

Of Colors, Kestrels, Caterpillars, and Leaves

According to color realism, object colors are mind-independent properties that cover surfaces or permeate volumes of objects. In recent years, some color scientists and a growing number of philosophers have opposed this view on the grounds that realism about color cannot accommodate the apparent unitary/binary structure of the hues. For example, Larry Hardin asserts,

the unitary-binary structure of the colors as we experience them corresponds to no known physical structure lying outside nervous systems that is causally involved in the perception of color. This makes it very difficult to subscribe to a color realism that is supposed to be about red, green, blue, black, and white—that is, the colors with which we are perceptually acquainted.¹

Similarly, Evan Thompson says:

There is no distal-based scheme that can generate the basic chromatic categories of human color vision (red, green, yellow, and blue) plus the resemblance and difference relations among hues that result from the opponent structure of these categories (red-green, yellow-blue).²

And Leo Hurvich, one of the founders of the opponent processing theory in color science (along with Dorothea Jameson), comments:

it should be clear by now that object color is not something that inheres in objects.³

Another related threat is posed by the possibility of higher-dimensional color distinctions in other animal species. While most humans are trichromats, there is strong evidence to suggest that some fish, birds, and turtles are tetrachromats, and pigeons may be pentachromats. This evidence compounds the problem posed by the unitary /

¹ “Reinverting the Spectrum,” in *Readings on Color*, vol. 1, eds. Alex Bryne and David Hilbert (Cambridge, Mass: MIT, 1997): 300.

² “Colour Vision, Evolution, and Perceptual Content,” *Synthese*, 104 (1995): 9.

³ *Color Vision*, (Sunderland, Mass: Sinaeur Associates, 1981): 61.

binary structure of the hues, since it may well be that tetrachromatic vision involves not just unitary and binary hues, but ternary as well.⁴

Thompson, Palacios, and Varela put the general difficulty for the view that colors are external, physical properties in the following way:

1. For something to be a chromatic color it must be a hue.
2. For something to be a hue it must be either unique or binary (or ternary).
3. Therefore, if hues are to be reductively identified with physical properties, these physical properties must admit of corresponding unique, binary (or ternary) divisions.
4. Organism-independent, external properties such as light-waves and spectral reflectances do not admit of such divisions.
5. Therefore, color cannot be reductively identified with such organism-independent, external properties.⁵

This argument, of course, is an argument for external irreducibility. It does not yet undermine color realism. For colors might be mind-independent, external properties that supervene upon physical properties without themselves having a hidden physical nature. Alternatively, colors might be emergent properties without a physical supervenience base, properties whose natures are wholly given to us in sense experience. Neither of these options is at all attractive, however. The former must countenance implausible epistemically basic yet metaphysically derivative bridge laws that link colors with underlying physical properties.⁶ The latter has the consequence that colors are causally inefficacious with respect to the physical world. For if colors emerged from the underlying physical configurations without supervening upon them, then the

⁴ See Evan Thompson, Adrian Palacios, and Francisco J. Varela, "Ways of coloring: Comparative color vision as a case study for cognitive science," *Behavioral and Brain Sciences*, 15 (1992): 1 – 74.

⁵ Thompson, *et al.* "Ways of coloring", 15.

⁶ For further criticism, see Michael Tye, *Ten Problems of Consciousness*, (Cambridge, Mass: MIT, 1995): Chapter 2.

colors of things might have been different while the underlying physical facts and laws remained the same. In that case, which colors objects have (or indeed whether they have any colors at all) makes no difference to their physical interactions. And that intuitively is false. Painting the walls of a room yellow causes it to be brighter than would painting the walls brown. Staring at a bright red light and looking away causes a characteristic neural response which generates a green after-image. Moreover, if colors make no difference to how light is reflected from objects, to the subsequent changes at the retina, in the optic nerve, and so on, then it follows that we do not see colors!⁷ That seems absurd. Worse still, if we do not see colors, then intuitively we do not see things at all. Intuitively, we see the facing surface of things by seeing their colors.

It seems, then, that if colors are external, mind-independent properties, then they must be reductively identifiable with physical properties. But how can such a reductive identification preserve the unitary/binary division of the hues and relatedly the possibility of higher-dimensional hue divisions elsewhere in the animal kingdom? The present paper provides an answer to this question. In our view, the recent tendency to suppose that we mistakenly project colors onto the world, their real home being in the mind and in the opponent structure of the relevant neural processing, is without adequate foundation. Colors, we maintain, are objective properties, out there in the natural world. That view, we shall argue, is perfectly compatible with color science.

The paper is divided into four sections. In Section I, we make some clarificatory remarks about the unitary/binary distinction and we present some reasons from scientific research on comparative color vision for taking seriously the claim that there may well be colors, unitary, binary, and ternary, humans cannot see. In Section II, we show how a simplified version of the opponent-processing theory in color science is supposed to provide a subjectivist explanation of the division of humanly perceptible hues into unitary and binary, and also how this explanation may be extended straightforwardly to ternary combinations of hues. In Section III, we offer an alternative explanation of the divisions among the hues, which locates these divisions out in the

⁷ We assume here that seeing x demands a causal connection with x .

world. In the final section, we consider an objection to realism for humanly inaccessible hues, based upon a case from comparative vision studies. As will be seen, our approach is strongly influenced by the opponent processing theory of color vision, but it resists the subjectivist metaphysical implications many adherents of the theory have mistakenly read into it.

I: On Hues, Unitary, Binary, and Ternary

Some hues are unitary, in particular, red, yellow, green, blue. Others are binary, for example, orange, purple and lime. Binary colors are always mixes of other colors. Orange is reddish yellow, lime is yellowish-green, purple bluish red. Unitary colors have shades that are not mixes of other colors. Red, for example, has a shade that is not a combination of any other hues. This is unique red.

What is meant by saying that binary hues are mixes or combinations whereas unitary hues are not? One reading of this claim is in terms of perceptual mixing.⁸ Something, in looking orange, for example, looks a bit reddish and a bit yellowish; but there is a shade of red such that anything in looking that shade does not look another color at all. Intuitively, however, when we say that orange is reddish-yellow, we are not saying merely making a remark about the looks of things. Intuitively, our supposition is that orange is a color such that something, in being orange, *is* a bit reddish and it *is* also a bit yellowish; moreover, any given object, in being a bit reddish and a bit yellowish in the same surface regions, *is* orange in those regions. Orange, thus, is naturally taken to be a conjunctive property: reddishness and yellowishness⁹. That, we suggest, is the commonsense view. And that provides the basis for the most straightforward and direct way of understanding the unitary/binary distinction. Binary chromatic colors are conjunctive properties whose conjuncts are exactly two of the following: reddishness, yellowishness, bluishness, greenishness. Unitary chromatic colors are colors for each of which there is a shade that is not conjunctive in this way.

⁸. See Hardin, “Reinverting the Spectrum”: 291.

The unitary/binary distinction, as we have just stated it, applies only to the hues humans can see. There is evidence, however, from scientific work on comparative color vision, that some hues are humanly inaccessible. Once these hues are admitted, a case can be made for supposing that they admit of corresponding unitary and binary classifications, and perhaps even ternary classifications too. Consider first some facts about kestrel vision.

The vole population in Northern Europe oscillates in a four-year cycle. A crash in the vole population in a region can result in a thousand kilometer migration of those kestrels that feed primarily on the voles. Up until a few years ago, we knew almost nothing about how the kestrels are able to track the vole population over such large areas of land. However, Viitala *et al.* recently discovered¹⁰ that when we illuminate vole scent marks, which male voles use to indicate their paths, with light from the ultra-violet (UV) portion of the spectrum, the marks contrast with their background. To normal human perceivers in standard conditions, these scent marks are indistinguishable from their backgrounds. To kestrels, however, they are not. Through extensive field experiments on wild kestrels, Viitala *et al.* showed that under normal lighting conditions, kestrels concentrated their hunting in areas containing straw that had been soaked in vole feces and urine, while ignoring areas containing straw that had been soaked in water. *Prima facie*, then, kestrels are seeing a color of vole urine we humans do not see—a color, the detection of which requires sensitivity to UV light.¹¹

⁹. This was suggested by Alex Byrne and David Hilbert, “Colors and Reflectances,” in *Readings on Color*, vol. 1, eds. Alex Bryne and David Hilbert (Cambridge, Mass: MIT, 1997): 280.

¹⁰. J. Viitala, E. Korpimaki, P. Palokangas, and M. Koivula, “Attraction of kestrels to vole scent marks in visible in ultraviolet light,” *Nature*, 373 (1995): 425 – 427

¹¹. One should not be tempted into thinking that the color birds see when looking at an object which reflects UV light is simply what we see when the object is illuminated by UV light alone. Under only UV-wavelength light, the vole urine will look brighter to us, but we will not see the hue the kestrel sees in that light (or in daylight).

Here is an analogous case. Suppose we take an object that reflects only light from the long (red) portion of the spectrum and we place it on a background that reflects only light from the short (blue) portion of the spectrum. Suppose we then illuminate the scene

Behavioral evidence supporting the possibility of UV vision in birds is not limited to raptors. Many of the thirty-one species of birds, whose UV vision has been demonstrated since 1972, forage on insects.¹² As we might expect, many of those insects reflect light strongly in the UV range.

The caterpillars of the gray shoulder knot moth (*lithophane ornithopus*) reflect maximally in the ultra-violet range. In the human-visible portion of the spectrum, they reflect a large percentage of the incident light in the short wave length region, and more in the middle than in the long. Furthermore, gray shoulder knot caterpillars are typically found on oak leaves in Northern Europe, and oak leaves reflect only minimal percentages of UV light, but a large percentage of the incident light in the short wave length region, and more in the middle than in the long. To humans, a caterpillar sitting on an oak leaf looks to be very similar in color to its background. But, to birds, the gray shoulder knot caterpillar contrasts strongly against the oak leaf. Hence, we can hypothesize that the strong UV markings on the caterpillar fill the same role for birds that the bright red markings on the poison dart frog fill for humans: they advertise distastefulness.¹³ *Prima facie*, thus, birds detect a color on the caterpillar that humans do not.

The evidence for higher dimensional color vision in birds is not restricted to observation of behavior. There is also physiological data. In recent years, biologists have isolated at least four spectrally distinct cone types in birds compared with our three. For example, four have been discovered in the retinas of mallards and five in the retinas of pigeons. The maximal sensitivity of avian cones is in the near ultra-violet range, varying

with light from only the long (red) portion of the spectrum. The object will reflect light, but the background will not. Now suppose we let a true color-blind person (monochromat) view the scene. Monochromats certainly can discriminate objects that reflect light from objects that cannot, and so to the monochromat the object will look brighter than the background. But evidently it would be a mistake to infer from this that the monochromat is seeing the color trichromats see as they view the object in the same circumstances (or in daylight).

¹². For an overview, see A.T.D. Bennett and I.C. Cuthill, "Ultraviolet vision in birds: What is its function?" *Vision Research*, 34 (1994): 1471 – 1478.

¹³. I.C. Cuthill, J.C. Partridge, A.T.D Bennett, S.C. Church, N.S. Hunt, and S. Hunt, "Ultraviolet vision in birds," *Advances in the Study of Behavior*, 29 (2000): 159 – 214

from 355nm in the Pekin robin (or red billed leiothrix) to 403nm in the penguin.¹⁴ Furthermore, avian cones contain droplets of oil that absorb parts of the 300 – 700nm range of light. Numerous different kinds of oil droplets have been identified, signifying a wide variety of color vision across avian species.¹⁵

It may be tempting to insist that birds cannot see colors we humans do not see, even though they do detect qualities that play a comparable role with respect to the birds' visual systems and behavior. For colors are fixed by their locations in color space; and there is simply no room in our color space for a region occupied by a genuinely novel hue.

This last remark is true, but it is far from decisive. Our color space is indeed completely filled. Its geometry cannot allow a completely new hue.¹⁶ But that is compatible with supposing that there are novel color spaces with different geometries. For example, there might be a tetrachromatic space, closed with respect to hue-saturation-lightness relations, that is connected by routes of resemblance to our color space and that contains the latter space as a part.¹⁷ Parts of this space would be closed off from human trichromats in much the way that parts of our color space are closed off from human dichromats (pure red-green dichromats see only yellows and blues among the chromatic colors). So, we would be unable to form a clear conception of what it is like to experience some of the colors in this tetrachromatic space just as a pure red-green dichromat cannot form a clear conception of what it is like to experience red.

¹⁴. While 403nm is within the human visual spectrum, the sensitivity of the relevant cone in the penguin's visual system extends further (into the UV range).

¹⁵. For overview, see A.T.D. Bennett and I.C. Cuthill, "Ultraviolet vision in birds: What is its function?" (1994)

¹⁶. Sensitivity to hue, saturation, and brightness varies between people. It may be the case that, while keeping saturation and brightness fixed, Joe can discriminate more red hues than can Bob. But any red hue Joe can discriminate lies between red hues Bob can discriminate. So, each of the former hues has a place within Bob's color space: in between hues Bob can pick out. Such hues, therefore, are not genuinely novel. Our color space already includes all hues than can possibly lie between the hues we know, and therefore it is closed with respect to hue.

¹⁷. This suggestion was made by Evan Thompson, "Novel Colors," *Philosophical Studies*, 68 (1992): 321 – 349

There is no general agreement as to just which features must be shared by *all* alternative color spaces. However, it seems reasonable to hold that a sufficient condition for qualities to count as hues is that they be discriminated via the eyes in response to the reflected light, that they exhibit color constancy¹⁸ and color contrast effects, and that they belong to a family of qualities with these effects (a family whose members are connected to one another by routes of resemblance), whether or not they are accessible to human vision.¹⁹ Color constancy and color contrast effects have been found manifested in the behavior of birds, goldfish, and honeybees.²⁰

Color contrast is the product of opponency among the hues. In our color space, red is opposed to green; yellow to blue. This is reflected in our color experience. We cannot conceive of experiencing a surface that is both red and green all over at the same time. Likewise for blue and yellow. If opponency of this sort is essential to something's being a hue, and it certainly seems essential to our hues, then humanly inaccessible hues will require opponent complements. So, if there is a hue we cannot experience, there must be two—that hue and its opponent complement. Accordingly, any novel tetrachromatic color space will need at least one opponent pair of novel hues among its six primary hues. Moreover, since our color space includes binary combinations of primary hues (orange (reddish-yellow), lime (greenish-yellow), purple (reddish-blue), turquoise (bluish-green)), there is some reason to think that novel tetrachromatic spaces will have binary combinations involving the novel hues and arguably even ternary combinations too, given the three opposing pairs of primary hues.

On this understanding of tetrachromatic vision, tetrachromats not only are able to see hues that we trichromats are unable to see, but they are (or may well) be able to see combinations of these hues that are inaccessible to us. The problem of accounting for the

¹⁸. For remarks on color constancy, see below, p. 13.

¹⁹ We address the question of what it is for a quality to be a color in detail in our “In Defense of Color Liberalism,” (in preparation).

²⁰. For an overview, see Christa Neumeyer, “Comparative aspects of color constancy,” in *Perceptual constancy: Why things look as they do*, eds. V. Walsh and J. Kulikowski (Cambridge: Cambridge, 1998): 323 – 351

distinction between unitary and binary hues now becomes a special case of a more general problem, that of providing an objective, external ground for the distinction between what might be called 'basic' and 'derivative' hues. And the prevailing view is that this problem cannot be solved by the color realist even in the unitary/binary case. We disagree.

II: A Simplified Quantitative Model of Opponent Processing and Subjectivism about the Hues

The model we shall consider initially is that presented by Hardin in *Color for Philosophers*.²¹ According to Hardin, chromatic color experience is generated by neuronal activity in two channels, one for red-green color experience and the other for yellow-blue. Where 'O' represents the base level of neural activity, that is, the level corresponding to no visual response, and 'L', 'M', and 'S' represent the neural activity in the relevant neurons connecting to the long, medium, and short wavelength cones in the eye, the difference in L and M activity yields the red-green channel while the sum of L and M activity minus the S activity gives the yellow-blue channel. Specifically, where $L - M$ is the red-green signal,

$(L - M) > 0$ yields the experience of (pure) red

and

$(L - M) < 0$ yields the experience of (pure) green,

assuming the yellow-blue channel is in balance. Similarly, where $(L + M) - S$ is the yellow-blue signal,

$((L + M) - S) > 0$ yields the experience of (pure) yellow

and

$((L + M) - S) < 0$ yields the experience of (pure) blue,

assuming the red-green channel is in balance.

²¹ Indianapolis: Hackett, 1988

This model is oversimplified, as Hardin notes, since (at a minimum) the above formulae should be assigned coefficients that correspond to appropriate weightings for the three cone types (corresponding to the proportions of each cone type in a given retinal region, the relative efficiency of each cone type in generating an output from the radiant energy, and so on).²² However, it suffices for present purposes.

How is this model relevant to the unitary/binary distinction among the hues? Recall that, for Hardin, the claim that orange is reddish yellow is to be understood in terms of perceptual mixing. Orange supposedly is a perceptual mix of red and yellow. On this view, one who has the experience of red and who also the experience of yellow thereby has the experience of orange. What is required, then, for the experience of orange, on the above model, is that the neural activity in the red-green channel be greater than zero and that the same be true for the activity in the yellow-blue channel. This, according to Hardin, is what grounds the claim that orange is a binary hue. By contrast, pure red is a unitary hue only in virtue of the fact that the experience of pure red occurs if and only if (i) the neural activity on the red-green channel ($L - M$) is greater than zero (thereby precluding the experience of green) and (ii) the neural activity on the yellow-blue channel ($(L + M) - S$) is in balance (thereby precluding the experience of either blue or yellow).

On this account, the distinction between unitary and binary hues is grounded upon facts about neural processing. It is also sometimes claimed that the hues themselves are best viewed as features of that processing—features that color experiences mistakenly represent as belonging to external things. According to this view, evolution has seen fit to wire us so that we project colors onto the world, but their real home is in the brain. Two well known cognitive scientists, Cosmides and Tooby, in their introduction to Simon Baron-Cohen's recent book *Mindblindness*, put the point this way:

The machinery that causes [color] experiences allows us to identify something as the same object across situations despite the different wavelength composites that it reflects from circumstance to circumstance. Far from being

²² For more on qualifications to the simple model, see below, p. 16.

a physical property of objects, color is a mental property—a useful invention that specialized circuitry computes in our minds and then "projects onto" our percepts of physically colorless objects. This invention allows us to identify and interact with objects and the world far more richly than we otherwise could. That objects seem to be colored is an invention of natural selection, which built into some species, including our own, the specialized neural circuitry involved.²³

Turning now to tetrachromatic vision, as we noted in the last section, there is empirical evidence that tetrachromats see hues that trichromats cannot.²⁴ In order to extend the opponent processing theory into tetrachromatic color space, it is necessary to hypothesize three chromatic channels instead of two. Further, behavioral responses to UV stimuli require UV-sensitive channels. Oversimplifying greatly, the three chromatic channels proposed by Thompson *et al.*²⁵ for the goldfish are as follows:

$$C1 = (UV + S) - L$$

$$C2 = UV + (S - M) + L$$

and

²³ Cambridge, Mass: MIT, 1995, xi

²⁴ It is worth pointing out that even for trichromats, the four unitary hues need not always be red, green, blue, and yellow, as they are for human-beings. It may be that, in some cases, the responses of the opponent processing channels are shifted along the spectrum. For example, honeybees are trichromats, but their vision is sensitive to UV light. Menzel & Backhaus ("Color vision in honey bees: Phenomena and physiological mechanisms," in *Facets of Vision*, eds. D.G. Stavenga and R.C. Hardie, (New York: Springer, 1989), 281 – 297) hypothesize that honeybees have two chromatic channels $X = (UV - (B + G))$ and $Y = ((UV - B) + G)$, where B and G represent activity on neurons connected to cones that are maximally sensitive at 435nm and 540nm respectively. X and Y yield opposing hues according to activity on the channels. When activity on X channel is greater than zero, it yields a hue X^+ , and when activity is less than zero, it yields X^- . The same holds for Y^- channel. Thus, for honeybees, there are four unitary hues (X^+ , X^- , Y^+ , and Y^-). Since the experience of each hue involves a response to UV light, and none of our color experiences do, it follows that honeybee color vision is truly inaccessible to humans.

²⁵ "Ways of Coloring", 14

$$C3 = (UV - S) + (M - L).^{26}$$

When activity on C1 is greater than zero, the experience of a novel hue (H^+) results.²⁷ When activity on C1 is less than zero, the experience of another hue (H^-) opposing H^+ occurs. Thus, just as it is impossible for trichromats to experience a binary combination of red and green, so too it is impossible for tetrachromats to experience a binary combination of H^+ and H^- .

According to the extended theory, tetrachromats can experience other binary combinations, however. Activity on the C1 channel, in combination with activity on one of the other two chromatic channels with the alternate channel in balance, will produce the experience of a novel binary hue, $H^+ + I^+$, for example, (where I^+ is a novel hue associated with C2, let us suppose). Furthermore, with both of the other two chromatic channels active (not in balance), the extended theory predicts the experience of novel ternary hues.

The extension of the subjectivist approach to color for the tetrachromatic case is obvious. Hue H^+ is really a feature of the neural processing of creatures able to experience H^+ . The experiences of these creatures represent H^+ as out in the world, but nothing outside the creatures' heads has H^+ . The binary hue, $H^+ + I^+$, is a combination of H^+ and I^+ *only* in that the experience of the first hue involves the experience of H^+ and the experience of I^+ . Experience of $H^+ + I^+$ is produced via activity greater than zero on both the C1 and the C2 channels. Ternary hues involve combinations of three unitary hues but only in a correspondingly subjectivist way.

III: Color Objectivism Regained

²⁶ All three channels have zero-crossings (indicating “rest” positions for neural activity) in the middle wavelength range. As the goldfish lives in water, we would expect that the goldfish’s visual system would not be very responsive to light in the blue-green portion of the spectrum.

²⁷ It is important to note that while all three channels will be responsive to ultra-short wavelength incident light, none of the hues associated with them should presumptively be identified with the hue, Ultra-Violet. The chromatic channel that yields the experience of blue in humans $((L + M) - S)$ responds to long wavelength incident light, yet we do not take that to show that the experienced hue is red.

The obvious view of color, at least as far as commonsense goes, is that the colors we see objects and surfaces to have are external properties of those objects and surfaces. We think of colors as inhering in surfaces, as, for example, in the case of the red that covers the outside of my car. We also think of colors as sometimes attaching to volumes, as in the case of the green that fills a piece of transparent green glass.²⁸ We take it for granted that objects typically retain their colors when they are not seen, thereby helping us to re-identify them.

Another important fact about color, which is manifest to us in our everyday life, is color constancy. Objects do not typically appear to change their colors during the day as the sunlight changes. Grass in the early morning looks to have the same color as it does at midday or late in the afternoon, even though the light is very different. Nor does it make much difference to the perceived colors of objects—plants, for example—when they are moved from outdoors to a setting of illumination by incandescent lamps. Moreover, wearing sunglasses has little effect on the colors objects appear to have.²⁹

Constancy in apparent color, we might add, is sufficiently robust that two objects with different colors can continue to appear as they normally do even when they reflect light to the eye of the very same spectral composition. For example, a bluish object lit only by reddish light of the setting sun continues to look blue, and a reddish object illuminated by the bluish light of the sky continues to look red even though the light the objects reflect back to the eye is the same.³⁰

The fact that objects appear to retain the same color through a wide variety of changes in the illumination conditions (though certainly not all) strongly suggests that colors are illumination-independent properties of those objects. But if this is the case,

²⁸ Further, we allow that colors can belong to thin films, as in the case of the blue of the sky.

²⁹ See David Hilbert *Color and Color Perception: A Study in Anthropocentric Realism*, (Stanford: CSLI 1987).

³⁰ R. Shepard “The Perceptual Organization of Colors: An Adaptation to Regularities of the Terrestrial World,” in *Readings on Color*, vol. 2, eds. Alex. Byrne and David Hilbert, (Cambridge, Mass: MIT, 1997) 311 – 356.

with which such external physical properties are colors to be identified? And how does that identification preserve an objectivist division of the hues into unitary, binary, ternary, etc?. Evidently, the disposition to reflect light of so-and-so wavelengths is not a suitable candidate for surface color. For that varies greatly with the illumination conditions, and it also varies greatly among objects of the same color.

The most promising objectivist proposal for surface color appeals to surface reflectance.³¹ The phenomenon of metamerism presents an immediate difficulty for this proposal, however. Metamers are objects which appear the same color even to normal perceivers in daylight but which have different overall reflectances. This shows that colors are not reflectances simpliciter. But it leaves open the possibility that surfaces of the same color have reflectances with something important in common in virtue of which the surfaces have that color.

Consider again the opponent processing theory. Recall that, according to the theory (in much simplified quantitative form), where $L - M$ is the red-green signal,

$(L - M) > 0$ yields the experience of (pure) red

and

$(L - M) < 0$ yields the experience of (pure) green,

provided that the yellow-blue channel is in balance. Similarly, where $(L + M) - S$ is the yellow-blue signal,

$((L + M) - S) > 0$ yields the experience of (pure) yellow

³¹ The reflectance of a surface is given by stating, for each wavelength in the spectrum visible to humans, birds, fish, and turtles (300 – 700 nm), the percentage of light the surface reflects at that wavelength. Proposals for color that appeal to surface reflectance are to be found in D. Hilbert *Color and Color Perception*, M. Matthen, “Biological functions and perceptual content,” *Journal of Philosophy*, 85 (1988): 5 – 27, R. Grandy, “A Modern Inquiry into the Physical Reality of Colors,” in *Mind, Value, and Culture: Essays in Honor of E.M. Adams*, ed. D. Weissbord, (Atascadero, CA: Ridgeview, 1989), 229-245, M. Tye *Ten Problems of Consciousness and Consciousness, Color and Content* (Cambridge, Mass: MIT, 2000), and A. Gibbard “Visible Properties of Human Interest Only,” *Philosophical Issues*, ed. E. Villeneuve, (Atascadero, CA: Ridgeview, 1996), 199 – 208.

and

$((L + M) - S) < 0$ yields the experience of (pure) blue,

provided that the red-green channel is in balance.

Now assume, as is surely intuitively reasonable, that, *ceteris paribus*, our color experiences under normal viewing conditions are veridical. It follows that, *ceteris paribus*, under normal viewing conditions, when we undergo opponent processing of a sort appropriate to the experience of red, something red is present.³² That processing, on the present proposal, is triggered by a key feature of the surface reflectances of red objects to which our visual systems are tuned. Specifically, *given the assumption that the oversimplified opponent processing model is correct*, where L^* is the amount of long wavelength light, M^* is the amount of middle wavelength light, and S^* is the amount of low wavelength light (corresponding to the neural activity, L , M , and S respectively), our claim is that a surface is (pure) red iff it has a surface reflectance that disposes it, under normal viewing conditions, to reflect light such that, for the reflected light, $M^* <_s$ (is significantly less than) L^* and $S^* =_a$ (is approximately the same as) the total quantity, $M^* + L^*$.³³ (Pure) red, thus, in our view, is an objectivist disposition common to surfaces with different reflectances. This makes surface redness appropriately illumination independent; for the disposition to reflect certain relative amounts of light given certain lighting conditions is fixed by the surface reflectance. Parallel proposals can be constructed for the other humanly accessible hues.³⁴

It is worth emphasizing that no claim is being made that there is, in nature apart from us, anything special about the relevant surface dispositions. We find them special

³² The *ceteris paribus* qualification is included here primarily because of contrast effects. These experiential effects interfere with or mask the real color.

³³ In their “Colors and reflectances,” Byrne and Hilbert make a remark about the color green that is in keeping with our proposal about red (p. 265). However, their remark is not developed into a general view, and it is not applied to the unitary/binary distinction.

³⁴ In this paper, we ignore light emitters; but the extension of our view to emitters is relatively straightforward.

because of how our visual systems are constructed.³⁵ In this sense, the colors we see are indeed anthropocentric. But their being so does not make them subjective. They are, we claim, real, objective properties, even if they are of no particular interest to creatures lacking our visual apparatus. The colors we see are tailored to the color detection system evolution has given us. The two fit one another like hand and glove.

It is also very important to appreciate that any actual counter-example to the proposal we have made will also be a counter-example to any subjectivist view of color based on the opponent-processing model presented earlier. Qualify the latter appropriately to handle the counter-example—it is, after all, by admission, very oversimplified—and, we maintain, the correspondingly qualified version of the former will handle the counter-example too. This point needs developing further.

Suppose, to begin with, that the formulae in the opponent processing model are qualified by numerical coefficients assigned to the values of S, M, and L—coefficients that reflect the different proportions of cone types on the retina. Patently, this poses no difficulty for our proposal, either quantitatively or conceptually. Appropriate coefficients now need to be introduced for the values of S*, M*, and L*. For example, if q and r are the coefficients assigned to L and M, then given that the ratio of long wavelength cones to medium wavelength cones is q to r, the revised requirement on L* and M* is that qL^* be (significantly) greater than rM^* .

Suppose now it is insisted that no mere assignment of numerical coefficients to the formulae in the simplified model will give a fully accurate account of how the opponent processing channels work. The spectral sensitivities of the cones vary in addition to the proportion of each cone type, so that in reality, the relevant functions are nonlinear.³⁶ This is the view taken by Hunt, for example.³⁷ According to Hunt, to generate

³⁵ See Gibbard, “Visible Properties of Human Interest Only.”

³⁶ Letting x and y be variables over a domain, a function f is linear iff, for any real numbered constants, A and B, $f(Ax + By) = Af(x) + Bf(y)$. A function is nonlinear iff it is not linear. Thus, a function involving exponents is nonlinear.

³⁷ R. W. G. Hunt, “A model of colour vision for predicting colour appearance,” *Color Research and Application*, 7 (1982): 95 – 112.

satisfactory opponent channels, we need to take the square roots of S, M and L before summing or subtracting. We also need to qualify with appropriate numerical coefficients. Werner and Wooten propose a somewhat different nonlinear model, under which $(pM + qL)^{3.5} - rS$ yields the yellow-blue channel, (where p, q, and r are the relevant coefficients).³⁸ Either way, there is no threat to color objectivism. So long as there is, for each channel, a well-defined function that connects the values of S, M, and L with the resultant color experience, that function, *linear or not*, will have an objectivist counterpart function connecting the relevant color with S^* , M^* , and L^* (under normal viewing conditions). Thus, as before, given how the human visual receptors collectively operate, for each color experience, there is a complex surface disposition normally tracked by the experience—a complex disposition with which the color represented by the experience may be identified.

We turn now to the unitary/binary distinction. We will assume that the oversimplified opponent-processing model is correct.³⁹ This is done purely to simplify the discussion. The points we make below apply *mutatis mutandis* to the more realistic versions of the model. Let us grant, then, that the experience of red (not pure red) occurs iff $(L - M) > 0$, and the experience of yellow (not pure yellow) occurs iff $((L + M) - S) > 0$. Let us also agree with Hardin that necessarily, when something looks orange, it looks reddish and it also looks yellowish. Indeed, let us accept that looking orange is one and the same as looking reddish and also looking yellowish. Let us further suppose that looking reddish is just looking red without looking pure red and likewise for the case of looking yellowish. The quantitative model now predicts that the experience of orange occurs iff $(L - M) > 0$ and $((L + M) - S) > 0$.

Our corresponding (vastly oversimplified) objectivist claim about surface orange is as follows: a surface is orange iff it has a surface reflectance that disposes it, under normal viewing conditions (NVC), to reflect light such that, for the reflected light, $L^* >_s$

³⁸ B. Werner and J. Wooten, "Opponent Chromatic Mechanisms: Relation to Photopigments and Hue Naming," *Journal of the Optical Society of America*, 69 (1979): 422 – 434.

³⁹ From Hardin, *Color for Philosophers*.

M^* and $(L^* + M^*) \succ_s S^*$. Since, on the proposed account, a surface is reddish (i.e., red but not pure red, as we are assuming) iff it has a surface reflectance that disposes it, under NVC, to reflect light such that, for the reflected light, $L^* \succ_s M^*$, and a surface is yellowish iff it has a surface reflectance that disposes it, under NVC, to reflect light such that, for the reflected light, $(L^* + M^*) \succ_s S^*$, orange is, quite literally, a mixture of reddishness and yellowishness. The first disposition is constituted by the last two. Orange, thus, is a binary hue.

Note that this line of response does *not* commit the physicalist to holding that red is purplely-orange. Looking purple is looking reddish and looking bluish. According to the model, the experience of blue (but not pure blue) occurs iff $(L + M) < S$. So, the experience of purple occurs iff $L > M$ and $(L + M) < S$. Accordingly, a surface is purple iff it is disposed under NVC to reflect light such that $L^* \succ_s M^*$ and $(L^* + M^*) \prec_s S^*$. Evidently, then, red is not a literal mixture of purple and orange. Indeed, no color is. For no reflectance is such that it allows the same region of a surface to reflect light that satisfies incompatible conditions. (Pure) red, according to the proposed account, is not a literal mixture of any other colors at all. It is thus a unitary color.

This is our preferred response to the unitary/binary objection to physicalist realism about colors. But it should also be pointed out that there is no difficulty for the physicalist even if we understand the unitary/binary distinction in the way Hardin suggests. For Hardin, as already noted, orange is reddish-yellow in that necessarily something, in looking orange, looks reddish and looks yellowish. By contrast, yellow is not reddish-green, since it is not necessary that when something looks yellow, it looks reddish or greenish. For unique yellow, when something looks *that* shade, it does not look red or green at all.

Orange, then, is a perceptual mix of red and yellow but yellow is not a perceptual mix of red and green. This, we claim, the commonsense physicalist with respect to color can happily accept. For facts about perceptual mixture are best taken as facts about how colors are represented in color experience. In experientially representing something as orange, we represent it as being reddish and also as being yellowish. However, there is a shade of yellow such that, in experientially representing something as having that shade

(unique yellow), we do not represent it as being reddish and being greenish. Nor do we represent it as being orange and lime. Thus, the determinables, red and yellow enter into the content of the experience of something's looking orange, whatever the shade of orange. But in the case of yellow, there is a shade such that the only determinable that enters into the content of something's looking that shade of yellow is yellow. This tells us that there is an important difference in how we represent orange and yellow in our color experiences, a difference that is naturally explicable in terms of opponent processing. But it presents no threat to the view that the colors, orange and yellow, are objective, physical properties of the same general type.

Admittedly, on the assumption that our color experiences are generally veridical, the reply just offered entails that orange things *are* reddish and also yellowish. That, however, is unproblematic for the reasons given earlier, if colors are objective dispositions of the sort we have proposed. So, there is nothing in the trichromatic unitary/binary distinction that should lead us to give up commonsense color realism.

Again, the extension to the tetrachromatic case is straightforward. Let us give one illustration. Consider the case of the goldfish. According to the earlier model, an experience of H^+ (not pure H^+) occurs iff $((UV + S) - L) > 0$. Likewise, an experience of I^+ (not pure I^+) occurs iff $(UV + (S - M) + L) > 0$. Hence, we claim, a surface has the hue, $H^+ + I^+$, iff it is disposed, under NVC, to reflect light such that, for the reflected light, the total quantity, $UV^* + S^*$, is significantly greater than L^* and the total quantity, $UV^* + S^* + L^*$, is significantly greater than M^* . Since a surface is H^+ -ish iff it is disposed, under NVC to reflect light such that the total quantity, $UV^* + S^*$, is significantly greater than L^* , the binary color, $H^+ + I^+$, is partly constituted by H^+ -ishness in a quite literal way. The ternary case is handled in a parallel manner. Further, certain hues goldfish experience, for example, pure H^+ , will be both objective and unitary.

For the goldfish, then, the binary hues are conjunctive properties whose conjuncts are exactly two (nonconjunctive) hues accessible to the goldfish, for example, H^+ -ishness and I^+ -ishness. The ternary hues are likewise conjunctive, but their conjuncts are three in number. The unitary goldfish hues are those that are not conjunctive in the above way.

IV: The Caterpillar and the Leaf

Consider again the caterpillar of the gray shoulder knot moth (lithophane ornithopus). Suppose that one such caterpillar is sitting on the underside of an oak leaf, as shown in figure 1.

INSERT FIGURE 1 HERE

Figure 1: Caterpillar and Oak Leaf pictures: images of the gray shoulder knot caterpillar (A) under UV illumination (300 – 400nm) and (B) in the human-visible spectrum (400 – 700nm).⁴⁰

To normal humans, the oak leaf and the caterpillar both look the same color in daylight (pure green, let us suppose⁴¹). But birds have the ability to discriminate between caterpillar and oak leaves based solely on color. Therefore, to normal birds, the oak leaf and the caterpillar do not look the same color in daylight. It is chauvinistic to say that we get the color right and birds get it wrong—after all, birds' characteristic interactions with caterpillars of this sort are beneficial to their viability. So, if we are to avoid arbitrarily giving preference to one species' color vision over another's, we are bound to say that the caterpillar and leaf are one color to humans, and two colors to the birds. How can this be?

There is no problem here for the projectivist. If colors are mental features wrongly projected onto the external world, then birds and humans project different colors onto the caterpillar, and both are mistaken in doing so. The caterpillar, in reality, is colorless. There is also no problem if colors are partly subjective, response-dependent dispositional properties. Since the typical subjective color response of a normal human perceiver to the caterpillar will be different from that of a normal bird to the caterpillar, the

⁴⁰ Cuthill, *et al.* "UV Vision in Birds," 186.

⁴¹ This assumption is for simplicity only. In reality, very few objects outside the laboratory are pure green.

caterpillar will have both colors. But, how can the leaf and the caterpillar be objectively the same color and yet objectively different colors? A corresponding question arises in connection with the case of kestrel and human vision of straw covered with water versus straw covered with vole urine.

According to our (grossly oversimplified) account, an object is (pure) green iff it is disposed, under normal viewing conditions(NVC), to reflect light such that, for the reflected light, $M^* >_s L^*$ and $S^* =_a$ the total quantity, $M^* + L^*$. Since this condition is met (let us assume for the sake of simplicity) by the caterpillar and the leaf, both are pure green. Let us now hypothesize that the bird's color detection system is such that, viewing the caterpillar, the bird has an experience of a hue we may call 'UV⁺-green'. UV⁺-green has the following possession condition: an object possesses UV⁺-green iff it is disposed, under NVC, to reflect light such that, for the reflected light, $M^* >_s L^*$ and $S^* =_a$ the total quantity, $M^* + L^*$, and further the amount of reflected light in the UV portion of the spectrum (UV^{*}) is sufficiently large relative to S^* , M^* , and L^* . This is, of course, very vague with respect to UV^{*}, but for present purposes, we can leave the proposal in this incomplete form.

The caterpillar and the leaf, then, are both pure green—that is, they are green without being yellowish, bluish or reddish—but the caterpillar also has the property UV⁺-green whereas the leaf, given its failure to reflect much UV-light, lacks that color. When we view the caterpillar and the leaf, our visual system picks up on the shared hue, pure green. The bird's visual system is tetrachromatic, however, and it picks up on a difference in color that it is beyond our capacity to discern. In a sense, then, colors are species specific. But, as we emphasized earlier, this sense is perfectly compatible with their being objective.

Perhaps it will be complained that it is extremely counter-intuitive to suppose that the caterpillar is *both* pure green *and* UV⁺-green (hereafter UVG, for short), that the caterpillar literally has *two* colors. Our intuitions certainly tell us that nothing can be simultaneously red and green. They also tell us that nothing can be simultaneously pure yellow and green. In these cases, our intuitions are working within trichromatic color space, which is closed to novel hues. The color, UVG, however, is not inside trichromatic

color space—it is located in tetrachromatic color space. We humans only have three types of cones in our eyes, and our lenses filter out UV light. We simply lack the hardware to see in tetrachromatic color space. Thus, when it comes to UVG, we have no clear idea what it is like to see this color, and we will never have a clear idea of what it is like to see it. Given this point, it is hard to see how our proposal is counter-intuitive.

Furthermore, it is not difficult to supply a possible conception of UVG that makes the claim we are advancing with respect to the color of the caterpillar intuitively very plausible. The caterpillar surface, in being pure green, is green without being reddish or yellowish or bluish. That is, it is green without having any other humanly accessible hue. But, of course, that is compatible with supposing that it has a further humanly inaccessible hue such that the latter hue and green comprise UVG. On this conception, UVG is a binary hue for the birds, one component of which is inaccessible to us. Thus, just as a surface can be orange and reddish, so too a surface can be UVG and pure green. And just as a red-green human dichromat would experience only the yellow in an orange surface and would have no clear idea of what it is like to experience orange, so too we trichromats experience only the green not tinged with any blue, red, or yellow, as we view the caterpillar, and we have no clear idea of what it is like to experience UVG.^{42,43}

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⁴² For more on color realism, see M. Tye, *Color, consciousness and content*, ch. 7.

⁴³ Talks based on this paper were given at Duke University and the University of Athens. We would like to thank Alex Byrne for his written comments, and Stuart Church for the use of his images, reproduced here as figure 1.