# IQ Colour Science

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In some order, there are four parts

1] The color space and the problems solved by using said space.

2] The definition of a meta printer and how to compand all elements of the print system to the meta space. The meta printer is defined by the color volume given by ISO-12640-3

3] The measurement of dot gain for all the primary colors and the pair wise combinations for 100 steps of dot area.

Using the colorimetric measure of each of the patches to determine the chromaticity gain and fold over in this function to limit the amount of colorant used.

Use the chromatic measurements to produce a uniform map of hue and saturation for the required amount of dye combinations that give the brightest color for the combinations used

4] Determine the brightness contributed for each hue and saturation pair.

This is the intrinsic brightness of that color

For a given pixel determine the hue and saturation index to find the color

Compute the Q brightness of the pixel. Ratio the Q brightness of the pixel to the Q brightness of the color. The ratio is equal to the amount of darkness that needs to be added to the color to match the brightness of the pixel color.

Start at the beginning with the color space

Wherein the step of providing the first plurality of tristimulus values for a selected pixel of the image further comprises:

converting a plurality of input RGB values to a plurality of ATD values

$$[\ X\ Y\ Z] = [\ R\ G\ B\ ] * [\ M\ ]$$

where [ M ] is a 3X3 matrix That converts one of several types of RGB to XYZ

then we convert to [ A T D] a well known opponent vision model.

substantially as $\begin{bmatrix} A \\ T \\ D \end{bmatrix} = \begin{bmatrix} 0.0 & 4.0 & 0.0 \\ 2.506 & -2.306 & -0.0688 \\ 0.4427 & 0.5988 & -0.9369 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$.

The ATD space is converted to Uniform Perception Space by first computing brightness. It is well known that Luminance given by either Y or A in the above equation does not predict the brightness of a given color. This is known as the Helmholtz-Kohlrausch effect where the chromatic channels of the visual system produce a brightness that is not equal to the luminance predicted by CIE Y.

A brightness term, Q, is defined, that does compensate for the Helmholtz-Kohlrausch effect.

Q = A + T/2 if D > 0
Else
Q = A +T/2 – 3* D/4

A uniform chromatic space is given

t = T/Q
d = D/Q

A hue, saturation and value space is defined as follows,

Value V = Q / Q white
Where Q white is the Q value of a D65 white for the system under study.
Saturation S = the greater of | d | or | t |
Hue H = ratio of t and d and is scaled

0 >= H <256

The ( QTD ) space is the basis for what follows.

These Definitions should ultimately become standards but should help teach the rest.

## THE META PRINTER

Michael Pointer was the first to explore the real world of color. He defined the limits of chromaticity for most of the colors in “The Real World”. The ISO standards body updated his work in standard ISO-12640-3. The colorimetric volume presented by this standard defines the meta-space that contains all other color systems.

With this definition, a meta-(RGB) vector space is defined that is the most compact vector set that contains the ISO-12640-3 color volume. Compactness yields the best use of the digital resolution of (RGB), i.e., very few bits are wasted in describing the volume of the meta space

The relation between the RGB space and the ATD space is as follows

$$A = R + 3 * G$$
$$T = R - G$$
$$D = (R + G) / 2 - B$$

This definition produces a isomorphic mapping of the spaces so that both display uniformity of color perception.

PRINTER CALIBRATION

The CIE XYZ tristimulus values are measured for each tint patch. The calculation of the tristimulus values has been modified for purposes of the new calibration procedure. The spectral reflectivities of the substrate and of the colorant on the substrate are measured at 10 nm intervals across the visible spectrum. The reflectivity of the colorant is corrected for the reflectivity of the substrate at each wavelength interval. The XYZ tristimulus values are computed for a D65 white point. This protocol is key to having the correct appearance of an image under a wide variety of illuminants.

The calibration of an output device starts by printing a number of tint steps from zero to 100 % dot area. Tint steps are made for the primary colorants and the combinations of dye sets. Uniform tint steps sent to the device do not result in equal steps in dot area. The dot area is calculated as follows;

$$DA = (1 - R\ tint) / (1 - R\ 100)$$

Where R tint is the reflectivity of the tint patch and R 100 is the reflectivity of the patch with the maximum of colorant used to make the patch. Reflectivity is a function of wavelength. The reflectivity used in the equation above is obtained from the wavelength band where the modal reflectivity is minimum for all tint steps.

The XYZ values are converted to hue, saturation and value. Saturation (chromaticity) is plotted as a function of the dot area. The saturation (chromaticity) gain is not a linear function of dot area . Maximum saturation usually occurs at values of dot area less than the maximum. Therefore maximum colorant use does not usually produce the maximum saturation. Dot areas are determined that will give equal steps in saturation. These areas are used to develop a denser sample grid from which the final printer map is developed. The samples from the dense sample grid are used to determine the maximum saturation at each sampled hue. These values are used in the next step where the saturation is companded to the saturation boundary of the meta space

COMPANDING

Most of color science uses 3X3 matrices to convert from one colorimetric system to another. If one is not concerned about compactness or the fact that a large volumetric space cannot be transformed to a smaller space without concern for some of the vector components becoming negative. This method described here eliminates this problem by use of a compander that either expands or contracts the color volume to fit the volume of the meta-printer.

The compander is of the form,

$$O = K1 * I / (K2 + I)$$

Where O is the output companded value and I is input to the compander.

Saturation and Value are companded. Hue must be reproduced accurately for the best appearance of the transformed color.

## CONGRUENCE

The input pixel (RGB) using the equations above determines the hue and saturation of the pixel in meta space. At each hue and saturation, the maximum brightness is known for that that particular combination.
The ratio of the maximum brightness to the brightness of the pixel determines how much darkness needs to be added to bring the brightness of the meta model to the level of the brightness of the input pixel.
The principle of congruence states that this ratio of darkness add will be applied to all devices used to reproduce the image.

## DARKNESS ADDITION

The photomechanical method of separating required that nearly equal amounts of Cyan, Magenta and Yellow are required to reproduce neutrals in an image. This model of CMY use has been maintained until the present time. The modern addition to this model is to use black to produce denser neutral images than can be produced with CMY alone.

Another modern variation is to replace the neutral component of a dark CMY pixel with black ink. For example if we had a pixel using 100% Magenta, 100% Yellow and 40% Cyan the current method would remove 40% of the Cyan and approximately 36% of the Magenta and Yellow component and replace them with about 40% black.

The problem with the Gray Component Replacement (GCR) is that the saturation is reduced from a 100% red to a 64% red. This loss of saturation is the major problem with GCR. As a result maximum GCR is almost never used.

A review of the colorimetric interaction of the colorant sets showed that once we removed the limitations induced by the photomechanical separation process that a new model for darkening the primary colorants could be developed.

In the example given above with a pixel using 100% Magenta, 100% Yellow and 40% Cyan , it was determined that the 40% Cyan was the component reducing the brightness of the Magenta and Yellow combination. Therefore the best way to darken that combination of Magenta and Yellow is to remove the Cyan component and replace it with approximately the same amount of black ink.

This model allows a new use of the Colorants. The Colorants can now be used to produce extra levels of darkness. The colorants can be used in any combination to make the incremental change in darkness.

The advantage of the new paradigm is that much less color ink is used for darkening. This has two benefits. First cost and material savings. Second, the metamerism induced by the use of large amounts of colorants common to the Photomechanical Method is nearly eliminated since only small amounts of colorant are used for darkness interpolation.

## DARKNESS COMPANDING

The darkness model is modified to correct for the darkness of the paper and the maximum darkness (density) that can be achieved with the available colorants.
Images on darker papers tend to have poor contrast and image quality. This problem can be corrected by using a visual effect called crispening. Increasing the contrast of the image at a given point on the darkness curve will give the appearance of higher dynamic range in the image. The crispening point is placed at approximately the 75% point in the darkness range. The slope of the contrast increase at this point depends on the difference in darkness between the minimum darkness of the substrate and the maximum darkness of the combination of the substrate on the maximum darkness that can be obtained from the colorants on the paper. The darkness companding function has the form,

$$Dout = K1 * (D - Cr) / (K2 + [D - Cr]) \text{ if } D > Cr$$

Else

$$Dout = K3 * (Cr - D) / (K4 + [Cr - D])$$

Where D is the darkness add for a perfect white substrate, Cr is the darkness of the crispening point, Dout is the darkness entry into the darkness tables. K1,K2,K3 and K4 are chosen to produce to desired slope correction at the crispening point

## COVERING POWER CORRECTION

The colorants used in graphic reproductions are transparent and not perfect in absorbing out of band radiation. This is usually termed lack of covering power. The lack of covering is a problem in the dark regions of an image. The inability of black to cover the chromatic components of the image produces unwanted contours in the image. A new concept has been added to the darkening model where the chromatic components of the image are reduced as a function of the darkness being added to the image. The equations for each of the output pixel colorants is,

$$Cout = K(D) * Cin + C(D)$$

Where Cout is the amount of colorant used in the reproduction, Cin is the amount of colorant for zero darkness, C(D) is the amount of colorant used for darkness interpolation at darkness level D and K(D) is the correction for lack of covering power at that darkness level.