fact that multimodal neurons receiving sensory information from more than one modality (e.g., vision and touch) are found in primates (Rizzolatti et al. 1981) and lower vertebrates (Nauta & Feirtag 1979). Furthermore, it has been argued that there are no clear-cut boundaries between the modalities (Shimojo & Shams 2001), and cells that typically belong to one modality can be recruited to function for another modality (Hyvarinen et al. 1981). These considerations lead me to suggest that flashes activate neurons for which stimulation with this time profile is common. This predicts that perception of flashes should share common features with other stimuli, such as a mechanical stimulation of the skin, that have an abrupt onset followed quickly by offset (e.g., a brief tap on the skin surface). The sensed position of a tap on the observer’s hand (say) occurs in hand-centered coordinates, and shifts with the movement of the hand. This explains why the perceived position of the flash occurs in retina-centered coordinates, and appears shifted in the direction of eye-movement.

B&H are correct in raising “Berkeley’s challenge,” which says that perceived color is not any more subjective than the more “basic” features such as object shape. However, if something as basic as visual location of objects in space is not physically “given,” how can color be? The above experiments suggest that the response of color-sensitive neurons (which perhaps exclusively serve a visual function) is modulated by the sensed spatial coordinates of objects.

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Have Byrne & Hilbert answered Hardin’s challenge?

Adam Pautz

Department of Philosophy, New York University, New York, NY 10003.
ap441@nyu.edu

Abstract: I argue that Byrne & Hilbert (B&H) have not answered Hardin’s objection to physicalism about color concerning the unitary-binary structure of the colors for two reasons. First, their account of unitary-binary structure seems unsatisfactory. Second, *pace* B&H, there are no physicalistically acceptable candidates to be the hue-magnitudes. I conclude with a question about the justification of physicalism about color.

In their impressive target article, B&H attempt to answer Hardin’s objection to physicalism about color. In my opinion, the attempt doesn’t succeed. First, their account of unitary-binary structure in terms of the representation of four hue-magnitudes (call the account “MR”) seems mistaken. Consider a possible world *W* where, as it happens, everything that is visually represented as circular is visually represented as (having a ratio of) **R** and **Y**. In *W*, circularity satisfies B&H’s formula, but it is not binary reddish-yellowish. It would not be satisfactory for B&H to reply that the reason why circularity in *W* is not reddish-yellowish is that it is not a color, that is, on B&H’s view, an SSR-property. Why should an SSR’s satisfying B&H’s formula suffice to make it reddish-yellowish, while a shape’s doing so does not suffice? Adding the modal operator “necessarily” to the original account may solve this problem (since in *W* it *only happens* to be the case that circularity satisfies B&H’s formula), but it raises another one. Since it is necessary that nothing is visually represented as prime, it is necessary that everything that is visually represented as prime is visually represented as **R** and **Y**. But primeness is not reddish-yellowish. To rule out such vacuous cases, a further proviso must be added to the effect that the property involved is possibly visually represented. Perhaps MR could be amended to avoid counterexamples, but even then I don’t think that it could be right.

B&H don’t say what they mean by “account,” but I take it that at a minimum, for *q* to be an adequate account of *p*, *q* must specify the way the world must be in order for *p* to be true.¹ But what

could make it the case that “That shade of orange is reddish-yellowish,” for instance, that it has the very complicated truth-condition B&H must assign to it? When we utter such a sentence, we don’t mean to attribute to the color a complicated relation to perceivers. Rather, it seems we mean to say something about its intrinsic nature. And an externalist/natural-kind account of how the sentence could have the required truth-condition seems inapplicable in this case. For this and other reasons (cf. Pautz 2002b), I think that MR does not correctly capture the unitary-binary distinction, and hence cannot be used to answer Hardin’s challenge.

Even aside from these problems there is reason to think that MR cannot provide a solution to Hardin’s challenge. MR appeals to four hue-magnitudes, but it is hard to see how these could be extradermal physical properties. B&H say that an object is reddish to a certain degree if it produces more L-cone activity than M-cone activity (sect. 3.2.3). However, they don’t want to identify a certain degree of reddishness with a disposition involving perceivers, but rather, with a corresponding extradermal physical property not involving perceivers (B&H, personal communication). What is this physical property? They don’t say. Could it be the disjunction of all the SSRs of all actual or possible objects that are (in their view) reddish to that degree? Or maybe the property of having an SSR whose S^* , M^* , and L^* components stand in a certain complicated relationship, where S^* , M^* , and L^* correspond to the short, medium, and long regions of the visible spectrum (Bradley & Tye 2001)? Aside from *a priori* problems to do with the explanatory gap between qualities and quantities (a problem which B&H don’t address), my main worry is that none of the extradermal candidates stand in the same higher-order relations of congruence and proportion that the degrees of reddishness, and so on, stand in. It doesn’t even make sense to say that the difference between the disjunctions of SSRs D1 and D2 is the same as the difference between the disjunctions of SSRs D2 and D3, or that D1 is twice as great as D2, while it certainly makes sense to say such things of degrees of reddishness. As for the second candidate, equal differences between degrees of yellowishness, for instance, do not map onto equal differences between the corresponding values of $[(L^* + M^*) - S^*]$, because the relationship between these variables is nonlinear (Werner & Wooten 1979). Since degrees of yellowishness and the corresponding values of $[(L^* + M^*) - S^*]$ stand in different congruence relations, they cannot be identical. (Compare pitch and frequency.) B&H might reply by adding co-efficients, exponents, and so on (following Bradley & Tye 2001). But these operations don’t apply to properties (it makes no sense to square a property), but to the numbers by which we index them. So this maneuver doesn’t yield a new set of physical properties which do correlate with degrees of yellowishness, but only a new way of assigning numbers to objects, that is, a new set of relations between objects and numbers. And degrees of yellowishness certainly aren’t relations to numbers.

MR also appeals to visual representation, but there is very good reason to think that it cannot be reduced. (I understand reduction broadly here to include identification with physical properties or physically-realized functional properties.) Visual representation is a relation between people and extradermal properties such as colors (on B&H’s view, SSRs). (Strictly speaking, it is supposed to be a relation between peoples’ *experiences* or *brain states* and *propositions*, but such niceties will not matter here.) So, in B&H’s view, if visual representation is identical with a physical/functional relation, it is identical with a physical/functional relation between people and (inter alia) SSR properties. Call this the “Relationality Constraint.” But what physical/functional relations obtain between people and SSR properties to which visual representation might be reduced? It seems that the only candidates are *extrinsic*, causal/teleological relations (Dretske 1995; Tye 2000). But there are good reasons to think that visual representation cannot be such a relation.

First, there are serious problems of detail (Loewer 1997). Concerning causal theories, B&H themselves say “we do not actually find any of these theories convincing” (sect. 2.6). Second, there

appears to be a very simple argument, from the opponent process theory of color vision (OPT) and representationism, to the failure of all such externalist accounts. (B&H appear to accept both premises. See Byrne & Hilbert [1997c] and sect. 3.5 of the target article.) Let w be the closest possible world where, owing to differences in our postreceptoral processing, our opponent channel states are regularly different, but where our receptor systems are the same, so that the states of our visual systems, though different, are optimally causally corrected with, and designed by evolution to indicate, the very same extradermal properties. By OPT, we have different color experiences in w , and so, given standard representationism, represent different color properties (in B&H’s view, different hue-magnitudes or different ratios of the same hue-magnitudes), under the same circumstances. But the states of our visual systems are *optimally causally correlated with* and *designed to indicate* the very same properties (e.g., the very same SSR properties). So, our representing different color properties in w cannot be accounted for in causal/teleological terms (for full details, see Pautz 2002a). Could visually representing a certain color then be reduced to a neurobiological (e.g., opponent channel) property, or to a forward-looking narrow functional property, concerning which other inner states and behaviors a given inner state is apt cause for? No, because (artificial tricks aside) these “internal” properties don’t satisfy the Relationality Constraint: none is a relation to a color. At most, visually representing a certain color (and hence, given standard representationism, color phenomenology) *supervenies upon* or is *constituted by* such an internal physical/functional property, without being reducible to it. (On supervenience/constitution without sameness of logical form, see Horwich 1998 and McGinn 1996.) For these reasons it appears that something like Primitivism is the right view of visual representation. Many would argue that this is not an isolated case, and that reduction (as opposed to the weaker relation of supervenience/constitution) is in general an unattainable aim.

This raises a question for B&H. Either they must convince us, as against these arguments, that there is a physical/functional relation between people and SSRs to which visual representation might be reduced,² and more generally that reduction is the rule; or else they must explain why, if the “plausibility” arguments for reduction (avoiding brute emergence, causal considerations) don’t work in general, we should think that they work in the case of colors, notwithstanding the considerable *a priori* and empirical obstacles standing in the way.

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NOTES

1. B&H say that their account explains why “a binary hue like orange *appears to be* a ‘mixture’ of red and yellow” and why “green (and yellow, red, and blue) are *said to be* ‘unique’ hues” (sect. 3.2.3, para. 3; my emphasis). Do B&H then deny that orange *is* reddish-yellowish, and that red *is* a unique color? B&H’s circumspection here suggests that, despite what they say (sect. 3.2, final para.), they are *error theorists* about the unitary-binary distinction, and that their goal is to explain the error. So it is not entirely clear to me what B&H are up to.

2. Hilbert and Kalderon (2000) give a kind of mixed theory of color representation, but I find it hard to make out. I cannot determine what physical/functional property a person must have, on this view, in order to *visually represent* a certain color (e.g., a certain determinate shade of unitary red).

Color as a factor analytic approximation to Nature

Adam Reeves

Department of Psychology, Northeastern University, Boston, MA 02115.
reeves@neu.edu

Abstract: Color vision provides accurate measures of the phase and intensity of daylight, and also a means of discriminating between objects. Neither property implies that objects are colored.

Byrne & Hilbert (B&H) claim that objects are colored. More precisely, colors can be usefully defined as classes of surface reflectances (or light source “productances,” sect. 3.1.2), which are equivalent for some organisms. In this view, the property shared by radishes, tomatoes, and traffic lights is a physical property. I find this definition questionable. If surface reflectance class is not interesting “from the point of view of physics or any other branch of science unconcerned with the reactions of human perceivers” (sect. 3.1.1), why define colors as physical? A useful term for things that are clearly mental, such as colored after-images, is lost. Individual differences become mysterious: Why should one person’s unique green count as “real” and everyone else’s as illusory? And if color is just another term for a set of spectra, color realism becomes true, but only by definition. I will present an alternative notion, that color is best understood through factor analysis of surface and illuminant spectra. This notion accounts for trichromacy and opponent encoding in many species, although it falls short of explaining the full intricacy of human color perception.

All phases of daylight (Das & Sastri 1965), and most natural surface reflectances (Cohen 1964; Vrihel et al. 1994), if measured at 5-nm intervals within the visible spectrum, can be well approximated by linear combinations of three “factors.” The factors are functions of wavelength. The approximation is a fairly good one. Thus, an analyzer with 50-plus sensors spaced every 5 nm throughout the spectrum would gain little more information than an analyzer with only three suitable sensors. Suitable sensors have spectral sensitivities that cover the range of visible light, are not identical, and overlap each other. Overlap is critical; sensors that partitioned the spectrum would not do. Our L-, M-, and S-cones are just such suitable sensors. With them: (1) Naturally-occurring reflectance spectra can nearly all be distinguished under any one phase of daylight, and (2), given a particular surface and a color memory, the different phases of daylight can also be distinguished. Our trichromatic vision maps neatly onto Nature; outside the world of artificial spectra, such as sodium, metamers are not a problem.

So what does this imply? In a noise-free system, any one rotation of the factors contains as much information as any other rotation. One can describe a point in three-dimensional space, say in a room, by distances from any three planes set at any angles, not just from three orthogonal planes, such as the floor and walls. In a system with “noise” or inherent randomness, however, using orthogonal dimensions, each tied to a distinct and physical variable, minimizes the effects of noise and maximizes the quality of the representation (Buchsbbaum & Gottschalk 1983). Spectral overlap implies that activities in the sensors are correlated. De-correlating their responses to extract orthogonal dimensions requires calculation. This can be done simply with sums and differences, for example, $L + M$ (“brightness”), $L - M$ (“red/green”), and $S - M$ (“blue/yellow”). Since it is impossible to extract three orthogonal dimensions by summation alone, even if in different proportions, some form of opponency (differencing cone outputs) is necessary.

The perceptual dimension of brightness is related to luminance. Luminance depends on the angle of declination of the sun, the presence of clouds, glare, the albedo and viewing angle of a surface, and so on. Brightness can be derived from activity in a single receptor class, such as rods in monochromats or M cones in protanopes, or from activity in a single receptor combination, such as $L + M$ cones in trichromats. Brightness is roughly proportional

to the cube root of luminance, and is almost entirely independent of wavelength distribution, except at the spectral extremes. It represents a single meaningful natural variable, light level.

The two remaining perceptual dimensions specify a plane of equally bright colors. One perceptual dimension in color space, the yellow/blue one, falls on the locus of the color temperature of daylight. Thus, it specifies a second physical variable, the phase of daylight. This measurement requires only two classes of receptors, for example, S and either L or M cones, so the yellow/blue dimension is present in dichromats and probably evolved in dichromatic species. There is no known physical variable that corresponds to the red/green dimension. Red/green is orthogonal to brightness and yellow/blue, however, permitting more of the natural variability of lights and surface reflectances to be picked up. With two of the three perceptual dimensions tied to natural and meaningful physical variables, intensity and phase of daylight, we have what may be described as a partial color physicalism.

Given a particular time of day, of course, variations along the yellow/blue or red/green dimensions permit discriminations between surfaces that differ in reflectance characteristics. So color is a useful signal for distinguishing among surfaces, but only in a nominal manner. The redness of a tomato, unlike the brightness of the sky, gives no insight to us as to its physical nature. Red things do not form a natural kind.

Supporters of color realism may object that colors are associated with surface reflectances independent of daylight (“color constancy”). However, subjects match surface colors in arbitrary color collages (Mondrians) only poorly when the illumination is changed from one daylight spectrum to another (Arend & Reeves 1986). The classic Mondrian experiments of Edwin Land have been taken to prove color constancy, but they were flawed (Worthey 1985). Extracting the color of a surface is error-prone, unless the surface is that of a known object. People are excellent at discriminating changes in the illumination from changes in surface color (Foster et al. 1997), but they do so by judging the pattern of chromaticity change across the display. Color constancy is cognitive and involves memory. The level of coding discussed here is primitive compared to the action of the cortex.

Reflectance-to-color mappings depend critically on spatial context

Michael E. Rudd

Department of Psychology, University of Washington, Seattle, WA 98195-1525. mrudd@u.washington.edu
<http://web.psych.washington.edu/aspscripts/template.asp?link=rudd>

Abstract: In visual science, color is usually regarded as a subjective phenomenon. The relationship between the specific color experiences that are evoked by a visual scene and the physical properties of the surfaces viewed in that scene are complex and highly dependent on spatial context. There is no simple correspondence between experienced color and a stable class of physical reflectances.

Most visual scientists regard color as a subjective phenomenon that is somehow generated by neural processes in the brain, rather than as an objective property of objects in the world. There is good reason for this viewpoint. One of the primary jobs of visual science is to investigate the mechanisms by which physical inputs to the sensory apparatus are processed and transformed by the nervous system to produce the contents of visual awareness. To make progress in this direction, we need a theoretical vocabulary that maintains a clear distinction between the properties of the physical world, on the one hand, and our phenomenological experiences of the world, on the other. Byrne & Hilbert (B&H) suggest that color should instead be thought of as an objective property of physical objects – specifically, as the class of reflectances that give rise to color percepts. But their suggestion prematurely begs the

question of the actual relationship between the classes of external stimuli that give rise to color percepts and the color percepts themselves. In fact, this relationship is one of the main things that color scientists are trying to figure out.

The requirement that the working vocabulary of the visual scientist should not confuse physical and psychological phenomena would be essential regardless of whether the correlation between colors and reflectance classes was as close as the authors suggest it is. But it is not. Although B&H correctly point out that no one-to-one mapping exists between reflectance and color because many reflectances can have the same color appearance, they miss the equally important point that a surface having a particular reflectance can be perceived as having any of an *infinite* number of colors, depending on the spatial context in which it is viewed. This latter fact greatly complicates the authors' story about how reflectance relates to experienced color.

The one-to-many mapping of reflectance to perceived lightness is nicely illustrated by a demonstration originally put forth by Gelb (1929; see also Cataliotti & Gilchrist 1995; Gilchrist et al. 1999). In Gelb's demonstration, a piece of construction paper having a low physical reflectance is illuminated by an intense light source, such as a motion picture spotlight, in an otherwise dark room. Viewed in the spotlight, the paper appears bright and self-luminous. A second paper, having a somewhat higher physical reflectance is then introduced into the spotlight along with the first paper. Now the second paper appears to glow and the first paper appears as a less intense white or light gray. A third paper having a still-higher reflectance is placed in the spotlight next to the first two papers. The third paper now appears bright, the second somewhat darker, and third darker still. This process can be continued with the result that the paper with the highest reflectance always appears bright, often glowing, and the other papers take on various shades of gray that are computed by the brain relative to the paper of highest reflectance. The Gelb demonstration has been taken as one piece of evidence for the highest luminance anchoring principle, which states that the highest luminance in a scene tends to appear either white or self-luminous and the appearances of all other regions are defined relative to the highest luminance (Gilchrist et al. 1999). Lightness anchoring is currently a topic of active interest within the field of achromatic color psychophysics (Bruno et al. 1997; Li & Gilchrist 1999; Rudd 2001; Rudd & Arrington 2001; Schirillo & Shevell 1996).

For our purposes, the main conclusion to be drawn from Gelb's demonstration is that a surface having a given reflectance can be made to appear to have almost any achromatic color, or even appear self-luminous, depending on the overall spatial context in which it is viewed. Not only can many reflectances produce the same color percept, as B&H note, but a surface having particular reflectance characteristics can also appear to have any one of a large number of colors. Thus, the claim that color can be identified in any simple way with a class of reflectances is wrong. In fact, the relationship between reflectance and achromatic color is complex and still pretty mysterious!

The results of a large number of studies suggest that, as the number of surfaces in the field of view is increased and as more information about the direction and spectral properties of the illuminant is made available to the observer, the appearance of a surface becomes increasingly resistant to alterations of either the spatial context or changes in the illuminant. But it would be a mistake to define color in such a way that its definition holds only under conditions that are optimal for judging surface reflectance (where color constancy is never exact, in any case). And it would be a mistake to construct theories of color based *solely* on how the visual system functions under such conditions or even under natural conditions, more generally. An adequate theory of color vision should be able to account for color vision under *any* stimulus conditions. To define color in such a way that the definition holds only under certain preferred conditions would make it difficult to talk about what is going on in important laboratory investigations, such as Gelb's, in which the relationship between reflectance and color

is not necessarily clear, and is in fact the subject of the investigations.

In the future, we are likely to encounter more and more situations in which theories of color vision will be expected to inform the development of technologies that have little to do with the conditions under which the visual system evolved to function. Already, for several decades now, color scientists have been called upon to offer expert advice about such non-ecological problems as how to construct television pictures displaying realistic skin tones from combinations of red, green, and blue phosphor emittances, or how to match car upholstery to colored plastic dashboards. Imagine a situation in the not-too-distant future in which a blind patient has a visual prosthesis attached directly to a color center of her brain. The device could perhaps be programmed to elicit a percept of the color green when the patient's word processor is ready to take dictation. In such a situation, any natural correlation between patterns of physical reflectance and perceived color will be entirely irrelevant. But we will still need a color vocabulary that allows us to talk coherently about the relationship between the physical input to the patient's brain and the contents of awareness that it elicits.

Surreptitious substitution

Barbara Saunders

Department of Anthropology, Katholiek University of Leuven, 3000 Leuven, Belgium. barbara.saunders@hiw.kuleuven.ac.be

Abstract: In this commentary I argue that Byrne & Hilbert commit a number of philosophical solecisms: They beg the question of "realism," they take the phenomenon and the theoretical model to be the same thing, and they surreptitiously substitute data sets for the life-world.

Byrne & Hilbert (B&H) are concerned with grounding the positive science of color on the notion of reflectance. They make of reflectance a reified "thing," even though it lacks crucial invariances, and needs mediation by devices to be captured as a truly human observable. It is interesting to note in this context that another philosopher of science, van Fraassen (2001), argues that reflectance (along with the rainbow, shadows, moving spots of light, and mirages) is a "public hallucination." The "thing" that B&H speak of is a visualization or picture or model, not the revelation of what exists behind ordinary phenomena.

B&H, however, treat reflectance (along with other theoretical entities of color science – photons, beams, photoreceptors, etc.) as a universal. Combining this assumption with *mathesis*, they have nothing to say about the historical ontology of reflectance, the slippage between model and phenomenon, the social character of experiment, the historical nature of the viewing subject, the framing/manipulation of the scientific narrative, the intrinsic connection between the control of visualizations and political authority, the committee negotiations on definitions, or any of their other intercalations. Thus, B&H's basic assumption is that the facts of reflectance (and thus color) transcend experience. In so far as this strategy is the basic premise of realism, they cannot be *arguing for* realism, because that was assumed *a priori*. In other words, their argument is question-begging.

B&H might more profitably acknowledge how the institution of color science *sets up* "the real." They could then show how the structure relating reflectance, color science, and the experimental transactions proper to it, are embedded within historical society, and how the phenomenological kinship between instruments, geometrical optics, and the visualizations they produce, has been blurred. The aim of this approach would be to show how such theoretical entities as "reflectance" move from the world of ideal forms (constructed *ex datis*, determined objectively, and placed by mathematics in the concrete universe of causality), to the status of public, cultural, and perceptual entities, defined not by theory but

by cultural praxis. This “new empiricism,” as Heelan (1997) calls it, in which science recursively feeds back into the life-world, provides elements for a better public, civic appreciation of its apodictic claims and ontologizing strategies. This would not mean dismissing the continent of the mathematical and physical sciences within which color and reflectance are defined, but would approach them rather as an open set of social and historical regions and relations in which praxis-ladenness – not theory-ladenness – is brought to the fore.

B&H might also come to see that, whereas in their model of reflectance the relationships are mathematical, in the world and between model and world, the relationships are factual (and therefore social/historical). There is confusion about this, particularly when Euclidean geometry is taken to be the normative model for theoretical-scientific objects and is then taken to be essentially normative for the phenomenon itself (in this case, for color). This is the widespread praxis of taking the phenomenon and the theoretical model to be one and the same thing.

B&H might come to realize that the mathesised model is a conceptual instrument humanly devised for designing the intervening instrumentation that is capable of preparing and disclosing to perception a scientific object not given to the senses. Rather, the model is prepared by and for measurement, “the real” being equated with “the measurable.” Accepting this could free up B&H to provide a richer, praxis-laden account of color, in which a perceptual object is displayed in a dynamic interactional world by multiplicities of appearances, irreducible to types of reflectance.

None of my points is new or original. Husserl articulated them in *The crisis* (1970). That epistemological questions mingle with experiments, data, and historiographic accounts to produce a historical ontology is gaining recognition. An excellent example is Johnston (2001) on the history of light and color measurements. Yet, none of this is acknowledged by B&H. I have described elsewhere the strategy they engage in (paraphrasing Husserl) as taking the real as a *methexis* in the ideal, affording the possibility to idealize it into a mathematical manifold. Then the “surreptitious substitution” takes the place of the mathematically substructured world of idealities for the only real world – our everyday life-world. A science of pure idealities, applied in a practical way to the life-world, obscures internal shifts between *a priori* theory and “guileless” empirical inquiry, and idealized, geometricized “color” becomes its only register. Thus, chromatic data-sets or types of reflectance come to define the chromatic world, which is like claiming that a computer performance of a Bach partita is the one true rendition (Saunders 2001, p. 311).

Color: A vision scientist’s perspective

David Y. Teller

Departments of Psychology and Physiology/Biophysics, University of Washington, Seattle, WA 98195-1525. dteller@u.washington.edu
<http://web.psych.washington.edu/aspscripts/template.asp?link=Teller>

Abstract: Vision scientists are interested in three diverse entities: physical stimuli, neural states, and consciously perceived colors, and in the mapping rules among the three. In this worldview, the three kinds of entities have coequal status, and views that attribute color exclusively to one or another of them, such as color realism, have no appeal.

In their target article, Byrne & Hilbert (B&H) define color realism as “the view that [physical] objects are colored . . . colors are physical properties, specifically, types of reflectance.” (sect. 1). They further argue that “the problem of color realism ought to be of interest to anyone working in the field of color science.” (sect. 1), and that “physicalism should be taken more seriously by color scientists” (sect. 4, “Conclusion”). The goal of this reply is to lay out a view of color vision that I believe is shared among most vision scientists. This view leads me to reject the false dichotomy on

which arguments about color objectivism versus subjectivism are based.

The key to understanding the perspective of vision scientists is that our goal is to unite three interestingly diverse kinds of entities: *Visual stimuli* (e.g., physical objects and their properties); *neural states* (the states of ensembles of neurons at many processing stages within the visual system); and *conscious perceptual states* (our visual perceptions of particular physical stimuli). We wish to discover and understand the regularities, or *mapping rules*, between physical states and perceptual states, between physical states and neural states, and between neural states and perceptual states. The first two kinds of mapping rules are the domain of visual science; the third kind has remained largely in the realm of philosophy (Teller 1984; but cf. Crick & Koch 1998).

The phenomenon of *color constancy* can be taken as a fundamental example. The term color constancy refers to the fact that a physical object tends to maintain the same perceived color across a range of viewing conditions. Color constancy, however, is far from perfect, and the perceived colors of objects can change dramatically with variations of illumination, surroundings, and other variables (Wandell 1995).

At the physical level, an object has a property called *surface spectral reflectance* – it reflects different percentages of the incident light at different wavelengths. Because the surface spectral reflectance of an object remains constant across viewing conditions, and the perceived color often remains nearly so, we can say that surface spectral reflectance maps reasonably consistently to perceived color. Just as perceived size provides the (imperfect) conscious representation of physical size, perceived color provides the (imperfect) conscious representation of surface spectral reflectance.

In fact, both kinds of mappings are complex. The difficulty is that both physical size and surface spectral reflectance are confounded with other variables in the package of light that arrives at the eye. Retinal image size confounds physical size and distance, and the retinal spectrum confounds surface spectral reflectance and the illumination spectrum. The analogy is exact. The only difference is that feasible computational schemes for deconfounding size from distance were worked out from geometry and anatomy many decades ago, and no longer seem problematic, whereas feasible computational schemes for deconfounding surface spectral reflectance from the illumination spectrum proved elusive. Color constancy seems impossible, and yet we have it. My sense is that this apparent mystery occasions the objective/subjective debate among color philosophers.

However, within the last two decades, vision scientists have begun to discover computational schemes that could support reasonable degrees of color constancy (Wandell 1995). These schemes are complex, not least of all because most of them require top-down processing, but at least some of them are clearly physiologically instantiable. Perhaps, as feasible algorithms for color constancy are more fully developed, the motivation for the objective/subjective distinction will dissipate.

Now, as far as I can see, color realism is the view that of the vision scientist’s three entities – surface spectral reflectance, neural signals, and perceived color – one *is* color, and the other two are not. But if you ask a color scientist which of the three entities *is* color, she will answer that the question is ill-posed. We need all three concepts, and we need a conceptual framework and a terminology that makes it easy to separate the three, so that we can talk about the mappings among them. Color physicalists can call surface spectral reflectance *physical color* if they want to, although *surface spectral reflectance* is a more precise term. But to call it *color* (unmodified) is just confusing and counterproductive, because for us the physical properties of stimuli stand as only one of three coequal entities.

It is true that modern vision scientists use color terms. Our custom is to use them to refer to perceived colors – the term *red* refers to a conscious perceptual state. When we are speaking carefully, we try not to say a “red light,” even though the circumlocu-

tions are notoriously difficult. We also try not to say “red cones,” nor a “red-green color channel,” nor a “redness neuron,” unless we are claiming that that neuron really is the immediate neural correlate of consciously perceived redness. So, in a sense, we line up our usage with the subjectivists rather than the physicalists. But I think the authors of the textbooks quoted by B&H are trying primarily to insist on the distinction between physics and perception, and only secondarily to reserve color terms for perception. We care much more about our fundamental distinctions than we do about who owns the word *color*.

In explaining their argument for color realism, B&H state: “If someone . . . looks at a tomato in good light, she undergoes a visual experience. . . . The color property represented by the experience is the property red . . . if the experience is veridical, the tomato is red” (sect. 1.3). This argument reeks of God and unicorns. A vision scientist would say, instead, that the tomato has a surface spectral reflectance function that in good light maps (roughly) to perceived red. There are well-described (complex) mapping rules between physical and perceptual states, and no particular mystery about them except the abiding mystery of qualia (Chalmers 1995).

Finally, throughout their article, B&H use terminology that incorporates their thesis, making it difficult for me as a visual scientist to sort out the arguments. And despite their best efforts to date, the argument for color realism still seems to me to collapse to an uninteresting terminological dispute. I invite B&H to try one more time to explain to color scientists why there is still substance to the debate. It would help if the argument were framed in a neutral terminology, and within (or in an instructive relationship to) the vision science worldview. Until then, I see no reason to agree with B&H that vision scientists should be interested in the argument for color realism.

Color realism and color illusions

Dejan Todorović

Department of Psychology, University of Belgrade, 11000 Belgrade, Serbia, Yugoslavia. dtodorov@f.bg.ac.yu

Abstract: As demonstrated by several example displays, color illusions challenge color realism, because they involve a one-to-many reflectance-to-color mapping. Solving this problem by differentiating between veridical and illusory colors corresponding to the same reflectance is hampered because of the lack of an appropriate criterion. However, the difference between veridical and illusory color perception can still be maintained.

Some color illusions, such as the achromatic displays presented in Figure 1, challenge the identification of colors with reflectances, because they show that the same reflectance may correspond to different colors. The target regions (four elliptical rings in Figs. 1a–1d, fifteen disks in Fig. 1e, and the background in Fig. 1f) have the same reflectance but don’t all look the same, presumably because of the differences in their neighboring regions. Set in equal contexts they do appear equal – just punch holes in a piece of paper to look at them with the immediate surround screened from view. More dramatically, under controlled conditions, a surface patch may span the complete achromatic appearance gamut from pitch black, through all shades of gray, up to white, and even shining, merely through manipulation of its surround luminance (Wallach 1976). Whittle (2002) has shown that a group of patches, which, when set on one background, span a limited chromatic interval (blue-to-violet or red-to-orange), startlingly display all the main colors of the hue circle, when set on another background.

The presented effects are formal inverses of metamerism: Whereas metamerism involves a many-to-one reflectance-to-color mapping, these illusions involve a one-to-many mapping, indicating that specifying the reflectance of a surface is not sufficient to specify its color. According to the authors, color illusions obtain

when objects look to have the colors they in fact do not have; for example, they describe neon color spreading as an illusion in which a region that is in fact white, nonveridically appears as pink. This distinction between real and apparent colors is emphatically expressed by Tye (2000):

The colors things are *experienced* as having as a result of the contrast of the real color of the stimulus and the real color of the background are merely apparent. They do not really exist. Our experiences represent them as being instantiated when in reality they are not. Such colors *on such occasions* are mere intentional inexistents (emphasis in original).

Thus, a potential strategy to meet the challenge from illusions is to identify the true color of a surface and to discard the others as misperceptions.

However, differentiating between reality and appearance is not straightforward. The target regions in Figure 1 all have the same reflectance (say 20%), but which of the corresponding phenomenal colors, if any, is veridical? I don’t know how to answer that question, and I don’t think that it has an answer. For example, is the correct color of the ring a light gray, veridically appearing in Figure 1a, but erroneously looking dark gray in Figure 1b, or is it the other way around? Which part of the ring in Figure 1c looks the color it “in fact” has, and which doesn’t, if any? In Figures 1e and 1f, the choice is between light, medium, and dark gray, but which one is correct for a 20% reflecting surface, and which are merely nonexistent intentionally? And does a single one of the continuously varying shades of gray appearing in the ring in Figure 1d reveal the true color, or is it that none of them “really exist”?

A potential reply is that our lack of a reality-appearance criterion does not negate this distinction as such. As in the authors’ example with unique green, this might be one of those unknowable facts about colors: Ontologically, the proper shade might have its place assigned in the achromatic rainbow up in Plato’s heaven, it is just that epistemologically we might never be able to pinpoint it. However, the problem here is not whether there exists an unknowable fact, but whether there exists a fact to be knowable. The crucial question is, by which method one would determine the veridical color of a 20% reflecting surface (or, of course, of any other surface). Except for Ganzfelds, any surface will appear in the context of other colors. Its phenomenal color, chromatic or achromatic, will be affected by the context – sometimes even more substantially in complex (“related”) conditions (Figs. 1d–f), than in simple (“unrelated”) conditions (Figs. 1a–b). One can define a particular context as standard – most pairings of cone activations and phenomenal colors that the authors mention apply for patches set on dark backgrounds – but this just determines the standard appearance of a surface per fiat, rather than its true color. Because of the dual complications of metamerism and context, perhaps the best one can do is to correlate sets of reflectances with sets of colors, and hope that in the real world neither set is too wide.

Denying that particular reflectances veridically correspond to particular colors does not entail giving up the talk about veridicality and illusion. For example, one can still claim that Figures 1a and 1b involve a perceptual error; however, the error is not in that one or both rings don’t look the color they physically are, but in that they look different although they are physically the same. The same logic applies for other modalities, for example, the Mueller-Lyer length illusion. Assessing veridicality in such cases does not involve examining a physical property of an object (such as reflectance or length), then examining a phenomenal property (such as perceived shade or appearance of length), and finally somehow comparing the physical and the phenomenal property with each other to check whether they are appropriately paired (“does it look what it is?”). Rather, it involves comparing physical properties of two objects (their reflectances or lengths) as to whether they are equal or not, then comparing their phenomenal properties (their perceived shades or lengths) as to whether they are equal or not, and finally comparing the outcomes of the two comparisons. If there is equality in both the physical and the phenomenal comparison, or if there is inequality in both, the percept is veridical,

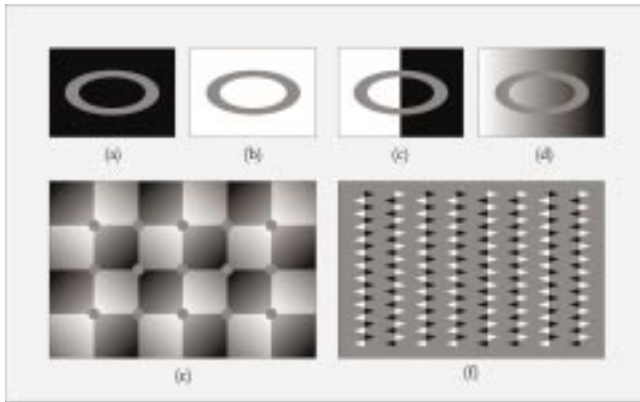


Figure 1 (Todorović). (a,b) *Simultaneous lightness contrast*. The two gray elliptical rings are physically identical but look different. (c) *The Koffka-Benussi ring*. The same ring set on a bipartite background looks different in the two parts, at least when one compares the extreme left and right ends. (d) *The gradient background effect*. The physically real black-to-white background gradient induces an oppositely directed illusory gradient in the physically uniform ring (McCourt 1982). (e) *The gradient chessboard effect*. The figure contains two types of squares, one type involving a black-to-gray gradient, and the other a white-to-gray gradient, in different diagonal orientations. All disks have the same reflectance, but some look dark gray, some medium gray, and some light gray. For related gradient effects, see Logvinenko (1999). (f) *The shimmering effect*. The figure consists of black and white triangles, distributed over a physically uniform background. However, the background interspaces between different triangle columns have different perceived shades of gray. For related effects involving backgrounds, see Adelson (1993) and Pinna et al. (2001).

whereas if the physical comparison yields equality and the perceptual comparison yields difference, or the other way around, the percept is nonveridical (see Todorović, in press, for extending this type of analysis to perceptual constancies). Appropriately elaborated, such an approach to perceptual truth and error, based not on cross-domain (physical-phenomenal) comparisons, but on relations of intradomain comparisons (physical-physical vs. phenomenal-phenomenal), should allow for assessment of perceptual veridicality without endorsing realism in the authors' sense.

Beautiful red squares

Robert Van Gulick

Department of Philosophy, Syracuse University, Syracuse, NY 13244-1170.
 RNVANGUL@syr.edu

Abstract: The reflectance types that Byrne & Hilbert identify with colors count as types only in a way that is more dependent on, and more relative to color perceivers, than their account suggests. Their account of perceptual content may be overly focused on input conditions and distal causes.

Byrne & Hilbert (B&H) defend the external physical reality of colors as mind-independent properties of ordinary physical objects against the objections of those who would deny their existence altogether, or psychologize them and drive their reality mentally inward. In their view, the redness of a tomato is as real a property of the tomato as its shape. They hold that from the facts about color perception and perceivers, "it does not follow that the colors themselves are in any interesting sense dependent on, or relative

to, perceivers or mental events" (sect. 1.3.3). Though there is a sense in which the properties that B&H identify with colors do not strictly depend on perceivers for their existence, there seem to be other interesting and important respects in which the reality of such colors is relative to, or dependent upon, the specific causal structure and dispositions of color perceivers.

B&H identify colors with reflectance types (at least in the primary case of opaque objects and surfaces). Any such type will include many specific reflectances, and the crucial issue is the basis on which they all count as belonging to one and the same type. The specific reflectances will differ physically not only in their underlying realization, but in their particular reflectance profiles – the proportions of light at various wavelengths and intensities that they respectively reflect and absorb. They count as one type only in so far as they are treated as equivalent by human color perceivers. The problem of metamers makes this especially clear, but even in more ordinary cases, the relevant reflectance types will embrace a diversity of more specific reflectance profiles which count as belonging to the same only by virtue of their psychophysical equivalence, either relative to the response curves of some set of cones or, more likely, relative to the computations of the opponent process system.

The fact that any given object O has a reflectance of the relevant type GR – for example, that identified by B&H with unique green – is independent of the existence of any actual perceivers, in the sense that if all such perceivers were to cease to exist, or even if they had never existed, it would still be true that O would have the power to produce the relevant response in such perceivers if any were to come into existence. Despite being perceiver-independent in that strict sense, the sense in which the relevant reflectances count as being of a single type does seem *interestingly relative to a class of perceivers*. Consider an admittedly artificial parallel. Imagine that someone – call him Adam – makes a list that consists of the following four properties: being made of sulfur, of iron, of table salt (sodium chloride), or being spherical. Being categorically inclined, he deems all objects that satisfy one of the four conditions to be of a single type – call it the "Adam's list" type or type AL. The AL type is, at one level, a list-independent type for the reason that, if Adam and his list were to cease to exist or even if they had never existed, the bar magnet on my desk and the salt crystals in my shaker would still be of type AL. However, it is equally clear that things of type AL have no interesting commonality other than their shared inclusion in Adam's list.

Do the reflectance types that B&H identify with colors, similarly count as types solely on the basis of their shared relation to color perceivers? They may not be quite as heterogeneous as the AL type items, but they are nonetheless diverse and there are likely no laws, causal explanations, or natural regularities into which they enter other than those that involve their interactions with color observers, as B&H more or less acknowledge.

In that respect, the relevant reflectance types are very much unlike the shapes of objects. In rejecting dispositionalism about colors, B&H ask rhetorically why those who suggest we identify colors with the dispositions to produce color experiences (under the relevant conditions) are not equally inclined to do the same for shapes, since an object's being square will dispose it to look square under the appropriate range of conditions. The obvious answer is that shapes, unlike colors, enter into a great many causal regularities not involving shape perceivers. The objective reality of shapes is anchored largely by their nonperceptual causal roles. Though the specific reflectances collected within a reflectance type may individually have some such nomic nonperceptual roles, it is unlikely that the reflectance types themselves enter into such regularities. In that sense, the reflectance types that B&H identify with colors, owe their integrity as types to perceiver-involving relations far more than do shapes. This of course does not imply the truth of dispositionalism, which identifies colors with dispositions or powers rather than with their categorical bases. However, it does seem to imply that B&H's reflectance types cohere *as types* in a way that is parasitic on their dispositional roles. An object's being red thus may be more like its being beautiful than its being square.

One might dispute the analogy between reflectance types and AL types by arguing that the former and not the latter are perceptually detectable. The fact that they are actually detectable is of course dependent on the existence of the relevant sorts of color perceivers. AL types are in principle perceivable, and indeed we could extend our imagined scenario so that Adam constructs a set of robots to search for and collect AL type objects using sensors and post-sensor analyzers that reliably produced AL representations when and only when an AL type object was present. Given the right sort of story, it would be fair to say that AL types were perceivable relative to the robots. Thus, in terms of perceptibility, AL types differ from reflectance types at most in *actual, in practice* perceptibility, which does not seem to undercut the analogy to any significant degree.

Let me mention one other difficulty which cannot be developed here at any length. B&H are concerned with experiential content and the properties that objects appear to have in perceptual experience. Their focus is on the distal causes of the relevant experiences and thus it is not surprising that they appear sympathetic to covariational accounts of content. However, mental content, including that associated with perceptual experience, is unlikely to be determined by input relations alone. Surely two creatures – two perceivers – could have detectors that detected exactly the same features of the external environment but which appeared to them quite differently. To one creature the detection of those features might make the relevant object appear nutritious and food-like, while to the other those same features would appear as noxious. The same distal tracking conditions would hold, but the content of the perceptual experience would surely differ.

Some may find it difficult to accept that objects can look nutritious or noxious, as opposed to being inferred to be such. I have no such difficulty but if you do, then shift from vision to olfaction, where it seems obvious that such properties can be smelled and where two creatures might differ drastically in the content of their perceptual experience despite the exact coincidence of their tracking and detection profiles. Insofar as perceptual content is not determined solely by input relations, the content of color experience may be determined by inner factors over and above the relevant facts about their distal causes on which B&H focus.

Confusion of sensations and their physical correlates

Richard M. Warren

Department of Psychology, University of Wisconsin-Milwaukee, Milwaukee, WI 53201-0413. rmwarren@uwm.edu

Abstract: The authors favor a “color realism” theory that considers colors to be physical properties residing in objects that reflect, emit, or transmit light. It is opposed to the theory that colors are sensations or visual experiences. This commentary suggests that both theories are correct, and that context usually indicates which of these dual aspects is being considered.

As the authors recognize, their position that colors are physical properties of objects, rather than the products of sensory evaluation of optical stimuli, is not held by the majority of color scientists. There is good reason for those doing experimental work in vision research to consider that color does not reside in objects or light rays, but rather in the visual response of color by viewers.

After many experiments with prismatic separation of colors and the nonadditive effects of mixing colored lights and pigments, Newton (1730/1952) also came to the conclusion that colors are sensations or visual experiences rather than physical properties. He stated that,

For the Rays to speak properly are not coloured. . . . so Colours in the Object are nothing but a Disposition to reflect this or that sort of Rays

more copiously than the rest; in the Rays they are nothing but their Dispositions to propagate this or that Motion into the Sensorium, and in the Sensorium they are Sensations of those Motions under the Forms of Colours. (Newton 1730/1952)

Newton also wrote, “And if at any time I speak of Light and Rays as coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame.”

I humbly differ from Newton on one point: It is not only “vulgar people” who fail to make the distinction between the stimulus serving as the physical correlate and the sensation it produced. Because it is the vital function of sensory input to allow us to evaluate accurately and respond appropriately to external conditions and events, it is not surprising that aspects of sensation are interpreted in terms of their external physical correlates (see my target article in this journal [Warren 1981] on the physical correlate of sensory intensity).

The distinction between a stimulus and the sensory/perceptual response that it produces applies to hearing, as well. Tones are in some respect similar to color: Changing the frequency or wavelength of the stimulus produces qualitative changes in the sensations that are evoked. According to the “official” definition of tones by the American National Standards Institute (ANSI 1973), a tone is both (1) a “sound wave” and (2) a “sound sensation.” This acknowledgment of dual usage of the term has caused no apparent concern or dissension among those working in audition: They readily make the proper distinction based upon context. As Newton observed, it is much simpler to refer to both a stimulus and its sensory correlate by the same term, while recognizing the distinction; for example, to describe both the pigments of a tomato and its appearance as red, or both the sound of a tuning fork and the pitch it produces as a tone.

In section 1.3.4 entitled “Subjective, objective phenomenal, and physical color,” Byrne & Hilbert (B&H) state that “nothing but confusion can come from using color terms to ‘denote sensations.’” On the contrary, it appears that emphasis on reserving color terms for the inherent “physical” color of objects, such as a ripe tomato, can make understanding color appearance more difficult. An example of such a difficulty is the shift in color observed by Purkinje while seated in a garden in the gathering twilight. He noted that the red flowers seemed black, while the blue flowers seemed gray. We now understand the basis of the “Purkinje shift” in terms of the consequences of switching from cone to rod receptors in the retina. But, if a blue flower appeared gray in the twilight, what was its “true” color at that time? Posed in this manner, the question cannot be answered: Although the physical nature of the flower’s pigments is unchanged, its color to an observer is no longer blue.

In their Abstract, B&H present their view that colors are physical properties of objects and the light they reflect, rather than the subjective responses they produce when being seen. Perhaps it is not necessary to choose between these views. The acousticians may have the right *laissez-faire* approach: Use the same term to describe both the stimulus and the sensory/perceptual response, and allow the context to make it clear which aspect is being considered.

Authors' Response

Color realism redux

Alex Byrne^a and David R. Hilbert^b

^aDepartment of Linguistics and Philosophy, Massachusetts Institute of Technology, Cambridge, MA 02139; ^bDepartment of Philosophy and Laboratory of Integrative Neuroscience, University of Illinois at Chicago, Chicago, IL 60607. abyrne@mit.edu hilbert@uic.edu
<http://mit.edu/abyrne/www/> www.uic.edu/~hilbert/

Abstract: Our reply is in three parts. The first part concerns some foundational issues in the debate about color realism. The second part addresses the many objections to the version of physicalism about color ("productance physicalism") defended in the target article. The third part discusses the leading alternative approaches and theories endorsed by the commentators.

Our target article had three aims: (a) to explain clearly the structure of the debate about color realism; (b) to introduce an interdisciplinary audience to the way philosophers have thought about the issue; and (c) to argue that colors are certain sorts of physical properties ("productances").

R1. Foundational issues

R1.1. The problem of color realism

Although most of the commentators appear to accept the way we frame the debate about color realism and agree that the issue is important, some do not. **Teller** clearly explains why she thinks that the debate is "an uninteresting terminological dispute," and **Warren** and **Reeves** seem to be of the same opinion. Visual science, according to Teller, is concerned with the regularities that obtain between three kinds of entity: visual stimuli (e.g., tomatoes and their properties), neural states (e.g., such-and-such activation in V1), and conscious perceptual states (e.g., a visual experience as of a red tomato).

In **Teller's** view, once the regularities between stimuli, neural states, and perceptual states have been accounted for, there is nothing left to explain. In particular, there can't be any interesting issue about the nature of colors, or about whether visual stimuli are colored. In one way of using "red," as standing for the properties of visual stimuli that cause certain color experiences, obviously tomatoes are red. In another way, as standing for "a conscious perceptual state," tomatoes are not red. The color realist, Teller thinks, is simply insisting on the first terminological usage; to claim that this is an important issue is "just confusing and counterproductive."

We conjecture that the reason **Teller** sees only a tedious squabble about words is that she fails to recognize fully the *intentionality*, or representational nature, of visual experience (see, in particular, the commentaries by **Jackson** and **Van Gulick**). If color experiences are "mere sensations," capable of being identified by their "qualitative feel" rather than in terms of what they represent, then Teller's position is perfectly understandable. Once we have accounted for the "regularities" between external stimuli and color experiences, it is hard to see why there would be a further question about whether color experiences represent the world as it really is. Color experiences are caused by such-and-

such external stimuli, and in that rather uninteresting sense may be said to represent those stimuli, as smoke may be said to represent fire, but that is all.

However, vision science does in practice have a richer notion of visual experience. In addition to finding the mechanisms that underlie and produce regularities of the sort **Teller** describes, vision scientists theorize about the information these mechanisms supply to other stages of processing. Consider some visual illusions: say, the Zöllner illusion, the Hermann grid illusion, or a case of apparent motion. When vision science tries to explain such illusions, the task is not solely to account for the "regularities" between the stimuli (parallel lines obliquely crossed with shorter lines; a grid of black squares on a white background; flashing lights) and certain sorts of "visual sensations." In the case of illusions, part of what is to be explained is why, in these circumstances, the visual system makes an *error*; that is, why it conveys to the perceiver the *misinformation* that the lines aren't parallel, that there are some gray spots on the white background, that the lights are moving. In **Funt's** terminology, an explanation is sought for why the visual system fails to "estimate" accurately various properties of the distal stimulus. Sometimes, for example, the explanation of visual illusions appeals to some "real-world assumption" of the visual system (say, that the illuminant is above the perceiver). These explanations presuppose that the visual system is estimating stimulus properties. And if it is, we can ask exactly which properties are being estimated. That is all we are doing in the case of color.

We emphasized that the problem of color realism is "primarily a problem in the theory of perception, not a problem in the theory of thought or language" (target article, sect. 1.1). **Maund** complains that this is a "false dichotomy." He thinks that because the properties of interest are picked out by English words like "red" and "green" (as we of course admit), this shows that the problem of color realism is fundamentally about "our ordinary concept of color." (Notice that this sort of argument would show that an inquiry into *anything* – black holes, life on Mars, dinosaurs, and so on – is fundamentally an investigation into the relevant concepts.) However, Maund seems to be assuming a description theory of reference. That is, he is assuming that the word "red" refers to a certain property because speakers associate a certain descriptive condition with "red" (for example, the property that causes such-and-such visual sensations). On this view, armchair "conceptual analysis" will tell us what that condition is, and color science will tell us whether there is any property of tomatoes that meets the condition. If there is such a property, then it is the property of redness and tomatoes are red. If there is no such property, then tomatoes aren't red. Maund is in good company (see, in particular, Jackson 1998), but for familiar reasons (Kripke 1980; Soames 2002) we reject his assumption (see also the discussion of **Jackson's** commentary below). No amount of conceptual analysis, we think, is going to provide a substantial descriptive condition that, together with the relevant empirical facts, will allow us to identify redness with, say, a type of reflectance. (In this connection, Maund briefly alludes to the distinction, much discussed recently by philosophers, between *conceptual* and *nonconceptual* content. There are different ways of understanding this distinction [Byrne 2003b], and we are not sure which one Maund has in mind, but at any rate it seems to us not to be particularly relevant to the present issue.)

MacLennan's interesting discussion of Ancient Greek color terminology nicely illustrates why it is a mistake to focus the color realism debate on concepts expressed by ordinary color words. The words may well carry lots of semantic baggage that is not relevant to an investigation into the properties represented by our visual systems.

Maud has a reasonable concern about our brisk early dismissal of sense-data (sect. 1.3.1), and we concede the issue deserves more discussion (for a recent useful treatment, see Smith 2002), although it would be out of place to pursue the matter here.

Saunders has some fundamental disagreements with us (and, clearly, most of the other commentators). One of her main complaints is that we "reify" reflectance, and by this terminology (see Quine 1953) she simply means that we hold that reflectances exist. Saunders's reason for saying this is a mistake is that reflectances "lack crucial invariances," by which she apparently means (see van Fraassen 2001, pp. 156–57) that there is no agreement between observers about the reflectances of objects. Since colorimetry obviously shows that this is false, it is not a very good reason. Saunders refers approvingly to van Fraassen's (2001) alleged claim that reflectances are "public hallucinations," but this is a complete misreading: van Fraassen's point is about rainbows, mirages, reflections on water, and the like, not reflectances.

R1.2. Intentionality

Jackson is sympathetic with both our physicalism and representationism, but he thinks that there is a problem about the representational content of color experience that we fail to address. The problem can be formulated as the following reductio ad absurdum argument: (1) Tomatoes look to have the property red. (2) Reflectance physicalism is true; specifically, the property red = reflectance type *R*. Hence: (3) Tomatoes seem to have *R*.

But this conclusion is incorrect: As **Matthen** puts it when presenting essentially the same argument, "it is obviously false that, simply on the basis of color experience, any proposition about reflectance becomes apparent to the (naïve) observer." The culprit must be either (1) or (2); (1) is plainly true, so (2) is false.

Matthen endorses this argument and concludes that colors are not reflectances. However, he does not explain why the argument is not a variant on the following philosophical chestnut: (1) Gottlob believes that the morning star (i.e., the heavenly body that rises in the morning) is visible; (2) the morning star = Venus, hence (3) Gottlob believes that Venus is visible. Since (1) is true and (3) is false (or so we may suppose), (2) is false: Venus is not the morning star. Because Matthen knows very well that this last argument is invalid, he must think that considerations peculiar to the color case prevent the standard diagnosis from applying to the first argument. But we are not sure why he thinks this.

Jackson's response to the first argument is to say that it fails for exactly the same reason as the second argument: basically, that one may represent *one* thing (say, the planet Venus) in *two* different ways (for example, as *the heavenly body that rises in the morning*, on the one hand, and as *Venus*, on the other). In fact, in Jackson's account, the parallel between the two arguments is exceptionally close. The property red is represented in our experience as the property that "plays such and such role," just as the planet Venus

is represented by Gottlob's belief as the thing that "plays the role" of rising in the morning.

We agree with **Jackson** that to respond to the first argument, a color physicalist needs to spell out how colors are represented in experience. In fact, we already sketched the beginnings of an account that is a rival to the sort Jackson has in mind: Color experience represents objects as having proportions of hue magnitudes (sect. 3.2.1).

In **Jackson's** proposal, the colors are represented as the occupiers of certain "roles." These roles are specified "topic neutrally" (Smart 1959), so as to explicitly allow for the possibility that physical properties might occupy the roles. If empirical science tells us that reflectance *R* occupies the redness role, then redness = *R*. In Jackson's view, this identity is contingent; as **Dedrick** explains, we hold that such an identity is necessary. In our account, color experience has no such topic neutral content. Therefore, unlike Jackson, we do not think that the conclusion that redness is such-and-such physical property is entailed by (1) a detailed specification of the content of color experience, and (2) various empirical facts about the physical properties of tomatoes and the like. By our lights, without a solution to the problem of "naturalizing semantics" we cannot clinch the case for physicalism (see sect. 2.6 of the target article). (In contrast, by Jackson's lights, the book on color physicalism can be closed without a naturalistically acceptable account of mental representation.)

Jackson agrees with our representationism about color experience, and its consequent rejection of the possibility of certain sorts of "inverted spectrum" scenarios. However, as **Kulvicki** helpfully points out, we (and Jackson, in fact) can accept the possibility of creatures that represent the colors very differently from ourselves. (**Van Gulick** rightly insists that this apparent possibility is genuine.) Relatedly, Kulvicki also notes that Revelation (Johnston 1992) fails in our account (which it also does in Jackson's).

In the target article, we expressed some skepticism about current attempts to reduce mental representation in physical or functional terms. We are not incorrigible skeptics – perhaps more progress could be made by taking **Van Gulick's** point about the importance of "inner factors." In any case, **Pautz** thinks our skepticism was well-placed, and buttresses it with some serious argument. Pautz claims that this poses a problem for reflectance physicalism: According to him, we have to explain why visual representation can be reduced, or at least why the representation of colors can be. What we don't see, however, is why a plausible case can't be made for reflectance physicalism even without the assumption that there is a reductive account of mental representation; after all, the target article attempted to do exactly that.

R2. Objections to productance physicalism

R2.1. Productance

Most recent philosophical discussions of color physicalism have focused on attacking or defending the thesis that color is to be identified with reflectance (or some derivative thereof). And, in fact, almost all the issues concerning physicalism can be raised and settled, limiting discussion only to reflectance. (This is why – to answer **Dedrick's** implicit question – "productance physicalism" appears only once in the target article. This Response also uses the terminology

of “productance” sparingly.) In discussing the colors of light sources and filters, however, a generalization of reflectance, which we call “productance,” is required (sect. 3.1.2). Colors, in our view, are anthropocentric productance-types (sect. 3.1.1) that – to a first approximation – are visually represented as proportions of “hue magnitudes” (sect. 3.2.1).

Kuehni misses the point that productance incorporates emission and transmission as well as reflection, and implies that we attempt to reduce emission and transmission to reflection. We establish a “uniform concept” by combining all three processes rather than reducing two of them to the third.

Dedrick thinks the main problem for our physicalist theory of color is that some nonreflectors appear colored, and he questions the motivation for our introduction of productance. The motivation is simply this: (1) light emitters, opaque reflectors, and transmitting filters are perceived as similar in color, and (2) it is plausible to think that these features are physical properties. We suspect Dedrick has missed the extent to which we are only supplying a name to previously recognized similarities among physical phenomena. We wouldn’t presume to say whether productance, as defined by us, will be useful to vision scientists, but that there are important similarities among light emitters, transmitters, and reflectors is already a part of vision science.

Jakab & McLaughlin are troubled by productance being undefined relative to zero illumination. Although they mention this only in the context of a light emitter, the denominator in the definition of productance is zero whenever the illuminant is zero, no matter what the numerator might be. This mathematical artifact is also a feature of the common definition of reflectance as the ratio between the light reflected by a surface and the light incident on it; this is not a problem with the definition of reflectance and neither is it a problem with the definition of productance. Jakab & McLaughlin seem to think that according to our account, a firefly in total darkness has no productance and hence no color. We thought we had made it clear that our view has no such consequences; evidently we did not. To repeat, according to our account, productances are relative to illuminants but they are also independent of the actual illumination: Objects including light sources have (finite) productances in total darkness. Jakab & McLaughlin also find a problem with the fact that productance relative to illuminant I approaches infinity as I tends to zero, a concern shared by **Mausfeld & Niederée**. However, this is entirely unproblematic, and the ordinary definition of reflectance again illustrates why.

Note that instead of using the terminology of “reflectance,” we could use “inverse reflectance” ($1/\text{reflectance}$). Speaking of inverse reflectance is obviously just another way of representing the same facts as speaking of reflectance, yet inverse reflectance approaches infinity as the amount of reflected light approaches zero. Of course, there may well be practical reasons to prefer the terminology of “reflectance” over that of “inverse reflectance”; likewise, there may be questions about the utility of “productance,” but we are not suggesting that color scientists should start using this terminology.

Decock & van Brakel attempt to use the fact that productances are relative to illuminants to pose a dilemma. Representing the productance of a surface relative to illuminant I by the function $p(\lambda, I)$, they ask whether we identify the color of a surface with “the binary function $p(\lambda, I)$

with variable I , or with the simple function $p(\lambda, I_a)$ for a given illuminant I_a .” We adopt the spirit, if not the letter, of their second horn. As mentioned earlier, we hold that colors are productance-types; an uncharacteristically simple example of a productance-type could be represented as the following set of productances: $[p_1(\lambda, I_a), p_2(\lambda, I_a), p_3(\lambda, I_b), p_3(\lambda, I_c)]$. (For a surface that does not emit light the illuminants can be ignored, because $p(\lambda, I_x) = p(\lambda, I_y) = r(\lambda)$, where $r(\lambda)$ is the reflectance function.) As Decock & van Brakel correctly point out, this has the consequence that surfaces have many colors – there is no such thing as “the” color of a surface. We do not understand why this is problematic.

Setting the alleged dilemma aside, **Decock & van Brakel** provide some examples that purportedly show the failure of productance as a complete account of color. When an orange laser beam is viewed sideways on, what one sees is (they imply) orange but, they say, on our theory “the object one is looking at is a cylinder of air,” which is presumably not orange. We do not understand why Decock & van Brakel think that our theory implies that nothing orange is seen. In the situation described, one sees a cloud of dust particles that reflect the laser light (perhaps this is what is meant by a “cylinder of air”); these nonorange particles appear orange, and in that respect, one’s experience is illusory. However, one also sees the orange light source (as one sees the sun on water, or the room lighting in a mirror), and in that respect one’s experience is veridical. A similar description applies to Decock & van Brakel’s example of a movie screen. They apparently think that the screen changes from white to multicolored when the show starts; we think that the screen’s appearance is an illusion, but the appearance of the light source (seen because it is reflected from the screen) is – at least to a significant extent – veridical.

(On a related point, we do not deny, as **Mausfeld & Niederée** claim we must, that an experience of a white object under red illumination is “an experience of two colors at the same location”; we have claimed elsewhere – Byrne & Hilbert 1997a, note 15 – that such an experience represents both the color of the illuminant and the color of the object.)

R2.2. Metamerism

Metamerism is often thought to pose a special problem for physicalism about color. We respond to this difficulty by claiming that color vision delivers information about types of reflectance, not determinate reflectances (sect. 3.1.1). Two objects that match metamERICALLY are, we say, represented as having the same reflectance-type. And if the objects do in fact have reflectances that fall within this reflectance-type, then they both possess the colors they appear to have. Some commentators contend that this response fails to accommodate the fact that metameric matches are very sensitive to changes in the illuminant – objects that appear the same in color under one illuminant can appear different in color under another similar illuminant. **Brill, Kuehni, and Mausfeld & Niederée** all ask how, given these facts about sensitivity, we define the relevant reflectance-types. They think we must somehow single out some illuminant as privileged, and define the reflectance-types that are the colors with respect to it. Since any such choice will be arbitrary, they conclude that there

will be no independently motivated way of defining the visually represented reflectance-types, and hence that our view is mistaken. This problem is at root the same as the one posed by interobserver variation in color vision (see sect. 3.4 of the target article, and R2.6, below), that there is no principled way of picking out some perceivers as privileged. The problem is not in identifying when two objects are represented as having the same reflectance-type: That will be true whenever they look to have exactly the same color. Rather, the commentators are asking us to identify precisely *which* reflectance-types are represented by *which* color experiences. We admit we cannot do that (see sect. 2.6 of the target article) but insist that this does not prevent us from mounting a convincing argument for reflectance physicalism. It is worth emphasizing that none of our critics is any better off: For example, relativists (see R3.1, below) can do no better at identifying the properties represented by color experiences.

Hahn claims that we do define the colors in terms of privileged perceivers (“normal human trichromats”) and privileged (“standard”) conditions, but his main point does not depend on this misinterpretation. He uses the fact that metameric matches can easily be broken by changing the illuminant to urge on us the conclusion that any difference in reflectance that can be detected under some illuminant is a difference in color. Consequently, for Hahn the determinate colors are just the determinate reflectances, not reflectance-types. Although the target article focuses on the visually determinate colors, we observe (note 28) that we don’t intend that our account conflict with the view that Hahn offers. In fact, one of us (Hilbert) has defended a similar view with a similar motivation (Hilbert 1987, pp. 83–87). There is no incompatibility between the claim that color vision only represents reflectance-types and the claim that every difference in reflectance is a difference in color.

R2.3. Hue magnitudes

To account for the perceived similarities between the colors and their opponent structure, we proposed that objects seen as colored are represented as having proportions of “hue magnitudes” (sect. 3.2.1; for a similar treatment, see Bradley & Tye 2001). This account allowed us to reply to various widely accepted objections to physicalism, notably **Hardin’s** (1993) charge that physicalism cannot account for the binary/unique distinction.

If this account and physicalism about color are correct, it follows that the hue magnitudes are themselves physical. We gave a rough indication of the sort of physical properties they are, in terms of relative cone responses (sect. 3.2.2). No doubt we should have emphasized more strongly that this was *not* any kind of definition of the hue magnitudes, even given the assumption of physicalism. (**Hardin** and **Jakab & McLaughlin** may well be under this misapprehension, for which they should not be blamed.) Whether an object has a certain value of a hue magnitude does not depend at all on human cone responses or even on whether any perceivers exist – hue magnitudes are simply certain reflectance types, and for that reason are perceiver-independent. **Kuehni, Jakab & McLaughlin**, and **Pautz** note that the relationship between cone responses and (perceived) unique hues is not at all straightforward, but this is no embarrassment; we were merely trying to illustrate our view using a very simple model, and to show how

there is no obvious barrier to supposing that individual hue magnitudes are physical properties.

Pautz thinks that the magnitude proposal cannot account for the unique/binary distinction. His purported counterexamples apparently assume that we endorse the following schema (“B&H’s formula”): property *P* is reddish-yellowish if everything that is represented as having *P* is represented as having the hue magnitudes *R* and *Y* in roughly equal proportion. His first example is a hypothetical case where everything that looks circular seems to have [a roughly equal proportion of] *R* and *Y*; but, **Pautz** objects, “circularity . . . is not binary reddish-yellowish.” However, we certainly do not endorse **Pautz’s** schema. First, note that **Pautz** is evidently taking a phrase like “property *P* is reddish-yellowish” to mean that property *P* *has the property of* reddish-yellowishness, rather than to mean that property *P* *is identical to* the property of reddish-yellowishness (in philosophical terminology, the “is” is the “is” of predication, not the “is” of identity). But, according to us, *objects* like tangerines (or their surfaces) are reddish-yellowish, not properties; therefore we think that instances of the left-hand side of **Pautz’s** schema are always false. (For more on this issue, see Byrne 2003a.) What we do endorse is this: The property orange (i.e., reddish-yellowishness) is identical to the property of having the hue magnitudes *R* and *Y* in roughly equal proportion. Once this is cleared up, **Pautz’s** objection dissolves.

Pautz has another objection: that magnitudes can’t be “extradermal physical properties” because, for example, an object’s proportion of *R* might be twice its proportion of *Y*, whereas it makes no sense to speak of the “proportion” of a property, extradermal or otherwise. But this objection confuses how properties are represented with the properties themselves. It is rather like arguing that temperatures aren’t properties on the grounds that while 4° Fahrenheit is twice 2° Fahrenheit, it makes no sense to say that one property is twice as great as another.

R2.4. Recovery of reflectance information

Both **Funt** and **Maloney**, in their very helpful commentaries, discuss the extent to which the visual system might recover object reflectances. They both take us to task for exaggerating the degree of color constancy characterizing human color vision. This may have been a defect in our presentation; we did not intend to give the impression that color constancy is “almost perfect” (**Funt**), and certainly not that it is “perfect” (**Maloney**).

Maloney thinks we are committed to perfect color constancy because he mistakenly attributes to us the view that the actual reflectance of a surface determines the color descriptors computed by the visual system. On the contrary, we admit errors in represented reflectance and hence mismatches between the estimated reflectance-type of the target surface and the reflectance-type of the surface itself (see sect. 3.4 of the target article, and R2.5, below). **Funt** emphasizes that the underlying mechanisms of color perception are subject to various kinds of error and variability, and we agree.

Both **Funt** and **Maloney** propose that a better version of our view would employ the distinction – to use **Funt’s** terminology – between a surface’s reflectance-type and the visual system’s “estimate” of its reflectance-type. However, – perhaps due to the opacity or unfamiliarity of our philo-

sophical jargon – they do not recognize that this very distinction features prominently in the target article. Our view that reflectance-types are represented in color experience is translated by Funt’s terminology as the claim that the color vision system estimates certain reflectance-types. Although this estimation will often be inaccurate, Maloney’s commentary raises the interesting possibility that in a range of certain naturally occurring environments it might be exceptionally good – although never perfect.

Funt also takes up some of our remarks about the CIE 1971 Standard Observer (sect. 3.1.1). We objected that tristimulus coordinates are not suitable to specify reflectance-types, partly on the ground that they are relative to an illuminant. Funt correctly points out that this objection does not run very deep; we welcome his suggestion that a perspicuous representation of reflectance-types could employ an amended version of the CIE system.

Reeves suggests that the spectral characteristics of the opponent systems can be explained by attunement to the phases of daylight and the necessity for decorrelating the cone signals. Whether this is right or not, we can be sure that the selective pressures driving the evolution of the primate visual system were surely complex; in any case, Reeves’s claim is compatible with the visual system having the overall function of acquiring reflectance information (Shepard 1992). Reeves also claims that color constancy for human color vision is quite poor; however, see **Maloney’s** commentary for a different perspective (see also Brainard et al., in press; Kraft & Brainard 1999).

R2.5. Contrast and context

Suppose we are right in contending that color vision functions to extract information about reflectance from the visual stimulus. Nothing follows from this about which aspects of the stimulus are used to generate the visual system’s estimate of reflectance-types. A multiplicity of scene features are of potential relevance to the task of estimating reflectance, and it is an open empirical question exactly which ones are used in which ways by the visual system. **Cornelissen et al.**, **Kuehni**, **Rudd**, and **Todovorić** imply that our account somehow neglects these facts. This is a mistake: Our claim that colors are reflectances does not imply that reflectance is the only causally important factor in color vision.

Color contrast effects are powerful and pervasive. Given complete control of the surround, a colored patch can be made to appear to have virtually any color. These facts suggest to **Decock & van Brakel** that it is more appropriate to think of the color as an object in relation to its surround, rather than as a reflectance-type (see also Clark 2000). However, they do not directly respond to our charge (sect. 3.1.3) that this confuses color with the conditions necessary for its perception. As Tye (2000, pp. 153–55) points out, there are also contrast effects for shape; yet this does not show that the shape of an object is a relation to its surround. In distinguishing between the properties color vision represents and the mechanisms by which color vision extracts information about these properties, we are not implying that the surround is a minor factor in color perception.

Hardin and **Todovorić** press the question of *which* surrounds reveal the true color of the target. This is just another instance of the demand for independent criterion of veridicality, which we reject (see sect. 2.6 of the target article and R2.2, above). It is also worth emphasizing **Rudd’s**

observation that for complex scenes like those typically encountered in our visual lives, the perceived color of an area is relatively independent of scene composition (see also Whittle, in press).

R2.6. Variation

Imagine a type of animal whose sense organs detect a range of physical properties P_1 , P_2 , and so on. Its sense organs afford the animal a fairly accurate view of the distribution of these properties in its environment. However, – partly because the computational problem of recovering information about these properties from the stimulus array is underconstrained – mistakes are made. Frequently, the animal’s sense organs will deliver the misinformation that an object has P_i , where the object in fact has a very similar property P_j . Further, because of natural variation between individual animals of this type, the following situation can arise. The same object appears to one individual to have P_i , and appears to another individual in the same circumstances to have a different but very similar property P_j . However, usually the difference between an object’s having P_i , and its having P_j is of no ecological significance, so these sorts of minor misperceptions, and minor differences between individuals, have no adverse practical consequences.

Described in this abstract way, our imagined animal seems quite biologically plausible; indeed, one would expect this kind of situation to be ubiquitous. And, in our view of color perception, this kind of situation is ubiquitous – which seems to have provoked consternation and alarm among many commentators.

Our view does not, *pace Cornelissen et al.*, “[reduce] the idea, that objects are colored, to an untestable belief.” To say that vision is our main source of evidence about which colors objects have is not to say that we do not have *enough* evidence. According to us, ordinary visual experience provides us with ample evidence that objects are colored, in particular, that tomatoes are red, and so forth. We were not as explicit as we could have been on this point. This is doubtless why **Jakab & McLaughlin** misinterpret us as saying that the reason, or a large part of the reason, for believing that tomatoes are red is that tomatoes look that way to the majority of perceivers. Their complaint that “it is hard to see why counting heads matters” is therefore misdirected.

However, the picture is complicated by determinate shades like unique green, about which there is substantial disagreement. Here we assumed that the fact of such disagreement would *undermine* an individual’s perception-based reason to believe that a certain chip is unique green. Thus, as we said in note 50 of the target article, we are prepared to countenance “unknowable color facts” – concerning, for example, whether a particular chip is unique green.

Hardin thinks that our insouciance about “unknowable color facts” is “a damning admission” and compares our attitude to a dogmatic proponent of the electromagnetic ether who holds that the Michelson-Morley experiment shows merely that facts about the Earth’s motion through the ether are unknowable. We do not think the analogy is apt. The ether hypothesis, in conjunction with some plausible auxiliary assumptions, predicts a non-null result in the Michelson-Morley experiment, which of course was not observed. Hardin’s imagined ether enthusiast preserves his theory at the price of an *ad hoc* denial of the auxiliary assumptions. Notice that what is wrong with the ether theo-

rist is not his invocation of unknowable facts, but his denial of the auxiliary assumptions. What is the parallel in the case of color realism? What is the prediction of the theory that is not borne out by experiment? Color realism predicts (in conjunction with some plausible auxiliary hypotheses) that some things are unique green. But here the parallel breaks down. It would be begging the question to insist that this prediction is incorrect. Rather, Hardin's argument at this point must simply be that if some things are unique green, they must be knowably so, which reduces his argument to the simple assertion that our position is unacceptable.

Averill describes some ingenious hypothetical cases of people whose color perceptions differ from our own (in particular, gold looks red to them), and claims that these possible cases show that, if reflectance physicalism is correct, no one knows whether anything is red. However, we agree with many contemporary epistemologists that remote "skeptical hypotheses" – for example, that Averill's hypothetical people, not ourselves, are right about the color of gold – do not need to be ruled out by some independent procedure for us to know that they do not obtain (e.g., Austin 1946; Goldman 1976). Averill protests that we do not take the epistemological concerns seriously enough. We agree that the epistemology of perception is a difficult business, but we deny that our view makes it especially hard to explain how we have access to colors. To the extent that there is a worry, it is just an instance of a more general problem, one that has nothing in particular to do with color, and still less with reflectance physicalism.

Cohen thinks that our Professor Plum analogy is flawed, because the background beliefs that support the conclusion that Plum was murdered by someone or other have no counterpart in Hardin's (1993) unique green example. We disagree. Imagine Hardin's Munsell chips arranged in a long line. Here are some background beliefs that, for all Cohen has shown, we are entitled to. First, the chips are all green. Second, those at the far left-hand end (say) are bluish-green and those at the far right-hand end are yellowish-green. Third, traversing the array from left to right, the chips get less bluish and more yellowish. It follows from these commonly agreed facts that the less distinguishable we make adjacent chips, the more likely it is that the array contains a chip that is neither bluish nor yellowish.

R2.7. Nonhuman color vision

We argue that there is no incompatibility between our version of physicalism and the thesis that many nonhuman animals have color vision. We do, however, claim that to possess color vision an organism must have the ability to extract information about reflectance from the visual stimulus. This understanding of what it is to have color vision is more restrictive than the one usually appealed to in the literature on comparative color vision. Organisms that are capable of discriminating between spectrally different, equiluminant stimuli possess color vision, according to the standard criterion. However, if they don't extract or represent reflectance information, then they lack color vision, according to us. **Dedrick** disparages this view as "cognitive imperialism." Here, we think, the dispute really is just about words. Suppose that color vision in human beings generates representations of reflectance-type and that in doing so it makes use of mechanisms that enable spectral discrimination. One terminological option would be to apply the term

color vision to visual capacities that extract information about reflectances. Another would be to apply the term to capacities that make use of mechanisms that support spectral discrimination, regardless of whether they extract information about reflectances. We prefer the first option but have no serious complaint against those who prefer the second. Once the nature of the mechanisms and the information they make available has been described, there is no further substantive question about whether the organism really has color vision or not.

R3. Other approaches

R3.1. Relativism

As **Cornelissen et al.** point out, grass is food for a cow, but not food to us, because cows can digest grass and we can't. (See also **Jakab & McLaughlin** on digestibility.) Strictly speaking, nothing is *simply* food: The proper locution is "food for *X*," where "*X*" is replaced by the name of an organism (either a type or an individual). Similarly, nothing is *simply* soluble: Some things are soluble in water, others are soluble in alcohol, and so forth. In the jargon, *relativism* is true about food and solubility. There is no single property of *being food*, rather, there is a family of properties: food for cows, food for humans, food for Smith, food for Jones, and so forth. Some commentators, in particular **Cohen** and **Jakab & McLaughlin** defend *color relativism* (see also **Matthen's** commentary; Cohen 2003; Jackson & Pargetter 1987; McLaughlin 2000; 2003). According to them, there is no single property of greenness: rather, there is a family of properties: green for perceiver P_1 in circumstance C_1 , green for perceiver P_2 in circumstance C_2 , and so forth.

Relativism can reconcile many apparent cases of disagreement. Smith says "Grass is food"; Jones says "Grass isn't food." Relativism (about food) allows that *both* may be right – if Smith means that grass is food for cows and Jones means that grass isn't food for humans, then there is no disagreement, and they both spoke truly. The basic motivation for relativism about color is that it promises to reconcile apparent cases of "perceptual disagreement," as in Hardin's example of unique green (see sect. 3.4 of the target article, and **Cohen's** commentary). "Color absolutists" like ourselves describe such cases as follows: A certain chip looks unique green to Smith and bluish-green to Jones; since nothing can be both unique green and bluish-green (this is a further assumption, but one we grant), either Smith or Jones (or both) is misperceiving the chip's color. Color relativists have a different account: The chip looks unique green for Smith in C_S to Smith, and it looks bluish-green for Jones in C_J to Jones (where C_S and C_J are the relevant "type of circumstance of visual observation," in **Jakab & McLaughlin's** phrase). Further, according to the relativist, the chip has *both* properties: It is unique green for Smith in C_S and bluish-green for Jones in C_J .

As **Jakab & McLaughlin** note, a color relativist can also be a color physicalist. So relativism offers the physicalist a solution to the problem of variation. Why don't we take it?

Because we think that widespread misperception of the determinate colors is not at all an unwelcome result, we do not think that a relativized version of physicalism has any advantage over our "absolutist" theory (as **Jakab & McLaughlin** call it). Relativism makes color illusions very rare (just how rare will depend on the details; the accounts

offered by Cohen [2003] and McLaughlin [2003] differ in this respect). The near-infallibility of color vision is a result to be avoided, not embraced. Moreover, although relativism might appear attractive at first glance, in fact it suffers from serious problems.

One difficulty for relativism can be brought out by a simple example. Imagine that you have just eaten a tasty crimson fruit, and that you are now looking at another fruit of the same kind. (To avoid irrelevant distractions about color language, imagine you are an Old World monkey.) You recognize the fruit as having the same distinctive shade of red as the first, and that's why you reach for it.

Rather surprisingly, this simple explanation of your behavior is not available to the color relativist. Call the first "type of circumstance of visual observation" (Jakab & McLaughlin's phrase) C_{F1} , and call the second C_{F2} . Unless the relativization to types of circumstances is to be pointless, the relativist must concede that the details of the example could be filled out so that C_{F1} and C_{F2} are *different*. We may assume, then, that $C_{F1} \neq C_{F2}$. According to the relativist, the color the first fruit appeared to have was what we can call "crimson for you in C_{F1} ," and the color the second fruit appeared to have was "crimson for you in C_{F2} ." Never mind how we should understand these unfamiliar expressions – the important point is that, because $C_{F1} \neq C_{F2}$, the expressions are supposed to pick out *different* properties (just as being soluble in water is a different property from being soluble in alcohol). According to the relativist, the first fruit seemed to you to have a *different* color than the second, and hence the relativist cannot endorse the simple and obvious explanation of your fruit-eating behavior. For this reason, among others, we reject relativism.

R3.2. Ecological and sensorimotor accounts

We can all agree that color vision is an evolved capacity possessed by a wide variety of types of animals occupying different environments and with different ecological requirements. Ben-Ze'ev, Huettel et al., MacLennan, and Myin claim that this fact favors a Gibson-inspired "ecological" or "sensorimotor" account of color over the view we defend.

As Clark, Funt, Huettel et al., Maloney, and Myin point out, recovery and processing of color information draws on many features of the scene (and the perceiver's relation to it) other than the reflectance of the target surface. One source of color information may well be changes in the proximal stimulus induced by the perceiver's motion through the environment, as suggested by Clark and Myin (see also Myin 2001; O'Regan & Noë 2001a; 2001b). However, as Clark evidently realizes (along with Funt and Maloney), none of these interesting and important proposals about *the sources organisms use to recover color information* is in any tension with the claim that *the information recovered* is about reflectances. Interpreted as a claim about what color vision tells us about the world, ecological and sensorimotor contingency accounts appear to conflate the sources of color information with color information itself. In any case, as Clark nicely demonstrates, one might use the genuine insights behind these accounts to support color physicalism, not to reject it.

MacLennan raises the issue, discussed in section 3.3 of the target article, of whether reflectances are insufficiently ecologically relevant to be identified with colors. As Mac-

Lennan says, reflectances derive their significance in the lives of animals from their correlation with other properties more directly connected with ecological needs. Many of the correlations that make reflectance information useful are, in addition, local and temporary. But although this shows that reflectances are rarely of primary ecological significance it does not begin to show that colors are not reflectances. On the contrary, this feature of reflectances is entirely welcome because color is rarely of primary ecological significance. Many of the correlations that make color information useful are also local and temporary and as a result many organisms adjust their responses to color cues on the basis of their past experience. (This is why we find Huettel et al.'s enthusiasm for the Gibsonian terminology of "affordance" misplaced. There is no single kind of behavior that the perception of a specific color affords.)

R3.3. Pluralistic realism

Matthen advertises "pluralistic realism," an interesting account of color that he has developed in a number of publications (1999; 2001; in press), and Decock & van Brakel profess a similar view. (Just how similar the two views are is questionable. The heady Quinean thesis of ontological relativity [Quine 1969] seems to be an important component of Decock & van Brakel's position, but it is no part of Matthen's view as we understand it.) One strand of pluralistic realism is that, although objects *are* colored, "there is no mind-independent property that all color perceivers track or detect, no one ecological problem that they all try to solve" (Matthen 1999, p. 84). Realist accounts like ours, which claim that all color perceivers (including nonhuman animals) detect reflectances (or productances), are not pluralistic in the intended sense. However, we agree with Matthen that color vision systems in different species are put to very different uses, and so despite our being "monistic" realists, we do not think there is a single ecological problem that all color vision systems try to solve.

Another strand of pluralistic realism is its commitment to relativism. According to Matthen, the tomato that I see as unique red and you don't, "really is unique red in my visual system's 'sense,' and really isn't in yours." As far as we can see, these two strands are entirely independent. At any rate, we reject the second strand for the reasons given in R3.1.

R3.4. Eliminativism

A number of our commentators hold that objects like tomatoes aren't colored and hence that creatures with color vision are all subject to a pervasive illusion: As Kuehni puts it, "color is a construction of the brain." The predominant motivation in the commentaries for eliminativism appears to be the fact of variation in color vision, which we dealt with in R2.5, above. However, Rudd and Nijhawan offer other arguments.

Rudd gives the following argument: "A surface having particular reflectance characteristics can . . . appear to have any one of a large number of colors. Thus, the claim that color can be identified in any simple way with a class of reflectances is wrong." But Rudd's conclusion does not follow from his premise. The one-many mapping between reflectance and apparent color only establishes the (unsurprising) fact that the *apparent* color of a surface cannot be identified with one of its reflectance-types, not that the *real*

color of a surface cannot be identified with one of its reflectance-types.

Nijhawan is not just a *color* eliminativist; according to him, apparent *spatial* properties are not possessed by objects like tomatoes. We are not completely sure why he thinks this, but here is one perhaps revealing remark: “If . . . processes early in the visual pathway are considered, then the after-image case, the prism displacement case [where the location of a red disk is misperceived], and the ‘normal’ viewing case, are all similar. So, a theory of color perception needs to explain all of these situations.” This suggests the following line of thought: Visual perceptions seem to depend only on “processes early in the visual pathway,” and not on how things *are* in the scene before the eyes, so what we perceive must be in our “inner environment,” not in our outer environment. And if we do not actually perceive things in our outer environment, we presumably do not have any reason for thinking that external objects are either colored or shaped. This is basically the notorious “argument from illusion” (see Austin 1962; Smith 2002).

Two general points about eliminativism are worth stressing. First, if eliminativism is correct, our perceptual apparatus, and that of many other animals, has evolved to represent a range of properties that nothing has (and maybe that nothing could have). Just how it could have done that is something of a mystery (for dissent on this point see Hardin 1990). Second, if eliminativism about color is plausible, the arguments for it can probably be adapted to show that other perceptual modalities are equally infested with error. If we are forced to conclude that nothing has any color, then sound, to take **Handel & Erickson’s** example, should be banished along with it. Eliminativism about color thus threatens to obliterate anything resembling our intuitive conception of a perceiver’s environment, as populated with variously colored, noisy, smelly, and tasty objects.

The second point can be turned around. If realism about sound is plausible, realism about color is too. Moreover, as **Handel & Erickson** insightfully recognize (see also O’Callaghan 2002), physicalism about sound (and other perceptible qualities) to a large extent stands or falls with physicalism about color.

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References

Letters “a” and “r” appearing before authors’ initials refer to target article and response, respectively.

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