# CREATING CONTENT WITH EXTENDED COLOR GAMUT FOR FUTURE VIDEO FORMATS

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*Abstract*

*New technologies in capturing and displaying images with extended color gamut and new standards for wide gamut color encoding enable a new market of extended-color-gamut content (video, images, games, electronic documents). What is the challenge and what are the issues when feature film production goes for extended color gamut? This paper discusses two topics: digital capture of extended color gamut scenes and color correction of wide color gamut footage. In film production, proof viewing and initial color decisions migrate from the post-production facility to the production site. When capturing digitally scenes with extended color gamut, what can be expected to be seen on the proof monitor? This white paper discusses the issues of sensitivity metamerism, color resolution and color clipping. Once captured, color correction creates the aimed looks for digital cinema viewing, TV home viewing, and other possible means of consumption. This paper discusses the issue of color correction with the constraint of multiple means of color reproduction. A new method is presented that supports the colorist to handle multiple color gamuts using the concept of soft gamut alarm.*

## INTRODUCTION

When looking into history of motion pictures and technology of argentic film, people always tried to enhance image quality and user experience. In 1932, Technicolor invented the 3-color-dye system starting worldwide the transition from black and white to colored motion picture. More recent efforts aimed to enhance resolution and image size from 35mm to 70mm argentic film [1] or from classical 2D film projection to 3D projection [2]. In all these examples, people tried to enhance image quality while preserving as much as possible from existing infrastructure. The color print of 1932 could be projected using the state of the art film projectors of that time. The film reels were the same. When testing 70mm film stock, the constraint was to keep the Digital Intermediate workflow of 35mm technology. For 3D film projection, the inventors [2] used classical film projectors and same film stocks, they just added an optical system.

In television and video, current standardization efforts include the increase of fidelity of color reproduction and the extension of color gamut. Aiming the fidelity of color reproduction, the EBU specified recently the reference monitors to be used in production and post-production [3]. The IEC specified a metadata format called “Gamut ID” to transmit color gamut information for better color reproduction [4, 5]. In order to increase the color gamut (and the image resolution) from High Definition (HD) to Ultra High Definition Television (UHDTV), the ITU-R (WP6C) looks into extending the color gamut. More precisely, they specify a video signal encoding format [6, 7] that allows conveying colors that are more saturated than specified in current HDTV color encoding format ITU-R BT. 709 [8]. Similar efforts have been done in SMPTE and IEC [9,10,11] but these solutions are not widely used.

If the video industry intends to migrate from HDTV to UHDTV, *production*, *distribution* and *consumption* of video needs to be adapted. For *consumption* of extended color gamut, display makers announce for 2012 first OLED TV screens able to show 40% and more of all visible colors (current displays are limited to 33%). Video *distribution* is addressed by ITU-R.

This paper focuses on the *production* of video with extended color gamut and presents two aspects.

First, extended color gamut will have impact on acquisition using digital cameras. While sets usually are prepared in a way that illuminance of surfaces and colors keep within usual ranges, directors now start to use lights and colors with peaky spectrum, or higher saturation. Three issues of digital acquisition will be discussed: sensitivity metamerism, color resolution and color clipping.

The second topic concerns color correction aiming multiple color displays with different, extended, color gamut and viewing conditions. The concept of soft gamut alarm will be introduced and illustrated.

## EXTENDED COLOR GAMUT IN DIGITAL ACQUISITION

New requirements in production using digital cameras include the capture of scenes showing colors with wider color gamut. Directors start to light scenes on production sets with colors that are out of the color gamut of usually used proof viewing devices (such as Rec. 709 monitors). For example in music life events, modern spot lights use programmable color filters able to generate light of high degree of saturation. In traditional production using digital cameras, such colors are avoided. In straight forward signal processing, illegal RGB values may be simply clipped somewhere in the imaging chain. This causes the color output on the reference screen to be widely different from the colors that can be seen in the scene. There is a need of controlled handling of out of gamut colors, in which the errors are minimized.

### Color encoding

Before discussing camera specific issues, some basic terms are recalled. The skilled color scientist will skip this section. When a color is expressed by color space coordinates, this is called color representation. When color representation includes aspects such as binary encoding and reduced validity such as device or observer dependence, this is called color encoding.

One type of color encoding is scene-referred color encoding. The principle of color encoding has been structured by the ISO [12] for the field of digital photography and desktop publishing, but the definitions are valid for the video domain, too. Scene referred color encoding identifies color coordinates that are meant to be directly related to radiometric real world color values. The raw RGB output values of a digital camera are usually transformed to scene-referred RGB values, such as defined by ITU-R BT.709 [8]. However, we will see later that this relation is ambiguous due to sensitivity metamerism.

Another type of color encoding is output-referred color encoding. As opposed to scene-referred color encoding, output-referred color encoding is used to represent reproduced colors. Output-referred color encoding identifies color coordinates that are prepared for specific output devices with their defined characteristics and viewing conditions. For example, RGB values of a video can be said to be output-referred color encodings since they are intended for a reference display under reference viewing conditions. Well-known output-referred color encodings are for example sRGB display input values or CIE 1931 XYZ values.

Output-referred color encodings are obtained by color matching experiments. An output-referred color space and the related color matching experiment are characterized by:

- the characteristics of the output device driven by the output-referred color coordinates;
- the characteristics of the observer that perceives the colors reproduced by the output device.

Let us take as example the output-referred RGB coordinates being input to a display. The related trichromatic color matching experiment is classical [13] and involves the CIE 1931 standard (human) observer, corresponding to the average behavior of a small group of test persons. In the experiment, an observer compares the color reproduced by the display with the color of a monochromatic light of a specific wavelength. For each wavelength, he adjusts the RGB values such that both colors match. The result of a color matching experiment are three color matching functions (red, green and blue) indicating, for each wavelength, which RGB coordinates should be input to the display in order to match the monochromatic light.

The classical color matching function results in the output-referred RGB color space of the specific RGB display that was used at the time of the experiment. An RGB space can be defined for any other RGB display.

Better known is the output-referred CIE 1931 XYZ space based on an ideal display with XYZ input signals and mathematically derived XYZ primaries. XYZ coordinates encode a color according to these standardized primaries and according to the CIE 1931 standard observer.

Less known is that we could build an $R^C G^C B^C$ or $X^C Y^C Z^C$ output-referred color space that is based on a digital camera as observer. Let us recall that output-referred color spaces not only depend on the aimed display but also on the referred camera used as observer.

Linear output-referred color spaces can be transformed into each other using a linear coordinate transform as far as the same observer is considered. Hunt [13] shows this for RGB-XYZ transform and the SPMTE [14] for different RGB spaces of different displays. Trichromatic observers (such as the human eye or a digital RGB camera) are characterized by the spectral sensitivities of their photoreceptors. The set of three spectral sensitivities are directly linked to a set of three XYZ color matching functions. One set can be derived from the other but they are of different nature.

Color characteristics of digital cameras

The color performance of a camera is determined by a series of elements:

- Optical system (chromatic aberration, transmission);
- Color filters (shape and coverage of spectrum);
- Primaries separation (beam splitting or CCD RGB pattern);
- Color signal processing (noise, colorimetry transform).

From color science point of view, a classical color image camera is a trichromatic observer. Another well-known trichromatic observer is the human standard observer.

A digital camera is characterized by its spectral locus, defined by the coordinates of all responses to monochromatic light in $R^C G^C B^C$ or $X^C Y^C Z^C$ or even $x^C y^C$ spaces. The spectral locus is the characteristic of a camera that corresponds to the color gamut of a display. The camera spectral locus is less known than the spectral locus of the human observer, but is of the same nature since a classical color image camera is just another trichromatic observer. The spectral locus is represented in an output-referred color space and can be derived directly from the corresponding color matching experiment (see further below). For example, from CIE 1931 XYZ color matching functions, a pair of xy coordinates can be calculated for each wavelength. Plotted in the chromatic xy diagram, these points define all together the curve of the spectral locus. The spectral locus circumscribes all colors that are visible by the observer.

<u>Sensitivity metamerism</u>

Metamerism happens when different spectral power distributions result in the apparent matching of colors for a human eye, or matching of color coordinates for a camera acquisition.
A camera transforms a real-word color stimulus, defined by a spectrum, into three RGB tristimulus values. Similarly to human vision, cameras are subject to metamerism. This raises issues in two directions:

- A given camera may produce identical tristimulus values for two (or more) different spectral stimuli, called a metameric pair (or metameric set, respectively);
- A camera with sensitivity curves different from the human eye differs in their metameric pairs from a human observer.

The link between scene-referred camera RGB values and CIE 1931 XYZ coordinates cannot be trivial since two different spectral sensitivity curves sets are involved, that of the camera and that of the human eye, respectively. Camera and human eye may differ in their metameric pairs leading no non-invertible relations between RGB and XYZ coordinates such as illustrated in Figure 1. Distinct *rg* points can correspond to the same *xy* point and vice versa. *rg* and *xy* chromaticity coordinates are obtained from the RGB scene-referred camera output values and from the output-referred CIE 1931 XYZ values, respectively, by normalization [13].

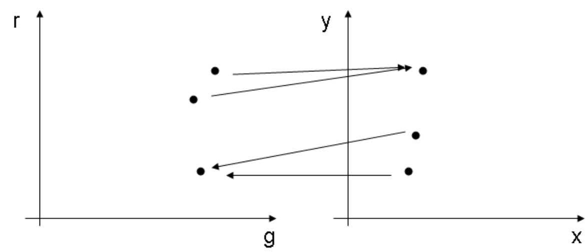


*Figure 1: Non-invertible relation between rg and xy due to sensitivity metamerism*

This problem is referred to as sensitivity or observer metamerism and can be avoided completely only if the camera satisfies the Luther condition [15] i.e. if its spectral sensitivities are linear combinations of the color matching functions of the CIE 1931 standard observer. Another solution is multispectral cameras [16].

<u>Color clipping in proof viewing</u>

A solution to the problem of sensitivity metamerism would require the estimation of scene-referred and human observer related color values, for example CIE 1931 XYZ values, from camera raw RGB output [15,17]. However, in proof viewing we have a different problem: How to reproduce captured colors on a given proof viewing monitor?

When proof viewing a camera raw RGB output signal on an RGB proof viewing monitor, the raw RGB values should be transformed into output-referred RGB values. We call this a proof viewing color transform. As shown in before, such a proof viewing color transform can exist only up to metamerism difference between the camera and the human eye.

For analysis, let us develop a straight forward proof viewing color transform. For presentation purpose we neglect any non-linearity. For a given camera and a given proof viewing monitor, a straight forward proof viewing color transform can be determined by the following steps:

- Determining the three scene colors that are within the color gamut of the proof viewing monitor;
- Measuring the camera output *RGB* values for these three colors;
- Determining the monitor input $R^m G^m B^m$ values for these three colors;
- Set a linear *RGB* transform *RGB* to $R^m G^m B^m$.

When applying this transform to the camera RGB output values, attention has to be paid to $R^m G^m B^m$ values that are outside of the valid coordinate range, for example [0;1] for normalized RGB values or [64;940] for 10 bit encoded RGB values in TV systems. The values should either be clipped, or soft clipped or compressed into the valid coordinate range.

Figure 2 shows an example for simple color clipping. We set a series of scene colors outside of the proof viewing monitor color gamut and captured them by a digital film stream camera. We applied the straight forward proof viewing color transform and RGB clipping. We displayed the processed RGB values on the proof viewing monitor and measured the CIE xy chromaticies on the monitor and in the scene.

As observed in Figure 2, color clipping modifies hue and saturation. While desaturation may be accepted by a director watching a proof viewing monitor, hue changes are not acceptable. A proof viewing color transform should address and solve this problem.

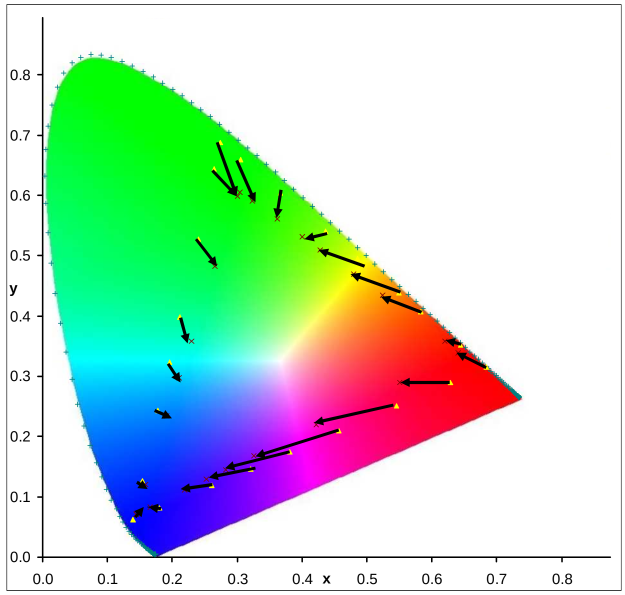


*Figure 2: Color clipping (see arrows) of sample real scene colors when displayed on a Rec. 709 proof viewing monitor*

Color resolution in digital acquisition

Another issue of digital acquisition when capturing scenes with extended color gamut is the color resolution:

- Difference of filter spectrum from spectral sensitivities of human eye;
- Restricted capacity to distinguish saturated colors;
- Impact on precision of captured hue.

We want to show in the following that these issues result in additional errors on a proof viewing screen:

- Hue shift;
- De-saturation and color clipping.

We will use in the following an ideal proof viewing monitor without color gamut limitations. Color clipping errors such as discussed before are thus excluded.

Let's take a series of test colors at constant magenta hue and with increasing saturation in perceptually uniform IPT color space [18].

Figure 3 shows one of the possible sets of spectral power distributions that correspond to the chosen test colors. (Note that an infinite number of spectral power distributions may result in the hue and saturation of a given test color.) The spectral power distributions in Figure 3 are representative for spectra becoming sharper with increasing saturation. As observed in Figure 3, the luminous contribution of the spectrum for wavelengths between 480nm and 580nm decreases with increasing saturation. The four most saturated test colors have even zero contribution.

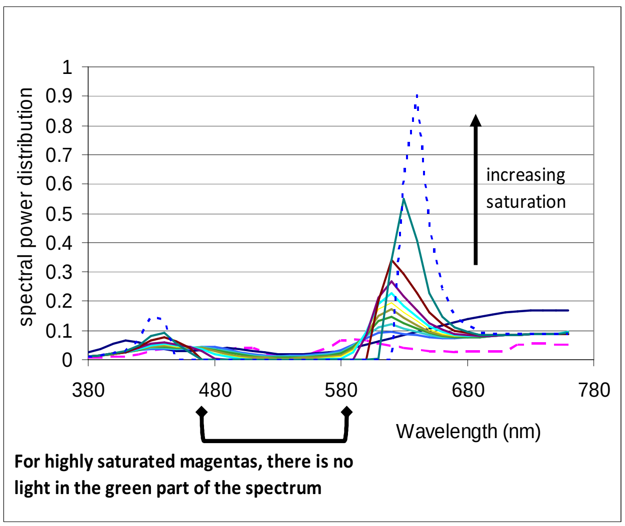


*Figure 3: A set of spectral power distributions corresponding to magenta test colors with increasing saturation from low (magenta dashed) to high (blue dotted)*

In such a case, one channel of the camera (here the green G channel) will have no signal and then the camera no more exhibits trichromatic characteristics, but only two channels are active/excited. Figure 4 shows how R, G and B channels evolve with increasing saturation at constant hue according the stimuli from Figure 3. We see the system becoming di-chromatic for stimulus S100 and above, where only the R and B channels integrate light. For these stimuli, hue and saturation deviate as the acquisition system is no more coherent with the usual three channel system behaviour.

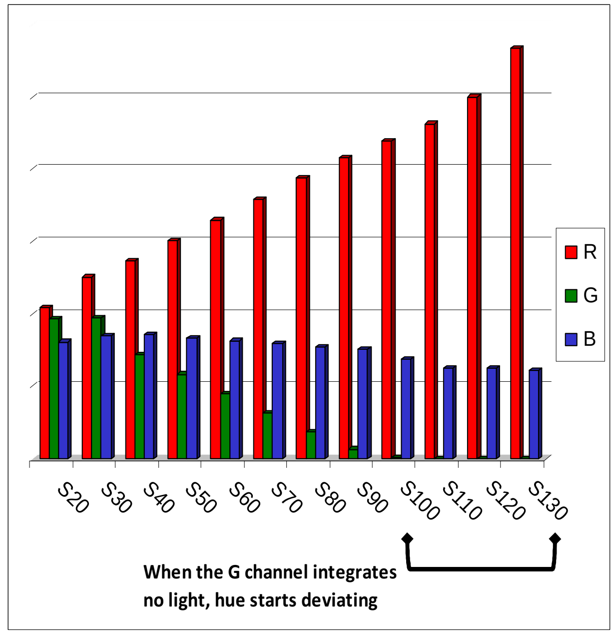


*Figure 4: RGB output with increasing R channel (red) decreasing B channel (blue) and decreasing and cropped G channel (green)*

A solution to this problem involves the optimization of the spectral sensitivity curves and is beyond the scope of this paper. Such a solution should include an evaluation of color precision such as carried out by Pujol et al. [19] on the number of distinguishable colors inside the McAdam limits.

## EXTENDED COLOR GAMUT IN COLOR CORRECTION

One of the artistic steps in production is color correction. Often a first phase is carried out to adjust roughly film footage or raw streams acquired by digital film stream cameras. Large mismatches in color balance and transfer function are compensated by linear matrices and non-linear one-dimensional transfer functions, respectively. Frequently, specific 3D Look-Up-Tables (LUT), also

called Cubes, are applied to produce a more pleasant version than the raw version. In a second phase, the director of photography and the colorist apply artistic color changes in order to obtain the desired look of the images.
In this artistic phase, the director of photography describes the intent of color correction while the colorist or a skilled operator has to translate the intent into an actual color transform applied to the footage. Such a color transform may include an increase of saturation, a change of color hue, a decrease of any RGB channel or an increase of contrast, for example. Color correction can be applied to an entire frame, to a set of frames, to a specific region in one single frame or even to all image regions in several frames corresponding to a specific color or semantic object (tracking).

Color reproduction during color correction

During this process, the director of photography and the color grading operator have to keep in mind what will be the impact of the applied color correction on the final reproduction medium. For example, if argentic film is first scanned and digitalized and then color corrected using a dedicated, digital proof-viewing projector, the operator verifies the applied color correction on the projection screen while the final reproduction is done by a film printer and then the film is projected.

Differences between the proof viewing display device (for example a digital proof-viewing projector) and the final reproduction device (for example a film printer followed by film projection) should be taken into account during color correction. Differences are due to different media, different equipment but also to different viewing conditions. Viewing conditions include ambient light, surround, background, reference white and adaptation state of the human eye. Differences between the proof viewing display device and the final color reproduction device can include objective, measurable differences of CIE 1976 hue angles, changes of CIE saturation, changes of contrast, differences in CIE 1976 luminance, differences in dynamic range, differences in color gamut as well as differences in color appearance such as changes in lightness, saturation and chroma. The latter three differences can not be photometrically measured.

A known solution to this problem is colorimetric color management (CMM) [14]. For CMM, the characteristics of the proof viewing device and the final reproduction device are measured, mathematically modelled and then compensated using a color transformation. CMM takes into account the color gamut of the devices. When an image contains colors outside of the color gamut of a display device or close to the border of the gamut, the applied color transform may contain color gamut compression, color clipping or other specific operations such that the transformed colors are inside of the device color gamut.

Issues of color correction

The difference of color gamuts of display devices is a problem for color correction. It may happen that the operator applies a color correction that generates the desired image on the proof-viewing device while the final reproduction device is not capable to reproduce some of the colors since the color gamut of the final reproduction device is different from the gamut of the proof-viewing device. It may happen that the operator wants to apply a specific color correction which would generate acceptable results on the final reproduction device but which cannot be visualized on a proof-viewing device with different color gamut.

A known solution is

- to detect out-of-gamut colors for the final reproduction device;

- to detect out-of-gamut colors on the proof view device;
- in the framework of CMM and
- to show a gamut alarm to the operator when an out-of-gamut color has been detected.

Figure 5 shows a typical example how gamut alarm is signaled to the operator. Each pixel that contains a detected out-of-gamut color is shown white.

Classical color correction systems offering gamut alarm functionality however do not address a series of problematic cases.

*Figure 5: Original image on the screen of the colorist without gamut alarm (top) and with gamut alarm (bottom)*

The first case is the difference in viewing conditions. The gamut alarm mechanisms are limited to colors that can not be rendered on a display in the framework of colorimetric color management. In this framework, colors are usually measured by CIE 1931 XYZ coordinates. These coordinates do not consider viewing conditions that influence the human observer while watching the display. In an appearance-based color management framework (appearance-based CMM), such influences are compensated. In such a case it may happen that a color that the operator desires on the proof viewing device can be reproduced on the final reproduction device in colorimetric terms but can not be reproduced when viewing conditions are compensated.

A second case is the consideration of an original reproduction device. When an operator works on footage that is aimed for a final reproduction device and proof viewed on a proof viewing device, it may be important to consider where the content comes from, i.e. for which device the content was originally prepared. This device is called here original reproduction device. It may happen that a color after color correction is well reproduced on the proof viewing and final reproduction devices but not on the original reproduction device. This case needs to be detected and indicated to the operator.

The third case is the uncertain nature of viewing conditions. In an appearance-based CMM framework, influences of viewing conditions are compensated. As soon as colors need to be modified since they are out of the gamut of reproducible colors taking into account viewing conditions, they should be indicated to the operator. This could be an advanced case of classical gamut alarm. Such colors could be marked on the proof viewing screen by specific false colors, for example red. Classical gamut alarm is binary: either on or off. This is well adapted for the case of out-of-gamut alarm considering well-defined color gamuts of display devices. A binary gamut alarm is not adapted to the gamut of reproducible colors considering viewing conditions since characteristics of viewing conditions are less well mastered and known than characteristics of display devices. A binary gamut alarm would be finally not useful for the daily work of the operator.

The fourth case is when the operator wants to modify out-of-gamut colors. There is a difficulty of interpretation of classical gamut alarm. If classical gamut alarm is shown on the proof viewing device, those regions of the image are marked with a false color that represents out-of-gamut colors. An example is shown in Figure 5. When the operator looks at the image with gamut alarm, he aims to identify the colors (their hue, their saturation, their luminance) that are out of gamut. Either he switches on and off the gamut alarm or he analyzes the image as it is.

There are situations where this is easy. In Figure 5, he will identify the blue tones in the sky that – once getting clearer – approach the gamut border and go slightly outside. The blue tones are easy to analyze since the blue sky region contains a variety of tones and transitions. By the position and shape of the out-of-gamut regions the operator can easily analyze the problem.

There are situations where the identification of out-of-gamut colors is difficult. In Figure 5, the red roofs and the brown walls are out out-gamut. Since transitions are lacking, the operator can not be aware which portion of red and brown tones is concerned. This problem is increased in animated and painted images where the color palette is often restricted. It is not visible whether the correction to be applied to these colors needs to be weak or strong. From the image in Figure 5, it is not clear to the operator what may happen to similar colors, those that may occur on the same objects but in following frames where light is slightly different.

This problem is solved today by trial and error as well as by switching on and off the gamut alarm. The operator applies corrections and verifies the gamut alarm. By “trying around” a couple of neighboured tones, he will understand the position of the concerned colors within the color gamut and apply an appropriate correction. This procedure takes time. Furthermore, the operator can not separate out colors being largely outside the gamut that need to be worked first. By watching the image in Figure 5, he can not establish a priority list for his work. This prevents from being quicker by neglecting colors which are only slightly out of gamut.

The fifth case is the growing variety of display technologies in the consumer world, when video productions are to be distributed to consumers with different display technologies, the color correction process using a single final reproduction device will fail to produce content that has controlled quality on displays with other characteristics than those of the targeted final reproduction device. In this case, there may be non-detected colors that are out of the color gamut of the actually used reproduction device.

## METHOD OF SOFT GAMUT ALARM FOR COLOR CORRECTION

This section introduces the new concept of soft gamut alarm that assists the colorist in future tasks of color correction with extended color gamut.

### Overview

The proposed method aims at proof viewing the visual content introducing the new concept of alarm.

The method has the four following advantages with respect to classical color correction:

- Differences between viewing conditions of different color reproduction devices are considered;
- The uncertain nature of knowledge about viewing conditions is taken into account and content can be created considering this uncertainty.
- The variety of final reproduction devices is considered and content can be created with regard to this variety;

- Reduction of degradations of content with respect to its original/raw version.

The proposed color correction method aims to correct original colors of original images targeting an original color reproduction device with respect to a set of final color reproduction devices. Each of these color reproduction devices is characterized by its color gamut of reproducible colors in device independent, absolute color space and its viewing conditions for color perception by human observers.

The method can be summarized by the following steps:

1. The original colors of the original images are displayed on a subset of the final color reproduction devices, these devices are called proof viewing color reproduction devices;
2. For each of the color reproduction devices, the distance of the original colors to the color gamut of the color reproduction device is determined;
3. For each of the color reproduction devices, the color appearance of the original colors and of the color gamut of the color reproduction device are determined, taking into account the viewing conditions of the color reproduction device;
4. For each of the reproduction devices, the visibility of the original colors is determined, each visibility being the distance of the color appearance of the original color to the color appearance of the color gamut;
5. On one of the proof viewing color reproduction devices, false colors are displayed instead of the original colors, where the false colors reflect the correspondent distance and visibility of the corresponding original color.

The original colors of the original images are color corrected by an operator. Original colors are replaced by modified original colors in a way that the corresponding distance is minimized and the corresponding visibility is maximized.

Figure 6 shows the color processing flow path according to the proposed system. From original colors, false colors are determined that depend on distances to color gamuts. Original and false colors are displayed.

The process can be assisted by automatic gamut mapping [20,21,22]. For all proof viewing color reproduction devices, gamut mapping is applied in such a way that the false colors can be switched off and a reproducible, mapped color is shown. Gamut mapping is preferably carried out in color coordinates representing the color appearance of the colors.

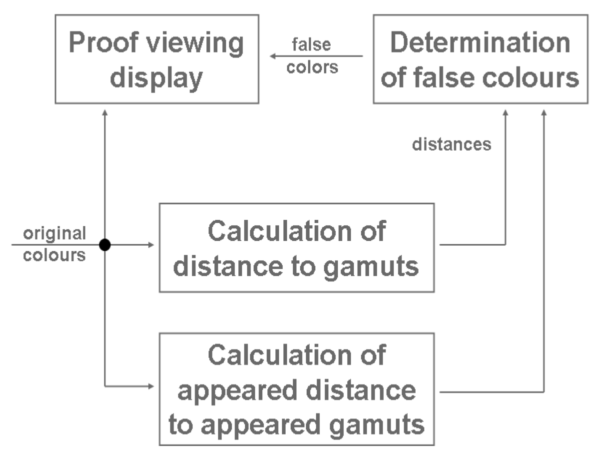


*Figure 6: Principle of the soft gamut alarm system*

The distance to the color gamut is determined as follows. For each of the reproduction devices, the distance of the original colors to the color gamut of the reproduction device is determined using the Euclidean or a weighted Euclidean distance. The distance is forced to zero for original colors being inside the color gamut.

The visibility of an original color for a human observer is determined from the so-called appeared distance that is determined as follows. The original colors aimed for the original reproduction device are transformed into an original device independent color using the device profile of the original color reproduction device. The original device independent colors are transformed into original appeared colors according to the viewing conditions of the original reproduction device, where the appeared colors reflect the color appearance for a human observer. For each of the color reproduction devices, viewing conditions of the reproduction device, the color gamut is transformed into an appeared color gamut. The appeared distance is determined as distance of the original appeared color to the appeared color gamut. For original appeared colors being inside the appeared color gamut, the appeared distance is forced to zero. The visibility is a monotonic function of the appeared distance.

The concept of soft gamut alarm can include more than one false color to be calculated shown instead of one single. For example, two false colors can be calculated as follows. A first false color is calculated from the distance between the original color and the color gamut of a selected color reproduction device. A second false color is calculated from the appeared distance between the original appeared color and the appeared color gamut of the selected reproduction device.

In the following, the proposed method of soft gamut alarm is applied to the case of proof viewing for color correction during post-production of a digitalized film.

<u>Reproduction devices</u>

Three reproduction devices are considered:

- A proof viewing digital projector under dark conditions;
- A digital cinema projector under dark conditions;
- A broadcast reference monitor under dim lighting conditions.

All devices are fed with RGB color values. By device characterization, for each reproduction device, a forward and an inverse device model is established. The forward device model calculates device-independent XYZ color values from device-dependent RGB color values. The inverse device model realizes the inverse operation. The devices model provides also the color gamut of the device.

<u>Consideration of color appearance</u>

The appeared color values and appeared color gamuts are established in the perceptual color space JCh of CIECAM-02. In this color space, J is lightness, C is Chroma and h is hue angle perceptual estimate.

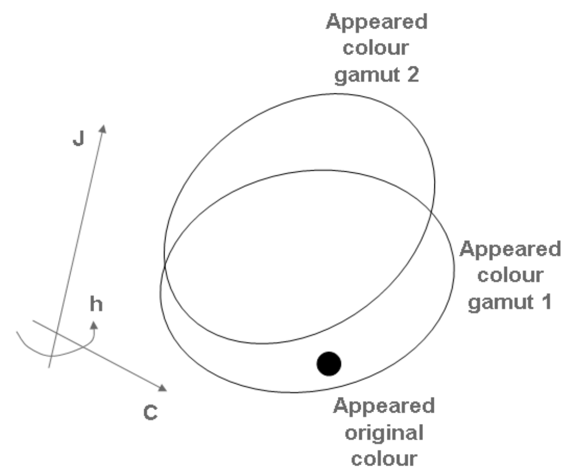


*Figure 7: Example of an appeared color that cannot be reproduced on device no. 2*

Figure 7 shows a sketch of an appeared original color and the appeared color gamut of two color reproduction devices no. 1 and no. 2 with different viewing conditions. On device no. 1, the appeared original color is close to the appeared gamut and has thus a bad visibility. On device no. 2, the appeared original color is outside of the gamut and is thus not reproducible.

The color appearance model (CAM) CIECAM02 is defined by the following viewing conditions parameters:

- The XwYwZw tristimulus values of the reference white; it can be set to the white point of the display obtained from the forward device model;
- La: this is the adapting luminance to which the observer is adapted; it is expressed as an absolute value in cd/m$^2$. It can be set to a value corresponding to 20% of the reference white luminance (mean video value).
- Yb: this is the background luminance which corresponds to the entire screen (or display) average white luminance. This value depends on the video content and may be specified as a percent of the reference white luminance. e.g. 20 for 20%.
- The surround type : there are four possible states:
- Average for day light vision (Yb>10cd/m$^2$);
- Dim for dim viewing conditions (3-5 < Yb < 10 cd/m$^2$);
- Dark for night viewing conditions (Yb<3-5 cd/m$^2$);
- Intermediate this is a linear combination between each of the three other states.

For the use of CIECAM-02, all these parameters need to be known. For the three reproduction devices, the parameters are chosen as follows:

- Proof viewing digital projector
  - XwYwZw: display white measured in the center of the screen
  - Yb: 20% of Yw
  - Dark surround
- Digital cinema projector
  - XwYwZw: display white measured in the center of the screen
  - Yb: 20% of Yw
  - Dark surround
- Professional television monitor
  - XwYwZw: display white measured in the center of the screen
  - Yb: 20% of Yw
  - Dim surround

Generation of soft gamut alarm

The false colors showing the gamut alarm are calculated for the original colors of the images. For each image pixel, and for each of the two other color reproduction devices (the DC projector and the reference monitor), two false colors are calculated for the original color of the image pixel. For each pixel in total, four false colors are calculated. In the following is explained, how two of these false colors are calculated for one of the two reproduction device, selected by the operator.

A first false color is calculated from a function of the color components of the distance vector that is related to the distance between the original color and the color gamut of the selected color reproduction device. More precise, the distance describes the Euclidian distance between the original color and the closest point of the color gamut.

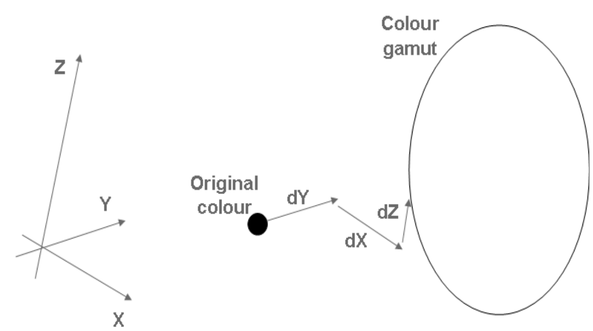


*Figure 8: Calculation of a first false color in CIE XYZ space from the distance between the original color and the color gamut*

For each color reproduction device, the distance of an original color to the color gamut of the color reproduction device is forced to zero for original colors being inside the color gamut. When the distance is zero, the related first false color is disabled and not calculated.

A second false color is calculated from a function of the color components of the distance vector that is related to the appeared distance between the appeared original color and the appeared color gamut of a color reproduction device. The components of the distance vector are calculated in the perceptual JCh color space of CIECAM-02 representing lightness, hue and saturation. By this choice, the second false color reflects the distance of the appeared original colors from the appeared color gamut of a reproduction device in aspects of lightness, hue and/or saturation, see Figure 9.

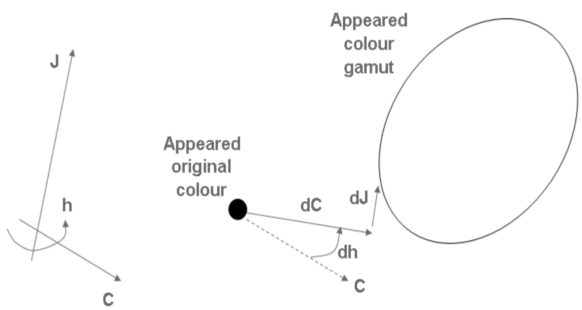


*Figure 9: Calculation of second false color from the distance between the appeared original color and the appeared color gamut*

The false colors are displayed according to the choice of the operator and will considerably help the management of wide color gamut.

## CONCLUSIONS

This paper discusses issues in digital acquisition and color correction of images with extended color gamut such as camera sensitivity metamerism, proof viewing color clipping and gamut alarm in color correction. Production equipment builders should address the increasing demand of directors to capture and proof view scenes with extended color gamut. Optimized color filters and wide color gamut processing modes need to be developed for cameras. Post-production and color correction facilities should adapt color transforms and the related functions of gamut alarm to extended color gamut including evolving viewing conditions, new display technologies and color appearance.

This paper provides some inputs to ease the production of extended color gamut content. However the distribution of this content raises additional issues to be considered, such as the adaptation to the device characteristics or the viewing conditions. However, it is clear that future video formats will integrate extended color gamut so as to better approximate and serve the human visual system capabilities.

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