GRAY COMPONENT REPLACEMENT:
A Practical Approach

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Introduction

The transformation of a digital image from a three-dimensional color space, such as RGB, XYZ, L*u*v*, etc., to four-dimensional colorant space (typically cyan, magenta, yellow, and black) is in general underdetermined. (The reasons for the addition of a black colorant are detailed in Yule. [1]) We therefore have a degree of freedom for colors within the three-colorant gamut; without loss of generality we may use this degree of freedom to fix the level of black.

Perhaps the most desirable method for calculating the black level is under Gray Component Replacement (GCR). GCR is a relatively new phrase, though the idea has been with us for many years (at least in theory). [2] The goal of successful color separation scanners has been, until recently, to emulate the function performed by film-based systems, which were not able to readily achieve a significant amount of GCR because of the logic (decision) involved in the process.

We view GCR as a twofold process; to be applied in practice the level of black must be calculated, and the levels of the other colorants must be adjusted for the presence of the black ink. Some of the earlier literature refers to this second task as Under Color Addition; [3] because we consider GCR in a colorimetric context we feel it is better to consider this second task a part of the GCR algorithm proper.

The concept of GCR is simple: If a pixel's color is not too dark or too saturated, it may be produced with two of the process colors (*e.g.,* magenta and yellow) and black. Typically, a greatly simplified model is used in the vendor literature [4] which assumes equal amounts of cyan, magenta, and yellow inks should produce a neutral.

Unfortunately, this greatly simplified model, based upon the assumptions of "perfect" inks, is inadequate. In order to derive a rigorous GCR algorithm it is helpful to use a different colorant space.

A More Rigorous Solution

Pobboravsky [5] provided an approach that is adaptable to digital color systems. His method involved first computing a three-color solution, using the chromatic inks, to obtain cyan, magenta, and yellow halftone dot areas. Corresponding to any cyan, magenta, or yellow dot area is an Equivalent Neutral Density (END), which is the density of the unique neutral composed of that ink and the correct amounts of the other two. The gray component of the target color was defined to be the smallest of the END values corresponding to the calculated cyan, magenta, and yellow dot areas. The density of the gray component is the smallest END.

(Our current approach bypasses the preliminary three-color solution, and uses a direct transformation from reproduction color to ENDs. This has the advantage of a faster solution, because the direct transformation required considerably less computational effort than a solution for the three-color inking levels.)

Consider Figure 1. In it are represented two different inking combinations which can produce colorimetrically identical colors, under a specific set of calibration conditions. The solution on the left, referred to as “Minimum GCR,” is composed of the three chromatic inks and no black. For darker colors, the Minimum GCR solution may contain some black ink; we should not infer that the Minimum GCR solution never contains black. At the right is the “Maximum GCR” solution.

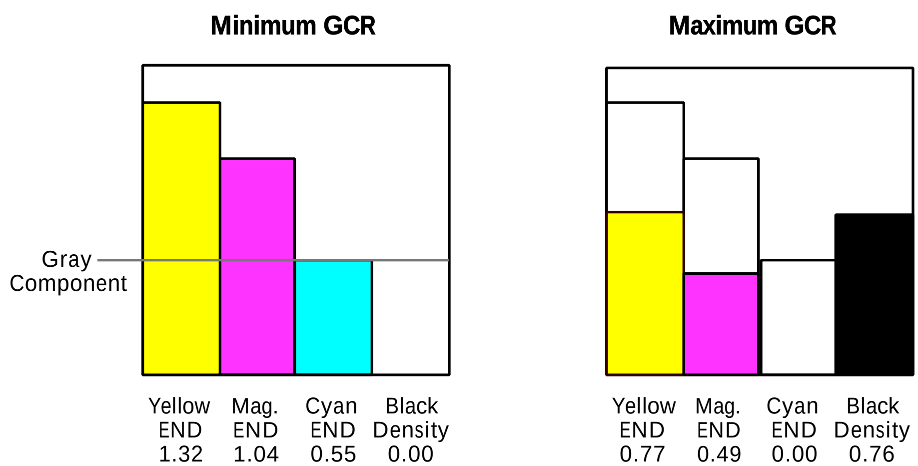

Figure 1.
Minimum and Maximum GCR Solutions.

Note that in the Maximum GCR solution, the densities of the chromatic inks have all been diminished by 0.55. We would expect the density of the black to be increased by this amount; in fact we see that it has been increased by a figure somewhat higher than this. The reason for this is that the densities of overprinted ink films do not add. [6]

In practice a solution intermediate to these two is selected to avoid several undesirable conditions. [7] It is customary to describe the degree of GCR as a fraction or percentage. In our work, we select a solution based upon the equation:

$$D_k = (1-G)\, D_{k\ min} + G \quad D_{k\ max} \tag{1}$$

where D_k is the density of the black;
G is the level of GCR, expressed as a fraction; and
$D_{k\ min}$ and $D_{k\ max}$ are the minimum and maximum levels of black possible for the color under consideration.

Typically, GCR levels of 60 to 80 percent are used. [7]

If the density of a pixel’s gray component exceeds that obtainable with the three chromatic colors alone, the minimum level of black will determined by this deficit. Otherwise, it will be zero. The maximum level of black will be either the density of the gray component (adjusted for the sub-additivity mentioned above), or the maximum density producible with the black ink, whichever is smaller.

Once the level of black has been determined, the ENDs of the three chromatic inks may then adjusted, using a model for the subadditivity effect. These ENDs may then be transformed into halftone dot areas. Or, if using a ”forward ” model which provides reproduction color as a function of inking level, such as Neugebauer’s, the level of black may be held constant throughout the iteration to a solution for the levels of cyan, magenta, and yellow.

Gray Component Replacement — In Summary

Our GCR algorithm contains three distinct steps. These are:

1. Transform the desired reproduction color into a set of three Equivalent Neutral Densities (ENDs).

2. Determine the minimum and maximum solutions for the black density. Choose a solution which is a predetermined combination of the two extremes.

3. Correct the ENDs of the chromatic inks for the presence of black.

References

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