A testing paradigm for quantifying ICC profilers

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Abstract

To reproduce colors in one system which differs from another system in terms of the color gamut, it is necessary to use a color gamut mapping process. This color gamut mapping is a method to translate a specific color from a medium (screen, digital camera, scanner, digital file, etc) into another system having a difference in gamut volume. There are different rendering intent options defined by the International Color Consortium [5] to use the different reproduction goals of the user [19].

Any rendering intent used to reproduce colors, includes profile engine decisions to do it, i.e. looking for color accuracy, vivid colors or pleasing reproduction of images. Using the same decisions on different profile engines, the final visual output can look different (more than one Just Noticeable Difference[16]) depending on the profile engine used and the color algorithms that they implement.

Profile performance substantially depends on the profiler engine used to create them. Different profilers provide the user with varying levels of liberty to design a profile for their color management needs and preference. The motivation of this study is to rank the performance of various market leading profiler engines on the basis of different metrics designed specifically to report the performance of particular aspects of these profiles. The study helped us take valuable decisions regarding profile performance without any visual assessment to decide on the best profiler engine.

Keywords: ICC, metrics, invertibility, round trip, gray balance, gamut mapping, Fogra, gamut volume etc

Introduction

Color management can be achieved using a variety of workflows [17]. ICC profiles form an integral part of cross device color communication. HP Latex printers [12] use ICC color management to convert colors from one device space to another. This is done by translating color information from a device dependent color space (printer CMYK, printer RGB etc) to a device independent color space (ex CIELAB. CIEXYZ etc). There are ways to characterize the device in this particular direction [11], referred to as the forward transform[10] which is done by printing a particular sampling of the device color space and then measuring the samples with a spectrophotometer or colorimeter, to establish the relation between the device color space and the independent color space.

Printing happens using the reverse part of the transform [10]. The image to be printed can be in any RGB or CMYK color space, but the final printing to be done on a particular device's CMYK space needs to undergo the ICC color management workflow. This happens by first converting to the device independent space using a forward transform, and finally for the printing to happen, it needs to use the reverse transform to translate to the device CMYK (dCMYK). The reverse transform needs the computation involved as the mapping now becomes from three to four dimensions (a point has the opportunity to be mapped to any point on a line). The process of inversion from CIELAB to dCMYK also involves decision regarding the black genera-

tion, which is an important factor for printing to control the grain and ink efficiency. This mapping might lead to an imbalance in the gray neutrality of mapped colors which can deeply influence color casts. Finally, from a gamut volume point of view, all these factors decide how many colors can be accessed by the printer in the device independent space and can be finally reproduced.

As most of these aspects are related to the colorimetric tag of the ICC profiles, these can be quantified using various metrics as have been done in the past with some studies [8] [7] and as suggested by the ICC itself [4]. In this study we modify and improve the existing metrics and create some new ones to quantify missing aspects. Hence, scores are reported according to our evaluation metrics. The intention of this study was to use only quantitative metrics instead of psychometric evaluation to avoid subjective and preferential aspects. This research is concentrated to have a single green-button approach for an ICC profile's performance without the requirement of printing any physical samples or visual assessment of the profile applied images/reproductions.

Profilers

Four ICC profilers were part of this study. These profilers have completely different color engines having different algorithms inside them. We name the profiles from these profilers as Profile 1,2,3 and 4 respectively. Accessible gamut has been calculated treating profile 1 as the reference profile to see relative increase/decrease, but the same methodology can be used to get absolute numbers. Profiles 2,3 and 4 were generated using the best settings provided by the profiler softwares in terms of black generation, GCR etc [20], All the profiles except profile 2 (which required a custom target characterization chart) were created using the same target chart (ECI 2002[13]) and printed using the same state of the printer to avoid any changes in the printer behaviour. The printer in discussion is an HP inkjet printer using Latex inks [12].

Metrics

In the subsequent sections all the metrics are defined for this study later followed by their results.

Forward Transform Accuracy of the Colorimetric Tag (A2B1)

This is an initial flag test to identify if the A2B1 tag of the ICC profile is a close match to the actual measurements of the target chart used in terms of their color difference (CIEDE2000 [14]). This is a requirement implicitly defined in the ICC conformations [19]. The A2B1 tag is encoded in relative colorimetry which is first converted to absolute colorimetry for this test. Sometimes, if the measurements are not respected in the A2B1 tag, this can result into unnecessary profile inversion problems, unless these changes are intentionally done. Since all the profiles used embed all the color transformations in the LUT, and the A2B1 tag contains the relative colorimetric values, the absolute colormetric values were extracted using the guidelines in ICC.1:2004-10 (section 6.3.2) [19]. These 16-bit values were

then converted to the respective ranges of L*, a* and b* and compared to the original CIELAB using CIEDE2000 [14] color difference formula for the node points of the CMYK quadruples of the actual target chart.

Profile Inversion

ICC specification ICC. 1:2004-10 [19] define that the A2B1 transform should be based on the measurements used for creating the profile. Ideally, to achieve proper preview and proofing goals, the BtoA1 transform should also be an exact inverse of the A2B1 tag but this does not happen usually due to various reasons like interpolation due to different in sizes of the forward and reverse transform LUTs, black generation and ink limiting preferences etc[10]. The inversion accuracy of a profile can be done by doing a round-trip of the all the in-gamut colors[10]. Out of gamut/boundary colors contribute to gamut mapping decisions and are bound to have a non-invertible response when round tripped. For in-gamut color, the inversion should hold true. This is done by following the algorithm below.
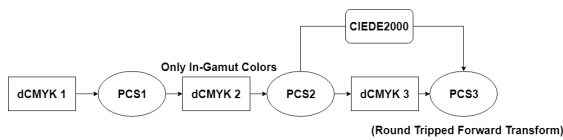
Figure 1. *Round trip error calculation algorithm.*

By passing the original dCMYK sampling through the extra step of PCS 1 and then to PCS 2 ensures that in PCS2 only in-gamut colors have been converted to CIELAB as PCS1 already had only the reproducible (in-gamut) CIELABs[10][Fig 1]. The CMYK values were incremented in each channel in steps of 2 as steps of 1 made the iteration computationally very expensive. Comparing the PCS2 to PCS3 CIELABs using the CIEDE2000 gave us the round-trip accuracy. The mean and the max round trip errors were reported. Top 2 percentile of the errors were reported in terms of CIELAB coordinates to identify which are the worst colors for round tripping, and if they follow a trend in terms of the primary colors being moved intentionally.

Accessible Gamut

Accessible gamut is defined by the total gamut that can be reproduced by an output device taking into account the physical limits of the device, for ex, the ink coverage, ink behavior etc [1] of the printer. As it is not possible to have a perfect dense modelling of the relationship between the total ink space sampling and their colorimetry, the gamut of a device is created by applying different gamut boundary descriptors' algorithms[1] to a sampling of the device space's colorimetric measurements. For this test, we evaluated the accessible printer gamut for the absolute and perceptual cases. A 33 node uniform sampling of the CIELAB color space is converted to dCMYK using the absolute and perceptual tag. The algorithm that a profiler applies to calculate the reverse transform, B2A, defines how the original CIELAB sampling would be converted to the dCMYK in this case. These constitute the final CMYK combinations that can be printed on the device using the B2A reverse transform incorporating the black generation and gamut mapping algorithms[1][17]. These dCMYKs are converted to CIELAB again using the A2B in absolute colorimetry to predict how they finally appear for the absolute and perceptual cases. As the B2A tables for the first step are different for each profiler for this test, this translates to different CIELABs in the final step and this impacts the gamut boundary of a particular device[1]. The

CIELABs are then triangulated[6] to create the gamut boundary of the points using the convex hull algorithm[2][Fig 2]. This gave us the accessible gamut volume of the of all the profiles in CIELAB units.
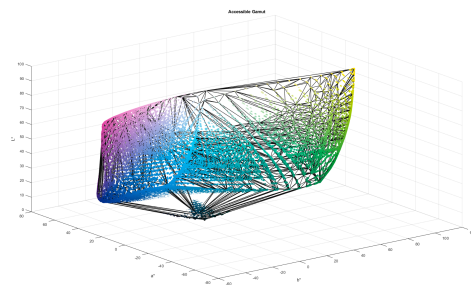
Figure 2. *MATLAB tool to visualize the accessible gamut using convex hull[2], CIELAB color space.*

Spot Color Library Coverage

For spot colors, it is imperative to have a close match to their colorimetry. If a Spot color lies inside the reproducible gamut of the profile, it can be printed with good accuracy. Spot colors can be emulated using an ICC profile by using the absolute colorimetric tag (B2A1) of the ICC profile. For this test, we used the Fogra53[9][Fig 3] characterization data as a pseudo spot color dataset but the same methodology can be applied to any standard spot color libraries to replicate the intended results.
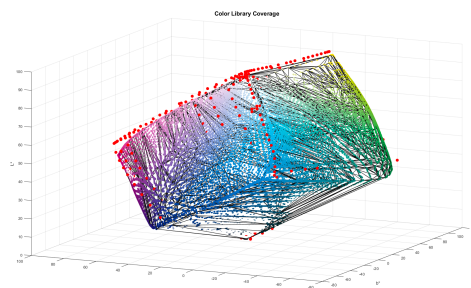
Figure 3. *Fogra53[9] dataset (red circles) plotted with the accessible gamut of Profile 4, CIELAB color space.*

The original CIELABs from the dataset are converted to dCMYK which are again converted to CIELAB in absolute colorimetry respectively. These CIELABs are searched inside the convex hull of the accessible printer gamut using a simplex search[6][18] to find out how many colors from the dataset can be reproduced using the printer profiles.

Skintones

Skintones are an important part of a profile's pleasantness especially in the perceptual tag. Primary adjustments implicitly done in profiles' perceptual tag often incorporate an unwanted color cast on skintones, thus making some profiles undesirable, for ex, colors might be too saturated in reds, which might result in reddish skintones etc. For this test a 16bit CIELAB image of the Roman16©[3] CIELAB skintones dataset was created [Fig 5]. It was also checked that all the 37 points of the Roman16 skintones lie inside the actual device gamut [Fig 4].

This image was converted to the dCMYK using the perceptual and relative colorimetric tag respectively. How these values would finally appear after printing were calculated by changing
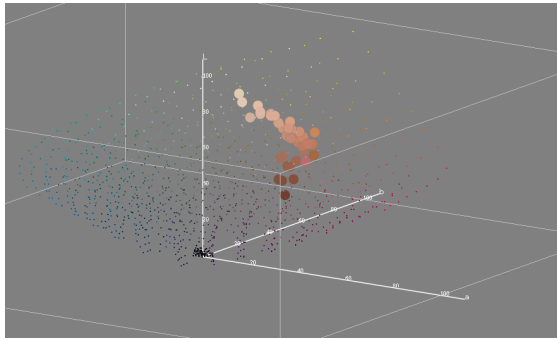
Figure 4. *Visualization of the Roman16 skintones (skin colored spheres) with the actual printer gamut on the CIELAB space to show that the Roman16 skintones LAB lie inside the device gamut and can be reproduced.*

these dCMYK to LABs using the absolute colorimetry. Finally, the CIEDE2000 between the original Roman16 dataset and the converted LABs were reported.

**Figure 5.** *The Roman16 dataset converted to 16bits CIELAB image.*

Gray Neutrality Index (GI)

Reproduction of gray colors is one the most sensible performance of a profiler. Usually the loss of gray neutrality comes from the printer device variability, but sometimes the ICC profile itself can introduce small deviations to the calculated gray axis that can be amplified by those printing variabilities. There are two different gray neutrality deviance (one in chroma and the other in hue angle) that we can observe and, to simplify the evaluation process, we created a single index that can combine together those deviations. Gray neutrality is expressed as the ability to reproduce the L* axis (a*=b*=0). Even if every device or every printing standard can have a different definition of gray reproduction, all will lie in that region.

$$ GI = \overline{\Delta C^*} \cdot \left[\frac{\sigma(\Delta h)}{2\pi} + 1 \right] $$

The formula used for the GI link together the average difference of chroma (ΔC* in LCh color space), that express the possible deviation from the neutrality, with the standard deviation of the hue (Δh in LCh color space) that express the presence of opposite hues around the neutral axis. This is because if the gray axis is not perfectly neutral, to have different hues at different L* levels (so called "rainbow effect")[Fig 6] is worse than a constant deviation with a small hue range.

The GI will raise up if the average of chroma is high or if the standard deviation of hue differences are high, or both. This index does not represent a new color space or perceptually uniform metric but is just a metric to be used comparing an attribute (gray-neutrality) that can present two types of deviations (chroma deviation and hue variations) as a root cause. This test was implemented by converting a pure L* image in steps of 1 with (a*=0,b*=0) and converting it using the colorimetric tag to predict how much chroma and hue is added to the pure neutral image in terms of the GI.
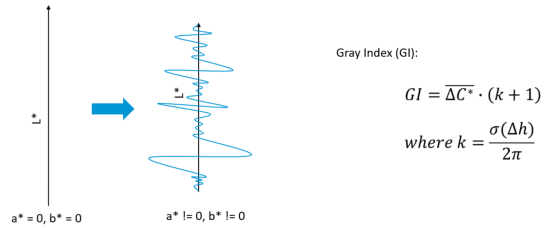
Figure 6. *The Gray Neutrality Index (GI)*

Out of Gamut to In-Gamut Transition

When out of gamut colors are converted to in-gamut using a profile, due to different gamut mapping techniques, there can be loss in the transition trend that was present originally between the original colors and the gamut mapped colors[17]. For a perceptual match to screen or the original, the out of gamut colors, once mapped inside the gamut should follow a similar transition trend. For this test 6 PRMG [19] primaries and secondaries were used (RGBCMY). PRMG lightness, chroma and hue angles were acquired by the ICC specification for the v4 profiles[19]. The profile's gamut boundary colors in the perceptual accessible gamut were extracted (B2A0 then A2B1 in absolute colorimetry). These points were first scanned in the L* range [-5 to +5 L* units of the PRMG primaries and secondaries] on the printer's accessible perceptual gamut boundary colors to find the closest L* match, and then the least match with respect to the hue angle was found. This defined the vector for the chroma search. Now the chroma was reduced in steps of 1 Chroma unit till the CIELAB of the gamut boundary color of the respective profiles were reached. For each of these points on the gamut boundary, the chroma was found out [Fig 7,8]. As the original vector had a constant chroma difference of 1 unit, thus resulting in original standard deviation of 0 unit for the consecutive Chroma differences, the gamut mapped Chroma differences also should have similar standard deviation.
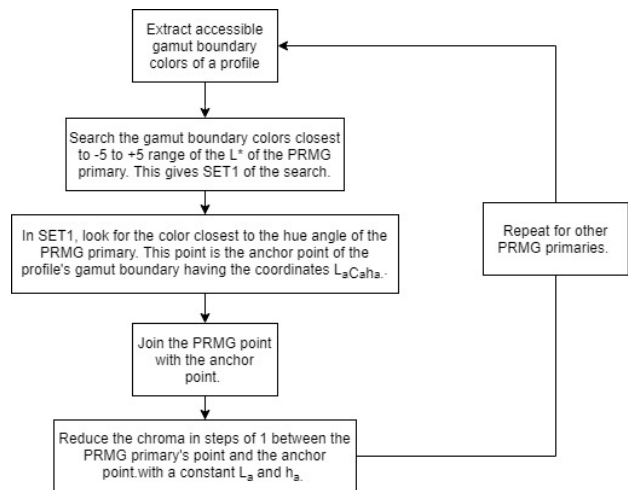
Figure 7. *Algorithm describing the method of quantifying change in chroma after perceptual gamut mapping*

Tools Used

The printer in discussion is an HP inkjet printer using Latex inks and Avery Dennison MPI3001 self-adhesive media printed with an 8 passes high quality printmode. Different target charts
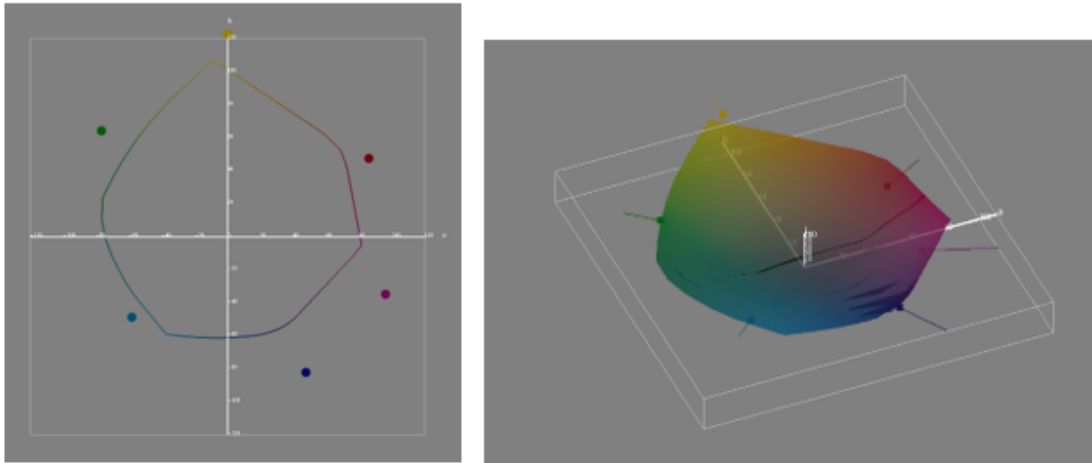
Figure 8. *(Left) The PRMG primaries projected into the CIEab plane with a profile's perceptual accessible gamut. (Right) An example of the anchor points on the accessible gamut boundary and the search vector joining the PRMG primaries to them. This defines the search direction by reducing the chroma, keeping the L* and hue angle constant. CIELAB space.*

were printed matching the requirements and demands of the profiler softwares respectively. The printed charts were measured using a Konica Minolta FD7 spectrophotometer. All the testing was done using the littleCMS [15] open source color management engine's C++ library and the data was processed using python's numpy library and Matlab 2017b.

Results

Overall results for all the tests are summarized in Table 1. The A2B1 colorimetric accuracy is very good for all the profilers except profiler 3. This implies that this profiler does some modifications to the actual measurements of the target chart used to create the profile and this reflects in the colorimetric tag of this profile. Profile 3 has the best round-trip average as well as the least round-trip maximum. During this test, the color coordinates having the highest two percentiles for the CIEDE2000 errors were identified. This helped us identify if there are certain colors that have worse invertibility. In Figure 9, the top 2 percentile errors of profile 4 for the round-trip can be seen.
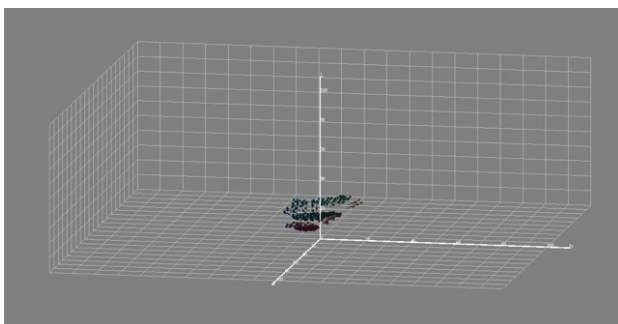
Figure 9. *Top 2 percentile of Round Trip Errors for profile 4 were concentrated in the shadow regions.*

For profile 4, there is worse invertibility for dark colors [Fig 9]. The length of the arrows signify the magnitude of the CIEDE2000 between the original CIELABs (PCS2) and the round tripped CIELABs (PCS3). The accessible perceptual gamut was compared to the reference Profile 1. Profiler 4 has the

highest accessible gamut ratio among all the profilers as well as the highest Fogra53 coverage. All the profiles performed quite bad in terms of preserving the Roman16 skintones as can be seen by the high CIEDE2000 values using the perceptual or the relative colorimetric workflow. Profile 4 has the best gray neutrality among the four profiles as can be seen by the low GI value. This means that a pure neutral CIELAB after the ICC application emerges out having the least chroma or hue added to the gray axis. This has a big impact on how the profile deals with pure neutral colors as there won't be any color cast on the neutral colors.
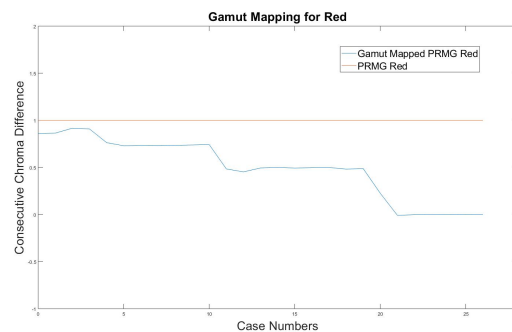
Figure 10. *An example of the anchor points on the accessible gamut boundary and the search vector joining the PRMG primaries to them. This defines the search direction by reducing the chroma, keeping the L* and hue angle constant in CIELAB space.*

An example of the change in chroma after gamut mapping can be seen in Fig 10. Out of gamut to in-gamut mapping is reported in terms of the standard deviation for the gamut mapped chroma [Table 2]. Profile 2 has better performance than the other profilers in mapping out of gamut colors except the yellow. It successfully conserves the chroma difference between the original colors which would lead to a reproduction with better transitions in terms of chroma for out of gamut colors.

In general, profile 2 and 4 have better performance than the rest with profile 4 performing better in gamut coverage and gray

Table 1: Metric results for all the tests. The last column defines the metric reported.

	Profiler 1	Profiler 2	Profiler 3	Profiler 4	Metric
Accuracy A2B1	0,27	0,12	0,61	0,25	CIEDE2000
Profile Inversion (RoundTrip Average)	1,26	0,31	0,19	0,39	CIEDE2000
Profile Inversion (RountTrip Maximum)	2,41	2,33	2,32	2.51	CIEDE2000
Accessible Printer Gamut (Abs)	(ref)	102%	99.9%	107.38%	% Coverage
Accessible Printer Gamut (Perc)	(ref)	102.05%	100.63%	108.34%	% Coverage
Gray Neutrality	0,28	0,31	0,30	0,19	GI
Spot Color Library Coverage	79,41%	80,09%	79,41%	81,82%	% Coverage
Skintones Perceptual	2.82	2.92	3.46	3.36	Max CIEDE2000
Skintones RelativeCol	3.24	3.65	3.38	3.45	Max CIEDE2000

Table 2: Standard deviation of the vector connecting PRMG primaries and secondaries and the anchor point found on the gamut boundary of all the profiles using the algorithm described in Figure 7.

PRMG	Red	Yellow	Green	Cyan	Blue	Magenta
Profiler 1	0.32	0.01	0.13	0.05	0.16	0.3
Profiler 2	0.06	0.39	0.09	0.09	0.19	0.08
Profiler 3	0.22	0.36	0.09	0.05	0.21	0.02
Profiler 4	0.28	0.5	0.19	0.05	0.06	0.01

neutrality. Profile 1 has the worst performance in terms of invertibility, gamut coverage and skin tone reproduction. The higher CIEDE2000 for skin-tones can be due to the primary adjustments affecting the color gamut region around skin-tones. All the profiles except profile 4 have worse performance in gray neutrality, which could lead to a color cast on the final printing.

Conclusions

Four different profiler engines were compared in this study quantitatively with a motive of having a completely digital workflow for evaluating profiles. Different weak points of the profilers' performance were identified. This enabled us to take valuable decisions regarding their utility. Some aspects have been left for future investigations, for example, quantifying gamut mapping in terms of lightness and hue preservation, quantifying GCR[20] performance, graininess etc.

References

[1] Arne M Bakke, Jon Y Hardeberg, and Ivar Farup. Evaluation of gamut boundary descriptors. In *Color and Imaging Conference*, volume 2006, pages 50–55. Society for Imaging Science and Technology, 2006.

[2] C Bradford Barber, David P Dobkin, David P Dobkin, and Hannu Huhdanpaa. The quickhull algorithm for convex hulls. *ACM Transactions on Mathematical Software (TOMS)*, 22(4):469–483, 1996.

[3] BVDM. *BVDM Roman 16 Skin-tones*.

[4] International Color Consortium. *Profile viewing and testing resources*.

[5] International Color Consortium et al. Specification icc. 1: 2004-10 (profile version 4.2. 0.0): Image technology colour management, 2004.

[6] Boris Delaunay et al. Sur la sphere vide. 7(793-800):1–2, 1934.

[7] Kristyn Falkenstern, Nicolas Bonnier, Hans Brettel, Marius Pedersen, and Françoise Viénot. Using image quality metrics to evaluate an icc printer profile. In *Color and Imaging Conference*, volume 2010, pages 244–249. Society for Imaging Science and Technology, 2010.

[8] Kristyn Falkenstern, Nicolas Bonnier, Marius Pedersen, Hans Brettel, and Françoise Viénot. Using metrics to assess the icc perceptual rendering intent. In *Image Quality and System Performance VIII*, volume 7867, page 786706. International Society for Optics and Photonics, 2011.

[9] Fogra Forschungsinstitut für Medientechnologien e.V. *New CMYK-based colour exchange space: FOGRA53 and eciCMYK released*.

[10] Phil Green and Michael Kriss. *Color management: Understanding and using ICC Profiles*. Wiley, 2010.

[11] Po-Chieh Hung. Colorimetric calibration in electronic imaging devices using a look-up-table model and interpolations. *Journal of Electronic Imaging*, 2(1):53–62, 1993.

[12] HP Inc. *HP Latex Printers*.

[13] European Color Initiative. *New ECI 2002 target and conversion tools*.

[14] ISO Joint and CIE Standard. Colorimetry—part 6: Ciede2000 colour-difference formula. *ISO/CIE*, pages 11664–6, 2014.

[15] LCMS. *LittleCMS*.

[16] K McLaren. Xiii—the development of the cie 1976 (l* a* b*) uniform colour space and colour-difference formula. *Journal of the Society of Dyers and Colourists*, 92(9):338–341, 1976.

[17] Ján Morovič. *Color gamut mapping*, volume 10. John Wiley & Sons, 2008.

[18] Katta G Murty. *Linear programming*. Springer, 1983.

[19] ICC Specification. 1: 2004-10 (profile version 4.2. 0.0). *International Color Consortium*, 2004.

[20] Kelvin Tritton. *Colour control in lithography*. Pira International, 1993.

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