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Comparative color vision as a case study for cognitive science 1

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Ways of coloring: Comparative  
color vision as a case study  
for cognitive science

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**Abstract:** Different explanations of color vision favor different philosophical positions: Computational vision is more compatible with objectivism (the color is in the object), psychophysics and neurophysiology with subjectivism (the color is in the head). Comparative research suggests that an explanation of color must be both experientialist (unlike objectivism) and ecological (unlike subjectivism). Computational vision's emphasis on optimally "recovering" prespecified features of the environment (i.e., distal properties, independent of the sensory-motor capacities of the animal) is unsatisfactory. Conceiving of visual perception instead as the visual guidance of activity in an environment that is determined largely by that very activity suggests new directions for research.

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wavelengths in the atmosphere, and so on. Then there are questions about the organism itself: Where does it live and what does it do? Exactly how you would draw on spectral information would depend on what visual tasks are appropriate to the organisms tempered by the spectral information locally available.

Consider an actual example – the visual/spectral problems confronting the fish (Levine & MacNichol 1979; Munz & MacFarland 1977). First, water absorbs light – the deeper the water the less light – but exactly which wavelengths are absorbed depends on the types of suspended organic particles. So, for example, clear water with little organic matter (such as in tropical oceans) will most easily absorb red and violet light. At depths below 25 meters, essentially all red and violet light has been filtered out, leaving only the intermediate “blue” wavelengths. Hence the “Mediterranean blue” appearance of such water to us. Marshes and swamps, but contrast, contain decomposing plants, tannins, lignins, and yellow-green plankton that effectively filter out almost all light at the depth of only three meters. The light that does survive, however, is in the red-orange region of the spectrum and gives the water its dark red-brown appearance. In addition, water molecules (and the suspended particles in water) scatter light – the medium of transport is itself “colored.” So, assuming that one visual task of the fish is to spot objects underwater, this detection must be done against a background of colored light.

One current hypothesis is that the rods and cones of some fish have evolved to function as *filters* that serve to highlight the contours of objects against the background space light. If the photopigment is “matched” (maximally sensitive) to the spectral range of the background light, then a dark object will be highlighted against the brighter background; if the photopigment is “offset” from the dominant wavelengths of the background light, then a bright object will be outlined against a poorly illuminated background. In fact, this scheme seems to be used in many species of fish. For example, the skipjack tuna, which spots its prey from below (dark object against a bright surface), has only one photopigment that is matched to the background light. The guppy’s retina is divided into two regions. In the lower region, which looks upward and is used to spot prey, there is one photopigment that is matched to the background space light. The upper region, which looks down on the colorful mating display of the male guppy, has three spectrally diverse cone types. Finally, the walleye, bluegill, and piranha, which inhabit dark, particle-laden (hence, red-shifted) waters, are each dichromats, with one cone type matched to the near-infrared – a wavelength common to their “black” water habitat during the dusk and dawn hours of feeding.

What the above examples illustrate, we think, is that the use of spectral information could take many forms. It could be used to recover the invariant surface reflectances of opaque objects; then again, it might be used for the delineation of object from ground, to discern shape, monitor motion (Dobkins & Albright 1990), as a cue for eye movement (Ballard, forthcoming), and so on. There is, in other words, no a priori answer to the question, “What role does spectral information play in a visual system?”

What are the implications of this fact for color vision? Questions of consciousness aside, color vision, as defined behaviorally, is a certain *kind* of chromatic visual function – a selective response to light stimuli of different wavelengths regardless of intensity. (There seems no need to second guess the kinds of visual function that are necessary for our color experience insofar as questions of ontology hinge on the facts about function. If the ontological conclusions can be reached for any kind of color vision, then they will hold for conscious color experience as well. Here, the form of such discriminations can vary immensely between species – the type of color vision a creature has will depend on the number of its color receptors, the response profiles of those receptors, and the additional “wiring” farther up the line. One can think of the initial “choice” of

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### More than mere coloring: The art of spectral vision

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Suppose you were God, with a month of free Sundays, and you decided to design a visual system for a small creature. What would you do with the abundance of spectral information available from the world? How would you make use of the fact that sunlight ranges in wavelength from about 320 nm. in the ultraviolet on out past 800 nm. in the infrared (NASA 1977), or of the fact that the refraction, absorption, and reflection of light by various media alters the composition of those spectral frequencies?

The right answer, we think (as Thompson et al. would agree), is just this – it all depends. First, you would (as a less than omnipotent god) be subject to the standard “materials” constraints. These are the various facts about the way the physical world is – the amount of energy it takes to break chemical bonds, what wavelengths of light would be absorbed by potential materials for the eye, the abundance or paucity of particular

receptors, the number and their response profiles, as providing a first filter on the spectral information available to the organism. For example, the kinds of receptors clearly restrict the range of spectral information that will be available (think of us and the bees). The wiring, on the other hand, is necessary to make accessible (or causally effective) certain kinds of information – to calculate hue (by disentangling intensity versus wavelength information for a monochromatic light source) or to disambiguate the spectral information from polychromatic sources. Wiring can also subserve computations that, although clearly useful, result in information loss, for example, by the categorization of spectral information (see Thompson et al.'s example of pigeon color categories) or by providing color constancy. Again, the "choices" made will depend on the uses to which that information is put.

Several points follow. First, what makes interspecies comparisons interesting is not their dimensionality, hence formal incommensurability, *per se*. (Consider that, in this sense, the color space of any tetrachromat would be "commensurate" with the gustatory space of man, or of any organism with four taste receptors). Rather, a comparison of color systems points to the "subjectivity" of color vision because each species represents a different informational "cut," constrained only by utility and possibility, on the objective spectral world.

Second, as Thompson et al. claim, the scientific explanations of color vision (and other visual tasks that use spectral information) will advert to the environment of the organism, the organism's other visual functions, and its behavioral repertoire. It will include events both internal and external to the organism. For example, in explaining why one species of fish, the sea raven is a trichromat, Levine and MacNichol (1982) say:

Sea ravens possess three pigments . . . which cover a much broader spectral range than one would expect in a fish that spends most of its life at depths of more than 100 meters. . . . In the sea raven's breeding season, which is in late fall, the fish moves to shallow and thus to brighter and spectrally broader light. The bodies of reproductive individuals turn bright yellow, orange and scarlet, and after fertilizations the eggs are deposited on a species of sponge that is colored bright orange or yellow.

Note, however, that, contrary to Thompson et al.'s view of codetermination, such functional explanations rely on a certain fixed explanatory ontology – of light frequencies and intensities, and even of sponges and "bodies." We explain the categories of fish color vision by first adopting a certain "scientific" vocabulary that will allow us to show how those categories came about. (In any explanation of a color system, we will use new terms and concepts as we discover and name new color categories and functions. But these terms will be part of what is to be explained, not part of the explanation itself.) This is so even in cases of coevolution – if, say, one were to explain the breeding coloration of the sea raven and the yellow color of the sponges in conjunction with the development of the sea raven color system. Of course, the trick in offering a legitimate explanation, we believe, will lie in not importing our own *a priori* biases, engendered by our conscious experience, into the initial vocabulary of explanation. But to say this is not to endorse the authors' view of ontological codetermination.