American Society of Cinematographers Technology Committee Progress Report 2016

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ASC Technology Committee Officers

Chair: Curtis Clark, ASC
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Introduction

ASC Technology Committee Chair:
Curtis Clark, ASC

Following on from our 2015 American Society of Cinematographers (ASC) Technology Committee progress report, we have been proactively engaged with several key technology developments shaping our motion imaging future. Prominent among these are high dynamic range (HDR), digital cinema laser projection, and wide color gamut (WCG) beyond both BT.709 and DCI P3. The rapid advance of HDR being deployed for ultra-high-definition (UHD) television (TV) consumer displays, including the proposed BT.2020 WCG, has raised urgent questions regarding standards-based implementation, which filmmakers need to support their creative intent and ensure consistent display quality across multiple content distribution platforms.

The release of the Academy Color Encoding System (ACES) 1.0 has encouraged wider industry adoption of this crucial standards-based color management system that supports filmmakers' creative use of WCG with HDR and defines an important new expanded creative canvas.

The following reports from our subcommittees cover in detail the crucial work being done to address the array of motion imaging technology developments that are impacting the art of filmmaking.

The ASC Technology Committee is guided by its primary mission to engage and influence motion imaging technology developments in ways that better serve and protect the filmmaker's creative intent and the role of the cinematographer in realizing a creative vision that best serves that creative intent.

I would like to thank all those who devote their time and expertise to support the mission of the ASC Technology Committee.

Digital Object Identifier 10.5594/JMI.2016.2592338
Date of publication: xx Month Year

Secretary's Comment

ASC Technology Committee Secretary:
David Reisner

For the past 15 years, our industries have continued to change at a remarkable rate, and the ASC Technology Committee has helped find, guide, defend, and expand artistic options through those changes.

The most significant recent issue is HDR imaging. I immediately changed from an HDR skeptic to an HDR believer when I participated in the first HDR color correction experiments for the Image Control Assessment Series (ICAS). When used judiciously, we were much better able to express the intent of the original footage, both for bright sunlit scenes (e.g., out the window of the diner) and for dark scenes (e.g., bicycle ride into the nighttime alley and subsequent festivity).

HDR is often immediately noticeable and desired by viewers. Some forms are being delivered by over-the-top (OTT) TV providers, who sometimes also have some control of TV settings/behavior, and others by UHD Blu-ray. However, although the UHD Alliance and the International Telecommunication Union (ITU) have published some HDR formats (e.g., hybrid log-gamma [HLG] and Dolby's perceptual quantizer [PQ]), we do not have a clear, single, consistent agreement on what HDR will be when ultimately delivered to the viewer. HDR capabilities are different for individual models of display, which makes it particularly difficult to deliver the artistic intent reasonably consistently. Image reproduction adjustments for significantly different display capabilities are particularly dependent on viewing environment—something we are only beginning to account for. We clearly still need additional work in handling of out-of-gamut and out-of-dynamic-range images on a display. BT.2020 defines a very good WCG—nicely encloses the Pointer's gamut (all colors reflected by the surface of real objects)—so it makes a good goal. However, we need to figure out an appropriate set of primaries that are less prone to metamerism and an economically reasonable way to illuminate those primaries. At this point, BT.2020 is "aspirational"—it describes a goal, not what we can widely build and deliver today. Partly for that reason, the current generation of consumer displays has taken P3—essentially movie film's color gamut and digital cinema's minimum gamut—as the de facto standard and reference for color performance. BT.2020 implementation is an issue for the new generation of TVs and will likely be an issue for any future wider gamut cinema.

For everyone who needs to deal with the issues of HDR, I strongly recommend a careful reading of this year's Advanced Imaging Subcommittee Progress Report, by Gordon Sawyer Award winner Gary Demos, whose expertise in motion picture imaging is exceptional. Demos is doing some of the most sophisticated and advanced exploration of HDR imaging characteristics and perception. It is in no way a "casual" read, but it raises a number of practical questions that should be considered. The ASC Technology Committee is exploring the possibility of research, testing, and demonstration to increase understanding and to find and test solutions on some of those issues. However, if you master content, make displays, or are involved in content delivery, I recommend that you read Demos' report and think about it carefully.

The next several years will probably show as strong an emphasis on digital motion picture camera lenses as on the camera bodies and imagers themselves.

Computational imaging—multiple sensors plus computation, rather than sensor plus lens—is going to be showing up very widely very soon. Computational imaging will show up on cell phones this year and next. It provides a different enough set of imaging choices that it is not clear when or if it will play a significant role in motion picture or TV entertainment imaging. Some versions of computational imaging fit right in with the revolution in cloud-based storage and processing that we are presently in. In addition, on the computer side of imaging, it is possible that an as-yet undeveloped application of artificial intelligence "Deep Learning," cloud storage, cloud computation, and a different slice through Big Data may actually hold our best promise for automatically creating and delivering HDR artistic intent for our wide range of devices and environments.

Our emphatic thanks to outgoing ASC president Richard Crudo, ASC, and new president Kees Van Oostrum, ASC, and to the ASC membership and the staff and team at the ASC. The ASC was formed 97 years ago to help industry experts work together as a team to produce exceptional imaging and tell exceptional stories. The modern ASC actively continues that tradition through the everyday work of its members, associates, and staff.

UHDTV Subcommittee

Chair: Don Eklund
Vice-Chair: Bill Mandel
Second Vice-Chair: David Reisner

It has been a busy year for the subcommittee members and for the industries involved in UHDTV, which can largely be attributed to HDR and WCG. All major manufacturers now have HDR-capable display devices in the market, with a range of content now available from UHD Blu-ray and OTT, and testing under way with cable and satellite networks. Early adopters and average consumers alike can now experience UHD with the resolution, color, and HDR capabilities that have been the subject of much work in standards developing organizations (SDOs) and other organizations.

While the performance of first-generation displays and content have often been impressive, there have been few, if any, commercial examples of "live" HDR, which will almost certainly be a driving force in the adoption of UHD. Broadcasters, multichannel video programming distributors, SDOs, trade organizations, and others have been focused on the challenge of finding the most effective means of making WCG and HDR available to consumers. Live content presents unique challenges, given the priority of servicing existing high-definition (HD) customers and supporting a forward-looking strategy that includes "4K" (3840 × 2160), HDR, and WCG.

Demonstrations of UHD leave little doubt that the effort being expended is worthwhile. While it represents an incremental change in multiple parameters, the result is more than that. For the first time, consumers can get an experience that looks "real" (at least when objects are not in motion). It should be noted that, for filmmakers, rendering a picture that looks like reality is not necessarily what they seek. At a recent event hosted by the ASC, a sample group of cinematographers were impressed by examples of what a high-performance HDR system can do, but none said it was essential for their next project.

The tools are available to create UHD content; however, despite published standards, they do not all perform equally or accurately. Cameras, grading tools, compression, and virtually every component of the production and post-production system need to be studied and tested to validate UHD performance. Consumer products also have performance problems, mostly related to signaling, but as of this writing, they are being addressed by their respective manufacturers.

The UHDTV subcommittee has maintained an open door for advocates to come discuss and present related technology, devices, and tools. Recently, Dolby has briefed our subcommittee on their IC_tC_p encoding intended as a replacement for nonconstant luminance $Y'C_bC_r$ with HDR and WCG signals. IC_tC_p is being considered for inclusion in ITU BT.2390 "HDR-TV," which specifies parameters for HDR-TV signals to be used for program production and international program exchange, using either perceptual quality (PQ) or HLG HDR signals.

The challenges of delivering an ideal UHD experience from the camera to the consumer's display are many. Distributing a format with the capability of UHD provides ample opportunity to break the "looks real" experience with any mistake. Conversely, when UHD parameters are well utilized, the results are outstanding and represent the opportunity to transform the industry and reset consumer expectations.

Input to the group is welcome, provided that it can be shared on a nonconfidential basis (contact asc-uhdtv@d-cinema.us).

Next Generation Cinema Display Subcommittee

Co-chair: Michael Karagosian
Co-chair: Eric Rodli
Co-chair: Steve Schklair

The Next Generation Cinema Display subcommittee is concerned with satisfying the creative intent of filmmakers with the emergence of new technologies for projection light sources and displays in cinemas. The subcommittee has over 70 members, representing all major projection technology providers, the major studios, and the creative and technology leaders within the motion picture community. Our goal is to provide expert review and guidance in the presentation quality of the cinematic image that best supports the filmmaker's aesthetic intent with the added objective of influencing the adoption of emerging technologies that improve image quality.

The group's scope has expanded to include all emerging display technologies for cinema, including systems utilizing red, green, and blue (RGB) laser and laser-phosphor illuminators. RGB laser-illuminated projection systems have the potential for higher light level and wider color gamut, whereas laser-phosphor illuminators target the broad market with a lower cost of ownership than xenon. We continue to monitor the direct-view light-emitting diode (LED) market with its potential for future high-resolution, WCG, and HDR large-screen displays.

To gain a deeper understanding of the laser illuminator market, in 2015, the group issued a Request for Information (RFI) to the several manufacturers of laser illumination systems, seeking information and recommendations concerning factors that affect performance, including primary selection and achievable dynamic range. The RFI also requested observational information concerning the visual artifacts of metameric variability and speckle. The majority of manufacturers, however, were not prepared to respond in detail. The common sentiment is that the laser illuminator market is in an early stage of development, and suppliers and/or specifications remain in flux. The good news is that there is room for guidance.

A more recent focus for our group has been the development of a test protocol for evaluating projected images in terms of the characteristics of interest for next-generation cinema. This includes practical limits for deep blacks and peak whites, practical primaries for a wider color gamut, and contrast. "Practical limits" include not only limitations imposed by environment and technology but also the point in which diminishing returns are perceived from improved performance. One might think of this as a visual obstacle course for both projectors and audience. A study group is working on this task as this report is being written.

The first phase of evaluations will utilize test charts and copyrighted content toward the determination of critical parameters and a trial baseline for higher performance. A second phase is targeted, in which a revised test protocol will be produced utilizing noncopyrighted content, with the goal to widely share the test protocol and test materials for the benefit of technology providers and other stakeholders worldwide. Other work for the group includes a study of new-generation cost-efficient light sources to evaluate their ability to generate the full P3 color space.

Advanced Imaging Subcommittee

Chair: Gary Demos
Vice-Chair: Jim Fancher
Vice-Chair: Bill Mandel
Secretary: David Reisner

The work of the Advanced Imaging subcommittee has continued to support the work of other subcommittees, including the UHDTV and Professional Display subcommittees. The emphasis has been on system architecture issues, which consider the entire workflow from scene capture (or synthesis) to presentation display.

Our research on high-quality delivery of artistic intent with the varied set of current displays and formats, as well as on these new approaches, continues. We are working on ways to further describe and demonstrate some of these issues and effects for a broader viewing audience.

Self-Relative Characterization

A methodology has been developed in which self-relative percentage deviation (percentage of deviation, compared to the magnitude of the sample value) is utilized to determine the visibility of undesirable artifacts, such as image contouring and quantization noise. This methodology provides a quick and simple approach to evaluating system architecture components, individually or in combination. System weaknesses and bugs have been found easily by testing codecs and transfer characteristics, through evaluating self-relative variations as a function of brightness and/or color (usually using RGB). Ultimately, the comparison can be checked against the perceptual threshold, although existing 10-bit HDR systems lie mostly (or entirely) above that threshold. Deviations that have a pattern, such as contour bands on smooth gradients, have inherently different visibility than noise thresholds and noise-related buildup due to coarse quantization. However, self-relative percentage deviation, using absolute measures as well as one or more multiples of the standard deviation, provides a directly useful characterization for all types of potentially visible deviations. The perceptual threshold self-relative percentage has proven broadly useful for evaluating HDR deviations of all types. Note that the self-relative percentage is about 1/4% across most of the HDR brightness ranges and for most colors (a little higher for blue), coming up from dark gray through the brightest scene elements. However, typical testing of current HDR systems shows deviations much higher than this threshold. Self-relative testing not only shows the comparison versus the perceptual threshold over the brightness range but also points the way toward future improvements to the system architecture (see **Fig. 1**).

Transfer Characteristic Considerations

There has been some testing of the PQ curve and, to a lesser extent, some preliminary testing of the HLG curve as transfer characteristics. Both of these curves are anchored by specific mappings to radiometric brightness that are specified in terms of candelas per square meter (cd/sq. m, also known as "nits") at D65 neutral. Both the PQ and HLG curves allow brightness to be sent to displays in which the image brightness can exceed the capability of the display. In this case, the change in image appearance and desaturation behavior for these brighter-than-the-display regions becomes undefined and can be implemented differently for each model of display. Such a concept differs from BT.709 (having BT.709 primaries and gamma 2.22/2.4) and D-Cinema (having minimum gamut P3 primaries and gamma 2.6). In BT.709 and D-Cinema specifications, the value of logical 1.0 (e.g., 1023/1023 or 4095/4095) is mapped to display maximum. Furthermore, in D-Cinema, the display maximum is set to 48 nits (14 fL).

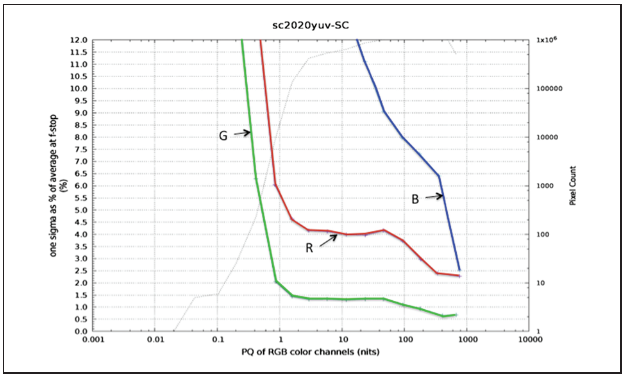


FIGURE 1. Sigma_compare RGB round-trip example.

Wide Gamut

In BT.709 and D-Cinema, the color behavior is specifically defined only to the BT.709 primaries, or to the P3 "minimum gamut" in D-Cinema. The D-Cinema X'Y'Z' (International Commission on Illumination [CIE] 1931 XYZ "tristimulus" values to the inverse gamma 2.6) allows colors to be specified outside of the P3 minimum gamut. However, the display or projector behavior is undefined. The BT.709 xvYCC extension also allowed colors beyond BT.709 primaries. Thus, the behavior outside of P3 for D-Cinema, and outside of BT.709 primaries for BT.709, is inherently device specific and not standardized.

This is also the situation when using the BT.2020 WCG primaries. However, BT.709 primaries and P3 primaries are specified in terms of "correlated color temperature" using CIE 1931 chromaticities. Thus, there is an infinite number of spectra that can be used to make any color (including neutral) in BT.709 and D-Cinema. When BT.709 (and CCIR 601) used primarily cathode ray tube (CRT) displays, the display emission spectra for RGB were similar, from mastering through distribution. In D-Cinema, if the projector used for mastering was made using the same technology as the final presentation, the same consistency of spectra existed. However, when changing projection technologies, particularly light sources, there is potential for individual and average deviation from intended colors. Similarly, as flat display alternatives have replaced CRTs in BT.709 presentation, the emission spectra also vary with each display technology. The inherent potential matching precision of a color specified in CIE 1931 chromaticity (or tristimulus) is reduced when the emission spectra vary between projectors or displays. This is due to CIE 1931 color-matching functions (or any color-matching functions) being approximate by their nature as a statistical average for color perception.

It should be noted that BT.2020 does not specify a minimum gamut as did D-Cinema. The implied intent is that chromaticities all the way to the spectrum locus are specifically allowed in any given master. However, as with brightness, there is no definition of the gamut boundary clip for displays having a gamut less than the entire BT.2020 gamut. Thus, any colors specified in an HDR/BT.2020 master that extend beyond a given display's gamut will have undefined colors (not matching the mastered colors). Gamut reduction is known to be difficult; thus, this is potentially problematic when using colors wider than a typical color gamut (e.g., BT.709 or P3).

BT.2020 primaries are very specifically defined as monochromatic red at 630 nm, green at 532 nm, and blue at 467 nm. However, there is a second definition using the corresponding CIE 1931 chromaticities. Unless a given display uses narrow-spectrum RGB emission at these wavelengths (e.g., using lasers), there is the same reliance on CIE 1931 color-matching functions as with BT.709 and D-Cinema. Even if lasers are used, individual (or average) color perception is significantly variable for monochromatic primaries. In other words, all colors specified as CIE 1931 chromaticities as well as the BT.2020 monochromatic primaries have inherently reduced color accuracy (versus every display being similar, as was the case with the CRT). This reduced color accuracy is due to weakness in the 85-year-old CIE 1931 color-matching functions, as well as to individual variation in color sensing and perception. Note that the subtended angular size of a color also affects color perception (due to the "yellow spot" on the retinal focus). This is the reason that the CIE made the 1964 "supplementary color standard observer" for 10° as an alternative to the 2° CIE 1931 color-matching functions. Age also affects the color perceived. The CIE 170-1:2006 "cone fundamentals" further make color perception parametrically variable by age and subtended angle.

In the past, we have done some testing on the behavior of CIE 1931 when used in cinema color gamut, brightness, and viewing environment. Similar testing may be of value in the very different gamut, brightness, and viewing environment of modern consumer displays.

Dark Behavior in HDR Systems

At low brightness, a small subtracted constant is commonly used (e.g., BT.1886) as a crude ambient black compensation. This subtracted constant should probably be removed in an HDR system architecture (e.g., above 250 nits), particularly in light of deep-black displays, such as organic LEDs (OLEDs), being a portion of the intended distribution displays.

It should also be a consideration that dark behavior for bright displays is inherently different from dark presentation, such as D-Cinema, or even historic BT.709/601 presentation. In D-Cinema, the darkest regions of the image cross the boundary of low-light vision. In the eye, bright portions of an image are perceived in color by the "cones," but dark regions (or dark scenes) are perceived without color by the "rods." D-Cinema at 48 nits (14 fL) crosses the cone/rod boundary. Cone bright color vision is called "photopic"; rod dark vision without color is called "scotopic." Images that cross the boundary, such as D-Cinema, are called "mesopic." (Generalizations of how and when scotopic vision and "Hunt" effect issues contribute are difficult for the dynamically changing brightness of moving images.)

Rod vision becomes prominent below about 0.1 nits (although there is variation between individuals). For D-Cinema, this is a high black at about 1/500th of the maximum 48 nits (14 fL). The transition region between rod and color (color) perception is gradual across the range of 0.1 to 10 nits, although rod vision is weak when it begins to see color starting at approximately 0.1 nits. However, there is a correlation between absolute brightness and perceived "colorfulness," which is the increased color that is seen by the rods, which extends from 0.1 nits all the way up to daylight brightness. Thus, a 12 nit (3.5 fL) 3D presentation will appear less colorful than a 48 nit (14 fL) presentation. Note that Laboratory Aim Density (LAD) at 10% of peak white in a 12 nit 3D presentation will be 1.2 nits (0.35 fL). Color perception certainly extends to brightness below LAD in this case, but with less colorfulness.

In the other direction, with each stop (factor of 2) of brightness increase, chromaticities will appear more colorful. This is called the Hunt colorfulness appearance effect (named after the color scientist R. G. W. Hunt who characterized it). A simple experiment at 50, 100, 200, 400, 800, and 1600 nits with identical chromaticities demonstrates that this colorfulness is a substantial appearance effect.

In addition to bright colors becoming more colorful in appearance, dark colors gradually move from rod vision up into photopic color vision. The 1/500th of peak white for a 2000 nit display will now be at 4 nits (if shown with the same pixel value proportions and chromaticities with respect to peak white). Even with reshaping of the brightness appearance curve, dark regions remain photopic. Given that dark image regions have thus become photopic on HDR displays, the use of desaturating S-curve processing becomes problematic. The implication is that color mastering and distribution concepts from D-Cinema and BT.709 cannot be extended into HDR. Rather, significant perceived color in dark image regions is required. Desaturated colors in dark regions adapted from D-Cinema or BT.709 masters will have an unnaturally dull appearance when presented directly on HDR displays. Repurposing standard dynamic range (SDR) masters for HDR must consider that dark regions in HDR are photopic.

This same issue has implications when attempting to extend a common master between HDR and SDR.

Parametric Appearance Compensation

Appearance variation is a significant issue given the variation in the capabilities of displays as well as the variations in the lightness of the rooms in which the displays are viewed. The colorfulness effect was already mentioned (a function of absolute brightness). In addition, ambient room brightness affects the perception of dark regions of an image. Essentially, a brighter room surround makes dark scene regions appear significantly darker. Failure to compensate for room surround appearance effects can cause dark portions of scenes to become darker and almost muddy in appearance. Facial expressions can even become invisible when viewed in bright surround, when having been mastered in dark surround (in which faces are perceived as being brighter).

Both LAD and midwhite are perceived most consistently if varied as a function of absolute brightness. In practice, it was convenient to combine the ambient surround and absolute brightness compensation into a single parameter. Brighter displays need a darker LAD and midwhite, and brighter surroundings need a brighter LAD and midwhite.

RGB Ratio Preservation

It was found to be a convenient enabler for our test HDR architecture to adjust brightness independent of chromaticity. For example, this allowed preservation of photopic vision in dark regions. It also allowed support for a wide variety of brightness ranges (both maximum brightness and dark range). By maintaining the relative ratios of R, G, and B for each pixel, the chromaticity remains constant. Note that this constancy is independent of color-matching functions if/when the color primaries are spectrally specified (e.g., as mastering display primary emission spectra for each of R, G, and B).

The one exception to chromaticity preservation is colorfulness compensation, which must vary saturation to achieve constant perceived colorfulness. Applying this as a delta to an otherwise constant chromaticity parametric architecture yielded a simple and effective means of unifying a variety of displays to approach a common mastered appearance. At some brightness, however, matching a mastering brightness, the chromaticity is unchanged, representing the mastered intent for colorfulness at that specific brightness.

The use of chromaticity preservation has the practical benefit of easier system calibration. Spectral radiometers and chromaticity meters become a direct tool for calibrating and verifying imaging system components.

Where Information Resides

It is necessary to consider where information resides related to parametric appearance compensation. The absolute brightness of a display is a function of the specific display type and its settings. The ambient surround is known only at a given display during viewing (and it will typically vary with daytime). The implication is that appearance compensation requires that the signal received at each display be in a neutral form appropriate for such appearance adjustments. Furthermore, each display must algorithmically compensate using those parameters that can be determined only at that specific display.

Note that some HDR system architectures do not take into account this issue of where appearance compensation parametric information is to be found.

Mastered Appearance

In working on the sample parametric HDR system, an end-to-end camera-to-display appearance model was experimentally utilized. This is a type of optical-to-optical transfer function with aesthetic appearance adjustment. It was found that such an automatic appearance adjustment could yield a master in which scene grading adjustments were made with respect to a neutral grade, with no appearance bias. This astounding discovery, although preliminary, suggests that it might be possible to have a neutral scene-referred appearance as input to grading. This concept could possibly be further extended to synthetic (e.g., computer generated) scenes, as well as composite scenes. Although there are many architectural components in an HDR system that is scene referred, such a system naturally extends the natural scene appearance to a range of displays. For example, even if the mastering display has limited range, the grading can include natural scene information (from cameras or synthetic scenes) beyond the master display's range. Although currently mostly untested, there may be application to extension beyond a mastering displays' gamut as well.

It should also be prominently noted that the chromaticities defined in the master form a natural archival record of the color appearance, although the dynamic range itself is intended to vary with the ranges of presentation displays. Together with a sufficient characterization of the mastering display, an archival HDR master becomes thoroughly defined by preserving chromaticities from the master within the intended system architecture.

Looking Forward

It can be seen from this description that there has been good progress, but substantial architectural exploration and refinement remain. Our work suggests that the mastered appearance needs to be parametrically extended to provide that same appearance on diverse displays (and in their environments), to the degree that this is possible. This suggests that such parametric appearance adjustment, utilizing information residing exclusively at each presentation display, is a necessary part of an HDR architecture. The parametric algorithms utilized to accomplish this should perhaps be considered for standardization, since correct HDR appearance requires not only the correct distribution of the HDR master but also the correct parametric adjustment of that master to yield the intent of the mastered appearance.

We look forward to doing additional research and testing in these areas. We are also working on providing clear demonstrations of some of these effects and behaviors to help people working in these areas understand the effects of their imaging and equipment decisions.

Professional Display Subcommittee

Chair: Jim Fancher
Vice-Chair: Gary Mandle

The subcommittee has been supporting several activities involving both UHD and HDR display. In particular, the monitor subcommittee has supported demonstrations organized by the UHD subcommittee.

The monitor subcommittee has been investigating post-production trends with regard to newer technologies used for finishing and quality control. These trends show a rapid movement toward HDR production and the expansion of HDR displays. In particular, there is a trend toward using SMPTE ST 2084 electro-optical transfer functions and increasing activity in 4K. Both liquid crystal display (LCD) and OLED displays are being used.

The subcommittee is in the planning stage of two separate future projects. The first project has identified the need to investigate the performance of some cell phone and tablet devices to determine their image accuracy. It is becoming more of a common practice for directors and directors of photography (DPs) to use these types of devices for color reference and general imaging decisions during production. The subcommittee would like to investigate and measure these devices and see on average what their performance is and draft a document that would help operators understand the performance level to be expected from such a display.

The second project that the subcommittee is planning is drafting a document describing a method for an operator to determine whether a display is performing to a level required for the production. The method described would use the minimum of tools so that anyone with knowledge of display calibration could judge the accuracy of the display in the field quickly and have the ability to make adjustments if the display is not calibrated.

Motion Imaging Workflow Subcommittee

Chair: Greg Ciaccio
Vice-Chair: Tim Kang
Vice-Chair: George Joblove
Current Subcommittee Focus: ACES

For the last couple of years, the ASC Technology Committee's Motion Imaging Workflow subcommittee has continued to focus on helping to educate and guide industry professionals on Academy Color Encoding System (ACES) benefits parallel with the efforts by the Academy of Motion Picture Arts and Sciences (AMPAS) Science and Technology Council.

The subcommittee is composed of key individuals in a variety of positions involved in production and post-production, who provide valuable real-world feedback. Frequently, prominent cinematographers attend and contribute with fresh perspective.

ACES v.1.0 was introduced at the end of 2014, and since then, a significant number of productions have used ACES. For a partial list, see www.shotonwhat.com/aces.

Our subcommittee continues to work in conjunction with the AMPAS Science and Technology Council and has created a clear and concise definition of ACES:

> The Academy Color Encoding System (ACES) is becoming the industry standard for managing color throughout the life cycle of a motion picture or television production. From image capture through editing, VFX, mastering, public presentation, archiving and future remastering, ACES ensures a consistent color experience that preserves the filmmaker's creative vision.

With so many new imaging advances being introduced concurrently (increases in spatial resolution, dynamic range, color gamut, etc.), it is vital to faithfully process and preserve creative intent by making sure that no bits are lost along the way. This is particularly important now as interest in HDR imagery has taken center stage, requiring a standard that can not only accommodate the extra range needed but also more easily produce the numerous versions needed for new and legacy sets of varying brightness capabilities.

Current subcommittee discussions include the creation of a section of the ASC site highlighting ACES benefits, including support documents and links to ACES-supporting manufacturer resources to help acclimate end users to the new standard. In addition, a list of ACES Product Partners is provided on the AMPAS site, shown below.

As ACES user experiences are shared within our industry, the practical benefits are being realized. Presenters and panelists at various trade events, such as the Hollywood Professional Association (HPA) Tech Retreat and CineGear, have presented real ACES benefits to attendees. At least one major studio has expressed great interest in integrating ACES into their production and post-production pipelines, as the benefits of ACES were realized in cost and time savings as well as in archival.

More information regarding ACES is available at http://www.oscars.org/aces.

Digital Intermediate Subcommittee

Chair: Lou Levinson
Vice-Chair: Joshua Pines
Secretary: David Reisner

This is a timely moment for our subcommittee to report. Although we have been quiescent as a subcommittee for many reasons, it has become obvious to those of us privileged to lead this group that we can no longer rest on our laurels and need to become more active.

There are still minor issues with the ASC Color Decision List (CDL), either unresolved or having arisen due to more recent developments that were not anticipated at the time of its creation. Some issues have arisen using the ASC CDL in an ACES or wide gamut context. The performance of the saturation operator out near the edges of wide gamut color spaces needs looking into. The fix could be as simple as fixing the math a bit, or it may require a more involved solution. We are actively investigating our options.

A topic that fell by the wayside but is now being discussed again is a way to allow for more complex user notes/metadata: nothing that requires action in the way of processing the images, but tools to help keep Leon Silverman's snowflakes off the driveway. There were a number of solutions proposed, but the current needs will require a solution of more complexity than we had been planning on. We are confident that we can keep the solutions inside the bounds of the CDL's simple but powerful philosophy.

An issue that seems to be moving to the fore is HDR imaging. There seems to be a general consensus that, while we all want to know about it and use it, there is no good, clear, universal definition of what it is and how it should be created and designed. We have proposed that all the relevant subcommittees of the ASC Technology Committee get together for an "HDR Fest" meeting and try to come to some conclusions about what to recommend to a community that is already going ahead and working in the HDR space, even if they do not know what it is. Among the topics could be the following:

- How are we defining an HDR image?
- What is the target or targets for a reference display?
- How do we define a reference display environment?
- How do we deal with HDR images on set?
- How do we exchange HDR images during content creation?
- How do we deliver HDR images to studios/content creators?
- What economic and studio political issues arise?
- What can we recommend regarding delivery to the consumer to yield the best and most accurate images possible on multiple platforms with diverse characteristics?

There is chaos and misinformation out there, and our subcommittee, with the entire ASC Technology Committee, would be a perfect place for the community to come for clarity. We have the knowledge and experience base in these matters, as well as a highly regarded, one-step-removed objectivity that this space seems to cry out for. It was once said about an ex-president who still had some eligibility left to serve: "He's tanned, he's rested, he's ready." While probably neither tanned nor rested, we are ready to once again help make content creation endeavors more predictable and dedicate ourselves to helping creative authors both in the creation process and in what may come after as deliverables and archive.

Our thanks to the ASC for support, as well as our best wishes for everyone going forward from here.

To get the current ASC CDL specification, send an e-mail to asc-cdl@theasc.com; an autoresponder will send terms and instructions. For additional information about the ASC CDL or the Digital Intermediate subcommittee, contact Joshua Pines at jzp@technicolor.com, Lou Levinson at western.light@yahoo.com, or David Reisner at dreisner@d-cinema.us.

Camera Subcommittee

Chair: David Stump, ASC
Vice-Chair: Richard Edlund, ASC
Vice-Chair: Bill Bennett, ASC

The ASC Camera Subcommittee engaged in a number of community activities this year.

Metadata

We have been interacting with ARRI, both in Los Angeles and in Munich, to revisit camera metadata, particularly in the realm of lens data. There is re-emerging interest at numerous camera manufacturers, lens companies, and software companies in moving forward to unify metadata standards in cinematography, particularly lens data for inclusion in image files. Accordingly, we have supplied spreadsheets of metadata fields that the subcommittee previously vetted for consideration in designing an eventual standard.

Panasonic VariCam LT

On 5 April 2016, Panasonic visited the Clubhouse to introduce their new VariCam 35 LT camera. It is a lighter, smaller version of their VariCam 35 camera, with a Super 35mm 4K sensor, weighing 6 lb, capable of in-camera 4K recording and simultaneous proxies. It has the same dual ISO capability of 800 and 5000 as the larger version of the camera.

Panavision DXL

Panavision introduced their new DXL cinema camera at the ASC Clubhouse on 1 June 2016—sensor type:

16-bit, 35.5-megapixel complementary metal oxide semiconductor provided by Red; digital resolution: 8192 × 4320; sensor size: slightly larger than the VistaVision film; format: 40.96 mm × 21.60 mm; diagonal: 46.31 mm; max frame rate: 60 frames/sec at 8K full frame (8192 × 4320), 75 frames/sec at 8K 2.4:1 (8192 × 3456); recording codec: 8K RedRAW with simultaneous 4K proxy (ProRes or DNx); recording media: Red SSD (up to 1 h on a single magazine); file type: .r3d (supported in RED SDK); color profile: light iron color (compatible with all popular gamuts and transfer curves); weight: 10 lb body only, without lens, battery, or accessories; lenses: directly motorize Primo 70 lenses through wireless control.

Radiant Images: VR Imaging Systems

Thirty percent of Radiant Images rentals are providing virtual reality (VR) camera systems and support. They offer more than ten different VR camera systems, ranging from simple arrays of GoPro cameras up to 17 camera arrays made from Codex Action cameras and RAW recorders. We learned one thing that was very informative: VR shots must be carefully designed to avoid people or objects crossing the "stitch boundary" between two cameras, at a distance closer than 4 to 8 ft, depending on the system. If crossing occurs closer than that distance, a producer must be prepared to spend between $30,000 and $50,000 per minute of finished footage to fix the crossing errors. We learned that this is not a simple "plunk the camera down, roll it, then post to YouTube" system, as many naive producers would like to think it is.

Fujinon Lens Demo Day

Bill Bennett helped Fujinon optics organize a lens demonstration day at the ASC Clubhouse on 24 May 2016, where the entire line of Premiere, Cabrio, and 2/3 in. broadcast lenses were demonstrated for the ASC membership and other interested industries. We lit a scene in the Clubhouse bar, shooting with an ARRI Alexa Mini and monitoring live HDR images on two 2000 nit monitors—the Dolby Maui and Canon HDR monitors. Several other cameras by different manufacturers—Sony, Red, Panasonic, etc.—mounted with Fujinon lenses were demonstrated in the Great Room. We set up a Chrosziel lens projector in the Boardroom, to do a lens projection demonstration, moderated by Mat Duclos of Duclos Lenses. Fujinon also introduced the new 20-120 mm T3.5 Cabrio Premier PL Lens, with removable zoom control.

Emerging Camera Technology

At the beginning of 2016, the Camera Subcommittee of the ASC received a request to evaluate a new prototype camera technology—the Lytro Light Field Cinema camera. As a matter of personal interest, Dave Stump has been following the development of Light Field capture and plenoptic computational imaging via the research papers on the topic that first came out of Stanford University; hence, after discussions with Lytro, Inc., The Virtual Reality Company (VRC), and Curtis Clark of ASC, he agreed to work as DP for director Robert Stromberg to shoot a short test film with the Lytro Cinema prototype camera.

The short film *Life* was developed and designed by Stromberg, and shots were defined together with Lytro's executive producer Jeff Barnes to produce a test that could demonstrate the capabilities of the technology. *Life* is a visual poem that tells the story of boy and girl as they traverse through the stages in life from youth to old age using colored walking paths as a metaphor for the various decisions that they make along the way. We knew that this project had to be ready for a National Association of Broadcasters (NAB) premiere, which gave us around 2 1/2 months from beginning to end. In light of where the prototype camera was in development, the undefined post-production pipeline and the short window before NAB, this was a brave experiment.

Since one of the test's goals was to determine how the Lytro Cinema camera and an ARRI Alexa would work in the same workflow and how the Lytro Cinema camera could intercut with conventional footage, it was decided to capture some of the shots in *Life* on an Alexa.

Because we were going to be working with a prototype camera, Stump visited Lytro's headquarters in Palo Alto, California, to get a feel for the camera and gauge the lighting and cabling needs. The prototype camera had a variable length extending from about 6 to 11 ft, depending on the framing and refocusing range. The camera also had a substantial weight; hence, from a planning perspective, we needed to adequately prepare for the mechanics of moving, panning, tilting, and dollying on set, but with proper preparation, the weight was not a major issue. We also had to take into consideration the parameters of shooting at very high frame rates, with a fixed T-stop lens at the sensor's native ISO, which was set at ISO 320. Given these circumstances, I went to Mole Richardson to speak to Larry Mole Parker to spec out lamps that would give us the light levels to create the beams and shafts of light in smoke that were designed into the storyboards.

The shoot was designed to function in a traditional workflow. In addition to capturing the Light Field data at 755 raw megapixels with 16 stops of dynamic range, the camera also captures QuickTime ProRes that allowed us to review files immediately after the take on set. The metadata in the Light Field is tied directly to the information in the preview capture; hence, the crew are able to make focus decisions on set in terms of focus range, and could manipulate the camera just like one would on a traditional shoot. Focus pullers, cinematographers, and creatives can make traditional on-set decisions that get baked into the metadata of the files and then see those versions in the real-time preview, just like any other system. As we shot, proxy files were being uploaded to our editor at VRC, and he began cutting while we were still on set. Most of the shots in the short were captured between 72 and 120 frames/sec, enabling post-production adjustment of synthetic output frame rate and shutter angle. The camera is capable of up to 300 frames/sec, and file size coming off of the camera is approximately 650 Mbytes/frame; camera data were moved through a 100 m fiber optic cable to a drive array. The eventual workflow design for the Lytro Cinema camera will be able to upload image files for storage and manipulation in the cloud.

There were several remarkable shots in the test short, among them a wedding scene in which the couple is standing at the altar in front of a preacher. The actors were photographed on a little walkway with an arch of flowers behind them, with reflective Mylar confetti flying through the air in front of them. This shot was accomplished on a bare stage, with grips walking behind the actors while the scene was shot, rather than shooting them against a blue or green screen. From the Light Field data, depth extraction was used to create mattes for the couple and to composite them into the final matte painting environment. Another notable shot featured a child actor playing baseball, rendered with an impossibly shallow stop of T.3 with an accordingly shallow depth of field, demonstrating the Lytro Cinema camera's ability to let the cinematographer select what to keep in focus in a scene and to then selectively change the aperture of that focal plane to any desired F-stop in post.

Joint Technology Subcommittee on Virtual Production

Chair: David Morin
Co-Chair: John Scheele

Since the last SMPTE report, the Joint Technology Subcommittee on Virtual Production of the ASC Technology Committee continued its series of case studies on the broadening use of real-time computer graphics on set.

Case Study: *The Walk*

The Virtual Production Committee held a case study of *The Walk* on 15 December 2015 on the Sony lot. Introduced by Tom Rothman, the chairman of Sony Pictures Entertainment Motion Picture group, the case study featured a live interview with director Robert Zemeckis and a making-of presentation by Kevin Baillie from Atomic Fiction. The evening also included a showing of *The Walk: VR Experience*, which was experienced individually by most in the audience (**Fig. 2**). This was the tenth meeting of the committee, and we paid an appropriate tribute to Robert Zemeckis, who contributed more than most to the development of virtual production in the pioneering days by directing *Polar Express* (2005) and the movies that he later made at his ImageMovers Digital studio, such as *A Christmas Carol* (2009). The case study highlighted how VR in production is gaining traction in the motion picture business and can be used successfully on a small production budget.

The Virtual Production Track at FMX 2016

For the fifth year in a row, the Virtual Production Committee curated the renamed "Virtual Reality for Production Track" at the Conference on Animations, Effects, Games and Transmedia (FMX) in Stuttgart, Germany. The track, held on 27 April 2016, was curated by Virtual Production Committee chair David Morin and showcased six case studies. The presentations covered the use of previsualization and virtual production on the films *Pan*, *Gods of Egypt*, *The Martian*, *The Walk*, and the newly released *The Jungle Book*, a milestone in virtual production (**Fig. 3**).

VR for Production

As we mentioned in our last report to SMPTE, virtual production is VR and augmented reality (AR) for production. Massive investments in VR and AR are producing new visualization and capture devices that are becoming commercially available at a high rate and are being used in production (**Figs. 4** and **5**).

Future Activities

The Virtual Production Committee will continue to pursue its goal of educating and helping to define the new workflow and is currently planning its meeting #11, along with other ancillary events, the Virtual Production track at FMX 2017, and the possible addition of a new workgroup on AR and VR, specifically. The subcommittee is planning to transform its proceedings at meeting #12, as per the original plan. More details on that transformation will become available during the upcoming year.

Participation is encouraged. Those interested may contact the following:
David Morin, Chair, davidmorin@davidmorin.com
John Scheele, Co-Chair, johnscheele@gmail.com

Digital Preservation Subcommittee

Chair: Grover Crisp
Vice-Chair: Michael Friend

As reported last year, preservation of moving images continues to be in a state of flux. As new workflows are

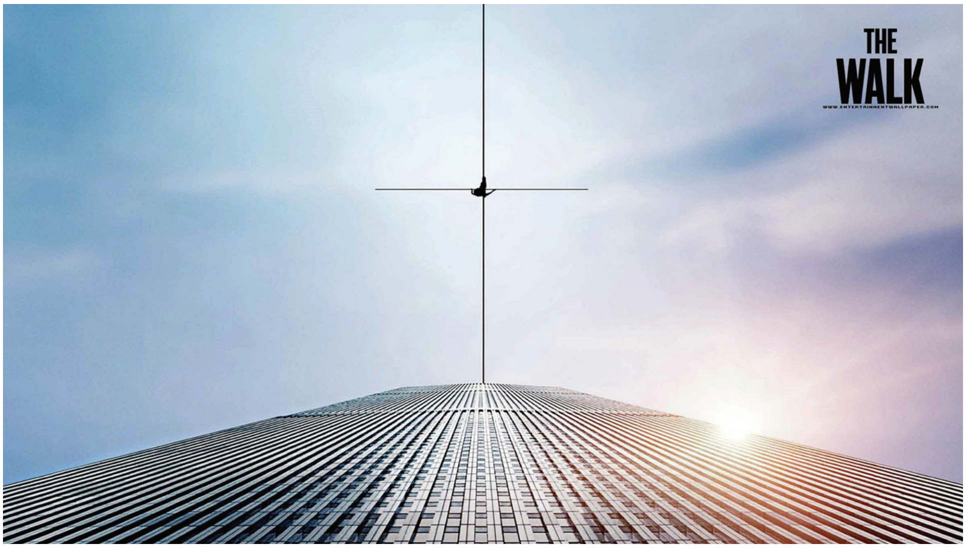


FIGURE 2. Intensive previsualization and on-set visualization were necessary to produce the vertiginous story on time and on budget.

developing in response to the breakdown of the standard model, challenges increase for archives and libraries, which are generally underfunded and find themselves trying to plan for a future that is technically uncertain. With the historical distribution methods in a state of disruption, it is not clear how to construct an economic model for the data archive.

We have entered a period of transition with an undefined time scale and an undefined objective for imaging standard and continually changing requirements. We have experienced the emergence of a platform-independent archive that serves a series of temporally available distribution scenarios. This new environment, which has been long expected, provides a challenge for the stabilization, retention, and representation of creative intent not just across time but also on multiple incompatible platforms.

The image-making standard of the classical film era has been completely displaced by technical developments in digital imaging. The superiority of the new cameras, in terms of spatial resolution, temporal resolution, image, and color stability, is not simply a set of relative advantages in digital. It now emerges as a new form of image making that is no longer only an emulation of film characteristics but regularly exceeds film in most parameters and constitutes a new and undefined medium. HDR, HFR, and VR are quickly deploying in mainstream image making, and there is a consequent adjustment in production workflows to accommodate platforms and data products, which means new classes of data that need to be captured in the archive. The implementation of ACES is just starting to transform practices in the moving image industry, with some studios beginning to implement ACES in all areas of image capture. The arrival of the BT.2020 color space and the display devices to support it is also having an effect on the archive, in terms of scale, file type, and metadata retention.

Because the capture, production, display, and archive environments continue to transform rapidly, it is difficult to predict how the archive will be deployed in the future. The model of a 35 mm original negative as the stable source of future images is a thing of the past, and black-and-white color separations on film—once the *ne plus ultra* of color retention—continue to attenuate as a viable methodology. The evolution from a static model of fixed elements toward the idea of high-quality, nonstandardized original data resources and a series of metadata components (which allow the transformation of these resources into specific and well-defined data products for specific uses) is now a reality. To capture, manage, and deploy a full range of production data, new pathways for acquisition will be necessary, and these may include accommodations, such as capture of camera files and metadata directly from the set. Along with the collection of more complex sets of data, the issues of metadata to characterize essence and to transform it are becoming central to new archival scenarios. Standardization of metadata is being introduced through SMPTE, but there is a considerable amount of conceptual work to be done with regard to what is sufficient and necessary as well as economically feasible for the archive. There is interest in exploring the viability of the Archive eXchange Format (AXF), and several studios are testing whether this format can play a role in the management of archival resources.

Cloud storage begins to assume greater importance and urgency for archives, not just from the pure storage perspective but also in association with the trend toward the virtualization of post-production services (including those required for preservation and for transition of data from preservation to distribution state) in a cloud environment. The proximity of storage-state data to online facilities that will perform required modifications is beginning to emerge as a dimension of cloud storage, despite the

FIGURE 3. A series of six case studies on VR for production was presented in Stuttgart, Germany, on 27 April 2016.

unresolved issues of cost prediction for services and withdrawal, security, access, and control.

SSIMWave HDR Evaluation Working Group

Coordinator: W. Thomas Wall

The purpose of this ASC Technology Committee Working Group is to assess, evaluate, and improve the preservation of the original creative intent of HDR, WCG, ultra-high-resolution digital video imagery during its distribution and delivery, from grading suite to consumers, as judged by cinematographers and colorists.

With the introduction of HDR, WCG, 4K, and UHD resolution displays and the upcoming delivery of such content to consumers freed from the constraints of traditional broadcast TV, the ASC has an opportunity to provide input and guidance into how such content delivery can best preserve the original creative intent of cinematographers. This Working Group was established at the end of 2015 to pursue these goals.

The Working Group will, with industry partners, perform the following:

1) Establish a controlled testbed environment in which cinematographers and colorists can evaluate the quality

FIGURE 4. Visualization: The HTC Vive VR headset became commercially available in May 2016.

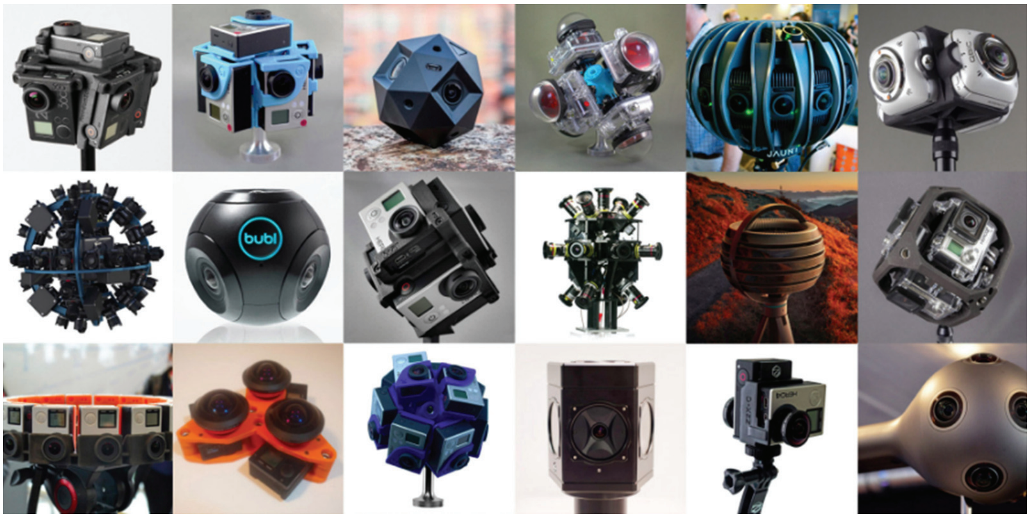


FIGURE 5. Capture: Many 360° cameras became commercially available. Professional camera rigs are exploring new formats. Image, courtesy of thefulldomeblog.com.

of HDR, WCG, ultra-high-resolution digital motion picture imagery as delivered to high-end consumer displays compared to that same imagery as seen and approved in a color grading suite.

2) Establish and execute a process to evaluate the efficacy of the Structural SIMilarity (SSIM) perceptual quality metric—as implemented in the latest SSIMWave Inc. quality metric software—to quantify the delivered quality of HDR, WCG imagery, as judged by content creators.
3) Evaluate the usefulness of SSIM perceptual quality monitoring software in the creative process.
4) Suggest improvements, where necessary, to improve such quality metrics and the delivered image quality to better preserve the original creative intent of cinematic imagery as viewed and approved in a color grading suite.

The SSIMWave software produces a grayscale map of the salient, noticeable differences between an original and an altered image, and a numeric "Quality of Experience" metric score, to indicate the level of perceptual differences between two images. This software is currently used to evaluate quality only in the final stages of cable and internet BT.709 delivery chains, and it has been evaluated and calibrated based on tests using "typical viewers" as subjects.

The Working Group has been collaborating with Dr. Zhou Wang, the winner of the 2015 Primetime Engineering Emmy Award for his development of SSIM, professor in the Department of Electrical and Computer Engineering at the University of Waterloo, Ontario, Canada, and chief scientist and cofounder of SSIMWave, Inc.; Dr. Abdul Rehman, chief executive officer and cofounder of SSIMWave, Inc. and a postdoctoral fellow at the University of Waterloo; and with Dr. Kai Zeng, chief technology officer of SSIMWave, Inc., to design and set up a testbed and evaluation by experienced content creators.

Two documents have been created and agreed to by SSIMWave, Inc. and the ASC, describing their respective roles in this evaluation process and the methodology that will be used. The study will be limited to HDR (ST 2084 PQ encoded), wide color (DCI P3 or BT.2020), UHD, or 4K digital imagery at up to 60 frames/sec and will evaluate how those images are perceptually altered from the beginning to the end of the internet OTT delivery chain by comparing the imagery as seen and approved in the color grading suite to that same imagery as delivered to a customer UHD, HDR-TV display over high-speed internet connections. (We will evaluate neither different consumer display devices nor different manufacturers or models of TV sets. Nor will the initial study evaluate or compare HLG or other encoding versus ST 2084.) The evaluation will be based on how well the original creative intent, embodied in cinematic digital imagery as viewed in a color grading suite, is preserved—not just how bright or how sharp any given image appears—as judged by professional cinematographers and colorists.

The evaluations have been designed consistent with the subjective user study protocol for perceptual quality assessment and will be performed, as shown in **Fig. 6**.

Based on input from internet content distributors, clips of well-calibrated, graded original ACES content will be transcoded, encoded, compressed, decompressed, and unencoded to reproduce how that content would be delivered to a consumer. Different levels of encoding and compression will reflect those used in typical, real-world distribution networks by distributors of high-quality HDR, WCG material. The SSIMWave software will then be used to generate difference maps and quality scores based on the perceivable differences in the two data streams. The original "as graded" and altered "as delivered" clips, and the

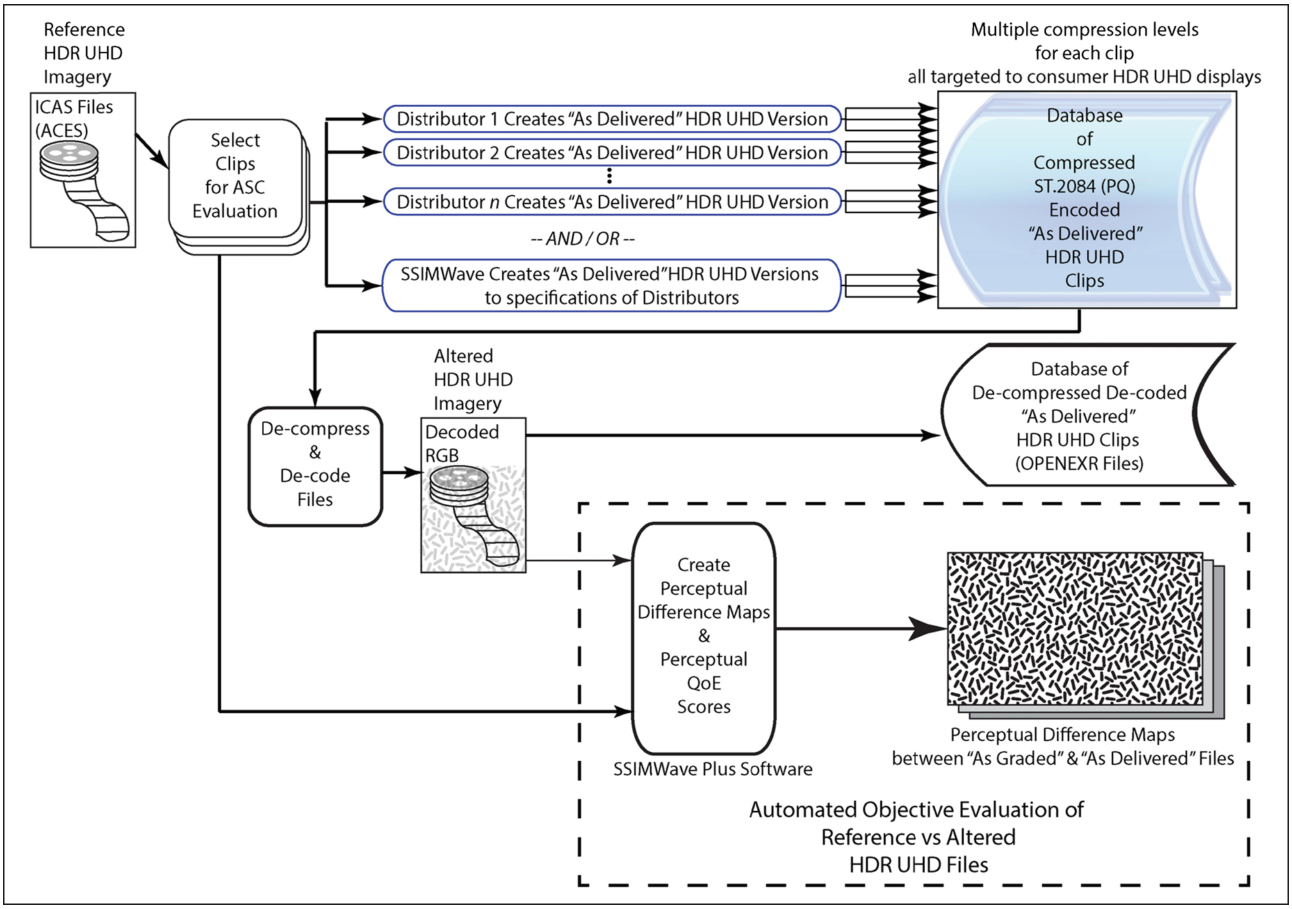


FIGURE 6. Test file preparation and objective evaluation stages.

SSIMWave metric results will be stored in a database. Clips will be chosen to illustrate a variety of content found in narrative motion pictures and TV.

The testbeds will be set up in environments to emulate those found in color grading suites. Two Sony BVM-X300 HDR, 4K reference monitors will be set up side by side to allow participants to view and compare the original and altered versions of each clip simultaneously. During each clip, the playback may be stopped or repeated as desired for close inspection. The participant will rate the degree of degradation between the "as graded" and "as delivered" versions and indicate the types of differences noted. The clip will then be played back again, this time with the results of the SSIMWave software being displayed on a third (consumer) UHD monitor; the participant will evaluate and record how well the quality metric software's automated evaluation matches their perceived image alterations and the overall degree of quality degradation (**Fig.** 7).

A report will be prepared by SSIMWave/University of Waterloo researchers, in collaboration with the ASC, describing the types of degradation and the degree to which they are detected by professional, experienced observers as altering the original creative intent. It will also report how closely the SSIMWave quality metric software reflects those professional judgments. Recommendations and suggestions will be solicited from participants, content creators, and content distributors, as well as the quality metric developers and researchers, as to how to improve and maintain creative intent throughout the delivery chain.

The Working Group has been set up with over 40 interested parties from the ASC and industry partners participating. SSIMWave, Inc. has agreed to devote considerable resources to this study and to ensure its scientific validity. We have begun involving HDR, UHD distributors, such as Amazon, with discussions ongoing for participation of other content distributors. Industry partners, such as EFilm/Deluxe, FotoKem, Sony, Panasonic, and others, have expressed interest in participating in the evaluations or providing testbed facilities and/or equipment. The ICAS ACES files are being prepared for use as source material in the study, and other test materials are being evaluated.

The Working Group met for an initial review of the study process and began filling out the details of its implementation. It was made clear that participants want to be sure that the study will be of use to both creatives and to HDR content distributors in educating all concerned with what happens once content leaves the grading suite and in encouraging the active participation of creatives in

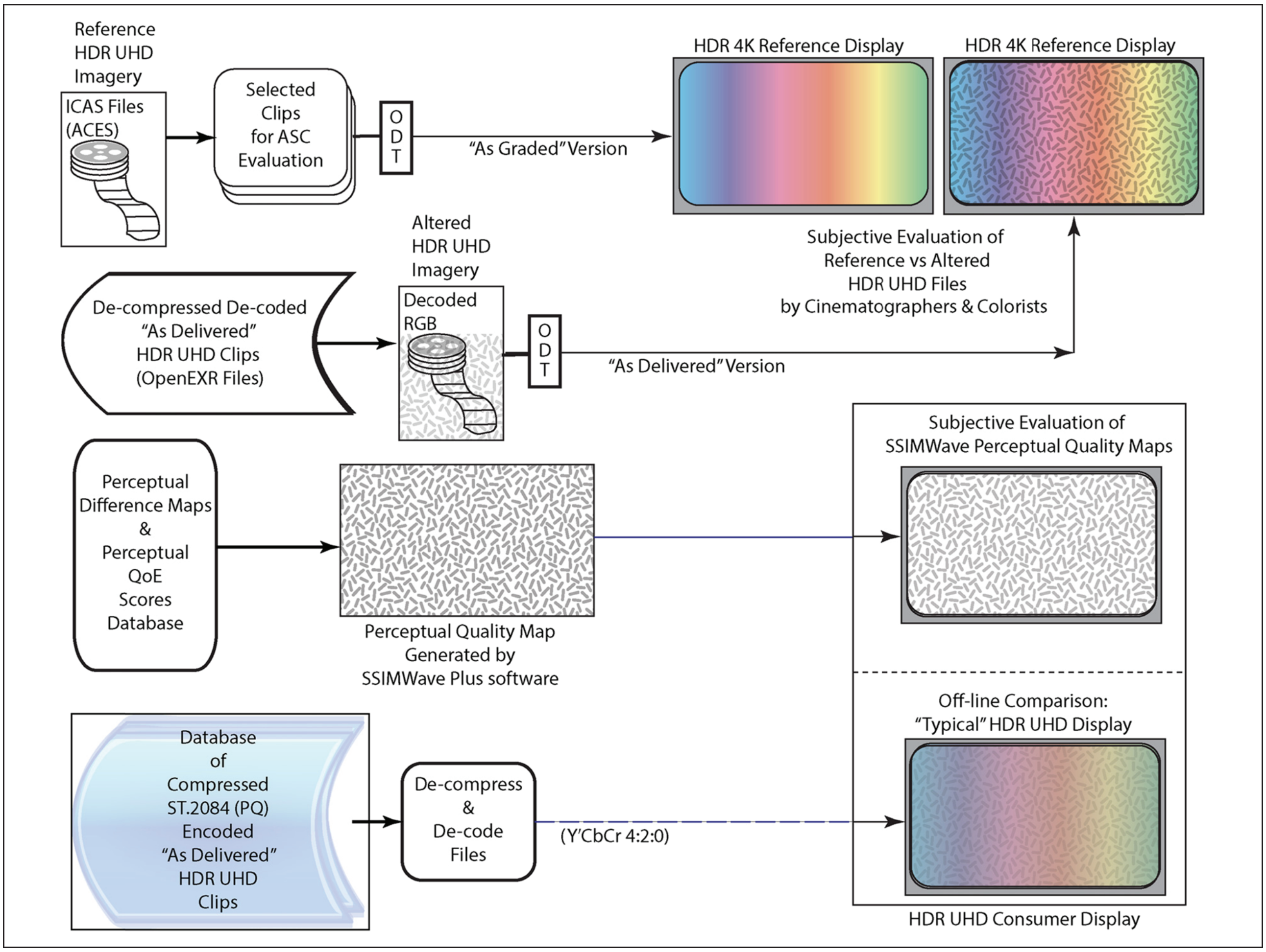


FIGURE 7. Subjective evaluation stage.

discussions and decisions on how their images will be delivered. This effort is ongoing.

Inquiries regarding the ASC Technology Committee should be sent to Delphine Figueras, delphine@theasc.com.

About 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 and directing numerous documentary films in Britain before transitioning to shooting feature films and TV commercials in Britain and the U.S. Following on the success of his short narrative film, "The Arrival," Clark more recently completed his highly praised short narrative film "Eldorado." He has just completed a short narrative film for Netflix entitled "Meridian."

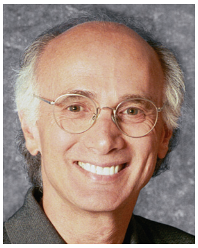
Clark is chairman of the ASC Technology Committee. Since its inception in 2003, the Committee under Clark's leadership has achieved a series of notable successes including its collaborative work with Digital Cinema Initiatives, LLC (DCI) to produce standardized evaluation material (know as StEM) for assessing the performance of digital projectors and other elements of DCI standards-based digital cinema systems, as well as the 2009 Camera Assessment Series and 2012 Image Control Assessment Series. Clark has been an active contributor to AMPAS working groups responsible for developing ACES (Academy Color Encoding System).

The ASC Technology Committee, at Clark's instigation, embarked on the development of a groundbreaking project to create cross-platform data exchange for primary RGB digital color correction known as the ASC CDL. The ASC CDL was recognized by the Academy of Television Arts and Sciences with a prestigious 2012 Primetime Emmy Engineering Award. Clark also received an AMPAS Technical Achievement Award recognizing his work developing the ASC CDL. Clark was recipient of the prestigious ASC Presidents Award in recognition of his creative and technology achievements. Clark is a member of the ASC and the ASC Board of Governors, as well as a member of AMPAS.

David Reisner received a 2014 Academy Technical Achievement Award and was recognized in a 2012 Primetime Emmy Engineering Award as a codesigner of the ASC CDL, which is used in the workflow of 95% of motion pictures, 70% of scripted TV, and 99% of visual effects turnover. He was a lead designer of the ASC-DCI Standard Evaluation Material used to determine the quality required for the deployment of digital cinema and was Vice Chair of the SMPTE Working Groups responsible for the digital cinema imaging and security standards. Ninety-seven percent of cinema screens worldwide now use digital cinema. Reisner also had leading roles in activities including design and production of the ASC and the Producers Guild of America (PGA) Camera Assessment Series and elements of the ACES. He made one of the first proposals for the Virtual Print Fee model used to fund the digital cinema rollout. Reisner's "firsts" include programmable portable computers, handheld video jukebox, and other computer and consumer electronics, and he originated very long instruction word (VLIW) computer architecture. He has produced concerts internationally and trained killer whales. Reisner is well published in books, technical articles, and has spoken widely, including on manned space exploration at the 2014 International Space Development Conference. He is a Member of the SMPTE, the founding secretary of the ASC Technology Committee and an ASC associate, and a member of the Visual Effects Society; he chaired committees for the Academy's Scientific and Technical Awards.

Don Eklund is the senior vice president for new format promotion with Sony Corporation of America. He has helped launch multiple consumer entertainment formats since starting his career with Sony. He codeveloped and staffed the operation that launched DVD with Sony Pictures and went on to oversee the development of software tools and hardware systems that supported compression, authoring, and quality control for Blu-ray. Eklund also participates in industry standards organizations and consortiums that focus on next-generation entertainment.

Bill Mandel is the vice president for technology at Universal Pictures. He has been involved with technology that the studio distributes through for more than 20 years. He has worked on technology and licensing related to many service and format launches, including DVD, electronic sell-through, interactivity, and HDR. His interests lie in formats, video, audio, digital rights management, and networks.



Michael Karagosian is the founder and president of MKPE Consulting LLC, a Los Angeles-based consultancy for business development in the entertainment technology. He is a 30-year veteran of the cinema industry and has been active in the digital cinema space for the past 11 years. Karagosian led the development of license-free standards for closed-caption systems in digital cinema. He served for eight years as senior technology adviser to the U.S.-based National Association of Theatre Owners. He is a member of the Board of Directors of In-Three and was an advisor to the U.K. Film Council in the U.K. government-financed rollout of digital cinema. In the late 1970s and early 1980s, Karagosian led the development of cinema and studio products at Dolby Laboratories. In the 1990s, he was a cocreator of the Peavey CinemAcoustics product line and led the development of networked audio and control systems for Disney theme parks. His company site is http://mkpe.com.

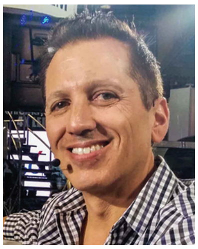
Eric Rodli has been involved in the management and development of entertainment technology since the late 1980s, when he became the president of Iwerks Entertainment, a pioneer in large-format film, motion simulation theaters, and other immersive technologies. He subsequently has had senior roles in a variety of entertainment and media organizations, including being a partner in the entertainment consulting practice of Pricewaterhouse Coopers, as well as a president of Kodak's Motion Picture Division. He currently provides strategic advisory services to companies in the entertainment technology industry. He is an associate member of the ASC. Rodli received a BA in economics from the University of California, San Diego, and an MBA from the University of Chicago.

Steve Schklair, photograph and biography not available at the time of publication.

Gary Demos has been a pioneer in the development of computer-generated images for use in motion pictures, digital image processing, and image compression. He was a founder of Digital Productions (1982-1986) and received the AMPAS Scientific and Engineering Award in 1984 along with John Whitney Jr., for their work on "For the Practical Simulation of Motion Picture Photograph By Means of

Computer-Generated Images." Demos also founded Whitney-Demos Productions (1986-1988), DemoGraFX (1988-2003), and Image Essence. LLC (2005 to present). Demos received the AMPAS 2005 Gordon E. Sawyer Oscar for lifetime technical achievement. He is actively involved in the ASC Technology Committee and has worked on the AMPAS ACES project. Demos has presented numerous papers at SMPTE, given an SMPTE webinar, is an SMPTE Fellow, and received the 2012 SMPTE Digital Processing Medal. He is the inventor of approximately 100 patents.

Gary Mandle has been working with new display technologies for the last 35 years, including CRT, field emission display, large-field-of-view LED, LCD, liquid crystal on silicon, and OLED. His work has included the introduction of LCD for professional monitoring, the implementation of Sony's digital cinema projection systems, and the development of Sony's OLED reference monitor technology. His current focus is on RGB and white OLED technologies. Mandle has been published in several journals for the SMPTE, the Institute of Electrical and Electronics Engineers (IEEE), and the Society for Information Display (SID) and has been a contributing author to the CRT, LCD, and OLED sections of several textbooks. His other areas of work include the design of camera image stabilization systems and charge-coupled device sensor development, in which he holds multiple patents. He is a member of a number of industry organizations, including SMPTE, IEEE, and SID, and he is an associate member of the ASC.



Greg Ciaccio is a post-production professional focused primarily on finding new location-based technology and workflow solutions for motion picture and TV clients. Previously, Ciaccio served in technical management roles for the respective Creative Services divisions for both Deluxe and Technicolor. Key developments include the first DP Lights deployments for Technicolor and full near-set dailies solutions for Deluxe Television. Ciaccio is a member of the SMPTE, the ASC Technology Committee, the AMPAS Science and Technology Council, the Hollywood Professional Association, and the Digital Cinema Society. He holds a BA degree in radio-TV-film from California State University, Northridge, where he currently teaches post-production part-time.

Lou Levinson is a long-time associate member of the ASC and the chair of the Digital Intermediate Subcommittee. A member of the ASC Technology Committee since its inception, he has been a frontline colorist from the "on the fly" analog era to today's advanced ACES and beyond digital pipelines, having worked with notables from Woody Allen to Rob Zombie. He is currently working for Apple in the San Francisco Bay Area.

David Stump is a working DP, visual effects DP, visual effects supervisor, and stereographer, earning an Emmy Award, an Academy Award for Scientific and Technical Achievement, and an International Cinematographers Guild Award. He is currently the chairman of the Camera Subcommittee of the ASC Technical Committee and a member of the AMPAS Science and Technology Council, where he chairs the Next Generation Cinema Technology Work Group and participates in the AMPAS ACES project. Under his guidance, the combined efforts of the PGA and the ASC produced both the ASC/PGA Camera Assessment Series and the ASC/PGA ICAS, which are side-by-side comparisons of virtually all of the high-end digital cinema cameras against film. He has lectured and taught classes in cinematography and visual effects and has spoken at many conferences and trade shows, including the National Association of Broadcasters and the International Broadcast Convention.

Bill Bennett has been a cinematographer for more than 35 years, primarily shooting TV commercials for hundreds of major clients: Ford, Lexus, Coca Cola, Apple Computer, American Airlines, McDonalds, and Budweiser. Bennett had the great honor of being the first cinematographer, with a career consisting of primarily shooting TV commercials, to be invited to join the ASC. In 2016, the ASC presented Bennett with the President's Award at the 30th Annual ASC Awards Show. He is currently serving as a vice president at the ASC. Bennett often advises ARRI, Zeiss, and others on equipment design.

David Morin is the president of David Morin, LLC, a diversified consultancy specializing in VR for production. Morin is also the chairman of the Joint Technology Subcommittee on Virtual Production, a joint effort of six Hollywood-based organizations: the ASC, the Art Director's Guild (ADG), the Visual Effects Society (VES), the Previsualization Society, the PGA, and the International Cinematographers Guild. He is also a past chair of the Autodesk Film CTO Advisory Council, a product focus group of large studio facilities, and a past co-chair of the ASC-ADG-VES Joint Technology Subcommittee on Previsualization, a committee that helped define the role of previsualization in the film industry.

Michael Friend is the director of the digital archive in Sony Pictures Entertainment's Asset Management group and teaches at the University of California, Los Angeles, in the Moving Image Archive Studies Program.

W. Thomas Wall is a retired computer systems designer and a professional photographer. He is a chief technology officer at LightView.