HANS – Unlocking New Print Control Alternatives By Bringing Color Separation And Halftoning Closer Together

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Abstract

Color separation is currently used to decide how much of each available colorant to use for each printable color and halftoning then builds patterns that meet those choices. Print color, however, depends not only on how much of each colorant is used, but also on how those colorants are superimposed. Furthermore, there are many halftone patterns that correspond to a given combination of ink amounts. HANS (Halftone Area Neugebauer Separation), which we introduced at last year's IS&T's CIC conference, is a move towards specifying halftone pattern statistics and enables control over print properties beyond their current limits. While the benefits of HANS for color gamut and ink use efficiency have been shown, at this year's NIP, we would like to look more closely at how to determine the set of all possible halftone patterns that match a given color and demonstrate how access to such sets – metamer sets – benefits print control. We will also illustrate how even for a simple CMY ink set, which using current approaches leads to exactly one ink combination per printable color, there are sets of alternative halftone patterns that match a given color. Such sets in turn allow for tradeoffs to be made, e.g., between grain and ink use, even in this simple case.

Introduction

Printing technology has seen dramatic advances over the past century, yet the color separation approaches used today are fundamentally the same as those implicitly taking place during the earliest photomechanical processes. Given source colors, amounts of the available colorants are determined first, which was done photomechanically by choosing appropriate color filters and is done digitally by algorithms that compute colorant amounts given colorimetric inputs. These colorant amounts are then turned into halftone patterns, by means of physical screens photomechanically or using halftoning algorithms digitally. The basic principle of deciding colorant amounts first and then performing halftone pattern generation remains unchanged.

As we have demonstrated previously [1], setting ink amounts before generating halftone patterns to match them greatly constrains what printable halftone patterns are addressable and this in turn underutilizes the potential of a set of colorants being used on a given substrate.

The key here is the fact that there are far fewer ink amount combinations (spanning an n–dimensional space for n inks) than there are ways to arrange a system's Neugebauer Primaries [2] (i.e., the at-pixel colorant combinations) to form halftone patterns. For a printer using n inks and being able to deposit up to k-1 levels per colorant, there are k^n Neugebauer Primaries (NPs), each of which can cover some part of a unit area of a print (Figure 1).

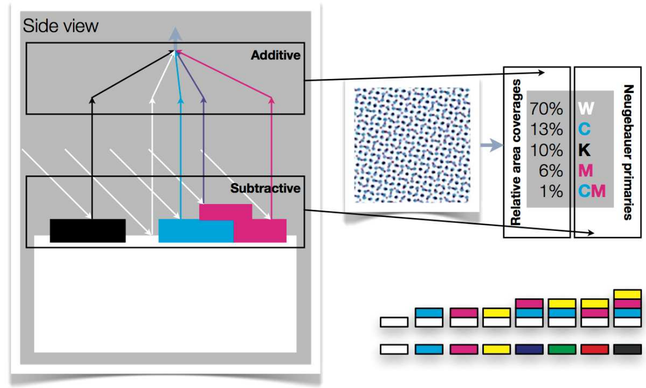

Figure 1. Print color formation.

Therefore, making choices in the nD colorant space will lead to far fewer alternatives (metamers) for each printable color than if choices were made in the k^nD NP area coverage space, which is the core of the HANS approach. This in turn means that HANS has the potential to give access to more color gamut, use less ink, have less grain, be more color constant, etc. on a given printing system than the current color control mechanism where color separation outputs colorant amounts and halftoning builds patterns on their basis.

The following sections of this paper will provide an overview of the HANS approach and share results about applying it to the simplest colorant set – CMY.

HANS workflow

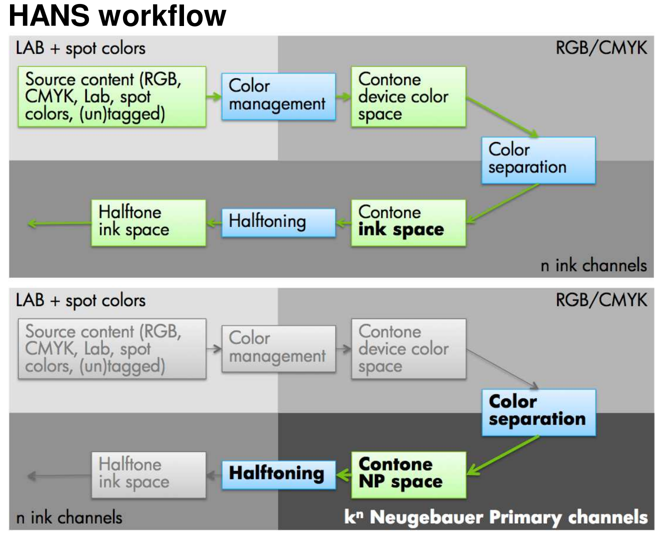

Figure 2. Current (top) versus HANS (bottom) printing workflow

Figure 2 shows a typical sequence of transformations that resulting in halftones, given a variety of color content. Starting with RGB, CMYK, Lab and spot color content some of which may be tagged with ICC profiles and some of which may be of unknown origin, the first step is to perform color management that addresses gamut differences, applies preferred color transformations and outputs device color data for a given printing system (i.e., printer + colorants + substrate). This device color data then forms the input to a color separation transformation, which will output continuous tone values in the printing system's colorant channels. Each of these colorant planes is then halftoned separately (with the possibility of specifying certain dependencies between pairs of the colorants) and the resulting n halftones are then sandwiched together to form the final print.

The workflow with HANS starts in exactly the same way by having color management provide device color inputs to color separation. The output of color separation is of a much higher dimensionality though (k^n versus n – e.g., 729 versus 6 for a CMYKcm printer capable of depositing up to two drops per ink) and halftoning needs to be able to take such Neugebauer Primary area coverage inputs and generate halftone patterns from them. Unlike in the colorant space approach, HANS halftoning is a single operation that selects one NP per pixel instead of operating on a colorant-by-colorant basis.

HANS optimization

The simplest way to obtain a HANS color separation is as follows:

1. Print and measure all NPs.
2. Compute NP convex hull in CIE XYZ and sample it.
3. Tessellate [3,4] the NP convex hull using hull vertex NPs only.

The end result is a set of CIE XYZ coordinates (i.e., those of the convex hull vertices) that span the full color gamut and where each has an NP assigned to it. To compute the NP area coverage (NPac) color separation for an arbitrary, in–gamut CIE XYZ input, the tessellating tetrahedron enclosing the input color needs to be found and barycentric coordinates of the CIE XYZ input can be computed in the enclosing tetrahedron. These barycentric coordinates are the area coverages of the corresponding vertex NPs and form the input to halftoning.

The result is a fully-formed HANS color separation, albeit one that is not tuned for any particular print attribute. All it does is give access to the NP convex hull, which is already a benefit over colorant space approaches and which can result in gamut increases of 10% or more.

To fully benefit from HANS, step 3 of the previous method needs to be made significantly more complex. Instead of considering only the one NPac that results from tessellating the NP convex hull vertices, all polyhedra (of which there are $\sum_{n=4}^{p}\binom{p}{n}$ for p NPs) need to be considered as candidates for providing an NPac that matches a given color.

Each color for which color separation needs to be defined is compared against each of the polyhedra that can be formed by NP colorimetries, and all polyhedra that enclose it result in metamers – i.e. NPacs that use the polyhedron's vertex NPs and whose barycentric coordinate weighted combination matches the given color. Each of a color's metamers can then be evaluated in terms of relevant print attributes such as ink use, color constancy, grain and assigned a score. Optimization then consists in selecting the NPac from among a color's metamer set that receives the highest score, given the priorities of the target application. E.g., a color separation set up for fine art reproduction would assign a lot of weight to grain and little to ink use, while industrial production of signage would have the inverse priorities. For a more in-depth look see [5, 6].

CMY results

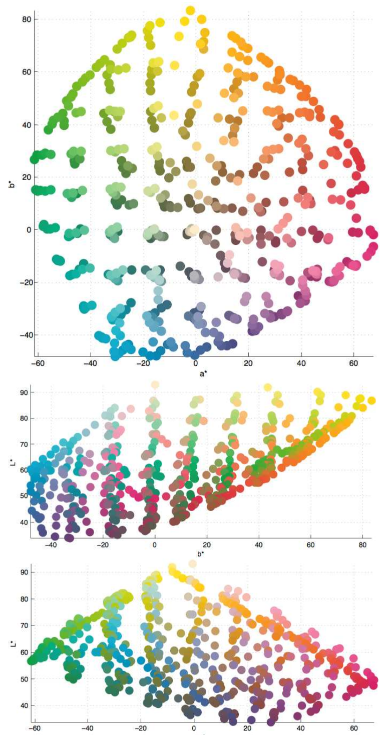

Figure 3: The set of 544 samples spanning the color gamut available using the CMY ink-set, printed and measured from the least-ink-using optimized NPacs.

The toughest test of a new print control paradigm like HANS is to apply it to the simplest color printing setup and see whether it still leads to benefits. As a result, the present section uses a printer with only three inks – CMY – and with only binary halftoning – i.e., where only some or no ink can be specified at any given print location.

In this case, colorant space approaches lead to exactly one CMY colorant amount combination per printable color, since any changes in the CMY ratios necessarily change the response of the three cone types of the human visual system. In other words, the 3D color to 3D colorant mapping is unique and has no redundancy.

Looking at this same three-colorant system from the point of view of HANS shows though that its eight NPs – blank substrates, C, M, Y inks by themselves, CM, CY, MY secondaries and the CMY tertiary – form an 8D space in which halftone patterns can be specified. The redundancy and 1–to–many nature of this 3D color to 8D NP mapping suggests that there are going to be metamers for printable colors as opposed to only single, unique answers.

Taking a set of 544 color samples that span the HANS color gamut of this CMY system and computing metamers sets for each one of them then allowed for quantifying the extent of benefits derivable from the underlying redundancy.

Taking one of these samples – a mid–gray – it can be seen that it had 115 metamers, which means that it was enclosed in 115 of the 1001 tetrahedra that can be formed from the colorimetries of the set of 14 basic NPac building blocks consisting of the within ink-limit NPs, the ink-limited out-of-ink-limit NPs as well as the extreme vertices of the convex hull. Each of the enclosing polyhedra had a different subset of NPs as its vertex and their convex, area–coverage weighed combinations resulted in metamers. This is in contrast to the single CMY colorant amount vector that matches the same color using the conventional approach.

Evaluating ink use, for the sake of simplicity, showed that the least and most colorant using metamers differed by 13% on average, which again is in contrast with no range when HANS is not used.

Conclusions

Halftone Area Neugebauer Separation (HANS) provides full access to the Neugebauer Primary (NP) space, which is vastly greater than the colorant spaces used traditionally. As demonstrated here, it even provides alternatives in a system where colorant space approaches have none and consequently allows for optimization of print attributes.

In addition to greater ranges of print attributes being accessible and directly optimizable, HANS is also fundamentally colorant set agnostic, where the same process can be followed to control a duotone or a CMYKRGB printing system.

The focus of future work will be the continued exploration of the benefits of HANS, the use of more accurate printer models and its application to the optimization of new print attributes.

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Author Biographies

Ján Morovič received his Ph.D. in color science from the Colour & Imaging Institute (CII) of the University of Derby (UK) in 1998. After working there as a lecturer in digital color reproduction, he became senior color scientist at Hewlett-Packard in Barcelona in 2003 and then Master Technologist in 2007. He is the director of the CIE's Division 8 on Image Technology and Wiley and Sons have published his book entitled 'Color Gamut Mapping.'

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