I became interested in the history and applications of color in graphics and machine learning after I joined Professor Ng’s lab. When I was introduced to several graphics concepts involving color such as precomputed radiance transfer, color compositing in volumetric rendering, and possible extensions to the NeRF paper that utilise color moments, I noticed that there were many different uses of terms describing aspects of “color” that had varying degrees of complexity. As such, one of the reasons I would like to join the course, is to become more acquainted with several color-related concepts that I currently only know at a superficial level, including topics in color theory (chromaticity), colorimetry (metamerism), image coding and more. Additionally, as several terms within color theory and graphics are very similar, differing only in slight nuance, I would like to be able to understand these terms at a more intuitive level, which would be useful for helping me with new theories and ideas within graphics research.

There are many aspects of color and color theory that branch into physics, biology and other fields in addition to graphics. Having learned about color in physics classes, I find it fascinating to learn new interpretations of color in those domains that could then be applied to graphics, and vice versa. For example, how the mindsets of these fields produce different ways of looking at similar topics, or how each field’s main uses of color differ. In addition, as the field of deep learning continues to grow, we could soon see even more novel approaches to color in machine learning -- yet another field that might approach the realm of color differently.

For all these reasons -- applications to research, making color more intuitive, and analyzing different mindsets that approach color -- I would like to join the Computational Color class.

I have done research in Professor Ng's lab on graphics-related topics (including on the recent Fourier Features paper). Additionally, I have done my own personal projects in rasterization and rendering, studied the graphics pipeline at a past internship and I have studied extensively from the CS 184 course materials in the past.

Representing Colors as Three Numbers

One major idea of the paper

One major idea described in the reading is the idea of chromatic adaptation -- the ability of the eye to adapt to changes in illumination to preserve color. This concept extends beyond ordinary tristimulus theory, connecting different types of cone responses (or, the ability to perceive color) to different types of illumination to describe how humans can experience constant perceived color even under different lightings. In image processing and graphics, the von Kries transform performs chromatic adaptation by theorizing that particular changes in response in each cone could be used to ensure color constancy. It does this by applying a gain to each L, M, S cone spectral response to keep the appearance of a reference color (white) constant. In order to perform this, the transform converts the color space from LMS to XYZ and back.

Idea that builds on the paper

The von Kries transform appears to have several assumptions which could be violated in real life. For example, it assumes that both eyes receive the same illumination; there might be a separate reaction if both eyes received different illuminations (such as if one eye were damaged). A potential way to extend this could be to conduct experiments to see if there is a discrepancy in seeing an object under two different illuminations simultaneously (with each eye seeing a different illumination), and if so, to measure this discrepancy. This could possibly be done by varying the illuminations in a certain way until the observer no longer feels confident that the objects are the same color, or if the perceived image is no longer continuous. When the separate visions are combined, then the von Kries transform could possibly be extended to possibly include a second matrix whose purpose is to take this extra information into account, and ensure color consistency across four separate illuminations (two in the beginning and two in the end).

Gene therapy for red-green colour blindness in adult primates

One major idea of the paper

One major idea described in this reading is that trichromacy doesn't actually stem from multiple genetic and environmental factors, such as evolutionary or developmental changes in addition to a third cone in the eye. Instead, it stems just from a third cone. They hypothesize that this is because this third cone just splits existing blue-yellow or similar circuitry, rather than producing a whole new color that requires neural rewiring. Experiments in gene therapy involving a computer-based color vision test were used to experimentally verify this result.

Idea that builds on the paper

One idea that could be built on further is the idea that trichromacy is naturally built into the brains of mammals such as humans or monkeys, to the point where adding a single cone could restore a damaged vision. Is trichromacy really built into the brain, or could it be possible to perform "neural rewiring" of the brain, or to allow one to visualize a four-basis color spectrum?

One experiment that could be used to verify this is to inject cones corresponding to light that extends past the traditional visual spectrum (such as extremely low light intensities) using similar techniques to the ones the scientists used in the paper. This could allow for the human eye to better visualize tetrachromacy, or if not, increased chromatic discrimination.

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In summary, predictions of both the standard model in which hue perception is based on L versus M midget and small bistratified ganglion cells or a revision of it where S-cone signals from small bistratified cells are combined with L versus M signals in the cortex are not consistent with experimental findings.

Here, we examine an alternative to the standard hypothesis that is compatible with the finding of unaltered hue perception in individuals with mGluR6 mutations.

Curing Color Blindness—Mice and Nonhuman Primates

One major idea of the paper

One of the most interesting ideas in this paper is the idea of a subset of midget bipolar cells that receive a feed-forward input from an S cone. This allows red-green color vision to emerge due to a receptive field, through an untransduced M cone providing direct input to the midget bipolar cell, and S cones providing input via GABA-mediated feed forward. This allows trichromacy to emerge in primates that were blind on the red-green spectrum beforehand. This particular feed-forward mechanism evolved specifically for the purpose of color vision. The addition of a third cone type splits the system into two pathways: one for red-green paths and the other for blue-yellow paths. This provides an insight as to how preexisting neural circuitry could allow further modifications through a similar type of gene therapy.

Idea that builds on the paper

Although primates are best suited for such vision, red-green vision can be given to multiple different types of non-primates. Additionally we discussed in the past group meeting how animals such as mantis shrimps don't actually see more colors than humans despite having more rods and cones. Could this possibly be extended to colors past the usual spectrum, such as into the infrared range? A potential issue is that as infrared light has less intensity, a sensitive cone designed for infrared might be overloaded by visible light. However, as snakes are able to see in the infrared range, it indicates that such an obstacle is not wholly insurmountable. It might be possible for a similar family of midget cells receiving feed-forward input from several neighboring cells to impart infrared sensing capabilities, through adding together several small excitations in the infrared spectrum. This could be done through a similar injection method described in the paper.

Neurobiological hypothesis of color appearance and hue perception

One major idea of the paper

One of the major ideas is the idea of color opponency through feedback from the cones, and how it can describe hitherto inexplicable phenomena such as how unique green is perceived so differently amongst color-normal individuals. The idea is that the S, M, and L cones, rather than producing different colors each due to trichromacy, instead combine input with horizontal cells to create cone opponent signals aligned with the unique hue axes. The character of opponent interactions will vary depending on the ratio of L and M midget cells around a given cone. This could also explain other phenomena such as colorblindness -- as S feedback to L and M would rotate the color axes of a small subset of L versus M midget ganglion cells, an individual without such a mechanism would just see color along the L versus M axis.

Idea that builds on the paper

One idea that could build on the rotation of the L-M axes could be more research on neural rewiring. As the current primate circuits rotate the L-M axes to be RG and BY, what would it be like if different colors were the defaults for uncontaminated hues instead of those? This could be done by modifying the cone cells to respond to different wavelengths. It might be that several colors might look the same overall, but be perceived differently from how they were before.

The elementary representation of spatial and color vision in the human retina

One major idea of the paper

There are two distinct populations of cells within the retina -- one that generates primarily achromatic responses to incoming light, and one that generates chromatic responses. This lends credence to the major idea that lower-resolution color signals and high-resolution achromatic signals are processed through two different neural pathways, indicating that achromatic stimuli are given higher preference. While S cells were primarily unstimulated at the test wavelength, L and M cells registered both their own types as well as white (achromatic). The cones most likely to generate strong neural responses were parvocellular neurons, which were surrounded on all sides by cones of the opposing type. Midget ganglion cells surrounding cones are thereby well suited for mediating spectral opponency, and also could have a role not only in color vision, but high-acuity spatial vision.

Idea that builds on the paper

The analysis in the discussion about the pivotal role of midget ganglion cells in color and spatial vision provides a potential combination with last week's paper on color-blindness in primates and mice. Interestingly, it could potentially disprove my original idea for potentially increasing the vision to tetrachromacy in primates -- I had assumed that all inputs to cones would be registered as chromatic, but the study in this paper indicates that such an implementation as my last idea would result in an achromatic response when encountering UV light. So an idea that could build on this would be to categorize this achromatic response to see how it relates to chromatic responses at different wavelengths. The experiments in this paper were primarily from one wavelength -- it could be easily modified to heavily stimulate the S-cone with different wavelengths, from which we could categorize a response. We could modify the temporal stimuli so that we could graph the response of the midget ganglion cells to different high-contrast, low-temporal frequency stimuli to properly see where this ends.

EXPERIMENTS ON COLOUR

One major idea of the paper

One major -- in fact, seminal -- idea of this paper is that every perceivable color may be considered as dependent on three primaries, in a manner such that its exact representation is defined based on the excess or defect on the amounts of each constituent color, and can thereby be described by a treble real number, such that the amounts of each integrant may be represented on three perpendicular coordinate planes. Through varied and followup experiments, Maxwell is able to construct the coefficients of colors showing the individual proportions of the elements of which they are composed. Additional experiments indicate that the theory agrees with calculation, and that while the eyes of different people vary in accuracy, they nevertheless agree with each other accurately, indicating a standard theory of color applies to all humans. This concept delineates the principles of color combination.

Idea that builds on the paper

Further experiments could be undertaken to indicate the difference in human perception between light and pigmentation. Additive and subtractive colors present different theories between the color we see from light and from pigments. More importantly -- how could pigments affect the colors we see compared to lights? In the Oz project, we see that stimulation of particular cones in the eye could result in new ways of looking at color. Would it be possible to construct glasses that would mask out particular cones entirely, resulting in a new interpretation of color? And would the theory of subtractive color hold for pigments, if these glasses were to be invented? These experiments could produce valuable insight into the nature of human color perception.

High-acuity vision from retinal image motion

One major idea of the paper

One major idea in this paper is that a moving retina averages out spatial inhomogeneities. When compared with a retina-stabilized image, subject performance decreases and blurriness increases, indicating that the signal generated by a moving retina jointly estimates the eye's motion and stimulus. Through experimentation, it can be confirmed that moving retina inputs result in a higher quality representation of the stimulus as compared to the signal generated by a stationary retina. What is interesting is that the interaction between the two theorized subpopulations of neurons can be modelled so accurately by an online modification of the expectation maximization algorithm. The success of the experiments further imply the neural representations of A and X are computed jointly by multiplicative interactions between the two subpopulations of neurons.

<u>One idea that builds on the paper</u>

One idea that could build on the work in the discussion section is to compare exactly how high-acuity vision networks could incorporate chromatic input as described in past papers. Or, in other words, how color could be used to help discriminate between two high-acuity targets. This could be done by incorporating additional terms into the update equations that simulate horizontal cells or parvocellular neurons similar to the terms described in past papers. These terms could probably be approximated at first by a difference of Gaussians that could be used for a band-pass filter to simulate color opponency activation or something similar. Running this algorithm could provide an indication as to how important chromatic vision is in distinguishing high-acuity targets

<u>**Cone photoreceptor classification in the living human eye from photostimulation-induced phase dynamics**</u>

<u>One major idea of the paper</u>.

The L, M and S cones can be accurately mapped out in any part of the eye through a K-means clustering algorithm applied to phase dynamics obtained from a method that includes optical coherence tomography (AO-OCT) to map out physiological activity occurring on different timescales within the eye (both fast and slow). The second experiment of the paper involved a directed 637 nm stimulus (for which the spectral sensitivities have L > M > S) followed by a directed 528 nm stimulus (M > L > S), and then a 450 nm stimulus. The phase traces formed a trimodal distribution that allowed K-means clustering, and the agreements between stimuli at 637 nm and 528 nm, 637 nm and 450 nm, and 528 nm and 450 nm were 97%, 94%, and 94%, respectively. These agreements held for all three subjects, including the deuteranope.

<u>One idea that builds on the paper</u>

In order to connect this paper to the Sabesan et al. paper, one could add experiments to either identify the ganglion cells surrounding each cone, or to identify a particular cone neighboring certain types of cones (such as parvocellular neurons, which are surrounded by cones of opposing type). This could further separate the population of cones, to indicate cones that produce achromatic stimuli, and cones that produce the strongest color-opponency response. As activation is not enough to produce a color sensation, one could experiment with different wavelengths of stimuli to see if the results outputted by K-means align with one or more of the hypotheses presented in the Sabesan paper regarding different types of cells (ie. L and M cones mostly signal achromatic percepts, with a small handful of cones signalling red or green), or just indicate more intricate subpopulations of cones using the same experiments in general.

Unsupervised Learning of Cone Spectral Classes from Natural Images

One major idea of the paper

To answer the question of how neural circuitry can classify individual cones according to their spectral class, to distinguish between L and M cones (which are virtually identical, differing only by the newly expressed opsin) and more accurately take advantage of the additional information, the authors provide an unsupervised learning algorithm that detects and learns the class of each cone from a retinal mosaic. The algorithm uses inter-cone response correlations to explicitly classify cones by their spectral type, by first taking in a natural image from a hyperspectral image dataset (to better model the responses), construct a space (x, y, z) where x and y are the spatial coordinates, and z represents the (continuous) maximum wavelength response of each cone, and lift each cone from the mosaic to the new space using non-metric multidimensional scaling. The 3D embeddings of the 20x20 correlation matrix separate the three cone classes along the z dimension of the representational space.

One idea that builds on the paper

An idea that could build on this paper is proposing neural circuitry mechanisms that could correspond to this unsupervised algorithm. We know from previous papers that primate brains have a natural mechanism for trichromacy, which is why dichromatic monkeys who were given extra cone cells developed trichromatic vision. The authors, in their Discussion section, note that there is a theoretical basis for using an unsupervised learning algorithm. Thus additional experiments testing inter-cone correlations could be conducted. An example of such an experiment could be simulating parvocellular neurons using a similar algorithm, but with more accurate assumptions that use a more accurate biological basis (such as a hexagonal photoreceptor grid), to see if there are better correlations with experimental results.

Color Naming Models for Color Selection, Image Editing and Palette Design

One major idea of the paper

One idea in this paper is the idea that color names have a relative effect on categorical color perception and memory, in addition to improving applications such as gamut mapping and image analysis. By modelling color-name associations using multinomial probability distributions that describe the likelihood of a color value given a color name, the authors then define applications such as selecting image regions, and evaluation tools for color palette design. The data for this was obtained from a survey consisting of native speakers of European languages, is preprocessed through 1) binning colors in the CIE LAB basis to encode good color distances, 2) removing noise through a low-rank matrix approximation, 3) smoothing and filtering the data using a blurring kernel. Then, the probability of a name given a color P(w | c) is evaluated and found.

One idea that builds on the paper

An idea that could build on this paper would expand the experiments to include deep learning in addition to a more accurate set of priors. First, more survey responses should be collected from individuals who do not speak European languages (such as native Bantu or Indian languages). Then, a modified deep learning model corresponding to a shallow 2-layer neural network such as word2vec could be trained on this large corpus, and the distances between colors could be mapped out using t-SNE, or clustered based on language family. This experiment could then be compared with the model described in the paper. This could serve to indicate how humans of different backgrounds consider color connotations (to be 'sharp', or to be associated with specific attributes, and how that differs based on region).

Deep Joint Demosaicking and Denoising

One major idea of the paper

The first step of the camera imaging pipeline (including image denoising and image demosaicking) consists of ill-posed reconstruction problems where at least two-thirds of the data is missing, and the existing data is corrupted with noise. Traditional methods in these areas use hard-coded, handcrafted heuristics as priors that result in visual artifacts. Prior deep learning-based methods also use hand-crafted priors that lead to a steep increase in computational cost due to the priors being nonlocal. This paper states that a network alone is not enough to overcome these issues. A major idea is that a dataset augmentation technique can be used to train a network specifically on poor/challenging image patches. This is done by looking for two classes of artifacts -- luminance artifacts and color moire -- and fine-tuning the network. This greatly increases the ability of the network so that it outperforms all other SOTA of the time. A CNN architecture is used for these tasks.

One idea that builds on the paper

There have been many advances in deep learning since 2016 that could be used to augment the experiments shown in the paper. For example, recent advances in ResNet architectures could be used to potentially produce a more accurate result, with color filter array patterns as input. Additionally, new neural denoising networks and superresolution networks could be used in tandem with this particular CNN in a pipeline to denoise or modify particular image patches to provide better results overall. A pipeline containing these networks in addition to re-training on varied demosaicking datasets that have come out more recently would serve to produce better results as well.

Convolutional Color Constancy

One major idea of the paper

Before this paper, most color constancy algorithms learned or analytically constructed generative models of the color distributions found in natural images viewed under a white light. However, Barron theorized that a discriminatively trained model (learned to tell the difference between white-illuminated images and non-white-illuminated images) would more accurately be able to obtain a naturally-colored image. Barron does this by reframing the problem of color constancy as the problem of localizing a template in some two-dimensional space (referring to the reducing of some number of unknowns from previous methods of posing the problem), constructing a histogram and converting it into log-chrominance space, and then posing the problem of maximizing the 'score' of tinted images as a convolution. This allows a simple convolution to maximize the score for each tinted version of the image, producing the one best suited for white-balancing. Posing an optimization problem for the best convolutional filter and solving it then gives the optimal discriminatively learned filter, which could be thought of as a histogram of colors in well white-balanced images minus a histogram of colors in poorly white-balanced images.

<u>One idea that builds on the paper</u>

Barron mentions using a deep set of filters, or a convolutional neural network, for this task. However, he notes that "the amount of training data in our datasets [was] insufficient to prevent overfitting." The experiments in the paper additionally indicated that color constancy algorithms would benefit from much larger datasets than were currently used. So the idea that builds on this paper is, using data augmentation to increase the amount of training data, how well would this convolutional algorithm perform on an expanded dataset? A convolutional neural network trained on a larger dataset would not necessarily overfit. How would this CNN compare to the algorithm described in the paper, and would there be cases in which the paper algorithm would generalize better than a CNN? Using more techniques learned from object detection may allow us to generate better performing CNNs than a naive implementation.

<u>Ming Thein's Blog Posts</u>

<u>The Four Things</u>

"There are four things to consider in making an image that 'works': light, subject, composition and the idea."

<u>One major idea of the paper</u>

One main idea of this blog post is that the four elements of composition (light, subject, composition, idea) work primarily because they are independent of subject, and have nothing to do with the technical qualities of an image. Instead, this is because our brains are wired to consider certain aspects of a scene, or of real life, in a particular way. While evolutionarily our brains are all the same, giving us a very strong underlying framework for us to work with, there are many opportunities for exploration of the abstract, and complex causal relationships between subjects, letting photographers explore their own style using the four main ideas.

One idea that builds on the paper

One idea that could build the blog post is exploring some of these abstract and complex relationships between subjects. If there are ways for these relationships to be qualified, at a very high level, it would be interesting to note what exactly these relationships are. Could they be grouped into two or three general ideas, or are the list of possibilities too expansive? Looking at many photographs might allow us to explore this in greater detail.

Structure

One major idea of the paper

One major idea of this blog post is that the nature of 'structure' in photographs is hard to define; it's the system of support that's not necessarily seen, but nevertheless forms the backbone for how order is created out of chaos. Given a uniform background, an image flows from increasing subject isolation (ie. the most outstanding element) to decreasing subject isolation (subsequent elements) by their order of separation. This works better if the image itself is aesthetically pleasing. There are ways for abstracts to be defined that consider these concepts metaphysically, to allow interesting elements to arise out of chaos without necessarily well-defined or aesthetically-pleasing borders.

One idea that builds on the paper

One idea that could build on the blog post could be exploring how chaos can be considered aesthetically. While Mr Thein includes examples of how this could be done, it would be interesting to see even more examples of how chaos could give rise to other forms of chaos, depending on how one looks at the image, or how different contexts could lead to a particular image being considered attractive in one and displeasing in another.

Color from a Workflow Perspective (Pts. 1, 2)

One major idea of the paper

In the early days of color photography, the best manufacturers could do was offer a range of emulsions that gave photographers choice. And despite improvements in film quality and chemistry, these familiar spectral biases remained, leading to camera makers taking their signature color response and translating it so that images from their cameras would look like images from their films. Many manufacturers then advertise their cameras as having a particular color palette, leading to the belief that one has no choice but to like a particular manufacturer's hardware if he likes the tonal palette. But through calibration and appropriate digital compensation, it's possible to have very close to perfectly accurate color reproduction. However, if one views the same print under different color temperature or spectra lights, he will get a different experience, which can be enough to erase subtle tonal transitions or shift dominant color. Thus it is important to have a workflow with a consistent set of colors, taking this into account.

One idea that builds on the paper

One idea that could build on the blog post could be exploring different types of color workflows (similar to the demonstration during the guest lecture) to show how they could impact the overall final image. What could be emphasized are the emotions, tones and context of the image, to indicate the differences of each color workflow in particular. This could also serve to underscore the impact that a good color workflow has on the emotions of the final image.

Adaptive optics for studying visual function: A comprehensive review

One major idea of the paper

In the early 2000s, there was a question as to whether the visual system was equipped to take full advantage of new, unprecedented spatial details delivered to the retina. One idea in this review on adaptive optics is that the native neural circuitry does not actually always perceive sharp, high-contrast images as high-contrast. Instead, it actually allows the eye to adapt to the blur generated by its own point-spread function. Several experiments, including Artal et al. (2004), showed that using AO to rotate the effective PSF of the eye actually resulted in less contrastive images. The adaptation to one's aberrations not only results in an apparent reduction in perceived blur, but also improves overall visual performance. This is useful in many different fields in neuroscience and vision, including accommodation. However, regarding accommodation, although cues from monochromatic aberrations exist, it remains to be seen as to how the eye actually uses them to aid accommodation on an object, and whether they would be helped or hindered by a correction.

One idea that builds on the paper

One idea that could build on the paper is determining how exactly cues from monochromatic aberrations could interact with corrections given using adaptive optics to potentially determine how aberrations effect the extent of defocusing. This could be done by creating an experiment with people that have different native visual acuities, such as emmetropes and myopes, and performing a similar experiment where a stimulus is displayed under different conditions, and then defocused in different ways. Additionally, the stimulus could be shown in different colors and under different lighting conditions. Then recording the responses of the eye might give an indication as to a correlation.

High Resolution Imaging in Microscopy and Ophthalmology Chapter 17

One major idea of the paper

One idea in the paper is that AOSLO techniques have determined that cone reflectivity varies drastically throughout the day, often many times in a single subject. Many theories were propounded as to why this was the case, including linkage to differences in light capture.

However, through experimentation, it was later determined that the reflectivity did not actually depend on the cone (L, M and S reflected similarly and differently), and that there was no relationship between brightness and cone sensitivity, and that cone reflectance in AOSLO images is not closely coupled to light absorbing efficacy. As a result, it is likely that another theory, which stated that light interference in the waveguiding cone plays a large role, is true.

<u>One idea that builds on the paper</u>
An idea that could build on this is analyzing how exactly light interference in the waveguiding cone plays the role. This could be done by testing different light sources on different cone models, and measuring the results to see if there is a correlation. More specifically, the Beam Propagation Method and others could be used to simulate the propagation of light within the eye. This experiment could be done at different times of day in order to provide an additional variable to the experiments.

<u>Richer color experience in observers with multiple photopigment opsin genes</u>
<u>One major idea of the paper</u>
One major idea of the paper is that women with four-photopigment genotypes experience a different percept from those with three-photopigment genotypes. Studies and controlled experiments indicated that they experienced significantly greater numbers of chromatic appearances than did the subjects with trichromat retinas. The tests that they did were closer to real-world complexity than standard Rayleigh match stimulus configurations, as they utilized a contextually complex stimulus consisting of a chromatic gradient of heterogeneous luminances. They hypothesized that a serine–180–alanine substitution in photopigment opsin gene, which only can occur in heterozygous females, is responsible for this.

<u>One idea that builds on the paper</u>
One idea that could build on the paper would be expanding on the tests described in the paper. This would be to measure exactly how the color percepts differ in heterozygous females with four photopigment genotypes change with respect to different stimuli. In combination with the next paper, the X-linked opsin arrays could be sequenced, and the tests in this paper could be repeated with respect to individuals with differing arrays, in order to obtain a possible correlation between genetics and increased color perception.

<u>The dimensionality of color vision in carriers of anomalous trichromacy</u>
<u>One major idea of the paper</u>
One major idea of the paper is that genetic analysis of the X-linked opsin arrays, which implies that subject cDa29 has three well-spaced photopigments in the long-wave spectral region, does not actually provide enough information as to reliably deduce whether an individual is strongly tetrachromatic. This is because it does not seem to be sufficient for exceptional performance on

the tests administered (MDS, Rayleigh). For example, cDa15 has an inferred spectral separation of 11 nm, but does not show an unusual performance on Rayleigh or MDS. More information is needed in order to make an accurate inference, such as taking into account the relative number of different types of cones, and the weightings given to them by the midget ganglion cells.

One idea that builds on the paper

One idea that could build on the paper involves continuing further tests in order to establish a reliable correlation between genetic analysis and strong tetrachromacy. It appears that the current sample size of 1 individual is rather small, and so more advanced testing might be necessary in order to further our understanding. More testing could be done in the form of interviews to see if the interviewee's experiences are similar to the results found in this paper. Also, potential online tests to select potentially strong tetrachromats could be useful in this area.

Individual Colorimetric Observer Model

One major idea of the paper

One of the major ideas of this paper was that Monte Carlo sampling could be used to generate a model simulating color-matching functions for humans. Some of the assumptions made were that each parameter actually formed a normal distribution, which was based off of prior work including population studies that determined that the normal distribution formed a reasonable assumption. In order to do this, studies were obtained for each particular variable (lens pigment density, macular pigment density, optical densities of L-, M-, and S-cone photopigments, and λmax shifts of L-, M-, and S-cone photopigments), with studies done on potentially vision-impaired individuals thrown out. Then, instead of scaling each SD individually, which would have been computationally expensive, two scalars were used instead -- one scales variabilities in lens and macular pigment densities, and the other scales photopigment variabilities. Then, Monte Carlo simulation was performed and 10,000 sets of CMFs were generated, followed by minimizing the differences between SDs from experimental results and SDs from the simulation. The proposed model thereby predicts CMFs of a color-normal population.

One idea that builds on the paper

One potential extension could be incorporating learning-based methods. Instead of doing Monte Carlo sampling followed by the minimization, one could instead try to use a machine learning model in conjunction with a feature subset selection algorithm such as forward stepwise feature selection to try to create a model able to predict CMFs, in addition to narrowing the feature space. We know that it will be around eight, given the results in this paper, so such a model might give us additional insight as to the structure of the functions, and if any variables are missing or extraneous.