Nominal Color Appearance

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ABSTRACT

The CIECAM02 color appearance model[1] is a powerful tool for computing perceptual attribute correlates over a range of viewing conditions. This paper begins with an overview of the CIECAM02 model and possible applications. The paper then considers one of the limitations of the model - it doesn't provide any way of determining what color name best corresponds to a given set of perceptual attribute correlates. The remainder of the paper considers nominal color appearance and provides a number of specific results based on an ongoing[2] multi-year color naming experiment conducted on the World Wide Web.

1. INTRODUCTION

Color appearance models[3] generally consider the fundamental question of how to describe or quantify the appearance of a colored stimuli as a scaling task such that the underlying perceptual attribute correlates, such as lightness or chroma, can be derived. In fact the title of the conference track in which this paper was presented at is: "Color Appearance: ordinal, interval and ratio scales." This paper reviews the most recent CIE color appearance model, CIECAM02, and then considers how nominal or name based color descriptions might be used to supplement and explore the perceptual attribute correlates. The CIECAM02 model includes a perceptual attribute correlate H or hue quadrature that expresses relative amounts unique red, yellow, green and blue. However the model provides no means to determine if a given set of perceptual attribute correlates is "purple" or "brown".

Color naming research has tended to focus almost exclusively on efforts to support,[4] refine[5] or refute[6] the existence and partially fixed sequence of adoption for color universals as hypothesized by Berlin and Kay.[7] While this is a critical and fundamental topic that intersects the fields of philosophy, psychology, anthropology and linguistics the controversy around the question of color universals has perhaps kept research into color naming too narrowly focused. For instance relative to the centroids for the basic color names, there is minimal data regarding the centroids for non-basic color terms. This paper does not address the central issue of the existence and nature of the basic color names but instead simply assumes that there exists a range of cognitive categories corresponding to color that are shared by a range of members within a given linguistic community. Patterns and trends in color naming will be explored using a large-scale unconstrained color naming database collected on the World Wide Web.[8] By convention, this paper refers to red, green, blue, yellow, brown, orange, purple, pink, gray, white and black as basic colors and all other color names as non-basic color.

The concept of hierarchical systems[9] is often encountered in the field of natural learning. It is interesting to consider how color appearance is perhaps a hierarchical system. Figure one shows one possible organization of color appearance from low-level vision to high-level vision that is implicit in CIECAM02 and current theories supporting universal color names. This figure is similar to one used proposed by Newell but is specific to color. In this figure low-level cone responses are pooled into opponent responses which are then pooled into perceptual attribute correlates. This sequence parallels the computational sequence for CIECAM02 in which a colored stimuli and an adopted white point are converted to perceptual attribute correlates. There is no single agreed upon mechanism for color naming on a cognitive level but implicit in much of the literature is an assumption that a non-basic color name is the highest level cognitive category that is somehow the most abstracted mental representation of color. For instances there are color naming studies that have used response times to compare basic and non-basic color naming.[10]

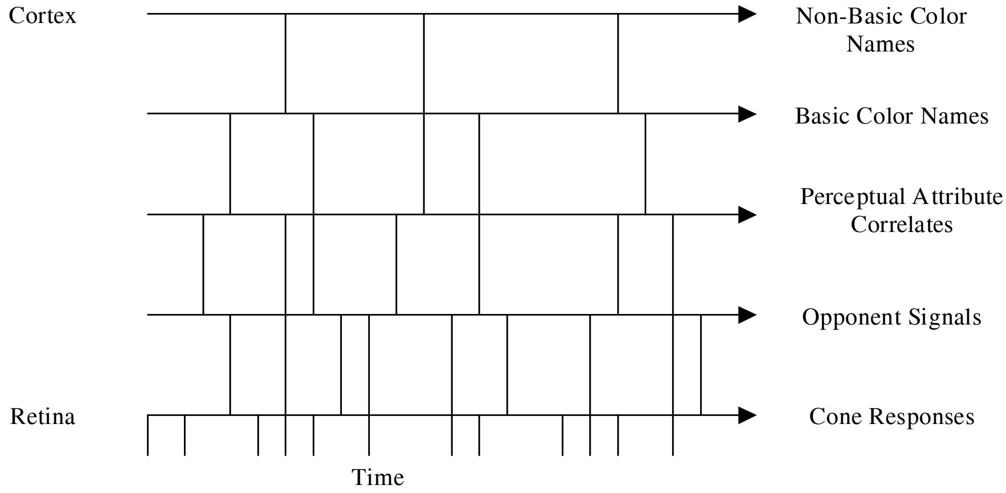

Figure 1: Simplified hierarchical configuration for color perception.

2. CIECAM02

The terms of reference for CIE TC8-01 were "to study, and recommend a color appearance model based on CIECAM97s for use in digital color management and to develop clear usage guidelines for common applications. Consideration is to be given to color and engineering requirements for open color management systems." The resulting CIECAM02 color appearance model provides forward and inverse equations for transforming stimulus tristimulus values to and from perceptual attribute correlates based on specific properties of the viewing conditions. This model embodies many years of research and development from a number of academic and industrial contributors.[11] The CIECAM02 model could be used to quantify and characterize changes in color appearance due to changes in viewing conditions. For example the model could be used to map perceptual attribute correlates for a given source device to a different destination device under different viewing conditions. A key consideration might include optimization of a gamut mapping procedure in CIECAM02.

In summary form, the model consists of a chromatic adaptation transform, a non-linearity and the calculations of the perceptual attribute correlates. The CAT is a von Kries type transform in an RGB space fitted to a number data sets. The CAT02 matrix can be written as

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix} = \begin{vmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{vmatrix} \begin{vmatrix} X \\ Y \\ Z \end{vmatrix} \tag{1}$$

and the full form of the transform includes a D factor, which allows for incomplete adaptation as a function of the luminance of the adapting field. After converting to Hunt-Pointer-Estevez space the following post-adaptation non-linear compression is applied

$$X_a' = \frac{400(F_L X'/100)^{0.42}}{27.13+(F_L X'/100)^{0.42}} + 0.1 \tag{2}$$

where F_L is a function of the luminance of the adapting field and X' is one of R',G' or B' values and X'_a is the resulting non-linearly compressed values. Note that if X' is negative, then the absolute value must be used and then the quotient in equation 2 must be multiplied by a negative 1 before adding the 0.1 value. The resulting values are used to create a set of temporary Cartesian coordinates that are then used to compute the hue angle and the hue eccentricity parameter. Hue quadrature can then be computed using a table of unique hue data. Next the achromatic response, lightness and brightness correlates are computed. A temporary magnitude quantity is then calculated and then chroma, colorfulness and saturation are computed. Final Cartesian coordinates can then be computed for corresponding correlates based on standard trigonometric transforms.

The unique hue data used during the calculation of hue quadrature provides a rough measure or redness, yellowness, greenness and blueness but does not necessarily provide boundaries or any other concept of the best corresponding color name. Yaguchi[12] has explored color naming in CIECAM97s but has considered it as a process of finding boundaries for the basic color names with respect to the perceptual attribute correlates. The remainder of the paper will consider nominal color appearance using the CIECAM02 color appearance model.

3. METHOD

Over 20,000 unconstrained color names were collected from over 3000 participants in 22 languages using an experiment conducted on the World Wide Web.[8] The experiment was coded in JavaScript and the responses were turned into an email message using FormMail. The basic task was to "provide the best possible color name" for seven colored squares randomly selected from a 6 by 6 by 6 sampling of "web safe" colors and displayed on a white background. The data was validated using self-scoring, sorting into known sub-populations and other analysis. Use of a distributed design also minimized disruptive influence from individual participants and kept the volunteer participation rate high. The site receives roughly 15 hits a day and has a voluntary participation rate fluctuating between 33% and 15%. It is estimated that over 97% of participants submit only one set of seven color names. It is also estimated that the disruptive participant rate is roughly 3% and incomplete submissions, which are treated as an opting out of the experiment, accounted for roughly 3% of submissions.

4. RESULTS

The end result of the on-line color naming experiment is a large-scale color naming database. This database can be analyzed and explored in many ways. Earlier results demonstrated that assuming sRGB[13] as a nominal display yielded reasonable correlations for the basic color centroids lightness and hues relative to previous laboratory studies. In fact the results for the web-based study agreed with previous studies as well as these studies agreed with each other.[8] Further results showed a reasonable agreement between the resulting centroids for non-basic color names such as flesh, sky and grass and results found with other laboratory studies.[14] Although there are a large number of variables that contribute to variability in the perception and reproduction of color, it seems like that averaging results for thousands of submissions will yield meaningful results on the average.

One simple analysis is keyword frequency for the unconstrained color names. Specific keywords to be considered are those that most closely correspond to the perceptual attribute correlates. For instance of the 23,765 color names 2,067 include the terms 'light' or 'dark' suggesting the relative frequency of which a color name modifier corresponding to the lightness correlate is used. In comparison the term or sub-string 'chroma' occurs zero times, 'colorful' occurs zero time, 'saturated' 6 times and 'vivid' 13 times. Other researchers have noted the relative ambiguity of the chroma correlate.[15,16] Basic patterns in natural language usage suggest the linguistic categories corresponding to chroma saturation or colorfulness are significantly under-developed and recent[17] relative to the more robust and more widely used lightness categories and the hue specific categories as defined by a specific basic or non-basic color names. It seems possible that while terms chromatic and saturated have specific and reasonably well-defined technical meanings with respect to scaling of colored stimuli in laboratory conditions they are not used by non-specialists to describe their perception of color.

The limited linguistic encoding of chroma or colourfulness is further reinforced by considering the distribution of average chromas for basic and non-basic color names. Setting aside the debate of universal versus relativistic theories of color names, non-basic color names are used and while perhaps less broadly than the basic color terms, they are likely robust when used by sub-populations comfortable with the given non-basic color name. A plot of name versus mean inferred CIECAM02 chroma can be seen in Figure 2 and shows that aside from the achromatic color names of black, gray and white the commonly used non-basic color names all have mean CIECAM02 chroma values of greater than 40. There is a lack of non-basic color names with lower chromas. This offset could be attributed to a number of factors, such as lack of robustness given environmental and observer variations, but it seems likely that the concept of chroma or saturation is not really even implicit in non-basic color naming. In this case the average CIECAM02 chroma values were computed assuming sRGB as a nominal display although the basic results of a lack of color terms with mean chromas in the range 20 to 35 remains. Lin et al. note that based on their research "when subjects chose a focal colour, they tended to select the most chromatic".[18] Given these results it is perhaps work considering the hierarchical system shown in figure one such that some perceptual attribute correlates such as chroma or saturation might in fact not be in the middle but at the top of the system.

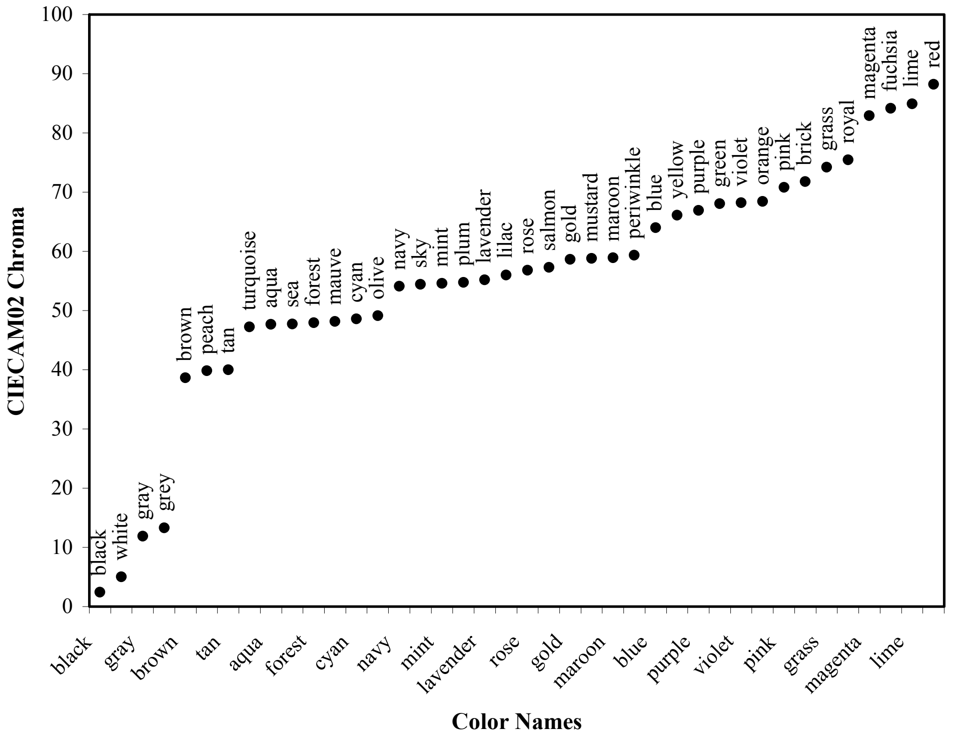

Figure 2: CIECAM02 Chroma for the average basic and non-basic color names.

It is also possible to infer a spatial configuration of the color names without assuming a specific nominal display. Instead it is the only assumption is that a nominal display exists and then patterns in name usage for given RGB triplets can be used to infer dissimilarities between a set of color names. Multidimensional scaling can then be applied to this dissimilarity matrix and the resulting spatial arrangement of color names can be considered.[14] For instance given 216 unique RGB triplets the terms 'cyan' and 'aqua' would have a low dissimilarity based on a Jaccard index because there would likely be many RGB triplets in which both the term 'cyan' and 'aqua' overlap. An example of the first two reconstructed dimensions resulting from using Matlab multidimensional scaling for a collection of color names is shown in Figure 3. This arrangement of points shows an ordering of the hues in a manner that is approximately consistent with red-green and yellow-blue opponency. This arrangement of point can then be compared to arrangements resulting from assuming an sRGB display and given uniform color space. For example using CIELAB there is a correlation coefficient of 0.51 for the normalized inter-name distances but for CIECAM02 this correlation is 0.60. This shows that at the range of color distances corresponding to the distances between color names, CIECAM02 provides a better fit than does CIELAB. The specific reason for this is primarily the significant blue to purple shift for CIELAB[19] that is not evident in CIECAM02.[20]

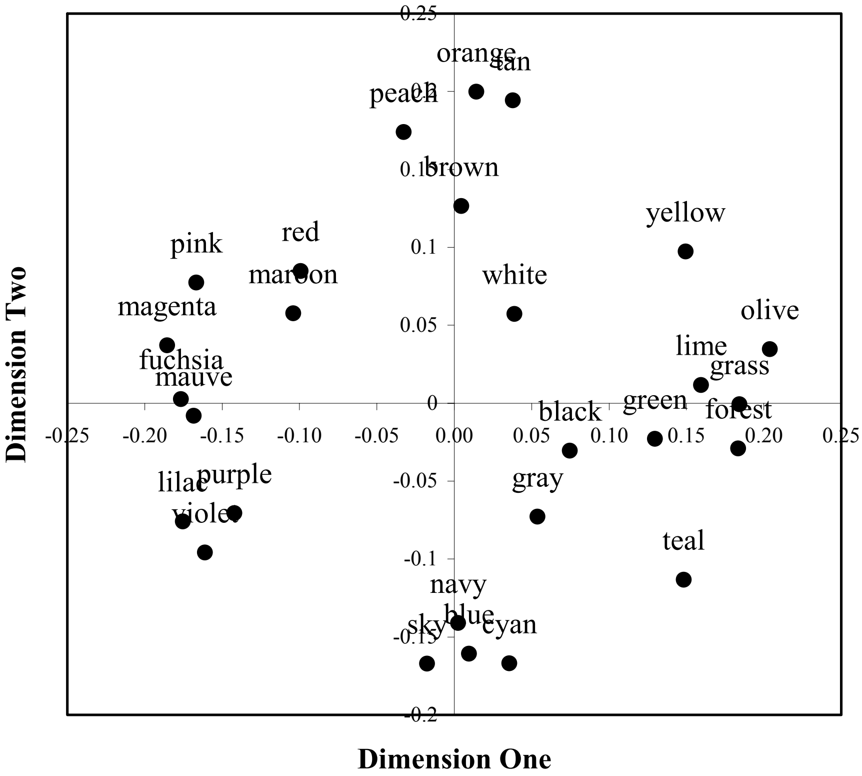

Figure 3: First two dimensions from multidimensional scaling of color name dissimilarities.

5. CONCLUSIONS

Color appearance modelling and color naming have generally been separate areas of research. Recent color appearance models, such as CIECAM02, provide a means of quantifying perceptual attribute correlates but don't have any capability to determine which color name corresponds most closely to a given set of correlates. However the results from a large-scale color naming experiment provide a database provide some additional considerations. The terms for chroma, saturation and colorfulness are essentially unused in general. Other terms such as vivid are used slightly more but still significantly less than terms for lightness. Basic and non-basic color terms also exhibit a distinct tendency to higher chromas with a sizeable gap for names corresponding to lower chroma colors. Finally multidimensional scaling can be used to infer inter-name distances that can be used to compare uniform color spaces on a large scale. Results from this type of analysis suggest that CIECAM02 has better overall inter-name distance uniformity than does CIELAB.

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