Digital Lab in Europe—The Situation Today and Tomorrow

By Jan Fröhlich and Markus Bäuerle

Post-production of motion pictures in the digital lab has become standard in the European film industry. Although there are still valid reasons for film-based projects to be finished in the analog film lab, there is no doubt that digital lab workflows are now well established. The high quality currently obtainable in digital post-production leads to the question: What developments might be possible in the near future? This article analyzes and illustrates where we are now and what might be coming next. The following considerations are based on the practical experiences of the authors in the field of motion picture post-production at CinePostproduction in Germany. Other applications might lead to different conclusions in terms of possible future evolution.

WORKING COLOR SPACE

The current situation: Due to the quality of DLP projection-hardware available today, the reproducible color space for DI-grading has been enhanced significantly in comparison to Rec. 709. Thus, using a 3-D look-up-table (LUT), derived from a calibration process, the typical print film gamut can be simulated with very high precision. Problems resulting from inadequate color consistency between digital grading and the final result on print film belong to the past.

Currently, 35-mm-printfilm is still the unchallenged standard in cinematographic theater projection and thus defines the current working color space for all film productions targeting a theatrical distribution. A digital cinema master in the form of a DCDM can be easily created by applying the 3-D preview LUT to the data and matricing to X'Y'Z'-color space. Of course, following the grading of the version for theatrical projection, a special grading-variant adjusted for the display on monitors in "home" viewing conditions (e.g., a HD video master) is created. However, the reference for these variants remains the print film version. In consequence, the logarithmic "Cineon Printing Densities" as defined by Kodak is the target color space of all current "digital intermediate" color corrections.

Possible situation in the future: In the past, it has been predicted several times that digital projection will replace print film in cinemas. The "Digital Roll Out" can be defined as the moment at which digital projection in cinemas will reach a critical mass and will thus herald the ending of analog projection. However, even now it cannot be predicted when this will become reality for the majority of movie theaters in Europe and further speculation is unwarranted. Independent of the question of the exact time, it is beyond dispute that the future of cinema projection will be digital. Hence, the question of which color space will replace print film as a standard for theatrical projection becomes relevant.

The DCI suggests using the hardware-independent X'Y'Z'-color space for encoding the DCDM and DCP. However, all aspects concerning a new target color space for mastering are not covered by this approach and have been purposely left open for consideration. Thus the specification published so far does not provide a satisfying answer to the question of a working color space for future cinema post-production.

Logarithmic vs. Linear

Basically, the storage of lightness image information in linear form can be considered to be relatively inefficient, since barely distinguishable differences in the brightness range of the visual system are not equidistant when stored linearly, but instead obey the Weber Fechner Law.[1] This means that between two dark grades of brightness significantly more differences can be distinguished than between two lighter grades of brightness. A visually equidistant grayscale results from the L*-Transformation.[2] Consequently, the logarithmic storage of image information appears to be prudent, even if subsequent copying to a high-contrast medium (such as classical print film in the current Cineon workflow) becomes obsolete.

If, in the future, color grading will be carried out only for digital distribution (in form of a DCP) and for a HD master (Rec. 709), the use of 3-D-LUTs would no longer be necessary if the use of a P3 or P7v2 color space for grading, respectively, was combined with a gamma that is near to L* under theatrical conditions. The targeted master formats could be produced using matrix calculations and 1-D-LUTs. This is desirable not only because of the simpler computability: the simulation of the characteristic advantages of print film (i.e., the S-shaped curve) using current preview-LUTs comes at the price of system-related disadvantages. When printing a neutral grayscale from a negative to current print stock these tend to produce a color-crossing between darker and brighter color-tones (e.g., the darker end of the grayscale turns a bit more greenish and the lighter end more toward magenta). A second disadvantage of current film stocks is the impossibility of obtaining pure colors. Exposing a film with a very saturated primary color will always result in some neutral density. These disadvantages inhibit the color range a DLP-projector is technically able to display.

However, a color grading without a print-preview LUT would result in the following problem: the S-shaped exposure curve of the print material, which is simulated using a 3-D LUT in the current Cineon workflow, allows the colorist to preserve very fine differences in the darker and brighter regions, even in gradings with a rather high contrast. Without this S-curve, the highlights and shadows would easily be clipped and cause unwanted artifacts. Thus performing a grading in a gamma-corrected P3/P7v2 color space requires a grading system with an internal softclip-compensation for white, black, and gamut. Future grading systems could work on the basis of a gamut LUT that can be loaded optionally, representing the gamut of the target display in form of a vectorfield. The colorist should then be able to define a threshold for the soft clipping compensation, as well as the shape of its curve. Ideally, the thresholds for luminance and chrominance should be adjustable independently. However, current grading systems are not yet equipped with equivalent tools.

An interim solution could be the implementation of an S-shaped gradation curve as a 1-D LUT at the output of the grading system. This would mimic the Cineon workflow without its disadvantages. A similar workflow is already successfully used today at CinePostproduction for the grading of logarithmically scanned S16mm raw footage for the production of TV master within the Rec. 709 color space.

Color-Correction-Related Communication Between Service Providers

For the communication between the service provider of the digital intermediate on the one side, and vfx companies on the other side, it is necessary to agree on a shared 3-D LUT format within the Cineon working color space. At CinePostproduction, it has proven valuable to make a shot-based nondestructive color grading in the form of metadata available to vfx service providers along with the scanned raw data.

The exchange of metadata can be done using the 3DL file format or as Truelight-profile. The advantage is that even with extreme color corrections, the raw color information remains available, because this can be crucial for vfx shots such as greenscreens, without having to handle the double amount of image data (with and without color grading). **Figure 1** shows the internal format used by CinePostproduction for 3-D-LUTs, represented by PNG squares. Addendum 1 contains sample MATLAB-code for creating these LUTs.

PNG squares (**Fig. 1**) are easily generated by computing the desired color transformation onto the original PNG file. The advantage of saving 3-D LUTs as PNG files is evident. Despite the support of a 16-bit precision, the files are only a few kilobytes in size. This allows even dynamic color corrections to be saved frame by frame without causing an excessive volume of data. Preserving complete slices through the "color cube" guarantees better human readability of the color correction in comparison to other image-based LUT formats. **Figures 2 to 4** show examples of color corrections applying PNG squares to the same scanned raw data to illustrate a sequential workflow. CinePostproduction recently completed a feature in which the raw scans were transferred weeks before the vfx pregrading. As the pregrading was done, 4 hours later 30 minutes of color grading information was transferred to the vfx company per FTP over a standard DSL line. This was only possible because the 43,200 PNG files were altogether only approximately 150 Mbytes in size.

SPATIAL AND TEMPORAL RESOLUTION

Spatial Resolution

The current situation: The most common spatial resolution for DI workflows in Europe is HD or 2K. Higher resolutions (e.g., 3K, 4K, or 6K) are usually applied if there is an immediate downsizing to 2K after scanning or if the footage is to be used for resolution-affecting vfx shots, such as zooming or using large background plates.

From practical experience, it is known that the overall image quality will deteriorate due to a lack of spatial resolution, with more degradation associated with wide-angle shots with a lot of small details in the frame. Therefore, the effects of increasing the spatial resolution will be easily visible (e.g., in static long shots of a landscape), whereas the differences to lower resolutions will be much more subtle when dealing with a hand-held or a close-up shot. In practice, this can be taken into account during shooting by using filming and recording formats with different spatial resolutions for different types of shots: 35mm/65mm (U.S.), 16mm/35mm (Europe), or digital SD and HD cameras. A disadvantage here is the complex logistics on the set. In the case of two different digital cameras, the time-consuming adjusting of color gamut in post-production must also be taken into account. As a result, using a combination of different formats on the set, according to the type of shot, in an attempt to improve the spatial resolution, is very rare in Europe.

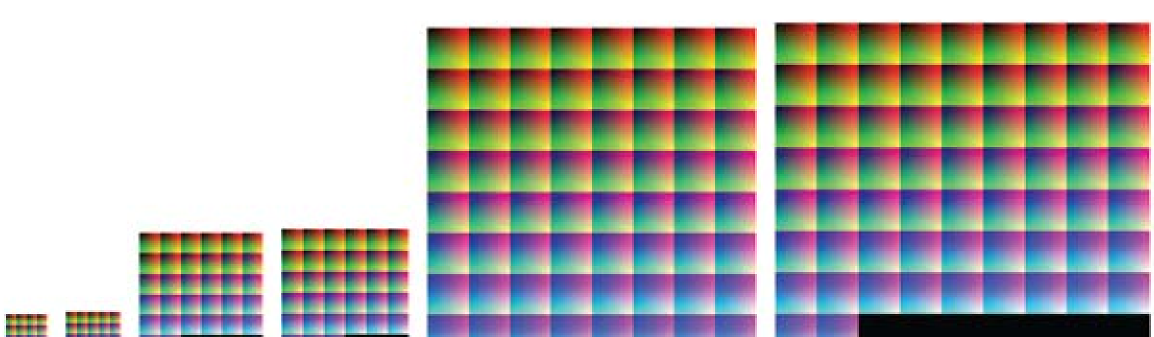

Figure 1. "PNG-Square" LUTs: 16x16x16, 17x17x17, 32x32x32, 33x33x33, 64x64x64, 65x65x65 sized 3-D-LUTs resulting in different precision, saved as 16-bit PNG-file.

Possible situation in the future: Digital intermediate post-production in a 4K resolution is currently practicable, where the technical tools are concerned. Nevertheless, for the vast majority of European films, the gap between the improvement in image quality and the cost of a DI work process, with four times the amount of data and bandwidth than in 2K, is still too large. And even if 4K scans or camera data were to be used, there is still a need for 2K proxies in some workflows, partly because handling several simultaneous streams of 10 Gbits/sec is still problematic for today's SAN architectures, and some crucial tools, such as the popular DLP projectors in the grading suites, which are still not capable of real 4K performance.

For digital lab functions, it is not a question of whether there will be workflows in 4K or higher resolutions, but when tools will be available that minimize the gap between costs and improvement of quality in a way that a wider range of productions can benefit from higher resolution workflows. Therefore it seems of much greater interest how tools

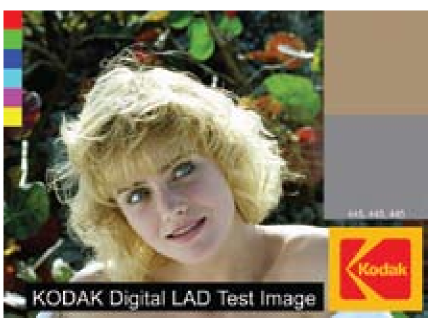

Figure 2. Marcie as an example for scanned sample footage.

that are available for reasonable prices today, such as scanners, film recorders, and resolution-independent grading systems, can be combined in a smart and efficient workflow to achieve a visibly enhanced quality in the principal deliveries (film print, DCDM and HD video master), without raising the costs for a DI too high. Essentially, it is the maximum output for the least invested money that might drive European filmmakers and post-production companies in this direction.

Hybrid Workflows with Different Spatial Resolutions in Post-Production

In the post-production process of films shot on 35mm negative, there is a promising opportunity to distinguish, with the advice of the DI service provider, between shots to be scanned and processed in 4K, because of the rich detail of information in the shots, and shots for which high resolution is not as crucial and a 2K scan might work just fine. In the case of hybrid scanning resolutions, the use of existing resolution-independent software tools enables the maintenance of the native scanning resolution up to final film recording. In this way, a visible difference can be achieved in all the deliveries, benefiting from higher spatial resolution in selective takes of the film scans. The use of resolution-independent, software-based grading tools, such as Lustre or Baselight, makes a seamless integration of mixed resolutions in one timeline possible.

It should be emphasized that this mixed-resolution workflow is not capable of delivering the same quality as a complete 4K workflow. However, in the transition period before the vast majority of European productions can afford an integrated 4K workflow, it is a promis-

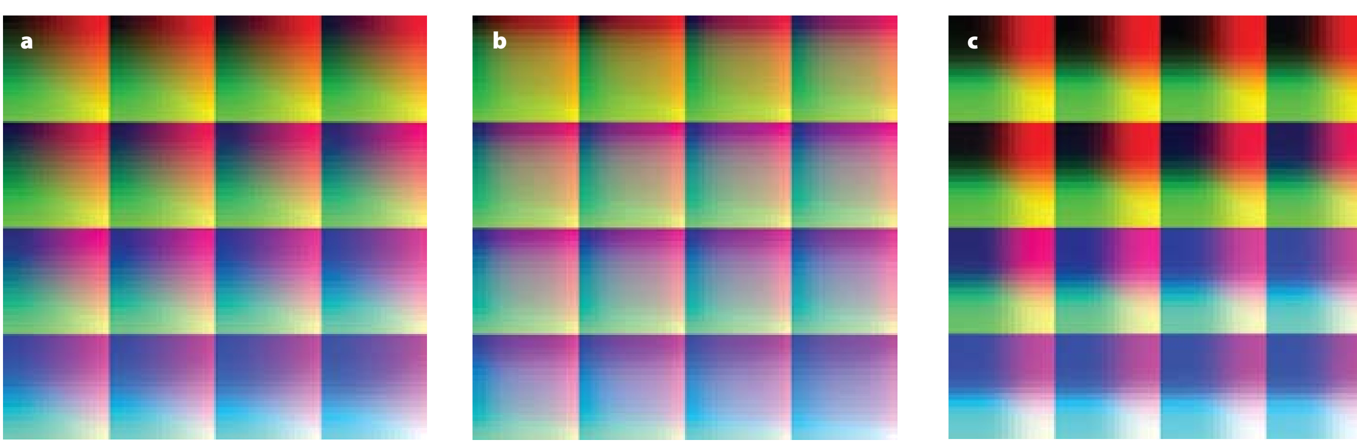

Figure 3. 16x16x16 LUTs for (a) uncorrected, (b) low-contrast, and (c) high-contrast.

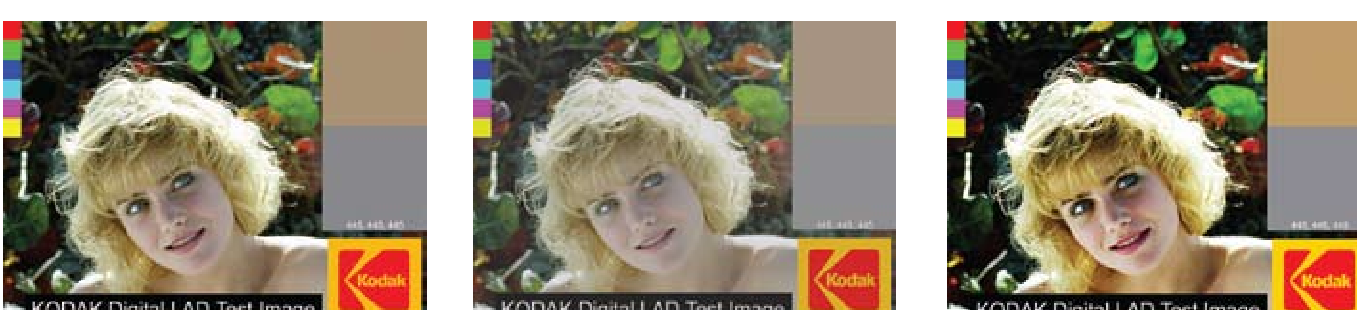

Figure 4. Images resulting from the LUTs in Fig. 3 applied to the sample-footage shown in Fig. 2.

ing opportunity to improve the image quality of those productions. It should also be noted that working with mixed resolutions throughout the whole post-production workflow means a substantial amount of additional work for a DI service provider. As a consequence, when a hybrid resolution workflow is being considered, each project should be considered individually to ensure that the best balance between quality and budget can be achieved.

Temporal Resolution

The current situation: Since the introduction of the Academy Standard, 24 frames/sec is a worldwide established standard in cinema projection. Due to the use of double or triple blade shutters, the actual projection frequency is a less flickering 48 or 72 Hz, respectively. However, this does not influence the temporal motion resolution of the film itself.

Apart from 24 frames/sec, in regions with a 50-Hz television broadcast standard, there are numerous theater releases with a frame rate of 25 frames/sec. Because print film is simply a continuous sequence of individual frames that can be played at any technically possible speed, in analog cinema it is fairly easy to project a film that has been shot with 25 frames/sec—either with a digital camera or a film camera—in its original frame rate. Thus, at festivals and premieres, a correct replay of picture and sound can be guaranteed in modern theaters with a projector that can be switched to 25 frames/sec.

In fact, in the world of analog film projection numerous, frame rates with a lower temporal resolution coexist with 24 and 25 frames/sec. Other frame rates of (mainly silent) archive footage are 8, 12, 16, 18, 20, and 22 frames/sec. Apart from special production formats such as Todd A.O., Super Dimension 70 or Maxivision 48, higher temporal resolutions such as 30, 48, 50, or 60 frames/sec, for example, have not played a relevant role in the distribution of theatrical movies so far. From the authors' point of view, the main reason for this is not because a resolution of 24 frames/sec proved to be ideal for the so-called "film look," but rather the realization that a higher frame rate in analog film projection results in a proportionally higher usage of raw material and the associated costs.

Possible situation in the future: In the DCI's current specifications (version 1.2), only two frame rates are stipulated: 24 frames/sec (4k or 2k) and 48 frames/sec (2k only).[3] The latter is currently mainly used for stereoscopic systems for the replay of 3-D content. In this special application, the higher frame rate does not result in an increase of motion resolution, because each eye continues to see only 24 frames/sec.

25 frames/sec Standard Necessary

From the European point of view, the lack of a 25 frames/sec standard in D-cinema projection is regrettable. For a film that has been mastered in 25 frames/sec to be prepared for DCI-compliant digital theater projection, the following additional production steps have to be carried out: rendering of the images into a 24 frames/sec container, conversion of the audio speed from 25 to 24 frames/sec (including correction of the tone-pitch), and adjustment of all titles and subtitles to 24 frames/sec.

In consequence, an initiative of the European Digital Cinema Forum (EDCF) and the European Federation of Cinematographers (IMAGO) spoke for an enhancement of the existing DCI-specifications at SMPTE DC28.10 regarding alternative temporal resolutions and an optional specification for archive footage with frame rates ranging from 8 to 22 frames/sec.[4] DC28.10 reacted with the foundation of an "Additional Frame Rate" ad hoc group, whose first draft of corresponding standards will be published by SMPTE in the near future.[5]

Interestingly, some manufacturers of D-Cinema playout servers already support a frame rate of 25 frames/sec. However, in practice these options fail due to lack of compatibility, because correspondingly encoded DCPs cannot be played without difficulty on all systems. From the post-production point of view it is desirable that frame rate conversions become obsolete with a 25 frame/sec D-Cinema standard.

Improved Depiction of Movement Desirable

Examples from analog film projection with high temporal resolutions of 60 full frames per/sec (e.g., the 70-mm Showscan projection), essentially demonstrate that a higher temporal resolution can improve the quality of the depiction of movement in cinema projection. With digital projection, the crucial economic argument against an increase of temporal resolution becomes obsolete, because with the lower production costs for a digital cinema print, the costs for a higher temporal resolution are not as significant as for a film print. Thus, frame rates higher than 24 or 25 frames/sec could be an interesting alternative to current standards. From the post-production point of view, it is arguable whether—as proposed by the DCI—48 frames/sec would meet the needs of a preferably conversion-free and quality-oriented workflow, because this standard is originally not supported by common recording- or post-production systems. However, 50 or 60 frames/sec are widely supported by the available digital cameras and, because of their compatibility to the corresponding television standards of 50 and 60 Hz, are relatively easy to implement in the field of post-production (**Table 1**). Furthermore, it can be expected that in the long run 50p and 60p formats will prevail in HD recording. Hence, the compatibility with corresponding frame rates in D-Cinema projection would be essential.

Freedom of Conversion by Use of Multiple Frame Rates

Indeed, the question that temporal resolution would be a suitable creative tool particularly for cinema projection does not need to be answered by standardization committees, but by the filmmakers themselves. However, a precondition for a possibility of a creative choice is that a real repertory of options is supported by existing projection standards. Thus, not only for reasons of downward compatibility, 24 and 25 frames/sec should remain a cinematographic standard. At the same time, for an increase of quality in the depiction of movement, higher temporal resolutions with 50 or 60 frames/sec, which are compatible to existing standards, have to become available in digital projection. For the field of post-production this could mean that conversions between frame rates become obsolete in the future.

Camera	Origin	Genesis	F35	Viper	F 23	D-21	SI-2K	Red One
Support for 50p	-	X	X	X	X	X	X	X
Support for 60p	-	-	-	X	X	X	X	X
Maximum frame rate	36	50	50	60	60	60	72	120

Table 1. Maximum frame rate of digital cameras, without respect to the actual realizable spatial resolution.

DATA-FORMATS

The current situation: In the field of uncompressed post-production in digital labs, the DPX file format has been established as an interchange format between service providers and between diverse soft- and hardware-platforms. It is available in color depths of 8, 10, 12 and 16 bits per channel. Furthermore, DPX supports metadata crucial for post-production. However, currently only the tags for time-codes and key-codes are widely used. Frequently, only the image's visual impression and its histogram will indicate whether a DPX file is based on an "open-range" signal deriving transparently from an SDI signal, i.e., code values ranging from 0 to 1023 (for 10 bit), or whether the "legal-range" (64 to 940) has been mapped onto the 0 to 1023 code values of the DPX file. This can cause misunderstandings between service providers.

Two limitations concerning the file formatting increase the complexity of workflows in digital labs—the lack of scalability prevents a fast preview, and the high demands regarding the read and write performance of the data storage used, cause high investment costs for storage upgrades.

Possible situation in the future—fast previews desired: Viewing the state of a project stored as a DPX image sequence is possible only on high-performance systems with a direct storage connection. This problem is addressed in the research project "Tools for Media Production: Scalable JPEG 2000-based media workflow for D-Cinema, HDTV and Broadcast," in which the CinePostproduction Bavaria Bild & Ton is participating. Here, the work-process is not based on DPX image sequences, but on compressed J2C files. This project also targets further aspects, such as database-oriented post-production, generation and administration of metadata, and nondestructive workflows.

Figure 5. Extraction of resolution- and quality-layers using discreet wavelet-transformation.

Working in a scalable format would make the browsing and replaying of low resolution formats significantly easier. Single J2C-images may be compressed in JPEG 2000 without loss of data. Thus workstations with no high-performance connection can extract an appropriate layer of resolution and quality from the J2C files and the possibility of viewing a film in 1K resolution (**Fig. 5**) via gigabit Ethernet becomes possible. A current limitation is the still rather time-intensive computation involved in the replay of JPEG 2000 image sequences.

Limitation to High-Performance Storage Hardware

A second limitation in current DPX-based workflows results from the immense requirements regarding the performance of the storage hardware used. Post-production based on sequences of independently stored single images creates a vast number of individual file accesses. A full feature movie of, for example, 100 minutes duration consists of 144,000 single image files. The replay of the movie causes extreme (mechanical) stress for the storage system, because the hard-disk's actuator arm has to search for the first sector of a file 144,000 times. Due to the search method, the query time is defined by at least half a rotation of the magnetic storage disk. Thus a hard-disk, which is advertised with a maximum read access of up to 100 Mbytes/sec, can barely ever perform at more a quarter of this figure under realistic conditions of use. To guarantee a realtime replay, the defragmentation process of multiple storages must recognize continuous image sequences and arrange the individual images in the correct order on the storage disk. Therefore, the data can be read continuously from the disk and the access arm of the hard disk does not have to perform time-consuming search processes. For post-production service providers, this media-specific requirement prohibits the use of off-the-shelf storage solutions. Instead, one has to invest in branch-specific and cost-intensive solutions.

Instead of individual image files, a container format could be used that contains all frames of one particular shot. Thus, the number of read accesses would be as low as the number of shots, approximately 1% of the number of frames. However, switching to common container formats such as QuickTime is often not possible, because these formats are not comprehensively supported by all systems typically used in a post-production workflow. In addition, common container format image information is displayed differently, depending on the respective system. One reason for this is an inconsistent implementation of the conversion from 4:2:2 to 4:4:4. Additionally, black level, white level, and gamma metadata may be interpreted by some systems, but not by others. In turn, other systems recompute these values based on the expected capabilities of the respective output devices.

Whether MXF will provide a comprehensive alternative cannot yet be concluded, because it is currently not widely supported by systems used in the field of high-end post-production. From the authors' point of view, a consistent use of MXF in the post-production pipeline would be desirable for the field of high-quality TV post-production (full feature movies, TV movies and premium series). This is due to the typically large number of parallel work processes, which must be completed within tight schedules, as well as cost pressures.

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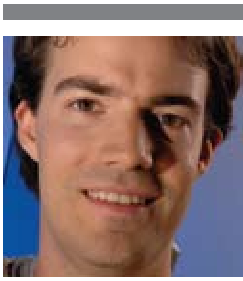
Addendum 1: Sample-MATLAB-code Creating PNG-Square LUTs

```
%Initialisations:
Qube.Size = 64; %try out different values.
%CinePostproduction usually uses 64x64x64 3D-Luts for maximum accuracy.
Qube.Path = 'C:';
Qube.Name = 'PNG_Square_Qube_SMPTE_TEST_64x64x64';
Qube.Data = uint16(repmat(0,[Qube.Size Qube.Size Qube.Size 3]));
for a=1:Qube.Size, for b=1:Qube.Size, for c=1:Qube.Size
Qube.Data(a,b,c,1)=(((a-1)/(Qube.Size-1)*65535));
Qube.Data(a,b,c,2)=(((b-1)/(Qube.Size-1)*65535));
Qube.Data(a,b,c,3)=(((c-1)/(Qube.Size-1)*65535));
end; end; end;
%Format the Qube:
disp('Writing PNG-Square Qube')
Width = Qube.Size* ceil(((Qube.Size^3)^(1/2))/Qube.Size);
Height = Qube.Size* ceil(((Qube.Size^3)^(1/2))/Qube.Size);
QubesPerLine=ceil(((Qube.Size^3)^(1/2))/Qube.Size)
for c=1:Qube.Size, for b=1:Qube.Size, for a=1:Qube.Size
Bild((rem(b-1,Qube.Size)+1+Qube.Size*floor((c-1)/QubesPerLine)),...
a+Qube.Size*rem((c-1),QubesPerLine),1) = Qube.Data(a,b,c,1);
Bild((rem(b-1,Qube.Size)+1+Qube.Size*floor((c-1)/QubesPerLine)),...
a+Qube.Size*rem((c-1),QubesPerLine),2) = Qube.Data(a,b,c,2);
Bild((rem(b-1,Qube.Size)+1+Qube.Size*floor((c-1)/QubesPerLine)),...
a+Qube.Size*rem((c-1),QubesPerLine),3) = Qube.Data(a,b,c,3);
end; end;
if Qube.Size>50, disp(strcat('Slice Number: ',num2str(c)));, end; end;
%Write the Qube to disk:
imwrite(Bild,strcat(Qube.Path,'\',Qube.Name,'.','png'),'BitDepth',16);
disp('PNG-Square Qube has been written')
```



Fröhlich

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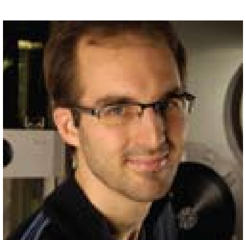

Bäuerle

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