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

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

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

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

The results of a large number of studies suggest that, as the number of surfaces in the field of view is increased and as more information about the direction and spectral properties of the illuminant is made available to the observer, the appearance of a surface becomes increasingly resistant to alterations of either the spatial context or changes in the illuminant. But it would be a mistake to define color in such as way that its definition holds only under conditions that are optimal for judging surface reflectance (where color constancy is never exact, in any case). And it would be a mistake to construct theories of color based *solely* on how the visual system functions under such conditions or even under natural conditions, more generally. An adequate theory of color vision should be able to account for color vision under *any* stimulus conditions. To define color in such a way that the definition holds only under certain preferred conditions would make it difficult to talk about what is going on in important laboratory investigations, such as Gelb's, in which the relationship between reflectance and color is not necessarily clear, and is in fact the subject of the investigations.

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

Surreptitious substitution

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

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

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

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

https://doi.org/10.1017/S0140525X03490018 Published online by Cambridge University Press

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

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

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

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

Color: A vision scientist's perspective

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

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

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

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

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

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

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

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

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

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