On the Structural Properties of the Colors[*]

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Total grandeur of a total edifice,
Chosen by an inquisitor of structures
For himself. He stops upon this threshold
As if the design of all his words takes form
And frame from thinking and is realized.
— Wallace Stevens, *To an Old Philosopher in Rome*

Primary quality theories of color claim that colors are intrinsic, objective, mind-independent properties of external objects — that colors, like size and shape, are examples of the sort of properties moderns such as Boyle and Locke called primary qualities of body.[1] Primary quality theories have long been seen as one of the main philosophical options for understanding the nature of color.

However, a recent, empirically motivated argument seems to have convinced many that primary quality theories cannot be sustained. This argument, in outline, alleges that colors bear structural relations to each other that no primary qualities bear to each other, and therefore that colors cannot be primary qualities. This argument has received considerable philosophical attention in recent years, and appears to have convinced many to abandon primary quality theories of color.[2] However, I believe the argument has been misunderstood. In this paper I shall examine arguments based on the structural properties of the colors in order to discern what they do and do not show about primary quality theories of color.

I'll begin by reviewing the empirical data concerning structural properties of the colors and then showing how these data have been used to argue against primary quality theories of color (§1). Then, after looking at some unsatisfactory responses to this argument (§2), I'll offer another response (§§3–5) that, it seems

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[1]Famously, Boyle and Locke themselves denied that colors were primary qualities, and instead took them to be secondary qualities — dispositions to produce certain sorts of experiences in perceivers. Primary quality theories of color have been defended (sometimes under other names, such as 'color physicalism' or 'color objectivism') by many, including [Armstrong, 1968], [Hilbert, 1987], and [Byrne and Hilbert, 1997a].

[2]I believe the argument is original to C. L. Hardin, although it has appeared (in different versions) in several places, including [Hardin, 1984], ([Hardin, 1988], xxi–xxii, 66–67), [Velleman, 1995], ([Thompson, 1995], 128–130, 135–139), and ([Maund, 1995], 42, 141, *et passim*). [Johnston, 1992] gives a related, but more complicated (and more epistemic) version of the argument that I shall not discuss here.

to me, is more successful. Next, I'll consider a closely related argument against primary quality theories that is typically insufficiently distinguished from the original argument (§6). Finally, I'll show that a primary quality theorist can respond to this second argument as well (§7). I'll conclude that, despite their prominence in recent philosophical writings about color, considerations involving the structural properties of the colors are unsuccessful in refuting primary quality theories of color.

1 The Argument from Structure

Before we can proceed, we need a description of the data. Just what are the structural relations among the colors? The most important sets of structural relations are the so-called unity relations and the unique/binary distinction.[3]

The unity relations are the similarity and exclusion relations that hold among the colors. For example, one such relation is that red is more similar to orange than it is to blue; another is that no shade of yellow is a shade of blue; others include that red and green, orange and blue, and yellow and purple are pairs of maximally dissimilar hues. By gathering all such facts, we can construct a Quinean similarity space of the colors, and assign to each color a place in this space. Johnston describes these relations as follows:

> Thanks to its nature and the nature of the other determinate shades, canary yellow, like the other shades, has its own unique place in the network of similarity, difference, and exclusion relations exhibited by the whole family of shades. (Think of the relations exemplified along the axes of hue, saturation, and brightness in the so-called

[3] Unity and the unique/binary distinction have been the most discussed structural relations of the colors in the literature. However, there are other important structural properties of the colors. For example, Matthen mentions these:

> *Categoricity*. The colors to which human languages give names are experienced across cultures as sharply different from one another. This phenomenon . . . is the cause of the banded look of the rainbow, or of a Munsell color chart. . . .
>
> *Affect etc*. Colors carry affective associations. Red has an agitating effect on people, for instance, while green is soothing. The warmth and coolness of colors . . . also have affective associations. Some of these are strongly cross-cultural, and seem to have a genetic component ([Matthen, 1999], 66–67).

In what follows, I shall ignore these additional structural properties of the colors, choosing instead to focus on unity and the unique/binary distinction for a number of reasons. First, the most discussed formulations of the argument from structure, and those that I take as my targets in the present paper, have tended to rest exclusively on unity and the unique/binary distinction. Second, it seems that the categorical and affective structure of the colors is rather poorly understood by vision science (in comparison, and as I shall discuss in §4, contemporary vision science seems to provide a reasonably good explanation for unity and the unique/binary distinction); until we know what the explanations for these features looks like, it will remain unclear that these explanations are any more difficult to reconcile with a primary quality theory of color than with some other theory of color. And third, I believe that the strategy of response to the argument from structure in §5 can be generalized to cover other structural properties of the colors, including their categorical and affective properties, once vision science provides us some insight into the mechanisms underlying these other properties.

color solid. The color solid captures central facts about the colors, e.g., that canary yellow is not as similar to the shades of blue as they are similar among themselves, i.e., that canary yellow is not a shade of blue) ([Johnston, 1992], 138).

A second set of structural relations among the colors involves the idea that there are precisely six phenomenally elementary colors, which are experienced as unmixed: red, green, blue, yellow, black, and white. That is, there is a shade of red that is experienced as not at all bluish and not at all yellowish, there is a shade of green that is experienced as not at all bluish and not at all yellowish, there is a shade of blue that is experienced as not at all reddish and not at all greenish, and there is a shade of yellow that is experienced as not at all reddish and not at all greenish. In contrast, the vast majority of colors are experienced as being mixed: for example, no shade of orange is experienced as not at all reddish and not at all yellowish, and no shade of violet is experienced as not at all bluish and not at all reddish. Indeed, even for the colors that have unmixed shades, most shades will be experienced as mixed: thus, although there is an unmixed shade of red, most shades of red are experienced as somewhat yellowish or somewhat bluish. Colors experienced as phenomenally unmixed are described as unique; the others are described as binary.

It's not entirely clear what it means to say that colors are experienced as mixtures of other colors, but the claim that some colors are so experienced while others are not has received quite robust empirical support. For example, as ([Hardin, 1997], 291–292) discusses, naïve subjects asked to describe light samples as a combination of percentages of color names have no difficulty describing samples to which they first apply the label 'orange' with a combination of 'red' and 'yellow', but cannot describe the region around 580nm (where most subjects find their best yellows) without using the name 'yellow' (cf. ([Hardin, 1988], 42) and ([Boynton, 1979], 210–211)). Similarly, Clark notes that the set of unique colors is such that (i) mixtures of its members can be found that will perceptually match any color, and (ii) each of its members cannot be perceptually matched by a combination of other colors ([Clark, 1993], 126–127).[4]

As I have said, several authors have appealed to the structural properties of the colors cataloged so far as a way of arguing against primary quality theories of color. The argument they have given, which I shall call 'the argument from

[4] The available evidence also suggests that the structural properties discussed so far are not merely conventional truths about them, passed down through linguistic or some other cultural means of transmission. Thus, Hardin points out ([Hardin, 1988], 40ff) that these structural relations have been reproduced in experiments using as subjects pre-linguistic infants (via habituation times; cf. [Teller and Bornstein, 1987]), members of the Dani people whose language lacks abstract words for the chromatic colors [Rosch, 1973], and even non-human (macaque) primates (cf. [Hardin, 1997], 293–294). If human beings whose color language and wider culture is vastly different from our own, and even infraverbals, can sort color samples based on the structural properties considered above, it's hard to see how these properties could be the product of convention (as is, say, the property red lights at traffic intersections have of compelling motorists to slow their vehicles). Instead, these results suggest, such properties should be understood as naturally occurring and independent of our explicit beliefs and culturally regimented conventions concerning colors.

structure', is a simple instance of Leibniz's law: colors have these structural properties, and therefore any set of properties that is identical with the colors must have them as well. However, it is suggested, the only plausible candidates proposed by primary quality theorists for being identical with the colors lack the structural properties in question, and therefore the purported identities cannot be sustained. Consequently, it is claimed, no primary quality theory of color could be true.

2 Unsuccessful Responses

To see the difficulties raised for primary quality theorists by the argument from structure, it is worth observing that at least some primary quality theorists who have attempted to meet its challenge have failed.

Thus, for example, in the course of defending the identification of the colors with spectral reflectance distributions, Hilbert defines a similarity metric over spectral reflectance distributions on which, he claims, the unity relations are preserved ([Hilbert, 1987], 117–118). On this story, if λ ranges over wavelengths of the visible spectrum, and R_S, R_M, and R_L are the (overlapping) wavelength ranges to which the three types of human color receptor cells (S-cones, M-cones, and L-cones, respectively) are sensitive, the metrical distance $\rho(h_1(\lambda), h_2(\lambda))$ between reflectances $h_1(\lambda)$ and $h_2(\lambda)$ is equal to the three-dimensional Euclidean distance between the triples $\langle \int_{R_S} h_1 d\lambda, \int_{R_M} h_1 d\lambda, \int_{R_L} h_1 d\lambda \rangle$ and $\langle \int_{R_S} h_2 d\lambda, \int_{R_M} h_2 d\lambda, \int_{R_L} h_2 d\lambda \rangle$, or

$$\sqrt{(\int_{R_S} h_1 d\lambda - \int_{R_S} h_2 d\lambda)^2 + (\int_{R_M} h_1 d\lambda - \int_{R_M} h_2 d\lambda)^2 + (\int_{R_L} h_1 d\lambda - \int_{R_L} h_2 d\lambda)^2}.$$

Hilbert's proposal, then, is that the similarity relations between colors (such as red's being more similar to orange than it is to blue) should be understood as claims about the relative metrical distances between the integrated triples of the reflectances that he identifies with colors. This metric is intended to preserve the similarity relations between the colors: the similarity between two colors should increase monotonically as the metrical distance between their integrated triples shrinks. Unfortunately, however, this proposal fails: as argued in ([Thompson, 1995], chapter 3), Hilbert's metrical relation correlates with the unity relations only in extraordinarily constrained circumstances — those in which samples are all of a constant lightness level viewed against a homogeneous surround.[5]

To take another example, Tye proposes to explain the unique/binary distinction among colors in terms of what we learn about the ways various pigments combine, e.g., by mixing paints in kindergarten ([Tye, 1995], 148). Unfortunately, this proposal is also implausible for empirical reasons. First, evidence that the unique/binary distinction made by (pre-kindergarten) pre-linguistic

[5] Hilbert has conceded the failure of his proposal in ([Byrne and Hilbert, 1997a], 285, note 32).

infants and non-human primates (see note 4) suggests that the distinction in question is not learned at all, *a fortiori*, not learned in the way that Tye suggests it is learned. Second, since kindergarten experimentation informs us that blue and yellow pigments combine to form green pigment, Tye's proposal predicts that green is binary, which it is not.[6]

The moral I wish to draw from these unsuccessful responses to the argument from structure is not, of course, that the argument succeeds in refuting primary quality theories of color. It is, rather, that that argument has teeth, and that it has resisted easy answers.

3 Structure and Color Experience

I propose to answer the argument from structure by constructing structural properties that are exemplified by primary qualities and that predict the data of §1. I'll develop this response in three steps. First, in the present section, I shall propose an account of the structural properties of unity and the unique/binary distinction that applies not to the colors, but to color experiences. Second, in §4, I'll offer a causal explanation for the structural properties of color experience that connects with color science. And third, in §5, I shall show how we can use the structural properties of color experiences to induce analogous structural properties of the colors themselves, as I have conceived them.[7]

My first task, then, will be to show how we may conceive of the structural properties already considered as properties of color experiences, rather than of the colors themselves. Of course, the data of §1 have usually been interpreted by those who offer the argument from structure as showing that the color properties

[6]Green pigment is obtained by mixing blue and yellow pigment, but green light cannot be obtained by combining lights of colors that are not at all greenish (blue light and yellow light combine to make white light). This is because the laws of subtractive color mixing that govern pigment combination differ from the laws of additive color mixing that govern light combination (see [Hurvich, 1981], 96–98; [Palmer, 1999], 690–694).

Could Tye recast his proposal as the suggestion that the unique/binary distinction captures learned truths about additive color mixing? Even on the somewhat implausible assumption that ordinary adult subjects in typical subject pools (e.g., students in university introductory psychology courses) had acquired beliefs about additive color mixing, this would still fail to explain how the distinction is made by subjects from remote cultures, pre-linguistic infants, and non-human primates (see note 4).

[7]The strategy of answering the argument from structure by regarding the structural properties primarily as properties of color experiences, and only derivatively as properties of colors, is not wholly novel. Some version of this strategy can be discerned in works including ([Shoemaker, 1990], 107–108), [Matthen, 1992], [Lewis, 1997], ([Byrne and Hilbert, 1997a], 274–9), [Byrne and Hilbert, 2001], [Jackson, 1998b], [Jackson, 2000], and [McLaughlin, 2002].

I believe my response differs from these others, although they share its basic strategy, in three respects. First, I present explicit constructions of the relevant structural properties (rather than simply suggesting that this could be done). Second, I have attempted to make clear the assumptions about the relations between color and color experience that are required by this strategy, and to show why these assumptions are compatible with primary quality theories of color. Finally, the discussion in §§6–7 distinguishes modal from non-modal versions of the argument from structure that are typically run together, and shows why the two versions cannot be answered in the same way.

stand in certain structural relations. That is, these data are typically interpreted as underwriting this claim:

(C) The set of color properties satisfy the structural properties of unity and the unique/binary distinction.

However, while I do not wish to reject this interpretation (indeed, I shall attempt to vindicate it in §5), I want to note that there is another interpretation according to which these data reflect relations between color experiences rather than colors themselves. On this second interpretation, what the data show is this:[8]

(E) The set of color experiences satisfy the structural properties of unity and the unique/binary distinction.

Now, writers typically introduce a second interpretation only in order to argue that a first interpretation is false. But it is not my intention to replace (C) with (E); rather, I want to begin by defending (E), and then ultimately use it to defend (C). The argument from structure, as we have seen, challenges primary quality theorists to explain how (C) could be true. My strategy for answering this challenge will be to explain why (E) is true, and then to use this claim to show that (C) is true as well.

To begin, then, I want to suggest that (E) is a plausible interpretation of the data. One reason that we might initially favor taking the data as supporting (E) (rather than (C)) is that the former choice provides a less controversial explanation for the capacity of theoretically naïve subjects to make the judgments cataloged in §1. How is it that naïve subjects will readily aver that red is more similar to orange than it is to green and sort color samples in ways that reflect a unique/binary distinction? It seems implausible that naïve subjects base their reports on a worked out theory about what the colors are or what sort of similarity relations obtain between colors. In contrast, it seems relatively uncontroversial that naïve subjects have access to their own phenomenal color experiences and (at least some of) the relations that obtain between them, and that their reports are based on their own experiences and the relations between them. If so, then it is plausible to take the data of §1 as pointing to the truth of (E).[9]

[8]The two interpretations considered will remain distinct only if we enforce a distinction between color properties and color experiences. Although this distinction will be rejected by some (e.g., perhaps some kinds of sense-data theorists), it will be accepted by the main parties to the debate over primary quality theories.

[9]Objection: If the immediate justifications for subjects' judgments are facts about color experiences rather than colors, why do subjects state that this or that property holds among the colors? Why do they not confine themselves to making statements about their experiences, which would hew more closely to the justifactory basis for their judgments? Are our allegedly theoretically naïve subjects all assuming a sense-data theory or some other account that collapses the distinction between colors and color experiences, so that data about the latter are, *eo ipso*, data about the former? And if not, then isn't (C) a more plausible interpretation than (E) after all?

Reply: I think this imputation of theoretical views to subjects is unwarranted. Rather, Suppose, then, that (E) is true, while remaining agnostic for the time being about the truth of (C). (E) is, of course, a claim about structural relationships that obtain among our color experiences. As such, (E) is a phenomenological generalization about subjects' comparative judgments. It says that color experiences stand in a similarity space (the dimensionality and other features of which can be gleaned from comparative judgment data by standard psychophysical techniques such as multi-dimensional scaling; see [Shepard, 1962a], [Shepard, 1962b]), and that subjects discriminate between certain of their color experiences that are phenomenally unmixed (those produced by monochromatic light of certain frequencies in the red, green, yellow, and blue ranges, and some white and some black stimuli) and all their other color experiences. As usual, the similarity space of color experiences, so defined, comes with a similarity metric ρ_E; for any three color experiences $e_1, e_2, e_3 \in E$, $\rho_E(e_1, e_2) < \rho(e_1, e_3)$ just in case subjects judge e_1 to be phenomenologically more similar to e_2 than e_1 is to e_3. Moreover, the distinction between phenomenally mixed and unmixed color experiences can be expressed in terms of a predicate, defined over the space E: let a color experience $e \in E$ be in the extension of the predicate u_E just in case subjects judge e to be phenomenally unmixed.

If what I have said is correct, the allegedly problematic structural properties of the colors are facts about color phenomenology that can be represented in terms of the metric ρ_E and the predicate u_E. In §5 I shall argue that these materials provide what is needed to secure (C), the claim that the colors themselves exemplify the structural properties at issue. However, before I come to this, it is worth pausing to connect what has been said so far with vision science.

4 Color Experience and Opponent-Process Theory

On the interpretation I am recommending, (E) is not the conclusion of an *a priori* argument, but an empirical generalization. This means that (E) is not in need of argumentative justification (it is, of course, in need of experimental support — which, as discussed in §1, it has in spades). However, even if no argument for (E) is needed, we might hope to provide it with a causal explanation.[10]

I think we should say, it is part of subjects' tacit understanding of their experience that it represents the world; in particular, that their color experiences veridically represent the color properties, and that properties of their color experiences represent properties of the colors. For this reason, they take themselves to be justified in inferring from facts about their color experiences to facts about colors, and normally phrase their reports in terms of the latter. If I am right about this, then we may retain our confidence in the interpretation (E) as a more modest alternative to (C), despite the language subjects use in the experiments discussed in §1.

[10]Needless to say, we must not assume that such an explanation can be given. It is epistemically possible that (E) is a brute phenomenological truth, not susceptible of causal explanation. However, as I hope to demonstrate, this epistemic possibility seems to be non-actual as a matter of empirical fact: current vision science apparently offers the materials for a principled explanation of (E).

Of course, whether we can supply a causal explanation for (E) is, in principle, irrelevant to my main purpose of responding to the argument from structure. For the purposes of my response to that argument, there is no need for a causal explanation of (E) at all; all that is necessary is that (E) is true, and that this allows the construction of structural properties of the colors carried out in §5. However, I think the present digression is justified insofar as it connects the argument from structure with important currents of mainstream visual science, and shows how these developments fit comfortably with primary quality theories of color (claims to the contrary in the literature notwithstanding).

Now, exactly how we should explain (E) will depend largely on we understand the metaphysics of color experience, and this is itself a point of intense philosophical controversy that I cannot hope to resolve here. However, I want to give an explanation of (E) that does not turn on tendentious metaphysical assumptions about the nature of color experience. This is possible because, despite controversies about the metaphysics of color experience, all sides are willing to admit that color experiences are correlated with states of the nervous system, understood broadly.[11] My strategy will be to explain (E) in terms of the structural relations holding among the states of the nervous system correlated with color experiences.

As it happens, vision science has made significant progress in understanding the correlate nervous system states and the relations among them in terms of opponent-process theory.[12] Opponent-process theory, initially proposed by Ewald Hering [Hering, 1964], is a neuro-computational account of color vision according to which color appearances are encoded along three independent neuro-functional channels: red-green, blue-yellow, and white-black. On this theory, the pair of color names for a given channel marks an opposition between the colors so named. Thus, since red and green oppose each other, nothing appears both red and green, and adding green to a red stimulus will inhibit the extent to which it appears red (similarly vice versa and for the other channels).[13] These oppositions are recognized in quantitative formulations of opponent-process theory by assigning negative values to one member of each opposed pair and positive

[11] If color experiences are *identical* with such states of the nervous system, then this would provide a simple and direct understanding of why the noted "correlation" holds. However, I don't want my proposed explanation of (E) to depend on assuming the truth of an identity theory of color experience; rather, I shall be making only the much weaker and much less controversial assumption that there is a *de facto* correlation between color experiences in us and certain physical states. I expect that no realist about color experiences (not even a dualist) would deny this.

[12] Because of ongoing disputes about the details, opponent-process theory might more aptly be regarded as a theoretical framework rather than a single theory. That said, this theoretical framework has been supported by several converging lines of research in different areas of color science (notably in psychophysics and cognitive neurophysiology), and is so well-established that, as Jameson and Hurvich (the authors of contemporary formulations of the theory) put it, "opponent neural processing as fundamental to color vision is by now universally accepted" ([Jameson and Hurvich, 1989], 187; cf. [Hurvich and Jameson, 1957], [Boynton, 1979], [Hurvich, 1981], [Hubel, 1988]).

[13] As Alan Gilchrist and Larry Hardin have emphasized in conversation, the black-white channel is a partial exception to this claim, since a given stimulus can be simultaneously blackish and whitish in appearance (viz., by appearing grey).

values to the other. Thus, conventionally, green, blue, and black are assigned negative values, while red, yellow, and white are assigned positive values along the red-green, blue-yellow, and white-black dimensions.[14]

This brief discussion of opponent-process theory is sufficient to provide a causal explanation of the structural properties of the unity relations and the unique/binary distinction among color experiences.[15]

First, we may represent a state of the opponent-process system by a triple of numbers: one for each of the three opponent-process channels. Thus, the first component of the triple will be the value for the red-green channel, the second component will be the value for the blue-yellow channel, and the third component will be the value for the black-white channel.[16] Since we can do this, and since color experiences are correlated with states of the opponent-process system, we can represent every color experience in terms of the ordered triple corresponding to the opponent-process state with which it is correlated. Having done this, we may explain the structural properties of color experiences as follows.

To accommodate the unity relations, we need to construct the graded similarity relation ρ_E over color experiences. The present suggestion is that we can do this in terms of the three-dimensional Euclidean distance between the opponent-process triples that encode them. Thus, for color experiences e and e' that are assigned to the opponent-process triples $\langle e_1, e_2, e_3 \rangle$ and $\langle e'_1, e'_2, e'_3 \rangle$, the metrical distance ρ_E will be defined as follows:

$$\rho_E(e, e') = \sqrt{(e_1 - e'_1)^2 + (e_2 - e'_2)^2 + (e_3 - e'_3)^2}.$$

In addition, we may construct the predicate u_E (recall that, under the intended interpretation, we want this predicate to apply to all and only the unique color experiences) over color experiences by holding that, for any color experience e corresponding to the opponent-process triple $\langle e_1, e_2, e_3 \rangle$, $u_E(e)$ iff:

(i) $e_1 \neq 0$ and $e_2 = 0$, or

(ii) $e_1 = 0$ and $e_2 \neq 0$, or

(iii) $e_1 = 0$, $e_2 = 0$, and $|e_3| > t$ (t is an empirically determined threshold).

[14] Opponent-process theory is discussed in much more detail in ([Hurvich, 1981], 17–22, chapters 5–7, chapter 12, *et passim*). See also the summaries in ([Byrne and Hilbert, 1997c], xvi–xviii) and [Hardin, 1988], 26–40.

[15] Notice that, since opponent-process theory is a theory about the organization of the normal human visual system, the account of the structural properties it provides will be anthropocentric. But I think this is appropriate: although the data for the attribution of structural properties to the colors is taken from a variety of humans (and macaques, the organization of whose visual system we have independent neuro-anatomical grounds for suspecting is at least highly similar to our own), color samples are not sorted into the same classes by organisms with very different visual systems (e.g., goldfish [Neumeyer, 1992], honeybees [Backhaus, 1998], pigeons [Thompson, 1995], or decachromatic mantis shrimp [Cronin and Marshall, 1989]). If the data are anthropocentric, then there can be no objection to explaining them by an anthropocentric theory.

[16] The procedure for assigning these numbers in a well-defined way is discussed in detail in [Hurvich, 1981], chapter 5.

Intuitively, this predicate will be satisfied under clause (i) by a color experience with no blue-yellow component (a unique red or a unique green experience), under clause (ii) by an experience with no red-green component (a unique blue or a unique yellow experience), and under clause (iii) by a color experience with no chromatic component at all and whose achromatic component is toward the extreme negative end of its range (a unique black experience) or the extreme positive end of its range (a unique white experience).[17]

I claim that these constructions of ρ_E and u_E are adequate to the structural properties of unity and the unique/binary distinction, construed as structural properties of color experiences. To see why, note that the opponent-process state produced in us by a red stimulus occurs when the red-green channel takes a positive value and the blue-yellow channel takes a value near zero (I am considering what we might call a pure red, as opposed to, say, crimson, pink, vermilion, etc.). Similarly, the state produced in us by a green stimulus occurs when the red-green channel takes a negative value and the blue-yellow channel takes a value near zero. That the state correlated with experience of red e_{red} and that correlated with experience of green e_{green} require opposite values on the red-green channel explains why these two states are maximally dissimilar — why $\rho_E(e_{\text{red}}, e_{\text{green}}) > \rho_E(e_{\text{red}}, e)$ for all $e \neq e_{\text{green}}$ and $\rho_E(e_{\text{green}}, e_{\text{red}}) > \rho_E(e_{\text{green}}, e)$ for all $e \neq e_{\text{red}}$. Now, the state correlated with experience of orange e_{orange} requires positive values on both the red-green and the blue-yellow channels, and therefore $\rho_E(e_{\text{orange}}, e_{\text{red}}) < \rho_E(e_{\text{orange}}, e_{\text{green}})$. By means of such explanations we can capture all the unity relations.

What about the unique/binary distinction? According to the definition set out above, the predicate u_E will apply to just those chromatic color experiences one of whose chromatic opponent-process values is zeroed out, leaving the remaining chromatic channel to make an unmixed contribution to the total appearance. There will be one color experience type in the extension of u_E, then, for each of the poles of each chromatic opponent-channel: these will be experiences of (pure shades of) red, green, blue, and yellow. In addition, u_E will apply to achromatic color experiences whose opponent-process states have zero values along both the red-green and blue-yellow channels and extreme values on the achromatic channel; in this case, the achromatic channel will make an unmixed and extreme contribution to the total appearance, resulting in either a pure black or a pure white experience. Of course, this means that u_E partitions the space of color experiences precisely as an (E) interpretation of the unique/binary distinction demands.

This shows how we can appeal to the opponent-process system to explain the structural properties of unity and the unique/binary distinction in ways that match the data of subject reports. Moreover, the theory of this neuro-computational system and the description of its computational behavior and physiological implementation are among the best-motivated, highly-elaborated, and widely-accepted neuro-scientific accounts in existence. Therefore, because

[17]Notice that, on this definition, chromatic unique opponent-process states have an achromatic component. This prediction is confirmed by the data (cf. [Hurvich, 1981], 61ff).

color experiences are correlated with states of the opponent-process system, this account provides a detailed causal explanation for (E).

5 Structure and the Colors

In §3 I proposed that the data of §1 justify (E) at least as well as (C), and in §4 I argued that we may look to opponent-process theory to provide a principled causal explanation for (E). This much will seem largely uncontroversial, I expect, to those who have deployed the argument from structure to argue against primary quality theories of color. What is much more controversial is what I want to do next: I want to use the results obtained so far to show that (C) is true, when colors are understood to be primary qualities. I shall proceed by constructing a similarity relation and a unique/binary distinction that hold over the primary qualities identified with the colors by primary quality theorists, and that correlate with the structural properties of the colors adduced in §1.

Recall that a primary quality theory of color is one on which colors are objective, mind-independent properties of external objects. Since I want the response I provide to be available to *any* primary quality theorist, no matter what primary qualities she takes the colors to be, I won't be making any assumptions about which objective, mind-independent properties of external objects are the colors. All I shall assume is what is common to primary quality theorists — that colors are not properties, states, or processes in the minds of observers, but are mind-independent properties of external objects in the world.

However, while primary quality theorists hold that colors are mind-independent properties of external objects in the world rather than properties of the minds of observers, they will nonetheless acknowledge happily that colors are systematically related to certain states of the minds of observers — viz., color experiences. In particular, they will hold, colors are systematically related to color experiences in the following way: instances of color properties are disposed to produce characteristic color experiences in observers. Indeed, this relationship between colors and color experiences is no accident, according to the primary quality theorist; the reason colored objects are disposed to produce color experiences, she will say, is that colors are the bases of the dispositions to produce color experiences — to look colored.[18] For example, the primary quality theorist will hold that the objective, mind-independent property *red* is the basis for the disposition to look red; that the objective, mind-independent property *green* is the basis for the disposition to look green; and so on for the other colors. Of course, primary quality theorists typically take the connection between colors and color experiences to be contingent, and they certainly don't want to *identify* colors with color experiences or dispositions to affect perceivers (that is the sort of identification that a secondary quality theorist such as Locke would advocate). But there is no reason a primary quality theorist should deny that colors are systematically related to these dispositions, or, therefore, to color experiences.

[18] For more on dispositions and bases of dispositions, see [McLaughlin, 1995].

Because primary quality theorists understand colors as systematically related to color experiences, and because we already have in place an explanation of the structural properties of color experiences, the primary quality theorist is now in a position to explain why the colors stand in the structural relations we have considered. The empirical generalization (E) (which is supported by the data of §1, and which can be causally explained in terms of opponent-process theory) makes a number of predictions about the structural organization of color experiences. Among these, it predicts (i) that an experience of red is more similar to an experience of orange than it is to an experience of green, and (ii) that experiences of red and green are phenomenally unmixed while experiences of orange are not. But, according to a primary quality theorist, colors are the bases for the dispositions to produce such experiences. Consequently, she may explain the structural relations among the colors in terms of the structural relations among the experiences colors dispose their bearers to produce.

This point can be put more explicitly as follows. We've already seen that the structure of color experiences is organized in terms of the metric ρ_E and the predicate u_E, defined over the class of color experiences, E. But, on a primary quality account of color, there is a simple mapping between elements of E and the colors, which are properties that dispose their bearers to look colored (i.e., properties that dispose their bearers to produce color experiences — members of E). Namely, for every color $c \in C$, we can define the mapping $d : C \to E$ such that, for any $c \in C$, $d(c)$ is the color experience for which c is the basis.[19] This mapping allows the primary quality theorist to provide the structural properties required by the argument from structure. For she can now define the metric ρ_C over C so that, for any $c, c' \in C$, $\rho_C(c, c') = \rho_E(d(c), d(c'))$; it is easy to see that $\langle C, \rho_C \rangle$ will be a metric space if $\langle E, \rho_E \rangle$ is one, and that ρ_C will match subject similarity judgments if (as the data in fact bear out) ρ_E does. Moreover, she can define a predicate u_C over C such that, for all $c \in C$, c is in the extension of u_C just in case $d(c)$ is in the extension of u_E; it is clear that u_C will have in its extension just those elements of C that are the bases for the dispositions to produce unique color experiences — viz., red, green, yellow, blue, white, and black. The similarity relation defined by the metric ρ_C, together with the property u_C, explain why (C) is true, and thereby answer the argument from structure.

6 The Argument from Necessity

I have shown how a primary quality theorist can respond to the argument from structure by giving an explicit construction of the structural properties that, some have alleged, no primary qualities can have. If this were the end of the matter, I think we would be justified in concluding that the primary quality theorist has adequately answered the argument from structure. However, there is a closely related argument, typically insufficiently distinguished from the original,

[19] So defined, the mapping d may not be injective, since there may be different primary qualities that serve as bases for the disposition to produce a given color experience $e \in E$.

that is worth discussing. In this section I want to set out this new argument — henceforth, the argument from necessity, and show why the response of §5 is ineffective against this new argument. However, after showing that the argument from necessity is, in this sense, a more pressing threat than the argument from structure, I'll go on to explain why it, too, is ultimately indecisive against primary quality theories of color (§7).

The argument from necessity, like the argument from structure, is based on the structural properties of the colors discussed in §1. However, the argument from necessity differs from the argument from structure in that it involves the allegation that the structural properties under discussion are *essential* features of colors — that they hold of the colors with the modal force of metaphysical (or perhaps conceptual) necessity.

Several philosophers have been attracted by the suggestion that the colors have their structural properties essentially. Thus, for example, Hardin writes that,

> If we reflect upon 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. Since these are necessary properties of hues, nothing can be a hue without having the appropriate properties necessarily ([Hardin, 1988], 66, emphasis in original; cf. xxi–xxii).

A similar point comes out in [Johnston, 1992], where Johnston claims that our beliefs about the unity relations are among the analytically necessary beliefs about colors: "were such beliefs to turn out not to be true we would then have trouble saying what they were false of, i.e., we would be deprived of a subject matter rather than having our views changed about a given subject matter" ([Johnston, 1992], 137).

The argument from necessity is, then, as its name suggests, a modalized version of the argument from structure. It is, like the argument from structure, an instance of Leibniz's law; but where the argument from structure trades on the premise that the colors have certain structural properties, the argument from necessity turns on a modal version of this requirement, which we may represent as follows:

(M) Colors have their structural properties necessarily.

The argument from necessity moves from Leibniz's law, together with (M), to the conclusion that any set of properties identical to the colors must have these structural properties necessarily as well. However, it is suggested, even if primary qualities stand in the right structural relations *de facto*, they do not have their structural properties as a matter of necessity. Consequently, the argument concludes, colors cannot be primary qualities.

The most important reason for distinguishing the argument from necessity from the argument from structure, as I have done, is that the argument from necessity survives the response to the argument from structure offered in §5. Recall that that response involved showing that the space of color experiences has the relevant structural properties, and then, by exploiting the relationship between colors (understood as primary qualities) and color experiences, inducing structural properties onto the colors themselves. That response is successful against the argument from structure because it shows that the primary qualities that are candidates for identification with the colors do in fact have the structural properties that, according to the argument from structure, colors must have. Unfortunately, however, this response cannot secure the claim that primary qualities have the relevant structural properties as a matter of necessity, and therefore it cannot be used to answer the argument from necessity.

This is because, according to the kinds of primary quality theories most discussed by philosophers, the relationship between the colors and color experiences is only contingent.[20] That is, according to these views, the color properties are only contingently connected to the color experiences for which they are the bases. These views hold that the color property *red* is a particular mind-independent structural property; if this property happens to be a basis for the disposition to look red, then this is only a matter of contingent fact. But if the relation between colors and color experiences is merely contingent, and if the structural properties of the colors are derived from the structural properties of the color experiences to which colors are related, then colors will have their structural properties contingently as well.

We can put this point more explicitly in terms of the constructions used in §5. Suppose, as before, that C is the class of colors and E is the class of color experiences, and that we define the mapping $d : C \to E$ such that, for any $c \in C$, $d(c)$ is the color experience for which c is the basis. Then the response of §5 defines the structural properties of the colors in terms of their images under d: we defined the similarity relations of the colors in terms of the equation $\rho_C(c_1, c_2) = \rho_E(d(c_1), d(c_2))$, and the uniqueness predicate u_C by holding that c is in the extension of u_C just in case $d(c)$ is in the extension of u_E. The present difficulty is that, since the primary quality theorist holds that the colors are only contingently related to color experiences, the mapping $d : C \to E$ will be modally unstable — the value of $d(c)$ (for a fixed $c \in C$) will vary between possible worlds even when c is held constant. But if, for a given $c \in C$, the structural properties of a color c are a function of $d(c)$, and if $d(c)$ is modally unstable, c will not have the structural properties assigned to it by these constructions in all worlds. To say this, of course, is just to say that, on the current proposal, the structural properties are merely contingent features of the colors, contrary to premise (M).

[20] The restriction to "the kinds of primary quality theories most discussed by philosophers" is intended to leave room for a different sort of primary quality theory on which the relationship at issue is not merely contingent; see note 23.

7 Is Necessity Necessary?

The argument from necessity differs from the argument from structure in its reliance on (M) — in its claim that the structural properties of the colors are not just features of the colors, but are (metaphysically or conceptually) *necessary* features of the colors. But if this modal difference makes the argument from necessity invulnerable to a move that draws the teeth of the argument from structure, it also opens the argument to the objection that its modal premise (M) is false.

Can the defender of the argument from necessity secure premise (M)? I can imagine two ways in which one might argue for this contested modal claim; however, I don't find either one of them convincing. Let me say why.

7.1 The Way of Science

First consider the way of science; suppose one attempted to bolster (M) by appealing to the empirical data of §1. One might suggest that because the structural properties of the color figure so centrally in our classification of colors, and since experiments on infraverbals suggest that they are not merely conventional features of the colors (see note 4), the structural properties must be intrinsic, essential features of the colors.

This line of reasoning seems unconvincing. For a primary quality theorist could point out that, even if the data show that the colors have their structural properties in the actual world, they are silent about the features of the colors in other possible worlds, and therefore cannot justify (M) without supplementation by philosophical intuition. Nor, she might go on to say, do the data about macaques and pre-linguistic infants secure the desired conclusion: whatever these data show about the ground for our knowledge of the structural properties of the color, they, too, come only from actual cases, and therefore tell us nothing, by themselves, about what is necessary.

It seems, therefore, that the way of science gives us no reason to endorse (M).

7.2 The Way of Intuition

Consider, then, the way of intuition: suppose that, instead of (or in addition to) pointing to empirical data, a proponent of the argument from necessity attempts to motivate (M) by a more standard technique in the philosopher's arsenal — the appeal to intuition. He might claim, on the strength of intuition, that a property simply could not be *red* unless it were more similar to *orange* than to *green* in every possible world, unless it were unique rather than binary in every possible world, and so on.[21]

[21] In fact, this is the avenue most often pursued by writers who have attempted to motivate (M) (see, for example, the quotations from Hardin and Johnston in §6; see also ([Velleman, 1995], 425)).

Unfortunately, it seems to me that this response, too, will be ineffective against a primary quality theorist.

First, the primary quality theorist will reject such bare appeals to intuition on the grounds that they are question-begging; after all, by asking for justification of (M), the primary quality theorist reveals precisely that she does not share (or, in any case, does not accept) the intuition in question. Consequently, it is question-begging to appeal to that very disputed intuition in an argument against her.

Moreover, the primary quality theorist can explain the source of the disputed intuition. Echoing the distinction between (C) and (E) developed in §3, she can reinterpret the (according to her, mistaken) intuition in favor of (M) as a correct intuition about color experience, rather than an intuition about color that she takes to be incorrect. She can say that, even if *red* does not have its structural relations to the other colors as a matter of necessity, the following is true: given the mechanisms underlying our color experience, our experience of *red* is necessarily structurally related in the relevant ways to our experiences of the other colors. Or, to put this in terms of §3, even if (C) is not necessary, (E) is necessary so long as the mechanisms underlying color experience are in place.[22] Thus, a primary quality theorist can not only respond to the argument from necessity by disputing the intuitive support marshaled in favor of (M), but can also explain why this intuition arises. The intuition of the necessity of (C) is, according to her, better understood as an intuition of the closely related claim that (E) is necessary, given our makeup.

Finally, the primary quality theorist can explain why her opponent misinterprets what she claims to be the real and correct intuition (that in favor of the necessity of (E), given our makeup) as an intuition in favor of (M). She will suggest, in a Kantian vein, that because we always think of the colors in terms of our experiences of them, we are prone to neglect the contribution of our own makeup to our color experiences, and to think of properties of color experiences exclusively as properties of colors. Having made this entirely natural error, the primary quality theorist will continue, the opponent mistakes a correct intuition about the necessity of (E) (given the perceptual and cognitive apparatus we in fact have) for the incorrect intuition of the necessity of (C), and then goes on to use that incorrect intuition as a premise in the argument from necessity.

The primary quality theorist, then, can deny the intuition used to support (M), and can offer an empirically motivated reinterpretation of the intuition that renders it powerless against primary quality theories. I conclude that the way of intuition, too, fails to provide adequate support for (M).

Thus, neither of the two motivations for (M) we have considered is successful. But if (M) is without support, then so too is the argument from necessity, which appeals to (M) as a premise.[23]

[22] Of course, this is not to say that the mechanisms underlying color experience must necessarily be as they are. It is, rather, to say that, given that these mechanisms are configured the way they are, color experiences have their structural properties necessarily.

[23] The response to the argument from necessity I have considered involves rejecting (M).

8 Conclusion

Although arguments involving the structural properties of the colors have figured at the center of contemporary philosophical attacks on primary quality theories of color, these arguments seem to be less than decisive. The simpler, non-modal, form of the argument (here called 'the argument from structure') can be answered directly by the construction of §5; this construction shows, explicitly and in terms of an extremely well-motivated body of scientific theory, how primary qualities have the structural properties many have claimed they cannot have. The more complex, modal, form of the argument (here called 'the argument from necessity') is more challenging to primary quality theorists; but it, too, is answerable. The primary quality theorist can respond to this second argument by rejecting its modal premise (M), and by providing motivated reinterpretations of the intuitions supporting that premise.[24]

Arguments concerning the structural properties of the colors, then, are ineffective against primary quality theories. Rumors of the death of primary quality theories of color, I suggest, have been greatly exaggerated.[25]

As I have indicated, I believe this rejection is plausible. However, there is a further question whether there could be a kind of primary quality theory that (unlike those I have considered here) accepts (M), but that avoids the conclusion of the argument from necessity by explaining how primary qualities have their structural properties necessarily. I believe not only that there can be such a view, but that there is one: the functionalist view of color I have defended elsewhere seems to me to be an example of a (non-traditional) primary quality theory of color that makes the structural properties necessary features of the colors (versions of functionalism are defended in such works as [Jackson and Pargetter, 1987], [Jackson, 1996], [Jackson, 1998a], [McLaughlin, 2002]; my own defense of color functionalism occurs in [Cohen, 2000b] and [Cohen, 2000a]).

Briefly, color functionalism is a functional analysis according to which colors are (not the dispositions to look colored, but) the (numerically distinct) properties that dispose their bearers to look colored — the properties in virtue of which things have their dispositions to produce certain kinds of experiences in perceivers. Color functionalism is distinct from standard Lockean secondary quality accounts of color since functionalism denies that colors are the dispositions to look colored, and instead takes them to be the properties in virtue of which things have their dispositions. At the same time, functionalism differs from traditional primary quality theories in that, according to the former view, what is constitutive of being a color property is not having some particular material makeup, but rather playing a certain functional role — viz., the functional role of disposing bearers of that property to look colored.

Color functionalism is interesting in the present setting, I believe, because it provides the materials for a response to the argument from necessity that, unlike the response considered above, is compatible with the acceptance of (M). For, according to color functionalism, colors are constituted in terms of their functional roles of disposing their bearers to look a certain way — to produce color experiences, and therefore are constitutively (and therefore necessarily) connected with color experiences. Because functionalism makes the connection between a color and the experience it disposes its bearers to produce a matter of necessity, the induction from (E) to (C) of §5 holds in every world; and this is just to say that (C) is necessary, according to color functionalism.

What this means is that, while denying (M) is one reasonable way in which a primary quality theorist can evade the argument from necessity, this denial is not mandatory.

[24] Moreover, a primary quality theorist can answer the second argument while accepting (M) if she is prepared to endorse a functionalist understanding of color (see note 23).

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