# Whitepaper: Colour management for film

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## 1 Introduction

While an ever-increasing proportion of films are utilising the digital intermediate (DI) process, one of the biggest challenges that still remains is eliminating the uncertainty about how the sequences will look when printed to film.

Differences between the colours displayed on various monitors, even those from the same manufacturer, makes achieving a consistent working colour space a difficult goal. The increasing use of LCD monitors in addition to their older CRT counterparts, plus the fact that digital projectors are rapidly improving, means that we are working with a vast range of devices that all have their own unique behaviour in response to image data.

Complicating the issue further, when working with film images we are attempting to make two completely different media look the same: a) an electronic display device of some variety; and b) a small piece of cellulose that has been exposed to light and then developed through a complex chemical process. Clearly this is not a trivial challenge.

The colour management challenge can be split into two separate but equally important problems:

1. Ensuring that all displays throughout a facility look the same; and
2. Making those displays look like a selected target, such as a particular film stock or an HD monitor.

Addressing the first problem means that no matter where in a facility the images are being viewed, the colour will be consistent. Having all artists, supervisors, producers and directors working with the same standard view vastly reduces time wasted sending work back and forth for minor adjustments resulting from incorrectly calibrated displays. Further, it enables greater flexibility, with artists able to work with their CRT or LCD monitors or digital projector matched to a reference standard, such as a broadcast monitor. This frees everyone from the limitations of having only a single grading station since the correct result is produced right from the start.

After establishing a baseline display standard for a facility, we can then address the challenge of matching to an output target such as film. Successfully solving this particular problem can result in significant cost and time savings by dramatically reducing the need for film-outs during the postproduction process. It also increases creative control over the DI process by enabling users to have an accurate representation of the final film look at every stage of the process.

## 2 Closing the loop

The basis of effective colour management is having an accurate understanding of what your display devices are actually showing. The fact that human eye is so effective in adapting to the surrounding environment is actually a drawback when trying to accurately assess the absolute colour response of a monitor. As such, accurate device *profiling* requires the use of a hardware probe to measure the colour output of a display.

By measuring the absolute output of a display in response to input data values, we can generate a *profile* of the device. Equally, a profile can be generated for a sample of film stock exposed with known frames and printed to LAD aims. We can also create profiles according to specifications such as sRGB, HD (rec 709) or Cineon 5400K.

Once we have profiles for both our display device (e.g. CRT monitor) and our target device (e.g. Kodak Vision film), we can perform mathematical transforms in software or hardware to make our display look like the desired target. The display device output is controlled using a look-up table (LUT) to determine the appropriate stimulus required for the correct colours.

## 3 LUT: What does it really mean?

Whilst the term look-up table (LUT) is being used with ever-increasing frequency, there remains some confusion as to what the term actually means and how LUTs can be used effectively within a colour pipeline. As such, it is worth spending a moment clarifying what we are talking about.

By definition, a look-up table is simply a data structure that maps any input value to an output value. In the context of colour management, this allows us to specify the conversion of the data value (corresponding to a specific colour) of each pixel in a frame to another value. Using a LUT allows us to replace a potentially complex runtime computation with a simpler look-up operation. This often enables playback to occur in real time, even when working with large frames, since the conversion of each pixel input value to output value is greatly simplified.

Working from this general definition, we can see that the range of potential applications for LUTs within a colour pipeline is rather large. Within video hardware, LUTs are used to determine the correct intensity of each screen pixel based on the data value of each pixel in the frame. We can also perform gamma adjustments or log-lin conversions using LUTs, in addition to making colour adjustments to emulate a particular film look or creative choice. Furthermore, a single LUT can be used to replace a complex series of mathematical transforms, minimising the processing overhead.

Broadly speaking, we can define two categories into which a LUT can be placed:

**Calibration & emulation LUT** —Used to match the display outputs of different devices and accurately mimic the colour characteristics of a particular target.

**Creative "look" LUT** —For applying creative colour decisions to a set of frames in order to obtain a desired "look".

The calibration & emulation LUT is a key part of the colour management pipeline. When used correctly, this type of LUT ensures that at every stage of the pipeline, a user can accurately see how their frames will look when transferred to film. This enables them to make accurate colour decisions right from the outset, rather than trying to compensate for accumulated errors just prior to film recording. Furthermore, this type of LUT allows us to view the result that would be obtained using a different film stock or lab process and make the necessary adjustments to compensate for changes to the pipeline.

Once the user has an accurate representation of the final output, they can use a creative "look" LUT to achieve the desired result. Changes to the colour balance, saturation and constrast, plus specific adjustments to shadows and highlights, can all be encompassed in this LUT, which applies the overall unique look to be used for a particular project.

Whilst is it technically feasible to combine both colour calibration and creative adjustments into a single LUT, it can be helpful from a conceptual standpoint to treat these as separate actions. The rest of this discussion will look deeper into the challenge of accurate calibration and emulation.

## 4 Matching to film: not all LUTs are equal

A given display device can be characterised in terms of a set of *primaries* (usually three). When mixed in various combinations, these primaries allow a wide range of colours to be generated. The choice of primaries will determine the *gamut*, or range of colours, that can be represented by the device.

Typical CRT monitors use red, green and blue phosphors to generate displayed colours and so the primaries are defined as R, G and B. However, the actual colour of each primary will be determined by the chosen phosphors and so each CRT monitor will have its own unique colour characteristics.

In a CRT monitor, the primaries exhibit *independence*, whereby a change in the intensity of one colour channel does not affect either of the other two channels for the displayed colour. Thus it can be said that the primaries *decouple*. A consequence of this is that the sum of all three primaries at maximum intensity will produce white. This also holds for any fraction of maximum intensity: the sum of the three components will equal the corresponding greyscale value, i.e.

$$x.R + x.G + x.B = x.W \qquad\qquad \text{where } 0 \leq x \leq 1$$

Looking at it another way, an input containing a value for only one primary, will produce an output colour containing only the corresponding primary, e.g.

$$[r\ 0\ 0] \rightarrow [r_R\ 0\ 0]$$

Similarly:

$$[0\ g\ 0] \rightarrow [0\ g_G\ 0] \text{ and } [0\ 0\ b] \rightarrow [0\ 0\ b_B]$$

For a device whose primaries do *not* decouple, we would obtain:

$$[r\ 0\ 0] \rightarrow [r_R\ r_G\ r_B]$$

Clearly, being able to assume that the primaries decouple results in much simpler modelling of the device and allows us to accurately match colour using a set of 3 one-dimensional (1D) LUTs. Since this corresponds to the way standard video hardware determines the correct output values to display, we can implement any colour correction at the operating system level rather than in specialised applications or hardware.

For all practical purposes, we can assume that the primaries of CRT and LCD monitors decouple correctly. Digital projectors, however, exhibit more complex characteristics due to the common use of an additional white component, used to boost output brightness, and additional primaries to extend the gamut. This means that the R, G and B primaries frequently do not sum to white in such devices.

Going a step further in complexity, film emulsions demonstrate significant *cross-talk* between dye layers, meaning that exposure to a single colour channel can produce changes in the recorded intensity of all three primaries. Also, whilst monitors and projectors produce colour using an *additive* process, film relies on *subtractive* colour based on the selective absorption of colour components. These factors make matching between monitors and film inherently more complex.

Our mapping of input values to output colour components now becomes:

$$\begin{bmatrix} r & g & b \end{bmatrix} \rightarrow \begin{bmatrix} r_R & r_G & r_B \\ g_R & g_G & g_B \\ b_R & b_G & b_B \end{bmatrix}$$

For these reasons, it is necessary to use 3D transforms when matching to certain targets such as digital projectors and film stocks. However, the use of 3D transforms is computationally intensive and requires either specialised hardware or software, rather than being performed at the operating system level.

Once we have obtained a profile of a given display device (e.g. CRT monitor) and output target (e.g. film stock), we can generate a *colour cube.* This cube is essentially a 3D LUT that describes the correct output values required to accurately match colours on the display to the target. A unique 3D LUT is

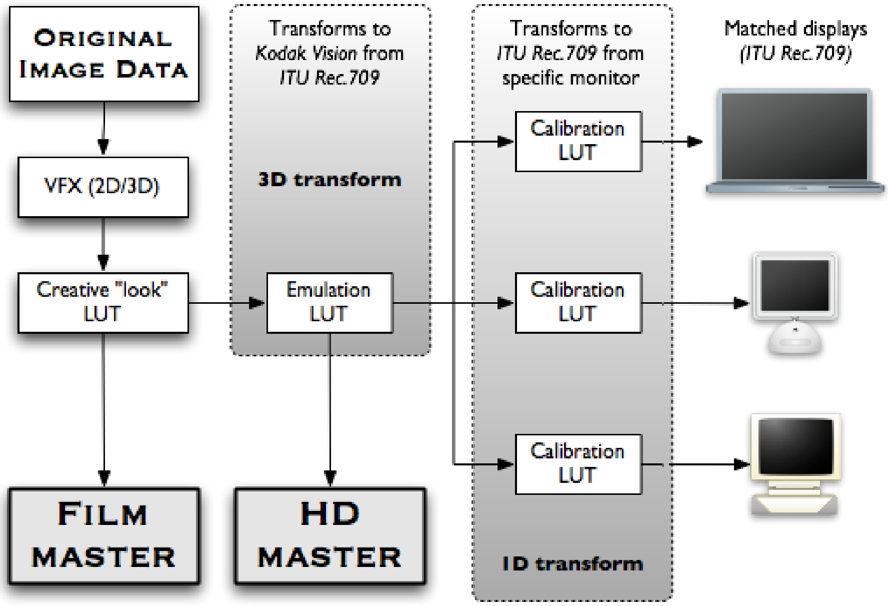

Figure 1: Emulation and calibration LUTs are used to provide viewing transforms that not only ensure multiple displays match another but also show the correct film look during post-production.

required to match each specific monitor to a particular film stock or HD target. Such 3D LUTs can then be loaded into specific hardware or software to enable viewing of frames in accurate colour.

By using a combination of 1D and 3D transforms, we can efficiently achieve the dual aims of matching displays to one another and ensuring they display the correct film look (Figure 1 - Kodak Vision film stock and ITU Rec. 709 are included as example output targets). The calibration and emulation LUTs are used to provide a *viewing transform* during effects work so that artists have an accurate picture of what the final result will look like. The creative “look” LUT, on the other hand, performs a *data transform* that modifies the frames before they are recorded to film.

When an HD master is required in addition to film, the emulation LUT can be “baked in” to the frames as a final step in the process. Using this workflow avoids the need to grade separately for the HD master, as it will already closely resember the look of projected film. This is one of the few times that the emulation LUT would be used to perform a data transform.

## 5 Defining a standard

Currently, various hardware and software manufacturers tend to use their own proprietary LUT formats. Whilst it is possible to provide tools that enable them to be interchanged between various applications, the process is inherently complex, prone to errors and often forces users to make undesirable changes to their colour pipeline.

To simplify the process and maximise flexibility for users, conformance of the 3D LUT file structure to an industry standard would enable different hardware and software tools to work together more effectively. The emergence of OpenLUT is a major step forward in this regard, providing a platform upon which users can build their colour pipeline. Eliminating the need to convert between numerous cube formats, OpenLUT allows user to generate one cube for use with all their hardware and software.

During 2D/3D visual effects work, OpenLUT standard colour cubes can be loaded into applications such as Shake and Digital Fusion. For real-time playback, the cubes can be used in specific standalone equipment or applications that support graphics acceleration hardware. In this way, all users can enjoy the ability to see things as they will appear on film without having to guess about the result.

## 6 The cineSpace solution

Addressing the dual challenges of colour management - getting monitors to match one another and ensuring that they all look like the desired target - is cineSpace. Recognising the various complexities of the numerous stages of a colour pipeline, cineSpace takes a “black box” approach and compares what is being displayed on users’ monitors with the desired output target. This information is then used to produce an accurate representation of the final output on every workstation.

To create profiles for each display device, the cineProfiler application utilises a hardware probe to measure the output generated through a series of colour test patches. This allows users to generate an accurate profile for each CRT monitor, LCD panel and digital projector throughout the facility. This may also include broadcast reference monitors so that all users are able to match to what is viewed at the colour grading workstation.

Then, using the equalEyes application on each workstation, we can match all monitors to a common target so that every user is seeing the same thing. Supplied with cineSpace are various video target profiles useful for this purpose, such as sRGB, PAL, NTSC and HD (rec 709). It is even possible to specify a preferred colour temperature and gamma if so desired.

Utilising the operating system’s standard 1D LUT, equalEyes can ensure that the entire desktop is correctly matched to the chosen target with no processing overhead. This then provides a standard workstation colour space from which we can match to complex targets (such as film) using 3D LUTs. Since the use of 3D transforms requires significantly more processing than basic 1D LUTs, they are incorporated into other applications. Generating the underlying 3D LUT that allows accurate matching requires advanced algorthims built into the cineSpace software. The use of specific interpolation during this process ensures a smooth fit to the finite number of points sampled during profiling.

The cinePlugins offer the ability to accurately match film targets within compositing applications such as Shake, Digital Fusion and Nuke. The colour matching can be performed through a cineSpace node in the tree, allowing users to both view their final result and, if required, burn-in the film look for output to HD, SD or Quicktime.

For other applications, the cineCube utility enables a user to generate cineSpace 3D LUTs for loading into various hardware and software tools. In addition to in-built support for Nucoda, Iridas, Scratch, Quantel, PFPlay and other applications, cineCube provides support for the OpenLUT standard. This ensures that users can have a cineSpace-matched display no matter what tools they choose to use in their colour pipeline.

Using cineSpace 3D LUTs to perform the dual tasks of monitor calibration and film emulation, the user is free to make creative choices and apply their own unique creative LUTs knowing that what they are viewing on-screen is an accurate representation of the final output.

# 7 Further details

For more information regarding colour management for film and cineSpace software, please contact Rising Sun Research.

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