Superior Digital Video Images through Multi-Dimensional Color Tables

TruVue eeColor™ Technology White Paper

Jim Sullivan
CEO, Entertainment Experience, LLC

About the Author

Jim Sullivan joined Entertainment Experience in September 2007 after 34 years at Eastman Kodak Company. Jim spent 20 years as a digital image scientist in all areas of digital color imaging including printing, professional imaging, graphics imaging, medical imaging and government imaging with numerous patents and technical papers. Jim also served as the CTO and COO for the Kodak Theme Park digital system business, the CTO for the Kodak Hollywood Post Production and Special Effects businesses, Cinesite in London and Laser Pacific in Los Angeles, and the COO for the Kodak Digital Cinema business.

Jim's scientific and operational digital imaging background is leading Entertainment Experience to be the premier solutions provider for home theaters.

1. Introduction

It is well known that color, brightness and contrast are the primary drivers of digital video quality. For some video displays and media, and some viewing environments, these factors are even more important than resolution. Televisions and video projectors have progressed significantly in the last ten years to address improved brightness and contrast, but until recently color quality has remained relatively unchanged and digital color standards have not changed since the 1970s.

In addition, the advent of high bandwidth communication technology has allowed video entertainment media to be targeted for all sorts of new display modalities including computers and small, portable devices that generally have much lower quality capability than televisions and projectors.

The recent color improvements in televisions and video projectors, the desire to enjoy entertainment media on smaller, lower quality devices and the static digital color standards have created a unique need for new video color processing technology.

Entertainment Experience is a solution company that integrates all aspects of display type, screen size, room lighting into its products. For the best color, contrast and brightness processing to optimize the full solution quality in these changing times, Entertainment Experience believes the answer is the full multi-dimensional visual science of eeColor. The next section will present the need for visual modeling following by a discussion of the use of eeColor in each of the following applications,

a. Video Color Mapping From Current Standards to Larger Color Gamut Displays
b. Color Mapping for Displays with Added White or White Point Targets
c. Color Mapping for Standard Color Displays in Various Viewing Environments
d. Creating a Cinema Color Experience and Customize Color Rendering Intents

2. Visual Modeling

To illustrate visual modeling, consider a bed of flowers on a bright sunny day. The flowers look very colorful. As the sun goes down the flowers appear less colorful and have lower contrast. Did the flowers lose color? The answer is no. The physics of flower light absorption and reflection still apply, and the flowers have the same purity of color. What makes them less colorful? The answer is the adaptivity of human vision. As the brightness decreases, the perception of colorfulness and contrast decrease. The human eye adapts. Perceived brightness, colorfulness and contrast are all interrelated. If an image is brighter it looks more colorful. If it is more colorful it looks higher contrast.

A second key element of visual modeling is the perception of memory colors like sky blue and flesh tones. Human vision is highly sensitive to changes in these memory colors with viewer reaction being quite negative is they do not look accurate and real. The perception of these memory colors is not only adaptive but the three dimensional volume of memory colors is difficult to define in any standard color space across all brightness levels. For example white, brown, red, olive and yellow skin at different brightness levels cover a fairly large three dimensional color volume and can only be well defined mathematically in perceptually adaptive color space.

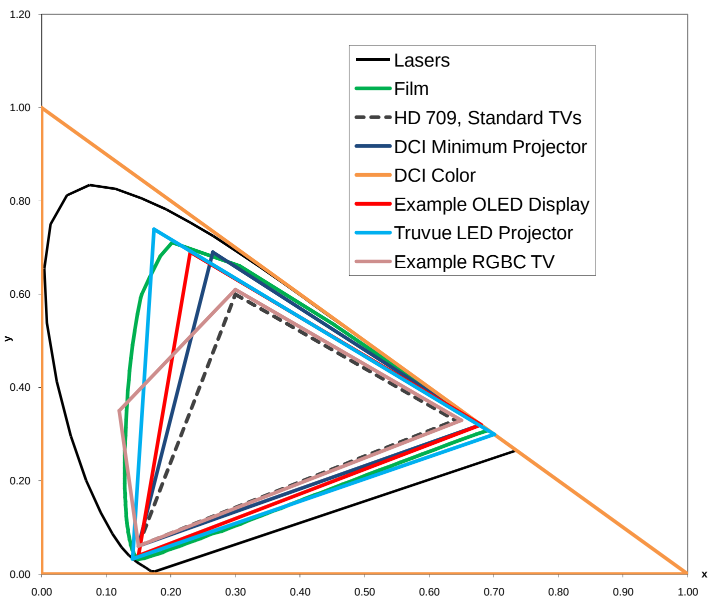
Visual models are not only adaptive but they are non-linear. Commonly used linear light models for video displays employing 1D gamma tables and linear color matrices are insufficient. These tools do not have the mathematical degrees of freedom to optimize color quality for any of the applications discussed below. eeColor™ Technology uses patent pending; multi-dimensional look-up-tables to implement these models and achieve the highest video quality.

3. Video Color Mapping From Current Standards to Larger Color Gamut Displays

Digital color standards and display color quality have been relatively constant for years. Digital color standards such as CCIR709 (HDTV), sRGB, EBU and SmpteC are very similar and sufficient to define the color intent of digital content for display devices that have color capabilities well matched to the standards. With the recent integration of bright RGB LED light sources in projectors and televisions, however, this has changed. RGB LED's can produce much more saturated colors than the standards due to their similarity to laser color purity.

Figure A shows representative color gamuts for the HDTV 709 standard, digital cinema projectors, cinema film, OLED displays, RGB LED displays and lasers which bound all physically realizable colors.

Figure A. Color Gamuts for Video Standards and Various Display Technologies



The larger color gamuts for OLED and the Entertainment Experience Truvue RGB LED Projector are significant. (The reader is cautioned to note that LED televisions may not be RGB LEDs but rather white LEDs with filters that have approximately the same color gamut as standard televisions.) Except for small color regions, the Truvue RGB LED Projector actually has a larger color volume than film and professional cinema projectors that are forced to use lamps to achieve brightness. This is a unique and exciting situation in color display allowing creative artists to explore much large color palettes in homes than even those available in professional cinemas.

Figure A also shows an example of a 4 color television with RGB and Cyan illustrating that the color gamut is larger than the HD709 standard, and the Hollywood Digital Cinema standard, DCI, used for professional cinema digital releases. DCI is the first color standard based on the color signals of vision, namely tri-stimulus values, and not a particular color rendering device. Hollywood studios and manufacturers established this standard to be truly future-proof because it totally encompasses laser colors meaning there is no physical display device that could ever produce a color outside this standard. Unfortunately this future-proof feature causes a significant increase in the required bits/color to 12 to accommodate the larger color volume that includes non-physical colors. It is also not compatible with current televisions and projectors and as such is unlikely to be adopted for consumer video distribution or capture in the foreseeable future.

In addition to more colorful light sources, additional colors beyond RGB such as yellow, Y, and cyan, C, are now being added to new video displays to further expand available colors. With these new larger color gamuts there are three simple approaches that can be implemented with the color processing tools of current televisions and projectors. They are to,

a. clip the larger display colors to the input standard using conventional matrix processing,
b. ignore the difference in input RGB and display R’G’B’ and map R-to-R’, G-to-G’ and B-to-B’, or
c. something in between.

Unfortunately, none of these produce anything close to the highest visual quality. The first approach often recommended by engineering purists dramatically de-saturates the available display colors which mutes color expression and prompts the question as to why we should have these extended display colors in the first place. Artists generally do not like to find out that their artistic expressions are limited by out-dated standards.

The second approach and any combination of approach one and two alters every input color away from the standard to a new output color. Sky blue and all memory colors like flesh tones will change. For LED projectors with the color gamut shown in Figure A, flesh tones become a disturbing red or orange color and sky blue takes on an unacceptable greenish caste. Experienced reviewers of the home theater industry have said that these projectors are unsellable with this color mapping. Actors will not accept the altered colors and Hollywood colorists and directors who spend many hours getting just the right color tones for their movies will not either.

An additional factor in driving optimal visual quality is to consider the viewing environment. It is well known that as brightness changes and the human eye is adapted to a surround that is brighter or darker than the viewed image, that perceptual contrast is reduced. This has been used in the design of motion picture film viewed in dark theaters since its inception. Including the contrast reduction caused by ambient light adding to the emitted or reflected video image, and one can see that increased brightness and color contrast is needed to produce optimal viewing.

eeColor™ Technology integrates all these factors, white point selection and full display color calibration into the solutions for optimal visual quality. It uses visual models of flesh tones and other memory colors, the interrelationships of brightness, colorfulness and contrast and viewing environment to maximize the perceived color quality and preserve key memory colors. For implementation these models can be sampled and integrated into multi-dimensional look-up-tables in all TruVue products.

4. Color Mapping for Displays with Added White or White Point Targets

As mentioned in the Introduction it is well known that overall brightness is a key factor of perceive quality. This is particularly true in standard room lighting where image brightness competes with ambient light. Video display engineers work hard to capture every photon and put it in the displayed image. For the very common time-sequential displays that sequence RGB colors with a single DLP, LCOS or LCD modulator, the brightness issue is tantamount because the total brightness is reduced by 67% due to the time sequencing. For light-starved, portable and computer-based OLED displays, white pixels have been added to increase brightness and contrast, and additional brightness can be achieved by further increasing the usage of white while boosting colors to raise colofulness.

Maximum display brightness is further confounded by the fact that maximum RGB brightness values do not generally produce the desired color temperature for white. Texas Instrument offers a partial solution to this last issue for its DLP devices by allowing white to be disconnected from maximum RGB values with independent tetrahedral definition of the RGBCYMW color primaries, secondaries and white. This approach has limited degrees of freedom and does not, however, have the ability to do full chromatic adaptation of images or incorporate visual models.

For portable displays, brightness and contrast become even more important because they are generally light starved and viewed in high ambient light surrounds.

For all of these applications, eeColor™ Technology is the only color processing approach that can increase brightness and contrast at the same time it preserves colorfulness and memory colors. To do this in an optimal manner so the viewer sees the best combination of color, brightness and contrast, eeColor™ Technology uses visual modeling. As mentioned in the section on Visual Modeling, the perceived colorfulness and contrast are a function of brightness and vice versa. With that knowledge, eeColor™ Technology can produce the largest total quality volume using 4D color tables.

Figure B shows an image example with a 33% added white to increase brightness 66% in a RGB sequential display. Figure C shows that same image with eeColor™ Technology processing to improve colorfulness and contrast while preserving the increased brightness. Note the significant improvement in overall quality but also that the image in Figure C looks even brighter. (The reader should note that these image examples will look slightly different depending on the display being used, but the modeled color gamut does not differ dramatically from the color gamut of standard computer displays so the comparisons are fair illustrations.)

Figure B. Flowers with 33% Added White in RGB Sequential Display

Figure C. Flowers with 33% Added White in RGB Sequential Display Including eeColor Processing

5. Color Mapping for Standard Color Displays in Various Viewing Environments

The previous section described the eeColor™ Technology solutions to displays with color gamuts that are larger than the distribution standards. It may come as no surprise to the reader that the visual impact of optimal visual color and quality can be even more impactful for displays with standard or sub-standard color gamuts, brightness and contrast. With these displays, the perceptual value of better colorfulness, contrast and brightness is even higher because they begin with such limited color capability relative to colors we commonly see at the cinema using film.

Again using visual models and preservation of flesh tones and memory colors, eeColor™ Technology can improve the overall visual quality of standard color displays. This improvement comes from actual and perceived increases in colorfulness, contrast and brightness in differing viewing environments. One way to think of this is that eeColor™ Technology transports the viewer to a far superior viewing environment where flowers look more colorful. This mapping is not an arbitrary color or contrast enhancement, but rather one based on the actual physics of adaptive vision wherein less bright lighting makes objects look less colorful and lower contrast and higher colorfulness makes objects look brighter and higher contrast. These same methods have been used by film makers for years without the full degrees of freedom offered by eeColor™ Technology and multi-dimensional digital tables.

6. Creating a Cinema Color Experience and Customized Color Rendering Intents

All digital displays produce colors by adding red, green and blue primaries. The number of possible colors a projector can produce is a function of how pure the primary colors are, i.e., how large the triangular color gamut is in Figure A. As mentioned in the Introduction, displays can also include additional colors like yellow and cyan to expand the triangular color gamut to 4-sided polygons and more. All of these color capabilities are linear and additive.

Film color gamuts are not linear, or additive but rather non-linear and subtractive. Figure A shows the curved, non-linear color gamut of a typical Hollywood film system. Figure A also shows that film color gamuts are larger than HDTV and standard displays. Can a standard display produce a good rendition of the film color so that a home audience has the same experience as the audience in a professional cinema? The answer is yes and the technology is eeColor.

To illustrate, Figures D and E show the same scene from a Hollywood movie rendered as HDTV and as film color by eeColor™ Technology. Both renderings utilized the same HDTV color gamut. Figure E shows the higher contrast of film color with better shadow detail and rich yellows. As the figures show, eeColor™ Technology has the visual modeling and degrees of freedom to customize displays to produce film color or other any color rendering intents. One can imagine color rendering intents for action games, love stories, outdoor movies and many other types of entertainment media. Entertainment media is art not bits.

Figure D. HDTV Linear Rendering of a Scene from a Hollywood Movie

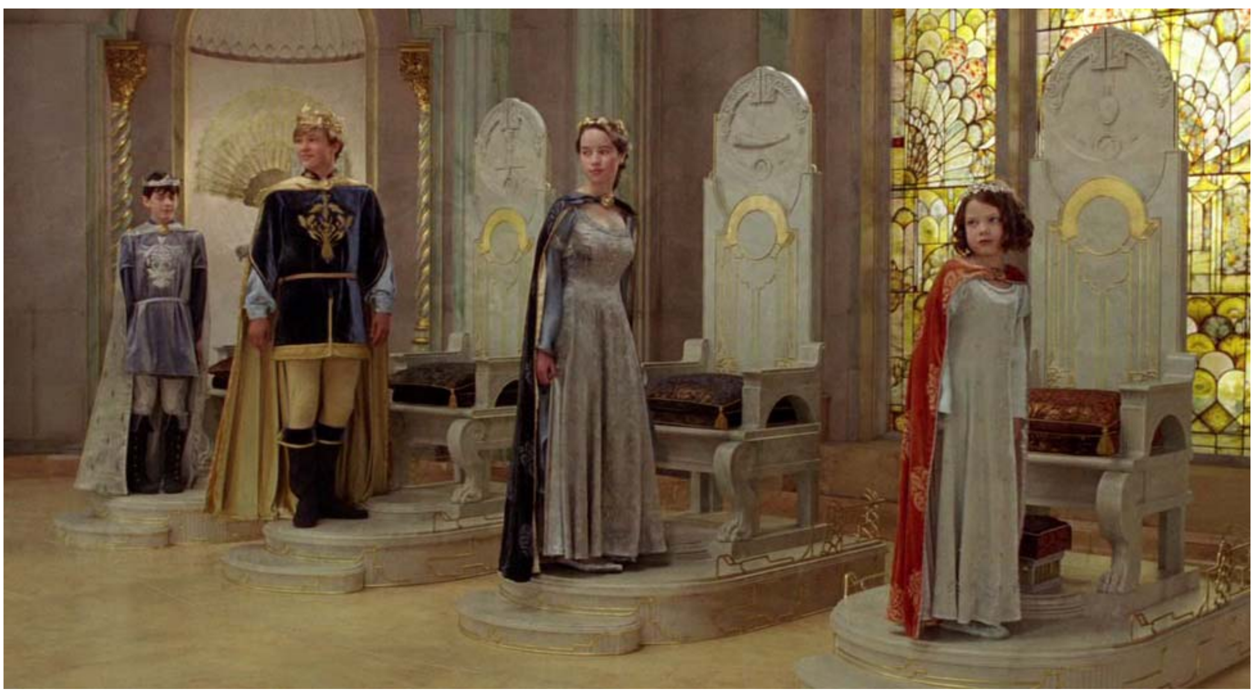
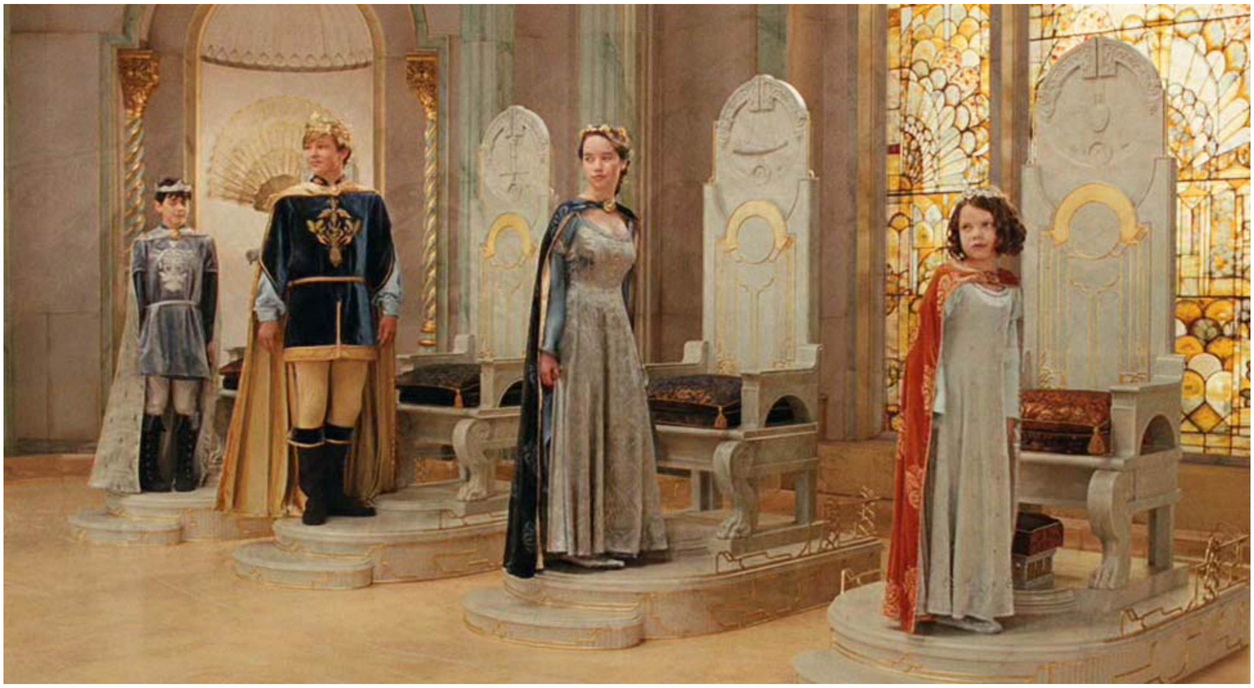


Figure E. Film Color Non-Linear Rendering of a Scene from a Hollywood Movie



The visual impact of eeColor™ Technology on the quality of digital images is clear. Through the deployment of 3D, 4D or more color tables, devices can have the ability to select white points and calibrate the colors of specific displays with additional 1D tables and linear matrices.

To get the best quality image in a home cinema system, be sure that the manufacturer as eeColor™ Technology integrated. The first fully integrated solution is the TruVue eX1 product family.

Entertainment Experience knows color and believes its eeColor™ Technology and TruVue products provide the optimal color solution and the best viewing experiences ever available.