The Chroma Zone

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Color-Appearance Modeling Between Reflection Prints and CRT Displays

Many factors contribute to the color of an object. The most basic factors include the spectral reflectance of the object's colorants and the spectral power distribution of the light source under which the object is being viewed. CIELAB, a color space recommended by the CIE (Commission International de L'clairage), uses these two factors to predict the appearance of a color and is commonly used in the color imaging industry. Other factors, not accounted for by CIELAB, include the lightness of the background, cognitive factors associated with the media being viewed, and the ambient surround (dark when viewing slides, possibly dim when viewing a CRT computer display, average or light when viewing printed images). More complicated color-appearance models attempt to correct for these effects. These include Fairchild and Berns' RLAB, and models by Hunt and Nayatani. In addition, other factors can contribute to an object's appearance such as previous experience about what the object should look like, the gloss, and the shading of the object. All these factors make the specification of the color of an object quite complicated. Describing the color of a scene or complex image is even more difficult because objects in the image have different background colors and interact with each other. My Ph.D. research focused specifically on the problem of accurately reproducing complex images when original prints viewed in a light booth were compared to reproductions viewed on a CRT.

The first goal of the research was to determine the most appropriate way to display images in later psychophysical experiments. In an office environment, the most common way to determine whether a print matches a CRT image is to hold the print next to the CRT. This is a common way to compare images, but does not account for the differences in white point chromaticity between the two media. Generally, CRTs have a bluish appearance compared to the cool white fluorescent lighting in many offices.

In order to match the CRT white, the paper would need to have a bluish appearance, which most people would find unfavorable. The difficulty with this technique is that the observer cannot adapt to both color temperatures concurrently. This viewing technique was compared with several viewing techniques in which observers were more fully adapted. These included memorization techniques in which observers viewed the original separately from the reproductions, as well as haploscopic techniques in which each of the observer's eyes viewed a different image. If our eyes can adapt independently, haploscopic techniques combine the advantage of complete adaptation of the memorization techniques with the ease of simultaneous binocular viewing. Each of these techniques were used in a color-appearance-matching psychophysical experiment and it was found that the haploscopic techniques did not yield the same results as the memorization techniques. Therefore, the memory viewing technique was chosen for the next phase of research.

The second research phase involved testing color-appearance models over change in media (print to CRT), white point, overall luminance level, background, and surround between the viewing conditions. These models were tested using a paired-comparison technique in which observers viewed the original print in the light booth, then compared pairs of reproductions on the CRT that were derived using color-appearance models. Observers chose which reproduction looked more like the original for every possible pair of models. It was determined that RLAB produced the most accurate matches to the original image across changes in white point, luminance level, and background. CIELAB and von Kries chromatic adaptation also produced relatively good matches. RLAB over predicted the effect of surround changes between the viewing conditions, but it would be a simple manner to lessen the surround factor in the RLAB model. Research by Cathy Daniels will provide a more clear indication of the appropriate factors to use.

The final phase of this research involved five expert observers adjusting CRT images at one white point to print originals at another. These observers used Adobe Photoshop to adjust the reproduction as a whole as well as specific objects in the image. The adjusted images for the

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five observers were combined to yield an average adjusted reproduction. Nave observers then compared these adjusted reproductions to reproductions produced with the color-appearance models, using the paired-comparison technique of the previous phase. The adjusted reproductions provided equal or better matches to the originals than the models did. This research suggests that this is a feasible method for gathering color-appearance data for images independent of any current model. The reproductions obtained from this technique can be compared to future modifications to the models or perhaps build a new model.

- Karen Braun

Some Considerations About Corresponding Colors Across Cross-Media Color Reproductions

About one and a half years have passed since I came to Rochester. During that period, many incidents have happened in Japan. The Tokyo Gas attack and Kobe earthquake are some examples of miserable ones. As for me, I have learned a lot of things, which are usually accompanied with great surprises. I have found a significant difference exists among the colors of crayons available between USA and Japan. Fortunately, I totally enjoy an American life so far.

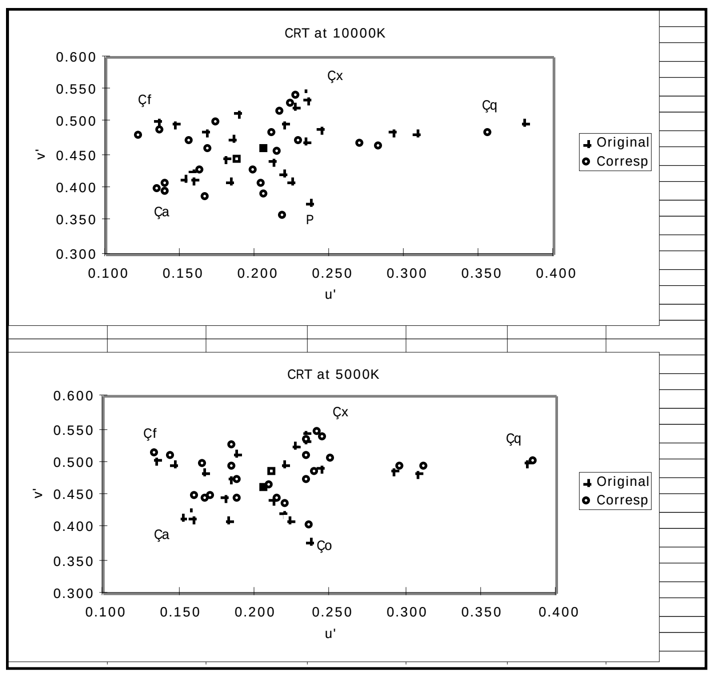
In the imaging industry, rapid and dramatic changes could be seen in recent years. Low-end digital cameras generate great sensations among consumers. Now it is expected that more than ever, people are taking digital images and putting them in documents or sending them through networks.

Taking advantage of attending the color appearance class, I made a comprehensive survey of past studies on the subject. This is really helpful for deepening my knowledge and now I am doing a series of experiments to investigate corresponding colors across cross-media color reproductions. Although the technological progress grows rapidly, there exists many invariable papers which motivate me to do such a project. Here, I would like to introduce some of the papers before introducing my experimental results.

It seems to be interesting that the papers written by C.J. Bartleson, E.J. Breneman, and R.W.G. Hunt have close relations with the evolution of photography. Bartleson and Breneman examined brightness functions in viewing complex stimuli over a range of illuminances. Breneman also investigated the perceived saturation in complex stimuli evoked by light and dark surrounds. Hunt et al. examined the preferred colors viewed under tungsten and daylight and figured out the difference. He also exhibited the idea of incomplete adaptation, which is now embedded in sophisticated color appearance models such as RLAB.

Although these papers were published between the late 1960s and 1970s, their ideas and essentials are still applicable for today's digital imaging technology. Just as quoting from D.L. MacAdam's words "Color scientists are coming back to the old ideas that have been neglected for many years," there is still some space for applying these olds ideas to cross-media color reproduction.

The first phase of my experiments is to examine the fundamental relationship of color appearance between a hard copy and a soft copy. There, to derive corresponding lightness, chroma, and hue, each stimulus in the booth was compared with that displayed on the CRT. The psychophysical experiments were achieved by using a short term successive binocular matching technique and probit analysis was employed for analysis. Examples of the results are shown in Fig. 1.



In Fig. 1, the corresponding hues of 27 chromatic stimuli in the booth illuminated at 6500K are plotted in CIE 1976 u'v' diagram for CRT observations at 10000K and at 5000K respectively. Then based on the experimental data, I examined the performance of typical color appearance models. The results are tabulated in Table 1.

Fig. 1 Corresponding chromaticities of stimulus viewing in the booth (6500K). ■ The reference white of the booth. □ The reference white of the CRT.

Table 1
Color Difference (mean ΔEu'v') between psychological experimental data and those estimated by typical color appearance models.

	Model	CRT 10000K	CRT 5000K
1	von Kries	0.0088	0.0078
2	RLAB	0.0112	0.0066
3	Hunt	0.0095	0.0099
4	Nayatani	0.0130	0.0200
5	ICC	0.0063	0.0086

The model performances were evaluated by taking the mean color differences between the estimated chromaticities and the experimental ones in u'v' color diagram. Table 1 suggests that in case of CRT observations at 10000K, ICC(International Color Consortium) transformation and von Kries transformations give better estimates, however, in case of CRT observation at 5000K, RLAB model and von Kries transformations give better predictions. It is interesting that in both cases, the relatively complicated models such as the Hunt and the Nayatani models could not estimate good results. This does not indicate the defects of these models directly. However, in case of color evaluations across media or in case of corresponding colors, some effects such as "induction" might occur and affect the results. Consequently, the relatively simple models may explain the psychological data as well.

The data obtained in the experiment may be also applicable for optimizing a parameter of discounting the illuminant factor, D, employed in the RLAB equations. The optimization exhibits that the factor of D=0.64 for CRT observations at 1000K and that of D=0.12 for CRT observations at 5000K can explain the psychological experimental data adequately. This means the degree of the discounting the illuminant effects depends on the viewing illuminant itself. In case of CRT observations at 5000K, this effect does not occur effectively, and that causes the observer to perceive yellowish tint strongly.

Now I am completing the second phase of the experiments. There, by using some pictorial images, the corresponding lightness, chromas and hue will be examined and compared with the data obtained in the first phase of the experiments. I hope my project will shape up nicely.

Finally, I would like to express my appreciation of all the kindness that the staff, colleagues, and my friends have given to me. Definitely, the Munsell Lab is an exciting, attractive place, and I am quite happy to be given the opportunity to study here.

- Kazu Takemura, Fuji Photo, CIS Visiting Scientist
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Welcome to Acadia Reniff Fairchild

Congratulations to Mark and Lisa on the birth of their daughter, Acadia. She was born on February 20. She weighed 6 pounds, 10.5 ounces, and was 20 inches long. She has quite a bit of light brown hair and she loves to sleep. Lisa, Acadia, and Mark are doing well and adjusting to their new lifestyles.

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