Reflectance physicalism about color: the story continues

Zoltan Jakab
Budapest University of Technology and Economics

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Abstract
A stubborn problem for reflectance physicalism about color is to account for individual differences in normal trichromat color perception. The identification of determinate colors with physical properties of visible surfaces in a universal, perceiver-independent way is challenged by the observation that the same surfaces in identical viewing conditions often look different in color to different human subjects with normal color vision. Recently, leading representatives of reflectance physicalism have offered some arguments to defend their view against the individual differences challenge. In this paper I challenge their defense. I argue that even though individual differences are present in shape perception as well as in color perception, the mechanisms of shape perception and those of color perception differ in ways which make them completely different regarding their evidential status for certain identity claims. Thus comparing color perception to shape perception offers no support for identifying hues with reflectances. On the other hand, drawing a parallel between the temperature-mean kinetic energy of molecules (MKE) identification and the proposed hue-reflectance identities is no support for reflectance physicalism either, since there is an important disanalogy between the two cases. While individual differences obtain in color perception, the effects of temperature (e.g., melting, thermal expansion) do not exhibit analogous variation, which makes the temperature-MKE identification unproblematic compared to the hue-reflectance identification. The success or failure of reflectance physicalism in turn has far-reaching consequences for representational externalist and disjunctivist theories of conscious experience.

Keywords: color, reflectance physicalism, individual differences, absolutism, relativism, revelation

1. Introduction.

Physicalism about color is the idea that colors are physical properties of environmental surfaces and volumes. As such, colors neither are, nor include, mental states or perceptual responses of any sort. Color physicalism comes in two main varieties: absolutist and relativist. On both varieties, colors are the bases of surfaces' dispositions to elicit color experiences (McLaughlin, 2003; Jackson and Pargetter, 1997). On color relativism, however, no object is *red, full stop*; instead, an object is red for a given subject, in a certain viewing condition (*mutatis mutandis* for other colors). Having the disposition to elicit the experience of red (subject and circumstance specified) is essential for a surface property to be red.

According to absolutist color physicalism, objects have their color independently of perceiving subjects and circumstances of perception. On the most elaborate version of this view (Hilbert, 1987; Byrne and Hilbert, 1997, 2003; Tye, 2000, Ch7), colors are identical with types of surface reflectance (Byrne and Hilbert, 2003, add some qualification in order to generalize their account to translucent volumes and light-emitting surfaces). This view is also called *reflectance physicalism*; it will be the main topic of this paper.

Reflectance physicalism has been the subject of an ongoing debate for several years now (Hilbert, 1987; Hardin, 1993; Byrne and Hilbert, 1997, 2003; Tye, 2000; Bradley and Tye, 2001; McLaughlin, 2003). It has been known for some time that the perception of determinate shades of color is subject to substantial individual differences. For instance, different color-normal subjects see pure green (green that is neither bluish nor yellowish) at different points in the visible spectrum, and on different samples of color chip sets (Kuehni, 2004). This problem generalizes to other determinate shades the perception of which is also affected by individual variation. Recently, opponents of reflectance physicalism have pointed out that empirical data indicate substantial individual differences at the level of broad color categories, in addition to narrow shades (Cohen et al., 2006, 2007; Malkoc et al., 2005). This, they argued, shows that the problems for reflectance physicalism are even more serious than previously thought. In response, defenders of reflectance physicalism suggested that their view can accommodate data on variation (Tye, 2006a, 2006b; Byrne and Hilbert, 2004, 2007a).

Byrne and Hilbert (2003) argue that since individual differences in shape perception do not call into question the objectivity, or observer-independence, of shape, nor should such differences undermine the objectivity of color.[1] However, there is a relevant difference between visual shape perception and color perception. For shape perception there is a test of correctness: for instance, we can measure whether the shape that some subject sees as spherical is indeed spherical. No test of this kind is available for color perception: reflectance measurements are unhelpful in deciding whose perception of a color stimulus is the correct one (Byrne and Hilbert, 2003, p17). Still, reflectance physicalists insist, there is a fact of the matter as to which reflectance is pure green, but this fact is one we may never be able to know (Byrne and Hilbert, 2003, p21n50; Tye, 2006a). The alternative view is that nothing is pure green, observer-independently: this is color relativism (McLaughlin, 2003), which reflectance physicalists reject.

The consequence that for each and every hue it is an unknowable fact what reflectance type it is might already appear to some as a reductio. However, Byrne and Hilbert embrace this consequence, because they think their view accommodates some other, highly plusible assumptions (Byrne and Hilbert, 2003, p21 n 50).

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[1] An observer-independent (stimulus) property is one that does not include any reaction or disposition of perceiving organisms. Such properties can be characterized in observer-independent terms, that is, without making reference to how the stimulus appears to any kind of perceiver, or how it is processed by the nervous systems of perceiving organisms.

This claim has already drawn some fire (Averill, 2003; Cohen, 2003; Hardin, 2003). Subsequently, Tye, Byrne and Hilbert offered their responses. Tye (2006a) argues that just as objects have determinate size despite all kinds of minor misperceptions of size, surfaces have determinate hue despite normal misperceptions of hue. That is, failure of determinacy does not follow from ineliminable variation.

Byrne and Hilbert (2004, 2007a; Byrne, 2006) offer two more arguments for unknowable color facts. Their first argument is that denying the existence of such facts is a verificationist move. As they put this point: "Generalizing, no one knows, of any object *o*, that *o* is unique green. … this is consistent with our knowing that some objects *are* unique green … Let us further concede … that … the theory of perceptual representation will never advance to the point where we will have some 'independent method' for determining exactly which properties our color experiences represent objects as having. … Now unless we make some controversial verificationist assumption, it is hard to see why this scenario makes no scientific sense or is otherwise objectionable." (Byrne and Hilbert, 2004, p42).

In the second argument (Byrne and Hilbert, 2004), we are asked to imagine a population of intelligent thermometers which (i) can measure temperature to a limited degree of exactness, exhibiting some individual variation (ii) can think certain thoughts about temperature (e.g., that *the temperature here and now is roughly 70 °F*), (iii) have just one way of measuring temperature (iv) they conjecture that they are representing something like mean kinetic energy of molecules, but (v) due to their lack of a theory of intentionality they cannot conclusively establish what property it is that they are measuring. There still are exact temperature facts, their unknowability to the intelligent thermometers notwithstanding. Moreover, the relation between intelligent humans and narrow shades is similar, which, Byrne and Hilbert suggest, makes the idea of unknowable color facts easy to comprehend.

According to Allen, (2010), inter-subjective differences are, on close scrutiny, not as dramatic as they appear at first glance. Moreover, there does not seem to be a straightforward generalization from unique green's highly variable location in the spectrum to other colors. Data on individual differences, Allen contends, is consistent with the view that colors are mind-independent properties that normal subjects more or less veridically perceive.

In what follows I reformulate the challenge to reflectance physicalism. Although reflectance physicalism remains a consistent view, its assumption of central importance, namely the reflectance-hue identities, is unsupported by relevant evidence – empirical or theoretical. The best explanation for this lack of evidence is that the hues (or narrow shades) are not identical with metameric ranges of reflectance.

My argument uses individual differences (or variation) as a premise. Fist I argue that even though individual differences are present in shape perception as well as in color perception, the mechanisms of shape perception and those of color perception differ in ways which make them completely different regarding their evidential status for certain identity claims. Due to the same difference, certain normative limitations arise from the working of shape perception, but no analogous norms apply to color perception. Thus comparing color perception to shape perception offers no support for identifying hues with reflectances. Second, drawing a parallel between the temperature-mean kinetic energy of molecules (MKE) identification on the one hand, and the proposed hue-reflectance identities on the other is no support for reflectance physicalism either, since there is an important disanalogy between the two cases.

In this paper I shall focus on the identity of narrow shades with metameric ranges of reflectance. The reason for this choice is that this is one of the most exciting and deep-running issues that I see in the philosophy of color. If the narrow shades are identical to reflectances (like water is identical to H_2O, or temperature is identical to the mean kinetic energy of particles), then reflectance properties determine, without involving any relation to observers, how they *should* appear colorwise when we look at them (i.e., how they appear when they appear correectly colorwise). If this is right, then the information that color vision picks up about reflectances, (or the access to reflectances via color vision) determines, in a strong metaphysical sense, the phenomenal character of color experience. This in turn means that phenomenal externalist accounts of color experience (Tye, 1995, 2000, 2009; Dretske, 1995; Byrne and Hilbert, 1997, 2003) are vindicated. My argument, if correct, strongly suggests that phenomenal externalism about color experience is untenable, and internalism about the phenomenal character of color experience must be correct.

Since my focus will be on narrow shades[2], let me specify the relevant connection between narrow shades on the one hand, and broader color categories on the other. If the narrow shades (the determinates) are not observer-independently identical to narrow ranges of reflectance, then it is hard to see how broad color categories (the determinables) could be observer-independently identical to broader reflectance types. If narrow shades of green are not type-identical with narrow, metameric reflectance ranges, then the broad color category green cannot be type-identical with a broader reflectance type either. Note that according to relativist color physicalism, observer-independent identity between colors and reflectances does not obtain. Other versions of color realism like that of Gert (2006, 2008), or realist primitivism (Byrne and Hilbert, 2007b) do not claim observer-independent indentity between broad color categories and types of reflectance either. Therefore these variants of color realism are unaffected by the present argument.

2. Conceptual revelation

According to some versions of color realism, our visual experience reveals to us the very essence of color. In order to know immediately, and exactly, what properties the colors are, all one needs is to see them. Although colors exist independently of observers, what perception reveals about them cannot be revealed by any other means – not at least via language (Johnston, 1997, p. 138; Campbell, 1997, pp. 178-179; Russell, 1912, p. 47; Strawson, 1989, p. 224; 2003; Stroud, 2000). I will call this notion *primitive revelation*. The notion of primitive revelation is not free of controversy, and I am not endorsing it in what follows.[3] Instead I propose a different notion of revelation which will play a key role in the argument to be presented:

[Conceptual revelation] Stimulus property P is revealed in perception iff perceiving some object having P *as P* plus intellectual reflection together can lead us to a concept of P's essence in perception-independent terms, that is, a concept that does not make reference to our perception, or experience, of P.

Note a few things about this principle. First, there is an emphasis on specific stimulus properties, in addition to highly generalized ones. Substitute for P something like being rectangular (as opposed to having shape), or being unique red (as opposed to being colored). The principle should work at both levels of generality in order for conceptual revelation to obtain in a perceptual modality. Second, by stimulus property P I mean a property which is *specifically causally responsible* for eliciting perceptual representations of type E in suitable perceivers and situations. In such cases, conceptual revelation is made possible by E perceptually representing its stimulus as (having/being) P. Thus, the property that is the specific cause of E is represented by E as the very property that it is. At first glance this

[2] I use 'hue' and 'narrow shade' interchangeably, meaning by both terms the determinates of object color.

[3] For discussion of this notion of revelation, and primitivist views of color with which it is intimately connected, see Smith, 1993; Yablo, 1995; McGinn, 1996; Johnston, 1998; Tye, 2000, pp. 26-32, 54-60, 149-150, note 4 on p. 167; Tye, 1995, pp. 169, 174; McLaughlin, 2003.

sounds like a very strict condition. However, our visual perception of shape seems to satisfy this condition at both levels or generality mentioned. If shape perception operates as it is supposed to, then visual percepts as of circular objects are triggered by circular objects (to a good approximation), and such percepts represent their cause as circular. Evidence for this latter claim is that visual percepts of circular objects are very helpful for deriving an abstract, geometrical concept of what it is to be circular (*mutatis mutandis* for many other shapes). That is, conceptual revelation obtains for particular shapes because the shapes that are the specific causes of our shape percepts are represented by those percepts as the shapes that they are. It is also reasonable to claim that shape perception helps us to form a general concept of the nature of shapes, for instance that shapes are types of distribution of matter in space.

According to reflectance physicalism, conceptual revelation is not true of color perception.[4] The stimulus properties that are the specific causes of color experiences are surface reflectances[5]. For instance, the specific causes of red sensations are surfaces which reflect most of the incoming light between 600-700 nm, and uniformly little of it between 400-600 nm. Percepts of red typically track reflectances within this broader category. However, this fact was discovered by science; reflection on color experience alone can never give us approximately correct concepts of particular surface reflectances. Reflectance physicalists are prepared to accept this idea (see Tye, 2000, p55). The next question is, what psychological differences underlie this difference between shape perception and color perception?

3. Structured and unstructured perceptual representations

3.1. Structure in visual shape percepts.

Certain variants of perceptual representation, simpler as they may be than conceptual representation, already satisfy the most general requirements of compositionality (Fodor, 1987, 1998). Indeed, these forms of perceptual representation constitute simple grammars with a finite number of elements plus rules of combination. The rules allow the elements to be assembled into complexes. The elements are shareable: one and the same element can occur in different complexes. The system is productive: a finite number of elements can give rise to an arbitrarily large set of complexes. It is also systematic (in Fodor's sense): even small subsets of the elements may be combined in different ways each standing for a different state of affairs. Just as whoever can think John loves Mary can also think Mary loves John, whoever can see, or imagine, that an apple rests on a leaf can also see (in appropriate circumstances), or imagine, that the same leaf rests on the same apple. In addition, the information conveyed by perceptual compositionality is quite often available to the conceptual faculty: in many cases we can report the details of perceived shapes and spatial layouts.[6]

Most psychological theories of visual shape perception are in accordance with this general view. One account proposes a decomposition of complex shapes into volumetric primitives (basic three-dimensional shapes like cylinders with varying height and diameter). (Marr, 1982; Marr and Nishihara, 1978; Biederman, 1987, 1990; Wallis and Bülthoff, 1999).

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[4] On color primitivism, conceptual revelation seems true of color perception, although there remains some controversy surrounding this issue (Byrne and Hilbert, 2007, and McLaughlin, 2003 help to illuminate the problem).

[5] This is too simplistic, but I will use it as a shorthand for a more complex notion. Even on reflectance physicalism, the causes of color experience are reflectances, or translucent volumes, or light-emitting surfaces. Byrne and Hilbert (2003) argue that these three types of properties have a common core that they call *productance*. Whether they are correct about this will not be addressed in this paper (however, see Jakab & McLaughlin, 2003 for critique).

[6] This is not always easy. See Biederman and Shiffrar, 1987, for a case where reporting shape information is very difficult.

The representations of shape primitives are thought to constitute a generative system of representation in which the rules of combination are fairly simple and flexible, somewhat similarly to the combination of Lego blocks (Wallis and Bülthoff, 1999).

View-based approaches to object recognition (Bülthoff and Edelman, 1992; Tarr and Pinker, 1989; Cyr and Kimia, 2004) propose that objects are represented as collections of 2-D views rather than configurations of 3-D shape primitives. View-dependence in object recognition is most noticeable for unfamiliar objects, and objects typically seen from a particular viewpoint, whereas for familiar objects, recognition is view-independent (Wallis and Bülthoff, 1999; Palmer et al., 1981; Edelman and Bülthoff, 1992; see also Palmer, 1999, 406-7).

In sum, the idea that visual representations of the shapes in human vision are compositional seems to be supported by evidence from psychology. The constituent structure of shape percepts serves *structural encoding*: a perceptual state E structurally encodes its stimulus S_E if (i) E has constituent structure, and (ii) its constituent structure reliably tracks, or maps some corresponding physical structure within S_E. I suggest that structural encoding is an important necessary condition for conceptual revelation.[7]

3.2. The unstructured nature of color experiences

Felt redness vs greenness, as well as felt yellowness vs blueness are two dimensions of color space, that is, attributes of color experiences. Both dimensions encompass a range of values: different outputs of the opponent channels of color vision. Such a value (channel output), when it obtains, constitutes an attribute of an occurrent color experience. Each such value (i.e., felt redness, greenness, yellowness, or blueness, at a certain intensity level) is primitive or unstructured in the sense that it does not contain further discernible features or constituents accessible to higher cognition (Jakab, 2000).

The chromatic dimensions of color space are not sufficiently structured to conceptually reveal the nature of their own stimuli. For example, experiencing reddishness plus reflection on the relevant experiences do not make it possible for the experiencer to realize that *reddish surfaces reflect more light at the long end of the spectrum than in its middle*.

Similarly, experiencing bluishness accompanied by reflection on one's experience does not let one know that felt bluishness indicates a strong reflectivity or emission at the short end of the spectrum compared to the long end. Learning this latter fact took scientific inquiry. This is just to say that felt redness vs. greenness and felt yellowness vs. blueness do not conceptually reveal the nature of the reflectance property they carry information about, via reliable covariation. Information about combination of the primitives is discernible in color experience, however. Perceived yellowishness vs. bluishness and perceived reddishness vs greenishness combine into the simple representational structure of binary color experiences, and derivatively, that of color space, and this feature is available to reflection.

Signals in general underdetermine the nature of their cause to some extent. Unstructured signals, in particular, radically underdetermine the nature of their source. If a system has access only to an unstructured signal (i.e., whether it is present or not, at a given time), from this information alone it will not be able to determine what the signal is about. Unstructured "on-off" signals can have features that help to discriminate them from one

[7] What the necessary and sufficient condition might be is a more difficult question. First, reflection on one's experience is needed as well, for conceptual revelation. Second, structural encoding is a matter of degree. For instance, the auditory system performs a crude Fourier analysis on acoustic stimuli. As a result, many listeners can decipher tones in a piano chord, or discriminate different sound sources like the rustling of leaves and the chirping of a cricket. Still the overtones in the sound of a single a piano key are much harder, if at all possible, to discriminate reliably.

another, but the distinctive features of unstructured signals do not characterize the nature of their cause.[8] This is what distinguishes a camera image and a red light bulb as indicators of a complex event (like airplanes landing on an airport): parts and features of the camera image carry information about parts and features of the image's triggering condition, which is not true of the light bulb. Combining two unstructured signals neither of which reveals the nature of its cause, we get a simple pattern of two signals. In such a case the combination may be deciphered by the processor that accesses the combined signals, but the nature of the cause of the individual signals still cannot. Note that in shape perception *it is the pattern of combination of representational primitives that structurally encodes stimulus shapes*. In addition, the number of primitives is much greater, and their ways of combination are much more complex than what we find in color vision.[9] To summarize, our color experiences are (almost completely) unstructured in the relevant sense, and this is why conceptual revelation does not obtain in color perception.

4. Reflectance and appearance: is there a standard?

There are two types of empirical findings in the field of color perception that are relevant in evaluating claims about hidden hue-reflectance standards. The first has already been mentioned: perceptual representations of the colors are, in an important sense, unstructured. The second is that color perception effects a systematically distorted presentation of its stimuli. The most common example of this distortion is that perceived similarities between the colors (which are often summarized as Euclidean distances within certain types of color spaces) differ substantially from similarities in terms of reflectance or light emission, characterized in the most suitable way for comparison. That is, even if we measure triplets of integrated reflectances (TIRs – reflectance values averaged over the sensitivity ranges of the three human photoreceptor classes: Hilbert, 1987), and compare them according to some version of the opponent processing theory of color vision (Tye, 2000, Ch 7; Byrne and Hilbert, 2003; Werner and Wooten, 1979; Hunt, 1982; Wuerger et al., 1995), the difference between these two metrics is still substantial. We need to add immediately that this issue has been hotly debated (for endorsing distortion see Hardin, 1988; Matthen, 1999, 2005; Jakab, 2005; for insistence on a match between the two similarity orderings see Tye, 2000, 160-165; Hilbert and Kalderon, 2000; Bradley and Tye, 2001). McLaughlin (2003, 115-6) argues that the two similarity orderings are independent: similarity at the level of color experiences may or may not be isomorphical to the similarity structure of color stimuli in terms of their relevant reflectance properties. Here I am not taking sides on this issue; my argument does not take as one of its premises that our perception of color similarity is systematically distorted. Two things, however, need to be noted.

First, both structure in perceptual representation and veridicality are needed for conceptual revelation to obtain in a given perceptual modality. Conversely, if either structure is missing, or veridicality is violated, then conceptual revelation cannot obtain. Thus whether or not color perception preserves the observer-independent similarity relations of its stimuli (in terms of TIRs, for instance), conceptual revelation is prevented by the relevantly unstructured nature of particular color experiences. Shape perception can be, and in some cases is, misleading due to distortion, as happens in astigmatism, for instance. Distortion in

[8] Barring the suggestion that different signals correspond to different causes; but even this suggestion may be misleading, as two different unstructured signals may indicate the same kind of event, even if their "on" states are uncorrelated with one another. For instance, a red light and a yellow light on an instrument panel may both indicate that airplanes are landing at a given airport, but at the time of each landing event, a random generator chooses which of the two lights will turn on.

[9] According to Biederman (1987, 1990), shape representations arise from combinations of 36 different geons, each of which has further parameters to determine its exact character in particular cases.

such cases tends to undermine conceptual revelation. Looking through a glass block spacer with a patterned surface, for instance, may seriously compromise object recognition and the ensuing description of what we see.

Second, the unstructured nature of particular color sensations prevents any normative connections from obtaining between narrow metameric ranges of surface reflectance and the experiences of narrow shades. Here is the argument.

If the particular sensory states within a perceptual modality are unstructured, then there cannot obtain a unique mapping between the stimuli and the sensory states that is preferable to any other mapping. This is Alan Gilchrist's *anchoring problem*. Gilchrist (1999, 798-799) formulates the problem in terms of achromatic lightness sensation. Consider a pair (A; B) of adjacent regions in the retinal image whose luminance values stand in a 5:1 ratio. This ratio informs the visual system only about the relative lightness values of the two surfaces, not their absolute lightness values. There is an infinite family of pairs of perceived shades of gray that are consistent with the 5:1 ratio. Region A may be represented by a sensation of white, and B by one of middle gray. Alternatively, A may be represented by a middle gray sensation, whereas B by the appearance of black. B might even trigger a sensation of white, and A that of a self-luminous array. Which mapping actually obtains in particular cases is a matter of empirical inquiry. "The anchoring problem is the problem of how the visual system ties relative luminance values extracted from the retinal image to specific values of *perceived black, white, and gray*." (Gilchrist, 1999, 798; my italics).

Note that any particular sensation of achromatic lightness is an unstructured representation: it has no discernible structure for processors of higher cognition. Lightness as a sensory dimension has a one-dimensional structure; however, the relevant fact in the present context is that particular lightness sensations are unstructured, for this is what gives rise to the anchoring problem. The lightness dimension has no uniquely correct mapping onto the physical dimension which it arguably represents (surface reflectance, averaged over the entire visible spectrum).

On the other hand, the structure in particular shape percepts goes a long way toward resolving this kind of ambiguity.

FIGURE 1 HERE

Figure 1A shows two alternative mappings between surface reflectances and *particular lightness sensations* (denoted by the squares of the gray scale). There is nothing inherently wrong with either mapping: one could function as well as the other. The case in figure 1B, however, is different. Perceptual representations can become part of concepts[10], and as such they can influence the inferences we draw about perceived objects. For instance, percepts as of circles and ovals involve some magnitude representations of the major and minor axes of the perceived circular or oval shapes.[11] These magnitude representations may then be representationally redescribed by abstract concepts, as a result of reflection on our perception. If a perceptual representation of some stimulus generates magnitude representations (e.g., ratios of the major and minor axes) that fail to correspond to the actual magnitude ratios of the stimuli, then perceptual error arises. Error at the level of perceptual representation may lead astray some inferential processes and thus result in corresponding error at the level of

[10] Or they can be part of the knowledge associated with concepts – terminology depends on what theory of concepts one endorses, but the present argument intends to be largely neutral on that issue. What is assumed is that concepts have a double function: (1) they latch onto types or particulars in the environment via some causal mechanism, (ii) they store knowledge related to their objects.

[11] Perceptual representations may involve, or give rise to, analog magnitude representations which are different from number concepts (see for instance Carey, 2009, Ch 4).

propositional representation. As fig. 1B shows, in the case of shape perception, *a single stimulus-to-perceptual representation assignment* may be inherently erroneous for this reason. In other words, a shape percept may covary with a type of stimulus whose structure it represents incorrectly. This can only happen because singular shape percepts are structured. As Figure 1A shows, this source of error is not present in the case of lightness perception. Singular lightness percepts are unstructured; therefore they are *silent* about any structure their stimulus might have. That is, they cannot present a misleading structure of their stimuli – they cannot present their stimulus as structured, but structured in a way it isn't actually structured. But shape perception can present its stimuli as structured in ways they aren't structured. This is a distinct source of error in shape perception, and this is what makes the second mapping in fig 1B systematically erroneous.[12]

Now consider the two chromatic dimensions of color space. First, felt redness greenness, yellowness, and blueness are sensory representations that are unstructured, just like achromatic lightness sensations. Second, both the redness-greenness scale and the yellowness-blueness scale have a neutral point: surfaces can be neither reddish nor greenish; they can also be neither yellowish, nor bluish. Shades of unique green, for instance, all lie at the cross-section of color space where the yellowishness-bluishness dimension has zero values. But which part (or subspace) of reflectance space is *correctly* assigned (i.e., represented by) the cross-section of color space with zero values on the yellowishness-bluishness dimension? According to Tye (2000, 163-4) surfaces that reflect the same amount of light in (i) the sensitivity range of the L cones and (ii) that of the M cones, are neither reddish nor greenish. Similarly, surfaces which reflect the same amount of light in the L and M sensitivity ranges together on the one hand, and in the sensitivity range of the S cones on the other will look neither yellowish nor bluish. Empirically, the first proposal is roughly correct: in general, red surfaces reflect more light in the L-cone range than in the M-cone range, and the reverse is true of green surfaces. The second, however, is off the mark: most surfaces that look neither yellowish nor bluish reflect more light in the L plus M ranges than in the S range; neutral white and gray surfaces are excellent examples (Jakab, 2001, 68-75). Bradley and Tye (2001) argue that even if these proposals need to be corrected somewhat, that does not affect the tenability of reflectance physicalism.

In my opinion it does, for the following reason. The neutral output of the red-green channel of color vision may be calibrated so that it indicates equal integrated reflectances in the L and M cone sensitivity ranges. However the same neutral point may also be calibrated so that it indicates a 1.2:1 reflectance ratio in the L and M ranges respectively; or a 2:1 ratio. What would be distinctly mistaken about the latter two options, as opposed to the first one? One might be inclined to claim that equality, that is, the 1:1 ratio is special in that ”true neutrality” in sensations of redness versus greenness is the point where reflectances in the relevant ranges are in perfect balance. However, as I have just said the neutral point of the B-Y dimension does *not* correspond to 1:1 reflectance ratio in the S vs L+M sensitivity ranges. Thus if *true chromatic neutrality* (in both the R-G and the B-Y dimensions) is *perfect balance of reflectance in the relevant ranges*, then pretty much all human beings are severely mistaken about perceiving the blue-yellow balance. For instance, surfaces that appear to us white or neutral gray are as a matter of fact quite yellowish – we are in error seeing them as chromatically neutral. To avoid this consequence, reflectance physicalism might reject the idea that true chromatic neutrality corresponds to perfect balance of reflectances in the

[12] Note that shape must not be confused with linear size, or overall image size: *there is no normative limitation on changing image size*. If we take a photograph of a wedding ring from a direction perpendicular to the ring's plane, the ring will be imaged as circular in the photo. If we make a small and a large version of this photo, the ring will be circular (i.e., the same shape) in both, regardless of enlargement sizes. However, if we compress the image along the horizontal axis by a 2:1 ratio, that does result in shape change – just like in Fig 1b.

relevant ranges, but in this case there remains no non-arbitrary ground for deciding what reflectance ratios in the relevant sensitivity ranges are to be identified with true chromatic neutrality.

Note that this is exactly what Byrne and Hilbert suggest is unknowable about the colors: different color-normal subjects see unique green in different color chips because their blue-yellow channels are calibrated differently. Since the perceptual representations of chromaticity are unstructured, the source of error illustrated by figure 1B is absent from color perception. Again, there seems to be no non-arbitrary way to decide who gets the Correctness of Hue Award.[13]

The same applies to Byrne and Hilbert's notion of hue magnitudes (Byrne and Hilbert, 2003, sec. 3.2.3). For instance, a surface has an **R** hue magnitude iff, under equal energy illuminant, it stimulates the L cones more than the M cones, and reflecting surfaces have **B** magnitudes iff they stimulate the S cones more than the L and M cones together. But since the photoreceptors of different color-normal subjects often produce different responses even in identical circumstances, the same question arises as above: whose L, M, and S cones serve as the basis for decision?

Alternatively, we may conclude that no biologically based normative limitations apply to the calibration of the chromatic dimensions, and the perception of narrow shades. For instance, any spectral light between 490 and 520 nm may equally well be represented by unique green sensations, in different trichromat subjects. By contrast, we did find a source of biologically based normative limitation on the shape – shape experience pairings. In sum, the lack of evidence for standards of correctness in color perception suggests that there are no such standards.

4.1 An objection

At this point we need to consider an objection and qualify our claim about normativity.[14] Consider again Fig 1. There we compared, in terms of their normative implications, a single gray-level sensation and the perception of a certain shape; then, based on this single comparison, we made the general claim that there are normative consequences in shape perception that are missing from achromatic lightness (and color) perception. On closer scrutiny, this generalization appears unfounded. For if we compare a *triplet of color patches* with a circle in terms of the conditions on their veridical perception, we immediately find normative constraints in the color case as well. Suppose that two color patches (A and B) are shades of orange, and the third (C) is blue-green. If, to subject S, A and C appear more similar to one another than any of them to B, then S is in error. Thus the generalized contrast in normativity between color perception and shape perception is lost – or so the argument goes.

Here is my response. First, note that visual representations of complex shapes include visual representations of simpler shapes that represent proper parts of the complex shape. We can readily recognize, for instance, the circular shape of a wineglass rim – not just the whole shape of the glass. We can also recognize arcs in the circular rim, and so on. Visual shape representation is recursive in the following sense: representations of complex shapes include representations of simpler shapes, which in turn include those of even simpler ones, and so on (for several steps and stages, although not *ad infinitum*). We have seen that this either does not happen in color perception, or it does only to a very limited degree.

Now suppose that some non-human perceptual system represents particular shapes by vectors (points) in a three-dimensional similarity space whose dimentions are highly

[13] Thus my argument does not assume that color perception *actually is* systematically mistaken. On the contrary, it is unclear whether color experience *could at all be* mistaken in such a way that individual differences are reasonably understood as involving error.

[14] This objection was raised by Katalin Farkas (January, 2012.)

derivative or gerrymandered: (D1) simple vs. complex; (D2) rectilinear vs. curvilinear; (iii) short vs. elongated. Suppose the dimensional positions of complex shapes are obtained by suitable calculations based on the shapes involved. A snake would be simple, elongated, and curvilinear; a tree including the details of its branches would be curvilinear, complex, and elongated, whereas a ball maximally simple, curvilinear, and short (i.e., extended in all three directions of space to the same degree). If shapes were represented by three-dimensional vectors in such a system, then *single shape representations would not include representations of simpler shapes at all*. In addition, normative constraints would not apply to single points in such a system. There seems to be no principled way to decide whether the complexity of a cube is better represented by D1 = 5 or by D1 = 6 (on a hundred-point scale, say).[15] Different calibrations may come with different utility, but hardly any difference in veridicality. Still, three-way comparisons between individual shapes could be judged according to their correctness: if a circle and an ellipse are represented in this 3D system as less similar to one another (i.e., their corresponding points farther away from one another) than the circle is to Australia's shape, that would reasonably be called an error.

On the other hand, some sophisticated system of color perception might represent surface reflectances as high-tech spectrophotometers do: by percentages of reflected light in each and every 1-nm interval (overlaps between neighboring intervals being minimized). In such a case, a single pairing of a reflectance (wavelength distribution) and a sophisticated *reflectance percept* could be inherently mistaken. If, in the actual reflectance distribution R, reflectance in the 450-455 nm wavelength range is twice as high as that in the 475-480 nm range, whereas it is indicated by the system that percentages of reflected light in these two ranges are equal, then there is error, which is arising from a single stimulus-percept pairing.

We conclude with two points. First, normative implications of perceptual representation are a matter of degree; still the nature of correctness conditions that apply in a given modality does depend on the characteristics of representation involved. In this respect, complexity of perceptual representation remains a crucial feature. Even if the system of perceptual representation under consideration is relatively simple (like achromatic lightness perception, or heat sensation) we can combine stimuli in such a way as to make some normative limitation apply to their perception. In particular, judgments involving comparison of stimuli have correctness conditions even when the individual stimuli to be contrasted are represented by unstructured symbols.

Second, to make our point about normativity, it does not matter what kind of color stimulus we compare to what kind of shape stimulus, for *one and the same stimulus* can be represented in more or less complex ways by different perceptual systems. A shape and a reflectance distribution can both be represented (i) in simple ways that entail little or no inherent normative constraint on stimulus-representation pairings, or (ii) in complex ways which entail a rich set of correctness conditions. It is contingently true that human shape perception represents singular spatial distributions in a way that does entail inherent normative constraints on individual stimulus-representation assignments, whereas human color perception represents singular wavelength distributions in a way that does not entail such normative constraints.

5. Logical structure of the unfolding argument

Here is a nice modus tollens to start our interim summary:

[15] D1=95 (out of 100) could just as well represent the relative complexity of cubical shape: larger numbers may represent simpler shapes – alternatively, the scale may be nonlinear.

P1. If the hues are identical to reflectances, then there are standards of correctness for hue perception.
P2. There are no standards of correctness in hue perception.
C. Hues are not identical to reflectances.

Where do the premises come from? P1 follows from reflectance physicalism: if the hues are one and the same as metameric reflectance ranges, then there is a fact about how a given reflectance appears to our color vision when it appears correctly. P2 is the premiss that I have been arguing for. Thus if P2 is true, then the falsity of reflectance physicalism deductively follows.

However, P2 itself does not deductively follow from what I have said about color perception. Byrne and Hilbert (2003 n50) admit that it is in principle unknowable which narrow reflectance range is pure green. Elaborating on this, I have tried to explain why it is hard to find evidence for standards of correctness in our perception of the hues – evidence that we easily find in shape perception. Thus the honest version of P2 is:

P2'. There is no evidence for standards of correctness in hue perception.

But from the lack of evidence it does not *deductively* follow that there are no standards of correctness in perceiving the hues – assuming otherwise would be verificationism.

Still, perhaps the best explanation for our failure to find relevant evidence for reflectance-hue identity facts is that there are no such facts. Perhaps we aren't ignorant about relevant aspects of color perception. Instead, we may have the basic empirical facts in, including the ones on which a theory of color content can be built. Moreover, the existing evidence concerning color perception suggests that there is no perceiver-independent standard for unique hue perception: P2 – the original premise – is quite likely true.

6. From epistemology to metaphysics: representation and identification

Here is another question. I have been claiming that we have no good evidence for identifying narrow shades with metameric ranges of surface reflectance in an observer-independent manner. Instead, as I am suggesting, our *knowledge of color perception* supports the view that no such identification is reasonable. Individual and contextual variation in the perception of narrow shades is thought to be a major argument for this position. This argument, however, can be challenged by noting the following. Human sensations of temperature have a one-dimensional structure; each particular temperature sensation that we may undergo is an unstructured representational state, just like lightness sensations. In addition, there is all kind of contextual variation in our temperature sensations (see Akins, 1996, for a philosophical assessment of this variation). Still, these facts about heat sensation are totally irrelevant when it comes to identifying temperature with the mean kinetic energy of molecules (MKE). What is going on? Why am I trying to build an argument against reflectance – narrow shade identifications on features of color *perception*?

To respond, let me begin by comparing the physical stimuli of teperature sensations to those of color sensations. The canonical cause of temperature sensations is the mean kinetic energy of molecules. The physical stimulus of color sensations is surface reflectance as it interacts with the ambient light. Temperature has been indentified with the mean kinetic energy of molecules, in a way that does not seem to raise serious philosophical problems. However, the identification of color with surface reflectance by reflectance physicalists remains a controversial philosophical position. Why is there this difference between the two identity claims? This question is all the more pressing, since there are important similarities between the two cases. The mean kinetic energy of molecules has a number of *non-*

psychological causal roles (melting, boiling, ingiting different substances, etc.). A certain range of temperatures also has the psychological effect of activating temperature sensations, and this effect is subject to individual and contextual variation. Up to this point, surface reflectances and mean kinetic energy levels are remarkably similar. Reflectances also have stable non-psychological causal effects – altering the spectral power distribution of the incoming light is one. Reflecting surfaces, when illuminated, also have the psychological effect of producing color sensations; moreover, we find very similar types of individual variation in heat sensation and in color sensation.

Now let's look for the differences. In trying to reductively explain temperature – the entity that plays the causal roles mentioned above – theorists' attention was focused on the non-psychological effects. I see two reasons for this attentional bias. First, the non-psychological effects of temperature are quite important for human life. Second, sensory experiences as of temperatures do not have very interesting, or fascinating phenomenal characters – much less so than color experience at any rate. By contrast, in the science and philosophy of color, attention is clearly focused on our experience of color, which many people are inclined to characterize as interesting or fascinating. In addition, the non-psychological causal effects of color stimuli like surface reflectances are generally less important for human life than those of temperature. Surfaces reflect the incoming light in a selective fashion; this is important for survival, but perhaps less so than cold weather, forest fire, or the drying out of local water sources in a hot summer. A related fact is that the non-psychological effects of temperature are often observable via perceptual modalities other than heat sensation – and these are the ones that are crucial for survival. One can see that the local forest is on fire in the hot summer weather (while also feeling the heat on one's skin), or that the local pond is frozen in winter mornings (while one is feeling badly cold). Thus cross-modal correlations between temperature sensations and perception in other modalities direct even the naive observer's attention to the non-psychological effects of temperatures. We can plainly observe that *temperature causes phenomena other than temperature*. Non-psychological effects of surface reflectances, however, are typically perceived in terms of color experience. A pink mug is standing close to a white wall, and casts some pink reflection on the wall when illuminated by white light; we see the reflection on the wall *as a pinkish area*. A green jar is used to cover a light bulb which illuminates a room; the jar turns the illumination green. In both cases we witness non-psychological effects of color stimuli (light reflection by the pink mug; filtering of light by the green jar), but experience these effects solely via color vision. As we apprehend the non-psychological effects of color stimuli, there is little in terms of cross-modal correlations; all we can perceive is that *color phenomena cause other color phenomena*. This is not necessarily so, but it is very typical.[16] That is, in the structure of our perceptual experience colors appear causally isolated from other events in the world. Given in addition the intriguing character of color experience, it is not surprising that philosophers are preoccupied with color experience when trying to understand the nature of object color. What is that property in objects that looks in this fascinating way? What exactly do I see when I see the purpleness of that flower? Is there a deeper explanation?

Next, notice that both the non-psychological effects of temperature, and the perceptual effects of color stimuli can be specified with sufficient precision. Whether ice is melting in a suitable measuring equipment can be established with high levels of certainty. Similarly,

[16] Suppose that there is a beeper activated by a light sensor that responds to 670 nm light. When the sensor is illuminated by a red laser, the beeper beeps; green or blue lasers have no such effect. This is cleary a non-psychological effect of a color stimulus (the *red* laser) – and an effect that can be perceived via modalities other than color vision. Thus it is possible that color stimuli and their non-psychological effects produce multimodal correlations in perceptual experiences, still, in everyday life such cases are infrequent.

whether a subject is sensing unique green or not is sufficiently well indicated by verbal report, for instance.

The next question is, do these precisely specifiable effects have invariant conditions that cause them? Non-psychological effects of temperature do. Melting point in general depends on the type of substance (iron, H_2O, etc.), and also on external pressure (usually slightly). Thermal expansion depends on the type of substance and the temperature range – for some substances and temperature ranges, it is negative (i.e., contraction with increasing temperature). Specifying these factors, melting point and thermal expansion are predictable in particular cases. Melting point is independent of such circumstantial variation as the size or shape of individual samples, for instance. It is always the same average kinetic energy of particles that initiates the melting of water ice at a given pressure (similarly for other non-psychological effects of temperature); moreover, it is these effects to which particular absolute temperatures were anchored in the first place.[17]

Now consider reflectances and color sensations. Broad categories of color experience do have (relatively) stable conditions of activation. For instance, in virtually all trichromat human subjects, sensations of red are caused by reflection or light emission predominantly at the long end of the spectrum; sensations of green are caused by light from the middle portion of the spectrum. For precisely specified effects, however, like sensations of maximally saturated unique green (and other narrow shades) there are no invariant conditions of occurrence. Fix the stimulus (surface reflectance), circumstances of perception, and the fact that trichromat human subjects are involved, and there is still variation in color perception. That is, *individual variation for precisely specified effects in fixed conditions* obtains for the relevant effects of surface reflectances (i.e., sensations as of different narrow shades), but not for the effects of temperature (e.g., the melting point of different substances).

Due to this difference in individual variation of the relevant effects, the working definitions for reduction perform differently in the two cases. For temperature this working definition is something like **temperature** := *the property that has such-and-such non-psychological effects*. For color, it is: **color** := *the property that evokes such-and-such types of visual experience*. Due to the stability of the relevant effects of MKE, particular temperatures became anchored to these stable effects, and consequently identified with particular MKE levels. Due to the instability of the relevant effects of surface reflectances, one can anchor colors (including color determinates: narrow shades) to types of color experience, but the next step of identifying narrow shades with reflectances will raise the problem of variation – unlike in the case of the temperature – MKE identification. Luckily, the consistency (though not the plausibility) of reflectance physicalism is saved by appealing to misrepresentation (i.e., that many trichromat humans are in minor errors perceiving the narrow shades). The same move is not available in the temperature case. Suppose that the MKE that initiates the melting of ice varies with the size and shape of particular ice samples in complicated ways. In such a case, if a particular temperature (e.g., 0 °C) were anchored to *the melting point of ice in general*, then the sample-independent identification of that temperature with a given MKE would not be possible. In this case the claim that some ice samples are ”mistaken about melting” would be outright nonsense, as melting is not an intentional phenomenon.

7. Summary and conclusion

Let me conclude with a quick three-way comparison between shape, color, and temperature. In general, to support identity claims – claims of reductive identification or

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[17] It is the Boltzmann constant **k** (the gas constant divided by the Avogadro constant) that constitutes a bridge between the macroscopic and microspopic physics. The thermal energy carried by each of the three degrees of freedom of the particles is on the order of magnitude of **k***T/2, where T is the temperature in kelvins (e.g., about 2.07×10^{-21} joule at room temperature).

functional specification – we need evidence: relevant empirical findings and theoretical considerations.

Reflection on color perception raises problems of identification: *What is color in objects* is a difficult question to which many different answers have been proposed. Our perception of shape, however, does not raise comparably deep problems of identification. *What is the shape of objects* is a question to which the answer is much more straightforward. Shapes are ways in which matter can be distributed in space; different shapes – even complex irregular ones – can be precisely specified using concepts of mathematics (those of coordinate geometry, for instance). Our question of focus has been: why is there this difference between shape perception and color perception? Why is it that one of them does, whereas the other does not, raise problems of identification?

Comparing shape perception and color perception, the following picture emerges. Perceptual representations in both cases are associated with perceptual concepts. Perceptual concepts are quotational-recognitional or indexical in character (Balog, 2009; Papineau, 2002; Loar, 1997; Tye, 2000, 2009).[18] These concepts either include a perceptual representation of the experience they are the concepts of, or a recognitional capacity for that experience, or an act of "mental pointing" to such a representation, like THIS EXPERIENCE. So far representations of color and those of shape are similar. The third level is that of reflective-theoretical concepts that attempt to grasp the essence of colors and shapes respectively. Conceptual revelation is simply the idea that perceptual representations of the shapes inform, in an especially effective way, the reflective-theoretical concepts of the shapes, whereas perceptual representations of the colors do not in the same way inform the theoretical concepts of the colors. The nature of the stimulus properties that undeniably cause the corresponding percepts is made accessible to abstract concepts in one case, but not in the other.

Differences between two modalities of perception and their relation to concepts are epistemological issues. They connect to metaphysics by making some identities pretty obvious (i.e., that the shapes we see objects as having *are* the shapes objects have observer-independently, and that the shapes *are* types of distribution of matter in space), whereas leaving others entirely unobvious (i.e., whether objects have the narrow shades they appear to have observer-independently, and whether the narrow shades are identical with types of reflectance). That is, color perception and shape perception have very different evidential status concerning the relevant identity claims, namely identity between the referents of perceptual concepts on the one hand, and those of the corresponding theoretical concepts on the other. For this reason, noting the observer-independence of the shapes does not support an automatic generalization to the observer-independence of color.

Thus the identification of narrow shades with reflectances remains an open theoretical question. To settle that question in light of the individual differences argument, we compared color to temperature, and found significant differences between the two cases. As a result, successful identification of temperature with MKE does not provide support for the hue-reflectance identities either.

Now we can respond to the arguments by Tye, Byrne, and Hilbert cited in the Introduction. As we have seen, Tye is surely right that ineliminable variation in perception does not *entail* indeterminacy between narrow shades and reflectances. But we have seen that *it counts as evidence against* reflectance-narrow shade identifications, especially if we add the relevant theoretical considerations. The principal effects of the narrow shades *as explananda* (i.e., not assuming their identity with reflectances) are psychological: their capacity to cause

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[18] According to Tye (2009) we do have concepts of our experiences, and may even call them phenomenal concepts, still these concepts are not substantially different from abstract or "non-phenomenal" concepts. I am inclined to accept this view, and it causes no complication for the present argument.

color experiences in us. As an explanation for their nature one may propose to identify narrow shades with reflectances. Reflectances do have invariant non-psychological effects. However, no non-psychological effects of the reflectances help to decide who is right about locating unique green in the spectrum; the very act of identification either creates problems (of reflectance – sensation variation), or at a minimum it is unhelpful in explaining individual variation in color sensation. The story about temperature is entirely different: temperatures as explananda (prior to their identification with MKE) were shown to have invariant non-psychological effects that supported their reductive identification.

Measuring temperature is an intentional phenomenon, unlike melting. Thus Byrne and Hilbert's intelligent thermometers can of course misrepresent temperatures. When they think about temperature and molecular energy, they have a choice what roles to seek fillers for: their own individual sensations of temperature (subject to calibration differences) or suitable natural signs of particular temperatures (like the melting of water ice) which are much more reliable. If, in their conscious experience, temperatures appear as deeply fascinating distal attributes of objects, then they may want to know what the observer-independent nature of *those* properties is. Then they might be disappointed to realize that, due to variation, the *canonical cause of their experiences* (MKE) cannot be straightforwardly identified with the fascinating temperature properties. (For remedy of disappointment, some of them may propose that the temperature properties are *sui generis* ones, different from MKE.)

In response to Allen (2010), note the following. If we found rife and rampant intersubjective variation in shape perception, then we could still immediately decide who is right and who is wrong. On the other hand, if artificial selection eliminated all variation in human color perception, that would not make color an observer-independent property, if it was not observer-independent already. Thus it is not facts about individual differences alone that militate against narrow shade-reflectance identifications; more important is the differences in how shape versus color perception picks up, and processes, information about shape and color stimuli respectively. Allen is right to point out that facts about variation in color perception have not been properly assessed in light of objectivist theories of color. But I think the core problem is that we cannot see how color stimuli (surface reflectances) could unambiguously metaphysically determine correct color appearance – something we fairly clearly see in the case of shape perception.[19]

Another reply to Allen's argument is this. Variation calls into question the identification of narrow shades with ranges of reflectance. But if color determinates aren't metaphysically identical with narrow ranges of reflectance, then how could color determinables be identical with broader ranges of reflectance? It seems that they could not. Thus substantial variation at the level of narrow shades may beat reflectance physicalism across the board, regardless of widespread between-subjects agreement about the perception of broad color categories.

Note also that shapes, just like temperatures, also have invariant non-psychological effects: for instance, whether keys fit into the key holes of locks, or whether wheels can roll on a smooth road without shaking the cart around. Having sufficient information about such dispositions might be enough to infer that shape S (characterized as exhibiting a group of invariant non-psychological dispositions) is spatial distribution of matter D_S. However, this is not how we come to know the essence of shapes. Visual perception is incredibly generous in that it gives us access to the essence of the shapes that is not mediated by inference from their non-psychological effects.

In this paper I have argued for a negative claim: if narrow shades cannot be identified with reflectances, then reflectance physicalism fails. In this case the theory of object color that

[19] In the case of size, we clearly see how the ratios of two sizes can be preserved in visual perception, or how mistake can intrude with respect to such ratios.

is best suited to underlie phenomenal externalist accounts of consciousness (and also direct realist and disjunctivist views of color) is out of business. Pending another, equally forceful reductive theory of color, we may tentatively conclude that internalism about color experience is the preferable way to take. A general note about the nature of dispositions may help to illuminate the situation.

Any property *could* be disposed to bring about just any effect. For example, the coastline of Australia could be disposed to initiate a cloning experiment if we mounted on a satellite a recognition module that output '1' for Australia's coastline and this output were properly connected to an automated genetic laboratory in an ocean-going ship somewhere in the Pacific. If we want to explain why the system produced a particular output (say, some kind of microorganism), then most of the explanation of this disposition would be about the triggered mechanism; Australia's shape simply acted as a start signal. A relatively minor change to the recognition module could result in its sensitivity shifting to Madagascar's shape as a start signal, while leaving the lab's output unchanged. I suggest this as a parallel for how color experience arises. The corresponding analogy for shape percepts is this: the recognition module outputs a matrix of data which in turn have a specific influence on the nucleotide sequence of the synthetized DNA. Thus Madagascar and Australia would produce different DNA sequences, and thus different microorganisms in the laboratory. In this case the pattern of input data plays a more specific role in explaining why the system produces the output it does – for the informational bottleneck is less narrow at the system's entry point.

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References

Akins, K., Hahn, M. (2000). The Peculiarity of Color. In Steven Davis (Ed.): *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives*. Oxford University Press, New York

Allen, K., (2010). Locating the Unique Hues. *Rivista di Estetica* (43). 13-28.

Averill, E., W. (2003). Perceptual variation and access to colors. *Behavioral and Brain Sciences*, **26** (1) 22.

Balog, K. (2009). In Defense of the Phenomenal Concept Strategy. *Philosophy and Phenomenological Research*, forthcoming

Biederman, I., Shiffrar, M.M. (1987). Sexing Day-Old Chicks: A Case Study and Expert Systems Analysis of a Difficult Perceptual-Learning Task. *Journal of Experimental Psychology: Learning, Memory, and Cogntion, 13*(4), 640-645.

Biederman, I. 1987. "Recognition by components: a theory of human image understanding." *Psychological Review*, **94**, 115-147.

---. 1990. "Higher-Level Vision." In *An Invitation to Cognitive Science*, ed. D. N. Osherson, S. M. Kosslyn and J. M. Hollerbach, Vol. 2. (Visual Cognition and Action). Cambridge, MA: MIT Press, 41- 72.

Bradley, P., & Tye, M. 2001. "Of colors, kestrels, caterpillars and leaves." *Journal of Philosophy*, **98**, 469-487.

Bülthoff, H.H., Edelman, S. 1992. "Psychophysical support for a two-dimensional view interpolation theory of object recognition." *Proceedings of the National Academy of Sciences USA* **92**, 60-64

Byrne, A. (2006). Comments on Cohen, Mizrahi, Maund, and Levine. *Dialectica* 60: 337-40

Byrne, A., Hilbert, D.R. 1997. "Colors and Reflectances." In Byrne and Hilbert, (eds.), *Readings on Color*, *Vol. 1.* (*The Philosophy of Color*), Cambridge, MA: MIT Press, 263-288.

Byrne, A., Hilbert, D.R. 2003. "Color Realism and Color Science." *Behavioral and Brain Sciences*, **26** (1), 3-64

Byrne, A., Hilbert, D., R. (2004). Hardin, Tye, and Color Physicalism. *Journal of Philosophy* 101: 37-43

Byrne, A., Hilbert, D., R. (2007a) Truest Blue, *Analysis*, 67: 87-92

Byrne, A., Hilbert, D., R. (2007b) "*Color primitivism*," with Alex Byrne, *Erkenntnis*, 66:73-105

Campbell, J. (1997). A Simple View of Color. In Byrne and Hilbert, (eds.), *Readings on Color*, *Vol. 1.* (*The Philosophy of Color*), Cambridge, MA: MIT Press, 177-190.

Carey, S. (2009). *The Origin of Concepts*. Oxford University Press

Cohen, J. (2003). Perceptual variation, realism, and relativization, or: How I learned to stop worrying and love variations in color vision. *Behavioral and Brain Sciences*, **26** (1), 25-26.

Cohen, J., Hardin, C., L., & McLaughlin, B. (2006). True Colours. *Analysis*, 66: 335-340

Cohen, J., Hardin, C., L., & McLaughlin, B. P. (2007). The truth about 'The truth about true blue' *Analysis*, 67: 162-166.

Cyr, C., M., Kimia, B., B. (2004). A Similarity-Based Aspect-Graph Approach to 3D Object Recognition, *International Journal of Computer Vision*, **57**, 5-22.

Dretske, F. (1995). *Naturalizing the Mind*. Cambridge, Mass. MIT Press

Edelman, S., Bülthoff, H.H. 1992. "Orientation dependence in the recognition of familiar and novel views of 3D objects." *Vision Research,* **32**, 2385-2400.

Fodor, J.A. 1987. "Why there still has to be a language of thought." In J. A. Fodor: *Psychosemantics*. Cambridge, MA: MIT Press, 135-154.

Fodor, J.A. 1998. *Concepts*: *where cognitive science went wrong* Cambridge, MA: MIT Press

Gert, J. (2006). A Realistic Colour Realism. *Australasian Journal of Philosophy*, **84** (4) 565-589.

Gert, J. (2008). What Colors Could Not Be: An Argument for Color Primitivism. *Journal of Philosophy* **105** (3):128-155.

Gilchrist, A. (1999). An Anchoring Theory of Lightness Perception. *Psychological Review*, **106** (4) 795-834.

Hardin, C.L. 1988. *Color for Philosophers: Unweaving the Rainbow*. Indianapolis, MA: Hackett.

Hardin, C., L. (1995). Color Subjectivism. In Alvin I. Goldman (ed.) *Readings in Philosophy and Cognitive Science*, Cambridge, MA: MIT Press, 493-507.

Hardin, C., L. (2003). Byrne and Hilbert's chromatic ether. *Behavioral and Brain Sciences*, **26** (1), 32-33.

Hilbert, D., R. (1987). *Color and Color Perception. A Study in Anthropocentric Realism*. Stanford: Center for the Study of Language and Information

Hilbert, D., R., Kalderon M., E. (2000). Color and the Inverted Spectrum. In Steven Davis (Ed.): *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives*. Oxford University Press, New York

Hunt, R., G., W. (1982). A model of colour vision for predicting colour appearance. *Color Research and Application*, **7**, (2), 95-112.

Jackson, F., Pargetter, R. (1997). An Objectivist's Guide to Subjectivism About Color, In Alex Byrne and David R. Hilbert (Eds.), *Readings on Color*, Vol. 1. (The Philosophy of Color), Cambridge Mass. The MIT Press, 67-79.

Jakab, Z. 2000. "Ineffability of qualia: a straightforward naturalistic explanation." *Consciousness and Cognition*, **9** (3), 329-351

Jakab, Z. (2001). *Color experience: empirical evidence against representational externalism*. Doctoral dissertation, Carleton University, Ottawa

Jakab, Z. (2005). Opponent processing, linear models, and the veridicality of color perception. In *Cognition and the Brain: The Philosophy and Neuroscience Movement*, edited by Kathleen Akins and Andrew Brook, Cambridge University Press 336-378.

Jakab, Z., McLaughlin, B., P. (2003). Why Not Color Physicalism Without Color Absolutism? (Commentary on A. Byrne and D. Hilbert: Color Realism and Color Science), *Behavioral and Brain Sciences*, **26** (1), 2003, 34-35

Johnston, M (1997). How to Speak of the Colors, In Byrne and Hilbert, (eds.), *Readings on Color*, *Vol. 1.* (*The Philosophy of Color*), Cambridge, MA: MIT Press, 137-176.

Johnston, M. 1998. "Are manifest qualities response-dependent?" *The Monist*, **81**, 3-43.

Kuehni, R., G.. (2004). Variability in Unique Hue Selection: A Surprising Phenomenon. *Color Research and Application*, **29** (2) 158-162.

Loar, B. (1997). Phenomanal states. In Ned Block, Owen Flanagan, and Güven Güzeldere (eds.) The Nature of Consciousness: Philosophical Debates, Cambridge Mass. MIT Press, 597-616.

Malkoc, G., Kay, P., Webster, M., A. (2005). Variations in normal color vision. IV. Binary hues and hue scaling. *Journal of the Optical Society of America*, A22, 2154-2168.

Marr, D. 1982. *Vision. A computational investigation into the human representation and processing of visual information*. New York: Freeman

Marr, D., Nishihara, H.K. 1978. "Representation and recognition of the spatial organization of three-dimensional structure." *Proceedings of the Royal Society of London, Series B*, **200**, 269-294.

Matthen, M. (1999). The Disunity of Color. *Philosophical Review*, **108**, 47-84.

Matthen, M. (2005). *Seeing, Doing, and Knowing*. Clarendon Press, Oxford.

McGinn, C. 1996. "Another look at color." *Journal of Philosophy*, **93**, 537-553.

McLaughlin, B., P. (2003). Color, consciousness, and color consciousness. In Quentin Smith (Ed.): *New Essays on Consciousness.* Oxford: Oxford University Press, 97-152.

Palmer, S.E. 1999. *Vision Science – Photons to Phenomenology.* Cambridge, MA: MIT Press

Palmer, S.E., Rosch, E., Chase, P. 1981. "Canonical perspective and the perception of objects." In *Attention and Performance*, ed. J. Long and A. Baddeley. Erlbaum, 131-151.

Papineau, D. (2002). *Thinking about Consciousness*. Clarendon Press, Oxford

Russell, B. 1912. *The Problems of Philosophy*, London, UK: Oxford University Press.

Smith, M. (1993). Color, Transparency, Mind-Independence. In John Haldane and Crispin Wright (Eds.): *Reality, Representation and Projection*. Oxford University Press

Strawson, G. 1989. "'Red' and red." *Synthese*, **78**, 198-232.

Stroud, B. 2000. *The Quest for Reality; Subjectivism and the Metaphysics of Color*. New York: Oxford University Press.

Tarr, M.J., Pinker, S. 1989. "Mental rotation and orientation-dependence in shape recognition." *Cognitive Psychology*, **21**, 233-282.

Tye, M. (1995). *Ten Problems of Consciousness.* Cambridge Mass. The MIT Press

Tye, M. (2000). *Consciousness, Color, and Content.* Cambridge Mass. The MIT Press

Tye, M. (2006a). The puzzle of true blue. *Analysis*, **66** (3) 173-178

Tye, M. (2006b). The truth about true blue. *Analysis*, **66** (4) 340-344

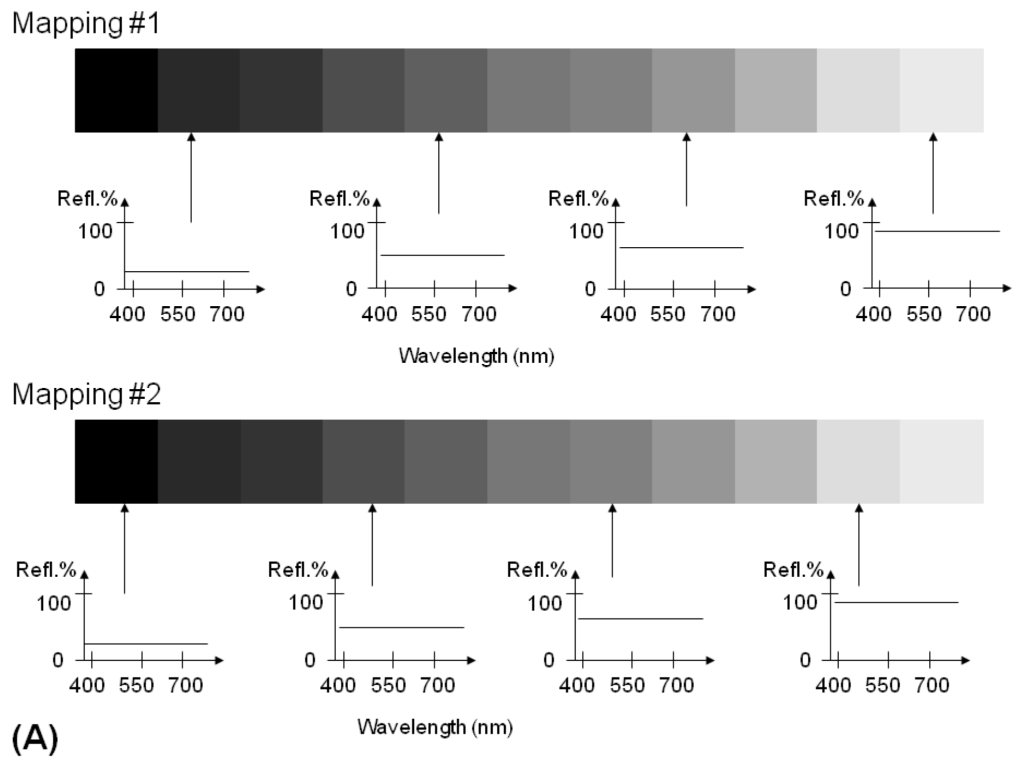
Tye, M. (2009). *Consciouness Revisited*. Cambridge Mass. The MIT Press

Wallis, G., Bülthoff, H. 1999. "Learning to recognize objects." *Trends in Cognitive Sciences*, **3** (1), 22-31.

Werner, J., S., Wooten, B., R. (1979). Opponent chromatic mechanisms: Relation to photopigments and hue naming. *Journal of the Optical Society of America*, **69**, 422-434.

Wuerger, S., M., Maloney, L., T., Krauskopf, J. (1995). Proximity Judgments in Color Space: Tests of a Euclidean Color Geometry. *Vision Research*, **35**, (6), 827-835.

Yablo, S. 1995. "Singling out properties." In: *Philosophical Perspectives*, ed. J. Tomberlin. Vol. 9. Atascadero, CA, Ridgeview.


Mapping #1
Refl.%
100
0
400 550 700
Wavelength (nm)
Mapping #2
(A)

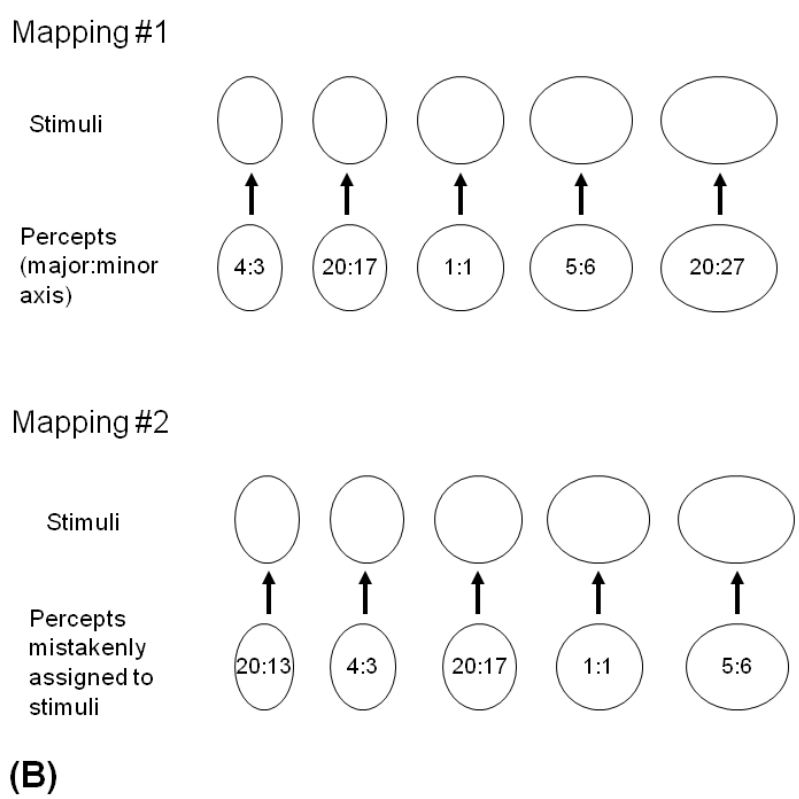

Mapping #1
Stimuli
Percepts (major:minor axis)
4:3
20:17
1:1
5:6
20:27
Mapping #2
Stimuli
Percepts mistakenly assigned to stimuli
20:13
4:3
20:17
1:1
5:6
(B)

Figure 1.

Figure 1. The key difference between perceptual representations of shape versus lightness. (A) In the lightness case different mappings of stimuli (surface reflectance averaged over the entire visible spectrum) onto lightness sensations (symbolized by squares in the gray scale) can work equally well; there is nothing obviously mistaken about either mapping. (B) In the case of shape perception, a single pairing of a stimulus and a perceptual representation may be inherently erroneous, therefore the upper mapping in (B) works better – provides more exact information to higher cognition about its stimulus condition – than the lower one. Ratios in the ovals symbolize analog magnitude representations implemented by visual representations of the stimuli (see Carey, 2009, Ch 4 for the relevant idea of analog magnitude representation).