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What, if Anything, is Colored?: Color Perceptions - Color Judgments - Without Color

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Acknowledgments:

This paper represents not only my honors thesis in the philosophy department, but also my capstone project for my self designed major, Neurophilosophy. Neurophilosophy is the application of neuroscientific ideas and techniques to ask and answer philosophical questions about the nature of the mind. While this can take many forms my particular focus has been the nature of perception, specifically the nature of color vision. As such, this paper is the culmination of both my coursework in the philosophy and neuroscience departments and an exploration of the intersection of these disciplines.

Both my major and this thesis would have been impossible without cross-departmental support and the invaluable input from professors in several departments. Without their help this paper would not have been possible. I would like to especially thank:

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Without Professor Pessin, of the philosophy department, neither my major nor this thesis would have ever been considered. Professor Pessin ignited my interest in philosophy and encouraged me to pursue my interests in both the philosophy and neuroscience departments through my self-designed major.

I would also like to especially thank my friends and family for their tireless support throughout this very long process.

INTRODUCTION: Why Study Color?

We are dissolved in color. It pervades our environments and our experiences. But despite, or perhaps because of, its ubiquity, the strangeness and magic of color are often ignored. Color is dismissed far too easily. It is thought of as a simple property of objects or of light. Alternatively color is seen as a production of the brain or the mind. Yet treating color in these simple ways makes it either intractably mysterious or else so simple as to be readily ignored. Furthermore, each of these conceptions, in their reduction of color to single aspects of our world or of our minds, is flawed.

But what does it matter? Poring over the particulars of color definitions seems irrelevant. After all, before writing this paper and developing a deeper understanding of color, I easily got through my day. But color *is* incredibly important. Though it may be overlooked, a sensitivity to color is incredibly valuable, not only in art or fashion, but also in the natural world, in advertising, architecture, surgery, and neuroscience.

To give a few examples of the utility of color: Green scrubs are widely used in operating rooms. When surgeons are focused on the surgical field their eyes become desensitized to red, if this area is surrounded by red's opposite – green – this fatigue can be ameliorated with a quick glance, allowing the surgeon to easily rest her eyes throughout long procedures.[1]

Color is also important in advertising – notice how almost all social media sites are blue? This may be because blue is the most popular 'favorite color,' which might explain why studies suggest that people spend significantly longer on predominately blue websites than identical websites in other colors.[2]

Countless guides exist on the practical use of color in presentations, informational guides, and data sets. These usually focus on aesthetic choices, and the interactions of particular colors. For instance, which is easier to read: This, or This? An excellent IBM publication[3] details why effective use of color gradients in data representation is essential; without sensitivity to the use of color, artifacts, and indeed blatant misrepresentation are common. Color clearly matters.

These applications are only a tiny percentage of the many uses of color. Though they may seem unrelated to philosophy they are the result of a cultivated understanding of our relationship with color. We clearly have strong ties to color. By examining the

nature of color, we can thus discover a great deal about ourselves. Though in this paper I seek to answer the question: “What, if anything, is colored?” In doing so I hope not only to reveal the nature of color, but also our relationship with it and how we can use this relationship to learn about ourselves.

A Brief Summary

In this paper I argue that color does not exist anywhere, physical or non-physical. This will amount to what I call a “double error” theory of color: Not only are we mistaken in our ordinary belief that physical objects are colored, we are also mistaken in believing that we perceive colors at all.

I begin with a discussion of our usual ideas about color. We usually think of color in the following way: color is a property of objects and/or light, it is simple and unanalyzable, and its nature is revealed to us with ordinary observation. These beliefs are then compared to rather more complex theories of color.

First, I examine the strengths and weaknesses of color-object realism, the view that color is a property of physical objects. Ultimately this theory fails to capture the importance of light in determining color and thus is discarded. Next, I examine color-light realism, the view that color is a property of light. This theory has a lot of support from physics and chemistry, but it too has fatal shortcomings, namely an inability to account for variation in color perception between perceivers. If you and I can both look at the same rose and the light it reflects and potentially see different versions of what we both call ‘red,’ then color cannot be a property that is really in the world, in either physical objects or in light.

I then consider color as a property of perceivers. This seems to hold up very well, as cellular processes explain many of the behaviors of color. For example, that there are three primary colors is thought to be the result of the three types of color sensitive cells in our eyes. However, many philosophers are unsatisfied with this approach to color and assert that our experiences of color cannot be reduced to brain activity. As such I next compare color as a property of the brain to color as a property of mind.

Colors cannot literally be in the brain, though they may be the result of brain activity. If this is the case colors must either not exist anywhere, or exist somewhere non-physical. Non-physical color, in the form of color experiences, (what we might call color qualia) is discussed next. I argue this conception of color is deeply problematic. Though I do not deny the existence of qualia, I do suggest that colors cannot exist as qualia.

I then conclude that color does not exist anywhere. There is simply no place left for it. Color is not a property of light, of objects, or of physical perceivers, nor of their potentially non-physical experiences. This may seem incredible, as we still seem to experience color. This is the question I turn to next: If colors do not exist, what is the nature of our color experience, and how can we have color experiences without colors?

It turns out that color experiences are not nearly as simple as we imagine them to be. They are not the simple observation of properties of our environment or of our minds. Instead color experiences are shown to be the complex product of our memories, language, knowledge, and other cognitive and sensory processes. Rather than speak of color perception or experience, I suggest we should speak of color judgments. I then demonstrate the complexity of these color judgments through numerous neuroscientific studies.

In short: Color perception – or rather – color judgments, without color.

Though color nihilism, as this theory of color is sometimes called, is not entirely new, the version defended here is novel both in its thoroughness and, in particular, in its incorporation of scientific evidence to provide a serious treatment of color experiences, even in the absence of color. It aims to provide a foundation towards future research helping to blend seamlessly the philosophical and the empirical approach to the study of color.

A Note on Structure

This paper is long and winding, but not without good reason. If I am to truly convince you that color cannot exist anywhere I must present thorough treatments of the problems associated with different color theories, ultimately seeking to dispel all of our usual beliefs about color.

Each chapter presents a narrative of a particular color theory. This begins with an outline of the theory in question along with supporting information. This is often quite detailed, as removing color is a very tricky business. Next, problems with these theories are presented along with potential responses to them. However, ultimately, these responses are insufficient to retain color anywhere at all.

A Note on Figures

All figure sources can be found on pages 124-129.

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Figuratively, colour has always meant the less-than-true and the not-quite-real. The Latin colorem is related to celare, to hide or conceal; in Middle English 'to colour' is to embellish or adorn, to disguise, to render specious, to misrepresent. Colour, then, is arbitrary and unreal.

– David Batchelor, *Chromophobia* [4]

CHAPTER 1: The Folk Conception of Color

ABSTRACT: Most people have some commonsense beliefs about what color is. These usually go something like this: color is a simple, intrinsic, property of objects or light whose nature is revealed to us with simple observation. These ideas are collectively termed the folk conception of color and provide a useful starting point for examining color in a more serious context. In this chapter, common folk beliefs are discussed.

Section 1: Folk Beliefs About Color

Color is a pervasive feature of most people's experiences. As such most people have some basic intuitions or opinions on what they think color is. These opinions are collectively termed the folk conception of color, and serve most people just fine in their simplistic interactions with color. These notions of folk color, though supposedly derived from common sense, actually require a good deal of careful 'unpacking' and clarification before an analysis of their implications can be undertaken. Several philosophers have attempted this task, notably Mark Johnston, a prolific philosopher of mind, ontology, and ethics, has provided a detailed account of what constitutes folk color.

Johnston describes folk beliefs as a 'cluster property.' This is useful as color beliefs do not constitute a rigid set, but rather, several recurring ideas about color that vary somewhat between individuals.[5] These rather fluid beliefs usually contain ideas along these lines: Color is a simple property. It inheres in objects or volumes, and importantly, is a real property that is out there in the world. Other beliefs usually include: That colors endure over time, that their nature is revealed to us with simple observation, and that colors are 'unified.'

These notions of folk color are by no means exhaustive, [6] and as C. L. Hardin, one of the most important contributors to the philosophy of color, has aptly pointed out, "Perhaps no set of beliefs can adequately describe what is termed folk colour." [7] As such, the discussion of folk color that follows is intended primarily as a tool for exploring some basic problems with color that will later be expanded upon.

Section 2: The Content of Folk Beliefs

Section 2.1: Simplicity

The idea that color is a simple property is historically well supported not only by common sense but also by a number of respected philosophers; McLaughlin,[8] Russell,[9] Moore[10] and others have all taken colors to be simple properties. What simplicity means in this context varies slightly depending on who is making the claim.

Despite small variations between different versions of simplicity, the general notion of simplicity, common to these various conceptions, is that simple properties are those that lack components and are thus unanalyzable or brute. Such properties cannot be subject to external analysis and essentially appear as they are. This seems to be the case for our usual experiences of colors.

But what does it mean for colors to be unanalyzable?[A] For example, is it problematic that orange seems to be made up of red and yellow? If colors can be mixed then they have components, and seem non-simple.

Though something like orange might have components, red and yellow are themselves simple. Thus reducing orange to red and yellow does not serve as a satisfactory analysis of orange as no non-simple properties have been uncovered. In this way color mixing is consistent with simplicity, as long as the components of the mixture are themselves simple, as red and yellow seem to be.

Section 2.2: Unity

The idea of unity, as Johnston terms it, is the idea that colors have particular relationships to each other, namely that red is more similar to orange than either color is to green. It further suggests that colors are describable in only colored terms. Though colors may have serious relationships to one another, they are not comparable to non-colored things.

[A] The question of what constitutes an analysis is not discussed here in detail, as it represents a heated and enduring area of philosophical debate. For an introduction to the literature on this topic, see The Stanford Encyclopedia of Philosophy’s entry on analysis.
<http://plato.stanford.edu/entries/analysis/>

Unity might seem at odds with simplicity. If colors have particular relations between them, this might seem to represent an analysis. This is directly analogous to the case of color mixing discussed in the previous section – because colors are not compared to anything non-simple no analysis occurs as none of the properties in question can be broken down or analyzed in any way.

Unity thus bolsters simplicity by suggesting that colors seem to be a particular sort of thing that is importantly different from other things that we encounter. *(A notable exception of this is synesthesia, or sensory mixing, discussed in chapter 6.)* If color could be meaningfully compared to other non-simple properties, an analysis would result and both unity and simplicity would no longer hold.

Note that unity does not mean that colors cannot have any relationships to other things. For example I might say that my favorite color is orange. This is consistent with unity as it is not a *comparison* between color and something else, but rather an external, causal, relationship between color and myself. Color may retain unity while be related to other things so long as these relations do not constitute explanations of the intrinsic nature of color.

Section 2.3: Revelation and Perceptual Availability

Revelation is considered by some philosophers[11] [12] to be a central tenet of folk color and generally means that we gain full and immediate knowledge of the nature of color with simple observation. This 'simple observation' is taken to mean merely looking at color with the unaided eye.

Revelation is sometimes conflated with an idea called perceptual availability. Indeed perceptual availability may subsume the concerns of revelation, as it seems to be a more specific treatment of color epistemology. Perceptual availability is the idea that my belief that an object in the world is yellow is vindicated because my perceptual apparatus tells me that it is. Johnston phrases this as: "if external things are canary yellow we are justified in believing this just on the basis of visual perception and the beliefs which typically inform it."[13] This essentially means that belief is vindicated or explained if you

are a sufficient perceiver and are observing an object in conditions that allow you to sufficiently perceive it.

That you have good reason to believe objects are colored comes down to a belief that you are not being vastly deceived in your normal observations, a la Descartes' demon.[B] This is perhaps unsatisfying after one has experienced various color illusions and the 'mechanisms' or explanations behind them. Despite this, perceptual availability is considered to be an apt folk belief. This is because even in the face of robust color illusions most people will not come to the rather dramatic conclusion that they are vastly deceived in their general perceptions. To provide a perhaps more convincing example: when people view spatial illusions (for example that two lines of the same length appear to be different lengths) they don't infer that space is an illusion. These illusions, of both color and space, are treated as exception to normal, veridical perceptions of the world.

Section 2.4: Color Location

Any satisfactory theory of color will point to a location for colors to reside. Folk theories (and indeed most other color theories) generally place color in objects or in light. Alternatively, color might be viewed as arising from the interactions of these locations.

Objects represent the most intuitive and common location for color. This is evidenced by the way most people talk about colors; namely describing objects as colored. This position has substantial and indeed growing support, notably Gert,[14 15] McGinn,[16] and Campbell [17] all support versions of color-object realism. Often the surfaces of objects are ascribed color-properties. These take a number of different forms, such as molecular structures and electron behavior, as in gemstones, or of layers of materials, as seen in the feathers of birds.

Despite the intuitiveness of objects as a location for color, this idea has met with a significant amount of resistance, especially since 1704, with the publication of Isaac

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[B] This is a notion from *Meditations*, and suggests that some nefarious agent who is "as clever and deceitful as he is powerful, who has directed his entire effort to misleading me" exists. This is in line with Descartes global skepticism. It suggests that our usual perceptions are vastly and continually mistaken. Though Descartes ultimately rejects this idea it has had a profound impact on philosophy to this day.

Newton's *Opticks.*[C] Newton's work with prisms more clearly characterized color, and importantly, introduced the idea of colored light. Today, when color is put into light, it is usually characterized as dependent upon wavelengths of light. These wavelengths have particular properties, and color is thought of as one of these properties or as simply identical to wavelength.

Color as a property of light garners tremendous support from the sciences, namely physics and chemistry, and increasingly from common sense. That this idea is entertained as a folk notion is largely a function of the growing prevalence of knowledge about these subjects. Furthermore, color as a property of light is often very consistent with folk ideas, largely because light, and thus color is considered to be a real property of the world.

Color location, perhaps more so than other folk notions of color, is quite variable. Each of the options mentioned here appeals to a particular brand of common sense. In chapters 2 and 3, the particular relationships between color-object, and color-light realisms and folk ideas about color as discussed in more detail.

Section 2.5: Enduring Color

The idea that light is important for color is not a new idea, and refers us to another key folk belief, namely that colors are relatively endurable over time. For example: If I turn out the lights the green apple that I am holding can still be felt, presumably this means it is still there. If colors are properties of the object, and nothing about the apple was fundamentally altered by turning out the lights, the apple is still green, despite no longer appearing to be green.

Alternatively, if you consider light to be the seat of color, the apple might never have been green, the colored light it reflected just made it appear green. Thus when the light is turned off the colorless apple remains uncolored, it just fails to reflect light and its uncolored-ness is vindicated by its appearance (or lack thereof). This notion of color might not seem consistent with enduring color, as colors vanish when the lights turn off. However, if color is seen as a property of light, this is unsurprising. We should expect

[C] Though Newton seems to embrace a form of color dispositionalism.

colors to endure only as long as light does. Therefore color can be viewed as enduring under color-light realism, albeit in a modified way.

Section 3: Folk Ideas and Color Theories

Section 3.1: Confused Folk Theories

Though folk beliefs provide a useful starting place for a discussion of color, there is a reason they are termed 'folk beliefs.' Many philosophers find folk theories trite, overly simplistic, or downright confused. Paul Churchland, (an important voice in Neurophilosophy) for example, is an eliminative materialist: he asserts that the various folk beliefs we hold about philosophy of mind are vastly in error. When we come to understand neuroscience more than the tiny amount we do currently, Churchland believes these various folk conceptions will evaporate.

Even if one is not willing to go as far as Churchland does, folk theories are still regarded as non-serious, or flawed. This may turn out to be the case, but the point of using folk ideas is to develop a clear basis for what we mean when we talk about color and then to compare this to other theories of color. In exploring this relationship, it may be the case that only some aspects of folk theory are carried into a rigorous scientific or philosophical treatment of color.

Section 3.2: Utilizing Folk Theories

Though different theories redefine color in particular ways, they usually relate to folk color in some meaningful way, almost always including at least a few aspects of folk color that were discussed above.

In the following chapters, three common theories of color are discussed: color-object realism, color-light realism, and color 'in the head.' Each of these conceptions relates to folk color to various extents, and as such they share important commonalities. The idea that folk theories are 'confused' might be remedied as these theories more rigorously define color and pick only the sensible aspects of folk theory. Folk theory as a parcel might be untenable, though aspects of it pervade almost all color theories.

What occurs when folk ideas are left behind entirely is the subject of chapter 6, wherein a double error theory of color is put forth. This suggests that color is so far removed from any aspects of folk theory as to be unrecognizable as ‘color.’ ‘Color’ as we typically understand it does not exist anywhere. This does not necessarily mean that ideas from folk theory are irreparably *confused*, but it might mean that they are irrelevant, or do not apply.

But before getting rid of colors, we must consider and understand some important theories of color. Color-object realism seems a natural starting point, and is discussed in the following chapter. This notion of color has the most in common with folk theory, and as such is considered the most intuitive explanation of color.

CHAPTER 2: Color in Bodies

ABSTRACT: Color is considered by many to be a property of objects. This is one of the oldest notions of color and is consistent with most of the ideas of folk color. In this chapter the general ideas of color-object realism, as well as its most significant problems, are discussed. Ultimately color-object realism is suggested to be inadequate in its consideration of color, as it fails to account for the importance of light.

Section 1: Color-Object Realism

Perhaps the most intuitive place to locate colors is in objects. Many folk theories espouse this idea, as do more 'serious' treatments of color. If color is a property of objects we should expect a number of things: That objects have a single true color, that this color is relatively constant or enduring, and if it is not constant there is a physical explanation. Let us call color-object realism the view that colors are intrinsic properties of physical bodies or objects. In this chapter a number of problems will be raised with this version of color.

A good deal of the ideas of folk color carry over into color-object realism, which views colors as perceptually available, simple properties that have unity. However, this notion of simplicity is sometimes discarded in response to problems raised with object color.

Many color-object realists also assert that color is an intrinsic property of objects, suggesting nothing outside the object determines its color. This notion has significant support. Notably, Armstrong,[18] Hilbert,[19] [20] and Ross,[21] all support slightly different notions of intrinsic object-color realism. Much of the impetus for treating colors as intrinsic to objects stems from considerations of common sense and a desire for our usual experience of color to be vindicated by (or to vindicate) deeper analysis of these experiences.

Color-object realism is a rather unpopular theory among color philosophers. However, modifications to it that attempt to maintain a positive relationship with common sense are somewhat prevalent. Most of these modifications of color-object realism are meant to resolve the various difficulties it often encounters. In the following section these problems will be explored, along with their potential resolutions.

Section 2: Why Objects? Problems and Resolutions

Many problems for color-object realism arise because its supporters have traditionally thought of colors as immutable constants, and attempt to deal with changes in viewing illumination, distance, etc. by writing off particular viewing conditions as somehow invalid and to be ignored. Though color-object realism appeals to common sense, many formulations of this color theory cannot adequately explain the problems that are presented below while maintaining the support of the folk notion of color.

Section 2.1: Color and Distance

When objects are viewed under a microscope or at great distance they appear to be different colors than when they are viewed 'normally.' For instance, when blood is viewed under a microscope it appears yellowish, though when the unaided eye views blood it appears red (Figure 01). Alternatively, mountains far in the distance often appear blue, though as one gets closer this blueness fades and the mountain appears to not be blue at all.

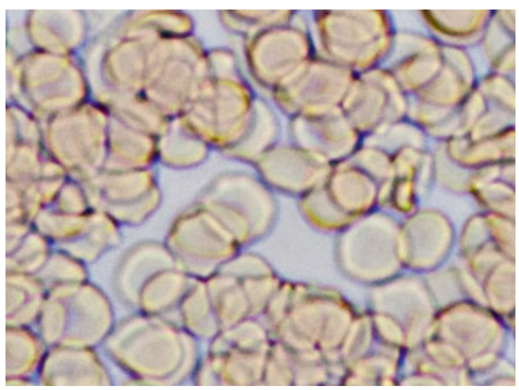

Fig. 01: Blood under 40x light microscope. The brownish discs are red blood cells.

A number of problems arise from these and similar situations. One problem is that the same object seems to have two different colors, and these colors are dependent not on features of the object, but how that object is viewed. This is problematic for many forms of color-object realism that assert objects have one true color, and further problematic because the viewer's perspective (namely how close or far away from the object they are) seems to be able to alter the color of the object.

This challenges notions of intrinsic color: If color really is a property of objects why it is that viewers and viewing conditions seem to alter object color?

Instead, color object realists assert that among the various viewing conditions and color changes they precipitate, only one of these conditions is the correct one. That is, only under this singular viewing condition is the real color of the object observable. This resolution should be obvious given the language used previously: suggesting that viewing objects from a great distance or under a microscope represents a departure from 'normal' viewing conditions. That some viewing conditions are privileged over others seems to create an epistemic problem, namely that we might not be able to know what the 'true' color of an object really is. This is an important concern, and will be further discussed in section 3.1.3.

Section 2.2: The Structure of Color

Another issue for color-object realism concerns the structure of colored objects. If we take an object and continue to divide it into smaller and smaller components, eventually we will run into pieces that are uncolored. This occurs largely because we stop being able to see colors, or objects at all, as our eyes can only see a finite amount of detail. (Though transmission electron microscopes now allow visualization of individual atoms this is decidedly different from usual vision, and the data produced are in black in white or in false color.)[22] This is a problem for color realism. It seems that if an object is of a particular, uniform color, all of the various components of that object, no matter how finely they are divided, should also be colored. If this were not the case it would seem that uncolored particles somehow make up colored objects.

Interestingly, this breakdown of properties is not unique to color. When things are broken down into small enough components they tend to lose their characteristic properties. For example the component atoms of water, hydrogen and oxygen, exist as gases at standard state,[D] while water is a liquid under the same conditions.

Armstrong, in his paper, *A Materialist Theory of Mind: The Secondary Qualities,*[23] attempts to use this to justify why colors seem to stop existing at a particular

[D] Standard state is 25°C, gases and liquids are pure and under 1 atmosphere of pressure.

point. He does so by examining the breakdown of properties that occurs when the fundamental parts of a substance are considered independently.

Armstrong asserts that a breakdown of properties, such as color, is acceptable if the properties of the substance can be attributed to underlying structural properties. He points to water, which is composed of hydrogen and oxygen and exhibits water-like qualities when these atoms are bound. However, these component atoms do not themselves exhibit water-like qualities, but rather, through their structural arrangement, cause water to have its observable characteristics.

Armstrong suggests that the same is true for color. When the smallest components of colored objects are examined their properties should, either through their structure or in other ways, demonstrate that they are importantly related to or involved in producing the color of that object. However, Armstrong fails to provide any indication of why this would be the case. Nor does he suggest examples to support this idea. Instead he asserts that we should only concern ourselves with the 'minimally visible' (Armstrong takes minimally visible to mean 'minimally visible with the naked eye') portion of an object, if these components appear colored then the object too should appear colored, and be considered colored.

Armstrong's response seems inadequate in that the minimally visible level of a colored surface (i.e. where color properties stop being visible) may vary from person to person. On the other hand the properties of water stop at a physically quantifiable level, namely when atoms are separated. Because color seems not to have underlying structural considerations, the way water does, this argument seems not to apply.

This is an even more robust formulation of red blood being made up of apparently yellow components. Here it seems that all objects that are colored are made up of fundamentally uncolored components. This issue is one that viewing conditions cannot resolve; instead it points to a fundamental structural problem with color-object realism.

However, a realist might respond to this concern by employing atomic emission spectra (an analytical technique in chemistry). In doing so color might be shown to have structural features in the same way that water does.

When a pure sample of an element is irradiated with a standard wavelength of light it will emit a characteristic series of colored lines, called an emission spectrum. Because each element has a unique emission spectrum, and elements differ from one another only in their subatomic characteristics[24] (i.e. electron configuration) it must be these invisible, structural characteristics that result in each element's unique, visible emission spectra. If this is the case color can be taken to have structural underpinnings just as water does.

Considerations of atomic emission spectra seem to resolve this problem of property breakdown for color. However, if we want to assert that color is an intrinsic property of objects we should be able to point to particular properties of objects that determine color. In the case of water, its properties are the result of electron configuration and atomic mass. However, no such property has actually been picked out for color; this structural appeal has merely suggested that physically quantifiable properties of color might exist.

Section 2.3: Rubies and Robins: The Disjunctive Problem

If there is a property of objects that determines color, as this previous section has suggested, we should expect that similarly colored objects have similar properties or structures that explain their similar colors. To explore this, let's examine a collection of red objects: rubies, robins, and roses, for example.

Rubies appear red because of their crystal habit, or arrangement of constituent atoms, namely Chromium, Aluminum, and Oxygen, and their electron orbitals, or regions of space of a particular shape around the nucleus of an atom where electrons are likely to be found.[25]

When light strikes these atoms their electrons become 'excited' and jump to a higher energy level. These energy levels have a particular amount (or quanta) of energy between them, thus the energy of the light which strikes these electrons must be equal to the energy change between energy levels in order for electrons to make this jump.

This 'jump' electrons make, is the absorption of light that falls on the ruby[E] particularly green and yellow light are absorbed, as they possess the right amount of energy to move these electrons.[26]

When the electron falls back down to its lower energy state light is emitted. However, some of this light's energy is lost as heat and is thus the emitted light is of lower energy than the incident light that excited the electron. As such, the light that is emitted makes the ruby appear red (this phenomenon of light emission is called luminescence).

It seems rubies are red because of electron movement and subsequent luminescence of red light. Roses, on the other hand, are red primarily due to the reflectance of red wavelengths and absorption of others. This is illustrated in figure 02. Light of a variety of colors hits the rose's surface; the rose reflects red light, while absorbing other colors of light. This selective reflectance causes roses to appear red.

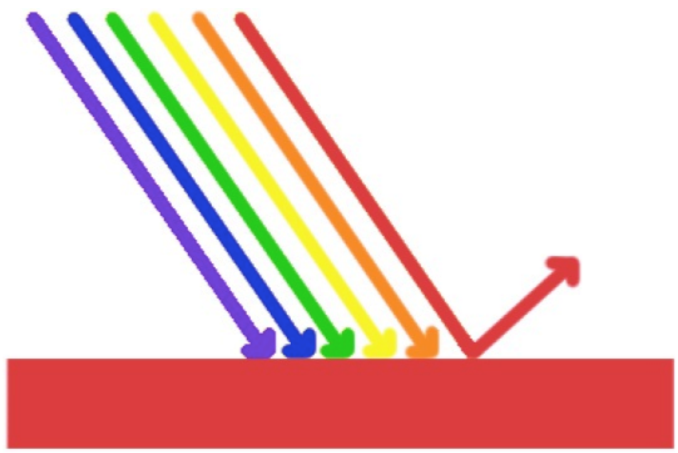

Fig. 02: Pigment selectively absorbing and reflecting colored light. Because red light is reflected the object appears red.

Robins are red for a combination of reasons, partially because of the same selective reflectance discussed above, but also because of structural elements in their feathers, called schemochromes. These are microscopic structures that interfere with the way light travels through and around them. This structural arrangement results in a phenomenon called iridescence, or colors that appear to change from different viewing

[E] Light that strikes an object is henceforth termed 'incident light.'

angles. This occurs because the surface of the object the light is striking is composed of several layers.

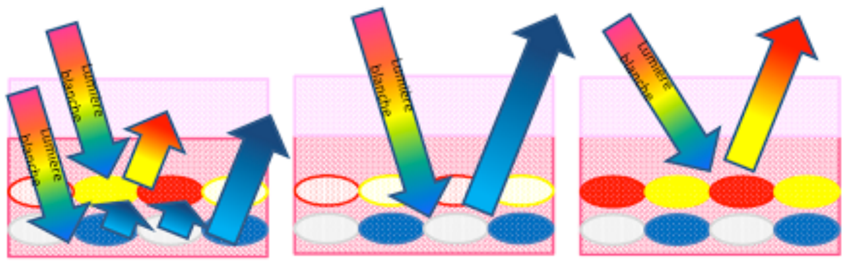

Fig. 03: Layers of schemochromes altering the way light is reflected and absorbed

Light travels through these layers at different speeds until it hits a 'bottom' layer where light is reflected back up. Because the light is travelling through these structures at different angles, as shown in figure 03, different colors appear, as shown in figure 04. The way this occurs is dependent on the wavelength and angle of incident light, thus as light travels through these different mediums it is either reflected or bent differently, causing different colors to be visible from different angles. This produces the shimmering or dancing colors iridescent objects seem to have.

Figure 04: schemochromes on *Chrysiridia rhipheus* (a butterfly) wing

These are only a few of the many ways objects interact with light and produce color; for a more extended treatment of this discussion see Hardin,[27] or Nassau,[28] who have enumerated the various sources of object color and come up with no less than 15 different options.

That there are so many different potential sources for object color is problematic for color-object realism. There seem to be no unifying physical properties of red objects that can be identified without an appeal to the common color of light that an object reflects. In all of these cases the notion of *colored light* has been central to the source of an object's color. Though the properties of the object no doubt influence the 'production' of this colored light, the unifying character of red objects is apparently a property of light, not a property of objects.

Section 2.4: The Object and Light Relation

Another problem for object realism is that objects seem to have different colors under different illuminations. This also challenges our idea that color endures over time.

Alexandrite, an aluminate of beryllium, appears to be two completely different colors under different illuminations. In sunlight it appears green, while under an incandescent light it appears pink. (Figure 05) But which of these is the true color of alexandrite? Some color realists might assert that both of these colors are legitimate colors of alexandrite; this option is discussed in section 3.1.4.

Fig. 05: A piece of alexandrite, illuminated by daylight (left) and incandescent light

This is a significant problem for color-object realism's idea that objects have one true color. Nor can we dismiss this as a unique property of alexandrite. Though it may exhibit a particularly vivid example of this illumination dependent color variation, it is definitely not the only case.

Some philosophers, such as Armstrong[29] have attempted to resolve this difficulty by asserting that the true color of the object is the one the object appears to have in sunlight. This is directly analogous to the aforementioned idea of privileging particular viewing conditions. In this case, instead of distance, the type of incident light needed to view an object's true color is in question.

Section 3: Deeper Problems for Color-Object Realism

It seems that color-object realism has a few problems to contend with. Primarily that objects don't seem to have particular properties that determine their color, and that the behavior of light seems too important to be discounted in the way that it is. Unfortunately, the solutions that object-color realism offers are unsatisfactory in responding to these concerns. Particularly troublesome are solutions that entail privileged viewing conditions.

Section 3.1: Viewing Conditions

When we look at objects we generally see them from a variety of distances, illuminations, etc., but it has been suggested that only a subset of these viewing conditions allow us to see the true color of objects. A number of problems exist in this designation of veridical viewing conditions.

Section 3.1.1: Vagueness: What Counts as a Viewing Condition

A sorites paradox seems to exist here. If only some rather close viewing distances allow us to see an objects true color, it is unclear at what point the viewing distance becomes unacceptable for viewing an object's true color. It might be suggested that when an object's color seems to be different than the color it has at arm's length that is the cut off point for true color viewing. However, it is vague how dramatic of a difference in color is needed for the object to be considered a different color and thus for the viewing condition to be a non-veridical one.

Differences in shades of a particular color are often so small as to be undetectable unless they are compared side by side. I.e. viewing a bright red, and then having that color shift to a slightly darker red might go unnoticed unless those two shades can be compared directly. An example of this is the sunset. The sky makes a very dramatic

transition from blue to bluish black, but the individual steps are often very small and are not noticed until the change has become dramatic in comparison to its starting point.

Fig. 06: Color gradient, at what point does red become purple?

Additionally, when a range of very similar colors is presented side-by-side it is difficult to tell where one color might end and another begins. Figure 06 demonstrates this. Though the left end of the figure appears purple, while the right appears red, the transition between them is so gradual it is difficult to find a meaningful point of distinction.

The same gradual color change occurs when objects are viewed at increasing distances. As objects get farther and farther away their colors change. However, there is not a point where a dramatic color shift occurs. It therefore seems difficult to point to a particular viewing distance and assert that the color viewed at that distance represents the true color of an object.

We now have two reasons for doubting the veracity of privileging viewing conditions. Firstly, because small changes in viewing conditions could cause a color change that would potentially go unnoticed unless there was an objective means to compare the two colors under different viewing conditions side by side (and even then it might prove difficult). And secondly, it seems difficult to point to a particular color and assert that it is the singular, true color, and not a small range of hues. It seems then that notions of one true color or one true viewing condition can at best be replaced with one true range. Unfortunately the limits of these ranges are very poorly defined. As such it renders this entire project dubious.

Section 3.1.2: Color and Vagueness

Not only is it difficult to discriminate between viewing conditions, but colors themselves might also be vague concepts. That colors seem to flow into one another seamlessly seems to make colors more vague than other apparently comparable physical properties. Physical properties are generally very strictly defined, for example the boiling point of pure water at sea level is 100 C. Any deviations from this standard are due to clear physical changes. For example, the addition of solutes, pressure changes, etc. all alter a substance's boiling point in formulaic ways.

On the other hand, color is not subject to such rigorously defined causes for the changes it undergoes. Furthermore, even color in its 'standard state' is difficult to define. Furthermore, the idea of standard state is essentially identical to the aforementioned idea of viewing conditions. These conditions turn out to be deeply problematic, and are discussed in section 3.1.3.

A pertinent example of the vagueness of color is in color naming. In figure 07, is the color presented orange, or red, or perhaps reddish-orange? Is reddish-orange meaningfully different from orangish-red? This may be a mere vagueness in color naming, and indeed there have been many attempts to analyze color (see chapter 4). However, as there are no particular properties of objects that colors consistently pick out, creating a rigorous analysis of color seems very difficult, if not impossible. Until these properties can be more clearly defined, colors will also continue to be poorly defined.

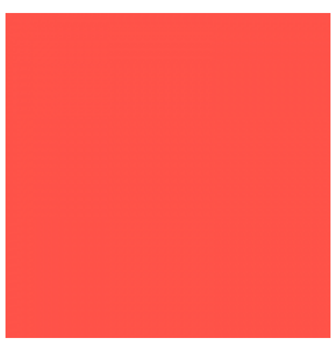

Fig. 07: What would you call this color?

Sorites arguments are notoriously dubious. However, problems in the relation between viewing condition and veridical color also exist here. Because viewing condition

and color are dependent upon one another, and both seem to be vague, there does not seem to be a good way to determine either. If only one was vague, the other could be used as a determinant. However, because both are vague, the realist is left at something of an impasse in defining either concept adequately.

This problem applies not only to viewing conditions concerned with distance, but under different illuminations, etc. This obviously doesn't remove all impetus for designating some viewing conditions as veridical, though it does cast some doubt on the practice.

Section 3.1.3: What Makes one Viewing Condition Better than Another?

One of the biggest concerns for appealing to viewing conditions is the question of how we can decide which is the 'true' viewing condition. It has already been suggested that viewing conditions are difficult to separate from one another. However, even if viewing conditions were very clear, deciding which out of the myriad of possibilities allows one to see an object's true color is also problematic.

In regard to illumination, many philosophers, such as Armstrong, have asserted that an object's true color is visible under sunlight. However, this choice is arbitrary and poorly defined. Why choose sunlight over other sorts of light? Objects are just as frequently viewed under incandescent light, or other types of artificial light as they are under sunlight. Furthermore, Armstrong must be clearer in his designation of sunlight; but this seems very challenging given the multitude of options. For example, sunlight in Alaska is dramatically different than sunlight in the tropics; and the sunlight that reaches Pluto is even more radically different, to say nothing of other suns in other solar systems.

Again, this issue also applies to adjudicating between distances; why is arm's length the best choice for viewing color? It seems just as easy to imagine that human vision might have instead developed to be microscopic or telescopic; in which case we would presumably choose a different veridical viewing distance.

This attempt to designate veridical viewing conditions reveals how anthropocentric these models of color are. Furthermore, in trying to solve problems for

object realism they remove its commonsense foundation. This will be further discussed in section 3.1.5.

Section 3.1.4: Multiple True Colors

A possible response to this issue might be to instead view objects as possessing a variety of true colors. As mentioned above, one of the main reasons color realisms have such serious issues is because they staunchly assert that each object has only one true color. Thus it would seem avoiding this point would resolve a number of key problems.

The issue here is that no properties of the object are actually altered when it is viewed in different circumstances. It was previously stated that if color is a property of objects we expect variation in color to be determined by variation in the object. The object is not itself altered by changes in viewing conditions, but its color is. Thus color doesn't seem to be intrinsic to the object.

Color-object realism requires that some physical property be identified with color. However, if color appears to vary, while physical properties of the object do not, this points to a deep problem for color-object realism as it would seem things aside from the unvarying object are important in determining color. Given the importance of light, as demonstrated in sections 2.3-4, it might be suggested that light is the culprit. This admission comes at the expense of intrinsic color-object realism, as color can no longer be identified with properties of objects alone.

Alternatively, a given object has a multitude of physical properties; instead of searching for a single property of objects to identify as color, many of these properties might contribute to the color of an object. That objects seem to change color might be attributed to changing interactions between these properties of the object.

Unfortunately, even treating multiple properties of objects as colored falls short; that colors are not visible in the dark remains unaccounted for, and changing illuminations still alter the color an object appears to be. Alternative responses to this problem suggest that object's react in particular ways to particular viewing conditions. Color dispositionalism argues something similar, suggesting that objects merely have a disposition to appear colored when adequate perceivers view them under adequate

conditions. This view does represent an important move in color philosophy, though evaluating it properly is outside the scope of this paper.

Section 3.1.5: Pervasive Error

A significant motivator for realisms is that they are vindicated by common sense. Unfortunately, in privileging particular viewing conditions this appeal to common sense loses a great deal of its strength.

If only a small subset of viewing conditions is actually accurate, the vast majority of viewing conditions must result in error, thus a significant part of our observations are actually incorrect. This is contradictory to the common sense view that we are generally correct in our observations. Though realisms might be able to respond to these differences in viewing conditions, it comes at the price of support from common sense.

Section 3.2: Color and Light

To return to the importance of light in color, it seems color-object realism fails to recognize the significant contribution of light in the production of color. In attempting to find a property of objects that explains color, the behavior of light becomes more important than any feature of objects. It appears that, similarly colored objects only appear similarly colored because of properties of light, not of objects (as per sections 2.3 and 2.4).

Another issue that color object realisms have to contend with is whether or not objects still have color in the dark. If colors are a property of objects it seems they should retain their colors in the dark, as other properties of objects, such as shape, definitely persist. The problem is that my shinbone can easily determine that my coffee table still retains its sharp edges in the dark, but there isn't a comparable way to determine if its colors persist.

There is a difference in our access to color and to shape that prevents me from accessing color in any way when I am in the dark. This access is cross modal for shape; it involves both my sense of touch and vision. However, color is only accessible with one sense. As I cannot access color there is no way for me to determine if it is still there or

not. This suggests an inconsistency with folk theory and color-object realism, as it seems colors do not endure in the absence of light.

This again highlights the importance of color in light. Color importantly influences light, as aptly demonstrated by alexandrite's dramatic color change. Furthermore, light seems to determine color in ways the structural properties of objects do not. That colors can't be seen in the dark further suggests that light is more important to color than color-object realists have given it credit for.

In the following chapter, an alternative to color-object realism is presented; namely color-light realism, or wavelength realism. This alternative is able to answer the various problems associated with color-object realism, as it considers color to be an intrinsic property of light.

CHAPTER 3: Color in Light

ABSTRACT: Given the various problems with considering color to be a property of objects, some philosophers instead consider color to be a property of light. This resolves a number of difficulties from color-object realism, though it also has its own problems. In this chapter, the basic tenets of wavelength realism are discussed, as well as its various problems.

Section 1: Wavelength Realism

The most common form of color-light realism is wavelength realism, which asserts that color is identifiable with light's property of wavelength. This idea is embraced by physics as well as many other sciences and seems a likely alternative to color-object realism. It is important to note that this version of color-light realism views color as intrinsic to light, not merely importantly dependent upon properties of it.

Visible light is a part of the electromagnetic spectrum (EMS). This spectrum describes the range of possible wavelengths with which electromagnetic radiation can propagate. Electromagnetic radiation is emitted from charged particles when forces act on them and cause them to accelerate. Figure 08 shows how light fits into this larger electromagnetic spectrum that extends from gamma to radio waves and beyond.

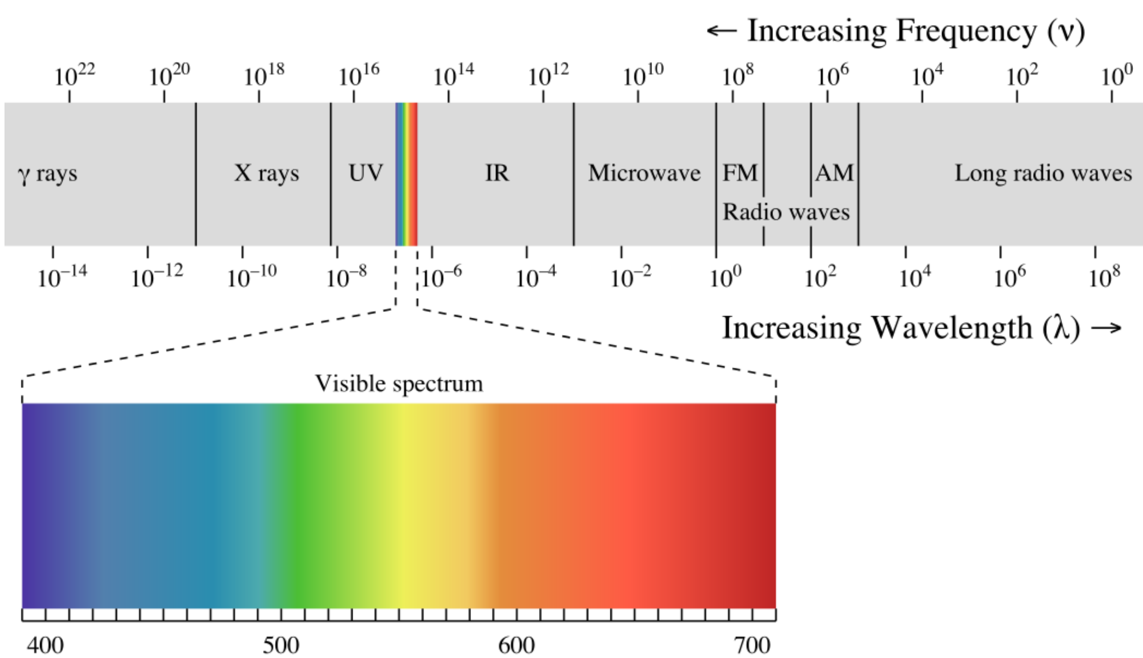

Fig. 08: The range of electromagnetic radiation, with close-up on the visible region

Note that visible light is only a tiny fragment of this spectrum, from about 380 to 750 nm, though these values are somewhat variable. Within this segment, light changes color from violet (380nm), through the spectrum to red (750nm). Colors are often defined as wavelength ranges within this spectrum, for example light with wavelengths between 750nm and 640nm are typically described as red, from 640-590nm as orange, etc.

Wavelength realism adheres to the EMS as a guide for colors, namely that light is merely electromagnetic radiation, and particular color is identified with the wavelength of this radiation.

Section 2: Wavelength Realism and Folk Color

Wavelength realism adheres to some aspects of folk color, and as such does appeal to common sense in many ways. However, it does also represent a departure from many ideas of folk color.

If color is wavelength then it is no longer a simple property. Simple properties are those that defy analysis. However, under wavelength realism color can be quantitatively analyzed in terms of wavelength composition. Additionally, because wavelength and frequency determine energy, colors can be said to have particular energies associated with them. Now anything quantifiable in energetic terms can also be compared to color in some sense. This also represents a problem for unity, as many non-colored things can be measured energetically.

Unity also has other problems under wavelength realism. When color was considered to be a rather vague property of objects it could not easily be compared to non-colored things. However, if color is wavelength it can be compared to other portions of the EMS, which are not colored. It is now meaningful to say radio waves are more similar to red than they are to blue.

It seems that colors also lack perceptual availability. When we look at objects, they appear to have color; if color is actually in light this is very misleading.

The notion that colors endure over time is potentially preserved from folk theory in wavelength realism. In folk theory this is meant to suggest that colors persist even

without human observation and remain constant overtime. In color-object realism this notion was problematic, as it is unclear at best if objects retain their color in the dark, and objects' colors seem to change based on illumination, viewing angle and distance without any corresponding change in the objects' properties.

If color is considered a property of wavelength, it can be seen as enduring, albeit in a somewhat modified way. As long as light is present, color is also present. That objects' colors appear to change is also due to changing properties of light. Illumination changes represent an obvious case, while changes due to distance can also be explained due to the diffraction of light over large distances.

Despite leaving behind many aspects of folk theory, wavelength realism preserves the important notion that colors are real properties of the world. Furthermore, as wavelength is a rigorously defined concept in physics and chemistry, this rigor can thus potentially be applied to color. This is a significantly better situation than color-object realism's assertion that color is some vague property of objects, especially given the disjunctive problem that results from these properties.

That color is a real property is perhaps the most important notion from folk theory, and by preserving it light realism is able to appeal to common sense despite its departure from other folk ideas about color. Despite color-object realism's firm hold on folk beliefs, it fails to explain color adequately. Almost every problem within color-object realism was ultimately rooted in its failure to account for the behavior of light. As such, considering light to be the bearer of color solves most of these problems immediately, while maintaining a hold on common sense. It seems wavelength realism is all in all a better solution, yet it has its own problems.

Section 3: Problems for Wavelength Realism

Section 3.1: Specific Interactions of Light and Objects

A significant problem for object color realism is the apparent importance of objects in determining color. Here, interactions of objects and light are discussed, followed by specific problems they pose for wavelength realism.

Surfaces and light can interact in a number of ways: surfaces may reflect, absorb, transmit, scatter, or refract (or some combination thereof) incident light. Reflection is the case discussed with roses in section 2.3 of chapter 2; incident light strikes the object, and red wavelengths are selectively reflected, while other wavelengths of light are absorbed. Absorption of light simply means that the energy of the light is conferred to the surface it strikes, as black objects absorb almost all of the light that falls on them they often feel very warm due to the energy transfer that occurs. On the other hand white objects reflect most incident light, and often feel cool even in bright light.

Fig. 09: Selective reflection and absorption of incident light

Refraction is what occurs when light enters a material, for example, a prism, which has a different refractive index, or propensity to bend light, than does air. Refraction causes a slight change in the angle of incident light. In the case of prisms this causes a separation of wavelengths, in other media this refraction may result in something called scattering. Scattering is simply refraction that occurs many times in various, disorderly directions. An excellent example of this is Rayleigh scattering, which causes the sky to appear blue.

Transmission is what occurs when light passes through an object without its wavelengths becoming scattered; this is what occurs in the transparent film case that will be discussed in the following section. Objects that are transparent allow a clear view of all the objects behind them. On the other hand, translucent objects scatter light to some extent, causing a blurring of the objects behind them. Opacity and transparency are determined by how much light is scattered as it passes through the object.

Section 3.2: Light and Objects

That light and objects interact is not itself a problem. Though objects might alter light, it is still properties of light that determine what color we see. However, if light really is colored then it seems odd that we don't ever see colored light alone; we only see colors when light interacts with objects.

For example, when I shine a flashlight I do not see the actual beam of the flashlight until it interacts with an object. In cases where the beam appears in the air we are not seeing white light, but rather we are seeing tiny particulates in the air that the light is reflecting off of. Nor is this unique to white light; the same situation arises if I put a piece of transparent red film over a flashlight, this causes the emitted beam of light to consist of only red light.

This is a strange problem for color in light, as the light travelling from the flashlight beam has all the properties that wavelength realism requires for something to be considered colored. Despite this it does not appear colored until it strikes an object.

Other examples where pure colored light seems to appear also turn out to be the interaction of light and objects. Rainbows for example are the result of particles, namely water droplets, causing light to refract. The sky might also seem like a possible case, however it is blue due to the interaction of light with particles in atmosphere, called Rayleigh scattering.[30]

Even when a light, like a flashlight or laser is shone directly into one's eyes pure light is not perceived. Instead the source of the light is observed. When you shine a light directly into your eyes a very bright patch is visible and it might be tempting to call this pure light. However, what you are actually seeing is the filament of the bulb.

The commonality between all of the provided examples is that light must first interact with an object before it can be considered colored. Furthermore, without delving into an intense discussion of controversial physics, light is considered by some[31] to behave as both a particle and a wave. This line of questioning will not be explored here, but perhaps light is just a rather strange sort of object.

That color in light is apparently invisible without objects is very problematic. How can it be that color really is a property of light if we can never see it without objects? Color-light realism may have been inadequate in its dismissal of light, but it appears wavelength realism is equally problematic in its dismissal of objects.

It seems that we cannot see color in light without the presence of objects, but this is just one of many problems for wavelength realism as the entire idea of 'light' turns out to be far less salient than it initially appears.

Section 3.3: The Continuous Spectrum, Is Ultraviolet a Color?

Though wavelength is rigorously defined, and light and its properties are talked about a lot, light itself is actually a quite poorly defined concept. Light usually refers to the portion of the EMS that we can see, thus the term *visible* spectrum. The lack of clarity in defining light stems from this notion of visibility; the upper and lower bounds of what constitutes visible light can actually vary quite significantly from person to person.

A particularly interesting case, which illustrates the ambiguity of 'visible light,' involves the perception of ultraviolet. Notice that just to the left of the visible spectrum (in figure 08) ultraviolet wavelengths exist. A number of people who have received artificial corneas (the outermost layer of the front of the eye) are actually able to see ultraviolet.[32] This is because 'natural' corneas don't allow ultraviolet wavelengths to enter the eye, whereas these artificial corneas do.[33]

Is ultraviolet really a color? Let's examine our criteria for color and its relationship to light. Light is the portion of the EMS that is visible to us, and each wavelength within this visible area is identified with a particular color. Thus ultraviolet meets both of these criteria: it has a particular range of the spectrum it is associated with and it is visible (at least to some people), so it should apparently be considered both light and a color.

However, this reveals something very important about color in light, namely that its characterization is utterly perceiver dependent. If ultraviolet were not perceived by anyone it could not be called a color. We determine if something has color by looking at it, if it appears colored it is called colored. This is worrisome, because if human color

perception plays an essential role in determining what is and isn't colored, then asserting that color is really out there in the world becomes more challenging.

Nor is there some recourse to the visible spectrum that will help more clearly define color without making it entirely perceiver dependent. The EMS exists as a continuum of wavelengths. In examining the character of these wavelengths there is nothing that distinguishes the visible spectrum from the rest of the spectrum. "Light, visible and invisible, consists of a uniformly graduated series of wave motions or energies. There is nothing to distinguish one part of the spectrum from another save the difference of wavelength."[34]

There is no sudden change in EM radiation that occurs when it becomes visible. Instead a gradual change in wavelength occurs as we pass through the spectrum. Without perceivers this portion of the spectrum is just like any other. Outside of perceivers, the visible spectrum seems to be just an arbitrarily selected portion.

Furthermore, other animals see far into the UV wavelengths and even the infrared range. This means different animals have different 'visible spectrums.' (For an example of this see section 3.1.1 of chapter 4) To push this point even more, it seems possible that the entire breadth of the EMS might be visible to some kind of alien perceiver who sees radio, cosmic, and gamma wavelengths in the way we see the arbitrary part of the spectrum we have designated as visible.

It seems possible then that the wavelength realist might assert that the entire EMS is indeed colored; it just doesn't appear to be colored to human perceivers. This seems like a very strange move, and is one that runs contrary to folk ideas about color. If something does not appear to us as colored, on what grounds can we consider it to be colored?

Indeed even if we are willing to allow that 'visible to humans' is a genuine property of light, the cut off points at either end of the visible spectrum (as mentioned above) vary from person to person. Indeed this is reflected in the conflicting end points different texts provide for visible light; ranging from 380nm-400nm on the lower end and 700nm-750nm on the upper end. It seems unclear how to decide where the visible portion

of the spectrum really ends, and thus what really constitutes the visible spectrum. This is troublesome for wavelength realism given its reliance on what are apparently vague, perceiver dependent properties.

Section 3.4: Problems with Prisms and The Weirdness of White

It seems then that wavelength realism is problematic not only in its failure to account for objects, but also its inability to account for the importance of perceivers in determining color. This next section provides further evidence to suggest that wavelength realism is insufficient in its considerations of human perceivers.

When white light travels through a prism, it bends in a particular way and results in a rainbow of colors (figure 10). This separation of colors from white light is largely due to Snell's law, which describes how light behaves when it travels through different materials. Namely, that light will travel at different speeds through different media. The way these speeds change is dependent partially on the wavelength, angle of the incident light, and the character of the material it travels through.

Prisms have a different refractive index – or propensity to bend light – than does air. This causes a slight change in speed among the incident wavelengths. White light is able to split into the visible spectrum because it is composed of the wavelengths that make up the spectrum. When these hidden different wavelengths strike the prism they bend slightly differently, resulting in wavelength dependent separation.

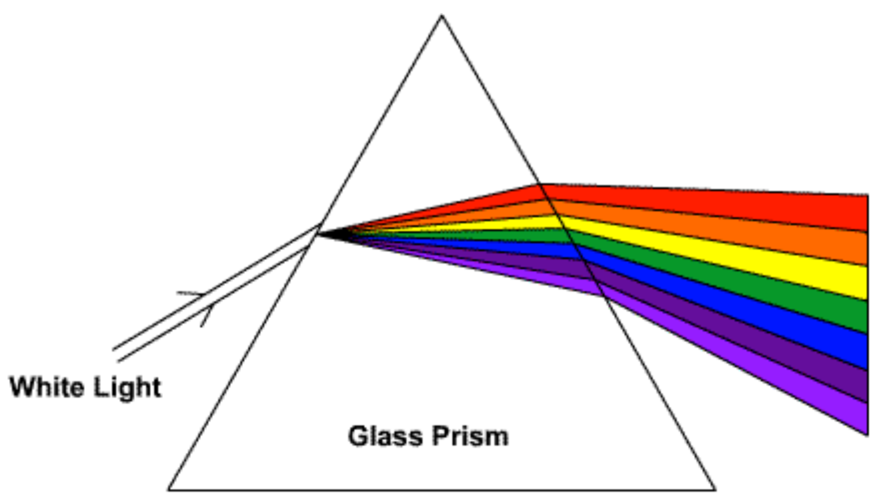

Fig. 10: White light travelling through a prism separates into constituent wavelengths

How can white light be made up of colored light? Recall that the criteria for colored light discussed above included that it possessed a wavelength of a certain range within the visible spectrum. White light possesses many wavelengths from the visible spectrum, yet because we do not see these wavelengths as color we do not call white light colored. The earlier point made about designating colors only when we see things as colors directly applies here.

That white light is made up of invisible colors presents a deep problem, and makes color either unintelligible or defined only by perceiver standards. Either colors exist in places we can never see them, and in ways that we can never verify, or they exist because a perceiver says that they do. Neither case is satisfactory for wavelength realism.

Given these problems with white light, a deeper look into its character follows. However, this raises even more problems for wavelength realism.

Section 3.5: Wavelength Fails to Explain Features of Color

White light is a combination of many different wavelengths, yet appears colorless despite its apparently colored components. White objects on the other hand seem more intelligible. Henceforth, white is used to refer to objects that appear white, whereas white light is used to refer to light that appears to be 'uncolored.'

The idea that we can't actually see white light poses still more problems for color in light. In *Remarks on Color* Wittgenstein poses a number of problems for color; particularly interesting are his treatments of films, namely white films. Wittgenstein asks, "Why is it that something can be transparent green but not transparent white?" [35] Completely transparent films may be of any other color, but a film that is white is always slightly opaque. (Black also presents an interesting case as transparent black films exist only as grays.)

In our response we have to be careful that we understand what is being asked here, and why it really is so problematic. Transparent objects are those that allow light to pass through them so that objects behind can be distinctly seen. Transparent objects are importantly different from translucent objects, sometimes called semi-transparent, which allow light to pass through, but not detailed images of the object behind them.

We may be fooled into thinking that we can imagine transparent white objects. However, these are always of diminished transparency as they are somehow milky or cloudy, there are no completely transparent films that also appear white.

Jonathan Westphal, a philosopher of visual logics and color, has offered an interesting treatment of this problem in his book, *Colour*.[36] He suggests that the reason white cannot appear colored is because white may only be a property of objects. This might seem odd but makes a good deal of sense given our conception of white.

White objects are those that reflect almost all incident light, absorbing or transmitting very little. The reason why we cannot have transparent white films now is more sensible, as transparent objects allow almost all incident light to pass through them. As white objects do the opposite we cannot possibly have a surface that both reflects and transmits almost all incident light.[37]

Westphal's suggestion is rather unusual; most people consider white light to be a confused mixture of wavelengths, and consider white objects to reflect an equally confusing array of wavelengths. This is an incredibly vague characterization and many surfaces and lights meet this rather arbitrary definition. By more clearly characterizing white, the intense relativity of color is revealed to a greater extent.

White light might instead be defined as light that does not darken an ideal white surface; this is far better than our initial white conception, but still we have a disparity between white light and white objects. White light isn't 'white' at all, but is rather a convenient name for a combination of many wavelengths that appears invisible. On the other hand, white surfaces are visible, and seem in line with what we mean when we call something 'white.' This is unfortunate for wavelength realism, as white seems to defy characterization by wavelength.

It is actually quite a good thing that white light isn't white in the way we speak of surfaces; otherwise we would see the world as if immersed in milky water or in a perpetual blizzard. But what is a white surface? An interesting phenomenon, the Gelb effect, demonstrates why the above treatment of white objects as reflecting a mixture of

wavelengths is insufficient. It also suggests that defining an ideal white surface is trickier than it might seem. As such appealing to such a surface might not be a very wise choice.

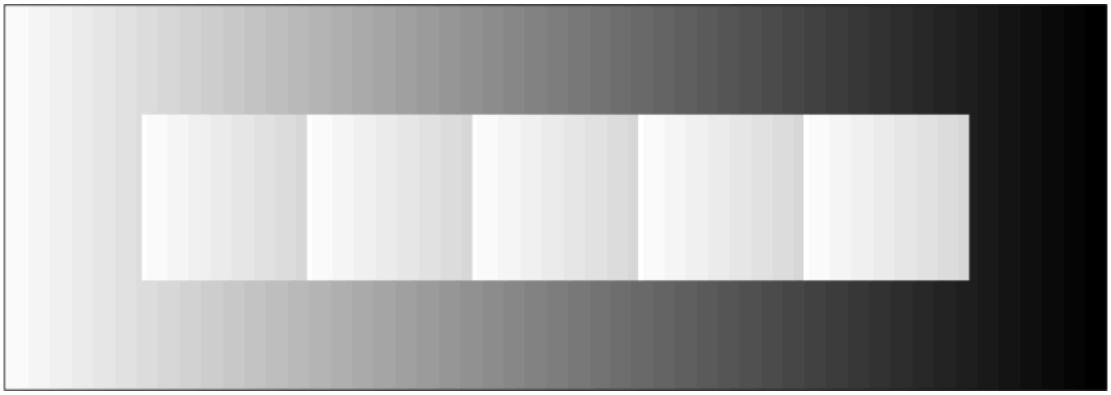

Fig. 11: Gelb or Staircase Illusion

Though these different patches of white in figure 11 appear to be different degrees of white, they are actually all the same shade. However because of the changing background they appear to be of varying shades of gray. (Each patch has a gradient, but in each case it is the same gradient, this is to make the illusion more robust.)

This demonstrates that to what extent surfaces appear white is not only dependent on the confused mixture of wavelengths they emit, but also on the relative brightness of surrounding areas. The material that surrounds a white object is just as important as the light scattered by the white object. The eye has some way of determining how much light is available by comparing the white surface with the area around it. If the background of a white surface also reflects a lot of light the surface appears grayer, while if it absorbs more light the surface appears whiter.

Westphal explains whiteness as "not connected with the quantity of light entering the eye but with the ratio of reflected and incident light, that is, what the surface typically *does* with the light." [38]

This illusion is robust and presents a deep problem for wavelength realism: Wavelength remains constant while color does not. In each section of the illusion the wavelengths of emitted light are identical. However, the perceived color differs depending on the brightness of its environment. It seems here that color is varying

independently of wavelength. The only potential explanation for this variation is perceivers.

Though the character of wavelengths differs for each part of the background, the wavelengths of the background and of the white gradients do not commingle; they are emitted from distinct areas of the image. The only place these wavelengths could potentially interact is within a perceiver who performs a comparison between the relative brightness of the backgrounds and the white gradients.

Furthermore, that environmental conditions alter color is not unique to white, indeed it seems to apply to many colors. As Eugene Delacroix, perhaps one of the most important French romantic painters, said, "I can paint you the skin of Venus with mud, provided you let me surround it as I will." [39] In the following section another robust illusion is considered, which employs brown and orange. As this illusion uses color it is perhaps more convincing than the previous illusion, given the strange nature of white. Though it demonstrates the same point – that color seems to be determined by perceivers.

Section 3.6: Pure Contrast

Previously, white was shown to be dependent largely on its environment. Another iteration of the importance of a color's environment (and thus of perceivers, who compare that color to its environment) is evidenced by brown and orange. That something appears brown or orange appears to be a function not of wavelength, but of environment. Because of this environmental dependency they are termed contrast colors. Contrast colors are those that appear to be radically different hues when they are put on backgrounds of varying brightness. Other contrast colors include olive green and yellow. Figure 12 (on the following page) demonstrates this occurrence.

The illusion this image produces is largely due to the influence of perceivers, who compare the luminance (how bright a particular color appears) of the surrounding area of the orange-brown squares to the squares themselves. This is directly analogous to the Gelb illusion. As the top of the cube has a surface that is very bright, the brown square appears comparatively darker and thus browner. On the side of the cube the same colored patch is relatively brighter than the surrounding area and thus it appears more orange.

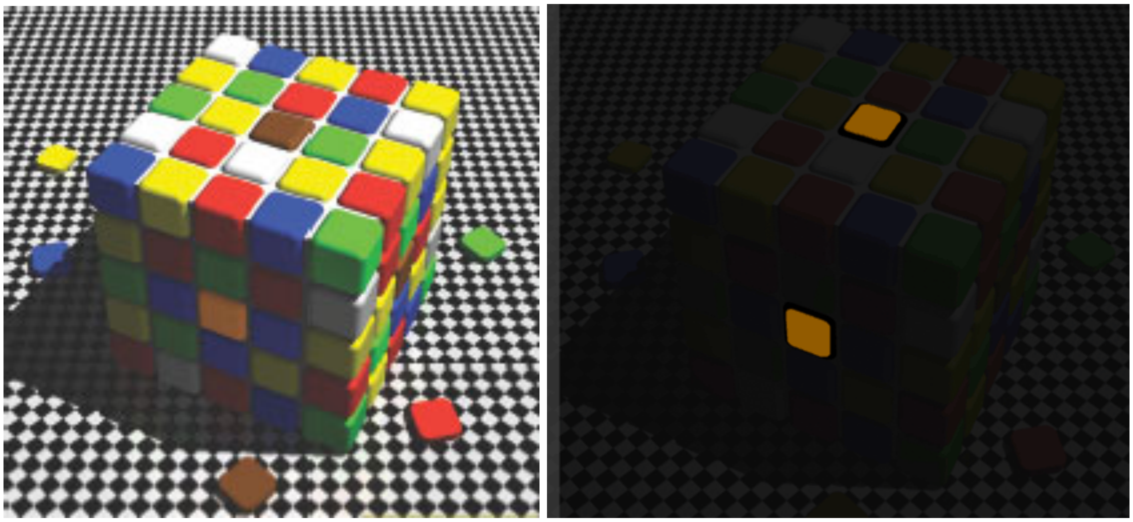

Fig 12: Contrast illusion; the bright orange square on the front side of the cube is actually the same color as the brown square on the top of the cube, as evidenced by image on right.

Again this comparison is not due to wavelengths alone, but rather because a perceiver compares wavelengths from the image. This comparison between target colors and their environment suggests that colors are importantly related to perceivers. It further suggests that color is not intrinsic to wavelength; as features of perceivers seem to alter color this means that colors cannot be explained entirely by properties of light.

Section 3.7: Sewing the Spectrum, Is Purple a Color?

Wavelength realism gives two criteria for color; that it is visible, and that it corresponds to part of the EMS. This presents an odd problem for purple, as it doesn't have a portion of the EMS designated to it. Purple is importantly different than violet; violet is considered a spectral color, as it is designated as the part of the spectrum between 380-420 nm. Violet is often less bright and more blue than purple, as shown in figure 13.

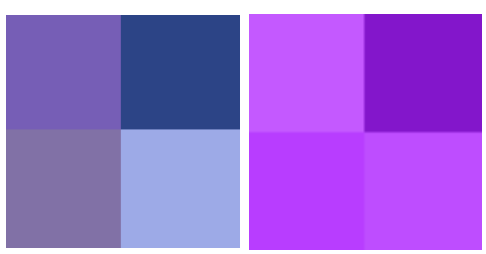

Fig. 13: Samples of violet on left, compared to samples of purple

Look at the progression of colors on the spectrum, from violet to red. This progression directly mirrors a color wheel; if we were to sew the red end of the spectrum to the blue we would seem to have our complete color wheel, however purple is conspicuously absent. Purple exists not as a particular portion of the EMS, but rather results when red and blue wavelengths overlap.

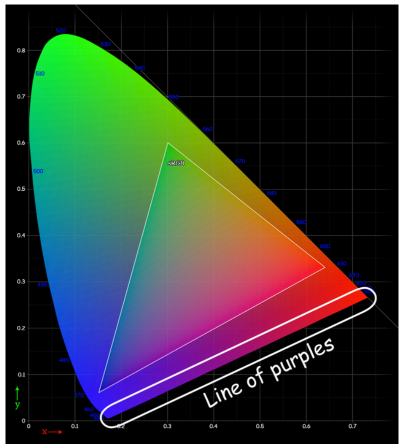

Fig. 14: CIE chromaticity diagram with line of purples

Figure 14 demonstrates this idea; this is a CIE chromaticity diagram. The rounded edge of the colored space, staring with violet corresponds to increasing wavelength as it goes up through green, yellow, and back down to red. Notice the abrupt line at the base of the figure, which represents the overlap of red and blue wavelengths, where purples occur.

Purple fails to meet the established criteria for color. Instead of existing as a particular wavelength it is instead a combination of wavelengths. This is itself somewhat of a problem, but it recalls an even larger problem involving spectral overlap and the mixing of color: that of metamers.

Section 3.8: Metamers

Given the previous considerations about the apparent shortcomings of wavelength realism it appears there is some motivation to revise our idea of color in light. However, a rather famous problem with wavelength realism has not been addressed yet. This is a serious problem for wavelength realism and one that further highlights the importance of perceivers in color.

This problem begins with the question: What determines color in light? Color is often misleadingly represented as 'dominant wavelength.' In other words, something is yellow if the majority of the wavelengths it reflects fall between 570-590nm. But if white light has taught us anything it is that color as wavelength is not as simple as it appears to be.

Newton, the first person to notice the unusual properties of color in light and bring them to public attention, has some interesting remarks about white light and this idea of dominant wavelength:

> The several Rays, therefore, in white Light do retain their colourific Qualities, by which those of any sort, whenever they become more copious than the rest, do by their Excess and Predominance cause their proper Colour to appear.[40]

The idea of dominant wavelength seems obviously true, and it is often the case that things that reflect predominately this 570-590nm area of the spectrum appear yellow. However, objects that appear yellow can reflect as low as 0% of this 570-590nm yellow wavelength region.[41]

This is largely due to the mixing of colors that occurs; objects rarely have reflectance profiles that are within a single color area of the visible spectrum and thus objects that reflect 620-740nm light (red) and 495-570 nm light (green) and very little 450-495 nm light (blue) appear yellow.

So there are combinations of red and green light that yield yellow. Surely this is the limit of combinations that yield yellow, and this mixing is an expected property of light. So why is it really a problem, given that yellow is a non-primary color in light-color mixing? (The particulars of what primary colors are and what they mean for color-light realism are discussed in chapter 4, section 2.1) The problem arises because it turns out there are arbitrarily many wavelength combinations that yield yellow.[42] Even more troubling, this occurs with primary colors as well. How can it be the case that any color can be identified with a particular wavelength, if there are multitudes of wavelength combinations that can make an object appear a particular color?

This problem is a very serious one for color, and is raised by a number of philosophers in their attacks on color realism.[43] [44] One possible wavelength-realist response to this is to see color as a disjunctive property and to formulate color in the following way. A particular color c is identified with the disjunction of every combination of wavelength that produces that color. The problem with this move is that such a disjunctive property seems artificial.

The classic example of a problematic disjunctive property is, 'is a raven or a writing desk.'[F] This seems like a very strange property for something to have, and indeed quite unlike any sorts of properties we are usually familiar with. This is for good reason. These two items have nothing in common aside from being in the disjunction, and so the disjunctive expression does not seem to demarcate a genuine physical property. The same problem occurs here if we wish to continue to argue that light can be colored.

That a color is defined by a set of wavelengths is artificial and arbitrary. Colors, when defined in this way, represent disjunctive properties. This points to a problem for wavelength realism. If color is not a natural property, but instead something that is arbitrarily picked out by perceivers because certain wavelengths 'look' certain colors, the rigor of defining color as wavelength evaporates. Colors cannot be considered to be genuine properties of light if the only unifying element in the set of wavelengths that constitutes a particular color is defined by how these wavelengths appear to perceivers.

Furthermore, a viewing condition problem develops here. Who is able to determine which wavelengths can be properly identified with a particular color? It is unclear that perceivers would consistently agree with which wavelengths should be considered a particular color. This was evidenced in chapter 2, as the same color might be designated orange or red by different people. Additionally, if the differences between colors are poorly defined, again as chapter 2 suggested, this presents a further problem as it is unclear where the cutoff points for different colors would be.

[F] This particular disjunction is attributed to Lewis Carroll, in *Alice's Adventures in Wonderland* in chapter 7, "A Mad Tea-Party." Lewis initially posed this as a question: "Why is a raven like a writing desk?" and intended that it be unanswerable, as the two have nothing whatsoever in common (aside from both being a part of the question).

Furthermore, in the case of color, the only thing the elements of a disjunctive set of wavelengths for a particular color have in common is that they appear to be a particular color to a perceiver. Even if one is willing to accept disjunctive sets as non-problematic, this perceiver dependency dooms wavelength realism. If colors are identified only because perceivers pick them out, color cannot be intrinsic to wavelength.

'But the set isn't disjunctive', the wavelength realist might say, 'all these combinations of wavelength result in yellow!' But this assertion is ultimately fruitless. What causes us to determine that objects are yellow is our perception of them. There seems to be no unifying physical property *outside of our perception* that would unify these wavelength sets. Furthermore, it seems tenuous to specify all of the various combinations of wavelengths that yield our perception of yellow, given their multitude.

Section 4: Shortcomings of Wavelength Realism

Wavelength realism initially seemed very promising, as it was able to answer many problems brought about by color-object realism. However, because wavelength realism is dependent on light, a poorly defined, perceiver dependent categorization, it ultimately fails to account for the various behaviors of color.

If wavelength is to be identified with color, we expect to see co-variation of color and wavelength; if color varies without wavelength, then problems arise. These problems have indeed arisen: Color is dependent not only on wavelength but surround, as is the case with orange and brown, and white as demonstrated in the contrast and Gelb illusions, respectively. Particular colors fail to match up to the given criteria for color, namely white and purple. Others, such as UV, seem to meet the criteria for color, and yet are not frequently deemed colored.

However the biggest problem for wavelength realism is one that also arose for color-object realism: that of perceivers. Perceivers seem to nicely account for a significant amount of the behavior of color, something neither wavelength nor object realism can happily deal with. As such, a new notion of color is needed to reconcile these problems; this is the subject of the following chapters.

CHAPTER 4: Perceiver Dependent Color

ABSTRACT: In this chapter color as a property of perceivers is discussed. Whether this means color is a property of the brain or the mind, or merely dependent upon one or both, is left open at this point. Given the shortcomings of color object realism, an alternative notion of color that accounts for perceivers is needed. Color as a property of perceivers is able to account for many of the behaviors of color that proved problematic for realisms, as presented in chapters 2 and 3.

Section 1: Against Intrinsic Color

Section 1.1: Color as a Perceptual Feature

The difficulties of color object and wavelength realism seem to come back to the importance of perceivers in viewing color. As such, some popular theories of color describe it as a property of the brain, or the mind. This distinction is not trivial, and will be discussed in depth in chapter 5.

Despite differences between color in the brain or mind, these two options actually treat color very similarly and have had good success in helping to explain the behavior of color. Because of these general similarities, in this chapter, I will remain neutral on the brain/mind distinction and instead explore the treatment of color as somewhere 'in the head.'

It should be noted that other theories of mind exist, for example Alva Noë, and Andy Clark[45] both assert (though with somewhat different specifics) that the mind supervenes [G] on both the brain and the environment. Cases like this may be consistent with ideas discussed here, as the main impetus for moving color into perceivers is to resolve issues that arise from treating color as a feature of only the world.

In fact, most theories that put color in perceivers do not utterly discount features of the environment, but instead assert that perceivers interpret physical information from objects and light as color. Importantly, these physical, environmental features are not

[G] Supervenience is an ontological relation wherein the properties of more complex things (for example consciousness) are dependent on lower level things (for example neural activity). Supervenience is considered to be weaker than reduction. If one were to assert that consciousness supervenes on neural activity it would mean that even though consciousness is dependent upon neurons, we cannot study consciousness using means appropriate to cellular biology alone.

themselves colored. As such it seems that theories of mind that do not adhere to strict distinctions between brain and mind can also be meaningfully discussed here.

Section 1.1.1: Precedent for Color in the Head

Color in the head has a rich philosophical tradition and begins (perhaps somewhat mistakenly[H]) with Descartes skepticism over his ability to distinguish between reality and dreaming in *Meditations*. He wonders if it is possible to determine if one is awake or asleep at a given moment as waking and dreaming perceptions are often very similar. As there seem to be no signs to distinguish one from the other it seems possible that I might be dreaming at any given moment.

Descartes skepticism also extended to sensory experiences. As optical illusions have been frequently employed in this paper, Descartes' claim about the uncertainty of the senses should resonate strongly.

> Whatever I have accepted until now as most true has come to me through my senses. But occasionally I have found that they have deceived me, and it is unwise to trust completely those who have deceived us even once.[46]

Without delving into the trajectory of modern philosophy too deeply, this skepticism inspired other early modern philosophers, such as Hume[47] to view colors as a feature not of objects, but of perceivers.

This concern is mirrored today in discussions of hallucinations, phosphenes (the colors that result when pressure is applied to the eyelids) and other experiences of color that seem to occur independently of the properties of the world that are usually considered colored, namely objects and light. That color is a property of perceivers is a popular theory today. S. K. Palmer, a notable cognitive scientist, explains the notion very clearly.

> Neither objects nor lights are actually 'colored' in anything like the way we experience them. Rather, color is a psychological property of our visual experiences when we look at objects and lights, not a physical property of those objects or lights.[48]

[H] As many philosophers suggest that Descartes was actually a color error theorist.

In this chapter color as a property of perceivers will be considered. Here the focus will be largely on neuroscientific and psychological processes that help explain color as a property of perceivers. This is not to diminish the importance of hallucinations or other similar color involving phenomena, but rather to enhance chapter 6, which requires a significant neuroscientific grounding to be successful. This is also not to support color in the brain over color in the mind. Most theories that consider color to be a property of the mind are happy to admit the importance of brain functioning. Therefore, to remain permissive to both theories, only properties of the brain are discussed.

Section 1.2: Viewing Conditions in Color-Object Realism

In chapter 2 and 3, it was suggested that color realisms are inadequate in their conception of color, primarily because of their inability to account for the effect of perceivers on color. This is especially obvious in color-object realism's use of viewing conditions, which necessitate perceiver involvement.

Viewing conditions are used to adjudicate between color changes that objects seem to undergo in different conditions: different viewing distance, illumination, etc. Because of this insistence that objects have only one true color, object realism is at a serious disadvantage; even if we can legitimately adjudicate between these vast numbers of viewing conditions we seem to have sacrificed realism given the pervasive, almost constant errors we make in our usual color experiences.

Additionally, it was suggested that allowing objects to have many colors and many true viewing conditions, makes colors importantly dependent on perceivers. As such, this is not a viable option for color as an intrinsic property of objects.

By making viewing conditions central to determining veridical color, color-object realism has admitted a fatal shortcoming: an inability to define colors in objective terms. Wavelength realism attempts to solve this problem by pointing to a quantifiable property of light as color. However, it too fails to satisfactorily define color as an intrinsic property of light.

Section 1.3: Perceiver Importance in Wavelength Realism

In chapter 3, it was suggested that wavelength fails to adequately define color for a number of reasons, particularly color contrast illusions and metamers. Both of these problems also come down to color's dependence on perceivers, which wavelength realism fails to account for.

Color contrast illusions suggest that environmental cues cause changes to color in non-wavelength dependent ways. How is it that an area surrounding an orange square can cause the same square to appear brown if that area's luminance is increased? Nothing in wavelength can explain this. Instead a perceiver has to make some sort of comparison between the target and its surround, something wavelength realism cannot address.

Additionally, the problem of metamers further suggests the importance of perceivers in color. It seems that arbitrarily many different wavelength combinations can yield a particular color. More troublingly is that the only thing uniting this set of random wavelengths is a perceiver, who determines that all of these unrelated wavelength combinations appear to be of a particular color.

Though wavelength realism might seem a better alternative to color-object realism at first glance, it too fails to account for the importance of perceivers in color. At best, each of these accounts might claim to describe color as a relational property, dependent upon both perceivers and light or perceivers and objects. However, their endeavors to describe color as intrinsic to light or to objects fail.

Section 1.4: Variation Between Perceivers: 'Red' by any other Name

At best it seems color is relational. It is importantly dependent upon perceivers *and* light or objects. If this is the case appeals to viewing conditions might actually be acceptable in that they incorporate both objects and perceivers. However, a deeper problem persists, namely that viewing conditions fail to account for differences in perceivers' color experiences.

This is a rather famous problem in the philosophy of color: You and I can both look at the same red rose, and both call it "red." However, for all I know we are

experiencing the rose's color in very different ways. For example, your experience of the rose's color might be very close to the way I experience the color of grass. Interestingly, because each of us has been taught to call our respective color experiences of the rose by the same name, red, our experiences might be vastly different and we would never know.[I]

What's even more compelling is that not only does our language prevent a comparison of our experiences; comparison of our experiences might be impossible even with very sophisticated technology. This will be discussed in detail in chapter 5.

For now, suffice it to say that each of us potentially has a very different color experience, even when we receive similar environmental data. Because of this, adjudicating between viewing conditions becomes even more problematic as each viewer perceives color differently and these differences are, at the very least, very challenging to discuss.

It seems an alternative approach to color is needed, one that can account for the variations between perceivers, as well as their influence on color. In the following section, color as a property of perceivers is discussed, particularly its ability to handle the various odd behaviors of color.

Section 2: Color Behavior as Told by Perceptual Color

Section 2.1: A Primary Success: Trichromatic Theory

Color as a property of perceivers has a good deal of philosophical support. For example, Evan Thompson, a philosopher of mind, asserts that, "being colored corresponds to the surface spectral reflectance as visually perceived by the animal." [49] [50] Much of the serious support for this idea has come from psychology and its success in making sense of several rather odd features of color that have defied explanation from color and light realisms. One of the first major successes of the theory that color is a property of perceivers is its explanation of a perplexing feature of color; namely that of primary colors.

[I] This is obviously not only a problem for color, but also a general problem for all of our experiences. Color represents but a single aspect of this deeply challenging problem.

Colors are typically divided up into two main categories: primary and secondary. This concept is best illustrated with a color wheel (figure 15). Primary colors are those that cannot be made by mixing other colors, for example you cannot mix orange and purple, nor any other combination of colors, to make red. Mixing adjacent primaries together forms secondary colors, and further mixing of these primaries and secondaries results in many of the other colors we encounter.

Note that these particular colors, red, blue, and yellow are the result of *pigment* mixing. This is analogous to mixing paints and is termed subtractive mixing; if all the colors were to be overlapped black (or very dark brown) would result.

Fig 15. Primary and secondary colors on the pigment color wheel

Another type of mixing, additive mixing, applies to the mixing of colored *lights*. Interestingly, the primaries for additive mixing are slightly different than for subtractive mixing; they are red, blue, and green. (Figure 16)

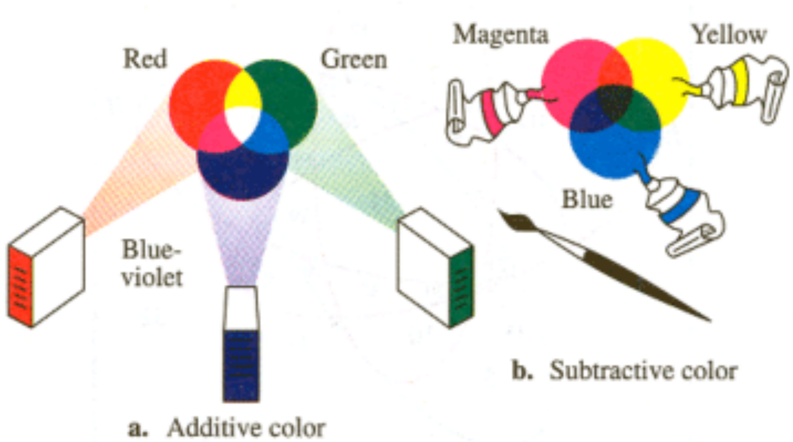

Fig 16. Additive (light) and subtractive (pigment) color mixing

Why these primary colors are different from all the others seems very mysterious; indeed it is something that color realisms can't very well explain. However, in the 1700s Thomas Young proposed that a mechanism in the eye was responsible for this. Young suggested there were three different types of photosensitive receptors in the human eye, and that different activations of these receptors caused color perception.[51] He further suggested that different ratios of activation were responsible for the secondary/primary color distinction. While red light activates red-sensitive cells, the combined activity of red and green sensitive cells causes the perception of yellow.

Though Young lacked concrete evidence for his idea, it later received support from Hermann von Helmholtz's color matching experiments.[52] In these experiments subjects were asked to match a target color by adjusting the ratios of intensity from three different lamps that emitted red, green, and blue light. Helmholtz showed that three lamps of these colors were the minimum number of lamps needed to match the target colors, providing the first empirical support for Young's suggestion.

Further vindication for this idea comes from our use of pixels in TV and computer screens. These pixels are made up from three colors: red, blue, and green. Through the manipulation of the ratios of these colors that each pixel emits, different pixels appear to be differently colored. When their different colors are coordinated, images may be formed.

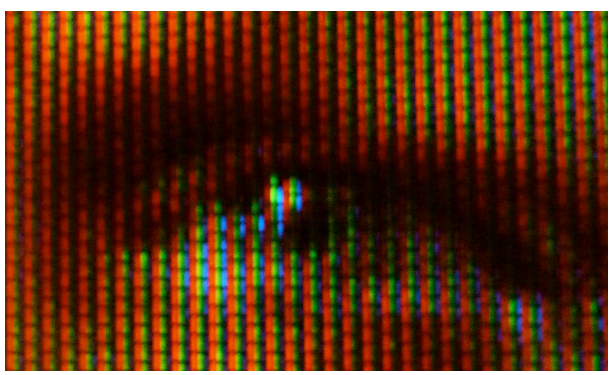

Fig. 17: Close up of pixels on TV screen, note red, blue, and green lines

Trichromatic theory is essentially a more technical explanation of Young's initial idea of photoreceptive cells. It asserts that there are three distinct types of color-receptive cells on the human retina, called cones. Each type of cone is receptive only to a particular

portion of the electromagnetic spectrum; these cones are termed L, M, and S and refer to the long (560), medium (530), and short (420) wavelength portions of the ems that they are each most receptive to.[53] In addition to these cones, there are light-only sensitive cells called rods. Figure 18 demonstrates the range of light wavelengths corresponding to the relative sensitivities of these cones. These cones are also sometimes called red, blue, and green cones; notice that the wavelengths of maximum sensitivity for each cone correspond to one of the primary colors.

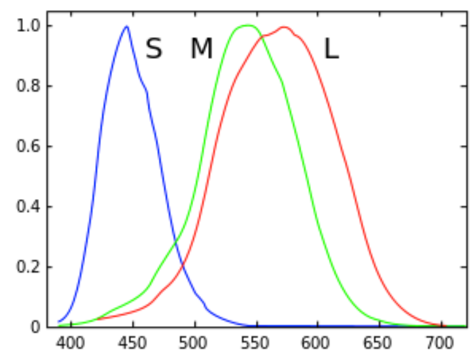

Fig. 18: Spectral Response Curves of Human Cones, wavelength (nm) on x-axis.

It could be the case that our eyes developed with sensitivity to these particular colors because primary colors are real properties of the world, or that primary-ness is a property of particular parts of the EMS. However, this is very unsatisfying, as other animals have different light sensitive cells in their eyes and are thought to experience different colors as primary. For example instead of three light sensitive cells, pigeons have five. It is thought that they experience whatever wavelengths those five cells are maximally responsive to as primary. Therefore, this primary-ness cannot be a property of the world, but is dependent on perceivers.

Section 2.2: After Image and Opponency

Though trichromatic theory may help explain why the primary colors of light are blue, green, and red, it is still unable to account for some other features of color, namely color illusions, like the one below. This is not a problem for 'color in the head' though it does suggest that trichromatic theory needs emendation.

Stare at the dot in the center of the fish below for about 20 seconds, and then look at the dot in the white rectangle next to the fish; a greenish fish on a blue-ish background

should become visible. This ghostly image is called an after-image. Trichromatic theory can help explain *why* this after-image appears; it is due to cellular fatigue. What it cannot explain is the particular colors that appear in the after-image. In order to better understand this a modification of trichromatic theory is needed, this is called opponent process theory. This theory can help place color in the head, as it explains a significant portion of color's behavior and is a function of a perceiver's sensory system.

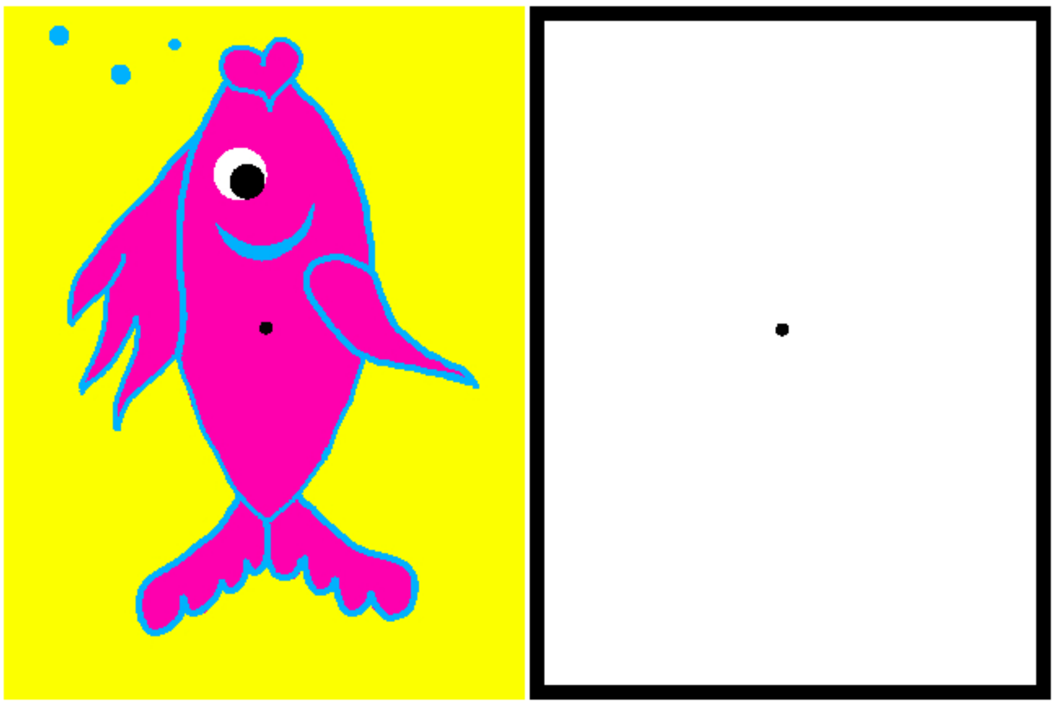

Fig. 19: After Image Illusion

Section 2.3: Opponent Process Theory

Ewald Hering, a physiologist, first proposed opponent process theory in 1892[54] when he noticed that certain color combinations didn't seem to exist (or at least to function in the same way other color combinations do), namely reddish-greens. When red and green paints are combined they produce browns, as do bluish-violet and yellow. Hering proposed that this occurs because cone and rod cells are arranged in groups: red and green cones are paired to form the red-green channel, while blue cones and the collected input from red and green cones are grouped to form the blue-yellow channel. This later grouping may seem strange, however, recall that combining red and green light results in yellow.

These groups of cones each stimulate another cell, called an opponent cell, which determines how the collected input of cone information will be interpreted. For example, a red cone and a green cone both are stimulated by light and send signals to an opponent cell. If this cell receives more input from the red cone, red is perceived. On the other hand, if the opponent cell receives more input from the green cone, green is perceived. If an opponent cell receives similar amounts of input from both it's red and green cones, white is instead perceived.[J]

The blue-yellow channel operates in a similar way; except input from red and green cones are combined to provide a yellow signal, which an opponent cell receives. The amount of yellow signal is then compared to the amount of stimulation the opponent cell is receiving from its blue cone. If more stimulation from the blue cone is received, blue is perceived. If the opponent cell receives more stimulation from the yellow signal, yellow is perceived. Again, if stimulation from blue cones, and the yellow signal are roughly equal, white is perceived. Opponent process theory does not discard trichromatic theory, but rather expands upon it; thus sometimes it is termed the trichromatic opponent process theory of color vision.

We can now better explain the why the after image of the fish illusion appears to be particular colors, namely the 'opposite' colors of the original image.[K] When cones are stimulated by particular light wavelengths, their light sensitive proteins (called photo-pigments) undergo a change. This change results in stimulation of opponent cells and then the perception of color. However these photo-pigments only exist in finite quantities and must be replenished by adjacent tissues in order for cone cells to continue being sensitive to incident light.

When you stare at the image in figure 19 for an extended period of time these photo-pigments become less abundant as the same population of cones is being stimulated in the same way, these cones become 'fatigued.' Normally your eye prevents

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[J] Whether brown or white is perceived is a result of the global stimulation of rod and cone cells – this gives a general representation of brightness. Roughly speaking, low brightness results in brown, high brightness in white.

[K] The particular nature of 'opposite' refers to a color wheel, as in figure 15, as in colors that are across from each other. These are often referred to as 'complements.'

this from occurring with tiny movements, called micro-saccades. These small movements allow different cone populations to be stimulated, and thus allow photo-pigments to replenish. However, these movements are insufficient if one makes a concerted effort to stare fixedly at the image, as the same cone cells are being stimulated and thus effectively run out of photo-pigment. When you were looking at the fish, red cone cells on a particular part of your retina were highly stimulated; in turn the opponent cells they are connected to were made to signal red, as green input was very low. However, after staring at this image for an extended period, the photo-pigments in these particular red cone cells become depleted.

Thus, when you shift your eyes and look at the white area next to the fish, suddenly all of the cone cells in you eye are stimulated, as white light contains all wavelengths of light. Now, the green cones, which were not active when you were looking at the fish, and thus still contain high amounts of unspent photo-pigments, send disproportionately high input to opponent cells. As red cones have diminished photo-pigment quantities their input to opponent these same cells is diminished. Therefore, a greenish afterimage results.

A similar case occurs for the yellow background, which results in a blue afterimage. It is because of opponent cells, and the paired nature of red/green and blue/yellow input that after images thus appear to be ‘opposite’ in color; these are called negative after images.

Essentially, the particular colors of afterimages are thought to be the result of cellular behaviors that occur within perceivers, this represents a significant step towards understanding what color in the head can be like and what sorts of processes it might depend on.

Thus far we’ve seen how important behaviors of color can be explained by invoking processes that seem to occur in the perceiver’s head. Now another important behavior will be similarly explained.

Section 2.4: Color Contrast

Another important feature of color that the opponent process theory can help explain is the phenomenon of simultaneous color contrast, shown in figure 20. *This illusion has a lot in common with the contrast in chapter 2, figure 12, though it involves color comparisons in addition to luminance comparisons.*

Fig 20: Color contrast illusion. Despite appearances, the Xs are identical in color

This illusion is very robust, and defies any kind of realist explanation. However, it can easily be accounted for with opponent process theory. When opponent cells receive input they compare adjacent cone cells; because the hue of the Xs has both brownish and greenish qualities, when it is compared to the very brown left portion of the image it appears far less brown, highlighting its green character. On the right, the reverse occurs.

Recall that in chapter 3, comparisons between parts of images caused two of the presented illusions, (the Gelb, and contrast illusions). It was suggested that this cannot exist in the world, but is instead a feature of perceivers. Opponent process theory nicely explains how this comparison functions and why these illusions work the way they do.

Section 2.5: The Purkinje Effect

Other cellular behavior, namely the behavior of rod cells also accounts for other features of perception that are intractable to the realist. As the sun sets green foliage begins to appear bluish-green, while warm-colored objects appear dimmer, closer to

black. This is called the Purkinje effect and is not the result of changes in reflectance profiles due to available light, but rather the activity of rods.[55]

Interestingly, rods have a wavelength sensitivity curve that appears very similar in shape to that of cone cells; it falls between the M and S peak. Given this sensitivity curve it seems odd that rods don't behave like cones. In fact, this is due primarily to the sensitivity of rods. Rods are about 100 times more sensitive than cones; thus at night they are more active in our visual perception.[56]

The Purkinje effect is due to this heightened rod activity; the peak sensitivity of rods becomes more apparent as the sun sets, causing greenish things to appear more green, and reddish things to appear black as rod-dominated or scotopic vision takes over. In very low light, you may notice that things tend not to look colored; this is again because vision is scotopic in these conditions.

This is another instance of the success of color psychology in explaining the various behaviors of color. Because these behaviors are found to have a substantial grounding in what goes on inside perceivers this also provides significant support for color in the head.

Section 2.6: The Shape of Perceptual Color

Patricia Churchland, a very important voice in Neurophilosophy, has offered a very apt analysis of color space in order to further advocate for perceptual color, though Churchland obviously takes a materialistic [L] view, her model can be used generally to help explain the behavior of color in perceptual terms and thus to further bolster color in the head generally.

Recall one property from folk color, namely the idea of unity: that colors have particular relationships to one another, for example, that red is more similar to orange than either is to green. Unity also suggests that colors cannot be compared to uncolored

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[L] A materialist believes that all of our perceptual experiences, behaviors, actions, etc. are entirely reducible to the activity of physical entities, like neurons and neurotransmitters. Note that 'physicalist' is often used interchangeably with 'materialist,' though the two terms have radically different histories.

things in meaningful ways. In wavelength realism there was a semblance of this relationship; red wavelengths are adjacent to orange wavelengths, which are both rather far away from green wavelengths on the spectrum. However, it fails to account for other relationships of color, particularly complementary colors, and differences in 'intrinsic brightness.'

Brightness, sometimes called value, is how bright a color appears. Each color has a characteristic brightness, for example blue is less bright than yellow is. This results in an odd situation; if you take a blue pigment and a yellow pigment and add black and white to each of them, creating an even progression of value changes, blue becomes almost black very quickly, while yellow turns white very quickly. Furthermore, when black is added to yellow (called a shade, which is the addition of black to a pure color), it becomes greenish. On the other hand, blue retains its blue-ness with the addition of black or white (the addition of white to a pure color is called a tint).

Fig. 21: Tints and shades of yellow and blue. The pure color is indicated with an X. Note that with the addition of black yellow quickly turns green, while blue retains its hue.[M]

This is an odd feature of color, and one that color scientists have long struggled with. Why is it that different colors have different characteristic Brightness? The project of ordering color is a task that Newton began with his 1704 publication of *Opticks*, which contained his famous color wheel.[57] This wheel represents only one dimension of color, namely hue, or the degree to which a color is similar to one of the unique hues, red, blue, green, or yellow. A unique hue is one that appears to be a pure color and not a mixture of two other colors. That these particular colors are considered unique is somewhat arbitrary, and some disagreement exists about which colors are indeed unique.

[M] It should be noted this transition from yellow to green with the addition of black is not a quirk of the pigments used in this figure. The same effect results regardless of the medium.

Over several centuries three dimensions of color space have come to be generally agreed upon. These are hue, saturation, and value. Saturation, sometimes called chroma, is the degree to which a particular hue is present; de-saturated colors are very muted and appear grayish. Value, sometimes called lightness or brightness, is the degree to which a color appears black or white, as mentioned above it can also be thought of as how bright a color appears.

Wilhelm Ostwald, a chemist and Nobel laureate, developed a system of dimensional color in 1916-17.[58] The Ostwald system defines colors in terms of 12 hues, including the unique hues and admixtures thereof, (radially) and lightness, with white at the top and black at the bottom. Each color is given a hue coordinate as well as a designation of how much white or black has been added to it. It is able to account for complements, as well as similarity of different colors in 3 dimensions.

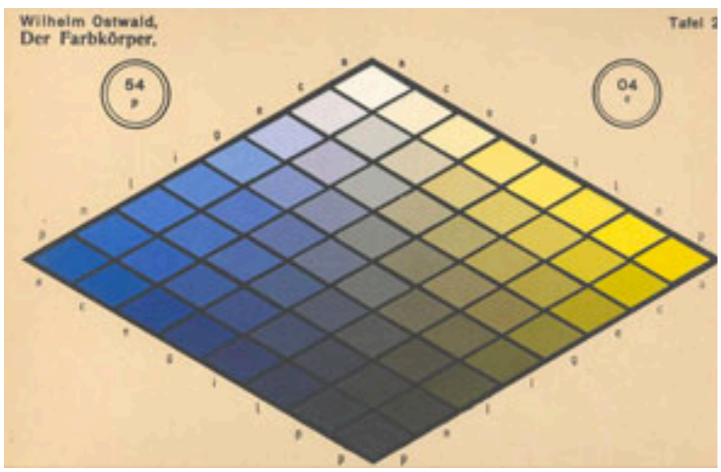

Fig. 22: Ostwald Color Space Section, Blue-Yellow Plate

Though the Ostwald system does represent a significant moment in color space history, it fails to account for our experiences of blue and yellow tints and shades; namely that it shows equal numbers of tints and shades for both blue and yellow. This space is compressed so that it is neatly symmetrical; the diamond shape above is effectively rotated about its center, creating a squat, double-ended cone. However, this symmetry actually represents a significant shortcoming with this space. The Munsell color solid, on the other hand, is able to respond to this problem by grounding itself in perception.

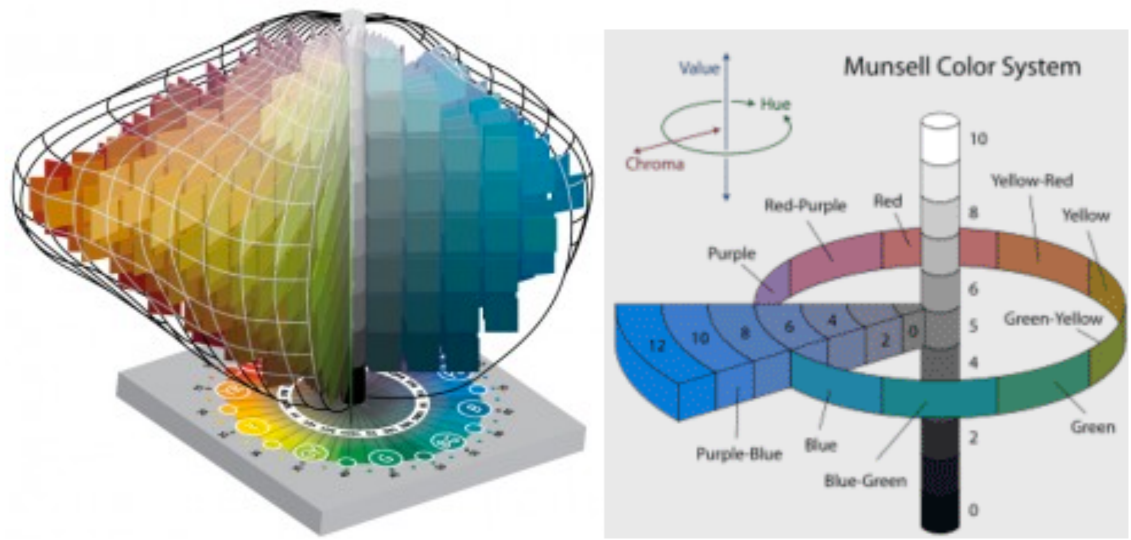

Fig. 23: The Munsell Color Solid

Through a series of empirical tests Albert Munsell, an American Painter, was able to construct a color space that is perceptually even in its progression.[N] Each step in its three dimensions, value, hue, and chroma, represents a *perceptually* equal one. This is in contrast with the Ostwald system, which uses increments of paint to create the steps in its space; this results in a symmetrical space, but one that does not capture perceptually even steps. This space is largely regarded to be the most successful technical color space that is also able to account for the importance of perceivers in color.[59]

What makes the Munsell solid so different from the Ostwald system is its use of perceptual steps as opposed to admixtures of pigments. This may seem counterintuitive, but mixing equal parts of black and white paint does not result in a medium gray; instead amounts must be manipulated until the gray 'appears' to be directly in the middle between white and black. Though this is somewhat arbitrary, by using a large sample of people to determine what constitutes medium gray, a better picture of what medium gray might actually mean can be established; one that also captures the perceiver-centric nature of color.

Because of this attention to perceptual color, the Munsell solid is asymmetrical; this captures the high intrinsic lightness of yellow, and gives it more tints than shades. On

[N] Munsell created this space between 1905-1915, before the Ostwald system. Though the Ostwald system has shortcomings, many find it useful.

the other hand, it allows blue, which has a lower intrinsic lightness to have more shades and fewer tints as evidenced in a cross section of the solid in figure 24.

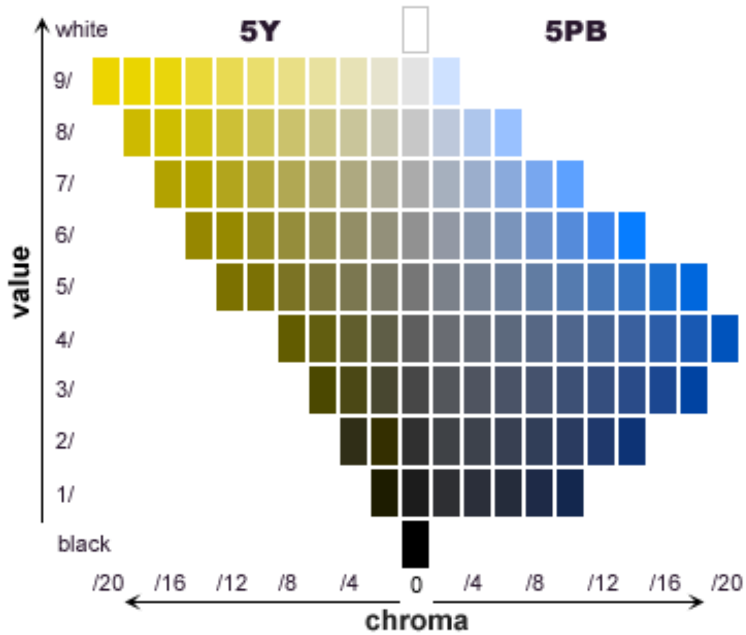

Fig. 24: The Munsell color solid plates for bluish-purple and yellow

Patricia Churchland has pointed out a very apt connection between the Munsell color solid, and a color solid generated via the actions of color opponent cells, namely that these spaces are almost identical.[O] This space is formed as a result of the combined activity of opponent cells; instead of hue, saturation, and value we have red-green, blue-yellow, and black-white (or brightness) opponent activity.

These easily substitute the usual dimensions of color space; the black-white channel is obviously analogous to the value dimension, while increasing saturation can be viewed by how pure a color signal is. If a color falls in the middle of either the Munsell solid, or the proposed opponent space, it appears de-saturated as both red-green and blue-yellow channels are active, producing muddy, grayish colors. Just as in the Munsell solid, the pure hues encircle the widest portion of the space, where both cones meet.

[O] A diagram of what this space might look like can be found in Patricia Churchland's book *Brainwise*, on Plate 5. It could not be reproduced here for copyright reasons.

Though this space appears more like the Ostwald solid, closer examination of how opponent cells are inter-related reveals a space almost identical to the Munsell Solid. Because opponent cells do not function entirely independently of one another, the shape of the solid becomes irregular. The particular shape these opponent cells create can be calculated by examining the overlap of cone response profiles. As Churchland points out, this represents what is essentially "the neuronal basis for our phenomenal color space." [60] That this space based on opponent process is almost identical to the Munsell solid is not trivial. The Munsell solid is one of the most widely used and well-regarded color spaces ever created. If neural activity can produce an analog to it, it seems color as a property of perceivers should be taken very seriously.

This is beneficial, even if we are to remain neutral on the brain/mind distinction, as it represents a significant step towards understanding color phenomena in more concrete terms. This cellular contribution doesn't have to be the entire story of color experience, but it does help solidify our conceptions of it.

Section 3: Resolutions from Perceptual Color

So far some odd behaviors or features of color, such as primary colors and color contrast, fit nicely with the idea that color is a property of perceivers. In previous chapters, problems for color realism were mentioned, now that the importance of perceivers has been explored to some extent, those problems might be dealt with in this new conception of color.

Section 3.1: Viewing Conditions

Viewing conditions were mentioned as particularly problematic for color-object and wavelength realisms as they seem to make color perceiver reliant. However, if color really is just a feature of perceivers this is expected. Color experiences between perceivers are expected to vary, and at least some of this variation can be explained by cellular activity

An apt example of this is color blindness. Deuteranopia, or red-green color blindness is actually quite common: approximately 8% of males with European ancestry have this color deficiency and are unable to distinguish between reds and greens.[61] The

absence, low population, or dysfunction of L-cones in the retina causes this form of color blindness.

Other forms of color blindness also exist that result from the absence of other cone types. Additionally, if a person has diminished populations of a particular cone type, for example the L cone, they can usually distinguish reds and greens, but not as well as people with ‘normal’ color vision.

To make this example even more robust, other species are thought to be able to see more colors than we can. Many birds are tetrachromats (possessing 4 different cone types), and thus have the potential to see color combinations we can't even imagine. Pigeons, for example are pentachromats, and are thought to see somewhere on the order of 50 billion colors (humans see approximate 7-10 million).[62] [63]

Section 3.1.1: The Mantis Shrimp

A particularly interesting example of how different colors are experienced by different species comes from the mantis shrimp. Mantis shrimp are an order of marine crustaceans and are notable for their immensely complex visual system.[64]

Humans have three types of visual pigments that allow for color detection; this is the basis for primary colors and ‘tri-chromatic’ vision as discussed in section 2.1. The mantis shrimp may possess as many as 16 different types of photopigment, 12 of which are for color perception, while the others appear to preferentially filter particular wavelengths in different part’s of the shrimp’s eye. These filters enable the shrimp to detect deep into the ultraviolet range [65] and might give it ‘multispectral vision.’[66]

Multispectral imaging is way of capturing data from the electromagnetic spectrum that our eyes are not sensitive to, such as UV, IR, microwave, etc. This imaging works by dividing the spectrum into different bands. The color filters in the mantis shrimps’ eyes are believed to function in a similar way. Though it is currently impossible to capture what it is like to see the world as a mantis shrimp, a sample of multi-spectral imagery (figure 25) provides a general idea, though how these different portions of the spectrum overlap in the shrimp’s experience is unknown.

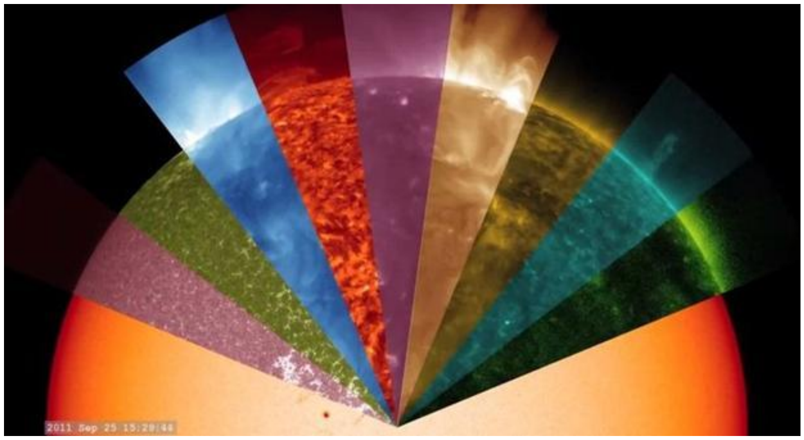

Fig. 25: False color Multispectral image of the sun, each band represents a different range of the spectrum being detected.

If this isn't impressive enough, one species of shrimp is sensitive to the full dimensions of polarized light, and many species have tri-ocular vision in each eye;[67] humans have binocular vision, meaning they have two eyes, each of which creates a single image. Because of this complexity and additional visual data the shrimp has access to, it is possible that these data might be interpreted in a similar way as color, although this is very speculative. This poses an interesting question for the folk idea of unity: if the mantis shrimp can visualize polarized light in a way similar to color, then it seems that polarity is importantly comparable to color.

Furthermore it suggests that the perceived relations that color may or may not have to other things are merely a function of sensory systems. It happens that human color seems to treat colors as unique. However, as this shrimp's vision suggests, this is not a necessary conception of color. A particularly compelling instance of this in humans does exist, and is termed synesthesia, or sensory mixing. This is discussed in chapter 6.

Though we might never know how the mantis shrimp experiences color, that its sensory apparatus is so radically different from ours further suggests that colors are perceiver dependent. This shrimp provides a single example into the immensely complex world of non-human vision. Interestingly, it is thought that color vision developed numerous separate times among different taxa.[68] [69] [70] Given the vast differences between different species' visual systems it seems inane to suggest that color is objective, as these systems each interpret color in unique ways.

If color is treated as a property of perceivers then these variations can be nicely accounted for; they represent different organisms' or individuals' interpretations of visual stimuli.

Fig. 26: The Peacock Mantis Shrimp, *Odontodactylus scyllarus*. Not only does its vision system seem alien, it also looks the part.

Section 3.2: What is a Color?

Another reason to consider color as a property of perceivers concerns how we actually determine that something is a color. As the mantis shrimp has demonstrated, other data from the environment might be experienced as color, if this is the case it seems implausible that color is an objective feature of the world.

Recall in chapter 3 the problem of ultraviolet light was addressed, namely that some people are able to see ultraviolet light after receiving artificial corneas that allow ultraviolet wavelengths to enter the eye. Under any sort of realism ultraviolet poses a problem for our definition of color as it meets the criteria that other colors do and reveals that our designation of colored is importantly dependent upon human perceivers.

If color is allowed to be a perceptual feature of perceivers, ultraviolet no longer poses a problem. Anything that appears to be a color *is* a color under this conception. Color is a changeable feature of perception, and finally we have a color theory that vindicates that belief.

Defining what counts as a color again recalls problems of interspecies variation, and variation within human perceivers. Many birds and insects are able to see ultraviolet light, while many color-blind people are unable to differentiate between regions of the visible spectrum. If color is considered to be a property of the mind, these differences do not necessarily mean organisms or individuals who see fewer colors are in some way mistaken, they just interpret the same visual data differently.

It might be tempting to say that people who are color blind are making a mistake, and thus this notion that color is a feature of the mind is thus problematic as it is unable to account for this. However, the notion that color-blind people are mistaken in their usual perception is problematic; people who are color-blind do not necessarily see less, again, they merely interpret data differently. A striking example of this is the Ishihara color vision test; namely plate 5, shown in figure 27.

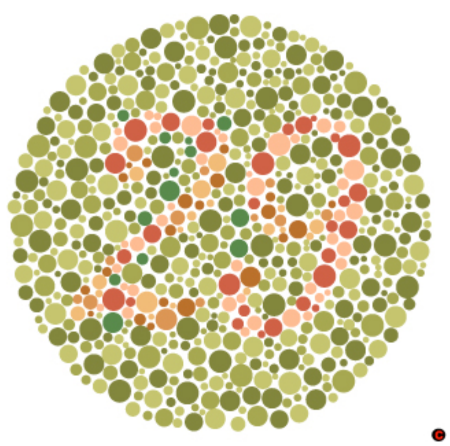

Fig. 27: Ishihara color plate 5; those with 'normal color vision' should see a 29, while those with some type of color blindness may see 70.

The Ishihara color vision test is one of the most frequently used tests for color vision.[71] It consists of a series of plates similar to the one shown above. In the plate above, people with 'normal' vision are expected to see a reddish 29. However, many people with 'normal' vision are unable to see a darker green 70. People with red-green color blindness are able to clearly see this 70; the difference they perceive between the light green background and the darker green 70 is thought to be as robust as the difference most people perceive between the red 29 and the green background.

Notice that color blindness does not necessarily entail a vision *deficiency*, but rather a different experience or interpretation of visual data. When color is treated as a property of the perceiver this can be nicely accounted for.

Section 4: Shortcomings of Perceptual Color

Section 4.1: Unexpected Behavior, Cornsweet Edges

Though opponent process theory is able to account for afterimages and primaries, and solves some issues from chapters 2 and 3, it fails to account for other aspects of color behavior; particularly a family of illusions called Cornsweet edges.

Fig. 28: Cornsweet-O'Brian edge illusion, a small central gradient gives the appearance that the two sides of the image are of different value. Blocking this central gradient reveals both sides of the image to be identical.

These illusions are interesting as they defy what one expects from opponent process; in the aforementioned contrast illusions, the target appears to be opposite from its ground. However in this illusion the reverse occurs. Note the slight gradient at the central left of the image; the center appears darkest, and gradually lightens to match the outer portion of the figure. On the right center the opposite gradient exists; it is lightest in the center and darkens to match the rest of the figure.

If opponent processing were responsible for this, we would expect the right side of the image to be compared to the lighter portion in the center, making it appear relatively darker. However this is not the case, instead we see the portion of the image next to the lighter gradient as lighter, and the portion adjacent to the darker gradient as darker.

Though this illusion is not necessarily a problem for color in the head, it does suggest that our current understanding of it, and of other behaviors of color, is far from complete and may need substantial revision. This particular illusion will become relevant again in chapter 6, and will provide potentially damaging evidence for certain theories of color. As such it's worth pointing out that this particular illusion is poorly understood under color in the head in its present form.

Section 4.2: Unexpected Behavior, Positive After Images

Another interesting phenomenon that defies opponent process theory is that of positive after-images. When you see a bright camera flash or stare at the sun for too long instead of a dark blue after image, as opponent process theory would suggest, (that you would see colors of opposite hue and intensity) you see a very bright patch of color. Though this color may be opposite to the thing that caused it (i.e. staring at the sun produces a blue-ish disc) it is unexpected that the afterimage is so highly luminous.

Section 4.3: Leaving Something Out

These problems for opponent process theory might be rather trivial; opponent process theory is still relatively new, and many of its details represent active areas of research so it's rather unsurprising that it can't explain all of the various behaviors of color. However this suggests a deeper problem.

Even if this neural story seems to tell us a lot about how we experience color, it leaves out an important point: That color is importantly experiential in a way that physical features of perceivers might never satisfactorily explain.

The concern here is that even if the entire cellular story was completed, we still might not be able to develop a clear link between particular cellular events and the *way* color acts on a perceiver, or why particular colors are experienced in exactly the way that they are. The closest we have gotten here is Patricia Churchland's attempt to create a physiological basis for our phenomenal color space. Importantly, even this does not come close to telling the whole story of our color experience.

The ultimate question of what it's *like* for a particular perceiver to see a particular color still goes unanswered, and the worry is that it might never be answered in physical terms. If this is the case, color might not be a property of the brain, but of the mind. If this is the case color might be a non-physical property. In the next chapter, consideration of experiential color will be addressed, and color as a non-physical property verses a property of the brain will be considered.

CHAPTER 5: The Color of Experiences

INTRODUCTION: In this chapter non-physical bearers of color are discussed with particular attention to qualia theories. Non-physical bearers of color are suggested to be inconsistent and problematic options for color, and the notion of a double error theory is suggested. Colors do not exist anywhere, physical or non-physical. As such, we are mistaken in our attribution of color to these 'places.' Despite this proposed error the question of qualia, and thus of materialism/dualism, remains largely open.

Section 1: Where are Colors?

In this paper two related, but ultimately distinct lines of questioning have been pursued but not yet clearly distinguished. The first, 'What, if anything, is colored?' seeks out potential bearers of color, or potential properties of the world that might be colored. The second is 'What is the nature of perceptual experiences of color?' namely, what processes and properties are important in these experiences. Though this distinction has been tacit through the paper, it is now time to distinguish these questions more carefully. This chapter will focus primarily on the first, while chapter 6 will focus on the second.

Section 1.1: What if Anything, is Colored?

What is color a property of? In the previous chapters I have suggested that treating color as a property of objects or light is insufficient as neither can satisfactorily explain the various behaviors of color. If color is real then, it seems the only place left for it is somewhere in the head; the question left then is exactly how color 'in the head' can be described.

No part of the brain is actually colored in the relevant way (though it is gray and white, after all) or becomes colored when colored experiences happen. If no part of the brain is colored, then color (if it is anywhere) must be non-physical.[P]

Before looking more into non-physical color, it's worth pointing out the particular assumptions at play in this claim that will later become highly relevant. These can be

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[P] A neuroscientist might take issue with this. What most neuroscientists mean when they refer to color as a property of the brain is not that the brain is literally colored, but that our experience of color is due to neural activity. This terminology is very problematic though, as where do these colored experiences exist? The following section will suggest an alternative to colored experiences that can help the materialist avoid non-physical facts.

stated in two distinct ways: (1) if color is real, then something exists that is colored. And (2) if color judgments can be true, strictly speaking, then something exists that is colored.

Section 1.1.1: A Word on Color Judgments

To clarify what is meant by color judgments an example is needed. A color judgment is something like this: "This rose is red." This judgment has a few components, it involves my experience of the rose as red, and then my attribution of the colored experienced to the rose that I am seeing.

As per (2), if I experience the color of a rose as red, and then claim that the rose is red, the assumption in play is that there must be something that exists that is red for this claim to be true. However, because I have discarded physical locations of color a rather odd situation results. The color is not actually in the rose, or anywhere physical at all. It would seem then that my color judgment refers to the wrong thing; and it does, it picks out the rose as colored. This cannot be the case as physical objects have been discarded as a potential location for color.

This might seem to mean that all my colors judgments are false, as they refer color to the wrong location. However this does not need to be so.[Q] I simply need to revise what my color judgment attributes color to. If colors exist somewhere (physical or non-physical) outside of the rose, the truth of my color judgment might rely on these properties and not the properties of the rose.

In the following sections it will be suggested that there are no non-physical bearers of color, henceforth referred to as non-physical colors. If this is the case then there *does* seem to be a problem with my color judgments: if colors do not exist physically or non-physically, then both (1) and (2) are both deeply problematic.

Section 1.2: Properties of Qualia

Before non-physical color can be discarded, an examination of what non-physical color means is first needed. In the relevant literature, one term often used to refer to non-physical color, or to other sensory or subjective processes is 'qualia.' In order to

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[Q] See chapter 6, section 9 for a treatment of the truth-value of these judgments.

understand what non-physical color might be like, some literature about qualia will be explored; one notable source is Daniel Dennett's "Quining Qualia." This paper attempts to deny the existence of qualia by asserting that nothing quite fits the standard conceptions of qualia, and that ultimately it is a deeply confused and unhelpful notion.[72] Despite Dennett's anti-qualia bent, he provides a very detailed and rigorous definition of what qualia actually or allegedly are. As I intend to remain neutral on questions of qualia, my focus here shall be on the properties qualia have. Dennett asserts that qualia are ineffable, intrinsic, private, and immediately apprehensible qualities of experience.

'Ineffable' refers to the idea that qualia, what it is like to experience a particular thing, cannot be explained except by first hand experience. There is significant support for this idea. Imagine that you and I are looking at a rose; though we both call the rose red we have no way of getting at what the other is actually *experiencing*. For example my experience of the color of the rose might be similar to your experience of the color of grass. However, we have no way of communicating this as we both use the same language to describe what are potentially very different subjective experiences.

Qualia are also considered private, that is, not only do you and I have no way of communicating our experiences of the rose to one another, comparing our experiences is actually impossible. Nagel offers an example of this in his famous paper "What is it like to be a bat?"[73] He suggests that even if you were to turn into a bat at this moment you would not have the experiences of a bat. Instead you would have the experiences of someone who has been a person their whole life and suddenly has been put into a bat's body. Comparing your experience as a person to the bat's experience as a bat is impossible because the filter of your previous experiences still exists.

This problem exists not only between bats and humans, but also between humans. The experiences of my life have shaped my perception in important ways. If I were to suddenly be able to look through the eyes of another person I wouldn't actually see what they are seeing, instead I would see their experience as filtered by my own experience.

Interestingly there doesn't seem to be a way around this, even hypothetically. Dennett proposes an elegant example, something he terms the brainstorm machine, which

allows you to plug into the head of another person and experience what they are experiencing. However, the problem with this is there is no way of calibrating the machine. Imagine you are experiencing another person's experiences with this machine. While doing this, McIntosh apples look green and the grass appears red.

You might think this accurately represents what the other person is experiencing, but now imagine the plug on the brainstorm machine is flipped around, and all the colors invert; now apples are red while grass is green. How can you tell which 'setting' on the machine was correct? You can't ask the person whose experiences you are stealing because it would result in the same linguistic comparisons that make both of us call a McIntosh apple *red*, but fails to compare what we actually experience as the apple's color.

In short, any kind of machine, or similar scheme to experience another person's experiences, must result in some kind of direct comparison of experiences if it is to be even possibly correct. As this comparison is impossible we cannot know if these machines are portraying another person's experience to us in an accurate way.

Another important attribute of qualia is that they are immediately apprehensible in consciousness. When you experience blue, you immediately know all that there is to know about that quale.[R]

Qualia are also said to possess all their defining properties intrinsically. This notion is perhaps less clear, but essentially means that nothing separate from the quale may affect or alter the nature of the quale itself. This might seem problematic, as chapter 4 discussed a number of physical processes that are understood to play a role in color experiences. For example if my L-cones are activated I should see red. It thus seems that different physical processes can produce different qualia in the observer's mind, making qualia non-intrinsic. Moreover, we have seen cases where, for example, surrounding context determines just which color qualia are produced.

The idea that qualia are intrinsic has taken a number of forms in the literature around qualia. Some philosophers take this to mean that experiences of color may vary

[R] This is directly analogous to the folk idea of revelation; everything there is to know about color is immediately available to you with simple observation.

independently of the physical processes that might seem to influence them.[74] This means only that the relationships our physical processes have to qualia are arbitrary, not necessarily that they have no causal bearing on our experiences.

That our qualia are arbitrarily linked to physical experiences might seem odd. However, one can just as easily imagine that what we experience as red, which is related to the activity of L-cones, could just as easily be experienced as green, while still being related to the activity of L-cones. There is no real reason that these cone responses *necessarily* correspond to the phenomenal colors we experience in the way that they do.

Similar remarks apply to the point about the effect of surrounding context on the production of qualia. Different contexts may produce different qualia, but these qualia still possess all their defining properties intrinsically.

In short, though there may be physiological processes that seem to produce our color experiences, in fact, the phenomenal experience of colors is only arbitrarily, not necessarily, related to these processes.

Section 2: Qualia and Folk Theories

Despite the rather strange properties of qualia, qualia maintain a decent relationship with the folk idea of color. Why exactly this relationship is important, followed by the particulars of this relationship, are the subjects of this section.

Section 2.1: The Importance of Folk Color

Whether a theory is consistent with folk ideas might not seem like a huge concern – we must simply revise our conception of color. It might seem strange that a non-rigorous conception of color might somehow result in the removal of color entirely. However, in many theories of color, a comparison to folk color is made and many philosophers, such as Jackson, feel that rejecting some notions of folk color might be acceptable, even unavoidable. However, if *all* of the various folk beliefs about color are inconsistent with a theory of color, it is unclear that that theory is referring to color at all.

Here's a scenario to illustrate why it is important that at least some common sense ideas about colors are preserved by a color theory. Someone at a museum points to a

piece in a gallery and says, “That’s a nice painting of a red, wooden, sail boat.” However, it turns out the thing they’re pointing to is actually a sculpture of a silvery, metal, truck.

If this is the case how can we be certain that the thing they are apparently pointing to and their entirely incorrect description are actually referring to the same thing? The pointing is useful, but they seem to have so badly misunderstood the piece in question that talking about it in any meaningful way would be basically impossible. The best we can say is probably, ‘it’s in this museum.’ But the actual content, or any other properties of the piece cannot be discussed fruitfully.

This is what is suggested here: preservation of color requires that a theory of color should have something in common with the properties typically ascribed to color. These general properties of color are derived from folk theory. Though folk theory is almost always inconsistent to some extent with other theories of color, every theory of color manages to retain some ideas from folk theory.

For example, in color-object realism, almost all of the aspects of folk color are retained. In wavelength realism, we moved further away from this folk notion, potentially discarding ideas of revelation, and simplicity, yet maintained other aspects of folk color, such as realism. In color in the head, many ideas from folk color were discarded including realism, revelation, and perceptual availability. However, two important aspects of folk color remained intact, namely simplicity and unity.

Later in this chapter it will be suggested that the way we perceive color is so different from our folk ideas of it as to render ‘color’ as we typically mean it, meaningless.

Section 2.2: Qualia and Inconsistencies with Folk Color

If a theory of color runs in direct opposition to what we mean when we talk about color, it should be viewed as a problem for the theory, or for the general notion of color. Here, the idea that qualia are the bearers of color seems to run contrary to folk theory, as colors are no longer properties of the world, but of non-physical consciousness. Indeed this immediately precludes the idea of color realism, removing color from objects and light.

Furthermore, colors seem to be properties of the physical world, but if they are actually part of qualia, their nature is definitely not revealed to us. As such revelation cannot fit with qualia as we are mistaken in our attribution of color to the world.

Simplicity and unity fit especially well with qualia. In fact a uniform red quale is often cited as the paradigm example of a simple experience.[75] When you look at a flat red surface the experience that results is perhaps the simplest version of red we have encountered so far. This is captured by properties of qualia, namely that they contain their defining properties intrinsically. In virtue of this property of qualia, nothing outside of qualia could possibly impact their nature; as qualia are ineffable and private, any sort of analysis is ruled out.

Unity readily follows from simplicity, as you seem able to compare your own colored experiences to one another, and color seems to be importantly different from other experiences. Indeed color as qualia is actually very consistent with color unity. Furthermore, these experiences can be sorted by similarity i.e. red and orange experiences are more similar than either is to a green experience.

Out of all of our various folk beliefs only simplicity and unity are consistent with qualia.

That folk theory and qualia are only somewhat consistent presents a minor problem for color as qualia. Furthermore, qualia's strange properties make them very difficult to nail down: you can't talk about them easily, you can't know about anyone's qualia but your own etc. As such there has been ample effort to resist this idea of qualia among some philosophers. However, they are met with a rather massive amount of argument in support of qualia. Notably, Frank Jackson, a philosopher of mind and epistemology, argues powerfully for the existence of non-physical facts that might suggest the existence of qualia.

Section 3: The Color of Mary's Experience

Qualia seem very strange yet many philosophers are deeply attached to them. Jackson's thought experiment in his famous paper, *What Mary Knew*[76] represents an argument for the existence of non-physical facts that employs qualia. Though these non-

physical facts aren't necessarily color bearing, they would likely include non-physical color, which could help us answer, what, if anything, is colored.

Section 3.1: Mary the Neuroscientist

Mary has lived in a black and white room for her entire life, or in some versions has had surgery to destroy her color vision (something like achromatopsia[S]).[77] In this thought experiment, physical sciences (neuroscience, physics, biology etc.) have been completed [T] and Mary has 'complete knowledge of all the physical sciences.' Thus, Mary should know everything there is to know about color perception, despite having never experienced color first hand. One day Mary is allowed to leave her black and white room, or receives corrective surgery so she can see colors. The question is: when this happens, when Mary experiences colors for the first time, does she learn something new despite her 'complete' knowledge of physical science?

Many people are tempted to say, yes, she does learn something new. Here Jackson is claiming that despite knowing all of the *physical facts* about color perception Mary lacks knowledge of *all* the facts about color perception. If Mary does learn something new when she experiences color, it would seem that *non-physical facts* about experience must exist; namely that "what it's like to see color" is, or at least involves, non-physical facts. Again, these non-physical facts seem to include the existence of non-physical colors as the basis of experience.

In responding to Jackson there seem to be two possible options relevant to my project of determining what, if anything is colored: (a) Mary does not learn anything new when she sees color for the first time, thus there are no non-physical facts and there cannot be non-physical color: or, (b) Mary might learn something new, and thus non-physical facts might exist, but these do not entail non-physical color. In the following two sections these options are explored. It is suggested that appeals along the lines of (a) are

[S] Cerebral achromatopsia is the loss of color vision due to damage to the ventral occipital cortex.
[T] For a discussion of what 'completed' science means (and the potential impossibility of its completion) see Churchland, Paul M. "Reduction, qualia, and the direct introspection of brain states." *The Journal of Philosophy* (1985): 8-28.

question begging, while (b) is more theoretically permissive and consistent with my suggestion of a color error theory.

Section 3.2: What Mary Didn't Learn

Among materialists option (a) is often the mode of choice in resisting Jackson, and a number of typical responses exist. However, a common theme within many responses is, I will argue, that they seem to result in question begging and disagreement about what the argument actually means. This potential question begging is the subject of the next few sections.

The knowledge argument presents a strong ontological claim about the existence of non-physical facts. This argument, when stated more rigorously goes:

> 1. Mary knows all the physical facts about human color vision before she views color for the first time. Because neuroscience is 'completed' so is Mary's physical knowledge.
> 2. There are some facts about human color vision that Mary does not know before her release.
> Therefore, there are non-physical facts about human color vision. [78]

As the knowledge argument's form is largely regarded as valid (even by Paul Churchland)[79] the concerns about it focus on the truth of its premises. Here it will be argued that support for, or contention with, the knowledge argument depends upon the type of knowledge Mary has, and if one imagines that completed physical science can account for this knowledge.

Indeed a frequent concern with the knowledge argument is that it is dependent upon one's ability to imagine what 'completed physical science' would look like, as well as the general possibility that physical science could possibly be completed. Here it is argued that this is the source of the question begging nature of the Knowledge argument. As Churchland, our prototypical materialist believes the knowledge argument gets this idea wrong he is not persuaded by the argument's dramatic conclusion. On the other hand, Jackson is satisfied with this conclusion, as he already believes physical sciences can never explain experiential consciousness.

Section 3.3: Imagination and Types of Knowledge: Materialism Leaves Something Out

This idea is captured by one of Churchland's responses to Jackson. (It should be noted other similar arguments exist.[80] [81] However, Churchland provides the clearest neuroscientific perspective.) He asserts that there are two different types of knowledge at play, and Jackson has mistakenly conflated them. Jackson mistakenly assumes Mary has complete physical knowledge, when all she really has is complete *explicit* physical knowledge, while lacking procedural (physical) knowledge.

If this is the case, Churchland argues, Jackson has painted an incorrect picture of what completed physical knowledge (and indeed what completed physical science) would look like. Thus it doesn't matter if Mary seems to learn something new, as Jackson's conception of completed physical knowledge is actually incomplete. Mary might indeed learn something new, it just happens to be a physical fact, of the 'procedural knowledge' sort.

To understand this a look at explicit and procedural knowledge is necessary. Explicit knowledge is factual knowledge, or 'knowing that.' It can be stated in the form of propositions and includes things like descriptive steps in how to tie a tie. Procedural knowledge, or 'knowing how' on the other hand, cannot be spelled out in descriptive steps. This type of knowledge includes things like how to move your hands about to properly tie a tie.

Interestingly, procedural knowledge (or something very much like it) might account for the unusualness of the knowledge argument. It has been demonstrated that in many cases when you learn something, there are clear brain changes that occur. One particular change that occurs is termed long term potentiation (LTP) and results in changes to cell structure and connectivity.[82] Particularly, LTP is an enhancement of communication efficacy between connected neurons. One particular region, the hippocampus, is notable in its apparent proclivity for LTP.

These changes in cell structure also occur in a very interesting set of hippocampal cells, called place cells. These cells have been demonstrated to respond to particular

environmental areas. For example: when a rat enters different parts of a maze it has been trained on, its place cells will preferentially respond to different locations in the maze.[83]

The changes the rat's brain undergoes, both in terms of connectivity and activation towards environments it has been in previously, can suggest a basis for experiential changes in neurophysiology and function that might explain experiential knowledge. These place cells develop different connections and activity patterns following exposure to different environments; each cell corresponds to a unique location and is preferentially active when the rat is in that location. This represents a neural change in response to an experience; the rat is perhaps recalling *what it is like* to be in that location again, and that experience is actually represented by neural firing.[U]

There thus seems to be support for some kind of experiential-neural knowledge, though the details of place cells and affiliated networks are still an active area of research. As such, it seems reasonable that Churchland asserts that experiential knowledge can be explained by neurological activity. A rat who has never been trained on a particular maze does not have place cells that will respond when it is placed in the maze; it must first experience that maze and learn what it is like – something that place cells seem to explain.

In the same way, Mary knows that experience can change how the brain is wired and behaves. However, her brain is not wired in that particular way so she cannot be expected to know beforehand what it would be like to see color, as her brain lacks some sort of color representation. If this is the case, Mary is still expected to learn something when she leaves the room; it just happens to be physically explicable. (In chapter 6 a more through examination of what a neurological explanation of color experiences might be like occurs.)

In response, Jackson asserts Churchland has gotten it wrong: it doesn't matter what *kind* of knowledge Mary has, but rather *what* she knows. Mary, according to Jackson, knows everything about physical sciences, so her physical knowledge cannot be

[U] What it is like to be a rat is obviously outside the scope of these experiments. However, the function of place cells seems to suggest the possibility of a physical basis for experiential knowledge. Presumably all we have to do now to prove this point is to wait for neuroscience to advance.

incomplete. This points to the fundamental difficulty: Churchland imagines completed science to contain experiential knowledge, while Jackson does not.

The Knowledge argument seems merely to function to test your ability to envision what completed science could look like and how this would change our understanding of consciousness. As this stumps most laypersons, (and many, if not most, neuroscientists) the argument seems to offer a very strong conclusion for the existence of non-physical facts and the impossibility that we could ever understand consciousness completely. The question begging nature of discussion surrounding the argument is further suggested with a look at Jackson's response to Churchland's second objection. Namely how closely this response mirrors Churchland's first objection to Jackson.

Section 3.4: Imagination and Types of Knowledge: Dualism Leaves Something Out

Churchland also asserts that the knowledge argument proves too much, and it can be turned around to suggest that dualism is actually false. He suggests that Mary, instead of having complete knowledge of physical science, has complete knowledge of something he calls 'ectoplasm' which is non-physical and completely explains the behavior of qualia and the nature of dualism. Mary then experiences color for the first time, and still seems to learn something new. If Mary has complete knowledge of ectoplasm (and thus of dualism) it seems that dualism leaves something out.

Jackson's response looks very much like Churchland's first objection about types of knowledge. He asserts that this knowledge of ectoplasm does not possibly contain knowledge of qualia as it leaves out the experiential component of this knowledge, the key to qualia. He even says,

> The premise in the knowledge argument that Mary has the full story according to physicalism has to be replaced by a premise that she has the full story according to dualism. The former is plausible; the latter is not.[84]

One can easily imagine Churchland's reply: the point is not what *kind* of dualistic knowledge Mary has, but rather, *what* she knows, namely everything about dualism. This exactly mirrors Jackson's response to Churchland's 'types of knowledge' argument.

In each case one side is unable to imagine the other's version of events; Churchland envisions completed neuroscience as able to explain experiential knowledge, whereas Jackson does not. If it could be shown that the relevant non-physical facts do not exist at all, it would suggest non-physical color also couldn't exist. However, the Knowledge argument represents a significant area of contention, largely because it is such a strange argument with such deep implications.

Section 3.5: Undesirably Strong Conclusions from the Knowledge Argument

Churchland's ectoplasm argument also suggests that the knowledge argument proves too much. By reformulating Jackson's argument and substituting dualism for materialism, Churchland seems to show that dualism leaves something out and is thus unsatisfactory in the same way that Jackson seemed to show that materialism left something out and was thus unsatisfactory. Especially given Jackson's reply to the ectoplasm argument, it seems that that the knowledge argument might serve only as a litmus test for your beliefs about what physical science can or cannot tell us.

The size of body of literature surrounding the knowledge argument is astounding, and the presented concern is only one of many. However, it reveals how much is apparently resting on the conclusion of this argument. Given the immense divide on this topic, a response that can remove non-physical color, while remaining neutral on the general existence of non-physical facts, is significantly more appealing. It is my intention to move forward with this more permissive line of inquiry.

Section 4: What Mary Might Have Learned

Jackson argues powerfully for the non-physical nature of experiential consciousness, yet he is only concerned with the experiences of the perceiver. As such it seems possible that Jackson can assert *experiences* of color are non-physical without implying anything about non-physical color itself. It might seem that color experiences imply colored entities. This was suggested previously by (2) [if color judgments can be true, strictly speaking, then something exists that is colored] but, it will be shown, the various properties of qualia actually preclude this. Furthermore, as Jackson only talks of experiences of color, (1) [if color is real, then something exists that is colored] is largely

irrelevant to the conclusions of the knowledge argument. If this is the case, it seems non-physical facts like qualia can exist without entailing the existence of colors.

A key component of statement (2) is that color experiences alone do not entail colored entities; the 'can be true' portion is essential as it suggests colored experiences can be meaningfully compared to, or are possibly dependent, on colored entities of some sort.

However, (2) can be discarded for two reasons, first, because it entails a correspondence theory of truth, which has largely fallen out of favor and second, because if correspondence theory is employed with qualia, a strange situation results.

Section 4.1: Correspondence Theory

Given (2), one way for color experiences to entail non-physical color would involve the assumption that some kind of correspondence theory of truth is in place. Such a theory suggests that in order for something to be true it must correspond to some fact or state of affairs, it is often stated in one of two ways: [V]

(A) x is true iff x corresponds to some fact;
x is false iff x does not correspond to any fact;
(B) x is true iff x corresponds to some state of affairs that obtains;
x is false iff x corresponds to some state of affairs that does not obtain.[85]

There is quite a lot of discussion over these different formulations, largely concerning their implications for falsehood.[W] Unfortunately, the correspondence theory of truth has largely fallen out of favor.

A number of concerns for the correspondence theory of truth exist, including its potential vacuity, and obscurity. In addition to these concerns, one more pertinent to the discussion of the truth of color judgments exists: That correspondence theories are unable to handle particular types of truth.

[V] "iff" is shorthand for "if and only if"

[W] For the sake of brevity these concerns will not be addressed here. A substantial discussion of a large literature on the subject can be found on the Stanford Encyclopedia of Philosophy's page on correspondence theory. <http://plato.stanford.edu/entries/truth-correspondence/>

Section 4.2: Correspondence Theories Cannot Handle Particular Types of Truth

Correspondence theories are notoriously unsatisfactory in dealing with the truth of mathematical, moral, or aesthetic claims. The reason for this is because these types of truth are not completely determined by physical states of affairs. For example, it's a well-known mathematical fact that there are infinitely many prime numbers.[86] However, there are not infinitely many objects in the world that these prime numbers could correspond to; thus it seems there is not a ‘state of affairs’ that could make that mathematical fact true.

Correspondence theory has a number of issues; the relevant concerns about it have to do with its unsatisfactory handling of non-physical states of affairs. As color has been removed from physical places then it seems similar concerns are also relevant to color.

Section 4.3: Properties of Qualia and Correspondence

Given that correspondence theory is not very well supported, and that it has difficulty dealing with non-physical entities, it seems undesirable that (2) should rely on it. However, in this section I will show that even if one is a supporter of correspondence theory, (2) does not entail non-physical colors because of the various properties of qualia.

In order to ascertain if our color judgments are true or not, according to correspondence theory, we need to compare them to some fact or state of affairs. As qualia seem the best possible location for non-physical colors it also seems they should be the state of affairs we are concerned with. However, if qualia are considered to be some sort of ‘object’ (albeit a non-physical one) that determine the truth-value of these color judgments, a problem results. As physical colors have been eliminated, qualia now are treated as objects of observation, which is highly problematic, resulting in a regression of sorts.

The key question here is: Just who is doing the observing?

This regression is referred to as a homunculus problem. The brain somehow examines qualia, as if they are images on a movie screen. This seems to imply there is a

tiny person, or homunculus, in the brain watching this movie screen. How then, can this homunculus see the movie? Another homunculus of course, watching the movie inside the brain of the first! But then how can this second homunculus see the movie? In order to answer this question, an infinity of nesting-doll homunculi is needed. This represents an infinite regress and is very unsatisfactory. In fact, this sort of problem is often used as a litmus test to determine is a theory of consciousness is adequate. If this problem arises the theory is often looked upon spuriously.

As such, it seems that even if we grant that the knowledge argument suggests the existence of non-physical facts,[X] these facts *do not* entail the existence of non-physical colors.

Section 4.4: Homunculi and Qualia

Though the homunculus problem has been introduced as a problem for correspondence theory, it may also represent a general problem for qualia. Under folk theory qualia are treated as objects of observation. Folk ideas of color suggest that we 'view' or 'see' colors. Thus, if color is identical to qualia then it seems that we are also seeing or observing qualia. This is an obvious example of the homunculus problem, and presents one of many problems for color as qualia. More of the many issues with qualia are discussed next.

Section 5: Concerns about Qualia

Dennett, again in "Quining Qualia," offers a number of not-quite-arguments against qualia, which he calls intuition pumps. These will not all be detailed here. However, a few pertinent examples will be discussed to demonstrate the kinds of push back against qualia that are possible.

Dennett poses the idea of intrapersonal qualia inversion in *intuition pump number five: the neurosurgical prank*.[87] One day, a devious neuroscientist performs surgery on you; when you awake from this surgery you find that the grass is red, that the sky is

[X] This conclusion will no doubt displease materialists, as it does not discard *the possibility* of non-physical facts. This is not to endorse these facts either, but rather to allow my theory to be considered independently of your stance on the existence of non-physical facts.

yellow, etc. As other people don't seem to be experiencing this difficulty, it seems that all of your qualia have been inverted; the problem is with your experience, not the world. Dennett suggests that because you are able to give a detailed account of your experience of this inversion, qualia seem like they might be legitimate properties after all.

However, there are two possible reasons for this inverted qualia as Dennett details in *intuition pump number six: alternative neurosurgery*.[88] It seems the neurosurgeon might have done one of two things. She might have (a) altered your early, pre-qualia producing channels such that data channels that once caused a red quale have now been switched with data channels that once caused a green quale. In this case, as qualia occur downstream from this switching event, it seems your qualia really have been inverted.

Or, (b) the neurosurgeon has left your pre-qualia channels alone, but instead has altered your memory access; causing you to essentially misremember which color qualia were associated with which sorts of objects. In this later case your qualia have not actually been inverted at all, merely your memories of them. It seems then that our access to our own qualia is not as privileged as we would like to think. Not only that, the neurosurgeon know knows more about the state of your qualia than you do.

This presents a huge problem for qualia. It was previously mentioned that perceivers have direct and privileged access to their quale, however in this case the unfortunate victim of this neurosurgical prank does not know the state of his own qualia; it is unclear to him if his qualia have been inverted, or the memories of his qualia have been inverted.

In the rest of Dennett's paper other arguments about qualia's insensibility are presented, making a more robust case to be rid of qualia. These arguments alone might not destroy qualia, though they do question their rigor and comprehensibility.

In this paper it is not my intention to get rid of qualia, though it is my belief that Dennett has done a rather excellent job in doing so. For the purposes of this paper I wish to remain as theoretically permissive as I can, while still making meaningful claims about the nature of color. It is preferable that my notion of color does not rest on the heated topic of whether or not the mind is entirely reducible to physical brain states. As such I

neither support, nor reject qualia. Ultimately, because color is suggested to not exist anywhere, whether or not qualia exist should be a moot point, so long as I have effectively demonstrated that colors do not reside in qualia.

The rationale for presenting problems with qualia is to provide further impetus to move color out of qualia. These are rather unusual arguments, and are quite unintuitive. On the other hand a lot force behind arguments like the knowledge argument involve appeals to common sense – as it really *seems* (to most people) that Mary does learn something new when she sees color for the first time. Therefore, it seems only fair to present some arguments against qualia to counterbalance the pull of common sense.

Ultimately, I have suggested that qualia are not an adequate place for color. Given the various problems with qualia it seems undesirable to place color in such a confusing and potentially flawed location if any more plausible alternatives are available. It is this question I turn to next.

CHAPTER 6: Color Judgments without Color

ABSTRACT: In this chapter the nature of color experiences will be examined with neuroscientific data. It will be suggested that the way color experiences actually occur is very far removed from what we normally mean when we talk about color. As such, a double error theory is suggested: not only are we mistaken in attributing color to the world, we are also mistaken in thinking colors can exist anywhere else, for example as subjective features of our experience, or other non-physical 'places.' Ultimately, we may still speak meaningfully of color experiences or judgments. Importantly we can do so even without the reality of color.

Section 1: Error

Given these problems with qualia, it might be best to not place color in qualia, though it is not necessary to discard phenomenal experiences as we continue our exploration of color. Nor, as we shall see, is it necessary to discard any of the physical properties or processes I have discussed in earlier chapters, even if we cannot identify any of them with colors. With that in mind, in this chapter I will suggest a new conception of how our color judgments are formed and what they are reliant upon.

This new conception of color will demonstrate that what actually brings about our color judgments is utterly divorced from our initial folk ideas about color. As such it introduces the idea of a color error theory.

Color error theories are not especially new: Boghossian and Velleman,[89] [90] Maude,[91] Hardin,[92] and earlier Locke[93] and Descartes[94] put forth what are considered to be versions of color error theories. Error theories of color are also termed color fictionalism, color irrealism, and color nihilism. Though these theories differ slightly in their formulations they generally consider the purported properties of color to be non-actual.

In the tradition of these error theories I will suggest that if color cannot be shown to match up with any of our usual ideas about it, then perhaps we are not talking about color at all. Ultimately I will suggest a double error theory. Not only are we mistaken in thinking colors exist anywhere, physically or non-physically, we are also mistaken in attributing color to our experiences.

What will set this particular error theory apart is where the vestiges of color end up, namely that talk of color judgments will replace standard notions and talk of color. It will be shown that our judgments of color arise from a complex set of reactive dispositions that are dependent upon language, attention, and memory, and perhaps other properties. If this is successful two things should result: (1) color, again, cannot possibly find a home in qualia (as we saw in the previous chapter) and (2) color is shown to be so radically different from our folk conception that even if qualia survive this argument, color, as we typically think of it, must be discarded.

In the following sections I will use data from neuroscience to further reject the idea of color as a property of any physical, or non-physical locations. In doing so, much of the focus will be on the nature of our color judgments or experiences.

Section 2: Color Experiences Without Color

I have now explored the first main question of this paper - what, if anything is colored? And suggested that the answer is nothing. Colors are not properties of anything physical or non-physical. I next turn more closely to the second, namely, what is the nature of perceptual experiences of color?

Folk color suggests a simple relation between colors and our experience thereof, namely it seems to hold that color perception = the perception of color, which seems to presuppose the reality of color. In the previous chapter it was suggested that color as qualia does not work very well due to problems with qualia itself as well as considerations about the truth of color judgments. In my treatment of the first main question, I have suggested that colors do not exist anywhere, physical or non-physical. It seems then that there is a problem with this folk notion of color experiences; particularly its right half, as there are no colors to be perceived.

In this chapter, I concentrate on the second main question of the paper, and focus on the left half of the formula. It will be suggested that color perception is not simply the perception of color; instead it is a complex set of processes involving physiology,

memory, attention, language and other seemingly disparate workings of our brains.[Y] Because of this complexity and non-intuitiveness, it is better to refer to "color perceptions" or "color experiences" as "color judgments" as they are actually complex cognitive processes as opposed to simple, straightforward reactions to environmental data.[95]

This chapter will attempt to show the complexity of color judgments and in doing so suggest that color judgments can and do exist in the absence of what we usually refer to as color.

In turning to color judgments as a last potential source for our ideas about color, it will be shown that none of the ideas from folk color can persist. As these color judgments have supplanted qualia as a non-physical option for color to reside in, it might be tempting to consider 'color judgments' as a simple linguistic replacement for 'qualia.' This is not the case. No one is tempted to call color judgments themselves, colored. As such they are very different from qualia, and are not a literal location for color. Just how very different color judgments are from color qualia will be demonstrated in this chapter.

If color judgments can be further divorced from aspects of folk color, the notion that color judgments can exist without color will make far more sense. Dissolving notions of folk color and thus removing the impetus to believe in colors in virtue of the complex nature of color judgments will be the business of the next sections. This will be accomplished by examining a number of cognitive aspects of color judgments, these will include:

1. Color judgments and memory, how our knowledge of objects influences the color judgments we make.

2. Color judgments and attention, what we focus on when making color judgments can influence the nature of these judgments.

3. Color judgments and language, having names for colors influences our color judgments; particularly having more color names enhances our ability to distinguish colors – by which I mean that we are able to make more fine-grained color judgments.

[Y] Though this sounds very materialist-focused, there is no reason that non-physical facts might be involved in the creation of color judgments – these facts are just not themselves colored.

4. Color judgments and rules of thumb or heuristics, our color judgments result largely from what we expect them to be in virtue of our past experiences, these include things like cues from shadows and object boundaries.

Section 3: The Aboutness of Sensory States and Color Vision without Color

Some previously provided evidence that helped remove color from objects and from light began to suggest that color judgments are not simply 'about' the world, as they seem to be. In Chapter 4 it was shown how opponent process and trichromatic theory can explain various color behaviors such as complementary colors, color mixing, and the primary colors.

These examples were used to show that color might be considered to be a subjective feature of perceivers. However, they also suggest that our sensory systems do not simply take data from the world and present it to us. Instead they alter or process the data we receive in important ways; this is the first step towards showing that color judgments can exist in the absence of color.

Kathleen Akins,[96] in her paper "The Aboutness of Sensory Systems," explores this question and argues that instead of accurately representing the world, the senses merely provide us with a narcissistic picture of the world that enables us to protect ourselves by responding to our environment.[Z] In this view, color is not a salient environmental feature, but instead something we project onto the environment to make better sense of our world. This notion is consistent with an error theory, as colors are pervasive errors that we create and mistakenly attribute to the world.

This picture of color becomes clearer when one looks at evolutionary reasons why color vision developed in the first place, not as a veridical representation of the world, but as a feature that enabled increased evolutionary fitness. This might seem inconsistent: Why would color vision be useful if colors don't exist anywhere?

[Z] Akins' paper is not focused on color; she presents arguments involving our thermoreceptors and offers examples such as the famous 'two hands in a bucket' problem. Despite this, many of her concerns are directly applicable to concerns about color.

Section 3.1: The Evolution of Color Vision in the Absence of Colors

Richard Hall has provided an interesting response to how color vision might have developed in the absence of color.[97] He asserts that though colors may not exist in objects or light, having a way of distinguishing objects that is relatively constant over time is evolutionarily beneficial even if that information doesn't point to anything 'real' about the object. The relationships between physical properties and color experiences are essentially arbitrary.

Here "arbitrary" is not taken to mean inconsistently or randomly, but instead without any logically necessary connection. If wavelengths and the phenomenal experiences they cause were necessarily connected it would be impossible to conceive of the various physical processes (such as wavelength and physiological responses) that lead up to a red color judgment as instead leading up to a judgment of green. Though it is the case that you are 'wired' such that L cone activity is consistently connected to red color judgments, there is no apparent contradiction in conceiving of these cones being wired to produce green experiences.[AA]

Though our color judgments may be somewhat arbitrarily projected onto the environment, they do provide information that is useful. For example it has been demonstrated that people with normal color vision are faster at picking out fruit amongst foliage than monochromats (who view the world in roughly[BB] black and white).[98] Though color judgments may be arbitrary they play a useful role in picking out objects, thus these judgments don't have to pick out particular physical traits to be meaningful. What matters from an evolutionary perspective is not that our color judgments actually correspond to things 'out there in the world' but rather that there is consistency in how our color judgments are related to physical properties.

[AA] This 'conceivability as a test of distinction' argument echoes classic arguments made by figures like Descartes and Saul Kripke.

[BB] There is some issue in claiming this, as there are no instances of someone developing monochromacy and thus no way to know what monochromats' color judgments are like in comparison to trichromats' judgments. Some researchers suggest that it is like seeing the world in shades of blue, as in many cases only the blue cone is functional. This is true of all monochromats and it is unclear what this description would really mean to them, as they only experience one hue.

It is interesting that fruit, a main source of food for primates tends to be red, the opposite color of its surrounding green foliage. This may seem to suggest that color is actually in the objects in question. However, an alternative scenario seems more likely given all the suggested problems for color-object realism. Because fruit represented a significant food source for our primate ancestors, those individuals who could better pick out fruit had an adaptive advantage. By forming color judgments such that contrasting colors were projected on fruit and foliage these arbitrary features helped increase evolutionary fitness.

That fruits tend to be red is a two way street. It could also be the case that because our ancestors were sensitive to the properties of particular food sources, these fruits became more prevalent as a result of the greater seed dissemination our ancestors afforded them.

Another interesting study shows that people with normal color vision can distinguish fruit from foliage much faster than can people with anomalous trichromatic vision.[99] This is importantly different from the first comparison between monochromats and trichromats. Anomalous trichromats are individuals who have all three types of cone cells, but express one cone type in lower frequency. This results in a form of color blindness, though this varies in severity between individuals. These individuals are still able to distinguish red and green, but this distinction is less clear.

These individuals receive roughly the same data from the environment as normal trichromats though they experience it differently. As their subjective experiences of red and green are less intense they cannot as immediately distinguish fruit from its surrounding foliage. This does not suggest that people with normal color vision are seeing the world 'correctly' but rather their perceptual experience allows them to interact with their environment more effectively.[CC] This evolutionary story is simply one of the ways in which color has proved to be a convenient, though fictional, feature of our perceptual experience. Again, evolutionarily, consistency between our color judgments

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[CC] That colorblindness has persisted instead of being selected against is an interesting question. Some studies suggest that some forms of colorblindness are latitude dependent – in higher latitudes colorblindness is more prevalent, suggesting it may confer some evolutionary advantage that is environment-dependent. What this advantage might be is currently unknown.

and physical properties is important. However, that color judgments actually be about a single salient feature in the world (which we call color) is unnecessary.

Section 3.2: Color Judgments and Sense Data

The problem with folk theory is that it seems to suggest we get color information from the environment and perceive it directly. Akins and Hall have already suggested an alternative view of this, which will soon become even more apparent.

My suggestion – that color judgments do not require color - does not discard the salient physical properties that are referred to by realists as color bearers. These features play an important role in the creation of our color judgments; our eyes are preferentially sensitive to different wavelengths of light, and the properties of objects that this light interacts with are meaningful in altering those wavelengths. Folk theory would have us believe that these features of the environment are directly perceived and it is these properties that *are* colored.

Under my conception of color judgments, it is not necessary to ignore the importance of these physical properties. The information we receive from our sensory apparatus about these properties definitely factors into our color judgments, yet they are so heavily altered by other cognitive aspects it is inappropriate to refer to these properties as color.

In the following sections it will be shown that our color judgments are created so as to offer a cohesive picture of the world; the various behaviors of color can be nicely explained by examining what exactly the brain is doing when we make color judgments.[DD] However, as previously mentioned, these color judgments are so far away from what we generally think of as color that we might instead discard color all together.

[DD] Again, this is not to explicitly support materialism, it is conceivable that non-physical facts could play a role in color judgments. However, as most dualists accept that the brain plays an important role in conscious experience, only discussing brain activity allows for a more permissive theory.

Section 4: Color, Memory, and Object Knowledge

An odd feature of color judgments is that they appear to be highly dependent on memory and object knowledge. This runs contrary to folk beliefs about color, which suggest color is a simple experience. Daniel Dennett, in his book *Sweet Dreams,*[100] offers a compelling treatment of this with a modified version of the knowledge argument.

In this scenario Mary is in the same position as she was initially; she has complete knowledge of physical science, but has never experienced color first hand. However, in this version, upon receiving color vision Mary is presented with a blue banana, but is not told that the banana is blue, or unusual in any way. Because Mary knows everything there is to know about neuroscience she will not be fooled by this and will notice that the banana is the wrong color. That Mary can identify that the banana is the wrong color suggests that she can presumably also identify when it is the correct color; if this is the case it seems like her lack of experiential knowledge is not a deficit, and that even in the absence of color experiences, Mary can know about the nature of color judgments.

Mary is aware of the blue banana deception because particular colors cause particular reactive states in perceivers. Yellow causes a response distinct from blue, for example, and these colors are associated with particular objects and experiences. It may seem odd that Mary would be able to tell that a banana is the wrong (or right) color given that she is an experientially naïve observer. However, this idea has some support from neuroscience, which will be discussed next.

Section 4.1: Unexpectedly or Abnormally 'Colored' Objects

One study suggests that viewing abnormally colored objects result in activation of different brain areas than are activated by objects that we judge to be of 'normal' color.[EE] In this particular study,[101] images of fruit were presented to subjects, as well as the same images with 'false colors,' as shown in figure 29.

[EE] Interestingly, a key point of this paper suggests that color pathways are not necessarily tied to form. However, that color may be processed independently of objects does not diminish the significance of object involvement in color judgments

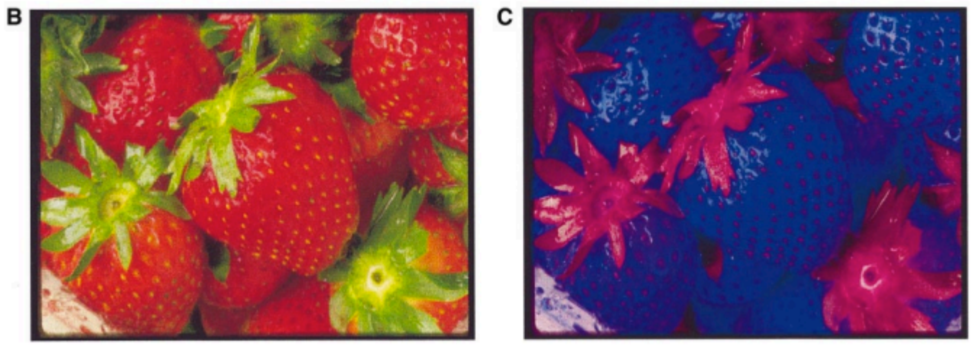

Fig. 29: Sample stimuli of normally & abnormally colored objects

Our color judgments are intimately tied up with objects and our reactions to these objects; we know what our color judgments about bananas are usually like, namely 'yellow.' However, this study demonstrated that when our color judgments are as we expect them to be, different brain areas are active then when these color judgments are atypical. Particularly, changes in activation of visual area four (V4), an area often termed 'the color center,' as well as hippocampal areas occur (the hippocampus is widely accepted to be importantly involved in memory). Changes in these areas suggest that memories of judgments about object color are important in forming new color judgments.

That there are apparently different processing pathways for normal and abnormal color judgments are directly supportive of Dennett's suggestion that Mary would indeed know if she was looking at a blue banana. This information is due to apparent differences in reactions to a stimulus, thus if Mary can examine these different reactions she can effectively know if her color judgment is correct or not.

Furthermore, that object knowledge (namely knowledge of which color judgments are associated with which objects) alters how our color judgments are processed runs contrary to the folk idea of simplicity. This constitutes an analysis, as we can point to distinct brain areas that result in different color judgments. This is just the first of many analyses that color judgments might be subjected to.

Section 4.2: Color Judgments and Language

In this section a version of the Whorfian Hypothesis is presented. In its 'strong' form, this hypothesis suggests that language largely determines our experience of the

world. This is sometimes referred to as linguistic determinism. This 'strong' version of the Whorfian hypothesis has been largely discredited and in fact is widely considered to be a blatant misinterpretation.[102]

The weak version of the Whorfian hypothesis suggests instead that language does influence our perception, but it is by no means wholly deterministic. This weak version actually has a good amount of empirical support, and it is generally accepted that language does play some sort of correlational role in determining our experiences.[103] [104] One of the main ways the Whorfian hypothesis is studied is through our color judgments. Numerous studies have been conducted, which suggest that color naming can importantly alter our color judgments. If this is the case we can further resist folk claims about color such as simplicity and unity, as color judgments are dependent upon higher functions like language. Two instances of this are examined below.

Section 4.3 An Extra Shade of Blue

An excellent example of language apparently influencing color judgments is a study conducted on native Russian speakers and English speakers. Russian has two words for blue, one for dark and one for light blue, English on the other hand only has these modifiers (light and dark) for blue.

Russian speakers in this study were able match shades of blue with one another with greater speed and higher accuracy than their English-speaking counterparts.[105] Though this is not very robust evidence it does suggest the weak form of the Whorfian hypothesis; suggesting that language might alter color judgments. This particular case does not necessarily alter *how* color judgments are made, but rather the speed at which they are made. (Though this speed may also be important, as the Stroop task suggests; this is discussed in section 4.5.) However, other cases exist where linguistic features are thought to alter the actual character of the color judgment.

Section 4.4 A Missing Shade of Blue

Jules Davidoff demonstrated a more dramatic example of this in an experiment conducted with the Himba tribe of Nambia; this tribe does not have a word for blue at all, and does not distinguish between blue and green.[106] Participants in this experiment were

shown a screen with 12 colored squares, 11 green and one blue and were asked to determine which square they judged to be a different color than the rest. Though one of the squares appears to be dramatically different to English speakers, Himba participants took significantly longer and made more mistakes in picking out the blue square than did their English-speaking counterparts.

Fig. 30: Member of the Himba Tribe with screen displaying 1 blue, and 11 green squares

Though the Himba do not have a word for blue, they do have several words for green. Another test in the same study reveals something very interesting that might implicate this linguistic fact in the results of this experiment. Participants were then shown another image (figure 31, though with the red/blue/green codes removed) and asked again to pick out the square that they judged to be a different color than the rest. When presented with this image, participants very quickly picked out the different square.

This suggests that color naming is very important for making color judgments, namely deciding which appear the same, and which are different. Though the difference between blue and green is very apparent to English speakers, who have distinct words for those color judgments, the difference is not very apparent to those who lack corresponding color words. On the other hand, as the Himba have words for distinguishing between shades of green, they quickly detect differences in figure 31 that are invisible to English speakers.

There's nothing out there in the world causing this difference, instead an arbitrary linguistic feature seems to determine how we make color judgments. What's more, our color judgment is apparently being altered by language in a profound way, suggesting a 'higher function' like language actually can significantly impact a seemingly simple sensory experience.

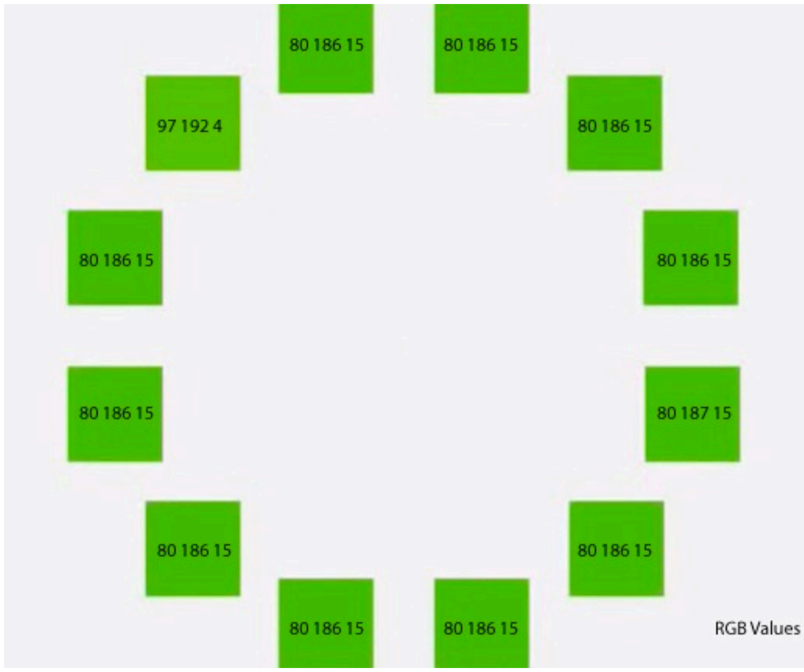

Fig. 31: Can you spot the difference? Note red/blue/green values on each square.

Section 4.5: Color Judgments, Language, and Attention

That color judgments are dependent upon language and other features outside of experience is further supported by a particularly interesting 2012 paper[107] that suggests that our reactions to objects are influenced by what color we judge them to be, and by how relevant this color judgment is to the task at hand.

In this experiment subjects were made to attend to color by participating in a Stroop task. This task requires participants to say the 'color' of the ink a color name is printed in, where the ink is a different color than the color name. For example, figure 32's first row would be read: " blue, red, green, yellow."

Fig. 32: Sample of the Stroop task.

People tend to have difficulty with this task because the brain can actually read words faster than it can form color judgments because forming color judgments is thought to require more attention than reading a color name.[108] As such, because the reading pathway happens faster, it interrupts the color judging and naming pathway, making the task challenging.[109] This is interesting as color perception is regarded as a more simple, or lower level process than reading is. But the Stroop task suggests otherwise. This again suggests that color perception is not merely the simple perception of color, as many color realisms assert.

To return to the initial experiment, subjects were given this Stroop task and shortly afterwards were made to perform a semantic judgment task, where they were required to determine if a word on a card named an animal or not. A control group was given the Stroop task after this semantic judgment task, and it was shown that participants who had been given the Stroop task first, and thus made to attend to their color judgments, were significantly faster at recognizing similarities between object pairs that are associated with the same color judgment (for example emeralds and grass) than those in the control group.[110]

This experimental set up might seem unduly complex. However, its results elegantly suggest that our attention to color judgments is very important. Color judgments are highly relevant to some tasks. For example finding a cucumber will require us to pay attention to its greenness, while chopping it does not require the same attention. In this case, we form different associations between objects depending on whether or not we are paying attention to the color judgments we form about them.

The Stroop effect and this semantic judgment task are important in demonstrating the complexity of color judgments; they demonstrate that seemingly unconnected aspects, such as language and attention, can alter our color judgments and that these judgments can alter other cognitive features.

Section 5: Heuristics and Color Judgments

So far it has been suggested that language, attention and memory can influence color judgments. However Donald Hoffman, a professor of cognitive sciences at

University of California Irvine, offers more compelling support for this idea in his book *Visual Intelligence.*[111] He seeks to demonstrate that everything we perceive visually is a creation of the visual system and has surprisingly little to do with real objects and occurrences in the world. Instead our sensory apparatus takes in this data from our world, and then works with memory, attention, and other 'higher functions' to create our judgments of color. If this is the case, it seems far more reasonable to assert that color judgments can occur in the absence of color, as they are merely a function of the visual system attempting to make sense of the world. This may seem ambitious and non-intuitive, but his findings are supported by significant neuroscientific evidence.

Hoffman attempts to formulate a number of rules that the brain's visual system follows to generate cohesive color judgments by examining the way we perceive various figures. This is actually a well-studied idea in neuroscience, called heuristics, or best guess.

Section 5.1: Heuristics: Shortcuts to Problem Solving

Heuristics are often described as rules of thumb that people either create through experience, or are genetically hard-wired; the exact nature of heuristics is still an active area of research.[112]

When people make decisions they consider issues in a variety of ways that may be divided into two general categories: 1) systematically, logically, and verbally, or 2) intuitively, globally, and emotionally.[113] Heuristics are a part of this process and enable individuals to consider only the relevant information in making a decision. It is thought that when an individual is solving a difficult problem, or attempting to make sense of a situation, heuristics instead substitute a simpler and more likely solution, without our awareness.[114] This is analogous to a mental shortcut.

A pertinent example of a well-known heuristic is the familiarity heuristic. This involves an assumption that the circumstances that brought about previous results continue to be relevant to a new, though similar situation. This heuristic is applied in interesting ways; particularly in that it seems to impact the way laypersons make health decisions.[115] This manifests in their decisions to seek treatment that has either worked in

the past (despite whether or not it has supporting medical evidence) or that they are otherwise familiar with. This is thought to play a large role in why people often prefer to use brand name drugs or products, as opposed to cheaper generic alternatives. As they have heard of these brand names before they consider them to be more trustworthy.

Section 5.1.1: Heuristics and Abductive Reasoning

Heuristics are very close to something referred to as inference to best explanation, or, as it is sometimes called, abductive reasoning. This sort of reasoning goes like this; suppose you are walking on the beach and see what appears to be a picture of Winston Churchill made out of sand. It could be that ants wandering around in the sand just happened to create this image, as per Putnam's imaged case.[116] [117] However, you think that it is far more likely that someone drew this image in the sand, and thus you infer that this is what happened to create the image of Churchill.

What exactly constitutes abductive reasoning is a subject of uncertainty. According to the Stanford Encyclopedia of Philosophy, abductive reasoning entails:

> Given evidence E and candidate explanations $H_1,\ldots, H_n$ of E, infer the truth of that H which best explains E.[118]

There is contention about this formulation, and some issues with it have been pointed out; these will not be detailed here. It is sufficient to say that heuristics fall very close to these sorts of best guess inferences, and indeed might be considered a more specific case of abductive reasoning. As such, concern is focused on particular heuristics, as opposed to abductive reasoning as a whole.

It seems odd that something like a heuristic might apply to color judgments. Despite this, Hoffman offers several compelling examples of what appear to be shortcuts in our visual processing and reliable rules about these shortcuts. These are the topic of the next several sections. It is important to note that the types of heuristics discussed below might not apply to all color judgments; they are merely intended to illustrate some potential examples.

Section 5.2: Luminance Heuristics

Though this may seem tangential to color judgments, luminance is a vital component of these judgments, for without it everything would appear black. It is important to treat computational luminance as a dimension of color judgments; as such many of the examples in *Visual Intelligence* deal with luminance.

Section 5.2.1: Object Boundaries

One of most important uses for luminance judgments is to determine where the boundaries of objects are. Mach bands provide an interesting example of this; in figure 33 the bands of different shades of gray produce an interesting effect; the borders of each band appear to contrast more intensely with its neighboring band. This is due to a process called lateral inhibition.[119]

Fig. 33: Mach bands

When light shines on the retina a population of rod cells are stimulated. However, some are more stimulated than others; namely those in the center of the illumination field. These cells will send inhibitory signals to those cells that are on the borders of the illumination field, producing a more robust contrast edge and enabling the formation of sharper visual image.[120]

Lateral inhibition allows for more fine-tuned edge perception based on both color and luminance judgments.[121] [122] Perceptual features create artificially enhanced differences between parts of the image in figure 34. This enables us to interact with and understand our environment more effectively. In short, this process helps us distinguish between objects; the increased contrast that we experience doesn't exist in the world, instead it’s something we create in order to better detect object boundaries.

Section 5.2.2: Meaningful Shadows and Luminance or Reflectance Boundaries

Another important judgment about luminance has to do with our ability to determine if a perceived border in an image is due to a change in material or in luminance. These changes are termed reflectance boundaries and luminance boundaries, respectively.

Fig. 34: These shadows appear to be caused by people sitting down

Our interpretations of shadows represent a salient example of this process. In figure 34 you expect that the image is caused by two people who are blocking a light source and thus casting a shadow on the wall (a luminance boundary), as opposed to a collection of random objects that that happen to block the light in a suspiciously people-like shape; or a dark stain on the wall (a reflectance boundary) that again, suspiciously happens to be people shaped. We make these judgments because we have encountered them previously and by assuming that people cause these shadows, as opposed to these other comparatively unlikely scenarios, we are able to more quickly make sense of our surroundings.

Interestingly, this process isn't fool proof; as it turns out these shadows are due to piles of rubbish, as shown in figure 35, on the following page. However, the instances where you encounter a person-shaped shadow, and it actually turned out to be a pile of rubbish are so infrequent that it isn't worth your brain power to consider this as a meaningful possibility.

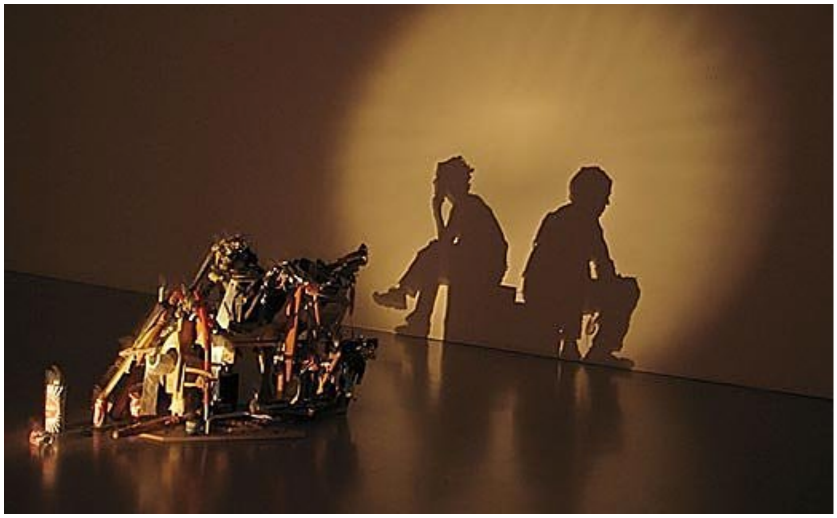

Fig. 35: Real Life is Rubbish by Tim Nobel and Sue Webster

Another example of a luminance heuristic from Hoffman, is related, though importantly different to the case of meaningful shadows. It has to do with the way people interpret boundaries of objects. In the figures below the central C-D shape seems to overlay the background in figure 36. However, in figure 37, if we shift this overlay such that its narrowest part overlays the luminance boundary of the background we no longer experience this C-D shape as a single transparent overlay. Instead we see the portions C and D as distinct figures in the plane of the background. Again this is an appeal to what we consider to be the most likely scenario that created these images.

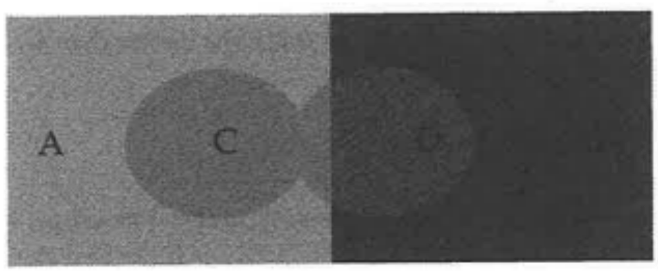

Fig. 36: A and B appear to be under the filter represented by object C-D.

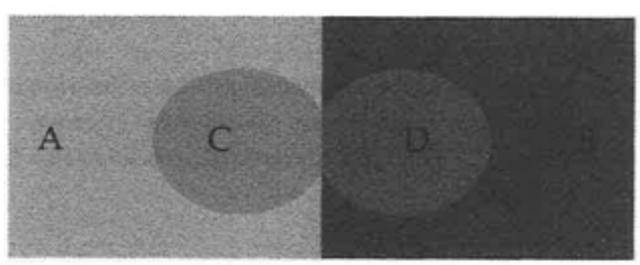

Fig. 37: A and B appear to be separate objects in the same plane as the background.

Another example reveals how transitions between boundaries are important in our judgments of luminance and how this contributes to our understandings of images. Essentially when there is a dramatic shift in luminance we interpret this as a reflectance boundary, while a more gradual change indicates a shadow as a luminance boundary. This is demonstrated in figure 38. On the right side of the image where the white bordered rectangle shadow fades out (its penumbra) we see this as a shadow. However if we alter the shadow so it appears to have a sharp edge, as has been done on the left, it no longer appears to be a shadow, but rather a new object in the image.

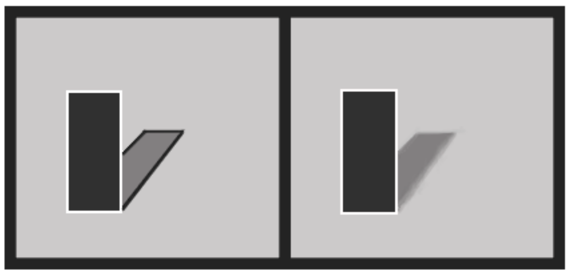

Fig 38: Effect of penumbra on interpretation of figure.

Another excellent example of luminance judgments is shown in figure 39. In this figure we view the green cylinder as casting a shadow onto the checkerboard. Because the checkerboard is a repeating pattern we expect it to continue in a uniform way across the image.

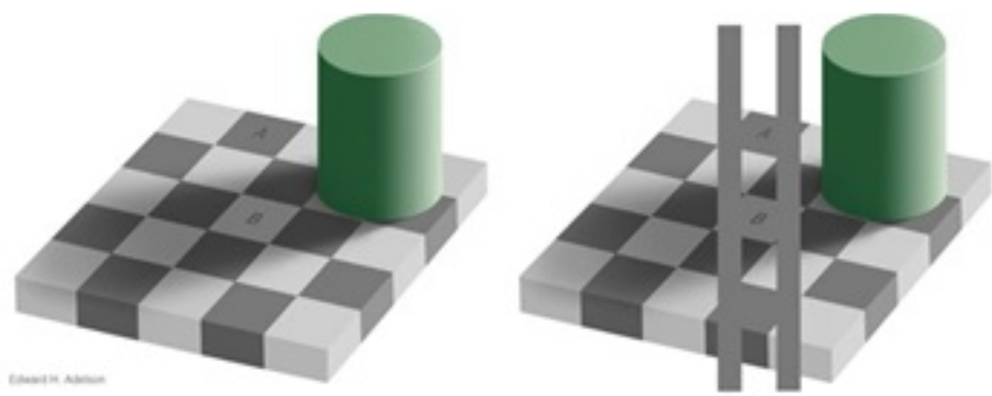

Fig. 39: Checkerboard shadow illusion,

Because the pattern suggests that square B should be lighter than square A, even though it is in shadow, we are surprised to learn that square A and B actually appear to be the same when put next to one another, as per the right side of the figure. In order to make sense of the shadow and repeating pattern in the image we interpret B as lighter

than A. Luminance judgments are made to make sense of our environments; we incorporate other environmental cues, such as repeating patterns and our expectations about shadows to form these judgments.

These examples demonstrate that we use subtle cues from our perception to interpret the stimuli presented to us. Most of these examples seem to be based on interpretation of objects. This should not be surprising as one of the main uses for color judgments is exactly this: interpreting where one object ends and another begins. Color and luminance are applied to help us make sense of our environment – these judgments are not based on simple sensory data, but instead are formed and attributed to our environment so as to tell the most consistent narrative about our world.

Section 5.2.3: Color Heuristics

Luminance provides a clear example of how heuristics are used to generate a cohesive picture of experience, namely of how we understand objects; it turns out that color heuristics are also used to similar ends.

This recalls interpretation of distance with parallax, focus, and obstruction cues that are well documented in psychology. This demonstrates how color judgments (or luminance, as this first example works just as well in black and white) can alter our interpretation of our environment.

In figure 40 (on the following page) even though all the shapes are actually in the same plane, the pink circle appears to be in front of the blue and yellow shapes because it obstructs your view of the other shapes in the image. Interestingly, in this figure I can refer to a square, even though what you actually see is a figure with four straight edges and a rounded edge; no square actually exists. But because you interpret that shape as ‘behind the circle’ it is more likely that it is actually a square that is being obstructed, not a shape whose edge happens to match up perfectly to the edge of the pink circle.

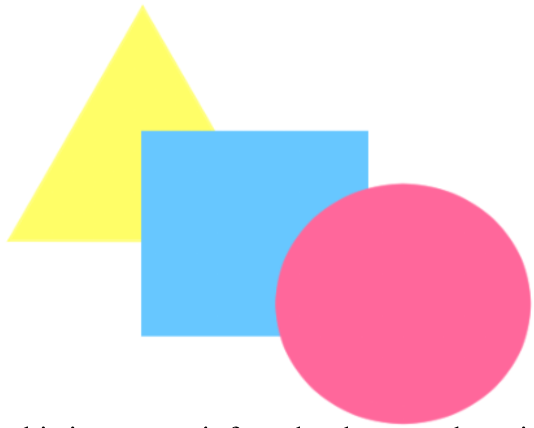

Fig. 40: The shapes in this image are inferred to be complete simple shapes in multiple planes, despite existing on one plane as incomplete shapes.

Judgments about hue and luminance may also work together to facilitate our understanding of our environment. The Mach bands, discussed earlier, also have a chromatic counterpart. In this case both hue and luminance interact to cause perceptions of enhanced contrast edges. In these chromatic Mach bands (figure 41) lateral inhibition works in the same way it did in the initial achromatic example as each band varies in brightness. Additionally, the activity of opponent cells causes the edges of each section to appear more pink or green, as they are compared to the relatively more green or pink areas adjacent to them.

Fig. 41: Chromatic version of Mach bands

Another example from *Visual Intelligence* again demonstrates the importance of color judgments in determining object boundaries with a very interesting illusion called the neon spreading illusion. In Figure 42, we observe a glowing square where the edges of the blue portions of the circle are smooth (on the left), while in the figure on the right, with blue circles bordering this transition, no glowing blue square is constructed.

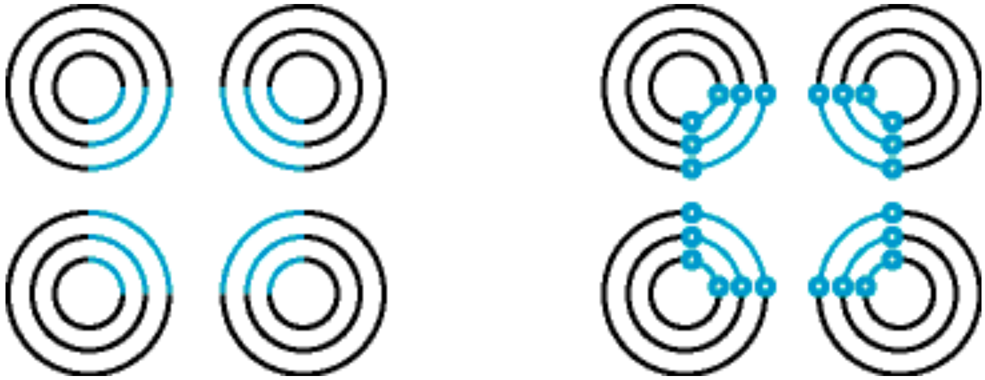

Fig. 42: Neon spreading illusion, a glowing blue square is visible on the left image

Hoffman attributes this to our brain's adherence to a generic view.[123] Your brain has relied on its past experience to construct the blue glowing area in the left side of the figure. When you have encountered edges as seen in the left side of the image it has usually been the result of a new object or filter that overlays the black concentric circles, in this case a blue square; not a coloring of portions of these circles that happens to line up at perfect right angles. The small blue circles destroy this illusion because the sharp edges of the imagined blue 'square' overlay are disrupted.

In all of the cases above, we do not simply see an image as it is; instead we make color and luminance judgments and construct an image that is consistent with what similar stimuli have turned out to be in the past. This may seem odd, but it actually has substantial neuroscientific support. Particularly, from two researchers, Lotto and Purves, who have worked extensively on these rules of visual construction and its apparent adherence to past experiences.

Section 6: Color Perception is a Feature of Statistical Judgments

In a rather ambitiously titled paper, *Evidence for a Wholly Empirical Strategy of Vision*, some very compelling evidence suggests that vision is based on how frequently we have encountered the stimulus in question in the past, and what these stimuli turn out to be as opposed to actual features of the perceived object.[124]

Often the stimuli that we encounter are ambiguous. That is, they are consistent with several possible physical states, though they appear the same to a perceiver. This ambiguity is obviously rather undesirable as an organism needs to react to the stimuli it

receives. If there are several possible situations it is unclear how the organism should react, thus making it more challenging for the organism to respond appropriately.

The brain has apparently solved this problem by appealing to statistics. Instead of leaving us in a state of uncertainty as to how we should respond to a particular ambiguous stimulus, it causes us to perceive the state that we have most frequently encountered from the stimuli at hand. This is particularly relevant for our perception of luminance and object borders and is supportive of Hoffman's computational thesis as well as my notion that color judgments do not match up with our folk ideas about color.

Section 6.1: Luminance

Fig. 43: Cornsweet Illusion; though the left and right halves appear to be different, they are identical. Hold your finger in front of the central gradient to demonstrate this.

Hoffman's point is furthered with a family of illusions produced from Cornsweet edges, mentioned previously in chapter 4 (Figure 43).[125] This illusion is unusual because it does not follow the usual contrast rules, as Mach bands and other contrast illusions do. It is expected that when a target is compared to a surround that is brighter than the target, the target will appear to darken, while if the surround is darker than the target, the target will appear lighter than it would otherwise.

However, in Cornsweet illusions the reverse is observed; where the two gradients meet in the middle the edge closer to the lighter surround appears lighter, while the edge closer to the darker surround appears darker. As mentioned in Chapter 4, retinal cell fatigue does not adequately explain this effect. Even more unusual is the size of the area that changes in this illusion. Normally only rather small areas are altered – in Mach bands only the edges of areas that have different luminance are altered as the eye directly compares these adjacent areas. However, the Cornsweet illusion involves a much larger

area – though the gradient is only in the very middle, the entirety of both areas on either side of it appear to be of different luminance.

This illusion is different than Mach bands or other contrast illusions because it is not due merely to retinal features, but instead is caused by knowledge and expectations of objects. We experience the Cornsweet edge in the way we do because we encounter stimuli that produce gradients that are essentially identical to the illusion the Cornsweet edge produces. Purves and Lotto provide two excellent examples of these sorts of stimuli,

> The surfaces bordering the gradients will sometimes have been generated by similarly reflective surfaces under the same illuminant [left, figure 44]. However, the same stimulus will often have been generated by differently reflective surfaces under different intensities of illumination [right, fig. 44]. [126]

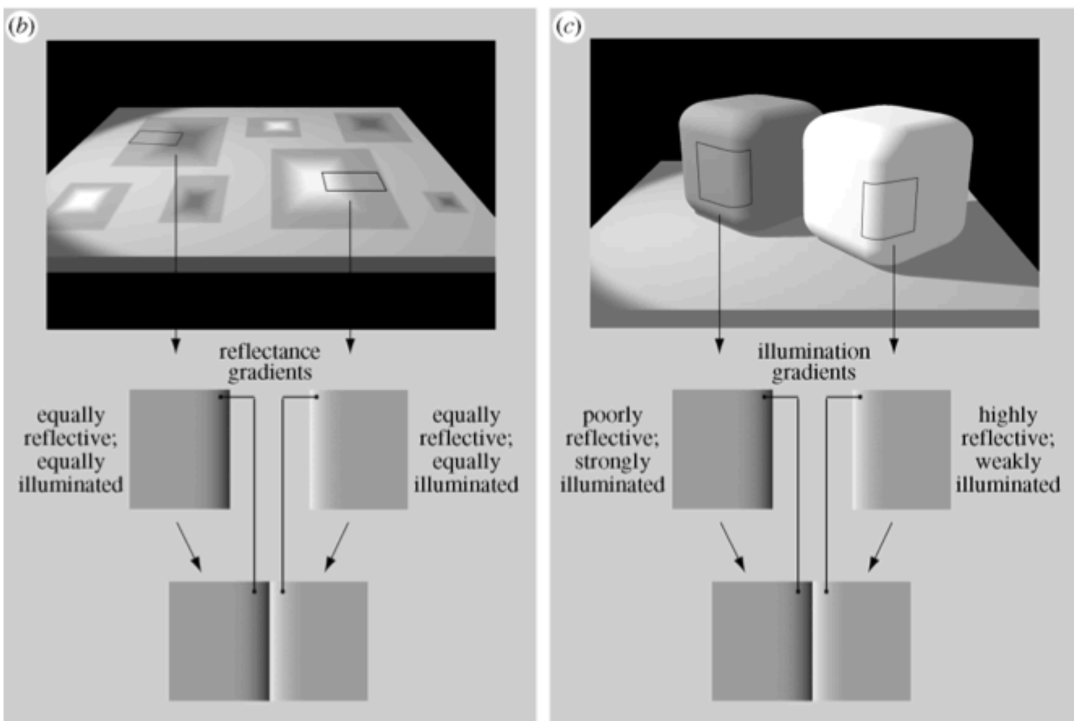

Fig. 44: Two possible stimuli both produce stimuli similar to Cornsweet edges.

The way we perceive these edges is a product of our past experiences and how frequently we have encountered an analogous stimulus and discovered it was one of the above options. In short this effect is caused by our knowledge of what objects typically look like. Because the illusion is apparently similar to objects we have encountered in the

past, our perception is actually altered in order to make it match more neatly to our memories of these objects.

It has been shown that modification of the Cornsweet effect to make it more similar to one of the above possibilities produces alterations in the perceived gradient such that they are more similar to a particular familiar stimulus.[127] For example, the target will appear lighter in cases where it is more likely that a more reflective surface is illuminated less, while a dimmer target is more consistent with a less reflective surface under greater illumination.

Section 6.2: Color (Hue)

Purves and Lotto also propose that color judgments can be explained probabilistically.[128] The case of simultaneous color contrast best illustrates this empirical explanation of color judgments, shown in figure 45.

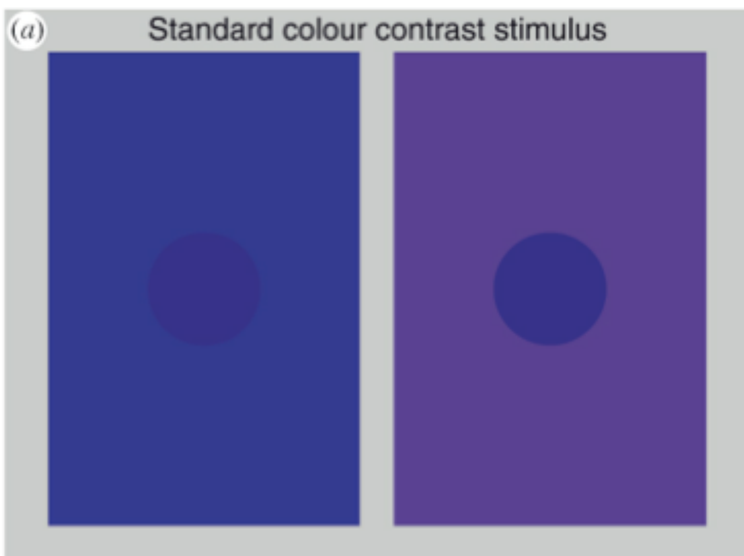

Fig 45: Simultaneous color contrast. The circles (or targets) in the center of each square are the same color, though with different surrounds they appear to be different colors.

In one sense, color contrast is the result of double opponent cells in the primary visual cortex, which compare color input from adjacent retinal cells. However, it is also the result of the brain comparing possible sources for the appearance of the targets. Just as in the Cornsweet illusion, multiple possible illuminations and sources could produce the above color perception. As Purves and Lotto suggest,

> In this scheme, the particular pattern of neuronal activity elicited in response to a given stimulus is ultimately dictated by the relative frequencies of occurrence of the real world combinations of reflectances, illuminants, and transmittances that have given rise to that spectral stimulus in the past.[129]

This conception means that when we experience ambiguous stimuli we perform some sort of computation, comparing what we are currently perceiving to previous experiences and our knowledge of what caused those experiences. If the stimulus in question is close enough to one of those previous experiences we perceive the stimulus as an iteration of that prior experience. Interestingly, this entails an actual change in our experience of the stimuli. For example, the differences in lightness on the left and right sides of the Cornsweet illusion are actually produced by our brain in an effort to make sense of our environment.

Again, in figure 45, with color contrast illusions a similar process occurs with hue in addition to luminance. This enables us to examine rather ambiguous stimuli and determine what the probably cause of that stimulus is. Thus our color judgments are not the direct result of 'color perceptions' but rather complex processes designed to make sense of the world. These judgments are not the simple perception of color, but are actively created based on previous experience, language, attention and other processes.

Section 6.3: Color and Mathematical Analysis

Color judgments essentially represent a shortcut for representing a great deal of information that would be difficult to keep track of if it existed as declarative information. Consider all of the various aspects of color judgments, discussed in the previous sections, which are very quickly and simply represented as 'color.'

If this information were kept track of in a different way it would enormously increase cognitive load, instead all of these cognitive functions culminate in changing one thing: our color judgments. In order to make sense of this, a brief trip into mathematics is needed to demonstrate how color is used as a shortcut to represent information.

In complex analysis, a branch of mathematical analysis, the idea of domain coloring is used when the function in question cannot be adequately graphed in three dimensions, for example, graphing a complex function is difficult to represent graphically

because you need two dimensions for the domain and two dimensions for the range – a total of four dimensions.[130]

Appealing to hue as a stand-in for these 'additional' dimensions often solves this problem. This is termed, domain coloring. For example the Riemann zeta function, figure 46, uses hue to represent its extra dimensions. Representing these data in some other fashion would be much more complex, as such using hue is regarded as a shortcut to represent information that would otherwise be difficult or impossible to represent.

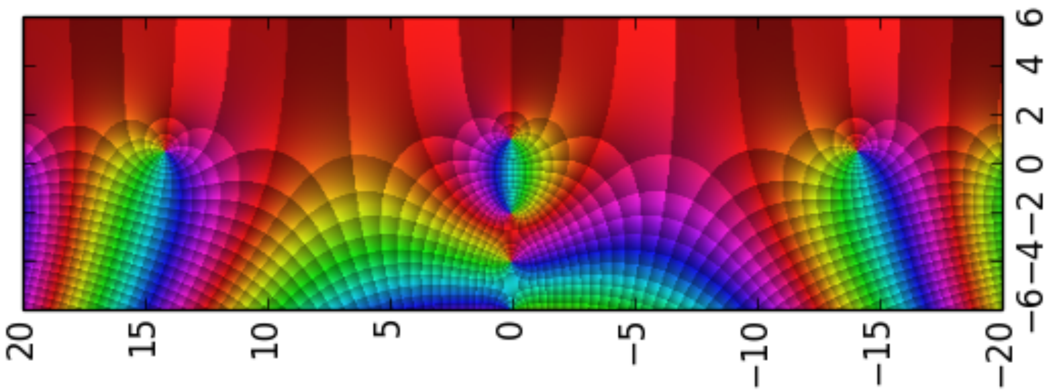

Fig. 46: Graph of the Riemann zeta function with 'domain coloring'

What's most interesting about this domain coloring is the hues that are used are arbitrary; in the Riemann zeta function these hues could easily be inverted, while displaying the same information.[131] Previously it was suggested that there is no non-arbitrary reason why our color judgments are related to our sensory and cognitive processes in the way that they are; for example the processes that lead to my red color judgments could instead have been wired to produce green colors judgments. This use of domain coloring represents a salient example of just this idea.

Though something like the Riemann zeta function does not represent an exact analogy, it does provide a useful way of understanding our color judgments – information that would otherwise be difficult to represent is quickly and effectively represented in the form of color judgments. In the case of color judgments, a large amount of both declarative and implicit knowledge (memory, object knowledge, language, etc.) is incorporated with information from our senses to create a shortcut that is apparently very effective in enabling us to use this information to better interact with our environment.

Section 7: Color Judgments and 'Color'

It has been demonstrated that our color perceptions are not simply the perception of colors. Instead they have been replaced with this notion of color judgments, which result from both cognitive and sensory processes. Given the complexity of these judgments, none of our notions about color from folk theory can remain intact. Furthermore, it seems color judgments can exist without entailing the existence of actual colors.

Section 7.1: Folk Color Again

Various properties of folk color have been discarded throughout the previous chapters. However, each version of color, in objects, in light, even in qualia, has managed to maintain some aspects of folk color. As it was suggested at the start of this chapter, our new conception of color as a computational feature that our brain 'applies' to the world precludes this.

In short, color judgments are not simply the result of simple sensory processes conveying information that is experienced in particular ways. Instead they are dependent upon higher brain functions, like language, association, object knowledge, and memory. This conception runs directly contrary to folk beliefs about color. The particular beliefs from folk theory that conflict with this revised conception of color judgments include:

1. Realism, that color is a real feature of the world; this notion was dissolved in chapter 5, when it was suggested that color cannot exist anywhere physical or non-physical.

2. Perceptual Availability, as color does not exist anywhere it isn't really available to us, instead we take environmental data and make color judgments about it in order to make a more cohesive picture of our environment. However, this process is not simple or straightforward in the way we imagine it to be.

3. Revelation is the idea that the nature of color is revealed to us with simple observation. Color seems to exist as a property of the world, but as per chapters 2 and 3, it doesn't, so this notion is also discarded. Furthermore, our color judgments are not formed in the way we imagine they are, instead quite a lot of empirical study is needed to reveal the complex nature of color judgments.

4. Simplicity is the idea that color is an unanalyzable or brute property. Color judgments have ben shown to involve memory, object knowledge, and language,

making color-judgments non-simple. Color judgments can thus be broken down and examined with a variety of empirical techniques.

Some trouble remains with the idea of unity and as such it deserves a bit of special consideration. Even if colors are computational features, they still seem importantly different from other features of our experience. If you are unconvinced that unity can be discarded because color is computational, a look at synesthesia might prove more compelling.

Section 7.2: Synesthesia and Unity

Synesthesia is the mixing of different sensory experiences, and occurs when stimulation of one sensory pathway causes autonomic, consistent stimulation in one or more additional sensory pathways.[132] [133] For example, one of the most common types of synesthesia is color-grapheme synesthesia; wherein people experience graphemes (units of words) as colored.[134] Another common type is color-sound, or chromesthesia; people may report that trumpets sound red, and that car horns sound yellow, for example.

There is astonishing variety in synesthetic percepts. Some synesthetes experience complex multisensory percepts; many tastes might cause distinct tactile and auditory stimulation, while others with mirror-touch synesthesia experience sensations that they observe other people having – for example when these synesthetes see someone get tapped on the shoulder, they also feel a tap on their shoulder.

Synesthesia is of unknown prevalence in the general population. Some studies suggest it occurs in *at least* 1 in 2000 people.[135] Estimates of synesthesia are difficult, as many people do not realize that they are synesthetes until they make a comment, such as "these peaches taste too red" that does not make sense to non-synesthetes around them who then point out the apparent strangeness of this comment. This interesting condition might demonstrate that color judgments aren't necessarily only like other colors, but can be meaningfully compared to other sensory experiences.

Up until recently synesthesia was not considered legitimate; synesthetes were regarded as liars, or attention seekers, or were thought to have overly active imaginations.[136] However, a variety tests, conducted primarily by Richard Cytowic,

suggested that synesthesia should be considered a legitimate phenomenon on the basis of its consistency, as well as proposed neural underpinnings. This early work by Cytowic has been expanded upon greatly. Synesthesia is now an active and important area of research.[137]

Cross activation is one of the main hypotheses for synesthesia. It suggests that the normal neural death, or synaptic pruning, that occurs in early childhood does not occur as completely for synesthetes in particular brain areas. Additionally, co-experiences of different sensations may help strengthen these connections. Thus robust connections between disparate brain regions remain intact, enabling these areas to interact. For example color grapheme synesthesia may be due to connectivity between the color processing area V4 and an adjacent region, which aids in letter identification.[138]

Given this model for synesthesia it seems that it is arbitrary that people do not experience color as related to other experiences. As synesthesia is possible, and indeed may be far more common than current estimates suggest, considering color judgments as necessarily different from other experiences is facile. It seems that unity, the last potential tie to folk color, can therefore be called seriously into question, if not entirely severed.

Section 8: Error Again

Folk color has provided a useful way of understanding what we mean when we talk about color. In this chapter, all of the various qualities of folk color have been shown not to apply. As such, it seems these judgments don't match up at all to what we mean when we talk about color. If this is the case it is ultimately meaningless to refer to color as we typically mean it.

In chapters 2 and 3 it was suggested that colors are not physical properties, and that we are mistaken in attributing color to the world. It was further suggested in chapter 5 that colors do not exist anywhere non-physical. Therefore, if (1) colors do not exist anywhere physical and (2) color perceptions or judgments are not themselves colored, color is in fact a 'double error.'

If color is indeed a double error, it means that we are mistaken in attributing color to the world, and also mistaken in thinking our experiences can be colored. Instead, as

this chapter has suggested, color judgments are a shortcut that help us to better interact with and understand our environment. They help us to detect object boundaries, providing a convenient way to represent complex and potentially disparate information from memory and sense information about these objects. Importantly, color judgments can exist in the absence of color, as they rely on the complex interaction and integration of information, not a single salient feature that we might call color.

Section 9: The Truth Value of Color Judgments

If color judgments do not refer to any colors, as colors might not exist anywhere, it seems a discussion of the potential truth-value of these judgments is needed. There are several options for what their truth-value might be. It is the desire of this paper to present an ontology of color that is theoretically permissive. Already I have presented an argument that is neutral on questions of materialism, qualia etc. As such the options presented below merely represent possibilities. It is also acknowledged that alternatives obviously exist.

Section 9.1: Color Judgments are False

If colors do not exist anywhere then it seems that color judgments might simply all be false, as they refer to something that does not exist. A famous example of a similar scenario is a claim like:

(A) The present King of France is bald.

This claim is problematic as it refers to something that does not exist, namely a present King of France; this is often termed a reference failure.

Claims like (A) seem to defy the law of excluded middle[FF] as the present King is neither among the things that are bald nor is he among the things that are not bald. Bertrand Russell,[139] a famous philosopher and logician, suggested a solution to claims that defy excluded middle. He suggests that this sort of claim is not actually an expression that refers, but is instead incomplete. He breaks down this claim into parts:

(1) There is an x such that x is presently the King of France
(2) At most there is presently one King of France
(3) That person is bald[140]

[FF] This law states that every proposition either must be true, or its negation must be true.

Because there is not an x that is currently King of France, (1) is false, therefore so is the entire claim (A). If color judgments are about something that does not exist, namely colors, then all color judgments must be false as they represent incomplete statements.

Section 9.2: Color Judgments are neither true nor false

Alternatively claims like (A) might be viewed as neither true nor false. This view is often attributed to Gottlob Frege (considered to be one of the founders of modern logic) and is the primary alternative to Russell.[141] Fregean analysis suggests instead that these kinds of claims do not contain something like (1) and do, in fact, refer to something. As such (A) does not necessitate the existence of a present King of France, but because it refers to something that does not exist (A) has a truth value that may not be defined.

Fregean analysis might also be applied to color judgments, as color judgments refer to colors, and colors do not exist, then color judgments are simply not the kinds of things that may not be true or false.

Section 9.3: Color Judgments may sometimes be true or false

Another potential option for color judgments is to consider them as meaningfully true or false, though we may not yet be in a place to assign these truth-values to color judgments. If color judgments can be attributed to wholly physiological processes then it seems that the reference failure issue of section 9.1 might be ignored. It is suggested in this paper that color judgments are not meaningless but instead shorthand representations of a variety of processes both sensory and cognitive.

Considering color judgments to be necessarily false would seem to do the various processes that underlie them a disservice; we are mistaken in thinking that colors represents a single salient feature. However color judgments *are* importantly about something, just not the things we usually consider them to be.

The processes that underlie color judgments might be determined to be fully explicable by neuroscience, and as such we might refer to these processes to ascertain their truth-value. That this seems strange, mysterious, or even impossible might be

largely due to the relative infancy of neuroscience. As neuroscience develops a basis for determining the truth or falsehood of these color judgments might become apparent.

There are also pragmatic concerns for giving color judgments truth-values. We clearly have at least a normative intuition about color judgments. While there is an inescapable subjectivity to these perceptions and judgments, there are cases where our intuitions tell us that we are misperceiving colors; a patent example are color illusions or hallucinations. In these cases it seems desirable to designate them as true or false, otherwise it becomes very difficult to distinguish between lucid and muddled perceptions. As such these pragmatic concerns suggest it is preferable to claim that some color judgments are true, while others are not.

Furthermore, current conceptions of qualia suffer from a great deal of problems, some of which are related to their truth-value. As such if we are eventually able to assign truth-values to color judgments they can be further divorced from qualia. This is a very attractive option for many philosophers and neuroscientists (though obviously unattractive to some).

Section 10: Benefits, Directions, and Conclusion

Why should we view color as an error? It certainly seems like we see color, and it's perhaps easier to refer to color as a property that is out there in the world. But in doing so we diminish the richness of our color judgments, discounting their multifaceted nature for the sake of convenience.

If colors don't really exist anywhere what does this mean, or why should we care? In essence, it means we dramatically oversimplify the thing we call color. While this has a rather small impact on the general public it has some interesting implications for the way neuroscientific studies are conducted, particularly with the advent of brain imagining techniques.

Many brain-imaging studies rely on presentation of stimuli to subjects while their brain activity is monitored by various imaging machines. Without delving into the

complexities and issues with these techniques, the importance of color can be briefly stated.

In one study,[142] teenage and adult subjects were shown black and white images of people expressing various emotions, like anger, happiness, etc. and fMRI data were collected during this process. Subjects were also asked to identify which emotion the person in the image was displaying. This study suggested that teenagers were significantly worse at correctly determining the emotion the person in the image was displaying and that they showed diminished activation in particular brain areas, namely the prefrontal cortex and amygdala.[143] [144] This lead the researchers to suggest that the immature teenage brain was unable to accurately identify emotions, and that this might explain why teenagers are so 'teenaged' when it comes to dealing with the emotions of others – they are genuinely worse at it.

To put aside these perhaps grandiose or overly speculative claims about teenage-ness, another study[145] [146] repeated this experiment – except this time colored images were used. In this study, teenaged participants were just as able as adults to determine the emotions the person in the image was displaying. Even more interestingly, their brain activity was not statistically different from their adult counterparts.

This demonstrates the importance of considering the other aspects of color judgments in neuroscientific techniques; by discounting the different exposure to color that teenagers and adults have had, (consider when color TV became widespread) the researchers missed a crucial point and thereby generated what appear to be, if not downright incorrect, at least questionable results.

Because color is often looked at as a simple property, or one that can easily be ignored, mishandling of color in experiments such as those cited above can have significant consequences. We should consider color not as a simple piece of sensory information, but rather as a complex representation of many aspects of perception and memory. In understanding our color judgments in a more thorough and less facile way we can further appreciate how complex even seemingly simple aspects of our experience really are.

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