Color Reproduction Algorithms and Intent

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Abstract

The effect of image type on systematic differences from strict colorimetric reproduction is investigated and discussed. Different situations, called "color intents," are described. We have identified four basic color intents. Color reproduction algorithms for each intent are presented, together with guidelines for selecting the appropriate intent.

Introduction

When reproducing a color image, it is often desirable to introduce systematic differences, rather than to produce a strict calorimetric match. This is particularly true if the source and destination images are in different media. These differences also depend on the type of image. The nature of these differences is discussed in the paper.

A color printer, for example, may be used to produce a large area of uniform color for a consumer package. In this case, a tristimulus (if not a spectral) match to a reference may be desirable. Such a match is out of the question for color transparencies (possessing a luminance range of 1000:1) reproduced in printed publications (with a luminance range of 100:1). The two images must be treated differently. We refer to this as "Color Intent."

Bar and pie charts usually contain large areas of uniform color. Popular software packages exist for creating these graphics on personal computers. Users select colors, size, and arrangement on the basis of the CRT display, which serves as the original image. Hard copy may be obtained by sending the graphic to a color printer. If the color specifications are manipulated to produce as close a calorimetric match as possible, the resulting image is unsatisfactory. Some colors are printed desaturated, even though they are within the gamuts of both the CRT and the printer. Clearly, a different approach is needed for this scenario.

Color Intents

We have identified four basic color intents. In summary form, they are:

Absolute

With this intent, the goal is to produce as exact a tristimulus match as possible. When the specified color is within the gamut of the destination device, it is generated. No white point, black point, or other adaptation compensations are performed. This intent is appropriate for a limited number of applications, such as generating completely filled-in pages of uniform color and consumer packages.

Relative

Applicable to a wider set of circumstances than the Absolute intent. A white point compensation is appropriate for this intent, so the effects of chromatic adaptation may be accounted for. This intent is most applicable to uniform areas, such as trade dress colors, on fields containing some unprinted paper to set the adaptation level.

Raster

This intent is appropriate for natural raster scenes, such as photographs. A white point adaptation compensation is performed. In order to compensate for different luminance ranges, tone compression is also performed. In addition, some adjustment is made to Chroma.

Business Graphics

This intent preserves the "purity" of a color. It avoids the introduction of "phantom" cyan or magenta dots in pure yellows, for example. It applies to images containing large uniform areas, for which the requirements of a relative match of tristimulus values are less important than preservation of the purity of the saturated colors.

The Absolute and Relative intents are quite similar, and differ in how they use (or ignore) white point information. One may distinguish between the two in practice in the following way: If the adapting white stimulus comes from within the image or the medium on which it appears, the Relative intent applies. An example of this is a logo on a sheet of stationery. If the adapting white stimulus is outside the image, the Absolute intent is the more appropriate of the two. An example of this situation is a package for a consumer product which will be displayed next to other packages of the same brand. Given the proximity between the two, the two different packages will be viewed under identical adaptation conditions, even if printed on different paper. A colorimetric match constitutes an appearance match when identical viewing conditions (and surface conditions) prevail.

Reference White

In the discussion of Color Reproduction Algorithms, mention is made of the Reference White of an image. For many images, this will be the specular highlight, the so-called "D-min" capability of the imaging system. We define it as the stimulus, which may or not be present in the image, which would tend to be perceived as being the white associated with that image. Images containing no specular highlight may be compared to images which do. One may take as the reference white of a sunset scene, which has no specular highlight, recorded on a particular type of color reversal film, the specular highlight of another frame which is judged to have the same degree of over- or underexposure, color cast, etc.

The reference white of images in certain media, such as CRT monitors connected to digital frame buffers, and four-color process printing on paper, may usually be considered the stimulus in that medium that produces the maximum luminance.

The reference white for reflective media is not the perfect reflecting diffuser, unless the image is framed by or printed on a material of unnaturally high reflectance. CIE recommendations for calculation of CIELAB coordinates were formulated to permit the use of a "specified white object color stimulus."[1]

Color Reproduction Algorithms

Frequently, a reproduction of an image will differ deliberately from the original. This is particularly true when the original and reproduction media have different luminance range capabilities. In an earlier work, one of the authors demonstrated how these deliberate differences can improve the perceived quality of the reproduction, and the form these differences should take for pictorial-type images.[2]

In this earlier work, the phrase "Color Reproduction Algorithm" (CRA) was introduced to describe the relationship between the colors in the original and the reproduction. We feel that this is a significantly more accurate nomenclature than the sometimes-heard phrase, "Gamut Mapping," for it describes the mapping of colors, rather than gamuts.

Gentile, Walowit, and Allebach[3] examined several types of CRAs. They applied clipping and compression (though not both at the same time) to various color coordinates. Their conclusion, based on psychometric evaluation of sample prints, is that viewers tend to prefer reproductions in which the Chroma component is clipped to the gamut limit (if outside), while Lightness and Hue are held constant.

We have found it quite fruitful to consider CRAs as having two components. The first component, termed the "General CRA," is applied to all colors. The second, the "Out-of-Gamut Mapping," is applied to colors which, after passing through the General CRA, are outside the reproduction device's color gamut. The purpose of the General CRA is to provide the "preferred" mapping of most colors. This often has the effect of reducing the number of out-ofgamut colors. It should be pointed out, however, that it should not in general eliminate them.

This bifurcated approach permits additional flexibility in selecting the nature of the mappings. In the previous work,[2] preferred results were obtained when compression on L*, in conjunction with partial compression on C*, was used as the General CRA, with clipping in CIELAB used as the Out-of-Gamut mapping. The partial compression in C* was large enough to reduce the number of out-of-gamut colors, yet small enough to avoid the impression of oversaturation.

Color Reproduction Algorithms for Different Intents

Recent efforts notwithstanding,[4] there is a dependence of CRA on the type of image. We present below the General CRAs for the different Color Intents:

Absolute Intent

The General CRA for the Absolute intent permits a normalization for differences in the absolute luminance of the reference white. It is appropriate to consider a separate reference white with this intent if the original and reproduction are in media of very different types, such as hard copy versus soft display. This corresponds to the goal of "Colorimetric colour reproduction" as discussed by Hunt.[5] The only change made in such a case would be a normalization for difference in highlight luminance.

In such a case, the tristimulus values in the reproduction would be proportional to the tristimulus values in the original, with the constant of proportionality being the ratio of the luminances of the reference whites.

If both original and reproduction are extent in similar media, and/or compared side-by-side, the same reference white may be used for both. The reproduction of the same tristimulus values would then be the goal. This correl sponds to the goal of Hunt's "Exact" color reproduction.

Relative Intent

The General CRA for the Relative intent has the effect of compensating for the luminance and chromaticity difference of the white points. It may be considered a solution to Hunt's "Equivalent" color reproduction, inasmuch as it uses some form of adaptation.

We have found the simplified von Kries adaptation model used in the CIELAB formulae to work well with most media. This model causes the tristimulus values of the reproduction to be proportional to the tristimulus values of the

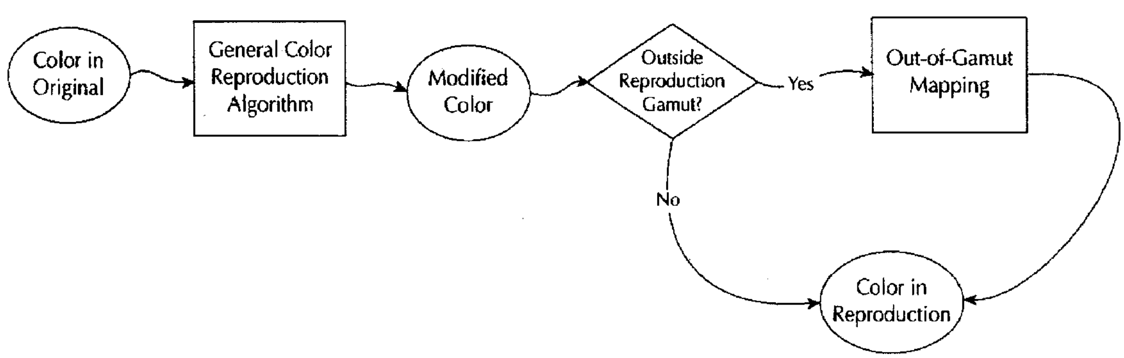

Figure 1. The dataflow from color in original to color in reproduction is illustrated. Note that the General Color Reproduction Algorithm is applied to all colors, while the Out-of-Gamut Mapping is applied only to colors falling outside the reproduction gamut. The determination is made after having applied the General CRA.

original. However, the constants of proportionality will be different for each tristimulus value. This permits compensation for the chromaticity, as well as the luminance, of the white points, and is manifested by a CIELAB color match.

Certain media do not respond well to the simplified von Kries model used by CIELAB. An example is a CRT monitor adjusted to a suboptimal white point, such as that of Illuminant A. In such a circumstance, a match in a color image appearance space, such as RLAB,[6] is indicated.

Raster Intent

The CRA for the Raster intent involves compression or expansion of the lightness component, so the shadow of the original maps to the shadow of the reproduction. When the original and reproduction are viewed with similar surround conditions, the compression or expansion is fairly linear in L*. We have found that uniform compression in Bartleson and Breneman Darkness space to provide superior results.

One could say that the CRA for the Raster intent compensates for differences between both the white point and black point of the original and reproduction media.

Some compression or expansion is also performed on Chroma. In an earlier study, it was found that a constant of proportionality midway between unity and the ratio of the L* ranges was satisfactory.2

Business Graphics Intent

In the Business Graphics intent, our goal is to reproduce the Red in the original media with the Red in the reproduction media, a Yellow in the original media with a Yellow in the reproduction media, and so on. Compensation for differences in White and Black points is accomplished through compression or expansion of the Lightness component, as in the CRA for Raster intent.

Lightness compression or expansion is performed on the canonical chromatic colors (Cyan, Magenta, Yellow, Red, Green, and Blue) of the original gamut. The amounts of each colorant needed to produce each of these colors in the reproduction medium is then determined, and the solutions examined. If the solution contains any "unwanted" component (*e.g.*, Cyan ink in the solution for Red, Green phosphor in the solution for Magenta), the unwanted component is clipped to zero. The solutions are also adjusted so the "principal" component (e.g., Magenta ink in the solution for Red, Green phosphor in the solution for Green) is at its maximum. These colorant amounts are then translated back into color coordinates using a model of the reproduction device. The remaining portion of the CRA is a color morphing routine, defined by these "before" and "after" colors.

Conclusions

Strict equality of tristimulus values is not always feasible in color image reproduction. The relationship between the colors in an original and a reproduction may be controlled by a Color Reproduction Algorithm (CRA), consisting of a General component, and a Out-of-Gamut mapping.

The selection of CRA is dependent upon the type of image being reproduced, and its intended mode of viewing. Four color intents have been identified: Absolute, Relative, Raster, and Business Graphics. General CRAs for each intent have been described. The CRAs differ in their compensation for difference between the original and reproduction media in White Point, Black Point, and the other canonical colors of the respective gamuts.

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