COLOUR PERCEPTION

Mind and the physical world

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OXFORD
UNIVERSITY PRESS

2003

CHAPTER 6

OBJECTIVITY AND SUBJECTIVITY REVISITED: COLOUR AS A PSYCHOBIOLOGICAL PROPERTY

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Preface

The status of sensory qualities has been a topic in philosophy since the ancient Greeks. In the history of thought about colour, scientific theories were formed in relation to a background of philosophy, and philosophical theories often arose in conjunction with, or as a result of, scientific work (as in the cases of Aristotle, Ibn al-Haytham, Galileo, Descartes, Boyle, Locke, and Newton). Through the end of the nineteenth century it was usual for colour scientists, such as Helmholtz and Hering, to address the philosophical assumptions and implications of their work. They engaged such assumptions directly, and examined them with philosophical thoroughness.

During the middle of the twentieth century philosophical and scientific thought about colour separated. Especially in the decades after 1950, philosophers offered 'physicalist' theories of colour without knowing much about the physics, physiology, and psychology of colour vision. Their work was often guided by what they imagined the 'ordinary' person would say. But this imagined 'ordinary' person usually advanced theses recognizable from previous, or old, philosophy and science.

At the same time, the scientists came to believe that they could proceed without philosophy, or without themselves adopting philosophical assumptions. In any area of active science which moves at the border of the unknown, there is no such thing as doing science without philosophy. To attempt to do so simply means that one's philosophical assumptions go unexamined. That may not cause much damage locally, but it can limit scientific imagination if one is stuck in old philosophy. It can be damaging in colour science if one's philosophical assumptions, imbibed in the final decades of behaviourism and expressed through an unthinking commitment to physicalist reductionism, lead one to be suspicious of phenomenal experience and biological function, and hence of the very substance of colour vision.

During the 1970s and 1980s philosophy of science, led by the subfields of philosophy of biology and philosophy of physics, but including philosophy of psychology as well, re-engaged the scientific literature. In philosophical theories about colour this meant coming to terms with the physics, physiology, and psychology (including the phenomenology) of colour vision. That was a good thing. However ubiquitous and 'obvious' colour experience may be, the basis of colour vision in the properties of objects, in the structure and functioning of the nervous system, and in the psychological processes of colour vision, is complex. 'Ordinary' assumptions about causation, propertyhood, and 'how things are or must be' cannot carry the day. In this area, as in many other areas of philosophy, one can't make philosophical progress without knowing anything else, that is, without engaging with what others know about colour. That's how it should be. Philosophy aims at generality, but must earn its broad perspective one step at a time, working from the bottom up, while keeping in sight the general vista it demands of itself. Workers in philosophy, as in other areas of the humanities, must earn their abstractions. They are fortunate to be able to do so through the pleasurable toil of understanding.

G. Hatfield

Introduction

Philosophical theories of colour divide into three. There are the so-called objectivists, who argue that colour is a mind-independent property of objects. There are the subjectivists, who argue that colour is not a property of objects, but an internal state of the perceiver or the subjective content of a perceiver's experience. And there are the relationalists, who argue that colour, considered as a property of objects, is a relational property; it is a property that surfaces and light sources have of causing experiences with various phenomenal characters in perceivers.

These philosophical theories differ on the question of what colour is. Objectivists think of colour as a physical property, which is in principle independent of colour experience and visual perception. Subjectivists make colour experience primary in their conceptions of colour; indeed, they think that the notion of colour has primary reference only to visual experience. Relationalists also define colour in relation to colour experience; however, they are able to define colour as a property of the surfaces of objects by considering the relation between objects and colour experience.

Proponents of all three positions marshal the available scientific evidence in their support. To support objectivism, Hilbert (1987, 1992) appeals to Maloney and Wandell's (1986) analysis of colour constancy as an inference to the spectral reflectance distribution of a given surface (see Maloney, Chapter 9 this volume). The objective colours of things are equated with individual surface reflectance distributions. In arguing for a subjectivist position, Hardin (1988) points to facts of perceiver variability and variety in the physical causes of colour phenomena. He argues that because colour cannot be equated with a specific physical kind, colour experience is a (useful) illusion. The relationalist uses similar sorts of data to argue that colour as a property of objects is constituted by the fact that illuminated objects have a disposition to cause perceivers to experience colour visually (Johnston 1992; Campbell 1993; Harman 1996). Some relationalists appeal to a functional notion of colour perception, perhaps supplemented with data concerning inter-species differences, to argue that colour is a psychobiological property, and that a primary function of colour perception is discrimination among objects (Hatfield 1992; Thompson 1995).

The frequent appeal to the facts of colour science in the philosophical colour literature is a good thing. It is an instance of the more general trend in philosophy of science to expect that the philosopher's examples and arguments are responsive to actual scientific positions and to common features of scientific practice (see Hatfield 1995). At the same time, attention to scientific practice reveals that interesting questions at the forefronts of science typically are not resolved by a bare appeal to facts, but to facts in relation to a background of scientific theory and philosophical assumption. The same feature is present in philosophical debates on colour. The three major positions just named depend heavily on background understandings of theoretical terms from both science and philosophy; two of the most important are the terms 'objective' and 'subjective' themselves.

In this chapter I will focus on the notion of colour as a property of the surfaces of objects. Examination of the arguments of the objectivists will help us understand how they seek to reduce colour to a physical property of object surfaces. Subjectivists, by contrast, seek to argue that no such reduction is possible, and hence that colour must be wholly subjective.

I will argue that when functional considerations are taken into account, a relationalist position best accommodates the primary data concerning colour perception, and permits a better understanding of the ways in which colour is both objective and subjective. The chapter ends with a reconsideration of the notions of objectivity and subjectivity themselves, and a consideration of how modern technology can foster misleading expectations about the specificity of colour properties.

Objectivism

Traditional objectivists hold that colour is a mind-independent physical property of objects. The most likely candidate for such a property is the surface spectral reflectance (SSR) of an object. The SSR is the percentage of the light at each wavelength across the visible spectrum that is reflected by a surface. The amount reflected depends on the percentage of the light absorbed by the surface, the remainder being reflected. Chapters 9 and 11 in this book include examples of surface spectral reflectance distributions (or reflectance functions). The most important characteristic of such distributions for our purpose is that they tend, in natural objects, to be relatively smooth functions, which differ in shape. As we will see, the relation between such distributions and perceived colour can be complex. But there are some regularities, such as that typical red objects will reflect more light toward the long wavelength or red end of the visible spectrum, and typical blue objects will reflect more light toward the short wavelength or blue end of the spectrum.

Sophisticated objectivists such as Hilbert (1987, 1992), Maloney (Chapter 9 this volume), and Wandell (1995, Chapter 9) identify object colours with surface spectral reflectances. They see the visual system as seeking to develop a stable representation of the surface reflectance (or a more basic physical property related to that reflectance, such as Maloney's bi-directional reflectance density function, see Chapter 9 this volume). The ability to develop a stable representation of surface colour under variations in ambient illumination is known as *colour constancy.* The light received at the eyes from an object is a function of both the object's reflectance properties and the spectral composition of the illuminant (e.g. dawn sunlight, incandescent light, midday sunlight, all of which differ). Therefore, if constancy is to be achieved, the illuminant properties must somehow be accounted for. As traditionally conceived, this would require solving a problem in two unknowns by contemplating only a single value (the light received at the eyes); so stated, the problem cannot be solved. Additional information of some sort is needed. Maloney and his colleagues have developed ingenious linear models of colour constancy that attribute to the organism some engineering assumptions concerning candidate spectral reflectance distributions and the candidate illuminants, making the problem soluble within certain ranges of accuracy. Some objectivists, including Barlow (1982), Hilbert (1992), and Shepard (1992), see colour constancy as the driving force behind trichromacy (the three-pigment system in human and some other primate eyes). That is, they think that trichromacy evolved because it allows the eye to serve as a better instrument by which the visual system can recover information about SSRs.

Two aspects of the objectivist stance are of interest here. First, its overall conception of the task of colour perception is what I have called a 'physical instruments' conception (Hatfield

1992, pp. 496–9). Objectivists see the perceptual system as seeking a representation of a distal physical property, such as the SSR. On such a conception, physics provides the appropriate concepts for describing the representational task in colour vision, which is to achieve a representation of physical properties described as such. Mausfeld criticizes this view of perception for treating the visual system as a 'measurement device' (Mausfeld 1998, p. 224; Chapter 13 this volume). The relationalist functional view presented below offers an alternative to this conception of the visual system's function in colour perception.

The second point of interest concerns the objectivist's response to the fact of metamerism. Metameric surface colours occur when different SSRs yield the same perceived colour under specified conditions of illumination. This means that physically distinct stimuli, which exhibit different functions relating wavelength to the absorption and reflection of light, yield phenomenally indistinguishable colour experiences. The phenomenon of metamerism is well established. The interesting question is how to interpret it.

Objectivists such as Hilbert (1987, Chapter 5) and Barlow (1982) respond by saying that there are many more colours than we perceive. Having defined surface colour in terms of SSR (or a related measure), they identify each SSR as a distinct colour. If the human visual system, or any visual system, fails to discriminate among SSRs, then it fails to discriminate all the colours there are. Consonant with their physical instrument conception of the function of colour vision, the physical description of surface properties provides the standard for individuating colours, and not the facts of colour experience.

Subjectivism

The position of subjectivism is most prominently associated with C. L. Hardin's 1988 book, *Color for philosophers*. This book raised the standard of philosophical discussions of colour by paying close attention to scientific work. Hardin examined the various objectivist and dispositionalist theories. (Dispositionalism is a type of relationalist theory.) He rejected objectivism and physicalism on the grounds that there is no single physical property corresponding to the colours we experience. In so doing, he adopted a phenomenalist stance: he took it that a theory of colour should be driven by the facts of colour perception. To this extent, he made colour experience, or at least colour response, fundamental in colour theory considered as a part of the theory of vision.

Hardin argued that if physical properties cannot be put into sufficiently direct relation to colour experience, the notion that colours are objective should be rejected (see also Boghossian and Velleman 1991). He disposed of an objectivism similar to Hilbert's (1987) by appealing to metamerism and certain other higher-order properties of colour, such as the finding that red, green, yellow, blue, black, and white are the primary colours. Hardin contended that since objectivists cannot explain the special status of these primaries by appeal to physical properties alone, their attempted reduction fails. (Jackson and Pargetter 1987, though not responding specifically to Hardin, provide the basis for an objectivist reply that allows subjective variability but identifies colour as the physical property that causes experience in individual perceivers in specific circumstances. This position, although interesting for its admission of the variability of relation between physical properties and

colour experience, fails to respond adequately to the objectivist desideratum of making colour a mind-independent physical property; on which see Hilbert 1992.)

In addition, Hardin (1988) moved against dispositionalist theories of colour vision, which he characterized as a variant of subjectivism. A common form of dispositionalism, descended from the natural philosophies of René Descartes and Robert Boyle, and made prominent in the philosophy of John Locke, holds that colours are secondary qualities (for a review, see Hilbert 1987, Chapter 1). A secondary quality is a property of an object that is defined by the object's standard effect on something else. In the case of colour, the standard effect is the 'idea' or experience of colour. In more recent language, the position holds that for an object to be a certain shade of blue is for it to produce a specific experience of blue in standard observers under standard conditions. The appeal to standard conditions takes account of differences in illumination; objects that look white in daylight may, in certain conditions, look red under red light. A dispositionalist theory might make daylight the standard condition, in which case the object would be classed as white. The notion of a standard observer rules out colour-blind observers, or observers in special states of adaptation or in drug-altered states.

Boyle and Locke expressed this position using the language of primary and secondary qualities. Primary qualities are physically basic. For Boyle and Locke, they include the size, shape, position, and motion of the microscopic corpuscles that they held to constitute matter. Candidates for the relevant primary qualities today might be the absorption and reflectance properties of surfaces, or the underlying atomic and molecular properties that determine those properties. Colours, sounds, tastes, odours, and tactual qualities such as hot and cold are secondary qualities. Physically, they are constituted from primary qualities (for Locke and Boyle, configurations of corpuscles). But they are defined as powers to produce sensations or ideas in the minds of observers. In this sense, they are relational properties. If there were no (actual, or perhaps possible) observers, there would be no secondary qualities—the existence of the secondary qualities depends upon there being observers in which the experience of colour, for example, can be caused.

Hardin (1988) sought to show that the notions of standard conditions and standard observers cannot support a view that colours are stable dispositions of objects to produce experiences. The scientific literature shows that colour constancy is not perfect. So if colour in objects is the disposition to produce colour experience of a specific hue (or shade of colour) in standard observers under standard conditions, nature does not cooperate. Under any natural (i.e. not artificially restricted) interpretation of what might count as standard conditions or standard observers, the conditions and observers can be fixed and yet the colour response vary (among standard observers and within the class of standard conditions). If the dispositionalist wants to assign to objects specific, stable, intersubjectively common hues using the relation between surface reflectance properties and the colour experience of observers, the evidence Hardin presents poses a serious problem.

In the end, Hardin argues that close scrutiny of the notions of standard conditions and observers reveals that colour is an interest-relative and subjective notion with no objective basis. He concludes that colour experience is a useful illusion; it presents objects as having properties they do not have. The illusion results from properties that objects and perceivers do have, hence has some foundation in reality, is persistent, and so permits the use of colour appearances in the classification of objects (Hardin 1988, Chap. 2). But, Hardin thinks, these findings undermine any attempt to ascribe colour as an objective property to objects (see also Boghossian and Velleman 1989).

In my view Hardin's response to the scientific evidence is too extreme. By re-examining the notions of subjectivity and objectivity and reflecting further on the notion of property, I think we can find a place for a relationalist functional theory of colour that permits colour to be a *subject-relative*, but in important respects *objective*, psychobiological property of objects. These reflections will not require that we examine or qualify the empirical results Hardin describes. For our purposes, we need not re-examine his facts. Rather, we will look at the theoretical context and philosophical assumptions he and others use to interpret those and other facts.

Relational functionalism

I agree with Hardin that colour experience should be an important component in any analysis of colour as a property. My analysis therefore begins from the place of colour in perception. From this position one might, or might not, come to reduce colour as a property of objects to a mind-independent physical property. In fact, I also agree with the tenor of Hardin's response to physicalist objectivism (Hatfield 1992). However, I think that the sort of facts he presents can be made consistent with a certain kind of objectivist view of colour, a relational functionalist view. My view is relationalist in that, like the dispositionalist, it accepts that colour as a property in things consists in the disposition of things to cause experiences of a certain sort in perceivers. It is functionalist in that it looks to the biological function of colour vision for guidance about what sort of property is constituted by the relations between objects and perceivers.

The analysis I will present disagrees with the physicalist objectivists on four important points. I will argue that:

1. Colour constancy need not be the driving force toward trichromacy.
2. To possess colour an object need not be assigned a precise shade of colour.
3. Properties can be species-relative.
4. Objectivity is not always incompatible with subjectivity.

These points, taken together, are consonant with a view that trichromatic colour vision evolved in primates as a means for discriminating objects by their surface properties, for which exact constancy is not needed. In opposition to Hardin's (1988) subjectivism, these points can serve as the basis for assigning colour to objects as an objective, subject- and species-relative property.

One way of asking what property coloured objects have is to ask what representational content is found in colour experience. That is, what does experienced colour represent about objects? The physicalist objectivist thinks that colour experiences do, or should, represent individual SSRs, and then concludes that to the extent that colour experience does not uniquely reveal SSRs, it falls short of its representational task. My approach is that colour experience represents surfaces as having properties that make them instances of a hue class.

It may do so by representing the surface as having a specific hue, but this does not mean that the object can or should be assigned that particular shade as its colour. Rather, the object is assigned a colour type, in relation to its appearance to colour observers of a specific type (e.g. normal human observers) under ecologically standard conditions (e.g. daylight viewing). If an object appears green, blue, red, yellow, etc., in daylight, then it is assigned that colour, but need not be assigned (as a stable, objective property) the particular shade it appears as having to an individual observer under a given instance of daylight.

This position arises from a functionalist conception of assigning representational content in perception. A functional approach assigns content in relation to a task analysis, or an analysis of the function of the representational system in question (Hatfield 1988, 1991; Matthen 1988). Thus, one function of vision is surely to represent the spatial layout; various spatial structures would be assigned as contents of visual experiences under this analysis. In the case of colour vision, to apply this sort of analysis one would seek to determine what the (or a) function of colour vision is for a given species. (There need not be only one function in a given species, or across species.) Ascriptions of such functions are based in biology, and typically appeal to evolutionary theory. The basic idea is that a structure or system is assigned a function in accordance with the selection pressures that lead to its evolution and maintenance in a type of organism. Consequently, if colour vision has come to have other, culturally defined functions that have not been active in natural selection, those functions are described as artefact functions, and are left out of the primary analysis of colour as a naturally occurring property (more on this below).

The long history of the evolution of eyes shows that visual pigments are adapted to prevailing light conditions. The pure rod retinas of deep-sea fish are adapted to the small segment of the visible spectrum that penetrates to their depth (Lythgoe 1972; Lythgoe and Partridge 1991). In those with only one type of rod pigment, the wavelength of maximum light sensitivity of the rods closely matches the peak ambient light. That sort of match would be effective for fish who hunt from below, seeing their prey as dark areas against the downward light.

Many fishes are dichromats. Investigators have wondered how a two-cone system could evolve. They have considered evolutionary scenarios in which a stable two-cone retina might evolve prior to the development of dichromatic colour vision itself. (The possession of two types of visual pigment is not sufficient for colour vision; the visual system must compare the outputs of the two types for colour discrimination to occur.) McFarland and Munz (1975) argue that the original selection pressure for two types of cones in ocean fish that hunt near the surface might have come from the demands of two sorts of discriminatory tasks. For hunting from below, such fish would be well served by cones with maximum sensitivity matching the peak wavelength in the available downwelling light, as for the deep-sea fish. That would make any object seen from below dark against a bright background. Along the horizontal line of sight, the peak available light is of shorter wavelength than the broad spectrum downwelling light (within several metres of the surface). Hence, for hunting objects along that line of sight, it is better to have a cone type with maximum sensitivity offset toward the long wavelengths. In that way, the ambient spacelight of the background would appear darker, and objects reflecting the broad-band downwelling light would stand out.

McFarland and Munz (1975) contend that two-pigment cone retinas might have evolved so that both sorts of discrimination could be served by a single eye. That would require separate visual pathways for each cone type, a precursor to colour vision. They conjecture that 'the evolution of high visual acuity with maximum contrast under varied photic conditions would favor the selection and maintenance of separate visual pathways for these different cases. In other words, we have described the elements necessary for color vision' (McFarland and Munz 1975, p. 1073). Colour vision would not be needed initially to explain the advantage of this system, and could evolve subsequently, once the two visual pathways were available to allow further selection on neural wiring.

Adopting a biofunctional and comparative attitude, we may ask what colour vision is 'for' in (at least some) mammals. After a thorough review of the literature, Jacobs (1993, pp. 456–7) concluded that colour vision serves the following functions:

(1) to provide contrast not based on achromatic brightness or lightness;

(2) to aid in the detection of small objects in a dappled environment, where lightness cues are largely masked (e.g. fruit in trees);

(3) to aid in segregation of objects divided by occlusion (e.g. fruit seen through leaves, see Mollon 1989);

(4) to identify objects by their stably perceived colour (requires something approaching colour constancy).

Only item (4) requires something approaching colour constancy, and even it does not require perfect constancy; it would suffice if environmentally salient objects could be stably re-identified by colour class. The fineness of the partition of the hue space needed to achieve this task would depend on the characteristics of the objects to be sorted (Hatfield 1992, 1999). That, of course, is an empirical matter that would require analysis of the photic properties of biologically significant objects on a species by species basis.

Much of the literature on comparative colour vision, and on the evolution of trichromacy in primates, stresses functions (1) to (3). Mammalian trichromacy is comparatively recent, having evolved in the Cenozoic era, after the adaptive radiation of mammals some 65 million years ago (Goldsmith 1990). Genetic analysis suggests that it evolved through selection on naturally occurring polymorphism in the middle-wavelength sensitive (MWS) cone. Thus, the short-wavelength cone is thought to have been stable, but the MWS cone to have exhibited polymorphic variance that provided instances of the MWS and LWS cone types, in relation to which selection for neural wiring to permit trichromatic colour vision might occur. Trichromatic colour vision of this sort would allow better discrimination of yellow, red, and orange objects found among green leaves. For such discrimination to occur, perfect or near-perfect colour constancy would not be needed. Rather, it would need only be the case that yellow, red, and orange fruit was more easily discriminable to a trichromat (by comparison with a dichromat) across a significant range of natural lighting conditions. This 'fruit detection' hypothesis has long been favoured as the explanation of the development of colour vision (e.g. Allen 1879, Chapter 6; Walls 1942, Chapter 12) and trichromacy (Polyak 1957, pp. 972–4), and receives support from recent empirical studies such as those reported by Mollon (1989) and Jacobs (1996).

According to this analysis, when trichromacy evolved things gained new colours, as the visual system became able to group things using a more fine-grained partition of the chromatic appearance of surfaces. Thus, fruit and leaves came to appear more distinctly different, chromatically, than before. For tasks (1) to (3), there is no need for precise colour constancy, nor any need that colour properties be equated with specific shades (that is, highly determinate hues).

Colour as a psychobiological property of surfaces

Colour is an attribute of objects that makes surfaces visually discriminable without a difference in brightness or lightness. Focusing for the moment on human colour vision, it makes objects discriminable because they appear with differing hue or chromaticity. More generally, ascriptions of colour vision to various animals can be made by finding that the members of a species (or a subpopulation of the species, e.g. normal trichromatic humans) can discriminate independently of brightness or lightness in E (an environment, normally specified by ecologically typical conditions).

Under this analysis, colour is a relational attribute, analogous to being a solvent. The existence of colour as an attribute of objects depends on the normal effects of objects on perceiving subjects. In humans, these effects include a phenomenal or experiential component. Accordingly, for an object to possess colour is for it to have a surface reflectance that produces a phenomenal chromatic visual presence that permits discrimination among objects independent of brightness or lightness by members of a type of population in E.

The colours under which objects appear can serve as the basis for categorizing objects. However, qualitatively similar clusters of colour experiences are not themselves categories (*pace* Thompson 1995, pp. 184, 196). For the colours of objects to be useful for categorization, the same object should appear with the same hue-type under a variety of conditions, but it need not appear with the same specific hue. It is consistent with an object possessing colour that it appear differently under differing conditions (of the perceiver, and/or the environment); such differences would be multiplied if there were no colour constancy, but objects would still possess the attribute of colour. Even with some degree of colour constancy, the expression of the attribute of colour can be affected by environmental conditions and the state of the perceiver.

Modern colour science has developed colorimetry, or the alignment of colour judgements with combinations of wavelengths, into an exact art (Kaiser and Boynton 1996, pp. 25–6 and appendix). This art is made possible by severely restricting the conditions under which colour observations are made by test observers. The high degree of accuracy achieved makes possible standardized dyes, and serves engineering functions, such as the production of colour television sets. The specificity found in laboratory colorimetry should not result in our treating the colour attribute as if it were realized by a set of finely differentiated colour properties (corresponding to the range of highly specific hues). For certain cultural, scientific, or industrial purposes, such specificity is desirable. However, when colour vision is regarded as a biological capacity of sighted animals, the resulting functional approach to the colour attribute suggests it is realized by surface characteristics that yield varying colour responses across differences in ambient conditions and type and state of Ss.

This variation also is recognized in colour science. The attitude toward it varies. We have seen that many objectivists view 'the colour of an object' as a highly specific physical property that may be recovered with more or less success by natural visual systems under ecological photic conditions; under this conception, the same response to differing SSRs, or differing responses to the same SSR, indicate error. Subjectivists have concluded that the extant variation undermines the very notion that objects are really coloured (have a colour property). In my view, the subjectivist gives up on colour properties too quickly, while the objectivist divorces the colour property from colour experience and misdescribes the function of colour vision.

There is a prejudice in ordinary philosophical uses of language against relational attributes and properties, and against attributes that don't stably possess determinate values. Yet there are perfectly good relational properties which, in virtue of their relativity, may be differently assigned to the one and the same object at the same time. An example is the biological property of being nutritious. To be nutritious is to be usable in metabolism. The property of being nutritious is species relative. Wood is nutritious for termites, not for humans; that is, it possesses the property of being nutritious for termites, but does not have a nutritive property in relation to humans. Its being nutritious depends on its physico-chemical properties. These physico-chemical properties have effects on all sorts of things, and interact with other chemicals during metabolism. Being nutritious does not add anything to the chemical constitution of wood. Yet it is a property that wood might or might not have. If there could be no wood-eating animals, wood would not be an animal nutrient. It would not be altered physically by facts about its being or not being a nutrient. But it would have, or not have, a biological property.

Colour as an attribute of objects is analogous to the property of being nutritious, except that the effect it has on organisms has a mental component. Hence, I denominate colour a psychobiological attribute. It is a property objects have, in relation to perceivers, of being visually discriminable by phenomenal hue rather than lightness or brightness. (Notice that I take phenomenal hue, colour, or chromaticity as primitives, and do not try to define them in terms of something else; that is a characteristic of theories that make colour experience, or colour discriminatory capacities, theoretically primary.)

Because colour properties are individuated in relation to perceivers, objects might be described under more than one colour name at the same time, in relation to various populations of seers. That is fine, because they have as many instances of the relational colour property as there are distinct classes of perceivers to which objects are related. Objects that may be assigned more than one colour name (e.g. they are yellow to certain dichromats but orange to trichromats) possess two (or more) distinct colour properties at the same time, depending on how many type-distinct classes of colour perceivers there are for whom they appear chromatically distinct. This does not, of course, imply that they have mutually exclusive properties (being yellow and being orange in the same respect) at one and the same time; they have as many different colour properties as there are types of perceiver in which they cause type-distinct colour responses. Moreover, if there were not (and could not be?) any chromatically endowed perceivers, there would be no colours. There would, of course, still be photons and reflectances.

The metaphysics of relational and dispositional properties is intricate (see Chapter 16 this volume, for an analysis). When I say that colour is a relational property that involves the disposition of objects to cause experiences of certain sorts in a population of perceivers, I am telling you what kind of property it is. I am not trying to capture ordinary language talk about colours. [Philosophical colour theories (see, for example, Jackson and Pargetter 1987; Johnston 1992) are often driven by 'ordinary' intuitions about property and causal talk, but such language has no particular authority in my view.] In particular, I am not trying to capture language about the causal relation between objects and colour experience, or about the notion of 'property' as distilled from ordinary talk of objects. My aim has been to locate the colour property within a biofunctional conception of the senses.

Once the basic notion of colour as a psychobiological property is in place, there is no reason to preclude use of a notion of 'physical colour' that is independent of colour as a visual property. Visually, colour is a relational property involving both objects and perceivers. But we could also speak of 'physical colour' as a property of reflecting light according to a specific SSR. Even while granting that the relational notion of colour as a psychobiological property is primary, we might choose to develop a perceiver-independent notion of 'physical colour' as a means of describing the reflective properties of objects, or the spectral composition of light. To avoid confusion, it would be necessary to keep in mind that such physical colours would be defined without relation to colour experience or colour perception; they would be defined in a purely physical vocabulary of wavelength or photon vibration.

Whatever language we choose for describing the physical properties of light and of surface reflectances, it is in virtue of its physical SSR that an object is able to affect light and produce a colour response in an observer. But the colours of objects cannot be reduced to or identified with SSRs. Rather, object colours are to be identified with properties objects have of causing colour experiences in perceivers. A physical SSR may help us identify this class, but using it alone, independent of the colour-discrimination capacities of organisms, we could not define real colours. There would be no physical reason for marking off the 'visible spectrum' or carving it into colour regions independent of the visual capacities of organisms. Colour is a perceiver-dependent property of objects.

Objectivity and subjectivity revisited

Hardin (1988) opposed his brand of subjectivism to the sort of objectivism espoused by Hilbert 1987 (Hardin in fact addressed earlier forms of the position, as in Armstrong 1961 and Smart 1961). The arguments of the various objectivists and subjectivists share a common conception of objectivity, according to which objectivity requires mind-independence. This conception of objectivity allows Hardin to argue that if there is no candidate colour property individuated by purely physical criteria independent of effects on perceivers, colour is not an objective property, but is wholly subjective or illusory. In my view this particular dichotomy of positions into objectivist and subjectivist relies on an overly coarse analysis of the notions of objectivity and subjectivity themselves.

The notion of objectivity is complex and many faceted. It can include at least the following aspects:

(1) pertains to a mind-independent reality;

(2) pertains to the object;

(3) sustains factual claims;

(4) pertains to publicly available states of affairs;

(5) is real.

Item (1) is often invoked in discussions of colour, but the other factors are important, too. Moreover, most or all of the other aspects are independent of (1). Although some philosophers still question whether there can be factual claims about mind-dependent or mind-supported states as affairs, such as the sensations, thoughts, and feelings of individual subjects, experimental psychology has been offering measurements of psychological states for more than 150 years. Of course, those psychologists who consider themselves to be determining the experiential sensory states of their subjects may be wrong, in the general sense that all science is fallible and not absolute. However, in what follows I will explore the implications of thinking that they are right.

The notion of the subjective is also complex and many faceted. It can include the following:

(A) is dependent on the mind alone (with no dependence on objects);

(B) pertains to the subject;

(C) varies idiosyncratically (no intersubjective agreement);

(D) pertains to experiential, private states of affairs;

(E) is not real.

The root notion of 'subjective' is that it pertains to the subject (B), which need not entail that it depends on the mind alone (A). A feeling of hunger pertains to the subject and involves a mental state, but it may depend on the state of the digestive system and blood chemistry. Students who accuse professors of 'subjective grading' have aspect (C) in mind. Aspect (D) is sometimes thought to preclude intersubjective knowledge of a subjective state, but that depends on what grounds there might be for inferences across subjects. It is sometimes suggested that something wholly mind-dependent 'is not real' or does not belong to the world (E). On the other hand, one might argue that minds (or brain-dependent experiential mental states) exist and so must belong to the world—that is, must be real. (Indeed, even dualists such as Descartes typically thought of the mind as existing in the natural world, and hence did not exclude dualistically conceived mental states from the 'reality' of the natural world; see Hatfield 2000.)

Colour as a psychobiological property of objects is 'objective' in senses (2) to (5). It lacks only (1), mind-independence. But even if (1) is denied, we can retain (2) to (4), which allow a robust notion of objectivity. Items (2) to (4) include pertaining to the object, sustaining factual claims, and pertaining to publicly available states of affairs. They permit a notion of objectivity including publicly available facts. I like item (5) as well; even though the relational notion of colour depends on mental experiences for its paradigm statement (in the case of human beings), one might well assert that human phenomenal experience is none the less 'real' (i.e. a part of the world).

Colours as relational properties of objects are objective in that they:

(2) pertain to the object;

(3) sustain factual claims;

(4) pertain to publicly available states of affairs;

(5) are real.

But this is not inconsistent with their:

(A′) being dependent on the mind, because attributed relative to effects on experience;

(B) pertaining to (an experiential effect on) the subject.

(A′) is rewritten from (A) to make explicit that mind-dependence can include relations to extra-mental or extra-brain states of affairs.

Even when colour is defined in relation to phenomenal experience, then, it has elements of both objectivity and subjectivity. It is subjective in senses (A′) and (B), but not (E). As regards (C), some intersubjective variation occurs, but it often (and increasingly with the growth of knowledge) can be explained in a systematic fashion by taking into account physiological differences among subjects. Sense (D) should be divided. Colour defined in relation to experience is subjective in sense (D′): the experiences of individuals are ontologically private, that is, a given instance of a colour experience can be 'had' by only one person. But it need not be, and typically is not subjective in sense (D″): epistemically private. Third parties can make reasonable claims about someone else's colour experience, arguing from analogy with their own experience (and, if needed, pointing to species-shared biological characteristics). Hence, the subjectivity of colour experience in senses (A′), (B), and (D′) is not inconsistent with the public availability of colour as species-relative property.

Culture, naming, and property specificity

Culturally, we have exploited the chromatic sensitivity of our visual systems to develop finely divided colour categories, and we exploit visual sensitivity to use colour in systems of identification and contrast, which we rely on for many practical purposes. Colour coding is used in medical and engineering contexts where life-or-death outcomes depend on colour discrimination. Artists and decorators rely on the availability of stable, reproducible paints and dies exhibiting a highly specific hue under a range of conditions. Such scientific and cultural uses of our abilities for fine-grained colour discrimination have led some to mistakenly concretize the colour names as well-behaved colour predicates for which we should expect to find a corresponding mind-independent physical property in the world. This has resulted in misplaced demands on candidate colour 'properties', as in expectations of transitivity of colour matches, excessively stable possession of determinate colour values, and so on.

These are unreasonable expectations about colour, which may come from supposing that if colour is to be a property it must be a mind-independent property and behave like a physically measurable state of an object, taken in isolation. Such unreasonable demands on analyses of colour as a property can be avoided by recognizing that:

- Colour as an experience is a way our visual system presents objects.
- Colour as an attribute of objects is defined in relation to the ways objects produce in us representations of their surfaces, discriminable by hue class.
- Biologically, colour attributes are broadly tuned dispositional relational attributes of objects.

Not every property is a physical property. The property of being nutritious is not. Neither is colour. They are both biofunctional properties. Colour, as a property defined in relation to phenomenal experience or psychological discriminatory capacities, is a psychobiological property. As such, its basis may be found in the relation of subjects to objects. It is in relevant respects both subjective and objective. As explained, there need be no paradox in that.

Acknowledgements

Earlier versions of this paper were presented at the Conference on Color Science and Philosophy, Institute for Research in Cognitive Science, University of Pennsylvania (April, 1994), to the Philosophy Colloquium, City University of New York Graduate Center (April, 1996), and in the colloquium series Perception and Evolution, ZiF, Bielefeld (May, 1996). I am grateful to members of the audiences on those occasions for their interest and conversation. I am indebted to Yumiko Inukai for helpful criticism of a recent version.

References

Allen, G. (1879). *The colour-sense: Its origin and development: An essay in comparative psychology.* Trübner, London.

Armstrong, D. M. (1961). *Perception and the physical world.* Humanities Press, New York.

Barlow, H. B. (1982). What causes trichromacy? A theoretical analysis using comb-filtered spectra. *Vision Research* **22**, 635–644.

Boghossian, P. A. and Velleman, J. D. (1989). Colour as a secondary quality. *Mind* **98**, 81–103.

Boghossian, P. A. and Velleman, J. D. (1991). Physicalist theories of color. *Philosophical Review* **100**, 67–106.

Campbell, J. (1993). A simple view of colour. In *Reality, representation, and projection* (ed. J. Haldane and C. Wright), pp. 257–268. Oxford University Press, New York.

Goldsmith, T. H. (1990). Optimization, constraint, and history in the evolution of eyes. *Quarterly Review of Biology* **65**, 281–322.

Hardin, C. L. (1988). *Color for philosophers: Unweaving the rainbow.* Hackett, Indianapolis.

Harman, G. (1996). Explaining objective color in terms of subjective reactions. In *Perception* (ed. E. Villanueva), Philosophical Issues Series no. 7, pp. 1–17. Ridgeview, Atascadero, CA.

Hatfield, G. (1988). Representation and content in some (actual) theories of perception. *Studies in History and Philosophy of Science* **19**, 175–214.

Hatfield, G. (1991). Representation in perception and cognition: Connectionist affordances. In *Philosophy and Connectionist Theory* (ed. W. Ramsey, D. Rumelhart, and S. Stich), pp. 163–195. Lawrence Erlbaum, Hillsdale, New Jersey.

Hatfield, G. (1992). Color perception and neural encoding: Does metameric matching entail a loss of information? In *Philosophy of Science Association 1992* (ed. D. Hull and M. Forbes), vol. I, pp. 492–504. Philosophy of Science Association, East Lansing, MI.

Hatfield, G. (1995). Philosophy of psychology as philosophy of science. In *Philosophy of Science Association 1994*, Vol. 2), (ed. D. Hull, M. Forbes and R. Burian), pp. 19–23. Philosophy of Science Association, East Lansing, MI.

Hatfield, G. (1999). Mental functions as constraints on neurophysiology: Biology and psychology of vision. In *Where biology meets psychology: Philosophical essays*, (ed. V. Hardcastle), pp. 251–271. MIT Press, Cambridge, MA.

Hatfield, G. (2000). Descartes' naturalism about the mental. In *Descartes' natural philosophy*, (ed. S. Gaukroger, J. Schuster, and J. Sutton), pp. 630–658. Routledge, London.

Hilbert, D. R. (1987). *Color and color perception: A study in anthropocentric realism.* Center for the Study of Language and Information, Stanford.

Hilbert, D. R. (1992). What is color vision? *Philosophical Studies* **68**, 351–370.

Jacobs, G. H. (1993). Distribution and nature of colour vision among the mammals. *Biological Review* **68**, 413–471.

Jacobs, G. H. (1996). Primate photopigments and primate color vision. *Proceedings of the National Academy of Science, USA* **93**, 577–581.

Jackson, F. and Pargetter, R. (1987). An objectivist's guide to subjectivism about colour. *Revue Internationale de Philosophie* **41**, 127–141.

Johnston, M. (1992). How to speak of the colors. *Philosophical Studies* **68**, 221–263.

Kaiser, P. K. and Boynton, R. M. (1996). *Human color vision* (2nd edn). Optical Society of America, Washington, DC.

Lythgoe, J. N. (1972). Adaptation of visual pigments to the photic environment. In *Handbook of sensory physiology, VII.1, Photochemistry of vision* (ed. H. J. A. Dartnall), pp. 566–603. Springer-Verlag, Berlin.

Lythgoe, J. N. and Partridge, J. C. (1991). Modelling of optimal visual pigments of dichromatic teleosts in green coastal waters. *Vision Research* **31**, 361–371.

Maloney, L. T. and Wandell, B. A. (1986). Color constancy: A method for recovering surface spectral reflectance. *Journal of the Optical Society of America A* **3**, 29–33.

Matthen, M. (1988). Biological functions and perceptual content. *Journal of Philosophy* **85**, 5–27.

Mausfeld, R. (1998). Color perception: From Grassmann codes to a dual code for object and illumination colors. In *Color vision: Perspectives from different disciplines* (ed. W. Backhaus, R. Kliegl and J. S. Werner), pp. 219–50. de Gruyter, Berlin.

McFarland, W. N. and Munz, F. W. (1975). Evolution of photopic visual pigments in fishes. *Vision Research* **15**, 1071–1080.

Mollon, J. D. (1989). 'Tho' she kneel'd in that place where they grew ...' The uses and origins of primate colour vision. *Journal of Experimental Biology* **146**, 21–38.

Polyak, S. L. (1957). *The vertebrate visual system.* University of Chicago Press.

Shepard, R. (1992). The perceptual organization of colors: An adaptation to regularities of the terrestrial world? In *The adapted mind: Evolutionary psychology and the generation of culture* (ed. J. H. Barkow, L. Cosmides, and J. Tooby), pp. 495–532. Oxford University Press, New York.

Smart, J. J. C. (1961). Colours. *Philosophy* 36, 128–142.

Thompson, E. (1995). *Colour vision.* Routledge, London.

Walls, G. L. (1942). *The vertebrate eye and its adaptive radiation.* Cranbrook Institute of Science, Bloomfield Hills, MI.

Wandell, B. A. (1995). *Foundations of vision.* Sinauer, Sunderland, MA.