Using ACES Look Modification Transforms (LMTs) in VFX Environments – Part 2: Gamut Mapping

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Abstract

In modern moving image production pipelines, it is unavoidable to move the footage through different color spaces. Unfortunately, these color spaces exhibit color gamuts of various sizes. The most common problem is converting the cameras' wide-gamut color spaces to the smaller gamuts of the display devices (cinema projector, broadcast monitor, computer display). So it is necessary to scale down the scene-referred footage to the gamut of the display using tone mapping functions [34].

In a cinema production pipeline, ACES is widely used as the predominant color system. The all-color compassing ACES AP0 primaries are defined inside the system in a general way. However, when implementing visual effects and performing a color grade, the more usable ACES AP1 primaries are in use. When recording highly saturated bright colors, color values are often outside the target color space. This results in negative color values, which are hard to address inside a color pipeline. "Users of ACES are experiencing problems with clipping of colors and the resulting artifacts (loss of texture, intensification of color fringes). This clipping occurs at two stages in the pipeline:
  - Conversion from camera raw RGB or from the manufacturer's encoding space into ACES AP0
  - Conversion from ACES AP0 into the working color space ACES AP1" [1]

The ACES community established a Gamut Mapping Virtual Working Group (VWG) to address these problems. The group's scope is to propose a suitable gamut mapping/compression algorithm. This algorithm should perform well with wide-gamut, high dynamic range, scene-referred content. Furthermore, it should also be robust and invertible. This paper tests the behavior of the published GamutCompressor when applied to in- and out-of-gamut imagery and provides suggestions for application implementation. The tests are executed in The Foundry's Nuke [2].

1. Out-of-gamut colors in the ACES pipeline

1.1. The problem

The problem is that during specific color conversions, out-of-gamut color values become negative. These negative color values often produce artifacts like loss of texture or intensification of color fringes. This happens at the color conversion from the camera vendor's wide gamut to the smaller ACEScg gamut or in the color conversion from ACES (AP0) to ACEScg (AP1).

Figure 1. *Out-of-gamut colors in an ACEScg converted image [3]*

1.2. The solution

To solve this problem, a Virtual Working Group to this scope has been established. This group of worldwide color experts created an algorithm, the *GamutCompressor*, based on Jed Smith's work. In the following this group is abbreviated as *GM_VWG*.

"The gamut compression algorithm runs per-pixel, and is controlled with a small set of constants. These constants control how much of the core gamut to protect, how much to compress each of the color components, and the shape of the compression curve. The algorithm operates in a purely RGB scene linear space (ACEScg)." [3]

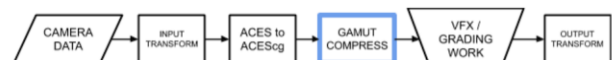It is intended to directly insert this algorithm in the ACES pipeline after the Input Device Transform (IDT).

Figure 2. *Module of GamutCompressor in ACES pipeline [3]*

1.3. Scope of the investigation

Due to the implementation as a module, no parameter settings can be made, and the algorithm is inserted "as is." In the following tests, it is investigated how the algorithm behaves with the default settings and what possibilities open up when the parameters are exposed to the user.

The tests include colors outside the Zone-of-Trust but inside the gamut and colors out-of-gamut. The Parameters' influence (Power Curve Exponent, Compression Thresholds, Distance Limits) is tested. Furthermore, the compression of out-of-gamut colors is investigated using compositing techniques. Finally, some suggestions are made for implementing the algorithm with parameters exposed in The Foundry's Nuke.

1.4. Analysis tools

The Foundry NukeX12.2v4, the film industry's central image processing program, is used as the host program. The GamutCompressor was provided in a GitHub repository by the GM_VWG [4]. A particular OpenColorIO configuration as the View Transform is used. It is a modification by the GM_VWG based on the *aces_1.2* version to avoid some problems in the RRT/ODT transform [5].

AbsMinus (Difference Node in Nuke): Difference between original image and image after GamutCompressor applied (amplified by 1000).

*"Absminus is the same as the <u>Merge</u> node, only with **operation** set to **difference** by default. It layers images together using the **difference** compositing algorithm: **abs(A-B)**. This algorithm calculates how much the pixels in input **A** differ from the pixels in input **B**. It can be useful for comparing two very similar images."* [6]

Pixel Analyzer in Nuke: Calculating the maximum of difference between original and compressed image.

"Nuke's Pixel Analyzer enables you to analyze single and multiple pixels, or the entire image, and compare color values between Viewers. The analyzer stores current, minimum and maximum, average, and median values which can then be copied by value to controls on other nodes." [7]
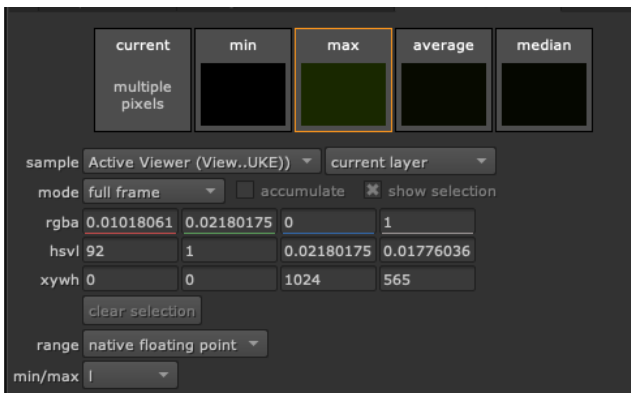
Figure 3. Pixel Analyzer in Nuke 12

Plot Chromaticity: A Nuke blinkscript tool for plotting an image on a chromaticity diagram [8]

Negative Value Display: Nuke Node Tree created to display the negative values on a black-white image. Core calculations are executed by an Expression node. (see. Fig. 5).
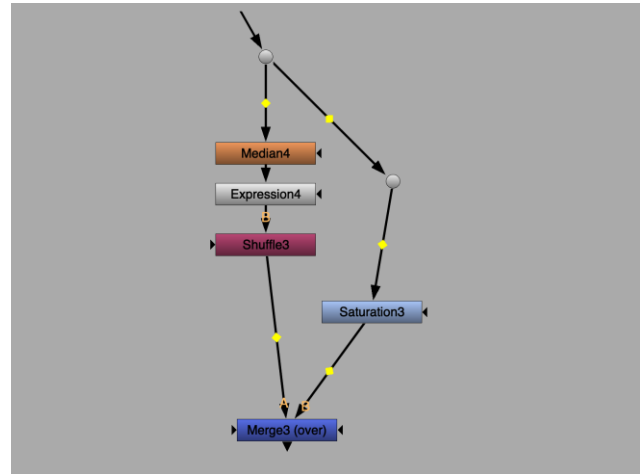
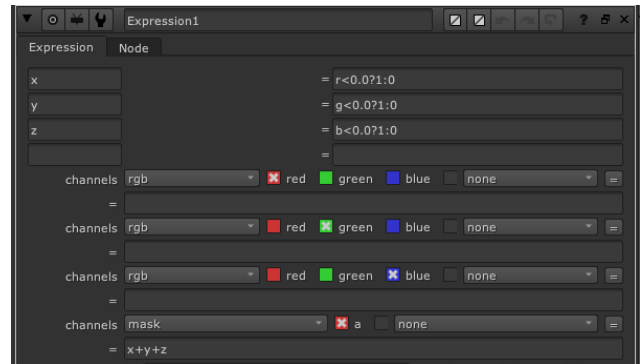**Figure 4.** Node tree to display negative colors

Figure 5. Nuke expression node

2. Analyzing colors outside the *Zone of Trust*

In the first analysis section, the GamutCompressor's behavior when compressing standard "everyday" images is investigated. The focus is on the color area between the gamut boundary and the *Zone of Trust.*

2.1. The *Zone of Trust*

The term *Zone of Trust* is not officially published but used in discussions throughout the algorithm's development. It describes an area in the CIE chromaticity diagram which is not affected by the Gamut compressor. It contains the positions of the classic ColorChecker 24 patches (Fig. 6).

2.2. Analysis method and results

To determine the Gamut Compressor's impact on the image colors in the tests, the difference between the original image and a compressed version was determined using the *AbsMinus* node in The Foundry Nuke. This difference was very small in almost all test images. To represent it, the luminance was amplified by a factor of 100 - 1000.
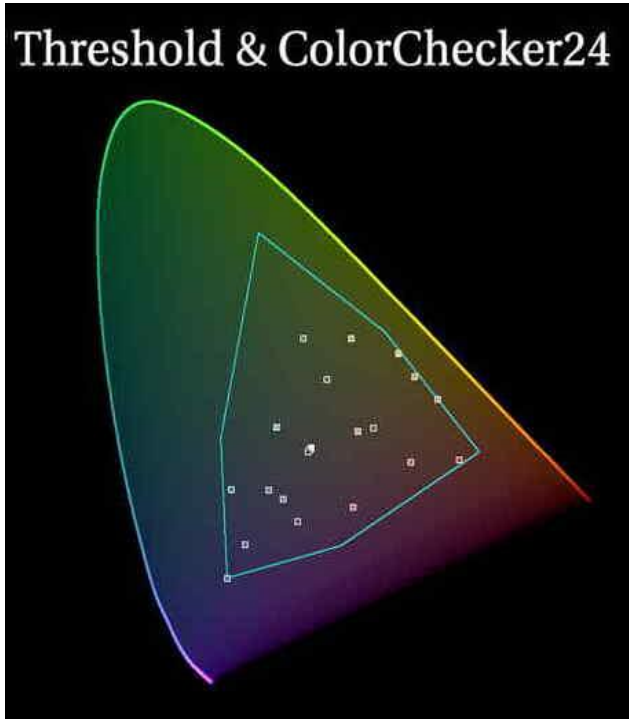

Figure 6. *Zone of Trust in CIE chromaticity diagram [9]*

In addition, the influence of the power curve exponent was determined with the help of the *PixelAnalyzer* in Nuke. Since the results of this tool depends on the displayed size of the images in the *Viewer*, all images were reformatted to an 1024 pixel width before the measurement in order to be able to compare them.

The tables show the maximum values of the red, green, and blue channels of the difference image for the power curve exponent of 1.2. Also, all luminance values of the difference image are given for the values 1.0, 1.1, 1.2, 1.3, and 2.0 of the power curve exponent. For better comparison, the exponent 1.2 was set to 100%.

The CIE Chromaticity Diagram's color distribution was compared before and after compression. To display the colors that were affected by the GamutCompressor, both images were processed in Affinity Photo. The adjusted colors are shown in white. There are also whites in the middle of the Zone of Trust, representing the monochromatic lights on the black body line.

2.2. Analyzing still images and single video frames

The following images and videos are tested:

1) JPEG-Images encoded in sRGB, Consumer cameras, DSLR Canon D5 Mark II – IV
2) MPEG-Movies encoded in Rec.709, Consumer cameras, Canon D5 Mark II - IV, GoPro

Nearly all imagery in the evaluation process was not affected by the GamutCompressor. Only in some particular images colors appear close to the gamut boundary and outside the *Zone of Trust* in the sRGB or Rec.709 color space. Fig. 7 shows some random images with a maximum difference between original and compressed < 0.0000001.

Figure 7. *Unaffected Images – PixelAnalyzer max. < 0.0000001 [10]*

The images depicted in Fig. 8 show higher maximum differences bigger than 0.0005. They are generated by some saturated colors like red leaves, a blue bicycle bag, and areas in rock and sand shadows.
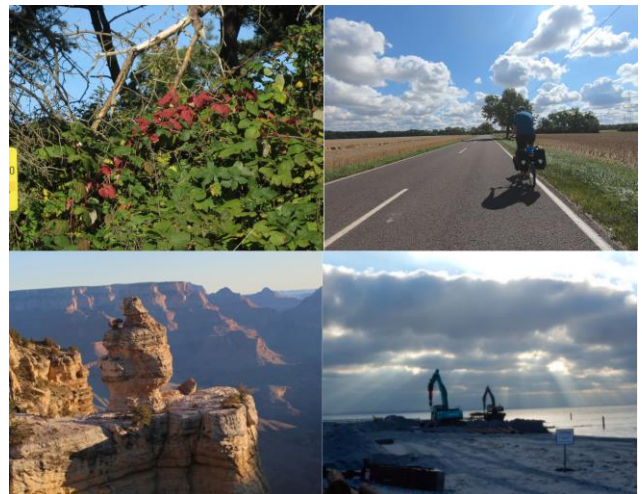

Figure 8. *Images with minimal affections – PixelAnalyzer max. < 0.0005 [10]*

The first image is an exotic bird with bright feathers. Usually, the difference is not visible with the naked eye, and it needs a heavy magnification with a factor of 1000 for better depiction. Because of the nature of the difference algorithm the

affected image areas are displayed complementary colors. The image was shot with a NIKON D40 in 2013.
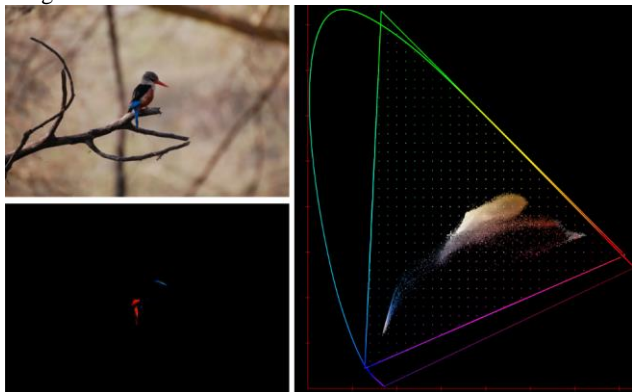

Figure 9. *Image of an exotic bird [11]*

	Difference values – Bird image				
	Red	Green	Blue		
RGB	0.00427	0.00224	0.0		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.00025	0.00032	0.00028	0.00022	0.00010
%	100%	128.72	113,45	88.16	39.53

Table 1. *Maximum difference values for an image of an exotic bird*

Table 1 shows the maximum difference from the PixelAnalizer for the three color channels. The maximum luminance of the difference for the *Power Curve Exponents* is also displayed. The individual maximum luminance values are compared in the next line, whereby exponent 1.2 is taken as 100%. Exponent 1.0 has the strongest influence on the Zone of Trust's colors, whereas exponent 2.0 causes much less change. This tendency appears in all images throughout the test.

The next image is a collection of sunglasses. Here, the extreme blues and reds are affected according to the white area in the diagram. The shot was done with a Samsung SM-G965F mobile in 2019.
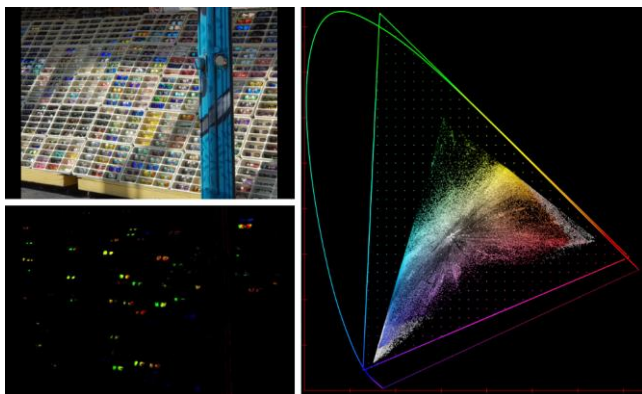

Figure 10. *Image of a collection of sunglasses [12]*

	Difference values – Sunglasses image				
	Red	Green	Blue		
RGB	0.01931	0.03942	0.0		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.03231	0.03553	0.03387	0.03085	0.02278
%	100%	109.97	104.82	95.48	70.51

Table 2. *Maximum difference values for an image of sunglasses*

Next, there is an aquarium shot. It is lit with highly saturated blue light. It produced the most considerable affected image area in all the analyzed photographs. The shot was done with a NIKON COOLPIX S8200 consumer camera in 2014.
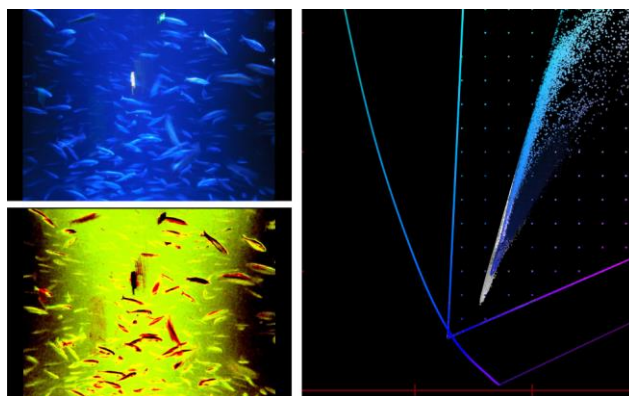

Figure 11. *Image of a blue lit aquarium [13]*

	Difference values – Aquarium image				
	Red	Green	Blue		
RGB	0.01741	0.03352	0.0		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.02768	0.03112	0.02934	0.02613	0.01776
%	100%	112.44	106.00	94.41	64.15

Table 3. *Maximum difference values for an image of a blue lit aquarium*

Another human-made object is an umbrella, with saturated red color. Here, some of the reds are reduced. The shot was done with a NIKON COOLPIX S9700 consumer camera in 2015.
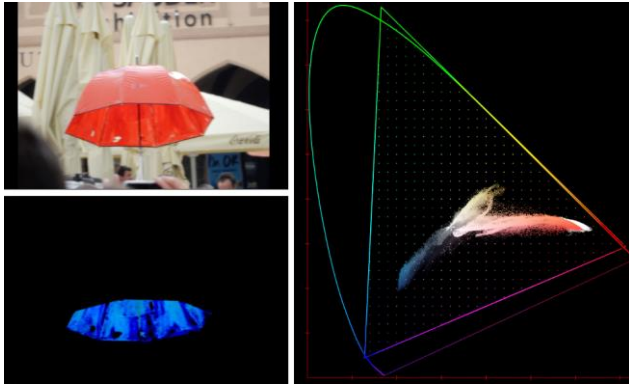
Figure 12. *Image of a red umbrella [14]*

	Difference values – Umbrella image				
	Red	Green	Blue		
RGB	0.0	0.00335	0.00789		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.00296	0.00379	0.00335	0.00262	0.00112
%	100%	127.88	113.08	88.44	37.74

Table 4. *Maximum difference values for an image of a red umbrella*

2.3. Analyzing DSLR RAW images

In the next section a DSLR RAW image is analyzed. It was shot by a Canon CR2 – D5 Mark III camera in 2017. The conversion was executed using *rawtoaces [15]*. The conversion process used an additional spectral sensitivity data set due to the paper [16].

This picture contains some negative values in the light areas. The Gamut compressor handles these values without problems.

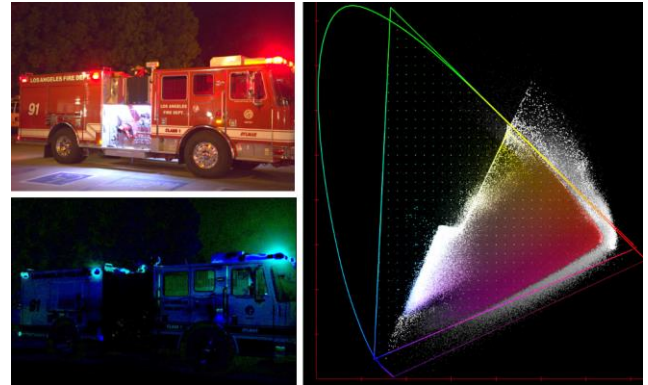**Figure 13.** *Out-of-gamut area (red) in a Canon CR2 image of a fire truck*

Figure 14. *Image of a fire truck (Canon CR2) [17]*

	Difference values – Fire truck image				
	Red	Green	Blue		
RGB	0.0	0.00345	0.00778		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.00303	0.00375	0.00337	0.00272	0.00130
%	100%	123.95	111.29	89.86	43.08

Table 5. *Maximum difference values for an CR2 RAW image of a fire truck*

2.4. Analyzing HDRI environment maps

Here two High Dynamic Range Image (HDRI) Environment maps are analyzed. The aim is to test how the Gamut Compressor processes the high luminance values and whether artifacts are produced. The first image has a relatively low maximum luminance of 25 (Fig. 15). In contrast, the second image (Fig. 16) has a very high maximum luminance of 300 000.
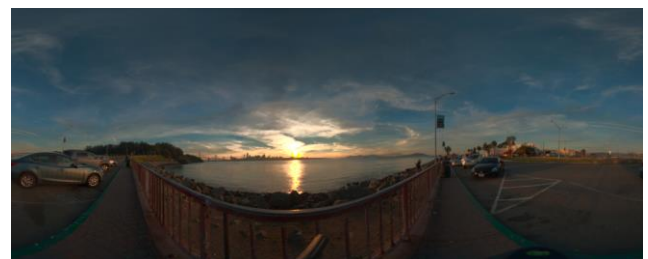

Figure 15. *HDRI Environment map of a sundown (L_{max} = 25) [18]*

Although the second image's luminance is very high, the maximum difference between the original and compressed version is relatively small (0.0007466). On the other hand, the first image shows significantly higher maximum difference values, which are naturally amplified by the high luminance values.

Figure 16. *HDRI Environment map of a sundown (L_{max} = 300 000) [19]*

In the first HDRI Environment map, the sun reflection in the water and sky causes some differences.

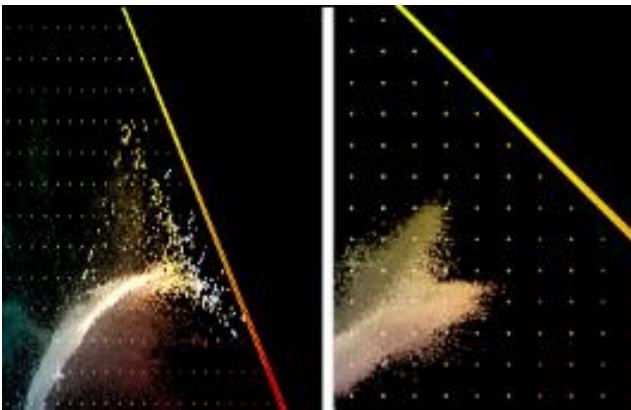**Figure 17.** *High Dynamic Range Image of a sundown difference (detail)*

Figure 18. *CIE chromaticity diagram comparison of the two HDRI environment maps (left: sundown, right: desert)*

	Difference values – HDR environment map				
	Red	Green	Blue		
RGB	0.0	0.0	0.94321		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.06800	1.07562	0.07167	0.06459	0.04638
%	100%	111.21	105.39	94.99	68.21

Table 6. *Maximum difference values for an HDRI Environment map*

2.5. Analyzing cg renderings

In this section, computer graphic (cg) renderings are examined. The rendering is done in SideFx Houdini [20], using the Mantra renderer in an education version 18.5 of the software.

First, metal materials with the following maximum differences are tested. Materials tending to be monochromatic do not show any difference. Only colored materials are affected; most noticeable gold paint.

Material	L_{max} difference
Aluminium	0.00000001
Copper	0.00001092
Gold	0.00001846
Goldpaint	0.00208561
Oxidiced Steel	0.00000000
Platinum	0.00000006
Silver	0.00000001
Titanum	0.00000003

Table 7. *Maximum difference values for cg metal materials*

Fig. 19 shows three renderings out of the Houdini Mantra renderer. Paint-coated shaders with the primary colors red, green, and blue are used. A white directional light and an Environment Map are lighting the scene to simulate a practical example. The materials are rendered out as linear scene-referred and imported into Nuke as ACEScg without further conversion. That's why the renders' primary colors match the ACEScg primaries.
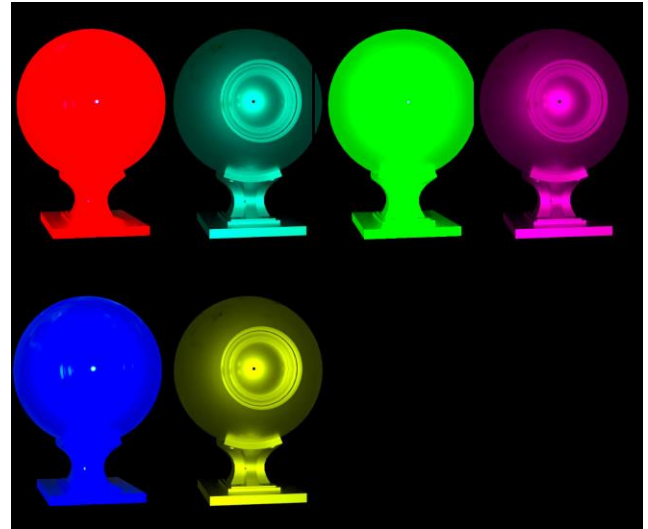

Figure 19. *CG renders and differences of primary colors out of Houdini Mantra*

Table 8 shows the maximum differences between original and compressed renders. The peak luminances of the differences are also given.

Difference values – Renders				
	Red (channel)	Green (channel)	Blue (channel)	
Red (image)	0.0	2.91147	1.91490		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	2.22093	2.41246	2.31346	2.1340	1.65118
%	100%	108.62	104.17	96.09	74.35
Green (image)	2.31804	0.0	1.91777		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.63085	0.68050	0.65492	0.6081	0.48161
%	100%	107.87	103.82	96.40	76.34
Blue (image)	2.32610	2.91467	0.0		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	2.57732	2.79063	2.68036	2.4803	1.93961
%	100%	108.28	104.00	96.24	75.26

Table 8. *Maximum difference values for coated-paint cg renders*

In the chromaticity diagram, straight lines from white to the fully saturated colors appear. Also, a second vector displays the Environment map's influence. The hue lines (see section 3.2) in the compression area are bent to some extent. The bending concerns both: the primary color lines and the Environment Map's influence. If brand colors are close to a primary color, they are affected as well.
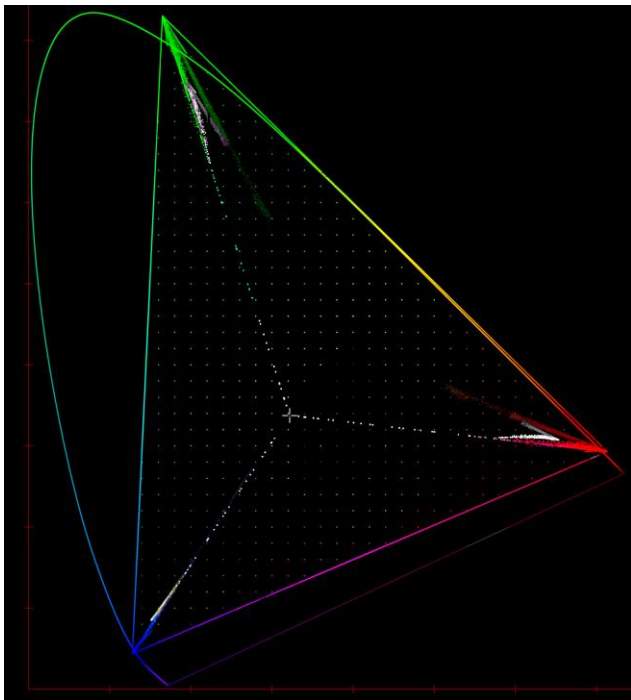

Figure 20. *CIE chromaticity diagram of CG primary renders after compression*

Figure 21. *Environment map used for cg lighting [21]*

2.6. Analyzing colors outside the Zone of Trust – conclusions

A very high percentage of the evaluated imagery in this section do not show any or only minimal differences between the original and the compressed image, not visible by the naked eye. Rare exceptions are bright and saturated colors in nature like flowers, mushrooms, and some animals.

Noticeable differences appear mostly in some human-made objects like bright-colored cloth, paint, and car paint create minor differences. Only lights may produce larger differences. The Gamut Compressor processes natural colors and artificial colors without significant artifacts.

The algorithm can also deal very well with RAW images, HDR environment maps, and CG renders. Renders of primary colors are bent to some extent in the compression area. This behavior is due to all images but clearer visible in the straight lines from white to the primary (and secondary) colors (see section 3.1).

3. Analyzing the parameters of the *GamutCompressor* algorithm

3.1. Power Curve Exponent

The Power Curve Exponent of the algorithm describes the strength of the compression. The default value is 1.2.

> *"Control the aggressiveness of the compression curve. Higher power values result in more compressed values distributed closer to the gamut boundary. This will increase the 'color purity' or 'saturation' once the image has been rendered through a display transform.*
> *A power value of 1 is equal to a Reinhard compression curve. Higher values have a smoother transition and approach C2 continuity." [22]*

> *"The value of the exponent is currently set at 1.2. There is no objective measure of the correctness of this value" [3].*

The relationship between Power Curve Exponent, Compression Threshold and Distance Limit is depicted in Fig. 22.
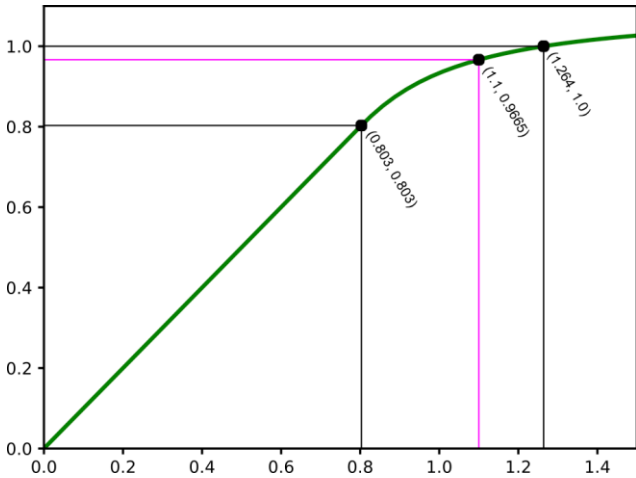

Figure 22. *Green Distance Compression Curve (Threshold=0.803, Limit=1.264, Power=1.2) [3]*
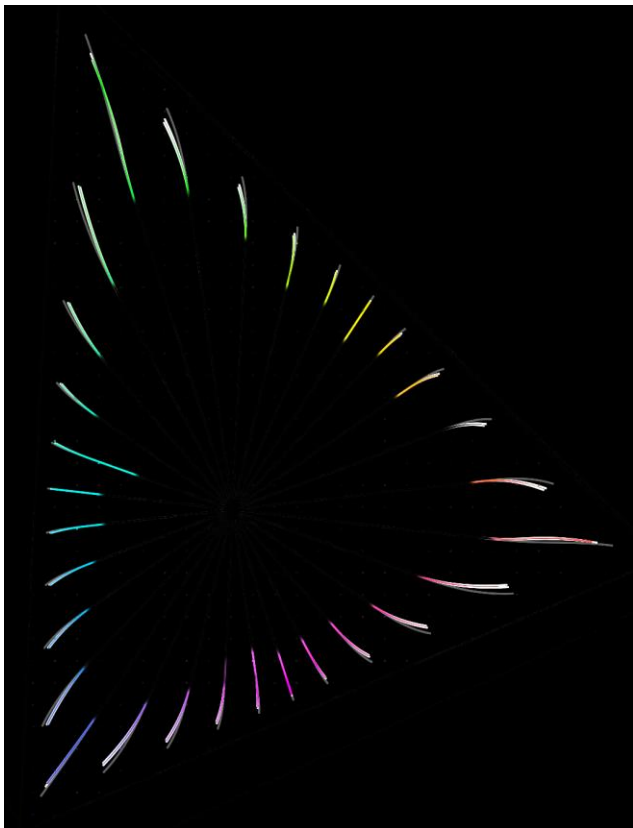

Figure 23. *Comparison of bent hue lines for the Power Curve Exponents (1.0 color, 1.2 white, 2.0 grey)*

In the following step, the Power Curve Exponent's influence on the compression is investigated. The values given by the Gamut Mapping Working Group in a testing scenario are 1.0,

1.1, 1.2, and 1.3. A value 2.0 is added to test a more extreme setting.

Fig. 23 depicts the compressed *hue lines*, where a *hue line* in this test in a scene-referred linear context is a linear ramp from white to the color on the gamut boundary. One may notice that the hue lies are bent inside the compression area; and that the 1.0 exponent is most aggressive while the 2.0 exponent keeps the lines in a more extensive straight.

To display the Compressor's chromaticity diagram areas, a colorful image with large painted areas is analyzed. The white parts of the xy-chromaticity diagram at the fringe display the colors that are affected. The table beneath shows the compressed color area percentage, with the default exponent 1.2 is set to 100%. Exponent 1.0 is the most aggressive and compresses more colors. Exponent 2.0 is less aggressive and leaves more colors untouched, while exponent 1.2 is right in the middle. It should be noticed that the Compressor in this example affects colors that are already in gamut, but it demonstrates the functionality of the power exponents.
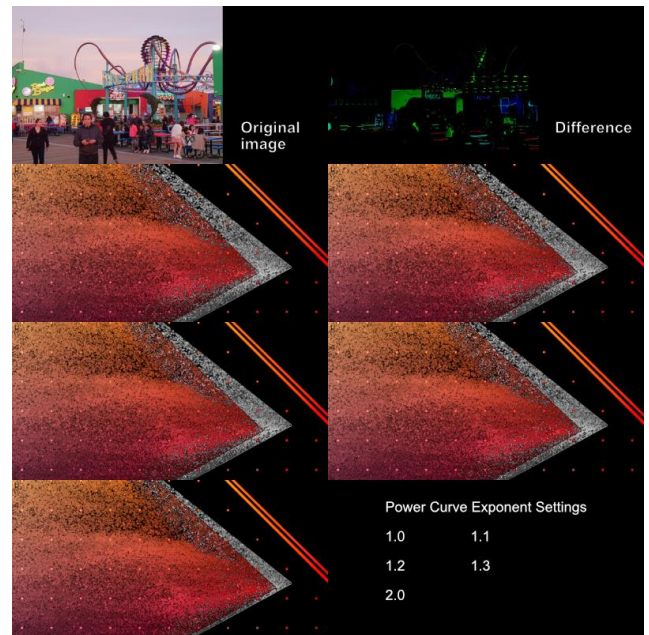

Figure 24. *Comparison of compressed image areas with different Power Curve Exponents – colors in-gamut [23]*

	Difference values – Pacific Park image				
	Red	Green	Blue		
RGB	0.00581	0.02171	0.0		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.01676	0.01899	0.01779	0.01581	0.01100
%	100%	112.72	106.13	94.3	65.64

Table 9. *Maximum difference values for an image with colorful painted surfaces*

Fig. 25 is an example of an image that contains colors outside the gamut. The power Curve Exponent's behavior is the

same as in the previous example. There is a gap between the color area and the ACEScg color space's gamut border. In the next sections, two possibilities of filling this gap are discussed.
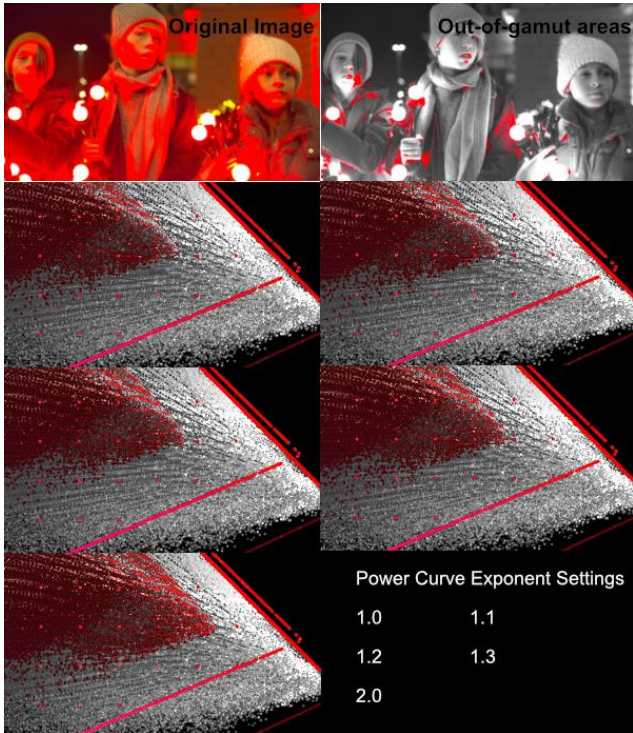

Figure 25. Comparison of compressed image areas with different Power Curve Exponents – colors out-of-gamut [24]

	Difference values – Red Christmas image				
	Red	Green	Blue		
RGB	0.0	0.42770	0.24721		
Exp.	1.2	1.0	1.1	1.3	2.0
L_{max}	0.32380	0.34914	0.33606	0.31227	0.25428
%	100%	107.83	103.79	96.44	78.53

Table 10. Maximum difference values for an image with out-of-gamut colors

Fig. 26 shows an example of a keyed blue screen image (Fig. 38) that contains out-of-gamut colors. When a keyer is applied, artifacts appear due to the compression. The 2.0 exponent shows the most prominent artifact, while exponent 1.2 the less one.

3.2. Compression Thresholds

In this step, the *Compression Threshold's* influence is investigated. It contains the percentage of the *Zone of Trust* (core gamut) that is protected.

Fig. 27 explains how the *Compression Thresholds* works in conjunction with the *Power Curve Exponent*. It comprises a vector from the primary color to the complementary color. The colored area contains all the unaffected colors for the 1.0 component. The small white area contains additional colors not

affected by the 1.2 exponent, and the gray area contains additional unaffected colors by the 2.0 exponent. Changing the threshold values moves the three areas closer or farther away from the gamut border. Larger numbers push the threshold towards the gamut border.
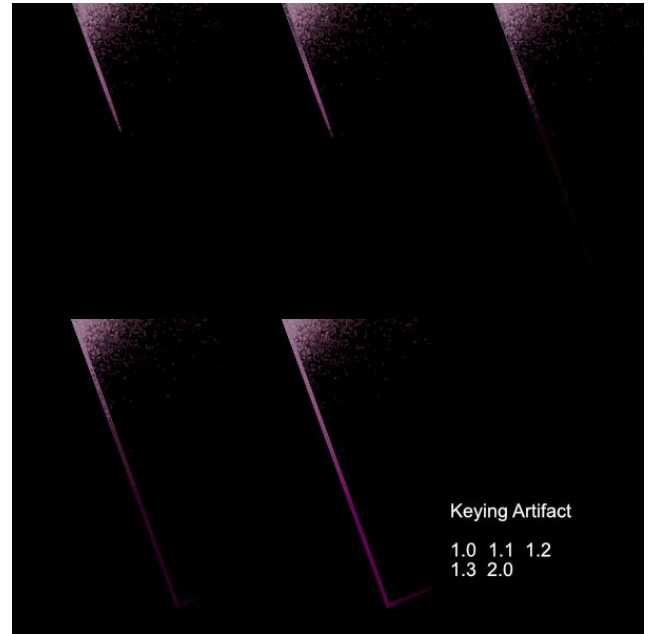

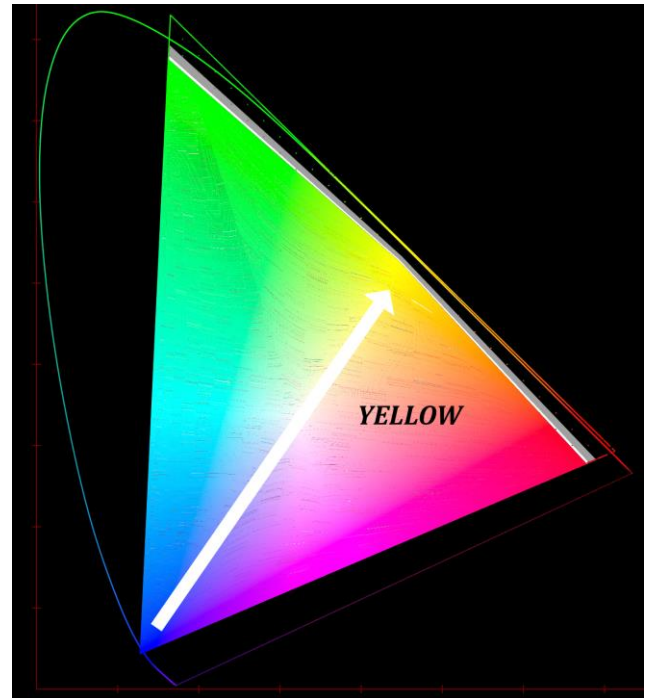Figure 26. Keying artifacts due to Power Curve exponent settings

Figure 27. Compression Threshold yellow with different Power Curve Exponent settings (color – 1.0, white 1.2, grey 2.0)

A short description is added to the Nuke interface to clarify the Compression Threshold's functionality (Fig. 28).
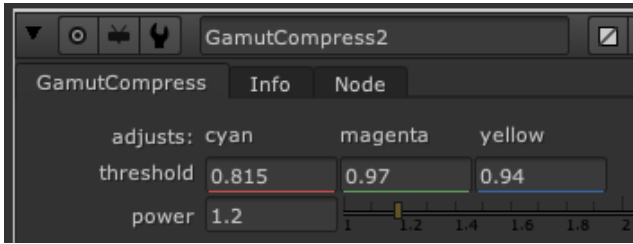

Figure 28. *New GamutCompressor Interface*

Now, a small experiment is performed. The GoPro 7 [25] shot in Fig. 29 contains negative color values due to the input color conversion (OCIO Input – GoPro – Curve – Protune Flat to ACEScg). When the gamut compressor is applied, the out-of-gamut colors are moved back into the gamut, but the sundown colors are moved away from their original position.
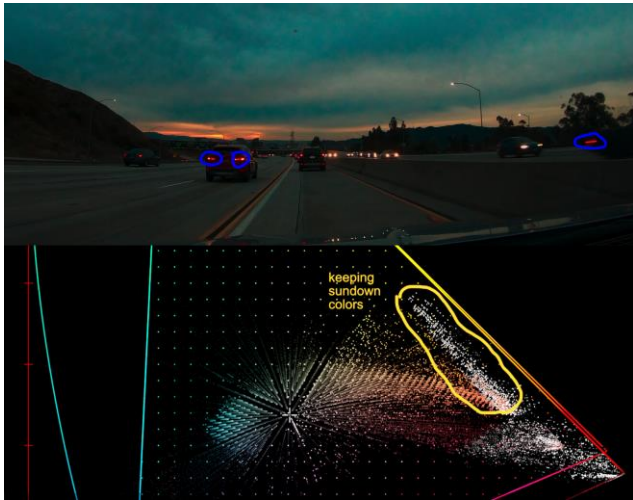

Figure 29. *GoPro-Protune shot with out-of-gamut colors (blue circled) and affected sundown colors [26]*

To move these colors back to the original position but keep all colors inside the gamut, the following steps are executed (Fig. 30):

1. First, the yellow threshold value (0.94) is increased and moves the yellow-orange sundown colors back into place.
2. The magenta threshold is also increased to 0.97. This operation moves the red colors back and fills the gap to the ACEScg boundary.
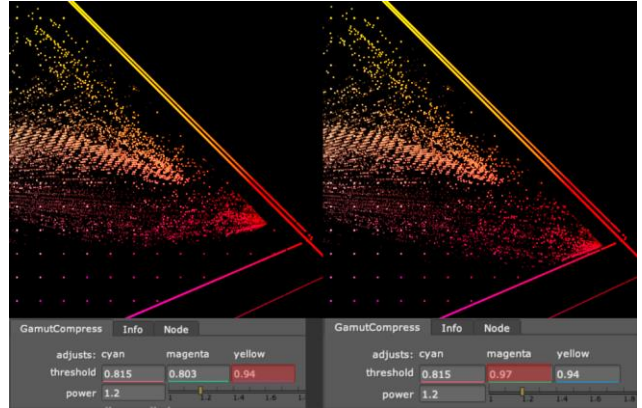

Figure 30. *Sundown colors moved back to original position (left). Gap to ACEScg boundary closed (right)*

3.3. Distance Limit

In the next section, the Distance Limit's influence is investigated.

"[Distance Limit is] the limit of distance from the achromatic axis that values will be compressed to the gamut boundary. The limit values have been set to constants chosen so that the encoding gamuts of all digital cinema cameras with official ACES IDTs (ARRI, RED, Canon, Sony, Panasonic) will compress to within AP1." [3]
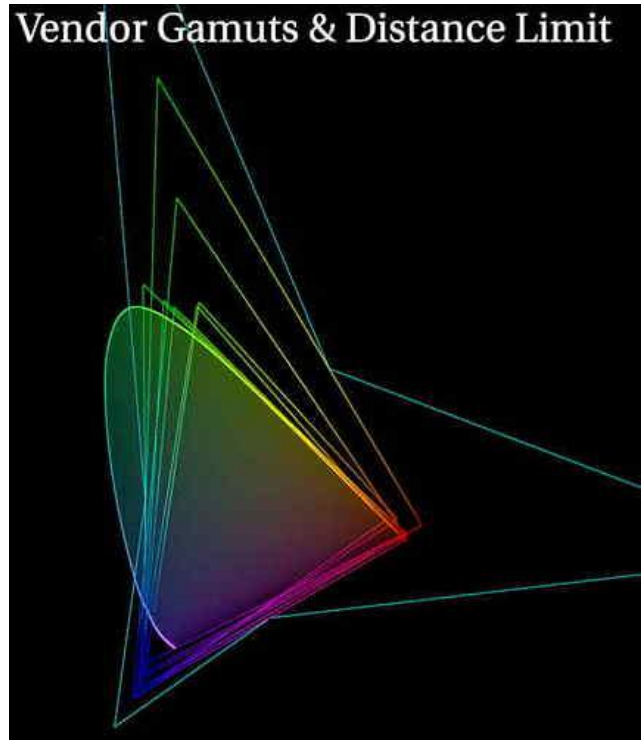

Figure 31. *Camera vendor gamuts and the distance limit (green outline) [9]*

Because of the vendor gamuts' unusual shapes, the out-of-gamut colors are pushed considerably deep into the gamut, leaving a gap to the gamut border. If one uses minimal values for the distance limit, the gap between the compressed colors and the gamut boundary can be closed (Fig. 32). Artifacts may appear due to the small target location area in some images.
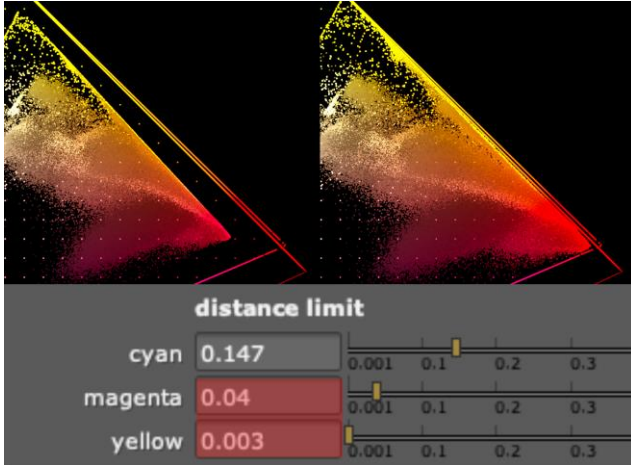

Figure 32. *Filling the gamut boundary gap by manipulating the distance limit*

3.4. Analyzing influence of parameters – conclusions

The following conclusion concerning the parameter settings for the *Power Curve Exponent, the Compression Threshold*, and the Distance Limit are:

1. Power Exponent 1.2 is a good default value.
2. Power Exponent 2.0 may be an excellent addition for soft compression in some circumstances.
3. *Compression Threshold* and *Distance Limit* parameters are useful for bringing colors back to their original position.

4. Analyzing the compression of images with out-of-gamut colors

4.1. Displaying the image areas with out-of-gamut colors

Fig. 33 shows the negative out-of-gamut colors using the Nuke's simple node tree from section 1.4. For better depiction, the original image has been converted to greyscale using an average of the three color channels.

4.2. Clamping negative colors after the compression

When this display function is applied to the compression results, it shows that negative values remain, obviously due to the image noise. Because the values are minimal and reside in the blacks, a clamp function is applied using the mask from the

display branch. The clamp sets set the remaining negative colors to black (see Fig. 34).

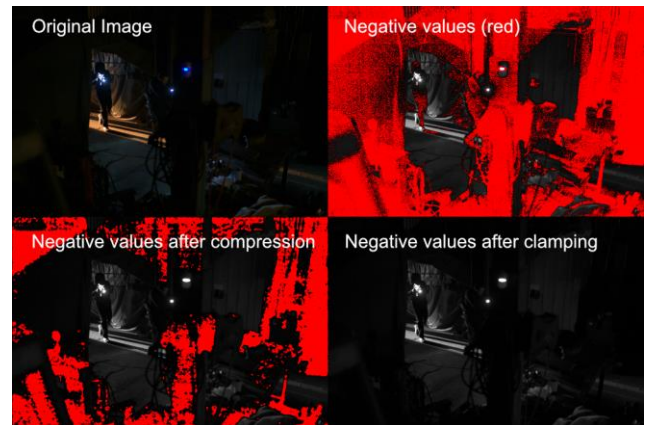**Figure 33.** *Original images (left) and out-of-gamut colors (right) [24][27]*

Figure 34. *Negative values after compression and after clamping [28]*

4.3. Masking the compression area

Now the mask from the display function is applied. This mask contains all the negative numbers and mask the appropriate image areas (see Fig. 25). The GamutCompressor compresses only the image areas with negative values and not adjacent colors in the image.

A problem is immediately visible. Heavily saturated borders between the affected and unaffected colors appear. If the mask is blurred, the problem is not solved because it is not clear how high the blur amount should be. Although with relatively high settings, the artifacts do not disappear. The results are somewhat unpredictable.

A slightly better approach is to mask out color areas that should not be processed, like these biscuits' brand colors. The GamutCompressor does not calculate the masked out image areas; these areas are not affected. The colors stay the same and show no difference in Fig. 36. This technique depends heavily on the shot and how the whole image is affected by the lighting.
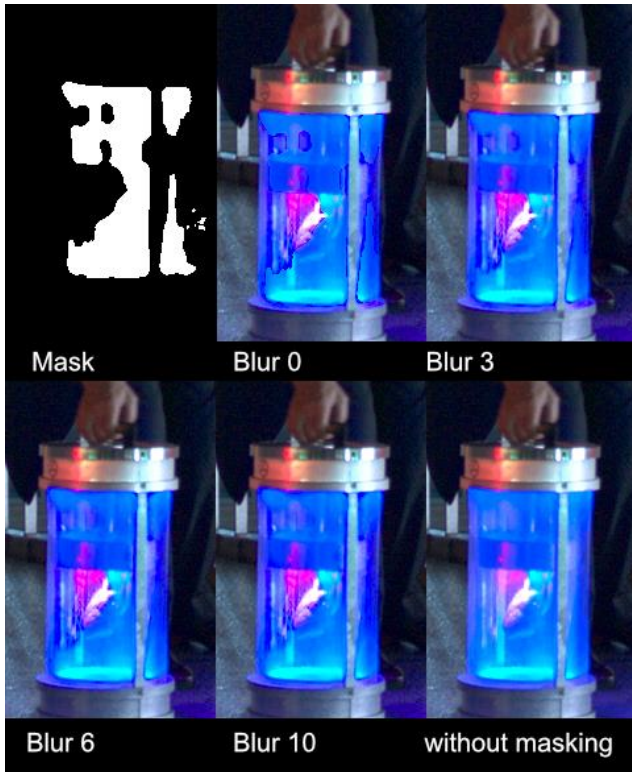
Figure 35. Artifacts appear when only image areas with negative values are compressed [29]
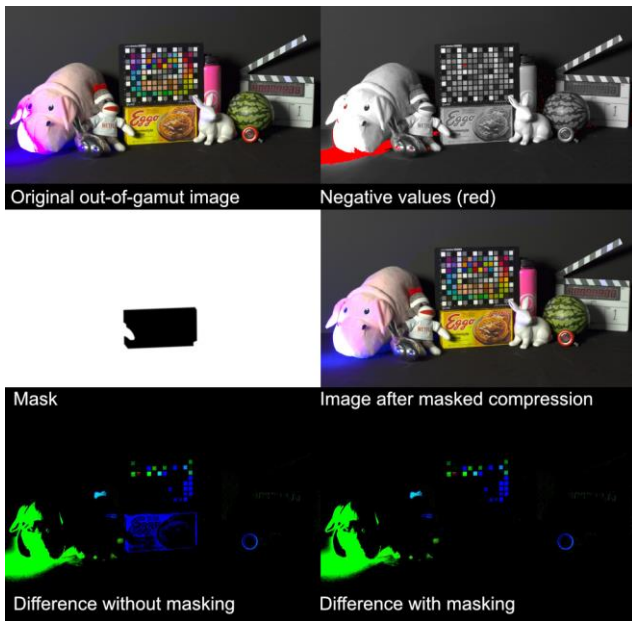

Figure 36. Masking out image areas that are not compressed [30]

4.4. Limits of parameter tweaking

Now a bluescreen image is examined. The basic idea is to set the thresholds so that the *Zone of Trust* also encompasses the Rosco Digital Green and Blue values [31]. These values for the

colors are available as angle and luminance in the vectorscope. Fig. 37 and Table 11 show the ACEScg values and the position of the bluescreen and greenscreen color in Nuke's vectorscope.

ACEScg RGB	Red	Green	Blue	Phase Angle	Luminance
#05710 Chroma KeyBlue	0.00125	0.00500	0.50000	342°	52
# 05710 Chroma Key Green	0.02523	0.0718	0.07241	242°	57

Table 11. *Rosco Chroma Key Blue and Green ACEScg and vectorscope values*
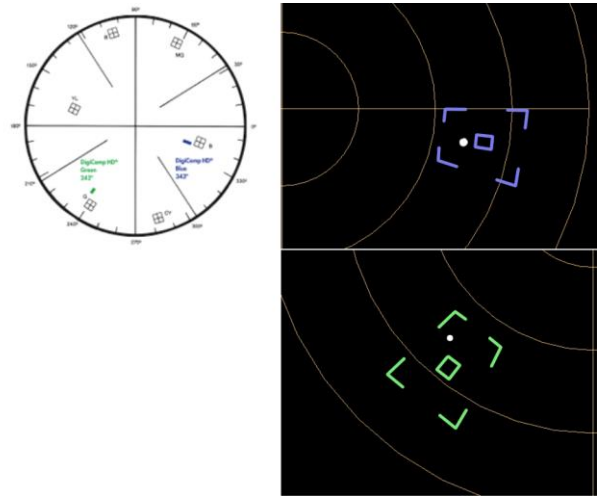

Figure 37. *Rosco DigiComp HD Blue and Green position in vectorscope [32]*

To keep the bluescreen and greenscreen color unaffected, the threshold of the values of the cyan and magenta thresholds is pushed very close to the gamut border until no differences between the original and compressed blue- and greenscreen color appear. The threshold changes for the green color are minimal and should not create problems. However, for the blue color, there is nearly no space for the out-of-gamut colors to be placed inside the gamut (Table 12).

Chroma Key Blue	Cyan	Magenta	Yellow
Original Threshold	0.0815	0.803	0.88
Modified Blue	0.998	0.99	0.88
Modified Green	0.0815	0.803	0.9

Table 12. *Modified thresholds to keep the bluescreen color inside Zone of Trust*

When the image in Fig. 38 is compressed, the bluescreen changes (middle). When this image is compressed using the threshold settings from Tab. 11, the original blue color is recreated. However, a visible artifact appears when a keyer is

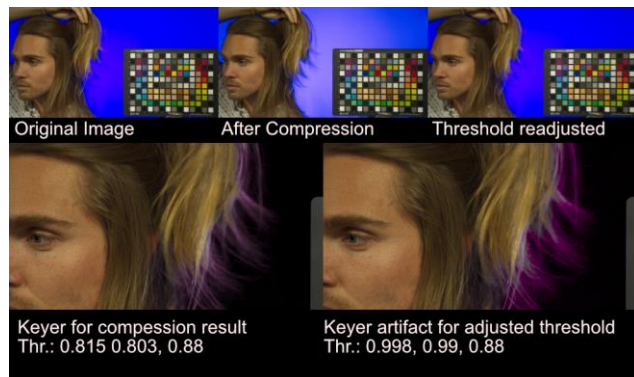applied because there is no sufficient place for a smooth transition between out-of-gamut and in-gamut colors.

Figure 38. *Visible artifact in close to border threshold settings [33]*

4.5. Analyzing images with out-of-gamut colors – conclusions

The conclusions for image compression with out-of-gamut colors are:

1. The Tool for displaying negative values is useful.
2. Maybe clamping is needed after the compression because of the noise's negative values.
3. Using the GamutCompressor only for image areas with negative values is not recommended, the results are unpredictable.
4. Better solution: Masking out colors to keep - but it depends on the image.

5. Recommendations for implementation

As stated in section 1.2, the Compressor is intended to be inserted in the ACES pipeline after the Input Device Transform (IDT). The ACES system consists – to this moment – of modules that lack parameterization. To integrate all possible case studies, some settings have been made very broad, especially the Distance Limit values. Naturally, this means that certain production pipeline problems cannot be treated specifically.

The recommendation is therefore to consider two different implementation scenarios:

1. Placing the GamutCompressor in the ACES pipeline with the default values directly after the Input Device Transform (IDT).
2. Additionally, the algorithm could be implemented directly into an application as a Look Modification Transform (LMT); for VFX work, it could be The Foundry's Nuke. To use this algorithm's powerful functionality, the parameters should be exposed to the user. This allows exceptional cases to be explicitly handled that would cause artifacts in other cases. For such an operator inserted directly into the application, it would be helpful to display the image areas with the out-of-gamut colors. Furthermore, the CIE xy-chromaticity diagram could be useful as an additional analysis tool.

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