

# Comparing LabPQR and the Spectral Gamut Mapping Framework

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## Abstract

In this paper, two strategies of spectral printing were implemented and compared: using the Interim Connection Space LabPQR and the Spectral Gamut Mapping Framework (SGMF). The LabPQR approach involved at first, converting spectral information to a lower-dimensional Interim Connection Space and then interpolation using a multi-dimensional lookup table. The SGMF approach involved at first, converting spectral information into CIELAB values for multiple illuminants and then performing direct searches of multiple histogram tables to find matches to these CIELAB values. Additionally, an optimization that used a CIEDE2000-based uniform color space was applied to both approaches. These approaches were tested and compared. The differences between these two methods involved the tradeoffs between interpolation (LabPQR) and indexing/searching of quantized predetermined tables (SGMF). LabP resulted in better colorimetric accuracy under a single illuminant with better spatial image quality. The SGMF approach resulted in slightly better spectral accuracy with a reduction in colorimetric accuracy and noticeable spatial artifacts in low frequency image areas.

## Introduction

Spectral reproduction involves both spectral image capture and spectral image output.<sup>1-3</sup> One significant goal of spectral reproduction (unlike a conventional colorimetric reproduction) is to minimize metamerism.<sup>4,5</sup> Spectral printing systems take spectral image data (expressed in terms of spectral reflectance factor for each image pixel) and attempt to output an image that has the same measurable spectral reflectance as the pixels in the source image.

Several large format ink jet printers now support additional inks to achieve larger colorimetric gamuts for fine art reproduction and photography. Typically, these printers have three additional inks (with red, green and blue hues) beyond conventional cyan, magenta, yellow, and black inks. These additional inks provide an extra three degrees of freedom that can be exploited for the purposes of spectral printing. However, even with seven degrees of freedom, there are still limitations in the spectral gamut that can be reproduced and gamut mapping remains a significant issue with the need to map colors that cannot be reproduced for any viewer/viewing condition, as well as finding a mapping when an exact spectral reproduction is not possible.<sup>6</sup>

Two general approaches to spectral reproduction have been taken to implement spectral image printing. The first involves trying to find a direct mapping of spectral input to device output. This can involve using optimization techniques<sup>7</sup> by performing a search of estimated spectral results using the printer's forward model.<sup>8-14</sup> Alternatively, Bastani, et al. proposed a method to find

device output values directly using linear regression.<sup>15</sup> The process of finding appropriate output values directly from spectral input can be computationally intensive making spectral printing systems that employ this approach impractical. Additionally, problems occur when an exact spectral reproduction is not possible. Some form of spectral gamut mapping is required, and simply minimizing spectral RMS error does not minimize color difference.<sup>16</sup>

The second approach to spectral image printing involves using the human visual system to first organize the spectral image data in terms of color appearance for an observer under a specific viewing condition. Then the spectral image information is used to select output values (between metamers) that meet other spectrally based objectives. A general flowchart for this second approach is shown in Figure 1.

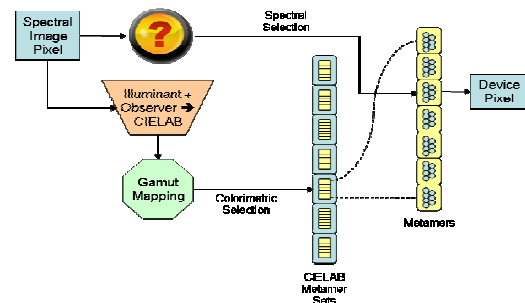


Figure 1 – General flowchart of two stage spectral printing

This second general approach has the advantage that gamut mapping can be performed in two stages. In the first stage colorimetric gamut mapping of non-reproducible colors is performed. In the second stage some form of spectral gamut mapping (spectral selection) is performed to find an appropriate metamer for each color that can be reproduced colorimetrically. Using this approach ensures that an exact match for at least one observer and viewing condition is obtained for all colors within the colorimetric gamut of the output device. Additionally, by first using human visual aspects before employing spectral selection, the dimensionality is greatly reduced allowing for the pre-computation of the involved transforms. This provides for the ability to efficiently process spectral images into device output values.

At least two methods have been proposed in recent years that can be considered to employ this two stage approach to spectral image printing – using an Interim Connection Space named LabPQR,<sup>17,18,22</sup> and the Spectral Gamut Mapping Framework (hereafter referred to as SGMF).<sup>20</sup>

Typically three components of the metameric black (PQR) are implied by the term LabPQR. Tsutsumi, et al. investigated methods of determining the required number of metameric black coordinates and ways of determining them when defining lookup tables for performing spectral printing.<sup>19-21</sup> Metameric black coordinates that were derived on the printer's spectral gamut were found to work well with LabPQ or even just LabP.<sup>21</sup> The conceptual flowchart of the LabPQR method is shown in Figure 2.

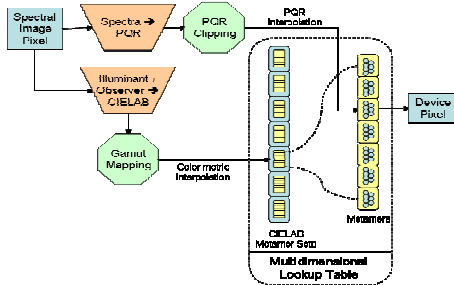


Figure 2 – Conceptual flowchart of LabPQR method

By design, the LabPQR method can be interpreted as a spectral extension of conventional ICC color management<sup>23</sup> based on interpolation with CIE LAB metamer sets and metamers all existing as part of a single multi-dimensional lookup table. Processing spectral image data with LabPQR for each pixel involves first converting spectral reflectance to LabPQR coordinates and then interpolating with a multidimensional lookup table to determine the output device pixel values.

The second method of employing two stages for spectral printing is the Spectral Gamut Mapping Framework based upon Human Color Vision (SGMF).<sup>24</sup> When applying this method to a spectral image Urban, et al. proposed using multiple colorimetric representations of the spectral image to convert to device output. Though Urban does not present the SGMF approach as two explicit stages, the method of gamut mapping proposed by Urban allows this approach to be interpreted in terms of Figure 1. In the representative implementation of the SGMF approach shown in Figure 3, the spectral image data are converted to three colorimetric representations under different illuminants. The first colorimetric representation is used to perform colorimetric based gamut mapping to select a set of color reproductions that all have approximately the same colorimetry under the first illuminant (referred to as metamer sets by Urban). The second and third colorimetric representations are then used to identify and select between metamer subsets and metamers to determine the actual device pixel values to use. Since these second and third colorimetric representations are selecting between metamers they perform some level of spectral gamut mapping. The number of additional colorimetric representations used for selection/searching will determine the accuracy of the spectral reproduction delimited by the printer's spectral gamut.

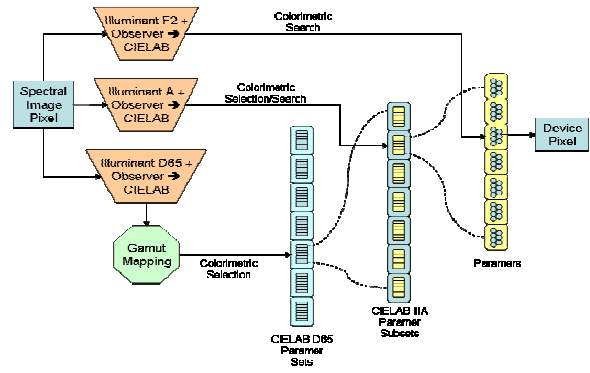


Figure 3 – Conceptual flowchart of a 3-level Spectral Gamut Mapping Framework method

Like the LabPQR approach, an implementation of the SGMF approach is made up of two parts – table generation (which is slow and computationally intensive), and table application to determine device output values for a spectral image (which is quick with low computational overhead). A SGMF approach can be represented as a multidimensional histogram (hashing table) that is filled by iterating through an exhaustive set of all possible output device combinations in one percent increments, calculating spectral reflectance using a printer, and assigning each combination to corresponding bins associated with the CIE LAB values for a single observer and viewing condition. The contents of each bin can then be recursively divided into sub-bins that are each associated with CIE LAB values for separate viewing conditions than the higher level bins. Each successive level corresponds to smaller and smaller metamer sets for different illuminants. The final bin level has actual device output values that achieve minimized metamerism for the illuminants associated with all the bin levels.

Converting a spectral image into device output values using these hashing tables involves first converting spectral image pixels into CIE LAB values for each of the observer/viewing conditions associated with the bin levels. Then, these CIE LAB values are used to find the sub-bin associated with all but the last CIE LAB value. The lowest level image CIE LAB values are then compared with the CIE LAB values in the deepest level bin to find the closest matching color, and the device values corresponding to the closest match are output.

The degree of accuracy for both the LabPQR approach as well as the SGMF is largely determined by the sampling rates used for populating the tables and bins. Because the SGMF approach uses histograms (hashing tables), the accuracy is determined directly by both the sampling of the device model used to populate the histograms as well as the number of bins associated with each level. Device values not sampled and placed in the tables will not be available as candidates for spectral printing. This can result in the possibility of posterization in image areas with slight visual differences. Additionally, granularity in the addressing of the bins for performance purposes can further limit accuracy. Since the SGMF application involves performing a limited search of the best match at the last level, the performance of this approach may vary depending upon the distribution of the image pixel content in SGMF bins. A significant difference between LabPQR and SGMF is that LabPQR utilizes a spectral selection of metamers using the

PCA decomposition of the metameric blacks from the printer whereas the SGMF approach is multi-colorimetric in its approach of metamer selection. The actual illuminants and order that are used in performing the indexing and searching may significantly affect the results of the SGMF approach. However this aspect was not investigated in this research.

LabPQR interpolation accuracy potentially involves a tradeoff between grid point granularity and accuracy determined by whether local linearity can be achieved. This may be a significant concern for PQR dimension grid points (which correspond to degrees of freedom in the metameric black) that may contain large differences in device values. This became a significant issue in the process of implementing and analyzing the results for the LabPQR approach, discussed below.

Another difference between these methods is related to the number of effective output levels. LabPQR is not limited in effective output levels since multi-dimensional interpolation is used; however since SGMF is based upon a search algorithm, it is limited by the bin granularity.

## Methods/Procedures

SGMF and LabPQR implementations were developed to compare and evaluate their differences. An HP Z3200 printer using seven inks (CMYKRGB) printing on ILFORD GALERIE Gold Fibre Silk media driven by the Onyx ProductionHouse Rip Software was modeled using a cellular Yule-Neilson modified Neugebauer (CYNSN) approach using the method of Chen, et al.<sup>8</sup> The printer primaries are shown in Figure 4.

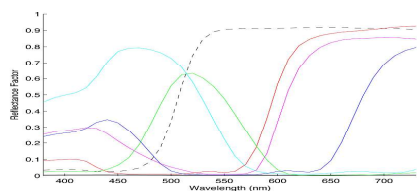


Figure 4 – Spectral reflectance of printer primaries (with yellow as dashed line)

The optimized CYNSN model that was used followed the approach used by Urban.<sup>23</sup> Only four-color combinations out of seven were used. Optimized grid points for four levels for each channel were determined and Neugebauer primaries for the 20 four-color combination cubes resulting in 5120 patches being printed and measured spectrally using the an X-rite iliSis. Although spectral measurements from the iliSis ranged from 380nm to 730nm in 10nm increments, only 400nm to 700nm in 10nm increments were used to reduce numeric processing overhead.

## Implementing the SGMF approach

For the SGMF approach, the implementation criteria used by Urban<sup>23</sup> were followed, and only two illuminants (D65 and Illuminant A) were used resulting in only two colorimetric lookup levels (rather than the three levels shown in Figure 3). To populate the histogram bins and metamer tables, all four-color combinations in 1% increments were iterated. (Note: Because the bin sizes represent a local region of CIELAB coordinates rather than a single point, the sub-metamer tables can be considered paramer<sup>28</sup> tables in this implementation). CIELAB values under D65 were

used to index the paramer bins with 128 levels for L\*, and 258 levels for a\* and b\* (with a\* and b\* ranging from -128 to 128). Into each paramer bin were placed output inking combinations along with each combination's associated integer CIELAB coordinate under illuminant A. Inking combinations with duplicate integer CIELAB values were removed in the process. A separate program was also created to apply these tables to get output ink combinations for each pixel in a spectral image.

## Optimization of the SGMF approach

The second implementation of the SGMF approach was devised incorporating an approximately perceptually uniform Euclidean color space<sup>25</sup> (hereafter referred to as Lab2000) based upon the CIEDE2000 color difference formulas to index SGMF paramer tables. Using Lab2000 for bin addressing resulted in smaller CIELAB color regions being associated with less chromatic colors and larger CIELAB color regions being associated with more chromatic colors. As a result the SGMF tables required 360.1MB whereas the Lab2000 based SGMF tables required 401.3MB indicating that there was less redundancy in metamer addressing and more available unique metamers.

## Implementing the LabPQR approach

By definition, the LabPQR address value for each grid point in an LabPQR table is associated with a single spectral reflectance curve that can be achieved approximately by the output device values stored at the LabPQR grid point. Any method that converts spectral reflectance to output device values is a candidate for populating device values in LabPQR table grid entries. Previous LabPQR implementations used an optimization search of a CYNSN printer model with five color combinations out of seven.<sup>21</sup> In this research identical printer modeling and four-color sub-sampling was used for both SGMF and LabPQR approaches to facilitate their comparison.

The first attempt at filling a LabPQR table involved directly applying a SGMF implementation. A LabPQR table with 50x41x41x7x5x5 grid entries was created. For each spectral reflectance associated with each LabPQR grid entry the SGMF approach was used to find appropriate ink values. This resulted in using the same gamut mapping strategy as for the SGMF approach. This LabPQR table was then applied using N-dimensional interpolation with the same images that were processed using the SGMF approach.

However this resulted in less than desirable results because only four out of seven colors were used at any one time, and there were too few connecting points available from the printer model to provide a smooth transition from one metameric black to another.

## Improved LabPQR table generation

A strategy for filling a LabPQR table was then devised to take into account the criticality of local linearity. This method populated the table outward from a central grid point selecting the metamers that met the simultaneous criteria of spectral reproduction accuracy as well as device ink value proximity with previously populated points. As a result, spectral accuracy was potentially sacrificed in order to try to achieve better linear behavior during interpolation. Population of the table was

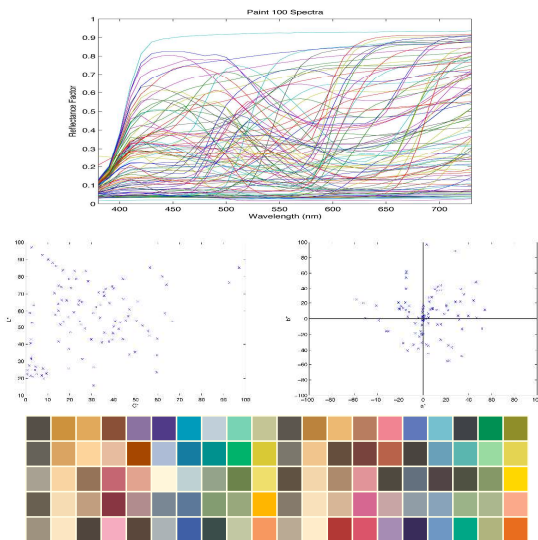
implemented as an N-dimensional extension of a queue based flood fill.<sup>27</sup>

However, this only resulted in a LabPQR table with slightly better results. In a further attempt to achieve local linearity it was then observed that since only four-color combinations are being used from the printer model, the extra degrees of freedom offered by PQR metamer addressing may have provided too much opportunity for problems with local linearity. Therefore, a LabP table (with empty Q and R dimensions) was generated with a similar total table file size resulting in much better printed results.

A second LabP table was also generated based upon the SGMF tables indexed using Lab2000. Only the LabP tables were compared with the two-illuminant SGMF approach

## Results/Analysis

The images used in the implementation comparisons were directly encoded as spectral reflectance for each pixel. No spectral capture modeling was performed. Two SPectral Binary (SPB)<sup>26</sup> images were used for testing purposes. The first image was made up of spectral reflectance measurements of 100 artist paint samples using 28 different pigments, either at masstone or mixed with white at different ratios (paint100pix.spb). This resulted in a spectral image with 20x5 pixels. A representation of the colors in this image are shown in Figure 5.



**Figure 5** –Colors in 100 artist paint samples: (Top) Spectral reflectances, (Middle-left) L\*-C\*<sub>ab</sub> plot, (Middle-right) a\*-b\* plot, (Bottom) Representative color chart

The second image was a fairly low resolution (204x291 pixels) Maccbeth color checker image (colorchecker.spb) downloaded from the www.multispectral.org web site.<sup>25</sup> Direct color analysis was not made of this second image, but as this image represented an actual spectral capture of an image the visual differences in smoothness were compared.

Both images were separated as CMYKRGB TIFF files using the LabPQR and SGMF tables (with and without the Lab2000 color space normalization) and then printed.

Spectral reflectance measurements were made of the patches on the 100 artist paint spectral image prints using an X-Rite i1 hand-held spectrophotometer fitted with a UV-cut filter. These measurements were compared to the 100 source spectra. Estimated colorimetric differences for the CIE 2° standard observer under D65, spectral RMS differences, and an index of metamerism with parametric correction<sup>29</sup> (going from D65 to illuminant A) were calculated. In Tables 1 through 3 are shown the best overall result for each category identified as **bold** and the worst overall result for each category identified as *italic*:

**Table 1 – D65 CIEDE2000 Color Differences**

	Ave	Max	Min	90th %-tile	Variance
SGMF	<i>1.89</i>	4.36	0.28	<i>2.99</i>	0.78
LabP	1.79	<i>5.28</i>	0.31	2.62	0.75
SGMF+Lab2000	1.49	4.47	<b>0.15</b>	2.50	<i>0.85</i>
LabP+Lab2000	<b>1.31</b>	<b>3.33</b>	<i>0.36</i>	<b>2.27</b>	<b>0.67</b>

**Table 2 – Spectral RMS Differences**

	Ave	Max	Min	90th %-tile	Variance
SGMF	0.049	<i>0.155</i>	0.005	<i>0.098</i>	<b>0.033</b>
LabP	<i>0.051</i>	0.150	<i>0.007</i>	0.095	<i>0.035</i>
SGMF+Lab2000	<b>0.046</b>	0.154	0.004	<b>0.091</b>	0.034
LabPQR+Lab2000	0.050	<b>0.142</b>	<b>0.004</b>	0.091	0.034

**Table 3 – Index of Metamerism (between D65 and Illuminant A)**

	Ave	Max	Min	90th %-tile	Variance
SGMF	1.09	3.99	<i>0.14</i>	2.35	0.80
LabP	1.47	4.46	0.05	3.01	1.01
SGMF+Lab2000	<b>0.99</b>	<b>3.92</b>	0.11	<b>2.08</b>	<b>0.74</b>
LabP+Lab2000	<i>1.71</i>	<i>5.26</i>	<b>0.03</b>	<i>3.08</i>	<i>1.15</i>

These results would suggest that SGMF and LabP (LabPQR) approaches are fairly close (which isn't too surprising since the LabP tables were populated based upon the SGMF implementation). Generally, the D65 CIEDE2000 color differences for the SGMF approaches were slightly larger than the LabP approaches, and using the Lab2000 color space improved the CIEDE2000 color differences. However, for both methods the first stage was based upon D65 colorimetry. Interestingly, the LabP approach resulted in the largest maximum color difference, yet using LabP based upon Lab2000 indexing resulted in the smallest maximum color difference for the 100 paint colors. However, despite the reasonably close color differences between the LabP and SGMF approaches, the LabP table file size was only about ¼ the size of the SGMF table file size.

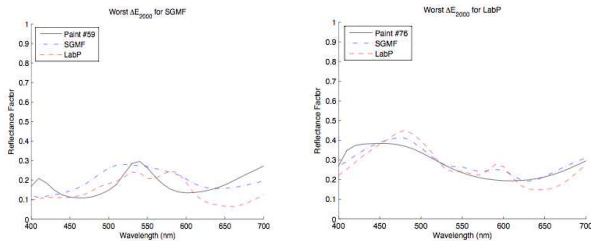
In comparing spectral RMS differences, the SGMF approach generally resulted in slightly smaller RMS differences than the LabP approaches. Once again using the Lab2000 color space for indexing purposes improved the performance. However, even though the average RMS differences were lower for the SGMF approaches, the maximum RMS differences were lower for the LabP approaches.

The average Index of Metamerism comparisons for the SGMF approaches were noticeably smaller than those for the LabP approaches. In contrast to the CIEDE2000 and RMS results, using Lab2000 indexing only improved the Index of Metamerism

comparisons for the SGMF approach while worsening the results of the LabP approach.

With the exception of an increased index of metamerism for LabP+Lab2000, it is apparent that using the Lab2000 color space for indexing purposes generally improved performance.

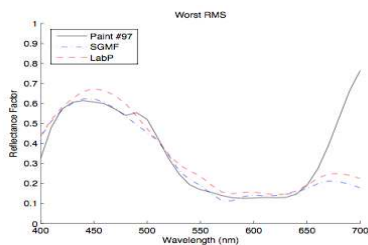
The spectral nature of the worst cases instances for Tables 1 – 3 are best analyzed as spectral reflectance plots (Figures 6 – 8). These plots only depict the approaches that included the Lab2000 indexing optimization. Following each figure is a table showing the CIEDE2000, spectral RMS differences, and Index of Metamerism values as compared to the spectral reflectance of the paint curve in each figure.



**Figure 6** - Spectral reflectances for Paint Patches with Worst  $\Delta E_{2000}$  reproduction for the SGMF+Lab2000 approach (left) and the LabP+Lab2000 approach (right)

**Table 4 – Measurement differences for curve comparisons in Figure 6**

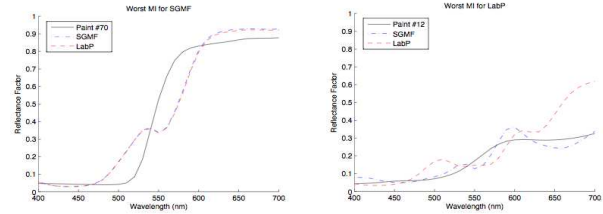
<u>Worst CIEDE2000 for SGMF</u>			<u>Worst CIEDE2000 for LabP</u>		
	SGMF	LabP		SGMF	LabP
<b>CIEDE2000</b>	<b>4.47</b>	0.76	<b>CIEDE2000</b>	2.79	<b>3.33</b>
<b>RMS</b>	0.062	0.078	<b>RMS</b>	0.028	0.051
<b>MI</b>	1.45	2.68	<b>MI</b>	0.36	0.57



**Figure 7** - Spectral reflectances for Paint Patch with worst spectral RMS difference for reproduction using both SGMF+Lab2000 and LabP+Lab2000 approaches

**Table 5 – Measurement differences for curve comparisons in Figure 7**

<u>Worst RMS</u>		
	SGMF	LabP
<b>CIEDE2000</b>	0.15	2.82
<b>RMS</b>	<b>0.154</b>	0.142
<b>MI</b>	1.09	0.96



**Figure 8** - Spectral reflectances for Paint Patches with Index of Metamerism reproduction for the SGMF+Lab2000 approach (left) and the LabP+Lab2000 approach (right)

**Table 6 – Measurement differences for curve comparisons in Figure 8**

	<u>Worst MI for SGMF</u>		<u>Worst MI for LabP</u>	
	SGMF	LabP	SGMF	LabP
<b>CIEDE2000</b>	2.72	2.98	<b>CIEDE2000</b>	0.73 0.75
<b>RMS</b>	0.117	0.119	<b>RMS</b>	0.033 0.12
<b>MI</b>	<b>3.92</b>	3.92	<b>MI</b>	0.27 <b>5.26</b>

From the spectra in Figures 6 – 8 it is evident that both the SGMF and LabP approaches were unable to perform an exact spectral matching of the spectral reflectances of the artist paints. Although many of the colors were within the colorimetric gamut of the printer, they were well outside the printer’s spectral gamut. Chromium oxide green (Figure 6, left) has a very distinct spectrum that cannot be matched with any other colorants, printing or otherwise. The long-wavelength “tail” of cobalt blue (Figure 7) could not be matched with this set of inks. Diarylide yellow (Figure 8, left) is a reddish yellow. Although its color can be easily matched with yellow, red, and magenta, its spectrum cannot be duplicated.

The SGMF approach used in these experiments only performed two levels of colorimetric indexing (first using D65 and then with Illuminant A). Since these are the same illuminants that were used for calculating the index of metamerism it is fitting that for each of the worst case patches in Figures 6 – 8 the index of metamerism for the SGMF approach is less than or about the same as the LabP approach. Since the LabP approach was optimized for both linear interpolatability as well as spectral RMS difference it is fitting that the maximum spectral RMS difference for all the patches is slightly smaller for the LabP approach (see RMS values in Table 6). However, since there is a dual optimization to both achieve linear interpolatability and minimize spectral RMS, this didn’t result in a lower average RMS difference for the LabP approach (see average values in Table 2).

Conceptually one would think that having extra dimensions would provide for a better spectral reproduction. However, as can be seen from Figures 6 – 8 an excellent spectral reproduction was not achieved because the desired colors were not within the spectral gamut of the printer and secondary color-reproduction criteria became important. This being the case, these approaches target excellent colorimetric results for D65 with the desire to get good behavior for other light sources by trying to minimize the spectral differences as much as possible. How good of an approximation that can be achieved is limited to the printer’s

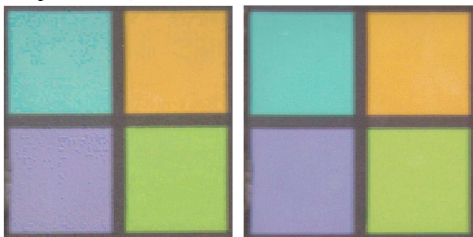
spectral gamut and the ability to address colors in the involved tables.

One other aspect that needs to be appreciated when considering the number of dimensions in a LabPQR approach is that the PQR dimensions provide for the interpolation of the metameric black component of the spectra. Using an example of just CMYK inks, this is equivalent to interpolating between GCR/UCR choices for a color with a specified CIELAB value. Black generation behavior is not broadly linear so the sampling needs to be sufficient in order to achieve local linearity.

With the CMYKRGB print mode used in these experiments there are additional degrees of freedom (with red generation, green generation, and blue generation in addition to multiple dimensions of black generation). However, only four colors (4 dimensions) were used at any point in time by the printer model in these experiments, and therefore the five, six, and seven color combinations were not available to linearly model the transitions from one set of four color combinations to another set of four color combinations.

By limiting the approach to four dimensions (using LabP) the number of sampling points can be increased (thus getting better local linearity), and the degrees of freedom that are needed by the model are more limited. Thus, spectral accuracy is partially sacrificed for better predictability. Trying to use more LabPQR dimensions in this case only introduced complexity that could not be entirely compensated for by the N-dimensional flood fill algorithm used along with the interpretability optimization function.

A visual comparison was also made of the printed output of the colorchecker.spb image file. A scan of a portion of the printed output is shown in Figure 9. (Note: Though the scanning and reproduction in this article might not portray the exact colorimetry of the printed reproductions, the relative visual differences between the SGMF printed output and printed LabPQR output are fairly well represented).



**Figure 9** – Partial scans of the colorchecker.spb image printed output. (Left – Color separation using SGMF), (Right – Color separation using LabPQR)

A visual comparison of the printed output (as well as between the scans of the output in Figure 9) revealed significant differences between the SGMF and LabPQR approaches in terms of visual artifacts. The spectral image reproduction made using the SGMF approach resulted in more noticeable artifacts due to quantization of both device sampling and bin addressing that are not as easily detectable in the LabPQR output.

From these visual results the LabPQR output appears visually smoother which generally agrees with the measurement results for the 100 paint samples that showed the LabPQR approach to have slightly better colorimetric accuracy. Apparently, the quantization of data in the SGMF approach results in noticeable posterization in

image areas with small color differences. This quantization was not as much of a factor for the LabPQR approach because interpolation is used to estimate unique ink values for slight gradations in image data.

## Conclusions

Spectral printing systems based upon the Spectral Gamut Mapping Framework (SGMF) and LabPQR were implemented for the purposes of comparison. Both methods are similar in that spectral image reproduction can be conceptually split into two stages - a stage based on colorimetry and a stage that uses extra information from the spectral image to select between metamers to determine final output values. This allows for both conventional gamut mapping to be used as well as data dimensionality reduction to occur. Both SGMF and LabPQR approaches can be used to convert high-resolution spectral reflectance images to device ink count values in a reasonable time. The accuracy between the methods was found to be similar with the SGMF being slightly more accurate and the LabP results more visually smooth with less sensitivity to small differences in image data.

Several attempts were made to get a LabPQR table with six dimensions that performed reasonably close to the SGMF implementation, but the best results in these experiments were found when only four dimensions were used. One conclusion from this is that it might be better to use more than four colors at a time in the printer model when populating a higher dimensional LabPQR table since more degrees of freedom are required to achieve better local linearity when additional dimensions of the PQR metameric black are used.

Because only four LabPQR dimensions (LabP) were needed to get reasonably close results for the 100 artist's paints to the SGMF implementation, it is reasonable to conclude that the approach of using an abridged spectral camera with only five effective channels might be sufficient for spectral reproduction of these artist's paints using this particular printer.

Since the LabPQR tables were filled in using results from the SGMF implementations it shouldn't be expected that the LabPQR implementations in this research would have much better results. However these results do indicate that the approaches used to populate and process the LabP tables did not result in significant differences in accuracy to the corresponding SGMF approaches.

Both the SGMF and LabPQR approaches were generally improved by using a more perceptually uniform color space for the purposes of indexing and searching data tables. The Lab2000 color space (based upon the CIEDE2000 equations) that was used in these experiments was found to provide for an effective sampling increase without significantly introducing additional storage overhead of extra sampling levels. In future research it is also plausible to consider using something like Lab2000 to improve the interpolation accuracy of more conventional approaches of color management. However, this approach can possibly add an additional processing overhead to perform an extra interpolation to the perceptually uniform color space.

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