How To Make Pictures and Please People

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Abstract

The various ways in which pictures can be made by both subtractive and additive displays are reviewed. Systems using these displays are all limited by errors caused by incorrect camera spectral sensitivities, and by the limited gamuts of reproducible colors. Subtractive systems are further limited by the unwanted absorptions of their colorants. Pictorial images are usually assessed by comparison with memories of familiar objects. Because such objects vary considerably in color appearance, the tolerances in images of pictorial scenes are quite large; however, these variations tend to be smallest for hue and largest for colorfulness, so that hue is the most, and colorfulness the least, important attribute in imaging. Six possible different objectives are described: spectral, colorimetric, exact, equivalent, corresponding, and preferred. Possible reasons for preferring increased contrast in images are discussed.

Introduction

The vast majority of pictures are made to be viewed by people. Imaging must therefore be people dominated. Hence the title: *How to make pictures and please people* (with acknowledgements to Dale Carnegie's *How to win friends and influence people*[1]).

Subtractive Systems

From prehistoric times pictures have been made by painting, but the first color pictures made by imaging were produced by Jacob Christoph Le Blon around 1720. Le Blon used half-tone images in yellow, red (magenta), and blue (cyan) inks, and his process was therefore the fore-runner of modern graphic arts printing by lithography, gravure, and letterpress. The first commercially successful subtractive systems of continuous tone color photography were *Technicolor*, the first three-color film being produced in 1932, and *Kodachrome*, invented by the two professional musicians Mannes and Godowsky, and introduced as a 16mm amateur movie film in 1935, and as a 35mm slide film in 1936. Color films in which the couplers were incorporated in the layers of the film were introduced by Agfa in 1936 and by Kodak in 1942.

In recent years, increasing numbers of color reflection prints have been made using the electrophotographic, ink-jet, and dye-diffusion transfer, technologies.[2,3]

Additive Systems

The first additive color images were demonstrated by James Clerk Maxwell, at the Royal Institution in London, in 1861, and the system he used was the fore-runner of the triple-projection cathode-ray tube displays widely used in lecture theatres and for in-flight entertainment in aircraft.

The inconvenience of triple projection can be avoided by viewing small adjacent red, green, and blue areas at a distance such that these areas are not resolved on the retina of the eye; among the earliest commercially successful of these mosaic processes were the *Autochrome* process introduced by the Lumiére brothers in 1904, and the *Dufay* process in 1908, a more recent example being the system used in the *Polavision* process for amateur movies introduced in 1976 and in the *Polachrome* process for slides introduced in 1984. The mosaic system is used in many television display devices: the shadow-mask tube is the most widely used, but liquid crystal, plasma, and light-emitting diode displays, are making increasing penetration into the display market.

Another way of adding the red, green, and blue light together is to view them in rapid succession; the first commercially successful example of this field-sequential system was the *Kinemacolor* process introduced in 1908, and the field-sequential principle is used currently in one version of the *Digital Mirror Device* (DMD) displays.

Yet another way of adding the red, green, and blue light together is by superimposing virtual images of the three records; this was first done in 1895 by F.E.Ives in his *Kromscop* viewers, and the same principle is currently used in another version of the DMD system.

Limitations in Making Pictures by Imaging

Systems using these displays, whether subtractive or additive, all have inherent limitations. These limitations are associated especially with the spectral sensitivities of their acquisition devices, and with the gamut and dynamic range of their reproducible colors; the subtractive displays have additional limitations imposed by the unwanted absorptions of their cyan, magenta, and yellow colorants.

Spectral Sensitivities

The correct spectral sensitivities to use in an acquisition device are the color-matching functions for the red, green, and blue primaries used in the display device. Because the primaries are unable to stimulate the three different cone types of the eye separately, these color-matching functions always have negative lobes. These negative lobes have so far proved impossible to replicate correctly in color films. In electronic cameras, the negative lobes can be introduced by matrixing linear signals, and this is normally done; however, the spectral sensitivities corresponding to the matrixed signals are usually only an approximation to the required color-matching functions. These incorrect spectral sensitivities introduce errors into the system at the very outset which can never be corrected later. The result is that some colors, which are spectrally different but look alike to the eye (metameric colors), may be reproduced as different colors in the system; and other colors, which look different to the eye, may reproduce the same in the system. A further complication in subtractive systems is that the effective primaries change, as different parts of the color gamut are reproduced, so that there is no unique set of associated color-matching functions which is correct to use.

Gamuts

The second limitation, the gamut of reproducible colors, also arises because of the unwanted stimulations of the cones by the primaries. In additive systems, the gamut of reproducible colors can be represented on a chromaticity diagram by the triangle formed by the three points at which the three primaries plot; in subtractive systems, the gamut is not a simple triangle, but the shape and location of subtractive gamuts, although a little larger, is not usually very different from a typical additive triangle. Both the additive and the subtractive gamuts are typically far smaller in size than the maximum gamut of all possible colors (represented by the spectral locus and the purple boundary[4]), but the gamut of colors commonly occurring in the real world is also much smaller than the maximum gamut,[5] and only slightly larger than the reproduction gamuts; it is this fact which makes the use of the reproduction gamuts viable. The gamut of the real world colors is restricted because the vast majority of them are produced by dyes and pigments which have broad spectral absorption bands, and which therefore cannot generate colors having only narrow spectral bands; however, colors which are produce by other means, such as the interference colors produced in some feathers of birds and in some scales of insects, for instance, or colors produced by lasers, may lie well outside the reproduction gamuts. The use of red, green, and blue lasers in additive displays has been tried,[6] but, although an increase in gamut can be obtained, this advantage has to be weighed against the increased cost, power consumption, and inconvenience, of these devices.

In graphic arts printing, the use of extra inks, typically an orange, a green, and a violet, in addition to the usual cyan, magenta, yellow, and black, has sometimes been used for the reproduction of original works of art,[7] and in the *Hexachrome* process additional orange and green inks are used to extend the gamut. In addition to extending the gamut, additional inks are useful in making it possible to reduce the degree of metamerism between an original color and its reproduction, and this can be important in the mail-order catalogue business.

Dynamic Range

The dynamic range of reproduction systems is always limited and liable to be exceeded by some types of scene. Reflection prints, when seen in typical room viewing situations, have dynamic ranges which are very dependent on the quality of the paper on which they are produced; with the best quality papers, a range of about 1.7 log units may be achieved, but with newsprint it may be only about 1.2 log units. The dynamic range of self-luminous television displays is usually limited by the ambient light reflected from the front surface of the device; when seen in dim surrounds, ranges of about 1.7 log units are typical, but the dim surround reduces this to an effective range of about 1.7/1.25 or about 1.4 log units of scene luminance. The dynamic range of projected images usually depends on the amount of ambient light present, but a typical figure for good projection conditions is about 2.7 log units; however, the effect of the dark surround is to reduce this to an effective range of about 1.8 log units of scene luminance. Some real scenes can have dynamic ranges of 3 or more log units, so that it is clear that, for such scenes, some parts of them will lie well outside the tonal gamut of the imaging system. Although flare light in the eye usually reduces the tonal range of the image on the retina to much less than 3 log units, an additional reduction by the imaging system can be very deleterious; moreover, by scanning the scene with eye movements, the visual system is able to extend its effective range and see into shadows in a way that is not available to most imaging systems.

Unwanted Absorptions

All subtractive colorants absorb in parts of the spectrum where, ideally, they should be perfectly reflecting or transmitting. These unwanted absorptions make the reproduced colors darker than they should be, and correction for their effects is essential. In photography, correction is provided in color negatives by the use of dye-forming couplers which are themselves colored; the yellow color of a magenta-forming coupler corrects for the unwanted blue absorption of the magenta dye, and the pink color of a cyan-forming coupler corrects for the unwanted green and blue absorptions of the cyan dye.

Unwanted absorptions are also corrected by the use of *inter-image effects* in which the amount of dye in one image is made to depend on the amount of dye in another image; for example, if the amount of magenta dye is made to decrease slightly as the amount of yellow dye increases, then the reduction in the amount of magenta can compensate for the unwanted green absorption of the yellow dye. In graphic arts printing, and in desk top publishing, similar adjustments to the amounts of the colorants are usually made electronically by means of suitable signal algorithms.

Although these means of correction are effective within the gamut of reproducible colors, the gamut itself is still reduced by the unwanted absorptions of the colorants.

The Basis of Assessing Images

Because of the limitations of color imaging systems, some errors of color reproduction are inevitable. The art of making pictures that please people is to confine the errors to those that are least noticeable visually. To know how to do this it is first necessary to consider how people usually assess colors in pictures.

The usual basis of assessment of colors in pictorial images is a mental comparison between a reproduced color and a memory of the usual color of similar objects. But both the reproduced color and the input from original colors to the memory are subject to a variety of physical, physiological, and psychological effects.

Physical Effects

In some objects, variations of hue are quite common. For example, fruit usually varies in hue as it ripens; the hue of foliage changes with the seasons, and is appreciably different on different types of plant; and skin color changes towards a yellower color with sun tan.

Variations of lightness in objects frequently occur. For instance, the lightness of many plants varies with the degree of moisture in the soil; that of stone and rocks with the weathering effects on their surfaces; and the lightness of clouds is very dependent on the weather conditions. Many surfaces also become partly bleached, and hence lightened, by prolonged exposure to bright sunlight.

Variations in the colorfulness of objects are very widespread indeed. For instance, the colorfulness of objects is reduced in shadow areas; it can also be greatly reduced if objects are viewed through appreciable atmospheric haze; and glossy surfaces have much lower colorfulnesses in those parts where light areas are reflected than where dark areas are reflected. Blue sky has a much lower colorfulness near the horizon than at higher angles, and blue water varies appreciably in colorfulness according to what is reflected by it.

Physiological Effects

Although the visual system adjusts its sensitivity to compensate for changes in the level of illumination, the compensation is only partial, and at lower levels both brightness and colorfulness are reduced.

Compensation for changes in the color of the illumination is also only partial, and this results in some residual changes in the appearance of objects seen in lighting of different colors.

Their surrounds affect the appearance of colors, dark and dim surrounds lowering apparent contrast. The backgrounds to colors also affect their appearance, tending to make them appear more like the complementary color of the background, especially in lightness.

Psychological Effects

Experiments have shown that memory colors of familiar objects are more colorful than the perceptions of the objects themselves.[8,9]

When the area of a color is reduced, the colorfulness usually decreases,[10] so that to evoke the memory color of a small object in a picture its chroma may have to be increased.[11]

It has also been shown experimentally that, for distant objects seen through hazy air, the eye partially discounts the visual effects of the air in the light path, and this increases the apparent contrast and colorfulness of such objects.[12,13,14]

Priorities in Color Reproduction

Many of the effects described above tend to make the least difference in hue, and the most in colorfulness; this is particularly true of the effects caused by changing the level of illumination, which is a very common occurrence in everyday life. In view of this, the following list of priorities for color reproduction can be drawn up:

1. Correctness of hues.
2. Correctness of lightnesses (tone reproduction).
3. Colorfulnesses proportional to those in the original.
4. Colorfulnesses and brightnesses the same as those in the original.

Correctness of hues implies that *color balance* is very important, because any overall bias in an image causes large distortions of hue for pale colors. Correctness of lightnesses emphasises the importance of good tone reproduction, without which an image may look too hazy or too garish. Proportional colorfulnesses will result in them changing in a way similar to that occurring when the level of illumination is changed. Having the same colorfulnesses and brightnesses as in the original is usually only possible if the luminances of the image and original are similar. Following these guidelines can help to balance the inevitable limitations of an imaging system in such as way as to give the most pleasing pictures.

Objectives in Color Reproduction

Given that the limitations of the systems introduce errors, and that these are best confined to certain types of error, it is now necessary to define the objectives from which these deviations will be made.

The objectives of an imaging system depend on the use to which its pictures are to be put. In different circumstances, any one of six different objectives may be appropriate.

Spectral color reproduction (equality of spectral reflectances or of relative spectral power distributions), although not attainable in most situations, provides a useful basis for determining the degree of metamerism of reproduction systems. This is a relevant objective in the mail-order catalogue business.

Colorimetric color reproduction (equality of chromaticities and relative luminances) is a useful criterion when the original and reproduction have the same viewing conditions and use illuminants of the same color; this is often approximately the case for reflection prints.

Exact color reproduction (equality of chromaticities, relative luminances, and absolute luminances) ensures equality of appearance for original and reproduction if the viewing conditions are the same for both. This may be a desirable objective in virtual reality displays.

Equivalent color reproduction (chromaticities, relative luminances, and absolute luminances such as to ensure equality of appearance) can allow for all effects of viewing conditions, but may be an unrealistic criterion if there is an appreciable difference in luminance level between original and reproduction.

Corresponding color reproduction (chromaticities and relative luminances such as to ensure equality of appearance when the original and reproduction luminance levels are the same) allows for all effects of viewing conditions except absolute luminance levels, and provides a realistic criterion for many situations.

Preferred color reproduction (departures from equality of appearance, whether at equal or at absolute luminance levels, in order to achieve a more pleasing result).

Increasing Contrast

Some commercial processes are run at higher contrasts than would be indicated by corresponding color reproduction; these higher contrasts increase the differences in brightness between light and dark parts of the picture and also increase colorfulness. Possible reasons for this preferred practice of raising the contrast include the following. First, when the original is a scene lit by natural daylight, the reproduction usually has a much lower luminance, and this lower luminance results in some reduction in perceived contrast,[15] and in lower brightnesses and colorfulnesses;[16] hence raising the contrast can result in images which appear more like the original scene. Second, the partial discounting of the effects of haze on distant objects can be mimicked in the imaging system by increasing its contrast. Third, the increase in the colorfulness of memory colors of familiar objects can be mimicked by increasing system contrast; the increased colorfulness acquired by other colors is then desirable to maintain consistency in the picture.

However, there is no doubt that, for some subjects, too much contrast reduces the quality of the reproduction markedly. This is particularly true of pictures of people in sunlight, and in this case good results may only be obtained either by using fill-in flash (or other supplementary illumination) to lighten the shadow areas, or by special treatment of these areas by signal processing.

Naturalness

Other reasons for departing from corresponding color reproduction have been reported in the work on *naturalness* of color reproduction by Yendrikhovsij, Blommaert, and de Ridder[11]. They have proposed a *naturalness index*; this index represents the likelihood that the perceived color of an image of an object falls in that part of perceived color space occupied by the range of memory colors typical for that category of object.

Graphic Arts Objectives

In graphic arts reproductions, Gary Field has identified three categories of preferred color reproduction as follows[17]:

Corrective color reproduction. Reproduction from another image which has defects. For example, a color photograph may have some highlight areas burnt out, or some shadow areas blocked up, because the original scene had a much larger dynamic range than the photographic system used to record it. Corrections are then applied to darken the light areas and lighten the dark areas.

Compromise color reproduction. Reproduction in which emphasis is given to rendering some important areas correctly at the expense of tolerating greater errors in some less important areas.

Creative color reproduction. Reproduction in which changes are made entirely for aesthetic or artistic reasons.

Conclusions

There are many different ways of making pictures in displays, but systems using them all have inherent limitations. Successful systems confine the inevitable errors to those that are least noticeable visually, and these are likely to be changes which are common in everyday life, such as those caused by changes in the level of illumination. The objective of an imaging system depends on the use to which the pictures are to be put, and six different objectives are possible. Departures from similarity of appearance to that of the original may be preferred because of physiological effects, such as adaptation and the effect of angular subtense on appearance, because of psychological effects, such as memory and discounting the effects of haze, and because of aesthetic or artistic requirements.

There are thus many factors to be reflected upon when designing imaging systems to make pictures that please people.

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