Custom Fan Deck for Multi-Primary Visualization

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Abstract

The visualization of color choices plays an important role in many applications. A printed fan deck is a common tool for visualizing and selecting colors for painting a room, for example. While there are many similar examples, almost all involve some standard pre-defined color palette that is professionally arranged onto a fan deck and printed in large quantities for future distribution to end users. However, what happens if any of the printing parameters changes (substrate, inks) or if you have a very specific task in mind that only requires a small subset of colors? In this case, a custom printed fan deck would provide a more up-to-date and efficient format for visualizing the color choices for this specific task. We developed a system for creating custom fan decks that works particularly well for visualizing colors in a multi-primary printing system. First, the set of colors to include in the fan deck is selected. This can be a challenging task when dealing with a system with more than 4 inks, as you cannot simply select an even sampling of colors in each dimension. Next, the colors are arranged in some visual order and then exported to PDF. A hue, saturation and lightness ordering of colors was employed. Finally, the fan deck is printed and finished. We prototyped our solution on an HP Indigo 7000 Digital Press loaded with HP IndiChrome Plus 7-primary inks: cyan, magenta, yellow, black, orange, violet and green, using both matte uncoated and glossy coated substrates.

Introduction

While fan decks have been widely used in the industry for a long time, there is limited technical detail about the design and engineering of these fan-decks. There are various proprietary systems with high-quality physical reference products, such as PANTONE®, the RAL System, the Natural Colour System and vendor-specific master-batch reference systems. There are also industries that include color critical decisions during purchase, such as architectural coatings. These systems may contain anywhere from a couple hundred to several thousand unique colors.

When a color selection has a final destination of being printed on a specific printer or commercial press, the issue of whether or not the color is inside or outside of the printing device's color gamut has an impact on the accuracy of reproduction. What if the designer had access to a fan deck that was reproduced using the same printing device, inks and substrate as their final printed piece? In this case, all the colors are guaranteed to be in gamut, and the visual appearance of the colors as represented in the fan deck are as close to the final product as possible.

Custom Multi-Primary Fan Deck

The design and creation of a custom 7-primary fan deck was a motivation for this work. For smaller number of channels or primaries, it is possible to construct color samplings either manually or with relatively simple color sampling schemes, such as uniform in device space. In the case of a 7-primary printing system, this would either be impractical or likely result in sub-optimal results.

For color patch selection, an automated void-filling approach was utilized with the goal of producing a set of colors that are evenly distributed in a device-independent color space, such as CIELAB. This irregular sampling scheme iteratively adds colors to a set based on a larger set of candidate colors. While the set of candidate colors can be generated using any number of sampling and separation schemes, it should be practical to measure the entire set, and should cover much of the device gamut as evenly as possible. To meet these constraints, a maximum black usage separation scheme was chosen that only uses 3 inks at a time: black and two neighboring primary colors. This has several advantages: large gamut size, stable neutral axis, low ink usage, and robust illumination sensitivity. Of course, any other ink separation method can be used, depending on the desired results. Using this scheme, a target consisting of approximately 9000 candidate color patches was printed on an HP Indigo 7000 Digital Press and measured with an X-Rite scanning spectrophotometer in under an hour. The void-filling algorithm was then applied to select the final set of 1001 fan deck colors. Further details of this algorithm are the focus of a paper submitted to another conference.

Once the final set of fan deck colors are selected, they are arranged in a way that is visually intuitive. An image of the resulting 7-primary custom fan deck is shown in Figure 1. This example is roughly 5 cm wide by 25 cm long by 3 cm thick. Each page has seven sample colors and the first page shows the multi-primaries used for the fan deck. Each page also includes a unique identifier and a sample 7-color separation corresponding to that colored patch. The colors are first sorted by hue angle and divided into groups of 14. Each group is then sorted by chroma and further divided into two groups of seven. These seven colors are then sorted by lightness to produce the final fan deck arrangement.

***Figure 1.** Example of a custom 7-primary fan deck.*

Even for naïve users, the solid color patches along with the explicit 7-color separation allow an immediate and obvious visualization of which colors in the fan deck make use of the added primaries and also the resulting color. This fan deck was also generated for different substrates.

Nearest Neighbor Analysis

One method of analyzing the relative packing density of different fan decks is to consider the statistics of the nearest neighboring point for each point in the fan deck. That is for each point in the fan deck, search the fan deck for the nearest neighbor and compute the corresponding ΔE. This will result in a collection of ΔE values that is the same size as the input fan-deck. The histogram or distribution of color differences can then be computed and compared. Tables 1 and 2 list ΔE^*_{ab} and ΔE_{00} summary statistics for 7 different fan decks.

Table 1. CIELAB nearest neighbor color difference statistics for seven fan decks

	Min	5%	Median	95%	Max
HP IndiChrome Plus Glossy	3.8	6.2	7.6	9.6	12.0
HP IndiChrome Plus Uncoated	4.0	5.6	6.9	8.3	9.9
Fan Deck: 1	0.4	1.8	4.4	8.4	13.5
Fan Deck: 2	0.3	1.3	3.5	7.1	12.4
Fan Deck: 3	0.9	1.9	4.9	10.2	14.9
Fan Deck: 4	0.0	0.7	2.5	5.9	11.9
Fan Deck: 5	0.0	0.0	1.4	4.4	14.0

Table 2. ΔE 2000 nearest neighbor color difference statistics for seven fan decks

	Min	5%	Median	95%	Max
HP IndiChrome Plus Glossy	1.6	2.5	3.9	6.2	8.3
HP IndiChrome Plus Uncoated	1.5	2.3	3.6	5.7	7.3
Fan Deck: 1	0.3	1.1	2.7	5.1	6.8
Fan Deck: 2	0.3	1.0	2.3	4.1	6.1
Fan Deck: 3	0.6	1.7	3.7	7.3	10.4
Fan Deck: 4	0.0	0.6	1.8	3.9	7.6
Fan Deck: 5	0.0	0.0	1.1	2.9	5.9

The results shown in Tables 1 and 2 demonstrate several interesting features. First is that the HP IndiChrome Plus fan decks are the only ones to have significantly larger values for fifth percentiles and median nearest neighbor color differences.

The fan deck color sampling can also be visualized directly in CIELAB space. Individual colors can be plotted as color coded data points and the resulting sampling densities can be visually assessed. In addition, neighboring colors on a given page of a fan deck can be visualized as contours or connected points in color space. Figure 2 shows the plotted CIELAB values for the HP IndiChrome Plus Glossy fan deck. The x-axis is a* and the y-axis is b* and the L* axis is plotted into the figure. Figure 3 shows the connected neighbors per-page of the same fan deck. The axes are identical to those used for Figure 2 but now the resulting contours are visualized instead of the individual points.

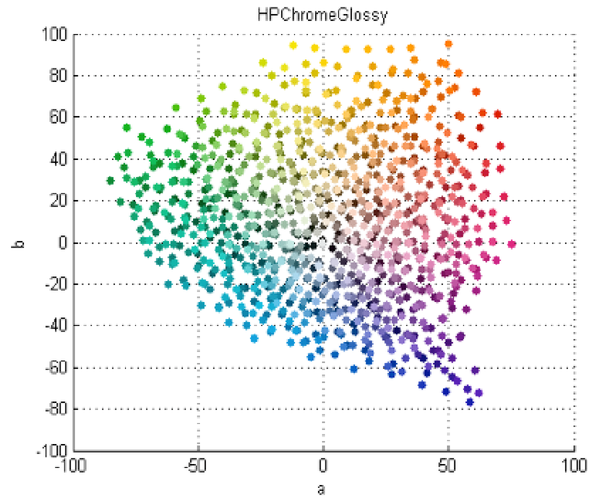

__Figure 2.__ HP IndiChrome Plus Glossy custom fan deck color sampling in CIELAB.

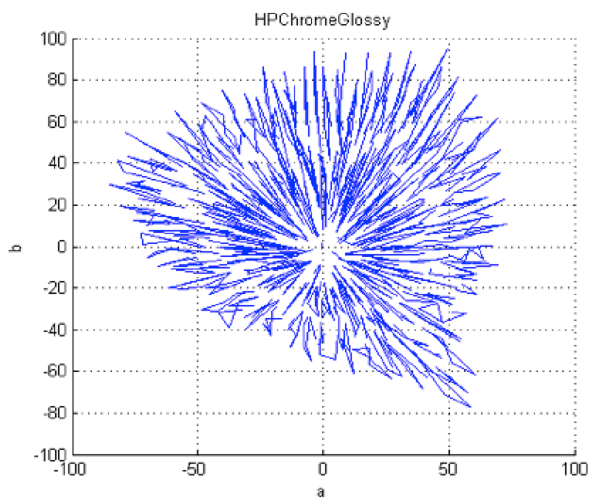

__Figure 3.__ HP IndiChrome Plus Glossy custom fan deck connected neighbors per-page in CIELAB.

In comparison, the CIELAB sampling and connected neighbors for a comparable commercial fan deck are shown in Figure 4 and 5. The results shown in Figure 4 exhibit both regions with fewer points or gaps and also regions with clustering or clumps of points. The connected colors per page as shown in Figure 5 exhibit overall smoother contours with fewer instances of local deviations. However these contours are also less linear in nature as compared to Figure 3 and are more like arcs in color space than vectors.

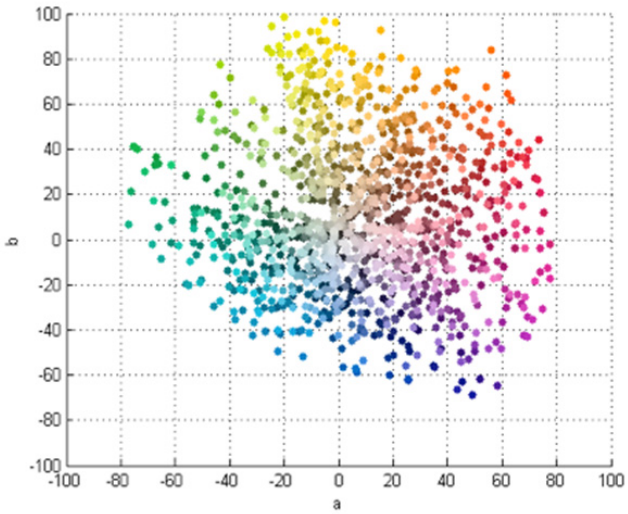

Figure 4. An unspecified fan deck color sampling in CIELAB.

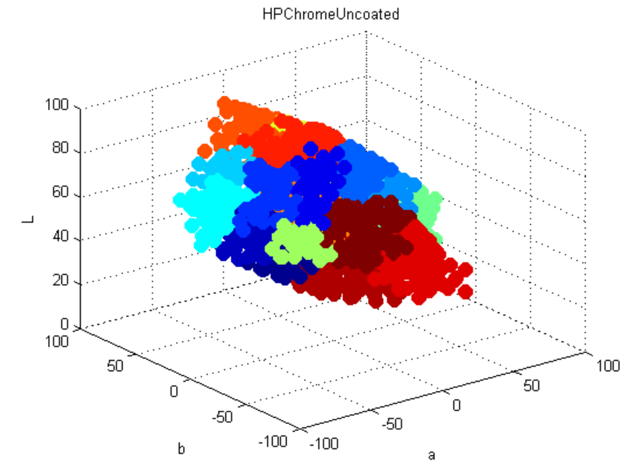

Figure 6. Competitive agglomeration results for the HP Chrome Uncoated fan deck.

Qualitatively the results shown in Figures 4 and 5 are also seen in other commercial fan decks. That is some degree of clustering, as well as regions of color space with lower sampling. Likewise there is a tendency for relatively smooth arcs in color space for per-page connected neighbors but these arcs tend to have a significant degree of curvature.

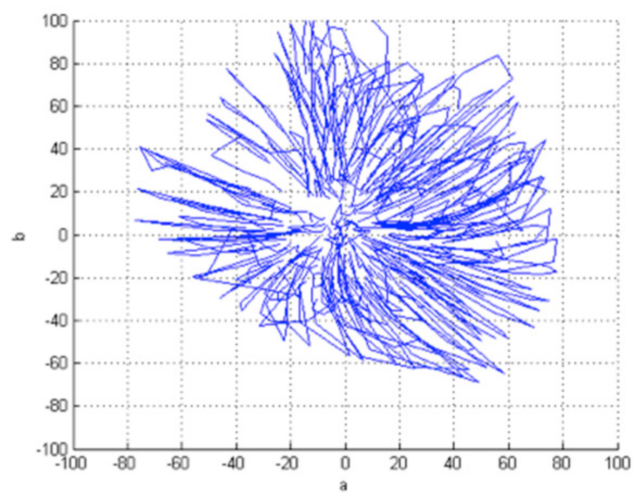

Figure 5. An unspecified fan deck connected neighbors per-page in CIELAB.

Cluster Analysis

As an additional analysis of the resulting fan decks, two forms of cluster analysis were applied to the data. First competitive agglomeration was applied to the HP IndiChrome Plus Uncoated fan deck. The maximum number of clusters was set to 10 and the Euclidean distance metric was used for optimization. The resulting clusters are shown color coded in Figure 6.

These results can also be visualized as a dendrogram or branching tree. Figure 7 shows the resulting dendrogram for the HP IndiChrome Plus Uncoated fan deck. The further up the tree a branch occurs, the less similar the color patches. While Figure 6 shows a portion of the data visualized in three dimensions, the dendrogram provides a visualization over a larger number of clusters, along a single measure of dissimilarity.

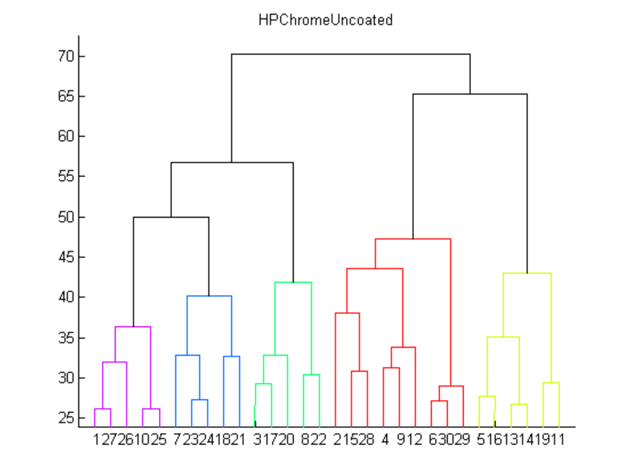

Figure 7. Dendrogram visualization of the HP Chrome Uncoated fan deck.

In comparison, the agglomerative clustering and dendrogram for an unspecified fan deck are shown in Figures 8 and 9. These results demonstrate two interesting features. First the HP IndiChrome Plus clusters show a much more uniform, consistently sized and lower areas of overlap as compared to the clusters shown in Figure 9. Second the HP IndiChrome Plus dendrogram has a much more balanced tree structure with branches of largely consistent sizes as compared to the dendrogram shown in Figure 9. Both of these results are consistent with the nearest neighbor analysis of the previous section but based on quantitative cluster analysis. Note that in all cases, the cluster analysis is carried out with a maximum of 10 possible clusters and Euclidean distance in

CIELAB as the metric. Results for other fan decks are consistent with those shown in figures 8 and 9 in that there is less uniformity and consistency in the resulting color clusters.

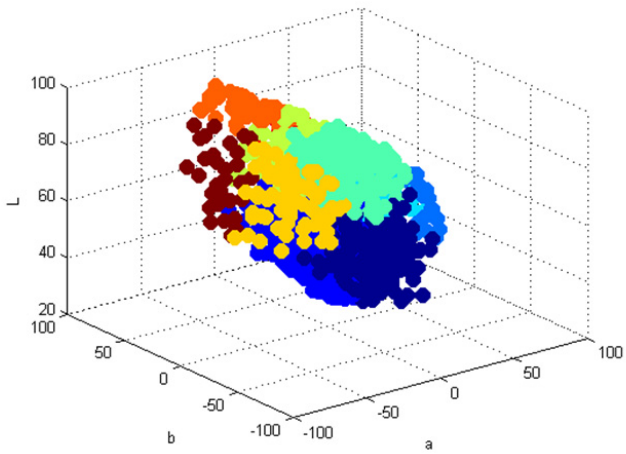

Figure 8. *Competitive agglomeration results for an unspecified fan deck.*

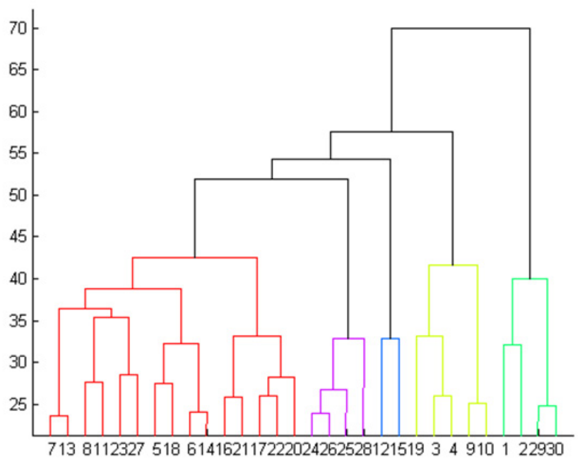

Figure 9. *Dendrogram visualization of an unspecified fan deck.*

Discussion

An alternate fan deck format was explored that is similar to the Munsell Book of Color, but with color samples arranged in terms of absolute lightness and chroma, instead of along a rectangular grid. A prototype was created on the HP DesignJet Z3200 inkjet printer and is shown in Figure 10. The same void-filling algorithm was used to select 1000 color patches out of a candidate set of 21-cubed uniform sampling in RGB. The colors were once again sorted in order of hue, then in lightness and chroma. The colors were then passed as input into a program which automatically generated a PDF file with the final layout. With further customization, any number of custom fan deck formats can be generated automatically.

Figure 10. *Custom multi-primary inkjet fan deck with color samples per page or hue angle plotted directly.*

Conclusions

A physical fan deck or swatch book provides a direct and useful method to visualize and communicate specific colors. Multi-primary print systems can achieve a range of possible colors that can vary by media, device configuration or processing choices, such as color separation. This paper describes a scalable process to construct custom fan decks for a multi-primary system. A specific contribution is the use of void-filling color sampling to achieve fan decks that are on the order of 1000 unique colors. These fan decks also have hue and lightness sorting for different pages. In addition to automatically selecting custom colors, this process also achieves a very high degree of uniformity without being constrained by a regular underlying sampling geometry. Analysis results are presented using nearest neighbor analysis and color clustering. These results are also presented with respect to unspecified commercially available fan decks. We conclude with some discussion of other physical formatting options for multi-color custom fan decks.

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Author Biography

Kok-Wei Koh earned his B.S. with distinction in Computer Science from the University of Washington in 1994, and his M.S. in Computer Science from Stanford University in 2002. He has been working in the Printing and Content Delivery Lab of Hewlett-Packard Laboratories in Palo Alto since 2000, where he helped develop HP Indigo photo and gray inks and the MagCloud self-publishing web service. He is currently serving as associate editor for the Journal of Imaging Science and Technology (JIST).

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Melanie Gottwals joined HP Labs in 1989 after receiving her B.S. in Electrical Engineering from the University of California at Davis. She started her career in storage technologies working on advanced read/write channels, media and heads to increase performance of disk and tape drives. In 2003, her research shifted to networked storage performance and evaluation of the roles of storage caching in SAN environments. In 2005, she joined the Digital Printing and Imaging Lab and began working on color technology. Here she has worked on a low cost colorimeter and height sensor and color correction via mobile phone applications.

Gary Dispoto is the research manager for the Automated Print Fulfillment project at HP Labs. He received his B.S. degree in electrical engineering from Stanford University in 1985, an M.S. from Stanford in 1989, and an MBA from Santa Clara University in 1992. He has worked extensively in color reproduction and more recently in overall print production workflow.

