A Gamut Boundary Metadata Format

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Abstract

Recent display technologies (LCD backlight, OLED) allow watching images with more contrast and more saturated colors than even digital cinema. Unfortunately, today's video content and broadcast cannot convey such colors due to the currently used colorimetry standard (ITU-R.BT 709). Solutions exist for more contrast and wider color gamut, but they are different in the video and photography worlds. New standardization initiatives for video (IEC 61966-2-4, ITU-R) try to set up a new, extended but fixed colorimetry, while digital photography applies - since a decade – flexible color management (ICC). However, in all these approaches the color gamut of either devices or contents is not described explicitly. This paper presents the new international standard IEC 61966-12-1 "Metadata for identification of colour gamut (Gamut ID)". This standard allows the precise and flexible description of a color gamut. The metadata supports graphics hardware, scalability, memory footprint efficiency, convex handling of non-convex gamuts, handling of fuzzy color gamuts, and handling of gamut cusps. This standard may be used in future systems for video color management or for image-dependent gamut mapping.

Introduction

Since the introduction of HDTV based on ITU-R BT.709 recommandation [8] in the 90ies, the technology of displays evolved considerably [10]. Plasma screen came first to market in 1995, but since several years, LCD screens are dominant. Today, mobile phones start to use wide color gamut screens based on OLED technology. For 2012, OLED TV displays are announced. Already available, LED backlight LCD displays reproduce extended color gamut using three or more primary colors to achieve this. Together with local dimming technology, the dynamic range can be extended dramatically.

The color in today's DVD, VOD and broadcast content is designed in a creative process within the post-production workflow. The resulting media encodes the colors according to the ITU-R.BT 709. This standard specifies the primary colors and the electrical-optical transfer function of an idealized camera. It is not always well understood that this document does not define the color characteristics of the post-production monitor. However, any display showing the content should have the same color characteristics as this reference monitor in order to reproduce colors as intended by the creator. The de facto post-production monitor has been for long a CRT monitor. Since this technology progressively disappeared, a monitor specification document is available from EBU [1] and work is ongoing in SMPTE.

Once created, colors of a video contents are conveyed to the consumer using ITU-R.BT 709 color encoding. However, and unfortunately, most of TV sets available on the market do not respect the EBU specification. Furthermore, color reproduction is used by TV manufacturers as a differentiator in stores, leading to a complete lack of color fidelity. The creative intent of the content creator can by no way be preserved in the current TV distribution context.

In order to ensure color fidelity on the consumer's screen and preserve the creator's intent, three well-known requirements need to be satisfied [4]:

1. The display should respect the color encoding defined by the ITU-R.BT 709 and EBU specifications;
2. Color gamut differences between the CE display and the EBU reference should be handled;
3. The viewing conditions need to be controlled or compensated for.

In this paper we address the second requirement. Since the content has been created using the post-production reference monitor, the colorimetric color gamut of the video content is included in and thus "compatible to" that of the monitor. If the CE display has a different color gamut, the following gamut mapping issues come up:

- Colors of the video content may be outside of the color gamut of the CE display and need to be mapped (gamut compression);
- Potential colors of the CE display are outside of the color gamut of the content and will never be addressed if content colors are not mapped (gamut extension).

Gamut mapping [2,3,7,9] is a well known topic. In this paper we rather focus on the availability of relevant information for color gamut mapping: the boundary of the content color gamut and the boundary of the display color gamut. In current imaging workflows like digital photography or video broadband services, color gamut boundaries are static and predefined. We are interested in future architectures where the gamut boundaries will be metadata of the workflow.

While this paper focuses on explicit 3D gamut boundary descriptions (GBD), other types exist. One example is the segment maxima method [11] or r-image [22] that uses a matrix defining for each segment of color space the most extreme color. The GBD can describe convex and non-convex color gamuts, but it depends on the definition of an origin in color space. Explicit 3D GBD can be generated for example by convex hull methods [13], Delaunay tetrahedrization or so-called alpha shapes [14] if the gamut is non-convex.

This paper is structured as follows. We first present the color gamut metadata format "Gamut ID" that became an international standard in 2011. We then discuss possible use cases for Gamut ID metadata.

Gamut ID metadata

Introduction to Gamut ID metadata

The main intend of Gamut ID metadata is to encode a geometrical representation of a single, actual color gamut, called generally Gamut Boundary Description (GBD). The representation uses triangular faces to describe the gamut surface in a three-dimensional color space, for example CIEXYZ. However, the scope of the metadata is larger than that.

The scope of the Gamut ID metadata format includes two different types of information:

1. Description of a color gamut
2. Specification of color reproduction

The description of a color gamut is mandatory while the specification of color reproduction is optional and intended to complete the description of the color gamut when necessary.

Typical applications of the Gamut ID metadata may include the following cases:

1. The metadata is associated to pictorial content (the source);
2. The metadata is associated to a reproduction device (the destination, typically a display).

Applications with full color management may even include both instances, see Figure 1. If the metadata is associated with content, the metadata defines the gamut for which the content was created. This may be the color gamut of a reference post-production monitor or any other color gamut encompassing all colors of the content. When sent downstream - together with the content - to a display, it can be used by the display for controlled color reproduction even if the display's color gamut is different from the one of the content. If the metadata is associated with a display, the metadata defines the display color gamut. When sent upstream to the creation side, it can be used during content creation to enable improved color reproduction.

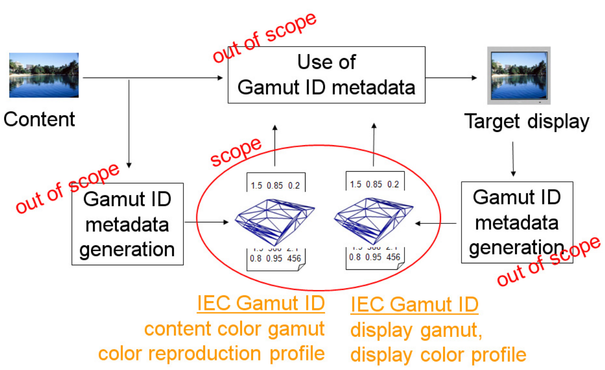

Figure 1. Scope of Gamut ID metadata

Architecture of Gamut ID metadata

The Gamut ID metadata format describes an actual, single color gamut. The metadata is based on two design principles that are explained hereafter:

1. The metadata may contain one, or more than one, alternative Gamut Boundary Descriptions (GBD) for the same color gamut;
2. A GBD is build from a modular, compact representation;

The first design principle allows several alternative GBDs describing the same, actual, color gamut, called here Gamut Instances (GI). Several GBDs allow addressing different complexity and precision requirements using a single set of metadata. For example, if a device receiving Gamut ID metadata has limited computational power, it will choose a low complexity GBD out of the available GBDs. In another case, a specific distribution channel (for example mobile phones) will not require the highest precision and will use a low precision GBD out of the available GBDs.

The second design principle imposes a modular, compact representation. The representation of the GBDs is structured into modules in a way that

- different GBDs can share common elements in order to reduce the metadata footprint and
- a complex GBD can be build from several sub-elements, having each less complexity, in order to reduce required computational power.

The modular structure is shown in **Figure 2**. The geometrical shape of the color gamut in a color space is approximated by a discrete surface defined by an indexed faces set such as known from computer graphics. The basic elements of the metadata are vertices (V) in the color space that define triangular faces (F). The faces all together approximate the surface of the color gamut.

The elements of the next higher level are called Gamut Components (GC). Each GC is a piece of approximated gamut surface. Each GC regroups a number of faces. Different GCs may share the same triangles without increasing the metadata footprint.

One level higher, Gamut Hulls (GH) are no longer pieces of a surface but each a complete, closed surface describing a closed and connex volume in the color space. Each GH refers to several components (GC) in order to build such a surface. A GH may not always describe the complete color gamut, but only one part of the volume of the color gamut. Different GH may describe different volumes that are distinct or that may overlap.

The highest level elements of Gamut ID metadata are called Gamut Instances (GI). As explained, each GI is a Gamut Boundary Description (GBD) of the actual color gamut. A GI refers to several Gamut Hulls (GH) in order to build the GBD. In fact the color gamut is described by the union of the volumes of all GHs that are referenced by a GI.

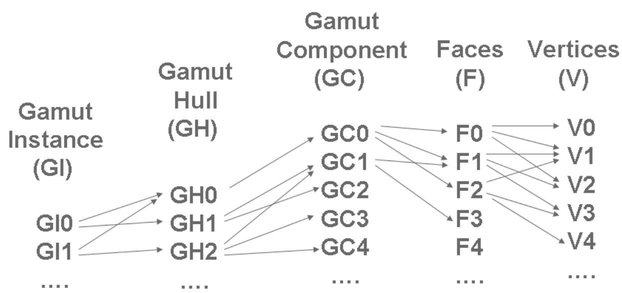

***Figure 2**. Modular structure of Gamut ID metadata*

Features of Gamut ID metadata

After having introduced its architecture, we now want to discuss what kind of useful, color gamut related information can be represented by Gamut ID metadata. We will discuss the following features:

1. Scalability of color gamut
2. Gamut convexity
3. Fuzziness of color gamuts
4. Color gamut ridges
5. Small metadata footprint

First of all, the representation of a color gamut using Gamut ID metadata can be scalable. The metadata architecture allows several Gamut Boundary Descriptions (GBD) for the actual color gamut to be described, called Gamut Instances (GI, see architecture section). In order to represent different levels of detail, the metadata can contain an ordered set of GIs each one characterized in that the number of triangular faces is higher than the precedent GI. Neither the way how these GBDs are generated, nor the rules defining which and how the GBDs should be used are specified.

Another feature of Gamut ID metadata is the handling of convex and non-convex color gamuts. Two features are linked to this topic. First, the metadata architecture allows that the different GIs that describe the color gamut differ (not only in level of details but also) in their convexity. For a given level of detail, there can be two GIs (GBDs). The first GI has a convex shape in color space and the second GI has a non-convex shape in color space. Once again, neither the way how these GBDs are generated, nor the rules defining which and how the GBD should be used is specified. The metadata creator's responsibility is to create the two GBDs according to their specification (the first convex, the second non-convex). The responsibility of the user of the metadata is to choose the GBD that corresponds to his computational capabilities or other specific need. Since the convex GBD requires less computation, the metadata should at least contain this type.

The handling of convex and non-convex color gamuts is addressed by a second feature. If the metadata contains GIs with a non-convex GBD, the representation of this GBD can be implemented in an efficient way. The architecture allows the definition of a GI by referencing several Gamut Hulls (GH), defining the color gamut to be the union of the volumes of all GHs (see the architecture section). This allows building several GHs of convex shape that together define a non-convex color gamut. The advantage is that the user of the Gamut ID metadata does not need to have the computational capacity to handle non-convex gamuts but just repeats processing of convex gamuts for each of the convex GHs composing the GI. The section on use cases presents the application example of a scene-wise gamut composition that builds on this feature.

Another feature of Gamut ID metadata allows establishing a sort of fuzziness in the description of the color gamut. This feature can be attractive for the representation of image color gamuts having very complex non non-convex shapes. Algorithms using a Gamut Boundary Description (GBD) may be built on a trade-off between accuracy and computational cost. The assumption is that a GBD is less complex when excluding a small subset of specific colors. The resulting shape of the reduced color gamut may require a smaller metadata footprint, may be faster to compute, may be easier to use and may be even convex instead of non-convex.

There are different ways to identify those specific colors to be excluded. A first possibility is to choose these colors aiming the highest simplification of the GBD focusing mainly on the reduction of metadata size and computational load for the metadata user. A second possibility is to guide the selection of the specific colors by content analysis. For example, rare colors, colors related to noise or colors corresponding to small image regions may be excluded. A third possibility is to guide the selection of the specific colors by the human visual system and to exclude those colors that will cause lowest impact on the visual experience. In any case, the selection of those colors is not specified by the standard, opening opportunities for clever algorithms.

The fuzziness of GBDs in the Gamut ID metadata, too, uses the possibility to use several GBDs (several GIs) describing the same actual color gamut. Each GI is characterized by the percentage of colors that are included in the GBD. We may have for example GIs with 100%, 98% and 95% of the actual gamut colors. Gamut ID metadata must always include a GI covering 100% of colors. It is up to the user of Gamut ID metadata to select one of the multiple GBDs and this process is not specified in the standard.

Another feature of Gamut ID metadata is to represent special colors on the boundary of the color gamut. These colors build so-called gamut ridges and are characterized in that the color gamut has, at these vertices, a non continuous surface curvature. Specifically, gamut ridges are represented by marking the related vertices (colors). Gamut ridges may include primary colors, secondary colors, the gamut cusp, the black and white points. This information may help the user of Gamut ID metadata to avoid smoothing off the gamut boundary near gamut ridges. Another example is to represent the cusp of the color gamut. The section on use cases presents an application example on cusp-based gamut mapping that builds on this feature. However, neither the selection of gamut ridges nor the use of this information is specified in the standard.

Another feature of Gamut ID metadata is to keep the footprint of the metadata itself small. As already mentioned in the architecture section, some elements of the metadata refer to other elements in a hierarchical manner. A first case of footprint reduction is that a same element can be referenced several times. For example, if several GIs do not differ from each other in a given part of color space, they may all refer to the same GH representing this part of the color gamut. A second case of footprint reduction is that a same element is referenced several times but with modified geometrical characteristics. For example, two adjacent GHs may both share the same piece of surface (represented by a GC) that separates the GHs. Since GCs have an orientation (identifying inner and outer side), the first GH may refer to the original GC while the second GH refers to the same GC but with inverted orientation. A third case of footprint reduction is included in the principle of indexed face sets where a single vertex of a GBD can be referenced by (can be part of) more than one triangular surface.

Profiles

Gamut ID metadata defines three profiles influencing the representation of the gamut boundary such as described above. In the full profile, all features are allowed, while the medium profile has the following restrictions:

- One or two levels of details;
- No fuzziness;
- Four of less Gamut Hulls;

- Four or less Gamut Components;
- No "inverted" Gamut Components.

The simple profile gives drastic restrictions. In the simple profile, the actual color gamut is described by 5 vertices for white, black, red, green and blue, respectively. There are no triangular faces, GC, GH or GI. All other features of GBD are disabled. This simple profile is available for very fast and rough GBD depiction and usage.

Description of color reproduction

The Gamut ID metadata may include associated color encoding information, which includes all information required for a controlled color reproduction. The color coding information notably creates the link between encoded color space coordinates (that specify vertices of a GBD) and radiometrically-linear CIEXYZ color space coordinates.

The color encoding information is scalable and may contain more than one color reproduction profiles. Each potential color reproduction profiles is inherited from the ICC profile format specification in ISO 15076-1:2005 [5], restricting the rendering intent to either the ICC-absolute colorimetric intent or the media-relative colorimetric intent. Additionally, the Profile Connection Space (PCS) is set to be CIEXYZ. Some more restrictions apply. For more details refer to the standard document IEC 91699-12-1.

Since ICC profiles assume adaptation to a white with D50 chromaticity, the profile may contain a Chromatic Adaptation Transform (CAT) that allows the user of Gamut ID metadata to use other white points than D50.

Binary format

Gamut ID metadata format is binary encoded according to the standard into the following sections:

- Header;
- Description of gamut geometry;
- Description of color reproduction.

The header includes color encoding parameters (color space, bit depth) as well as pointers to the other sections of the metadata. The description of gamut geometry itself includes a geometry header that defines the parameters of the elements discussed in the section on Gamut ID features.

Use cases for Gamut ID metadata

In this section we want to present some use cases for Gamut ID metadata that exploit each specific part of its architecture and its features. The use cases are:

- Scene-wise gamut composition: handling the color gamut of video content exploiting scene cuts
- Restoration of different film prints: using the color gamut to analyze and restore film prints
- Cusp-based gamut mapping: enhanced gamut mapping using a rich GBD

Scene-wise gamut composition

One application example is the estimation of the color gamut of video content knowing that several scenes are separated by scene cuts. **Figure 3** and **Figure 4** show, respectively, each one keyframe from two scenes of a famous motion picture.

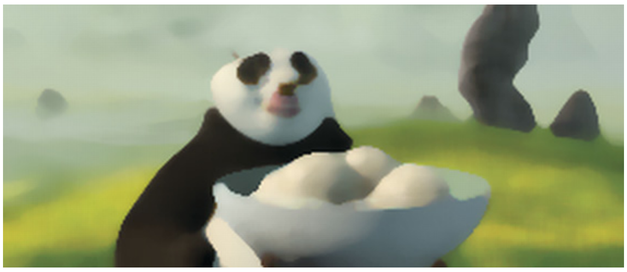

***Figure 3**. Key frame from a first scene of a well-known motion picture (median filtered for legal reasons)*

***Figure 4**. Key frame from a second scene of a well-known motion picture (median filtered for legal reasons)*

Figure 5 and **Figure 6** show the colors in CIELAB space corresponding to the two scenes, respectively. It can clearly be seen that the first scene has greenish colors and the second scene has reddish colors.

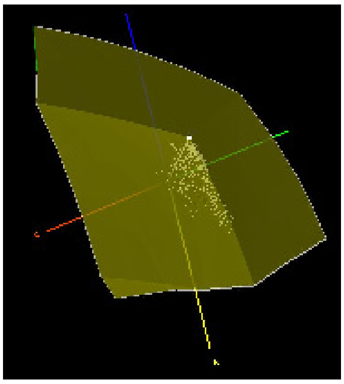

***Figure 5**. Colors from first scene (white points) within the gamut of the post-production monitor (dark yellow semi-transparent surface)*

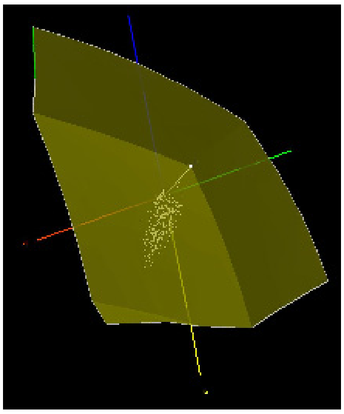

***Figure 6**. Colors from second scene (white points) within the gamut of the post-production monitor (dark yellow semi-transparent surface)*

Let us assume an image-dependent gamut mapping scheme that requires the color gamut of the video content. Calculating a convex GBD for all colors of both scenes will result in the GBD shown in **Figure 7**: A single GBD including both greenish and reddish colors.

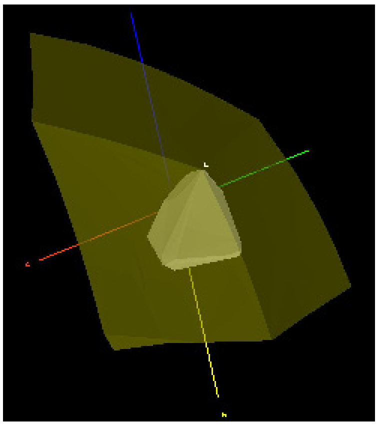

***Figure 7**. Color gamut (white and small) of the two scenes within the gamut of the post-production monitor (dark yellow semi-transparent surface)*

As an alternative we may calculate the GBDs of each scene separately, leading to the GBDs shown in **Figure 8**, one for the first scene, one for the second scene.

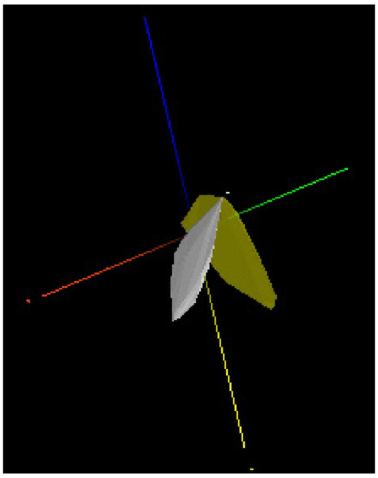

***Figure 8**. Color gamut of first (yellow) and second (white) scene when calculated individually: concavity is preserved*

The image-dependent gamut mapping scheme may operate in three ways. The first way is to carry out gamut mapping on each of the two scenes separately, using the two gamuts shown in **Figure 8**, respectively. The second way is to carry out gamut mapping in the same way for all scenes using the GBD shown in **Figure 7**. The third way is like the second way but using a non-convex, efficient gamut representation. In fact, the convex color gamut of the video can be represented as the union of the two color gamuts shown in **Figure 8**. If these two gamuts are encoded as Gamut Hulls (GH) in the Gamut ID metadata, the footprint is small and processing does not need to handle non-convex geometry.

Restoration of different film prints

Another application of color gamut metadata is restoration. **Figure 9** shows the part of a frame from the feature "Cobra Woman", a cult classic from 1940 starring Maria Montes. When restored in 1995 from the original negative, the color grade was carried out without comparing to the 1948 print resulting in a different artistic result shown in **Figure 10**. The pictures shown in this paper are sample digital photographs of a side-by-side projection of the film in theatre.

***Figure 9**.Detail from the 1940 feature "Cobra Woman" printed in 1948 (median filtered for legal reasons)*

***Figure 10**.Detail from the feature "Cobra Woman" in a restored version with color grading from 1995 (median filtered for legal reasons)*

The color gamut description of the reddish 1948 version is shown in **Figure 11** while **Figure 12** shows the color gamut description of the greenish version from 1995. When comparing both versions such as shown in **Figure 13**, color gamut descriptions are valuable information. They may be used

- To measure color difference between or variation along different content versions;
- To guide a restoration process converting the "look" of a first content into the "look" of a second content.

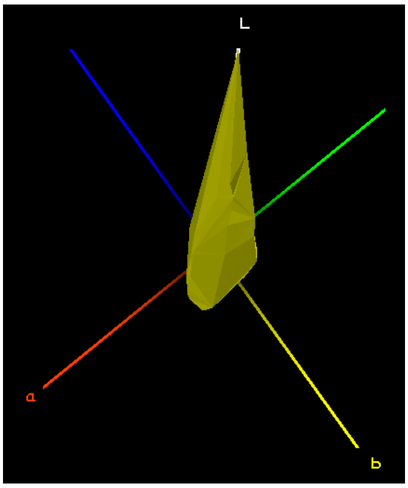

***Figure 11**. Color gamut of original "Cobra Woman" having a reddish cast*

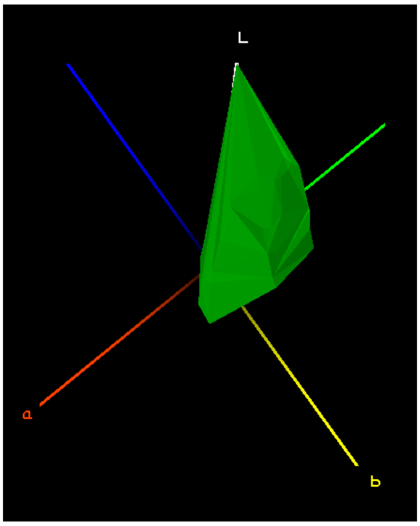

***Figure 12**. Color gamut of restored "Cobra Woman" having more greenish colors*

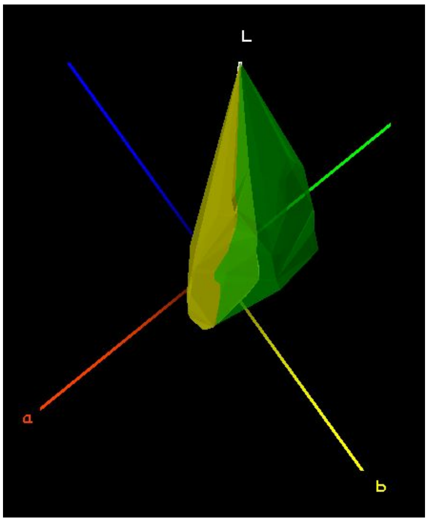

***Figure 13**. Comparison of color gamuts of original (yellow) and restored (transparent green) "Cobra Woman"*

Cusp-based gamut mapping

When mapping colors from one color gamut into another color gamut, some methods exploit the cusps of the color gamuts. The cusp of a color gamut includes for each hue the most saturated color. One gamut mapping algorithm using the cusp of the target color gamut is *cusp mapping* [6]. It maps all colors of a given hue into the direction of a so-called anchor point having the same lightness as the cusp. Another example is *cusp-to-cusp mapping* [2] that maps colors close to the cusp of the source color gamut onto colors close to the cusp of the destination color gamut. By this way, saturation is better preserved and the destination gamut is better exploited.

The estimation of the cusp from a given GBD can be performed automatically based on geometry criteria [2]. The performance is satisfactory for a large variety of gamuts including mathematically perfect standard gamuts (**Figure 14**), measured, approximately additive gamuts (**Figure 15**) and even subtractive gamuts (**Figure 16**). The size of Gamut ID metadata is typically 10-20kb, while the cusp representation within Gamut ID takes typically less than 50 bytes.

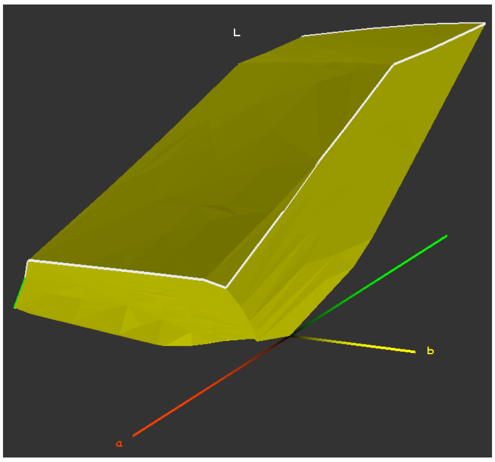

***Figure 14**. Estimated cusp in CIELAB space (white line) for the color gamut of a standard TV production monitor according to EBU requirements [1]; Metadata footprint is 11kB, among that 41 bytes for the cusp*

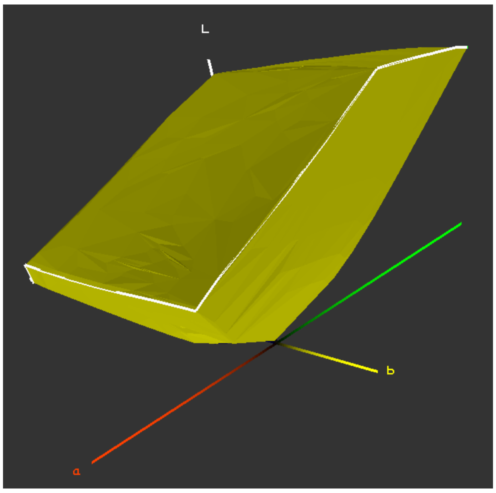

***Figure 15**. Estimated cusp in CIELAB space (white line) for the color gamut of an LCD LED backlight wide color gamut display; Metadata footprint is 16kB, among that 30 bytes for the cusp*

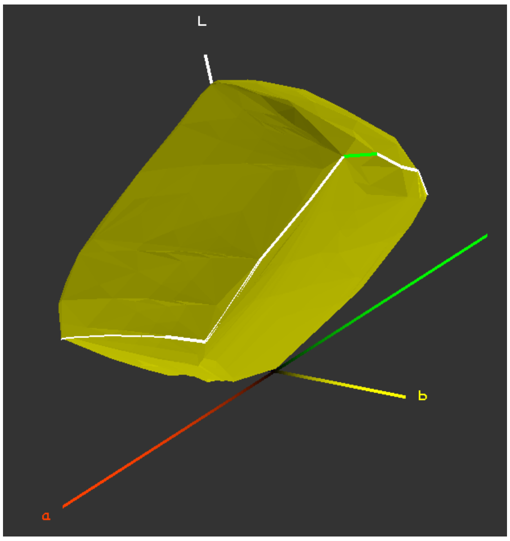

***Figure 16**. Estimated cusp in CIELAB space (white line) for the color gamut of positive 35mm film print*

Conclusion

Current approaches for color management in video or digital photography do not describe the color gamut of either devices or contents explicitly. In this paper, we present the new international standard IEC 61966-12-1 “Metadata for identification of colour gamut (Gamut ID)”. This standard allows the precise and flexible description of a color gamut. The metadata supports graphics hardware, scalability, memory footprint efficiency, convex handling of non-convex gamuts, handling of fuzzy color gamuts, and handling of gamut cusps.

Gamut ID metadata may be used in color management, restoration, content creation, and other applications where color gamuts need to described precisely. Future work and standardization initiatives will define best use cases.

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Author Biographies

Jürgen Stauder received his PhD degree in 1999 from the University of Hannover (Germany) in the field of computer vision. He then stayed with INRIA (France) for two years before joining Technicolor Research Labs in Rennes (France). He is guest lecturer at several universities for applied color science. His research interests are computer vision, color science, and computer graphics with application to video asset management, color management, and content production.

Corinne Porée received her DEA in Optics and “Magistère de physique” from University of Grenoble (USTMG) in 88 and her Master of Signal Processing from Supélec in 1989. Since then she has worked in the Thomson Research Labs in Villingen (Germany) and now at Technicolor R&D France in Rennes. Her work at present focuses on Wide Color Gamut for the moving picture industry.

Patrick Morvan received his Electronic Engineering diploma from Polytech' Nantes (France) in 1989. Since then he has been with Technicolor R&D France in Rennes. His work is now focused on color management topics for the moving picture industry.

Laurent Blondé is graduate engineer of the Institut d’Optique (1985). Hired as a research engineer at Thomson Research Labs (now Technicolor R&D France), he participated in more than a few R&D projects including: Infrared Image Synthesis, Special Effects and Virtual Studio, Display processing, Anti-Camcorder and Color Management for Cinema applications, 3D Perception. Image, color and vision expert and multi-project Technical Advisor at Technicolor, he tries to be a creative technical leader enriching image processing with Physics and Perception