Cross Platforms Display Calibration and Profiling (MacOs and Windows)

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Abstract

The monitor is an important part in many digital applications, including graphic design, digital photography and prepress proofing. In fact, designers and prepress personnel rely on their monitor for good color decision for a printed job.

The aim of this research is to achieve a consistent color across platform using the same hardware (CPU, monitor, video controller, etc.) In addition, it is to describe the main issue that affects the accuracy of monitor profiles. ICC profiles were generated for a monitor in Windows and MacOS platforms, using GretagMacbeth ProfileMaker Pro version 5.0 and X-Rite MonacoPROFILER 4.8 ICC profiling software. In the laboratory environment, we used a GretagMacbeth Eye-One to calibrate the LCD monitor. An open source library program was then customized and used to read some required and optional tags from all tested monitors profiles. After evaluating the profiles we then used the customized programming code to rebuild a new LUT-based-profile that contains averaged data of the tested tags and applied the profiles in Windows and Mac platforms. The quality of the new customized profile was then tested and evaluated. The results show that there are many factors that affect the quality of monitor profiles, such as the correct calculation of characterized data in LUT tables, accurate loading of the video card gamma tag into video card and show the different between the matrix-based and LUT-based profiles.

Introduction

The International Color Consortium (ICC) was formed to define the standards for color device characterization. The ICC standards defined "Profiles" that can be used across computing platforms to characterize imaging devices [1,2]. The color transformation between devices is then performed by the color matching module or color matching method (CMM), by combining different device profiles. [3-5]

The basic structure of ICC Profiles consists of: file header, tag tables and tagged element data. The header file contains necessary information about the device type [4,5]. The actual profile data are stored in the tagged element, where they're pointed from the tag tables. Generally, the information inside ICC profiles depends on the device type. [5]

There are three types of profile tags: required, optional and private tags. Monitor profiles for LCD or CRT have the same set of the required tags as per the ICC specification [4]

Media White Point (wtpt), XYZ colorant, Tone Reproduction curve and A2B0 tags are some of the required tags that are part of monitor profiles and they affect the monitor gamma value and therefore the gamma of the image display. Moreover, the video card gamma tag is a special tag that has been part of the Mac OS since ColorSync 2.5. This tag contains gamma correction data that are used to correct the CLUT (Color lookup Table) of the video card. The content of the vcgt tag may be treated differently across platforms.

Generally, ICC Profiles use two ways to generate their characterization data and therefore, there are two models of profile based on that: Matrix-based profiles using on 3x3-matrix and Tone Reproduction Curves (TRC), and Table (LUT) -based profiles [5,6].

ProfileMaker and MonacoPROFILER are two examples of profiling software that are used to create and edit ICC profiles for all devices. The main aim of these programs is to create accurate profiles that represent the best device characterization.

Overall, the digital color display depends on the monitor, the correlation of a computer and the platform it's on and the type of video card available. The Video card contains a color look up table (CLUT) that holds the color values of each pixel of the monitor. By altering these pixels values that are stored in the table, the image color can change indirectly. [5] Different platforms use different methods for storing the adjusted CLUT values that correspond to a new monitor profile.

In Addition, the accuracy of monitor profiles depends on many factors. For example, a monitor profile contains an accurate characterization of monitor output and new CLUT adjustments. These adjustments are stored in the 'vcgt' tag of the profile. In MacOS the vcgt tag instantly downloads its content to the CLUT, altering the display when a profile is selected. However, in other platforms loader programs, which are placed in the startup directory, are used to set the CLUT at booting time. Problems can occur in case the monitor profile is adjusted after booting, in which case the profile and the CLUT do not correspond to one other.

Moreover, the precision of color conversion between device colorspace to PCS reflects the accuracy of profiles. There are two models that can be used for this conversion, Matrix-TRC models (linear transformations) and CLUT-models (nonlinear transformations). Due to the different structure between CRT and LCD monitors, matrix- TRC profiles models are accurately used in CRTs, while the CLUT-models are more often used in LCDs [7].

To increase the understanding of ICC profile performance, an open source program, ICC Profile I/O library (Icclib), was used. This program was designed by Graeme Gill and it consists of a set of C programming language API's that supports the ICC profile format. This library supports reading/writing from ICC profiles, creating accurate profiles for all devices and many more feature. It's also part of Argyll CMS (color Management System). [8]

The goal of this research is to achieve consistent gamma mapping across platforms. This could be done by using the average values calculated for some profile tags, as target values for new customized profiles, to limit the data deviation that occurs in profile tags due to different use of profiling software or platforms.

An open source library program (icclib) was used to disassemble the ICC profile to be able to read and write profile tags into and from profiles. Next, we test the quality of the customized profiles.

Experimental

An Apple iMac machine was used to assist this research with the following specifications:

- Processor: Dual-Core Intel Xeon
- Monitor: 20" Apple widescreen LCD Display
- Video card: ATI Radeon X1600
- Three operating systems (Mac OSX 10.4.x, Windows XP SP2 and Gentoo Linux) were loaded in the iMac machine for triple booting.

A set of monitor profiles was created in Mac and Windows operating systems, using GretagMacbeth ProfileMaker Pro 5.0.7 and X-Rite MonacoPROFILER 4.8 software with the assistance of an Eye-One Pro spectrophotometer as a measuring instrument. Each profile has different settings (white point and gamma) depending on the profiling software. The same set of profiles was used in Windows and Mac. The brightness and contrast of the monitor were not changed and were set to the highest values for both platforms. All profiles that were built in ProfileMaker were LUT-based profiles and all the profiles that were built in MonacoPROFILER were Matrix-TRC- based profiles. The profiles were then selected as the system monitor profile for each platform.

Using the open source library icclib [8], a C++ code was designed and customized (using Microsoft Visual Studio 2005 and VC++ version 8) to read some of the required monitor tags from all the tested profiles and store the values in a text file. The selected tags were rXYZ, bXYZ, gXYZ, rTRC, gTRC, bTRC and wtpt tags plus the optional vcgt tag. The reason these tags were selected is because they all affect the display gamma.

Reading Tags

There are some basic functions to open and read tags from a profile using icclib. First we need to open the profile using new_icmFileStd_name(), then create an ICC object using new_icc(), where all tags in the file will be translated to it and access the tags from it, without worrying about the file format details. Next we need to read the header file tags and save them in the ICC object-using read().

When we want to read tags from the profile we need to find the tag by its signature using find_tag(), then we will be able to read its contents using read_tag().

Building Customized Profiles

Profiles with D50 white point and gamma equal to 1.8 were chosen for more detailed investigation. The reason for choosing this white point is because Photoshop does all its Lab calculations based on a D50 reference white point.

The average values of the white point tags were calculated from all profiles that were created using MonacoPROFILER across platform and used to build new customized profiles that represent MonacoPROFILER software. A similar procedure was done for all profiles created using ProfileMaker software. Furthermore, the same process was done for XYZ colorant, TRC and vcgt tags. A previously built LUT-base profile created by ProfileMaker under the Mac platform was used to update its tags with the new values. The result was building of two customized profiles (Monaco-D50 and PMaker-D50) that represent the two profiling software packages (i.e. MonacoPROFILER and ProfileMaker).

A C++ code was designed and customized with the assistance of icclib library to disassemble the LUT-based profile and write the new updated values of the customized tags.

The basic steps of updating tags with new data are similar to those for reading them. Except that after reading the profile header we need to use the read_all_tags() function, which will read all tags from the tested profile and store in the ICC object.

To update the tags with new data, the tags need to be found by signature using find_tag(). Then the old tags will be deleted from tag list via the delete_tag() function. Next a new tags will be added using the add_tag() function.

The tested ICC profile will then be opened using the same function new_icmFileStd_name(), but in writing mode. All updated tags were stored in the ICC object that was created before starting deleting or adding any tags. All the updated values of all the tags will now be translated to the ICC profile by using the write() function.

Profile Quality Tests

To test profiles performance across platform, three separate series patches were selected to create three separate RGB scale ramps by Adobe Photoshop CS2 and then displayed to be measured. For the red color, for instance, the patches values were (0,0,0) (15,0,0)...(255,0,0). Similarly the same sets of values were used for green and blue color patches

In the Windows platform, after selecting the monitor profile, the computer needs to be restarted. Restarting the computer will allow the Adobe Gamma Loader (a CLUT loader program), to load the vcgt content to the video card to assure that the set profile and the system CLUT correspond. The Mac platform differs from Windows in dealing with the vcgt content. When selecting a monitor profile via the ColorSync utility, the content of the vcgt loads directly to the video card and alters the system display without the need of restarting the computer. The tested monitor profile was then set and assigned in Photoshop.

Results and Discussion

Reading Tags

The values of the media white point tags and the XYZ colorant tags were close to one another across all the investigated profiles. For TRC data tags, the values of all investigated profiles created by MonacoPROFILER software were close in contrast with profiles created by ProfileMaker as demonstrated in **Table 1**.

TABLE 1: TRC data (gamma values) for ProfileMaker profiles across platform.

	Windows		Mac	
	Profile Size			
	Large	Default	Large	Default
rTRC	1.79	1.79	1.53	1.60
gTRC	1.79	1.79	2.29	2.29
bTRC	1.79	1.80	2.31	2.31

The green and blue gammas for D50 profiles created in the Mac platform are higher than in the Windows platform. Furthermore, they are also higher than the target gamma (gamma equal to 1.8) by ProfileMaker software when they were created. In contrast, the corresponding profiles built in the Windows platform and the RGB gammas are almost identical to the target gamma.

On the other hand, the red gammas of the D50 profiles built on the Mac have the opposite behavior, in a way that the resulting values are less than the target gamma.

Reading Video Card Gamma Tag

All the investigated profiles represent the vcgt tag as a table with 3 channels. Each channel has 256 entries and the entry sizes were 16-bit, with the exception of the profiles built with ProfileMaker on the Mac. The contents of these channels could be thought of as the contrast corrections of the CLUT of the video card. Following are evaluations of all the tested profiles based on their vcgt tags for both profiling software packages across platform.

X-Rite MonacoPROFILER 4.8

Some of the vcgt contents inside the native white point profile that was created by MonacoPROFILER under the Windows platform are shown in **Table 2** (The values were divided by 256 for easiest comparison). These point out the differences between the vcgt channels generated for ICC version 2 and version 4 profiles in Windows.

TABLE 2: some of vcgt data content of the native white point profile created by MonacoPROFILER under Windows showing the differences produced for ICC version 2 and ICC version 4 profiles.

	vcgt Channels / 256					
	ICC version 4			ICC Version 2		
Ent	**Ch1**	**Ch2**	**Ch3**	**Ch1**	**Ch2**	**Ch3**
1	0	0	0	0	0	0
2	3	3	3	1	1	1
4	7	7	7	3	3	3
91	108	107	111	90	89	92
92	109	108	112	91	90	93
93	110	109	113	91	91	94

Despite that the same specifications of the native white point profile were assigned when created by MonacoPROFILER across platform, there are significant differences between the vcgt contents of that profile under the Windows platform between ICC version 4 and ICC version 2, as **Table 2** indicates. Overall, for all other investigated profiles across platform, they have not identical, but close to identical vcgt contents.

GretagMacbeth ProfileMaker Pro. 5.0.7

Although the content of the vcgt tags were almost the same for all the investigated profiles across platform, the only difference was that all the vcgt tag entry size for profiles that were built under the Mac platform were of 8-bit size. Some of the contents are exposed in **Table 3**.

TABLE 3: some of vcgt data content of native white point profile created by ProfileMaker under Mac platform.

	Profile size					
	Large			Default		
Ent	**Ch1**	**Ch2**	**Ch3**	**Ch1**	**Ch2**	**Ch3**
1	0	0	0	0	0	0
2	3	3	3	3	3	3
4	8	8	7	8	8	7
254	253	236	203	253	236	204
255	254	237	204	254	237	205
256	255	238	205	254	238	205

Profile Quality Tests

Color Chromaticity Quality Test

GretagMacbeth MeasureTool was used with the assistance of the Eye-one Pro spectrophotometer to measure the XYZ values of the RGB scales patches. After being normalized to Y=100 at the white point, the XYZ measurements were evaluated and compared for the two customized profiles to test the quality of the measurement instrument along with the monitor display.

Table 4 represents comparisons of results of tristimulus values for some of the Red ramp patches (Red values = 225, 240 and 255) that were displayed in Adobe Photoshop and assigned to the investigated profiles.

TABLE 4: Tristimulus measurements for some of the red color patches in the red ramp.

Monaco-D50					
Windows			Mac		
X	**Y**	**Z**	**X**	**Y**	**Z**
40.83	21.72	1.37	40.42	21.51	1.27
45.79	24.33	1.44	45.14	23.93	1.45
50.03	26.48	1.50	50.27	26.59	1.45
PMaker- D50					
X	**Y**	**Z**	**X**	**Y**	**Z**
40.81	21.77	1.36	41.15	21.99	1.39
45.61	24.24	1.43	46.00	24.45	1.58
50.36	26.64	1.43	50.79	26.91	1.51

The overall comparison shows the tristimulus values were approximately the same among all profiles. Similar were the results for both green and blue chromaticity values. This indicates that the measurement instrument and monitor display were accurate and stable enough to provide these close values.

Color Transformation (RGB to LAB) Quality Test

The measured XYZ for all tested RGB scale and RGB primary patches along with the white color patch were converted to LAB for the chosen illuminate, D50, after being normalized to Y=100 at the white point. Other LAB values for the patches were measured and normalized from the info pallet in Adobe Photoshop CS2. To test the performance of color transforming from RGB to LAB, a ΔE was generated between the calculated LAB and the measured LAB from Photoshop info pallet.

Three profiles were used for this test, the two customized profiles representing profiling software and a MonacoPROFILER profile that was build across platform as an original profile.

Figure 1 demonstrates the average ΔE values for calculated and Photoshop displayed info platted L*a*b* values for each RGB ramp**.**

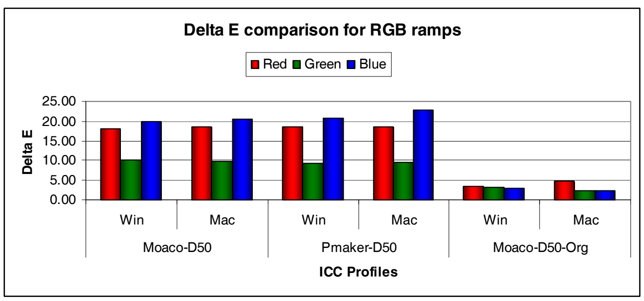


***FIGURE 1** Average ΔE comparisons for each RGB ramps for different ICC profiles.*

Figure 1 demonstrates the significant differences between the average ΔE values for the customized profiles (average of ΔE greater than 10) and the original one (average of ΔE less than 5). It is shows that the green ramps have the lowest average of ΔE values relative to red and blue ramps for the customized profiles.

These high ΔE values indicate that inaccurate color transformations occurred between Device and PCS (LAB color space). For LUT-based profiles, the color transformation is influenced by the precise information stored in the A2B0 tag. The A2B0 tag contains a 3D CLUT (or multidimensional lookup tables) with information that is interpreted by the CMM to transform color information between native device color spaces.

Another possible explanation for the higher values of ΔE could be the inconsistency of loading of the vcgt tags into the video card.

In this research, the only working profile that could be used by the open source C++ code to update its tag contents was the LUT-based profile that was created by ProfileMaker under the Mac platform, due an error that occurred when using the other investigated profiles. For accurately checking its A2B0 tag, a red color patch was created and displayed in Photoshop after assigning the investigated profile to it under the Mac platform. LAB values of the patch were measured from the Photoshop info pallet. Another set of LAB values were measured using the DigitalColor Meter from Mac utility. By using the MeasureTools software the Tristimulus value of the red patch was measure and used to calculate its equivalent LAB values. To study the quality of the color transformation, two sets of ΔE value were generated one between the Photoshop palette and DigitalColor Meter LAB values and second between Photoshop palette and calculated LAB from Tristimulus values. The same test was repeated using three different D50 ProfileMaker profiles one LUT-base profile built under the Mac platform with a default size profile, another LUT-based profile built under Windows platform with a large profile size and finally a Matrix-base profile that was also built under Mac. The compared LAB and ΔE values for all tested profiles are demonstrated in **Table 5** and **Table 6**.

TABLE 5: L*a*b* values for Red patch for ProfileMaker profiles

	Photoshop			DigitalColor Meter		
Tested Profiles	**L**	**A**	**B**	**L**	**A**	**B**
LUT-Based (Mac) –Large	47	103	81	47	103	81
LUT-Based (Mac) –Def	48	103	83	48	102	83
LUT-Based (Win) -Large	59	81	78	59	81	77
Matrix-Based (Mac)	58	81	78	59	81	77
	Tristimulus measurements					
	X	**Y**	**Z**	**L**	**A**	**B**
LUT-Based (Mac) –Large	89	47	2	59	81	78
LUT-Based (Mac) –Def	90	48	2	59	82	79
LUT-Based (Win) -Large	89	47	2	59	81	79
Matrix-Based (Mac)	89	47	2	59	81	78

TABLE 6: ΔE values for Red patch for ProfileMaker profiles

Tested Profiles	Photoshop vs. DigitalColor Meter	Photoshop vs. Calculated
LUT-Based (Mac) –Large	0.0	25.1
LUT-Based (Mac) –Def	1.0	24.7
LUT-Based (Win) -Large	1.0	0.7
Matrix-Based (Mac)	1.4	0.5

The closest ΔE values as shown in **Table 6** between Photoshop palette and DigitalColor Meter indicates that both programs read the LAB values in the same way (as shown in **Table5**).

Furthermore, the above tables demonstrate that the A2B0 tag for the LUT-based profile that was created under the Mac platform has inconsistent values in terms of high (a*) value and ΔE values (between the Photoshop palette and calculated LAB values from Tristimulus values) of the red patch in comparison with the same values in profiles created under the Windows platform and to the Matrix-base profile created under the Mac. The inconsistency with the red primary will also affect the consistency of the target white point. In conclusion, Profiles created by ProfileMaker software under Mac platform have inconsistence CLUT information stored in A2B tags.

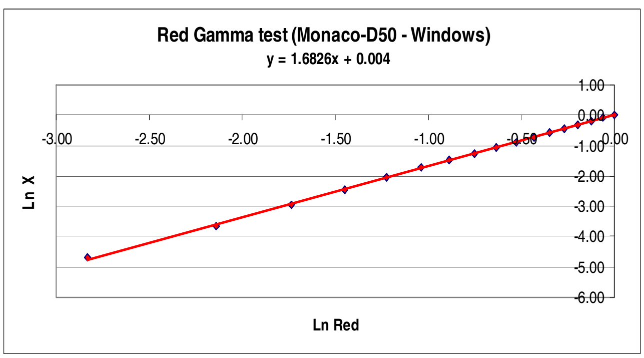
Color Gamma Quality Test

The display gamma value reflects its contrast, which has a significant influence on the image-displayed color. Using the measured XYZ values for each RGB scale, three graphs were created by plotting the log-normalized values of each RGB patch against its corresponding measured XYZ values. The slope of the graphs that represent the actual displayed gamma for RGB primaries were calculated and evaluated [5]. This comparison shows how close the monitor gamma curves are to the target gamma values that are stored in the TRC data tags. In addition, the same gamma test was applied to non-customized monitor profiles that were created by MonacoPROFILER in both platforms for comparisons. All compared results are demonstrated in **Table 7**.

TRC tags can be defined by a set of points where the first point represent no colorant or phosphor (black) and the last point represent 100 present colorant or phosphor. Or it can be defined by a single gamma value the represent the slop of the TRC curve. In this research, the TRC tags were represented by a single gamma value.

Figure 2 is an example of fit gamma curve to the red color using the customized Monaco-D50 profile under the Windows platform. The axes of the curve are the log normalized Red values against the log normalize the corresponded X values.

FIGURE 2 gamma curve (fit) for customized Monaco-D50 profile under



the Windows platform

It is possible to have different gamma values for different colors as shown in **Table 7** in the target values for PMaker-D50. The target values are the average estimated results for TRC data tags from each set of profiling software packages. It is essential that the monitor use the target gamma and display it accurately.

TABLE 7: gamma values results from gamma (fit)

	Monaco-D50			PMaker-D50			Monaco-D50 ORG	
	Target	Win	Mac	Target	Win	Mac	Win	Mac
R	1.79	1.68	1.63	1.68	1.66	1.59	1.70	1.66
G	1.79	1.61	1.66	2.04	1.62	1.69	1.62	1.71
B	1.79	1.61	1.65	2.05	1.64	1.69	1.67	1.67

A monitor that used customized PMaker-D50 profile to display the Red scale under Windows platform has the closest gamma values compared to the target gammas for the Red channel as shown in **Table 7**. Overall, the result gamma values for RGB scales using the two investigated profiles across platform are generally close, which indicates that the content of the vcgt tag was loaded and used accurately in displaying a color image.

In addition, the same gamma test was applied to non-customized monitor profiles that were created by MonacoPROFILER in both platforms for comparisons. The above values clearly show that both customized profiles have a similar behavior to the original profile in terms of closely displayed gamma values for RGB scales. Therefore, this indicates that a close gamma values could be achieved across platform, if the video CLUT has been adjusted to the same values of vcgt tag.

Table 7 shows also how different are the measured gamma (results from fitted gamma curves for each RGB scale) from the target values, as they are generally less than the target values, which indicates that LUT-based profiles didn't use the adjusted gamma values that were stored in TRC tags. In addition, it was previously shown that the A2B0 tag has inconsistent values. Thus, not only the color transformations are negatively influenced by this inconsistency, but also the displayed gamma.

Due to the different response between CRT and LCD monitors[9] for gamma curves, an LCD needs to use more patches when calibrated or use 8-bit or 16-bit LUT tables to achieve a gamma response behavior similar to a CRT. The linear gamma response for CRT makes the matrix-based profiles more accurate to use [7]. Further investigations need to be done to study the accuracy of both matrix and LUT base profiles on LCD monitors across platform.

Areas for Future Research

ICCLIB Library Bug

Icclib open source was used to disassemble ICC profiles and therefore read their contents. Future work needs to be done in solving the bugs of reading all the tags and recognizing the data types for all profiling software in such a way to be able to write or update the contents.

Profiling Software Errors

This research has shown that both MonacoPROFILER and ProfileMaker have different unexplained behavior across platform. For instance, there are different vcgt entry values between profiles saved under different ICC versions, if using MonacoPROFILER under the Windows Platform. Moreover, In ProfileMaker, we found that all profiles built on the Mac platform have different vcgt entries sizes than the corresponding ones built on the PC platform.

New Customized Profiles

For more future tests, new customized profiles will be built with the assistance of the open source library (icclib) program, instead of building profiles via profiling software.

Gamma and Color Transformation

Matrix-base and LUT-based profiles use different models to transform color information between device and PCS and to generate device gammas. In display devices, LCD monitors mostly used LUT-based profiles to generate the same gamma response behavior as CRTs. Future research needs to investigate the accuracy of using matrix-based profiles in LCDs monitors and what influence factors could affect that accuracy.

Furthermore, the A2B0 tag that contains a CLUT table need to be studied in detail to understand its structure and influence on the accurate color transformation between device to PCS and generating display gamma.

Conclusions

- It is possible to have different gamma value sets for each color in TRC tags. However, in MonacoPROFILER profiles, all of the gamma values stored in the TRC are equal, in contrast with ProfileMaker profiles
- For only native white point profiles created by MonacoPROFILER under Mac platform, there is a difference in the vcgt contents between profile saved under ICC version 2 and ICC version 4.
- All profiles created by ProfileMaker under the Mac platform among different white point references, the entry sizes for all channels in the vcgt tag have 8-bit size, while the corresponding profiles created by the same profiling software, but under the Windows platform have 16-bit size.
- The closeness of XYZ values for all RGB scale patches that were measured by MeasureTool software with the assistance of the Eye-One spectrophotometer indicates that both instrument and display device is reading color chromaticity correctly.
- The chromaticity of the Red color should be always the same, as it used to calculate the D50 reference white point.
- High ΔE values calculated for L*a*b* values between the Photoshop info palette (and the DigitalColor Meter on the Mac) and calculated values from measured XYZ for each of RGB scales indicates that an inconsistency occurred in color transformation information that is used by the CMM to transform color between the display device and PCS. This information is stored as a CLUT in the A2B0 tag.
- The ΔE between original matrix-based profiles (profiles built using MonacoPROFILER) and the customized profile (LUT-based) is larger than 18, which means that the customized LUT-based profiles didn't use the adjusted TRC gamma to calculate the matrix.
- The A2B0 tag in the LUT-based profile created by ProfileMaker software under Mac platform contains inconsistent CLUT values, which affect the displayed RGB scales.
- The fits (gamma curves) resulting from the gamma quality test for the customized profiles have gamma values that are less than the target gamma that is stored in the TRC tags.
- Matrix-based profiles use the TRC gamma to calculate the matrix that is used in color transformations.
- LUT-Base profiles do not use the TRC gamma to calculate the matrix; instead they use an 8-bit or 16-bit CLUT for color transformation.
- The quality of the A2B0 CLUT contents has a significant influence on the display gamma.

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