What Color Is It?

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Color management allows the deterministic handling of color data from input to output. This, of course, assumes that the first digital representation of our data is the "correct" color. It assumes that we did not make any errors in the input definitions, did not use wrong color input profiles, captured the user's intent, or fell prey to a host of other potential problems.

After we have made those assumptions, we now can deterministically transfer the color from one place to another. Note that there is a big difference between "reproducing" one color at a different location and "deterministically transferring one set of color data to another location". The deterministic transfer is limited to the small set of physical metrics we decided to call "color". All other components of color are ignored.

Before getting to the problem of correctly identifying the input type on the scanning side of our color chain, it is helpful to consider what is done on the output side in order to get a better understanding of what we might have to expect on the input.

Printing

A mere 120 years ago a color print might have been created in a way that could be described as:

There is one plate for each color -- buff, yellow, pink, brown, blue, crimson, and so on, altogether fourteen color plates. There are no less than nine separate printings on, say, a child's face: two yellow tints, three flesh, two gray, besides a brown and blue.[1]

Or, in general, a "color" was still reproduced by attempting to use the actual color in the printing process. It was one of the great inventions in color printing to find a way to create color prints using only three of four colors. There is, however, still a market for the "old" way of printing and at least one printer in the US uses screenless lithography with "four cyans, four magentas, three yellows, orange, green and violet", coincidentally again 14 colors.

How did the reduction from many colors to only three or four colors happen ? The discovery that the human visual system is trichromatic was one of the requirements. However, there was a second, maybe even more fundamental property that had to be understood. This property is the basic property exploited in virtually any printer on the market today - called halftoning. In itself, halftoning is nothing other than using the Spatial Dimension of color[2], albeit in a very simple form.

Figure 1 shows an example of this, using a simple engraving from a 1901 Encyclopædia, where a human created the required spatial modulation to simulate a gray level for printing.

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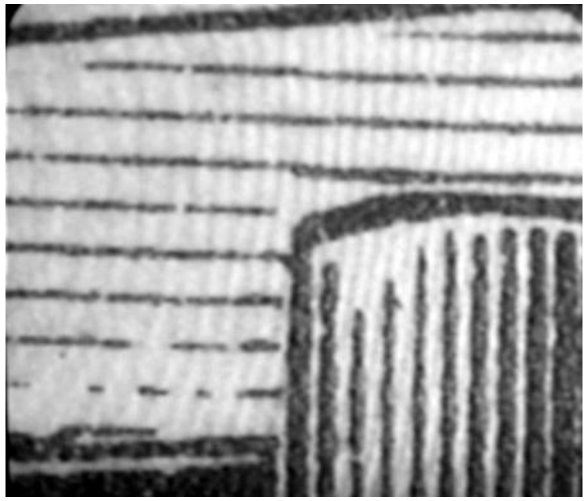

Figure 1. Standard engraving used around 1900 to represent "continuous" tone images in print.

Color around that time was still done as a chromolithograph, an example of which is shown in Figure 2. Note that the actual image is very colorful and vibrant which can not be reproduced in this black and white rendering.

Figure 2. Chromolithograph around 1900 (b&w reproduction of a color print).

Scanning

After looking at the printing side of color, let's switch focus to the scanning side. Scanning is in essence a simple color measurement process, where the measurement is performed along a two-dimensional grid, making some very simple assumptions about color.

The first assumption is that three components are sufficient to get an "accurate" representation. However, it is well known that this is only true if, among other things, the three filters used for the scanning would match the human visual system. Consequently, scanning system require the user to indicate the source material, be it offset, xerographic, or the like, in order to avoid metamerism introduced by the different filter transmissions. Only then can the correct color profile be identified. Attachment of the correct color profile is essential, since a wrong profile on the input will void all color reproduction and color accuracy efforts taken later in the chain. It should be noted that other aspects of color[2], like gloss, translucency, etc. are neglected in this description

If we assume that the source profile will be manually attached to the input, we have to understand that there might be operator error. How good or accurate do we expect the user to be in determining the source of the paper document that he or she will scan ? How much does this depend on the skill or lack thereof of the user ? In an article entitled "Hard to tell them apart" by John Larish in Advanced Imaging[3], he described an experiment where observers were asked to name the type of device which created the print. The results showed that the vast majority of the prints were misclassified by the observer. That simple experiment did not conform to the requirements of a well controlled experiment, but it was sufficient to indicate the difficulty in determining the print type in an easy setting. Now assume that somebody you know has to identify the source of the print when they are in a hurry, or when they have simply no interest in spending their time on a task that they do not understand the reason for. After all, which user understands color filters and metamerism ? In essence this means that a human interaction on the input side is highly error prone, thus creating a color reproduction chain that *accurately reproduces the wrong color*.

Identifying the input type

The obviously error prone procedure of manually assigning input types on a scanner should be replaced by an automated way that makes the user interaction unnecessary. One "easy" but costly answer is the introduction of additional filters into the system, thereby eliminating / reducing the problem. But ,assuming that the hardware can not be exchanged and that the conventional three filters have to be used, is there a way to get at least a good guess about the input type ? Is there a good way, if we restrict ourselves to a few broad classes of possible media, say "inkjet", "photo", "offset" and "xerography" ?

From a pure colorimetric sense one is inclined to answer this question with "no", since only a three component measurement is available and in that measurement space metameric colors can not be distinguished.

At this point in time it becomes clear why the review of printing was given in the early parts of this paper: the printing of color images is itself a spatial process, meaning that a "color" in the sense of "seen by the observer" is actually a two-dimensional distributions of measurable colors used by the printer. Since the scanner has a two-dimensional layout, it should in theory be possible to analyze the spatial structure of the color. What this means is that a constant color patch printed on different devices will be printed as a patch of same macro appearance, but that at any individual location of the printed patch, a strong color deviation is visible in the microstructure. So, the average color should match that of the desired patch, but the color at every pixel should be different from the patch color. This spatial distribution potentially carries a fingerprint of the marking technology used to create the print.

Thinking back at the experiment described by John Larish, one can see that the assumption is not unreasonable. How could a human observer distinguish the marking technology if the technology did not leave its traces in the data. At the same time, we would without hesitation assume, that under a loupe differentiation is possible. But what is the difference between a scanner at 600dpi and a loupe ? So again, there is a strong indication that it should be possible to identify the media type from the fine structure of the scanned data.

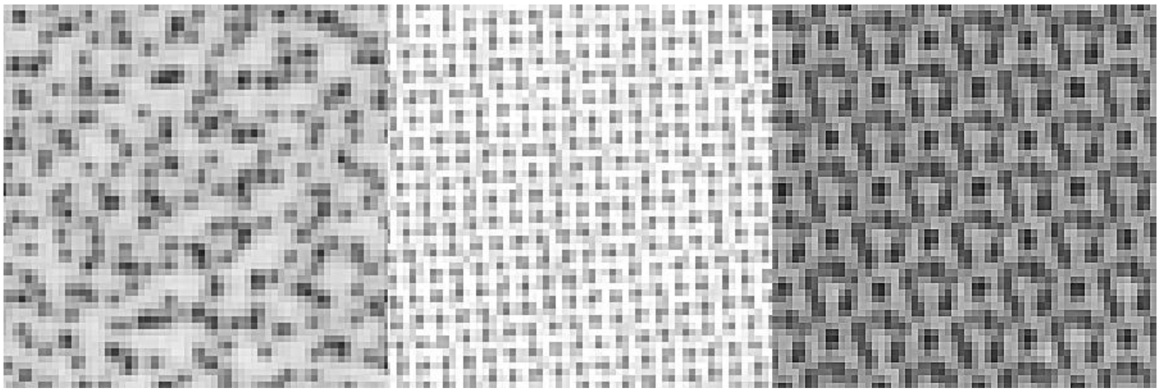

Figure 3. Microscopic view of different rendering technolgies.

Identification of Fingerprint Characteristics

As indicated above, the approach we are trying to take is similar to the approach a human would do with a loupe. Taking a loupe to the different media results in the following images of Figure 3.

The individual parts of Figure 3 are intentionally not identified for the purpose of this paper. Looking at Figure 3 one sees some simple attributes that might form the basis for the differentiation. A first attribute is the dispersedness or regularity of the distribution. A second might be the dominant frequency of the distribution. A third one might be the noise property of the distribution.

Dispersedness

There is a strong correlation between the dispersedness of the print and the print technology used. For xerographic and lithographic processes, dispersed dot printing is normally very cumbersome and also lacks the desired stability in the print unless great effort is taken. So, dispersedness is a strong indicator - not a proof - for inkjet based technologies, be they TIJ, piezo or even solid ink. Being a strong indicator, this attribute will be used in the analysis.

Dominant Frequency

The dominant frequency of a print is directly related to the print resolution and the expected process stability. Over the years, the two parameters have improved considerably. For instance in the xerographic domain, 300dpi printers have been the mainstream for a long time, however, they have been replaced by 600dpi printers which in turn are already in the process of being replaced by even higher resolutions. Any decision based on the dominant frequency of the print will likely be outdated in a short timeframe and dominant frequency was thus not chosen as a parameter for the analysis.

Noise Properties

Offset printing is a wet process whereas xerography (xeros: Greek "dry") is a dry powder technology. The physical characteristics of the two processes are very distinct and, consequently, the noise characteristics of the two processes should also be distinguishable. This does not simply mean that the actual noise level of on process is higher than the noise level of the other process, but rather that other statistical properties of noise could and should also be incorporated.

Decision Process

Using the two criteria of dispersedness and noise characteristics, we can establish a decision process that allows the distinction of the different input types for the determination of the correct profile during scanning. The dispersion metric we use for dispersedness was described by David and Moore. In this metric, an area is selected and within that area random areas are examined and a count of events of those areas is tabulated. A perfectly dispersed process should have a

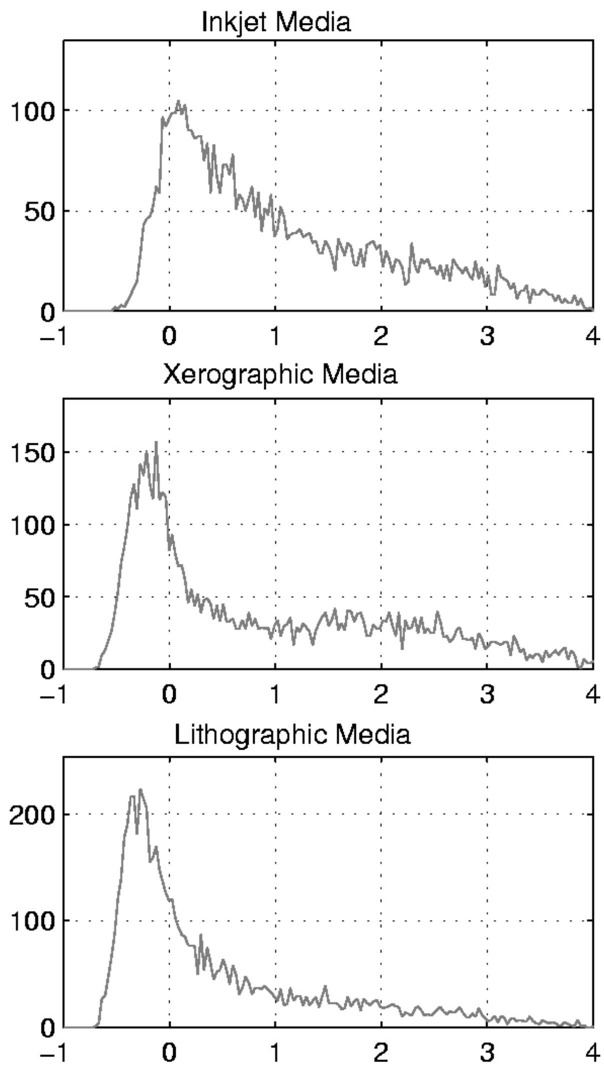

Figure 4. Dispersion metric

dispersion number of "0", with a tail of positive numbers. Regular processes or clustered events should have a negative dispersion value with a less developed tail. Figure 4 shows three typical graphs of applying the David&Moore dispersion metric to images of the kind shown in Figure 3. Note that binary versions of the images have to be created first. As can be seen from Figure 4, the dispersion metric displays the expected shape, offering a strong indicator or marking technology.

The second metric used is the inter-event distance of the distribution. The inter-event distance histogram is the count of the distances between "on" pixels in the scanned distribution (after binarization) and is indirectly correlated with the noise characteristics. Looking at Figure 5, we can identify that the red and green channels (top two rows) in the left column have strong peaks at multiples of the base distance, whereas the center column shows no such secondary peaks. We also not that the higher order peaks are in general stronger for the offset print than for the xerographic print. The indication is that the left column represents an offset print, the center column and inkjet print and the right column a xerographic print.

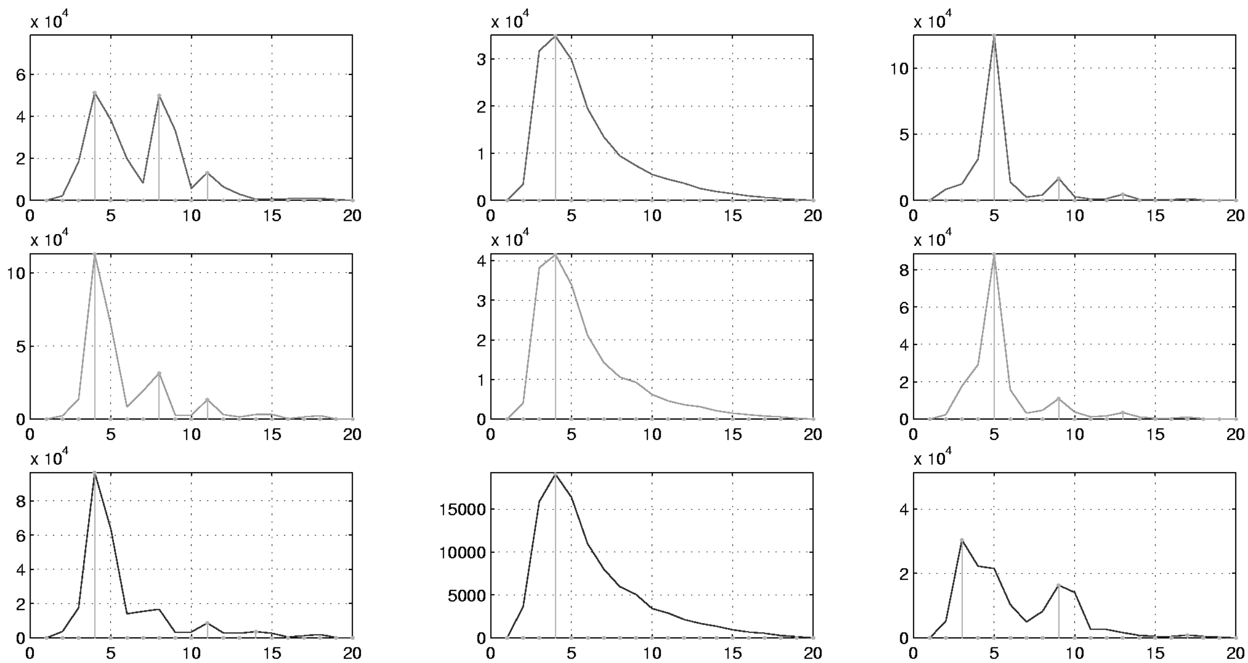

Figure 5. Inter-event distance histogram showing the relationship of higher harmonics.

Using dispersedness and the ratio of higher harmonics we can now develop a "truth" table that correlates the measured data with the input type. In a simplified version, the table has the form given in Table 1.

\ Dispersedness Harmonic Ratio \	High	Low
High		Offset
Low	Inkjet	Xerography

Table 1. Truth table correlating measurement and input type.

The simplifications of Table 1 omits the color area the data was measured (red, green or blue channel with different transfer and noise characteristics), symmetry of the process (x- and y-direction) etc. And is meant as an illustration only to show that spatial characteristics can be used to derive and deduce color characteristics.

Summary

In order to describe "reality" we habitually and successfully separate the world around us into distinct areas and treat phenomena isolatedly inside these area. This approach has been the basic of almost all science as it allows the necessary abstractions and it eliminates burdensome side issues. Often, however, we lose track of the reasons for our initial segmentation and separation of our problem and then overlook solutions or approaches to solutions that lie just outside of our artificially defined problem boundaries. Color science is one of the areas where the separation benefited the progress for a long time, but also where a lot of problems are located right at the boundary line and crossing that line might be helpful in addressing the problem. The identification of color input type, as done in this paper, is just one example of this. Similar problems and solutions exist on the output side in gamut mapping, preference rendering and the like[2].

The reason that the separation of problems in color science is less well maintainable is that "color" essentially always has the human observer as the final element of the chain. Segmenting the problem along physical and mathematical lines often runs counter to the separations of human perception in real world scenarios. When was the last time a "non expert" has described a color to you in terms of L*a*b* or even red, green and blue ? When was the last time the same individual described a color as vivid, dull, shiny, rough ?

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[1] "How the London Graphic Produced Their 14-color Engravings " Reprinted from an 1882 issue of The (London) Graphic at http://www.historybuff.com/library/reflondon.html

[2] Challenges in Color Reproduction: Towards Higher Dimensions, by Raja Bala, *See this Proceeding*

[3] Unfortunately no exact reference can be given, since the Archive of Advanced Imaging underwent some changes and lost the content of certain past issues.