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Philosophy and Science in the Modern Age

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1 Introduction

The study of color expanded rapidly in the 20th century. With this expansion came fragmentation, as philosophers, physicists, physiologists, psychologists, and others explored the subject in vastly different ways. This fragmentation was sometimes amicable, sometimes not.

There are at least two ways in which the study of color became contentious. The first was with regard to *the definitional question*: what is color? The second was with *the location question*: are colors inside the head or out in the world? Neither question was settled by the end of the century, and fissures between competing views were amplified by differences in theoretical goals, resources, and methodologies.

In this chapter, we summarize the most prominent answers that color scientists and philosophers gave to the definitional and location questions in the 20th century. We identify some of the different points at which their work intersected, as well as the most prominent schisms between them. One overarching theme of the chapter is the surprising proliferation of different views on color. Whereas some assume that progress in science must take the form of convergence, the 20th century history of color exhibited a marked divergence in views. This chapter leaves it an open question whether an ultimate unification of views is possible, or whether the only thing that ties together the study of "color" is the shared inheritance of a word.

2 Color Science and the Problem of Defining Color

In the first half of the 20th century, color scientists wrestled both with how "color" should be defined, as well as who should define it. This problem was motivated by the two most prominent competing theories of color vision of the 19th century, those of Hermann von Helmholtz and Ewald Hering. Helmholtz and Hering both held that progress in color science requires introducing a strict distinction between the objective and subjective aspects of color. On the objective side, there is the structure of the physical stimuli that cause color experiences (i.e., wavelengths of light, which admit of continuous variation across the visible spectrum); on the subjective side, there is the qualitative character of color experiences (i.e., how colors look, which can be divided into a small number of discrete categories). This distinction is crucial for understanding the role that the physiology and psychology of the perceiving subject play in color vision, but these distinctions do not, on their own, answer the definitional or location questions. The most heated debates in color science in the first half of the 20th century were caught up in the ways that color scientists from different camps proposed to study the objective and subjective aspects of color.

Helmholtz's *trichromatic theory* was the dominant theory of color vision for the first half of the century. It was primarily supported by a discovery about the mixture of colored lights: varying the intensity of three appropriately chosen wavelengths of visible light suffices to produce stimuli that match all colors. Helmholtz's theory explains this discovery by positing three types of receptors in the human retina, each of which is maximally sensitive to a different point in the visual spectrum, and which were thought to produce red, green, and blue experiences, respectively. All other color experiences were held to be the result of a simultaneous stimulation of multiple receptors; for example, yellow was held to be the result of stimulating both the red and green receptors. Helmholtz took this physiological account of color vision to imply that colors are properties of *sensations* located inside our heads, and that their apparent location in the world is an illusion. His sensation-based account appealed not only to physiologists, but also to physicists interested in the effects of mixing colored lights.

Hering's *opponent processing theory* was never as popular as Helmholtz's trichromatic theory, although it always had advocates. Hering's main criticism of Helmholtz was that his theory mischaracterized the phenomenology of color experience—our introspective awareness of what colors are like. Specifically, Hering observed that pure yellow appears unmixed—that is, as a *unique* hue—on par with Helmholtz's three primary colors—rather than as a mixed—that is, a *binary* hue—like orange or purple. Hering also observed that it is impossible to imagine a perceptual mixture of red with green or blue with yellow. Hering took these observations to show that there are four primary colors: red, green, blue, and yellow. He proposed his own competing physiological account of color vision to explain these observations. Hering's account posits three types of receptors which can be positively or negatively stimulated, thereby producing one or the other side of an opposing pair of experiences: red/green, blue/yellow, or black/white. For example, the excitation of the receptor for experiencing red would thereby inhibit its ability to produce experiences of green. Hering also rejected Helmholtz's proposal to study colors as properties of sensations. Hering noted, "sensations mean in our language something that one perceives in or on one's body, but colors always appear outside of our body and especially outside our eyes" (1905/1964, 4). He proposed that color *perception*—that is, our everyday experience of colors as visual qualities of external objects—should be the central topic of color science.

For the first half of the century, Helmholtz and Hering each had their own dedicated groups of supporters, but neither could claim to offer a complete explanation of color vision.[i] The debate between Helmholtz's and Hering's supporters was in part a debate over which discipline is best positioned to study color: physiology or introspective psychology. The debate between these camps became increasingly contentious, with the best-recorded disagreement occurring within the "Committee on Colorimetry" (henceforth CoC), a group of about twenty American scientists in different fields developing multidisciplinary reports on the status of color science.[ii]

The first CoC opens: “That the nomenclature and standards of color science are in an extremely unsatisfactory condition is manifest to practically all workers in the field” (1922, 528). After “protracted debate” the CoC settled on Helmholtz’s position and defined color as “the general name for all sensations arising from the activity of the retina of the eye and its attached nervous mechanisms” (1922, 531-2).

This report and its definition were the starting point for the 1931 conference by the International Commission on Illumination (called by its French initials, the “CIE”). This conference provided the definitive international standards for measuring color, represented by the CIE 1931 color triangle (see color image 1). The CIE attempted to connect the subjective and objective aspects of color by proposing a one-to-one mapping of subjective qualitative experiences with objective physical stimuli. The qualitative character of color experience was defined in terms of hue, saturation, and brightness. The subjective aspects of color were arrived at by averaging the results from 17 test subjects in color-matching experiments. The physical stimuli were defined in terms of relative intensities of red, green, and blue light sources. This benefitted the field by introducing an “average observer” and “standard conditions” that provided shared reference points for laboratories and factories worldwide.

For introspective psychologists, however, the CoC and CIE grossly mischaracterized visual experience. The sensation-based picture treats color vision as a measuring device that detects the set of wavelengths produced by mixtures of lights in a narrowly circumscribed viewing situation. But this experimental setup is radically different from everyday color vision, in which the majority of colors we see are not lights, but illumination-independent properties of the surfaces of objects. Many members of the CoC argued that color’s definition should reflect our perception of it as a property of objects, not as an inner sensation.

For the next CoC report, the introspective psychologists pushed for the adoption of a perceptual definition more in line with Hering’s position. For support, they drew upon the contemporaneous work of the (Hering-inspired) German “Gestalt school.” This school held that in perceptual experience we encounter visual forms irreducible to their parts (see black and white image 1). They held our experience is not simply the aggregate of different sensations; we perceive complete scenes consisting in colored objects as part of a larger context.

The most influential Gestalt color theorist during this period was the psychologist David Katz. His studies involved perceiving color in more natural circumstances: whereas physiologist’s experiments often focused on a single colored light viewed in isolation, Katz investigated colors viewed against the backdrop of other colors, on shiny or matte objects, and seen across a variety of lighting conditions. He contended that the many ways we encounter colors—what he called their “modes of appearance” (1935, 7-27)—make important differences to our phenomenal experience of them.

Katz's work produced two major findings: first, that the colors of objects remain constant under different lighting conditions; second, that perceivers can identify the color of the lighting independently of identifying the color of the objects in the scene. Both findings had been noticed before, but Katz's work made them central to what colors are. The former finding, *color constancy*, showed that even when the illumination color of a scene changed, the color of the objects in the scene does not appear to change. The latter, *perception of illumination*, suggested that our color experience of a scene generally contains two colors: the color of the object and the color of the illumination. These findings imply that we cannot treat color as identical to the local stimuli—that is, just the wavelengths emitted or reflected by an object—since the surrounding scene also plays an integral role.

When the CoC met a decade later to write an updated report, many members rejected the sensation-based account in favor of the perceptual account. But while Katz's version of the perceptual account provided a better description of color experience, it achieved this at the cost of increased complexity. As Katz notes, "objects on the one hand are blue, yellow, red, etc., and on the other hand sparkle, shine, glitter, etc." (1935, 33). Faced with specifications of color far more complex than simply hue, saturation, and brightness, the chairman of the report, L. A. Jones, noted, "the Committee did not react favorably" (1953, 8). The committee debated these issues for several years with little progress; as Jones later recalled: "this discussion continued for more years than the chairman likes to remember, and a stalemate between the physical and psychological viewpoints seems to have been reached" (1953, 9). Jones finally proposed a psychophysical definition: "color consists of the characteristic of light […] of which a human observer is aware through the visual sensations which arise from stimulation of the retina" (1953, 221). This psychophysical definition represented a notable attempt to tie together the diverging views: it acknowledged the role of sensations in color vision but treated them as the means by which we perceive properties of external objects.

The final CoC report provided separate chapters for physics, psychophysics, sensation, and perception. This divided up the field of color in a way that allowed for each discipline to make their case for how to think of color—but also highlighted the gaps between them.

By the middle of the 20^{th} century, the study of color was splintered, with colorimetrists embracing the sensation-based definition and distancing themselves from concerns about color experience. Other committee reports, such as those by the U.S. Physical Society (1948), the Inter-Society Color Council (1949), and the CIE (1970), also acknowledged terminological problems associated with the word "color" and similarly proposed drawing stark contrasts between the different ways in which it is defined. As one prominent introduction to color noted:

> It has become customary to divide the subject of color into three broad fields called 'physical, psychophysical, and psychological.' … The word 'color' has at one time or another been assigned to one or more of these categories by various

> writers or groups and in unmodified form has become almost completely ambiguous. (Evans 1974, 8)

Although these different approaches to color science coexisted, and were published alongside each other in committee reports, they often regarded one another as having debatable presuppositions, contentious definitions, and questionable scientific merit. The result was a series of parallel programs, each making room for the others while being suspicious of them as well. The unexpected result was that the more color was studied, the more difficult it became to talk about consistently.

3 Philosophy and the Autonomy of Color

As color scientists divided the study of color into a number of distinct disciplines, many philosophers attempted to develop an account of color that would be independent of scientific debates altogether. These philosophers adopted a strategy defining color in terms of its qualitative character—what came to be called its *quale* (pl. *qualia*).[iii] Qualia were taken to identify what is distinctive about the conscious experience of different colors: e.g., red quale refers to the redness of red and green quale refers to the greenness of green. By defining color in terms of conscious experience, many philosophers held that it is possible to offer an understanding of color that is independent of science altogether.

The rise of this new sense of “qualia” was due in part to the emergence of introspective approaches in philosophy and psychology. The philosopher-cum-psychologist G. F. Stout introduced a generation of students to scientific debates on color with his 1899 *Manual of Psychology*. Regarding color and other sensible qualities, Stout wrote:

> The sensible qualities perceived are by no means identical with the cause of sensation. The colour-sensation, for instance, is due to a vibratory motion of the particles of the luminiferous ether, giving rise to certain chemical or physical changes in the organ of vision, and to a certain modification of connected parts of the nervous system. But these conditions are not what a man sees when he perceives the colour red or blue. (Stout 1899, 118)

Stout argued that when we experience color we do not *see* wavelengths of light or their chemical or physical effects on the visual system.

Stout’s idea that our experience of color is independent from the scientific study of light and vision was taken up by some of his advisees, chief among them Bertrand Russell, G.E. Moore, and C. D. Broad. Moore, in an influential passage, echoed Stout:

> Consider yellow, for example. We may try to define it, by describing its physical equivalent; we may state what kind of light-vibrations must stimulate the normal eye, in order that we may perceive it. But a moment’s reflection is sufficient to

> shew that those light-vibrations are not themselves what we mean by yellow. *They* are not what we perceive. (1903, 62)

Moore takes this to show that colors are a paradigmatic example of a "simple, unanalyzable, indefinable" property of objects (1903, 90), and that visual experience of these indefinable properties makes possible a sort of knowledge that is irreplaceable by any other kind of knowledge. This view was later reiterated by Russell and Broad. For example, Russell wrote, "I know the colour perfectly and completely when I see it, and no further knowledge of it itself is even theoretically possible" (1912, 73-4; see also Broad 1923, 280). Taken together, these writings motivated the view that there is a kind of knowledge of color that is *autonomous* from all present and future scientific discoveries: the knowledge of color qualia. A. J. Ayer later provided a perfect encapsulation of the appeal of this view: "So far as anything can be, qualia are pre-theoretical" (1968, 335). In response to the conflicting scientific theories of color, these philosophers maintained that color is pre-theoretical: we know color simply by experiencing color qualia.

One cost of the idea of color qualia was that it raised a host of questions about what qualia are and how they fit into the world. Part of the difficulty was that definitions of qualia tended to be negative: qualia are *not* physical properties of objects, *not* definable in other terms, and so on. As E. A. Singer quipped early in the century, "If I am not mistaken, the best English into which we can render the Latin *quale* is not *what*, but what *not*!" (1917, 341). Nevertheless, over the second half of the 20th century, qualia came to play an increasingly prominent role in debates in the philosophy of consciousness, with color as the archetypal example invoked; as David Chalmers put it, "Among the many varieties of visual experience, color sensations stand out as the paradigm examples of conscious experience, due to their pure, seemingly ineffable qualitative nature" (1996, 6). Color's role in two of these debates will be highlighted here: in *the inverted spectrum thought experiment* and in *the knowledge argument*.

The inverted spectrum thought experiment concerns the possibility of color experience varying between persons in ways that are completely undetectable. At the beginning of the 20th century, Henri Poincaré offered a vivid articulation of this thought experiment:[iv]

> The sensations of others will be for us a world eternally closed. We have no means of verifying that the sensation I call red is the same as that which my neighbor calls red. Suppose that a cherry and a red poppy produce on me the sensation A and on him the sensation B and that, on the contrary, a leaf produces on me the sensation B and on him the sensation A. It is clear we shall never know anything about it; since I shall call red the sensation A and green the sensation B, while he will call the first green and the second red. (1907, 136)

Poincaré takes the possibility of undetectable variation to show that color experience is ineliminably private. Over the course of the 20th century, the inverted spectrum scenario went on to be invoked in a variety of different philosophical contexts,[v] but central to all of them is the incommunicable nature of the qualitative aspects of color experience.

Perhaps the most influential invocation of the inverted spectrum was as a criticism of *functionalist* accounts of the mind, which rose to prominence in the 60s and 70s. Functionalism holds that mental states are constituted not by their intrinsic makeup, but by the functional roles that they play in relating mental states to one another, as well as in linking sensory inputs to behavioral outputs. Critics of functionalism thus invoked the possibility of an inverted spectrum as a counter-example to the very idea of defining mental states in functional terms. Here is Ned Block's version of this criticism:

> If [the inverted spectrum] is true, then there is a mental state of you that is functionally identical to a mental state of me, even though the two states are qualitatively or phenomenally different. So the fundamental characterizations of mental states fail to capture their "qualitative" aspect. (Block 1980, 257-8)

Critics such as Block held that insofar as functionalism fails to capture the qualitative character of color experience it is fundamentally incomplete as a theory of the mind.

Color experience also featured prominently in the knowledge argument. This argument invokes the putative ineffability of color experience to support a different conclusion: that conscious experience essentially involves non-physical properties. If this conclusion is true, it precludes the view that physical facts exhaust reality—the view known as *physicalism*. The most influential version of the knowledge argument was Frank Jackson's thought experiment involving an imaginary color scientist named Mary:

> Mary is a brilliant scientist who is […] forced to investigate the world from a black and white room via a black and white television monitor. She specialises in the neurophysiology of vision and acquires, let us suppose, all the physical information there is to obtain about what goes on when we see ripe tomatoes, or the sky, and use terms like "red," "blue," and so on. [...] What will happen when Mary is released from her black and white room or is given a color television monitor? Will she learn anything or not? It seems just obvious that she will learn something about the world and our visual experience of it. But then it is inescapable that her previous knowledge was incomplete. But she had all the physical information. Ergo there is more to have than that, and Physicalism is false. (1982, 130)

This thought experiment rests squarely upon the idea of the autonomy of color qualia: it takes for granted that Mary learns something from color experience that is completely independent of any possible physical knowledge.

The inverted spectrum and the knowledge argument demonstrate how intuitions about the qualitative character of color experience have played a pivotal role in larger philosophical debates about the mind and its place in the world. Given the stakes of these larger debates, many philosophers responded by arguing that the very idea of qualia is mistaken. One approach that some critics took was to argue that our inability to describe the qualitative character of color experiences is an artifact of the incomplete state of color science (e.g., Perry 1912, 134). According to other critics of qualia, the problem was more fundamental: the very idea of qualia distorts the sort of knowledge that color experience makes possible. Advocates of qualia claim that a person who sees, for example, a red cherry and a green leaf comes to know something over-and-above how to visually discriminate these colors and how they relate to each other and other colors; they also grasp a further, directly apprehensible fact: the redness of red and the greenness of green. Many critics of qualia have argued that there simply is no such further fact. For example, Hans Reichenbach wrote:

> The structural relations between impressions have been distinguished from the specific *quale* of each of them; only the structural relations, it is said, are communicable; the quale is known only to ourselves. The fault of this conception, it seems to me, lies in the idea that we ourselves know more than structural relations. […] The relation of sameness has been substantialized—turned into a certain substantial entity called the quale, a fallacy frequently occurring in logic. (1938, 253)

Reichenbach contended that the qualia view takes the perceptual discriminations and awareness of structural relations that color experience makes possible and mistakenly reifies them into a fact about our own private experience of colors. As a way of bringing out why there is no such knowledge, Reichenbach proposed the following thought experiment of his own:

> Now imagine that […] one day we see as usual, the next day with exchanged colors [i.e., cherries come to appear to have the quale previously experienced when viewing leaves], the following day as the first day, etc. If this exchange affects our recollection images as well [i.e., our memories of what qualia look like], we never should become aware of it. We should believe then in a constant quale of our impressions, whereas this quale in fact always changes. This shows that the quale is an untenable concept. Its tenable basis is nothing but the relation of sameness. (1938, 254)[vi]

Reichenbach's point was not just that the qualia-switching person's perceptual discriminations and structural relations would be the same as someone whose qualia and memories of qualia stay constant. His point was that both people's thoughts about their qualia would be exactly the same. But if their thoughts about their qualia are the same, and their qualia are different, there's nothing for them to *know* about their color qualia just in virtue of having color experiences. Reichenbach concluded from this that since knowledge of color qualia is something we're supposed to be able to have just in virtue of experiencing a color, there is no such knowledge to be had.

Although many critics of qualia followed Reichenbach's lead, as the century progressed an even greater number of advocates of qualia emerged. By the century's end, the idea of qualia produced a multitude of philosophical debates that aimed to discern whether conscious experience really is autonomous, or if there might be some way to render subjective experience into something amenable to scientific investigation.

4 Later Developments in Color Science

In the second half of the 20^{th} century, there were many impressive developments in color science. Notably, these developments did not depend upon the emergence of a single comprehensive approach that commanded universal assent among scientists. There was progress without consensus, and many deep disagreements persisted. In spite of this, new technologies played a role in settling some old debates, but these developments also led to the emergence of new debates, which themselves had philosophical repercussions.

Progress on the Helmholtz-Hering debate began with the development of new electrophysiological and microspectrophotometric techniques for studying the biological mechanisms underlying color vision.[vii] These techniques provided physiological support for both Helmholtz and Hering, but they also suggested a way beyond their debate. Helmholtz's theory was supported by experiments measuring the spectral sensitivities of individual cone cells. Researchers discovered three types of cones in the human retina that are sensitive to short, medium, and long wavelengths of light, respectively. The discovery of three types of receptors that are maximally sensitive to three different points in the visible spectrum aligned with Helmholtz's trichromatic theory. Hering's theory was supported by the discovery of opponent cells in the retinal pathway and further downstream in the lateral geniculate nucleus. These cells were excited by wavelengths of light from one part of the spectrum and inhibited by wavelengths of light from another part. The discovery of these cells aligned with Hering's theory of opponent processing.

In the 1950s and 1960s, Leo Hurvich and Dorothea Jameson used these developments to bring about a partial resolution to the Helmholtz-Hering debate. They first entered the debate by providing psychophysical evidence that supported Hering's theory of opponent processing. In their hue cancellation experiments, they showed that blue light can be combined with sufficiently intense yellow light in such a way that both hues are cancelled in a subject's experience; they found the same was possible with combinations of red and green light.[viii] This supported Hering's idea that there are two chromatic opponent processing channels, and that these correspond to four phenomenologically-primitive colors. They then went on to reconcile their discoveries with Helmholtz's theory by proposing a two-stage theory of color vision, according to which Helmholtz was right about the first stage, Hering about the second.[ix] At the first stage, there are receptors that are responsive to three different wavelengths of light; at the second, there are cells that are excited or inhibited by the signals from the receptors. Hurvich and Jameson's work was notable not just for helping to resolve the Helmholtz-Hering debate, but also for showing how work in psychophysics, physiology, and psychology could be profitably integrated into a multi-disciplinary account of color vision.

During this same period a new approach to studying vision emerged, one that led to new disagreements in color science. The new approach was motivated, in part, by the development of a new technology: Edwin Land's invention of the Polaroid camera. In the late 1950s, while working to develop a process for instant color photography, Land first discovered that a full-color image could be produced using only red and green light. Intrigued, he then removed the green filter, leaving an image produced solely through a combination of red and white light, and found that even this combination could still produce a full-color image, albeit a muted one (this is called the "Land effect;" see color images 2 and 3). Land concluded from this that the color perceived at a location in space could not be reduced to the specific wavelengths of light emitted or reflected by that location.

Land rediscovered Katz's finding: color cannot be identified with the local stimulus. What was new was what Land did with this rediscovery. Land looked at it as an engineering problem: how could a three-color visual system, solely by absorbing wavelengths of light, perceive objects as having stable colors across changes in illumination? Land's influential answer was that the visual system solves this problem computationally. To support this answer, Land and John McCann wrote a computer program that tracked the constant colors in a scene by discounting the illumination conditions. The goal of Land's computer program was to determine the *reflectance profile* of a surface in a scene. A reflectance profile is the percentage of each wavelength of light that something is disposed to reflect, across the visible spectrum (see black and white image 2). The reflectance profile of a surface stays the same across changes in lighting, so even if one scene was darker than another, its reflectance profile nonetheless remains constant. Land and McCann's computer program ended up producing results that were functionally similar to those of human vision. The result of Land's work was to put color into the ambit of cognitive science, or "psychology by reverse-engineering" (Haugeland 1997, 1). A burgeoning number of computational scientists took on the challenge of developing simulations far more complex than Land's, and a whole new approach to studying color vision was born.

Over this same period yet another approach to studying vision emerged from psychology. Beginning in the 1950s, J. J. Gibson proposed a novel account of perception and its objects, as part of developing an ecological approach that drew heavily from evolutionary considerations. Gibson argued that perceptual systems must be studied in real-world contexts, rather than in artificially constrained laboratory conditions. He pointed out that these real-world contexts varied from species to species according to their specific evolutionary histories. Gibson took this to imply that it is mistaken to treat the inputs to perceptual systems in species-independent terms (such as wavelengths of light). Rather, Gibson proposed that the objects of perception should be characterized in action-oriented terms specific to the selection pressures of that specific species. Gibson referred to these species-specific objects of perception as "affordances," and included colors among the sorts of affordances that animals can perceive (1979, Chap. 8).

While these different approaches each pulled in different directions, they all regarded color vision as more complex than just the selective absorption of wavelengths of light. In contrast to midcentury, late-century color scientists became increasingly comfortable with a pluralistic approach to studying color. For example, after summarizing a variety of philosophical, physical, physiological, and psychological accounts of color, Hurvich's 1981 color textbook simply concludes, "color is all of these things" (1981, 13). With the rise of neurological and computational approaches to color vision, however, it became increasingly common for color scientists to follow Land in locating color within various processes inside the head.[x] This tendency proved to be a provocative challenge to philosophers.

5 The Rise of Empirically-Informed Work in Philosophy

In the 1980s, a new generation of philosophers emerged who drew extensively upon recent advances in color science. C. L. Hardin was the most programmatic member of this new generation. His avowed goal was to, "promulgate within the philosophical community the opinion that, henceforth, discussions about color proceeding in ignorance of visual science are intellectually irresponsible" (Hardin 1988, xvi).

The need to argue for the relevance of science for understanding color shows how pervasive the autonomy view had become. Ludwig Wittgenstein, in his *Remarks on Colour*, was the most prominent advocate of this view. He wrote, "phenomenological analysis (as e.g. Goethe would have it) is analysis of concepts and can neither agree with nor contradict physics" (1950/1977, §16).[xi] Wittgenstein investigated color as an example of a sort of knowledge that seemed both to be based upon experience yet revelatory of necessary truths. For example, he puzzled over why it seems impossible to conceive of reddish-green hues or transparent whites. He took these reflections to reveal an insight into color that science could not provide.

In response, Hardin and other like-minded philosophers sought to show the relevance of color science for these questions, and more. Broadly speaking, this new generation of empirically-informed philosophers fell into three camps: *computational objectivists*, *neurophysiological subjectivists*, and *ecological relationalists*. The debates between these camps often mirrored the debates between color scientists outlined in the last section.

The most prominent computational objectivist in this period was David Hilbert. His 1987 *Color and Color Perception: A Study in Anthropocentric Realism* is notable for several reasons. First, in opposition to how many computational color scientists interpreted the implications of their own work, Hilbert argued that the computational approach can explain how color vision tracks the distal properties of external objects.[xii] To support this claim, Hilbert pointed out that computational accounts of color constancy (like Land's) track the reflectance profiles of objects across changes in illumination conditions and lines of sight. Second, Hilbert proposed that it is possible for colors to be objective, physical properties of external objects while at the same time granting that they are "anthropocentric" in the sense that their similarity-and-difference relations seem arbitrary from the point of view of physics. To support this, Hilbert distinguished between the objectivity of a property (i.e., whether it can be identified without reference to human experience), and the explanatory significance of that property (i.e., whether it makes an ineliminable contribution to science). As Hilbert put it, "There are many objective properties of material properties that do not figure in the explanations of scientists" (1987, 10). For example, the present distance between Koko the Gorilla and the Empire State Building is an objective property that is extremely unlikely to figure prominently in any scientific explanations. Finally, Hilbert tied these considerations together into his own positive definition of color: colors are the reflectance profiles of objects, such that, "every difference in reflectance implies a difference in color" (1987, 99).

Hilbert's book drew philosophers' attention to computational approaches and introduced valuable distinctions to philosophical discussions about objectivity. But his positive account of color was not without its problems. The first is something Hilbert discussed at length: *metamerism*. Metamerism occurs when two objects with different reflectance profiles appear to be the same color; for example, a banana and a color photograph of a banana might appear to have the same color while nonetheless having very different reflectance profiles. This raises a problem for Hilbert's reflectance physicalism, insofar as it implies that two things can appear to be the same color to ordinary perceivers in ordinary circumstances, and yet be different colors. A second problem for Hilbert's identification of color with reflectance profiles is that there are many colors that do not involve reflection, such as the colors of lights, translucent volumes, the sky, afterimages, etc.[xiii] An account that identifies colors with reflectance profiles seems to leave out these sorts of colors altogether.[xiv]

The most prominent neurophysiological subjectivist in this period was C. L. Hardin. His 1988 *Color for Philosophers* had two main goals: first, to familiarize philosophers with recent developments in color science, and, second, to marshal this science to establish a counter-intuitive philosophical conclusion: that colors are illusions. Hardin argued that we should "be eliminativists with respect to color as a property of objects, but reductionists with respect to color experiences" (1988, 112). Through focusing on Hurvich and Jameson's work on opponent processing, he proposed that many aspects of color experience can be explained in neurophysiological terms.

In addition to reinvigorating debates about the reality (or lack thereof) of colors, Hardin made several other significant contributions to the philosophy of color. First, he attacked the long-standing assumption that color experiences are simple and unanalyzable. According to this assumption, the redness of red cannot be explained through comparing and contrasting it with other colors. Against this, Hardin proposed a more holistic picture of color. He drew attention to structural features of color experience, such as the distinction between unique and binary hues (i.e., the distinction between unmixed colors like red and mixed colors like orange), and used these structural features to define the similarities and differences between colors. Second, he used these observations about structural features of color experience to introduce a new criterion for philosophical theories of color: is the theory able to explain why colors stand in these relations to one another? Hardin invoked this criterion as a criticism of objectivist views such as Hilbert's, since distinctions such as the unitary/binary distinction do not correspond to any known physical relationships between objects. By contrast, in support of his own position, Hardin proposed that these structural relations can be explained by opponent processing. The problem Hardin identified here has come to be known as *the structure preservation problem*, and it has become much discussed. Finally, he attacked a view that many philosophers had come to think of as common sense: the view that the colors of objects are defined by how the objects are disposed to look to "normal" observers in "standard" conditions (i.e., *dispositionalism* about color).[xv] Against dispositionalism, he argued that neither "normal" observers nor "standard" conditions suffice to identify determinate colors for objects. With regard to "normal" observers, he drew upon psychophysical studies that revealed wide variation in what otherwise "normal" (i.e., non-color-blind) observers identify as unique green. This variation makes it impossible to define the greenness of something in terms of *the* way it looks to "normal" observers. Against "standard" conditions, Hardin pointed out that standard industry guidelines for colorimetry do not specify a single set of conditions for all objects; rather, they propose different sorts of viewing conditions for different sorts of objects, and they make it clear that the specification of these conditions depends much more on the interests of the viewer than on the nature of the object.

Hardin's book had a tremendous impact in philosophy. It raised issues that any subsequent philosophical theory of color must address, and also provoked a number of debates about Hardin's own eliminativism. One debate concerned how much the neurophysiological evidence actually explains. Although Hardin took opponent processing to explain the distinction between unique and binary hues, others were not convinced, and question of whether neurophysiology can explain this and other structural features of color experience remains open. Further, his conclusion that color is an illusion raised the question of why color vision would have evolved in the first place.[xvi] Finally, Hardin's discussion of philosophical theories of color largely takes the form of dilemma: either colors must be reducible to physical properties, or they cannot be in the world. The possibility that colors might be *sui generis* qualitative properties of objects that supervene on the physical properties of objects without being reducible to them is not discussed at length.[xvii]

The most prominent ecological relationalist in this period was Evan Thompson. In his 1994 *Colour Vision*, he aimed to move beyond what he saw as a series of false dichotomies that pervade debates about color. Two such dichotomies he attacked were the mental/physical distinction (underlying the definitional question) and the inner/outer distinction (underlying the location question). Thompson argued that an adequate account of color must regard it as *both* mental and physical, inner and outer. Following Gibson, Thompson argued that color vision serves a variety of biological functions (against Hilbert's exclusive focus on tracking reflectance profiles), and that serving these functions plays as essential role in helping animals skillfully cope with the world (against Hardin's claim that color vision is pervasively illusory).

Rather than accept either horn of these dichotomies, Thompson proposed that colors are species-specific ways that organisms relate to their particular environmental niches. Thompson drew upon a considerable body of empirical work on different species' visual systems to reorient color debates around a new question: what makes a visual system a *color* visual system in the first place? To answer this, Thompson explored the many uses of color vision, which include "object detection, spatial segmentation, and object identification" as well as tracking the "hormonal and motivational state" of conspecifics (Thompson 1994, p. 176). From this, he concluded that color vision is, "an adaptation for integrating a physically heterogeneous collection of distal stimuli into a small set of visually salient equivalence classes" (Thompson 1994, p. 197).

A major challenge facing Thompson's account is showing how it is possible it to move beyond the dichotomies structuring the color debate. For many, these dichotomies—especially the subjective/objective dichotomy—are so entrenched that any attempt to deny them seems atavistic. A related worry is whether thinking of colors as affordances provides us with a new way of thinking about colors that is not reducible to thinking of them as either physical properties in the world, or psychological properties in the head.

Despite their differing views, Hilbert, Hardin, and Thompson were united in thinking that we can make progress on many traditional philosophical puzzles by drawing upon color science. For example, whereas Wittgenstein held that the difficulty of conceiving of a reddish-green hue rests upon our color concepts, it turns out that this difficulty might have more to do with our physiology than anything else: color scientists have devised ways of manipulating our visual system that produce experiences that have been described as reddish-green.[xviii] In a similar way, the detectability or undetectability of an inverted spectrum might admit of empirical investigation: an inverted spectrum might always be detectable because our qualitative color space is asymmetric (because, e.g., we are able to discriminate more shades of blue than of yellow). By the end of the century, it became common to invoke these sorts of empirically-informed considerations in philosophical debates about color.

Since Hardin's seminal book came out, an increasing number of scientifically-minded philosophers have become involved in the philosophy of color. Many books, articles, and edited collections have promoted this approach. In 1997, Alex Byrne and David Hilbert published a two-volume anthology, *Readings on Color*, with one volume devoted to the philosophy of color and the other to the science of color. The aim was to expose each community to the work of the other, and thereby bridge disciplinary divides. At the turn of the 21st century, it became increasingly common for philosophers and scientists to attend the same conferences, discuss the same topics, and be published alongside one another.[xix]

6 Conclusion

In the middle of the twentieth century, Wilfrid Sellars claimed that a central challenge of philosophy is to combine two apparently conflicting images of the world: the *scientific* and *manifest* images.[xx] Many have taken color to be a vivid illustration of this problem: whereas science depicts a world in which electromagnetic radiation is selectively absorbed and reflected by objects, our conscious experience presents us with a world of colored objects. This can make it seem like the most fundamental problem in the philosophy of color is to explain whether these images can be fused into a single unified picture, or whether the gap between them is too great to be bridged.

The history in this chapter puts a novel twist on Sellars's challenge. The story we have told is one of the fragmentation of the study of color: there was much greater variety of ways of studying color at the end of the 20th century than there was at the beginning. As such, there simply is not such a thing as *the* scientific image of color, and it is not clear that there ever will be a single account. It could be that all we will have is a diverse set of approaches to studying a variety of visual phenomena that are grouped together by nothing more than the shared word "color." As such, the question of whether *the* scientific image of color can be reconciled with the manifest image of color is misplaced. (There is an additional question of whether there is such a thing as *the* manifest image of color.)[xxi]

In conclusion, the 20th century did not produce definitive answers to either the definitional or location questions. But it did yield a healthy awareness of the complexity of color phenomena, as well as a new model for what the future study of color might look like. This new model is wholeheartedly interdisciplinary and eschews terminological disputes for more substantive disagreements about the nature of color vision, its various biological functions, and its relationships to other parts of our perceptual and cognitive lives.[xxii]

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[i] These were not only two theories in play at the time; see Boring (1942, 210-6).
[ii] For histories of the CoC, see Jones (1953) and Johnston (2001).
[iii] See Crane (2000).
[iv] The inverted spectrum thought experiment goes back at least to 17th century, but it took on a new significance at the turn of the 20th century; see Daston and Galison (2007).
[v] For a summary, see Byrne (2016).
[vi] Much later in the century Dennett (1988) used a similar thought experiment to a similar end.
[vii] For a useful history of these studies, see Jacobs (2014).
[viii] See Hurvich and Jameson (1957).
[ix] Hurvich and Jameson mention several notable two-stage precursors to their own account. But earlier theories did not provide Hurvich and Jameson's psychophysical and physiological evidence.
[x] For prominent examples, see Sekuler & Blake (1985, 181); Goldstein (1989, 140); Backhaus & Menzel (1992, 28); and Palmer (1999, 95).
[xi] For discussion of Wittgenstein's work on color, see Westphal (1987).
[xii] Hilbert here drew upon the work of the computationalist Laurence Maloney, who argued that "what we call color corresponds to an objective property of physical surfaces" (Maloney 1984, 119).
[xiii] Nassau (1983) is a useful overview of the fifteen different causes of color experience.
[xiv] Hilbert's later work with Alex Byrne discusses these other sorts of colors in detail. See Byrne and Hilbert (2003).
[xv] Adams (2015) offers an account of how dispositionalism came to seem to be common sense among one group of philosophers from this time.
[xvi] Hardin (1992) offers his own response to this question.
[xvii] Broackes (1992) explores this possibility.
[xviii] Crane and Piantanida (1983) is the most famous such experiment.
[xix] Prominent examples include Hardin and Maffi (1997), Backhaus, Kliegl, and Werner (1998), and Mausfeld and Heyer (2004).
[xx] See Sellars (1963).
[xxi] For skepticism in this regard, see Adams and Hansen (forthcoming).
[xxii] We would like to thank David Hilbert, C. L. Hardin, and Evan Thompson for discussing their contributions to the debates discussed in this chapter with us, and Jay Elliott, Adam Gies, Nathaniel Hansen, Daniel Harris, Joseph Lemelin, Chauncey Maher, Eliot Michaelson, and James Trybendis for providing us with helpful comments on draft versions of this chapter.