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Evaluation and use of gamut information in ICC output profiles

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Abstract

A device's color gamut is an important parameter in color managed workflows. With the increasing use of expanded gamut workflows and the need for more colorful products in large-format inkjet printing or packaging, the management and prediction of in-gamut colors is critical information for the content creator. When device color capability information is stored within the structure of an ICC profile, this information becomes readily available to any software utilizing the ICC profile in conjunction with an image or image data. A product may for example offer a gamut stain or warning to indicate to the user that the color under consideration is out of gamut of the destination print process. This research compares the gamut predictions of Adobe Photoshop, ArgyllCMS, BabelColor PatchTool, Esko Color Engine Pilot, Little CMS and MathWorks MATLAB. It is shown that the different tools may use different methods to determine the color gamut of a system. In general, the methods available include a Round Trip test, use of the ICC profile Gamut Tag and a Gamut Boundary Descriptor process. The Gamut Tag was read-in and displayed for different ICC profiles and differences in the tag contents was demonstrated. In total, 1729 CIELAB values, representing the PANTONE+ Solid Coated Library V2 were used and the percentage of in-gamut values using each software product was computed for different output print processes. There was a large difference in the predictions between the different products tested; the software tools variously predicted that 30–65 % of the library was in-gamut. A general philosophy of an ICC workflow is predictable result; while the ICC architecture is not intended to change a device's gamut capabilities, it should be able to communicate accurate and consistent gamut information. As more and more software systems are starting to present gamut data, it is important that systems do not predict disparate results.

Keywords: color gamut, color management, lookup tables, PANTONE, ICC Gamut Tag

1. Introduction

A first step in color management is often generation of print characterization data, where target patches of known CMYK inking are printed and measured to produce CMYK-CIELAB pairs. Print characterization data inherently contains color gamut information and therefore so does an ICC profile that is made from this data. Color gamut is defined as the range of colors that a device can reproduce. Gamut information, embodied within an ICC profile, can be accessed by software programs which display to the user whether a requested color is in or out of gamut of a given print process. In this research we use a set of known CIELAB values, in this case the CIELAB values that represent the PANTONE+ Solid Coated Library V2, and compare the gamut predictions of a range of software tools for different characterization datasets and ICC profiles (GRACoL, SWOP #3, SWOP #5, Fogra39, etc.). The software tools used in this project range from mainstream products such as Adobe Photoshop to programmable tools such as MATLAB, ArgyllCMS or C++ libraries from Little CMS.

After color characterization data has been empirically determined for a device, this information is implicitly and explicitly available within an ICC profile. Device gamut information is implicitly available within ICC profile lookup tables that can be used in a *Round Trip* test, or software developers can determine and populate an explicit *Gamut Tag* in an ICC output profile. Finally, color characterization data can be used to determine a *Gamut Boundary Descriptor*. The prediction from the different approaches to describe a device's color gamut are compared in this research.

There are many instances where an accurate description of a device's color gamut is necessary. A software system may offer, for example, a gamut stain or flag warning to indicate to the user that the color under consideration is out of gamut of the destination process and cannot be accurately reproduced. The user can choose to either change the output process or change the color to another color that is within gamut. In a number of packaging workflows, it is important to use

spot colors that are bright and vivid in order to catch the customer's attention on supermarket shelves. It is advantageous therefore to be able to select colors that exploit the color gamut of the output process by choosing the most colorful color that can be accurately reproduced. Gamut data also provides useful information that can be used in studies where we seek to evaluate, for example, different paper or media types and to maximize the color gamut based on the influence of the substrate interactions (Perales et al., 2009). Another use for an empirically derived color gamut is to compare it to the color gamut predicted by an analytical model and hence to see how well the analytical model is suited for the calculation of gamut boundaries (Zhao, 2007).

With the interest in expanded gamut and multi-color workflows, new software tools and dialogs are becoming available to provide gamut warnings and an important issue for the end user is that the different tools provide similar feedback relating to a color's in or out of gamut status. A designer should be able to select a color, verify that it is in-gamut and should not later receive a conflicting message when the file reaches prepress or plate making or press. It is inconvenient and time wasting if one system indicates a color is in-gamut and the user continues with its use only to find that the color is out-of-gamut and they are unable to achieve this color on final output. Software tools are beginning to provide a gamut prediction, so it is important that the information provided is accurate and also consistent between different products. In this research we see that the different programs available to the end user predict widely differing estimates of the percentage of in-gamut colors for a given PANTONE library.

Results are presented that test the gamut ability of a device in terms of the percentage of PANTONE colors that are in-gamut of a system. When PANTONE certifies a manufacturer's printer for reproducing PANTONE colors, this assessment is an important part of that process. The number of in-gamut PANTONE colors is a metric that has been used in marketing information by HP and others.

We note that the HP Designjet Z Photo Printer series makes claims to be capable of successfully simulating over 80 % of a PANTONE library (HP, n.d.). Industry benchmarking studies by IDEAlliance have shown that digital presses can reproduce 40–55 % of a PANTONE library (Sharma, 2009) and in the area of large-format inkjet printing, Sharma and Rong (2014) have shown that commercial devices can reproduce up to 64 % of the PANTONE library. The percentage of in-gamut PANTONE colors is a simple metric that is understandable and relevant to the average user. If a device is able to achieve 50, 60, or 70 % of a given PANTONE library, this is directly related to the

underlying color gamut of the system under consideration and is an easy to understand metric that is directly applicable in a print shop. Consider an alternative metric in which the color gamut volume is expressed in terms of cubic CIELAB units, perhaps a device has 400000 or 420000 cubic volume; it is not easy to interpret or utilize the information when presented in this format.

In this experiment, a set of known CIELAB values was used, in this case the 1729 CIELAB values of the colors composing the PANTONE+ Solid Coated Library V2. However, because of the irregularity of the gamut and the irregularity of the data set, the test process used here may not be applicable to a situation where we seek to compare the gamut volume of two devices. Deshpande, Green and Porter (2014) propose a method to compare color gamuts. Their work looks at how similar two gamuts are in order to determine how well suited a particular gamut is for the color reproduction of another gamut, as relevant in situations where images are being retargeted from one output medium to another.

The structure and format of ICC profiles are specified by the ICC Specification (ICC, 2004) or the corresponding ISO standard – ISO 15076 (International Organization for Standardization, 2005). These documents describe the various profile elements that are available to software developers to use, including an ICC output profile "Gamut Tag". It is useful to note that in order to be a valid output class profile, the Gamut Tag must be present, but the content or "goodness" of any ICC profile tag, including the Gamut Tag, is not described by the ICC Specification nor ISO 15076.

The ICC Specification does not describe the contents of a profile in terms of quality or accuracy (Sharma, 2006). Because the ICC Specification does not stipulate the contents of a profile, individual vendors may populate the contents of a profile's lookup tables with any data they like. This leads to the situation where a profile can conform to the ICC Specification, yet there is no guarantee to the quality of the profile tag behavior. There is much anecdotal discussion relating to the behavior of the Gamut Tag; in this research we demonstrate and document the behavior of the Gamut Tag in a number of different ICC profiles.

In this study, we use the above mentioned processes on a set of CIELAB values to establish whether or not they are in gamut, defined as:

- Round Trip – where Profile Connection Space (PCS) values are converted to CMYK and back again
- Gamut Tag – where the 0 values in this look-up table are used to indicate in-gamut values
- Gamut Boundary Descriptor (GBD) – tetrahedral segmentation search for in-gamut values

When provided with an ICC profile, a number of different commercial, and open source software products have the ability to flag or stain an image to indicate out-of-gamut colors.

In this project, the following systems were used to estimate the device gamut ability:

- Adobe Photoshop CS6
- ArgyllCMS 1.7
- BabelColor PatchTool 4.7
- Esko Color Engine Pilot v14
- Little CMS 2.7
- MathWorks MATLAB R2015a

2. Methods for evaluating device gamut

Color characterization data empirically defines the gamut of a device, and this information can be stored implicitly and explicitly within an ICC profile. Given that gamut information is stored within an ICC profile, there are a number of methods to test and see if a CIELAB value is in or out of gamut. Device gamut information is implicitly available within ICC profile A2B/B2A lookup tables that can be used in a *Round Trip test*. Software developers can determine and populate an explicit *Gamut Tag* in an ICC profile. Color characterization data can be used to determine a *Gamut Boundary Descriptor*. We now describe each of these processes in detail.

2.1 Round Trip test

The Round Trip test can be used to determine colors that are out-of-gamut, based on their ΔE_{ab}^* between start and finish. In this process, CIELAB values from the PCS are converted to CMYK using the PCS-to-device part of an output profile, using the absolute colorimetric rendering intent. CMYK values are then processed back to CIELAB, using the device-to-PCS part of the same profile. The ΔE_{ab}^* between the start and finish CIELAB values is calculated. If a color is in-gamut, then the ΔE_{ab}^* between start and finish values is usually very small, based primarily on the mathematical accuracy of the forward and reverse lookup-table interpolation and Color Management Module (CMM) processing errors. If $\Delta E_{ab}^* < 1.0$ between the start and finish values, we can consider this value as the in-gamut one and the differences constitute the cumulative error of all parts of the forward and reverse processing. If a color is out-of-gamut of the device, then the CIELAB value will be clipped and constrained, and on reverse processing we will see $\Delta E_{ab}^* > 1.0$ between start and finish values. A threshold can be used to determine if the color is in or out of gamut of the destination device.

The Round Trip test uses the B2A1 and A2B1, i.e. PCS-to-device and device-to-PCS lookup tables. The Round Trip

The following ICC profiles were used in this project:

- GRACoL2006_Coated1v2 (IDEAlliance’s version from ICC profile registry – color.org)
- Coated GRACoL2006 (Adobe’s version of the above profile)
- SWOP2006_Coated3v2 (from ICC profile registry – color.org)
- SWOP2006_Coated5v2 (from ICC profile registry – color.org)
- Fogra39L_VIGC_300 (from ICC profile registry – color.org)
- Heidelberg_PM74 (custom profile for Ryerson University’s 4-color offset press)

process was conducted in MATLAB in this testing and also by color software product – BabelColor PatchTool. BabelColor provides a document that describes the Round Trip process and how it is implemented in their software (BabelColor, 2009).

2.2 Gamut Tag in ICC profiles

The structure and format of ICC profiles is specified in the ICC Specification or the corresponding ISO standard – ISO 15076. These documents describe the various profile elements that are available to software developers to use, including the Gamut Tag. The Gamut Tag has a tag name of “gamutTag” and signature of “gamt” – the signature is displayed in the profile header. The Gamut Tag is a required tag in output profiles (it is not required in input, display, abstract, color space or named color profiles). It is useful to note that in order to be a valid output class profile, the Gamut Tag must be present; however as noted earlier, the content of any ICC profile tag, including the Gamut Tag, is not described by the ICC Specification nor ISO 15076.

The Gamut Tag format and structure is a normal lookup table tag type that can be modeled on any of the existing ICC lookup table types – lut8Type, lut16Type, or lutBToAType. These are multi-dimensional structures allowing data to be encoded by some or all of the provided data types including 1-dimensional lookup tables, matrix multipliers and n-dimensional lookup tables. For a definition on the interpretation and processing mechanisms of these lookup table types, Green and Kriss (2010) have provided an excellent compilation of developer-level topics.

The Gamut Tag provides a lookup table in which PCS values are the input and a single output value for each input value is the output. If the output value is 0, the PCS color is in-gamut (Figure 1). If the output is non-zero, the PCS color is out-of-gamut. The Windows Color System (WCS) has also implemented a similar

ences in the Gamut Tag information for the same print process, this would lead to one profile predicting a color is in-gamut while another version of the profile could predict a different result.

Consider the GRACoL 2006 profile. One version of the GRACoL 2006 profile has been created by IDEAlliance and is available from the ICC Profile Registry (ICC, n.d.). This profile is called “GRACoL2006_Coated1v2.icc”. We see that in practical implementation, Adobe has provided within the Creative Suite (CS) and Creative Cloud (CC) a different ICC profile with a similar name. The Adobe’s version of the profile is called “Coated GRACoL 2006 (ISO 12647-2:2004)”. In examining the profile Gamut Tag (Figure 2), we see that the lookup table contents are different and Adobe’s version of the profile will predict that many more colors will be in-gamut.

In Section 4, we use MATLAB to understand the effect caused by the differences between the GRACoL profiles from the ICC Profile Registry vs. Adobe.

2.3 Gamut Boundary Descriptor (GBD)

When processing data using a lookup table, in general there are two conditions – a search for a point that is bounded and contained within known node points and a search for a point that is not totally bounded by known node values. If a point is within the gamut volume and is bounded by known node points then this is a simple interpolation issue and different interpolation techniques are routinely used. If the point is not bounded on all sides and contained within a known set of node points we have to consider a gamut boundary. An issue with the 3D convex hull is that the points can be connected by a straight line, concave or convex line, or a more complex version of all of these. If a concave surface is wrongly assumed, then the color gamut is under-estimated, if a convex boundary is wrongly assumed then the color gamut is over-estimated. A useful summary and accepted reference is the work of Morovič (2008).

The determination of the color gamut volume or gamut boundary can be done using an analytical/model

approach or geometric/empirical approach. In the analytical approach spectral data is used to build a model using Neugebauer, Yule-Nielson modified Neugebauer or Kubelka-Munk theoretical models and thus map device colorant instructions (RGB/CMY) to CIEXYZ or CIELAB. This type of model can produce accurate results with a relatively small number of samples, but such characterization schemes rely on the ink-media mixing and are very process dependent, so a model can be used only on a specific type of printing process and it is necessary to develop a new model for each variation of the printing process.

In most ICC applications, an empirical process is employed where many colorimetric measurements are taken from printed patches of known CMYK inking levels. A larger number of patches are needed, compared to the above analytical approach, however with faster scanning spectrophotometers this is no longer such an onerous task. An issue of this approach is that because the test targets are defined in device space (RGB/CMYK) there is no apriori knowledge of the gamut boundary values in CIELAB space, that are on, or inside, the gamut surface. A pre-determined IT8.7/4 or ECI 2002 targets are evenly spaced in ink coordinates which do not consider the natural boundary of a gamut. If the samples cannot describe the gamut surface, or if there are only few points on the gamut surface, an incorrect gamut description will result. Zhao (2007) has compared the analytical and empirical approaches and proposed a generic color gamut descriptor.

In this research, an open source software library called Little CMS (Maria, 2015) was used. Little CMS implements the Segment Maxima algorithm (Morovič and Luo, 2000). Using the Segment Maxima algorithm, the gamut boundary of an output process is described by a table containing the most extreme colors for each segment of color space. This segmentation can be carried out either in terms of L^* , C^* , and b_{ab} , or spherical coordinates, whereby spherical coordinates can be calculated from orthogonal CIELAB coordinates. In this research, the color characterization data was the input to Little CMS, from which the program created gamut information and subsequently the program was able to predict if a CIELAB value was in gamut.

3. Software tools and procedures

Different commercial software products are able to flag or stain an image to indicate out-of-gamut colors. A number of tools were used in this research that ranged from the ubiquitous Adobe Photoshop to command line, C++ libraries in Little CMS. In this section we describe each tool used and where known we indicate which technique each system uses to determine in-gamut colors.

Adobe Photoshop CS6 was used to create a gamut stain and indicate which colors were out-of-gamut. A list of CIELAB values, representing the PANTONE+ Solid Coated Library V2 were converted into a TIFF image, which was opened in Photoshop. With the Color Settings dialog set to Absolute Colorimetric, a Gamut Warning was applied to the image and the number of patches with a stain were considered to be out-of-gamut (Figure 3).

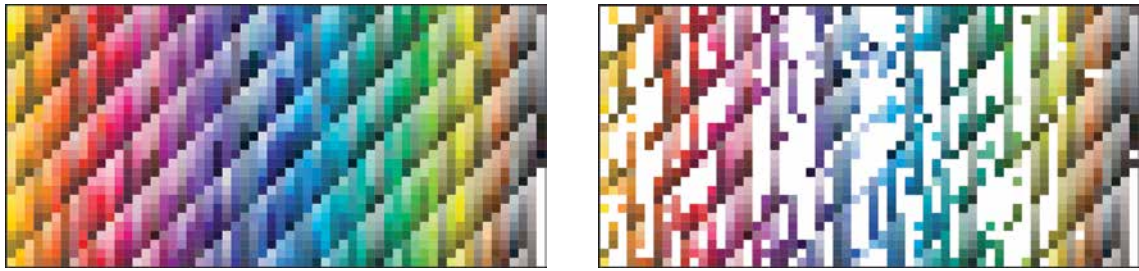


Figure 3: The PANTONE+ Solid Coated Library V2 of 1729 spot colors was converted into a $L^*a^*b^*$ TIFF image (left) and a gamut stain in Photoshop was used to indicate out-of-gamut colors for each ICC profile (right)

The number of patches were counted manually as the stain does not alter the underlying image pixel values and cannot be saved or exported for image processing.

ArgyllCMS 1.7 is a command line program that was run using the Terminal prompt of MacOS X. ArgyllCMS provides the ability to access different profiles, different lookup tables within the profile and process a list of CIELAB values indicating clipped values. ArgyllCMS does a “one way trip” from PCS to CMYK. If there is no CMYK that exactly matches the PCS, the color is out-of-gamut (Graeme, 2015).

BabelColor PatchTool 4.7 is a Windows or MacOS, GUI based software tool. PatchTool provides a number of sophisticated color analysis tools, one of which is gamut “Clip check” (Figure 4).

PatchTool uses the Round Trip method for gamut determination; BabelColor provides a document that

describes the Round Trip process and how it is implemented in their software (BabelColor, 2009).

Esko Color Engine Pilot v14 is a color management tool that is part of the Esko Automation Engine workflow product for workflow automation, targeted primarily at packaging applications. Color Engine Pilot is an example of how vendors are now providing an easy to use dialog to the user to compute in-gamut spot colors for a given print process (Figure 5).

Little CMS 2.7 is an open source color management library that can be used within C++ applications. It is an OEM type library that provides transformations, color space conversions and other color-related functionality. Little CMS is a library and requires a wrapper or program within which it can be implemented. In this research we implemented Little CMS within a Microsoft Visual Studio C++ compiler and development environment. Little CMS creates a GBD from the charac-

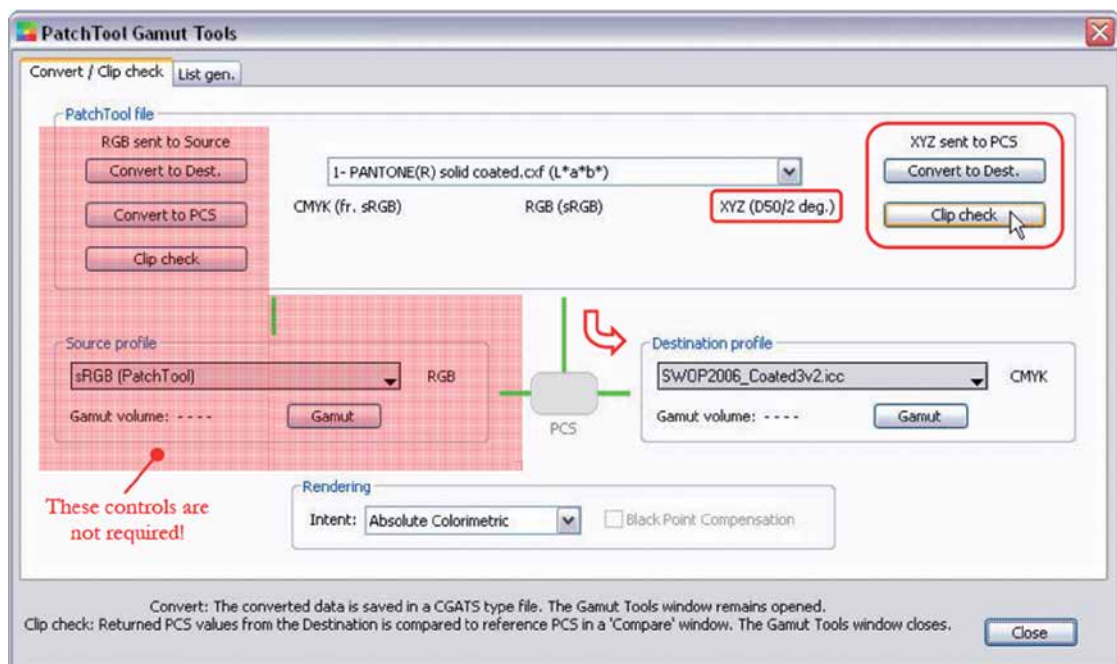


Figure 4: BabelColor PatchTool provides a built-in gamut check function

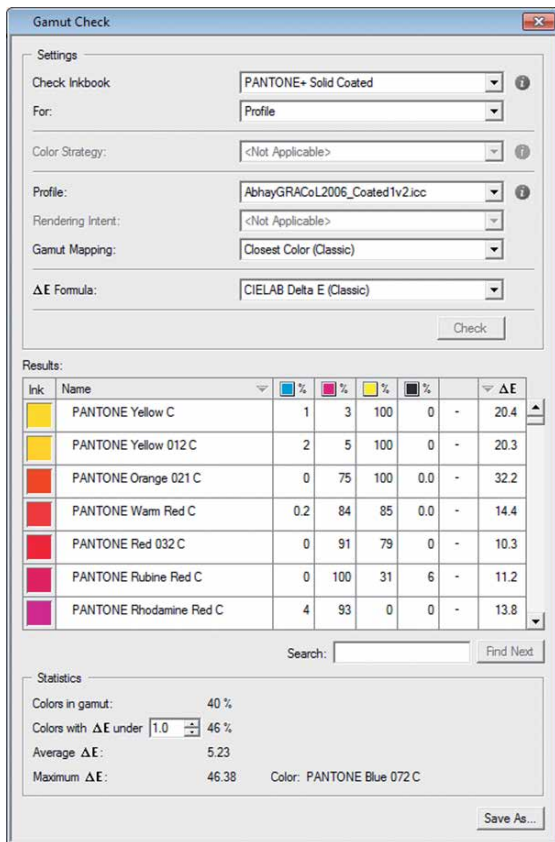


Figure 5: Esko Color Engine Pilot has a dialog that allows the user to easily see the number of colors that are in-gamut for a given print process

terization data and does not directly use an ICC profile (Maria, 2015).

MathWorks MATLAB R2015a is an established scientific software program used widely in academic environments and research for software simulation and image processing. MATLAB's Image Processing Toolbox and matrix constructs provide a user-friendly framework for working with ICC profile lookup table information. MATLAB was used in this research to conduct both

4. Experimental results

In the first test we used the list of 1729 CIELAB values, representing the PANTONE+ Solid Coated Library V2, to determine the in-gamut colors for different ICC profiles using the Round Trip test and the Gamut Tag. Useful information can be derived by a comparison of the Round Trip test (that uses the B2A1 and A2B1, PCS-to-device and device-to-PCS lookup tables) with a test that uses the Gamut Tag, both contained within the same ICC profile. In order to determine if the Gamut Tag information correlates with the information within the B2A and A2B lookup tables, MATLAB was used to compare both processes. MATLAB can be directed to

the Round Trip test and testing of the Gamut Tag information.

PANTONE do not make available lists of their libraries as CIELAB values, so PANTONE Color Manager 2.1 program was used (Figure 6). This program can export a PANTONE library in a number of formats from which it is easy to extract a CIELAB list of values. It is possible to export a color library either as a Named Color ICC profile, or CxF (XML) file or other format, from which a list of CIELAB values can be created. The library chosen for this project was the PANTONE+ Solid Coated Library V2, with 1729 spot colors. The CIELAB list was presented to the above list of programs and each program was used to determine which colors from this list were in-gamut. The CIELAB list was also converted into a TIFF image and analyzed for in-gamut information in Photoshop.



Figure 6: PANTONE Color Manager was used to extract and create a list of CIELAB values for the PANTONE + Solid Coated Library V2

process a list of CIELAB values using the B2A1 and A2B1 lookup tables or can be instructed to predict the color gamut using the Gamut Tag lookup table. MATLAB is a useful tool as both processes are available within a single application, this allows us to process B2A/A2B lookup tables or Gamut Tag lookup tables, using a single CMM. A comparison between the two processes was conducted for six different ICC profiles used in this project (Figure 7).

In the Round Trip test, each spot color value was processed from CIELAB to CMYK via each profile used

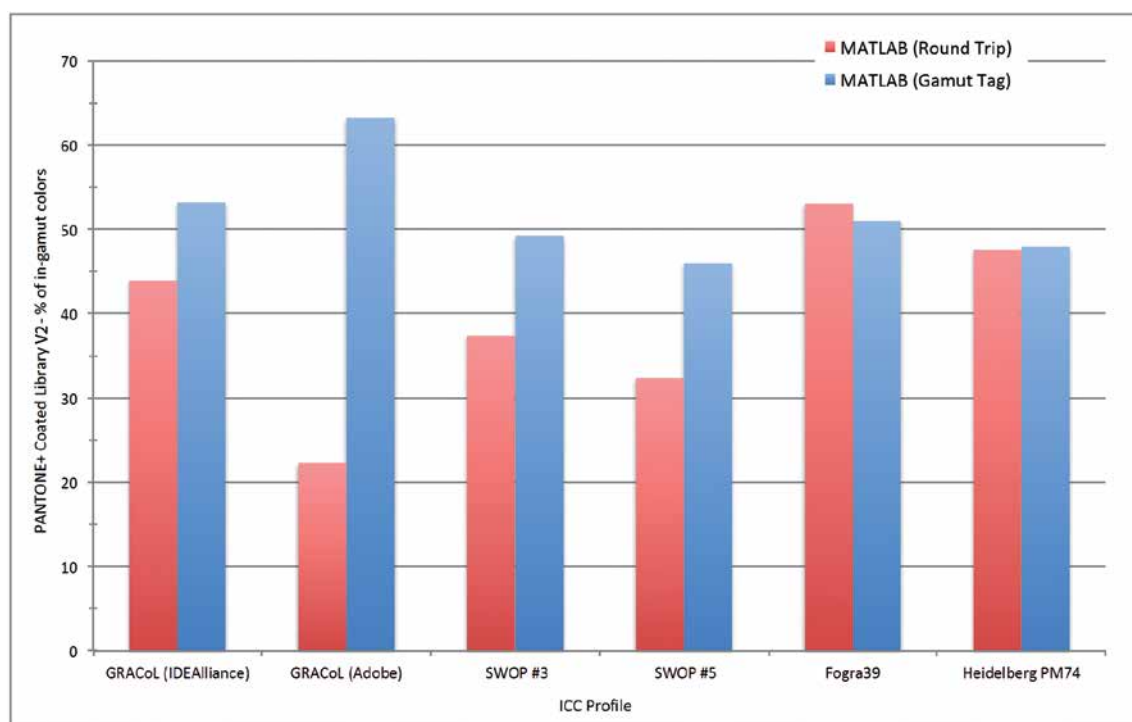


Figure 7: MATLAB computation results of in-gamut colors using the Round Trip and Gamut Tag methods

in this study, with absolute colorimetric rendering. The CMYK values were returned to CIELAB and compared to the original values. If the difference between the starting and returned value $\Delta E_{ab}^* < 1.0$, the spot color was considered as the in-gamut one.

Next, the spot color values were processed via the Gamut Tag lookup table. MATLAB extracted the Gamut Tag from an ICC profile and stored it in a lookup table structure and each CIELAB value was processed via this lookup table. The data in a Gamut Tag is 0 for an in-gamut color and non-zero for an out of gamut color. 1-D look-up tables and/or matrix elements were applied as appropriate, and in a Gamut Tag, while they are populated for reasons of conformance, they often have values with null response, such as a unity matrix.

We see that the Gamut Tag in the IDEAlliance's profile predicts 53 % of the colors are in-gamut colors while the same tag in the Adobe's profile predicts 63 % are in-gamut colors. The result is as expected and agrees with Figure 2, where it is clear that Adobe's Gamut Tag will predict more colors are in-gamut.

A general expectation is that both processes – Round Trip and Gamut Tag, should produce similar results. Use of the Gamut Tag may be more succinct and convenient during run time, but should not, in general, differ from the manual approach of processing data from CIELAB to CMYK, and back to CIELAB. From Figure 7, we see that the GRACoL (Adobe) profile has very different predictions for the in-gamut colors based on the Round Trip and Gamut Tag computations, while the Fogra39 and Heidelberg PM74 profiles have very good agreement for these two test methods.

In order to understand this data it is necessary to consider the underlying lookup tables used by these profiles. To do the Round Trip test, a look-up table transform based on the ICC profile absolute colorimetric look-up tables is created. We note that an ICC profile does not explicitly contain the absolute colorimetric look-up tables. At run time, data for the absolute colorimetric intent is generated using the relative colorimetric tables (B2A1/A2B1) via a white point scaling. We consider therefore the lookup table size, for the relative colorimetric tables (Table 1).

Table 1: Analysis of the ICC profile colorimetric lookup tables

Number of nodes	GRACoL (IDEAlliance)	GRACoL (Adobe)	SWOP #3	SWOP #5	Fogra39	Heidelberg PM74
B2A1	33	33	33	33	37	37
A2B1	17	11	17	17	25	25

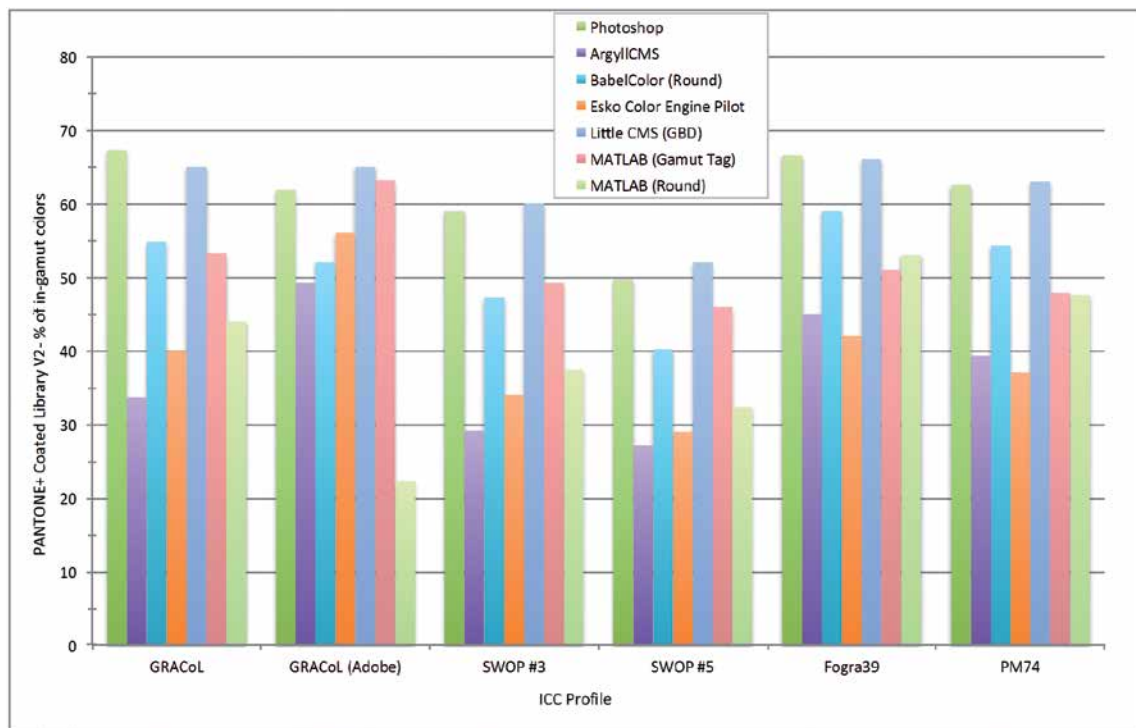


Figure 8: Different tools used to predict the number of in-gamut PANTONE colors, give very different feedback for the same ICC profile, depending on the tool used

The Adobe generated GRACoL profile shows the largest discrepancy between the two tests, where the Gamut Tag predicts 63 % of values are in-gamut and the Round Trip test predicts only 22 % are in-gamut. From Table 1, we see that this profile has only 11 cube nodes in the A2B1 table. We see that the Fogra39 and Heidelberg PM74 profiles have a large number of cube nodes in both lookup tables, 37 nodes in the B2A1 (PCS-to-device) table, and 25 nodes in the A2B1 (device-to-PCS) table. This higher number of cube nodes increases the file size of the ICC profile, i.e. more MB as disk storage, but does provide an increased accuracy for reversibility of the CIELAB data. In the Round Trip test, if the returning CIELAB value had $\Delta E_{ab}^* < 1.0$, the color was considered as in-gamut. In order to accommodate for the smaller number of cube nodes and thus reduced accuracy, a similar in-gamut prediction was obtained if the allowable tolerance, for the GRACoL Adobe profile, was set to $\Delta E_{ab}^* < 5.5$.

If the Round Trip and Gamut Tag produce similar results, then different software tools can use either process to determine and indicate in-gamut colors. However, due to the decimated lookup tables in some profiles used in this study, these procedures are not equivalent and as a result, for the same ICC profile, one predictive tool may use the Gamut Tag and suggest a color is in-gamut, while another tool may conduct a Round Trip test and suggest the same color is not in-gamut. Only for profiles with a large number of cube nodes in the

A2B and B2A tables, both processes will predict similar results, as we see for the Fogra39L and Heidelberg PM74 profiles.

In the next series of tests, the six selected output profiles were used in turn with each of the six software tools. In each case, 1729 CIELAB values representing the PANTONE+ Solid Coated Library V2 were presented to each program and the number of in-gamut colors predicted by each program was computed (Figure 8).

There are some caveats to the data presented in Figure 8. The Esko Color Engine Pilot application used its own internal version of the PANTONE+ Solid Coated Library V2 and the program reported that it was based on 1799 CIELAB values, while the list used for the other programs contained 1729 values. Another point to make is that the data for the GRACoL 2006 profile when using Little CMS is generated from the underlying characterization data file, so the result for both the IDEAlliance's and Adobe's versions of the profiles is identical and not related to the ICC profile, per se.

From Figure 8 we see that in all cases Photoshop and Little CMS are very similar, thus we may conclude that both these products are using the Gamut Boundary Descriptor method for in-gamut prediction. Generally, BabelColor and MATLAB can produce similar results using the Round Trip methodology, the difference seen in Figure 8 is due to the tolerance of BabelColor that was

not user selectable and in BabelColor $\Delta E_{ab}^* < 2.0$, while in MATLAB $\Delta E_{ab}^* < 1.0$ was used, thus BabelColor always predicts (in this test) a larger number of in-gamut colors.

5. Conclusions

In this research, we have proved that the different programs available to the end user predict widely differing estimates of the percentage of in-gamut colors for a given PANTONE library. These different gamut predictions are not desirable in printing and proofing workflows. In practice, the implications in a printing workflow of unwittingly selecting an out-of-gamut color is that it cannot be accurately reproduced, which leads to customer dissatisfaction, delays and re-working of the job.

It is an expectation that all products working in compliance with a given specification produce similar results. It is important, therefore, that a gamut metric as calculated in this work shows some consistency, irrelevant of who computes it and how it is computed. To have different results in this part of the system that predicts whether a color is in or out of gamut does not imbue confidence. The unreliability of the gamut prediction also conflicts with the general philosophy of the ICC system that is predicated on a reliable and predictable workflow. The ICC stipulates the structure of an ICC profile tag, but not its contents. This leads to the situation illustrated by the IDEAlliance's and Adobe's GRACoL profiles whereby the two profiles have differing content in the Gamut Tag and also different results on application. A Gamut Boundary Descriptor is being developed in iccMAX specification for a future ICC v5 format.

A metric is suggested whereby the percentage of in-gamut PANTONE spot colors is used as an indicator

of the gamut volume. However, the spread of the spot colors in CIELAB space is not uniform, thus this metric should be used with caution. Nevertheless, it is a metric that is understandable to the average user. In general, in this work, we see that a print process can usually reproduce between 40 and 60 % of the CIELAB values of a PANTONE+ Solid Coated Library V2.

ArgyllCMS and Esko Color Engine Pilot produce similar results and as this is true, even for the GRACoL (Adobe) profile, we can assume that these products do not use the traditional Round Trip test to determine in-gamut colors.

This research provides documentation of the behavior of the Gamut Tag, as compared to the other methods for gamut determination, thus we provide quantitative evidence to the much discussed anecdotal behavior of the Gamut Tag. Given the differences we see in different mainstream commercial products and specialist color image processing tools, it is suggested that the Gamut Tag provided within the ICC architecture be better defined and better implemented. Currently, for example, there is no documentation to describe the non-zero values in the Gamut Tag. There is no documentation to what the values are within a Gamut Tag and how they are to be used, what is the encoding and how should these values be interpreted.

With the growing use of expanded gamut proofers and workflows, and the growing demand for brighter, more vivid colors, there has been an increase in applications and software providing feedback to the user in terms of in-gamut colors. From a user standpoint, it is important that there is some consistency between these products, and we hope that the testing shown here will assist us in creating closer agreement between software predictors.

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References

- BabelColor, 2009. *Application Note #6: Evaluating an ICC profile coverage of the Pantone and IDEAlliance data sets.* [pdf] The BabelColor Company. Available at: <http://www.babelcolor.com/index_html_files/AN-6%20Evaluating%20an%20ICC%20profile%20coverage%20of%20the%20Pantone%20and%20IDEAlliance%20data%20sets.pdf> [Accessed 12 January 2016].
- Deshpande, K., Green, P. and Pointer, M.R., 2014. Metrics for comparing and analyzing two colour gamuts. *Color Research and Application*, 40(5), pp. 465–471.
- Graeme, G., 2015. *Discussion.* (Personal communication, 6 June 2015).

- Green, P. and Kriss, M., eds., 2010. *Color Management: Understanding and Using ICC Profiles*. New York: John Wiley & Sons.
- HP, n.d. *HP Designjet Z3100 Photo Printer series*. [pdf] HP. Available at: <http://www.argebaltic.lt/media/catalog/brochures/HP_Z3100.pdf> [Accessed 7 June 2015].
- Microsoft, n.d. *CheckColors function*, [online] Available at: <<https://msdn.microsoft.com/en-us/library/windows/desktop/dd371823%28v=vs.85%29.aspx>> [Accessed 3 June 2015].
- ICC, n.d. *ICC Profile Registry*. [online] Available at: <<http://www.color.org/registry>> [Accessed 3 June 2015].
- ICC, 2004. *Specification ICC.1:2004-10 (Profile version 4.2.0.0): Image technology colour management — Architecture, profile format, and data structure*. [pdf] International Color Consortium. Available at: <<http://www.color.org/icc1v42.pdf>> [Accessed 3 June 2015].
- International Organization for Standardization, 2005. *ISO 15076-1:2005 Image technology colour management — Architecture, profile format, and data structure — Part 1: Based on ICC.1:2004-10*. Geneva: ISO.
- Maria, M., 2015. *Little CMS – How to use the engine in your applications, v2.7*. [pdf] Little CMS. Available at: <<http://www.littlecms.com/LittleCMS2.7%20tutorial.pdf>> [Accessed 21 January 2016].
- Morovič, J., 2008, *Color Gamut Mapping*. New York: John Wiley & Sons.
- Morovič, J. and Luo M.R., 2000. Calculating medium and image gamut boundaries for gamut mapping. *Color Research and Application*, 25(6), pp. 394–401.
- Perales, E., Martínez-Verdú, F.M., Viqueira, V., Fernández-Reche, J., Díaz, J.A. and Uroz, J., 2009. Comparison of color gamuts among several types of paper with the same printing technology. *Color Research and Application*, 34(4), pp. 330–336.
- Sharma, A., 2006. Methodology for evaluating the quality of ICC profiles – scanner, monitor, and printer. *Journal of Imaging Science and Technology*, 50(5), pp. 469–480.
- Sharma, A., 2009. *IPA Digital Print Forum 2009 – Procedures & Protocols v2*. [pdf] IDEAlliance. Available at: <idealliance.org/files/Digital-Print-2009-version-2.pdf> [Accessed 21 January 2016].
- Sharma, A., and Rong, X., 2014. Establishing standards for color and print quality in large format inkjet printing. *Journal of Imaging Science and Technology*, 58(3) pp. 030504–035041.
- Zhao, X., 2007. Generic device color gamut description. *Color Research and Application*, 32(5), pp. 394–408.

