

What is Color Vision?

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Consider the following set of propositions:

1. Color is a mind-independent property that some objects possess.
2. To have color vision is (at least in part) to have the ability to see the colors of objects.
3. There is no single mind independent property that is visually detected by all organisms with color vision.

There are serious reasons for accepting each of these propositions individually but there are apparently insurmountable difficulties with accepting all three of them simultaneously if we assume that color is a single property. 1) and 2) together seem to imply that there is some property which all organisms with color vision can see and 3) seems to imply that there can be no such property. If these implications really are valid then one or more of these propositions will have to be rejected in spite of whatever reasons can be given for their apparent acceptability. Before going on to discuss possible resolutions of this apparent contradiction it is worth pointing out there our three propositions are not all of a kind. Proposition 1) is a metaphysical thesis about the ontological status of color and proposition 3) is an empirical thesis about what properties organisms with color vision are capable of detecting. If you accept 1) then 2) will appear to verge on the trivial, but if 1) is denied then the status of 2) will appear more problematic. In what follows I will have more to say about why we either should or should not accept all three of these propositions.

There are many philosophers (and more than a few visual scientists) to whom the appropriate resolution of this difficulty will seem obvious. Proposition 1) asserts the objectivity of color and to these philosophers the incompatibility of our three propositions just adds another piece of evidence to

the already overwhelming case against the objectivity of color. If we toss out proposition 1) there is no difficulty reconciling the remaining two propositions.¹

There are also philosophers who will wish to reject proposition 2) as well as 1).² Those who deny that there are colors at all will not be sympathetic to the thesis that to have color vision is to have the ability to see color unless they wish to deny not just the existence of color but the existence of color vision. Some recent discussions of color ontology seem to arrive at conclusions that entail the falsity of both 1) and 2). (Hardin 1988, Boghossian & Velleman, 1991) For those who are inclined to doubt that color is an objective property or to doubt whether there is any such property as color (or at least that there are any objects that are colored) there is no problem about how to resolve the apparent contradiction between our three propositions. For those sympathetic to color objectivism, however, the difficulty remains and it is to proposition 3) that we must turn our attention.

Proposition 3) asserts that there is no single property that all organisms with color vision detect. The support for proposition three comes primarily from the literature on comparative color vision; the study of color vision, its variations and distribution across the various kinds of living organisms. This literature apparently reveals that color vision plays rather diverse roles in different kinds of organisms. For human beings color is primarily a property of surfaces and our color vision has significant adaptations that allow it to recover surface properties from the visual stimulus.³ Other kinds of organisms apparently have color vision that is better suited to tasks such detecting silhouettes against the sky, or detecting gradients in a source of illumination. This apparent variability seems to make any attempt to find a single property that it is part of the function of all color vision systems to detect futile. If proposition 3) does really have adequate evidential support then it would seem to raise serious problems for any plausible form of color objectivism.

¹ Something like this argument is I think the main burden of the critique of color objectivism that is made by Thompson *et al* (Thompson *et al* forthcoming) although the current form of the argument represents a considerable abstraction from their presentation.

² If we interpret 1) as a conceptual claim rather than an ontological one then there may be those who would accept 1) and deny 2). In this paper I will be concerned only with 1) interpreted ontologically.

³ Most notable among these is the relative independence of the perceived color of a surface in many viewing situations from changes in illumination. This feature of human color vision is known as color constancy and will figure importantly in the argument below.

There are two problems, however, that arise in attempting to use the empirical literature to settle the status of 3). First, most of the literature on comparative color vision is devoted to physiological and anatomical characterization of the color vision system or to psycho-physical characterization of the color vision of the organism in question. These kinds of studies often leave obscure the function color vision plays in the life of the organism and can even fail to significantly constrain which distal properties could possibly be detected using the visual apparatus. This leaves open the possibility that although given the differences in their ecology organisms may put the information about color that they acquire to rather diverse uses it is the same sort of information in every case. Second, in order to investigate the range of properties that organisms that possess color vision can use this aspect of their visual system to detect we need to apply some criterion for the presence or absence of color vision. I will argue below that it is only if we mistake an important necessary condition for the possession of color vision for a condition that is both necessary and sufficient that the claim that different organisms use their color vision to detect different properties will look at all plausible. I will argue that once we get clearer about what color vision is then proposition 3) will lose most of its plausibility.

In the large and growing literature on comparative color vision there is, in fact, a widely accepted and fairly precise characterization of the grounds on which color vision is to be attributed to an organism. In this literature an organism is said to possess color vision if it possesses the ability to discriminate between some lights of different wavelengths independently of the relative intensity of those lights. (Jacobs 1990, p. 287) In other words an organism possesses color vision if there are some pairs of monochromatic lights of different wavelengths that are discriminable by the organism even when they are equally bright. On this criterion color vision requires some sensitivity to the spectral power distribution of stimuli, where the spectral power distribution reflects the distribution of energy in the stimulus across the different wavelengths of the visible spectrum. An organism that is only capable of responding to overall intensity differences does not have color vision. For an organism that is completely lacking in color vision any pair of spectrally different lights will be indiscriminable for some set of relative intensities.

Organisms that lack color vision respond to light stimuli along a single dimension like the black through grey to white dimension of human vision. To

lack color vision on this criterion is not, however, to always be unable to discriminate between stimuli that differ in color to a human observer since most stimuli that differ in color will also differ in brightness for a color blind organism. In fact, one of the great difficulties of research in comparative color vision is to control for brightness cues and ensure that the experimental subject is responding solely on the basis of chromatic differences. This difficulty is exacerbated by the fact that for a given pair of lights the relative intensity at which those lights will appear equally bright for a given observer is highly variable. A pair of lights that to a normal human observer seem equally bright and to differ only in hue or saturation may to another kind of observer or a color anomalous human being to differ only in brightness and not at all in hue or saturation. With sufficient diligence and persistence it is, however, possible to adequately control for brightness cues and the presence of color vision on this criterion has been established for a number of different species. In fact, using this criterion the vast majority of organisms that have been adequately tested turn out to possess at least some degree of color vision and the absence of color vision has been established for very few vertebrate species.⁴

This criterion for the presence or absence of color vision refers only to an organism's sensitivity to features of the proximal stimulus. If the organism has the ability to respond differentially to certain kinds of visual stimuli then it has color vision, if it lacks such an ability then it lacks color vision. No use is made of any information the stimulus may or may not carry about distal properties of the environment nor is any reference made to any subjective features of the organism like the presence or absence of color experience. Looking only at discriminative abilities with respect to the proximal stimulus brings with it a number of advantages for research in comparative color vision. Vexed questions concerning whether or not animals have color experience do not have to be addressed and questions about the function of this visual ability similarly can be ignored in assessing the presence or absence of color vision. Although the experiments used to assess color vision in animals can be difficult to carry out and interpreting the results complicated and controversial there are no serious, in principle, obstacles to empirically determining the presence or absence of color vision in a given organism. Finally, and of increasing recent relevance, advances

⁴ The only mammal for which the complete absence of color vision has been established is the rat (Crawford et al 1990). There are presumably other mammalian species that also lack color vision but have not yet been adequately investigated.

in the knowledge of the neurophysiological structures that support color vision has made it possible to assess color vision in many organisms using anatomical and physiological techniques rather than behavioral ones. For the many organisms which are difficult to maintain in the laboratory, or to train or condition, most of what is known about their ability to see color relies on physiological rather than behavioral assessment.⁵

The determination of the presence or absence of color vision on this criterion is of relatively little interest by itself. This is partly a consequence of the fact mentioned above that most organisms that have been investigated have turned out to possess at least some degree of color vision. More importantly, merely knowing that an organism possesses the ability to discriminate between lights on the basis of wavelength does not allow any very strong inferences to either the neurophysiology or the behavior and ecology of the organism in question. Although the presence or absence of color vision is not itself of great importance for most purposes a more detailed characterization of the kind of color vision an organism possesses can be a useful bit of natural history.

The most basic classification of types of color vision is in terms of the number of receptors involved. Normal human beings have three types of photo-receptors that are involved in color perception in ordinary circumstances. A number of features of human color vision can be explained on this basis including the well-known fact that any light can be matched in color by suitable

⁵ Although comparative color vision is currently an active field of research those organisms that have had their color vision investigated form a rather heterogeneous set. Among the vertebrates quite a few species of mammals have been investigated, although the interest here has been chiefly on the primates although the list also includes squirrels and a number of the more common laboratory animals such as rats and cats. There is relatively little known about the larger mammals presumably because of the logistical difficulties involved in getting an animal, the size of an elk say, into an illumination controlled environment, properly oriented to the display, and trained to respond properly to the stimuli. Other vertebrates that have been extensively investigated include several species of fish, several species of birds, where again issues of experimental control and access play a large role in determining which species are investigated. For fish, in particular, the development of anatomical and physiological methods for investigating color vision has played an important part in widening the range of species of which something is known about their color vision. For invertebrates, the coverage is even spottier with bees being the primary group to which behavioral techniques have been applied and in other groups information about color vision inferred from physiological evidence. The spottiness of the distribution of investigated species and the often opportunistic reasons why those particular species have been studied are one of many difficulties that face those who attempt to provide accounts of the evolution and ecology of color vision. (Jacobs 1981, 1990)

combinations of three appropriately chosen primaries.⁶ The difference between a normal color perceiver and the most common forms of human color blindness is a difference in the number of types of photo-receptors operative in color vision. As opposed to the trichromacy of a normal subject most color-blind individuals are dichromats, that is they have only two types of photo-receptors active in producing their perceptions of color. Dichromats do, however, possess color vision on the criterion under discussion since there will be some stimuli that they are able to discriminate on the basis of their wavelength composition independently of their relative intensity. There will be other pairs of stimuli, by contrast, that are discriminable at equiluminance by a trichromatic individual that will be indiscriminable by the dichromatic one. Monochromacy, the condition of having only a single type of photo-receptor, is not compatible with possessing color vision. Monochromacy, true color blindness, is rare although not completely absent among human beings and seems to be the normal condition for few species of vertebrates.

With these preliminaries out of the way, we can turn to the question of whether or not the ability to discriminate between stimuli on the basis of wavelength alone is an acceptable criterion for the possession of color vision. Earlier I mentioned some of the advantages that this criteria possesses. Foremost among these is the relative ease with which the criterion can be applied in a laboratory setting and its connection with reasonably well understood anatomical and physiological characteristics of the visual system. There are several reasons, however, for thinking that this criterion is at best a necessary condition for the possession of color vision and that an animal that possesses the requisite discriminatory abilities may nevertheless lack color vision.

First, it is possible that an organism could possess a visual system which combined receptor outputs in such a way that the necessary discriminations could be made but that information about the spectral power distribution of the

⁶ Although the sufficiency of three primaries to match any other light is well-known it is less well-known that any three physically realizable primaries will require negative amounts of one of the primaries to match some stimuli. This is accomplished in color matching experiments by adding that primary to the test light rather than to the matching light. Color reproduction systems, like color television sets, do not have this option and in consequence the gamut of colors reproducible by any system involving only three primaries does not include all humanly perceivable colors.

stimuli is not preserved.⁷ Although an organism with a visual system organized in this way would exhibit the kind of discriminatory behavior supposed to imply color vision it would not be able to tell of two stimuli presented in different contexts whether they are the same or different in their spectral power distribution. One way to describe such an organism is that is capable of discriminating two stimuli on the basis of their wavelength but that it is not sensitive to what the difference is between the discriminated stimuli. Another more contentious description might be that these organisms are capable of visually detecting differences in color without being capable of seeing color itself. It seems plausible to claim that in order to possess color vision it is necessary to be able not only to see that two things that differ in color are different but also to be able to perceptually determine at least some facts about their color over and above the mere fact of difference.

Although it is easy to imagine how to construct a detector, or a neural circuit, that would exhibit color discrimination without color detection, there is little evidence on the question of whether this possibility is realized in any existing organism.⁸ There is, however, some evidence that some species of invertebrates actually have visual systems with a variant on this possibility. Some invertebrates display forms of behavior that are wavelength-selective in the sense that organism responds differently to stimuli based on their spectral

⁷ This possibility is discussed in (Gouras 1985) and in (Thompson *et al* forthcoming). Here the distinction is framed in terms of the presence or absence of chromatic contrast effects. The suggestion is that these are indicators that the visual system is sensitive to the nature of the color difference and not just to the fact that there is some difference between the stimuli.

⁸ There is, however, at least one reported case of a person with acquired color blindness whose visual capabilities were interestingly analogous to the possibility under discussion. Mollon *et al* report on a subject who became color blind following an illness.(Mollon *et al* 1980) This subject possessed normal visual acuity on some clinical tests and testing revealed that all three cone mechanisms were functional. The subject was however completely unable to sort objects by color or to correctly name colored stimuli. On one common test of color vision, however, the subject performed in a very interesting manner. When shown the Ishihara pseudoisochromatic plates (those familiar pictures consisting of colored spots in which persons with normal color vision will see a numeral or letter and those with color vision deficiencies a different symbol or none at all) the subject failed all plates at normal reading distance performing as would a monochromat. However shown the same plates at a distance of two meters the subjects was able to identify the symbols. Thus in some circumstances this subject was able to identify contours defined only by hue, although information about the particular hues of objects were never available to the subject. The most straightforward interpretation of these results is that there were some remaining visual mechanisms that were able to make use of chromatic information although the mechanisms that normally extract information about the hue of an area from the stimulus were not themselves intact.

power distribution and independently of the relative intensity of the stimuli. These organisms would seem to satisfy the criterion for the possession of color vision. Their discriminatory behavior may be the result, however, of their having different receptor types independently driving different response mechanisms. A receptor most sensitive to long wavelengths may be connected to a system that causes the organism to move towards the light source and a receptor most sensitive to short wavelengths may be connected to a motor system that causes the organism to move away from the light source. Over a wide range of relative intensities of a blue light and a red light the organism will always move away from the first and towards the second and consequently seem to be making a color discrimination. Since the outputs from the two receptor types are never combined, however, there is no representation of color or even of color difference produced by the visual system and consequently little reason to credit these kinds of organisms with the possession of color vision.

What I think these possibilities point to whether realized or not is the inadequacy of any attempt to provide a criterion for the presence of color vision that relies only on discriminatory behavior. In order to possess color vision it is necessary to be able to perceptually acquire information about what color an object is and not just to be able to tell that two objects that differ in color are different. The information acquired through the different photo-receptor mechanisms must interact somehow. One indicator that such an interaction is taking place is the presence of chromatic contrasts. Hue contrast effects demonstrate that the outputs of the different photo-receptors are combined at some point in visual processing. Another indicator would be the ability to classify stimuli as more or less similar on a dimension different from brightness. This again requires interaction between the outputs of the different classes of photo-receptors in a way that the ability to discriminate stimuli does not. Although no organism that is incapable of discriminating stimuli on the basis of their spectral power distribution alone can possess color vision this ability is not by itself sufficient to support a claim that an organism possesses color vision. This is not to deny that a great deal can be learned about the characteristics of an animal's visual system by looking at the kind of discriminatory behavior it is capable of. Discriminatory abilities are very revealing in uncovering the way in which vision, including color vision, varies throughout the animal world and useful in classifying the visual systems of different kinds of organisms. What

discriminatory tests cannot do is establish that an organism possesses color vision.

If the ability to discriminate stimuli of different spectral power distributions at equiluminance constitutes only a necessary and not a sufficient condition for the possession of color vision the question of what an adequate characterization of color vision would be remains open. My strategy in what follows will be to first show that the inadequacy of the discriminatory criterion opens up a way out of the dilemma with which we began. An apparent defect in this response forces a return to the question of how to more adequately characterize the nature of color vision. I will argue that objectivism requires a particular kind of criterion for the possession of color vision, a criterion stated in functional terms. One particular version of such a criterion can be independently motivated and has some degree of empirical support. Finally, I will discuss the apparent contradiction between the characterization of color vision required by the objectivist and the characterization current in the visual science community.

Color objectivism requires that there be some mind-independent property that is color. If, however, there is no single property that all organisms with color vision are capable of visually detecting then the objectivist is seemingly faced with dilemma. He must either deny that the possession of color vision entails that the organism has the ability to visually determine the color of a surface or give up his claim that color is an objective property. The objectivist cannot escape the dilemma by embracing the first alternative since that alternative eliminates the motivation for thinking that whatever objective property we have identified with color is color. Since color is a property that is typically discussed only in the context of the interactions of human beings and other kinds of living things with their environment we cannot look to the physical sciences to help us motivate the identification of a property with color. If there were no living organisms there would be little need to talk of color in describing and explaining what goes on.⁹ Colors that cannot be seen using color vision are not plausibly colors at all.

Our discussion of the criterion used in the literature on comparative color vision, however, shows us the route an objectivist must take to escape this dilemma. It is true that if it were established that an organism with color vision

⁹ The fact that color is rarely relevant to describing or explaining the interactions of inanimate objects is no obstacle to its objectivity as I argue at length in (Hilbert 1987).

was incapable of visually acquiring information about the objective property that is color then objectivism about color would face insurmountable objections. It is not easy to see, however, how such a claim could ever be established to the satisfaction of an objectivist. If an organism is not capable of visually detecting the property the objectivist claims is color the objectivist can always question the grounds for attributing color vision to the organism in question. The organism may possess interesting visual abilities, including ones relating to the ability to see color, but in the absence of the ability to see color there is no motivation for the claim that the organism possesses color vision. Rather than question the correct identification of color with an objective property the objectivist always has available the option of questioning the correct identification of an organism as having color vision. Facts about the visual characteristics and ecology of non-human organisms seem incapable of raising difficulties for color objectivism.

There is grounds for a worry here that this defense of objectivism is circular. As just noted the main motivation for the identification of a particular property with color derives from the fact that it is a property that is detected using color vision. When it is objected that some organisms with color vision fail to detect this property the response is that only organisms that detect this property have color vision. This form of objectivism seems to use features of color vision to pick out which property is color but at the same time to use the ability to visually detect this property as the criterion for the possession of color vision. It may seem as if there needs to be some independent route to either color or color vision if this account is not to be vacuous.

Our earlier discussion of criteria for the possession of color vision indicates that the empirical literature is not going to provide us with an independent characterization of color vision that will be helpful. As we saw that literature primarily makes use of an important necessary condition for the possession of color vision. There is no worked out theory of what color vision is that would allow us to determine conclusively that an organism possesses this visual ability. There may be necessary conditions for the possession of color vision other than the wavelength discrimination condition but these are just as much in need of independent motivation as is the objectivist's criterion in terms of property detected. In the earlier discussion of the insufficiency of the wavelength discrimination criterion for possession of color vision I avoided the question of how to go about justifying various criteria as being either necessary or sufficient for possession of color vision. My criticisms of taking that criterion as providing

a sufficient condition for possession of color vision relied only on intuition, intuitions presumably based on how different an organism that met only that criterion could be from the paradigm case of an organism that possesses color vision, a normal human being. What is needed now is some firmer basis to on which to make judgements about what features of a visual system are necessary for possession of color vision, which, if any, sufficient, and which irrelevant.

One way in which to characterize the features of a visual system is in terms of the functions it performs. Most generally the function of the visual system is to extract information about the properties of distal objects from the structured light in the environment. In an evolutionary sense it is because this information is useful to organisms that they have visual systems. A visual system is a set of anatomical structures devoted to the performance of this function. It is because we characterize visual systems in this functional way that we are able to talk sensibly about both bees and chimps as having visual systems in spite of the large anatomical and physiological difference that characterize virtually all aspects of their respective visual apparatus. We can distinguish between the mechanisms of vision and the function that these mechanisms subserve and in this way can characterize both the similarity in function and the differences in mechanism of the visual systems of these two kinds of organisms.

The visual system, however, can also be functionally characterized in a more fine-grained way. For example, one function that the human visual system performs is the extraction of information specifying the relative distance of objects in the line of sight. An organism whose visual system performs this function is said to have depth perception. Just as organisms can use different mechanisms to accomplish the general function of vision, different organisms can make use of different mechanisms in order to visually determine the distances of objects. What is necessary for the possession of depth perception is that the organism's visual system subserve the function of determining the relative distance of objects in the line of sight. This point may be made clearer by considering that in human beings there appear to be multiple mechanisms that play a role in allowing us see depth. Suggested mechanisms include binocular stereopsis (the use of the difference in retinal position between the two eyes of the image of an object at a depth different from the fixation plane), shape from shading (the use of shading gradients to recover relative depth and orientation information), structure from motion, and a host of other mechanisms involving cues like occlusion, texture gradients, size cues, aerial perspective etc. The point

here is not to endorse any proposal for a mechanism involved in depth perception but rather to emphasize the distinction between the mechanism and the function it performs, in this case the recovery of information about the relative position of various parts of the scene.¹⁰

It is important, then, not to confuse a mechanism that fulfills a function with the function. For example, it appears that for human beings and our near primate relatives, mechanisms that make use of binocular disparity are the most important contributors to depth perception, at least for objects that are relatively close to the perceiver.¹¹ On the other hand, some species of crabs appear to possess mechanisms that use the (monocular) vertical position of the retinal image of an object alone to recover depth information from the visual stimulus (Zeil *et al.* 1986). These mechanisms are effective in the flat environments occupied by these crabs but would be less effective given the more varied topography that characterizes human environments. In spite of these differences in mechanism there is something that both crabs and humans have in common, depth vision. The fact that stereopsis in these crabs is likely to be poor, if present at all, is no reason to deny to them the possession of depth perception given the presence of alternative mechanisms for fulfilling the same function.

Just as the same function can be fulfilled by different mechanisms, it can also be the case that similar mechanisms can fulfill different functions in different organisms. One way of describing those hypothetical organisms described earlier which discriminated between stimuli on the basis of wavelength but which had no access to the spectral power distribution of the discriminated stimuli is that they share some of the mechanisms that mediate color vision in those organisms that have that ability but put it to a somewhat different use. The similarities in the number of receptors and possibly the early stages of signal processing are compatible with rather different functions being performed by the system as a whole. Rather than subserving the recovery of the surface properties of objects, as in human beings and some other primates, these

¹⁰ Just as the general function of vision may be subdivided it may be the case that depth perception itself is similarly divisible into finer grained functions. It may even turn out that there is no good reason to think that there is a single well-defined visual function, depth perception. This would not affect the main point of this example which is the distinction between mechanism and function.

¹¹ The idea that binocular disparity is the most important “cue” for the perception of depth is a very old one, traditionally credited to Kepler. For a recent review of binocular stereopsis see (Regan *et al.* 1990).

mechanisms may contribute only to object detection and/or the perception of form. Similarity of mechanism does not by itself imply similarity of function.

The distinction between function and mechanism is a familiar one in biology. For example, an organ is a heart if it has the function of pumping blood, while a fluid counts as blood if it has the function of distributing oxygen and other nutrients throughout the body of an organism. The physiological details of how the various kinds of hearts and the different varieties of blood accomplish their intertwined functions are different in different kinds of organisms. In spite of these differences, all of those organisms that have an organ whose function is to pump blood have a heart. The solution to the difficulties that the comparative study of vision poses for color objectivism is to suppose that the relevant criterion for possession of color vision in this context is a functional one.¹² In particular, as in the case of the visual functions just discussed, the relevant function that provides the criterion for possession of color vision is a function defined in terms of the visual acquisition of information about some distal property. Any organism whose visual system has this function, among others, will possess color vision. Although color vision is not an anatomical structure like the heart the analogy can nevertheless be made exact. We can talk of the color vision system meaning that anatomical structure that performs this function. To have color vision, then, will be to possess a color vision system. If an analysis of color vision that has this form is correct then the color will turn out to be whatever property it is the function of the color vision system to detect.¹³

Merely pointing out that the criterion for possession of color vision is a functional criterion, even if this claim is correct, does not by itself lead to a satisfactory resolution of the objectivist's difficulties. Not just any functional analysis will serve the objectivist's purpose. For example, it would not serve the objectivist's purposes if the relevant function were to produce experiences of some characteristic type.¹⁴ If the analysis is to lead to a plausible objectivist

¹² A proposal along these lines has been made by Mohan Matthen although with an eye to solving somewhat different problems (Matthen 1988).

¹³ Since it is still an open question as to the degree of functional separation present in the visual system it may turn out the color vision system shares many anatomical structures with other visual subsystems. The proposal that color vision is a functional concept is independent of the way in which this question is resolved.

¹⁴ This proposed function is not a particularly plausible in the sense of function I am using here. Attributions of biological function are grounded by facts about the evolutionary history of the organ in question. It is supposed to be the case that the presence and characteristics of the organ

account of color the function of color vision will have to be the detection of some distal property. Any other kind of function will lead to an account of color that is either not objectivist or that makes color a property that is very different from our pre-theoretical conception of color.

But now it seems that we have re-entered the circle that characterized the initial defense of objectivism against the problems posed by non-human organisms. Color is that property that it is the function of the color vision system to detect and the color vision system is that part of the visual system that has the function of detecting color. If this defense is not to be completely question begging we need some way to break into the circle. We need some way to get at least a crude grasp of what either color or color vision is that does not depend on prior knowledge of the other. There are several ways to go about this only one of which I will discuss. In the case of human beings introspection reveals an aspect of our visual experience that is clearly different from figure, texture, depth, to which we give the name color experience. The characteristics of these visual experiences can be investigated as can their correlations with various features of both the proximal and distal stimulus. The underlying neuro-biology can also be elucidated. The results of these investigations can lead to various hypotheses about the biological function of the system that produces these experiences. In fact, something like this process is the route that has led to our present knowledge of the characteristics of color vision and our best guesses as to what color vision is good for. Shortly, I will discuss some of these results and what their implications for the correct functional analysis of color vision may be. But first it is important to notice that this method of investigation is unavoidably anthropocentric. Human color vision is the paradigm that supplies the criterion for what is to count as color vision. It may turn out that other organisms possess color vision on this criterion and it may even turn that out there are varieties of color vision which are different from the human case in important respects. Nevertheless, the function of color vision will be whatever it is for human beings and other organisms that use similar physiological machinery for different purposes will not have color vision. There is nothing objectionable about this sort of anthropocentrism since all it amounts to is reserving the name color vision for a

in question are the results of natural selection. Although not impossible it seems unlikely that the production of color experience by itself makes the kind of contribution to fitness that would be necessary for it to be selected for.

particular visual ability possessed by human beings and shared with many others. The claim is not that human beings have the best color vision or that human characteristics are more central than those of other organisms. Nor does taking the human case as paradigmatic involve inappropriately assuming that other organisms are similar to human beings. They may possess visual abilities that humans lack and as long as we are careful to classify organisms as having color vision only on functional grounds we will only impose similarity on organisms that really are similar in the relevant respects.

There are number of pitfalls involved in speculating about biological function but there are also rewards to be gained in doing so. In this case there are, I think, some plausible conclusions that can made as to the function of human color vision. In a nutshell, the function of human color vision is the extraction of information about the reflecting properties of surfaces from the visual stimulus. In addition, this information includes at least a partial specification of the variation of these reflecting properties with wavelength. Included in this functional characterization is the idea, introduced earlier, that it is not enough to just get information about sameness or difference of reflecting properties. The information must at least support classification in terms of degree of similarity in a dimension independent of brightness. There are a variety of kinds of evidence that seem to support this conclusion but the most important is one of the most interesting and least understood features of human color vision, namely color constancy. As the illumination of a given scene changes the spectral power distribution of the light reaching the eye from the surfaces in the scene will change proportionally. In spite of this change in what seems like it should be the most important aspect of the proximal stimulus the perceived color of the surfaces in the scene will, in many circumstances, remain relatively stable. This stability of percept in spite of variation in the stimulus is what is called color constancy. One interesting consequence of the constancy exhibited by human color vision is that in many circumstances the perceived color of a surface will be more closely correlated with the (stable) reflecting properties of that surface than it will with the (variable) spectral power distribution of the light reaching the eye from that surface. That human color vision exhibits some degree of color constancy is a well-established fact. The actual amount of constancy (or even how to measure the amount of constancy) and the mechanisms that produce it are matters of considerable controversy.

The existence of color constancy suggests that the function of color vision is to determine aspects of the reflecting properties of distal surfaces. If we suppose that this characteristic of human color vision reflects a genuine evolutionary adaptation and not an artifact of selection acting on other characteristics it is hard to see what other function could be subserved by a visual sub-system that displays color constancy. There is thus some evidence to support the objectivist's claim that the function of color vision is recover information about a property of the distal stimulus, namely, its reflecting characteristics. We have also seen how this attribution of function need not depend on antecedent commitment to a particular objectivist analysis of color. It is interesting to notice that this supposition about function brings with it certain constraints on the mechanism of color vision. Depending on the kind and amount of variation in the range of illuminants and reflectances that organism encounters in its environment different numbers of photo-receptor types will be required to achieve color constancy. In the kinds of terrestrial environments occupied by human beings there is evidence that at least three photo-receptor types are necessary for color constancy and consequently for color vision (Maloney & Wandell 1986, Maloney 1986, Shepard 1990). There will be a strong prima facie case against the possession of color vision by species for which dichromacy is the normal case.¹⁵ There will also be a strong prima facie case against possession of color vision by any organism in which local properties of the stimulus completely determine perceived color (or appropriate behavioral response). The objectivist's attribution of function is clearly a claim with empirical consequences.

The only way an objectivist can meet the challenge posed by the apparent fact that color vision functions to detect different properties in different kinds of organisms is deny that this really the case. As I have tried to argue objectivism requires a more restrictive criterion for possession of color vision than the one that is most commonly used in the literature on comparative color vision. To possess color vision on this conception is to possess a visual system one of whose functions is the recovery of information about the reflecting characteristics of surfaces. If this is admitted as the correct criterion for possession of color vision

¹⁵ This does not immediately imply that human dichromats do not possess color vision. We might assess function in terms of evolutionary history rather than individual characteristics. There will be some difficulties in this area since at least one species of monkey has a sex-linked polymorphism between trichromacy and dichromacy. What to say in functional terms about color vision for these monkeys is not at all clear.

then it is no longer a possibility that some organisms might possess color vision and use it to detect properties different from the ones that human beings do. I have tried to argue that this move by the objectivist is not an ad hoc response to this particular problem but one that can be motivated independently and indicated at least one kind of empirical support for the functional criterion that objectivism requires. This functional conception of the nature of color vision is, in fact, deeply imbedded in the logic of the objectivist position I have defended here and elsewhere (Hilbert 1987). One consequence of this feature of color objectivism is that its tenability depends on an empirical claim about human color vision. If color constancy and the other features of color vision that suggest that it functions to provide information about distal surfaces are artifacts and not adaptations then this form of color objectivism will be untenable. Whether or not it is possible to be an objectivist about color depends in part on the truth or falsity of empirical claims about the nature of color vision.

The upshot of this discussion of the nature of color vision and its implications for objectivism about color has been that objectivism requires a certain conception of color vision if it is to be capable of accounting for the empirical results produced by comparative visual scientists. It may be troubling to some readers that the account of the nature of color vision I have given may seem to imply that visual scientists are mistaken about what they seem to know best, namely, the correct characterization of the visual system. There are two things to be said about this worry. First, a significant portion of the vision community uses the functional characterization of color vision that I have defended at least some of the time. It is certainly true, however, that many visual scientists, especially the more physiologically oriented ones, use the discrimination criterion I earlier rejected, although not without occasional misgivings. The correct way to understand this usage, I believe, is to recognize that the term “color vision” is used in more than one way in the color science community. Many researchers are primarily interested in the mechanisms that underlie visual processes and classify the visual processes of organisms in terms of these mechanisms (or their psycho-physical and behavioral consequences). For these researchers questions about the biological function of the entire color vision system are not pressing (although questions about the function of various mechanisms within the system are often given considerable attention). It is not that it is denied that color vision has a function or even that knowledge of this function is important. It is just that the primary objects of interest are the

mechanisms, especially the physiological mechanisms, of vision. Nothing in the analysis of color vision I have presented suggests any kind of massive confusion in the color science community but rather an understandable and only rarely misleading ambiguity in the term “color vision”. As we have just seen, however, it is in just those cases where we wish to draw more philosophical conclusions from the empirical data that this ambiguity is likely to lead to difficulties. If we wished to regiment the language of visual science we might introduce the new term “chromatic mechanism” to describe those physiological mechanisms that organisms with and without color vision can share and thereby remove the possibility of confusion. There is no pressing need, however, to introduce such novelties as long as we are careful to make the necessary distinctions when circumstances require. It is scarcely a surprising conclusion that philosophers occasionally need to make distinctions which are less pressing to those with other kinds of interests.

References

- Boghossian, P.A., and Velleman, J.D. [1991]: Physicalist theories of color. *Phil. Rev.* 100: 67-106.
- Crawford, M.L.J. et al [1990]: Interspecies comparisons in the understanding of human visual perception. In L. Spillman and J.S. Werner (eds.), *Visual Perception: The Neurophysiological Foundations*. San Diego: Academic Press, pp. 23-52.
- Gouras, P. [1985]: Color vision. In E.R. Kandel and J.H. Schwartz (eds.), *Principles of Neural Science*. New York: Elsevier Science Publishing Co, pp. 384-395.
- Hardin, C.L. [1988]: *Color for Philosophers: Unweaving the Rainbow*. Indianapolis: Hackett Publishing Co.
- Hilbert, D. [1987]: *Color and Color Perception: A Study in Anthropocentric Realism*. Stanford: Center for the Study of Language and Information.
- Maloney, L.T. [1986]: Evaluation of linear models of surface spectral reflectance with small numbers of parameters. *J. Opt. Soc. Am. A* 3: 1673-1683.
- Maloney, L.T. and Wandell, B.A. [1986]: Color constancy: a method for recovering surface spectral reflectance. *J. Opt. Soc. Am. A* 3: 29-33.
- Matthen, M. [1988]: Biological functions and perceptual content. *Phil. Rev.* 85: 5-27.
- Mollon, J.D., Newcombe, F., Polden, P.G., and Ratcliff, G. [1980]: On the presence of three cone mechanisms in a case of total achromatopsia. In G. Verriest (ed.), *Colour Vision Deficiencies V*. Bristol: Adam Hilger, pp. 130-135.
- Regan, D. et al [1990]: The perception of stereodepth and stereomotion: cortical mechanisms. In L. Spillman and J.S. Werner (eds.), *Visual Perception: The Neurophysiological Foundations*. San Diego: Academic Press, pp. 317-347.
- Shepard, R.N. [1990]: Possible evolutionary basis for trichromacy. In M.H. Brill (ed.), *Perceiving, Measuring, and Using Color*. Proc. SPIE 1250: pp. 301-309.
- Thompson, E., Palacios, A. and Varela, F.J. [forthcoming]: Ways of coloring: Comparative color vision as a case study for cognitive science. *Behavioral and Brain Sciences*.
- Zeil, J., Nalbach, G., Nalbach, H.-O. [1986]: Eyes, eye stalks and the visual world of semi-terrestrial crabs. *J. Comp. Physiol. A* 159: 801-811.