Rob Hummel, Chair, Public Programs and Education Subcommittee, began his career at Technicolor Laboratories then joined Douglas Trumbull's visual effects company during the making of *Blade Runner* (1982), a Visual Effects Oscar nominee, and went on to do post-production work on the groundbreaking *Tron* (1982). A former president of DALSA Digital Cinema LA, Hummel has also served as senior vice president of production technology at Warner Bros., where he oversaw digital post-production and restoration work on such classics as *Gone with the Wind* (1939) and *The Wizard of Oz* (1939). He worked in post-production, animation and Imagineering at Walt Disney Studios, headed animation technology at DreamWorks, and helped launch digital cinema units at Technicolor and Sony. Hummel is a founding member of the Academy's Science and Technology Council and is currently president of digital archival company Group 47, Inc.

Andy Maltz, Director, Science and Technology Council. The Academy reconstituted its Science and Technology Council in 2003, and as its first director, Maltz is responsible for developing and implementing its operational plan, administering the Council's day-to-day operations and individual contributions to selected Council initiatives. Previous to the Academy, Maltz was CEO of Avica Technology Corporation, where he led the first worldwide commercial deployment of digital cinema servers, drove the development of key technologies for digital cinema, and was heavily involved with the digital releases of many major motion pictures in the U.S., Europe, and Asia. Previous to Avica, Maltz served as a consultant to companies such as Sharp Electronics and Microsoft, where he spearheaded the development of the Advanced Authoring Format. Prior to these assignments, he was executive vice president of operations and engineering for nonlinear editing pioneer Ediflex Digital Systems.

Maltz serves on the U.S. National Archives Public Advisory Committee for Electronic Records Archives, is an associate member of the American Society of Cinematographers, and is a fellow of SMPTE where he serves on several engineering committees and the SMPTE Journal Board of Editors. Maltz received a BSEE from the State University of New York at Buffalo.

Recent Developments in Acquisition and Workflow

By Curtis Clark, ASC, David Stump, ASC, and David Reisner

Our industry has experienced remarkable change during the past decade. We have had both economic upheaval and major technological changes. Change has become almost a daily phenomenon in motion imaging. Cinematographers and their filmmaker collaborators appreciate the rich look and response of working with film, but we have recently reached the point where film is becoming seriously challenged and in some ways surpassed by well-handled digital cameras. Part of this is due to continued improvements in digital camera response, including wider dynamic range, increased color bit depth, combined with true 4K (4096 x 2160) resolution. It is also in part due to very wide dynamic range and very wide color gamut workflows that utilize ACES (the Academy of Motion Picture Arts and Sciences' Academy Color Encoding System), which enables rigorous interchange of images, including more effective utilization of on-set or near-set Look Management applications, and wide utilization of the ASC CDL (American Society of Cinematographers' Color Decision List). In addition, there is an increased awareness of the critical role of properly calibrated monitoring. And part is due to improving industry practices. We are also exploring new image representations, including very high resolution, stereoscopic 3D presentation, and uses of higher frame rates.

Effective Look Management for Digital Motion Picture Cameras

The Need for Look Management

"Look Management" generally refers to the use of color grading applications and tools used either on-set or near-set during production (including pre-production and principal photography) to establish creative look references for scenes that can be applied to dailies and/or editorial media. Although usually applied ("baked in") to dailies and editorial media, these creative look references also exist as metadata that can then be used as a starting point for the final color grading. NB: These reference looks should not be "baked in" to original camera image capture data. The ASC CDL is frequently used in look management because of its convenient cross platform implementation of primary RGB color grading parameters Offset (lift), Slope (gain), and Power (gamma), a 'global' saturation function. (See "ASC Color Decision List in Modern Workflows," later in this report) Although not as modifiable, Look Up Tables (LUTs) can also be used.

The Look Management Challenge for Cameras that Exceed HD Video

As the production community accelerates the transition from shooting with film cameras to an increasingly routine use of digital motion picture cameras (DMPCs), the issue of effective look management, both on-set and/or near-set options, has become ever more important. New DMPC cameras continue to be introduced that exceed the HD imaging parameters of Rec. 709 contained within a 1920 x 1080 spatial resolution. “RAW” camera data output can be vulnerable to color and look management mishandling, especially during the shooting and editorial phases of production. Some camera manufacturers and third-party vendors have developed their own proprietary color and look management options to address this issue. RAW generally refers to digital camera data output from sensors (usually CMOS) that use Bayer pattern or other color filter arrays to compensate for not capturing RGB pixel-for-pixel; subsequently requiring “de-Bayer” or “de-mosaic” processing to interpolate to RGB and create viewable images.

The Needs from On-Set/Near-Set through Final Color Grading

Sophisticated look management applications have been introduced as on-set and/or near-set options for establishing creative look references that can be applied to editorial and/or dailies, as well as create metadata that can provide a starting reference for final color grading. Since there is still a considerable amount of confusion and misunderstanding regarding an appropriate implementation of on-set and/or near-set look management, there is a pressing need to establish recommended best practice procedures for effective look management from on-set/near-set through final color grading throughout a workflow. To achieve consistently reliable results across the various look management and color grading platforms, a unified, transparent and standardized color encoding and color management system is urgently needed to maintain the integrity of image capture and best protect the filmmaker’s creative intent.

ACES solution

AMPAS (Academy of Motion Picture Arts and Sciences) created ACES (Academy Color Encoding System) to address the now widely recognized need for an unambiguous and transparent color management framework within current production and post-production workflows. ACES not only protects a wider (16-bit) color gamut, but also accommodates an exceptionally wide dynamic range of scene tones. It is currently working its way through the SMPTE standards process (SMPTE Standard ST 2065-1). In addition, ACES provides unambiguous transforms between scene linear and log encodings, as well as unambiguous transforms between different color spaces, e.g., camera RGB to ACES RGB; ACES RGB to DCI P3 and/or Rec.709, etc.

For digital motion picture cameras that can capture a wide dynamic range of scene tones within a color gamut that is wider than Rec. 709, ACES has proven that it can faithfully preserve the full scope of their image capture. Even though the primary commercial distribution platform may be HD Rec. 709 for HDTV or Blu-ray, the ACES color encoding and color management system has amply demonstrated its ability to better protect both a wider dynamic range of scene tones and a wider color gamut of camera output than is the case when rendering the original scene capture directly within the constraints of Rec. 709. Rendering the original scene capture within the ACES color encoding and color management system preserves both color gamut and dynamic range of original scene tones and accurately maps them within the specific color gamut (e.g., DCI P3 or Rec. 709) of the selected reference display device (monitor or projector).

For advanced digital motion picture cameras like the Sony F65 and ARRI Alexa, we need to thoroughly clarify the importance of preserving wide color gamut and expanded tone scale from image capture through post finishing so that filmmakers and their post facilities can understand how to best achieve the filmmaker’s creative vision by utilizing the full range of camera data output within the ACES color encoding and color management framework. Otherwise, they run the risk of inadvertently clipping highlight detail, crushing shadow detail and/or restricting color gamut.

There is an urgent need to demonstrate the advantages of ACES-based color management solutions as implemented within the leading on-set/near-set look management applications, e.g., Filmlight (Truelight on-set), Fujifilm CCBox, Colorfront, Technicolor (DP lights), Assimilate Scratch, Adobe Speed Grade, Blackmagic Resolve, etc., using accurate reference monitoring.

It is crucial that filmmakers understand how advanced digital motion picture cameras that record RAW image data have moved beyond the imaging constraints of HD video Rec. 709, thereby enabling digital image capture comparable to or exceeding film negative. We also need to clarify the proper way to use accurately calibrated on-set reference monitoring. (Monitoring is usually configured for HD Rec. 709 video. DCI P3 configured monitoring can also be used with some reference monitors for productions intended primarily for theatrical release.)

Accurate reference looks need to be created so they can be applied to dailies and editorial (e.g., Avid or Final Cut Pro). Look management metadata (e.g., ASC CDLs) must be reliably transferred from on-set/near-set look management applications to an ACES compliant color corrector for use during the final color grading of the camera original 16-bit OpenEXR files.

ACES Implementation of the ASC CDL—the Cross Platform Color Decision List

The ASC CDL provides an effective and efficient cross platform ACES Look Modification Transform (LMT—the place within ACES that creative decisions live) for creative looks that can be applied to dailies and editorial, as well as provide a starting point for final color grading.

ASC Color Decision List (ASC CDL) in Modern Workflows

The American Society of Cinematographers (ASC) Technology Committee, Digital Intermediate (DI) subcommittee—with participants from the ASC, color correction system vendors, post production facilities, color scientists, and studios—created the ASC Color Decision List (ASC CDL) to allow basic primary color correction data to be passed from set to dailies to post and to be interchanged between color correction systems made by different manufacturers. This standardized interchange, when accompanied by good communication and consistent viewing conditions—and especially when used with systems utilizing the Academy of Motion Picture Arts and Sciences (Academy) Academy Color Encoding System (ACES)—can create the same results on multiple systems, substantially improving the consistency and quality of the resulting images while also increasing efficiency and reducing cost. Of critical importance to cinematographers, directors, and the creative team who design and build the look of a motion picture, the ASC CDL helps communicate intended look through the production pipeline in a modifiable fashion that can form the basis for the next stage’s color work. The ASC CDL is currently used in the workflow of about half of all major studio feature motion pictures.

The ASC CDL defines a small set of operations—*transfer functions or primitives*—that provide the most basic set of color correction operations—operations that can be implemented in all color correction vendors' systems. They are *Slope*, *Offset*, and *Power* that are applied to each of the red (R), green (G), and blue (B) signals independently, and *Saturation* which operates on R, G, and B in combination. These ten parameters describe any ASC CDL color correction.

Most color correction systems natively provide vendor-specific *Lift*, *Gain*, and *Gamma* functions. *Slope*, *Offset*, and *Power* are similar but mathematically purer functions. The original intent was that vendor-specific Lift, Gain, and Gamma would be translated into some combination of Slope, Offset, and Power for interchange between systems. In practice, most vendors have put the ASC CDL functions directly in the user interface and only interchange corrections that are exclusively using those operations.

The ASC CDL defines mathematical operations that are applied to all image data, regardless of the format/encoding of that data. The ASC CDL defines the math, not the encoding-specific interpretation of that math. Each of the operations will have quite different results on log data than on linear data. For example, a Gain of 2.0 multiplies the image code values by 2.0. If the image data is linear, that will brighten the image by one stop. If the image data is log, a Gain of 2.0 will double the contrast of the image.

The application of the ASC CDL provides no "interpretation" of the underlying metric of the image code values. A given correction applied on two systems that are assuming data in different formats will almost certainly produce inconsistent results. But awareness of the data metric and encoding-customized operation is outside the scope addressed by the ASC CDL.

Because of the critical importance of ACES in modern and future workflows, the ASC has taken special care that the ASC CDL and ACES work well together. ACES uses a color gamut encompassing the entire range of human color perception, a very wide dynamic range, and encodes color data linearly using 16-bit OpenEXR floating point numbers. ACES is still being rolled out and implementations within current color correctors do internal math in various vendor-specific nonlinear or log encodings. This is particularly true for on-set systems. To get consistent and transportable results between these systems, the Academy Science and Technology (Sci-Tech) Council and the ASC Technology Committee DI subcommittee are in the process of defining a standard/official integer "log ACES" in 10-bit and 12-bit as well as 16-bit versions to be used for internal math on systems not yet able to support OpenEXR linear ACES computation. This will allow predictably consistent results between manipulations in on-set systems and full DI systems. That consistency is fundamental to ASC CDL function. It may also be necessary to define a floating-point log ACES exclusively for internal math on systems that are using float but have difficulty supporting linear due to configuration of their color grading tool sets. ACES support has also required small changes in the ASC CDL—definition of the range of ACES values that the ASC CDL operates on and removal of some clipping in definition of primitives.

A correction applied to the right data in the right way on two systems must still be viewed with correct output transforms and on calibrated displays and in very similar viewing conditions to communicate the intended look. Coordination of data metrics and viewing conditions is also outside the scope of the ASC CDL and must be handled elsewhere in a project's workflow.

In a workflow, the set of ten ASC CDL parameters for a correction is interchanged via ASC CDL-defined XML files, by new fields in ALE and FLEx files, or special comments in CMX EDL files.

ASC CDL corrections are metadata that are associated with individual shots—they are not baked-in to the original camera image. Look-up Table (LUT)-based corrections are fixed—they can be viewed, or additional corrections can be layered on, but they cannot practically be adjusted or tuned. But ASC CDL correction metadata can be viewed and modified at each point where it is used. Corrections later in the workflow can be based on earlier ASC CDL corrections without modifying the image data multiple times—yielding highest possible image quality. They can be applied to dailies and editorial. Sharing an ASC CDL correction gives information about how the cinematographer was thinking about his/her look during production.

The ASC CDL supports only the most basic color correction operations. Not all operations of interest (e.g. log/linear conversions, 3D LUTs, windowing, tracking) can be expressed with these operations. Future releases may carry additional metadata and broaden interchange but are unlikely to add new primitives.

The ASC CDL does not handle everything necessary to communicate a look, but when used as part of a workflow utilizing ACES—which rigorously defines color space, data representation format, and display behavior—only proper display calibration and viewing environment needs to be independently managed.

Higher Frame Rates in Digital Cinema

The release of James Cameron's *Avatar* was an important driver of the success of 3D cinema and especially for the penetration of 3D cinema in exhibition. The cinema marketplace received much subsequent criticism from moviegoers and critics alike as 3D screenings increased in number following the release of *Avatar*, citing insufficient image brightness, 3D artifacting and general visual discomfort. Recently it has widely been proposed that increasing cinema frame rates could improve the cinema experience in 3D. Creative discussions and demonstrations are being conducted to press for these new higher frame rates.

Interest in higher frame rates in 3D increased when Peter Jackson announced he would be shooting *The Hobbit* at 48 frames/sec per eye, and soon after that James Cameron showed tests shot at both 48 frames/sec per eye and 60 frames/sec per eye and declared he wanted to use one of those camera speeds for his next film *Avatar II*. Shortly thereafter, Dutch director Eugenie Jansen shot her next movie in 3D using 50 frames/sec per eye.

The SMPTE publication of ST 428-11-2009 "Additional Frame Rates for D-Cinema" currently allows for 3D projection at up to

30 frames/sec per eye, and some implementations actually support this in current practice, but no speeds higher than 30 frames/sec have yet been described in SMPTE recommended practice documents.

As these developments in the creative community have thrust the subject of high frame rates into the forefront in the standards community, it is clear that the exhibition world will need guidance and standards if they are to reap the benefits of showing these groundbreaking new movies. In addition, providers of mastering software also need guidance with regard to which frame rates and compression ratios they should develop and include in their applications.

Any transition to higher frame rates will impact the entire workflow: from production, post-production and packaging, to distribution and exhibition. DCI requirements and SMPTE standards will almost certainly need to change across the board to make way for the use of higher frame rates.

SMPTE recently established a Study Group (SG) with proponents from the ASC, IMAGO and the EDCF to study the creation of standards that will allow distribution and projection of content at several of these new proposed speeds: 48, 50 and 60 frames/sec per eye in 3D. The intent of the Study Group is to define what accommodations must be made in order to facilitate the implementation of digital cinema exhibition systems that allow higher frame rates

It has been demonstrated that the limited temporal resolution of film projection frame rates of 24 frames/sec or 25 frames/sec cause many more problems in 3D than they do in 2D. The SMPTE DC28 stereoscopic Study Group report (2005) mentioned this and showed some interest in higher frame rates for 3D.

Compression artifacts and spatial resolution issues affect 3D images very differently than they affect 2D images. There are many challenges to consider in upping exhibition frame rates to 48/50/60 frames/sec per eye in 3D. Bitrate studies for compression of these higher frame rate (HFR) sequences need to take into consideration what happens when there are left eye right eye discrepancies of content or compression artifacts which can effectively damage or destroy the 3D effect.

Frame rate capability depends on hardware and software bandwidth. Bitrate is impacted by that frame-rate, and also by the size of each frame/image in bits. Higher resolution means more bits, as do many other aspects of higher image quality. Each system combination—server, connections, and projector—has a resulting cascaded bandwidth limit.

Some of the newer 4K-ready Image Media Blocks (IMBs) are already capable of outputting 2K in 2D at 120 frames/sec. It is also currently possible to show 3D content at 30 frame/sec per eye and up, if you're willing to compromise on the bits per image. This is currently being accomplished in 3D by using a triple flash technique, where each frame is projected three times to reduce flicker. By encoding each image at a higher compression ratio, it is possible to present 30 frames/sec to each eye. Starting from 24 frame/sec content, and employing triple flash processing, the systems can actually run at 144 frames/sec, with each individual frame repeated (flashed) three times.

Once a projector has been upgraded to output 2K @ 120Hz, it can also show 3D @ 60Hz per eye. At these frame rates, the projection artifacts that triple flash tries to resolve are much less visible, so it seems probable that showing 60 frames/sec per eye will not require double or triple flash.

The earliest demos of digital cinema projection at higher frame rates have employed dual projector/server setups, eliminating potential temporal artifacts between eyes. For *The Hobbit* 48 frame/sec demonstration at Cinemacon 2012, an outboard server was used to drive two projectors. By June 2012, the first theatrical installation was used to demonstrate some of *The Hobbit* 48 frame/sec footage on a single projector, double-flashed, effectively producing 192 images/sec from the projector. By the time of publication, it is anticipated that 60 frame/sec demonstrations will likewise be able to be handled on a single projector.

Upgrades are not viable on Series I Digital Light Processor (DLP) projectors (the first batch of digital cinema projectors deployed). Additionally, Series 1 installations cannot be augmented with the addition of a Series 2 projector for dual projection of HFR content.

For LCD and Series I DLP projectors, a very small few of the currently available systems may require only a software upgrade to their IMBs to enable higher frame rates, but very few current IMBs are likely to be forward compatible with new HFR standards coming down the road. HFR functionality will probably become standard in future implementations.

One of the priorities of the HFR Study Group effort is to lead us to well thought out full 2K XYZ (1931 CIE 2 degree Standard Observer tristimulus color space encompassing the entire visual gamut—used by the D-cinema Digital Cinema Distribution Master (DCDM), SMPTE 428-1) 12-bit to JPEG 2000 encoding workflow solutions, rather than adopting temporary compromises such as showing HFR 3D movies in YCbCr (lower bandwidth luminance-chrominance encoding) 10 bit or in XYZ 4:2:2 (chroma sub-sampled) 10 bit.

The critical issue, which the HFR Study Group must address is the question of what additional compression encode rates will be needed in order to accommodate the new frame rates. It is becoming clear that the current bit rate of 250 Mbits/sec is insufficient for use in this circumstance, so the SG is embarking on a program to generate content for testing, which will demonstrate what encode bit rates will provide sufficient image quality and work efficiently throughout the system.

To this end, the SG will be shooting numerous 3D content tests with the help and support of the major 3D and studio communities, in an effort to build an open source, rights unencumbered library of test media for use in evaluating what new standards will need to be created. This important work will help determine the characteristics of HFR products that will emerge in the not too distant future.

Attached for Reference Is an Outline of The Scope of Focus of The Study Group

1. Short term studies

   A. Capability of in-field or about-to-be-released equipment;

   * IMBs
   * AJA (GDC)
   * Christie Digital
   * Doremi
   * Mikrom (Dolby, Qube, Cinesoft, and Leonis)
   * NEC
   * USL
   * Barco?
   * Maximum bit rates and sustainable system bit rates

   B. Projectors

   * Christie
   * Barco
   * Sony
   * NEC

   C. Playback of HFR on legacy equipment (frame skipping):

   * Dolby
   * Doremi
   * GDC
   * Quvis

2. Longer Term Studies

   A. Ensure there are no visible artifacts (higher compression bit rates):

   * Content
   * Evaluators / Locations
   * Recommendations for evaluation systems
   * Methodology for grading
   * Select bit rates for evaluation

3. Impact on other elements of the composition:

   A. Mastering impacts: John Hurst

   B. IMB impacts: Michael Karagosian

The Authors

Curtis Clark, ASC studied theater at the Art Institute of Chicago's Goodman School of Drama and cinematography at the London Film School. After graduation, he began his career by shooting numerous documentary films in Britain before transitioning to shooting feature films.

Clark's feature film credits include such critically acclaimed narrative films as *The Draughtsman's Contract*; *Alamo Bay*; *Dominick and Eugene*; *Extremities* and *Triumph of the Spirit*. He started shooting television commercials in the early 1990s, which put him on the forefront of the digital/film frontier. He continues to add to his hundreds of commercial credits working with cutting-edge directors and ad agencies. Clark recently completed his highly praised short film *Eldorado* which was shot with Sony's innovative new F65 4K digital motion picture camera.

Clark is a member of the American Society of Cinematographers and its Board of Governors, as well as chairman of the ASC Technology Committee, an important motion picture industry forum that both investigates and influences the development of emerging digital technologies that impact filmmaking practice. Since its inception in 2003, The ASC Technology Committee has achieved a series of notable successes including its collaborative work with Digital Cinema Initiatives (DCI) to produce standardized evaluation material for assessing the performance of digital projectors and other elements of digital cinema systems.

Dave Stump, ASC, began his career in film in the late 1970s, first as a TV producer for several cable shows and then at ABC where he helped put together a late night TV show called "Completely Off the Wall." He worked on a number of pictures with Clive Donner then worked for Francis Coppola in his camera department at Zoetrope Studios, working on all Zoetrope pictures such as *One from the Heart* until the studio moved to San Francisco. He worked on "The Day After" TV miniseries that won a VFX Emmy Award.

In 1991 Stump started a rental company, Motion Control Rental Services, which grew into the model for Visual Effects rentals in Hollywood. He has worked as DP, VXF DP and VXF supervisor on numerous large motion pictures and television productions and earned another Emmy nomination and an Academy Award for Scientific and Technical Achievement. He is a member of the ASC and chairs the Camera subcommittee of the ASC Technology Committee, helping to shape the future of digital cinematography.

David Reisner's motion picture work emphasizes creative flexibility and best practices in image quality, color, workflow, Digital Intermediate (DI), and digital imaging in production and post-production.

Reisner has been Secretary of the ASC Technology Committee since its founding and is an industry leader in areas including DI, workflow, advanced imaging, and camera assessment. He was a principal in designing and creating the ASC Color Decision List (ASC CDL), ASC-PGA Camera Assessment Series, ASC-DCI StEM (Standard Evaluation Material) test movie, and the ISDCF 3D projection luminance demonstration. He helped educate cinematography societies worldwide about the digital cinema transition.

Reisner designed one of the first digital music synthesizers, the first VLIW computer, the first popular portable video player, an early Internet music and movie distribution service, and co-designed the first lightweight portable computer. He has trained killer whales and shot magazine covers and book jackets.

Reisner is an Associate Member of the ASC.