American Society of Cinematographers Motion Imaging Technology Council Progress Report 2019

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Chair: Curtis Clark, ASC
Vice-Chair: Richard Edlund, ASC
Vice-Chair: Steven Poster, ASC
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Introduction

ASC Motion Imaging Technology Council Chair:
Curtis Clark, ASC

Since its formation 100 years ago on 8 January 1919, the American Society of Cinematographers (ASC) has been consistently focused on the motion imaging technologies that underpin and enable the cinematographer's creative toolset essential to artistic expression in narrative storytelling. From cameras, lenses, lighting, exposure metering and camera support equipment to the evolution of film stocks from B&W (orthochromatic/panchromatic) to color (2 strip/3 strip Technicolor and eventually integral tri-pack single strip color from Eastman Kodak, the ASC and its cinematographer members have consistently been at the forefront of critical technology developments that have influenced the advancement of their art form.

During the 1930s, the ASC ran this statement in the pages of *AC*: "The American Society of Cinematographers was founded … for the purpose of bringing into closer confederation and cooperation all those leaders in the cinematographic art and science whose aim is and ever will be to strive for pre-eminence in artistic perfection and technical mastery of this art and science. Its purpose is to further the artistic and scientific advancement of the cinema and its allied crafts through unceasing research and experimentation as well as through bringing the artists and the scientists of cinematography into more intimate fellowship."

ASC Motion Imaging Technology Council (MITC) has continued that tradition for the past 16 years as we navigate the disruptive waters of the digital imaging revolution. In the April 2019 issue of *American Cinematographer* magazine you will find an excellent article documenting the continuity of this 100 year tradition. The article is entitled "Continuity of Mission" and a direct link to it on the ASC website is provided below. I strongly urge you to read it: https://ascmag.com/articles/continuity-of-mission

There's certainly no doubt that digital imaging technology has been a disruptive force impacting our traditional filmmaking workflow. The creative role of the cinematographer as a key contributor to the artistic vision of a film was firmly established during the photo-chemical era when the cinematographer was generally considered to be responsible for overseeing the creation of a 'look' established in collaboration with the director. After all, the cinematographer needed to have a practical knowledge of and experience with the film-based photographic system to effectively practice the art of cinematography.

With the advent of digital imaging technologies, things have certainly become more complex, and the traditional value of the cinematographer's creative contribution needs to be reinforced. This includes having a practical knowledge of and experience with the creative possibilities enabled by the new digital imaging canvas, e.g., expanded dynamic range (HDR), wide color gamut (WCG) Academy Color Encoding System (ACES), etc. Also, look management, starting with previs, needs to be recognized as a purview of the cinematographer, especially with increasing integration of visual effects (VFX) and virtual production techniques.

I believe it's possible to retain and reinforce the traditional role of the cinematographer in this new era by demonstrating the ability to apply these digital imaging tools to the creation of images that support a creative vision in collaboration with the director.

As always, the ASC Motion Imaging Technology Council is guided by its primary mission to engage and influence motion imaging technology developments in ways that best serve the filmmaker's creative intent and the role of the cinematographer in realizing a creative vision that best serves that creative intent. As we traverse this radical terrain of unprecedented technology transition, it is imperative that we persevere in our mission a path embracing the new while preserving the artistic achievements of the past that have defined the art of filmmaking.

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Building on our 2018 Progress Report, our 2019 Progress Report incorporates the most recent work being done by our committees, subcommittees, and working groups.

I would very much like to thank all those who generously devote their time and expertise to support the mission of the ASC Motion Imaging Technology Council.

Secretary's Comment

ASC Motion Imaging Technology Council
Secretary: David Reisner, dreisner@d-cinema.us

In a significant event for our Council: The Academy of Motion Picture Arts and Sciences gave the ASC Motion Imaging Technology Council's founder and chair, Curtis Clark, ASC, the John A. Bonner Award "in recognition of his extraordinary service to the motion picture industry." Clark has led the ASC Motion Imaging Technology Council (formerly the ASC Technology Committee) thru its 16 years of guiding the motion picture industry into the digital production era.

The digital transition is firmly in place in the motion imaging industries. Year-over-year, we continue to see a high pace of not-always-expected development and, even when we expect slowdowns, introduction of new production, post, imaging, and exhibition technologies. The American Society of Cinematographers Motion Imaging Technology Council, ASC MITC, actively continues its role of helping guide and technically inform those developments to be better tools for creative artists to tell stories and, with engineers, to more efficiently and more effectively provide best audience experiences on the wide range of platforms and formats that now make up our entertainment ecosystem.

Camera development continues, including higher resolutions and new sensors. The present generation of imagers so far seem to be OK for high dynamic range (HDR) and wide color gamut (WCG) usage, although there will almost certainly continue to be significant interactions with filters and with lighting. The Lens Committee is creating impressive historical records. Lens manufacturers are including increasingly detailed metadata on lens characteristics and use, as will be increasingly important with higher resolution lenses and with computational imaging techniques, and for high-end VFX matches. The DI Committee is attempting to balance maintaining ASC CDL consistency and identifying any legitimate needs for changes. Many of these issues flow into the Motion imaging Workflow Committee, who are trying to help give them some organization in practical workflows, with ACES and ACESnext as baselines. Look for wide industry interaction by the new Solid State Lighting Subcommittee.

As the Next Generation Cinema Display Committee is excitingly and painfully aware, once we have created our movies and shows, they will be displayed on an increasingly wide range of devices in and outside the home, as well as the Gold Standard of large-screen theatrical display. Some of the expectations from HDR and WCG home displays are applying pressure to theatrical exhibition to expand beyond current standards, aided by new technologies like flat-screen emissive displays, but with the great difficulty of maintaining consistent presentation of artistic intent. To provide a baseline and reference, we are exploring creating StEM2 – HDR Standard Evaluation Material – a potential high-value reference for a wide range of industries and audiences. The on-set production and the in-post mastering, and eventual home viewing, of that material will require high performance displays of known characteristic, as being examined by our Professional Display and UHD TV Committees. The Advanced Imaging Committee continues to look for ways to put a solid technical footing under all of that and to make the material be targeted at the highest fidelity to a range of displays and environments at reasonable mastering effort.

Virtual Production, when we first started the committee, was exotic. It is now a standard tool on a large fraction of movies. The Virtual Reality and Computational Cinematography/Plenoptic Committees look at some of the new ways entertainment imaging will be created and used. There are significant technical and creative challenges across the board, so watch for significant developments and changes. The SSIMWave HDR Evaluation Working Group is mixing a commercial activity to measure image transmission quality with some of MITC's needs for HDR material and tools.

Issues and developments I see coming down the line include: Higher resolution cameras and displays, whether they provide actual audience benefit or not. Bit-by-bit, progress in the intelligent use of higher frame rates in shooting and display – as needed for pleasant HDR imaging, and because of the "more is better" compulsion. Increased amounts of metadata and better support for retaining and using that metadata. Starting to use "AI" and Machine Learning in imaging and their further use in story analysis/description, cataloging, management, localization. I remain sure that AI will ultimately play a significant role in delivering Creative Intent to audiences across the very wide range of platforms on which entertainment and stories are now delivered. Starting to develop how we implement, communicate, and use computation-heavy and data-heavy techniques like light field and plenoptic imaging and display, and development of cameras, processing, and displays to go with them. Both heavy and lighter-weight computational imaging, like when a cellphone with multiple fixed lenses lets you adjust the depth of field of an image after you've taken the picture, or offers variable or object-aware depth of field and focus. Lighter-weight computational imaging is now showing up for day-to-day use in cellphones and some other products. Exploration of artistic uses of VR (as shown at this year's SXSW). At some point, the explosive growth of Augmented Reality in practical-world situations (engineering, health, etc.). And, eventually, an explosive growth in sensor bearing, fine-mesh emergent networks (as in my 1990s proposals of Pervasive Computing).

As always, to continue to provide rich and moving experiences for our audiences, our industries will need to be vigilant about arranging and finding schedule and budget to support cinematographer involvement in imaging and design thru the entire life of projects. This is especially true with new techniques like VR, computational, and light field imaging, where the image can remain very fluid through the whole production.

The ASC was formed 100 years ago for cinematographers, with the participation of other industry experts, to share important information and experiences to develop and advance the industry's ability to produce exceptional imaging and tell exceptional stories. The modern ASC actively continues that tradition through the everyday work of its Members, Associates, staff, and the ASC Motion Imaging Technology Council.

Camera Committee

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

As we moved into the beginning of 2019, the trend toward "Large Format" digital cinema cameras continued. The term "Large Format" has come to be used for sensors with an area similar to the 24mm × 36mm classic Leica still camera format first invented by Oskar Barnack at Ernst Leitz Optische Werke, Wetzlar, in 1913. Now, here we are 106 years later, with history repeating itself.

There continues to be a trend to create physically smaller cameras, more versatile with multiple monitoring and auxiliary power outputs. Some manufacturers are moving toward increased photosite count on their sensors, while others like ARRI have retained the same photo site dimensions as used in the original ALEXA classic introduced in 2010.

There is an ongoing reassessment of ACES IDTs for the different cameras, to optimize their full potential within an ACES color managed workflow. A proper implementation of ACES starts on-set, or near-set, with the conversion of native camera output (preferably camera RAW) to ACES via an IDT. Also, ACES proxy is a 10-bit version designed primarily for use on-set for quick and easy viewing of ACES images during shooting.

This year's camera developments include:

- ARRI introduced the **ALEXA Mini LF**, a full frame version of the **ALEXA Mini,** using the same sensor as the **ALEXA LF**, and sharing the same LPL lens mount. A PL to LPL adapter is available. Sensor size: 36.70 × 25.54 mm, 4448 × 3096 photo sites. Up to 40 fps when using the entire sensor, up to 90 fps when using a smaller area of the sensor. Weight: 2.6 Kg/5.7 lbs for the camera body, minus the viewfinder. The camera is also supplied with a new MVF-2 viewfinder, with an OLED screen, 1920 × 1080 resolution, and a swing-out screen for menu and viewfinding. Recording Media: a new, small Codex Compact Drive, 1 TByte, recording uncompressed/unencrypted .ari ARRIRaw, or ProRes. Power: 65W, 11 to 34VDC.
- Panavision introduced the **DXL2** full frame camera, utilizing a sensor from RED Digital Cinema, 40.96 × 21.6 mm, 8192 × 4320 photo sites. P70 Lens mount, with adapters to PV or PL. 60 fps when using the entire sensor, 120 fps when using a smaller area of the sensor (and recording in ProRes.) The camera is provided with a 600 nit wide color-gamut viewfinder. Weight: 4.5 Kg/10 lbs. Recording Media: SSD, recording compressed/encrypted .r3d REDcode with a simultaneous ProRes or DNx proxy. Power: 11–18VDC at 85 watts.
- RED Digital introduced the **RANGER**, an integrated large format camera, which is an all-in-one camera that is *not* modular like their earlier cameras, such as the **Helium** or **Monstro.** This model will only be available from RED authorized rental houses. Sensor size: 40.96 × 21.60 mm, 8192 × 4320 photo sites. Lens Mount: PL, Canon EF, Nikon F, or Leica M. Up to 60 fps when using the entire sensor, up to 300 fps when using a smaller area of the sensor. Viewfinder: RED Touch LCD or OLED, 4.7 in. up to 9 in., or Bomb EVF with either OLED or LCOS. Weight: 3.3 Kg/7.3 lbs. Recording Media: RED Mini-Mag, recording compressed/encrypted .r3d REDcode, ProRes, DNxHD, or DNxHR. Power: 11.5–32VDC, 72 watts.
- RED Digital introduced the **GEMINI**, more light-sensitive sensor with larger pixel size, in S35 format. Sensor size: 30.72 × 18 mm, 5120 × 3000 photo sites. Dual ISO capability. Up to 75 fps using the entire sensor, up to 300 fps when using a smaller area of the sensor. Lens Mount: PL, Canon EF, Nikon F, or Leica M. Viewfinder: RED Touch LCD or OLED, 4.7 in. up to 9 in., or Bomb EVF with either OLED or LCOS. Weight: 1.5 Kg/3.35 lbs. Recording Media: RED Mini-Mag, recording compressed/encrypted .r3d REDcode, ProRes, DNxHD, or DNxHR. Power: 11.5–17 VDC, 60 watts.

Lens Committee

Co-Chair: Jay Holben
Co-Chair: Michael McDonough, ASC, BSC
Vice-Chair: Christopher Probst, ASC
ASC Motion Imaging Technology Council Lens Committee Filter Classification Subcommittee
ASC Motion Imaging Technology Council Lens Committee Focus Accuracy Subcommittee
Chair: Matthew Duclos

Formed in the fall of 2016 the Lens Committee has been hard at work examining multiple issues facing cinematographers and filmmakers today concerning cinema optics. There are several projects in which the Lens Committee is currently involved.

Comprehensive Cinema Lens Database

At the forefront of the committee's work is the Comprehensive Cinema Lens Database, a project initially started by Committee co-chair, Jay Holben, and vice-chair, Christopher Probst, ASC, to catalog the technical aspects of all cinema lenses in history.

The database currently lists more than 3,400 cine-style optics from the evolution of cinema to today's modern lenses along with as much technical information that can be gathered for each lens: Manufacturer; Original format designed for; Type (Prime or Zoom or Specialty); Shape (Spherical or Anamorphic); Special identifiers: family name, model number, genealogy, attributes; Focal length; *f* or T stop calibration; Maximum aperture; Minimum aperture; Close focus distance (MOD) (imperial & metric); Manufacturer stated image circle; Year/decade of introduction; Country of origin; Number of iris blades; Number of glass elements; Number of glass groups; Number of aspherical lenses; Number of exotic glass elements; Type of coatings; Type of focus mechanism (cam or helical); Focus rotation; Iris rotation; Zoom rotation; Front diameter; Front filter thread diameter; Length (imperial & metric); Weight (imperial & metric); Any mounts available for the lens; Intelligent electronics; Lists of films shot; and any special notes. It is a wealth of information, much of which cannot be easily found elsewhere. The information recorded in the database doesn't just rely on rental house website statistics, but rather meticulously researched, corroborated, and vetted information.

Some of the more esoteric bits of technical information cataloged in the CCLDb may not be available for all lenses. For instance, not every manufacturer readily offers the number of glass elements, groups, aspheric surfaces, and/or exotic glass elements in their products. To some cinematographers, however, this is pertinent and valuable information. A common theory regarding the three-dimensionality perspective of lenses, those which present the world with more depth cues, surrounds the number of glass elements in the lens. The fewer the elements, the more dimensionality a lens has. The more elements, the more flat the lens' perspective may be. Although actual optical design theory proves this concept only to be *somewhat* valid, some cinematographers seek out optics based, primarily, on their number of elements. For a cinematographer looking for a high-performing, low-aberrant lens, information on the number of aspheric surfaces and exotic glass elements is very crucial to their decision making. As noted earlier, not every lens will have this particular information listed for it, but the Committee endeavors to make it available for as many of the lenses in the database as possible.

The ambitious goal of the CCLDb is to offer detailed technical data for any cinema-style lens that has ever been used on a film camera in the history of motion picture production.

The Database will reside on the ASC website as a free service to the community and will continue to be updated and refined on a constant basis.

Historical Lens Registry

A project proposed by one of the committee's founding members and co-chair currently on sabbatical, Michael McDonough, ASC, BSC, is to catalog specific lenses utilized on seminal films throughout the history of motion pictures – possibly down to the specific serial numbers. The goal is to identify what lenses were utilized on a project of cinematographic significance (starting with Academy Award nominees and winners as well as those films named on the ASC's list of top 100 photographed films of all time). The project has received early support from rental houses to "open their doors" to records of films they have been involved with. The project will seek to engage the involvement of film students and volunteers to track down the necessary archaeological data to attach to a particular optical device.

Image Circle Database

Another ancillary aspect of the Comprehensive Cine Lens Database is a catalog of lens image circles. This is a hotly debated subject as sensor sizes continue to not only grow but fall into random, non-standard sizes and cinematographers continue to question, 'will *this* lens cover *this* sensor?'

It is not an easy question to answer. Within a particular family of lenses, longer focal lengths may naturally project larger image circles that *may* happen to cover larger sensors than the lenses were originally designed for. The image circle size can change depending on focus distance setting, iris setting, and zoom (if applicable) setting. Within the design of a lens the center is always where the optics perform their best, and the optical designer must work very hard to maintain that performance (or a high percentage thereof) out to the edges of the image. Lenses, therefore, have what can be called the circle of good definition – the diameter of an image circle for which the lens was originally designed to cover. By the very nature of optics, there *may* be image-forming light that encompasses an area larger than this circle of good definition (called extra covering power), but the optical performance of the image may degrade in this additional area. Some cinematographers don't mind the degradation of image – in fact, for some artistic interpretations, it may even be *preferred*. For other cinematographers, the loss in image quality is unacceptable. These factors make defining what can be identified as the image circle an extraordinary complex issue.

The Lens Committee is investigating, through cooperation with Duclos Lenses (a company located in Chatsworth, California), a methodology of recording the *illumination circle* from the lens – purely the value (measured in stops relative to the center of the lens) of light that the lens is capable of projecting at a specified diameter. Each lens measured will need multiple reference points (multiple stops, focus and zoom positions) to be recorded in the Comprehensive Cine Lens Database.

This project is still in its very early stages, and full details are still being discussed.

Smart Lens Metadata

Since the origin of the Lens Committee, the investigation into the protocol, potential standardization, promotion, and further integration of lens metadata has been a primary goal. The original intention was to examine the various technological approaches and solutions, namely the Cooke /i and ARRI LDS systems, and to examine the potential for a uniform standard for the industry.

Internal lens metadata requires a computer chip and built-in encoders within the lens that transmit specific data to the camera: focus distance, iris setting, zoom focal length are the common pieces of information that are recorded per frame of recorded image. Further expansion on this data includes specific lens vignetting/shading and distortion data per stop, focal distance, and focal length at a per-frame resolution. This expansion of the metadata, coupled with software programming in the post suite, allows visual effects artists to "dial out" the shading and distortion, completely or partially, from the image to create "clean" effects and then re-apply the distortion and shading to whatever degree is artistically required. This form of extended metadata – currently available in the Zeiss CP.3 lenses and in the Cooke S7/i primes – eliminates the need to shoot distortion and shading tests in preproduction; a task that has beleaguered visual effects supervisors and camera assistants for many decades.

Since the initial discussions of this subject, the industry at large has spoken, and many other lens, camera, and software manufacturers have adopted the Cooke /i open-license system as their metadata of choice. Aaton, Andra, Angenieux, ARRI, Atmos, Avid, Birger Engineering, Black Magic Design, Canon, Cinematography Electronics, Cmotion, Codex, CW Sonderoptic, Element Technica, Fujifilm, Global Boom International, IB/E Optics, Mark Roberts Motion Control, Opitiek, Ovde, Panavision, Preston Cinema Systems, RED, Service Vision, Sony, The Foundry, The Pixel Farm, Transvideo, Vision Research – Ametek Materials Analysis Division and Zeiss have all signed on to become /i technology partners.

Currently, the focus for the subcommittee is to investigate the needs and desires of the post-production community, cinematographers, camera assistants and software designers regarding lens metadata: how they wish to utilize it, how it might best be of benefit to them, what new data can be recorded/included to be of aid. The committee's secondary goal is in educating these various disciplines in the industry about the technology and its possible applications. This effort has also joined forces with the MITC's Motion Imaging Workflow Committee Advanced Data and Metadata Management Subcommittee under the chair of Jesse Korosi as well as the Metadata Committee under chair David Stump, ASC.

Two other projects of the Lens Committee have grown in scope and focus to merit breaking off into their own subcommittees: smart lens metadata; filter classification and focus accuracy.

Filter Classification Subcommittee

Report by Lens Committee Co-Chair Jay Holben and Sub-committee Chair Matthew Duclos

The Filter Classification Subcommittee strives to quantify and qualify a variety of diffusion class motion picture filters. The motivation behind this mission is not only to further the available knowledge of current camera diffusion filter choices but also to catalog the same parameters in vintage filters as well.

By way of anecdotal research, it has been determined that most cinematographers choose their diffusion filters based on their own subjective testing and experience. Lens diffusion filters are a bit of a voodoo science, and many cinematographers only have the opportunity to test a select few for a specific project and then end up employing the filters that they're already familiar with on future projects. The exact mechanism of image manipulation is often not clear and generally comes down to highly subjective "taste" for a specific project's look. Very few cinematographers seem to have an intrinsic understanding of what the filters are doing, technically, to their image and descriptors of filters often fall into nebulous labels such as silky, smooth, creamy, soft, etc. There is an extraordinary wealth of filters from which to choose and crafting a more precise calibration system that clearly identifies the nature of image manipulation will allow the cinematographer to select their filter with more accurate application to their creative needs. Further, the ability to choose an alternate filter when the desired one is unavailable seems to be a complicated process requiring further subjective testing and a lot of guesswork.

There are three primary characteristics we'll investigate for our classification: halation, contrast, and resolution. As we see it, these are the three main aspects modified by means of diffusion filtration. The methods by which each characteristic is measured is unique to each filter and filter manufacturer, which will present its own challenges. The consistency and repeatability of the tests are paramount as we want to be able to confidently and accurately add new filters as they're released into the market in the future.

The proposed testing is two-fold. Firstly, an objective attribute measurement system that is purely agnostic of camera and lens to quantify the three parameters. Secondly, two subjective tests utilizing traditional photography and both human and computer analysis to measure the amount of alteration each filter makes to the three parameters listed above; one a series of technical photographs and another a series of more "cinematic" photographs to demonstrate the filter's attributes.

One of the most practical uses for this classification effort will be to identify the three characteristics with a firm metric. If measured and recorded accurately, this would allow cinematographers to investigate vintage diffusion filters that may no longer be available and match as close as possible to modern diffusion filters with similar characteristics.

The Subcommittee will endeavor to formulate an empirical testing methodology and classification system to objectively measure the image manipulation aspects of all currently available lens diffusion filters and classify them within a numerical system (proposed to be 0–100 in each category) in an effort to provide the cinematographer more precise information to inform their selection of available filtration. A particular theoretical filter might have a 25-contrast adjustment, 60 resolution adjustment, and 15 halation adjustment. If the cinematographer likes the contrast and halation factor of that filter but is unhappy with the amount of resolution loss, they need only seek out another filter that has the same contrast and halation rating, but a lower resolution rating. It provides a more technically accurate system of selecting specific filters for further testing based on objective and empirical data. The data will be offered to the individual manufactures, many of whom are participants of the Subcommittee, to label/identify their filters.

Current Subcommittee members include cinematographers, representatives, and technicians from Tiffen, Schneider and Formatt (three of the top diffusion filter manufacturers), lens manufacturers, rental houses, cinematographers and optical experts.

Focus Accuracy Subcommittee

A third subcommittee was formed based on a proposal presented by Howard Preston of Preston Cinema Systems for the investigation of manufacturer methodologies for calibrating and marking focus accuracy on lenses.

As imaging technology has improved, digital cinema cameras with high-resolution sensors of 4K or greater are now mainstream. Further, a recent trend for larger sensor cameras results in imagery with extremely shallow depth of field. Additionally, lens performance in sharpness and contrast have also significantly improved. All of these attributes contribute to a need for more precise control over focus to accurately and consistently achieve the requirements set by the cinematographer and director.

To achieve the high precision necessary in today's digital world a lens needs sufficient focus markings, typically between 20 and 40 markings; the opto-mechanical design of the lens must support accurate interpolation so that an accurate distance can be determined for any focus setting, not just on the specific engraved mark – but *between them* as well; the accuracy must be consistent from −20C to 40C and; the accuracy must be maintained over time and the heavy use found on set.

For a lens to accurately reproduce focus under any condition, its tolerances must be less than the minimum depth of field that the lens is capable of reproducing. Many high-end cinema lens manufacturers utilize modulation transfer function measurements in cooperation with 20m+ optical benches to engrave accurate focus marks. This allows a high degree of precision, which is required for today's super fast lenses. The faster the lens, the more accurate the focus marks need to be. Other manufacturers of lower-priced lenses often utilize less accurate methods. The mix of methods can make integration of smart follow focus systems more than a challenge and can make repeatable, actuate focus during production equally challenging.

The Subcommittee is currently formulating a questionnaire to submit to cinematographers, camera assistants, rental houses, visual effects artists and lens service technicians to find the needs, demands and expectations of professionals in the field to further determine how refined methodologies of improved focus accuracy from the manufacture's end might aid the industry at large.

Metadata Committee

Chair: David Stump, ASC
Vice-Chair: Jesse Korosi

It is now possible to record the positions of Shading Data, Distortion Grids, Focus, Iris, and Zoom as data embedded in the image stream. This has the potential to create enormous efficiencies in visual effects work in post-production, and the notion of automating the data process is gaining momentum in the Hollywood technical community.

Cooke's /i Technology enables film and digital cameras to automatically record key lens data for every frame shot and provide it to post-production teams digitally. Focal length, focus distance, and f-stop are digitally recorded for every frame, at any frame rate up to 285 fps, film or digital, and stored as metadata. Metadata is then passed through to post-production to improve VFX creation and DI calibration. CG artists can sync the /i lens data to the 3D camera data to produce a more natural looking 3D model of the shot significantly faster than using traditional manual tracking and match moving processes.

This improves efficiency in visual effects workflows by reducing the amount of time spent reverse engineering VFX plates. Cooke /i technology digitally records vital lens data frame-by-frame, all synced to Timecode, including focus setting, T stop, and depth-of-field. Using a Cinematography Electronics /i Lens Display Unit assistants can see a continuous remote readout of the precise focus setting, T stop and depth-of-field using Cinematography /i Lens Display Unit in conjunction with their Cinetape. Digital cinema cameras that are equipped include ARRI, RED, Silicon Imaging, Sony, and Panasonic. Lenses incorporating Cooke's /i "Intelligent" technology are Cooke, Zeiss, Fujinon, and certain Leica, Sony, RED, and Panavision lenses.

How this data is passed along through each department and ensuring it doesn't get lost along the way is a vital step in each job's workflow. Depending on the software used, or the file format delivered to VFX, this metadata could easily be lost between departments. However, if handled correctly, this new update from Cooke will provide many efficiencies for post-production. ARRI LDS continues to evolve as well with the new LDS2 update, providing metadata from lenses alongside image data.

The Advanced Data Management Subcommittee of MITC, outside of data management, also has a keen focus on metadata. They believe that centralizing metadata from various sources for each job, to provide information for any department that needs it, providing analytics, and or to help automate specific tasks with media connected is where the industry is headed. However currently, all cameras that are used on set, even when talking about the simplest forms of metadata, are all labeling their columns different. Therefore, trying to centralize this information currently requires custom scripts or software, which most people do not have available to them. Even for editors that have metadata going into their nonlinear editing application for reference, cannot simply have a preset column layout for metadata, considering where the data resides will change for each camera, as well as for each post facility that handled dailies if multiple units had different facilities processing dailies.

What the ASC ADM committee would like to see is a short list of agreed upon columns, all with the same naming convention used between each camera manufacturer, that software vendors will ensure tracks through into ALE's, CSV's or any other file making it much easier to ensure this data does not get lost.

Digital Intermediate Committee

Co-Chair: David Reisner
Co-Chair: Joshua Pines
Report contributor: Jim Houston

The DI Committee's most significant output has been the ASC CDL (American Society of Cinematographers Color Decision List) – used in the production and post process of the substantial majority of all feature movies and scripted series television shows, and essentially all VFX, worldwide. It continues to be implemented nearly universally and is now supported in the Adobe production suite.

For those reasons, we want to keep the ASC CDL stable and only pursue changes very cautiously. The DI Committee continues to evaluate if and how the ASC CDL transforms might be modified to better serve the requirements of newer production workflows, particularly ACES and HDR production.

We occasionally hear reports of problems using Sat(). Investigation so far suggests these issues may occur with the Rec. 2020 color space, wide color gamut digital imagers, ACES, and some solid-state lighting, perhaps due to ACES containing a virtual negative primary, or issues with IDT creation. In some cases, newer LED lighting equipment and digital imagers may cause issues that are exacerbated by the Sat() function (probably by making spikes in the light source/imager combined response more visible as color artifacts).

To resolve this, we need concrete examples – hopefully, combinations of camera output, finished material that shows the problem, and a characterization of the equipment and lighting used (sent to the e-mails at the bottom of this section). Then we can see if the problem can be mitigated with different saturation mathematics tailored for these wider color gamut working spaces. Since we have a large installed base, if we find a problem, we will likely retain the existing Sat() function unchanged and add a Sat2() function that behaves well in these cases.

There are few minor additions to the ASC CDL metadata pending to support organization of sets of color correction collections, and more strongly use existing features to document viewing transforms and possibly viewing environments.

When we have resolved these issues, we will move expeditiously to submit the revised document to SMPTE for release of a SMPTE Registered Disclosure Document (RDD), or other form. (While the committee has members with a lot of SMPTE Standards experience, volunteer time is sometimes in short supply. Hint: If some company has funds or a volunteer has time for some practical lifting and carrying, we would be pleased to discuss.)

The DI Committee is the ASC MITC's primary resource on post-production and the practical understanding and application of color science. We will continue to work actively with the other MITC Committees on color correction strategies, specifically targeting HDR workflows, wide color gamuts, researching and documenting current HDR workflow "best practices," and recommending procedures for color grading including surround lighting specifications.

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

Motion Imaging Workflow Committee

Chair: Greg Ciaccio
Vice-Chair: Tim Kang
Vice-Chair: Chris Clark
Vice-Chair: Jesse Korosi

2018 was a significant year for Motion Imaging Workflow, as we added two noteworthy subgroups and formalized our ACESnext efforts. Our organizational structure is shown below:

- ACESnext Working Group
- Solid State Lighting Subcommittee
- Advanced Data Management Subcommittee

Since workflows connect almost every facet of our MITC Committees, additional subgroups may be formed to help ensure tight integration needed in our industry as we move from the linear processes of yesterday to more fluid parallel workflows of today and tomorrow.

ACESnext Working Group

Chair: Greg Ciaccio
Vice-Chair: Chris Clark

For the last several years, the ASC MITC Motion Imaging Workflow Committee (Workflow) has continued to focus on helping to educate and guide industry professionals on ACES benefits in parallel with efforts by the Academy of Motion Picture Arts and Sciences' Science and Technology Council (Sci-Tech).

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

Since its introduction, a significant number of productions have used ACES. A fairly comprehensive list can be found here: http://www.imdb.com/search/title?colors=aces

> A clear definition of ACES is posted on the Academy's website:
> 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. In addition to the creative benefits, ACES addresses and solves a number of significant production, post-production and archiving problems that have arisen with the increasing variety of digital cameras and formats in use, as well as the surge in the number of productions that rely on worldwide collaboration using shared digital image files.

A forum has been established to enable global ACES discussion and collaboration and has been instrumental in functioning as a central repository for our industry. This forum, ACES Central, can be found here: www.acescentral.com. The ASC's site includes a link to ACES Central. https://theasc.com/asc/committees/aces.

Our Workflow Committee is contributing to the development of the ACESnext roadmap by gathering feedback on ACES experiences among the ASC Membership. An ACES survey was sent to the ASC Membership, and feedback was shared with the SciTech Council's ACES team.

As ACES user experiences are shared within our industry, the practical benefits are being realized. A series of case study interviews will be created and shared via the ASC website, offering unique perspectives on ACES benefits.

The MITC ACESnext Working Group will also help to create ACES workflow support documentation adding to the AMPAS Sci-Tech Council's Quick Start docs on the ACES Central site. Our first effort will be devoted to the Cinematographer in the form of a Quick Start guide.

One recent addition to the Sci-Tech Council's ACES Virtual Working Groups (VWG) aims to preserve critical imaging metadata, and so the ACESclip

VWG was launched, helmed by Chris Clark, our MITC Workflow vice-chair. ACESclip metadata will be a mechanism to hold ASC CDLs or other Look Transforms associated with a camera clip – an essential aspect of capturing and maintaining a cinematographer's creative intent.

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

More information regarding ACES is available at http://ACESCentral.com.

Lastly, it has become clear that new standardized evaluation material (StEM) is needed, as the original StEM media from 2003 was created long before newer technological innovations such as HDR and Wide Color Gamut were in common use. Efforts are being organized at the time of this writing to produce updated motion imagery in both main image essence data as well as metadata to better leverage modern tools and workflows.

Solid State Lighting Subcommittee (SSL)

Chair: Tim Kang

On March 13, 2019, the ASC MITC's Workflow committee convened its inaugural Solid State Lighting Subcommittee meeting to gauge and garner interest from key members of the creative and scientific motion picture community on how to improve LED lighting technology.

11 prominent LED manufacturers, 2 post houses, 2 camera manufacturers, a camera house, 2 gel/filter manufacturers, 6 cinematographers, 2 color scientists, 2 colorists, 1 director, 1 camera & lighting retail facility, and 1 set lighting technician participated in a spirited conversation throughout the proceedings.

Passions run high due to interest in this topic of tackling LED lighting challenges as an industry. The breadth of representation testifies to the power of the ASC MITC to inspire and effect real change in our industry.

We will meet again after CineGear to choose our first major task to tackle in the form of an event or test. The inaugural meeting already discussed the following issues as possible future subcommittee tasks:

- Narrowband LEDs do not sufficiently create satisfactory saturated color results for object rendering within photography.
- What spectrum should LED manufacturers should strive to hit CCT, especially in the daylight range?
- How can manufacturers learn to understand and utilize SSI as a confidence metric?
- How can manufacturers learn to understand the interaction between LED spectrum, object reflection response, and camera sensitivity response?
- Should a standardized spectrum exist to define saturated colors that all cameras can equally see?
- How can the committee organize efforts to educate the public (i.e., lighting technicians, cinematographers, filmmakers at large, etc.) about the merits and issues of different metrics like CRI, TM-30, TLCI, etc.?
- Should LED manufacturers agree to adopt or modify ESTA standards dealing with lighting control and conform them towards cinema workflow needs? Would this group function to provide these standards?
- What usable, physical, daylight standard should LED manufacturers use to define daylight?
- How can the committee make technological concepts discussed and explored in this committee relevant to production?

Here is the Inaugural Meeting Agenda

1) Welcoming Remarks: Tim S. Kang (cinematographer, Workflow vice chair)
2) SSL Mission Statement
3) Introduction of MITC & Workflow Committee: Greg Ciaccio, Workflow chair
4) SSL Workflow Case Study Presentation: Sandra Valde, cinematographer
5) Discussion:
    a) Color Scientists
    b) Camera Manufacturers
    c) Cinematographers
    d) LED Manufacturers
6) Past work and currently available tools:
    a) AMPAS SSL work & SSI
    b) Scene-Referred Scopes
        i.) Brad Dickson
    a) CIE 1931 & other empirical control schemes
7) Invitation to Participate
    a) Possible Roles
        i.) Chair
        ii.) Co-chair
        iii.) Secretary
        iv.) Event coordinator
    b) Possible activities & events

Background

The foundational history of motion picture and stills industries developed its analog and digital

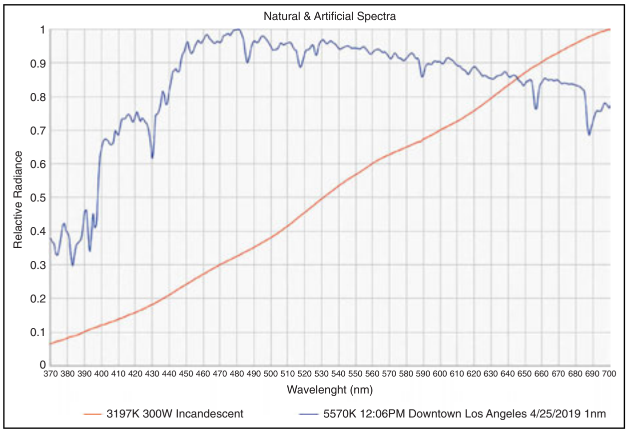


FIGURE 1. Spectral power distributions used for typical photographic illuminants throughout history.

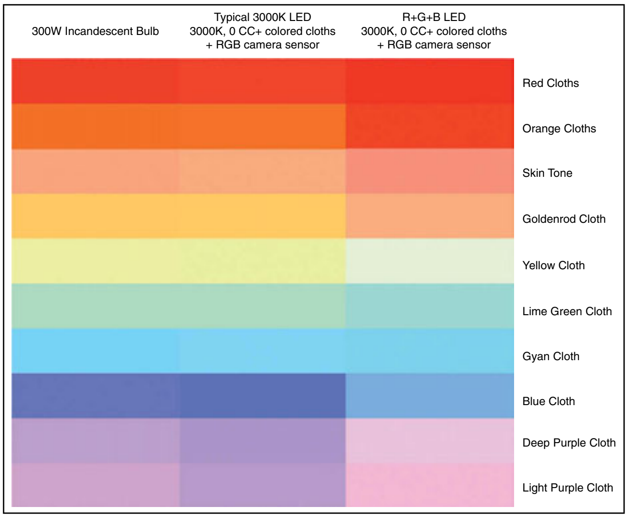


FIGURE 3. Typical cloth dye color responses under different illuminants with the same CCT and duv measurements photographed by the same camera.

photographic cameras to capture lights that had relatively smooth and even visible spectrum at different color temperatures (**Fig. 1**).

SSL illuminants, i.e., LED-based lights, have now proliferated set lighting kits to the point where they've become indelible and ubiquitous tools in motion picture and stills photography lighting.

Problems

However, the design of these SSL lights generally derives from the consumer market industry that does not have a requirement for photographic quality. The industry has become a wild west of illuminant design practices that cause irreversible consequences in the photographic color workflow:

- Most of the lighting color control gels, metering tools, and quality metrics that cinematographers have previously employed no longer work for the current state of SSL lighting exposure and color control.
- For example, an RGB LED illuminant (**Fig. 2**) common within the lighting industry can meter correctly for color temp and tint, but real-life objects (especially faces) will show up incorrectly in camera with no possible fix in post (**Fig. 3**). Colors can change hues, or incorrectly saturate, and blend irreversibly.

Instead of addressing these and the many other unstated deficiencies head-on, the following practices posed as novel solutions by manufacturers may not solve the issue:

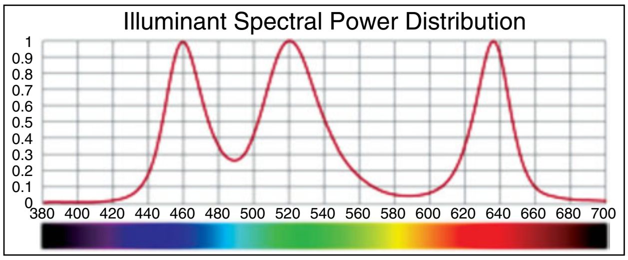


FIGURE 2. Typical "RGB" LED illuminant spectral power distributions.

- Matching gel number or CIE 1931 chromaticities using narrow band LED illuminants.
- Color temperature and tint operations that don't actually produce expected results in camera.
- Advertise spurious color science claims that end up causing irreversible problems in post-production.

These practices that mask these inherent color spectrum deficiency issues result in the following irreparable problems downstream in the motion imaging color workflow:

- Incorrect makeup, wardrobe, and set design decisions made due to LED illuminants not matching illuminants used in final photography
- Wasted hours and time on set trying to create colors with LED illuminants that will never render correctly on camera
- Wasted hours in post-finishing to correct LED-related color issues
- Reshoots done for shots that had irreparable LED color issues
- Inability to execute cinematographer's intent

Proposed Activity

The SSL Subcommittee would like to engage the motion picture production and post-production imaging community and LED lighting manufacturers to identify these fundamental and downstream problems and to create a consensus of best practice recommendations for the lighting industry to address these problems.

These activities will eventually include (among others):

- Providing a "safe harbor" context for lighting manufacturers, cinematographers, camera manufacturers, and post-production technicians to frankly and constructively discuss what problems exist, what metric standards to meet for different lighting parameters (white light spectrum standards, hue, +/− green correction, etc.), and any other unforeseen SSL related issues

- Devising and hosting educational events for core groups in the industry to understand these issues and the relevant ramifications for their craft (ASC Membership, cinematography guild, set lighting technicians, art directors, hair/makeup, editors, colorists, producers, and directors).
- Providing foundational education for subcommittee participants to tackle these issues.
- Promoting the understanding and adoption of Spectrum Similarity Index (SSI), a new AMPAS industry metric as a vital component to improving LED illumination quality.
- Conducting technical tests & activities to assess and address these issues.

Advanced Data Management Subcommittee (ADM)

Chair: Jesse Korosi

An Introduction to Our Data Management Focus

Ensuring proper backups with validation to confirm the integrity of a production's negative is of utmost importance. In today's modern age of filmmaking, there are many workflows and processes in place for file backup that change job to job, based on the software and or talent operating the position. No real standard or best practices are in place from production to post when it comes to checking file integrity.

Some people managing the production's digital assets will use a checksum during a file copy, some will not. There are many forms of checksums and where they are placed is commonly different depending on the person doing the work. The wrapping and formatting of these hash files are often different job to job and, if any copies are made, there is no standardized or common process that is followed by post-production. If checksums are made during post-production, is anyone actually comparing these against the original hash? Or are they comparing them against their own hashes created only in post-production?

A002R2EC_20190107_080228_0001.mhl

A002R2EC	The name of the folder that is covered by the ASC-MHL file
20190107	Year-Month-Day -Date of creation
080228	Hour Minute Second -Time of creation
0001	Generation Number A 4 digit sequential number identifying how many copies of the specified folder have been made.

FIGURE 4. File naming convention.

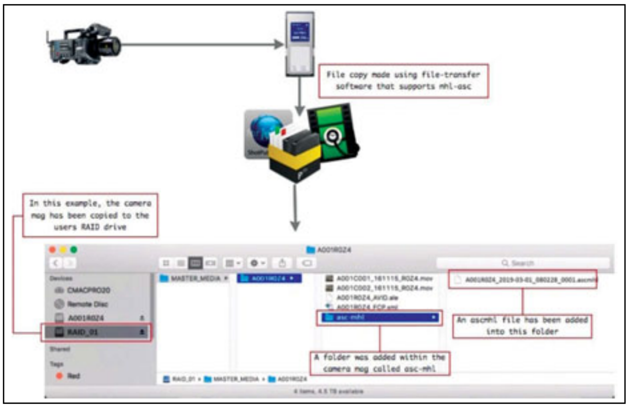


FIGURE 5. Original file copy of example.

Creating checksums adds time to the process of copying files to varying degrees depending on the chosen method. We understand that some productions may choose to go with XXHash, or SHA-1, some MD5, and others C4. This is a flexibility/decision we feel should be left to individual productions to choose but are proposing placing these in one standardized manifest format, the ASC MHL. This would also be placed within a standard folder directly within the mag, to ensure this critical metadata stays with the camera master files during file copies.

Checksums are often performed on set by the person on point for the initial download from the camera cards. However, by the time this media is ready to be LTO'd, or archived to the cloud in post-production, there is no easy way to know just how many times these files have been copied since the initial download. Also, there is no easy way to tell if there has been damage, or when that damage took place.

We are proposing that the ASC MHL create a chain of custody by tracking every copy made between the media's initial download on set all the way through to final archival in an XML format that is human readable (**Figs. 4–6**).

ASC MHL was designed with your existing file workflows in mind and offers the ability to attach your existing scripts and tools.

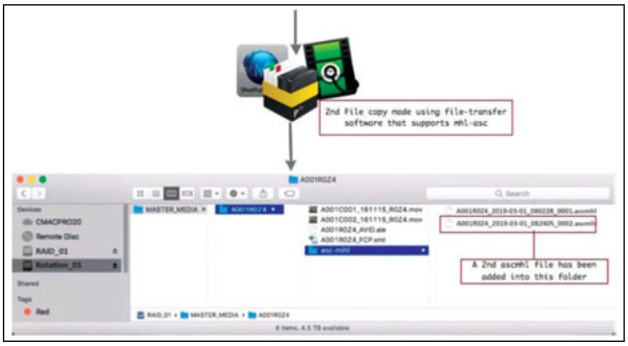


FIGURE 6. Second file copy example.

ASC MHL Current Status and Next Actions

We have created the first draft of a white paper outlining workflow examples and scenarios for how the code would be presented in its XML format, depending on the situation. This document has been distributed to key DIT's and post-production facilities to get feedback.

Once we agree on all of the vital information to be included within the checksum, we will begin working on implementation plans with Pomfort, a key committee participant.

Next Generation Cinema Display Committee

Co-Chair: Eric Rodli
Co-Chair: Joachim Zell
Co-Chair: Wendy Aylsworth

The specific mission of the NGCD Committee remains linked to the overall mission of MITC, in that our committee supports the ASC's overarching goal that the filmmaker's creative intent with his or her image is ultimately consistently displayed accurately in theatrical exhibition as well as in the home. A specific focus of our committee is to influence the commercialization of new cinema display technologies that enhance the theatergoing experience to help support a vibrant exhibition industry in the face of dramatic improvements in the home theater experience.

There have been a number of advancements in cinema projection technology over recent years, most recently centered on RGB laser projection, which our committee continues to monitor. In particular, several companies have been demonstrating projection technologies with much higher dynamic range and brightness than previously possible with mainstream projection systems, with the exception of the very high-end systems from Dolby and IMAX. One very interesting example is the new "light steering technology" being developed by Barco.

A particular focus of the Next Generation Cinema Display Committee over the last 12 months has been understanding the implications of the emerging direct-view emissive displays that are in the initial stages of commercialization. This technology, which is different than that employed in consumer displays, has demonstrated dynamic range and luminance capabilities that exceed the current state-of-the-art in RGB laser projection technologies.

The NGCD Committee, in conjunction with the SSIMWave Working Group, recently organized a demonstration for NGCD and MITC members and guests on the Samsung Onyx emissive display at Pacific Theater's Winnetka Cinema, using content provided by Bill Bennett, ASC and Curtis Clark, ASC. Content was specifically remastered for this display by Roundabout Entertainment post-production. Sony has also demonstrated a theatrical emissive display technology.

The NGCD Committee sees the promise of direct-view cinema displays. The emissive display technologies hold great promise when it comes to total luminance and contrast ratio. But, as was very clearly explained by both Bennett and Clark, even "HDR" content needs to be re-timed in order to take advantage of these display's capabilities while also maintaining the original creative intent.

In order to help studios, exhibitors and ultimately cinema display vendors to continue to invest in enhanced cinema display technologies and accelerate ultimate commercialization to improve the theatrical experience, the NGCD Committee believes it is time to investigate the creation of a "StEM 2" HDR Standard Evaluation Material to help influence future distribution and display standards. Major advances in technology since the original StEM was produced in 2004 have created a need for a new version that addresses new demands. The original StEM has served the industry very well, and the NGCD Committee and the MITC hope to recreate the very successful partnership between the ASC, DCI, and an army of industry volunteers that created it. Due to the significant advances in technology since 2004, some aspects of this next version may be more complex and would likely benefit from involvement of a wider range of vendors and participants. In particular, we believe the industry needs a high-production-value source material that is designed to evaluate HDR and high brightness images but will also likely include wider color gamut and possibly variable frame rates as key parameters. Since these same image parameters are impacting both consumer and professional monitors, MITC has recently formed a special working group comprised of the NGCD, UHD TV, and the Motion Imaging Workflow committees to investigate and hopefully lead the creation of such footage. The initial meeting to review the original StEM and discuss StEM 2 was hosted recently by EFILM. A set of active ASC Members are supporting this effort, as they did the production of the original StEM.

Finally, and saving the best for last, MITC and the NGCD Committee are very pleased to announce that Wendy Aylsworth has graciously joined the NGCD as co-chair. She brings enormous relevant experience from her time at Warner Bros. as well as chair of SMPTE DC28 and president of SMPTE.

Professional Display Committee

Co-Chair: Gary Mandle
Co-Chair: Jim Fancher

The ASC MITC Professional Display Committee has been reviewing technology changes in the area of master reference monitors. In particular the reversal from OLED back to LCD based designs. This has opened the door to more monitor manufacturers and a larger selection of models than in previous years. The committee decided that it might be helpful to the Membership if a comparison could be made in a controlled environment using known test patterns and images that would exercise the displays at levels required for absolute reference applications.

In the middle of January, the Chair of the Professional Display Committee suggested we should partner with manufacturers which would allow the Membership to compare the breadth of reference monitors models that are currently available.

The committee put together a test plan and list of invited manufacturers for a subjective side by side test. The requirements for invitation was limited to displays intended and sold as master reference monitors between 24 and 32 in. diagonal. Invitations were sent to Canon, EZIO, Flanders Scientific, iKan, Ikegami, JVC-Kenwood, Marshall, Panasonic, Postium, Sony, and TVLogic. Of those, iKan, Marshall, and Panasonic declined.

Displays that were used in the test (**Fig. 7**) included:
Canon DP-V2411 and DP-V2420
EZIO CG-3145
Flanders Scientific XM-310K and XM-311K
Ikegami HQLM-3125X
JVC Kenwood DT-U31PRO and DT-U31PRO+
Postium OBM-X310 and OBM-U310
Sony BVM-HX310
TVLogic LUM 313G and LUM 318G

The committee solicited test materials with responses from Sony Pictures, Universal Pictures, Image Essence, and ColorFront, who provided a mixture of moving content as well as static test images. This resulted in a 40-minute clip that tested everything from uniformity to color accuracy, to HDR clipping, black performance, and test monitor signal processing accuracy.

AJA agreed to provide terminal equipment including a KUMO 64 × 64 router and control which guaranteed that each monitor had its own independent source. Also included was an AJA HDR Image Analyzer which was used to confirm the levels and quality of the images sent to the test displays.

ARRI provided an ARRI ALEXA LF camera, lighting and diorama which was used as a live source.

Source material was played out using a ColorFront Konverter system and server with corresponding signal quality monitoring, and at each hour, the camera was switched to all of the monitors for live comparison. Also provided was a Sony BVM X300 OLED reference monitor as an absolute reference.

All source material was delivered to the displays as quad 3G (SMPTE ST 424) 12 bit 4:4:4 RGB square division signal format. Image format was 4096 × 2160 resolution at D65 white point, 2.6 or PQ (SMPTE ST2084) OOTF.

Preparations started in early January 2019 and concluded with the system detail and testing at ColorFront's Santa Monica facility on 28 February. The ASC staff prepared the room with drapery, table, and podium for placing all the monitors at eye level for viewer comparison. They also prepared a separate area for the camera, lighting, and diorama.

Setup started on the morning of 1 March at the ASC Clubhouse (**Fig. 8**) and completed at around noon that same day. The doors opened at 1:00 p.m. for member viewing. Approximately 100 people attended between 1:00 p.m. and 7:00 p.m. to view the displays with the majority arriving between 2:00 and 4:00 p.m. The test environment was kept dark and resulted in

FIGURE 7. Presentation of the monitor lineup. Monitor participant entries. The lineup was displayed in alphabetical order from left to right. Participant manufacturers were allowed two samples with one displayed on the upper level and one on the lower level.

FIGURE 8. Vendors finalizing setups. Vendors putting the last touches on their models and confirming that they have correctly aligned their entry.

a blind test situation where the viewer couldn't initially tell the manufacturer or model of the displays. Labels were provided for each display, but required the viewer to use their cellphone as a flashlight to read them.

In the main meeting area, we posted a running presentation which described what to look for with some of the test slides and gave the monitor manufacturers a place to talk about the models they were showing. This was kept separate from the test area and no verbal presentations were allowed.

There were many viewer comments and observations on different models, depending on the type of content shown on the displays. Artifacts or errors could be viewed on each monitor at some point during the test. All of the monitors shown used LCD technologies. No OLED monitors were shown in this size other than the reference model, for the simple reason that OLED panels in this size and designed for this application are no longer being manufactured. All of the models shown were available for purchase at the time of the meeting. No prototypes or concept designs were allowed. There was a significant performance difference between models using luminance modulators and models that used local dimming. Local dimming technologies demonstrated a lack of contrast and typically had elevated black levels with loss of black details. The luminance modulated models showed black levels equal or almost equal to the OLED reference with matching black detail. All models, including the OLED showed some off-axis differences. One item of note was that the OLED showed a magenta shift while the luminance modulated models showed only a luminance drop with no color shift. However, the change in picture would start at a lower horizontal angle on the LCD than on the OLED. Some monitors did show errors in picture content. One test used a zone plate test pattern, and several monitors showed significant aliasing. Some ramp tests showed quantization errors on displays even though they did claim to use 10-bit panels. Other models showed artifacts (rainbowing) around highlights. It was agreed that this new luminance modulator technology was a good replacement for RGB OLED, and the consensus was that the tests were valid and showed a good test of each monitor's performance.

Due to viewer responses, the committee has started working on two new projects. The next project is to perform a similar test and demonstration using displays offered for on-set monitoring. We will only invite/show models from 17 to 27 in. diagonal size and sold into "On set" applications. The second project is intended to be in partnership with the Hollywood Professional Alliance and will look into the options of dual display solutions for post-production.

UHDTV Committee

Chair: Don Eklund
Vice-Chair: Bill Mandel

With each passing year since UHD HDR motion picture releases have become available, we have seen increased use of the contrast and color palette made possible by HDR displays and formats. For the consumer to reproduce a close approximation of the image seen by the colorist they must ensure that the television and the signal path have been optimally configured. Further to this, the room lighting must be set appropriately so as not to mask information in the deepest shadows of the image. The UHDTV committee held workshops over the past year, specifically to explore the impact of ambient light on consumer TV HDR reproduction. With the help of industry experts, a controlled environment and a set of reference images, data was collected which showed that different real-world scenes/images required different compensation be applied in order to give a result aesthetically similar to the image that would be seen in a color grading suite. The results of this study have been shared with several TV manufacturers with the intent of informing the development or refinement of future TV light compensation features.

Consumer TVs continue to be sold with multiple picture adjustment settings that need to be understood in order to achieve the closest possible approximation of a 'reference' picture. Organizations like the UHD Alliance (UHDA) which seek to maximize the quality of the consumer viewing experience are actively exploring methods to reduce complexity and model-specific knowledge that a consumer needs to reproduce the intended picture. Sony Pictures has made available a test clip which the reader can use to verify correct picture decoding here: https://spetechdev.cimediacloud.com/r/hFFhpAXNde5Y

Emissive screens, which can be constructed in various dimensions, are producing extraordinary pictures in auditorium environments. Through experimentation, we can easily see that while this type of technology produces outstanding results, particular care must be taken in two respects. First, motion judder becomes proportionally visible and increasingly objectionable as a result of the dramatically higher contrast produced by an emissive display. While consumer TVs have similar contrast characteristic, the wide viewing angle made possible by a large screen means that panning shots presented at 24 fps require extra care or alternative technical solutions must be used to avoid a jarring distraction when pans occur that are otherwise acceptable on conventional cinema screens. The second area of concern relates to broad areas of the image at high brightness levels.

Emissive screen technology does not typically have limitations on what percentage of the screen can achieve a given luminance value. This differs from the behavior of consumer TV's and most grade 1 monitors where various design factors necessarily limit full screen light output versus the peak output of a smaller percentage of the screen. When reproducing content graded on a power limited desktop display on an emissive auditorium screen, the viewer may become uncomfortable when a scene where the luminous energy presented is more than an order of magnitude higher than during mastering. The state of the viewers light adaptation based on the APL of the preceding scene should also be considered.

The UHDTV committee looks forward to further exploration of image reproduction and viewing condition compensation, and we would like to thank all those who have generously contributed their time and expertise.

Input to the Committee is welcome, provided that it can be shared on a non-confidential basis. Contact asc-uhdtv@d-cinema.us.

Advanced Imaging Committee

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

Common Useful Color Matching Functions

The use of CIE 1931 x y chromaticities implies the 2-degree x_bar, y_bar, z_bar Color Matching Functions (CMFs) from CIE 1931 (**Fig. 9**). There exists a similar but different set of CMFs from the CIE 1964 "10-degree Supplementary Standard Observer." There also exists a Vos/Judd 1970 adjusted 2-degree set of CMFs.

Note the high variability near some of the more sensitive wavelengths. These variations indicate that pure monochromatic spectra (e.g., lasers) near these wavelengths will yield substantial variations in chromaticities as determined utilizing each of these various color matching functions. Another way to think about this is that the spectrum locus is inherently imprecise.

This has implications relative to color gamuts defined using x y chromaticities on the CIE 1931 spectrum locus (e.g., BT.2100-2 Table 2, as originally specified in BT.2020), as well as for color gamuts defined beyond the spectrum locus (e.g., ACES AP0 as specified in SMPTE ST 2065).

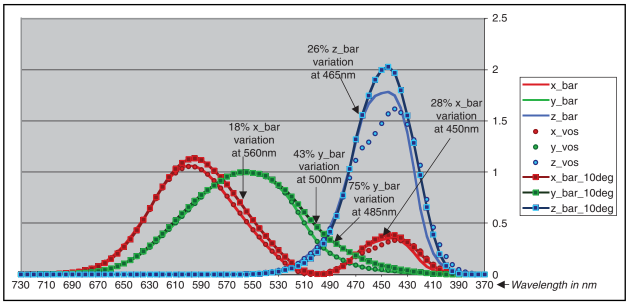


FIGURE 9. Several x_bar, y_bar, z_bar Color Matching Functions for 2-degree CIE1931, for 2-degree Vos/Judd 1970, and for 10-degree CIE1964. Reference: Wyszecki and Stiles, Color Science, 2nd Edition, 1982.

Defining Gamuts Without CMFs

However, it should be noted that BT.2100-2 Table 2 has a second definition that does not use CIE 1931 chromaticities. In this second definition, the primaries are defined using monochromatic wavelengths at 630nm, 532nm, and 467nm, as shown in BT.2100-2 Table 2 in the column entitled "Optical spectrum (informative)". The whitepoint is also spectrally defined as D65 ISO 11664-2:2007. BT.2100-2 Table 2 primaries and whitepoint are thereby (informatively) specified without utilizing ***any*** color matching functions.

It is potentially useful to consider concatenating definitions of primaries onto this BT.2020-2 Table 2 definition. For example, ACES AP0 primaries could have a new definition utilizing a normalized matrix applied to BT.2100-2's primary wavelength and whitepoint spectrum specification. A matrix is a linear operator that can be applied to monochromatic wavelengths to define primaries that are independent of color matching functions. This could be done initially using CIE 1931 chromaticities to determine the appropriate matrix. For example, using 630nm, 532nm, 467nm, at a spectrally-defined D60 whitepoint, the matrix would be as follows:

$$\text{Red\_AP0} = .6847914 * r + .1514042 * g + .1638024 * b$$
$$\text{Grn\_AP0} = .0459818 * r + .8597984 * g + .0942223 * b$$
$$\text{Blu\_AP0} = 0.0 * r + .0277513 * g + .9722461 * b$$

where r is at 630nm, g is at 532nm, b is at 467nm and r=g=b=D60 is spectrally-defined

Note that this matrix has all positive terms.

We could thus define a new variant of ACES AP0 that is independent of Color Matching Functions. However, as was mentioned above, the variations in useful CMFs imply a spectrum locus that is inherently imprecise. Perhaps a better description is that each set of CMF's comes with its own unique spectrum locus. Therefore, even though a matrix plus monochromatic primaries is a precise definition, any CMFs will see those primaries on various different spectrum loci (corresponding to each such set of CMFs).

Let's consider how a spectrum locus is determined. Given a set of CMFs, a single monochromatic wavelength is swept across all visible wavelengths (typically from 370nm to 730nm). The CMFs have three values, X, Y, and Z at each such wavelength. When such values are normalized such that x = X / (X+Y+Z) and y = Y / (X+Y+Z), the resulting x and y are the chromaticities of the spectrum locus.

It is not the wavelength energies that vary, it is the CMFs. The variations in CMFs lead to the variations in chromaticities, which chromaticities are specific to that set of CMFs.

Making Use of These Distinctions

BT.2100-2 Table 2 provides dual definitions for red, green, and blue color primaries and a D65 whitepoint. There are CIE 1931 chromaticity definitions. However, there are also "Optical spectrum (informative) definitions at 630nm, 532nm, and 467nm, with a D65 spectrally defined whitepoint as ISO 11664-2:2007.

This is the first television system to be defined in this way. Although the emphasis is on the CIE 1931 chromaticities, the spectral definitions provide a new and different perspective.

Let's consider some ways to put the variability of the CMFs into context. An example was given above of using CIE 1931 to define a matrix, that could be applied to the monochromatic wavelengths and spectral whitepoint to yield a definition of new hypothetical ACES AP0 primaries defined without using CMF's. However, the matrix was defined using CIE 1931, so CMF's were used implicitly in this example. This suggests some alternative approaches. One such approach might be to use various matrices, corresponding to various CMF's, while holding the 630nm, 532nm, and 467nm and spectrally-defined D65 constant. Were we to define a new variant of ACES AP0 this way, the primaries would vary due to varying the matrix, corresponding to applying primaries in multiple CMFs.

In practice, if we were doing color processing for an OLED display using ACES AP0, we could use the hypothetical version of ACES AP0 defined using a matrix corresponding to the Voss/Judd CMFs.

Using various CMF's boils down to using multiple corresponding matrices for various steps. CMFs are not needed when spectra match. For example, if all displays were using lasers at 630nm, 532nm, and 467nm, no CMFs are required to go from one display to another. However, cameras capture with sensing spectra that is typically unique to each make and model of camera. Also, displays have a wide variety of spectral emission primaries corresponding to the specific display or projector and the technology being used.

For all circumstances where sensing spectra vary and or emission spectra vary, CMFs are fundamental. Such variation is the norm. Given this, the specification of primaries that do not vary with CMF's is interesting to consider. However, in practice, finding that there are substantial variations in CMFs and that each such set of CMFs has its applicable use case, the ubiquitous specification of CIE 1931 CMFs is an oversimplification for today's moving image infrastructure.

The example provided earlier relied upon implicit CIE 1931 CMFs for the matrix to the hypothetical ACES AP0. Varying the matrix is equivalent to varying CMFs. Color primaries are used with corresponding matrices, and vice versa. Thus, the need for a broader perspective with respect to CMFs beyond CIE 1931 implies more variability in matrices used for motion imaging.

Locking down color primaries independently of CMFs does not avoid these issues. However, having such a definition in BT.2100 Table 2 provides new perspectives that may lead to new ways of architecting image processing.

Computational Cinematography/Plenoptic Committee

Co-Chair: Pete Ludé
Co-Chair: David Reisner

With significant increases in computational power, large-scale cloud data storage, and high-speed data communications, new methods of digital imaging have become possible. These techniques allow new production workflows and new types of exhibition experiences, including immersive forms. We see the early fruits of computational imaging in the imaging capabilities of multi-lens cellphones, but for cinematic and immersive work, production in these forms requires collecting large amounts of data, including types of information that we have not traditionally gathered in making movies. And a vastly larger amount of image composition and shaping can and must be done in postproduction.

The development of these plenoptic cameras and the capabilities of the subsequent workflows requires the full collaboration of technologists, creatives, equipment manufacturers, and network distribution operators and a full ecosystem incorporating capture, editorial, distribution, and display. ASC cinematographers and the ASC MITC are uniquely well suited to provide the artist and movie/TV side of the input to this industry-in-development.

One of the challenges in plenoptic and light field imaging is how to abstract, communicate, and edit the massive data sets. The industry group IDEA – the Immersive Digital Experiences Alliance (announced at NAB 2019) – was formed by key industry players CableLabs, Charter Communications, Light Field Lab, OTOY, and Visby to address some of these issues. IDEA is a very high-powered group and has hit the ground running. See https://immersivealliance.org/ and Pete Ludé's report on the Light Field Imaging Ecosystem elsewhere in this issue.

Joint Technology Committee on Virtual Production

Chair: David Morin
Co-Chair: John Scheele

Over the period since the last SMPTE report, the Joint Committee on Virtual Production of the ASC Motion Imaging Technology Council continued its activities around the broadening use of real time computer graphics on set.

The Virtual Production Track at FMX 2019

A series of seven presentations on virtual production were showcased at FMX in Stuttgart, Germany on 1 May 2019 (**Fig. 10**).

For the eighth year in a row, Virtual Production committee chair David Morin curated the "Virtual Production Track" at FMX2019 in Stuttgart, Germany. The track showcased seven presentations that took place on 1 May 2019. The presentations covered the use of previsualization and virtual production in movies such as *The Meg, Aquaman, Mad Max Fury Road, X-Men Dark Phoenix, Welcome to Marwen, Avengers: Infinity War,* and *Avengers: End Game,* along with the demonstration of immersive game-engine based virtual production technologies for projects such as the *Troll* realtime raytracing short film and the "Cine Tracer" app for cinematographers. You can see more details on the program at https://fmx.de/program2019/list?t=884

Future Activities

The Virtual Production Committee has one meeting left in the cycle of 12 case studies that we set out to do when we created this committee in 2010. We are currently looking at Meeting 12 as the opportunity to regroup and restructure committees of the ASC Motion Imaging Technology Council that have converged on the topic of immersion, virtual reality, and game engine technology, as they relate to motion picture production and the role of the cinematographer in virtual production.

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

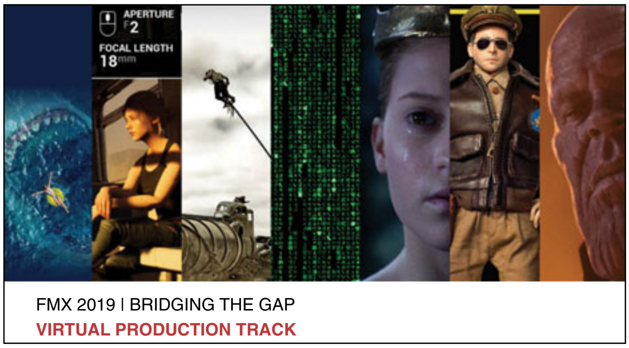


FIGURE 10. FMX 2019 Virtual Production Track.

Joint Technology Committee on Virtual Reality

Virtual Reality Committee

Chair: David Morin
Vice-Chair: Michael Goi, ASC
Vice-Chair: Mike Sanders, Activision

- **VR Committee meeting #4**: took place on 5 September 2018 at Stargate Studios, stargatestudios.net, that demonstrated multiple applications of VR and AR in production, including a LED video wall and ARRI light panels driven by an ARRI camera through the Unreal engine, for actors-driving-in-car scenarios (**Fig. 11**). More details on the agenda in the invitation at https://event.pingg.com/VR4. About 75 people attended.

More specifics:

The main event was an in-camera composite for an in-car shot demonstration (**Fig. 11**). It was generated in realtime by using an LED background display that was providing the moving environment from a previously recorded spherical plate running as a 'screen' within Unreal. The perspective of the background is corrected in realtime with camera tracking being fed to Unreal. To enhance the matched lighting, pixeltrack was used to sample light positions within Unreal and feed values to strategically placed light panels in the live scene – these values are also driven in realtime per the simulated movement of the background plate.

FIGURE 11. VR Committee meeting #4 at Stargate Studios showcasing in-camera composite using Unreal and LED displays on set.

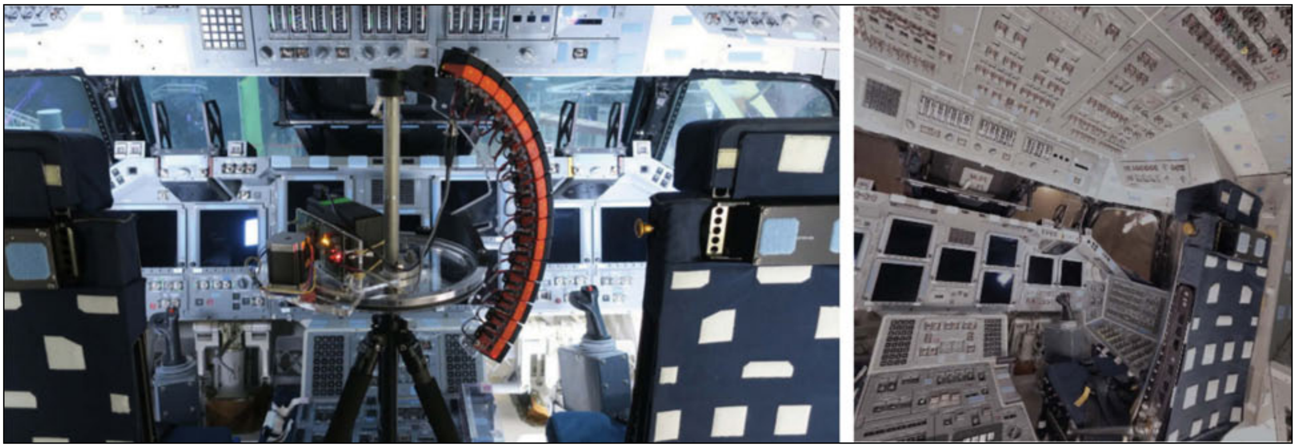


FIGURE 12. Google's light field camera array and processed output.

Google provided a demonstration of light field technology, using a go-pro camera array on a motorized head (**Fig. 12**), a series of images and specialized algorithms create a static spherical output that can be viewed in a VR headset that allows for a limited range of parallax shift in viewing to simulate being immersed in a virtual environment.

Short Film Production Section Report

As technology continues to evolve, the rapid development of Augmented Reality (AR) as a platform which incorporates Virtual Reality (VR) and elements of real life has necessitated an examination on the potential future of purely VR content.

The VR short film demo project is currently being re-imagined as something that would incorporate XR as a production and distribution platform, and exploring ways in which XR could enhance the storytelling capabilities of a production. As with the intent of this committee's mission from the outset, finding the manner, in which the technology can support the artistry most effectively is the primary objective.

The inclusion of the traditional crafts of cinematography and production design in XR becomes much more imperative. The need for these crafts to be involved from the initial stages of pre-production through to the final stages of post-production directly affects the efficiency and decision-making process regarding the merging of real world elements and virtually-created environments and props. Supervising the execution of color matching, lighting continuity, texture mapping, character positioning, camera movement, and many other facets of cinematography and production design take on heightened importance in this technology.

As we are now living in the reality of the world of "The Matrix" (1999), where the real world is affected by the purely computer generated world and vice versa, this committee will endeavor to continue its mission of suggesting best practices, clarifying the role of traditional crafts in the new technology, and providing insights gleaned from the collaborative contributions of the world's most prominent practitioners of AR and VR from both the artistic and technological fields.

Food for Thought – VR vs AR vs MR vs XR

As VR is put on a slow burn and AR takes the spotlight, there is a bit of confusion as to what AR/VR means. Here is a perspective on it as there is no definitive categorization on this rapidly evolving emerging market. VR has cooled because of the technology barrier to entry for the average consumer (typically takes a high-end PC/graphics card and $500 headset) and the lack of the 'killer app' or compelling reason to be immersed in the content, and the anti-social aspect of the tech. AR doesn't suffer the content criticism, doesn't diminish the viewers faculties, and projects to have more utility in purpose.

XR, in general, is meant to cover all things within this space and could be construed as e**X**tended **R**eality.

VR, **V**irtual **R**eality, in commonly accepted definition is a full immersion experience or an expanded ability to have agency within content, most likely via a VR headset (see **Fig. 13**).

VR video: This content would typically be 180–360-degree stills or video, live or post-produced, that can be viewed on any display such as a monitor, panel, or mobile device (including immersive goggles –VR

FIGURE 13. VR headset, fully immersed vision of stereo content driven from viewer's perspective.

FIGURE 14. AR see-through glasses w/graphics in viewport.

headsets, that block out external visibility). The key component is the agency, or rather the ability of the viewer to actively pick perspective and possibly affect or interact with the content. This is typically linear live action footage or pre-rendered content.

VR games: This content includes tradition video games or VR specific video games that are displayed through VR headsets (specifically because of the immersive nature of the headset). Note that playing a video game on a panel or mobile device isn't considered VR. Typically, this is completely rendered cg content.

AR, **A**ugmented **R**eality is likely the most complicated category. The key components here are 'reality' which suggests restriction to the viewers perspective and augmentation, or the adding of something to the content (audio, visuals/graphics, image processing, etc.). The display possibly matters here as well, typically it would be see-through glasses or goggles (HUDs in helmets, Hololens/Magic Leap, and a host of enterprise glasses – (**Fig. 14**), or a mobile device – specifically managed by the viewer to provide a point of view (**Fig. 15**).

There is a misnomer in production that seeing realtime graphics in a live camera feed is Augmented Reality – this is merely a realtime composite. Technically, it would be AR to the camera operator as their live view is being augmented, but when the content is recorded, or even broadcast in realtime, it isn't necessarily 'reality' to the viewer (because they do not have agency

FIGURE 15. AR on mobile tablet, graphics overlay on live video relative to the viewer's perspective.

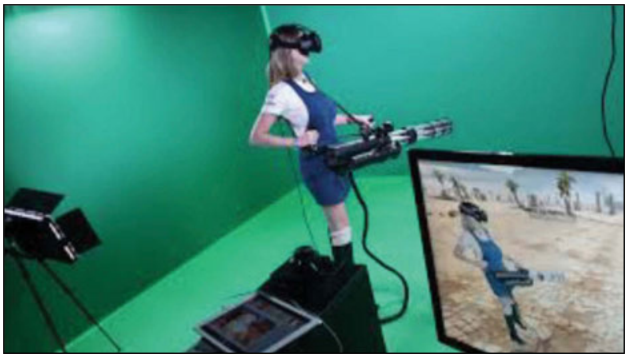


FIGURE 16. MR is the realtime composite from a tracked camera and greenscreen replacement of render content being viewed on the flat panel. The subject is wearing VR goggles that render stereo content of same environment but from her perspective.

in the perspective). Similarly, graphics augmented in sports broadcast would fall in the same category, it is choreographed linear content with realtime compositing – unless the content was viewable via the previous explanations of VR and AR, meaning the viewer is picking the perspective. This is definitely an arguable topic.

MR, **M**ixed **R**eality, is a derivative term, sometimes used in place of XR (and before XR became fashionable), but more likely represents the realtime compositing mislabeled as AR. In this case, the reality represents linear footage (live or recorded) without viewer agency but with augmentation of graphics (via camera tracking and compositing – (**Fig. 16**). This category is also sometimes used in a situation where AR and VR are sort of happening at the same time. For example – a VR headset that closes external visibility but within that headset is a composite of realtime graphics over a streaming video feed from cameras embedded externally in the headset, all being driven from the perspective of the viewer (Technically this is VR). Sometimes it depends on the content as well. Some would say that adding graphical objects to a live background is AR and adding live objects to a graphical background is MR. This is complicated.

Participation is encouraged. Those interested in the VR Committee may contact:

David Morin, Chair, davidmorin@davidmorin.com.
Michael Goi, Vice-Chair, mgoi@aol.com.
Mike Sanders, Vice-Chair, Mike.Sanders@activision.com.

SSIMWave HDR Evaluation Working Group

Coordinator: W. Thomas Wall

The primary objective of this Working Group is to help maintain the visual integrity and original creative intent of modern cinematic motion picture imagery as delivered to high-end consumer devices that can adequately display such content.

To that end, our purpose is

To assess, evaluate, and improve the preservation of the original creative intent of HDR, wide color gamut, ultra-high resolution digital motion picture imagery during its distribution and delivery, from final color grading to consumer devices.

To do that, we are attempting to judge how well the original creative intent is preserved, *whatever that is,* during distribution and delivery to customers:

- *NOT* based on just how bright or how wide the dynamic range or how colorful or on how sharp a given image appears, but
- How well the delivered images match the original creative intent
- As seen and approved during color grading by those creatives
- Versus how it is delivered to customer devices
- Based on the judgment of experienced professional cinematographers and colorists who create such original imagery.

To that end, we are performing a scientific study under the guidance and with the participation of the following researchers:

Dr. Zhou Wang: University Research Chair & Professor, Dept. of Electrical & Computer Engineering University of Waterloo Image and Vision Computing Laboratory University of Waterloo, Ontario Canada Winner, Engineering Emmy® Award for development of Structural SIMilarity (SSIM) perceptual quality metric

Dr. Abdul Rehman: CEO and co-founder SSIMWAVE Inc. Postdoctoral Fellow, University of Waterloo

Dr. Kai Zeng: Research Lead, SSIMWAVE Inc. Postdoctoral Fellow, University of Waterloo

Thilan Costa: PhD Candidate, graduate student, University of Waterloo, Image and Vision Computing Laboratory

Along with Saj Jamal, VP Marketing, SSIMWAVE Inc., all are involved in research into digital image signal processing and image and video quality assessment, and how it can be applied in real-world distribution systems. SSIMWAVE Inc. is a technology spinoff company sponsored through the University of Waterloo.

These researchers have worked very collaboratively with us to design a study that will

1) evaluate visually perceptible differences between HDR, WCG material as graded, reviewed and approved by cinematographers and colorists, compared to how that material is processed and ultimately delivered to high-quality consumer displays;
2) be judged by professionals who create the visual imagery of narrative motion pictures (rather than by non-professional "typical viewer" test subjects);
3) evaluate high-quality HDR motion imaging test material in terms that such knowledgeable imaging experts commonly use, rather than just a single "good" or "bad" numerical score;
4) evaluate whether, or how well, the SSIMPLUS quality-of-visual-experience metric software, as developed at the University of Waterloo Image and Vision Computing Laboratory and currently implemented in the SSIMWAVE Inc. SSIMPLUS software, accurately reflects such expert judgment when applied to HDR WCG material.

Note that this evaluation does not start with the deliverables *to* distributors of visual content, but rather what was created, seen, and approved *before* being delivered for distribution. That is because degradation of that imagery can start even in that very first step of the delivery pipeline, based on the file formats, codecs, color space, frame rate, resolution, aspect ratio, and bit depth of the mezzanine files specified as acceptable by a network or distribution channel.

Our evaluation then involves the accurate recreation of the types of transcoding, color sub-sampling, resolution re-sampling, HEVC compression, de-compression, re-compression, and possible frame rate alterations, among other factors, involved in actual delivery pipelines of online streaming services. The resulting "as delivered" image data will be displayed to study test subjects, to be compared against the original imagery as it was intended to be seen and approved by the DP and colorist.

A first requirement of any such study is suitable original HDR, wide-color gamut, UHD-1 or full 4K resolution test material.

Starting in April 2018, we worked jointly with the ASC MITC Next Generation Cinema Display Committee, with the outstanding help of Joachim Zell at EFILM, to evaluate potential reference cinematic HDR material. Select clips from the ASC MITC's Image Control Assessment Series (ICAS) tests were chosen to be graded in HDR by the DPs who were involved in its creation. Also chosen were desert scenes shot by Bill Bennett, ASC, as a lens test of Zeiss lenses on an ARRI ALEXA 65. Those selected clips were transferred to Roundabout Entertainment, where Senior Color Scientist Jerome Dewhurst had agreed to allow us time on the revolutionary Samsung Onyx emissive LED cinema screen at Roundabout West, along with the industry standard Sony BVM-X300 reference monitor, to create that HDR grade. Starting from original camera RAW files from Sony F65 and ARRI ALEXA and ALEXA 65 cameras, the three ICAS and two desert scenes were graded in HDR with luminance levels that ranged from 0 nits (zero emitted light) up to 300 nits peak, in P3 color space, with D65 white point, using an ACES 1.1 workflow. These luminance levels were the choices of the DPs and colorists involved, not limitations of the equipment. The DP primarily responsible for the grading the ICAS clips was Dave Stump, ASC, working with colorist Bryan McMahan, along with Jerome Dewhurst and Curtis Clark, ASC, monitoring the proceedings; Bill Bennett worked with these colorists to grade the desert scenes. The resulting HDR grades were saved as graded ACES 1.1 masters, in openEXR format, ACES 2065-1 AP0 color space. Together with the graded ACES master of Curtis Clark's "Meridian", shot for Netflix and graded at FOTOKem with dynamic range from 0 nits up to 1000 nits peak, these clips dramatically illustrate the full 14+ f-stops and color fidelity that these digital cinema cameras, and professional DPs, can capture and utilize in a cinematic context.

In addition, we had obtained permission from RealD Inc. to re-grade *Flamenco* in HDR, the short produced by Tony Davis to demonstrate his TrueMotion software for reduction of the strobing and judder that can appear in HDR imagery whenever there is motion of high-contrast edges across the screen, either due to camera motion (e.g., panning) or motion within the scene. Bill Bennett, ASC was the DP. Again, in order to obtain an acceptable high-dynamic range grade with full P3 color fidelity and without banding or clipping of either highlights or shadow detail, we had to begin with the "camera RAW" original source material – which in this case meant the pre-de-Bayered output of the TrueMotion software, as this was then selectively used within individual shots – sometimes even within power windows – during the original grading of *Flamenco*. Once again, Bill Bennett, Bryan McMahan, Jerome Dewhurst, and the team at Roundabout Entertainment donated large amounts of their time, working to produce the HDR grade using the Samsung Onyx emissive HDR cinema screen. Although shot at 120 fps (in stereo 3D), the TrueMotion output is at the cinema-standard 24 fps – to demonstrate the lack of strobing when displayed at that frame rate.

All of this required until November of last year to complete.

In the meantime, the group at University of Waterloo and SSIMWAVE were working to further develop the software needed to allow accurate comparison of original "as-graded" source material vs. the "as-delivered" version of that content. This required designing custom software, which was implemented primarily by graduate student Thilan Costa, working with Professor Wang and Dr. Zeng.

Significant aspects of that software include:

- To maintain the original HDR image quality at 4K or UHD-1 resolution as seen in a high-end grading theater requires driving an HDR reference monitor with 12-bits per color RGB ST 2084 PQ-encoded signals at the highest frame rates those monitors will accept.
- To facilitate comparison of two versions of an image on a single reference monitor, a "swipe" is allowed between the two versions, which must be maintained in perfect frame synchronization without stuttering or dropped frames.
- A user interface on a separate computer monitor must allow a test subject to easily and intuitively enter their evaluation of perceived differences between two versions of the same clip, indicating which visible aspects, if any, are noticed at a given time in a given clip.
- Representative "as delivered" versions of the above ASC MITC reference HDR test material must be created, at various compression levels typically encountered, in a format suitable for use by the testbed software.

Of course, to allow DPs and colorists to actually perform evaluations required for our study requires computer hardware with sufficient capability to handle the high data throughput and processing required. HDR reference monitors that can handle the required 12-bits per color at full 4K resolution and at least 30 fps without compression have until recently all required quad 3G SDI connectors. Until near the end of last year, there were only two models of adapter cards that could reliably handle the data rates required for our needed resolution and frame rates without color sub-sampling (which would alter the integrity of the images we are evaluating). And their availability was in short supply. To drive those cards requires disk subsystems with adequate capacity to hold our test data and that can maintain sustained data rates near 3 GBytes/sec, connected to a motherboard that can provide such sustained data transfer rates without swamping other memory access channels - all on zero budget for any of this. We have been entirely dependent on the donation of all equipment necessary to carry out this study.

Over the last several months of last year, all of the hardware necessary for our study test bench was assembled and tested. Generous donations from Lenovo (Thinkstation P510) and Liqid Inc. (3TB, 3GB/sec NVMe SSD), along with loaner equipment from Canon (V3001 30-in. HDR reference monitors) and Blackmagic Design (Decklink 8K Pro with quad 3G SDI) made this possible. Test material files were offloaded and stored on G-Tech hard disk systems donated by G-Technology. This in turn allowed testing of the software developed at the University of Waterloo on the hardware systems we will use in our study.

On 29–30 October 2018, Prof. Zhou Wang, Dr. Kai Zeng, and Thilan Costa, PhD graduate student at the University of Waterloo, traveled to Burbank to prepare the physical setup that would be used to demo the testbed system to a meeting of the Working Group at Canon's Burbank facility. A Beta version of the software that will be used in our study was installed successfully on the testbed workstation. Transcoded and compressed versions of ASC MITC HDR test material, prepared by the University of Waterloo and SSIMWAVE Inc. to reflect how that material would likely be altered during distribution and delivery to distributors and then to consumers, was loaded onto the Liqid SSD on that workstation (totaling over 2 TB of test material). Thanks to the very helpful support of Canon Burbank staff, those preparations went extremely well.

Prof. Wang and his team were also able to meet with colorists and others involved in the actual post-processing of digital cinema productions. This helped give them a better perspective on this crucial part of creating and delivering such content of which most academic researchers have little direct contact.

For the first time, we were able to review the complete testbed system in an environment that will be close to what will be used for the actual study. During conference calls the following week, we agreed on changes that would be made to the software user interface to better reflect how expert professional cinematographers and colorists can evaluate and record differences they perceive between "as graded" vs. "as delivered" image versions. Improvements to the software interface were implemented and reviewed over the course of the next weeks.

On 14 November, the resulting proposed testbed system was presented to members of the Working Group for their review, at a meeting held at Canon Burbank. To provide context for how this study may benefit the industry, Prof. Wang gave a brief overview of the SSIM "visual experience" quality metric, and of the current SSIMPLUS software that is included in the SSIMWAVE Inc. commercial software. Dr. Zeng and Saj Jamal described how that software is being developed and deployed and currently used:

- SSIMPLUS is the result of over 14 years of research and development into the visually perceptible differences viewers can detect between two versions of the same image, of both stills and moving imagery, and algorithms to approximate that human visual response.
- The SSIMPLUS software provides both numerical "scores" indicating the degree of noticeable alterations to an original reference version, and a quality "map" – a gray-scale representation of where and which kind(s) of differences the software algorithm detects between the original source and the test version.
- The SSIMWAVE Inc. commercial software allows distributors to use the SSIMPLUS metric to monitor the degree of visual degradation of their content in real time – currently primarily in terms of compression level vs available data transmission rate, for standard dynamic range material. Since it is used by content distributors mainly to monitor links in their distribution chains, there is no comparison to what was originally intended by creators.
- This testbed provides a way to evaluate how well current distribution systems maintain the overall visual creative intent of HDR, UHD-1 and 4K resolution material from end-to-end, under the constraints of limited bandwidth while maintaining temporal continuity.

This was followed by hands-on (and over-the-shoulder) review of the testbench workstation and software by Working Group members, along with lively interactive discussion with the researchers.

As a result of that meeting:

A "to-do" list of follow-up items was prepared, which are currently being worked on, including

- Further updates to the testbed software;
- Arranging for more detailed information from distributors such as Netflix, Amazon, Hulu, and Apple on their distribution pipeline processes;
- Understanding how finishing houses prepare material for transport and delivery to various distributors (e.g., processing before and during creation of mezzanine files that alter the visual quality);
- Beginning discussions/further demonstrations to companies that could host our study testbed.

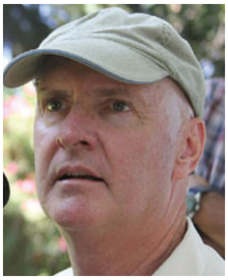
Further testing and then startup of the actual study is awaiting availability of the necessary reference monitor and adapter card, which as of this writing is being negotiated with manufacturers. The process of preparing for and performing this study started over two years ago, continues.

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 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 film, *The Arrival*, Clark completed his highly praised short film *Eldorado*. His most recent short film, *Meridian* (Netflix), is a creatively accomplished work that has already gained the status of an essential demonstration for High Dynamic Range imaging. Clark is chairman of the ASC Motion Imaging Technology Council (MITC). Since its inception in 2003, the Council 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 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. The ASC Motion Imaging Technology Council, 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, as well as the Motion Picture Academy's 2019 John A. Bonner Award in recognition of extraordinary service to the motion picture industry. In addition to the ASC, Clark is a member of the Academy of Motion Picture Arts and Sciences and has worked on the development and implementation of ACES. He is also a member of the Directors Guild of America.

David Reisner received a 2014 Academy Technical Achievement Award, a 2014 Hollywood Post Alliance Judges Award for Creativity and Innovation, and was recognized by the Academy of Television Arts and Sciences with a prestigious Prime Time EMMY Engineering Award as co-designer of the ASC CDL, now used nearly universally in the workflow of motion pictures, scripted TV, and visual effects turn over. He was lead designer and co-producer of the ASC-DCI StEM Standard Evaluation Material used to determine the quality required for the deployment of digital cinema, and Vice-Chair'ed the SMPTE Working Groups responsible for digital cinema imaging – showing on 97% of cinema screens worldwide – and security standards – protecting $35B of IP each year. Reisner also had leading roles in activities including design and production of the ASC-PGA CAS Camera Assessment Series and elements of the Academy Color Encoding System. He made one of the first proposals for the Virtual Print Fee model used to fund the digital cinema roll-out. Reisner's "firsts" include programmable portable computers, the handheld video jukebox, and VLIW computer architecture – one of the enablers of modern multi-processor computing. He made early contribution to the introduction of neural networks – the basis of modern Artificial Intelligence and Machine Learning – and originated Pervasive Computing – a parent of IoT (Internet of Things). He has shot celebrity and fashion for books and magazines including Vogue Italia, produced concerts internationally, and trained killer whales. Reisner is well published in books, technical articles, and has spoken widely (largest webcast audience 29,000), including on manned space exploration at the 2014 International Space Development Conference. He is a member of SMPTE; the founding Secretary of the ASC Technology Committee and an ASC Associate; a Member of the Visual Effects Society; and has Chaired committees for the Academy Scientific and Technical Awards.

David Stump, ASC 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 Committee of the ASC Motion Imaging Technology Council 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, ASC has been a cinematographer for over 35 years, primarily shooting television 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 television commercials, to be invited to join the American Society of Cinematographers. In 2016, the ASC presented Mr. Bennett with the President's Award at the 30th annual ASC Awards Show. He is currently serving as Vice President at the ASC. Bennett often advises ARRI, Zeiss and others on equipment design.

Jay Holben is an independent producer and director in Los Angeles, California. A former cinematographer, he is the author of two commercially-published books on cinematography, a previous technical editor for DV Magazine, a current editor and contributor for over two decades for *American Cinematographer Magazine*, faculty instructor for Global Cinematography Institute and international lecturer. He is an Associate member of the American Society of Cinematographers and chair of the ASC Motion Imaging Technology Council's Lens Committee.

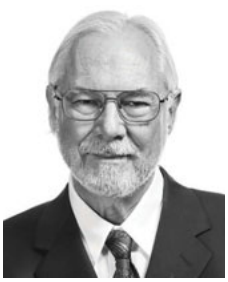
Jesse Korosi is the Director of Workflow at Sim and Chair of the ASC MITC Workflow Advanced Data Management sub-committee. Korosi currently oversees a global workflow and development team and provides technical-level direction and management. Over the past 18 months, Jesse and his team have overseen the dailies/post production workflow on over 100 projects spanning the globe, collectively managing over 10 Petabytes of media. Aside from working on notable television shows and feature films, Korosi counts creating Sims new client facing metadata aggregation/ automated transcoding database Metabanq, as his greatest achievement. Korosi has a lifelong love of filmmaking and has worked in many different on-set and post-production roles over the last decade including: 24 frame playback editing/compositing both on and off set, on-set visual effects editing, data management, dailies, offline/ online editing, and final color. Korosi uses this wealth of knowledge to provide his clients with customized workflows, that are tailored to successfully meet their unique requirements and the specific needs of their projects.

Eric Rodli has been involved in the management and development of entertainment technology since the late 1980's when he became 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 PwC as well as president of Kodak's Motion Picture Division. He currently is the executive director of the ASC. He is also an Associate member of the ASC. Rodli received a BA in economics from the University of California, San Diego and MBA from the University of Chicago.

Joachim Zell is Vice President of Technology at EFILM/ Deluxe, where he designs and monitors production workflows from onset production to movie release. Previously he was VP of Advanced Technology at Technicolor Thomson in Burbank and before that Marketing Manager Americas at Grass Valley Thomson. During his time in London Zell worked as Product Manager Digital Film Systems for Pandora Int. He is a SMPTE Hollywood Section Manager, was part of the ASC Technology Committee team that created the ASC CDL, and holds the position of ACES Project Vice Chair at the Academy of Motion Picture Arts and Sciences. Zell holds a master's degree in film and television engineering and was co-writer on four image processing patents.

Gary Mandle Owner of Outtahand Displays, Mandle works on the development of new imaging technologies as both a design engineer and product strategist. Prior to forming Outtahand Displays, Mandle was senior product manager at Sony Professional Solutions Group for the display group. Products that Mandle has been involved with include the introduction of Sony technologies such as Multi-frequency CRT, LCD, SXRD, GLV, AC Plasma, and OLED products. Mandle has been published in several SMPTE, IEEE and SID journals and has been a contributing author of several technology text books with regard to CRT, Plasma, LCD and OLED. Other areas of work include the design of camera image stabilization systems and CCD sensor development where he holds multiple patents. Memberships include CIE, IEEE, SID, OSA, Associate member of the American Society of Cinematographers, as well as a board member of SMPTE as Western Area Governor.

Don Eklund serves as Chief Technology Officer for Sony Pictures Entertainment. He has helped launch multiple consumer entertainment formats since starting his career at Sony. He co-developed and staffed the operation that launched DVD at Sony Pictures and went on to oversee the development of software tools and hardware systems which supported compression, authoring and quality control for Blu-ray. Eklund participates in a number industry standards organizations and consortiums, which focus on next-generation entertainment.



Gary Demos, BS 1971, DAA 2018 Caltech, has been a pioneer in the development of computer-generated images and digital image processing for use in motion pictures. He was a founder of Digital Productions (1982-1986), and was awarded an Academy of Motion Picture Arts and Sciences (AMPAS) Scientific and Engineering Award in 1984 along with John Whitney Jr. "For the Practical Simulation of Motion Picture Photograph By Means of Computer-Generated Images." Demos also founded DemoGraFX (1988-2003), and Image Essence LLC, Perris, CA (2005 to present). Demos is the recipient of the AMPAS 2005 Gordon Sawyer Oscar for lifetime technical achievement. Demos is actively involved in the ASC Technology Committee and has worked on the AMPAS ACES project. He has presented numerous papers at SMPTE, given a SMPTE webinar, is a SMPTE Fellow, and received the 2012 SMPTE Digital Processing Medal. Demos is the inventor of approximately 100 patents.

Greg Ciaccio, creative technologist, is passionate about finding new technology and workflow solutions for the Motion Picture and Television industry. Ciaccio has served in executive operations management positions for Creative Service divisions at Ascent, Technicolor and Deluxe, and has led product development teams creating leading-edge products including Technicolor's DP Lights and Deluxe's Mobilabs near-set dailies solutions. In 2014, Ciaccio, along with key members of the ASC Technology Committee's DI Subcommittee, won an HPA Judges Award for the creation of the ASC/CDL, now a commonly used format for the exchange of basic primary color grading information. Ciaccio serves as Chair of the ASC Motion Imaging Technology Council's Workflow Committee, which includes Lighting and Advanced Data Management Subcommittees, as well as the ACESNext Working Group. He is also a member of the UHD Committee. Additionally, he is a SMPTE Hollywood Section Manager, founding member of DCS and is an adjunct professor at CSUN teaching Post-Production Management for Film and Television.

Tim Kang is a Los Angeles-based cinematographer, working in the film & TV industry primarily as a director of photography on narrative, commercial, music video and documentary projects. In addition to multiple features, pilots, and shorts, his list of commercial clients includes: Cover Girl, Delta, LA Kings, Disney Interactive, DreamworksTV, NBC Universal, and YouTube. He has taught cinematography classes and seminars at AFI, Chapman University, and Woodbury University. For formal training, he received his Master of Fine Arts (MFA) in cinematography at the renowned American Film Institute Conservatory and proudly received mentorship from Stephen Lighthill, ASC; Robert Primes, ASC; David Stump, ASC; Greg McMurry, ASC; and Ron Garcia, ASC. He previously studied biomedical engineering at Johns Hopkins University, worked in the scientific imaging world for seven years at Mount Sinai School of Medicine, and developed his photographic skills in the streets, subways, and byways of New York City.

Jim Houston is a consultant on digital production workflows, ACES, color science, metadata systems, and new cinema technologies such as Direct View LED, and has worked at Sony Pictures, Disney, Mainframe Entertainment, Postworks, Pacific Title & Art Studio, NASA/Ames, and others. He has been a member of the MITC committee since its inception as well as a former member of the Academy's Science and Technology Council and Science and Technical Awards committee and has received two Academy Science and Engineering Awards.

Pete Ludé is co-chair of the Plenoptic and Computational Imaging Committee. He is past-president of SMPTE, and a SMPTE Fellow. Ludé has been involved in advancing motion imaging technology for several decades now, and currently serves as chief technology officer of Mission Rock Digital, an engineering consultancy based in San Francisco.

David Morin is head of the Epic Games Los Angeles Lab. He is also executive director of the Academy Software Foundation. At Epic Games, Morin works to develop the use of the Unreal Engine in the Film and Television industries. At the Academy Software Foundation, David works for the Premier Members to develop the use of open source software in the motion picture industry. Previously, Morin was president of David Morin, LLC, a diversified consultancy specializing in immersive production with clients such as the Academy of Motion Picture Arts and Sciences, Arri Inc., Autodesk, Epic Games, Shotgun Software and others. Morin is also chairman of the Joint Technology Committee on Virtual Production, the Joint Technology Committee on Virtual Reality, and a past co-chair of the Joint Technology Subcommittee on Previsualization. He earned a BScA in computer science from Laval University (Quebec City, Canada) and has participated in the development of motion capture and 3D software since *Jurassic Park* at companies such as Softimage, Microsoft, Avid Technology, Autodesk and now Epic Games.

Michael Goi, ASC, ISC is a past president of the American Society of Cinematographers and is the editor of the 10th Edition of the ASC Manual. He is a member of the National Executive Board of the International Cinematographers Guild and a member of the Academy of Television Arts And Sciences and the Academy of Motion Picture Arts And Sciences. He directed the feature film *Mary*, starring Gary Oldman to be released this fall.

Mike Sanders is the senior visual director for Activision's Central Studios, overseeing innovation in art, animation and production across Activision's game franchises, most notably Call of Duty. He is focusing on bringing film VFX quality to game development and emerging AR/VR markets. Sanders was previously director of virtual production for Industrial Light & Magic, collaborating with Disney divisions such as Lucasfilm, Pixar, Marvel, and Imagineering and built much of the foundational creative technology of the ILMxLAB. He has many patents awarded for digital production and virtual cinematography. In 2009, he was recognized by the Producer's Guild of America as a member of their inaugural Digital 25 list for the most notable contributors to digital storytelling. Sanders has worked with most top directors and every major studio, including such memorable projects as the digital cast in *Titanic*, many of the effects in the *Star Wars* prequels and sequels, the behind-the-scenes tech that launched *Avatar*, and the believable characters in *Pirates of the Caribbean*.

W. Thomas Wall is a retired computer systems designer and professional photographer. He is CTO of LightView.

Inquiries regarding the ASC Motion Imaging Technology Council should be sent to Alex Lopez: alex@theasc.com