

# Motion Picture Colour Science and film ‘Look’: the maths behind ACES 1.0 and colour grading

## 1. INTRODUCTION

One of the biggest colour-related problems for the film production and post-production industry is two-fold: to ensure that the creative “look” of video content, as envisioned by the cinematographer, is preserved throughout ([1]–[2]), and to be able to consistently reproduce this ([1], [3]). That also has to be independent both on digital cameras or computers generating and animating it (as input), and on finished asset specifications for the end-users to watch and enjoy it (as output) — be it either in a dark digital cinema theatre, at a home TV setting, or using a Video-on-Demand (VoD) or Internet-streaming application, in a day-lit room or even open sunlight.

In recent years many proprietary/commercial tools and workflows emerged, each driven by specific, not always cross-compatible needs (e.g. on-set grading, Digital Cinema mastering, VoD, etc.). This results in proliferation of a plethora of different formats vs. the scarce number of really interoperable standards.

The author has put lots of efforts to provide a unified mathematical formalism and usability to most of the colour-management technologies used in the post-production world, both on independent publications and in collaboration with several entities in the business (like the SMPTE and the AMPAS). After a minimal introduction to such colour-mathematical terminology ([4]–[6]) and ColorLUTs, two brand new colour-management techniques from high-profile moving-picture digital imaging (CDLs and ACES) will be described, as they aim at colour interoperability for the analysis and synthesis of digital ‘looks’, both on-set (production) and along the Digital Intermediate (DI) phase.

ACES in particular, which the author has been active contributor to since 2012, is an Academy-originated initiative for facilitating colour interoperability across the Media & Entertainment industry.

## 2. COLOUR SCIENCE MATHEMATICAL FORMALIST

A gamut mapping between colour spaces ([5]–[7]) is a vector field  $\mathbf{L}(\mathbf{c})$ , where  $\mathbf{c} \in \Gamma$  is the input colour in the source gamut  $\Gamma \subseteq \mathbb{R}^m$  (which is, to every practical aspects, a connected, linearly-

and superficially-connected  $m$ -dimensional domain—often even a convex one), with  $\dim \mathbf{L}(\Gamma) = n$ . Let the input and output spaces be both RGB model ( $m=n=3$ ) and their canonical bases be the left-handed triple  $\{\mathbf{r}, \mathbf{g}, \mathbf{b}\}$ , so any input colour  $\mathbf{c} \in \mathbb{R}^3$  is coordinated as  $\mathbf{c} = r\mathbf{r} + g\mathbf{g} + b\mathbf{b}$  and, for the input regular RGB cube,  $(r, g, b) \in [0, 1]^3$ . The output colour is thus  $\mathbf{L}(\mathbf{c}) = R\mathbf{r} + G\mathbf{g} + B\mathbf{b}$ ; by the Hodge-Helmholtz’ theorem, the *orthogonal* decomposition holds ([4]–[5]):

$$\begin{aligned} \mathbf{L}(\mathbf{c}) &= R(r, g, b)\hat{\mathbf{r}} + G(r, g, b)\hat{\mathbf{g}} + B(r, g, b)\hat{\mathbf{b}} \\ &= \mathbf{T}(\mathbf{c}) + \mathbf{H}(\mathbf{c}) = \nabla\chi(\mathbf{c}) + \nabla \times \boldsymbol{\eta}(\mathbf{c}) + \mathbf{I} \end{aligned}$$

where  $\mathbf{T}(\mathbf{c})$  and  $\mathbf{H}(\mathbf{c})$  are the conservative (curl-free) and the solenoidal (divergence-free) parts of the colour map, each derived from a potential field — a scalar one  $\chi(\mathbf{c})$  for the former, and a vector one  $\boldsymbol{\eta}(\mathbf{c})$  for the latter. Due to simple connectedness of  $\Gamma$ , no *harmonic* component is present in the above: the constant ‘lift’ term  $\mathbf{I}$  represents an overall colour bias (either neglected or incorporated into  $\mathbf{T}$ ) for chromatically-additive colour models like sRGB, as well as CIE XYZ and DCI X’Y’Z’.

The gradient of the gamut mapping can also be considered, which is a more complete (and complex) mathematical object, called a  $(n, m)$ -tensor field, [4], depending on both the source  $m$  channels and the target  $n$  channels.  $\mathbf{T}$  is the generalized tonal mapping, or transfer characteristics which, in RGB spaces, models overall colour correction (incl. lightness and saturation changes).  $\mathbf{H}$  is the field describing local colour-component cross-talks and global hue shifts. Notably,  $\mathbf{T}$  field too may incorporate hue shifts, especially for those colours  $\mathbf{c}$ , where the inter-channel ratios are not preserved, i.e.  $R(\mathbf{c}) : G(\mathbf{c}) : B(\mathbf{c}) \neq r : g : b$ .

Colour-correction languages often use the luma-chroma colour model (e.g. the  $L a^* b^*$ ,  $Y'UV$ ,  $Y'c_B c_R$  and  $Y'c_X c_Z$  spaces), or the cylindrical colour model (e.g. the HSL space). In the case of HSL for example, the author usually suggests joining hue  $h$  and saturation  $\sigma$  together into a complex parameter called *chroma*  $\zeta$  and defined as, [5]:

$$\zeta := h e^{i\sigma} = \sqrt{a^{*2} + b^{*2}} \exp\left(i \arctan_2 \frac{b^*}{a^*}\right)$$

(where  $\arctan_2$  is the secondary arc-tangent, which is reminiscent of quadrant allocation

for  $b^*$  and  $a^*$  and commonly found in all the programming languages).

### 3. COLOUR LOOK-UP TABLES, AKA COLORLUT, AKA CLUT, AKA SIMPLY 'LUT'

While the above formalism is useful for technical operations like colour space conversions and “overall” colour corrections not done on a scene-per-scene basis, more complex transformations may be needed, especially when creative intent is included, [8]–[10]. In this case a closed-form formula for the transform might not exist; interpolation, though existing in principle, might not be computationally compatible with the creative need of real-time playback of high-resolution (often uncompressed) image/video files (essential for evaluating and creating the so-called grades). For this reason the continuum formalism may be well abandoned at this stage, and replaced by a ColorLUT (colour look-up table, or CLUT, [6]) which is a discrete-mapping representation of it on a finite,  $m$ -dimensional grid of  $N$  points per input colour channel, with each point being a  $n$ -tuple in the output colour space (e.g. in the shape of a  $N \times N \times N$  RGB cube). It is an explicit mapping between a sample of input code-values into output code-values (which may or may not act between the same colour space), while the result on intermediate source colours is obtained by interpolation [3]: for this reason a CLUT can be also used to approximate continuum formulae as those for mapping a colour space into another (e.g. from a RGB one like Rec.709, [10], to CIE XYZ, cfr. Fig. 2c). A type of CLUT approximates the mapping channel by channel (therefore called 1D-LUT, or *colour curve* in different contexts); another type acts as a full orthogonal sampling of input colours; the latter —because it usually maps between 3-channels colour spaces— is specifically called a 3D-LUT whereas, mathematically, it is a discrete  $n$ -dimensional vector field  $\mathbf{L}(\mathbf{s})$ , where  $\mathbf{s} \in \Gamma$  is the input colour codevalue of the source  $m$ -channel gamut  $\Gamma \subseteq \mathbb{R}^m$  (cfr. several samples in Fig.1, where  $m=n=3$ ).

The reason why the CLUT implementation is so widely used is manifold: first of all, provided the appropriate density of  $N$  input value per channel is used ( $17 \times 17 \times 17$  samples in Fig. 2 is a common, but yet not enough coarse-grained choice), it can represent any non-linearities in the colour transform (accounting from the most complex primary colour corrections, up to a 35mm film’s dye cross-talk, as is the case for 3D-LUTs). Secondly, it is implemented via simple (and usually linear) interpolations on the other non-sampled colours, fairly scaling with the CLUT size  $N$ , and has therefore a smaller footprint in terms of CPU power and memory size needed to

“run” the algorithm, than applying more complex mathematical formulæ.

Third, a CLUT can hardly be interpreted only by specific software able to read its encoding and is useful only on specific picture(s) it was intended for: quite a black-box ingredient for the motion-picture recipes. The latter aspect may have been advantageous in the past, but is now mostly a downside, when cinematographers, colourists and VFX artists really need to transfer colour corrections from the on-set pre-grading sessions throughout the whole post-production pipeline, up to the theatre room, and capable of doing so in the most advantageous and, above all, *interoperable* way (cfr. §5). Moreover, lots of workflows with so different and “undisciplined” uses of CLUTs exist —be it either for technical and creative intents— such that no generalized use can be made of a CLUT as long it is tailored for a specific project. It is hard to invert (i.e. to “reverse-engineer”) the mathematical operations baked into a CLUT, especially for post/VFX labs which do not enforce a thorough colour management across their pipelines. That is even worsened when materials from different sources (camera makes, film emulsions, CGI rendering, ...) come all together in place.

Discrete-calculus tools allow the extraction of quantities essential for the analysis or synthesis of a colour transformations: estimating colour differences, hue shifts in degrees, boundary wedges for evaluating Out-of-Gamut (OoG) colours, etc..

When technical problems of higher level arise in colour correction (e.g. colour characterization of specific input or output devices, or proper gamut mappings between footage with different colorimetry), this usually translates into more sophisticated mathematical tools to be employed, often derived from Differential Geometry, Harmonic Analysis and multi-dimensional interpolations, [4].

For example, a more careful shaping of a tone-scale curve is usually necessary when modelling the transfer characteristic of a non-digital device, e.g. sensor noise or the sought-after 35mm *film print emulation* (FPE, cfr. Fig.2): three control points as provided by a CDL ([11]) or a 3-way color-corrector (CC) are no more enough and the three channel functions  $R(r)$ ,  $G(g)$  and  $B(b)$  need to stay non-decreasing (i.e. invertible). This helps better trim the effective contrast on all the tonal ranges. When the three functions are uneven with each other, a hue shift inevitably occurs, as the hue is not preserved by the same input triple  $(r, g, b)$  any more. Imposing hue-invariance means adding constrains that need to be correctly formulated, i.e.:

$$\nabla \times \mathbf{L}(\mathbf{c}) = \nabla \times \mathbf{H}(\mathbf{c}) = \left( \frac{\partial B}{\partial g} - \frac{\partial G}{\partial b} \right) \hat{\mathbf{r}} + \left( \frac{\partial R}{\partial b} - \frac{\partial B}{\partial r} \right) \hat{\mathbf{g}} + \left( \frac{\partial G}{\partial r} - \frac{\partial R}{\partial g} \right) \hat{\mathbf{b}} = \mathbf{0}$$

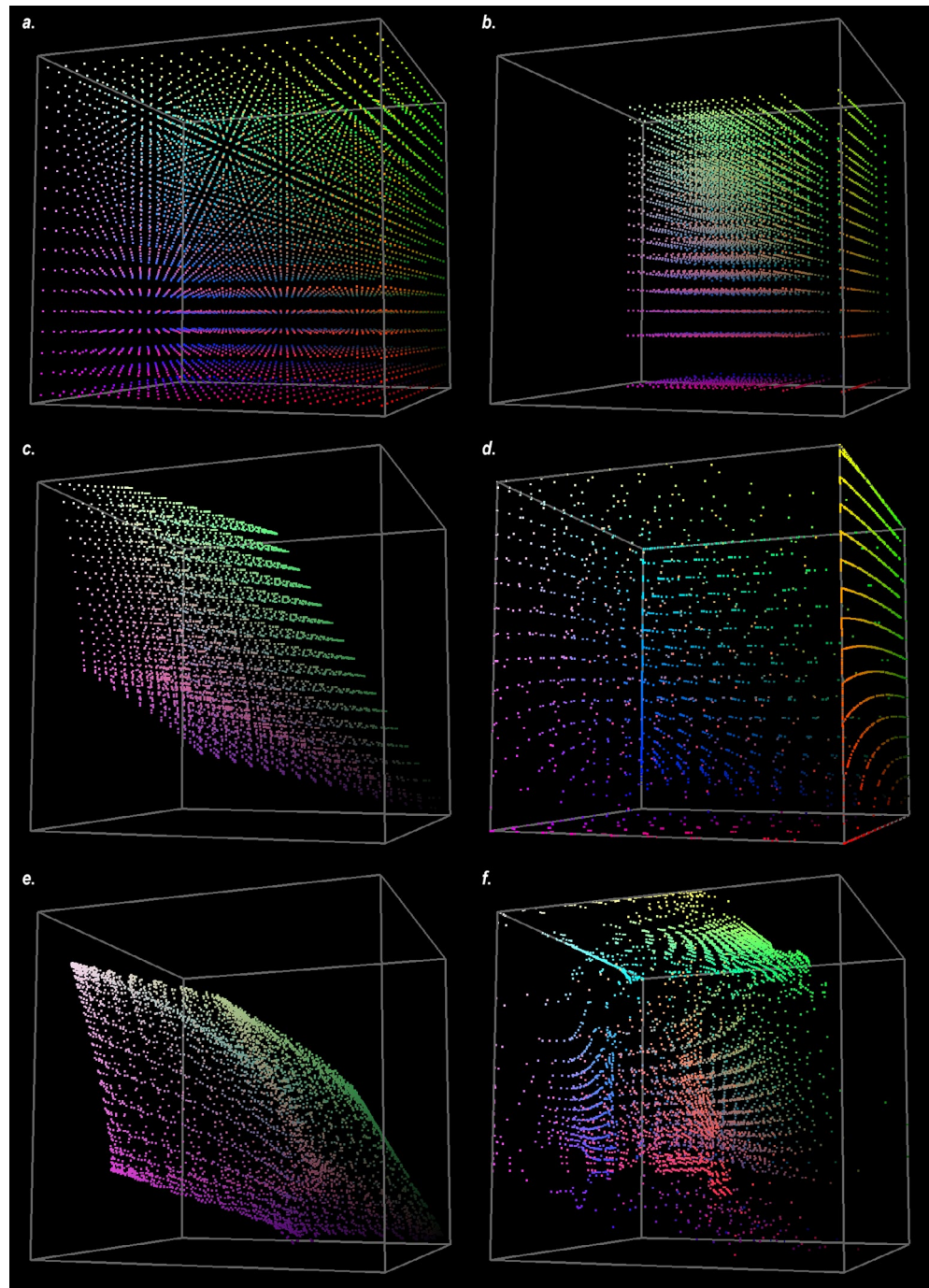
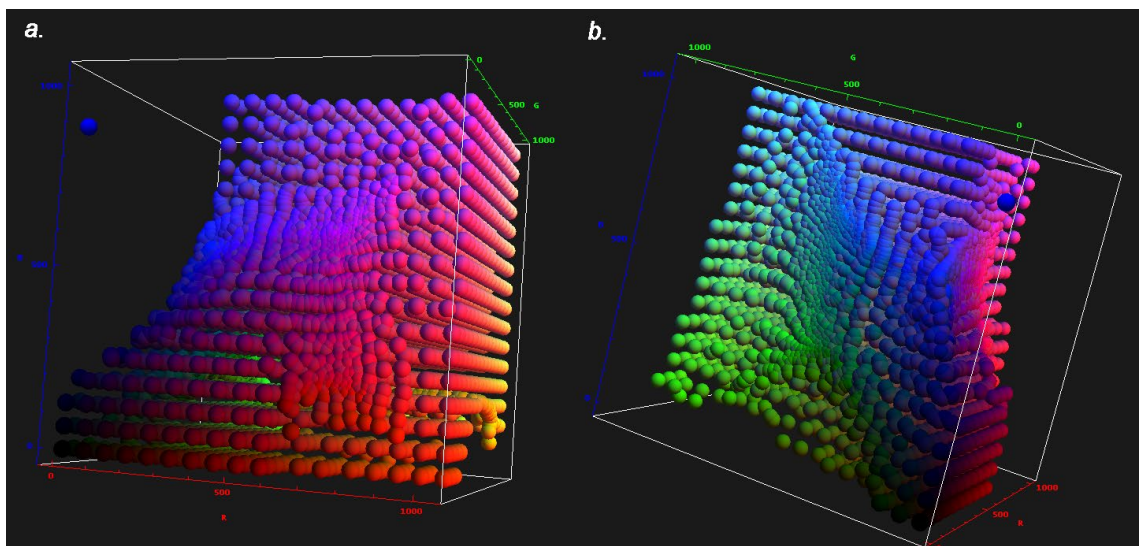


Figure 1 - Plots of the output gamut  $L(I)$  of 3D LUTs  $L$  whose input is the 173-points RGB cube  $I$ : **a.** identity mapping; **b.** colour-space conversion between HDTV's "Rec.709" and Cineon Printing Density (CPD) "logarithmic" RGB spaces; **c.** from "Rec.709" (gamma  $\gamma=2.6$ ) to Digital Cinema (DCI) CIE XYZ colour space; **d.** from CIE XYZ to DCI's P3 RGB colour space ( $\gamma=2.2$  – notice the clipping at the cubic gamut boundary of P3); **e.** from Cineon Printing Density log. RGB to CIE XYZ colour space; **f.** scene-specific creative Colour Grading LMT including 35mm print-film emulation.

Figure 2 – Two different views of output gamut  $L(I)$  of a Print-Film Emulation (PFE)  $L$  engineered by the author (Technicolor laboratories, Rome, 2009), showing the synthesis work done adding additional points to the gamut of a Kodak Vision film in order to expand its latitude prior to 35mm scanning.



More often simpler definitions of hue and saturation are used though, like

$$\text{sat}(\mathbf{c}) = \frac{1}{2} \sqrt{\|\mathbf{c}\|^2 - gb - rb - rg}$$

$$\text{hue}(\mathbf{c}) = \arctan_2 \frac{\sqrt{3}(g-b)}{2r-g-b}$$

which allows to have simpler analytical properties like

$$\nabla \text{sat}(\mathbf{c}) = \frac{1}{\text{sat}(\mathbf{c})} \begin{pmatrix} 2r-g-b \\ 2g-b-r \\ 2b-r-g \end{pmatrix}$$

$$\nabla \text{hue}(\mathbf{c}) = \frac{\|\nabla \text{sat}(\mathbf{c})\|}{\text{sat}(\mathbf{c})} = \frac{\sqrt{3/8}}{\text{sat}(\mathbf{c})}$$

Imposing hue-invariance, means in this case solving the algebraic equation

$$\text{hue } \mathbf{L}(\mathbf{c}) = \text{hue}(\mathbf{c}) \Leftrightarrow \frac{G-B}{2R-G-B} = \frac{g-b}{2r-g-b}$$

Another important constrain that is sometimes necessary, is the existence-of-inverse condition. This is especially important to guarantee that, once a grade is 'burned' within the raster pixels, original colours can still be recovered without degradations.

It's worthwhile noting that current post-production tools only 'burn' a colour grade as the last stage of the process (earlier the information on the grades is carried along the pipeline as *metadata-only* by the colour-correction software). This is formulated as in [2]:

$$\det \frac{\partial \mathbf{L}}{\partial (r, g, b)} = \begin{vmatrix} \frac{\partial R}{\partial r} & \frac{\partial R}{\partial g} & \frac{\partial R}{\partial b} \\ \frac{\partial G}{\partial r} & \frac{\partial G}{\partial g} & \frac{\partial G}{\partial b} \\ \frac{\partial B}{\partial r} & \frac{\partial B}{\partial g} & \frac{\partial B}{\partial b} \end{vmatrix} \neq 0$$

## 4. ON-SET COLOUR GRADING AND ITS COLOUR LANGUAGE (CDL)

Since things are now shot digitally and stay digital throughout the pipeline, one of the movie-chain blocks to recently take advantage of this is principal photography, where early colour correction/grading can be done effectively, on-set, just minutes after each clip is shot, cfr. [11], Fig.3.

Creative colour correction (grading) information can be transported, from clip to clip, as they are originally shot, as a series of simple non-linear transformations controlled by 10 parameters (3 parameters by each of the 3 RGB channels, plus 1), each representing one degree of freedom of the creative colourist: 'slope', 'offset', 'power' triples, plus a 'saturation' parameter. A set of such quantities, transported for a whole video asset, cut per cut, makes up the 2014 OSCARS®-winning American Society of Cinematographers' *Colour Decision List* (ASC CDL) and is a well-known example of simple mathematical equations at the creative service of motion picture colourists [5], [11]. This can also be re-written by means of three functions  $S$  (slope),  $O$  (offset) and  $P$  (power) and let  $s, o, p$  be the respective controlling parameters with identity values 1, 0, 1 respectively:

- Slope  $S(c;s)=sc$  (CDL analogue for colourists' *lift*, despite slope fixes black point at codevalue 0.0, whereas lift fixes whitepoint at codevalue 1.0);
- Offset  $O(c;o)=c+o$  (CDL analogue for colourists' gain);
- Power  $P(c;p)=\max(0,s)^p$ , which is the CDL analogue of a gamma-correction.

$$\begin{aligned} \mathbf{L}(\mathbf{c}) &= (o_R + s_R r)^{p_R} \hat{\mathbf{r}} + (o_G + s_G g)^{p_G} \hat{\mathbf{g}} + (o_B + s_B b)^{p_B} \hat{\mathbf{b}} \\ &= P(O(S(r; s_R); o_R); p_R) \hat{\mathbf{r}} + P(O(S(g; s_G); o_G); p_G) \hat{\mathbf{g}} \\ &\quad + P(O(S(b; s_B); o_B); p_B) \hat{\mathbf{b}} \end{aligned}$$



Figure 3 – Example of commercial colour grading software GUI with the main 3-way colour-corrector wheels.

This is a *non-orthogonal* decomposition in 1<sup>st</sup>- and 2<sup>nd</sup>-degree polynomials (slope + offset), plus a *nonlinear* function (power), thus the inner products may not “*behave*” well. It can be shown however (and this is in fact well-known practice done by every non-mathematician colourists working on still or moving pictures), that a sufficiently low number of such operators, governed by a few parameters (like weighting coefficients in a linear combination for Linear Algebra) allow for quite good approximation, thus leading to orthogonal decompositions of colour operators.

$$\mathbf{L}(\mathbf{c}) = \sum_{k=1}^c \mathbf{I}_k(\mathbf{c}; \theta_k)$$

where all the 1-parameter vector fields  $\mathbf{I}_k$  are known a priori, whereas the coefficients and the parameters  $\theta_k$  themselves are the real descriptors of the “*look*”.

## 5. THE ACADEMY COLOR CODING SYSTEM (ACES)

The Academy of Motion Picture Arts and Sciences (AMPAS)’s Science and Technology Council has been gathering a group of variegate experts from all the top-level production, post-production facilities and software houses in the industry to put forward a solution unifying such colour management issues: ACES, [1], [12].

The reason behind ACES is the need to particularly address the plethora of colorimetries set by manufacturers’ digital equipment (both image-creating and -reproducing) — even many more so in the digital era than film processes ever had in the past. A similar need has already surfaced in the Digital Cinema industry: that is why its  $D_{60}$   $X'Y'Z'$  colorimetry derives from the device-independent CIE  $XYZ$  colour space ([3], [10]). Unfortunately, as neither *colorimetric* cameras nor monitors/projectors exist as of yet, this colour-space choice has lead to reverting to a one within the RGB model, which is more practical, as well as ACES mostly pertains to TV

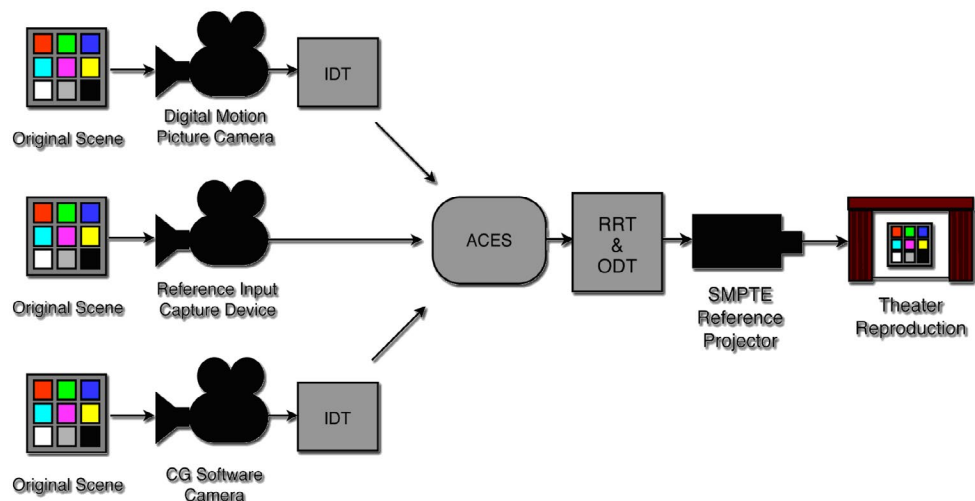
and moving pictures. Every colour-correction operators in the involved pipelines (from camera controls, to colour-grading suites, to projectors’ and TVs’ balance controls) are, in fact, RGB-based.

Version 1.0 of ACES, [12], whose project the author has been cooperating on with the AMPAS experts since 2012, is a framework with centralized colour-management paradigm, developed after many years of pre-testing among facilities and companies in the industry, where the image is evaluated according to its colorimetric digital representation. Please refer to Fig.4 for a schematic throughout this Chapter. First of all, ACES defines APO and AP1: two sets of RGB primaries for the four ACES colour spaces. APO, whose CIE  $xy$  chromaticities are (0.73470,0.26530) for Red, (0.,1.) for Green and (0.0001,0.0770) for Blue. AP1 primaries’ chromaticities are (0.713,0.293) for Red, (0.165,0.830) for Green and (0.0128,0.044) for Blue. Both use CIE  $D_{60}$  illuminant (0.32168,0.33767) as white-point and physical blackpoint at CIE  $XYZ$  triple  $\mathbf{0}_3$ .

Within ACES colour pipeline the image is considered as virtually captured by a *Reference Input Capture Device* (RICD), which is an idealized digital ‘camera’ recording in a RGB colour space called SMPTE2065 after the standard that defines it. Another important aspect is that SMPTE2065 is a *scene-referred* colour space, i.e. the code-values represent mean relative exposures to the one captured from a perfect reflecting diffuser — apart from a 15% glare. In APO, this accounts for a normally-exposed 18% grey card acquired by a RICD mapped to the RGB triple (.18, .18, .18).

Any real camera imagery and colorimetry is brought into the pipeline by means of a colour gamut mapping called *ACES Input Transform*, which basically converts all the camera’s colorimetry into SMPTE2065. Currently, Input Transforms for most of the patented, cinema-grade cameras like the ARRI ALEXA, the cameras

Figure 4 - Sketch of the ACES paradigm: the original scene is either captured by a real camera or generated in CGI. Whatever the source, the corresponding Input Transform converts the code-values into the SMPTE2065 colour space (except for the “ideal” RICD, which already produces SMPTE2065 pictures). Using the Output Transform the pictures can then be transferred to any output device, like monitors (with any technologies), projectors, TVs, etc.



by RED™, the Fx5 family by Sony, the cameras by Blackmagic Design, and the Cinema-EOST™ family by Canon, are provided; each maps the sensor's proprietary gamut (called ARRI Log.C, RED.Log, S-Log/S-Gamut, BMD.Log and CanonLog respectively), parametrized by shooting settings like equivalent sensitivity (ISO) or correlated colour temperature (CCT), into scene-referred SMPTE2065 codevalues.

The author has also been active in Italy for promoting the use of ACES with several initiatives, [1], including a real-world, on-set test to compare ACES framework originating from different, high profile cameras, up to a full VFX and Digital Cinema mastering pipeline: Fig.5 is the result of the technical photography session. At the other end of the pipeline, SMPTE2065 colorimetry is converted to the gamut of the displaying device and chromatic adaption by means of an ACES Output Transform: among the others there is one, for example, for Digital Cinema mastering (DCI P3) in a dark surround, two for standard broadcast TV gamut (Rec.709), and two for UHDTV (Rec.2020) — each having one for a bright- and one for a dark-surround adaption. From a Colour Appearance Model (CAM)'s perspective, the Output Transforms take care of the viewing environment as well: so several Output Transforms may exist for the same device, but under different chromatic adaptations. All the Output Transforms have a common first mathematical block, called the *Reference Rendering Transform* (RRT). Please refer to Fig.5 for a block-diagram of ACES version 1.0 main components.

All in all, SMPTE2065 space uses AP0 primaries, has trivial transfer characteristics (i.e. it is

photometrically linear, i.e. “*gamma-1.0*”) and represents the baseline for all the ACES pipeline — and the widest gamut as well, which is also suited for long-term archiving, cfr. Fig.6. Codevalues are usually encoded as 16 bits/channel floating-points (‘half-floats’ as per IEEE 754-2008 standard), and archived in a specific frame-per-file variant of the OpenEXR file format, cfr. [14]–[15].

It is within this space that images are mainly worked on, with exceptions when it is technically convenient or mandatory to use temporary, well-defined colour-spaces for specific purposes:

- **ACEScc** has AP1-primaries, “*logarithmic*” transfer characteristic, 32 bits/channel float encoding optimized for film-style colour correction, [13];
- **ACEScg** has AP1-primaries, photometrically-linear, 16 or 32 bits/channel integer code-values, optimized for CG and painting applications that scarcely support images represented by floating-point codevalues, [16];
- **ACESproxy** has AP1-primaries, the same logarithmic characteristic as ACEScc, 10 or 12 bits/channel integer encoding, optimized for real-time transport of images over physical links (e.g. the SDI cables family) that only support integer code-values, yet logarithmic encoding is still needed for on-set color correction applications, [17];

Similarly, output-device compatibility is provided by first mapping to another ideal

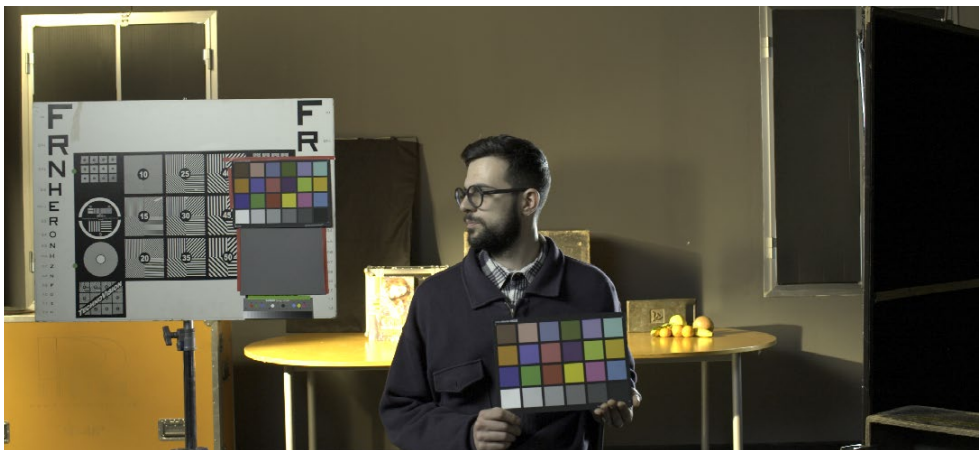


Figure 5 - Real-world ACES testing to compare ARRI Alexa XT (shown here), RED™ EPIC and Sony F55 cameras on the same technical set and ACES colour space (also courtesy of DIT E. Zarlenga).

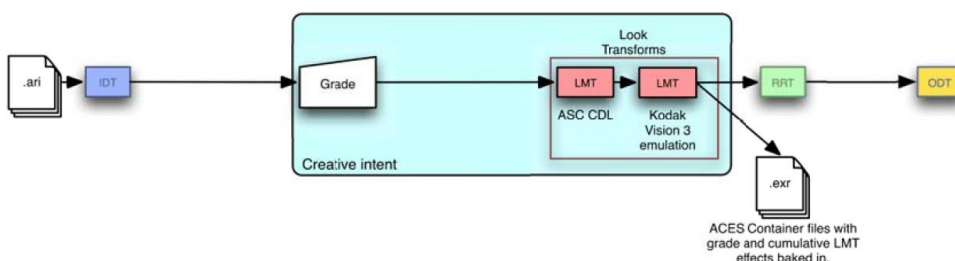


Figure 6 - Main ACES v1.0 components in place: footage shot in Alexa camera's native ARRIRAW frame-per-file format (in Log.C colour space) is technically processed by an Input Transform to become scene-referred SMPTE2065 colour space. This is where color grading is applied upon (in temporary ACEScc space). The CDL designed during principal photography (on-set) pre-grading is conceptually applied above this grade, but below optional creative-technical transforms like PFE. The file is then ready to be saved in ACES-compliant OpenEXR sequence (SMPTE2065 colour space) or can be sent to a display device passing through an Output Transform.

output Reference Display Device (RDD) via the aforementioned RRT, and, whence, by means of a discrete mathematical formula called Output Device Transform (ODT), which depends on the output colour space and, ultimately, on the output device's transfer characteristics (e.g. monitors, projectors, printers, D-Cinema devices, etc.). ACES images are stored in frame-per-file ordered sequences, encoding each frame as a OpenEXR file [14], together with ACES-specific metadata optionally written as well in a "sidecar" XML file called ACES clip-container. Ideally, any sensitive colour operation (both for technical and creative intent) should take place in either the SMPTE2065 or the ACEScc colour spaces (which act like a PCS in the ICC paradigm), where any operator acts unambiguously. Creative-intent operations, in particular, are stored in the so-called *Look Modification Transform(s)* (LMT), which are applied before the Output Transform.

## 6. CONCLUSIONS: THE COLOUR 'LOOK' OF A FILM

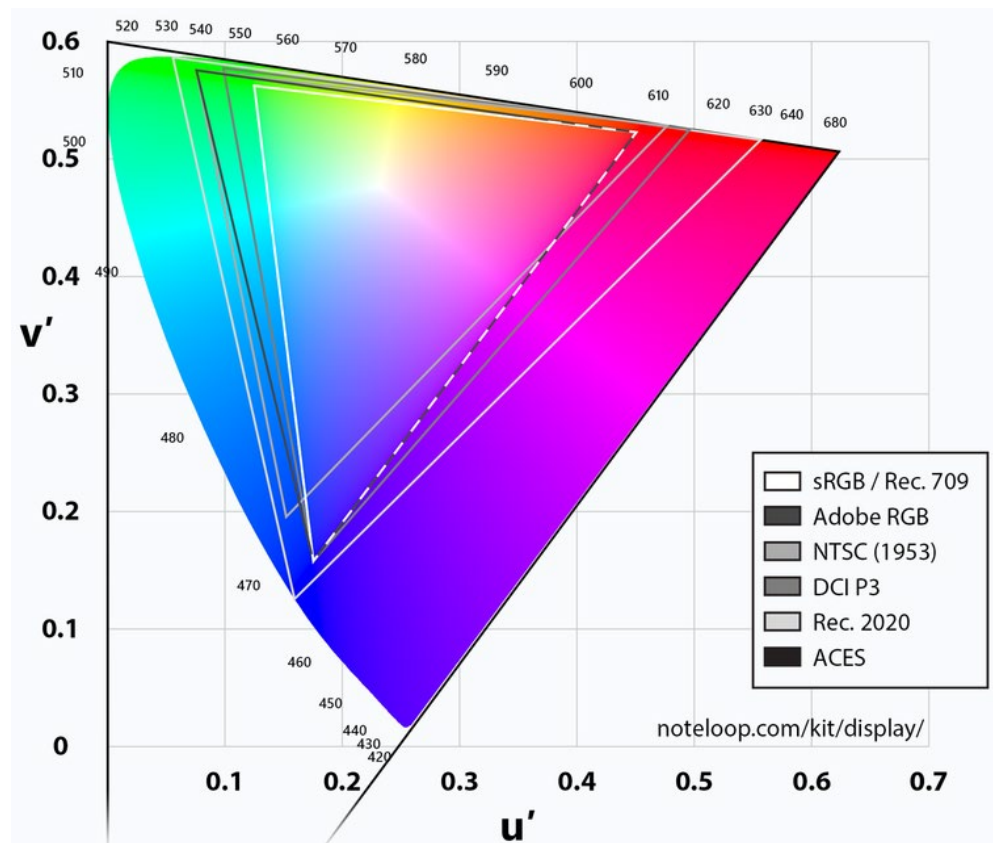
Several professionals in the video, post-production and DI world, as well as colour scientists and vendors, have long tried to define what technically "look" means in this context. In the author's opinion, science, experience and common practices can sum up together to the statement that currently a "look" is the *ensemble* of creative *colour decisions* made for a specific set of scenes (e.g. scenes shot to represent the same lighting and dramatic situation, if not even

possessing location/temporal unity) that neither pertain the technical properties of the colours themselves nor the devices/media used to reproduce them. In this sense "look" is different from "film look", as the latter also includes colour characteristics due to combination of a film's emulsion, development and printing processes (which can of course be emulated).

A look applied to two differently-exposed and -coloured scenes not to chromatically match them (that's what the same-name phase of a colour correction session is about), but rather to give both the same visual impact, in the director's and/or cinematographer's minds, the incisive 'colour fingerprint' unique to that specific product and cinematography; the 'look development' phase has therefore been starting earlier and earlier in the production phase, up to taking place on-set, with the help of proper pre-grading workflow (e.g. the one proposed by Technicolor DI supervising colourist Peter Doyle for *Harry Potter VII*, *Dark Shadows* and *Paddington* full-feature films).

The lack of interoperable schemes, incompatible file formats and colour operations —even a unified terminology— has prevented many colour manipulations from currently happening, or at least made this much more difficult and prone to errors or lack of precision. This cannot be any more delayed since all film processes have turned completely digital, and this is where the author's contributions have been focusing on in the latest years. Unifying the post-production terminology and mathematical

Figure 7 - Chromaticity comparison between ACES (SMPTE2065) gamut other well-known RGB colour spaces.



formalism (which were traditionally tied up to different post-production laboratories' own film processing technologies and manufacturers' secret sauces) means creating a common baseline to start from and communicate with mainstream Color Science. ACES is another step up in the attempt to create common processes and workflow to ease interoperability and help to future-proof archival footage. Of course all of this is a process, therefore it is not meant to be set in stone but rather continually progress as new technologies, methodologies and, above all, creative eyes and minds turn up bringing along their expression techniques and visions — for this process to drive them all along together.

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