Film Look in Digital Post-production

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Abstract

In cinematographic post-production, the traditional analogue film workflow co-exists today with the Digital Intermediates (DI) workflow. In DI, the film timing operations are replaced by digital colour correction. During colour correction high quality CRT displays and digital projection replaces the film, however, final results in colour and dynamics are always assessed via a film print. To ensure film-like colour rendering on a target display other than a film projector, a 3D Look Up Table (LUT) based colour transformations needs to be used. The LUT is calculated from colour measurements on film and on target display. This paper analyses current post-production workflows with respect to their needs in colour management. We discuss the principle approach on how to obtain a LUT considering practical constraints. The paper presents two new contributions that show (a) how to choose a set of colours and (b) how to measure them in order to capture film look. Finally, verification and subjective tests are discussed in order to ensure the quality of digital film look.

Post-production workflows

Currently, in post production traditional argentic film and Digital Intermediate (DI) processing co-exist. This section will introduce typical workflows of cinematographic content processing (see [1] for more details).

In each workflow, two distinct colour-changing operations are carried out. The first operation is colour correction. Being a manual, artistic process, colour correction aims to change film colours such that a desired, artistic effect is achieved. Colour correction can be "primary" when applied to the whole image (example: blue is added to a night scene). It can be "secondary" when only parts in colour space - often corresponding to specific, spatially limited objects in the scene - are modified (example: changing the colour of the shirt of a person).

The second operation not artistic and is linked to colour management (CMM). It aims to reproduce same colours on any output device, typical devices being film projector, digital projector and CRT monitor. This operation is a presupposition of colour correction and depends on the workflow. As will be seen in the next section, colour management takes also in account the Digital Cinema distribution as one of the possible output "devices".

Colour is among the most important aspects of film beside resolution, grain, jitter, scratches and weave. Therefore, mastering cinematographic colour correction opens high-quality content to different types of audiences while keeping artistic and emotional intent. However, the more complex and heterogeneous the imaging chain is, the more difficult is it to keep colour reproduction coherent. Imaging chains may include carrying processing workflows employing different types of equipment and media. CMM is the explicit consideration of different device types and media in order to ensure correct colour reproduction.

Up to present time, argentic film is still most-used support in film production. People involved master the medium. Multiple artistic effects depend on it [4]. The argentic film support has also recognized objective qualities compared to digital acquisition [5]. The first one is spatial resolution, which is much higher than what can be achieved with digital acquisition systems (video or even film-look digital cameras). The second one is colour rendition, with an important colour dynamic, especially in the dark levels. For these qualities, film is used today as shooting support through three main post processing workflows:

1. Film Processing,
2. Digital Film Processing (DI),
3. TV Post Production

Film processing is of course the historical and most "natural" workflow for film. Film processing is mainly a chemical process, transforming the stage shots into theatre film releases to be distributed worldwide. The film processing involves many precise steps, fruit of a long experience. After developing the camera negatives, the first step of the workflow is cutting and assembling to create a work copy. Secondly this assembled negative is "colour graded" or colour corrected meaning that the colour is adjusted by expert colourists. Colour grading is performed for several reasons: - adjusting colorimetry between different shots of the same scene (for example a same scene, shot on different days with different lighting conditions, that must appear continuous on the final rendering), - giving an artistic look to the film content (for example as if it had been shot by a personal camcorder), - making the scene warmer or colder, or reddish, etc, according to the artistic intent of the director of photography. Colour adjustments are performed on several work copies, until the desired result is achieved in term of colour rendition. The expertise and experience of the colour graders is critical all along this process. Colour correction is applied in this workflow by controlling the illumination colour of the film printers. A duplication master is created from the approved work copy, serving as base for the release prints duplications.

Digital Film Processing – also called Digital Intermediates (DI) is a second, relatively new, option to transform stage shots into film releases. Although it can be considered as a more complex process, Digital Film Processing allows more complex effects. Indeed special effects are easier to perform in the digital world. Concerning colour, local, secondary colour correction, such as changing the colour of a T-shirt, can be realized in a powerful way. The first step of the workflow is film scanning, mapping the analogue film into a digital representation. It is performed by a class of devices called "datacine". A "datacine" outputs digital image files for processing, while the traditional "telecine" use analogue image signals. Then, the engineers can perform all operations of film editing to recording and organize the scenes along the film timeline. Thanks to dedicated colour engines, a similar workflow to that one done on the film is performed. The objective is once again to translate the artistic intent of the Director of Photography (DP) into reality in high quality images. Compared to the analogue film path, the digital film processing uses three kinds of output devices:

- High Definition (HD) monitors in smaller booths, able to give a real time feedback of the effects applied,
- Digital Cinema projectors in projections rooms, giving real time feedback with colour appearance closer to film than HD monitors,
- Film projectors, after a digital to film over night transfer was realized by dedicated equipment.

Here arises a major challenge concerning colour management. Indeed, these three rendering paths do not have the same colour rendition capacities. However, it is important to obtain the same look, more precisely the look of the used film stock and film processing across all these displays methods.

TV post-production is the third exploitation workflow of film content. Shooting scenes on film is so appreciated by production people that it is used even for shooting TV programs replacing TV cameras by film cameras. This is the case for example for TV series or for TV commercials. In that configuration, the transfer is between film content and TV signal. TV signal means here a high-definition (HD) signal master that is later transcoded to standard resolution. As for digital film processing, the first step of TV post-production workflow corresponds to film scanning. Compared to digital film, the used HD format is of lower resolution. Next steps are editing and colour processing, with the same objectives as before. The resulting video is finally stored on digital HD tape for further use in the TV domain. In this application, obtaining the "film-look" is also a goal, both during the processing when monitoring the colour adjustments, and later on the final result.

Generation of Digital Film Look

Post-production hardware is based on non-linear RGB tri-stimulus signals, usually coded in 10 bit and connected by one, two or up to eight HD-SDI links for resolutions of 2k 4:2:2, 2k 4:4:4 or 4k 4:4:4 signals, respectively. In order to master the colour rendering of a display device, hardware-based RGB-to-RGB colour Look Up Tables (LUTs) are linked into the signal chain.

Such an RGB to RGB LUT is calculated offline from a forward reference device model (RGB to XYZ) and an inverse target device model (XYZ to RGB) according to the classical colour management principle [2]. A LUT can be represented as

$$\left\{\left(R_j, G_j, B_j, \hat{R}_j, \hat{G}_j, \hat{B}_j\right) \backslash\, j \in [0, (P-1)^3]\right\} \quad (1)$$

with P being the resolution of the LUT. For example, resolution can be $P=65$ in order to have 64 intervals. Each colour value has a given fixed bit depth M, e.g. M=10 bits.

A LUT for calibration of a target device in a "look" as of a reference device is calculated as follows:

$$\left(R_j, G_j, B_j\right) = \left(\frac{p\left(2^M-1\right)}{P-1}, \frac{q\left(2^M-1\right)}{P-1}, \frac{j\left(2^M-1\right)}{P-1}\right) \quad (2)$$

$$\left(\hat{R}_j, \hat{G}_j, \hat{B}_j\right) = f_{RGB}^{TARGET}\left(f_{XYZ}^{REF}\left(R_j, G_j, B_j\right) \right) \quad (3)$$

with $p = j \bmod P^2;\ q = j \bmod P;\ 0 \leq j < P^3$

where f_{RGB}^{TARGET} is the inverse device characterization model of the target device and f_{XYZ}^{REF} is the forward device characterization model of the reference device.

In our scheme, the forward device characterization model ensures the estimation of XYZ output values from given RGB input values according to:

$$(X, Y, Z)^T = f_{XYZ}(R, G, B), \quad (4)$$

while the inverse device characterization model ensures the estimation of RGB input values from given XYZ output values according to:

$$(R, G, B)^T = f_{RGB}(X, Y, Z). \quad (5)$$

RGB are device dependent colour input signals of the considered device, XYZ are values from CIE 1931 XYZ space for 2-degree observer and $(\ )^T$ is the transpose operation.

Device characterization models are obtained from device measurements. The models are more or less sophisticated interpolation schemes. For example, M. Gupta [7] compares several linear methods using different neighbourhoods. In our system we use a splines based interpolation scheme. Direct use of measurements in LUTs is not feasible since they are usually not available in sufficient number due to limited measurement time. Even the final LUT is not calculated in full resolution. For processing a 3×10bit RGB signal, the most sophisticated hardware solution of the market allows for a $2^8 \times 2^8 \times 2^8 \times 30$ bit table that is linearly interpolated.

Measurement of Film Look

One aim of this paper is to show how film look can be measured. This problem is discussed in two steps: first, which colour should be measured and second, which measurement methodology should be used. The following steps for device characterization and LUT calculation are not in the scope of this paper.

The first step for choosing the colours to be measured is here referred to as colour sampling. The chosen colour samples are represented in RGB 10 bit values being input to the film imaging chain.

The second step is measuring projected colours on screen in CIE XYZ space as output of the film imaging chain. The input RGB values are either recorded to positive film and the film is directly projected or negatives are recorded and a negative to positive printing is carried out additionally.

Step 1: Colour sampling for film measurement

A simple sampling scheme could be regular sampling directly in RGB space resulting to a regular grid inside the RGB cube. In our scheme we want to cover the colour space with colour samples in an optimized manner with respect to human vision. Furthermore we want that each colour sample has a large neighbourhood of samples in equal distances to ease further exploitation for device characterization. Our sampling scheme is therefore designed as follows:

1. Colour sampling is carried out in a psycho-visual space in order to optimally distribute errors of device characterization with respect to the human eye.
2. Colour sampling is done on a hexagonal grid in order to have large neighbourhoods of equal distances.

Regular sampling in a psycho-visual space has the advantage that colour distances measured in the colour space correspond to colour distances perceived by the human eye. If any two colours have a certain distance in that colour space and a second set of two colours have the same distance, then a human observer perceives ideally the same distance between the first two and between the second two colours. Any errors of the characterization model will be equally distributed. Additionally, the large neighbourhood of equally distributed hexagonal samples allow better precision of interpolation-based models.

In this paper, the sampling scheme is introduced using the CIE L*a*b* space. Sampling is carried out in L*a*b* space inside film gamut. We therefore build a first, preliminary film characterization model based on regular RGB sampling in order to determine the gamut. The chosen L*a*b* values need to be transformed into RGB values. Here, the inverse of the preliminary model is used.

Figure 1 shows a regular sampling scheme in two dimensions. The colours are distributed on a hexagonal grid in the a*-b* plane of CIE L*a*b* space. The distance between neighboured colour samples is constant and equals d_{ref}. This is ensured as follows. Regarding a line in *a**-direction with constant *b** value, the distance between colours is set to d_{ref}. Two neighboured lines are shifted in *a**-direction by Δa and their distance is Δb. To ensure equal distance between colour samples, the condition $\Delta a^2 + \Delta b^2 \overset{!}{=} d_{ref}^2$ has to be fulfilled. Thus, Δa and Δb are chosen as follows:

$$\Delta a = d_{ref} / 2 \tag{6}$$

$$\Delta b = \left(\sqrt{3}/2\right) d_{ref} \tag{7}$$

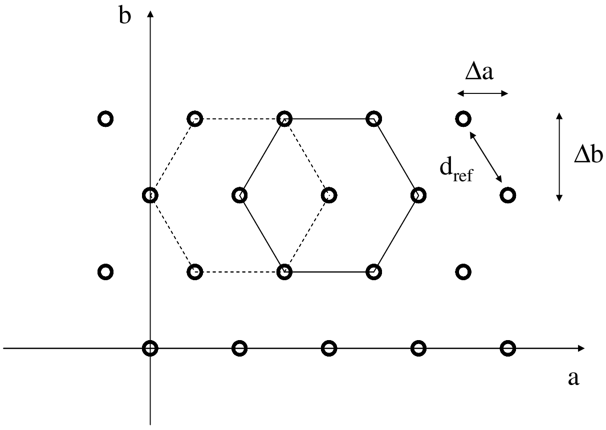

Figure 1. *Regular sampling in the a*-b* plane of CIE L*a*b* space*

To extend this sampling scheme into 3D colour space, several equidistant a*-b* planes are constructed. Figure 2 shows the sampling in two a*-b* planes at lightness level *L* and $L + \Delta L_1$. The 2D sampling in the second plane follows the same principle as the sampling in the first plane, but the schemes are shifted in *a**-direction by Δa_1 and in *b**-direction by Δb_1.

In order to satisfy the requirements of equidistant sampling, the condition

$$\Delta L_1^2 + \Delta a_1^2 + \Delta b_1^2 \overset{!}{=} d_{ref}^2 \tag{8}$$

has to be fulfilled. First, the shift in *a**-direction is chosen

$$\Delta a_1 = d_{ref} / 2 \cdot \tag{9}$$

The shift in *b**-direction is chosen such the angle shown in Figure 2 has 30 degrees resulting in the condition $\Delta b_1 / \Delta a_1 = \tan 30^o = 1/\sqrt{3}$. It comes out that

$$\Delta b_1 = \frac{1}{2\sqrt{3}} d_{ref} \cdot \tag{10}$$

Inserting these results into Eq. (8) gives

$$\Delta L_1 = \sqrt{\frac{2}{3}} d_{ref} \cdot \tag{11}$$

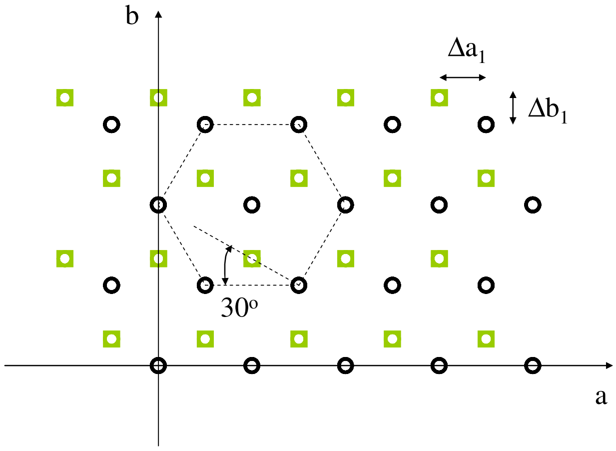

Figure 2: *Regular sampling in two a*-b* planes of L*a*b* space*

The colour samples defined until now will be used for device measurement and characterization, while additional colour samples are necessary for the verification of the model. Figure 3 shows additional colour samples in a third *a***b**-plane at lightness level $L + \Delta L_2$ which is in between the levels *L* and $L + \Delta L_1$. For symmetry reasons, the following lightness level is chosen:

$$\Delta L_2 = \Delta L_1 / 2 = \frac{1}{\sqrt{6}} d_{ref} \cdot \tag{12}$$

Furthermore, the shift in *a**-direction is chosen as follows:

$$\Delta a_2 = \Delta a_1 = d_{ref} / 2 \cdot \tag{13}$$

Regarding the verification colour sample *A* in Figure 3 (a red cross), it has several neighbours in its 6-neighboorhood of different distances. There are two neighbours, such as the neighbour *B*, in a distance $\overline{AB}$, two neighbours, such as neighbour *C*, in a distance $\overline{AC}$ and two neighbours, such as neighbour *D*, in a distance $\overline{AD}$. Requiring a maximum number of neighbours having the same distance, the shift in *b**-direction is chosen as follows:

$$\Delta b_2 = 2\Delta b_1 = \frac{1}{\sqrt{3}} d_{ref} \cdot \tag{14}$$

This brings four neighbours into a distance of $\overline{AB} = \overline{AC} = \sqrt{\Delta L_2^2 + \Delta b_1^2 + \Delta a_2^2} = \frac{1}{\sqrt{2}} d_{ref}$ and two other neighbours into a distance of $\overline{AD} = \sqrt{\Delta L_2^2 + \Delta b_2^2} = \frac{1}{\sqrt{2}} d_{ref}$, i.e. all six neighbours are equidistant.

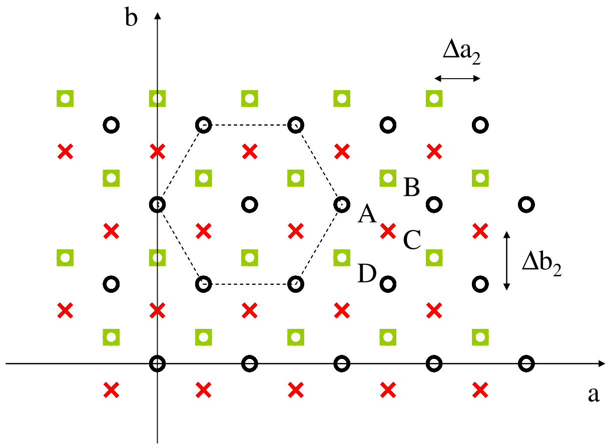

Figure 3: *Regular sampling in three a*-b* planes of L*a*b* space*

Figure 4 to Figure 6 show a sample result of the described sampling procedure. A number of 123 colour samples plus 67 verification samples have been generated having an equal distance of ΔE=21 using an initial film model obtained from regular RGB sampling of 6×6×6 colours.

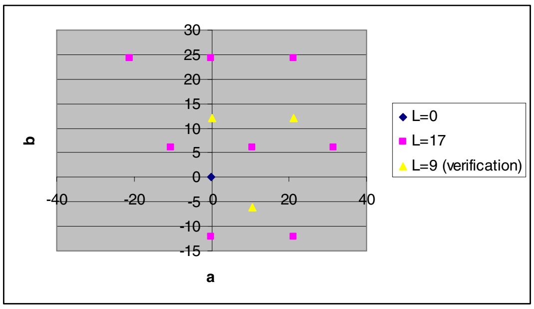

Figure 4: *Regular sampling for lightness from 0 to 25*

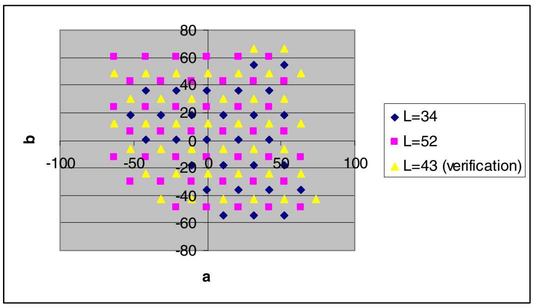

Figure 5: *Regular sampling for lightness from 25 to 60*

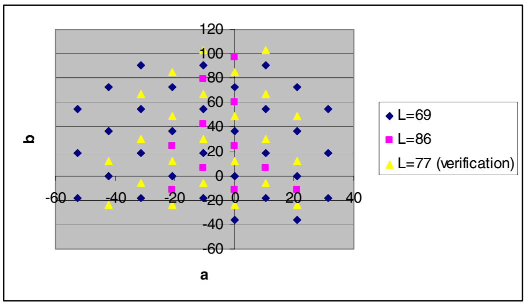

Figure 6: *Regular sampling for lightness from 60 to 100*

Step 2: Measurement of projected film colours

This section describes the methodology of colour measurement for argentic film. The goal is to capture the colour rendering result of the film imaging chain for given RGB colour samples as chosen in the last subsection.

For argentic film, the input of the colour characterisation process is a set of RGB colour values in the Digital Intermediates (DI) space. Colours are regrouped into colour charts, themselves recorded on film loops of about 120 frames each. The characterisation consists in measuring XYZ values after developing the film prints and projecting them in a reference theatre.

We use an imaging colorimeter based on five optical filters to realise the simultaneous acquisition of one or several colour patches projected on the screen. Such system acquires in a single shot a total matrix of XYZ values as would do a digital still camera. Of course, in this case, output values are not simple RGB values but high dynamic calibrated XYZ measures in the visual domain.

Actually, the film projector always presents a fall-off from the centre to the sides of the screen possibly combined with a spatially variable attenuation of the imaging colorimeter optical system. The acquisition has to be corrected from this spatial attenuation before using the measures (see below).

In order to characterize the film imaging chain, we can use two kinds of colour charts. A first kind of chart comprises just a single monochrome patch, while a second kind comprises a rectangular matrix of patches. Figure 7 illustrates an example of colour chart of the second kind, displaying 63 colour patches arranged in a 7x9 matrix. It should be noted that the use of these two kinds of colour charts is often complementary. For example, multiple colours charts are used for the highest light levels while monochrome charts are used for low light levels where more precision in the measure is needed.

On the one hand, the use of monochrome colour charts naturally requires much time and in practice limits the number of colours due to the need to print and project one film loop per colour. On the hand, experience has taught that the use of colour charts with colour patches in matrices causes a horizontal modulation problem: the measured value of a patch differs depending on its horizontal position even if the spatial attenuation is corrected in average. This is probably due to the east-west inhomogeneity of several elements of the film chain: digital to film transfer, film printing and screen gain during the film projection.

That is the reason why we propose a new solution that is faster than using monochrome colour charts, while in the same time overcoming the horizontal modulation problem.

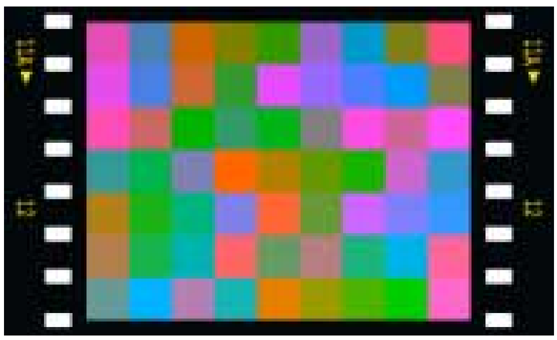

Figure 7: *Traditional colour chart*

Figure 8 illustrates the proposed new colour chart. The colour chart comprises a number of rectangular, horizontally oriented, colour patches. For each colour patch, measurements are performed by the imaging colorimeter at a series of points and averaged to obtain an estimate of the colour value. The east-west variations are by this way integrated for each colour patch and consequently do not disturb the measure. At the same time, the new colour chart reduces measurement time with respect to monochrome charts.

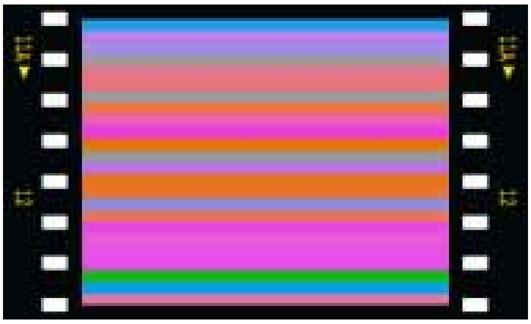

Figure 8: *New colour chart*

As said above, images need to be corrected from spatial inhomogeneity caused by the projection. A typical XYZ image acquired is presented below. The left image of Figure 9 presents an uncorrected patch image (XYZ values visualized as false colours). The effect of the attenuation can be seen on the left and right sides of the colour stripes. The actual attenuation can be better observed on the white image with iso-curves here presented on the right side of Figure 9.

Figure 9: *Acquisition (left) affected by the effect of attenuation (right)*

The correction procedure consists in using a reference uniform image as the white image above to evaluate a pixel by pixel map of the attenuation. As the input signal is uniform over the whole field, the attenuation is simply computed in each point normalizing by the image maximum. The normalisation performed on X, Y and Z can be used separately or they can be averaged. This will depend on the potential chromatic influence of the projector or of the cinema screen. The obtained attenuation maps are then applied to the acquired patch image, dividing it pixel by pixel by the estimated attenuation. Figure 10 shows the result of the spatial homogeneity correction.

Figure 10: *Acquisition after compensation of attenuation*

Once a certain number of XYZ values is measured, an interpolation-based scheme is applied to generate a device model for the film imaging chain.

Evaluation of digital film look

The performance of digital film look is verified at different levels. First, the film characterization model according to Eq. (5) is verified using a set of additional verification measurements. The characterization error is expressed in CIE L*a*b*. The inverse characterization model of the digital projector is expressed in CIE L*a*b* space after transformation from RGB into L*a*b*.

A second verification is carried out for the film look LUT according to Eq. (2). The RGB colour samples used for film characterization are passed trough the LUT and displayed by a digital projector. The error between film colours and digital colours are expressed in L*a*b* space.

Finally, a series of subjective tests is carried out [3]. A first test compares three versions of moving picture: film, digital film look under test and an existing digital film look reference. We project different content versions one after the other. For the two digital versions we ask for quality assessment with respect to the film version. We call this method Double-Stimulus Continuous Relative Quality Scale method (DSCRQS) which is derived from the Double-Stimulus Continuous Quality Scale method (DSCQS) proposed by Rec. ITU-R BT.500-10 [8]. The DSCRQS test allows non-biased, temporal digital versus film comparison. A second test, derived from ITU's DSIS and SDSCE tests, allows more detailed side-by-side comparison, but is biased. Finally a third test is introduced as a free in-depth side-by-side comparison to collect expert's comments. The subjective tests are based on a number of principles such as use of real film content, consideration of use cases and limitation of bias.

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Authors Biography

Jürgen Stauder received in 1999 the PhD degree from University of Hannover (Germany) in the field of computer vision. He then stayed with INRIA (France) for two years, before joining Thomson Research Labs in Rennes (France) as Technical Advisor. Jürgen is guest lecturer at University of Rennes for applied colour science. His research interests are computer vision, colour science and computer graphics with application to video asset management, colour management and content production. He is author of numerous publications and patent in these fields.

Laurent Blondé is a Sup'Optique engineer (1985) and started with Allen Bradley on industrial vision. Then, hired as research engineer in the Rennes lab of THOMSON R&D, he worked first on infrared image processing and synthesis, since then he has been part of several R&D projects: Virtual Studio, TV and display processing, and colour management for cinema applications. His research interests are on many domains of image processing and synthesis as well as on new displays.

Joshua Pines is vice president of imaging research and development technicolor digital intermediates. joshua is currently in charge of imaging and colour science projects at technicolor digital intermediates, which provides the motion picture industry with digital colour correction processes for theatrically released films. he joined technicolor after more than 10 years at industrial light & magic, where he supervised their film scanning/recording department from its inception, and worked extensively with both traditional and digital cinema technologies. he started his career teaching film courses at the cooper union in new york city after earning his degree in electrical engineering there. he began working in visual effects at MAGI in 1982 at the tail end of their work on "tron", went on to lead the computer graphics division at r/greenberg associates in new york city, and then supervised film effects and film recording at degraf/wahrman in los angeles before working for ilm. he is a member of the academy of motion picture arts and sciences and has credits on several zillion feature films. joshua has always thought that computers could be a useful tool in making movies better, and he still hopes that one day this may come true.

Philippe Colantoni received in 1998 the PhD degree from University Jean-Monnet of Saint-Etienne in the field of computer vision. He then stayed for 13 months in University of California Irvine for a post-doc position (Virtual Reality Lab), before joining University Jean-Monnet as "Maître de Conférences". His research interests are computer vision, colour science and computer graphics with application to multi-spectral imaging, general-purpose computation using graphics hardware, 3D visualization and colour management.

Alain Trémeau is professor, in Colour Imaging at the Université Jean Monnet (Saint Etienne, France). Alain Trémeau is at the head of LIGIV (http://www.ligiv.org), a research laboratory working on computer Graphics, Vision Engineering and Colour Imaging Science. He is currently mainly focused on mathematical imaging and colour science with reference to human vision and perception. He works also in colour metric with regard to colour appearance and rendering measurements. He has written numerous papers or book chapters on Computational Colour Imaging and Processing. He was until 2005 at the head of the French Colour Imaging Group.