5, rue de la Verrerie
38120 Le Fontanil (France)
Tel : + 33 476 26 1976 - Fax : + 33 476 26 2593
www.tcube.tv

Using 1D and 3D LUT for Color Correction

By Jean-Luc GRIMALDI, Tcube technical director

Introduction

LUT is an acronym for Look Up Table.
As LUT techniques become more common for Color correction applications, users are often confused by the multiplicity of available solutions present on the market.
Purpose of this document is to present in a simple way the pros and cons of the different techniques and to emphasize on most important features of each solution to help customer decision.

Technological background

Display on an electronic screen

Picture is formed from light emitted from the 3 primaries (Red, Green and Blue).
In these systems (LCD or CRT and also projector with 3 color beams), the 3 primaries are **totally independent**, i.e. level of each is not influenced by the levels of the others (no pollution).
By the way, that does not mean that colorimetry is guaranteed identical from one screen to another ! Differences will arise from primaries of the screen, and from rendering of intermediate levels of the RGB (linearity).

Display using a projector of printed materials

Picture is formed from a white beam passing a color filter representing the image.
This is the case for film cinema, electronic projector and printed photos.
In these cases, the primaries are not independent, that means that level of one component will interfere with the others.
Of course, differences between the different screening devices also exist.

Gamma correction, non linear technique for color rendition

Applying a gamma curve for color correction is an heritage of the analogue times, initially implemented to compensate for CRT non linearuty fo light versus electron beam.
In fact, in digital form it is a **dedicated 1D LUT** transformation.

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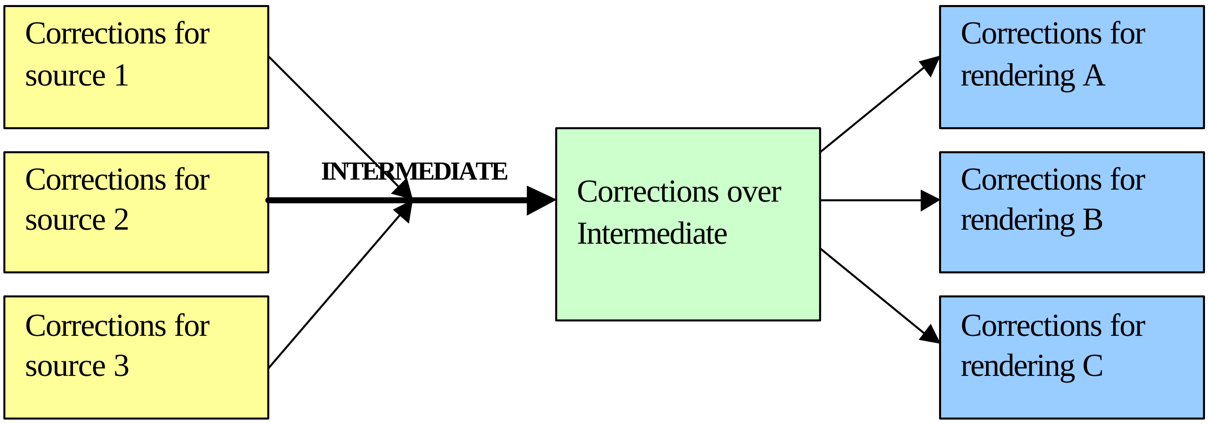
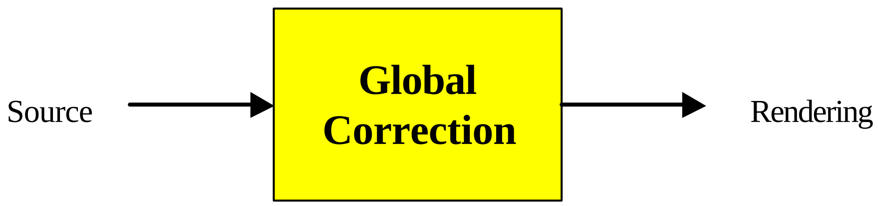
What is expected from a color correction chain ?

Ideally, to get an **Intermediate form** independant from source origin and rendering destination.

Doing so, all corrections applied on the Intermediate will be visible whatever the rendering destination.



In implementation where only one source and one rendering device exist and where intermediate is not important (example display of rushes just after shooting) , all corrections (source, intermediate and rendering) can be combined into a single :



The quality of rendering depends on all processes involved during production. Therefore to obtain the best transparency possible requires very high sophisticated products to compensate for all non linearities in the gamut domain.

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The 3D LUT

In a theoritical form, to get the full transparency fron source to rendering, it is sufficient to allocate to each possible input color a correction to get adequate rendering. So to each source triplet (R, G, B) is associated a RGB rendering triplet.
This is what a 3D LUT is (3D relies to the three components R, G and B)

Now consider an 8 bit system (or more than 16 millions of colors). It does not exist a system able to make in real time such a large number of corrections… and what if we go 10 or 12 bit per component.

But as source and rendering devices are overall linear and continuous, experience shows that managing a much smaller number of corrections is perfectly adequate.
Use of this proprety leads to drastic reduction in the number of nodes involved (a *node* a is a RGB triplet where a correction is allocated).
Other values of RGB (in between nodes) will be interpolated from the adjacent nodes.
In 10 or 12 bit system, a common partcice is to allocate **17 nodes per component** that proves to be the **best trade off** between harware complexity and overall quality.

Demystifying Marketing argumentation
Marketing arguments to introduce a new technique (moreover in this case relatively difficult to apprehend) must be taken with calm and objectivity. Among the different arguments often found, two have proved to be troublesome:
a/ The larger number of nodes, the better the transparency
b/ The highest accuracy per node, the better the result

Argument a : true in theory, false in practice. Indeed, increasing the number of nodes above 17 assumes that the processing chain is highly non linear (otherwise the interpolation would be sufficient). But having a highly non linear process will inherently produce poor quality results.
Moreover, when creating the 3D LUT, processing 257 nodes (example) instead of 17 increases the number of nodes from 4.913 to 16.974.593. Finally managing such a high number of nodes increases hardware costs.

Argument b : false. There is no need to go beyond system accuracy by (artificially) increasing the number of bit. Regarding the required accuracy of interpolated values, care must be taken to obtain the input resolution. By example, for a node accuracy 10 bit, and interpolation from 8 adjacent nodes, intermediate computations must add 3 bit (LSB).

Summary on 3D LUT pros and cons

++	Will work whatever system distorsions
+	Exact correction on nodes, linear interpolation in between
+	Very simple to use 3D LUT created by 3rd parties
--	Creation of 3D LUT requires technical skill with good methodology, but many companies exist that have the technology.
-	No possible adjustment.

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The 1D LUT

Camera and Vision operators are trained to set up black, white and gamma levels to adjust picture colorimetry.
Globally in digital form, such corrections introduce a transfer function (input to output) of each primary (R, G, B). So vision operators have been using 1D LUT since ages, without knowing it !
Digital technologies however have widened possibilities to creating 1D LUT of any shape (not only gamma style limited) like signal inversion (negative) or S shape trasfer curves (film like).

The 1D LUT technique offers many advantages :

- Accurate. Each input value is allocated to an output value. No interpolation.
- It provides excellent results as long as there is no or small interaction between primaries
- From the user side, 1D LUT proves to be quite intuitive, easy to create (refer to Photoshop color corrector) and to use.

At the opposite, there are some 'cons' :

- It does no compensate completely distorsions where correlation between primaries exist (like in film or print or video projection);
- So easy to use that users might force their talents by creating curves that will reveal impossible to reproduce during film printing for example.

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Which Tcube product for which use?

Once posed the different concepts, one can split user needs into different categories.

Application	Needs	Tcube
Normalization before transmission	Legalizer and YUV Limiter	CO479
Video Production, Correction for On Stage displays	RGB Color Corrector (Black, Gain, Gamma)	CO509
Video Post production, D Cinema	RGB Color Corrector (Black, Gain, Gamma) plus 1D LUT per component	LUT409
D Cinema (derushing, look film)	Gamut converter using 3D LUT	LUT509
D Cinema (derushing and light post prod)	Gamut converter using 3D LUT plus RGB Color Corrector (Black, Gain, Gamma) plus 1D LUT per component	LUT559

To operate, users require in a non exclusive form:

- Hardware interface like Camera control unit (for Black, Gain, Gamma) (see Tcube **RC-CO**)
- Software interface (see Tcube **TOMATO**) to get access to all product features, included download of 1D/3D LUT files, 1D LUT graphical design and 3D Lut viewer.