Comparing different ACES Input Device Transforms (IDTs) for the RED Scarlet-X Camera

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Abstract

The RED film cameras are important for professional film productions. Therefore, the Academy of Motion Picture Arts and Science (AMPAS) included among others a couple of RED color space conversions into their new Input Device Transforms (IDTs) in ACES 1.0.3. These transforms are intended to establish a linear relationship of the recorded pixel color to the original light of the scene. To achieve this goal the IDTs are applied to the different RED color spaces, which are provided by the camera manufacturer. This results in a linearization of recorded image colors.

Following this concept the conversion should render comparable results for each color space with an acceptable deviation from the original light of the scene. In color science color space conversions need a documentation of the three main components of the individual color spaces: primaries, whitepoint and transfer function. For the RED colorspaces in question these parameters are only available for the REDWideGamutRGB color space, whereas the other color spaces are not documented. For this reason the behavior of the color conversion can only be tested, but not calculated.

The goal of this paper is to compare the results of the color conversions of the main RED color spaces: REDWideGamutRGB, REDcolor4 and REDdragoncolor2. Additionally a conversion to the for television usage important color space REC2020 (ITU-R BT.2020) is added. The test setup contains a GretagMacbeth ColorChecker, which is recorded by a RED Scarlet-X camera and a mobile spectrometer (rgb photonics Qmini). The latter captures the spectral distribution of the individual ColorChecker patches under the same lighting conditions. To compare the results, the recordings of both devices were converted to the CIE xy-chromaticity diagram using The Foundry Nuke11X. Additionally a comparison to reference data provided by the ACES document TB-2014-004 is included. Finally it is reviewed if the ACES IDT concept is working for the RED Scarlet-X camera.

1. The Input Device Transform (IDT) in an AMPAS-ACES Workflow

Shortly after the beginning of the new century the *Academy of Motion Picture Arts and Sciences (AMPAS)* started development of its own color system, the *Academy Color Encoding System (ACES)*, with the main goal to unify and simplify the process of interchanging and archiving digital motion picture images. Currently version 1.0.3 is in use and contains dozens of color conversion tools mostly to and from their own ACES color spaces. One important part of the ACES system is the Input Device Transform (IDT).

In the first step of the ACES system the IDT converts an image from a certain source, mainly a film camera but also Computer Graphic (CG) renderings to a unified color space. To ensure that all converted images are looking the same, all transfer functions (gamma, log) and all picture renderings applied by the manufactures have to be removed. After applying the IDT to all input images, they can be combined without additional color correction – a main goal in modern compositing

For this reason the built-in functionality of an IDT has to ensure that the resulted image maintains a linear relationship to the light of the scene. To maintain a fixed relationship between scene colors and encoded RGB values ACES created a *Reference Input Capture Device (RICD*) which can distinguish and record all visible colors and an extraordinary luminance range way beyond "contemporary or anticipated physical cameras" [1]. It makes sure by applying an Input Device Transform (IDT) that the camera recording a physical scene and a virtual CG camera rendering a virtual scene are converting the resulting image data into the ACES RGB color space correctly. That's why an IDT is not a simple color space conversion device and an accurate color representation is an important task.

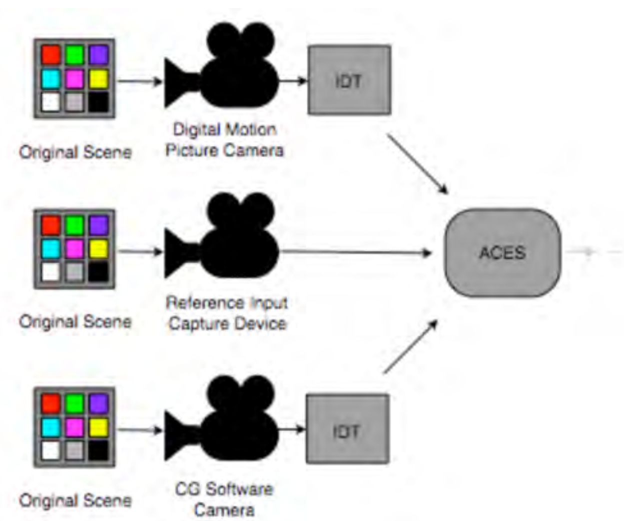

Figure 1. *The ACES Input Device Transform section with the Reference Input Capture Device*

2. RED Color Spaces

In the history of RED cameras (see *figure 2*) a couple of colorspaces have been provided to encode the *.r3d* files. Each color space is part of the metadata and set up during recording. It can be changed losslessly during the postproduction process.
The current color spaces are as indicted in The Foundry Nuke11[2]:

- DRAGONcolor2
- REDcolor4
- REDWideGamutRGB
- Rec2020

In the legacy setting of the REDCINE-X PRO 50 application some legacy color spaces are available:

- RedColor
- RedColor2
- RedColor3
- DRAGONcolor1
- RedSpace
- CameraRGB

Additionally the following standard color spaces are accessible as well:

- sRGB
- REC 709 and
- Adobe1998

Figure 2. *RED Scarlet-MX camera [3]*

In the IPP2 color system version of REDCINE-X PRO software package (version 50 used in this test) [4] only the *REDWideGamutRGB* color space and the transfer function *Log3G10* are available. Beside the well-documented standard color spaces like Rec 2020, only the parameters of the *RedWideGamutRGB* colorspace are published [5]. All three primaries of this color space are outside the visible spectrum and for this they cannot be displayed on physical display, which makes this colorspace a theoretical space just like ACES2065-1 (see *figure 3).*

	x	y
Red	0.780308	0.304253
Green	0.121595	1.493994
Blue	0.095612	-0.084589
White Point (D65)	0.3127	0.3290

Table 1. *Chromaticity coordinates of REDWideGamutRGB color space in CIE xy-chromaticity diagram [5]*

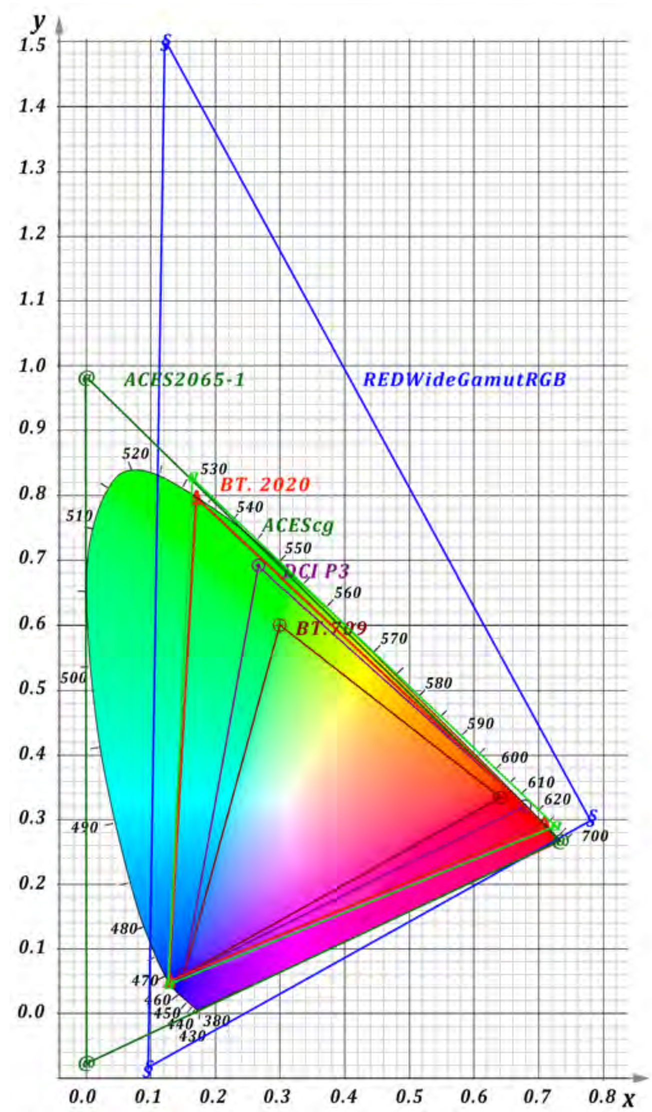

Figure 3. *RED Wide Gamut RGB color space in comparison to other film/video color spaces*

The main problem with the other proprietary RED color spaces is the absence of documentations. Mostly the missing primary chromaticity coordinates made it difficult to compare conversion methods. We researched the problem in paper [6].

3. Test setup and methodology

The test setup follows a practical approach to mimick the situations on a film set with a film camera and a mobile spectrometer. Both devices were capturing the *GretagMacbeth ColorChecker* [7] (see f*igure 4*) under the same lighting conditions. All color conversions were taking place inside *The Foundry NukeX v.11.2[8]* which is the central software in modern film pipelines *[9]*. The image processing for the RED footage were done using the built-in *OpenColor IO [10]* system to gain access to the current ACES version 1.0.3, which provided the necessary IDTs.

***Figure 4**. GretagMacbeth ColorChecker (pocket version) and identifiers used in the test*

The test took place at the campus of the University of Applied Sciences in Brandenburg in early December 2017 at noon. Four different color spaces were compared and provided in Nuke's *Read* node reading in the RED RAW footage (.r3d).

- DRAGONcolor2
- REDcolor4
- REDWideGamutRGB
- Rec2020

We applied no further color correction or white balancing but used only ACES IDTs.

The spectral data were recorded using a mobile spectrometer, the *rgbphotonics Qmini* (see *figure 5*). It consists of the device itself with an USB connection to a laptop and an optical fiber cable as the input. While ensuring to maintain the same lighting conditions (clouds) every patch was captured individually and the values were stored in a spreadsheet (see *Appendix A*). It has to be pointed out that this process lasted around 5 minutes.

Once captured, the spectral data recorded by the *rgb photonics Qmini* spectrometer (see *figure 5*) was converted from the scene illuminant (around 5700 K) to CIE D65 for better comparison.

***Figure 5**. The spectrometer used in this test, the rgb photonics Qmini [11]*

Following the ACES recommendation we used ACEScg as the host color space in NukeX. The imported RED footage was then converted from the ACEScg color space to CIEXYZ using the following matrix [12] and then to CIEYxy using the built-in *Colorspace* node:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.65223754 & 0.12823614 & 0.16998225 \\ 0.26767218 & 0.67433999 & 0.05798783 \\ -0.00538182 & 0.00136906 & 1.09307051 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

***Formula 1.** ACEScg RGB to CIE XYZ*

In the input conversion process for the Rec2020 color space an error appeared. The scaling of the patch positions within the CIE xy-chromaticity diagram using NukeX's Read node did not work as expected and rendered a heavily desaturated result. To investigate the conversion from RED Rec2020 to ACEScg color space without error we used a different approach.

The RED footage was imported into the proprietary REDCINE-X PRO application (version 50) with the import color space set to *Rec2020*. We set the color space transfer function to *linear*, and all other settings derived from the meta data. The imported image was then exported as a 32bit floating point OpenEXR file with no transfer function applied encoded to *Rec2020* color space.

This file was then read into Nuke using the *OCIO Utility-Linear-Rec2020* as an IDT. This method delivered a sufficient result (see section 6), which fell inside the tolerances retrieved from other conversions. This import error should be fixed in one of the next updates in NukeX.

As an additional test to proof the concept we used the chromaticity positions of the ColorChecker patches in ACES RGB provided in the ACES *Technical Bulletin TB-2014-004 [1]*. We set up a Nuke session in ACES2065-1 color space with CIE illuminant D60 and read in the test footage using all four RED color spaces.

With compositing techniques (masking and grading) we separated the primary and secondary patches (red, green, blue, yellow, magenta, and cyan) of the ColorChecker and corrected them to the appropriate values. Then we applied a luminance correction – no white balancing – to the four RED color spaces by setting the green value of patch #d1 to 0.86792 as given in [1]. With a simple difference operation we checked the ACES RGB values against the four colorspaces to indicate the color shift applied by the ACES RED IDTs (see *figure 6*).

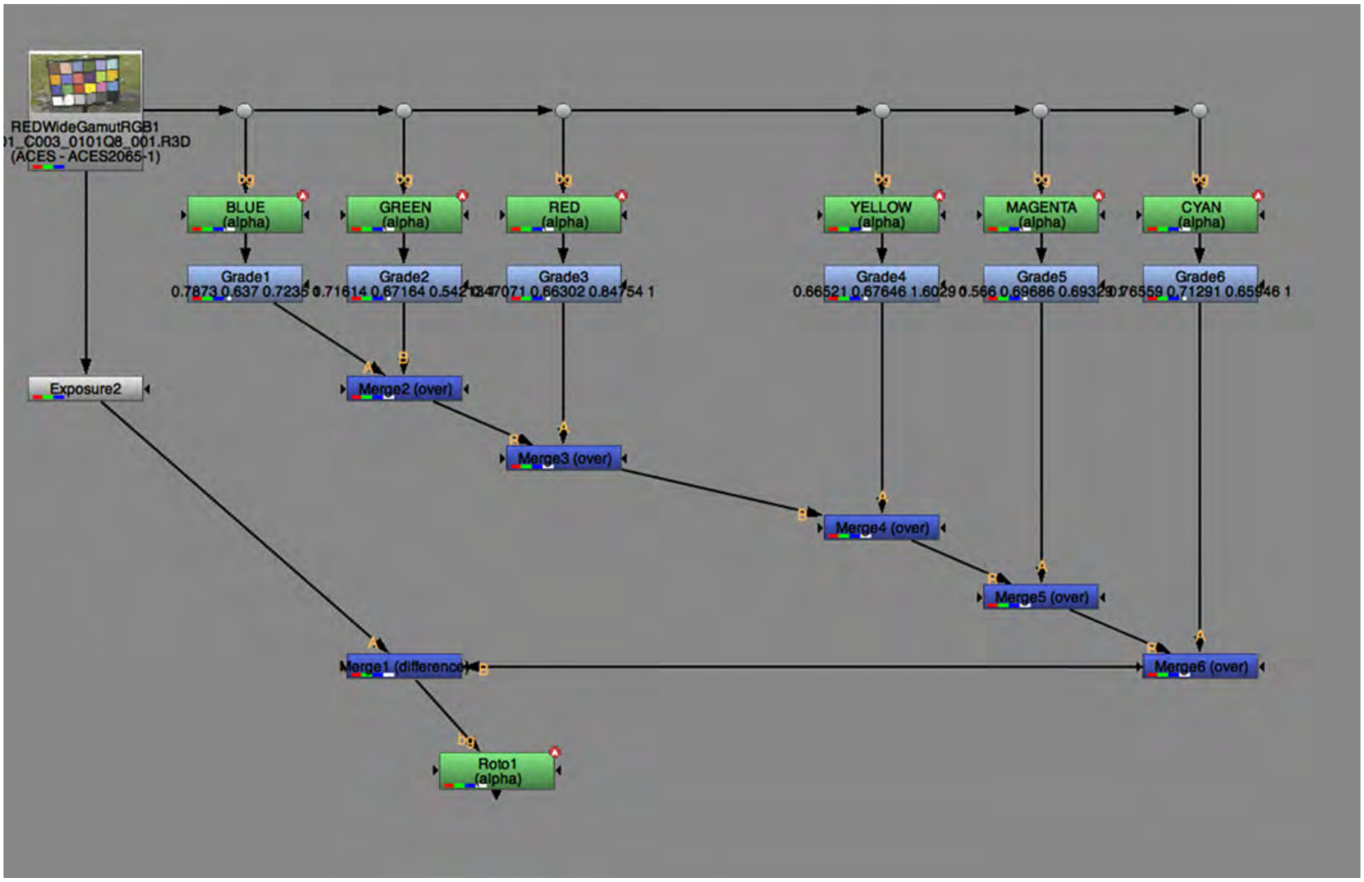

***Figure 6**. NukeX setup for calculating the difference between recorded ColorChecker ACES RGB values and ACRES RGB values given in TB-2014-04*

4. Comparing the recorded spectral data with ColorChecker reference positions

To proof the concept that a mobile spectrometer can create reliable results we compared the color of the individual patches of the ColorChecker recorded by the mobile spectrometer with a reference data set derived from document *RGB Coordinates of the Macbeth ColorChecker* published by Daniel Pascale [13].

The positions of the individual patches in the CIE xy-chromaticity diagram in [13] are available only for CIE illuminant D50. Evaluating the camera metadata of the cameras in this test a color temperature around 5700 K was detected. To compare the results of the color calculations all data has to be converted to a common CIE illuminant. Although the illuminant of both host ACES color spaces used in this test is D60, we choose the CIE D65 illuminant – above all for the possibility to compare the results of the color conversion to other tests.

Because the color temperature in this test was outside the D series of illuminants defined by the CIE we used a simple XYZ scaling by choosing the ColorChecker patch 19 (#d1) as reference for the illumination of the scene with a D65 illuminant. First we converted the CIE Yxy color space positions derived from the spectrometer to CIE XYZ. Then we performed a white balancing to the CIE Illuminant D65 *XYZ [95.047, 100, 108.883]* by applying the following matrix:

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0.97107 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1.13314 \end{bmatrix} \cdot \begin{bmatrix} X_{rec} \\ Y_{rec} \\ Z_{rec} \end{bmatrix}$$

***Formula 2.** CIE XYZ recorded to CIE D65 simple scaling*

To convert the reference ColorChecker patches from D50 to D65 we used two methods. The first one uses the Bradford matrix version published in [13] to calculate the target positions of the color patches.

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0.9556 & -0.0230 & 0.0632 \\ -0.0283 & 1.0099 & 0{,}0210 \\ 0.0123 & -0.0205 & 1.3299 \end{bmatrix} \cdot \begin{bmatrix} X_{D50} \\ Y_{D50} \\ Z_{D50} \end{bmatrix}$$

Formula 3. *CIE D50 to CIE D65 Bradford matrix*

Additionally we applied a simple XYZ scaling – as with the spectral data – to get an idea how the results using both methods will differ. Comparing both data sets we could conclude how the deviation between the Bradford matrix and the simple XYZ scaling appears, and if it would be acceptable.

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0.98853 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1.34464 \end{bmatrix} \cdot \begin{bmatrix} X_{D50} \\ Y_{D50} \\ Z_{D50} \end{bmatrix}$$

Formula 4. *CIE D50 to CIE D65 simple scaling*

As the last step we converted the data from CIE XYZ to CIE Yxy. We used the build-in *Colorspace* node inside NukeX. The CIE Yxy values for the respective color patches were derived using the Nuke color picker.

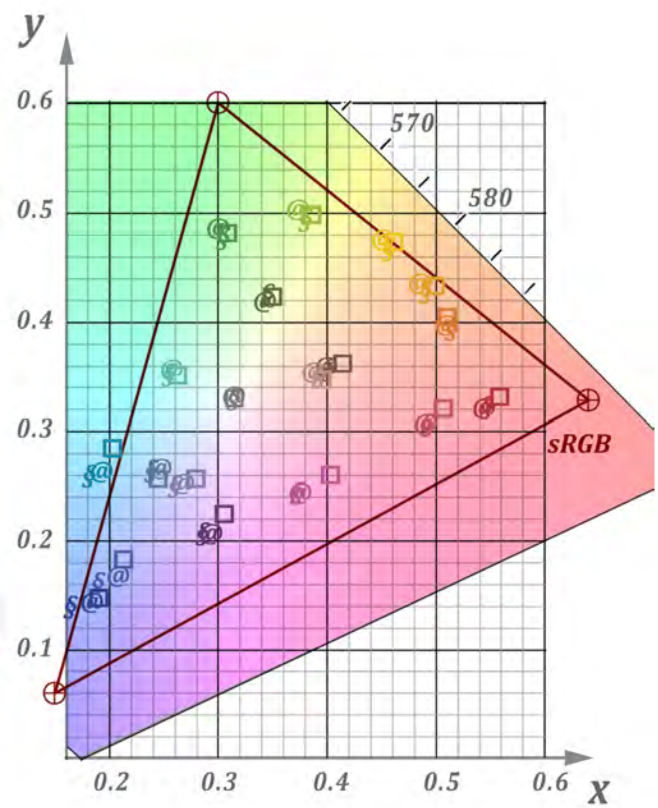

Figure 7. *Converted ColorChecker positions from D50 to D65. Hollow square: Spectral data simple scaling. @ Reference data Bradford matrix, § simple scaling*

In *table 10* in *Appendix A* all the calculated values for the individual ColorChecker patches are listed using all three methods. *Figure 7* shows the results of all the three conversions in CIE xy-chromaticity diagram.

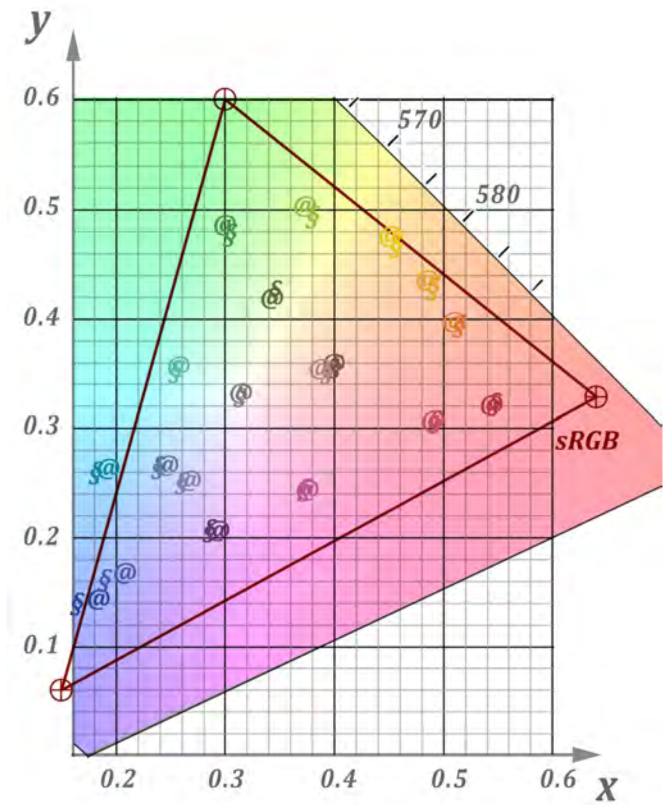

Figure 8. *Converted reference ColorChecker positions from D50 to D65. @ Bradford matrix, § simple scaling*

Figure 8 displays both reference color patch conversions from *D50* to *D65*. The calculations indicate some deviations in the blue region where the simple scaling method exceeds the positions calculated with the Bradford matrix. *Figure 9* displays the result from the spectral data conversion to the reference data set using the Bradford matrix. Here only the magenta and cyan patch show larger deviations.

5. Discussing the results using the spectral data

In this section we are comparing the ColorChecker chromaticity values of the spectral recordings with the results of the RED footage imported by the ACES Input Devices for the individual RED color spaces. Because we left the import as is and did not apply further white balancing, different results for the ColorChecker patch #d1 for each color space were created by the IDTs. We provide them in tables along with the overall deviation between the two data sets. These deviations were retrieved by calculating an absolute difference for each the x-values and the y-values within the CIE xy-chromaticity diagram. Both values were added to generate the overall deviation. Only simple difference calculations were applied.

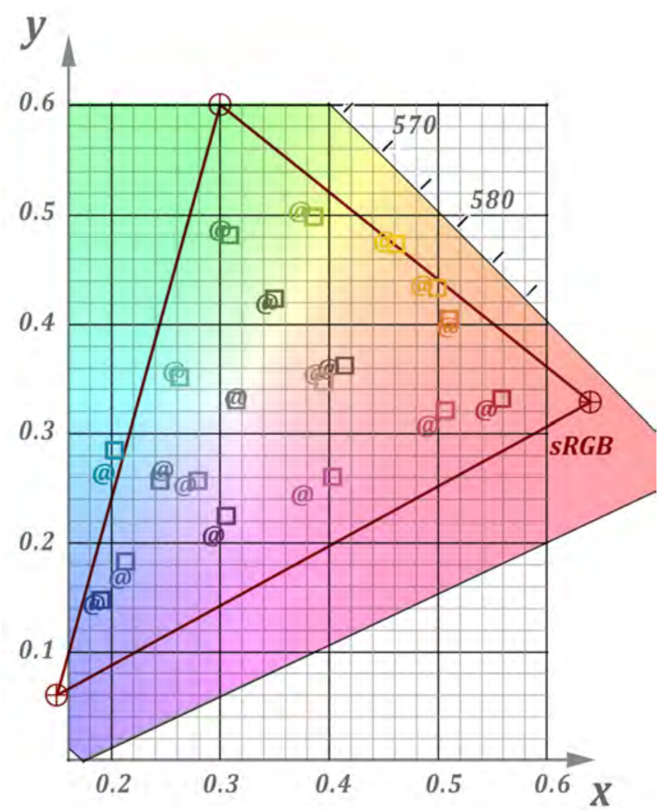

Figure 9. *Converted ColorChecker positions from D50 to D65. Hollow square: spectral data, @ reference data Bradford matrix*

5.1. REDWideGamutRGB

The Input Device Transform for the *REDWideGamutRGB* color space converts patch #d1 (white) to superwhite as seen in table 2. The conversion produces a deviation of 0.5412. The largest deviations appear at #b6-orange yellow (y 0.0421) and #c1-blue (y 0.0420). Considering the deviations in the other blue (#a3-blue sky, #b2-purplish blue, #b5 blue flower) and yellow/orange (#b1-orange, #b6-orange yellow) patches, a noticeable shift towards yellow happens, whereas the other patches are staying more or less close together. This indicates that picture rendering has not been completely removed. This color space encompasses two patches (#b6-orange, #c1-blue) with deviation in one direction larger than 0.04, three patches larger than 0.03 and six patches larger than 0.02.

	X	Y	Z
Patch d1 White	1.18797	1.24253	1.35063

Table 2. *Coordinates of patch #d1 in CIEXYZ*

	x	y	∑
Deviation	0.2086	0.3327	0.5412

Table 3. *Differences between spectral data and color space conversion for REDWideGamutRGB*

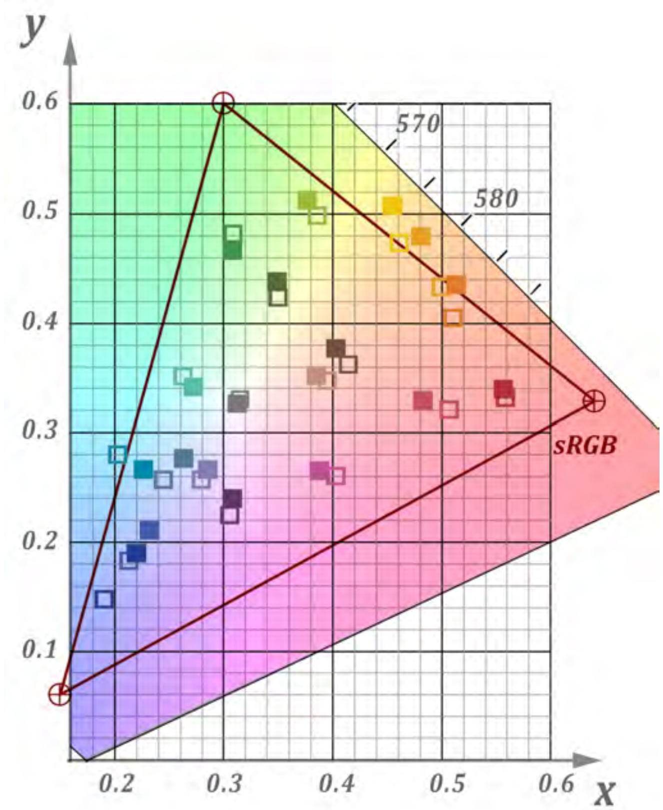

Figure 10. *Positions of the ColorChecker patches (solid) in the CIE xy-chromaticity diagram for REDWideGamutRGB color space in comparison to the spectral data positions (hollow)*

5.2. REDColor4

The Input Device Transform for the *REDWideGamutRGB* color space converts patch #d1 (white) to superwhite with a slightly brighter result (*table 4*). The conversion produces a deviation of 0.5353, which is comparable to the result using the *REDWideGamutRGB* color space. Looking closer the deviation is larger for REDcolor4 in x and lesser in y. The highest deviation for the individual patches appears for #c1-blue (x – 0.435) as compared to *REDWideGamutRGB<* (y – 0.0421), another indication that the ACES IDT concept may work to a certain extend, but a noticeable smaller deviation appears for #c2-green (x – 0.433) as compared to (x – 0.0032) for *REDWideGamutRGB*, which may indicate the contrary. In comparison the individual patches of the two color spaces show a more homogeneous distribution for the *REDWideGamutRGB*, above all in the primary colors, especially in the red and green areas. The *REDColor4* color space encompasses two patches (#c1-blue, #c2-green) with deviation in one direction larger than 0.04, two patches larger than 0.03 and five patches larger than 0.02.

	X	Y	Z
Patch d1 White	1.19820	1.24496	1.37748

Table 4. *Coordinates of patch #d1 in CIEXYZ*

	x	y	∑
Deviation	0.2989	0.2364	0.5353

Table 5. *Differences between spectral data and color space conversion for REDColor4*

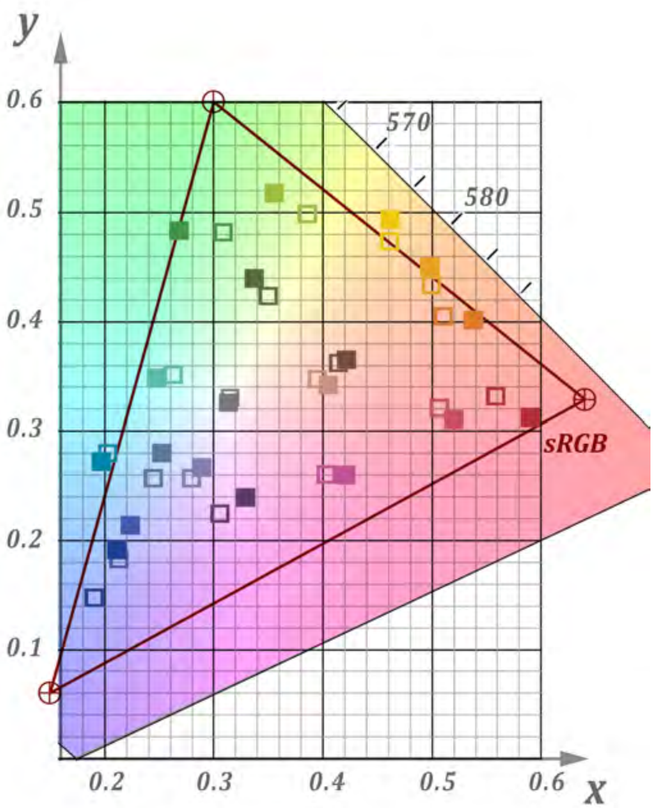

Figure 11*. Positions of the ColorChecker patches (solid) in the CIE xy-chromaticity diagram for REDColor4 color space in comparison to the spectral data positions (hollow)*

5.3. REDDragoncolor2

The Input Device Transform for the *REDWideGamutRGB* color space converts patch #d1 (white) to superwhite with a result comparable to *REDColor4* (*table 6*). The conversion produces a deviation of 0.4622, noticeable smaller then the other color space conversions

The visual representation in *figure 12* compared *to figure 11* (REDColor4) shows that the positions of most of the patches are more or less identically. The deviation in the green area is slightly reduced. Also noticeable is that the red and yellow-orange patches are closer to the spectral positions, which removes the oversaturation in this area widely. The largest deviations appear at #c1-blue (y 0.0464) and #c2-green (x 0.0410), which is comparable to the REDColorspace4.

	X	Y	Z
Patch d1 White	1.19822	1.24553	1.37700

Table 6. *Coordinates of patch #d1 in CIEXYZ*

	x	y	∑
Deviation	0.2455	0.2167	0.4622

Table 7. *Differences between spectral data and color space conversion for REDDragoncolor2*

The *REDDragoncolor2* color space encompasses two patches (#c1-blue, #c2-green) with deviation in one direction larger than 0.04, only one patch larger than 0.03 and four patches larger than 0.02, the best result in the test considering this approach.

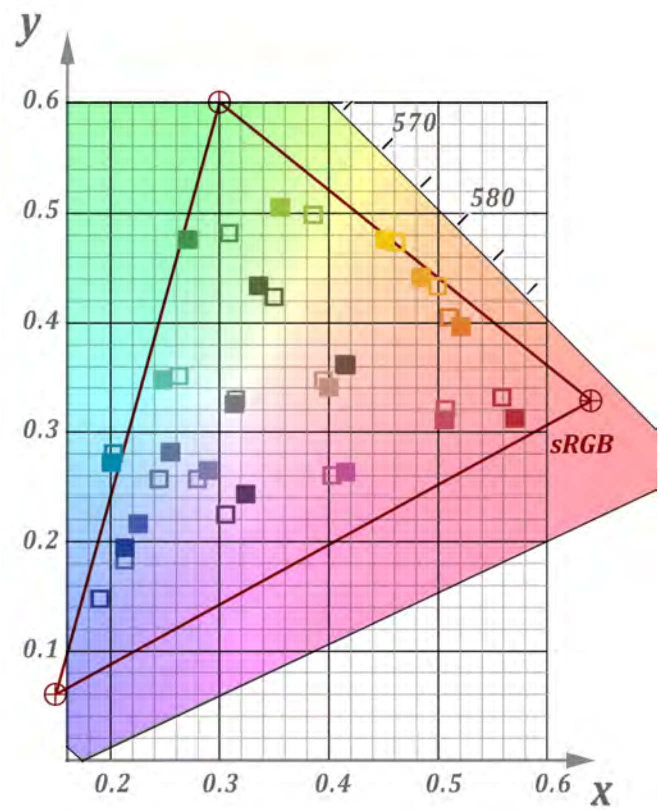

Figure 12*. Positions of the ColorChecker patches (solid) in the CIE xy-chromaticity diagram for REDDragoncolor2 color space in comparison to the spectral data positions (hollow)*

5.4. Rec2020

The Input Device Transform for the *REDWideGamutRGB* color space converts patch #d1 (white) to superwhite as seen in table 8. The conversion produces a deviation of 0.5880, the largest in the test. The visual comparison to the other three conversions shows a similar distribution to the *REDWideGamutRGB* color space with a slight deviation towards blue what moves the yellow/orange patches closer to the spectral data positions. The largest deviation appears for #c1-blue in the y-direction (0.0429), the same as in the other conversions and in the x-direction (0.0328) nearly the same as for *REDWideGamutRGB*. Obviously *REDColor4* and *REDDragoncolor2* at one side and *Rec20202* and *REDWideGamutRGB* on the other side are using a different subset within the IDTs provided by the RED company.

The *Rec2020* color space encompasses one patch (#c1-blue) with a deviation in one direction larger than 0.04, three patches larger than 0.03 but the high number of nine patches larger than 0.02.

	X	Y	Z
Patch d1 White	1.22168	1.27334	1.39935

Table 8. *Coordinates of patch #d1 in CIEXYZ*

	x	y	∑
Deviation	0.2729	0.3151	0.5880

Table 9. *Differences between spectral data and color space conversion for Rec2020*

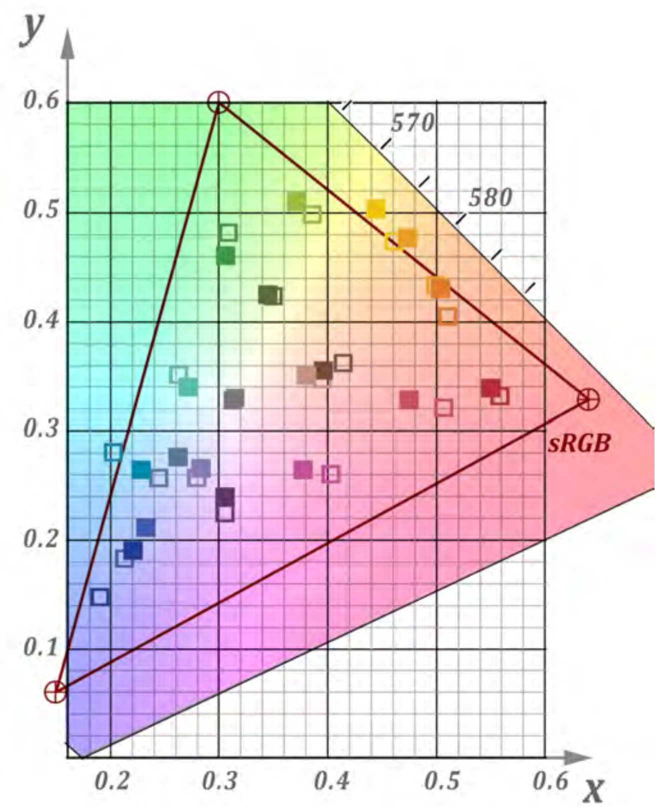

Figure 13*. Positions of the ColorChecker patches (solid) in the CIE xy-chromaticity diagram for Rec2020 color space in comparison to the spectral data positions (hollow)*

6. Discussing the results using the ACES reference data

To proof the concept we executed another test described in section 3. Here we used the data set of the ColorChecker patches for ACES2065-1 RGB provided in ACES document *TB-2014-004* [1]. We color corrected one data set to match the ACES RGB values and luminance corrected the conversions of the individual Red color spaces. We applied a simple difference operation for selected patches (blue, green, red, yellow, magenta and cyan).

The advantage in this test is that there is no additional white balancing and other color operations applied outside and all calculations are taking place inside the ACES system, so no potential outside errors will occur. The results are shown *in figure 14*.

Figure 14. *Differences between ACES RGB data set of selected ColorChecker patches and ACES IDT converted RED Scarlet-X recordings*

Here the two interpretations of an IDT described in section 5 are very clear to see. The wide color gamut color spaces *REDWideGamutRGB* and *Rec2020* at the one hand are nearly identically and the *REDColor4* and *REDDragoncolor2* render also a near identically result. Both concepts are showing a color shift toward red above all in the red and magenta patch. Whereas the other four patches in the wide gamut section are coming close to black (no difference) and the offset for red and magenta is only marginal, the color shifts toward red are much more prominent with the other two colorspaces.

This may indicate that the utility color spaces are closer to the light of the scene than the obviously more artistically oriented “Color” spaces. Consequently in the proprietary RECINE-X PRO [4] software the input is set to *REDWideGamutRGB,* which cannot be changed without using the legacy settings.

7. Summary and conclusion

In comparison to previous tests [6] substantial progress had been made in the ability to capture the original light of the scene using the ACES IDTs. Although the company related picture rendering was not completely removed, the distribution of the patches is more convincing and the overall deviation to the light of the scene is much better. Obviously there are two strategies in designing the IDTs, one rather towards an original representation of the light of the scene with a slight shift towards red (REDWideGamutRGB, Rec2020) and a more artistically driven approach (REDcolor4, REDDragoncolor2), where the shift towards red is more prominent. As a recommendation for a VFX pipeline the REDWideGamutRGB color space should be used.

Interestingly using the spectral date as reference both “Color” colorspaces exhibit less deviation, than the Wide Gamut colorspaces with less deviation using the ACES data set. This may be caused by the simple XYZ scaling used to convert to the spectral data and footage to CIE D65. In future research we will try to refine the approach and test some alternative white balancing methods.

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Reiner Creutzburg received his Diploma in Math from the University of Rostock, Germany (1976). Since 1992 he is professor for Applied Informatics at the Brandenburg University of Applied Sciences in Brandenburg. Germany. He is member in the IEEE and SPIE and chairman of the Multimedia on Mobile Device Conference at the Electronic Imaging conferences since 2005.

Appendix A - Calculation Results

	Spectral data 5700 K		***Spectral data D65***		***Reference data D65 Bradford matrix conversion***		***Reference data D65 Simple XYZ scaling***		***Difference spectral data and reference data***	
Patch	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**		
a 1	0.4303	0.3668	0.4118	0.3616	0.3997	0.3589	0.4021	0.3559	0.0121	0.0027
a 2	0.4124	0.3579	0.3930	0.3513	0.3872	0.3538	0.3892	0.3512	0.0058	0.0025
a 3	0.2629	0.2702	0.2421	0.2561	0.2470	0.2661	0.2388	0.2639	0.0049	0.0100
a 4	0.3647	0.4295	0.3484	0.4224	0.3423	0.4316	0.3462	0.4253	0.0061	0.0092
a 5	0.2988	0.2687	0.2766	0.2561	0.2668	0.2522	0.2593	0.2505	0.0098	0.0039
a 6	0.2789	0.3641	0.2605	0.3503	0.2568	0.3567	0.2539	0.3528	0.0037	0.0064
b 1	0.5296	0.4004	0.5176	0.4028	0.5098	0.3975	0.5142	0.3933	0.0078	0.0053
b 2	0.2318	0.1959	0.2105	0.1832	0.2081	0.1671	0.1918	0.1639	0.0024	0.0161
b 3	0.5221	0.3211	0.5039	0.3193	0.4905	0.3059	0.4924	0.3064	0.0134	0.0134
b 4	0.3306	0.2361	0.3064	0.2252	0.2935	0.2068	0.2854	0.2060	0.0129	0.0184
b 5	0.3956	0.5082	0.3835	0.5073	0.3728	0.5044	0.3801	0.4941	0.0107	0.0029
b 6	0.5037	0.4356	0.4924	0.4384	0.4849	0.4355	0.4905	0.4292	0.0075	0.0029
c 1	0.2085	0.1596	0.1877	0.1481	0.1841	0.1435	0.1643	0.1393	0.0036	0.0046
c 2	0.3256	0.4888	0.3115	0.4815	0.2998	0.4858	0.3047	0.4768	0.0117	0.0043
c 3	0.5702	0.3301	0.5557	0.3311	0.5439	0.3208	0.5464	0.3213	0.0118	0.0103
c 4	0.4697	0.4711	0.4587	0.4739	0.4509	0.4758	0.4577	0.4668	0.0078	0.0019
c 5	0.4266	0.2677	0.4028	0.2603	0.3750	0.2429	0.3723	0.2435	0.0278	0.0174
c 6	0.2218	0.2962	0.2036	0.2800	0.1930	0.2627	0.1809	0.2595	0.0106	0.0173
d 1	0.3331	0.3401	0.3127	0.3289	0.3132	0.3308	0.3127	0.3288	0.0005	0.0019

Table 10 *Positions of the ColorChecker color patches in the CIE xy-chromaticity diagram for the spectral data, reference data and difference between both*

	REDWideGamutRGB		***Rec 2020***		***REDColor4***		***REDDragoncolor2***	
Patch	**x**	**y**	**x**	**y**	**x**	**y**		
a 1	0.4026	0.3774	0.3967	0.3756	0.4221	0.3648	0.4158	0.3628
a 2	0.3850	0.3521	0.3799	0.3510	0.4049	0.3424	0.4000	0.3417
a 3	0.2632	0.2773	0.2623	0.2763	0.2527	0.2801	0.2545	0.2817
a 4	0.3491	0.4386	0.3452	0.4355	0.3374	0.4401	0.3361	0.4341
a 5	0.2849	0.2664	0.2830	0.2662	0.2885	0.2672	0.2895	0.2645
a 6	0.2719	0.3415	0.2713	0.3392	0.2474	0.3486	0.2483	0.3478
b 1	0.5133	0.4361	0.5038	0.4347	0.5374	0.4016	0.5207	0.3965
b 2	0.2321	0.2117	0.2326	0.2115	0.2235	0.2135	0.2256	0.2164
b 3	0.4823	0.3297	0.4746	0.3285	0.5194	0.3099	0.5063	0.3112
b 4	0.3090	0.2405	0.3062	0.2393	0.3293	0.2402	0.3291	0.2438
b 5	0.3764	0.5141	0.3716	0.5097	0.3581	0.5177	0.3554	0.5062
b 6	0.4820	0.4804	0.4727	0.4771	0.4976	0.4509	0.4845	0.4421
c 1	0.2199	0.1902	0.2205	0.1910	0.2108	0.1916	0.2130	0.1945
c 2	0.3083	0.4657	0.3065	0.4614	0.2682	0.4834	0.2705	0.4760
c 3	0.5567	0.3393	0.5497	0.3391	0.5904	0.3110	0.5705	0.3122
c 4	0.4546	0.5087	0.4449	0.5037	0.4612	0.4870	0.4509	0.4759
c 5	0.3841	0.2655	0.3782	0.2646	0.4205	0.2600	0.4152	0.2635
c 6	0.2267	0.2658	0.2280	0.2656	0.1974	0.2709	0.2004	0.2723
d 1	0.3128	0.3260	0.3132	0.3278	0.3136	0.3258	0.3136	0.3259

Table 11 *Positions of the Macbeth color patches in the CIE xy-chromaticity diagram for the RED colorspace IDT conversions*

	REDWideGamutRGB			*Rec 2020*			*REDColor4*			*REDDragoncolor2*		
Patch	**x**	**y**		**x**	**y**		**x**	**y**		**x**	**y**	
a 1	0.0092	0.0158		0.0151	0.0140		0.0103	0.0032		0.0040	0.0012	
a 2	0.0080	0.0008		0.0131	0.0003		0.0119	0.0089		0.0070	0.0096	
a 3	0.0211	0.0212		0.0202	0.0202		0.0106	0.0240		0.0124	0.0256	
a 4	0.0007	0.0162		0.0032	0.0131		0.0110	0.0177		0.0123	0.0117	
a 5	0.0082	0.0103		0.0064	0.0101		0.0119	0.0111		0.0129	0.0084	
a 6	0.0114	0.0089		0.0108	0.0111		0.0131	0.0017		0.0122	0.0025	
b 1	0.0043	0.0333		0.0138	0.0319		0.0198	0.0012		0.0031	0.0063	
b 2	0.0216	0.0285		0.0221	0.0283		0.0130	0.0303		0.0151	0.0332	
b 3	0.0216	0.0104		0.0293	0.0092		0.0155	0.0094		0.0024	0.0081	
b 4	0.0026	0.0153		0.0002	0.0141		0.0229	0.0150		0.0227	0.0186	
b 5	0.0071	0.0068		0.0119	0.0024		0.0254	0.0104		0.0281	0.0011	
b 6	0.0104	0.0420		0.0197	0.0398		0.0052	0.0125		0.0079	0.0037	
c 1	0.0322	0.0421		0.0328	0.0429		0.0231	0.0435		0.0253	0.0464	
c 2	0.0032	0.0158		0.0050	0.0201		0.0433	0.0019		0.0410	0.0055	
c 3	0.0010	0.0082		0.0060	0.0080		0.0347	0.0201		0.0148	0.0189	
c 4	0.0041	0.0348		0.0138	0.0298		0.0025	0.0131		0.0078	0.0020	
c 5	0.0187	0.0052		0.0246	0.0043		0.0177	0.0003		0.0124	0.0032	
c 6	0.0231	0.0142		0.0244	0.0144		0.0062	0.0091		0.0032	0.0077	
d 1	0.0001	0.0029		0.0005	0.0011		0.0009	0.0031		0.0009	0.0030	
Sum x, y	**0,2086**	**0,3327**		**0,2729**	**0,3151**		**0,2989**	**0,2364**		**0,2455**	**0,2167**	
Overall	**0,5412**			**0,5880**			**0,5353**			**0,4622**		

Table 12 *Differences between the position of the color space conversions and the positions of spectral data for the individual ColorChecker patches*